第四次業務における現地業務結果報告書
（エルサルバドル国　地震・津波情報の分析能力強化 Phase 2、2021～2023 年）

令和 4 年7月 26 日版

JMBSC 森　滋男

1. 作業日程実績

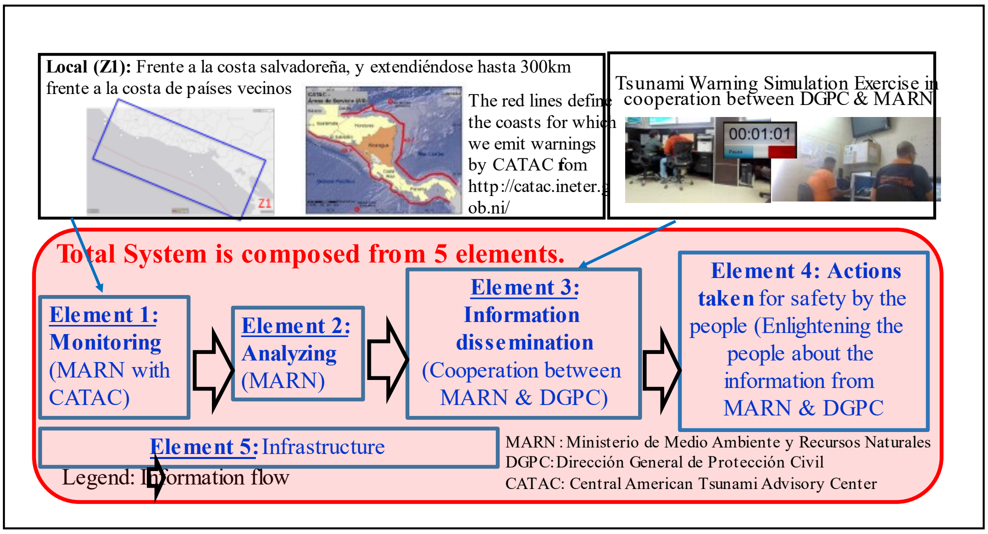
第四次業務ワークプラン [1]に従い、現地での実施が不可欠な事項を中心にして、状況に応じて日程を一部手直ししつつ、現地業務を実施した。現地業務の作業経過は**付録1**に示した。この経過表では、現地での実施が不可欠な事項は赤文字で示した。なお、プロジェクト全体の日程概要は**付録2**に示した。

2. 成果

2.1 現地での実施が不可欠な事項

次の事項が該当し、それぞれ地震・津波情報の分析のシステムの要素（**下のコラム参照**）における位置づけも示した：

1）調達機材の現状確認（要素1～5）
2）市民防災局（DGPC）の本部及び監視センターのそれぞれの運営施設の現状把握・評価（要素3、4）
3）監視当番職員の引継ぎ参観・評価（要素1，2，3）
4）監視総局内部津波警報発表訓練参観・評価（要素1，2、3）
5）沿岸地域の津波対策の現状確認・評価1（ラ・リベルタ：社会環境において津波に脆弱）（要素3，4）
6）沿岸地域の津波対策の現状確認・評価2（ウスルタン：自然環境において津波に脆弱）（要素3，4）
7）機材調達の販売代理店との相談（要素2）
8）関連する他機関プロジェクトの聞き取り（京都大学科学プロジェクト）（要素1、5）



2.2 現地での実施が不可欠な事項の結果

2.2.1 調達機材の現状確認

「**調達機材の現状 24Jul22**」に示す通り、当初予定分は、未到着のワークステーション以外について利用されていることを確認した。

2.2.2 市民防災局（DGPC）の本部及び監視センターのそれぞれの運営施設の現状把握・評価

「Draft minutes of the meeting with DGPC held on 01Jul22」（DGPC に確認を依頼中）の中に示した通り、市民防災局長のご意向も含め次の課題を見出し、次のように対応していく予定：

[1] Work Plan of the Short-term Expert Dispatch to MARN in El Salvador as of 09Jun22

1） MARN と DGPC と共通の作業手順の構築（市民防災局長のご意向）。真意は確認しつつ今後対応していく。
2） 公式情報伝達手段である無線及びファックスのうち、後者は監視センター移設の関係で当日は設置されていなかった。MARN においてもこのことを把握していなかった。7 月 15 日頃設置見込みとの話であった。26Jul22MARM との定例打合せで未確認。メールで確認中。
3） 一方、WhatsApp が非公式ながら便利な伝達手段として既に日々利用されていた。この手段の公式利用を相談していく予定であったが、より早期に相談を始めたい。

2.2.3 監視当番職員の引継ぎ参観・評価

「Draft results from observation of the shift takeover process as of 05Jul22」の中に示した通り次の課題を見出した。それぞれに示した対応を行っていく。

1）DGPC との伝達手段の点検リスト案について現状と乖離がある。このため、リストについては、実情を反映させ、一方で、公式プロトコルの改正を相談していく。

2）引継ぎ時の主な内容は、機器の不具合。この日は観測設備、監視・解析設備、伝達手段、及び火山監視カメラに不具合があった。それぞれのその後の対応状況を把握できていないので、今後確認し、課題の有無をさらに確認する。

2.2.4 監視総局内部津波警報発表訓練参観・評価

「Draft results from the tsunami exercise of MARN held on 07Jul22 as of 12Jul22」に示した通り、参観しているだけでは、実施状況の全容は確認できなかった。

1） しかし、MARN が説明してくれた Assessment_Drill_120722（MARN 作成）の中で課題とされていることが、参観をしていたことで、本質的な課題ではないのではと理解できた。
　即ち、訓練では、実施担当者は緊張し、訓練手順に示された作業をいくつか実施しそこない、かつデータ入力の誤りもあった。これについて、MARNは練習でこのようなことをなくしていくことが必要との認識を示した。森は、作業手順が多過ぎることと、本番と訓練との作業条件の違いがあることから、あ）練習だけではこのことは解決せず、い）作業手順の簡素化が不可欠と見解を述べた。加えて、作成途中の津波ガイドラインの訓練前での一読も提案した。今後さらに相談することとしている。
2） 今回の訓練ではシナリオ設定や訓練実施担当者の選択において、初めて、予め準備した「Scenarios of tsunami simulation exercise as of 06Jun22」に基づいて対応した。この文書は今回の結果を踏まえ、見直すこととしている。

2.2.5 沿岸地域の津波対策の現状確認・評価1（ラ・リベルタ：社会環境において脆弱）

「Draft results from the visit to the coastal area of la Libertad implemented on 14Jul22ver4」に示した通り、次の項目に課題を見出した。それぞれについて、今後検討していくこととしている。

1） 同沿岸地域で利用されている情報伝達手段を踏まえた情報内容のありかた
2） 情報内容の理解の促進方法（MARN 津波地震ガイドブックの利用の促進やその学校の生徒児童への提供）
3） 遊泳者等への情報伝達手段（津波フラッグ；**次頁コラム参照**）

Points to note when operating tsunami flags

As a result of continuing to communicate tsunami flags in operation, such as waving tsunami flags, evacuation of the implementers should not be delayed. Depending on where the earthquake occurred, a tsunami may hit the coast without time. For this reason, only in cases where the safety of the person who carried out the transmission is ensured, the flags should be used. And it is important that the implementer of this transmission fully recognizes this and fully informs users of the beach.

Note 1: Tsunami Flag Specifications

1) It has been proposed that **the size** should be at least 100 cm on the short side, but there is no provision. This will be judged based on the size of the coast.

2) **Red** is not a detailed color specification.

3) The **checkered pattern** is similar to the "U flag", which is one of international maritime signal flags.

Note 2: The international maritime signal flag is a universal flag used to communicate between ships on the sea. The usage is determined by the International Code of Signals (INTERCO), and the signal by the international maritime signal flags is called Flag Signaling.

Note 3: The U flag is an international signal flag that means "your ship path is at risk" and is used overseas as a flag to signal emergency evacuation from the sea. On the other hand, the U flag can be a different meaning when combined with other international signal flags. For example, if you use a combination of "U flag" and "W flag", it means "pray for safety navigation".

Note 4: Price of the flag A company in Japan shows 8000yen (70 US Dollars; ￥7300 & $ 63 without tax). Its size is 100cm×150cm. Its material is plain weave of polyester 100%.

4） 潮位計の保守

5） 避難指示版

2.2.6 沿岸地域の津波対策の現状確認・評価2（ウスルタン：自然環境において脆弱）

「Draft results from the visit to the coastal area of Usulután on 19Jul22ver2」に示した通り、次の項目に課題を見出した：

1）同沿岸地域で利用されている情報伝達手段を踏まえた情報内容のありかた

2）津波避難施設の存在を踏まえた情報内容のあり方

3）情報内容の理解の促進方法（MARN 津波地震ガイドブックの利用の促進）

4）避難指示版

2.2.7 機材調達の販売代理店との相談

（27 日 9 時から実施予定；右コラムにある2つの GPS の高度化利用について打合せ予定）

Expert should consider how to get real-time data from the stations #1 and #2.

Parámetros de estaciones GPS El Salvador (2018-2019-2020)

No.	COD-ID	Estation	Antenna Type	Receiver Type	How to get the data	Ref.	Sampling rate	Memory capacity in the receiver	Processing	Surveying type	positioning
1	LNUB	Las Nubes	TPSCR.G5	Topcon NetG3A	**Internet**	JICA	30 sec (1Hz can be used.)	15 Gb	Post-Processing	Static (kinematic can be used)	DGPS or Absolute
2	ALAR	Lomas de Alarcón	TPSCR.G5	Topcon NetG3A	**Internet**	JICA	30 sec (1Hz can be used.)	15 Gb	Post-Processing	Static (kinematic can be used)	DGPS or Absolute
3	ACAJ	Puerto de Acajutla	TRM41249.00	Trimble NetRS	**Internet**	UW-UPM	30 sec (1Hz can be used.)	1 Gb	Post-Processing	Static (kinematic can be used)	DGPS or Absolute
4	SNJE	San José	TRM41249.00	Trimble NetRS	**Internet**	UW	30 sec (1Hz can be used.)	1 Gb	Post-Processing	Static (kinematic can be used)	DGPS or Absolute
5	CNR1	Centro Nacional de Registro	TRM41249.00,	Topcon GB1000	**Internet**	UW	30 sec (1Hz can be used.)	100 Mb	Post-Processing	Static (kinematic can be used)	DGPS or Absolute
6	SSSV	San Salvador	SEPCHOKE_B3E6	SEPT POLARX5	**Internet**	JPL	1Hz (resampling to 30 sec)		Real Time and post-processing	Static (kinematic can be used)	DGPS or Absolute
7	AIES	Aeropuerto Internacional El Salvador	TRM41249.00	Trimble NetRS	On site	UW	30 sec (1Hz can be used.)	1 Gb	Post-Processing	Static (kinematic can be used)	DGPS or Absolute
8	LALI	Puerto de La Libertad	TRM41249.00	Topcon GB1000	On site	UW-UPM	30 sec (1Hz can be used.)	1 Gb	Post-Processing	Static (kinematic can be used)	DGPS or Absolute
9	SVCI	San Vicente	TPSCR.G5	Trimble NetRS	On site	JICA	30 sec (1Hz can be used.)	1 Gb	Post-Processing	Static (kinematic can be used)	DGPS or Absolute
10	VMIG	Volcán de San Miguel	TRM 57971-00	Trimble Net R9	On site	UW	30 sec (1Hz can be used.)	4 Gb	Post-Processing	Static (kinematic can be used)	DGPS or Absolute
11	PATI	Patio de Finca Santa Isabel	TRM41249.00	Trimble R7	On site	MARN	30 sec (1Hz can be used.)	100 Mb	Post-Processing	Static (kinematic can be used)	DGPS or Absolute
12	PMON	Piamonte	TRM41249.00,	Topcon GB1000	**Internet**	UW-UPM	30 sec (1Hz can be used.)	1 Gb	Post-Processing	Static (kinematic can be used)	DGPS or Absolute

2.2.8 関連する他機関プロジェクトの聞き取り（京都大学科学プロジェクト）

「Draft minutes of the meeting on a scientific project with the professors from Kyoto University in Japan」に示した通り、我々のプロジェクトに関わる課題を見出すことはなかった。ただ、MARN からの説明で EEW がチャンネル10で緊急放送されている説明があった。MARN は情報を自動オンラインで試験的にチャンネル10に送信している。チャンネル10での一般向け放送での取り扱いは未確認だが、実施されていない模様。MARN が実情をチャンネル10に確認することとした。下のコラム参照。

EWBS issue

6) Result 2-2: MARN has explained the “test of EWBS” under the EEW project and has provided the document with the below explanation in the column.

> In the following link, I have placed a report generated in the earthquake early warning project, on pages 21 to 24 you can find information on theEWBSs that Japan delivered to El Salvador within the framework of the JICA-SIGET project, as well as preliminary results of the tests that have been carried out to measure the delay times from the moment the earthquake occurs until it is transmitted by digital television.
> Now in El Salvador only digital television is broadcast for the Metropolitan Area of San Salvador.
> https://drive.google.com/file/d/1d2nbUUv5UPACyrUgdz9wSEqSuU0_LhYz/view?usp=sharing

Expert has updated the EWBS document made by himself. -> Expert thinks that EWBS could be used not only for EEW but also for Tsunami warning to the public. So, itmight be better for us to talk the idea of its usage for tsunami warning to DGPC.

2.3 第四次業務のその他の項目の結果

その他の項目は、主に、「現地での実施が不可欠な事項」の実施を通じて下表に示すような進展があった：

目標とする成果 / 目標とする成果の型	仕様書 第四次	仕様書 第五次	成果達成状況（2022年6月13日現在）赤：済/青：未（注：「計画」とは「業務の課題と改善の方向性についてのDGOAとの協議」を踏まえた「DGOA担当職員と定める技術移転・研修計画」）；緑：26Jul22での現状
実施した津波予測システム改善内容について、最終的な承認を得る。		(14)-②	未着手
実施した津波予警報ガイドライン・プロトコル改善内容について、最終的な承認を得る。		(14)-③	未着手
本件技術移転についてセミナーを実施し、成果をDGOA、DGPC、CATAC内で広く共有する。		(14)-⑤	未着手
①移転した知識・技術・知見が先方政府組織内に定着し、長く活用されるための工夫・取組について検討する。 ②中南米地域では、これまでJICAが取り組んできた防災分野の協力の成果を、ネットワーク化（仮想的なネットワーク）による域内の他国にも展開していく構想がある。エルサルバドルにおける地震・津波分野についても、その成果提供の一つのリソース国として、教材作成・提供、動画作成・提供、経験・成果の発信、エルサルバドル国内での学びの場の提供などを検討する。		(17)	未着手
目標とする成果1	(11)-②③	(14)-②③	
1) フェーズ1での導入内容の現状確認・評価	(11)-②③	(14)-②③	
a) 地震発生検知～津波警報発表の時間：20分以上を3年間で5～10分短縮 / 津波・地震監視システム：安定稼働の仕組確立（地震・津波の監視体制改善、津波データベース改善）	(11)-②	(14)-②	確認・評価済、計画策定中（第204回会議から）
b)発震機構とMwの利用：地震発生後15～30分で監視業務で利用可能化（CMT 解析の導入）	(11)-②	(14)-②	確認・評価済、計画策定中（第205回会議から）
c) その他			
c-1) 津波監視手引書	(11)-③	(14)-③	確認・評価済、計画策定中（第206回会議から）、改訂版作成必要・作成中
c-2) 津波監視現業体制での技術レベル：維持・改善研修体制確立	(11)-②③	(14)-②③	確認・評価済（改訂版開発必要・開発中）
2) 見届けることとしていた課題	(8)-②	(8)-②	
a) CMT解析機能：M6.5未満の地震をカバーするよう地域の地震波速度特性を取込だグリーン関数データベース（GFDB）調達	(11)-②	(14)-②	課題解決確認済、計画策定中（第207回会議から）
b) 津波データーベース運用改善：地震パラメーター自動入力機能開発及び津波データーベース改良	(11)-②	(14)-②	課題解決確認済、計画策定中（第214回会議から）
c) 地震観測網復旧の効率的な取扱いのための道具：開発（地震観測網復旧の手順書作成）	(11)-②③	(14)-②③	課題未解決確認済（機材調達で対応中）
d) 津波警報解除手順書：作成	(11)-③	(14)-③	課題解決確認済（補足必要・作成中）
e)バックアップシステムの適正化：対応	(11)-②	(14)-②	課題解決確認済（更新計画確認中）
f) その他			
f-1)現業当番者手引書、公式津波プロトコル、及びガイドライン：共有化・確立	(11)-③	(14)-③	課題未解決確認済（監視総局内部津波警報発表訓練参観の結果を踏まえ、手引書の訓練準備時での利用をすること、作業手順の単純化の促進を図ることとした。）
f-2) MARNガイドブック：確立	(11)-③	(14)-③	確認・評価済（沿岸地域の津波対策の現状確認の結果を踏まえ、更新版作成とともに学校向けのダイジェスト版の作成、そのSNSでの提供の実施など検討することとした。）
f-3)e-mailの公式利用、FAX点検の日課への導入：確立	(11)-②③	(14)-②③	課題未解決確認済、対応中、計画策定着手（第206回会議から）（市民防災局本部及び監視センターのそれぞれの運営施設の現状把握の結果、及び監視当番職員の引継ぎ参観の結果を踏まえ、公式津波プロトコルの改訂も含めて、実態に即したものの提案をすることとした。）

f-4) 異常地震活動対応標準手順:確立	(11)-③	(14)-③	課題解決確認済(改訂の必要性検討中)(滞在期間中に7月15日2時41分にエルサルバドル西部のAhuachapánで発生したM4.4での対応結果を踏まえ、1)MT図の利用、2)Calm情報の利用のそpれぞれの促進を図ることとした。)
f-5) 津波警報解除後の注意喚起情報:導入検討	(11)-②③	(14)-②③	課題済(更新の必要性検討中)
f-6) 津波の高さが小さくなってきた以降に襲来する大きな津波の予想:検討	(11)-②③	(14)-②③	確認・評価済(MARNに津波シミュレーションを実施してもらいさらに検討中)
f-7) 津波実況監視手段Tide Tool の利用:現業者での利用推進	(11)-②③	(14)-②③	課題対応未確認(津波シミュレーションに見いだされた課題とともに検討予定)
f-8) 津波監視現業技術レベル維持・改善のための研修体制:部外者参加も含めた検討(目標とする成果 1-1 c-2参照)	(11)-②	(14)-②	確認・評価済(改訂版開発必要・開発中)
目標とする成果 2	(11)-②③	(14)-②③	
CATACから発出される津波情報がDGOAの津波予測システムに適切に反映	(11)-②③	(14)-②③	遠隔打合せ2回実施済、課題整理済(CATACは公式運用にはいる許可をIOCから得ていない。一方、本格的な試験運用も開始していない。今後理由や予定を確認することとした。)
DGOAとCATAC間のシステムのバックアップ機能を構築	(11)-②③	(14)-②③	遠隔打合せ2回実施済、課題整理済(CATACは津波処理システムSeisCOPMの更新を終えていない。MARNは終えている。この更新を待って改めて相談することとしている。)
CATACとの情報の共有化の促進	(11)-②③	(14)-②③	遠隔打合せ2回実施済、課題整理済(同上)
CATACとともに、津波警報内容の理解促進と連携強化を目的とした共同津波警報訓練、及び合同ワークショップを立案実施	(11)-②③	(14)-②③	7月4日～6日コスタリカで開催されたEWS会合の際、MARNはCATAC担当者と打合せ:CATACよりPACWAVE22での訓練実施提案があり、世界津波の日のDGPCとの実施予定と合わせて検討中
目標とする成果 3(DGPCと共有する津波予警報ガイドライン・プロトコルを改善)	(11)-②③	(14)-②③	
DGOAがDGPCと共有する現状の津波予警報ガイドライン・プロトコルを整理、課題に対し助言	(11)-③	(14)-②③	合同訓練1回実施済、ワークショップ1回開催済、課題対応中(市民防災局の本部及び監視センターのそれぞれの運営施設の現状把握の際、市民防災局長からMARNとDGPCとの共通の手順を確率すべきとの提案があり、検討することとした。)
津波予警報ガイドライン・プロトコルに、CATACから発出される津波情報を適切に反映	(11)-③	(14)-②③	合同訓練1回実施済、ワークショップ1回開催済(市民防災局の本部及び監視センターのそれぞれの運営施設の現状把握の際、CATACの情報のことを紹介した。CATACの本格テスト運用が始まるまでに対応を相談することとしている。)
DGOAとDGPC間の情報共有促進に資する助言、DGOA担当職員とともに、適宜、DGPCと意見交換	(11)-③	(14)-②③	合同訓練1回実施済、ワークショップ1回開催済、課題対応中
DGPCとともに、津波警報内容の理解促進と連携強化を目的とした共同津波警報訓練、及び合同ワークショップ立案実施	(11)-③	(14)-②③	合同訓練1回実施済、ワークショップ1回開催済、課題対応中
目標とする成果4	(11)-④	(14)-⑤	
今後の業務改善に向けた提言	(11)-④	(14)-⑤	
策定された地震・津波監視業務の高度化に向けた今後の指針を関係者に共有するためのセミナーを実施		(14)-⑤	未着手
1) GPS観測網の地震監視現業での活用(GPS 観測システムから得られるリアルタイムデータの活用) / 津波地震や浅発地震を対象にしたWphaseによるMw及び発震機構推定	(11)-④ア)		GPS測量網の現状確認済、必要な機材等調査中
2) 地震波形を用いた解析による震源断層の滑り量分布の把握	(11)-④イ)		機材調達において現状確認済、提言検討中
3)モーメントレート関数表示機能(震源時間関数の把握)	(11)-④ウ)		調達機材で対応可を確認済、詳細確認中
4) その他	(11)-④ウ)～カ)	(14)-⑤	
地震波初動解析による発震機構把握	(11)-④ウ)～カ)	(14)-⑤	既存のシステム及び調達機材で対応可を確認済、詳細検討中
マグニチュード過小評価手法 / 日本の地震・津波監視業務に関し、過去事象の教訓・課題・改善共有			提言検討中
内陸地震活動の震源分布推定の精度向上のためのDD手法			未着手
複数地震同時発生への自動震源解析の信頼性向上のためのIPF手法			未着手
震源決定精度向上のための観測点への重みづけの微調整 / ステーションコレクションの導入			提言検討中
津波警報の精緻化のための海岸を分割した警報発表手法			提言検討中
津波観測測器がない海岸のボランティアによる監視安全・効率化			提言検討中
エルサルバドルの地震マイクロゾーニング地図の更新のためのガイドラインの検討			未着手
機材			
機材調達(当初予定分)			済(未到着のワークステーション以外について利用状況を確認した。)
機材調達(追加分)			作業中(津波フラッグについては、沿岸地域の津波対策の現状確認の結果を踏まえ、ラ・リベルタのサンディエゴ浜のライフセーバー監視所5箇所で試験運用することを市民防災局との津波訓練評価ワークショップまでに相談することとした。)
他の国際協力機関の関連活動の状況把握			
ユネスコによるTsunami Readyプロジェクト			状況確認継続(沿岸地域の津波対策の現状確認において、津波避難経路の標識が設置されていることなど確認したが、他の避難経路標識との運用との調整や、同標識の保守管理などの課題が見いだされ、津波警報を発表する際にこの現状を踏まえた何らかの対応が必要と認識した。)
スイス(Swiss Seismological Service, SED)によるEarthquake Early Warning(EEW)開発、EWBS			状況確認継続(チャンネル10でEWSのバナー字幕が出るとのこと。運用責任者や運用形態を確認する。)
米州開発銀行(Inter-American Development Bank, IDB)による地震危険度評価プロジェクト			状況確認継続

付録 1 作業経過

Visit-activities 17Jun22 - 31Jul22 with El Salvador Time as of 26Jul22				
2022			Meeting numeric orders	Contents of the activities of the Expert in El Salvador Time (JST is obtained by adding 15 hours to El Salvador Time.)
Month	Day			Actual
Jun	17	Fri		(National holiday: Dia del Padre) Departure from Japan JST (Transit stay at Houston in US)
Jun	18	Sat		Arrival at El Salvador El Salvador Time
Jun	19	Sun		Activities should start in El Salvador.
Jun	20	Mon	501	14:20-14:40 meeting to discuss 1) GPS, 2) Activity plan. Gernerally 07:30-12:30 and 13:10-15:30 Stay in the office. In principle on Mondays, Wednesdays, Fridays: 15:00-15:30 meeting
Jul	21	Tue		09:50 Greeted to DG who has come to me 1015-10:30 Talked about GPS status with Douglas in his room Around 11:00 Talked about "later attack simulation issue" eith Luis at his seat To prepare the coming meetings
Jun	22	Wed	502	To rearrange the Work Plan to follow the idea from JICA headquarters -> To tentatively "fix" interpreteres hiring date and time. 15:00-15:30 meeting to discuss 1) Draft minutes of the meeting held on 14Jun22 & 20Jun22, 2) Category 6, 3) Review of the items prioritized in handling because those depend on the counterpart related to their progress like a) Guideline, b) CATAC, c) GPS, d) Self-training, 4) AOB
Jun	23	Thu		15:00-16:00 To greet JICA and to report the Work plan / To take the actions accroding to the activity-timeflow.
Jun	24	Fri	503	11:20-11:50 To report the Work plan to DG 15:00-15:30 meeting to discuss 1) Category 7, 2) Guideline, 3) CATAC, 4) GPS, 5) DGPC
Jun	25	Sat		To take the actions accroding to the activity-timeflow.
Jun	26	Sun		To take the actions accroding to the activity-timeflow.
Jun	27	Mon	504	Checked the equipment procured with JICA support 15:00-15:40 meeting to discuss 1) Element 1 and Guideline, 2) CATAC, 3) GPS, 4) DGPC, 5) Self-training system
Jun	28	Tue		Discussed the internal tsunami simulation exercise scenario and its metod with Luis Handled the GPS issue with the information goven from Topcon company Took the actions accroding to the activity-timeflow.
Jun	29	Wed	505	15:00-15:30 Discussed 1) Element 1 and Guideline, 2) CATAC, 3) GPS, 4) DGPC, 5) Self-training system
Jun	30	Thu		Prepared the contents for the meeting with DG of DGPC
Jul	1	Fri	506	09:05-10:55-12:05-12:35 Visit DGPC headquarters and the monitoring center together with interpreter and meet with DG of DGPC a) to explain the cooperation status between MARN and DGPC, b) to make greetings to DGPC, c) to understand the status of their facilities conditions 15:00-15:30 meeting to discuss 1) Element 2 and Guideline, 2) CATAC, 3) GPS, 4) DGPC, 5) Self-training system
Jul	2	Sat		To take the actions accroding to the activity-timeflow.
Jul	3	Sun		To take the actions according to the activity-time flow.
Jul	4	Mon	507	(EWS meeting during 4-6 of July in Costa Rica, which Griselda participated in. There Griselda talked with Dr. Strauch about CATAC issue.) 15:00-15:30 meeting to discuss 1) Element 5/b, 2) Guideline, 3) DGPC, 4)Self-training system
Jul	5	Tue		07:00-07:30 To observe the shift takeover process
Jul	6	Wed	508	15:00-15:30 meeting to discuss 1) Element 5/b, 2) Guideline, 3) DGPC, 4) Self-training system
Jul	7	Thu		Prepared the itinerary of La Libetad 13:30-14:30 Internal tsunami simulation exercise with interpreter
Jul	8	Fri	509	15:00-15:30 meeting to discuss 1) Element 5/b, 2) Guideline, 3) DGPC, 4)Self-training system
Jul	9	Sat		To take the actions according to the activity-time flow.
Jul	10	Sun		To take the actions according to the activity-time flow.
Jul	11	Mon	510	15:00-15:30 meeting to discuss 1) Element 3/c, 2) Guideline, 3) CATAC, 4) GPS, 5) Self-training system
Jul	12	Tue		13:30-14:30 Review of the Internal tsunami exercise with interpreter To take the actions according to the activity-time flow.
Jul	13	Wed	511	15:00-15:30 meeting to discuss 1) Element 3/c, 2) Guideline, 3) CATAC, 4) GPS, 5) Self-training system
Jul	14	Thu		Visit La Libertad to understand the status of the coastal conditions
Jul	15	Fri	512	15:00-15:30 meeting to discuss 1) Element 3/c, 2) Guideline, 3) CATAC, 4) GPS, 5) Self-training system
Jul	16	Sat		To take the actions according to the activity-time flow.

Jul	17	Sun		To take the actions according to the activity-time flow.
Jul	18	Mon	513	07:30-08:00 meeting to discuss 1) Element 1/d, 2) Guideline, 3) CATAC, 4) GPS, 5) DGPC
Jul	19	Tue		Visit Usultan (Península San Juan del Gozo; Bahia de Jiquilisco) to understand the status of the coastal conditions with MARN
Jul	20	Wed	514	07:30-08:00 meeting to discuss 1) Element 1/d, 2) Guideline, 3) CATAC, 4) GPS, 5) DGPC
Jul	21	Thu		To make PCR Test reservation with support from Rodolfo To take the actions according to the activity-time flow.
Jul	22	Fri	515	07:30-08:00 meeting to discuss 1) Element 1/d, 2) Guideline, 3) CATAC, 4) GPS, 5) DGPC 08:50-11:20 meeting with Kyoto Univ Prof. Ito and Prof. Nakano (El Salvador during 20th and 23rd). To prepare the Report of the visit-activity in Japanese.and to share it with JICA
Jul	23	Sat		To take the actions according to the activity-time flow.
Jul	24	Sun		To take the actions according to the activity-time flow.
Jul	25	Mon		To take the actions according to the activity-time flow.
Jul	26	Tue	516	07:30-08:05 meeting to discuss 1) Procurement of equipment, 2) Guideline, 3) CATAC, 4) GPS, 5) DGPC, 6) Self-training system 15:00-16:00 Reporting the results to JICA
Jul	27	Wed	517	09:00-10:00 Meeting with GPS dealer with a sequential interpreter 10:40-11:10-11:30-12:00 PCR Test at Analiza Laboratorios Clinico Escalopn with Rodolfo 13:30-14:00 Reporting to DG (the date and time are tentative and they should be confirmed) 15:00-15:30 meeting to discuss 1) Procurement of equipment, 2) Guideline, 3) CATAC, 4) GPS, 5) DGPC, 6) Self-training system
Jul	28	Thu		To get certificate of PCR negative proof
Jul	29	Fri		Departure from El Salvador El Salvador Time (Transit stay at Houston in US)
Jul	30	Sat		
Jul	31	Sun		Return to Japan JST

付録 2 プロジェクト全体の日程概要

Work Schedule (Dispatch of Expert) as of 23May22

JMBSC work in El Salvador　JMBSC remote-work

Year	2021										2022												2023			
Month	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4
Work periods in El Salvador																										
Days			10 (17 virtual-meetings)				30 (26 virtual-meetings)					30 (26 virtual-meetings)					8 (7 virtual-meetings), 45 (visit), 22 (26 virtual-meetings)						90			

Period

第四次業務結果報告書

（エルサルバドル国　地震・津波情報の分析能力強化 Phase 2、2021～2023 年）

令和 **4** 年 **9** 月 **23** 日

JMBSC 森　滋男

1. 作業日程実績

当初のワークプラン[1]に従い、一部手直しして作業を実施した。その作業経過は、**付録２**に示した。また、プロジェクト全体のスケジュールについては**付録１**に示した。なお、和文報告書のみにおいて、**付録７**に「仕様書に示された目標とする課題の達成状況」も添付した。

2. 達成状況

2.1 ワークプランに示した目標とする成果と作業手順

下欄に目標とする成果を示し、下の**図１**と**図２**とに作業手順を示した。**図１**に示すように、第四次業務は、全ての成果１～４及び機材調達に取り組むこととしていた。

<u>上位目標</u>

MARN の DGOA をカウンターパート（以下、「C/P」）機関とし、地震・津波監視及び警報発令業務の実施能力の向上

<u>目標とする成果</u>

成果１：フェーズ1で導入・提案した内容が適切に実践される。

成果２：CATACから発出される津波情報がDGOAの津波予測システムに適切に反映され、両者間の情報共有が促進される。

成果３：DGOAがDGPCと共有する津波予警報のためのガイドライン・プロトコルが改善される。

成果４：地震・津波監視システムの高度化に資する技術が紹介され、システムの高度化に向けた今後の指針が定まる。

図１ 作業手順

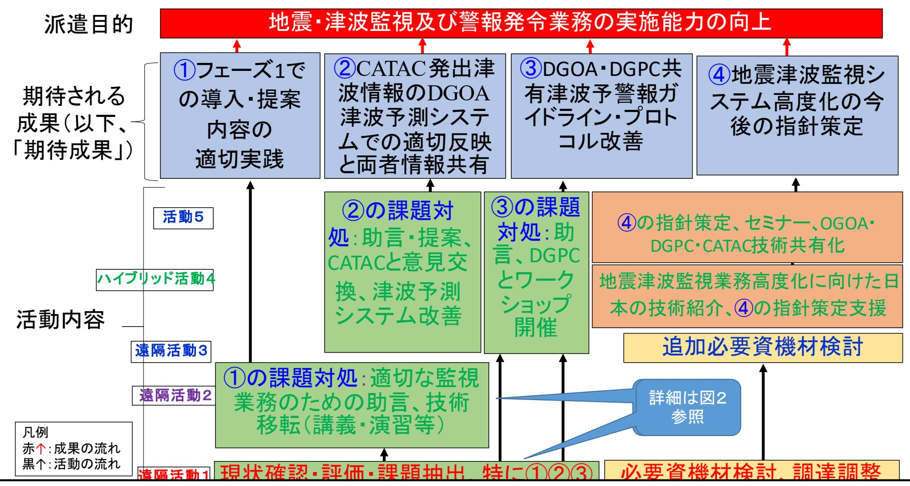
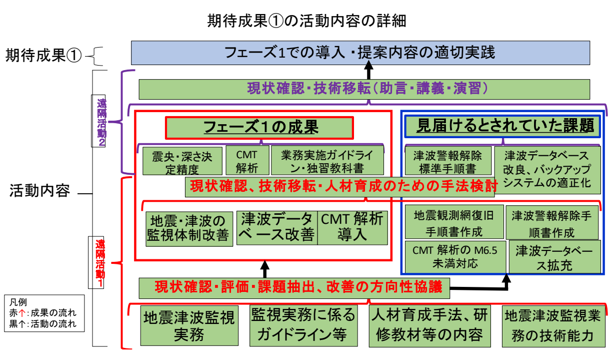


図２　期待される成果１の作業手順



---

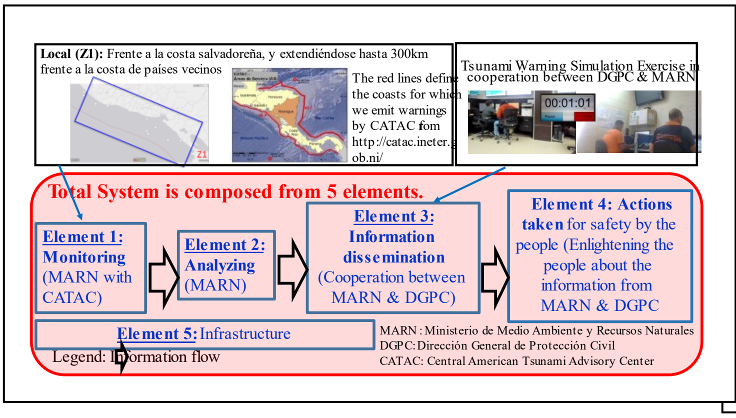
[1] Work Plan of the Short-term Expert Dispatch to MARN in El Salvador as of 09Jun22

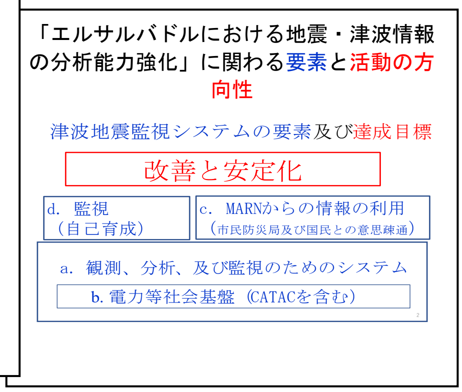
2.2 第四次業務における目標の詳細と達成状況

第四次業務で扱うべき「目標（成果）」と、それに向けての活動内容について、ワークプランでは次の欄に示したように述べている。

<u>目標（成果） １について、</u>
活動１　Phase1 提案/確立された技術の実装と適切な機能の検証再開
活動２　提案・研修により Phase1 提案/確立された技術の改善再開。特に、監視シフト担当官が毎月作成する「地震月報」の充実に取り組み、これの作成を通じた自己啓発体制の確立を図る
活動３　アンケートや訓練を通じて、適宜してきた研修資料を適宜見直し、修正。特に自己啓発体制の確立のために、地震月報作成作業の実施を支援する。その際、地震活動分析の道具（ソフトウェア）を提供する
<u>目標（成果） ２について、</u>
活動４　以下の実施を通じて、目標を達成する（第五次業務に継続）：
a）DGOA の津波警報システムに CATAC からの津波情報を適切に反映させるための助言・提案
b）DGOA と CATAC の間の相互バックアップ機能を構築するために DGOA に助言・提案
c)DGOA と CATAC との間の情報共有の促進に資する提案、DGOA と共に適宜 CATA と意見交換
d)CATAC との 津波警報発表訓練・ワークショップの企画・実施
<u>目標（成果） ３について、</u>
活動５　以下の実施を通じて、目標を達成する（第五次業務に継続）：
a)DGOA が DGPC と共有している現在の津波警報ガイドライン/プロトコルを整理し、課題について提案
b)CATAC から発せられた津波情報を「津波警報ガイドライン・プロトコル」に適切に反映
c)DGOA が DGPC と共有する情報の促進に資する提案、DGPC と意見交換
d）DGPC と共同で、津波警報訓練及び共同ワークショップの実施
<u>目標（成果） ４について、</u>
活動６　以下の実施を通じて、DGOA の地震・津波監視業務の高度化を支援し、そのための今後の指針を作成：日本の技術等の提示など次の事項の実施、
a)GPS 観測網の地震監視現業での活用（GPS 観測システムから得られるリアルタイムデータの活用） / 津波地震や浅発地震を対象にした W-phase による Mw 及び発震機構推定）
b)地震波形を用いた解析による震源断層の滑り量分布の把握
c)モーメントレート関数表示（震源時間関数の把握）
d）日本における地震・津波監視活動の経験の共有
e）津波・地震監視作業の将来の改善に向けた課題抽出のための DGOA との協議
f）DGOA による地震・津波監視システムの高度化ガイドライン作成支援
<u>機材調達について、</u>
活動７　調達された機材の運用状況確認
活動８　DGOA が追加の資材・設備を調達する必要があるかどうかを確認し、必要に応じて JICA エルサルバドル事務所に提案

上記４つの目標（成果）の下には小目標を設定した。第四次業務での小目標への到達状況を**次頁の表**に示した。この表では、目標（成果）・小目標を**下の２つの図**に示すように「エルサルバドルにおける地震・津波情報の分析能力強化」に関わる全体システムを、５つ（1～5）又は４つ（a～d）の要素（Elements）に分類し、さらに、日々の監視業務に関連する技術の内容に応じて７つに分類した。





目標とした成果（改善させる機能）及び小目標 「津波警報システムを構成する要素」及び「各要素の基本機能」に応じて分類 「計画」とは「業務の課題と改善の方向性についてのDGOAとの協議」を踏まえた「DGOA担当職員と定める技術移転・研修計画」）	目標達成状況 9月21日現在
要素 2/a:観測、分析、及び監視システム	24Aug22以降分類別に順次計画策定 07Sep22津波指針作成
分類1: 地震津波監視	18Sep22計画策定
1-1-a 地震発生検知～津波警報発表の時間:20分以上を3年間で5～10分短縮 / 津波・地震監視システム:安定稼働の仕組確立（地震・津波の監視体制改善、津波データベース改善）	課題あり、対応策提示
1-1-c-1 津波監視手引書	課題あり、対応策提示 津波監視手引書に記述
1-2-b 津波データーベース運用改善:地震パラメーター自動入力機能開発及び津波データーベース改良	課題あり、対応策提示
1-2-f-1 現業当番者手引書、公式津波プロトコル、及びガイドライン:共有化・確立	課題あり、対応策提示
1-2-f-4 異常地震活動対応標準手順:確立	課題あり、対応策提示
4-4-e 震源決定精度向上のための観測点への重みづけの微調整 / ステーションコレクションの導入	課題あり、対応策提示
分類2: CMT及びMw監視	24Aug22計画策定
1-1-b 発震機構とMwの利用:地震発生後15～30分で監視業務で利用可能化（CMT 解析の導入;Mwはモーメントマグニチュード）	課題あり、対応策提示
1-2-a CMT解析機能:M6.5未満の地震をカバーするよう地域の地震波速度特性を取込だグリーン関数データベース（GFDB）調達	課題なし
4-3モーメントレート関数表示機能（震源時間関数の把握）	課題あり、対応策提示
4-4-a 地震波初動解析による発震機構把握	課題あり、対応策提示
分類3:津波対応	18Sep22計画策定 1課題増
1-2-d 津波警報解除手順書:作成	課題あり、対応策提示
1-2-f-5 津波警報解除後の注意喚起情報:導入検討	課題なし
1-2-f-6 津波の高さが小さくなってきた以降に襲来する大きな津波の予想:検討	課題あり、対応策提示
1-2-f-7 津波実況監視手段Tide Tool の利用:現業者での利用推進	課題あり、対応策提示
要素5/b: CATACを含む電力等社会基盤	18Sep22計画策定
分類4: 復旧及びバックアップ	計画策定（要素5/bの計画に含めた）
1-2-c 地震観測網復旧の効率的な取扱いのための道具:Platform開発（地震観測網復旧の手順書作成）	課題あり
1-2-e バックアップシステムの適正化:対応	課題あり
分類5: CATACとの協力を含むデータ及び情報収集	計画策定（要素5/bの計画に含めた）
2 CATACとの情報の共有化の促進	課題あり、対応策提示
4-1 GPS観測網の地震監視現業での活用（GPS 観測システムから得られるリアルタイムデータの活用） / 津波地震や浅発地震を対象にしたWphaseによるMw及び発震機構推定	課題あり
スイス（Swiss Seismological Service, SED）によるEarthquake Early Warning（EEW)開発（EWBS）	課題あり、対応策提示
要素3/c: MARNからの情報の利用（市民防災局、国民）	26Aug22計画策定
分類6: DGPCとの協力を含む防災のための津波警報の発信	計画策定（要素3/cの計画に含めた）
1-2-f-3 e-mailの公式利用、FAX点検の日課への導入:確立	課題あり、対応策提示
3 DGPCの津波警報利用:適切化	課題あり、対応策提示
要素1/d: 監視（人材育成）	02Sep22計画策定
分類7: 自主研鑽	計画策定（要素1/dの計画に含めた）
1-1-c-2 津波監視現業体制での技術レベル:維持・改善研修体制確立	課題あり、対応策提示
1-2-f-2 MARNガイドブック:確立	課題あり、対応策提示
1-2-f-8 津波監視現業技術レベル維持・改善のための研修体制:部外者参加も含めた検討	必要に応じて検討
4-2･4-4 今後の業務改善に向けた「他の技術の地震津波監視への導入」に係る提言	19Sep22他技術導入指針策定
1) 4-4-b マグニチュード過小評価手法 / 日本の地震・津波監視業務に関し、過去事象の教訓・課題・改善共有	課題あり、対応策提示
2) 4-4-c 内陸地震活動の震源分布推定の精度向上のためのDD手法	課題あり、対応策提示
3) 4-4-d 複数地震同時発生への自動震源解析の信頼性向上のためのIPF手法	課題あり、対応策提示
4) 4-2 地震波形を用いた解析による震源断層の滑り量分布の把握	課題あり、対応策提示
5) 4-4-f 津波警報の精緻化のための海岸を分割した警報発表手法	課題あり、対応策提示
6) 4-4-g 津波観測測器がない海岸のボランティアによる監視安全・効率化	課題あり、対応策提示
7) 4-4-h エルサルバドルの地震マイクロゾーニング地図の更新のためのガイドラインの検討	IDBプロジェクトが対応中

上表の目標達成状況は､達成状況に応じて文字の色分けをした｡赤は達成見通しがたったもの｡青はまだ途中段階のもの。但し、緑色の項目は、プロジェクトの成果品となる文書を示す。第四次業務では、このほか、機材調達及び本プロジェクトに関わりが深い「他の国際協力機関のプロジェクト」（**下表**）の状況把握も行った。

他の国際協力機関の関連活動の状況把握
米州開発銀行（Inter-American Development Bank, IDB)による地震危険度評価プロジェクト
ユネスコによるTsunami Readyプロジェクト

3. 活動内容及び小目標の最新の状況

実施した活動について、第 2.2 節の最初の部分に示した「目標とする成果」の順に報告する。また、その結果としての各小目標の最新状況の詳細について、達成見通しを得る途中段階のものを中心に報告する。なお、以下「計画」とは「業務の課題と改善の方向性についての DGOA との協議」を踏まえた「DGOA 担当職員と定める技術移転・研修計画」のことである。

3.1 目標（成果）1 について

1）活動 1

活動１　Phase1 提案/確立された技術の実装と適切な機能の検証再開
活動２　提案・研修により Phase1 提案/確立された技術の改善再開。特に、監視シフト担当官が毎月作成する「地震月報」の充実に取り組み、これの作成を通じた自己啓発体制の確立を図る
活動３　アンケートや訓練を通じて、適宜してきた研修資料を適宜見直し、修正。特に自己啓発体制の確立のために、地震月報作成作業の実施を支援する。その際、地震活動分析の道具（ソフトウェア）を提供する

Phase 1 で提案/確立された技術の実装と適切な機能の検証を実施し、**小目標 1-1 と 1-2** は以下の項目を除いてほぼ達成された。

a)「地震津波監視(分類 1)」については、領域 Z1 に発生する M6.4 と初期段階で判断された地震は、津波警報処理から抜け落ちる懸念があったが、M5.5 より大きい地震への対応の中で取り扱われ、抜け落ちることはないとのことであった。専門家はこのことについて確認することとしている。

分類 3 の「計画」を参照 [2]。

b)「復旧及びバックアップ(分類 4)」については、次の課題がある：

- Platform なしで地震観測ネットワークを効果的に維持する方法の検討
- 建物または施設からの地震津波監視職員が避難を余儀なくされた場合のバックアップ体制の検討。緊急時対応計画を、この検討を通じて作成。

要素 5/b の「計画」を参照 [3]。

c) 「DGPC との協力を含む防災のための津波警報の発信(分類 6)」については、次の課題がある：**Memo for conducting a trial use of the inspection list for DGPC as of 07Mar22** に基づき、DGPC への情報発信手段を日常的に点検する手順の確立に向けて、

- MARN の津波プロトコルを実態に応じて改正、
- DGPC への情報発信手段それぞれについて、位置づけを DGPC と合意する。

要素 3/c の「計画」参照 [4]。

d)「自己研鑽(分類 7)」については、次の課題がある：

- 「地震月報作成作業」を自己研鑽システムとしての利用の確立（準備作業を順次実施；地震月報作成の支援となる無料ソフト導入）。
- 地震津波カタログ確立。
- 自己研鑽教材の整理（特に CMT 分析に関する資料）。
- 地震・津波ガイドブック 2017 年更新（「要素 4 ：情報利用者」への啓発活動；国際地震センターや津波フラッグも盛り込む）。

[2] Category 3 as of 18Sep22
[3] Element 5(b) (Category 4 & 5) as of 18Sep22
[4] Element 3(c) (Category 6) as of 26Aug22

要素 1 / d の「計画」参照 [5]。

2）活動 2

Phase 1 で提案された/確立された技術の実装と適切な機能を強化するために遠隔打合せなどで確立された技術の確認と必要に応じた改善提案など実施した。しかし、上記活動 1 の結果に示す課題が残されている。

3）活動 3

「研修内容・資料」については、3.6 節に示す渡航時の活動、遠隔会議、津波訓練などを通じて、見直しを行ってきた。その内容は、「計画」、遠隔会議議事録などに記した。今後、これらは、自己研鑽用資料としてとりまとめることが必要。

3.2 目標（成果） 2について

活動４　以下の実施を通じて、目標を達成する（第 5 次活動に継続）： a）DGOA の津波警報システムに CATAC からの津波情報を適切に反映させるための助言・提案 b）DGOA と CATAC の間の相互バックアップ機能を構築するために DGOA に助言・提案 c)DGOA と CATAC との間の情報共有の促進に資する提案、DGOA と共に適宜 CATA と意見交換 d)CATAC との 津波警報発表訓練・ワークショップの企画・実施

4）活動 4

遠隔会議等で上記**活動 4-a、b、c、d** を実施することで、CATAC とあらゆる情報を共有するという目標を目指してきた。CATAC との打ち合わせの結果、次の 5 つの項目を検討することとなっている：

項目 1 地震・津波処理結果を実時間交換

項目 2 地震発生後短時間で、CATAC と MARN それぞれが発表する地震速報の処理結果統一 [6]

項目 3 音声ビデオについて、CATAC と MARN の永続的な接続を導入

項目 4 CATAC と MARN 間の衛星インターネット接続の確立

項目 5 CATAC に障害が発生した際に、MARN が CATAC のバックアップとなること。

これらについて以下の課題がある：

a) 項目 1~3 については、CATAC における SeisComP の ver3 から ver 4 へのバージョンアップ後にどのように処理するか CATAC と相談。また、合同の津波訓練とワークショップの開催。

b) 項目 4 については、予算的な課題があり、一覧から削除し、将来の課題とする。

c) 項目 5 については、**Backup of CATAC from Memo for the talk via email on 13Mar22 as of 22Aug22** という文書を作成し、8 月末に MARN の DG に提案した。この作業を進める。その内容は、現在の MARN の実施している機能の範囲内で CATAC バックアップとなるとするもの。

要素 5/b の計画を参照 [7]。

3.3 目標（成果） 3について

活動５　以下の実施を通じて、目標を達成する（第 5 次活動に継続）： a)DGOA が DGPC と共有している現在の津波警報ガイドライン/プロトコルを整理し、課題について提案 b)CATAC から発せられた津波情報を「津波警報ガイドライン・プロトコル」に適切に反映 c)DGOA が DGPC と共有する情報の促進に資する提案、DGPC と意見交換 d）DGPC と共同で、津波警報訓練及び共同ワークショップの実施

---

[5] Element 1(d) (Category 7) as of 18Sep22

[6] MARN は約 20 年前、ニカラグアとエルサルバドルが独立して異なる Magnitude の情報を発表し、人々を混乱させたことがあるので、発表する地震パラメータの統一について前向きに考えた方が良い。

[7] Element 5(b) (Category 4 & 5) as of 18Sep22

5）活動 5
DGPC と共有する津波警報ガイドライン/プロトコルを改善するために、渡航時や遠隔打合せにおいて**行動 5-a、b、c、d** を実施した。以下の課題がある：
a) MARN と DGPC が定期的に以下の協力活動を行うようにすること。
- 毎年津波訓練
- 毎年ワークショップを開催し、協力して、津波訓練の結果の点検や津波警報システムの改善状況の検実施
- CATAC からの情報の有効活用
- 最新の津波処理手順の共有
- その他残された課題への継続的な対処（参考資料：“MARN internal challenges”, “Workshop minutes”[8], “Queries from MARN to DGPC in 07Feb22 13:26 El Salvador Time”, and “EWBS issue”）。

b) 津波警報の適切な解除方法など、津波警報処理における共通手順の確立
d) 津波警報で地域住民の対応をどう把握するかの検討
要素 3/c の「計画」を参照[9]**。**

3.4 目標（成果） ４について

活動６　以下の実施を通じて、DGOA の地震・津波監視業務の高度化を支援し、そのための今後の指針を作成：日本の技術等の提示など次の事項の実施、 a)GPS 観測網の地震監視現業での活用（GPS 観測システムから得られるリアルタイムデータの活用） / 津波地震や浅発地震を対象にした W-phase による Mw 及び発震機構推定） b)地震波形を用いた解析による震源断層の滑り量分布の把握 c)モーメントレート関数表示（震源時間関数の把握） d) 日本における地震・津波監視活動の経験の共有 e) 津波・地震監視作業の将来の改善に向けた課題抽出のための DGOA との協議 f) DGOA による地震・津波監視システムの高度化ガイドライン作成支援

6）活動 6
地震・津波監視システムを強化する追加技術の導入に関する手引書[10]**を策定するため、**地震津波システム性能の診断を行った。その際、活動 6-a、b、c、d、e、f の活動や検討等も実施した。以下の課題への対応が必要：
a) **「CATAC との協力を含むデータ及び情報収集」（分類５）**の「GPS 観測網の地震監視現業での活用（GPS 観測システムから得られるリアルタイムデータの活用） / 津波地震や浅発地震を対象にした W-phase による Mw 及び発震機構推定」**(小目標 4-1)**
この小目標については、１）GPS 製造会社トプコンのエルサルバドルの販売代理店に、既存の２つの GPS 受信機を高度化するためのソフト開発の可能性などを相談し、その見積もりを依頼している。 また、２）メキシコの教授とチリの教授からこの問題について所要の情報の提供をしてきてもらっている。 専門家は、問題の進捗状況を加速するために情報をまとめる必要がある。 **要素 5/b の「計画」参照**[11]**。**
b) **「CMT 及び Mw 監視」（分類 2）** については、以下の活動を個別に実行することで、分析結果が豊富になる：
- 「地震波形を用いた解析による震源断層の滑り量分布の把握」**(小目標 4-2) <-活動:** 監視システムにこの機能を導入するための様々なツールの検討
- 「モーメントレート関数表示機能（震源時間関数の把握）」**(小目標 4-3)の作成 <-活動:** ISOLA を用いて導入し、実際の地震マグニチュードを早期に把握するための実用的な手順を開発

[8] Minutes of the workshop held on 25Jan22ver2
[9] Element 3(c) (Category 6) as of 26Aug22
[10] Guideline for introduction of the additional technologies in monitoring tsunamis and earthquakes as of 19Sep22
[11] Element 5(b) (Category 4 & 5) as of 18Sep22

- 「地震波初動解析による発震機構把握」**(小目標 4-4-a)<-活動**: OSOP と ISOA を用いて発震機構を把握するための実用的な手順を開発。

c) 「地震津波監視」**(分類 1)**については、以下の活動を個別に実行することで、分析結果が豊富になる：
- 「マグニチュード過小評価手法 / 日本の地震・津波監視業務に関し、過去事象の教訓・課題・改善共有」**(小目標 4-4-b)<- 活動**: "M100s"手法を監視システムに導入
- 「内陸地震活動の震源分布推定の精度向上のための DD 手法」**(小目標 4-4-c)< -活動**: DD 法のフリーソフトウェアを監視システムに導入
- 「複数地震同時発生への自動震源解析の信頼性向上のための IPF 手法」**(小目標 4-4-d) <- 活動**: 監視システムへの導入を念頭に、IPF 法を調査

d) 「津波対応」**(分類 3)** については、以下の活動を個別に実行することで、津波監視システムを高度化：
- 「津波警報の精緻化のための海岸を分割した警報発表手法」**(小目標 4-4-f)<-活動**: 「海岸分割による警報発表手法」の津波監視システムに導入するために、以下のことを確認・検討: 1)津波データベースの精度レベル、2)海岸分割の基準の設定（行政区域、地形、社会条件、海岸の傾斜度など）、3)住民にとっての利便性。
- 「津波観測測器がない海岸のボランティアによる監視の安全・効率化」**(小目標 4-4-g) <- 活動**: 海況を確認する観測員の安全を守るシステムの開発

追加の技術の導入については、「Guideline for introduction of the additional technologies in monitoring tsunamis and earthquakes as of 19Sep22[12]**」、及び分類 1 の「計画」**[13]**参照**

3.5 機材調達について、

活動７　調達された機材の運用状況確認 活動８　DGOA が追加の資材・設備を調達する必要があるかどうかを確認し、必要に応じて JICA エルサルバドル事務所に提案

下欄に示されている機材は、調達後、使用されているか点検がなされた。
“Status of the equipment procured by JICA as of 24Jul22 partially **verified by Expert”** 参照。

MARN-Procurement as of 18Sep22

EQUIPMENT DESCRIPTION	COMMENTS/JUSTIFICATION	QUANTITY
Digital radios: Brand: Ubiquiti. / Model: AirFiber 5XHD / Range: Greater than 100Km Frequency 5Ghz / 802.11 security protocol	To strengthen the operation rate of the seismic network through the improvement of transmission lines using digital technology. To be used at the three locations: One of the sets of antennas, which is the below "link c", use "34dBi gain" due to the long distance between the locations that use the radio communications. a) SanJose - Jayaque (Codes: SNJE-JAYA, latter has a repeater.) -> (changed to) Tecapa volcano towards Cerro Las Pavas. - pending installation. -> (changed to) Link: Cerro Loma Larga - Marn (Installation date: end of August). b) Las Nubes - Lomas de Alarcon (Codes:NUBE-LOAL, latter has a repeater.) -> (changed to) Cerro Pacayal towards Tecapa volcano - pending installation.-> (changed to) Link: Cerro Tecapa - Cerro Pacayal (Installation date: end of September). c) Centro de Gobierno (repeater point) - Marn. Through this link, information comes from the Pacayal station (Code: PACA.) or "CEL government center towards MARN". Already in operation.	**6**
Ubiquite brand dish antenna, **model AF-5G23-S45**, frequency 5Ghz, 23dBi gain, range greater than 15km, include hardware for installation.		**4**
Dish antenna Ubiquiti brand, **RocketDish 5G34 model,** 5Ghz frequency, 34dBi gain, range greater than 15km, include hardware for installation.		**2**
Workstation: Workstation Model: Precision 7920 Tower Chassis CL. Processor: Intel Xeon Silver 4210R (2.4GHz, 3.2GHz Turbo,10C, 9.6GT/s 2UPI, 13.75MB Cache, HT (100W)) DDR4-2400. Operating System Windows 10 Pro for Workstations (6 Cores Plus) Multi - English, French, Spanish. Memory: 64GB 4x16GB DDR4 2933MHz RDIMM ECC Memory. Graphics Card: NVIDIA® Quadro® P1000, 4GB, 4 mDP (7X20T). Hard / Drive: M.2 1TB PCIe NVMe Class 40 Solid State Drive. Keyboard: Dell Black Wired 10 Key Numeric Keypad KB813 Smart Card Keyboard. Mouse: Dell USB Laser 6-Button Mouse. Monitor: Dell 27 Monitor - P2722H.	1. To run specialized seismological and tsunami monitoring software. 2. More focused on tsunami simulations in real time	**1**
Laptops: screen display size 13.3 Inches, max Screen Resolution 1920 x 1080 Pixels Processor 1.6 GHz i5 / RAM 8 GB SDRAM / Hard Drive 256 GB ssd Wireless Type 802.11ac	To be used in the field in the configuration and maintenance of the seismic network.	**2**
ISOLA (MatLab software & specific toolboxes) Perpetual Standard License Individual: it is allowed to install the software on 4 PCs but there can only be one user, who will have unique credentials, with which they can access the software and others tools.	To get 1) Display of moment rate function to understand the actual seismic magnitude earlier 2) Flexible calculation of GFDB and handling in-depth analysis related to the determination of the CMT Note 1 Its calculations are not in real time. Note 2 OSOP CMT doesn’t have the above functions but can work in real time. Note 3 Both can handle initial motion (polarity) analysis for grasping focal mechanisms by entering polarities.	**1**

[12] Guideline for introduction of the additional technologies in monitoring tsunamis and earthquakes as of 19Sep22
[13] Category 1 as of 18Sep22

右欄に示されている機材等 は、追加で調達することになったもの。
- 2 番目の項目は、Platform ソフトの開発は、開発業務への応募者と予算面で折り合いがつかず調達中止となった。
- 1 番目の項目は、契約がなされ、開発中。
- 3 番目の項目は内容調査中。
- 4 番目の項目は 11 月上旬頃に納品見込み。
- 津波フラッグと教科書類の調達は、専門家が仕様書作成を準備する。

MARN-Procurement additional items as of 18Sep22

EQUIPMENT DESCRIPTION	QUANTITY
GUI messages application (procurement of local engineer)	1
Seismic Station network maintenance platform (procurement of local engineer)	1
To telemeter the GPS of "Topcon NET-G3A (Reference station GNSS Receiver)" to get real time data from the stations	2
Workstation for GPS data	1
Tsunami flag	5
Textbook	6

3.6 渡航時の活動と関連事項
第四次業務のワークプランに基づき、渡航時、渡航不可欠な事項を中心に実施した。その活動内容は 、資料「Report on the results of visiting activities in the fourth activities ver3」に詳述。概要は次の通り：
1) 調達機材の現状確認(要素 1~5 に関連)
2) 市民防災局の本部(DGPC)及びその監視センター(要素 3,4 に関連)がある施設の状況の把握及び評価
3) 地震津波監視担当者の業務引継ぎの実情を見て評価(要素 1～3 に関連)
4)DGOA の内部津波警報シミュレーション訓練 (要素 1,2,3 に関連)の観測・評価
5) 沿岸域における津波対策の確認・評価 1(ラ・リベルタ: 社会環境面で津波に脆弱)(要素 3,4 に関連)
6) 沿岸域における津波対策の確認・評価 2(ウスルタン: 自然環境面で津波に脆弱)(要素 3,4)
7) GPS 製造会社トップコンの機器調達販売代理店との相談（要素 2 に関連）
8) 他機関の関連プロジェクト(京都大学科学プロジェクト)の聴取(要素 1,5 に関連)
9)「イスラ・デ・メンデス(ヒキリスコ)での 26Aug22 津波記念式典」への遠隔参加。**Wrap up the Ceremony on 26Aug 22"参照。**

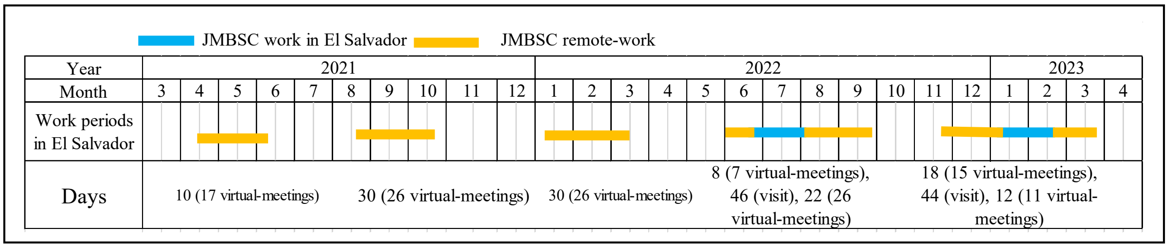
3.7 成果品
次のものが、第四次業務で、（作業途中ものもあるが）作成された。これらはプロジェクト終了時に成果品となる。
1) 津波ガイドライン(暫定版)
2) 地震・津波ガイドブック(作業中)
3) 自習教材(整理中)
4) 津波訓練シナリオ（暫定版）
5) 要素別・分類別技術移転・研修計画
6) 地震・津波監視システムを強化する追加技術の導入に関する手引書
7) 地震津波カタログ

3.8 第四次業務終了～第五次業務開始までの活動事項
今後 11 月下旬の第 五次業務開始までに、以下の項目に対処する。
1) 津波警報訓練の計画・実施（10 月 10 日、10 月 13 日、11 月 7 日前後の 3 回実施を想定）
2) 2022 年地震・津波ガイドブックの作成・印刷・配布（10 月末配布を想定）
3) 津波フラッグについて、DGPC との協議、及び調達・配布（11 月 7 日利用を想定）
4) ＧＰＳの高度化に向けた調達（9 月末までに見積もりを得ることを想定）
5) 地震・津波カタログ作成（上記第 2 項ガイドブック作成の基礎資料として利用できることを目指す）

3.9 本プロジェクトに関わりが深い「他の国際協力機関のプロジェクト」

ラ・リベルタードやウスルタンなどの現地視察の結果から、他の国際協力団体が実施した津波避難経路の標識が設置されていることが確認できた。しかし、a）目的に応じて異なる避難経路標識があることからその調整、b）標識の計画的な保守が必要であるような印象を持った。 津波警報を発表する際には、何らかの形でその状況を考慮に入れる必要がある。

付録 1 プロジェクト全体のスケジュール



付録 2 作業経過

Activities 01Jun22 - 19Sep22 with El Salvador Time as of 16Sep22				
2022			Virtual meeting numeric orders	Contents of the activities of the Expert in El Salvador Time **(JST is obtained by adding 15 hours to El Salvador Time.)**
Month	**Day**			Actual
Jun	1	Wed	401	15:00-15:45 Virtula meeting to discuss the Work plan on the 4th activity.
Jun	3	Fri	402	15:00-16:00 Virtula meeting to discuss a) Draft minutes of the meeting held on 01Jun22, b) Category 1 and the Guideline, c) Review of the items prioritized in handling because those depend on the people related to their progress like 1) CATAC, 2) GPS, 3) DGPC, and 4) Self-training system, and d) AOB (additional procurement).
Jun	6	Mon	403	15:00-16:00 Virtula meeting to discuss a) Draft minutes of the meeting held on 03Jun22, b) Category 2, c) Review of the items prioritized in handling because those depend on the people related to their progress like 1) Guideline, particularly “series of drill scenarios” for “Tsunami warning”, 2) CATAC, 3) GPS, 4) DGPC, and 5) Self-training system, and d) AOB.
Jun	8	Wed	404	15:00-16:00 Virtula meeting to discuss a) Draft minutes of the meeting held on 06Jun22, b) Category 3, c) Review of the items prioritized in handling because those depend on the people related to their progress like 1) Guideline, 2) CATAC, 3) GPS, 4) DGPC, and 5) Self-training system, and d) AOB.
Jun	9	Thu		14:00-15:00JST United Nations for Disaster Risk Reduction, UNDRR, Making Cities Resilient 2030（MCR2030）<https://mcr2030.undrr.org/>
Jun	10	Fri	405	**10:00-11:00JST** Programa (Fomentando la Cooperación Científica Técnica), Fortalcimiento de las capacidades y medidas contra el cambio climático (SATREPS): Investigación interdisciplinaria para la mitigación del desastres compuestos asociado a grandes terremotos y tsunamis en la costa del Pacífico de América Central y América del Norte 15:00-16:00 Virtula meeting to discuss 1) Draft minutes of the meeting held on 08Jun22, 2) Category 5, 3) Review of the items prioritized in handling because those depend on the counterpart related to their progress like 1) Guideline, 2) DGPC, and 3) Self-training system, 4) AOB
Jun	13	Mon	406	15:00-16:00 Virtula meeting to discuss 1) Draft minutes of the meeting held on 10Jun22, 2) Category 5, 3) Review of the items prioritized in handling because those depend on the counterpart related to their progress like a) Guideline, b) DGPC, and c) Self-training system, 4) AOB 17:00-18:00 (19:00-20:00 Boston Time; 08:00-09:00 14Jun22 JST) Virtula meeting with Topcon in Boston to explain what we need.
Jun	14	Tue	407	15:00-16:00 Virtula meeting to discuss 1) Draft minutes of the meeting held on 13Jun22, 2) Review of the items prioritized in handling because those depend on the counterpart related to their progress like a) Guideline, b) CATAC, c) GPS, d) DGPC, e) Self-training, 3) Category 6, 8) AOB
Jun	17	Fri		(National holiday: Dia del Padre) Departure from Japan JST (Transit stay at Houston in US)
Jun	18	Sat		Arrival at El Salvador El Salvador Time
Jun	19	Sun		Activities should start in El Salvador.
Jun	20	Mon	501	14:20-14:40 meeting to discuss 1) GPS, 2) Activity plan.
Jul	21	Tue		09:50 Greeted to DG who has come to me 1015-10:30 Talked about GPS status with Douglas in his room Around 11:00 Talked about "later attack simulation issue" eith Luis at his seat To prepare the coming meetings
Jun	22	Wed	502	To rearrange the Work Plan to follow the idea from JICA headquarters -> To tentatively "fix" interpreteres hiring date and time. 15:00-15:30 meeting to discuss 1) Draft minutes of the meeting held on 14Jun22 & 20Jun22, 2) Category 6, 3) Review of the items prioritized in handling because those depend on the counterpart related to their progress like a) Guideline, b) CATAC, c) GPS, d) Self-training, 4) AOB
Jun	23	Thu		15:00-16:00 To greet JICA and to report the Work plan / To take the actions accroding to the activity-timeflow.
Jun	24	Fri	503	11:20-11:50 To report the Work plan to DG 15:00-15:30 meeting to discuss 1) Category 7, 2) Guideline, 3) CATAC, 4) GPS, 5) DGPC
Jun	25	Sat		To take the actions accroding to the activity-timeflow.
Jun	26	Sun		To take the actions accroding to the activity-timeflow.
Jun	27	Mon	504	Checked the equipment procured with JICA support 15:00-15:40 meeting to discuss 1) Element 1 and Guideline, 2) CATAC, 3) GPS, 4) DGPC, 5) Self-training system
Jun	28	Tue		Discussed the internal tsunami simulation exercise scenario and its metod with Luis Handled the GPS issue with the information goven from Topcon company Took the actions accroding to the activity-timeflow.
Jun	29	Wed	505	15:00-15:30 Discussed 1) Element 1 and Guideline, 2) CATAC, 3) GPS, 4) DGPC, 5) Self-training system
Jun	30	Thu		Prepared the contents for the meeting with DG of DGPC

Jul	1	Fri	506	09:05-10:55-12:05-12:35 Visit DGPC headquarters and the monitoring center together with interpreter and meet with DG of DGPC a) to explain the cooperation status between MARN and DGPC, b) to make greetings to DGPC, c) to understand the status of their facilities conditions 15:00-15:30 meeting to discuss 1) Element 2 and Guideline, 2) CATAC, 3) GPS, 4) DGPC, 5) Self-training system
Jul	2	Sat		To take the actions accroding to the activity-timeflow.
Jul	3	Sun		To take the actions according to the activity-time flow.
Jul	4	Mon	507	(EWS meeting during 4-6 of July in Costa Rica, which Griselda will participate in. There Griselda will talk with Dr. Strauch about CATAC issue.) 15:00-15:30 meeting to discuss 1) Element 5/b, 2) Guideline, 3) DGPC, 4)Self-training system
Jul	5	Tue		07:00-07:30 To observe the shift takeover process
Jul	6	Wed	508	15:00-15:30 meeting to discuss 1) Element 5/b, 2) Guideline, 3) DGPC, 4) Self-training system
Jul	7	Thu		Prepared the itinerary of La Libetad 13:30-14:30 Internal tsunami simulation exercise with interpreter
Jul	8	Fri	509	15:00-15:30 meeting to discuss 1) Element 5/b, 2) Guideline, 3) DGPC, 4)Self-training system
Jul	9	Sat		To take the actions according to the activity-time flow.
Jul	10	Sun		To take the actions according to the activity-time flow.
Jul	11	Mon	510	15:00-15:30 meeting to discuss 1) Element 3/c, 2) Guideline, 3) CATAC, 4) GPS, 5) Self-training system
Jul	12	Tue		13:30-14:30 Review of the Internal tsunami exercise with interpreter To take the actions according to the activity-time flow.
Jul	13	Wed	511	15:00-15:30 meeting to discuss 1) Element 3/c, 2) Guideline, 3) CATAC, 4) GPS, 5) Self-training system
Jul	14	Thu		Visit La Libertad to understand the status of the coastal conditions
Jul	15	Fri	512	15:00-15:30 meeting to discuss 1) Element 3/c, 2) Guideline, 3) CATAC, 4) GPS, 5) Self-training system
Jul	16	Sat		To take the actions according to the activity-time flow.
Jul	17	Sun		To take the actions according to the activity-time flow.
Jul	18	Mon	513	07:30-08:00 meeting to discuss 1) Element 1/d, 2) Guideline, 3) CATAC, 4) GPS, 5) DGPC
Jul	19	Tue		Visit Usultan (Península San Juan del Gozo; Bahia de Jiquilisco) to understand the status of the coastal conditions with MARN
Jul	20	Wed	514	07:30-08:00 meeting to discuss 1) Element 1/d, 2) Guideline, 3) CATAC, 4) GPS, 5) DGPC
Jul	21	Thu		To make PCR Test reservation with support from Rodolfo To take the actions according to the activity-time flow.
Jul	22	Fri	515	07:30-08:00 meeting to discuss 1) Element 1/d, 2) Guideline, 3) CATAC, 4) GPS, 5) DGPC 08:50-11:20 meeting with Kyoto Univ Prof. Ito and Prof. Nakano (El Salvador during 20th and 23rd). To prepare the Report of the visit-activity in Japanese, and to share it with JICA
Jul	23	Sat		To take the actions according to the activity-time flow.
Jul	24	Sun		To take the actions according to the activity-time flow.
Jul	25	Mon	516	15:00-15:30 meeting to discuss 1) Procurement of equipment, 2) Guideline, 3) CATAC, 4) GPS, 5) DGPC, 6) Self-training system
Jul	26	Tue		Reporting to DG (the date and time are tentative and they should be confirmed) 15:00-16:00 Reporting the results to JICA
Jul	27	Wed	517	08:00-09:00 Meeting with GPS dealer with a sequential interpreter 10:40-11:10-11:30-12:00 PCR Test at Analiza Laboratorios Clinico Escalopn with Rodolfo 15:00-15:30 meeting to discuss 1) Procurement of equipment, 2) Guideline, 3) CATAC, 4) GPS, 5) DGPC, 6) Self-training system
Jul	28	Thu		To get certificate of PCR negative proof
Jul	29	Fri		Departure from El Salvador was cancelled
Jul	30	Sat		Departure from El Salvador El Salvador Time (Transit stay at Mexico City in Mexico)
Jul	31	Sun		Trip
Aug	1	Mon		Official holiday in El Salvador. Return to Japan JST
Aug	8	Mon	408	15:00-15:45 virtual meeting to discuss 1) Target 4, 2) Guideline, 3) CATAC, 4) GPS, 5) DGPC, 6) Self-training system
Aug	10	Wed	409	15:00-16:00 virtual meeting to discuss 1) Element 2/a, 2) CATAC, 3) GPS, 4) DGPC, 5) Self-training system
Aug	12	Fri	410	15:00-16:00 virtual meeting to discuss 1) Element 2/a, 2) CATAC, 3) GPS, 4) DGPC, 5) Self-training system

Aug	15	Mon	411	15:00-16:00 virtual meeting to discuss 1) Element 2/a, 2) CATAC, 3) GPS, 4) DGPC, 5) Self-training system
Aug	17	Wed	412	15:00-16:00 virtual meeting to discuss 1) Element 5/b, 2) Guideline, 3) DGPC, 5) Self-training system
Aug	19	Fri	413	15:00-16:00 virtual meeting to discuss 1) Element 5/b, 2) Guideline, 3) DGPC, 5) Self-training system
Aug	22	Mon	414	15:00-16:00 virtual meeting to discuss 1) Element 5/b, 2) Guideline, 3) DGPC, 4) Self-training system
Aug	24	Wed	415	15:00-16:00 virtual meeting to discuss 1) Element 5/b, 2) Guideline, 3) DGPC, 4) Self-training system
Aug	25	Thu		(09:00-)10:00 Virtual meeting on GPS issue with UNAM
Aug	26	Fri		09:00-11:40 Virtula meeting to join Celebration at Usultan
Aug	29	Mon	416-417	15:00-16:00 virtual meeting to discuss 1) Element 3/c, 2) Guideline, 3) CATAC, 4) GPS, 5) Self-training system
Aug	31	Wed	418	15:00-16:00 virtual meeting to discuss 1) Element 3/c, 2) Guideline, 3) CATAC, 4) GPS, 5) Self-training system
Sep	2	Fri	419	08:00-09:30 virtual meeting on GPS issue with Topcon 15:00-16:00 virtual meeting to discuss 1) Element 1/d, 2) Guideline, 3) CATAC, 4) GPS, 5) DGPC
Sep	5	Mon	420	15:00-16:00 virtual meeting to discuss 1) Element 1/d, 2) Guideline, 3) CATAC, 4) GPS, 5) DGPC
Sep	6	Tue		16:00-17:15 ICG/PTWS HTHH Interim Procedures and PTWS Products Informational Webinar Note 1: HTHH = Hunga Tonga–Hunga Ha?apai (a submarine volcano in the Kermadec-Tonga Ridge in South Pacific, a ridge formed by the convergent boundary where the Pacific Plate is subducted by the Indo-Australian Plate, forming a long volcanic and island chain. Note 2: HTHH volcano lies almost completely underwater, with the exception of two small volcanic islands, Hunga Tonga and Hunga Ha?apai. Note 3: Agenda = (Meeting Logistics: ITIC Director) 1. Welcome (5 min):PTWS Chair / 2. Background (10 min): HTHH Task Team Chair / 3. PTWS Interim Procedures and PTWC Products (20 min): PTWC Director / 4. Discussion (20 min): Moderator, ITIC Director / 5. Closing (5 min):PTWS Chair
Sep	7	Wed	421	15:00-16:00 virtual meeting to discuss 1) Element 1/d, 2) Guideline, 3) CATAC, 4) GPS, 5) DGPC
Sep	8	Thu		17:00-18:00 Revew of the celebration on 26Aug22 with interpreter
Sep	9	Fri	422	15:00-16:00 virtual meeting to discuss 1) Element 1/d, 2) Guideline, 3) CATAC, 4) GPS, 5) DGPC
Sep	12	Mon	423	15:00-16:00 virtual meeting to discuss 1) Target 4, 2) Guideline, 3) CATAC, 4) GPS, 5) DGPC, 6) Self-training system GUI developer starts his work.
Sep	13	Tue		03:00-04:30 El Salvador Time (12:00-13:30 JST) PacWave22 Informational Webinars (English)
Sep	14	Wed	424	15:00-16:00 virtual meeting to discuss 1) Target 4, 2) Guideline, 3) CATAC, 4) GPS, 5) DGPC, 6) Self-training system
Sep	15	Thu		Día de la Independencia
Sep	16	Fri		Day off in El Salvador
Sep	19	Mon	425-426	15:00-16:00 virtual meeting to discuss the report on the 4th activity
Sep	20	Tue		15:00-15:30 virtual meeting to report the report on the 4th activity to DG of MARN
Sep	22	Thu		16:00-17:00 virtual meeting to report the report on the 4th activity to JICA

付録 3 第四次業務で収集した文書類

下には打合せで **MARN** から提供された資料を会議番号（左端の数字 **403**〜**516**）順に示した。なお、**400** 番台（**407** までが **6** 月、**408** からは **8** 月と **9** 月）の会議は遠隔、**500** 番台の会議は渡航時会議室。

403: Performance CMT-Tool_ISOLA-06June_Nicaraguan (ppt file to explain the issues in Item 1 and Item 2)
404: bosquejo-plataforma-desempeno-red-sismica
407: 1. 24_Mareogramas
 2. marn2022_Mexico_Mw82_H47km_30arcseg_energy_propagation_MARN
 3. marn2022_Mexico_Mw82_H47km_30arcseg_POIS_altura_maxima_MARN
 4. marn2022_Mexico_Mw82_H47km_30arcseg_tiempos_arribo_MARN
 5. ssh
 6. Tabla_Alturas_Arribos_Ola
413: 1. Agenda-conmemoracion-tsunamie
 2. lista-invitados-especiales
 3. preguntas-testimonio
 4. 1Broshure (1)
 5. 2Broshure
415: WhatsApp Image 2022-08-22 at 3.42.25 PM
416: 1. IMG_20220824_093421
 2. Documento_Implementación_de_software_ISOLA
 3. Dr_Cabral_items_GPS_meeting
419: 1. GMT20220826-153445_Recording_640x360
 2. GMT20220826-153445_Recording
421: 1. Parte_compendio_tsunamis_Griselda_V2
 2. Tabla de enjambres actualizada-agosto-2022
 3. INERV-20feb18-final-corregido
422: Answers by the expert from the Chilean Seismological
423: estado-equipos-proyecto-JICA
502: Comparative analysis of tide records from Chiapas EQ
507: 1. 2014 - Tsunami-2012 (for the feature of the 2012 El Salvador event; a drill scenario)
 2. Comparative analysis of tide records from Chiapas EQ (for the later attack tsunami 2017 issue)
 3. The_2017_M_w_8.2_Chiapas_Mexico_Earthqua (for the later attack tsunami 2017 issue)
 4. 2018Mexico (Chacon paper; for the later attack tsunami 2017 issue)
 5. blaser2010 (for the scaling law used for tsunami database)
 6. Boletin Mensual de Actividad Sísmica -Mayo 2022 (for self-training)
509: July_14th_visitver2
511: 1. Mori_Request_EasyWave_Bathymetry
 2. Assessment_Drill_120722
512: Evento sísmico de Ahuachapán
515: GPS_SeismoPaper
516: 1. ATTAC_FactSheet_Feb2022
 2. poster- Conferencia Costa Rica

付録 4 第三次国内遠隔活動で収集した文書類

Target (To make the plan on technology transfer & training in the project)	Documents provided by MARN during the 3rd aremote activities
Element a:"Observation, analysis and monitoring systems"	
Category 1: seismic and tsunami monitoring	
1-1-a The proper & stable judgement on generation of tsunami	
1-2-b Introduction of auto-filling-function and elaboration of depth handling in the tsunami database	1. Timeline_English_Version (305) Tonga issue 2. Timeline (305) Tonga issue 3. Tsunamis En El Salvador-Generación_ Medición y Mitigación-(1) (307)
1-1-c-1 Tsunami Monitoring Manual	
1-2-f-1 Establishment of the Tsunami Monitoring materials	
1-2-f-4 Establishment of the standard procedures that handle any abnormal seismic activities	
4-4-e Station weighting/correction for enhancement to hypocenter determination	
Category 2: CMT and Mw monitoring	
1-1-b The CMT analysis in the practical monitoring task to get focal mechanism and Mw	
1-2-a Introduction of GFDB based on the local seismic velocity structure to cover the events under M6.5 in CMT	
4-2 Grasping the distribution of amount of slips on the seismic source fault surface by analyzing the seismic waves	
4-3 Making displaying source time function to understand the actual seismic magnitude earlier	
4-4-a Initial motion analysis for grasping focal mechanisms	
Category 3: tsunami handling	
1-2-d Establishment of tsunami warning cancellation procedures	
1-2-f-6 Introduction of estimating the arrival of larger tsunamis afterdiminishing of initial tsunamis	
1-2-f-7 Promotion of using the Tide Tool in the tsunami monitoring procedures to seize live tsunami arrivals	
1-2-f-5 Introduction of the "Tsunami Forecast" that alerts the people about the small remaining tsunami	
Element b: "Use of the Infrastructure systems including CATAC"	
Category 4: recovery and backup	
1-2-c Introduction of the recovery procedures with the "Platform" to effectively maintain seismic observation network	
1-2-e Establishment of backup for the tsunami warning system	
Category 5: data and information acquisition including cooperation with CATAC	
2 Promoted DGOA to share any information with CATAC	
4-1 Use of the real time data of the GPS stations in the system in order to get accurate Mw earlier through observing W-phase with the data	
EEW by Swiss **(EWBS)**	2021-12-21-resultados-proyecto-eew-VF
Element c: "Communications with users including DGPC"	
Category 6: issuance tsunami advisory for disaster prevention including cooperation with DGPC	
1-2-f-3 Introduction of the daily inspection of radio, fax, and email as the authorized transmission methods to DGPC	**For Workshop** (MARN) 1)"Result of tsunami exercise of DGPC and MARN on 05Nov21 as of 26Jan22" 2)Tsunamis En El Salvador-Generación_ Medición y Mitigación-(1) 3)Protocola para actuación ante Tsunamis 4)Assessment_Drill_051121 5)Evaluation of the tsunami drill carried out on Friday, November 5, 2021. 6)Perspective of the DOA-MARN 7)Evaluación del simulacro de tsunamis realizado el viernes 5 de noviembre de 2021. 8)Perspectiva del DOA-MARN 9) Discussion items for Workshop that reviews and plans the tsunami simulation exercises 10)GMT20220125-144012_Recording_1920x1080.mp4 11)Grabación_Simulacro_Tsumani_5.11.21.mp4 (DGPC) 12)Versión Final 12NOV21 13)Procedimiento Operativo ante Tsunami-SOP´s Nacional-DGPC Formato autorizado 14)Plan Nacional Tsunami
3 Reinforced protocols and procedures on tsunami threat - in use by MARN and DGPC	
Element d: "Monitoring Shift actions"	
Category 7: self-training	
1-1-c-2 The self-training system & materials to keep the tsunami handling skills in the monitoring shift officers	
1-2-f-8 Consideration on the "self-training system"	
1-2-f-2 Establishment of the MARN guidebook to make DGPC and the people properly use the information sent from MARN	
Element e: Equipment	
Equipment procurement	1. Solicitud de un programador_Proyecto_Prof_Mori (304) 2. Request for specialist in software development (304) 3. Outline of the Specification on making graphic applications as of 17Jan22_ModifiedLMixco_18Jan22 (306) 4. English_version_Plattform_Software_Developer_Plattform_Seismic_Network_Monitoring_10-02-2022 (316)
Target 4 Established the guideline for introduction of the additional technologies that would enhance the seismic and tsunami monitoring system through making diagnosis of the latest system performance	
4-4) Any other technologies	
4-4-b Tools for evaluating the **underestimate of Magnitude**	
4-4-c DD method on enhancement of **hypocenter determination** for inland seismic activities	
4-4-d IPF method for enhancement of automatic hypocenter analysis against **multi-occurrence of earthquakes**	
4-4-f Segmentation of coasts in tsunami warning to make it elaborate	
4-4-g Development of a**ny safe & effective system in the tsunami observation by humans** at coasts without tide gauges	
4-4-h Consideration on the guideline for updating **the seismic microzoning maps** of El Salvador	
Seismic Risk by IDB project	
Watching the other related cooperation activities that are being handled by other international	
Tsunami ready project by UNESCO	

付録 5 第二次国内遠隔活動で収集した文書類

目標	MARNが提供してくれた資料
要素 a:観測、分析、及び監視システム	
分類1: 地震津波監視	
1-1-a 地震発生検知～津波警報発表の時間：20分以上を3年間で5～10分短縮 / 津波・地震監視システム：安定稼働の仕組確立（地震・津波の監視体制改善、津波データベース改善）	1.Tsunami_Drills_issue (20Aug21) 2. Documento_Mensajería_Tsunamis_LMixco2021(1) (30Aug21) 3. TsunamiProtocol (20Sep2) 4. Answer to the Question 2_ made by Prof Mori (29Sep21) 5. CheckList 2.0 (06Oct21)
1-1-c-1 津波監視手引書	
1-2-b 津波データーベース運用改善：地震パラメーター自動入力機能開発及び津波データーベース改良	
1-2-f-1 現業当番者手引書、公式津波プロトコル、及びガイドライン：共有化・確立	
1-2-f-4 異常地震活動対応標準手順：確立	1. Earthquakes Protocol (13Sep21) 2. Replicas_seiscomp_nicaragua_evento_Mw64 (29Sep21) 3. Magnitud del sismo del 10 de octubre 1986 (11Oct21)
4-4-e 震源決定精度向上のための観測点への重みづけの微調整 / ステーションコレクションの導入	1. 2021-08-25-pregunstas-mori (23Aug21)
分類2: CMT及びMw監視	
1-1-b 発震機構とMwの利用：地震発生後15～30分で監視業務で利用可能化（CMT 解析の導入；Mwはモーメントマグニチュード）	1. Performance CMT-Tool_ISOLA-12May_event (23Aug21) 2. Performance CMT-Tool-22Sept_Nicaragua_event_stations_used (22Sep21)
1-2-a CMT解析機能：M6.5未満の地震をカバーするよう地域の地震波速度特性を取込だグリーン関数データベース（GFDB）調達	
4-2 地震波形を用いた解析による震源断層の滑り量分布の把握	
4-3モーメントレート関数表示機能（震源時間関数の把握）	
4-4-a 地震波初動解析による発震機構把握	
分類3:津波対応	
1-2-d 津波警報解除手順書：作成	None
1-2-f-5 津波警報解除後の注意喚起情報：導入検討	None
1-2-f-6 津波の高さが小さくなってきた以降に襲来する大きな津波の予想：検討	None
1-2-f-7 津波実況監視手段Tide Tool の利用：現業者での利用推進	None
要素b: CATACを含むインフラの利用	
分類4: 復旧及びバックアップ	
1-2-c 地震観測網復旧の効率的な取扱いのための道具：Platform開発（地震観測網復旧の手順書作成）	None
1-2-e バックアップシステムの適正化：対応	PPT_Mexico_PTWC_CATAC_DELL_HP (13Sep21)
分類5: CATACとの協力を含むデータ及び情報収集	
2 CATACとの情報の共有化の促進	None
4-1 GPS観測網の地震監視現業での活用（GPS 観測システムから得られるリアルタイムデータの活用） / 津波地震や浅発地震を対象にしたWphaseによるMw及び発震機構推定	1. GPS type and feature as of 28Sep21filled by Douglas (29Sep21)
スイス（Swiss Seismological Service, SED）によるEarthquake Early Warning（EEW）開発	None
要素c: DGPCを含むMARNからの情報の利用者との意思疎通	
分類6: DGPCとの協力を含む防災のための津波警報の発信	
1-2-f-3 e-mailの公式利用、FAX点検の日課への導入：確立	None
3 DGPCの津波警報利用：適切化	1. Drill Proposal (06Oct21)
要素d: 監視担当者の対応（人材育成）	
分類7: 自主研鑽	
1-1-c-2 津波監視現業体制での技術レベル：維持・改善研修体制確立	1. Punteo_reunión_7sep2021_LMixco_observaciones-ingles (08Sep21) Punteo_reunión_7sep2021_LMixco_observaciones-ingles (reviewed by MORI) (08Sep21)
1-2-f-2 MARNガイドブック：確立	
1-2-f-8 津波監視現業技術レベル維持・改善のための研修体制：部外者参加も含めた検討	1. Boletin Mensual de Actividad Sísmica - Enero2021 (30Aug21) 2. Boletin Mensual de Actividad Sísmica - julio 2020 (30Aug21) 3. Boletin Mensual de Actividad Sísmica - Marzo 2021 (30Aug21)
要素e: 機材	
機材調達	1. Cotizacion_Workstation_Tower7920_DELL (25Aug2) 2. MARN_Quote 12492635_Licencia Perpetua Individual de MATLAB (30Aug21() 3. PPT_Mexico_PTWC_CATAC_DELL_HP (13Sep21) 4. Cotizacion_Workstation_HP Z8 G4 (13Sep21) 5. Cotizacion_Workstation_Tower7920_DELL2 (13Sep21) 6. Marn-Procurement as of 06Sep21ver4 (revised 13Sep21) (13Sep21)

付録 6 第一次国内遠隔活動で収集した文書類

Priority in 1st activity	Target With priority 1&2: to be achieved as close as possible in the 1st acitivity With priority 3: to be handled in the 1st activity With priority 4: N/A in the 1st activity	Documents provided by MARN (partially collected by the Expert)
1	Target 1	Target 1
1	1) Verified the latest status of the technologies, the materials, or the s	
1	a) **The proper & stable judgement** on **generation of tsunami** (**Timing,** within 10 min. **Accuracy,** kept at the enough level)	tabla_twitter
1	b) **The CMT analysis in the practical monitoring task** to get focal mechanism and Mw	Performance CMT-Tool-12May
2	c) Other technologies, materials or systems	
2	c-1) **Tsunami Monitoring Manual**	1. Tsunami Protocol (IAM-MFN-PA-03 PRotocolo de actuación por amenaza de tsunami en El Salvador rev 1 18nov2019) 2. Tsunami Protocol Word version (IAM-MFN-PA-03_Protocolo_de_Actuación_por_amenaza_de_Tsun_ami_en_El_Salvadorfinal 18NOV2019)
1	2) Verified the actions on some issues that were left in Phase 1 to be t	
1	a) Introduction of **GFDB** based on the local seismic velocity structure to **cover the events under M6.5 in CMT**	Performance CMT-Tool-12May
1	b) Introduction of **auto-filling-function** and **elaboration of depth handling** in **the tsunami database**	Presentation_LMixco26-04-21 (ppt file; the "development of the new web page where seismic events are automatically placed in real time")
1	c) Introduction of the recovery procedures with the "Platform" to effectively maintain seismic observation network	estadisticas-funcionamiento-estaciones-V3
1	d) Establishment of tsunami warning **cancellation procedures** (Target 1-1 c-1) including DGPC	1. recopilacion-acciones-sismos-8.1-mexico 2. 8sep17_ChiapasMexico_Marigrams_ITIC
3	f) Other actions	
3	f-1) Establishment of the **Tsunami Monitoring materials** (Targets 1-1 c-1 & 1-2 d)	By the Tsunami Protocol (IAM-MFN-PA-03 PRotocolo de actuación por amenaza de tsunami en El Salvador rev 1 18nov2019) and the Tsunami Protocol Word version (IAM-MFN-PA-03_Protocolo_de_Actuación_por_amenaza_de_Tsun_ami_en_El_Salvadorfinal 18NOV2019)
3	f-2) Establishment of the **MARN guidebook** to make DGPC and the people properly use the information sent from MARN	1. Presentation_LMixco26-04-21 (ppt file; "improvement of the panel that sends information for the social network") 2. Guia de sismos y tsunamis 2017 half size 3. guia-de-sismos-y-tsunamis-2017 https://cidoc.marn.gob.sv/documentos/guia-de-sismos-y-tsunamis-2017-2/ Guía de sismos y tsunamis 2017 | CIDOC Virtual<https://cidoc.marn.gob.sv/documentos/guia-de-sismos-y-tsunamis-2017-2/>
3	f-4) Establishment of **the standard procedures** that handle any **abnormal seismic activities**	Protocol for the seismic activity (IAM-MFN-PA-08 Actuacion por Amenaza de Sismos en El Salvador 2021)
1	Target 2	
1	Promoted DGOA to share any information with **CATAC**	1. CATAC tsunami exercise held on 11Nov20 (Ejercicio Regional CATAC_Pacwave) 2. Technical explanation of the CATAC tsunami drill held in 11Nov20 (Simulacro-CATAC-TSUNAMI-CA-20) 3. Comments from MARN on the CATAC tsunami drill held in 11Nov20 (Comentarios sobre simulacro) 4. LOG OF CATAC_DRILL_11-11-2020 5. Regional Drill, CATAC_Pacwave, by CATAC translated from Spanish 6. Emails on seismic activity sent from CATAC (ex. CATAC-INETER_ M=4.2, 58 Km al suroeste de Pochomil, Nicaragua)
1	Target 3	
1	Reinforced **protocols and procedures on tsunami threat** - in use by MARN and **DGPC** (Targets 1-1 c-1, 2 d, and 2 f-1)	1. local leaders interview report 2. Presentation_LMixco26-04-21 3. webinar_DGPC_report.

3	Target 4	
3	Established **the guideline for introduction of the additional technologies** that would enhance the seismic and tsunami monitoring system through making diagnosis of the latest system performance	
3	1) Use of the real time data of the **GPS** stations in the system in order to get **accurate Mw earlier through observing W-phase** with the data	Continuous-gps-station-ElSalvador-2021
3	2) Grasping the **distribution of amount of slips on the seismic source fault surface** by analyzing the seismic waves	1. Presentation_LMixco23-04-21 (ppt file; ISOLA CMT software) 2. ISOLA CMT manual (ISOLA_bookchapter_English) 3. b_installation
3	3) **Making displaying moment rate function** (or source time function) to understand the actual seismic magnitude earlier	Ibid.
4	4) Any other technologies	
4	Initial motion analysis for grasping **focal mechanisms**	Ibid.
4	Consideration on the guideline for updating **the seismic microzoning maps** of El Salvador	PPT_IDB_Project
1	Equipment	
1	Equipment procurement	1. Marn-Procurement-28May2021_LMixco

付録 7 仕様書に示された目標とする課題の達成状況

目標とする成果 赤は達成見通しがたったもの。青はまだ途中段階のもの。緑は、プロジェクトの成果品となる文書 「計画」とは「業務の課題と改善の方向性についてのDGOAとの協議」を踏まえた「DGOA担当職員と定める技術移転・研修計画」	仕様書 第四次	 第五次	成果達成状況（2022年9月21日現在）
実施した津波予測システム改善内容について、最終的な承認を得る。		(14)-②	未着手
実施した津波予警報ガイドライン・プロトコル改善内容について、最終的な承認を得る。		(14)-③	未着手
本件技術移転についてセミナーを実施し、成果をDGOA、DGPC、CATAC内で広く共有する。		(14)-⑤	未着手
①移転した知識・技術・知見が先方政府組織内に定着し、長く活用されるための工夫・取組について検討する。 ②中南米地域では、これまでJICAが取り組んできた防災分野の協力の成果を、ネットワーク化(仮想的なネットワーク)による域内の他国にも展開していく構想がある。エルサルバドルにおける地震・津波分野についても、その成果提供の一つのリソース国として、教材作成・提供、動画作成・提供、経験・成果の発信、エルサルバドル国内での学びの場の提供などを検討する。		(17)	未着手
目標とする成果1	(11)-②③	(14)-②③	
1) フェーズ1での導入内容の現状確認・評価	(11)-②③	(14)-②③	
a) 地震発生検知～津波警報発表の時間:20分以上を3年間で5～10分短縮 / 津波・地震監視システム:安定稼働の仕組確立(地震・津波の監視体制改善、津波データベース改善)	(11)-②	(14)-②	課題あり、対応策提示
b)発震機構とMwの利用:地震発生後15～30分で監視業務で利用可能化(CMT 解析の導入)	(11)-②	(14)-②	課題あり、対応策提示
c) その他			
c-1) 津波監視手引書	(11)-③	(14)-③	課題あり、対応策提示 津波監視手引書に記述
c-2) 津波監視現業体制での技術レベル:維持・改善研修体制確立	(11)-②③	(14)-②③	課題あり、対応策提示
2) 見届けることとしていた課題	(8)-②	(8)-②	
a) CMT解析機能:M6.5未満の地震をカバーするよう地域の地震波速度特性を取込だグリーン関数データベース(GFDB)調達	(11)-②	(14)-②	課題なし
b) 津波データーベース運用改善:地震パラメーター自動入力機能開発及び津波データーベース改良	(11)-②	(14)-②	課題あり、対応策提示
c) 地震観測網復旧の効率的な取扱いのための道具:開発(地震観測網復旧の手順書作成)	(11)-②③	(14)-②③	課題あり
d) 津波警報解除手順書:作成	(11)-③	(14)-③	課題あり、対応策提示
e)バックアップシステムの適正化:対応	(11)-②	(14)-②	課題あり
f) その他			
f-1)現業当番者手引書、公式津波プロトコル、及びガイドライン:共有化・確立	(11)-③	(14)-③	課題あり、対応策提示
f-2) MARNガイドブック:確立	(11)-③	(14)-③	課題あり、対応策提示
f-3)e-mailの公式利用、FAX点検の日課への導入:確立	(11)-②③	(14)-②③	課題あり、対応策提示
f-4) 異常地震活動対応標準手順:確立	(11)-③	(14)-③	課題あり、対応策提示
f-5) 津波警報解除後の注意喚起情報:導入検討	(11)-②③	(14)-②③	課題なし
f-6) 津波の高さが小さくなってきた以降に襲来する大きな津波の予想:検討	(11)-②③	(14)-②③	課題あり、対応策提示
f-7) 津波実況監視手段Tide Tool の利用:現業者での利用推進	(11)-②③	(14)-②③	課題あり、対応策提示
f-8) 津波監視現業技術レベル維持・改善のための研修体制:部外者参加も含めた検討(目標とする成果 1-1 c-2参照)	(11)-②	(14)-②	必要に応じて検討
目標とする成果 2	(11)-②③	(14)-②③	
CATACから発出される津波情報がDGOAの津波予測システムに適切に反映	(11)-②③	(14)-②③	課題あり、対応策提示
DGOAとCATAC間のシステムのバックアップ機能を構築	(11)-②③	(14)-②③	
CATACとの情報の共有化の促進	(11)-②③	(14)-②③	
CATACとともに、津波警報内容の理解促進と連携強化を目的とした共同津波警報訓練、及び合同ワークショップを立案実施	(11)-②③	(14)-②③	
目標とする成果 3(DGPCと共有する津波予警報ガイドライン・プロトコルを改善)	(11)-②③	(14)-②③	
DGOAがDGPCと共有する現状の津波予警報ガイドライン・プロトコルを整理、課題に対し助言	(11)-③	(14)-②③	課題あり、対応策提示
津波予警報ガイドライン・プロトコルに、CATACから発出される津波情報を適切に反映	(11)-③	(14)-②③	
DGOAとDGPC間の情報共有促進に資する助言、DGOA担当職員とともに、適宜、DGPCと意見交換	(11)-③	(14)-②③	
DGPCとともに、津波警報内容の理解促進と連携強化を目的とした共同津波警報訓練、及び合同ワークショップ立案実施	(11)-③	(14)-②③	
目標とする成果4	(11)-④	(14)-⑤	
今後の業務改善に向けた提言	(11)-④	(14)-⑤	
策定された地震・津波監視業務の高度化に向けた今後の指針を関係者に共有するためのセミナーを実施		(14)-⑤	未着手
1) GPS観測網の地震監視現業での活用(GPS 観測システムから得られるリアルタイムデータの活用) / 津波地震や浅発地震を対象にしたWphaseによるMw及び発震機構推定	(11)-④ア)		課題あり
2) 地震波形を用いた解析による震源断層の滑り量分布の把握	(11)-④イ)		課題あり、対応策提示
3)モーメントレート関数表示機能(震源時間関数の把握)	(11)-④ウ)		課題あり、対応策提示
4) その他	(11)-④ウ)～カ)	(14)-⑤	
地震波初動解析による発震機構把握	(11)-④ウ)～カ)	(14)-⑤	課題あり、対応策提示
マグニチュード過小評価手法 / 日本の地震・津波監視業務に関し、過去事象の教訓・課題・改善共有			課題あり、対応策提示
内陸地震活動の震源分布推定の精度向上のためのDD手法			課題あり、対応策提示
複数地震同時発生への自動震源解析の信頼性向上のためのIPF手法			課題あり、対応策提示
震源決定精度向上のための観測点への重みづけの微調整 / ステーションコレクションの導入			課題あり、対応策提示
津波警報の精緻化のための海岸を分割した警報発表手法			課題あり、対応策提示
津波観測器がない海岸のボランティアによる監視安全・効率化			課題あり、対応策提示
エルサルバドルの地震マイクロゾーニング地図の更新のためのガイドラインの検討			IDBプロジェクトが対応中

第五次業務結果報告書
（エルサルバドル国　地震・津波情報の分析能力強化 Phase 2、2021～2023 年）

令和 5 年 3 月 22 日
JMBSC 森　滋男

1. 作業日程実績
当初のワークプラン[1]に従い、一部手直しして作業を実施した。その作業経過は、**付録２**に示した。また、プロジェクト全体のスケジュールについては**付録１**に示した。さらに、プロジェクト全体のまとめを**付録３**に示した。なお、和文報告書のみにおいて、**付録４**に「仕様書に示された目標とする課題の達成状況」も添付した。

2. 活動及び結果

2.1 プロジェクト全体の目標及びその結果
下欄に目標とする成果の全容及び第五次業務終了時での結果を示した。

上位目標
MARN/DGOA（以下、「C/P」）について、地震・津波監視及び警報発令業務の実施能力の向上
目標
目標１：フェーズ1で導入・提案した内容が適切に実践されていることの確認。->事例調査、MARN内遠隔セミナー及び遠隔実地研修の実施により、実践されていることを確認したか、そうでない場合、必要な措置をとり改善を図った。
目標２：CATACから発出される津波情報がDGOAの津波予測システムに適切に反映され、両者間の情報共有が促進される。->遠隔会合2回及び遠隔セミナー実施により、情報共有の促進を図った。
目標３：DGOA が DGPC と共有する津波予警報のためのガイドライン・プロトコルが改善される。->DGPC 局長との面談、津波訓練 2 回、訓練評価のためのワークショップ 2 回、沿岸地域調査 2 箇所、ウスルタンでの「2012 年津波記念式典」遠隔参加により、 ガイドラインの改善を図った。
目標４：地震・津波監視システムの高度化に資する技術が紹介され、システムの高度化に向けた今後の指針が定まる。-> MARN内遠隔セミナーの実施及び定例会議での議論などを通じて今後の指針を定めた.。

2.2 第五次業務における活動目標と結果
ワークプランでは活動目標として**下の表**にある項目を示している。これらについて結果を

第五次業務での活動目標と結果
(1) 現地業務開始時に、DGOA にワークプランを提出し、合意を得る。なお、先方との協議にあたっては、必要に応じて、JICA エルサルバドル事務所からの参加を得るものとする。-> 実施した。
(2) ここまでの業務で実施した津波予測システム改善業務を継続する。また改善内容について、最終的な承認を得る。 -> 「業務の課題と改善の方向性についての DGOA との協議」を踏まえた「DGOA 担当職員と定める技術移転・研修計画」策定するとともにいくつかの成果物を提示し、改善内容を示すこれらについて承認を得た。なお、この改善に係る MARN 内セミナーや地震活動分析ソフトについて実地研修も実施した。
(3) ここまでの業務で実施した津波予警報ガイドライン・プロトコル改善業務を継続する。また改善内容について、最終的な承認を得る。 -> 上記（２）に述べた通りであり、改善内容について承認を得た。なお、この改善に係る DGPC とのワークショップも実施した。
(4) ここまでの業務で実施した地震・津波監視業務の高度化に向けた今後の指針策定支援を継続する。また、策定された指針を関係者に共有するためのセミナーを実施する。-> 同指針を策定するとともに、上述の通り、共有のための MARN 内セミナーを実施した。

[1] Work Plan of the Short-term Expert Dispatch to MARN in El Salvador as of 21Nov22

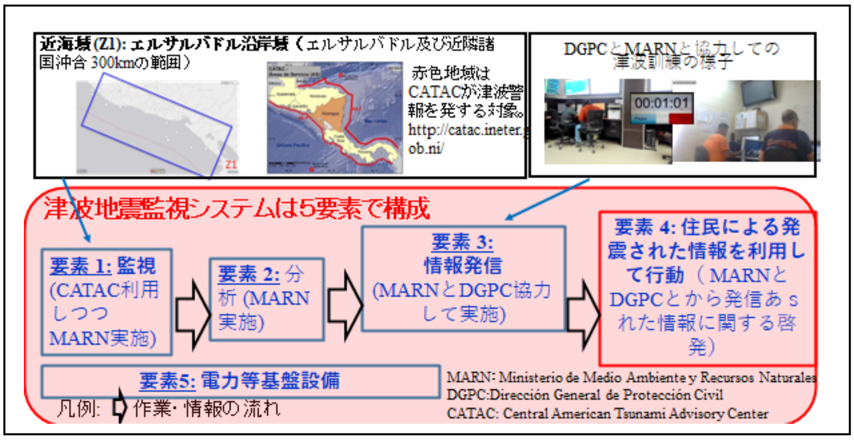
第五次業務での活動目標と結果 (5) 本件技術移転についてセミナーを実施し、成果を DGOA、DGPC、CATAC 内で広く共有する。-> CATAC とセミナーを開催した。 (6) 現地業務完了に際し、業務の成果、更なる発展に向けた道筋やそのための課題、今後の提言などを含む現地業務結果報告書（英文）を C/P 機関に提出し、報告する。-> 同報告書を MARN に提出し、総合監視局長へその内容を報告した。

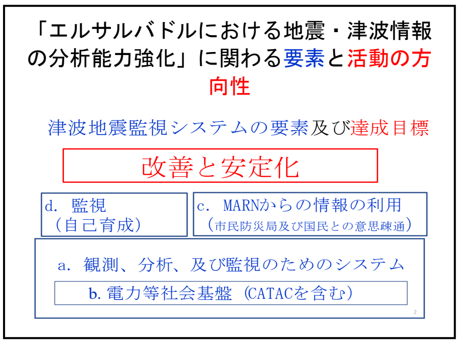
この表に示した。

2.3 結果の詳細

2.1 節に示す４つの目標の下には、小目標を設定しており、それぞれについて、結果の詳細を**次頁以降に示した表**に整理した。

一方、「エルサルバドルにおける地震・津波情報の分析能力強化」に関わる全体システム（同システムは、津波地震監視システムまたは津波予測システムと適宜呼んでいる。）は５つの要素から構成されている（**右図**参照。**右下の図**では右図における要素２と３は要素 a 一つにまとめてある。）。第五次業務の結果の詳細も**次頁以降の表**にまとめた。この表では、５つの要素に振り分けるとともに、技術内容や日々の仕事との関係に応じて７分野に振り分けてある。





目標とした成果（改善させる機能）及び小目標 「津波警報システムを構成する要素」及び「各要素の基本機能」に応じて分類 「計画」とは「業務の課題と改善の方向性についてのDGOAとの協議」を踏まえた「DGOA担当職員と定める技術移転・研修計画」）	結果（2023年3月22日現在） 赤色は結果の報告書類。緑色は成果物。
(1) 現地業務開始時に、DGOAにワークプランを提出し、合意を得る。なお、先方との協議にあたっては、必要に応じて、JICAエルサルバドル事務所からの参加を得るものとする。	
(2) ここまでの業務で実施した津波予測システム改善業務を継続する。また改善内容について、最終的な承認を得る。	
要素 2/a:観測、分析、及び監視システム	津波指針作成
分類1: 地震津波監視	「計画」策定。青字内容は本プロジェクト終了後もMARNの対応が要請される事項。
1-1-a 地震発生検知～津波警報発表の時間：20分以上を3年間で5～10分短縮 / 津波・地震監視システム：安定稼働の仕組確立（地震・津波の監視体制改善、津波データベース改善）	GUIの導入などで手順の改善・簡素化と合わせて、十分な頻度の津波訓練の実施。
1-1-c-1 津波監視手引書	済
1-2-b 津波データーベース運用改善：地震パラメーター自動入力機能開発及び津波データーベース改良	津波データベースの改善について、暫定的に採用することとした考えにおいて、次の事柄は実行可能な時期に速やかに対応することとする：1）データベース内の未対応のデータについて、宇津2001のスケーリング則で再計算、2）データベースの解像度が十分でないため、予想された中から県域で最も高い津波波高推定値を発信。
1-2-f-1 現業当番者手引書、公式津波プロトコル、及びガイドライン：共有化・確立	緊急作業手順を簡便に復習する道具として、ピラミッド形状ものを検討してきた。しかし、緊急作業手順の自動化や高度化の変化が大きいことから、必要に応じて監視担当官が自らこの主の道具を発案することが要請される。
1-2-f-4 異常地震活動対応標準手順：確立	2022 年 7 月 15 日の午前 2 時 41 分にエルサルバドル西部のアフアチャパンで発生した M4.4 イベントに対して取られた対応の結果に基づいて、内陸域での異常地震活動対応の標準作業では次のことを促進することとする：a) MT図使用、b) Calm 情報使用 / c) エルサルバドル沿岸域（Z1）での把握可能Mの下限値説明 / d) ベルリンと首都圏が特別扱いされる理由説明。
4-4-e 震源決定精度向上のための観測点への重みづけの微調整 / ステーションコレクションの導入	済
分類2: CMT及びMw監視	「計画」策定。
1-1-b 発震機構とMwの利用：地震発生後15～30分で監視業務で利用可能化（CMT 解析の導入；Mwはモーメントマグニチュード）	済
1-2-a CMT解析機能：M6.5未満の地震をカバーするよう地域の地震波速度特性を取込だグリーン関数データベース（GFDB）調達	済
4-3モーメントレート関数表示機能（震源時間関数の把握）	済
4-4-a 地震波初動解析による発震機構把握	済
分類3:津波対応	追加事項も含めた「計画」策定。青字内容は本プロジェクト終了後もMARNの対応が要請される事項。
1-2-d 津波警報解除手順書：作成	この問題については以下の事情があるため、MARN の解除情報を使用するよう、引き続き DGPC と話し合う必要がある: a) DGPC は MARN情報 に加えて PTWC情報 を使用、b)「解除」という用語は、DGPC が提供する文書「Procedimiento Operativo ante Tsunami-SOP´s Nacional-DGPC Formato autorizado」のみに示されているが、「解除」を判断するための情報源が示されていない。
1-2-f-5 津波警報解除後の注意喚起情報：導入検討	済
1-2-f-6 津波の高さが小さくなってきた以降に襲来する大きな津波の予想：検討	遅れて襲来する大きな津波の速度として、48km/hを設定したが、これはMARN内において、暫定的にこの津波の到着時間の予想に、第一近似値、として使用することとする。対象海域は、メキシコのサリナ クルス沖～ニカラグア沖の海底が浅い海域。また、毎年の津波訓練や毎年のワークショップで、DGPC にこの問題を定期的に思い起こしてもらうようにする。
1-2-f-7 津波実況監視手段Tide Tool の利用：現業者での利用推進	Tide Toolの有効活用のため、この監視方法の検討を進めることとする。また、La Libertad の潮位計は適切に管理する。

要素5/b: CATACを含む電力等社会基盤	「計画」策定。青字内容は本プロジェクト終了後もMARNの対応が要請される事項。
分類4: 復旧及びバックアップ	
1-2-c 地震観測網復旧の効率的な取扱いのための道具：Platform開発（地震観測網復旧の手順書作成）	Platformが無い状況では、監視担当職員は、地震波形を日々分析する中で、観測所の稼働状況の確認を着実に行う。また、観測所の復旧における優先順位付け基準を定期的に見直す。
1-2-e バックアップシステムの適正化：対応	- 監視センターから避難を余儀なくされた場合、監視担当職員の業務机に設置された公用スマホを利用してWhatsAppでCATACからの情報を使用する。 - 不測の事態対応計画策定推進。 - CATAC での津波監視システム SeisComP の更新を待ち、相互バックアップの問題に関する議論を進める。
分類5: CATACとの協力を含むデータ及び情報収集	
2 CATACとの情報の共有化の促進	①「地震・津波処理結果」をリアルタイムに交換／② 地震発生後、短時間で発表する情報の内容を統一／③永続的な音声およびビデオ接続を確立について、次の対応が必要： ①については、「CATACからリアルタイムで取得」、b)「MARNからリアルタイムで提供」上での「仕様」（内容、タイミング、安定性、信頼性、コスト）を明確にする。 ② については、CATAC の試験運用の状況を見つつ、統一する手順を確立する ③については、Skype と WhatsApp をテストしており、それらの使用方法に関する手順を作成する。 共同津波訓練と訓練の結果の評価のためのワークショップを毎年開催することに合意した。
4-1 GPS観測網の地震監視現業での活用（GPS 観測システムから得られるリアルタイムデータの活用） / 津波地震や浅発地震を対象にしたWphaseによるMw及び発震機構推定	Wphaseについては、広帯域地震計を使用することとする。 GPS に関しては、必要な予算が確保できるまで、情報を収集をさらに続けることとする。 また、予算としては、自局（現在2局）から「リアルタイムデータ」を取得することを優先する。そして、周辺国と協力してGPSリアルタイムデータを交換することを検討する。
スイス（Swiss Seismological Service, SED）によるEarthquake Early Warning（EEW）開発 (EWBS)	済
要素1/d: 監視（人材育成）	「計画」策定。青字内容は本プロジェクト終了後もMARNの対応が要請される事項。
分類7: 自主研鑽	
1-1-c-2 津波監視現業体制での技術レベル：維持・改善研修体制確立	自習システム、自習用教材、資料「既存カタログ」を作成した。 自習システムの考え方はMARNに引き継がれ、実施される。 「既存のカタログ」は、地震と津波のカタログの作成を支援する。
1-2-f-2 MARNガイドブック：確立	MARN Guidebook 2023 を作成した。 - 同ガイドブックには ISC と 津波Flag を含めなかったため、同ガイドブックの web版 を準備することとし、それに実装する。 - 沿岸部を訪問して津波対策の状況を調査した結果を踏まえ、同ガイドブックの学校向けにダイジェスト版を作成し、SNSへの投稿を検討することとした。このため、このことをさらに検討する。
1-2-f-8 津波監視現業技術レベル維持・改善のための研修体制：部外者参加も含めた検討	フェーズ 1 では、MARN が部外者 (CTC や UES の学生など) を招待して、自習システムの活動に参加させるべきだと考えた。今後、パンデミックの状況及び自習システムの運用状況を見て、対応方法も含めて再度検討する。
要素3/c: MARNからの情報の利用（市民防災	「計画」策定。青字内容は本プロジェクト終了後もMARNの対応が要請される事項。
分類6: DGPCとの協力を含む防災のための津波警報の発信	
1-2-f-3 e-mailの公式利用、FAX点検の日課への導入：確立	通信手段の点検は、点検表に基づいて実施することとする。DGPC に、毎週月、水、金の午前 7 時 30 分頃に MARN と一緒に点検を依頼することとする。 この手順を確立した上で、津波プロトコルを実情に応じて改正することとする。 また、公式利用するとした通信手段について、DGPCの理解を確認することとする。
3 DGPCの津波警報利用：適切化	今年のワークショップでは、以下の項目が検討されたことから、今後、津波警報の取り扱いと解除の共通手順が確立されることが期待できる： ・CATACからの情報の有効活用 ・津波対応手順の共有化 ・ 残された課題へ継続的な対応 ・津波警報対応における共通の手順の確立 ・津波警報を適切に解除するための共通手順の確立

(4) ここまでの業務で実施した地震・津波監視業務の高度化に向けた今後の指針策定支援を継続する。また、策定された指針を関係者に共有するためのセミナーを実施する	
4-2・4-4 今後の業務改善に向けた「他の技術の地震津波監視への導入」に係る提言	「計画」策定。青字内容は本プロジェクト終了後もMARNの対応が要請される事項。
1) 4-4-b マグニチュード過小評価手法 / 日本の地震・津波監視業務に関し、過去事象の教訓・課題・改善共有	済
2) 4-4-c 内陸地震活動の震源分布推定の精度向上のためのDD手法	済
3) 4-4-d 複数地震同時発生への自動震源解析の信頼性向上のためのIPF手法	済
4) 4-2 地震波形を用いた解析による震源断層の滑り量分布の把握	必要に応じて、津波地震監視システムに機能を導入するためのさまざまなツールを学習する必要がある。
5) 4-4-f 津波警報の精緻化のための海岸を分割した警報発表手法	この問題は、定期的な津波訓練の実施を通じてさらに検討する。
6) 4-4-g 津波観測測器がない海岸のボランティアによる監視安全・効率化	海岸での海面監視者の安全を守るための仕組みを考える必要がある。
7) 4-4-h エルサルバドルの地震マイクロゾーニング地図の更新のためのガイドラインの検討	済
他の国際協力機関の関連活動の状況把握	
米州開発銀行（Inter-American Development Bank, IDB)による地震危険度評価プロジェクト	済
ユネスコによるTsunami Readyプロジェクト	済
(5) 本件技術移転についてセミナーを実施し、成果をDGOA、DGPC、CATAC内で広く共有する。	
(6) 現地業務完了に際し、業務の成果、更なる発展に向けた道筋やそのための課題、今後の提言などを含む現地業務結果報告書（英文）をC/P機関に提出し、報告する。	

3. 機材調達

当初から予定していた下欄の機材は、MARN への譲渡手続きを完了した。

MARN-Procurement as of 18Sep22

EQUIPMENT DESCRIPTION	COMMENTS/JUSTIFICATION	QUANTITY
Digital radios: Brand: Ubiquiti. / Model: AirFiber 5XHD / Range: Greater than 100Km Frequency 5Ghz / 802.11 security protocol	To strengthen the operation rate of the seismic network through the improvement of transmission lines using digital technology. To be used at the three locations: One of the sets of antennas, which is the below "link c", use "34dBi gain" due to the long distance between the locations that use the radio communications. a) SanJose - Jayaque (Codes: SNJE-JAYA, latter has a repeater.) -> (changed to) Tecapa volcano towards Cerro Las Pavas. - pending installation. -> (changed to) Link: Cerro Loma Larga - Marn (Installation date: end of August). b) Las Nubes - Lomas de Alarcon (Codes:NUBE-LOAL, latter has a repeater.) -> (changed to) Cerro Pacayal towards Tecapa volcano - pending installation.-> (changed to) Link: Cerro Tecapa - Cerro Pacayal (Installation date: end of September). c) Centro de Gobierno (repeater point) - Marn. Through this link, information comes from the Pacayal station (Code: PACA.) or "CEL government center towards MARN". Already in operation.	**6**
Ubiquite brand dish antenna, **model AF-5G23-S45**, frequency 5Ghz, 23dBi gain, range greater than 15km, include hardware for installation.		**4**
Dish antenna Ubiquiti brand, **RocketDish 5G34 model,** 5Ghz frequency, 34dBi gain, range greater than 15km, include hardware for installation.		**2**
Workstation: Workstation Model: Precision 7920 Tower Chassis CL. Processor: Intel Xeon Silver 4210R (2.4GHz, 3.2GHz Turbo,10C, 9.6GT/s 2UPI, 13.75MB Cache, HT (100W)) DDR4-2400. Operating System Windows 10 Pro for Workstations (6 Cores Plus) Multi - English, French, Spanish. Memory: 64GB 4x16GB DDR4 2933MHz RDIMM ECC Memory. Graphics Card: NVIDIA® Quadro® P1000, 4GB, 4 mDP (7X20T). Hard / Drive: M.2 1TB PCIe NVMe Class 40 Solid State Drive. Keyboard: Dell Black Wired 10 Key Numeric Keypad KB813 Smart Card Keyboard. Mouse: Dell USB Laser 6-Button Mouse. Monitor: Dell 27 Monitor - P2722H.	1. To run specialized seismological and tsunami monitoring software. 2. More focused on tsunami simulations in real time	**1**
Laptops: screen display size 13.3 Inches, max Screen Resolution 1920 x 1080 Pixels Processor 1.6 GHz i5 / RAM 8 GB SDRAM / Hard Drive 256 GB ssd Wireless Type 802.11ac	To be used in the field in the configuration and maintenance of the seismic network.	**2**
ISOLA (MatLab software & specific toolboxes) Perpetual Standard License Individual: it is allowed to install the software on 4 PCs but there can only be one user, who will have unique credentials, with which they can access the software and others tools.	To get 1) Display of moment rate function to understand the actual seismic magnitude earlier 2) Flexible calculation of GFDB and handling in-depth analysis related to the determination of the CMT Note 1 Its calculations are not in real time. Note 2 OSOP CMT doesn't have the above functions but can work in real time. Note 3 Both can handle initial motion (polarity) analysis for grasping focal mechanisms by entering polarities.	**1**

また、追加で調達することになった次頁の上表のものについては、GUI、GPS 用ワークステーション、津波フラグ、及び教科書 6 冊のうち 3 冊が、MARN に譲渡手続きを終えた。一方、Platform と GPS 高度化は、コストの問題で調達を見送った。

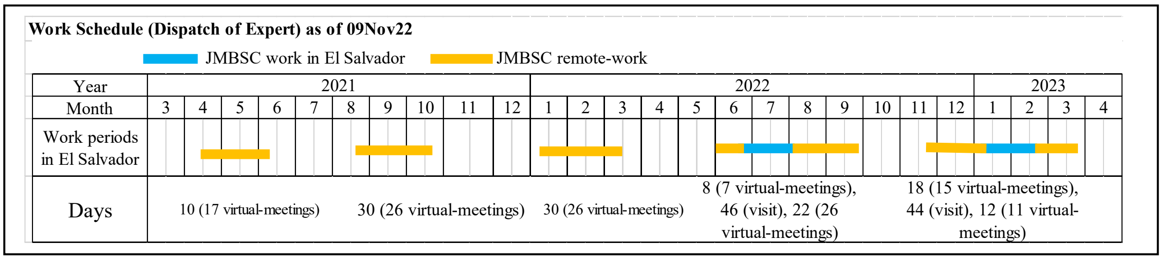
また、調達できなかった教科書 3 冊は、在庫がないなどの理由で調達を断念した。
加えて、追加調達することとした**右下表**のサーバーのバックアップ用ハードドライブ（HD）が譲渡手続きを終えた。なお、HD はサーバーに直ちに設置されるが、サーバーの停止を含む作業のため、十分な作業手順を計画して実施することが必要であり、体制が整い次第実施される。
また、MARN ガイドブック 2023 (200 部) が MARN に譲渡された。

MARN-Procurement additional items as of 18Sep22

EQUIPMENT DESCRIPTION	QUANTITY
GUI messages application (procurement of local engineer)	**1**
Seismic Station network maintenance platform (procurement of local engineer)	**1**
To telemeter the GPS of "Topcon NET-G3A (Reference station GNSS Receiver)" to get real time data from the stations	**2**
Workstation for GPS data	**1**
Tsunami flag	**5**
Textbook	**6**

	Servers	Datos disco	Quantity to be procure
1	SC-4 (2019)	Disco 10K SAS DS 1.2TB 872737. Servidor HP ProLiant DL380 Gen10	
2	SC-4-EEW (2018)	Disco 512GB SATA 6GB SSD. Servidor Dell, ST:4ZN9XQ2	
3	SC-3 (2017)	Disco 7.2K SAS 1TB 765872. Servidor HP ProLiant DL360 Gen9	
4	Shakemap (2022)	Discos 480 GB SATA 6gb SSD. Servidor DeLL EMC R440	
5	Earthworm (2022)	Disco 1.92 TB SATA 6Gb SSD. Servidor DELL EMC R740xd	
6		Discos 480 GB SATA 6gb SSD. Servidor DeLL EMC R440	

付録 1 プロジェクト全体のスケジュール



付録 2 作業経過

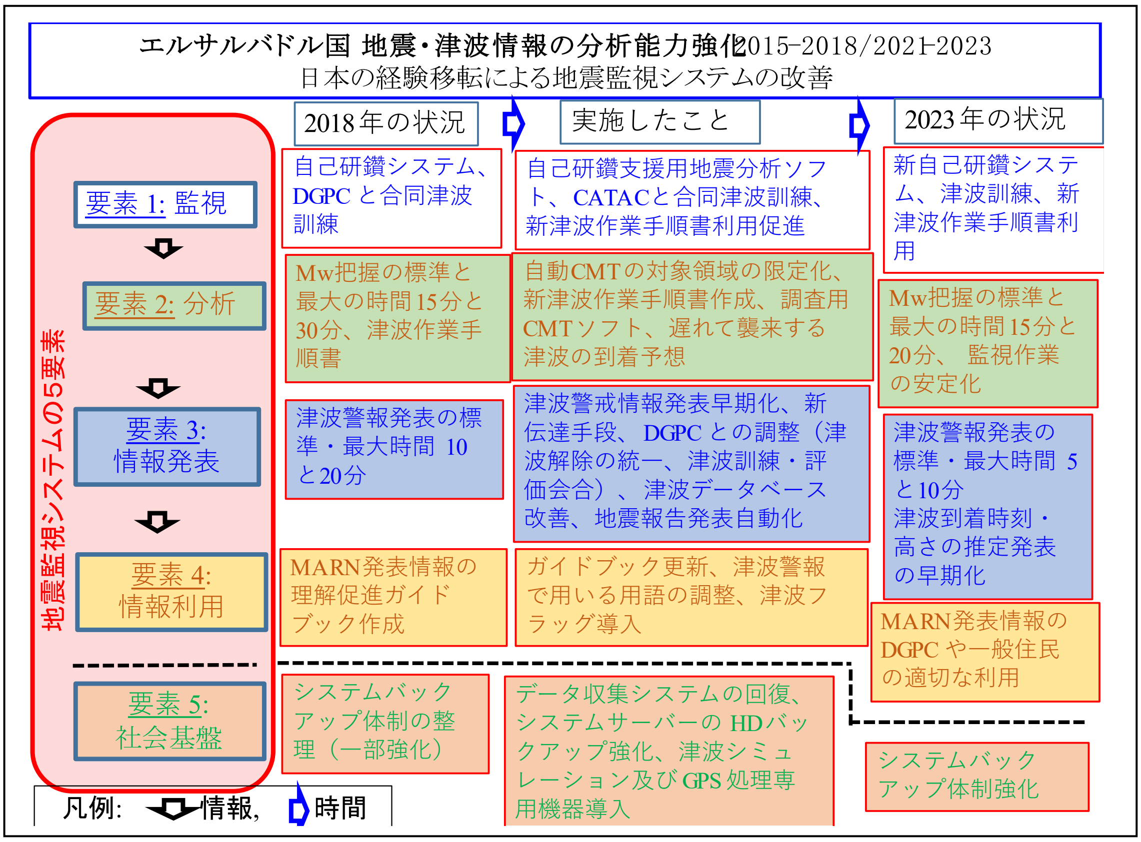
Activities 21Nov22 - 20Mar23 with El Salvador Time (JST-15h) as of 20Mar23				
2022-2023				Virtual meeting numeric orders
Month	Day			Actual
Nov	21	Mon	701	To prepare the draft seismic Catalogue. To review the procurement of the textbooks. To submit the work plan to MARN and JICA El Salvador Office. To obtain agreement at the start of activities through having a virtual meeting with MARN during 15:00-15:35.
Nov	22	Tue		To take the actions according to the activity-time flow. (10:00-10:40 AM To observe the tsunami drill (Trial usage of Tsunami Flags)). 16:00-16:40 To explain the work plan to JICA office
Nov	23	Wed	702	15:00-15:40 1) Draft minutes of the previous meeting, 2) How to make tsunami and seismic catalogue, 3) Review of the tsunami guideline and the seismic guideline, 4) How to coordinate with DGPC on the "tsunami drill review workshop" and on Tsunami Flag Video, 5) Any Other Business - GUI development, - Procurement of the textbooks, - GPS sophistication.
Nov	24	Thu		To take the actions according to the activity-time flow.
Nov	25	Fri	703	15:00-15:45 1) Draft minutes of the previous meeting, 2) Review of the Categories 1, 2 and 3, 3) Review of coordinating with DGPC on the "tsunami drill review workshop", 4) Review of coordinating with lifeguards (DGPC) on Tsunami Flag Video, 5) AOB (Procurement of the textbooks, GPS sophistication). To study Seismic Intensity.
Nov	28	Mon	704	15:00-15:55 1) To consider the draft MT figures for the Guidebook, 2) to review of Element 5/b (Infrastructure including CATAC), 3) to review of self-training materials (mainly CMT handling), 4) Any Other Business - Procurement of the textbooks To study JMA Tsunami simulation.
Nov	29	Tue		To review self-training materials (mainly CMT handling). To study Tsunami database & Tsunami chart issue (Tsunami Simulation).
Nov	30	Wed	705	15:00-15:55 1) Brief review of Element 1(d) (Category 7), 2) Any Other Business - Procurement of the textbooks, - An additional material for Seismic catalogue, - Introduction of focal mechanism from SeisPC, With the function, we can see an additional feature on the mechanism of the 2012 event & the 2014 one, - Tsunami simulation software, - One idea on how to handle later attack tsunami . To study the Mexicn event scientific paper.
Dec	1	Thu		To wrap up the Element 5/b "Use of the Infrastructure systems including CATAC" To make the aftershock page for Guidebook.
Dec	2	Fri	706	To study scaling law for making Guidebook. 15:00-15:55 1) To wrap up of the Categories 1, 2, and 3 including Tsunami database & Tsunami chart issue, 2) Any Other Business - Procurement of the textbooks, - Tsunami simulation software, - One idea on how to handle later attack tsunami, - Revised existing catalogue and the stress field shown by GCMT data, - Scaling Law for Tsunami simulation
Dec	5	Mon	707	To continue coordinating with DGPC on the "tsunami drill review workshop", and with lifeguards (DGPC) on Tsunami Flag Video. To negotiate with CATAC on backup issue and a virtual meeting and data sharing issue. 15:00-16:00 1) To wrap up Element 1/d "Monitoring Shift actions" (Category 7 Self-training), 2) to check the delivery status of textbooks.
Dec	6	Tue		To review and to catch up the remained issues described in the minutes of the 701 - 706 meetings. To handle the tsunami simulation software and the scaling law issue.
Dec	7	Wed	708	15:00-16:00 1) To negotiate with CATAC on backup issue and a virtual meeting and data sharing issue, 2) To review Element 3/c "Communications with users including DGPC" (Category 6: issuance tsunami advisory for disaster prevention including cooperation with DGPC)

Activities 21Nov22 - 20Mar23 with El Salvador Time (JST-15h) as of 20Mar23				
2022-2023			Virtual meeting numeric orders	
Month	Day			Actual
Nov	21	Mon	701	To prepare the draft seismic Catalogue. To review the procurement of the textbooks. To submit the work plan to MARN and JICA El Salvador Office. To obtain agreement at the start of activities through having a virtual meeting with MARN during 15:00-15:35.
Nov	22	Tue		To take the actions according to the activity-time flow. (10:00-10:40 AM To observe the tsunami drill (Trial usage of Tsunami Flags)). 16:00-16:40 To explain the work plan to JICA office
Nov	23	Wed	702	15:00-15:40 1) Draft minutes of the previous meeting, 2) How to make tsunami and seismic catalogue, 3) Review of the tsunami guideline and the seismic guideline, 4) How to coordinate with DGPC on the "tsunami drill review workshop" and on Tsunami Flag Video, 5) Any Other Business - GUI development, - Procurement of the textbooks, - GPS sophistication.
Nov	24	Thu		To take the actions according to the activity-time flow.
Nov	25	Fri	703	15:00-15:45 1) Draft minutes of the previous meeting, 2) Review of the Categories 1, 2 and 3, 3) Review of coordinating with DGPC on the "tsunami drill review workshop", 4) Review of coordinating with lifeguards (DGPC) on Tsunami Flag Video, 5) AOB (Procurement of the textbooks, GPS sophistication). To study Seismic Intensity.
Nov	28	Mon	704	15:00-15:55 1) To consider the draft MT figures for the Guidebook, 2) to review of Element 5/b (Infrastructure including CATAC), 3) to review of self-training materials (mainly CMT handling), 4) Any Other Business - Procurement of the textbooks To study JMA Tsunami simulation.
Nov	29	Tue		To review self-training materials (mainly CMT handling). To study Tsunami database & Tsunami chart issue (Tsunami Simulation).
Nov	30	Wed	705	15:00-15:55 1) Brief review of Element 1(d) (Category 7), 2) Any Other Business - Procurement of the textbooks, - An additional material for Seismic catalogue, - Introduction of focal mechanism from SeisPC, With the function, we can see an additional feature on the mechanism of the 2012 event & the 2014 one, - Tsunami simulation software, - One idea on how to handle later attack tsunami . To study the Mexicn event scientific paper.
Dec	1	Thu		To wrap up the Element 5/b "Use of the Infrastructure systems including CATAC" To make the aftershock page for Guidebook.
Dec	2	Fri	706	To study scaling law for making Guidebook. 15:00-15:55 1) To wrap up of the Categories 1, 2, and 3 including Tsunami database & Tsunami chart issue, 2) Any Other Business - Procurement of the textbooks, - Tsunami simulation software, - One idea on how to handle later attack tsunami, - Revised existing catalogue and the stress field shown by GCMT data, - Scaling Law for Tsunami simulation
Dec	5	Mon	707	To continue coordinating with DGPC on the "tsunami drill review workshop", and with lifeguards (DGPC) on Tsunami Flag Video. To negotiate with CATAC on backup issue and a virtual meeting and data sharing issue. 15:00-16:00 1) To wrap up Element 1/d "Monitoring Shift actions" (Category 7 Self-training), 2) to check the delivery status of textbooks.
Dec	6	Tue		To review and to catch up the remained issues described in the minutes of the 701 - 706 meetings. To handle the tsunami simulation software and the scaling law issue.
Dec	7	Wed	708	15:00-16:00 1) To negotiate with CATAC on backup issue and a virtual meeting and data sharing issue, 2) To review Element 3/c "Communications with users including DGPC" (Category 6: issuance tsunami advisory for disaster prevention including cooperation with DGPC)

Jan	20	Fri	804	15:00-15:30 meeting to discuss Element 5/b “Use of the Infrastructure systems including CATAC (Element 1)”.
Jan	21	Sat		To take the actions according to the activity-timeflow.
Jan	22	Sun		To make the draft Guidebook.
Jan	23	Mon	805	To prepare the workshop. 15:00-15:30 meeting to discuss Element 1/d “Monitoring Shift actions” and to chekd the La Libertad tide gauge nursing condition
Jan	24	Tue		02:38-4:08 PM the workshop with DGPC.
Jan	25	Wed	806	15:00-15:55 meeting to check the progress of the activity To review the status of the photos of the procured items.
Jan	26	Thu		10:00-11:30 To conduct SeisPC OJT. To review the status of the photos of the procured items. 19:00-20:00 JICA Meeting for the Central America disaster prevention
Jan	27	Fri		To take the actions according to the activity-timeflow.
Jan	28	Sat		To take the actions according to the activity-timeflow.
Jan	29	Sun		To take the actions according to the activity-timeflow.
Jan	30	Mon	807-808	To take the actions according to the activity-timeflow. 15:00-15:30 meeting to discuss the latest issues.
Jan	31	Tue		To make the final Guidebook.
Feb	1	Wed	809	To take the actions according to the activity-timeflow. 15:00-15:30 meeting to discuss the latest issues.
Feb	2	Thu		To take the actions according to the activity-timeflow.
Feb	3	Fri	810	To take the actions according to the activity-timeflow. 15:00-15:30 meeting to discuss the latest issues.
Feb	4	Sat		To take the actions according to the activity-timeflow.
Feb	5	Sun		To take the actions according to the activity-time flow.
Feb	6	Mon	811	To take the actions according to the activity-timeflow. 15:00-15:30 meeting to discuss the latest issues.
Feb	7	Tue		09:00- 11:00 To have a virtual meeting with CATAC.
Feb	8	Wed	812	09:00- 10:00 To have a virtual meeting with Nicaragua JICA CATAC.To take the actions according to the activity-timeflow. 15:00-15:30 meeting to discuss the latest issues.
Feb	9	Thu		To take the actions according to the activity-timeflow.
Feb	10	Fri	813	To take the actions according to the activity-timeflow. 15:00-15:30 meeting to discuss the latest issues.
Feb	11	Sat		To take the actions according to the activity-time flow.
Feb	12	Sun		To take the actions according to the activity-time flow.
Feb	13	Mon	814	To take the actions according to the activity-timeflow. 15:00-15:30 meeting to discuss the latest issues.
Feb	14	Tue		09:00-11:00 To have Seminar to share the formulated guidelines for the advancement of earthquake and tsunami monitoring operations.
Feb	15	Wed	815	To establish the Tsunami Guideline. 09:00-10:00 To get the GUI results. 15:00-15:30 To report the results from the visit activities to MARN.
Feb	16	Thu		08:30- 09:30 To have a meeting with SICA To take the actions according to the activity-time flow.
Feb	17	Fri	816	To have final approval for the content of the improvement on the seismic and tsunami monitoring system from MARN (1st day from 3 days). To establish the formulated guidelines for the advancement of earthquake and tsunami monitoring operations. 10:00-11:00 Repor t on the results to JICA office. To hand over the items procured to MARN from JICA. 15:00-15:45 1) MARN seismic and tsunami Guidebook/2) AOB:2-1) Procured items: a) Textbooks delivered should be checked by Expert. / b) The location of the radio and the antenna that are pending due to the tower problem / 2-2) Feature of an event / 2-3) GUI preparation time
Feb	18	Sat		To take the actions according to the activity-time flow.
Feb	19	Sun		To take the actions according to the activity-time flow.
Feb	20	Mon	817	15:00-15:30 1) MARN seismic and tsunami Guidebook / 2) CATAC seminar / 3) DGPC workshop / 4) AOB: 4-1) Handover document for the procured items / 4-2) Multi event handling (Case study on the January 15 (UTC) M5.1.) / 4-3) To check the status of the La Libertad tide gauge nursing / 4-4) Analysis of initial wave polarity data to get focal mechanisms that cannot be obtained by CMT

Feb	21	Tue		Departure from El Salvador El Salvador Time (Transit stay at Mexico City in Mexico)
Feb	22	Wed		Trip
Feb	23	Thu		Return to Japan JST
Feb	24	Fri	716	To take the actions according to the activity-time flow. 15:00-15:30 Virtual meeting to discuss the latest status.
Feb	27	Mon	717	15:00-16:00 Virtual meeting to have final approval for the content of the improvement on the seismic and tsunami monitoring system from MARN.
Feb	28	Tue		To take the actions according to the activity-timeflow.
Mar	1	Wed	718	15:00-16:00 Virtual meeting to have final approval for the reinforced protocols & procedures against tsunami threat from MARN (2nd day from 3 days).
Mar	2	Thu		To take the actions according to the activity-timeflow.
Mar	3	Fri	719	15:00-16:00 Virtual meeting to have final approval for the reinforced protocols & procedures against tsunami threat from MARN.
Mar	6	Mon	720	15:00-16:00 Virtual meeting to establish the formulated guidelines for the advancement of earthquake and tsunami monitoring operations
Mar	7	Tue		To take the actions according to the activity-timeflow.
Mar	8	Wed	721	To take the actions according to the activity-timeflow. 15:00-15:30 Virtual meeting to discuss the latest status.
Mar	9	Thu		To take the actions according to the activity-timeflow.
Mar	10	Fri	722	To take the actions according to the activity-timeflow. 15:00-15:30 Virtual meeting to discuss the latest status.
Mar	13	Mon	723	To take the actions according to the activity-timeflow. 15:00-15:30 Virtual meeting to discuss the latest status.
Mar	14	Tue		To take the actions according to the activity-timeflow.
Mar	15	Wed	724	To take the actions according to the activity-timeflow. 15:00-15:30 Virtual meeting to discuss the latest status.
Mar	16	Thu		To take the actions according to the activity-timeflow.
Mar	17	Fri	725	To take the actions according to the activity-timeflow. 15:00-15:30 Virtual meeting to discuss the latest status.
Mar	20	Mon	726	To take the actions according to the activity-timeflow. 15:00-16:00 to report the results of the work to DG of MARN
Mar	22	Mon		To submit a report on the results of the work (in Japanese and English) to the JICA El Salvador Office.
Mar	23	Mon		15:00-16:00 to report the results of the work to the JICA El Salvador Office

付録３　プロジェクトのまとめ



付録４　仕様書に示された「目標とする課題」の達成状況

目標	仕様書 第五次	関係要素	関係分野	成果達成状況 2023年3月21日現在 赤:「改善」内容の説明文書(「計画」文書)及び実施イベント、緑: プロジェクトの成果品となる文書、青: プロジェクト終了後もMARNが実施すべき事項。「計画」:「業務の課題と改善の方向性についてのDGOAとの協議」を踏まえた「DGOA担当職員と定める技術移転・研修計画」
実施した津波予測システム改善内容について、最終的な承認を得る。	(14)-②			済:「計画」文書承認獲得
実施した津波予警報ガイドライン・プロトコル改善内容について、最終的な承認を得る。	(14)-③			済:「計画」文書承認獲得
本件技術移転についてセミナーを実施し、成果をDGOA、DGPC、CATAC内で広く共有する。	(14)-⑤			済:部内セミナー、CATACとのセミナー、DGPCとのワークショップ実施で対応
①移転した知識・技術・知見が先方政府組織内に定着し、長く活用されるための工夫・取組について検討する。 ②中南米地域では、これまでJICAが取り組んできた防災分野の協力の成果を、ネットワーク化(仮想的なネットワーク)による域内の他国にも展開していく構想がある。エルサルバドルにおける地震・津波分野についても、その成果提供の一つのリソース国として、教材作成・提供、動画作成・提供、経験・成果の発信、エルサルバドル国内での学びの場の提供などを検討する。	(17)			*作業中*
目標とする成果1	(14)-②③			
1) フェーズ1での導入内容の現状確認・評価	(14)-②③			
a) 地震発生検知～津波警報発表の時間:20分以上を3年間で5～10分短縮 / 津波・地震監視システム:安定稼働の仕組確立(地震・津波の監視体制改善、津波データベース改善)	(14)-②	2	1	津波監視手引書、カテゴリー1の「計画」
b)発震機構とMwの利用:地震発生後15～30分で監視業務で利用可能化(CMT 解析の導入)	(14)-②	2	2	津波監視手引書、カテゴリー2の「計画」
c) その他				
c-1) 津波監視手引書	(14)-③	2	1	津波監視手引書、カテゴリー1の「計画」
c-2) 津波監視現業体制での技術レベル:維持・改善研修体制確立	(14)-②③	1	7	自主研修体制、自主研修素材、, 既存地震カタログ一覧、要素1の「計画」、MARN内eminar, OJT
2) 見届けることとしていた課題	(8)-②			
a) CMT解析機能:M6.5未満の地震をカバーするよう地域の地震波速度特性を取込だグリーン関数データベース(GFDB)調達	(14)-②	2	2	津波監視手引書、カテゴリー2の「計画」
b) 津波データーベース運用改善:地震パラメーター自動入力機能開発及び津波データーベース改良	(14)-②	2	1	津波監視手引書、カテゴリー1の「計画」
c) 地震観測網復旧の効率的な取扱いのための道具:開発(地震観測網復旧の手順書作成)	(14)-②③	5	4	要素5の「計画」
d) 津波警報解除手順書:作成	(14)-③	2	3	津波監視手引書、カテゴリー3の「計画」
e)バックアップシステムの適正化:対応	(14)-②	5/	4	要素5の「計画」
f) その他				
f-1)現業当番者手引書、公式津波プロトコル、及びガイドライン:共有化・確立	(14)-③	2	1	津波監視手引書、カテゴリー1の「計画」
f-2) MARNガイドブック:確立(関係要素4)	(14)-③	1 /4	7	MARNガイドブック、要素1の「計画」
f-3)e-mailの公式利用、FAX点検の日課への導入:確立	(14)-②③	3	6	DGPCとのワクショップ、要素6の「計画」
f-4) 異常地震活動対応標準手順:確立	(14)-③	2	1	津波監視手引書、カテゴリー1の「計画」
f-5) 津波警報解除後の注意喚起情報:導入検討	(14)-②③	2	3	津波監視手引書:、カテゴリー3の「計画」
f-6) 津波の高さが小さくなってきた以降に襲来する大きな津波の予想:検討	(14)-②③	2	3	
f-7) 津波実況監視手段Tide Tool の利用:現業者での利用推進	(14)-②③	2	3	
f-8) 津波監視現業技術レベル維持・改善のための研修体制:部外者参加も含めた検討(目標とする成果 1-1 c-2参照)	(14)-②	1	7	要素1の「計画」
目標とする成果 2	(14)-②③	5	5	
CATACから発出される津波情報がDGOAの津波予測システムに適切に反映	(14)-②③	5	5	CATACとのセミナー、要素5の「計画」
DGOAとCATAC間のシステムのバックアップ機能を構築	(14)-②③	5	5	
CATACとの情報の共有化の促進	(14)-②③	5	5	
CATACとともに、津波警報内容の理解促進と連携強化を目的とした共同津波警報訓練、及び合同ワークショップを立案実施	(14)-②③	5	5	
目標とする成果 3(DGPCと共有する津波予警報ガイドライン・プロトコルを改善)	(14)-②③	3	3	
DGOAがDGPCと共有する現状の津波予警報ガイドライン・プロトコルを整理、課題に対し助言	(14)-②③	3	6	津波監視手引書:、DGPCとのワークショップ、要素6の「計画」
津波予警報ガイドライン・プロトコルに、CATACから発出される津波情報を適切に反映	(14)-②③	3	6	
DGOAとDGPC間の情報共有促進に資する助言、DGOA担当職員とともに、適宜、DGPCと意見交換	(14)-②③	3	6	
DGPCとともに、津波警報内容の理解促進と連携強化を目的とした共同津波警報訓練、及び合同ワークショップ立案実施	(14)-②③	3	6	

目標とする成果4	(14)-④			
今後の業務改善に向けた提言	(14)-④			
策定された地震・津波監視業務の高度化に向けた今後の指針を関係者に共有するためのセミナーを実施	(14)-④			部内セミナー実施
1) GPS観測網の地震監視現業での活用（GPS 観測システムから得られるリアルタイムデータの活用） / 津波地震や浅発地震を対象にしたWphaseによるMw及び発震機構推定		5	5	CATACとのセミナー、要素5の「計画」
2) 地震波形を用いた解析による震源断層の滑り量分布の把握				地震・津波監視業務の高度化に向けた今後の指針
3)モーメントレート関数表示機能（震源時間関数の把握）		2	2	津波監視手引書、カテゴリー2の「計画」
4) その他	(14)-④			
地震波初動解析による発震機構把握	(14)-④	2	2	津波監視手引書、カテゴリー2の「計画」
マグニチュード過小評価手法 / 日本の地震・津波監視業務に関し、過去事象の教訓・課題・改善共有				地震・津波監視業務の高度化に向けた今後の指針
内陸地震活動の震源分布推定の精度向上のためのDD手法				
複数地震同時発生への自動震源解析の信頼性向上のためのIPF手法				
震源決定精度向上のための観測点への重みづけの微調整 / ステーションコレクションの導入		2	1	津波監視手引書、カテゴリー1の「計画」
津波警報の精緻化のための海岸を分割した警報発表手法				地震・津波監視業務の高度化に向けた今後の指針
津波観測測器がない海岸のボランティアによる監視安全・効率化				
エルサルバドルの地震マイクロゾーニング地図の更新のためのガイドラインの検討				
他の国際協力機関の関連活動の状況把握				
スイス（Swiss Seismological Service, SED）によるEarthquake Early Warning（EEW）開発、EWBS		5	5	CATACとセミナー、要素5の「計画」
ユネスコによるTsunami Readyプロジェクト				
米州開発銀行（Inter-American Development Bank, IDB）による地震危険度評価プロジェクト				

Period

Report of results from 5th Hybrid activities for "Capacity Development of the Analysis for Earthquakes and Tsunamis of El Salvador, Phase 2" during 2021-2023

Handled by the short-term seismic expert dispatched to MARN in El Salvador by JICA

Prepared/revised by Expert on 20Mar23/22Mar23

1. Activities time flow during the 5th activities period

The activities time flow has followed the one in the initial **Work Plan**[1] **(hereinafter called Work Plan)** with some modifications. The actual one is shown in the **Appendix 2**. As for the project whole schedule, see the **Appendix 1**.

2. The activities and the results

2.1 The whole targets in the project and their results

The below list shows the whole targets of this project and their results from whole activities including those implemented until today.

Upper Target

Enhancement of Seismic & Tsunami Observation and Analysis Practical Technologies in the Directorate General of the Environmental Observatory (DGOA) of MARN

Target 1 To verify the implementation and proper functioning of the proposed / established technologies in the Phase 1**,** and enhanced them, if needed. -> Verified and enhanced accordingly through implementing several case studies, an internal remote seminar, and a remote OJT.

Target 2 To make DGOA handle the tsunami information issued from the Central American Tsunami Advisory Center (CATAC) in **the seismic and tsunami monitoring system** and promoted DGOA to share any information related to the tsunami warning with CATAC further -> Done accordingly through implementing remote meetings (twice) and a remote seminar.

Target 3 To reinforce **the protocols & procedures against tsunami threat** shared by MARN with the Directorate General of Civil Protection (DGPC) -> Done accordingly through implementing tsunami drills (twice), remote workshops (twice), visiting two coastal areas and the remote participation in the "memorial ceremony for the 2012 tsunami" at Usultan.

Target 4 To establish the guideline for introduction of the additional technologies that would enhance **the seismic and tsunami monitoring system** through making diagnosis of the latest system performance-> Done accordingly through implementing the internal seminar and discussing in the regular meetings.

2.2 The planned actions for the targets in 5th activity and the results

The Work Plan tells that the actions should be as follows in **the below list**. The results are shown in the list.

Actions in the 5th activity and the results

(1) To submit a work plan to the C/P and obtain agreement at the start of activities. In consultation with the C/P, participation from the JICA El Salvador Office shall be obtained as necessary. -> Expert has done accordingly.

(2) To continue the actions to improve **the seismic and tsunami monitoring system**. In addition, final approval will be obtained for the content of the improvement from the C/P. -> Expert has made Plans on the technology transfer & the training about all Categories and has made the several outcomes. Further, Expert has implemented Internal seminar and OJT.

(3) To continue those to reinforce **the protocols & procedures against tsunami threat**. In addition, final approval will be obtained for the content of the improvement from the C/P. -> Expert has made Plans on the technology transfer & the training about all Categories. Further, Expert has implemented Workshop with DGPC.

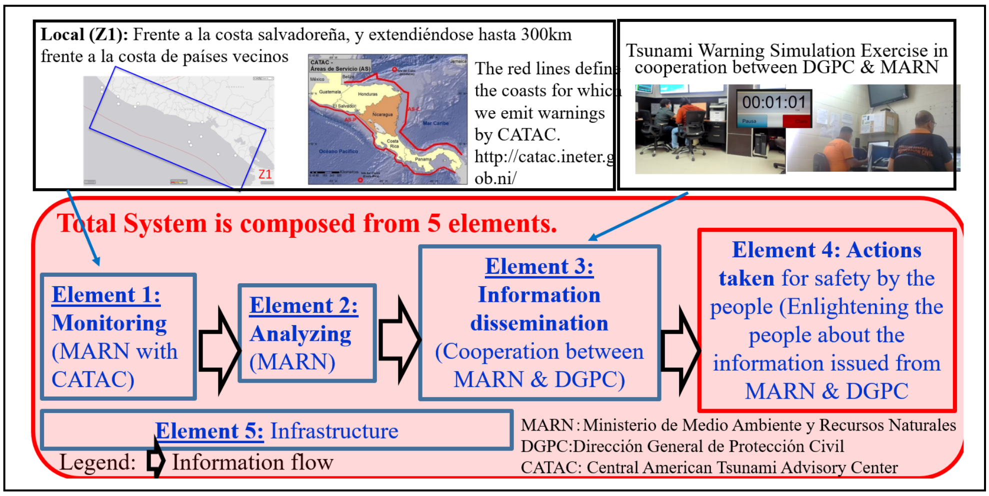
(4) To continue to support **the formulation of future guidelines for the advancement of earthquake and tsunami monitoring operations. In addition, a seminar will be held to share the formulated guidelines with related parties**. -> Expert has made the Guideline and has implemented Internal seminar as mentioned above.

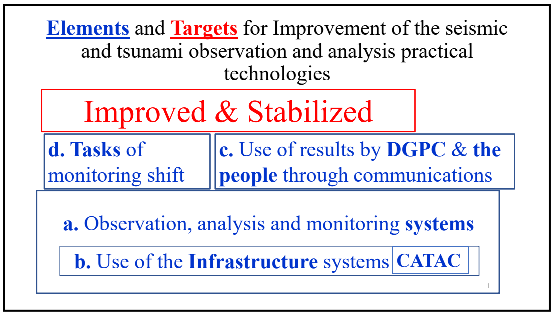
[1] Work Plan of the Short-term Expert Dispatch to MARN in El Salvador as of 21Nov22

Actions in the 5th activity and the results
(5) To hold **a seminar on the Technology Transfer and widely share the results within DGOA, DGPC and CATAC**. -> Expert has implemented seminar with CATAC.
(6) **Upon completion of the work, to submit a report on the results of the work (in English) to the C/P** including 1) the results of the work, 2) the path for further development, 3) the issues to be solved for the development, and 4) any proposals for the future. -> Expert has submitted the report and reported DG of MARN on the results.

2.3 Details of the results

Based on the relation with the "5 elements" **(See the right figures.** The "Elements 2 & 3" are combined into one element as "Element a" in **the right bottom figure**, though.**)** that compose the seismic and tsunami monitoring system in El Salvador, the results from the 5th activities are wrapped up **in the lists of the below pages**, where they are categorized into 6 elements including "equipment procurement"; and further they are categorized into total 7 categories according to the related technologies or the related daily works.





List 1 Sub-targets and the results after the 5th activities 1/3

Sub-targets with actions "Plan" is the planning on technology transfer & training.	Results (Red items are reports on the results. Green items are outcomes.)
(1) To submit a work plan to the C/P and obtain agreement at the start of activities. In consultation with the C/P, participation from the JICA El Salvador Office shall be obtained as necessary.	
(2) To continue the actions to improve the seismic and tsunami monitoring system. In addition, final approval will be obtained for the content of the improvement from the C/P.	
Element 2/a: "Observation, analysis and monitoring systems"	The tsunami Guideline has been made.
Category 1: seismic and tsunami monitoring	Plan has been made. The below blue letters should be handled by MARN further even after finishing this project.
1-1-a The proper & stable judgement on generation of tsunami	Together with the improvement/simplifying the procedures like introducing GUI, we should implement tsunami drills of sufficient frequency.
1-1-c-1 Tsunami Monitoring Manual	None
1-2-b Introduction of auto-filling-function and elaboration of depth handling in the tsunami database	We have tentatively approved to take the idea to improve the tsunami database. The below Ideas 1-2 and 1-3 should will be done soon: 1-2) Other data in the database should be re-calculated with the "Utsu scaling law, Utsu 2001" of "MARN guidebook 2017" / 1-3) We should inform the public of the highest estimation in the area because our database does not have high resolution.
1-2-f-1 Establishment of the Tsunami Monitoring materials	As a tool for easily reviewing emergency work procedures, we have studied a pyramid-shaped one. However, due to the large changes in the automation and sophistication of emergency work procedures, it is requested that monitoring officers voluntarily devise the tool as needed.
1-2-f-4 Establishment of the standard procedures that handle any abnormal seismic activities	Based on the results from the actions taken to the M4.4 event that occurred at Ahuachapán in western El Salvador at 2:41 a.m. on July 15, 2022, it was decided to promote a) use of the Magnitude & Time (MT) diagram / b) use of Calm information, / c) explanation of the complete coverage magnitude in the local area (Z1) / d) explanation of the reason why Berlin and Metropolitan are handled specifically.
4-4-e Station weighting/correction for enhancement to hypocenter determination	None
Category 2: CMT and Mw monitoring	Plan has been made.
1-1-b The CMT analysis in the practical monitoring task to get focal mechanism and Mw	None
1-2-a Introduction of GFDB based on the local seismic velocity structure to cover the events under M6.5 in CMT	None
4-3 Making displaying source time function to understand the actual seismic magnitude earlier	None
4-4-a Initial motion analysis for grasping focal mechanisms	None
Category 3: tsunami handling Addition: We have described how to handle non-earthquake tsunami in the tsunami Guideline.	Plan has been made with an additional issue. The below blue letters should be handled by MARN further even after finishing this project.
1-2-d Establishment of tsunami warning cancellation procedures	We should continuously talk DGPC to use only MARN's cancellation information because we have the below status on the issue: a) DGPC uses PTWC's in addition to MARN's, b) the term "cancelación" is shown only in the document, "Procedimiento Operativo ante Tsunami-SOP´s Nacional-DGPC Formato autorizado", provided by DGPC, c) but that doesn't show any information source to judge cancellation.
1-2-f-5 Introduction of the "Tsunami Forecast" that alerts the people about the small remaining tsunami	None
1-2-f-6 Introduction of estimating the arrival of larger tsunamis after diminishing of initial tsunamis	This velocity, 48km/h, could be internally and tentatively used to estimate the arrival time of the later attack tsunami as the 1st approximation for the events occur in the area with shallow sea depth from the sea off Salina Cruz (Mexico; SC) to the sea off Nicaragua. We should make DGPC regularly remind this issue in annual tsunami drills and in annual workshops.
1-2-f-7 Promotion of using the Tide Tool in the tsunami monitoring procedures to seize live tsunami arrivals	It might be better for us to consider how to monitor it in order to use it effectively. The tide gauge at La Libertad should be properly nursed.

List 1 Sub-targets and the results after the 5th activities 2/3

Sub-targets with actions "Plan" is the planning on technology transfer & training.	Results (Red items are reports on the results. Green items are outcomes.)
Element 5/b: "Use of the Infrastructure systems including CATAC (Element 1)"	Plan has been made. The below blue letters should be handled by MARN further even after finishing this project.
Category 4: recovery and backup	
1-2-c Introduction of the recovery procedures with the "Platform" to effectively maintain seismic observation network	Without the platform, a) we should steadily conduct checking seismic stations performance through daily analyzing seismic waveforms by monitoring shifts, and b) we should regularly review the station prioritization criterion.
1-2-e Establishment of backup for the tsunami warning system	In the case that we should evacuate from the monitoring center, we should use the information from CATAC with WhatsApp in the official smartphone equipped at the monitoring desk. To make the contingency plan. To wait for the update of tsunami system, SeisComP, at CATAC to start the discussion on the mutual backup issue.
Category 5: data and information acquisition including cooperation with CATAC	
2 Promoted DGOA to share any information with CATAC	We have below items: Item 1 To exchange "seismic and tsunami processing results" in real time / Item 2 To unify processing parameters and definition of common event bulletin in a short time after the occurrence of earthquakes / Item 3 To install a permanent voice and video connection. Regarding item 1, we should make the below issues clear: the "specifications" of a) "getting them from CATAC in real time" and b) "providing them from MARN in real time" (Note: Specifications = Contents, Timing, Stability, Method's reliability, and its cost). Regarding item 2, it might be necessary to establish the procedures to unify seismic parameters through seeing the full spec trial of CATAC. Regarding item 3, we have tested Skype and WhatsApp and should develop the procedures on how to use them. Further, we have agreed to annually have a joint tsunami drill and a workshop to review the drill.
4-1 Use of the real time data of the GPS stations in the system in order to get accurate Mw earlier through observing W-phase with the data	As for the W-phase, we should use Broadband seismometer. As for GPS, we will continue to collect information until the necessary budget is secured. Also, as for the budget, priority is given to acquiring "real-time data" from our own station (currently two stations). And we should consider exchanging GPS real-time data in cooperation with neighboring countries.
EEW by Swiss (EWBS)	None
Element 1/d: "Monitoring Shift actions"	Plan has been made. The below blue letters should be handled by MARN further even after finishing this project.
Category 7: self-training	
1-1-c-2 The self-training system & materials to keep the tsunami handling skills in the monitoring shift officers	Self-training System, self-training materials and the document, "existing catalogue" have been made. The idea of the system will be followed by MARN. The document, "existing catalogue", will support the establishment of the seismic and tsunami catalogue.
1-2-f-2 Establishment of the MARN guidebook to make DGPC and the people properly use the information sent from MARN (Element 4)	MARN Guidebook 2023 has been made. We are not able to include ISC and Tsunami Flag in the Guidebook 2023. So, we should consider implementing the issue by chance like when preparing the 2023 version for web of MARN. Based on the results from surveying the status of tsunami countermeasures in coastal areas through visiting there, it was decided to make a digest version for schools and to consider posting the digest one on SNS. So, we should further consider implementing the issue.
1-2-f-8 Consideration on the "self-training system"	In the phase 1, We thought that MARN should invite outsiders (CTC , UES students, etc.) to participate in the activity for the self-training system. In the future, we will review the situation of the pandemic and the operation status of the self-training system, including how to respond.

List 1 Sub-targets and the results after the 5th activities 3/3

Sub-targets with actions "Plan" is the planning on technology transfer & training.	Results (Red items are reports on the results. Green items are outcomes.)
(4) To continue to support the formulation of future guidelines for the advancement of earthquake and tsunami monitoring operations. In addition, **a seminar** will be held to share the formulated guidelines with related parties.	
4-2 & 4-4 Any other technologies for introduction in monitoring tsunamis and earthquakes	Guideline for the introduction has been made. The below blue letters should be handled by MARN further even after finishing this project.
1) 4-4-b Tools for evaluating the underestimate of Magnitude	None
2) 4-4-c DD method on enhancement of hypocenter determination for inland seismic activities	None
3) 4-4-d IPF method for enhancement of automatic hypocenter analysis against multi-occurrence of earthquakes	None
4) 4-2 Grasping the distribution of amount of slips on the seismic source fault surface by analyzing the seismic waves	If necessary, we should learn the various tools to introduce the function into our monitoring system.
5) 4-4-f Segmentation of coasts in tsunami warning to make it elaborate	This issue should be considered further through conducting regular tsunami drills.
6) 4-4-g Development of any safe & effective system in the tsunami observation by humans at coasts without tide gauges	We should develop the system to keep the safety of the monitoring people.
7) 4-4-h Consideration on the guideline for updating the seismic microzoning maps of El Salvador	None
Watching the other related cooperation activities that are being handled by other international cooperation organizations	
Seismic Risk by IDB project	None
Tsunami ready project by UNESCO	None
(5) To hold **a seminar** on the Technology Transfer and widely share the results within DGOA, DGPC and CATAC.	
(6) Upon completion of the work, to submit **a report on the results of the work (in English) to the C/P** including 1) the results of the work, 2) the path for further development, 3) the issues to be solved for the development, and 4) any proposals for the future.	

3. Procurement

Below items have been handed over to MARN.

MARN-Procurement as of 18Sep22

EQUIPMENT DESCRIPTION	COMMENTS/JUSTIFICATION	QUANTITY
Digital radios: Brand: Ubiquiti. / Model: AirFiber 5XHD / Range: Greater than 100Km Frequency 5Ghz / 802.11 security protocol	To strengthen the operation rate of the seismic network through the improvement of transmission lines using digital technology. To be used at the three locations: One of the sets of antennas, which is the below "link c", use "34dBi gain" due to the long distance between the locations that use the radio communications. a) SanJose - Jayaque (Codes: SNJE-JAYA, latter has a repeater.) -> (changed to) Tecapa volcano towards Cerro Las Pavas. - pending installation. -> (changed to) Link: Cerro Loma Larga - Marn (Installation date: end of August). b) Las Nubes - Lomas de Alarcon (Codes:NUBE-LOAL, latter has a repeater.) -> (changed to) Cerro Pacayal towards Tecapa volcano - pending installation.-> (changed to) Link: Cerro Tecapa - Cerro Pacayal (Installation date: end of September). c) Centro de Gobierno (repeater point) - Marn. Through this link, information comes from the Pacayal station (Code: PACA.) or "CEL government center towards MARN". Already in operation.	**6**
Ubiquite brand dish antenna, **model AF-5G23-S45**, frequency 5Ghz, 23dBi gain, range greater than 15km, include hardware for installation.		**4**
Dish antenna Ubiquiti brand, **RocketDish 5G34 model,** 5Ghz frequency, 34dBi gain, range greater than 15km, include hardware for installation.		**2**
Workstation: Workstation Model: Precision 7920 Tower Chassis CL. Processor: Intel Xeon Silver 4210R (2.4GHz, 3.2GHz Turbo,10C, 9.6GT/s 2UPI, 13.75MB Cache, HT (100W)) DDR4-2400. Operating System Windows 10 Pro for Workstations (6 Cores Plus) Multi - English, French, Spanish. Memory: 64GB 4x16GB DDR4 2933MHz RDIMM ECC Memory. Graphics Card: NVIDIA® Quadro® P1000, 4GB, 4 mDP (7X20T). Hard / Drive: M.2 1TB PCIe NVMe Class 40 Solid State Drive. Keyboard: Dell Black Wired 10 Key Numeric Keypad KB813 Smart Card Keyboard. Mouse: Dell USB Laser 6-Button Mouse. Monitor: Dell 27 Monitor - P2722H.	1. To run specialized seismological and tsunami monitoring software. 2. More focused on tsunami simulations in real time	**1**
Laptops: screen display size 13.3 Inches, max Screen Resolution 1920 x 1080 Pixels Processor 1.6 GHz i5 / RAM 8 GB SDRAM / Hard Drive 256 GB ssd Wireless Type 802.11ac	To be used in the field in the configuration and maintenance of the seismic network.	**2**
ISOLA (MatLab software & specific toolboxes) Perpetual Standard License Individual: it is allowed to install the software on 4 PCs but there can only be one user, who will have unique credentials, with which they can access the software and others tools.	To get 1) Display of moment rate function to understand the actual seismic magnitude earlier 2) Flexible calculation of GFDB and handling in-depth analysis related to the determination of the CMT Note 1 Its calculations are not in real time. Note 2 OSOP CMT doesn't have the above functions but can work in real time. Note 3 Both can handle initial motion (polarity) analysis for grasping focal mechanisms by entering polarities.	**1**

Further, **the right items** have been handled as follows: GUI, Workstation for GPS, Tsunami flag and 3 out of 6 textbooks have been handed over to MARN. Platform and GPS have been stopped due to cost issue. The remained textbooks have been given up due to no stock or other reason.

MARN-Procurement additional items as of 18Sep22

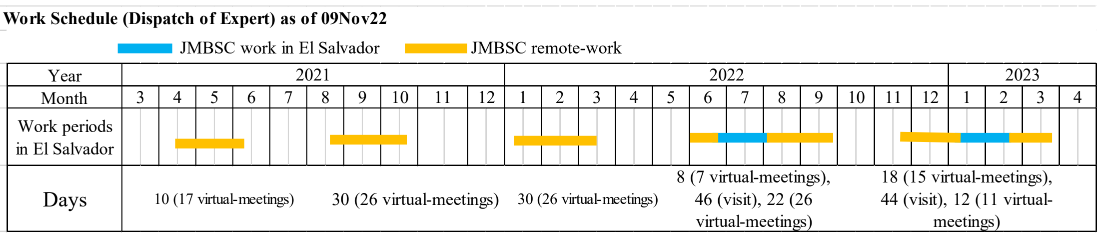
EQUIPMENT DESCRIPTION	QUANTITY
GUI messages application (procurement of local engineer)	**1**
Seismic Station network maintenance platform (procurement of local engineer)	**1**
To telemeter the GPS of "Topcon NET-G3A (Reference station GNSS Receiver)" to get real time data from the stations	**2**
Workstation for GPS data	**1**
Tsunami flag	**5**
Textbook	**6**

Additionally, **right items** have been handed over to MARN. They are the backup hard drives (HDs) for the servers; they have been decided to procure additionally. Although the HDs will be installed on the servers immediately, it is necessary to plan sufficient work procedures because the work includes stopping the servers. So, it will be implemented after preparing the plan.

	Servers	Datos disco	Quantity to be procured
1	SC-4 (2019)	Disco 10K SAS DS 1.2TB 872737. Servidor HP ProLiant DL380 Gen10	1
2	SC-4-EEW (2018)	Disco 512GB SATA 6GB SSD. Servidor Dell, ST:4ZN9XQ2	1
3	SC-3 (2017)	Disco 7.2K SAS 1TB 765872. Servidor HP ProLiant DL360 Gen9	1
4	Shakemap (2022)	Discos 480 GB SATA 6gb SSD. Servidor DeLL EMC R440	1
5	Earthworm (2022)	Disco 1.92 TB SATA 6Gb SSD. Servidor DELL EMC R740xd	1
6		Discos 480 GB SATA 6gb SSD. Servidor DeLL EMC R440	1

Further, the MARN Guidebook 2023 (200 copies) have been handed over to MARN.

Appendix 1 The project schedule



Appendix 2 The actual time flow

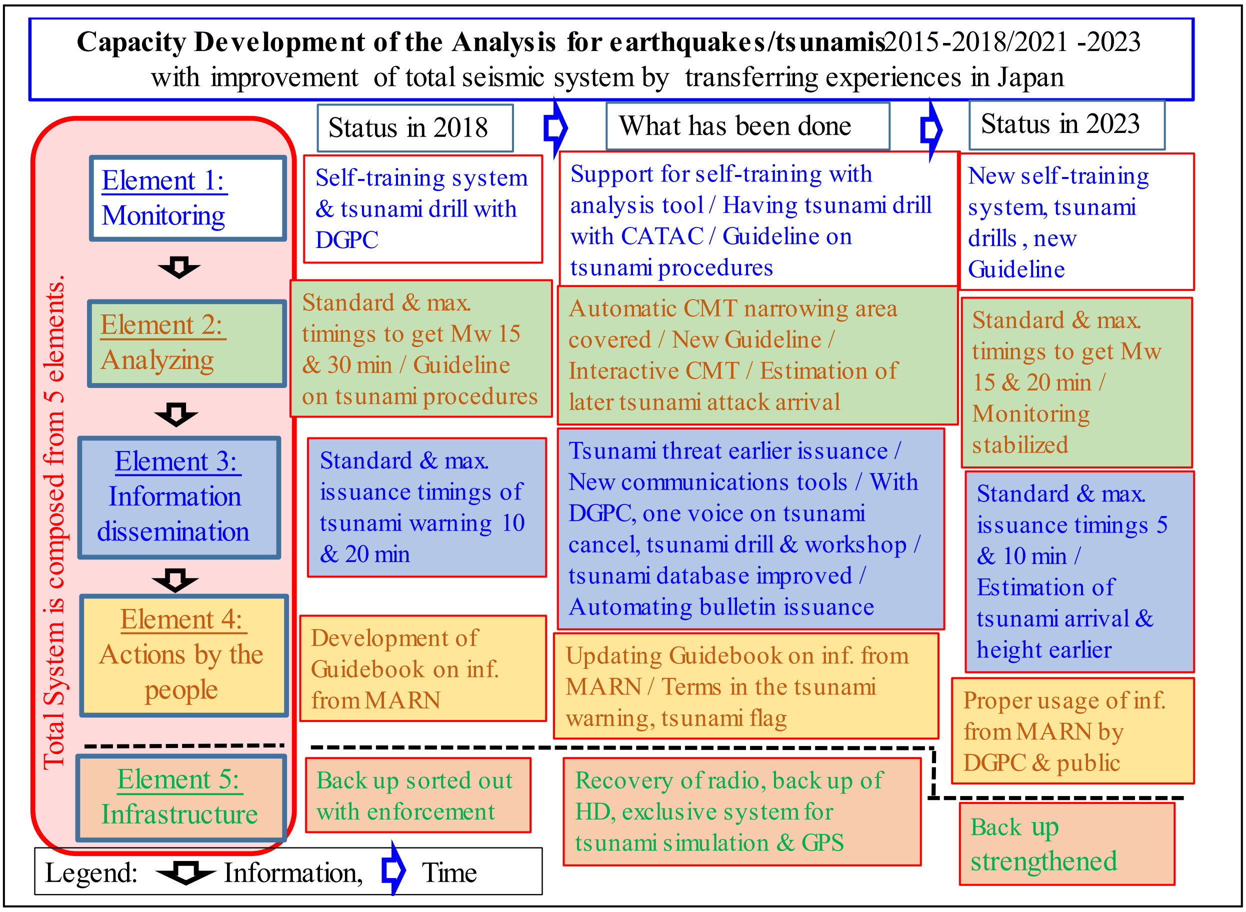
Activities 21Nov22 - 20Mar23 with El Salvador Time (JST-15h) as of 20Mar23				
2022-2023			Virtual meeting numeric orders	
Month	Day			Actual
Nov	21	Mon	701	To prepare the draft seismic Catalogue. To review the procurement of the textbooks. To submit the work plan to MARN and JICA El Salvador Office. To obtain agreement at the start of activities through having a virtual meeting with MARN during 15:00-15:35.
Nov	22	Tue		To take the actions according to the activity-time flow. (10:00-10:40 AM To observe the tsunami drill (Trial usage of Tsunami Flags)). 16:00-16:40 To explain the work plan to JICA office
Nov	23	Wed	702	15:00-15:40 1) Draft minutes of the previous meeting, 2) How to make tsunami and seismic catalogue, 3) Review of the tsunami guideline and the seismic guideline, 4) How to coordinate with DGPC on the "tsunami drill review workshop" and on Tsunami Flag Video, 5) Any Other Business - GUI development, - Procurement of the textbooks, - GPS sophistication.
Nov	24	Thu		To take the actions according to the activity-time flow.
Nov	25	Fri	703	15:00-15:45 1) Draft minutes of the previous meeting, 2) Review of the Categories 1, 2 and 3, 3) Review of coordinating with DGPC on the "tsunami drill review workshop", 4) Review of coordinating with lifeguards (DGPC) on Tsunami Flag Video, 5) AOB (Procurement of the textbooks, GPS sophistication). To study Seismic Intensity.
Nov	28	Mon	704	15:00-15:55 1) To consider the draft MT figures for the Guidebook, 2) to review of Element 5/b (Infrastructure including CATAC), 3) to review of self-training materials (mainly CMT handling), 4) Any Other Business - Procurement of the textbooks To study JMA Tsunami simulation.
Nov	29	Tue		To review self-training materials (mainly CMT handling). To study Tsunami database & Tsunami chart issue (Tsunami Simulation).
Nov	30	Wed	705	15:00-15:55 1) Brief review of Element 1(d) (Category 7), 2) Any Other Business - Procurement of the textbooks, - An additional material for Seismic catalogue, - Introduction of focal mechanism from SeisPC, With the function, we can see an additional feature on the mechanism of the 2012 event & the 2014 one, - Tsunami simulation software, - One idea on how to handle later attack tsunami . To study the Mexicn event scientific paper.
Dec	1	Thu		To wrap up the Element 5/b “Use of the Infrastructure systems including CATAC” To make the aftershock page for Guidebook.
Dec	2	Fri	706	To study scaling law for making Guidebook. 15:00-15:55 1) To wrap up of the Categories 1, 2, and 3 including Tsunami database & Tsunami chart issue, 2) Any Other Business - Procurement of the textbooks, - Tsunami simulation software, - One idea on how to handle later attack tsunami, - Revised existing catalogue and the stress field shown by GCMT data, - Scaling Law for Tsunami simulation
Dec	5	Mon	707	To continue coordinating with DGPC on the "tsunami drill review workshop", and with lifeguards (DGPC) on Tsunami Flag Video. To negotiate with CATAC on backup issue and a virtual meeting and data sharing issue. 15:00-16:00 1) To wrap up Element 1/d “Monitoring Shift actions” (Category 7 Self-training), 2) to check the delivery status of textbooks.
Dec	6	Tue		To review and to catch up the remained issues described in the minutes of the 701 - 706 meetings. To handle the tsunami simulation software and the scaling law issue.
Dec	7	Wed	708	15:00-16:00 1) To negotiate with CATAC on backup issue and a virtual meeting and data sharing issue, 2) To review Element 3/c “Communications with users including DGPC” (Category 6: issuance tsunami advisory for disaster prevention including cooperation with DGPC).

Dec	8	Thu		To take the actions according to the activity-time flow.
Dec	9	Fri	709	15:00-16:00 1) To review the negotiation with CATAC on backup issue and a virtual meeting and data sharing issue, 2) to review the formulation of future guidelines for the advancement of earthquake and tsunami monitoring operations, 3) to review the other related cooperation activities that are being handled by other international cooperation organizations.
Dec	12	Mon	710	15:00-16:00 To coordinate the issues related to the Workshop with DGPC. To review the whole schedule.
Dec	13	Tue		To make stress field page for Guidebook. To collect GPS sophistication information from JMA and any GPS specialist in Japan. To consider 1) the Platform, 2) the "Pyramid" issue. To study 1) tsunami height, 2) "reacting events" and to report Luis on the results from the study, 3) "Usultan photos", 3) the DD method tomography and location, 4) IPF method, 5) ocean bottom deformation estimation. To study ocean bottom deformation estimation. To make CATAC/PTWC page for Guidebook. To continue negotiating with CATAC on backup issue and a virtual meeting and data sharing issue.
Dec	14	Wed	711	15:00-16:00 To continue coordinating the issues related to the Workshop with DGPC. To take the actions according to the activity-time flow.
Dec	15	Thu		To take the actions according to the activity-time flow.
Dec	16	Fri	712	15:00-15:30 To take the actions according to the activity-time flow.
Dec	19	Mon	713	15:00-15:30 To take the actions according to the activity-time flow.
Dec	20	Tue		To make rough draft Guidebook. To check the delivery status of textbooks.
Dec	21	Wed	714	15:00-15:30 To take the actions according to the activity-time flow.
Dec	22	Thu		To take the actions according to the activity-time flow.
Dec	23	Fri	715	15:00-16:00 To make a draft of "the self-training system to keep the tsunami handling skills in the monitoring shift officers", 2) to wrap up the Element 3/c "Communications with users including DGPC" (Category 6: issuance tsunami advisory for disaster prevention including cooperation with DGPC), 3) to wrap up the formulation of future guidelines for the advancement of earthquake and tsunami monitoring operations, 4) to wrap up the other related cooperation activities that are being handled by other international cooperation organizations.
Dec	26	Mon		To take the actions according to the activity-time flow.
Dec	27	Tue		To take the actions according to the activity-time flow.
Dec	28	Wed		To take the actions according to the activity-time flow.
Jan	4	Wed		To take the actions according to the activity-timeflow.
Jan	5	Thu		To take the actions according to the activity-timeflow.
Jan	6	Fri		To take the actions according to the activity-timeflow.
Jan	10	Tue		To take the actions according to the activity-timeflow.
Jan	11	Wed		Departure from Japan JST (Transit stay at Mexico City in Mexico) Arrival at El Salvador El Salvador Time
Jan	12	Thu	801	To review the protocols & procedures against tsunami threat (Element 3/c "Communications with users including DGPC" (Category 6: issuance tsunami advisory for disaster prevention including cooperation with DGPC)). To review the delivery status of textbooks. To review the status of the photos of the procured items including radio communications. 15:00-15:30 meeting to review the workplan
Jan	13	Fri		To review the status of the photos of the procured items including radio communications. 14:00-15:00 meeting with JICA to review the workplan; to get the SIM for the safety at the departing process.
Jan	14	Sat		To take the actions according to the activity-timeflow.
Jan	15	Sun		To take the actions according to the activity-timeflow.
Jan	16	Mon	802	To review the GPS sophistication issue. To check GUI on the "18% x 4". 15:00-15:30 To review the event schedule.
Jan	17	Tue		To take the actions according to the activity-timeflow. To check the vide provided from MARN to make Tsunami Flag Video 14:00-15:00 meetingwith JICA to reimburse the payment and to review the procurement issue and interpreter hiring issie.
Jan	18	Wed	803	15:00-15:30 meeting to discuss Categories 1, 2, and 3.
Jan	19	Thu		To take the actions according to the activity-timeflow.

Jan	20	Fri	804	15:00-15:30 meeting to discuss Element 5/b "Use of the Infrastructure systems including CATAC (Element 1)".
Jan	21	Sat		To take the actions according to the activity-timeflow.
Jan	22	Sun		To make the draft Guidebook.
Jan	23	Mon	805	To prepare the workshop. 15:00-15:30 meeting to discuss Element 1/d "Monitoring Shift actions" and to chekd the La Libertad tide gauge nursing condition
Jan	24	Tue		02:38-4:08 PM the workshop with DGPC.
Jan	25	Wed	806	15:00-15:55 meeting to check the progress of the activity To review the status of the photos of the procured items.
Jan	26	Thu		10:00-11:30 To conduct SeisPC OJT. To review the status of the photos of the procured items. 19:00-20:00 JICA Meeting for the Central America disaster prevention
Jan	27	Fri		To take the actions according to the activity-timeflow.
Jan	28	Sat		To take the actions according to the activity-timeflow.
Jan	29	Sun		To take the actions according to the activity-timeflow.
Jan	30	Mon	807-808	To take the actions according to the activity-timeflow. 15:00-15:30 meeting to discuss the latest issues.
Jan	31	Tue		To make the final Guidebook.
Feb	1	Wed	809	To take the actions according to the activity-timeflow. 15:00-15:30 meeting to discuss the latest issues.
Feb	2	Thu		To take the actions according to the activity-timeflow.
Feb	3	Fri	810	To take the actions according to the activity-timeflow. 15:00-15:30 meeting to discuss the latest issues.
Feb	4	Sat		To take the actions according to the activity-timeflow.
Feb	5	Sun		To take the actions according to the activity-time flow.
Feb	6	Mon	811	To take the actions according to the activity-timeflow. 15:00-15:30 meeting to discuss the latest issues.
Feb	7	Tue		09:00- 11:00 To have a virtual meeting with CATAC.
Feb	8	Wed	812	09:00- 10:00 To have a virtual meeting with Nicaragua JICA CATAC.To take the actions according to the activity-timeflow. 15:00-15:30 meeting to discuss the latest issues.
Feb	9	Thu		To take the actions according to the activity-timeflow.
Feb	10	Fri	813	To take the actions according to the activity-timeflow. 15:00-15:30 meeting to discuss the latest issues.
Feb	11	Sat		To take the actions according to the activity-time flow.
Feb	12	Sun		To take the actions according to the activity-time flow.
Feb	13	Mon	814	To take the actions according to the activity-timeflow. 15:00-15:30 meeting to discuss the latest issues.
Feb	14	Tue		09:00-11:00 To have Seminar to share the formulated guidelines for the advancement of earthquake and tsunami monitoring operations.
Feb	15	Wed	815	To establish the Tsunami Guideline. 09:00-10:00 To get the GUI results. 15:00-15:30 To report the results from the visit activities to MARN.
Feb	16	Thu		08:30- 09:30 To have a meeting with SICA To take the actions according to the activity-time flow.
Feb	17	Fri	816	To have final approval for the content of the improvement on the seismic and tsunami monitoring system from MARN (1st day from 3 days). To establish the formulated guidelines for the advancement of earthquake and tsunami monitoring operations. 10:00-11:00 Repor t on the results to JICA office. To hand over the items procured to MARN from JICA. 15:00-15:45 1) MARN seismic and tsunami Guidebook/2) AOB:2-1) Procured items: a) Textbooks delivered should be checked by Expert. / b) The location of the radio and the antenna that are pending due to the tower problem / 2-2) Feature of an event / 2-3) GUI preparation time
Feb	18	Sat		To take the actions according to the activity-time flow.
Feb	19	Sun		To take the actions according to the activity-time flow.
Feb	20	Mon	817	15:00-15:30 1) MARN seismic and tsunami Guidebook / 2) CATAC seminar / 3) DGPC workshop / 4) AOB: 4-1) Handover document for the procured items / 4-2) Multi event handling (Case study on the January 15 (UTC) M5.1.) / 4-3) To check the status of the La Libertad tide gauge nursing / 4-4) Analysis of initial wave polarity data to get focal mechanisms that cannot be obtained by CMT

Feb	21	Tue		Departure from El Salvador El Salvador Time (Transit stay at Mexico City in Mexico)
Feb	22	Wed		Trip
Feb	23	Thu		Return to Japan JST
Feb	24	Fri	716	To take the actions according to the activity-time flow. 15:00-15:30 Virtual meeting to discuss the latest status.
Feb	27	Mon	717	15:00-16:00 Virtual meeting to have final approval for the content of the improvement on the seismic and tsunami monitoring system from MARN.
Feb	28	Tue		To take the actions according to the activity-timeflow.
Mar	1	Wed	718	15:00-16:00 Virtual meeting to have final approval for the reinforced protocols & procedures against tsunami threat from MARN (2nd day from 3 days).
Mar	2	Thu		To take the actions according to the activity-timeflow.
Mar	3	Fri	719	15:00-16:00 Virtual meeting to have final approval for the reinforced protocols & procedures against tsunami threat from MARN.
Mar	6	Mon	720	15:00-16:00 Virtual meeting to establish the formulated guidelines for the advancement of earthquake and tsunami monitoring operations
Mar	7	Tue		To take the actions according to the activity-timeflow.
Mar	8	Wed	721	To take the actions according to the activity-timeflow. 15:00-15:30 Virtual meeting to discuss the latest status.
Mar	9	Thu		To take the actions according to the activity-timeflow.
Mar	10	Fri	722	To take the actions according to the activity-timeflow. 15:00-15:30 Virtual meeting to discuss the latest status.
Mar	13	Mon	723	To take the actions according to the activity-timeflow. 15:00-15:30 Virtual meeting to discuss the latest status.
Mar	14	Tue		To take the actions according to the activity-timeflow.
Mar	15	Wed	724	To take the actions according to the activity-timeflow. 15:00-15:30 Virtual meeting to discuss the latest status.
Mar	16	Thu		To take the actions according to the activity-timeflow.
Mar	17	Fri	725	To take the actions according to the activity-timeflow. 15:00-15:30 Virtual meeting to discuss the latest status.
Mar	20	Mon	726	To take the actions according to the activity-timeflow. 15:00-16:00 to report the results of the work to DG of MARN
Mar	22	Mon		To submit a report on the results of the work (in Japanese and English) to the JICA El Salvador Office.
Mar	23	Mon		15:00-16:00 to report the results of the work to the JICA El Salvador Office

Appendix 3 Summary of the Project



Period

Guideline for how to proceed with the Tsunami Monitoring Duty in El Salvador

Elaboró:	Revisó:	Autorizó:
Shigeo MORI (JICA Expert for MARN during 2015-2018, 2021-2023)	Luis Mixco (Seismologist) Douglas Hernandez (Geological monitoring coordinator)	Manuel Díaz (Geology manager)
24Mar23	XXMar23	XXMar23

(Note 1: The blue-letter issues should be reviewed time to time.)
(Note 2: The red-letter issues should be essential in this document.)

I. OBJECTIVE

Under the condition of having **the authorized protocol**[1] (called **the Tsunami Protocol** hereinafter) for handling tsunami, to establish the guideline for

1) the actions within 30 minutes after detecting any remarkable phenomenon such as a large earthquake or a massive volcanic eruption located in front of or outside our coasts, with tsunamigenic characteristics,
2) those until issuance of tsunami warning cancellation,
3) those of daily monitoring works.

In addition, under the condition of having **another authorized protocol**[2] (called **the Seismic Protocol** hereinafter) for handling abnormal seismic activities, to establish the one for

4) the actions against typical earthquakes.

With the guideline, it is intended that each technician on monitoring duty should easily remind the actions to be taken at the time of the occurrence of the above phenomena and should issue timely information to the population that could be affected by the tsunami.
A particular situation may require additional decisions or actions with some variants, though.

II. SCOPE

The tsunami monitoring shift officers should regularly review this guideline before, during, or after taking the shift. Therefore, this document should be simpler under the condition of following the Tsunami Protocol and Seismic Protocol.
This guideline has been developed based on experiences of the JICA-Expert and tsunami monitoring conditions made by "events occurred" and "existing threats" and should be updated and improved when new conditions arise like any internal and external additional demand for any new or any improved technologies.

III. DEFINITIONS

1. TERMS

We should refer to the Tsunami Protocol and the Seismic Protocol, where the below terms are found: Accelerograph, Amplitud del tsunami, Cancelación de la alerta de tsunami, DART, Datum, Distancia de inundación, Magnitude, Microtsunami, Mareógrafo, Profundidad del flujo, Replicas, Run-up, Seismic swarm, Seismic Intensity, Seismic Series, Shakemap, Earthquake, Local earthquake, Regional earthquake, Seismograph, Sismo-tsunami o sismo lento, Tsunami, Tsunami local, Tsunami regional, Tsunami transoceánico o distal, Tiempo de arribo.
TIDE TOOL: Open-Source Sea-Level Monitoring Software for Tsunami Warning Systems

2. ACRONYMS USED

AMSS: Metropolitan Area of San Salvador.
CISN: California Integrated Seismic Network

[1]Protocolo de Actuación Por Amenaza de Tsunami en El Salvador autorizado por Directora General de Observatorio de Amenazas y Recursos Naturales 18/11/2019 (IAM-MFN-PA-03_Protocolo_de_Actuación_por_amenaza_de_Tsun_ami_en_El_Salvadorfinal 18NOV2019)
[2]Actuación por Amenaza de Sismos en El Salvador autorizado por Directora General de Observatorio de Amenazas y Recursos Naturales 00/00/2021 (IAM-MFN-PA-08 Actuación por Amenaza de Sismos en El Salvador 2021)

CMA: Centro de Monitoreo de Amenazas
CTC: Scientific Technical Commission made up of specialists in the area, from institutions such as Civil Protection, Universities, Government Institutions.
DART: Deep-ocean Assessment and Reporting of Tsunamis
DOA: Direction of the Environmental Observatory.
EEW: Early Warning System
EWBS: Emergency Warning Broadcast System
GMT: Greenwich Mean Time.
NOAA: National Oceanic and Atmospheric Administration.
PTWC: Pacific Tsunami Warning Center.
RMS: Root Mean Square
SAT: Sistema de Alerta Temprana
SNPC: National Civil Protection System.
TTT: Tsunami Travel Time.
TsuCAT: Tsunami Coastal Assessment Tool
USGS: United States Geological Survey.
VAAC: Volcanic Ash Advisory Center

3. Define Zone

The below is excerpted from the Tsunami Protocol.
Local (Z-1): Frente a las costas hasta 300km (aprox. hasta frontera Guatemala-México y frontera Nicaragua-Costa Rica).
Regional (Z-2): De 300km a 1000km (Desde las costas mexicanas hasta la costa de Colombia-Ecuador).
Distal (Z-3): Más de 1000km (toda la cuenca del Pacifico).

IV. DESCRIPTION

1. Procedures timeline

The procedures timeline is shown **in the below columns**.

Tables of actions against the events with Magnitude 6.5 or larger
(for "Aviso y Alerta de Tsunami" for LOCAL (Z1); the red actions are the main body of this table.)

Elapsed time (min)	Status of the environment	Procedures to be started by the elapsed time: Actions taken by Seismic shift	Procedures to be started by the elapsed time: Actions taken by Landslide shift
0	Occurrence of an earthquake (Origin Time (OT) = Time of detecting the event - around 10 sec): Starting the procedures		
1	Given observed seismic waveforms of any stations		
2	Given automatic hypocenter & M	Issuing and disseminating **Calm message** via radio, WhatsApp (fax), Twitter	Checking information in CISN
3		Selecting hypocenter & M according to the criteria based on data number & average RMS	
		Checking consistency with other information collected until this timing	
5	Receiving seismic parameters & tsunami potential level from outside	Issuing **Preliminary message** with checked M, epicenter location, indication of tsunami threat, and any term to tell what to do, via radio & WhatsApp (fax); disseminating it via Twitter & Web Issuing and disseminating **Tsunami Bulletin 1** with estimated tsunami arrival times (ETA) via radio, WhatsApp (fax), email, Twitter & Web	Responding to supervisors and to the public
		Evaluating the latest hypocenter according to **the criteria** / Calculating manually seismic parameters / Selecting M according to **the criteria**	
10		Issuing **Final message** with degree of tsunami threat via radio & WhatsApp (fax); disseminating it via Twitter & Web	
10-20		Assessing the information from CATAC, PTWC, USGS and other outside organizations; judging necessity of updating the information; disclosing the information by adding to the Tsunami bulletin	Issuing and disseminating **Tsunami Bulletin 2** with seismic parameters, degree of tsunami threat, ETA , and estimated tsunami height via WhatsApp, fax, email, Twitter & Web

Procedures timeline (Continued from the previous page)

15	Getting Mw from CMT	Judging necessity of change of tsunami degree based on the Mw / **If necessary,** issuing and disseminating the message with updated information via WhatsApp (fax), Twitter & Web	Checking the information in the Twitter & Web / Sea level gauges are monitored with Tide Tool (arrival times and heights)/ Disseminating **the data** via Twitter &Web / **Informing authorities of the CMA** / Communicating with officials in the coastal zone / Monitoring the information in international agencies, media, twitter & web
15-20		Issuing & disseminating **the ShakeMap** with WhatsApp (fax) Twitter & Web	
		Locating aftershocks manually	
20-30		Addressing media	

Note 1: Issuance & dissemination of Preliminary and Final messages are handled separately by Seismic and Landslide officers now. But when we introduce the "GUI" developed into the procedures, Issuance & dissemination would be done together by Seismic officer.
Note 2: The parentheses for fax like "WhatsApp (fax)" means that "fax" should be redundancy for "WhatsApp".

(Note 3: The first 15 min actions should follow this guideline.)
(Note 4: Descriptions from the top of this document to here should be reviewed frequently.)
(Note 5: Those from here to the bottom of this document should be reviewed once a year and when any events have occurred.)

----

2. Detail of procedures

1) Issuance of Calm Message

We should initiate the procedures when detecting any event that should be felt by people. Namely, at that time, Calm Message should be issued as the 1st step of tsunami handling procedures. Shift officer should thus follow the system's instruction that is automatically prepared according to the criterion[3] with the data collected at that time to anticipate if the event has been felt or not. The Calm Message is to make people know that MARN is taking care of any events, and to put their minds at ease.

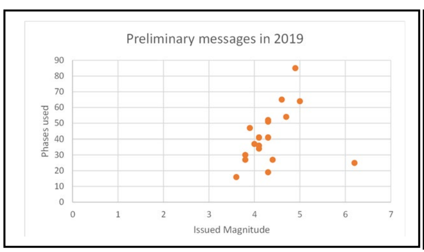
2) Selecting Hypocenter and Magnitude

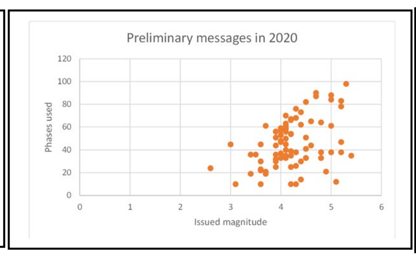
a) Magnitude

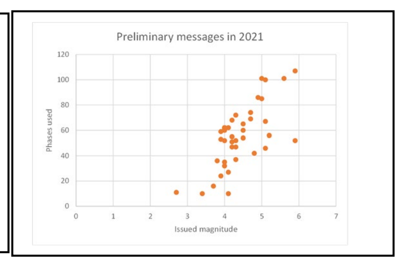
Preliminary Message: We should adopt one of the Magnitudes automatically 1) obtained by using 10 data or larger number and having smaller than 1 (sec) as its RMS of timing. Further, in the case of that the M reaches 5.5 or larger, we should take the largest one from them in the SeisComP.

Note 6: the data number, **10 or larger**, has been obtained from **the below 3 columns** and the case study[4] on the event of "15Jan23 M5.1 23:07:53 UTC".

Note 7: As for the events having **6.5 or smaller** as their Magnitude, it seems that the M automatically obtained might give us any **over-estimated result**. For example, in a case that Mw is 6.2, the M was 6.5. On this case, the "Average M" was adopted.







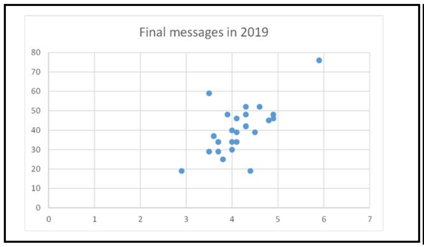
Final Message: Even if the M is smaller than 6.7, the actions should be continued until issuance of Final Message. The M for the Final Message should be selected from M using data of 25 or larger and having smaller than 1 (sec) as its RMS of timing; and we should take the largest one from them.

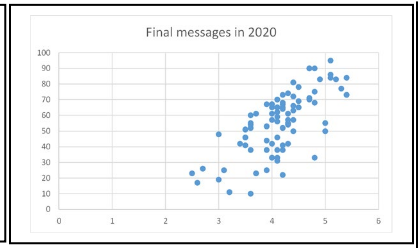
Note 8: the data number, 25 or larger, has been obtained from **the below 3 columns.**

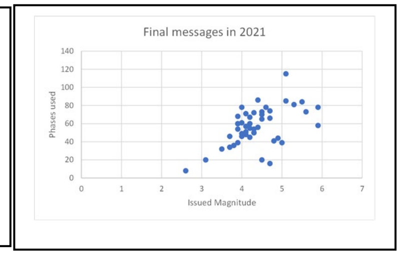
---

[3] The criterion has been established around 06Jun22 by MARN. **See the Appendix 5.**

[4] Informe Tecnico 2 "Continua actividad sísmica entre territorio guatemalteco y el municipio de San Lorenzo, Ahuachapan" (File name: Informe_Técnico_2_San_Lorenzo_Guatemala_230123). "Multi event handling (Case study on the January 15 (UTC) M5.1.)" (File name: Multi event handling)

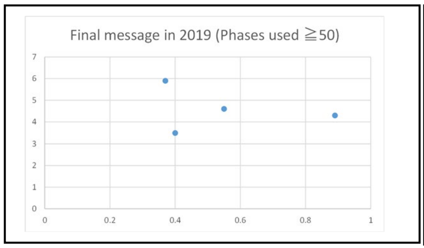


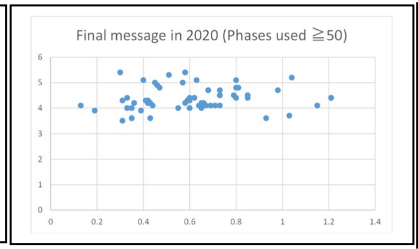


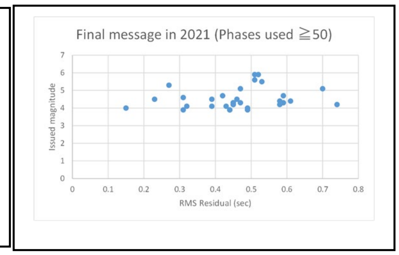


b) Hypocenter

We should follow the procedures shown in the M. The criterion used to select M, as mentioned above, that RMS should be smaller than 1.0 could be understood with **the below 3 columns**.







3) How to get Mw from CMT analysis and to get focal mechanism

We should calculate CMT to get Mw and focal mechanism in the below cases:

Case 1: If the Final message shows that M should be 5.5 or larger, any damage should be expected at the epicenter area; so, we should get focal mechanism from CMT[5] to understand the feature of the event and to consider the perspective of the aftershock activity.

Case 2: If the Final message shows that M should be 6.5 or larger, any tsunami should be expected; so, we should additionally get Mw from CMT to understand the feature of the event and to consider the reliable tsunami level.

Case 3: If the Final message shows that M should be 7.0 or larger, M from amplitude data should has some possibility of underestimate; so, CMT should be calculated as early as possible to get reliable M or Mw.

3. Daily monitoring works

1) Works just after taking over the shift duty

The check list shown **in the next page right column** should be used in the morning. In addition, the inspection of communication tools should be carried out with the checklist shown in the **next page left column** through asking DGPC to take actions together with MARN on every Monday, Wednesday, and Friday around 07:30 am.

(Note 9: The inspection of communications tools could be practically carried out when MARN should handle small size seismic phenomena that should be assigned to around an intensity MMI III[6] that may not be felt. That means shift officer can handle the issue without upset to issue any Calm message and can check the communication tool function simultaneously.)

2) Handling non-earthquake tsunami

(Note 10: The emergency procedures to handle non-earthquake tsunami are shown **in the chapter 6**.)

According to the case on the day, monitoring officers should conduct as follows:

Case 1: No remarkable activity of volcanoes located in any lake of El Salvador,

a) Checking TideTool at any fixed time, 7h, 12h, or 19h through referring the DART locations

b) Checking information issued from PTWC or VAAC according to the results from the above action

Case 2: Remarkable activity of volcanoes located in any lake of El Salvador,

a) Checking the volcanic activity

[5] We should establish to use initial motion polarity data to get focal mechanism in the future.

[6] The "MMI III" means "Sentido en el interior. Objetos suspendidos oscilan. Vibraciones como si pasara un camión ligero. Duración apreciable. Puede no ser reconocido como un terremoto. (English: Sense inside. Suspended objects oscillate. Vibrations as if passing by a light truck. appreciable duration. It may not be recognized as an earthquake.)".

b) When it becomes high stage, taking the emergency procedures (or to tell beforehand the people staying the coastal area to prepare to evacuate.)
c) To monitor the volcanic body continuously.

Lista de verificación para que DGPC inspeccione las herramientas de comunicación entre MARN y DGPC ver.2
(Nota: los siguientes "elementos a verificar" deben ser los de las comunicaciones entre MARN y DGPC. Los elementos solo para la comunicación interna no deben aparecer en esta lista).
Fecha (fecha, mes): , Hora de El Salvador 2022

Estado		Herramienta	Elementos a comprobar	MARN	DGPC
Autorizado por ambos		Radio (Voz de "prueba")	Función		Conexió ☐Ok / ☐No
Autorizado por ambos		Fax (Hoja de prueba)	Función		Conexió ☐Ok / ☐No
			Papel		Certificado ☐Sí / ☐No
Equipo esencial para el uso del fax		Impresora	Función		
			Papel		
A autorizar	Copia de seguridad para radio	WhatsApp (Voz de "prueba")	Función		Conexió ☐Ok / ☐No
Autorizado por ambo		Email (Mensaje de "test from MARN")	Función		Emitido/Recibido ☐Ok / ☐No
Autorizado por cada instituciónn		MARN Twitter	Función		
		MARN Web-site	Función		
Autorizado por cada institución		DGPC Twitter	Función		Marcado ☐Ok / ☐No
		DGPC Web-site	Función		Marcado ☐Ok / ☐No

Lista de verificación para que MARN inspeccione las herramientas de comunicación entre MARN y DGPC ver.2
(Nota: los siguientes "elementos a verificar" deben ser los de las comunicaciones entre MARN y DGPC. Los elementos solo para la comunicación interna no deben aparecer en esta lista).
Fecha (fecha, mes): , Hora de El Salvador 2022

Estado		Herramienta	Elementos a comprobar	MARN	DGPC
Autorizado por ambos		Radio (Voz de "prueba")	Función	Conexió ☐Ok / ☐No	
Autorizado por ambos		Fax (Hoja de prueba)	Función	Conexió ☐Ok / ☐No	
			Papel	Certificado ☐Sí / ☐No	
Equipo esencial para el uso del fax		Impresora	Función	Certificado ☐Sí / ☐No	
			Papel	Certificado ☐Sí / ☐No	
A autorizar	Copia de seguridad para radio	WhatsApp (Voz de "prueba")	Función	Conexió ☐Ok / ☐No	
Autorizado por ambo		Email (Mensaje de "test from MARN")	Función	Emitido/Recibido ☐Ok / ☐No	
Autorizado por cada instituciónn		MARN Twitter	Función	Marcado ☐Ok / ☐No	
		MARN Web-site	Función	Marcado ☐Ok / ☐No	
Autorizado por cada institución		DGPC Twitter	Función		
		DGPC Web-site	Función		

CHEQUEO DEL TURNO SISMOLOGICO

Encargado: ______________ Fecha: ______________
Etapa: MONITOREO ◯ PRE-AVISO ◯ AVISO◯ ALERTA ◯

Entrega de turno sismológico: Hora Entrega ________			
Recibió comentarios sobre el turno:	Si ☐	No ☐	
Reviso PC's y equipos:	Si ☐	No ☐	Horas:__________
Conteo de sismos turno anterior	Si ☐	No ☐	
Revisar Sismogramas y Espectrogramas	Si ☐	No ☐	Horas:__________
Informe de CAPRES (hasta nuevo aviso)	Si ☐	No ☐	Horas:__________
Envío de Informe Integrado	Si ☐	No ☐	Horas:__________
Envío de RSAM de VSM	Si ☐	No ☐	Horas:__________
REVISAR APLICACIONES			
CISN Display	Si ☐	No ☐	Horas:__________
Seisgram – SeisComp	Si ☐	No ☐	Horas:__________
Cámaras de Vigilancia	Si ☐	No ☐	Horas:__________
TideTools	Si ☐	No ☐	Horas:__________
Registró sismos (procesados)	Si ☐	No ☐	Nº:__________
Registró sismos sentidos:	Si ☐	No ☐	Nº:__________
Envió Informe por Twitter, SMS y Radio	Si ☐	No ☐	
Datos finales por Twitter, SMS y Radio	Si ☐	No ☐	
Registró evento(s) distal relevante	Si ☐	No ☐	Nº:__________
Recepción de información PTWC:	Si ☐	No ☐	
Elaboración de mapa TTT:	Si ☐	No ☐	
Chequeo de registro Tide Tools:	Si ☐	No ☐	
Envío de datos Twitter, SMS y Radio:	Si ☐	No ☐	
Sismicidad Local Importante:	Si ☐	No ☐	
Localización de sismicidad:			
Número de Eventos:			
Cambio de Etapa por evento:	Local◯ Regional◯	Distal◯	Volcán◯
Elaboración de página de conteo:			
Cambio a: Pre-Aviso:◯	Aviso:◯	Alerta:◯	Regreso a Monitoreo:◯
Informe Especial:	Si ☐	No ☐	

Recibe: ______________

4. Elaboration of cancellation procedures

The cancellation should be followed the Tsunami Protocol. In addition, we should take care of the arrival of larger tsunamis after diminishing of initial tsunamis.
(Note 11: **To regularly talk DGPC to use only MARN's cancellation information.** Reportedly DGPC uses PTWC's in addition to MARN's. But its detail criterion has not been established, even though one of three documents provided by DGPC, "PROCEDIMIENTOS DE OPERACIÓN ESTÁNDAR FRENTE A EVENTOS DE TSUNAMI" (File name: Procedimiento Operativo ante Tsunami-SOP´s Nacional-DGPC Formato autorizado), shows the term, Cancelación, in it.

5. Tsunami warning drill

1) The internal drill should be implemented roughly once for two months.
2) Series of drill scenarios should be prepared based on the view in the "Scenarios of tsunami simulation exercise as of 26Oct22" and "Series of Scenarios as of 24Jan23".
3) The officer who is designated to take the exercise on the drill should review the present document, "Guideline for how to proceed with the Tsunami Monitoring Duty in El Salvador" (File name: Guideline for how to proceed with the Tsunami Monitoring 10Mar23), and, if noticing anything, the officer should propose any revision of it.

6. Terms in tsunami warning/advisory

The **below table** shows the terms related to urge the people to take any actions with the tsunami warning/advisories issued from MARN.
(Note 12: This issued should be shared with DGPC.)
(Note 13: The messages related to actions like "preparation", "evacuation" and "take actions", must be clearly understood as well by the officers of both of DGPC and MARN to be able to explain to the people or to the media. On the workshop for reviewing the exercise, this must be one of topics to be clarified through explained their own understandings by both of DGPC and MARN.)

Term	Aim	Expected phenomenon	Expected tsunami height	Zone (Expected tsunami arrival timing)			What we should do
				Local	Regional	Distant	
OBTENER INFORMACIÓN ***(to be informed)***	To urge the public to get information	Low	< 0.3 m	Local	Regional	Distant	To get information with caution throuhg stopping any marine activities
PREPARACIÓNP ***(to prepare)***	To urge the populations near to coasts to prepare for evacuation and to follow the instructions of emergency managers	Middle	0.3 -1.0 m	Local	Regional	Distant	To restrict recreational activities like swimming, fishing, diving, sailing in the threatened areas / To prepare for evacuation and to follow the instructions of emergency managers
TOMAR ACCION ***(to take action)***	To order the populations to take actions such as evacuation from coast areas	Significant	1.0 -3 0 m	Local	Regional	Distant	To take actions such as evacuation from the coasts in the threatened areas.
	To order the populations to evacuate from all Salvadoran coast.	Severe	> 3.0 m	Local			To evacuate from any Salvadoran coasts

7. Non-earthquake tsunami handling procedures

1) Detection of tsunami
   See the above daily work procedures in **Chapter 3**.
2) Arrival time and height after detection of tsunami
   Evaluating the information from PTWC and issuing the tsunami advisories according to the results from the evaluation. **See the below table**.
   (Note 14: We should talk with Weather section to get VAAC from WMO/GTS.)

Proposal on the interim "SOP" of MARN as of 09Feb22

Feature of tsunami from the Tonga volcano eruption			PTWC interim SOP against tsunami from Tonga	Proposal on the interim "SOP" of MARN	
Effect to sea wave from acoustic waves		"Tsunami"		Tsunami from Tonga	Non-earthquake tsunami including the one generated by acoustic waves
Detection of tsunami			DART buoy near Tonga	To monitor 1) Tide Tool actively in any proper interval, 2) PTWC information passively, 3) volcanic eruption in Pacific Ocean from VAAC through WMO/GTS. If possible, to do passively 4) issuance of tsunami advisories from any countries in Pacific Ocean.	
Arrival time	Earlier: first arrival of tsunami is generated higher velocity acoustic waves	First arrival is around the time when the acoustic wave arrives	To issue EAT with any notification *like "any sea wave change should arrive earlier" or something*	PTWC information according to the Interim SOP	PTWC information
		Arrival of high amplitude is around the "Estimated Arrival Time of ordinary tsunamis" (EAT)			
Amplitude	Larger in distant area: height of sea wave is amplified by the slower velocity acoustic waves	First arrival is not "so large"	To estimate according to the experience in the event		
		Arrival after EAT is larger than the estimated on the ordinary tsunamis			

7. Challenges and actions against them with any future improvement expected

1) To expect to use the information from EEW in the Preliminary messages.
2) To expect to use EWBS to inform tsunami warning messages to the public.
3) To expect to introduce, by DGPC through MARN, the Tsunami Flags into evacuation at the coastal area against tsunami threat.

Appendix 1 Criterion on selection of velocity models

To take the global crustal model for the events of M 8.3 (Fault length L = 200 km) or larger. And to take the global crustal model for the distant events.

(Note 15: As shown in **the right column**, MARN can use several velocity models that would be used in the hypocenter determination. One of them, IASP91, is the standard "global crustal model". Two of them are "regional crustal models" that were developed in the Phase1. / As for the tsunami warning, we should use the global one, because the events that we should take care of for tsunami handling are relatively large and globally observed. So, the system should use data not only from the stations located near to the epicenter but also from those in foreign countries. / On the other hand, as for inland events and small events, it might be better for us to use the regional crustal models.

2-3) Velocity model handling

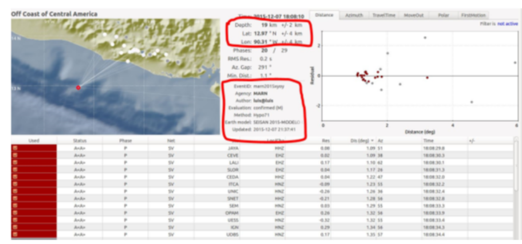
Result 2-3: Expert showed the below upper figure that told reginal crustal mode of STA had been best. But the data used to calculate the hypocenter come from the stations within 2 degrees or 220 km. That means the data come from regional stations. (Note: El Salvador costal length is around 230km.) On the other hand, the hypocenter calculation for Nicaraguan event used data from 260 km as shown in the below lower figure.

The comparison results tell that STA is the apparently best velocity structure.

SeisCOMP3 Hypo71-STA

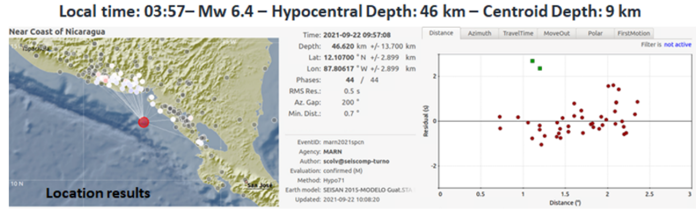
Result in the Phase 1

Model	Feature	Example of calculated depth (km)	Depth error (km)	# of phases used
IASP91	Global	8	9	21 out of 29
STA	Regional Inland	19	2	20 out of 29
STF	Regional ocean	16	164	16 out of 29



Expert and MARN should consider the tsunami handling procedures in how to handle the velocity model.

Local time: 03:57– Mw 6.4 – Hypocentral Depth: 46 km – Centroid Depth: 9 km



Note 16: This issue has come from the handling in the Nicaraguan events shown in **the below list.**

	Messages posted on the MARN twitter of the public on the Nicaragua event of 22Sep21 03:57 a.m. (OT, local time)				
	Type of message	Elapsed time from OT	Contents	Purpose *(to be confirmed)*	Actual description (Translated into English by the Expert and adder the blue letters)
1	Calm	2 min	Felt, occurrence e of earthquake	To calm	Preliminary parameters of the earthquake felt in Salvadoran territory will be released shortly.
2	Preliminary	4 min	Preliminary M and the epicenter location (feature off the event)	To tell how to consider the event (Loca event z1; 6.5 -> tsunami maild threat)	Seismic magnitude 6.5, off the coast of Nicaragua
3	Final	15 min	Final seismic parameter **with the epicenter map**	To tell how to consider the event (z1; 6.3-> no threat)	Seismic magnitude 6.3, off the coast of Nicaragua117 km south of Playa Las Tunas (in El Salvador). Depth. 46km
4	Tsunami	20 min	Judgement on the tsunami threat	To tell if we should consider tsunami	Based on the parameters of the earthquake, there is NO tsunami threat to El Salvador.

https://twitter.com/MedioAmbienteSV/status/1440619938834645006 https://twitter.com/MedioAmbienteSV

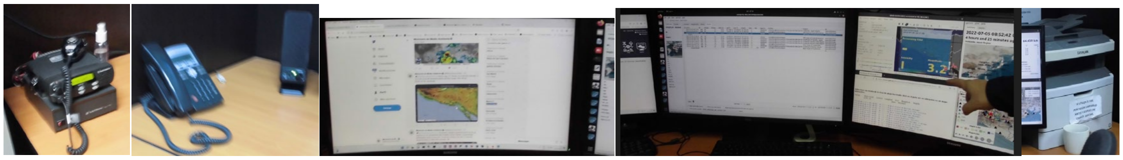
Appendix 2 How to use and how to maintain the present Guideline

1) It should be read just before tsunami warning drills by the monitoring shift officers who should participate in the drills. Further we should follow the **"II. SCOPE"**.

2) When a) we additionally have experienced any actual tsunami related events in the future or b) we have carried out tsunami warning drills, we should review the actions taken in the events as soon as possible and should review this guideline as well. According to the results from the above reviews, this guideline should be revised, if necessary.

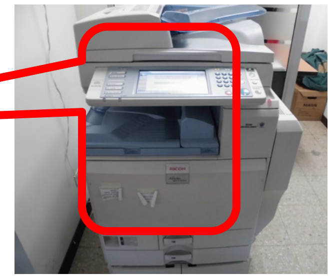
3) Further, if the above revision (improvement) would have any concern about any violation of the Tsunami Protocol or Seismic Protocol, we should consider if we should revise any Protocol.

Appendix 3 Locations of monitoring and communicating tools



Radio Telephone / Smartphone (WhatsApp) Three displays FAX

Backup Radio for the Monitoring Shifts



Appendix 4 Scenarios and Magnitude to determine the action under Tsunami threat

Below is the excerpt from the **Tsunami Protocol**.

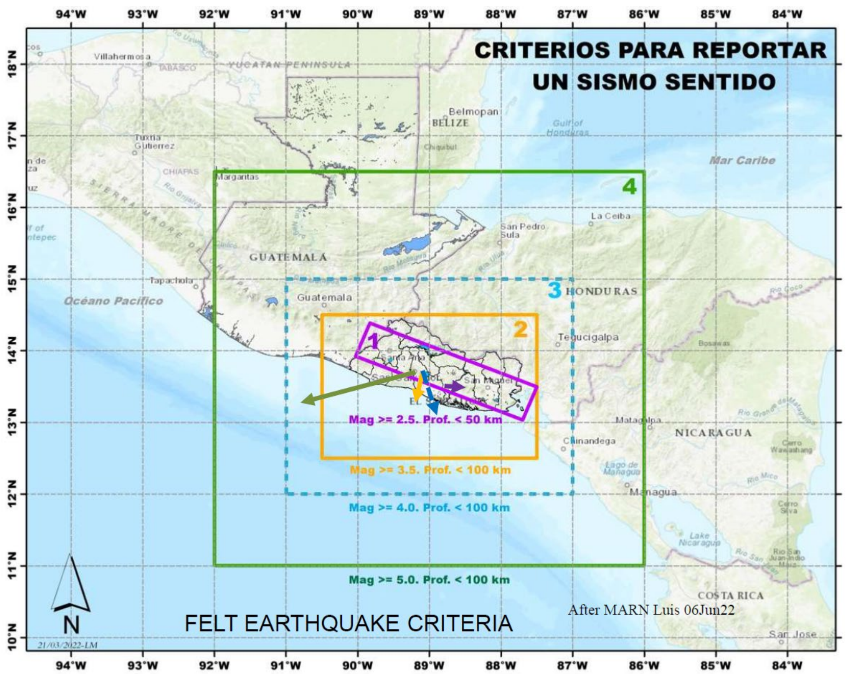
Tabla 1. Escenarios y Magnitud para determinar la actuación en caso de amenaza de Tsunami con base en información histórica.

Magnitud	Sismo local (Z1)	Sismo regional (Z2)	Sismo distal (Z3)	Consideraciones particulares
	Ubicados en la cuenca del Pacífico y con Profundidad < a 100 km			
<6.5	No amenaza	No amenaza	No amenaza	1. Para el caso de sismos lentos (sismos-tsunami), que ocurran frente a la costa salvadoreña, con magnitudes superiores a 7.1, se podrían alcanzar la etapa de EMERGENCIA (con alturas de ola superiores a 3.0 m), para zonas focalizadas o generalizadas de la costa. 2. Para el caso del escenario regional, se podría alcanzar la etapa de EMERGENCIA, con sismos de magnitud superior a 8.7, siempre que los boletines del PTWC establezcan alturas de ola superiores a 3.0 m para la costa salvadoreña. 3. Para el caso del escenario distal, se podrían alcanzar las etapas de ALERTA y EMERGENCIA, con sismos de magnitud superior a 8.7 siempre que los boletines del PTWC establezcan alturas de ola superiores a 1.0 m para la costa salvadoreña.
6.5-7.0	Amenaza de tsunami leve / Pre-aviso	No amenaza	No amenaza	
7.1-7.5	Amenaza de tsunami moderada / Aviso	No amenaza	No amenaza	
7.6-7.9	Amenaza de tsunami alta / Alerta	Posible amenaza de tsunami leve/ Pre-aviso /se evalúa acorde con dato PTWC	No amenaza	
8.0 -8.6	Amenaza de tsunami muy alta / Emergencia	Posible amenaza de tsunami moderada/ Aviso / se evalúa acorde con dato PTWC	Posible amenaza de tsunami leve/ Pre-aviso /se evalúa acorde con dato PTWC	
≥ 8.7		Posible amenaza de tsunami alta / Alerta / se evalúa acorde con dato PTWC	Posible amenaza de tsunami moderada/ Aviso/ se evalúa acorde con dato PTWC	

El establecimiento de los umbrales de magnitud de la tabla 1, se determinó con base en el análisis de escenarios locales modelados por el MARN durante el 2018. Para los escenarios regionales y distales se empleó la base de datos de TsuCAT versión 4.0.

Appendix 5 The criterion to judge if an event should be felt or not

It was established around 06Jun22 by MARN. **See the below column.** The arrows are added by Expert. So, if the event has M2.5, 3.5, 4.0 or 5.0, the felt area should have the radius with the length of arrow violet, orange, blue or green respectively. The length has been obtained from **the below upper right figure 1.** Each arrow is within each square having the same color. That means the criteria show consistency with **the figure 1** and show adopting "safety side" to judge felt or not.



The right figure 1 tells that the M5.5 event would be felt within 250km (epicentral distance); and the M7.9 event would be felt roughly within 1500km. Further, at 110km (epicentral distance), events of M4.5 or larger would be felt. The Japanese Human Perception I is roughly felt and is around II & III of MMI. **See the below figure 2.** Further, it seems to be less or around 10 gal (PGA). **See the right below figure 3.** The Instrumental Intensity 1.0 is roughly near to the Japanese Human Perception I.

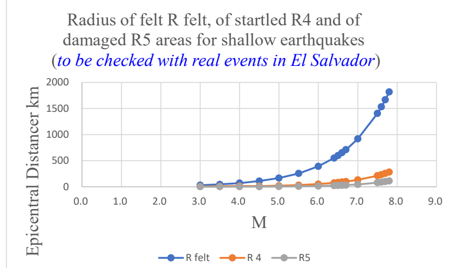


Figure 1: After Ichikawa 1960, Katsumata & Tokunaga 1971, Muramatsu

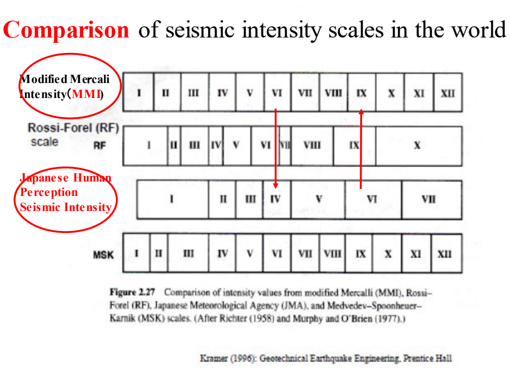


Figure 2

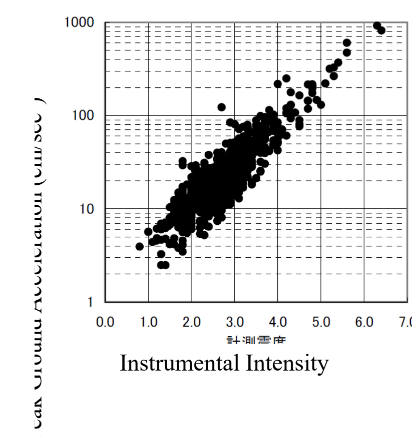


Figure 3

Appendix 6 The excerpt from the Tsunami Protocol

The below is the excerpt translated from Spanish. It shows the term, “two hours”, that is reportedly obtained from PTWC. PTWC has reportedly introduced the “two hours” just to keep the safety side in cancellation of very diverse types of tsunamis.

Conditions to be met to cancel tsunami threat

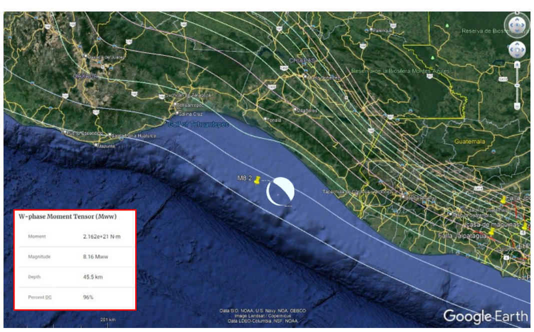
- That the final parameters of the earthquake do not meet the threshold of tsunamigenic eventgeneration.
- Do not observe significant changes or increases in sea level (less than 10 cm) in tide gauges near the coast of El Salvador after the estimated time of arrival of the tsunami.
- Do not observe changes or increases in sea level (less than 10 cm) in tide gauges near the seismic source after the estimated time of arrival of the tsunami. (In case of regional or distal sismos) .
- Corroborate the direction of energy propagation from PTWC products.
- Sufficient tsunami decay after a long time (at least two hours according to PTWC after estimated arrival times).
- That the PTWC indicate that the threat has passed to the Salvadoran coasts.
- That local conditions do not continue to produce strong water currents in canals or ports that require the prolongation of the tsunami warning state.
- That the area has not been hit by damaging waves for at least two hours.

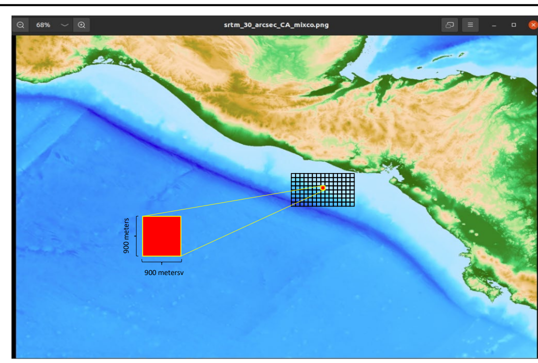
On the issuance of the cancellation

Finally, DGPC is informed of the cancellation of the threat and the cancellation is disseminated by the different media and social networks, for this see in annex 3 the formats of cancellation messages, in addition to including in the closing report of the event the cancellation of the threat.

Appendix 7 The source area where we should expect “later attack by tsunami

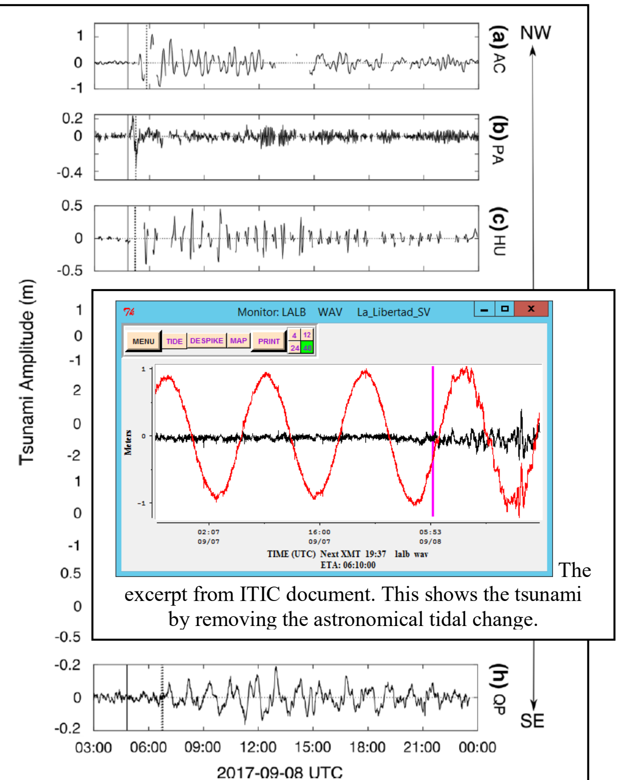
We have observed the interval between the first tsunami arrival and the highest tsunami arrival was 11 hours. We tentatively understand that this phenomenon should have been generated with the shallow sea depth from Eastern area of Mexico (95-96 W) through to Nicaragua as shown in the below column. Namely, the shallow area should have trapped the tsunami energy, and the velocity of tsunami is slow. We tentatively understand that these features should have made the phenomenon.





Note 17: It was observed in the Mexican event of 07Sep17[7] shown in **the right column and in the next page column.** One of the figures shows that the interval between the first tsunami arrival and the highest tsunami arrival was 11 hours.

Note18: How to handle the phenomenon is explained in the document, **Plan on the technology transfer & the training about tsunami handling (Category 3)** (File name: Category 3 as of 09Mar23).



The excerpt from ITIC document. This shows the tsunami by removing the astronomical tidal change.

Figure 6
Filtered records of the 2017 México tsunami at gauges within 690 km north and south the epicenter and at Quepos. **a** AC: Acapulco (México), **b** PA: Puerto Ángel (México), **c** HU: Huatulco (México), **d** SC: Salina Cruz (México), **e** PCh: Puerto Chiapas (México), **f** AJ: Acajutla (El Salvador), **g** LL: La Libertad (El Salvador) and **h** QP: Quepos (Costa Rica). Gauges locations are shown in Fig. 1. Vertical lines mark the earthquake time (solid line) and the forecasted arrival time by PTWC (dotted line). Arrows show the orientation of the gauges in relation to the epicenter (NW: northwest and SE: southeast), depicted with a red star. Mexican records were provided by the Servicio Mareográfico Nacional de México and El Salvador records by the Ministry of Environment and Natural Resources (MARN), all of which were downloaded from the IOC/UNESCO website

After Chacon 2018

[7] File name is "The_2017_M_w_8.2_Chiapas_Mexico_Earthqua; title is "The 2017 Mw 8.2 Chiapas, Mexico, Earthquake: Energetic Slab Detachment" by Lingling Ye, Thorne Lay , Yefei Bai , Kwok Fai Cheung , and Hiroo Kanamori; 2017

Guía de Sismos y Tsunamis

2023

GOBIERNO DE EL SALVADOR

MINISTERIO DE MEDIO AMBIENTE Y RECURSOS NATURALES

Guía de Sismos y Tsunamis

2023

Guía de sismos y tsunamis 2023

Ministerio de Medio Ambiente y Recursos Naturales (MARN) El Salvador,
Centro América

Elaboración
Dirección del Observatorio de Amenazas y Recursos Naturales

Edición y diagramación Unidad de
Comunicaciones

200 ejemplares

San Salvador, marzo 2023

Con el asesoramiento técnico del experto japonés asignado por la Agencia de Cooperación Internacional del Japón (JICA)

Ministerio de Medio Ambiente y Recursos Naturales (MARN)

Kilómetro 5 ½ carretera a Santa Tecla, calle y colonia Las Mercedes, edificios MARN, instalaciones ISTA, San Salvador, El Salvador, Centroamérica.

Tel: (503) 2132-6276
Sitio web: www.marn.gob.sv
Correo electrónico: medioambiente@ambiente.gob.sv
Facebook: www.facebook.com/MedioAmbienteSLV Twitter:
@MedioAmbienteSV
YouTube.com/MARNsv

Prefacio

El Ministerio de Medio Ambiente y Recursos Naturales (MARN) de El Salvador tiene como misión recuperar el entorno estratégico ambiental salvadoreño y reducir los riesgos socioambientales, a través de la promoción de una cultura ciudadana y coordinación interinstitucional bajo principios institucionales.

La información sobre sismos, tsunamis y prevención a desastres emitida por el MARN es para salvaguardar la vida de la población en riesgo, por tanto, debe ser comprendida y utilizada adecuadamente por las instituciones del Sistema de Protección Civil y de la población en general.

La presente Guía sobre sismos y tsunamis brinda información general referente a estos fenómenos, los procedimientos y tiempos requeridos en la emisión de la información, los medios oficiales de divulgación; los criterios para emitir aviso por amenaza de tsunami y el tipo de información que se divulga para la población bajo amenaza; los instrumentos de registro, las escalas de medición, comportamientos históricos, entre otra información.

Contenido

I. Terminología

Términos relacionados a los sismos[1]

Enjambre sísmico: serie o grupo de sismos de magnitud similar que ocurren en el mismo lugar en un periodo de tiempo relativamente corto (días, semanas e incluso meses). El MARN hace difusión pública del enjambre cuando el número de sismos es mayor o igual a 25 en menos de 24 horas.

Epicentro: es el punto en la superficie de la tierra verticalmente arriba del hipocentro (o foco).

Falla: es una fractura a lo largo de la cual los bloques de la corteza se han movido uno con relación al otro en paralelo a la fractura.

Hipocentro: es el punto dentro de la Tierra donde comienza la ruptura de un sismo. Este se encuentra directamente debajo del punto en la superficie de la tierra llamado epicentro (o foco).

Intensidad sísmica: es un número (escrito como un número romano) que describe la severidad de un sismo en términos de sus efectos en la superficie de la tierra, en los humanos y sus estructuras. La intensidad de un sismo depende de dónde se encuentre la persona que lo percibe, a diferencia de la magnitud, que es única para cada sismo. Una de las escalas de intensidad más utilizadas es la escala Modificada de Mercalli (MM).

1 Algunos términos han sido adaptados de: https://earthquake.usgs.gov/glossary/earthquake-hazards-program

I. Terminología

Magnitud: generalmente expresada con "M", es una medida cuantitativa del tamaño de un sismo en términos de la energía sísmica liberada. Se mide en una escala logarítmica, de tal forma que cada unidad de magnitud corresponde a un incremento de raíz cuadrada de 1000, o de aproximadamente 32 veces la energía liberada. Por ejemplo, un sismo de magnitud 8 es 32 veces más grande que uno de magnitud 7; 1000 veces más grande que uno de magnitud 6; 32,000 veces más grande que uno de magnitud 5, y así sucesivamente. Para calcular "M" se utiliza la máxima amplitud de las formas de onda registrada por los sismómetros. Para calcular la magnitud también se utiliza el momento sísmico, el cual es una cantidad proporcional al área de ruptura y al deslizamiento ocurrido en la falla geológica y se expresa como "Mw" en lugar de "M".

Profundidad focal: se refiere a la profundidad del hipocentro del sismo.

Réplicas: sismos que siguen al choque más grande de una secuencia sísmica. Son más pequeños que el sismo principal y se encuentran a una distancia de 1 a 2 longitudes de ruptura del sismo principal. Las réplicas pueden continuar durante un período de semanas, meses o años; en general, cuanto mayor sea el sismo principal, más grandes y numerosas serán las réplicas, y por más tiempo continuarán.

Región de origen: se piensa que el rápido deslizamiento dentro de la tierra -que es la causa directa de los terremotos (movimientos sísmicos)- es causado por la fractura de las rocas. La región donde ocurrió esta ruptura se llama región de origen. En grandes terremotos, la región de origen varía entre varias decenas y cientos de kilómetros; no es razonable considerar esto como un solo punto, sin embargo, con los valores observados de los tiempos de llegada de las ondas sísmicas en varios lugares, si calculamos como un punto el lugar donde se generaron las ondas sísmicas, se determinará un punto sin ningún inconveniente. Este punto se denomina hipocentro y es el lugar donde ocurrió la ruptura por primera vez, a menudo se encuentra más cerca del borde que del centro de la región de origen.

I. Terminología

Serie sísmica: serie de sismos ocurridos en un periodo de tiempo corto, en un área determinada. Si en la serie ocurre un sismo con magnitud mayor que el resto, a la serie se le da el nombre de "series de réplicas y premonitores", dependiendo de si ocurren antes o después del sismo principal. Cuando en la serie de sismos no se distingue ningún sismo principal, a la serie se le denomina "enjambre sísmico".

Shakemap: mapa del movimiento del suelo en términos de intensidad instrumental en la escala de Mercalli Modificada.

Sismo: es un movimiento de la tierra, que puede ser generado por el deslizamiento repentino en una falla, actividad volcánica o magmática, u otras fuentes.

Solución del mecanismo focal: es una forma de mostrar la falla y la dirección de deslizamiento de un sismo, usando círculos con dos curvas que se cruzan y que parecen pelotas de playa. También se llama una solución de plano de falla.

I. Terminología

Términos relacionados a los tsunamis[2]

Altura de inundación: o altura de tsunami, es la elevación alcanzada por el agua del mar; es la suma de la profundidad del agua y la altitud topográfica local. Esta se mide en relación al nivel medio del agua o el nivel del agua en el momento de la llegada del tsunami en una distancia de inundación específica.

Amplitud del tsunami: normalmente determinada por un registro de nivel del mar, es: 1) el valor absoluto de la diferencia entre un seno o un valle particular del tsunami y el nivel normal del mar en reposo a la hora indicada, 2) la mitad de la diferencia entre un seno y un valle sucesivos, corregida por el cambio de marea entre ellos. Representa la verdadera amplitud de la onda del tsunami en algún punto del océano, sin embargo, es a menudo modificada de alguna forma por la respuesta del mareógrafo.

Datum: sistema geométrico de referencia empleado para expresar numéricamente la posición geodésica de un punto sobre el terreno. Cada datum se define en función de un elipsoide y por un punto en el que el elipsoide y la Tierra son tangentes.

Fuente del tsunami: punto o área de origen del tsunami. Normalmente es el lugar en el que un terremoto, erupción volcánica o deslizamiento de tierras ha causado un rápido desplazamiento de agua a gran escala dando origen a las ondas del tsunami.

2 La mayoría de términos han sido tomados de: Comisión Oceanográfica Intergubernamental. Glosario de tsunamis, cuarta edición, 2019. Colección Técnica de la COI, 85. París, UNESCO, 2019; https://unesdoc.unesco.org/ark:/48223/pf0000188226_spa/PDF/188226spa.pdf.multi

I. Terminología

Intensidad del tsunami: medición del tamaño de un tsunami basada en la observación macroscópica del efecto de sus olas en los seres humanos y objetos, como embarcaciones de diferentes tamaños y edificios. La escala original fue publicada por Sieberg (1923) y posteriormente modificada por Ambraseys (1962) para crear una escala de seis categorías.

Papadopoulus e Imamura (2001) propusieron una escala de intensidad de 12 grados que fuera independiente de la medida de los parámetros físicos como la amplitud de la ola, susceptible a las pequeñas diferencias en los efectos de un tsunami, y lo suficientemente detallada para cada grado como para abarcar los distintos tipos de impacto de un tsunami que pudieran existir sobre los seres humanos y la naturaleza.

Magnitud del tsunami: medida para determinar el tamaño de un tsunami basado en la medición de sus ondas por mareógrafos y otros instrumentos. La escala, originalmente descriptiva y más similar a la de intensidad, cuantifica el tamaño usando mediciones de la altura de las olas o de *runups* de tsunami. Lida et ál. (1972) describió la magnitud (m) como el logaritmo en base 2 de la altura máxima de la ola medida sobre el terreno y que corresponde a una magnitud que va de -1 hasta 4

$$\mathbf{m = \log_2 Hmax.}$$

Posteriormente, Hatori (1979) extendió esta escala conocida como Imamura-Lida para los tsunamis de campo lejano incluyendo la distancia en la fórmula.

Mareógrafo: también conocido como mareómetro, sensor del nivel de mareas o estación de nivel del mar. Es un instrumento utilizado para medir y registrar el nivel del mar.

Peligro de tsunami: la probabilidad de que un tsunami de una determinada magnitud impacte en una zona de la costa en particular.

I. Terminología

Runup: diferencia entre la elevación de penetración máxima de un tsunami (línea de inundación) y el nivel del mar en el momento del tsunami. En términos prácticos, el *runup* sólo se mide en la costa en la que hay clara evidencia de inundación.

Tiempo de arribo: Es el tiempo estimado que un tsunami tardará en llegar a un lugar específico luego de su generación, lo cual es determinado por medio de la velocidad y la refracción de las olas del tsunami a medida que viajan desde su origen. La velocidad de la ola del tsunami es controlada por la profundidad del agua, cuando la profundidad del mar es mayor a los 6,000 m, las olas de un tsunami pueden viajar a velocidades de hasta 800 km/h. La velocidad es mucho menor en aguas costeras, donde la altura de la ola comienza a incrementarse dramáticamente.

Tsunami: término japonés que literalmente significa "ola en puerto" (*tsu*: puerto, *nami*: ola). Serie de ondas de longitud y período sumamente largos, normalmente generados por perturbaciones asociadas con sismos que ocurren bajo el fondo oceánico o cerca de él. También llamado "ola sísmica" y, de manera incorrecta, "ola de marea". Asimismo, las erupciones volcánicas, los deslizamientos de tierra submarinos, los derrumbes costeros de montañas, y el impacto en el mar de un meteorito de gran tamaño, también pueden dar origen a la generación de un tsunami.
Las ondas de un *Tsunami* pueden alcanzar grandes dimensiones y viajar por toda la cuenca oceánica perdiendo energía; se propagan como olas de gravedad normales con un periodo típico de entre 10 a 60 minutos. Al acercarse a aguas someras, o poco profundas, las ondas de tsunami se amplifican y aumentan en altura, inundando áreas bajas, y donde la topografía submarina local provoca amplificación extrema de las olas, éstas al llegar a la playa pueden causar daños importantes. Los tsunamis no guardan relación con las mareas.

I. Terminología

Siglas

CATAC: Centro de Asesoramiento de Tsunamis para América Central
DGPC: Dirección General de Protección Civil
MARN: Ministerio de Medio Ambiente y Recursos Naturales
PTWC: Centro de Alerta contra los Tsunamis en el Pacífico (*Pacific Tsunami Warning Center*)
USGS: Servicio Geológico de los Estados Unidos (*United States Geological Survey*)
UTC: Tiempo Universal Coordinado (UTC=tiempo de El Salvador + 6 horas)

II. Advertencia e información ante desastres

Procedimiento de emisión de información

La advertencia de tsunami e información relacionada es remitida a la Dirección General de Protección Civil (DGPC) y a la población, en los tiempos establecidos, de acuerdo a los procedimientos operativos estándar a través de los medios de comunicación institucionales como las redes sociales (Twitter, Facebook), sitio web, correo electrónico, radio y fax. Ver detalles en la Figura 1 y 2

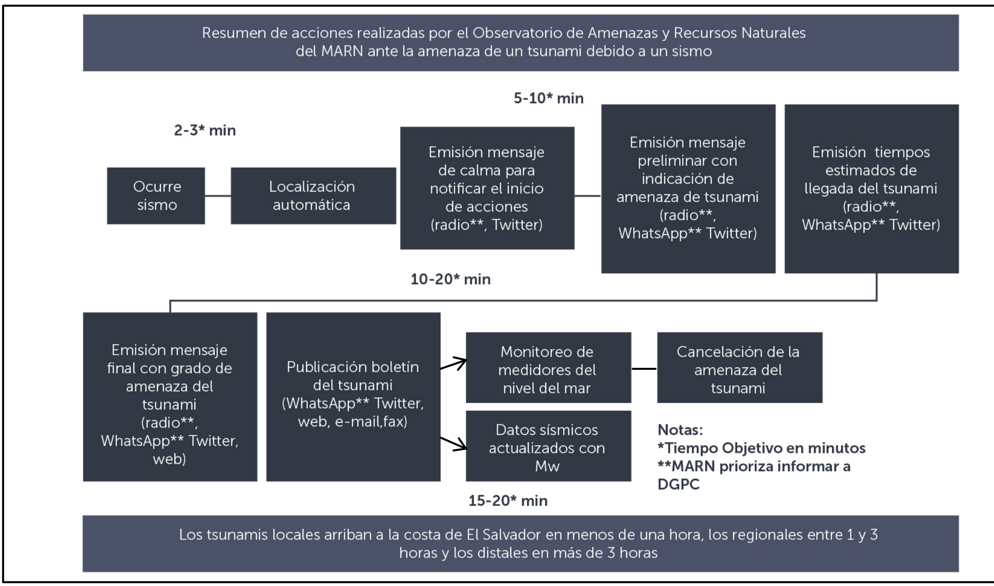


Figura 1. Acciones realizadas por sismo con amenaza de tsunami

Tiempo transcurrido desde la detección del sismo		Herramientas	Radio	WhatsApp	Fax	Twitter	Web
	Acciones	Hacia	DGPC y autoridadess locales	DGPC y autoridadess locales	DGPC	Público	Público
0 min	Ocurre sismo						
2-3 min	Localización automática						
	Emisión de mensaje de calma para notificar el inicio de acciones		Primero	Segundo	Copia de redundancia para WhatsApp	Segundo	
5-10 min	Emisión de Mensaje Preliminar con indicación de amenaza de tsunami						Tercero
	Difusión de los tiempos estimados de llegada del tsunami (ETA)						
10-20 min	Emisión del mensaje final con grado de amenaza de tsunami						
	Emisión y difusión del Boletín de Tsunami con parámetros s ísmicos, grado de amenaza de tsunami, ETA, y de altura estimada de tsunami			Primero	Segundo (Junto con emal)	Tercero	
	Los datos emitidos por PTWC y CATAC son evaluados y divulgados.				Copia de redundancia para WhatsApp		
15-20 min	Parámetros sísmicos actualizados con Mw, en caso de ser necesario						
	Difusión de mapas de intensidad instrumental (ShakeMap)						

Figura 2. Herramientas y medios utilizados en la emisión de información

Mensajes de calma, preliminares, finales y boletín

Ejemplos de los mensajes de calma, preliminar, final y boletín divulgados en twitter (Figura 3, 4, 5 y 6, utilizados internamente en el ejercicio de simulación de tsunami en 2021). **El mensaje de calma** se emite aproximadamente dentro de los 2-3 minutos posteriores a la ocurrencia del sismo para informar que ha sido percibido o sentido por las personas cercanas al epicentro (Figura 3). **El preliminar** tiene los datos del sismo evaluado aproximadamente dentro de 5-10 minutos para informar si el evento sísmico tiene potencial de generar un tsunami (Figura 4). Posteriormente, **el mensaje final** tiene los datos recalculados utilizando nueva información disponible para una mejor precisión en la evaluación del nivel de amenaza y las alturas estimadas de tsunami (Figura 5). **El boletín** tiene datos e información provisional más detallada sobre el tsunami (Figura 6). este informe es actualizado a medida que el evento evoluciona.

Ministerio de Medio Ambiente
@MedioAmbienteSV

📌 #ElObservatorioInforma Parámetros preliminares del sismo sentido en territorio salvadoreño se darán a conocer en breves momentos.

Figura 3. Ejemplo de mensaje de calma publicado en twitter

Ministerio de Medio Ambiente
@MedioAmbienteSV

📌 #ElObservatorioInforma DATOS PRELIMINARES:
Sismo Mag. 7.8, frente a la costa de La Libertad. [2021-11-05, 15:15:00].

Con base en la información disponible hasta este momento, EXISTE Amenaza MUY ALTA de tsunami para El Salvador. Se espera un nivel de impacto SEVERO en la costa salvadoreña. TOMAR ACCIÓN.

Figura 4. Ejemplo de información sísmica preliminar publicada en twitter

Ministerio de Medio Ambiente
@MedioAmbienteSV

📌 #ElObservatorioInforma DATOS FINALES:
Sismo Mag. Revisada: 7.9, frente a la costa de La Libertad. A 114 km al suroeste de playa San Diego. Prof. 15 km. [2021-11-05, 15:15:00].
ACTUALIZACIÓN: Se mantiene la existencia de una amenaza MUY ALTA de tsunami para El Salvador. TOMAR ACCIÓN.

Figura 5. Ejemplo de información sísmica final publicada en twitter

II. Advertencia e información ante desastres

GOBIERNO DE EL SALVADOR | MINISTERIO DE MEDIO AMBIENTE Y RECURSOS NATURALES

Ministerio de Medio Ambiente y Recursos Naturales
Dirección General del Observatorio Ambiental
Gerencia de Geología – Área de Sismología
Teléfono: 2132-964

BOLETIN 1

TOMAR ACCIÓN

CON BASE EN LA INFORMACIÓN DISPONIBLE HASTA ESTE MOMENTO, EXISTE POSIBLE AMENAZA DE TSUNAMI MUY ALTA PARA EL SALVADOR, POR SISMO FRENTE A LA COSTA DE LA LIBERTAD. MAGNITUD PRELIMINAR: 7.8

Fecha y hora de emisión: viernes 5 de noviembre del 2021, Hora local: 15:35

Parámetros preliminares del sismo

Fecha (local)	05-11-2021
Hora origen (local)	15:15:00
Magnitud preliminar	7.8
Coordenadas	12.464724 N, -89.475383 O
Profundidad	10.0 km
Localización	Frente a la Costa de La Libertad

Evaluación del Tsunami

Con base a las características preliminares del sismo, se estima que por el momento existe una posible amenaza de tsunami MUY ALTA para la costa de El Salvador.

Una amenaza de tsunami MUY ALTA indica un escenario para el que se prevén fluctuaciones en el nivel del mar MAYORES de 3 metros con respecto al nivel de la marea. Estas variaciones constituyen un riesgo sumamente importante, implicando un máximo grado de evacuación para toda la costa de El Salvador, con el fin de proteger las vidas de la población amenazada,.

Tomar en consideración que el fenómeno aún está bajo evaluación, por lo que el grado de amenaza y nivel de impacto podrían ser actualizados tan pronto se tenga mayor información.

Nivel de impacto esperado: SEVERO

Representa un peligro a la vida humana. Corresponde a una destrucción casi completa de estructuras costeras como puertos y muelles, e infraestructuras de las zonas costeras bajas como viviendas, restaurantes y hoteles.

Kilómetro 5½ Carretera a Santa Tecla, Calle y Colonia Las Mercedes,
Edificio MARN No. 2 (anexo al Edificio ISTA), San Salvador. El Salvador. Centroamérica.
http://www.snet.gob.sv

GOBIERNO DE EL SALVADOR | MINISTERIO DE MEDIO AMBIENTE Y RECURSOS NATURALES

Ministerio de Medio Ambiente y Recursos Naturales
Dirección General del Observatorio Ambiental
Gerencia de Geología – Área de Sismología
Teléfono: 2132-964

Recomendaciones y acciones a tomar

~ Evacuación de las playas y los puertos de TODA LA COSTA salvadoreña, movilizándose hacia partes altas.
~ Si se encuentra en la playa y observa que el mar retrocede, ALÉJESE a un lugar seguro en altura.
~ Siga las rutas de evacuación ante tsunami y DIRÍJASE hacia una zona segura (un lugar elevado) determinado por su municipalidad.
~ Evite el pánico durante la evacuación y SIGA las indicaciones que proporcionan las autoridades.
~ Alejarse de ríos y esteros, ya que las olas del tsunami pueden penetrar kilómetros tierra adentro.
~ NO regrese a la zona de costa afectada por tsunami hasta que autoridades indiquen que es seguro y se haya cancelado la amenaza.
~ Restricción en actividades de recreo tales como: natación, pesca, buceo, surf y navegación en barcos.
~ A las pequeñas y medianas embarcaciones abstenerse de zarpar durante las siguientes horas después de ocurrido el sismo.

Actualización e información adicional

El siguiente boletín será emitido posteriormente se obtenga una revisión de la magnitud del sismo.

En el siguiente boletín se mostrará una estimación de los tiempos de arribos y alturas de ola por un posible tsunami, sobre ciertos sectores específicos de la costa salvadoreña.

El MARN dará seguimiento a este evento sísmico para informar oportunamente a la población sobre la evolución de este fenómeno. Se recomienda atender las indicaciones emitidas por las autoridades de la Dirección General de Protección Civil y no prestar atención a rumores o a información no oficial acerca de esta situación.

Kilómetro 5½ Carretera a Santa Tecla, Calle y Colonia Las Mercedes,
Edificio MARN No. 2 (anexo al Edificio ISTA), San Salvador. El Salvador. Centroamérica.
http://www.snet.gob.sv

Figura 6. Ejemplo de boletín del tsunami.

II. Advertencia e información ante desastres

Información sobre la intensidad sísmica

La intensidad de un sismo disminuye con la distancia, debido a la capacidad del suelo de amortiguar las ondas sísmicas a medida se alejan de su fuente.

En la Figura 7 se muestra un ejemplo del mapa de intensidad sísmica instrumental (*ShakeMap*) que se publica en el sitio web del MARN después de la ocurrencia de un sismo. El siguiente mapa es una representación gráfica del movimiento del terreno y los posibles efectos causados por un sismo (niveles de intensidad sísmica instrumental), con base a la escala de Mercalli Modificada.

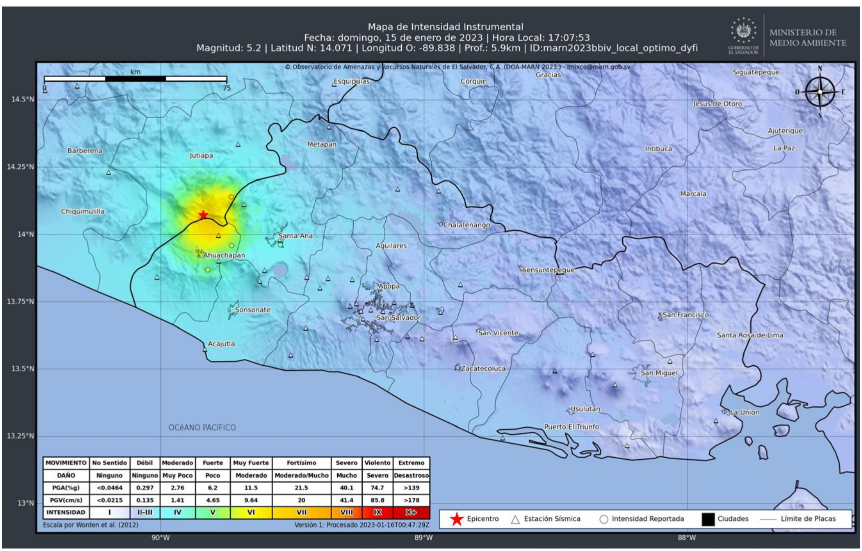


Figura 7. Mapa de intensidad sísmica (ShakeMap)

II. Advertencia e información ante desastres

Información web de sismos sentidos

En el sitio web del MARN se encuentran publicados los datos de los sismos que han sido reportados como sentidos por la población desde el año 2002. Los últimos 10 sismos sentidos se encuentran en http://www.marn.gob.sv/ultimos-10-sismos/. Para una búsqueda de los sismos por fecha de ocurrencia, se utiliza la opción de mapa dinámico http://www.marn.gob.sv/mapa-dinamico/ donde se pueden generar mapas y listados de sismos (Figura 8).

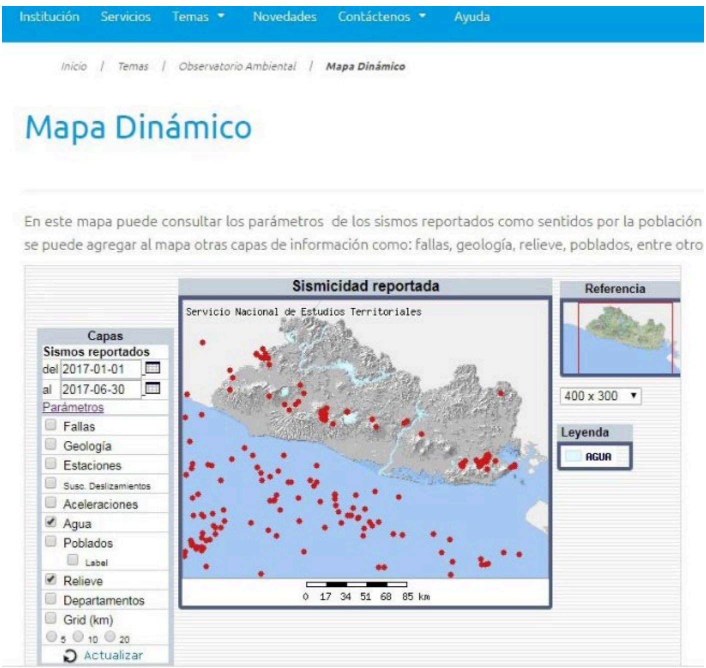


Figura 8. Datos de sismos sentidos disponibles en la web del MARN

III. Acciones en el monitoreo de sismos y tsunamis

Cálculo de hipocentro y magnitud del sismo

El hipocentro sísmico es el punto en el interior de la tierra donde inicia la ruptura que genera el sismo. La proyección del hipocentro sobre la superficie de la tierra es el epicentro. La magnitud está relacionada con la energía sísmica liberada. Para el cálculo de estos parámetros se requiere de los datos registrados por los sismógrafos. Se realizan varios cálculos (proceso iterativo) hasta obtener información lo suficientemente precisa para ser emitida a la Dirección General de Protección Civil y a la población. En la Figura 9 se muestra un ejemplo de todos los epicentros calculados para un mismo sismo.

Location | Magnitudes | Event | Events

Origins | Focal Mechanisms

Created(GMT)	OT(GMT)	Phases	Lat.	Lon.	Depth	RMS	Stat	Agency	Author	Region
2016-09-19 16:54:37	**16:27:45**	**48**	**12.87 N**	**88.91 W**	**29 km**	**0.8**	**C**	**MARN**	**sismologia@sismologia**	**Off Coast of Central America**
2016-09-17 16:38:25	16:27:45	46	12.87 N	88.88 W	38 km	1.3	A	MARNtel	scautoloc@seiscomp	Off Coast of Central America
2016-09-17 16:36:49	16:27:45	45	12.89 N	88.88 W	37 km	1.2	A	MARNtel	scautoloc@seiscomp	Off Coast of Central America
2016-09-17 16:36:24	16:27:45	44	12.89 N	88.88 W	37 km	1.3	A	MARNtel	scautoloc@seiscomp	Off Coast of Central America
2016-09-17 16:35:59	16:27:45	43	12.89 N	88.88 W	36 km	1.3	A	MARNtel	scautoloc@seiscomp	Off Coast of Central America
2016-09-17 16:35:34	16:27:45	42	12.89 N	88.88 W	36 km	1.3	A	MARNtel	scautoloc@seiscomp	Off Coast of Central America
2016-09-17 16:35:14	16:27:46	39	12.92 N	88.88 W	33 km	1.3	A	MARNtel	scautoloc@seiscomp	Off Coast of Central America
2016-09-17 16:34:54	16:27:46	38	12.89 N	88.90 W	42 km	1.1	A	MARNtel	scautoloc@seiscomp	Off Coast of Central America
2016-09-17 16:34:34	16:27:46	37	12.90 N	88.90 W	41 km	1.1	A	MARNtel	scautoloc@seiscomp	Off Coast of Central America
2016-09-17 16:34:16	16:27:45	34	12.88 N	88.90 W	24 km	1.0	A	MARNtel	scautoloc@seiscomp	Off Coast of Central America
2016-09-17 16:33:49	16:27:43	33	12.81 N	88.92 W	10 km	0.9	A	MARNtel	scautoloc@seiscomp	Off Coast of Central America
2016-09-17 16:33:29	16:27:44	32	12.85 N	88.90 W	17 km	0.8	A	MARNtel	scautoloc@seiscomp	Off Coast of Central America
2016-09-17 16:32:09	16:27:43	34	12.81 N	88.94 W	10 km	0.7	A	MARNreg	scautoloc2@seiscomp	Off Coast of Central America
2016-09-17 16:31:49	16:27:43	33	12.81 N	88.93 W	10 km	0.7	A	MARNreg	scautoloc2@seiscomp	Off Coast of Central America
2016-09-17 16:30:59	16:27:44	31	12.83 N	88.92 W	10 km	0.7	A	MARNtel	scautoloc@seiscomp	Off Coast of Central America
2016-09-17 16:30:44	16:27:43	30	12.79 N	88.93 W	10 km	0.6	A	MARNtel	scautoloc@seiscomp	Off Coast of Central America
2016-09-17 16:30:24	16:27:44	30	12.86 N	88.91 W	24 km	0.5	A	MARNreg	scautoloc2@seiscomp	Off Coast of Central America
2016-09-17 16:30:21	16:27:43	29	12.79 N	88.93 W	10 km	0.6	A	MARNtel	scautoloc@seiscomp	Off Coast of Central America
2016-09-17 16:30:09	16:27:42	29	12.70 N	88.95 W	10 km	0.2	A	MARNreg	scautoloc2@seiscomp	Off Coast of Central America
2016-09-17 16:30:07	16:27:42	28	12.71 N	88.94 W	10 km	0.3	A	MARNtel	scautoloc@seiscomp	Off Coast of Central America
2016-09-17 16:29:54	16:27:42	28	12.70 N	88.95 W	10 km	0.2	A	MARNreg	scautoloc2@seiscomp	Off Coast of Central America
2016-09-17 16:29:48	16:27:42	27	12.71 N	88.95 W	10 km	0.3	A	MARNtel	scautoloc@seiscomp	Off Coast of Central America
2016-09-17 16:29:43	16:27:44	30	12.90 N	88.95 W	10 km	2.9	A	MARNloc	scautoloc3@seiscomp	Off Coast of Central America

Created(GMT)	TP	M	Count	RMS	Agency	Author
2016-09-19 16:55:13	ML	5.35	29	0.5	MARN	scmag@seiscomp
2016-09-19 16:55:13	MLv	5.07	31	0.5	MARN	scmag@seiscomp
2016-09-19 16:55:13	Mjma	4.99	24	0.2	MARN	scmag@seiscomp
2016-09-19 16:55:13	Mwp	5.37	3	0.1	MARN	scmag@seiscomp
2016-09-19 16:55:13	Mw(Mwp)	5.12	3	0.4	MARN	scmag@seiscomp
2016-09-19 16:55:13	mB	5.62	6	0.7	MARN	scmag@seiscomp
2016-09-19 16:55:13	Mw(mB)	5.12	6	0.7	MARN	scmag@seiscomp
2016-09-19 16:55:13	mb	4.93	13	0.3	MARN	scmag@seiscomp
2016-09-19 16:55:13	**M**	**5.09**	**31**		**MARN**	**scmag@seiscomp**

Figura 9. Todas las ubicaciones realizadas para un mismo sismo, hasta obtener la mejor precisión posible

Monitoreo de aceleraciones

Para registrar las aceleraciones generadas por los sismos, se tiene una red de acelerógrafos distribuida en todo el país. Con los datos registrados se puede conocer la respuesta del suelo ante el paso de las ondas sísmicas. En la Figura 10 se muestra un ejemplo de la aceleración registrada en función del tiempo en los componentes vertical, norte-sur y este-oeste por un acelerógrafo ubicado a un metro de profundidad (superficie) y otro a una profundidad de 17 metros (fondo), nótese como la amplitud del registro es afectado por el espesor del suelo, por ejemplo en la componente vertical el equipo en superficie registró una aceleración de 3.006 cm/seg^2 cm/s y el equipo en fondo una aceleración de 1.366 cm/seg^2.

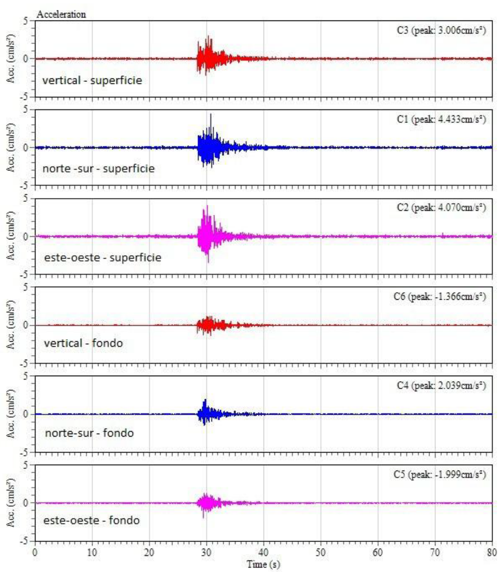


Figura 10. Aceleración sísmica registrada en las componentes vertical, norte-sur, este-oeste por equipo ubicado en superficie (trazas superiores) y equipo ubicado a 17 metros de profundidad (trazas inferiores). En cada traza sísmica se indica el valor de aceleración pico en cm/seg^2

III. Acciones en el monitoreo de sismos y tsunamis

Método de juicio para emitir aviso por amenaza de tsunami

Para emitir un aviso por amenaza de tsunami, se evalúan datos como localización, profundidad y magnitud del sismo; así como el tiempo de arribo y altura del tsunami. El tiempo de arribo se refiere a lo que tarda el tsunami en viajar desde la localización del sismo hasta la costa salvadoreña. En la Figura 11 y Figura 12 se muestran los criterios utilizados.

Magnitud	**Sismo local (Z1) Desde Guatemala - hasta Nicaragua**	**Sismo regional (Z2) Desde México - hasta Colombia**	**Sismo distal (Z3) Toda la cuenca del Pacífico**
	Ubicados en la cuenca del Pacífico y con profundidad < a 100 km		
<6.5	No amenaza	No amenaza	No amenaza
6.5-7.0	Amenaza de tsunami leve / Pre-aviso	No amenaza	No amenaza
7.1-7.5	Amenaza de tsunami moderada / Aviso	No amenaza	No amenaza
7.6-7.9	Amenaza de tsunami alta / Alerta	Posible amenaza de tsunami leve/ Pre-aviso /se evalúa acorde con dato PTWC	No amenaza
8.0 -8.6	Amenaza de tsunami muy alta / Emergencia	Posible amenaza de tsunami moderada/ Aviso / se evalúa acorde con dato PTWC	Posible amenaza de tsunami leve/ Pre-aviso /se evalúa acorde con dato PTWC
≥ 8.7		Posible amenaza de tsunami alta / Alerta / se evalúa acorde con dato PTWC	Posible amenaza de tsunami moderada/ Aviso/ se evalúa acorde con dato PTWC

Figura 11. Escenarios y Magnitud para determinar la actuación en caso de amenaza de Tsunami

Tipo de información	**Amplitud de la ola del tsunami (metros)**	**Nivel de impacto esperado**	**Acciones recomendadas**	**Palabra clave para el informe**
AMENAZA DE TSUNAMI	> 3.0	Severo	vacuación de toda la costa salvadoreña.	Tomar acciones para toda la costa
	1.0 -3 0	Significativo	vacuación de las playas y los puertos en zona amenazada.	omar acciones para algunos lugares de la costa
	0.3 -1.0	Medio	Restricción en actividades de recreo en zona amenazada tales como natación, pesca, buceo, navegación, etc.	Estar preparados y seguir las instrucciones de los encargados de emergencias
	< 0.3	Bajo	Precaución para el desarrollo de actividades marinas.	Estar informados
POSIBLE AMENAZA DE TSUNAMI	1.0 -3 0	Significativo	vacuación de las playas y los puertos en zona amenazada. [1]	omar acciones para algunos lugares de la costa
	0.3 -1.0	Medio	Restricción en actividades de recreo en zona amenazada tales como natación, pesca, buceo, navegación, etc.[1]	Estar preparados y seguir las instrucciones de los encargados de emergencias
	< 0.3	Bajo	Precaución para el desarrollo de actividades marinas.[1]	Estar informados
NO AMENAZA DE TSUNAMI				in embargo, mantenerse informados sobre la evolución del fenómeno
[1] Se recomendará esta acción siempre que el grado de amenaza haya sido confirmado con información del PTWC).				

Figura 12. Niveles de impactos y recomendaciones para la población

III. Acciones en el monitoreo de sismos y tsunamis

Estimación de la hora de llegada y altura del tsunami

Cuando ocurre un sismo tsunamigénico se elabora un mapa que muestra líneas de tiempo de arribo del tsunami. Estas son calculadas desde la localización del sismo hacia diferentes puntos del litoral (Figura 13).

La altura del tsunami para cada uno de los municipios costeros de El Salvador se obtiene de una base de escenarios previamente calculados y se presentan usando diferentes rangos de magnitud (de 0.1 a 0.3, de 0.3 a 1.0, de 1 a 3 y mayor a 3 metros) tal como se muestra en la Figura 14.

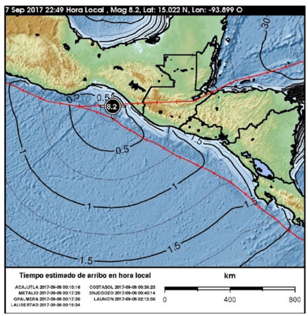


Figura 13. Ejemplo de tiempos de arribo de un tsunami

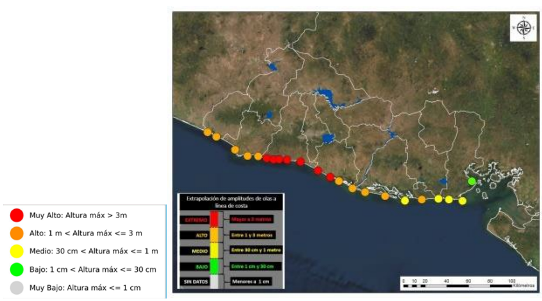


Figura 14. Ejemplo de altura de ola estimada para un tsunami

IV. Observación de sismos y tsunamis

Red de observación de sismos

Se dispone de diversos equipos sísmicos distribuidos en todo el país (Figura 15 y 16), para detectar la sismicidad generada por el proceso de subducción de la placa de Cocos bajo la placa del Caribe; así como la sismicidad producida por el reacomodo de las fallas geológicas locales y la actividad volcánica. Los datos obtenidos se transmiten a la central de procesamiento por medio del uso de diversos medios de comunicación (radio, internet, señal microonda y satélite).

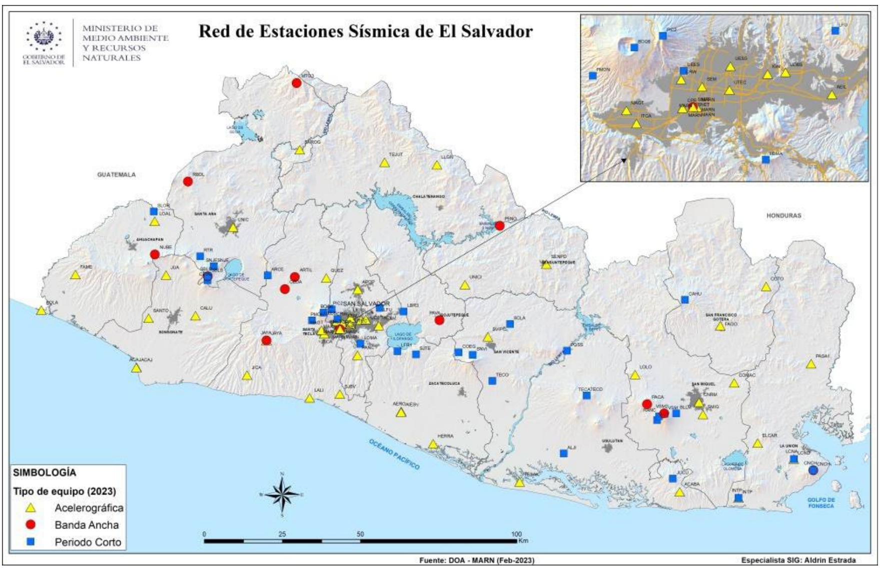


Figura 15. Ubicación y tipo de estaciones sísmicas

IV. Observación de sismos y tsunamis

Tipo de equipo sísmico	Cantidad
Periodo corto analógicas	14
Periodo corto digitales	19
Banda Ancha	13
Acelerográficas (modelo Etna)	6
Acelerográficas (modelo SMA1-Retrofit)	5
Acelerográficas (modelo Basalto)	21
Acelerográficas (modelo Fortimus)	25
Total	103

Figura 16. Tipo de equipos sísmicos

Red de observación de tsunamis

El monitoreo de tsunamis en la costa salvadoreña se realiza a través de tres estaciones mareográficas ubicadas en los puertos de Acajutla, La Libertad y La Unión (Figura 17a). Adicionalmente, se cuenta con dos cámaras ubicadas en los puertos de Acajutla y La Libertad.

IV. Observación de sismos y tsunamis

Se realiza mediciones del nivel del mar cada minuto y se transmiten los datos cada 5 o 15 minutos vía satélite a través de *Global Telecommunication System* (GTS). Las cámaras realizan la transmisión de datos vía internet, para visualizar los datos del nivel del mar de toda la cuenca del Pacífico, se utiliza el software TIDE TOOL (Figura 17b). El registro del nivel del mar se muestra a través de un gráfico en el cual, en su eje vertical, presenta la altura y en su eje horizontal el tiempo, siendo los valores extremos de la curva la pleamar (marea alta) y bajamar (marea baja), ver Figura 17c.

a) b) c)

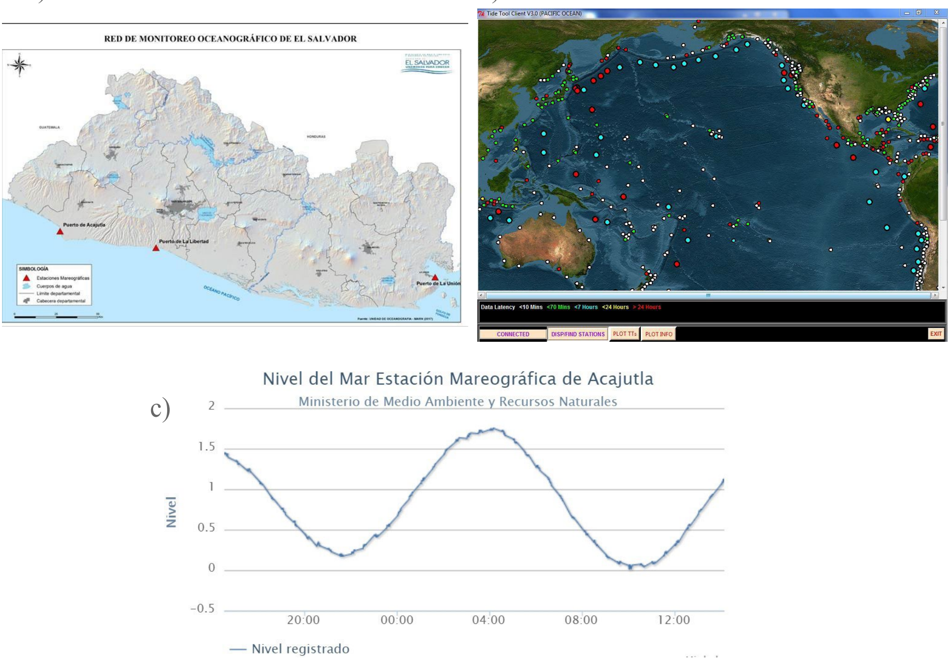


Figura 17. (a) Estaciones de monitoreo del nivel de mar en El Salvador, (b) Estaciones visualizadas con el software Tide Tool, (c) Ejemplo de registro del nivel del mar

IV. Observación de sismos y tsunamis

Red de medición de la deformación de la corteza terrestre (red de GPS)

La red está integrada por 11 GPS de precisión milimétrica, con el propósito de medir la velocidad de la deformación de la corteza terrestre (Figura 18 a). Con los GPS móviles se desarrollan mediciones en todo el país, para complementar el monitoreo, y estudiar la deformación volcánica. Los datos de estas mediciones son la base para implementar el sistema de alerta temprana ante un tsunami. La Figura 18b muestra los vectores de velocidad de deformación de la corteza terrestre obtenidos en diferentes puntos de observación para el año 2013. En este caso, las mayores velocidades de deformación se identifican en el occidente de El Salvador.

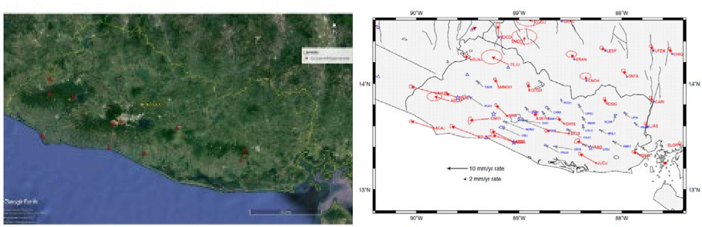


Figura 18. a) Ubicación de las estaciones de GPS permanentes y b) vectores de velocidad de deformación de la corteza (representados por su tamaño y orientación)

Sensores sísmicos (banda ancha, periodo corto, acelerógrafos)

El MARN usa los modelos Trillium Compact Trillium 120P y STS2 como sensores de banda ancha; los modelos Episensor, Titan, Fortimus y T-Sensor como acelerómetro o sensores de movimiento fuerte. Algunos de los digitalizadores usados con los sensores arriba indicados son:

Q330, Centaurus, Earthdata, Basalt. Como periodo corto se utilizan los sensores SS-1, S-13 y Sixaola (sensor + digitalizador), ver Figura19.

Los instrumentos de periodo corto se usan para registrar la microsismicidad en zonas de enjambres y volcanes activos; los datos registrados con banda ancha son de utilidad para el cálculo de sismos de gran magnitud (magnitud Mw, tensor de momento sísmico); los datos registrados con los acelerógrafos son para determinar la característica del movimiento del terreno en el sitio (factores de aplicación, periodos predominantes).

En la Figura 20 y 21 se muestra un esquema e imágenes de la instalación de los equipos sísmicos en campo, en donde se puede observar que en una estación sísmica, además del equipo sísmico, se requiere de un sistema de alimentación (baterías + paneles solares o energía comercial), un GPS para sincronizar el tiempo del registro sísmico y un sistema de comunicación (radios + antenas, *router*, etc.)

Equipo sísmico utilizado en el MARN		
Sensores de banda ancha		
		
Trillium 120P	Trillium	STS2

Acelerómetros y acelerógrafos		
		
Fortimus	Titan	Basalt
Digitalizadores		
		
Centaur	EarthData	Q-330
Sensores de periodo corto		
		
SS-1	Sixaola	S-13

Figura 19. Equipo sísmico utilizado en el MARN

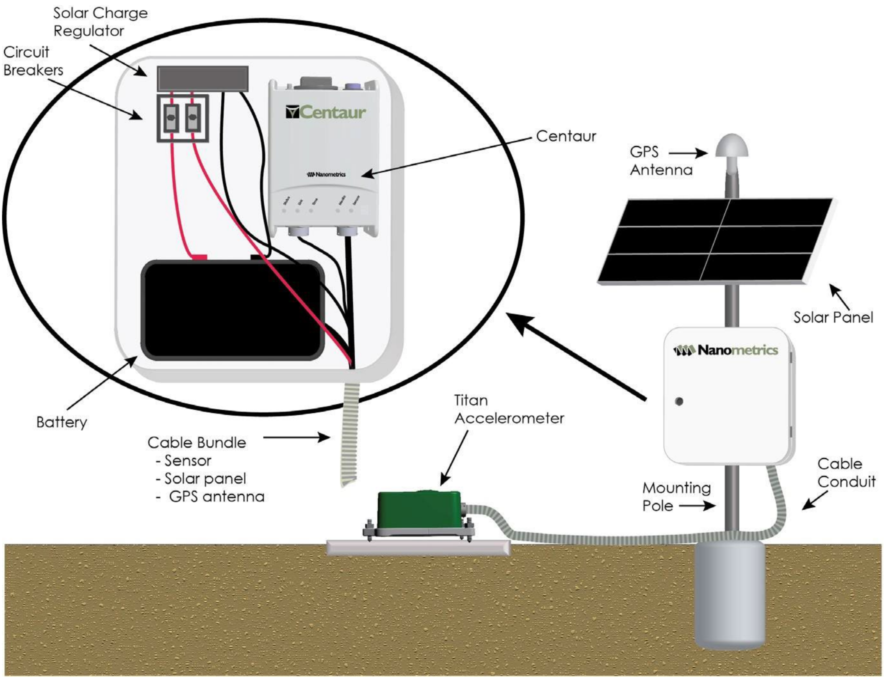


Figura 20. Esquema de la instalación de los equipos sísmicos en campo[3]

3 Nanometrics. Product Overview, Centaur Digitizer.

IV. Observación de sismos y tsunamis

Figura 21. Equipos sísmicos y de GPS del MARN instalados en campo

Indicador de marea y cámara

Las Figuras 22, 23 y 24 muestran parte de los equipos desplegados en campo para registrar el comportamiento del nivel del mar. Las estaciones transmiten los datos en tiempo real al Centro de Monitoreo Integrado de Amenazas para su respectivo procesamiento.

Figura 22. Estación mareográfica ubicada en el puerto de La Libertad. La estación cuenta con un sensor de ultrasonido

IV. Observación de sismos y tsunamis

Figura 23. Cámara web en puerto de La Libertad

Figura 24. Estación mareográfica en puerto de Acajutla

Observación de sismos. Ejemplo 1: Series sísmicas

Serie sísmica ocurrida en el Área Metropolitana de San Salvador (AMSS), entre los municipios de Antiguo Cuscatlán y San Salvador, durante el 6 de abril al 2 de mayo de 2017 (Figura 25). Esta serie se caracterizó por desarrollarse en tres episodios sísmicos no consecutivos.

El primer episodio se generó únicamente el 06 de abril, con un total de 10 sismos, de los cuales 2 fueron sentidos. El segundo, inició el 09 abril y finalizó el 18 del mismo mes, con un total de 532 sismos, de los cuales 53 fueron sentidos; en este período ocurrió el sismo de mayor magnitud (M 5.1), el 10 de abril. El tercer episodio fue entre el 22 de abril y el 2 de mayo, con un total de 80 sismos, de los cuales 15 fueron sentidos. En total, para esta serie se registraron 622 sismos, de los cuales 70 fueron reportados como sentidos por la población.

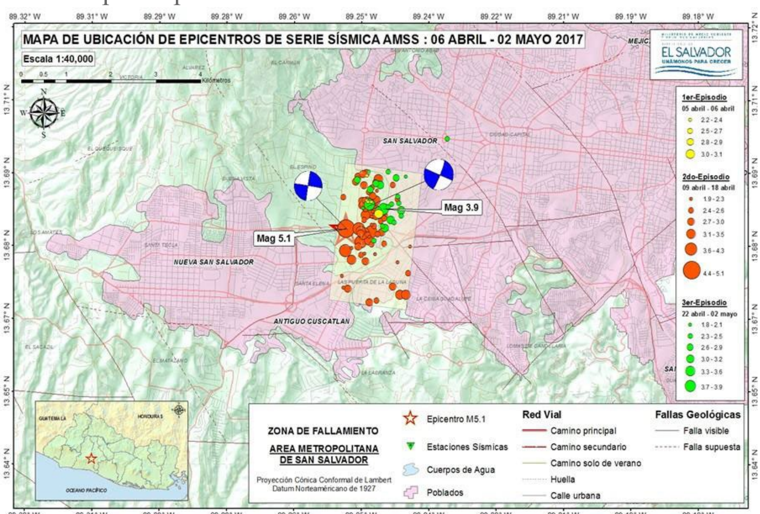


Figura 25. Localización de la serie sísmica en el AMSS

IV. Observación de sismos y tsunamis

La Figura 26 corresponde al registro sísmico del 10 de abril de 2017 en la estación Piamonte (PMON), ubicada a unos seis kilómetros al oeste-noroeste del área epicentral de la serie sísmica ubicada entre los municipios de Antiguo Cuscatlán y San Salvador (Figura 25).

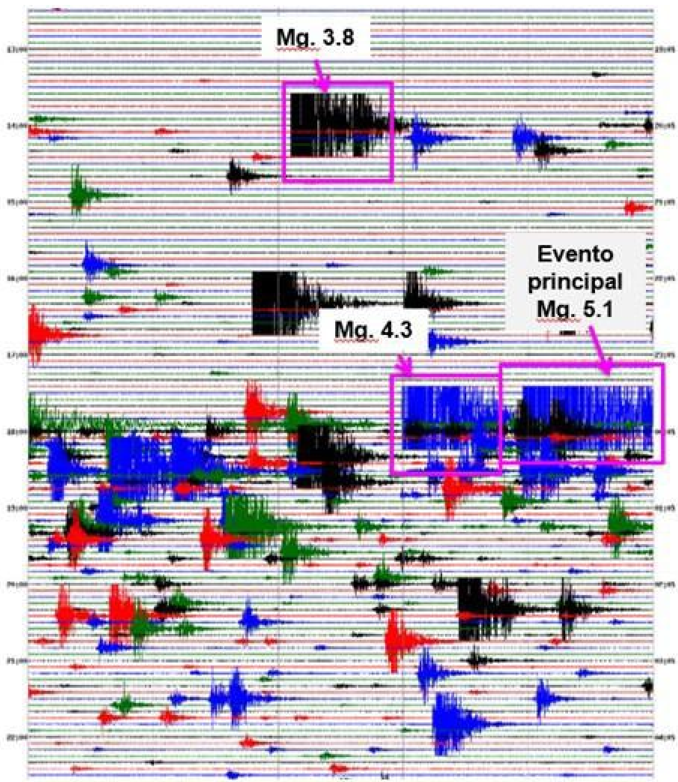


Figura 26. Registro sísmico, 10 de abril de 2017, estación Piamonte, municipio de Colón

IV. Observación de sismos y tsunamis

Observación de sismos. Ejemplo 2: Un año de sismicidad

Localización de los epicentros, profundidades (Figura 27) y magnitudes (Figura 37) de los sismos registrados por la red sísmica del MARN con magnitud (M) mayor o igual a 3.0 durante el año 2022. El tamaño de los símbolos está relacionado con la magnitud y los colores con la profundidad de los hipocentros de los sismos.

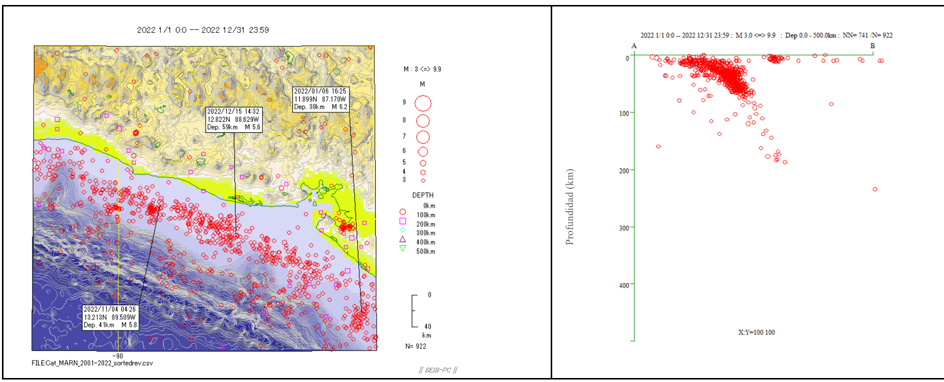


Figura 27. Ubicación (izquierda) y profundidad (derecha) de los sismos ocurridos en 2022[4]

4 Las figuras 27, 28, 37 y 40 fueron elaboradas con el software SEIS-PC.

IV. Observación de sismos y tsunamis

Observación de sismos. Ejemplo 3: Réplicas

El terremoto M 7.3 que ocurrió el 27 de agosto UTC en 2012 tuvo réplicas notables cuya área de ocurrencia cubre 63 km x 31 km, estas réplicas se muestran con círculos en azul al sur del departamento de Usulután (Figura 28).

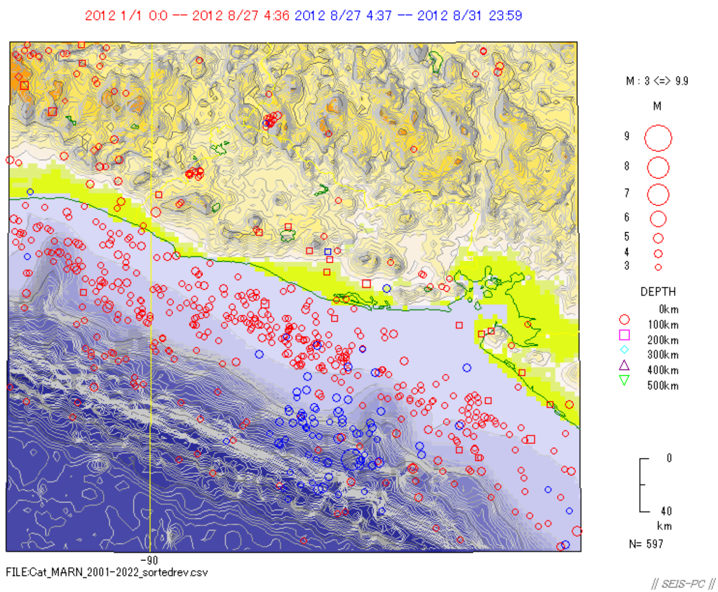


Figura 28. Sismos mayores o iguales a M4.0 registrados por la red de observación sísmica del MARN. Los círculos en rojo corresponden a epicentros ocurridos entre el 1 de enero y 27 de agosto de 2012, los círculos en azul son las réplicas del sismo de M7.3 del 27 de agosto

V. Actividad tectónica, sísmica y entorno geológico

Marco tectónico[5]

Desde un punto de vista tectónico, El Salvador se encuentra en el norte de Centroamérica, en el margen activo del noroeste de la placa Caribe (Figura 29). Enmarcado en el límite entre las placas Coco y Caribe, caracterizado por la subducción de la primera bajo la segunda a una velocidad que supera los 70 mm/año. Esta convergencia se traduce, a su vez, en la existencia de un sistema de fallas de desgarre en el continente, alineadas con la cadena volcánica. La velocidad de la Zona de Fallas de El Salvador (ZFES) que atraviesa al país de este a oeste, y la mayor de este sistema de fallas, alcanza los 14 mm/año.

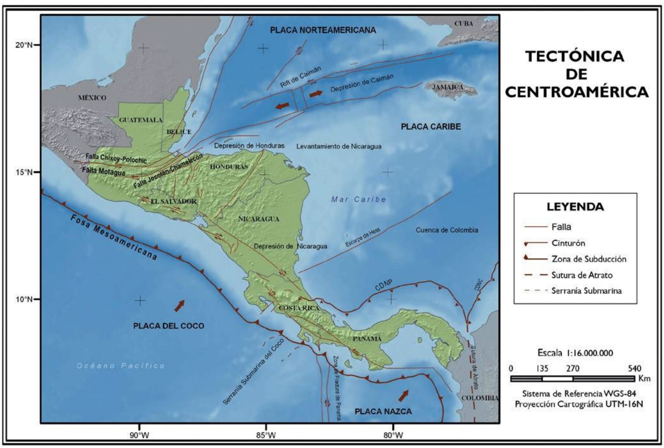


Figura 29. Tectónica de Centroamérica[6]

5 Adaptado de: Staller Vásquez, A. (2014). Modelización de las deformaciones en El Salvador (Centroamérica) mediante la integración de datos geodésicos (GPS), geológicos y sismológicos. Tesis doctoral. Universidad Politécnica de Madrid.

6 Benito, M.B., Lindholm, C., Camacho, E., Climent, A., Marroquín, G., Molina, E., Rojas, W., Talavera, E., Escobar, J.J. (2009). Marco Sismotectónico. En Benito, M.B. y Torres, Y. (Eds.), Amenaza sísmica en América Central. Madrid: Entinema

Experiencia de fuertes terremotos

La interacción entre las placas Coco y Caribe es la principal fuente sísmica que afecta a El Salvador, la cual puede generar sismos con magnitud superior a siete. Ejemplos recientes han sido los sismos del 13 de enero de 2001 (Mw=7.7), 26 de agosto de 2012 (Mw=7.3), 13 de octubre de 2014 (Mw=7.3).

Sin embargo, los sismos con mayor potencial de destrucción son los que ocurren en el eje volcánico, debido a profundidades focales menores a 10 km y cercanía con los centros de población (Figura 30). El ejemplo más significativo es el sismo ocurrido el 10 de octubre de 1986, en San Salvador, con magnitud 5.7 (Mw) y 8 km de profundidad. Este sismo causó 1,500 muertos y pérdidas económicas entre 1.5 y 2 billones de dólares. Cerca del hipocentro del evento de 1986, tuvimos otro evento desastroso que ocurrió el 3 de mayo de 1965, que supuestamente podría haber debilitado los edificios. Finalmente, otro de los sismos importantes ha sido el del 13 de febrero en San Vicente, con una magnitud de 6.6 (Mw)

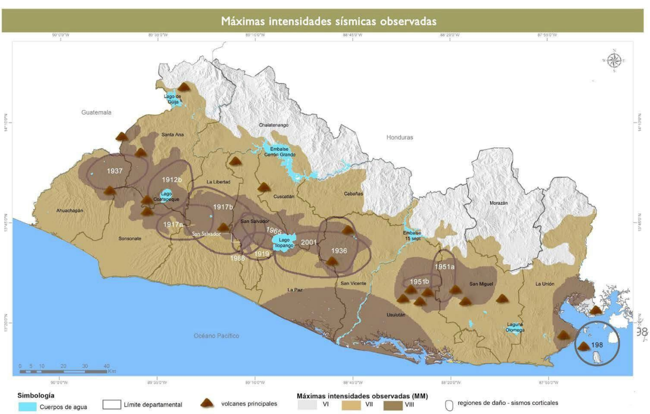


Figura 30. Máximas intensidades sísmicas observadas y regiones con daños por sismos en el eje volcánico

V. Actividad tectónica, sísmica y entorno geológico

Ambiente geológico y distribución de volcanes[7]

El Salvador está constituido por las siguientes unidades geomorfológicas: montaña fronteriza, fosa o graben central, cadena volcánica joven, cadena costera y planicie costera. Cada unidad forma una banda de orientación este-oeste (E-O) que se extiende por el país paralelamente a la costa (Figura 31). Las unidades tienen un marcado control tectónico en su origen, pues su desarrollo está condicionado por una combinación entre la tasa de subducción elevada y una intensa actividad sísmica y volcánica.

En la parte sur del graben central se elevan los volcanes cuaternarios, formando el eje volcánico que atraviesa el país de este a oeste.

La mayor parte del territorio salvadoreño está ocupado por materiales Plio-Cuaternarios y de origen volcánico (Figura 32). Se trata de rocas efusivas de composición riolítica, dacítica, andesítica y basáltica, así como materiales piroclásticos.

En El Salvador se reconocen cuatro familias de fallas principales con orientaciones noroeste-sureste (NO-SE), nor noroeste-sur sureste (NNO-SSE), nor noreste-sur suroeste (NNE-SSO) y este-oeste (E-O), siendo esta última la de mayor importancia, debido a que atraviesa todo el territorio a lo largo del eje volcánico.

7 Copiado de: Canora Catalán, C. (2011). Análisis sismotectónico, neotectónico y paleosísmico de la zona de falla de El Salvador, Centro América. Tesis doctoral, Universidad Complutense de Madrid, España

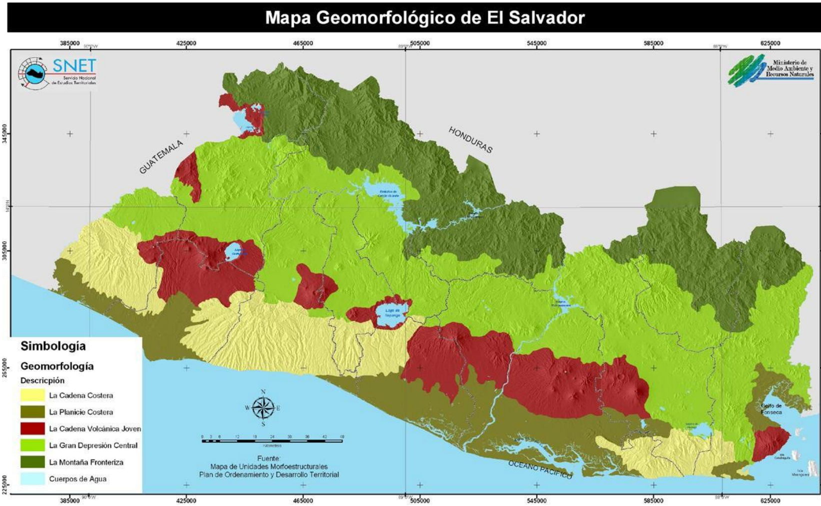


Figura 31. Mapa geomorfológico

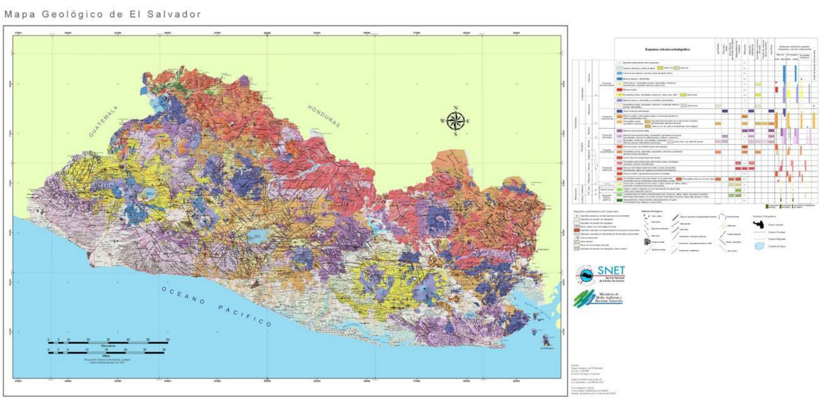


Figura 32. Mapa geológico

VI. Cooperación internacional

Cooperación internacional para la vigilancia de tsunamis

El Centro de Alerta de Tsunamis del Pacífico (PTWC), con sede en Hawái, Estados Unidos, desde 1965 emite alertas internacionales de tsunamis a los países de la cuenca del océano Pacífico. Estas alertas se realizan con el propósito de apoyar en la evaluación de la amenaza por tsunami en sus costas.

Posterior a la ocurrencia de un sismo con potencial de generar un tsunami, el PTWC ofrece productos de texto y gráficos con los datos pronosticados del tsunami a los puntos focales identificados en cada país. En el caso de El Salvador, el punto focal que recibe la información del PTWC es el Observatorio Ambiental del MARN.

Los productos de texto son recibidos por correo electrónico y fax, estos contienen información preliminar de los parámetros del sismo tales como: las costas con pronóstico de amenaza, los rangos de altura de ola esperados, los tiempos estimados de arribo, recomendaciones, entre otros.

Los productos gráficos recibidos son varios mapas que muestran la direccionalidad prevista de la energía del tsunami, la posición prevista de la onda inicial a lo largo del tiempo y las amplitudes de onda esperadas en alta mar y en la costa (Figura 33). Los rangos de altura de ola utilizados para el pronóstico en la costa son: menor a 0.3, de 0.3 a 1.0, de 1.0 a 3.0 y mayor a 3 metros.

En 2023, el Centro de Asesoramiento de Tsunami para América Central (CATAC), con sede en Managua, Nicaragua, ha comenzado su etapa de prueba. El MARN dará seguimiento a su progreso para utilizar en el futuro la información de CATAC como respaldo para emitir alertas de tsunami en El Salvador.

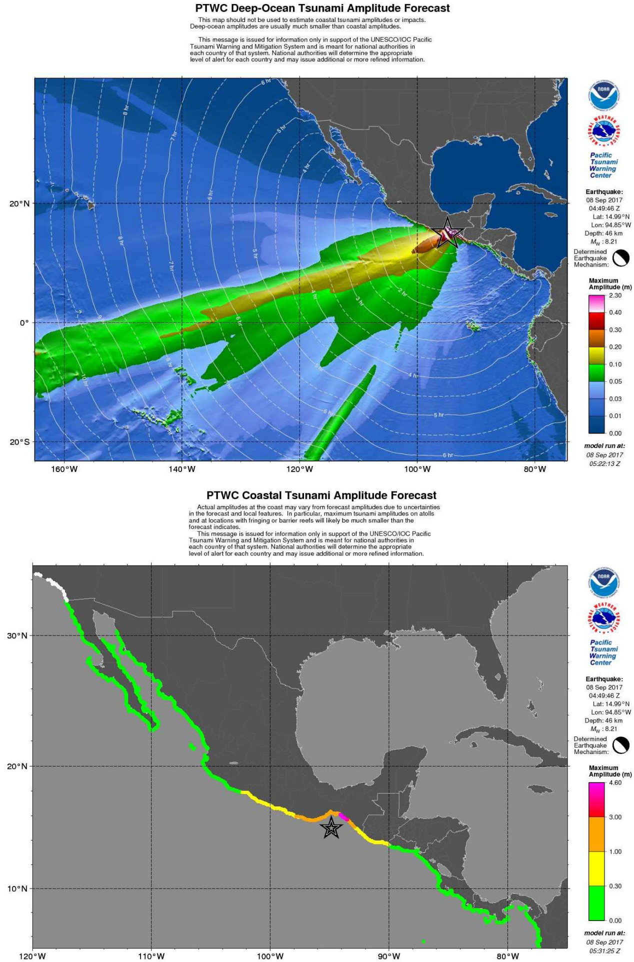


Figura 33. Ejemplo de los productos gráficos emitidos por el PTWC. En la imagen superior la dirección prevista de la energía del tsunami, amplitud en alta mar y tiempo de viaje. En la imagen inferior la amplitud máxima esperada del tsunami en la costa

VII. Información adicional

Tsunamis observados en la costa salvadoreña

En la costa salvadoreña se han registrado u observado 24 tsunamis en el período 1859-2022 (Figura 34 y 35). De ellos, ocho tuvieron su fuente en la costa de El Salvador. El tsunami del 26 de febrero de 1902 ha sido el más devastador, afectó a la zona occidental del país, en Barra de Santiago y Garita Palmera. Causó 185 muertes y daños materiales importantes, abarcó 120 kilómetros de costa aproximadamente.

DATOS DEL SISMO			DATOS DEL TSUNAMI EN EL SALVADOR	
Fecha (UTC)	**Magnitud**	**País**	**Lugar de El Salvador donde se registró u observó**	**Altura del agua en El Salvador (m)**
25/08/1859	6.2	**El Salvador**	La Unión	Tsunami probable
09/12/1859	7.0	**El Salvador**	Acajutla	Tsunami probable
26/02/1902	7.0	**El Salvador**	Barra de Santiago	Tsunami probable
			Acajutla	Tsunami probable
			Barra de Santiago y Garita Palmera	Tsunami probable
31/01/1906	8.8	Ecuador	Los Negros	Tsunami definitivo
25/05/1906		**El Salvador**	Los Negros	Tsunami cuestionable
07/09/1915	7.9	**El Salvador**	Barra de Santiago	Tsunami muy dudoso
05/10/1950	7.7	Costa Rica	La Libertad	0.09
			La Unión	0.10
23/10/1950	7.5	**Guatemala**	La Unión	0.10
04/11/1952	9.0	Rusia	La Libertad	0.58
09/03/1957	8.6	Estados Unidos	Acajutla	0.50
			La Unión	0.03
22/05/1960	9.5	Chile	La Unión	0.53
28/03/1964	9.2	Estados Unidos	Acajutla	0.20
			La Unión	0.10
19/09/1985	8.0	México	Acajutla	0.29
13/01/2001	7.7	**El Salvador**	Acajutla	0.25
26/12/2004	9.1	Indonesia	Acajutla	0.16
27/02/2010	8.8	Chile	Acajutla	0.25
11/03/2011	9.1	Japón	Acajutla	0.48
			La Unión	0.05
27/08/2012	7.3	**El Salvador**	Península San Juan del Gozo	6.3
			Acajutla	0.10
			La Unión	0.03
07/11/2012	7.3	**Guatemala**	Acajutla	0.10

14/10/2014	7.3	**El Salvador**	La Unión	0.02
16/09/2015	8.3	Chile	Acajutla	0.17
			La Unión	0.07
24/11/2016	6.9	**Nicaragua**	La Libertad	0.08
			Acajutla	0.03
08/09/2017	8.2	México	Acajutla	0.58
			La Libertad	0.38
			La Unión	0.06
15/01/2022	Erupción volcánica	Tonga	Acajutla	0.26

Figura 34. Tsunamis que han sido observados o registrados en El Salvador, según datos del National Centers for Environmental Information NGDC/WDS Global Historical Tsunami Database, 2100 BC to present. Recuperado el 13/02/2023 en https://www.ngdc.noaa.gov/hazard/tsu_db.shtml

Figura 35. Ubicación de sismos que han generado tsunamis y han sido registrados u observados en costa de El salvador

Sismicidad registrada durante 2022

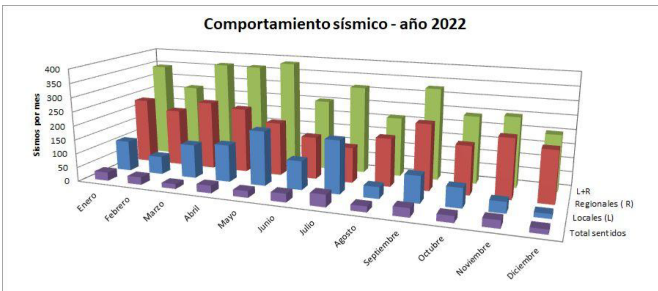
Durante el año 2022, la red sísmica del MARN registró un total de 3,520 sismos, de los cuales 314 fueron reportados como sentidos por la población salvadoreña. Del total de sismos registrados, 1,167 fueron generados por las fallas geológicas en el territorio salvadoreño y 2,353 por la interacción de las placas tectónicas Coco y Caribe, o en fallas geológicas de los países vecinos. En la Figura 36 se presenta la distribución de la sismicidad por mes y en la Figura 37 la ubicación de los sismos con magnitud mayor o igual a 4.0.

VII. Información adicional

El sismo de mayor intensidad en territorio salvadoreño durante el año 2022, ocurrió el 3 de noviembre a las 10:26 p.m. (4 de noviembre a las 04:26 UTC), con epicentro frente a la costa de La Libertad, con magnitud de 5.8 (Mw), a una profundidad de 41 km, con una intensidad en San Salvador de IV-V en la escala de Mercalli Modificada.

Durante el 2022 se reportaron solamente tres enjambres sísmicos, uno en el municipio de Berlín, entre el 20 y 28 de mayo, compuesto por 61 sismos, de los cuales, solo uno fue reportado como sentido, con magnitud 2.7. El segundo fue en el municipio de Chinameca entre el 23 y 26 de junio, compuesto por 54 sismos, de los cuales cinco fueron reportados como sentidos, la máxima magnitud fue de 3.4. El tercero tuvo su epicentro entre los municipios de Ahuachapán, San Lorenzo y Atiquizaya, entre el 15 y 25 de julio, con 151 sismos; de ellos 20 fueron sentidos y la máxima magnitud fue de 4.4 (Figura 37).

Durante este año también registramos un pequeño tsunami el día 15 de enero, debido a la erupción del volcán Hunga Tonga-Hunga Ha'apai, ubicado a más de 10,000 km de El Salvador, en donde el mareógrafo de Acajutla registró una altura máxima de 26 cm.



	Enero	Febrero	Marzo	Abril	Mayo	Junio	Julio	Agosto	Septiembre	Octubre	Noviembre	Diciembre
Total sentidos	30	27	17	27	23	30	43	20	31	23	27	16
Locales (L)	109	64	120	132	194	102	187	41	94	69	39	16
Regionales (R)	235	205	245	232	191	151	126	171	233	171	210	183
L+R	344	269	365	364	385	253	313	212	327	240	249	199

Figura 36. Actividad sísmica 2022

VII. Información adicional

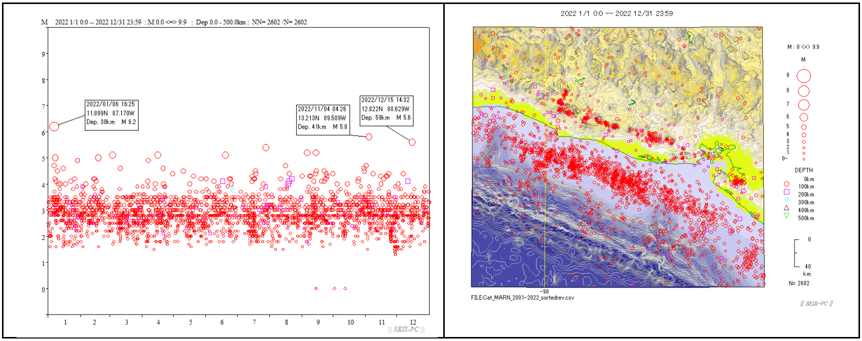


Figura 37. Magnitud y ubicación de los sismos ocurridos en 2022. La ubicación y profundidad de los sismos con magnitud ≥ 3.0 se encuentran en la Figura 27.

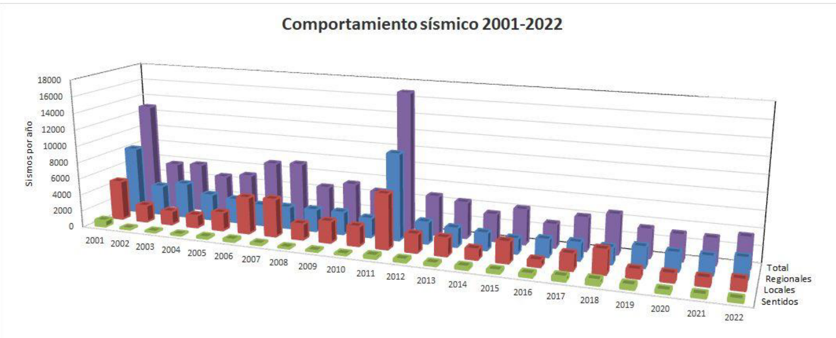
Sismicidad 2001-2022

Miles de sismos son registrados cada año por la red sísmica del MARN. La Figura 38 muestra la distribución anual de sismos por año y los clasifica en: sismos sentidos por la población salvadoreña, sismos locales (generados por fallas geológicas en el territorio salvadoreño) y sismos regionales (generados por el proceso de subducción de la placa tectónica de Coco bajo la placa del Caribe, o en fallas geológicas de los países vecinos).

Durante el 2001 – 2022, el mayor porcentaje de la sismicidad registrada se clasifica como regional y corresponde al 57% y la sismicidad local es el 43 %. Del total de sismos registrados, aproximadamente el 5% fue reportado como sentido por la población. Tal como se evidencia en la Figura 38. En algunos años, la sismicidad local ha sido superior a la regional (años 2006, 2007, 2015 y 2018).

La mayoría de la sismicidad localizada anualmente, para el periodo en análisis, tiene magnitud menor a 4.0 (se encuentra entre el 91% y 96 %). En la Figura 39 se hace una comparación de los sismos por rango de magnitud localizados entre las coordenadas de 12° a 15° latitud norte y de -91° a -87° longitud oeste, por ser la zona de influencia sísmica para El Salvador.

En la figura 40 se presentan los epicentros de todos los sismos, también se muestra un filtrado de los sismos con magnitud mayor o igual a 5.5, por ser sismos que en la mayoría de los casos son fuertemente sentidos por la población. En dicha Figura también podemos apreciar que solo cuatro sismos han sido mayores o igual a magnitud 6.9, estos ocurrieron en los años 2001, 2012, 2014 y 2016, y dos de ellos (2012 y 2016) fueron generadores de tsunamis, tal como se indica en la Figura 34. También se presenta en la Figura 40 los mecanismos focales de los cuatro sismos con magnitud mayor o igual a 6.9.



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Sentidos	739	107	100	106	174	259	159	84	105	114	326	299	272	321	326	368	502	573	449	322	324	314
Locales	4729	1996	1618	1459	2149	4364	4499	1849	2521	2303	6464	2130	2091	1188	2432	717	1857	2755	935	924	888	1167
Regionales	8099	3572	4177	3102	2858	2485	2576	2617	2647	2257	10332	2535	2193	1991	1690	2007	2046	1866	2351	2104	2093	2353
Total	12828	5568	5795	4561	5007	6849	7075	4466	5168	4560	16796	4665	4284	3179	4122	2724	3903	4621	3286	3028	2981	3520

Figura 38. Comportamiento actividad sísmica 2001-2022

Año	Mag. ≥ 0.1	Mag. ≥ 4	Mag. ≥ 5	Mag. ≥ 6	Mag.≥ 6.9
2001	8394	329	30	5	1
2002	2215	121	6	0	0
2003	3286	175	12	1	0
2004	2665	160	13	1	0
2005	2649	138	20	1	0
2006	2578	149	21	0	0
2007	2813	120	17	1	0
2008	2432	148	11	1	0
2009	2380	125	11	1	0
2010	2427	131	8	0	0
2011	2938	146	14	0	0
2012	2505	233	18	1	1
2013	2057	110	10	2	0
2014	2240	137	11	2	1
2015	1989	115	9	0	0
2016	1980	166	17	1	1
2017	2510	150	21	2	0
2018	2598	184	27	1	0
2019	2546	186	18	2	0
2020	2191	135	9	0	0
2021	2500	190	23	1	0
2022	2598	130	11	0	0
TOTAL	60491	3478	337	23	4

Figura 39. Sismos por rango de magnitud. Los datos de 2001 – 2019 han sido tomados de la base seisan y los del periodo 2020-2022 de la base de seiscomp del MARN

VII. Información adicional

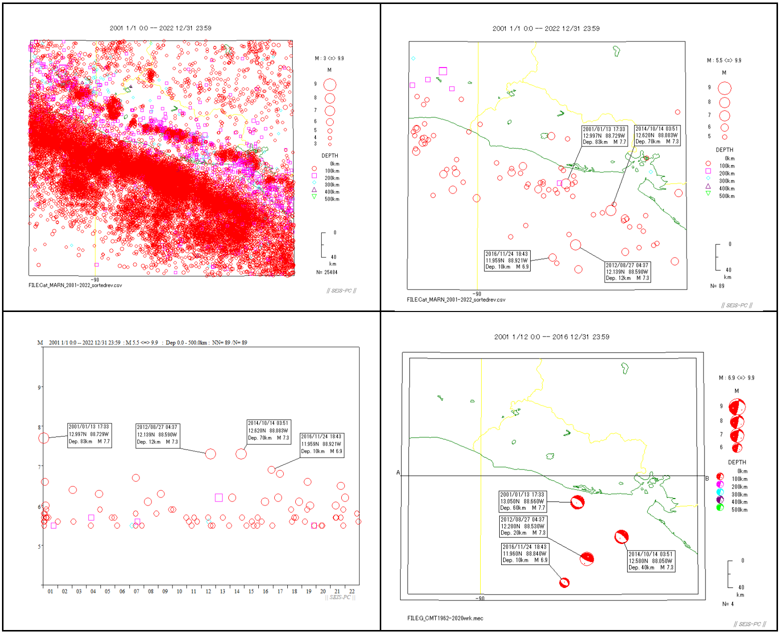


Figura 40. Comportamiento actividad sísmica 2001-2022. En la Figura superior izquierda se muestran todos los epicentros, en la imagen superior derecha solo los epicentros con magnitud ≥ 5.5 resaltando lo del mayor magnitud, en la Figura inferior izquierda las magnitudes ≥ 5.5 con respecto al tiempo y en la imagen inferior derecha los mecanismos focales de los cuatros sismos de mayor magnitud.

VII. Información adicional

Parámetros de una falla

El movimiento de una falla, representada por el movimiento entre dos bloques, se define por tres parámetros: *acimut* o *strike*, buzamiento o *dip*, desplazamiento o *rake* (Figura 41).

El acimut o *strike* (Φ), es el ángulo que forma la traza de la falla con el norte geográfico, puede tener valores entre 0 y 360 grados. El buzamiento o *dip* (δ), es el ángulo que forma el plano de la falla con el plano horizontal, puede tener valores entre 0 y 90 grados. El desplazamiento o *rake* (λ), es el ángulo entre la dirección del vector de deslizamiento (*slip*) o dislocación y la horizontal, medido sobre el plano de falla, puede tener valores entre -180 y 180 grados.

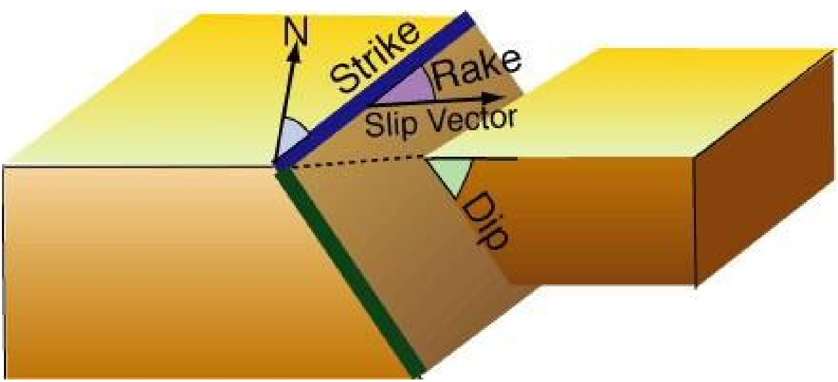


Figura 41. Parámetros que definen el movimiento de una falla[8]

8 https://igppweb.ucsd.edu/~gabi/sio15/supps/fault.gif

VII. Información adicional

Escala de intensidad sísmica Mercalli Modificada[9]

En 1931, en los Estados Unidos, H.O. Wood y F. Neumann recopilaron los trabajos de Mercalli, Cancani y Sieberg, y publicaron la escala que se ha llegado a conocer como Mercalli Modificada (MM). Una nueva versión de la escala MM fue presentada por C.F. Richter en 1956. Esta escala, compuesta de niveles crecientes de intensidad, que van desde sismos imperceptibles hasta destrucción catastrófica, se designa con números romanos (Figura 42). Estas no tienen una base matemática, es una clasificación arbitraria basada en los efectos observados.

Intensidad	Descripción/Daños
I	No sentido.
II	Sentido por personas en posición de descanso, en pisos altos o situación favorable.
III	Sentido en el interior. Objetos suspendidos oscilan. Vibraciones similares al paso de un camión ligero. Duración apreciable. Puede no ser reconocido como un terremoto.
IV	Objetos suspendidos oscilan. Vibraciones similares al paso de un camión pesado o sensación de sacudida como de un balón pesado golpeando las paredes. Los automóviles parados se balancean. Ventanas, platos, puertas vibran. Los cristales tintinean. Los objetos de barro se mueven. En el rango alto de IV, los tabiques y armazones de madera crujen.
V	Sentido al aire libre; se aprecia la dirección. Las personas que están durmiendo se despiertan. Los líquidos se agitan, algunos se derraman. Objetos pequeños inestables desplazados o volcados. Las puertas se balancean, se cierran y se abren. Contraventanas y cuadros se mueven. Los péndulos de los relojes se paran, cambian de período.
VI	Sentido por todos. Muchas personas se asustan y salen al exterior, caminan inestablemente. Ventanas, platos y objetos de vidrio se rompen. Adornos, libros, etc. se caen de las estanterías. Los cuadros se caen. Los muebles se mueven o vuelcan. Los revestimientos débiles y las construcciones de tipo D se agrietan. Las campanas pequeñas suenan (iglesias, colegios). Árboles, arbustos sacudidos visiblemente.

9 Copiado de: Bommer, J. (1994). Sismología para Ingenieros. Papeles técnicos UCA, serie: fundamentos. Universidad Centroamericana José Simeón Cañas

VII	Difícil mantenerse en pie. Sentido por los conductores. Objetos suspendidos tiemblan. Muebles rotos. Daño a edificios del tipo D incluyen grietas. Las chimeneas débiles se rompen a ras del tejado. Caída de cielos rasos, ladrillos sueltos, piedras, tejas, cornisas, también antepechos no asegurados y ornamentos de arquitectura. Algunas grietas en edificios de tipo C. Olas en estanques, agua enturbiada con barro. Pequeños corrimientos y hundimientos en arena o montones de grava. Campanas grandes suenan. Canales de cemento para regadío dañados.
VIII	Conducción de los carros afectada. Daños en edificios del tipo C; colapso parcial. Algún daño a construcciones de tipo B; nada en edificios de tipo A. Caída de estuco y algunas paredes de mampostería. Giro, caída de chimeneas, rimeros de fábricas, monumentos, torres, depósitos elevados. Las estructuras de las casas se mueven sobre los cimientos si no están sujetas; trozos de pared sueltos, arrancados. Ramas de árboles quebradas. Cambios en el caudal o temperatura de fuentes y pozos. Grietas en suelo húmedo y pendientes fuertes.
IX	Pánico general. Construcciones del tipo D destruidas; edificios C seriamente dañados, algunas veces con colapso total; edificios tipo B con daños importantes. Daño general en los cimientos. Estructuras de armazón, si no están sujetas, desplazadas de los cimientos. Armazones arruinados. Daños serios en embalses. Tuberías subterráneas rotas. Amplias grietas en el suelo. En áreas de aluvial, eyección de arena y barro, aparecen fuentes y cráteres de arena.
X	La mayoría de las construcciones y estructuras de armazón destruidas con sus cimientos. Algunos edificios bien construidos en madera y puentes destruidos. Daños serios en presas, diques y terraplenes. Grandes corrimientos de tierras. El agua rebasa las orillas de canales, ríos, lagos, etc. Arena y barro desplazados horizontalmente en playas y tierras llanas. Carriles torcidos.
XI	Carriles muy retorcidos. Tuberías subterráneas completamente fuera de servicio.
XII	Daño prácticamente total. Grandes masas de rocas desplazadas. Visuales y líneas de nivel deformadas. Objetos proyectados al aire.
Para evitar ambigüedades de lenguaje, la calidad de la construcción, ladrillo u otro material, se especifica por las siguientes letras:	
A	Estructuras de acero y concreto reforzado, bien diseñadas, calculadas para resistir fuerzas laterales. Buena construcción, materiales de primera calidad.
B	Estructuras de concreto reforzado, no diseñadas en detalle para resistir fuerzas laterales. Buena construcción y materiales.
C	Estructuras no tan débiles como para fallar la unión de las esquinas, pero no reforzadas ni diseñadas para resistir fuerzas horizontales. Construcción y materiales corrientes.
D	Construcciones de materiales pobres, tales como el adobe; baja calidad de construcción. No resistente a fuerzas horizontales.

Figura 42. Escala de intensidad sísmica Mercalli Modificada

VII. Información adicional

Leyes de escalamiento sísmico

Existen relaciones entre la magnitud del sismo (M), la longitud de ruptura (L) en kilómetros y el desplazamiento (U) en metros de la falla que genera el sismo. Por ejemplo en Utsu (2001)[10] se presentan las siguientes relaciones:

$$\textbf{Log U(m)=0.5 M -3.1}$$
$$\textbf{Log L(km)=0.5M -1.85}$$

En la Figura 43 se presentan los valores de longitud de ruptura y desplazamiento en la falla para sismos con magnitudes entre 5 y 9.1

M	U (m)	L (km)	M	U (m)	L (km)	M	U (m)	L (km)
5	0.25	4.47	6.4	1.26	22.39	7.8	6.31	112.20
5.1	0.28	5.01	6.5	1.41	25.12	7.9	7.08	125.89
5.2	0.32	5.62	6.6	1.58	28.18	8	7.94	141.25
5.3	0.35	6.31	6.7	1.78	31.62	8.1	8.91	158.49
5.4	0.40	7.08	6.8	2.00	35.48	8.2	10.00	177.83
5.5	0.45	7.94	6.9	2.24	39.81	8.3	11.22	199.53
5.6	0.50	8.91	7	2.51	44.67	8.4	12.59	223.87
5.7	0.56	10.00	7.1	2.82	50.12	8.5	14.13	251.19
5.8	0.63	11.22	7.2	3.16	56.23	8.6	15.85	281.84
5.9	0.71	12.59	7.3	3.55	63.10	8.7	17.78	316.23
6	0.79	14.13	7.4	3.98	70.79	8.8	19.95	354.81
6.1	0.89	15.85	7.5	4.47	79.43	8.9	22.39	398.11
6.2	1.00	17.78	7.6	5.01	89.13	9	25.12	446.68
6.3	1.12	19.95	7.7	5.62	100.00	9.1	28.18	501.19

Figura 43. Longitud de ruptura (L) y desplazamiento (U) en las fallas con el uso de leyes de escalamiento, para diferentes magnitudes (M)

10 Utsu T (2001) Jishingaku 3rd edn. KyoritsuShuppan (en japonés)

GOBIERNO DE EL SALVADOR

MINISTERIO DE MEDIO AMBIENTE Y RECURSOS NATURALES

Existing Catalogue				Priority				
Organization	Period (Note: WWSSN was established in 1964.)	M size	Covering feature	M	Depth	Tsunami	Disaster	Centroid
MARN **(closed)**	*Apr22* -Oct22	M>=2.0	Examined; dtails of seismicity in El Salvador	1	1	1	1	1
	Jan01 -Mar22	M>=3.0	Examined; dtails of seismicity in El Salvador	1	1	1	1	1
MARN	*Recent 10 events*	M>=2.0	Examined; dtails of seismicity in El Salvador	1	1	1	1	1
Reference http://www.snet.gob.sv/ver/sismologia/monitoreo/sismos+reportados/ultimos+10+sismos/								
MARN	*Jan01* -Oct22	Felt; M>=2.5	Emergency final; details of seismicity in El Salvador					
Reference http://www.snet.gob.sv/ver/sismologia/monitoreo/sismos+reportados/intensidad+instrumental/								
CATAC	*Jan01* -Oct22	M>=*5.5??*	Emergency final?; dtails of seismicity in El Salvador	Pending				
Reference https://www.ineter.gob.ni/articulos/areas-tecnicas/geofisica/monitoreo-de-sismos-en-tiempo-real.html								
NOAA	1859-2022	Historical events	covering the period 1859-1903 for large events, and tsunami data	2	2	2		
GCMT	(1962-2020) 1976-2020	M>=5.5	focal mechanisms, centroids, and confirming M, if necessary	3				2
ISC	1904-2018	M>=5.0 (recent part), large ones	covering the period 1904-2000, and confirming large M	4	3			
PDE (USGS)	1638-2022	M>=4.0 (recent part), large ones	covering the period 1638-1908, confirming M, if necessary	5	4			
QED (USGS)	2013-2022, Jan23	M>=4.0	confirming M, if necessary	6	5			
EM-DAT (CRED)	1524-2014	Disastrous events	covering the period 1524-1637, and disasters	7	6	3	2	
Damaging Earthquakes in the World	Ancient times through 2017	Damaging Earthquakes in the World	Damaging events; including the events that occurred before 1524	7	6	3	2	
Reference https://iisee.kenken.go.jp/utsu/index_eng.html								

How to handle CMT in the emergency status for tsunami warning

Approved by MARN on 15Mar23
Revised by MORI on 16Mar23

Contents of this document

How to handle CMT in the emergency status for tsunami warning

1) When, where, and for what we use CMT analysis,
2) How to handle CMT analysis.

<u>Self-training materials</u>

3) Why we use CMT analysis,
4) What CMT analysis is,
5) What Green function is.

Contents of this document

How to handle CMT in the emergency status for tsunami warning

1) When, where, and for what we use CMT analysis,
2) How to handle CMT analysis.

Self-training materials

3) Why we use CMT analysis,
4) What CMT analysis is,
5) What Green function is.

When and for what we use CMT analysis are explained in the “**Guideline for how to proceed with the Tsunami Monitoring Duty in El Salvador**” as follows:

3) How to get Mw from CMT analysis and to get focal mechanism

We should calculate CMT to get **Mw** and **focal mechanism** in the below cases:

Case 1: If the Final message shows that M should be 5.5 or larger, any damage should be expected at the epicenter area; so, we should get **focal mechanism** from CMT to understand the feature of the event and to consider the perspective of the aftershock activity.

Case 2: If the Final message shows that M should be 6.5 or larger, any tsunami should be expected; so, we should additionally get **Mw** from CMT to understand the feature of the event and to consider the reliable tsunami level.

Case 3: If the Final message shows that M should be 7.0 or larger, M from amplitude data should has some possibility of underestimate; so, CMT should be calculated as early as possible to get reliable **M or Mw**.

Exact timing when we use CMT analysis is also shown in the "**Guideline**". See **the right table** of procedures timeline.

Tables of actions against the events with Magnitude 6.5 or larger
(for "Aviso y Alerta de Tsunami" for LOCAL (Z1); the red actions are the main body of this table.)

Elapsed time (min)	Status of the environment	Procedures to be started by the elapsed time	
		Actions taken by Seismic shift	Actions taken by Landslide shift
0	Occurrence of an earthquake (Origin Time (OT) = Time of detecting the event - around 10 sec): Starting the procedures		
1	Given observed seismic waveforms of any stations		
2	Given automatic hypocenter & M	Issuing and disseminating **Calm message** via radio, WhatsApp (fax), Twitter	Checking information in CISN
3		Selecting hypocenter & M according to the criteria based on data number & average RMS	
		Checking consistency with other information collected until this timing	
5	Receiving seismic parameters & tsunami potential level from outside	Issuing **Preliminary message** with checked M, epicenter location, indication of tsunami threat, and any term to tell what to do, via radio & WhatsApp (fax); disseminating it via Twitter & Web Issuing and disseminating **Tsunami Bulletin 1** with estimated tsunami arrival times (ETA) via radio, WhatsApp (fax), email, Twitter & Web	Responding to supervisors and to the public
		Evaluating the latest hypocenter according to **the criteria** / Calculating manually seismic parameters / Selecting M according to **the criteria**	
10		Issuing **Final message** with degree of tsunami threat via radio & WhatsApp (fax); disseminating it via Twitter & Web	
10-20		Assessing the information from CATAC, PTWC, USGS and other outside organizations; judging necessity of updating the information; disclosing the information by adding to the Tsunami bulletin	Issuing and disseminating **Tsunami Bulletin 2** with seismic parameters, degree of tsunami threat, ETA , and estimated tsunami height via WhatsApp, fax, email, Twitter & Web
15	Getting Mw from CMT	Judging necessity of change of tsunami degree based on the Mw / **If necessary,** issuing and disseminating the message with updated information via WhatsApp (fax), Twitter & Web	Checking the information in the Twitter & Web / Sea level gauges are monitored with Tide Tool (arrival times and heights)/

Judging necessity of change of tsunami degree based on the Mw / **If necessary,** issuing and disseminating the message with updated information via WhatsApp (fax), Twitter & Web

Comparison of exact timing when we can use CMT analysis for the events larger than or equal to M6.5

(Note 1: Below shows the status of several years ago. **The latest should be reviewed**.)
(Note 2: If the Mw is so large like around 9.0, CMT analysis needs longer time to get result.)

OSOP CMT (Almost always usable for the "target event")
  MARN: 15 - 20 minutes.

Global CMT (Almost always usable for the "target event")
  Harvard: 30 min
  USGS: 30 min

Regional or local (Almost always usable for the "target event")
  JMA: 15 min

W-phase (not always usable)
  JMA: 6 min

When we use CMT analysis is also explained in the "Procedures to use initial motion focal mechanisms" as follows:

1. When we calculate hypocenter and M as the daily routine work, we should try to analyze initial motion focal mechanism by OSOP or ISOLA. But we should set the limit of the M to be handled; and it should be larger than or equal to M3.0 that is "completely" covered by the seismic network we use now.

(Note 1: The average number to be analyzed would be 3 or 4 events per day, because we will have around 920 events, which have M>=3.0, per year as shown in the data in 2022. That means we should analyze average 3.5 events/day **including events to be analyzed by "CMT" analysis.**

Excerpt "How to use Initial motion focal mechanism"

Contents of this document

How to handle CMT in the emergency status for tsunami warning

1) When, where, and for what we use CMT analysis,
2) How to handle CMT analysis.

Self-training materials

3) Why we use CMT analysis,
4) What CMT analysis is,
5) What Green function is.

What should we take care of to use CMT analysis properly **in emergency actions against tsunami**?

Namely,

1. What should we do for properly using it for the information to the public?
2. What should we consider the acceptance of the result?

Regarding data from observation to handle CMT analysis,

the essential issue is that the they should have **sufficient Signal to Noise ratio (S/N).** If the S/N is not enough, noise affects the result from CMT analysis.

And there are roughly two types of broad-band (BB) seismometers to observe velocity of the motion with sufficient dynamic range.

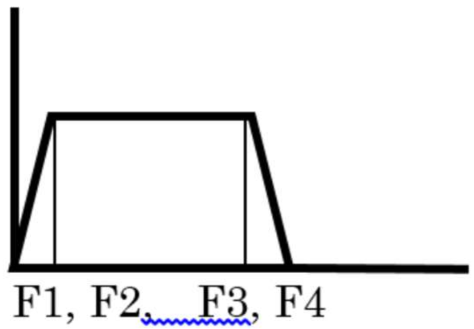
One of them has intrinsic period is very long like 360 sec (Ex. STS-1; Wielandt & Streckeisen 1982), but it is weak against strong motion.

The other has intrinsic period is moderately long like 120 sec (Ex. STS-2), but it is a little bit stronger than the previous one.

(Note: Recently we have more varied types of broad-band seismometers, which are not only the types to observe velocity but those to do acceleration. But when we see them from the viewpoint of BB seismometer, we should check its dynamic range, its intrinsic period and its robustness against strong motion.)

We should use "Trapezoidal Filtering" to get proper waveforms. OSOP will automatically handle this issue, though.

Trapezoidal Filtering



F2 0.028Hz, F3 0.010Hz

After Usui et al 2010

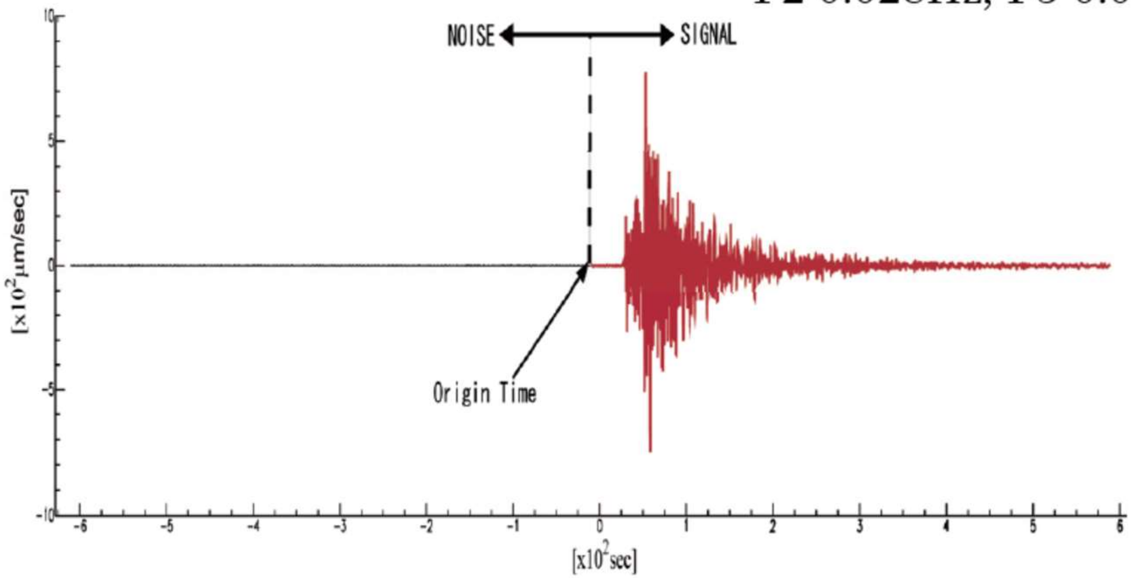


Fig. 2-1 Example of a seismic waveform observed at Aomori Tenmabayashi station (TENMAB).

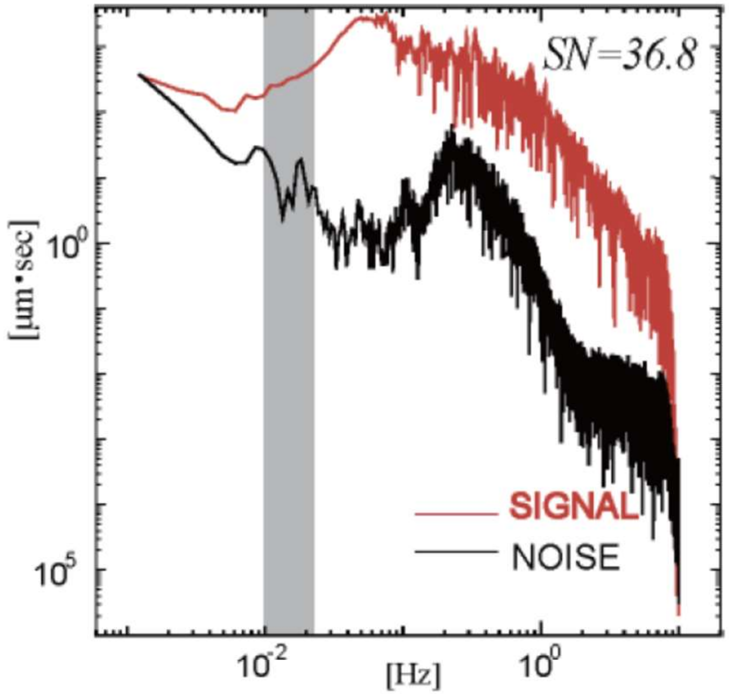


Fig. 2-2 Displacement Fourier amplitude spectrums of the signal and noise waveforms in Fig.2-1. The gray area indicates the frequency used for the CMT inversion analysis.

What should we do for using properly the information to the public in the emergency status?

Once we have a large earthquake, the OSOP provides us with results of CMT analysis one by one according to the increase of amount of data (waveforms) that we can use. So, we should select one with sufficient accuracy as early as possible from them to issue any important information to the public as soon as possible.

How should we consider the acceptance (accuracy) of the result? 1/2

The CMT analysis would provides us with its result having the evaluation indexes: **"Misfit", "DC** (proportion of double couple component)**", "CLVD** (proportion of "compensated linear vector dipole"; extension/contraction to a direction with shrinking/expansion to keep the volume)**"** and **"Monte Carlo inversion plot** (inversion for random station set)**".**

We should establish **the criterion for the earlier judgement on acceptance of the result**.

How should we consider the acceptance (accuracy) of the result? 2/2

Steps to fix the criterion for analysis in any emergency status

Step 1: With "Misfit", "DC", "CLVD" and "Monte Carlo inversion plot", to initially set a start criterion like "Condition 1: Misfit (=1-VR) < 0.3" AND "Condition 2: DC > 70%" AND "Condition 3: CLVD> 40%", these "parameters" can be seen in the SeisComP module "scolv".

Step 2: If necessary, to revise the above initial numbers and/or to introduce other conditions.

variance reduction (VR): VR= 1 – ($res^2/data^2$), where res^2 denotes misfit

$$\left(1-\frac{\int_0^T [o_i(t)-s_i(t)]^2\,dt}{\int_0^T o_i(t)^2\,dt}\right)\times 100$$

Step 3: To fix the conditions.

One idea on the criterion for automatic analysis (The below will miss good results somehow. After Usui et al 2010)

Condition 1: **Fit (VR) > 0.3** / **Condition 2:** Distance between centroid and hypocenter =< L (60 km for M 7.2/7.3) obtained form "Utsu 2001 scaling law", / **Condition 3**: In the case of the centroid =< 20 km and dip =< 6 degrees, it should not be accepted because the event with the feature has the tendency of over-estimate of Mw like 0.3-0.4 larger for around M6.0. (Note: The Mw7.3 Usultan event in 2012 had the centroid 12 km and dip15 degrees.)

One feature of the result from CMT analysis

When we mainly use the regional waveforms in the analysis for the emergency status, as mentioned in **the previous slide**, we should establish **the criterion** that should tell if we can use the **Mw** and/or the **CMT focal mechanism** provided from the CMT analysis. Even though **Mw** is acceptable, sometimes **CMT focal mechanism** cannot be acceptable because the "phase shift" or any "ambiguous" waveforms induced by insufficient S/N of the waveforms will easily affect the focal mechanism. See **the below two slides.** **If we only need Mw, we can refer the result without its focal mechanism in the emergency status to consider the tsunami threat to be on the safety side.**

An example M_j8.2 of the "phase shift" affecting the result

The result on **the right figure** has some "phase shift" due to insufficient S/N. But it is improved, as shown in **the left figure**, by using data with sufficient S/N.

After Usui et al 2010

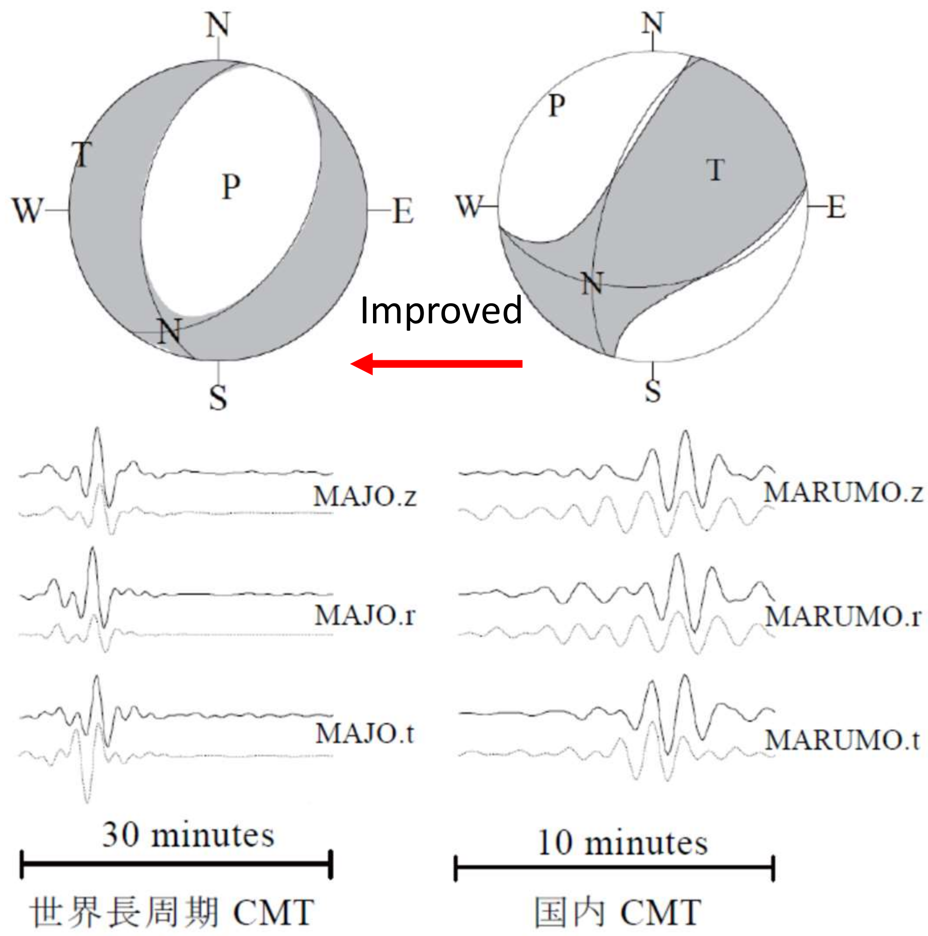
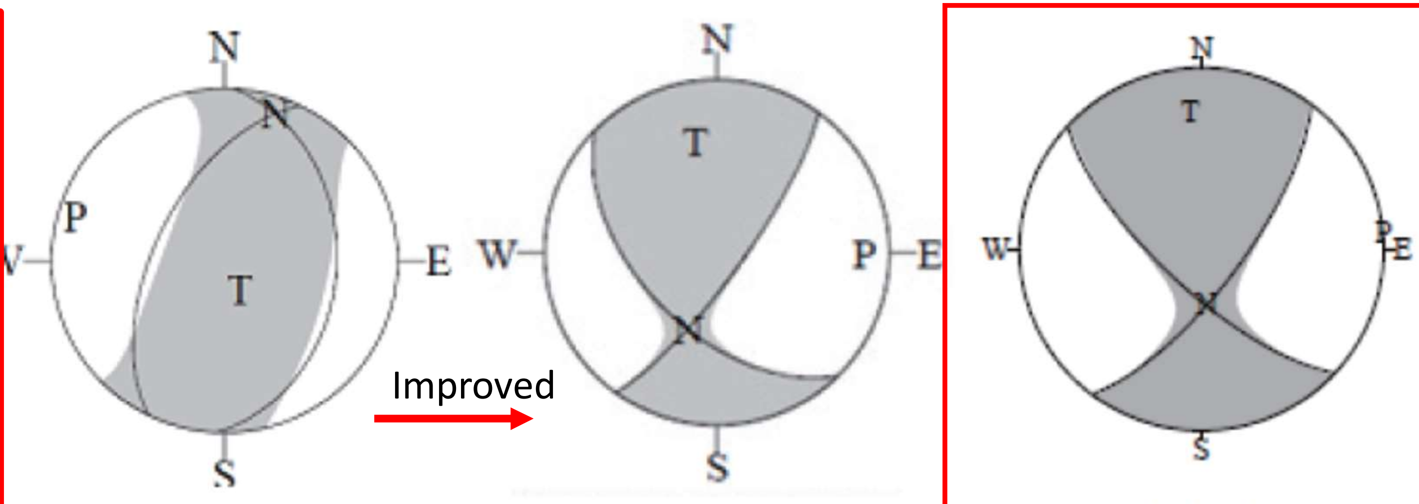


Fig. 11 Results of the global lower-frequency automatic CMT inversion analysis (left) and the regional automatic CMT inversion analysis (right) for the event near the Kuril Islands on January 13, 2007.

An example M_j6.2 of using additional data from the world to surround the epicenter with better S/N for improving the CMT analysis result

The result on the left (a) figure was obtained only from data of one side of the epicenter. With addition of the data to surround it, the result on the central (b) figure was obtained. It is like the target one on the right (c) figure.

After Usui et al 2010



(a) F-net

(b) F-net, MAJO, INCN, PET

(c) Global CMT

Target focal mechanism

Fig. 12 Comparison between the CMT inversion solutions for the event near the Kuril Islands on October 25, 2007. (a) is analyzed using the F-net STS-1 network only, (b) is analyzed using the F-net STS-1 network and three LISS stations near Japan and (c) is a solution for the same event in the Global CMT catalogue.

Contents of this document

How to handle CMT in the emergency status for tsunami warning

1) When, where, and for what we use CMT analysis,
2) How to handle CMT analysis.

Self-training materials

3) Why we use CMT analysis,
4) What CMT analysis is,
5) What Green function is.

Why we need/use CMT analysis in monitoring earthquakes

Seismic moment, Mo, for Mw is obtained by CMT analysis.

We thus need CMT analysis to get Mw, and additionally focal mechanism having the average feature of the source displacement.

Excerpt from "Guía de sismos y tsunamis 2023"

Magnitud: generalmente expresada con "M", es una medida cuantitativa del tamaño de un sismo en términos de la energía sísmica liberada. Se mide en una escala logarítmica, de tal forma que cada unidad de magnitud corresponde a un incremento de raíz cuadrada de 1000, o de aproximadamente 32 veces la energía liberada. Por ejemplo, un sismo de magnitud 8 es 32 veces más grande que uno de magnitud 7; 1000 veces más grande que uno de magnitud 6; 32,000 veces más grande que uno de magnitud 5, y así sucesivamente. Para calcular "M" se utiliza la máxima amplitud de las formas de onda registrada por los sismómetros. Para calcular la magnitud también se utiliza el momento sísmico, el cual es una cantidad proporcional al área de ruptura y al deslizamiento ocurrido en la falla geológica y se expresa como "Mw" en lugar de "M".

To calculate the magnitude, the seismic moment is also used, which is a quantity proportional to the rupture area and the slippage that occurred in the geological fault and is expressed as "Mw" instead of "M".

How to get **Moment Magnitude**, Mw

$Mo = \mu \times D \times S = \mu \times U \times (L \times W)$

μ: Rigidity

U, D: Average displacement on the fault area

S: Source area size

L: Fault length

W: Fault width (= L / 2)

Formula for calculating the magnitude (Kanamori, 1977)

$Mw = (\log Mo - 9.1)/1.5$ N·m

What is Magnitude?

<u>Data frequency feature</u> (to be obtained beforehand from the seismometer features and the analysis-filter features)
<u>Maximum amplitude</u> (to be observed)
<u>Distance from the hypocenter</u> (to be analyzed by the arrival time observed)

Formula for calculating magnitude
M = a log (Maximum amplitude) + b log (Distance) + c
a, b, and c are constants determined to get any magnitude.
The versatile magnitude would be M (average in the Seiscomp3), M_J, or M_s.

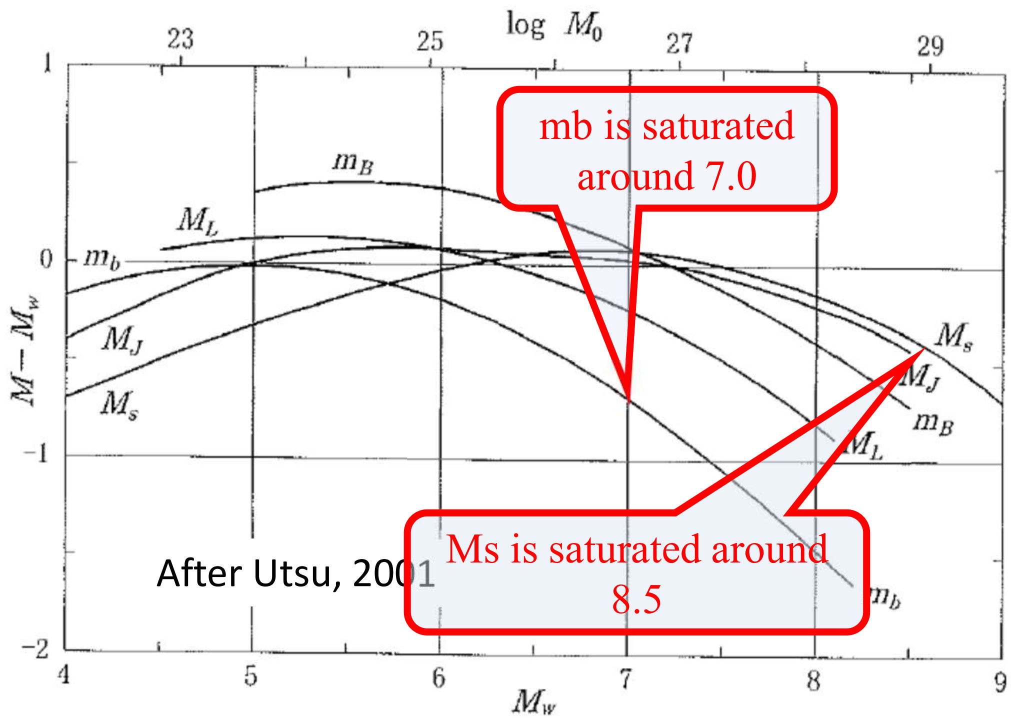
Magnitude obtained by various methods

Magnitude name	Shown in Seiscomp 3	Phase: Body-wave	Phase: surface-wave	Phase: Whole-wave	Seimometer: Any	Seimometer: Broad-band	Seimometer: Wood-Anderson (T_0=0.8sec)
Mb		○			○		
mB	○	○				○	
Mw(mB)	○	○				○	
M(summary)	○	○	○		○		
mb	○	○ p-wave			○		
Ms			○		○		
M_J at JMA	△		○		○		
ML			△				○
MLv	○		△		○ with vertical		
Mw				○		○	
Mw(avg)	△	○	○		○		
Mwp	△	○ p-wave			○		
Mw(Mwp)	△	○ p-wave			○		

What is Magnitude ?

It has been developed as one of <u>measures of earthquake size</u> with the recorded amplitude. Currently the term Magnitude is used as a measure of earthquake size without depending on amplitude.

But it saturates in large events. So, we need Mw.



Relation among various kind of M

, where "log M_o" is shown with the "dyn・cm unit system", so, if reducing 7 from the numerals shown there gives us those with the "N・m unit system"

Meaning of focal mechanism (background inf. 1/2)

Focal mechanism is also called **Earthquake Mechanism.**

Focal mechanism tells what kind of motion caused seismic waves observed;

so, **a)** it explains the released force at the point of the hypocenter. When the focal mechanism is **b)** double couple (quadrant) type, **c)** its **fault plane solution** (its nodal plane) is obtained from the push-pull distribution of the P-wave initial motion.

(Note: On the other hand, the mechanism obtained from **CMT** explains **the averaged released forces** in the source area. And it indicates the location of its centroid.)

Terms

Fault: one plane, with which a relative displacement of the bedrock is recognized as the boundary.

Earthquake source fault: the fault that generated the earthquake.

Fault parameters: the **location** and the **size** of the fault, the **direction** and the **amount** of **relative displacement** of the fault, the **amount of stress reduction** by the earthquake occurrence.

Excerpt from Draft "How to use Initial motion focal mechanism" Prepared by MORI as of 13Mar23

How to use focal mechanism (background inf. 2/2)

We can use it **d)** to get the stress change caused by the earthquake that occurred at that time in the stress field estimated by the collected focal mechanism.

The mechanism obtained from "initial motion" shows the feature of the released force at the hypocenter. 1) It can tell the main feature of the released force for moderate/small size events. 2) It can thus show the stress change caused by the occurrence of the earthquake around the source area. 3) It can additionally roughly show the stress field in the area through adding it to focal mechanisms collected for a long period until the day and mapping them

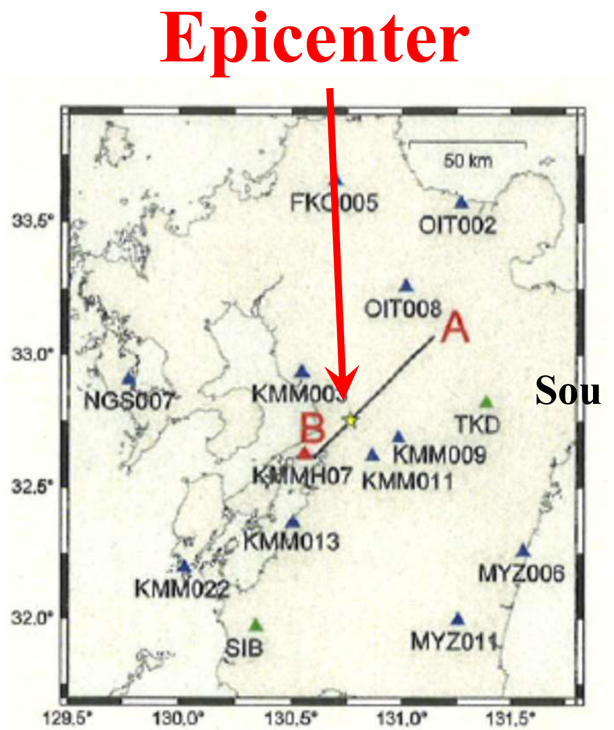
(Note: the released force is related to the stress field at the source area and is controlled by the **internal friction**. Further, sometimes it is related to **faults existing** at the source area.)

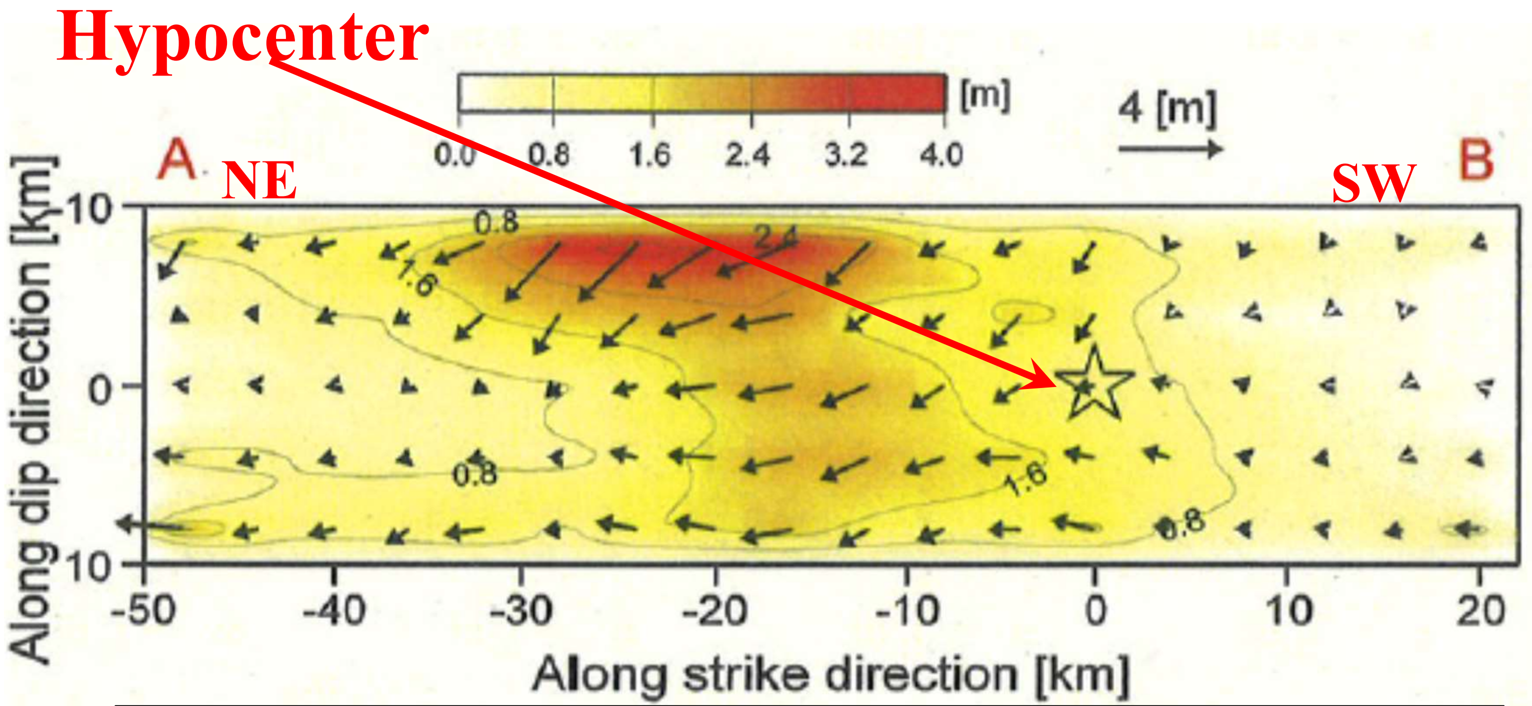
Note: **The CMT** can handle the mechanism of large event like larger or equal to M6.5. And the "**initial motion**" can cover moderate or small earthquakes that are not able to be handled by the CMT because those would not generate long period waves having enough energy to be handled by CMT analysis.

Excerpt from Draft "How to use Initial motion focal mechanism" Prepared by MORI as of 13Mar23

Ex. 1: Source Process of the 2016 Kumamoto M7.3

Inversion analysis with the data of Strong Motion Waveforms by NIED





Observation Station distribution Triangles are the stations. Star is the epicenter calculated by NIED. A-B is the fault projection to the earth surface.

The final **slip distribution** on the fault. The vectors show **the slip (as a point source)** of **the hanging wall of the fault.** The Star shows the start point of the slip or the hypocenter. Strike 224 degrees. Dip 88 degrees. Length 72km. Width 20km. Upper edge depth 3.1km. Maximum slip amount 3.3m.

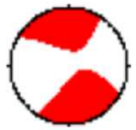
Based on the page 10 in the http://www.static.jishin.go.jp/resource/monthly/2016/2016_kumamoto_2.pdf

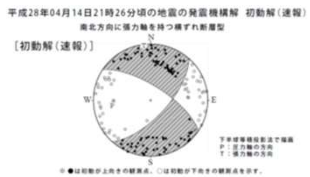
2016 Kumamoto M7.3 in the Global CMT Catalogue

Foreshock

201604141226A KYUSHU, JAPAN

```
Date: 2016/ 4/14   Centroid Time: 12:26:41.1 GMT
Lat=  32.80  Lon= 130.78
Depth= 14.7   Half duration= 3.0
Centroid time minus hypocenter time:  4.7
Moment Tensor: Expo=25  -0.260 2.040 -1.780 -0.056 -0.583 1.030
Mw = 6.2    mb = 0.0    Ms = 6.2   Scalar Moment = 2.26e+25
Fault plane:  strike=300    dip=76   slip=-8
Fault plane:  strike=32    dip=82   slip=-165
```

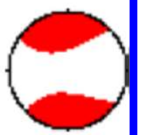


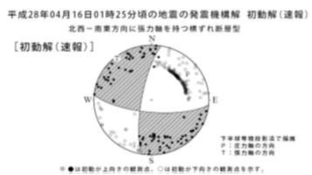


Main shock

201604151625A KYUSHU, JAPAN

```
Date: 2016/ 4/15   Centroid Time: 16:25:15.7 GMT
Lat=  32.85  Lon= 130.81
Depth= 12.0   Half duration= 8.0
Centroid time minus hypocenter time:  9.4
Moment Tensor: Expo=26  -1.710 5.090 -3.380 0.160 0.802 0.782
Mw = 7.0    mb = 0.0    Ms = 7.0   Scalar Moment = 4.46e+26
Fault plane:  strike=128    dip=74   slip=-14
Fault plane:  strike=222    dip=77   slip=-163
```

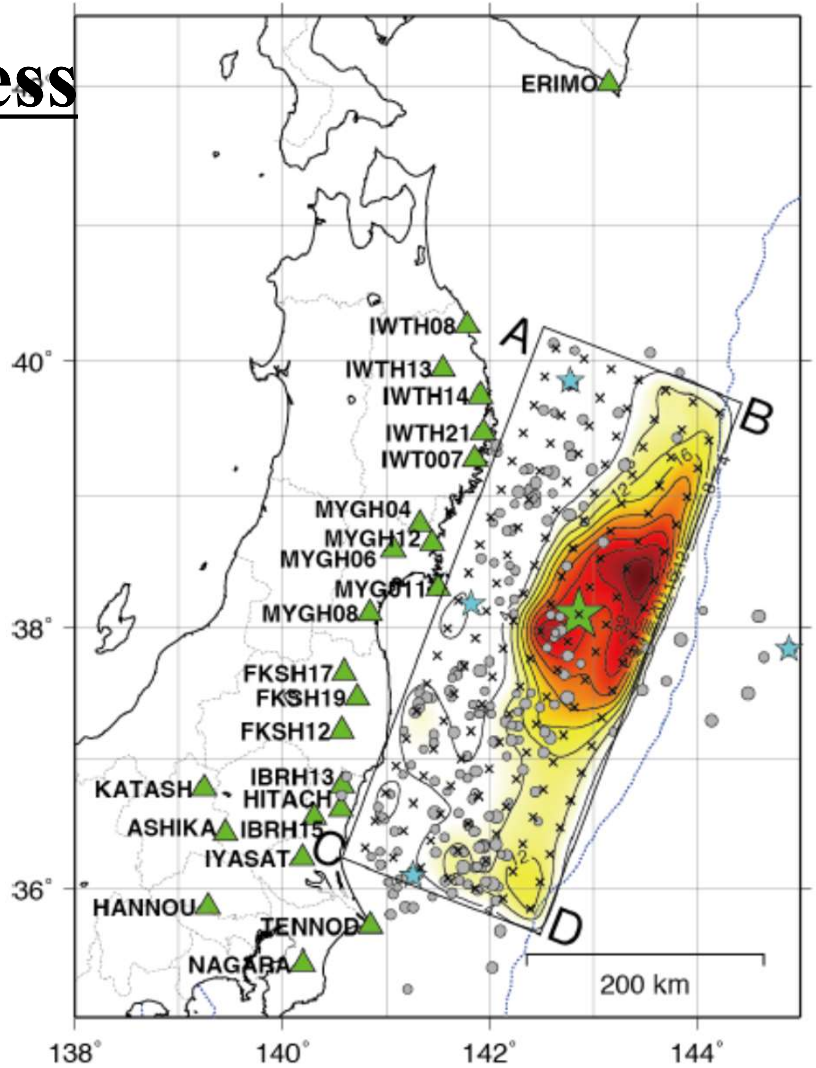




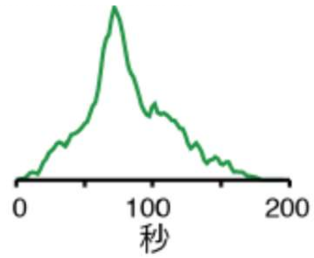
http://www.globalcmt.org/CMTsearch.html

Ex. 2: Source Process of the "11Mar11 M_w 9.0" event

The estimation of the distribution of displacements of the main shock shows that they are extremely inhomogeneous.



Source Time Function



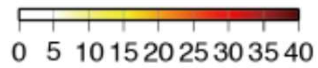
Epicenter

Epicenters of larger than M7 since 09Mar11

Epicenters of larger than M5 during 1 day after the main

Stations used for the analysis

Mo = 3.4 x 10^{22} Nm (M_w=9.0)



Displacement (m)

Contour distance is 4m

Distribution of displacement (at point sources) on the fault
of the main shock estimated from source process analysis

Based on a report (JMA)

Contents of this document

How to handle CMT in the emergency status for tsunami warning

1) When, where, and for what we use CMT analysis,
2) How to handle CMT analysis.

Self-training materials

3) Why we use CMT analysis,
4) What CMT analysis is,
5) What Green function is.

Moment by single couple force 1/3

When a force acting not on the origin but on the arbitrary point like ***x'*** = *(x_1', x_2', x_3')*, the displacement made by it is given by replacing ***x*** with ***x-x'*** and putting |***x-x'***| for r in the formulae (Fig. 2.94; see **the next slide**) to get displacement, $u_i^k(x, t)$, induced by a point force. For example, the forces acting at the same time on the points *(h/2, 0, 0)* and *(-h/2, 0, 0) with the direction of* x_2 and $-x_2$ respectively as shown in the Figure 2.24 (a), the displacement to be made by them should be as follows:

$$u_i^2\,(x_1-h/2,\, x_2,\, x_3,\, t) - u_i^2\,(x_1+h/2,\, x_2,\, x_3,\, t) \quad (2.96)$$

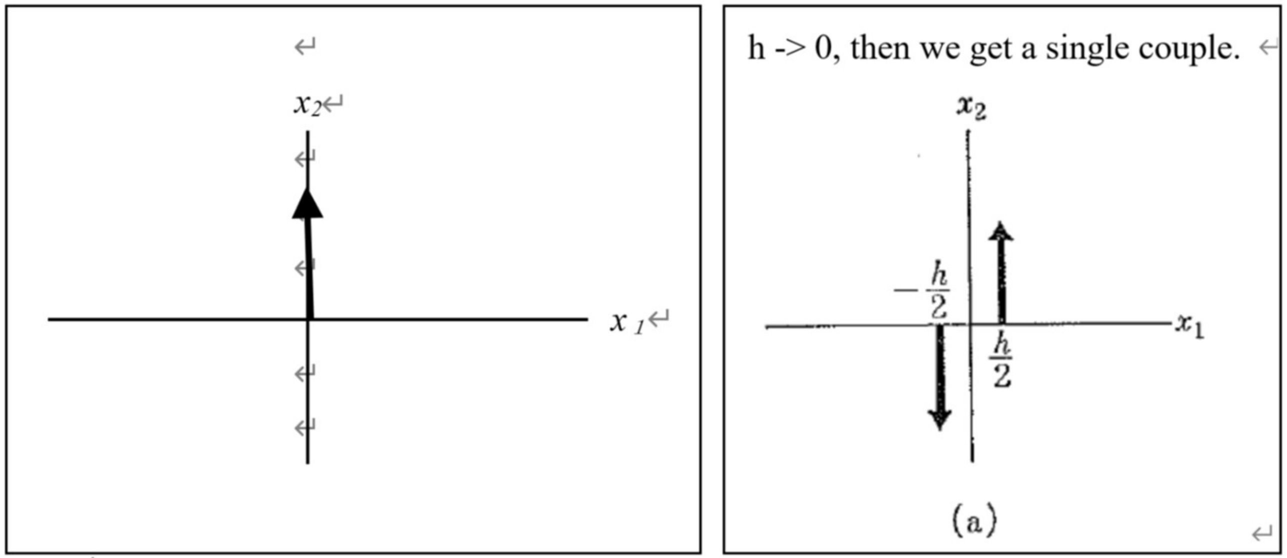


Figure 2.24. A point force acting to the x_2-direction, (a) Single couple.

Dynamic displacement with the point force

The dynamic displacement $u_i^k(x, t)$ of x_i component induced by the point force $F(t)$ operating to x_k direction can be obtained as follows:

$$u_i^k(\mathbf{x}, t) = \frac{1}{4\pi\rho}\frac{\partial^2 r^{-1}}{\partial x_i \partial x_k}\int_{r/\alpha}^{r/\beta} \tau F(t-\tau)\mathrm{d}\tau$$

Near Field Term

$$+ \frac{1}{4\pi\rho\alpha^2 r}\frac{x_i x_k}{r^2} F\left(t - \frac{r}{\alpha}\right)$$

Far Field Term of P wave

$$+ \frac{1}{4\pi\rho\beta^2 r}\left(\delta_{ik} - \frac{x_i x_k}{r^2}\right) F\left(t - \frac{r}{\beta}\right) \quad (2.94)$$

Far Field Term of S wave

$$\alpha = \sqrt{\frac{\lambda + 2\mu}{\rho}}$$

$$\beta = \sqrt{\frac{\mu}{\rho}}$$

ρ *is* density. α is P-wave velocity. β is S-wave velocity. r is hypocenter distance.

Kronecker's Delta
$\delta_{ij} = 1$ when $i = j$
$= 0$ when $i \neq j$

3) What CMT analysis is

Moment by single couple force 2/3

If we consider making "*h*" smaller to the limit through expressing these forces with *M(t)/h*, we can get the Single Couple having x_2 as the force direction and ***M(t)* as the moment around x_3 pole when the "*h*" reaches to 0**; and we can get from the (2.96) the displacement, v_i, made by the Single Couple; namely,

$$v_i = \lim_{h\to 0} u_i^2 (x_1-h/2,x_2,x_3,t) - u_i^2 (x_1+h/2,x_2,x_3,t)$$

whereas *F(t)* in the formula (2.94) should be replaced by *M(t)/h*.

Finally, we get the followings:

$$v_\mathrm{i} = -\frac{\partial}{\partial xi} u_i^2 \quad (2.97)$$

Whereas *F(t)* and F_0 in the formula (2.94) should be replaced by *M(t)* and M_0.

Moment by single couple force 3/3

With the formula (2.97), we get far field approximation through neglecting the terms having the order of higher than 1/r through considering r >> 0 as follows:

As for the dynamic displacement in the far field, we get the below:

$$v_i = \frac{1}{4\pi\rho\alpha^3 r}\gamma_1\gamma_2\gamma_i M'\left(t - \frac{r}{\alpha}\right) + \frac{1}{4\pi\rho\beta^3 r}(\delta_{i2} - \gamma_2\gamma_i)\gamma_1 M'\left(t - \frac{r}{\beta}\right) \quad (2.98)$$

, where $\gamma_i = x_i/r$

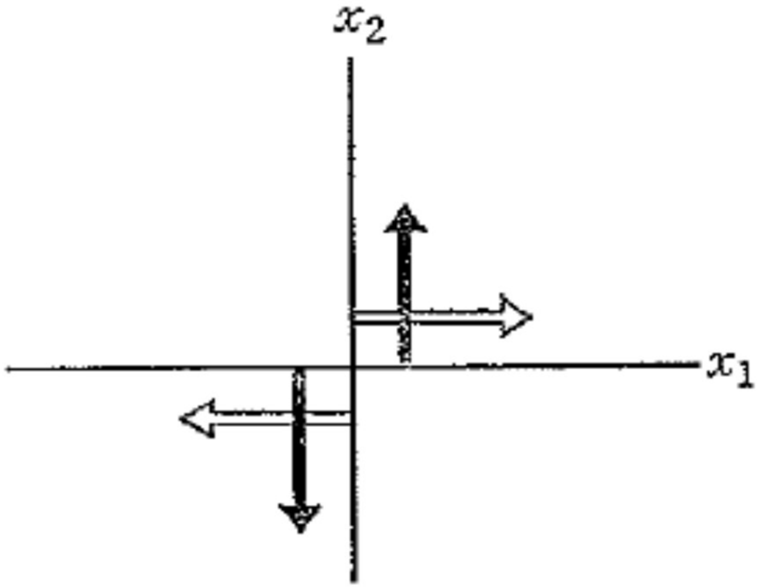
The formula (2.98) shows the dynamic displacement when a Single Couple acting with the force of x_2-direction and <u>the moment</u> of x_3-direction on the origin.

Double couple (a set of Single Couple) 1/3

In the same manner we can take an additional Single Couple acting with the force of x_1-direction and the moment of x_2-direction on the origin as shown in the below figure (b). In the case that the latter one acts together with the former one, we call the set of Single Couple as Double Couple. The displacement to be made by it should be as follows:

$$v_i = -\frac{\partial}{\partial x1}u_i^2 - \frac{\partial}{\partial x2}u_i^1 \quad (2.100)$$

Whereas $F(t)$ and F_0 in the formula (2.94) should be replaced by moments, $M(t)$ and M_0.



(b)

Double couple (a set of Single Couple) 2/3

With the formula (2.100) in the previous slide, we get far field approximation through neglecting the terms having the order of higher than 1/r through considering r >> 0 as follows:

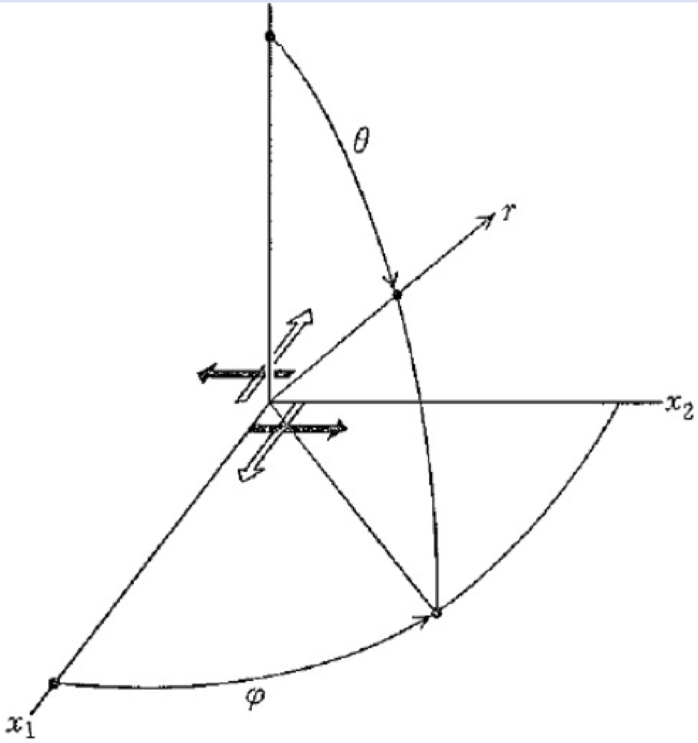
As for the dynamic displacement in the far field, we get the below:

$$v_i = \frac{1}{4\pi\rho\alpha^3 r} 2\gamma_1\gamma_2\gamma_i M'\left(t - \frac{r}{\alpha}\right) + \frac{1}{4\pi\rho\beta^3 r}(-2\gamma_1\gamma_2\gamma_i + \delta_{i1}\gamma_2 + \delta_{i2}\gamma_1) M'\left(t - \frac{r}{\beta}\right) \quad (2.101)$$

, where $\gamma_i = x_i/r$

The formula (2.101) shows the dynamic displacement when a Double Couple acting on the origin with the force of x_1 *and* x_2 directions in the x_1x_2 plane in a homogeneous isotropic elastic body having finite space.

Coordinates transformation to the polar ones



$$\gamma_1 = x_1/r = \sin\theta\cos\phi$$
$$\gamma_2 = x_2/r = \sin\theta\sin\phi \qquad (2.103)$$
$$\gamma_3 = x_3/r = \cos\theta$$

Figure 2.25 Definition of the polar coordinates

$$\begin{pmatrix} v_r \\ v_\theta \\ v_\varphi \end{pmatrix} = \begin{pmatrix} \sin\theta\cos\varphi & \sin\theta\sin\varphi & \cos\theta \\ \cos\theta\cos\varphi & \cos\theta\sin\varphi & -\sin\theta \\ -\sin\varphi & \cos\varphi & 0 \end{pmatrix} \begin{pmatrix} v_1 \\ v_2 \\ v_3 \end{pmatrix} \qquad (2.\,104)$$

After Fukao 1978

Double couple (a set of Single Couple) 3/3

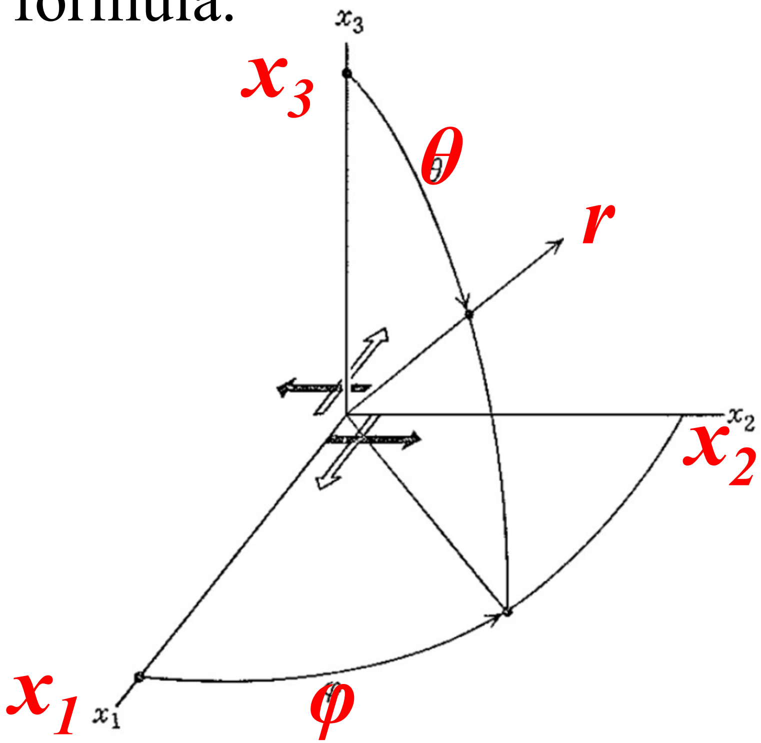
By introducing 2.101(showing the dynamic displacement when a Double Couple acting on the origin with the force of x_1 *and* x_2 directions in the x_1x_2 plane in a homogeneous isotropic elastic body having finite space), and 2.103 in the previous page into 2.104 in the previous page, we get the below formula.

Dynamic displacement with Double Couple force

$$\left.\begin{aligned} v_r &= \frac{1}{4\pi\rho\alpha^3 r} M'\left(t - \frac{r}{\alpha}\right) \sin^2\theta \sin 2\varphi \\ v_\theta &= \frac{1}{4\pi\rho\beta^3 r} M'\left(t - \frac{r}{\beta}\right) \frac{1}{2} \sin 2\theta \sin 2\varphi \\ v_\varphi &= \frac{1}{4\pi\rho\beta^3 r} M'\left(t - \frac{r}{\beta}\right) \sin\theta \cos 2\varphi \end{aligned}\right\}$$

ρ: density
α: P-velocity
β: S-velocity
r: hypocentral distance

(2-105)



In the case that the coordinate (x_1, x_2 and x_3) has an arbitrary direction of the double couple force, **its focal mechanism can be expressed with 6 independent fault solutions**. See **the next slide**.

Seismic fault has a finite area size, but when we handle long period seismic waves, we can approximately deal it as point moment tensor source in time and space. The point location can be regarded as hypocenter centroid. Then, **the moment tensor solution** having specific centroid is called **Centroid Moment Tensor (CMT)** one.

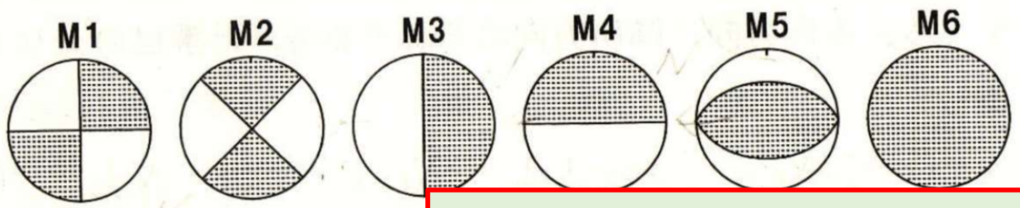
After Kikuchi 2003

If we use whole waveforms to get focal mechanism, the focal mechanism we get is the one for Centroid.

What CMT analysis is

Focal mechanism can be expressed with 6 independent fault solutions, M1, M2, M3, M4, M5, and M6 as shown below. Their "strike, dip, rake" are (0, 90, 0)/(135, 90, 0)/(180, 90, 90)/(90, 90, 90)/(90, 45, 90)

$$[M]=a_1[M_1]+a_2[M_2]+\cdots+a_6[M_6] \qquad (2.13)$$



M6 is the isotropic element.

Figures 2.105 & 2.94 (dynamic displacements with Double Couple Force and Point Force) are shown in the slides 27 & 21 in this document.

If we use $w_{jm}(t\,;p)$ as Green function, below gives us synthetic waveform. **Green function** is explained in the end of this document.

$$f_j(t\,;p)=\sum_m a_m w_{jm}(t\,;p) \qquad (2.14)$$

After Kikuchi 2003

$w_{jm}(t\,;p)$ can come from **2.105** through setting *M'(t)* with *hδ'(t)* for M1 through to M5, and from **2.94** through setting *F(t)* with *δ(t)* and integrating whole directions. *p in 2.14 should be* ***x***.

Then, we should compare synthetic wave forms, $f_i(t; p)$, with observed ones, and should have the solution with the least square method to get a_i ($i = 1,2,3,4,5,6$).

After Kikuchi 2003

See **the next slide** that shows procedures to get the CMT solutions of two types of CMT analysis software, “Automatic JMA/CMT procedures” and “Automatic Scisola procedures”.

The procedures of OSOP are not checked by Expert , but it should have similar ones to those of the next page two types.

CMT analysis procedures

Phase selection

Trapezoidal Filtering

Step	Automatic JMA/CMT procedures	Automatic Scisola procedures
1	Obtaining initial hypocenter Obtaining Noise waveforms	Obtaining initial epicenter (**Origin Triggering**)
2	Removing instrumental effect	**Station Selection based on** epicenter **Distance**
	Station Selection based on S/N and epicenter distance	**Bad Station Data Filtering** (discarding unavailable streams and data having gaps or clips)
	Rotating waveforms for getting radial and transverse components	**Station Data Correction** 1 Rotating waveforms for getting necessary components 2 Correction of data length 3 Removing instrumental effect 4 Resampling
3	Collection of the data, which have been previously selected; their windows or data lengths should be according to the set values.	**Station Selection based on Azimuth** (Station weighting procedures)
4	Theoretical waveform calculation	**Green's Functions Computation**
5	CMT calculation	**Inversion Computation** (maximum 21 stations) **Result Plotting**
6	Selection of the best solution Judging the accuracy of the results Counter measurement against the judgement results	Revise Mode

GFDB

Earth structure(Q-value, density)

Contents of this document

How to handle CMT in the emergency status for tsunami warning

1) When, where, and for what we use CMT analysis,
2) How to handle CMT analysis.

<u>Self-training materials</u>

3) Why we use CMT analysis,
4) What CMT analysis is,
5) What Green function is.

Explanation of the Green function

<u>General feature of Source/Action</u>

In general,

Superposition of Source/Action (*x, t*)

-> **Physical System (Green Function)**

-> Result/Reaction (***x'***, *t'*)

In an elastic body,

Seismic source process

-> **Earth structure** (velocity structure, Q-factor, boundaries; **Green Function**)

-> **Seismic motion** at any surface of the earth

Note: u (t', **x'**) generated by $\delta(t)$ $\boldsymbol{\delta}(\mathbf{x})$ is G (t', **x'**).

$$u(t', \mathbf{x}') = \int \iiint_{\infty}^{\infty} G(t' - t, \mathbf{x}' - \mathbf{x})\, \delta(t)\, \boldsymbol{\delta}(\mathbf{x})\, dt\, d\mathbf{x} = G(t', \mathbf{x}')$$

Therefore, G (t', x') can be obtained with pulse like very small earthquake.

<u>In an elastic body (earthquake of the earth),</u>

Source: **<u>Action</u>** or Force f (t, **x**)

Point (place; **x**): Hypocenter

Instant (time; t): Origin Time,

Unit action (strength): Magnitude

Feature (double couple force): Focal Mechanism

Green function G (t', x')

Through Elastic mechanical system

Result: **<u>Motion</u>** u (t', **x'**)

Place (**x'**): Seismic Station location,

Time (t'): Arrival time

Waveform of three component: Amplitude

$$u(t', \mathbf{x}') = \int \iiint_{\infty}^{\infty} G(t' - t, \mathbf{x}' - \mathbf{x})\, f(t, x)\, dt\, \mathbf{dx} = G(t', \mathbf{x}') * f(t, \mathbf{x})$$

, where " * " is mathematical convolution.

<u>**In a general physical body,**</u> <u>**Source/Action**</u> on a point **x** for an instant at a time t
-> <u>**Physical body (Green Function)**</u> -> <u>**Result/Reaction**</u> on a point x' at t'

Ex. 1: In a <u>**dielectric body**</u> with ε as dielectric constant, <u>**putting**</u> **a point electric charge** with Q makes **static electricity** around it as follows:

$$\phi(\boldsymbol{r}) = \frac{Q}{4\pi\varepsilon}\frac{1}{|\boldsymbol{r}|} \qquad (1.1.1)$$

If we distribute electric charge $\rho(\boldsymbol{r})$ in the dielectric body, dielectric potential is obtained as follows:

$$\phi(\boldsymbol{r}) = \frac{1}{4\pi\varepsilon}\int\frac{\rho(\boldsymbol{r}')}{|\boldsymbol{r}-\boldsymbol{r}'|}d\boldsymbol{r}' = \frac{1}{\varepsilon}\int G(r,r')\rho(r)dr'$$

, where Green function $G(r, r')$ is as shown below:

$$G(r,r') = \frac{1}{4\pi|r-r'|} \qquad (1.1.4)$$

After Imamura 1978

Ex. 2: In an **elastic body**, **given single force** $\boldsymbol{f}(\boldsymbol{x}, t)$

-> through elastic mechanical system $\mathbf{G}(\boldsymbol{x}', t'; \boldsymbol{x}, t)$ -> **Motion** $\mathbf{u}(\boldsymbol{x}', t')$

$$\mathbf{u}(\boldsymbol{x}', t') = \int \iiint_{\infty}^{\infty} \mathbf{G}(\mathbf{x}' - \mathbf{x}, t' - t)\, \boldsymbol{f}(\boldsymbol{x}, t)\, d\mathbf{x} dt$$

$\mathbf{u}(\boldsymbol{x}', t')$ generated through setting $\boldsymbol{\delta}(\mathbf{x})\delta(t)$ as $\boldsymbol{f}(\boldsymbol{x}, t)$ is $\mathbf{G}(\boldsymbol{x}', t')$

or $\mathbf{u}(\boldsymbol{x}', t') = \int \iiint_{\infty}^{\infty} \mathbf{G}(\mathbf{x}' - \mathbf{x}, t' - t)\, \boldsymbol{\delta}(\mathbf{x})\delta(t)\, d\mathbf{x} dt = \mathbf{G}(\boldsymbol{x}', t')$

The descriptions shown in the below slides explains how to get the displacement $\boldsymbol{u}(\boldsymbol{x}', t')$ at each point in the elastic body occupying infinite space by a body force $\boldsymbol{f}(\boldsymbol{x}, t)$ for a unit mass, which works on a micro volume V, and is applied at the time "t" in the direction of working force indicated by the vector $\boldsymbol{l} = (l_x, l_y, l_z)$. So, $\boldsymbol{u}(\boldsymbol{x}', t')$ *could be* **Green function for the elastic body** through setting $\boldsymbol{f}(\boldsymbol{x}, t) \propto \delta(\mathbf{x})\delta(t)$, where $\delta(\mathbf{x})$ and $\delta(t)$ are Dirac's Delta functions working at **x** or t.

Thank you!

¡Gracias!

How to use (procedures)
Initial motion focal mechanism
with self-training materials
Prepared by MORI as of 15Mar23

Procedures to use initial motion focal mechanisms 1/2

1. When we calculate hypocenter and M as the daily routine work, we should try to analyze initial motion focal mechanism by OSOP or ISOLA. But we should set the limit of the M to be handled; and it should be larger than or equal to M3.0 that is "completely" covered by the seismic network we use now.

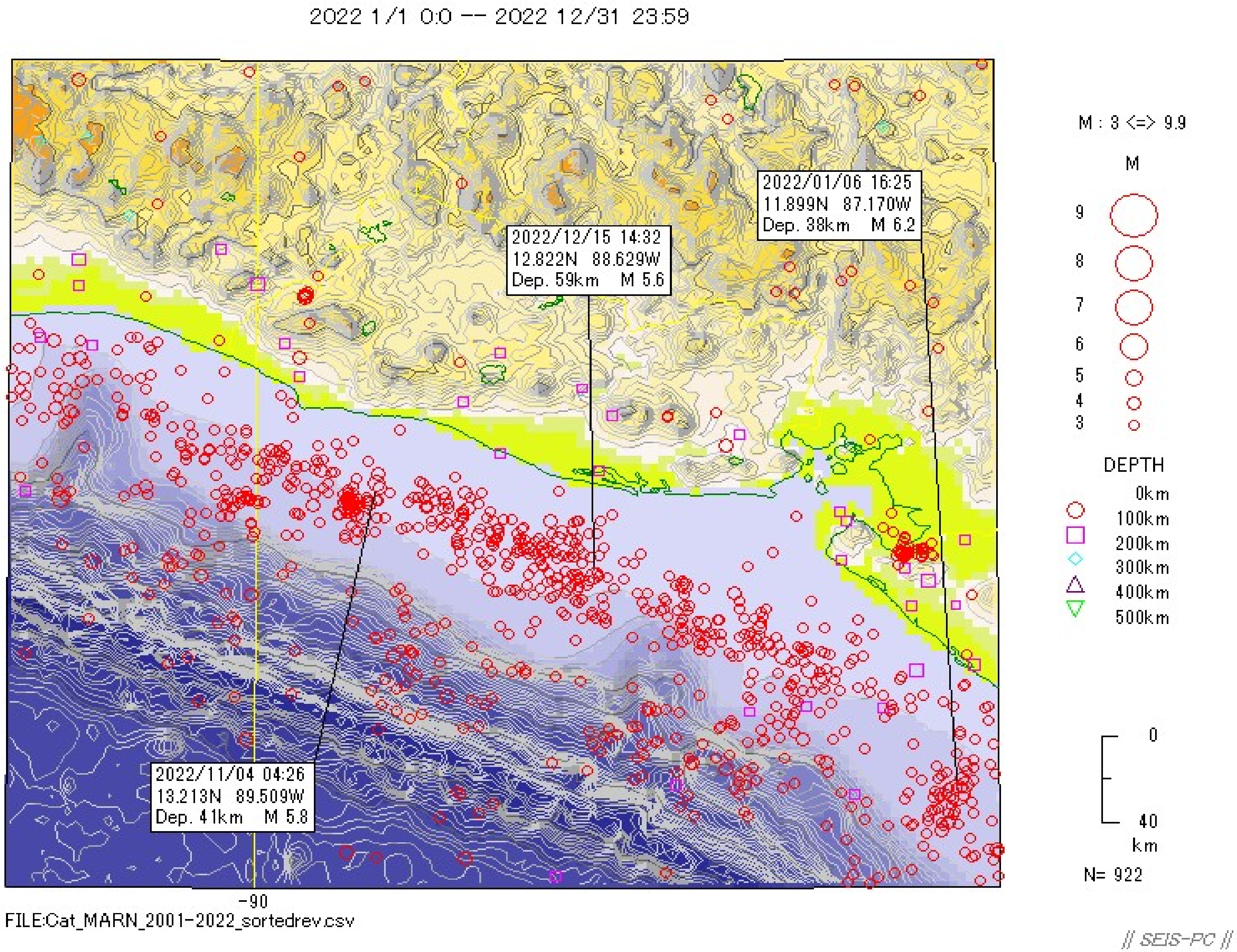
(Note 1: The average number to be analyzed would be **3 or 4 events per day**, because we will have **around 920 events, which have M>=3.0, per year** as shown in the data in 2022. **See the next slide**. That means we should analyze average 3.5 events/day including events to be analyzed "CMT", because,

920 events/(365days x (5/7)) =3.5 events/day.)

(Note 2: We should prepare the instruction on how to use OSOP or ISOLA to analyze initial motion focal mechanism.)

Earthquakes with M >= 3.0 in 2022

Total number of earthquakes plotted is 922.



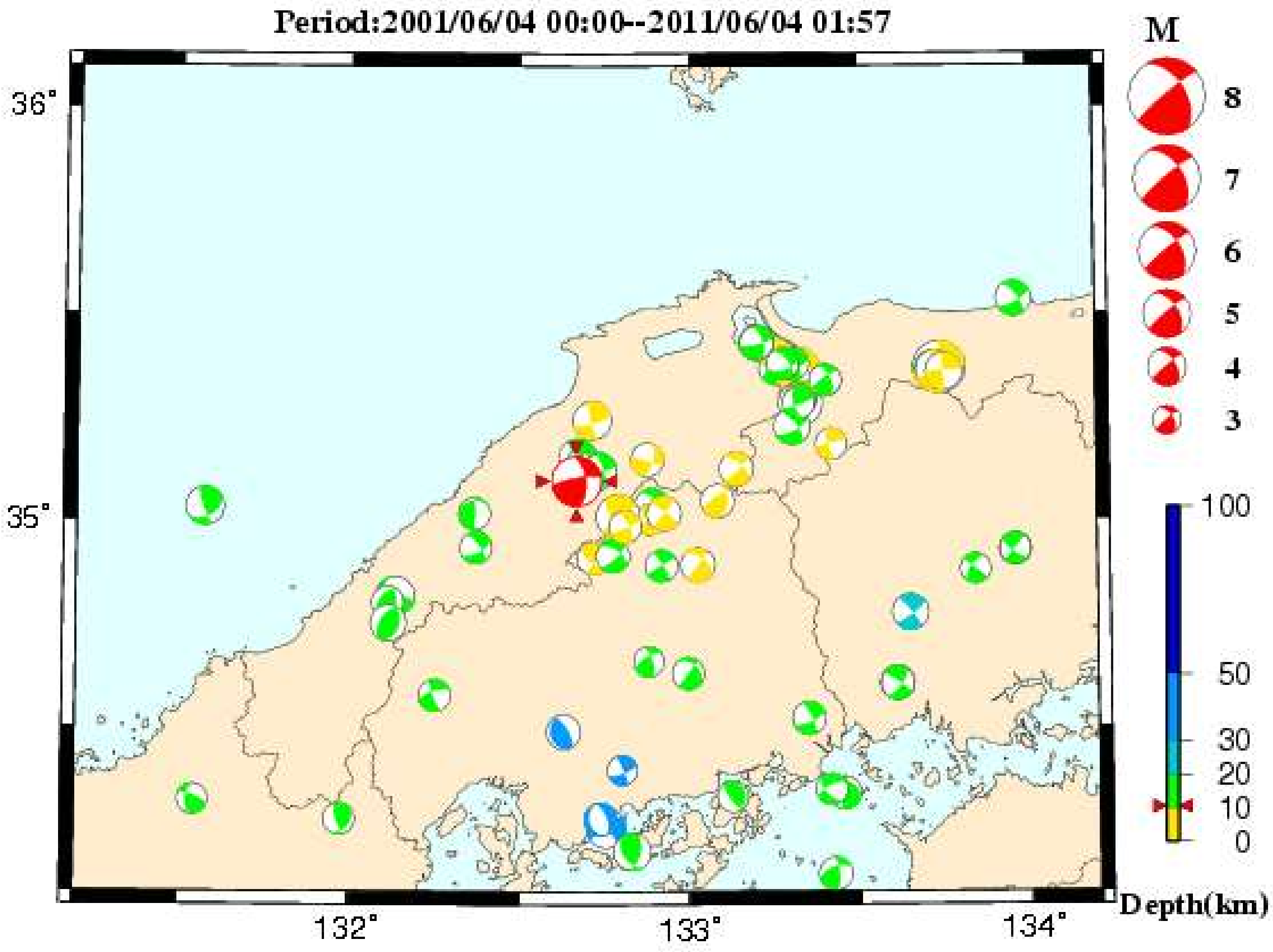
Procedures to use initial motion focal mechanisms 2/2

2. We should plot, with SeisPC, the results in the map with focal mechanisms analyzed until the previous year.

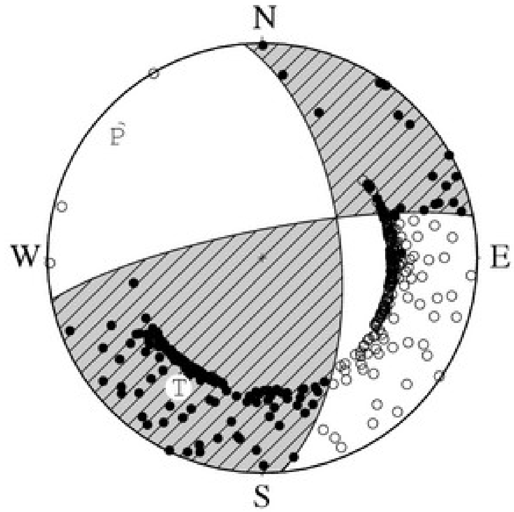
3. We should compare the results with the ones distributed around them. See **the next slide** that shows an example in Japan.

This document has a self-training materials that try to explain how OSOP/ISOLA (possibly) gets initial focal mechanisms and how we should see and use the mechanism that we could get.

After JMA, 2011



Regarding the event of "04Jun11 East of Shimane pref. M 5.2", the focal mechanism obtained is put on its epicenter and is compared with those of events occurred during "recent" ten years.



Meaning of focal mechanism (background inf. 1/2)

Focal mechanism is also called **Earthquake Mechanism.**

Focal mechanism tells what kind of motion caused seismic waves observed;

so, **a)** it explains the released force at the point of the hypocenter. When the focal mechanism is **b)** double couple (quadrant) type, **c)** its **fault plane solution** (its nodal plane) is obtained from the push-pull distribution of the P-wave initial motion.

(Note: On the other hand, the mechanism obtained from **CMT** explains **the averaged released forces** in the source area. And it indicates the location of its centroid.)

Terms

Fault: one plane, with which a relative displacement of the bedrock is recognized as the boundary.

Earthquake source fault: the fault that generated the earthquake.

Fault parameters: the **location** and the **size** of the fault, the **direction** and the **amount** of **relative displacement** of the fault, the **amount of stress reduction** by the earthquake occurrence.

How to use focal mechanism (background inf. 2/2)

We can use it **d)** to get the stress change caused by the earthquake that occurred at that time in the stress field estimated by the collected focal mechanism.

The mechanism obtained from "initial motion" shows the feature of the released force at the hypocenter. 1) It can tell the main feature of the released force for moderate/small size events. 2) It can thus show the stress change caused by the occurrence of the earthquake around the source area. 3) It can additionally roughly show the stress field in the area through adding it to focal mechanisms collected for a long period until the day and mapping them

(Note: the released force is related to the stress field at the source area and is controlled by the **internal friction**. Further, sometimes it is related to **faults existing** at the source area.)

Note: **The CMT** can handle the mechanism of large event like larger or equal to M6.5. And the "**initial motion**" can cover moderate or small earthquakes that are not able to be handled by the CMT because those would not generate long period waves having enough energy to be handled by CMT analysis.

Contents of the self-training materials

1) **Observed results**,
2) Meaning of getting the **stress change** caused by the earthquake in the stress field,
3) **Nodal plane of the earthquake** obtained from the push-pull distribution of the P-wave initial motion,
4) **Initial motion focal mechanism** explaining the released force at the point of the hypocenter,
5) **Double couple forces** (quadrant type of focal mechanism).

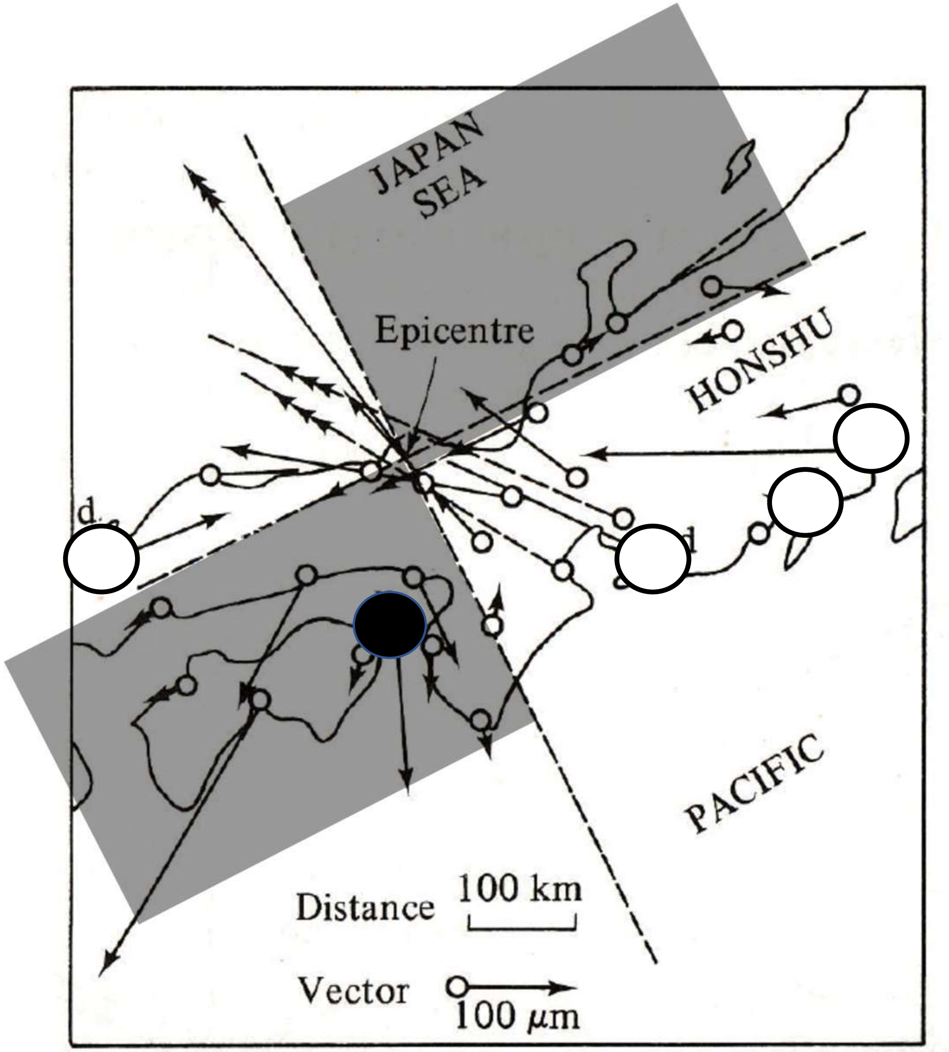
Contents of the self-training materials

1) **Observed results,**
2) Meaning of getting the **stress change** caused by the earthquake in the stress field,
3) **Nodal plane of the earthquake** obtained from the push-pull distribution of the P-wave initial motion,
4) **Initial motion focal mechanism** explaining the released force at the point of the hypocenter,
5) **Double couple forces** (quadrant type of focal mechanism).

Fault Plane Solution

1) Observed results

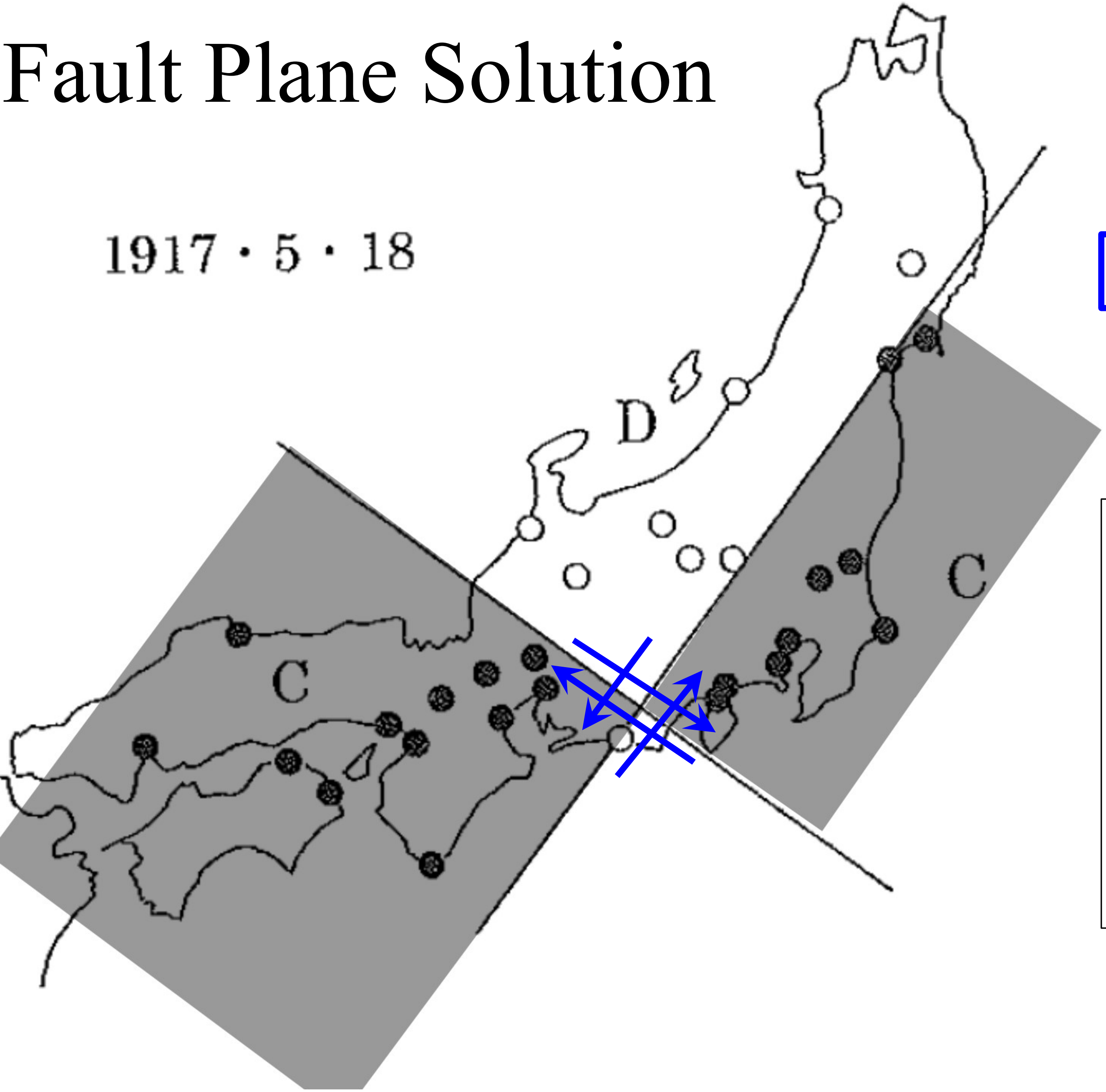
Left lateral Strike slip faulting



Separation of compressions from dilatations on a map is relatively easy in cases as that shown in the left figure, when many stations are located around the source.

Ground movements in the initial P-phase for the Tango earthquake in Japan (1927, **M=7.5**). The source **depth is so shallow** that a fault emerged on the surface and that it left permanent displacements around the source area. Symbols u ● & d ○ denote the upward & the downward initial P-pulses respectively. (Shown in Kasahara 1981 after Honda 1957)

Fault Plane Solution

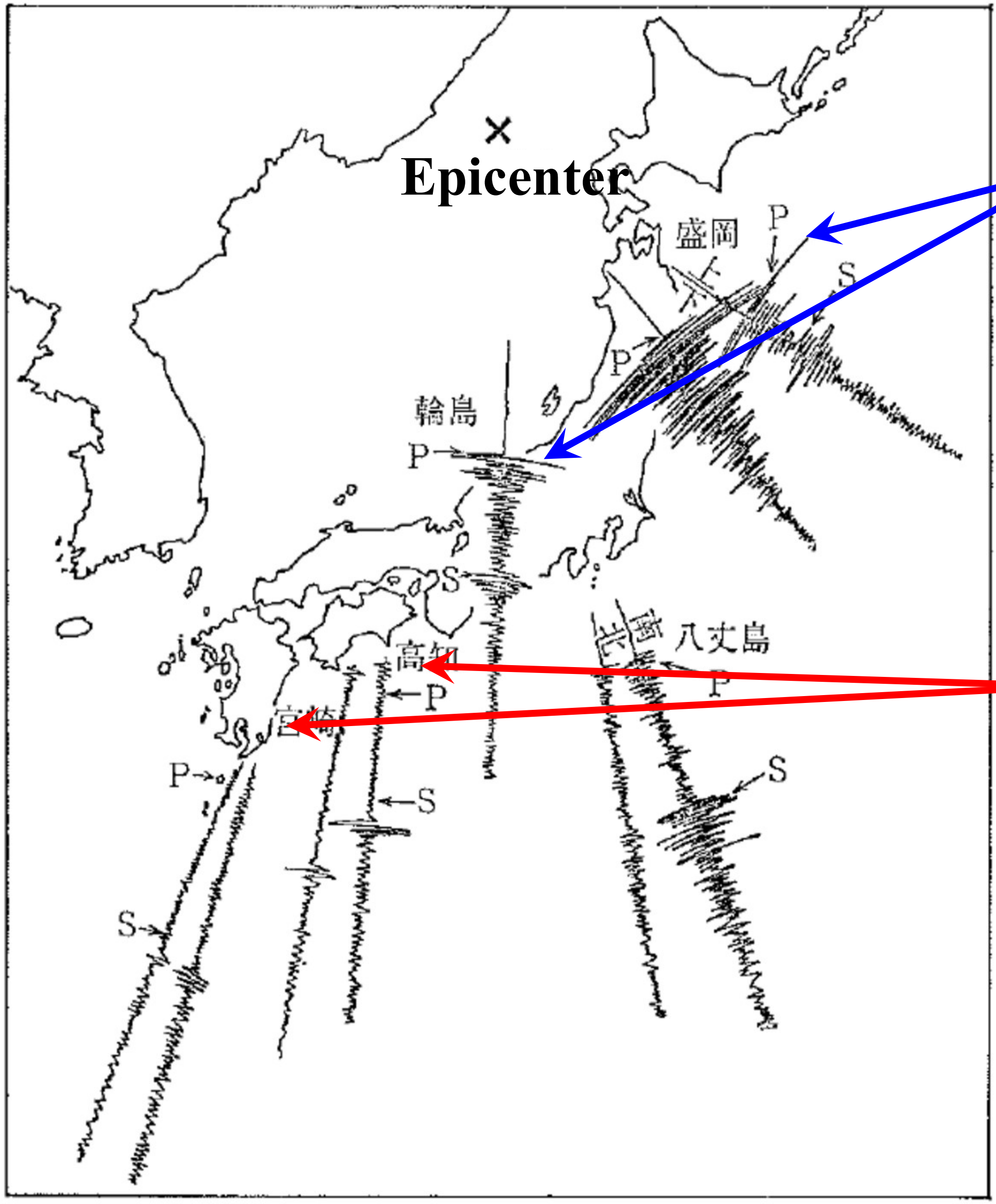


1) Observed results

Right lateral Strike slip faulting

Ground movements in the initial P-phase for the Central Shizuoka-prefecture Earthquake in Japan (1917, **M=6.3**). The source **depth was 20 – 30 km**. Symbols C (compression) ● & D (dilatation) ○ denote the upward & the downward initial P-pulses respectively.

After Utsu 2001, Shida 1917



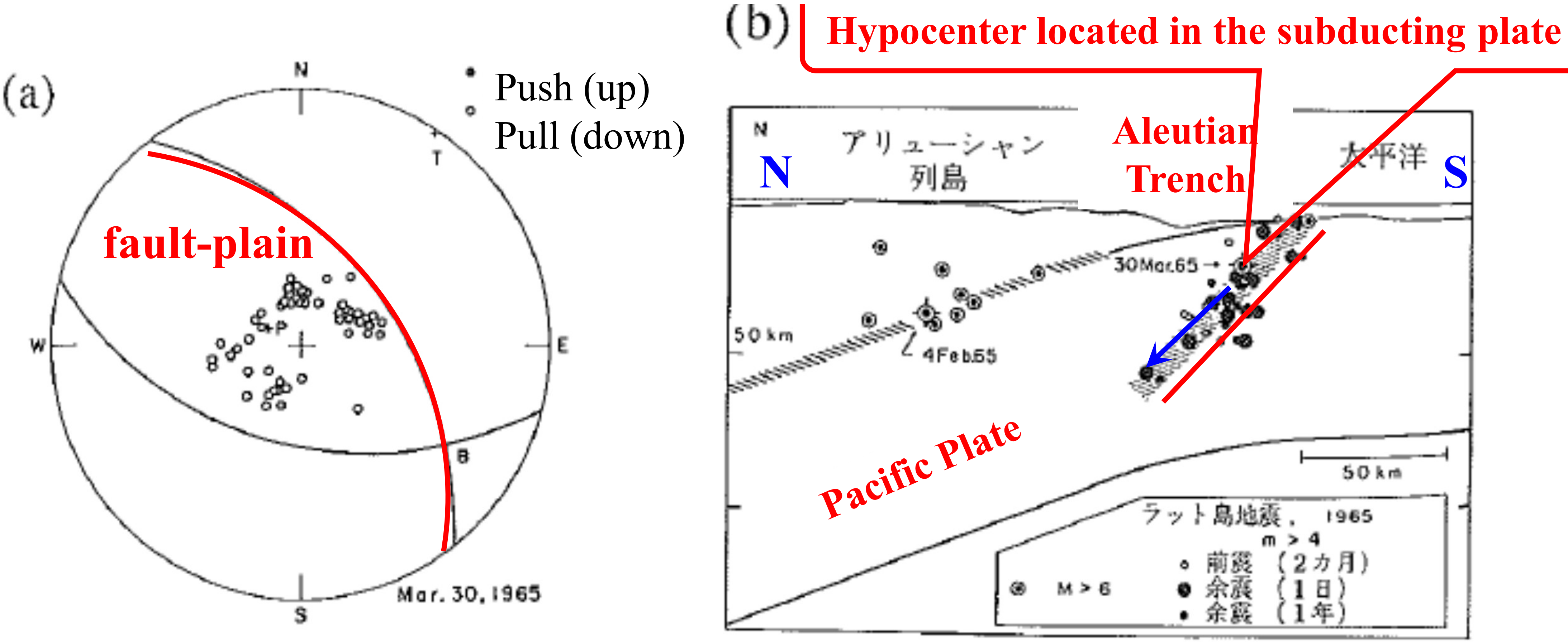
1) Observed results

Stations away from the nodal plane; the amplitude of P-phase is large.

Stations near to the nodal plane; the amplitude of P-phase is slight.

Deep earthquake 13Nov, 1932

After Honda 1977



Example of focal mechanism (Abe 1972) after Seno 1995
(a) 1965 Rat Island earthquake M7.5, (b) Aftershock distribution cross section

1) Observed results

Contents of the self-training materials

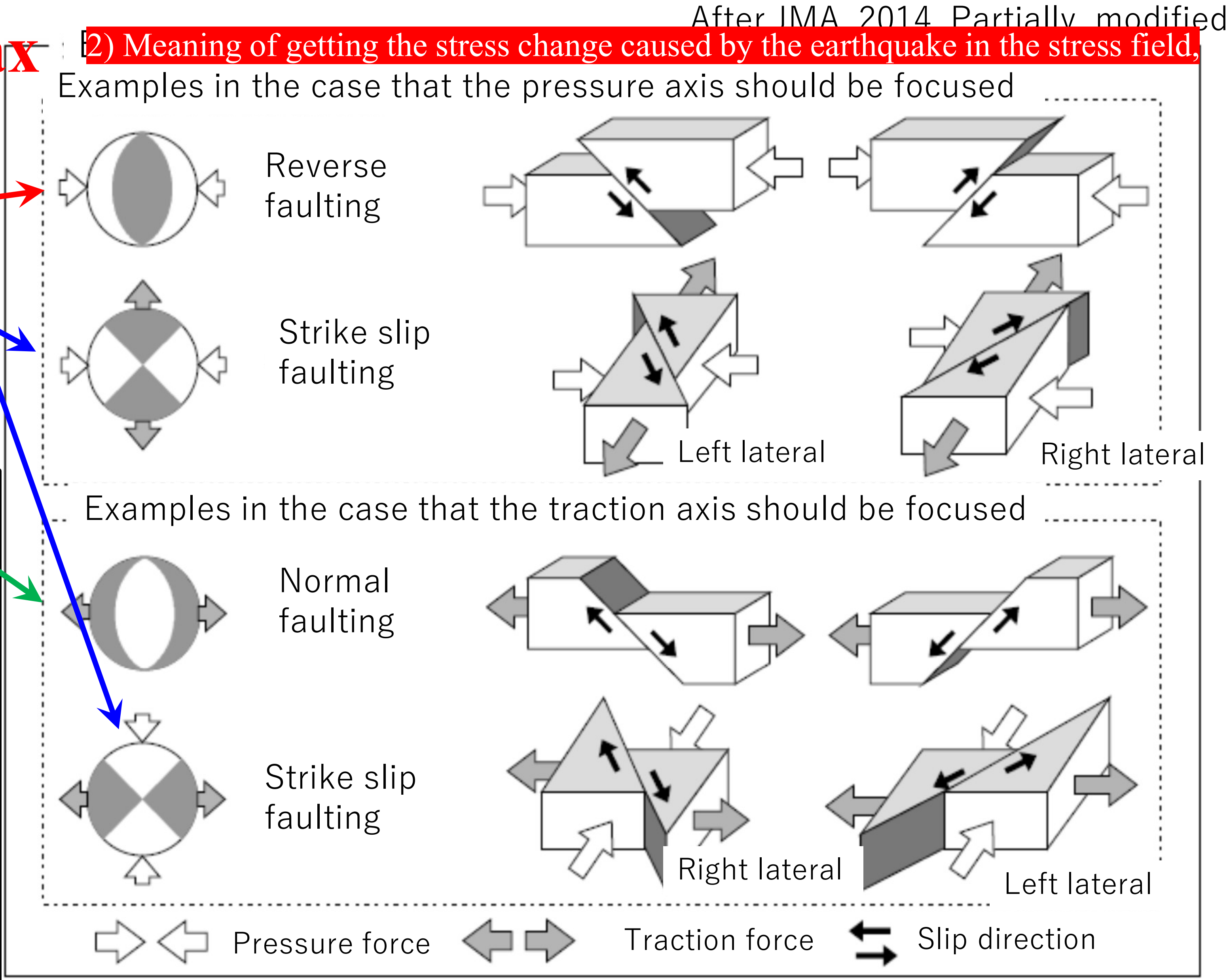
1) **Observed results**,
2) Meaning of getting the **stress change** caused by the earthquake in the stress field,
3) **Nodal plane of the earthquake** obtained from the push-pull distribution of the P-wave initial motion,
4) **Initial motion focal mechanism** explaining the released force at the point of the hypocenter,
5) **Double couple forces** (quadrant type of focal mechanism).

Directions of max & mini stresses

$\sigma_v < \sigma_H$

$\sigma_{Hmin} < \sigma_v < \sigma_{Hmax}$

$\sigma_H < \sigma_v$



Legend

Stress

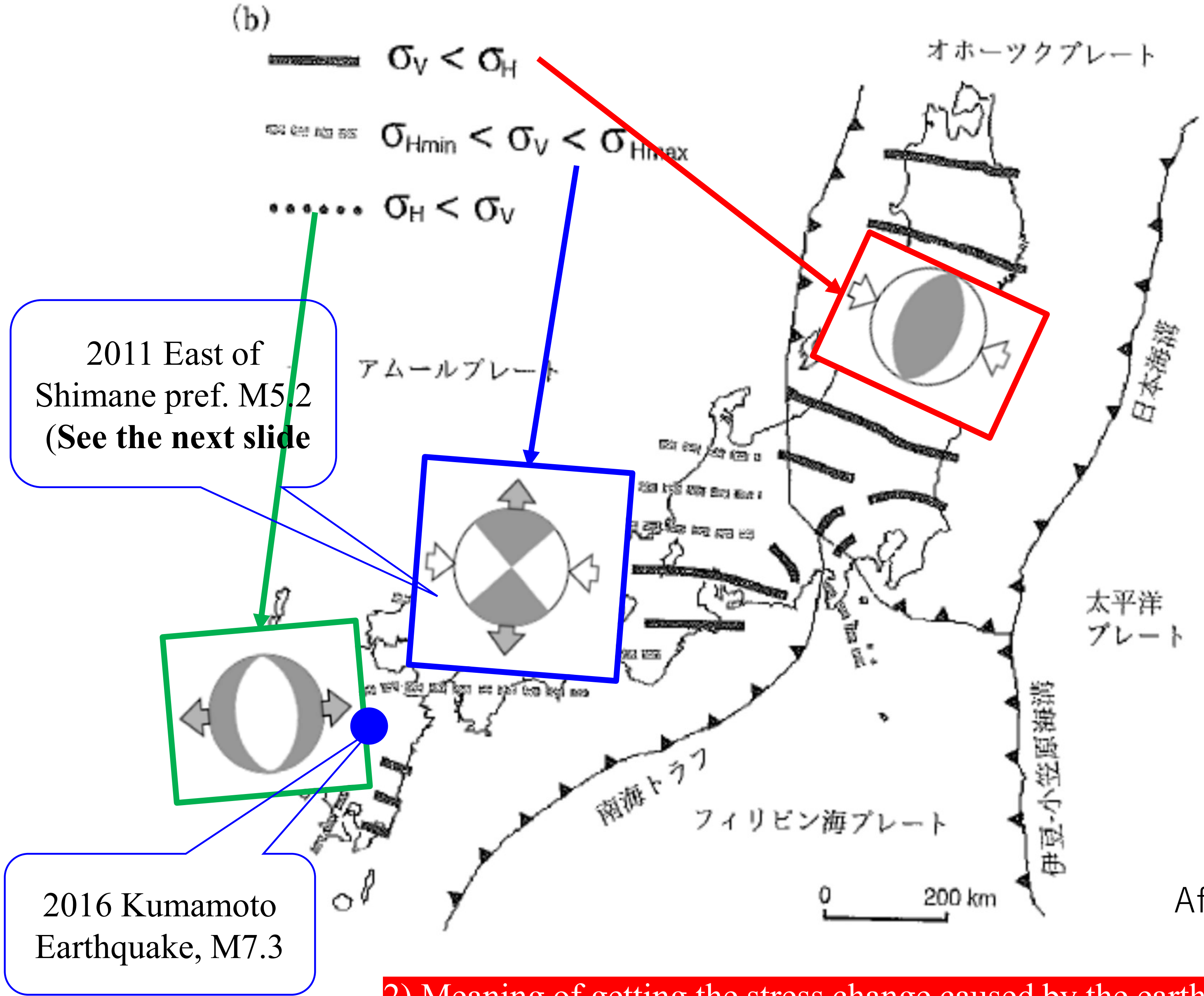
σ_v: Vertical

σ_H: Horizontal

σ_{Hmin}: Horizontal Minimum

σ_{Hmax}: Horizontal Maximum

Wide area stress field in Japan



<u>Legend</u>

Stress

σ_v: Vertical

σ_H: Horizontal

σ_{Hmin}: Horizontal Minimum

σ_{Hmax}: Horizontal Maximum

After Seno 2001, partially modified

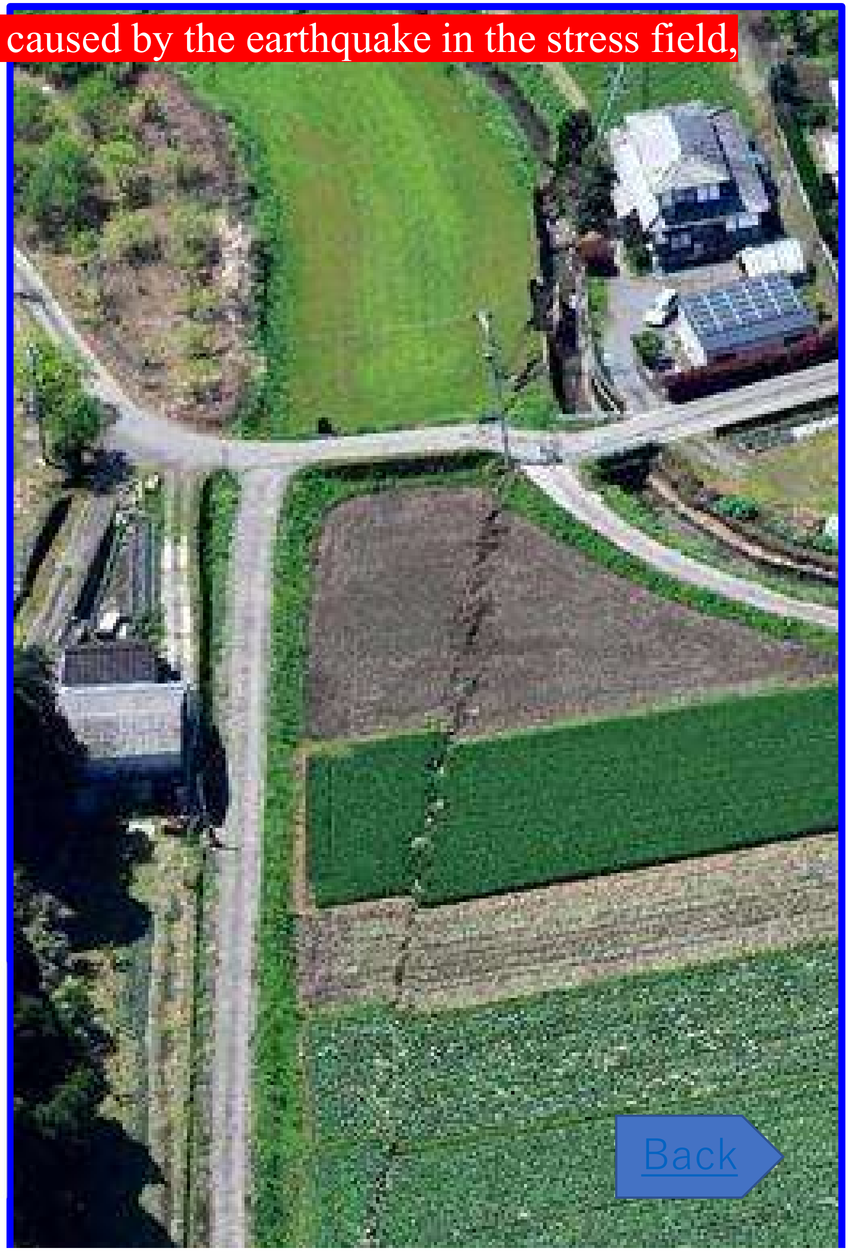
2) Meaning of getting the stress change caused by the earthquake in the stress field,

2) Meaning of getting the stress change caused by the earthquake in the stress field,

Right-lateral break about 2m made by the 2016 Kumamoto Earthquake, M7.3

The exact place is not clarified.

© 産経新聞 提供　断層と見られる亀裂＝１７日午前１１時５１分、熊本県益城町（本社ヘリから）



http://www.static.jishin.go.jp/resource/monthly/2016/2016_kumamoto_2.pdf

Back

Contents of the self-training materials

1) **Observed results**,
2) Meaning of getting the **stress change** caused by the earthquake in the stress field,
3) **Nodal plane of the earthquake** obtained from the push-pull distribution of the P-wave initial motion,
4) **Initial motion focal mechanism** explaining the released force at the point of the hypocenter,
5) **Double couple forces** (quadrant type of focal mechanism).

3) **Nodal plane of the earthquake** is obtained from the push-pull distribution of the P-wave initial motion.

Steps of initial motion focal mechanism analysis

Step1 Defining the fault-orientation parameters

Step2 Drawing a focal sphere after selecting the projection type from "the equal area" and "the stereographic"

Step 3 Plotting the initial motion data with black (up, push) & white (down, pull) on the plain after selecting the hemisphere from upper and lower

Step 4 Drawing the nodal plains (lines) based on the black & the white distribution

Essential issues
for getting the initial motion focal mechanism

1. We consider only 1) the **far field** term and 2) the **dynamic displacement**.

2. We assume the **double couple forces** that is equivalent to the **Stress field.**

3. We can see only **the start of earthquake** phenomenon; namely, we can get information on the released stress that has influenced the hypocenter surroundings only.

In order to identify **the focal plane** from two planes, we should get the **distribution of the aftershocks** that occurred during several hours just after occurrence of the mainshock.

3) **Nodal plane of the earthquake** is obtained from the push-pull distribution of the P-wave initial motion.

<u>Step1</u> Defining the fault-orientation parameters

The figure 1 defines the event source parameters.

Figure 1 Definition of the fault-orientation parameters (its strike and dip)

Strike ϕ_s, its direction is measured clockwise round from north, with the fault dipping down to the right of the strike direction: $0 \leqq \phi_s < 2\pi$

Dip δ, its direction is measured down from the horizontal: $0 \leqq \delta < \pi/2$

Rake λ, the angle between strike direction and slip is measured anti-clockwise round from horizontal on the surface of the foot wall $-\pi < \lambda \leqq \pi$

(After Aki & Richard 1980)

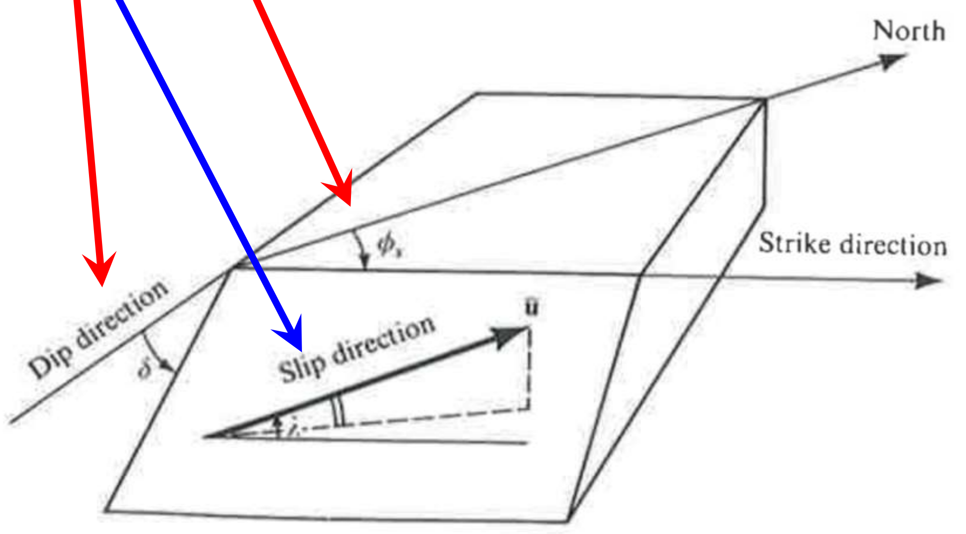


FIGURE **4.13**

Definition of the fault-orientation parameters (strike ϕ_S, dip δ), and slip-direction. ϕ_S is measured clockwise round from north, with the fault dipping down to the right of the strike direction: $0 \leq \phi_S < 2\pi$. δ is measured down from the horizontal: $0 \leq \delta \leq \pi/2$.

The fault has two surfaces. The surface illustrated is the surface of *the foot wall*. The other surface is known as *the hanging wall*.

Step2 Drawing a focal sphere 1/3

Mapping point P to the point P' by the stereographic projection

Figure a: Shown here is a vertical plane through the center of the focal sphere and the point P.
Figure b: A plan view of the horizontal plane viewed on edge in Figure a. (After Aki & Richard 1980)

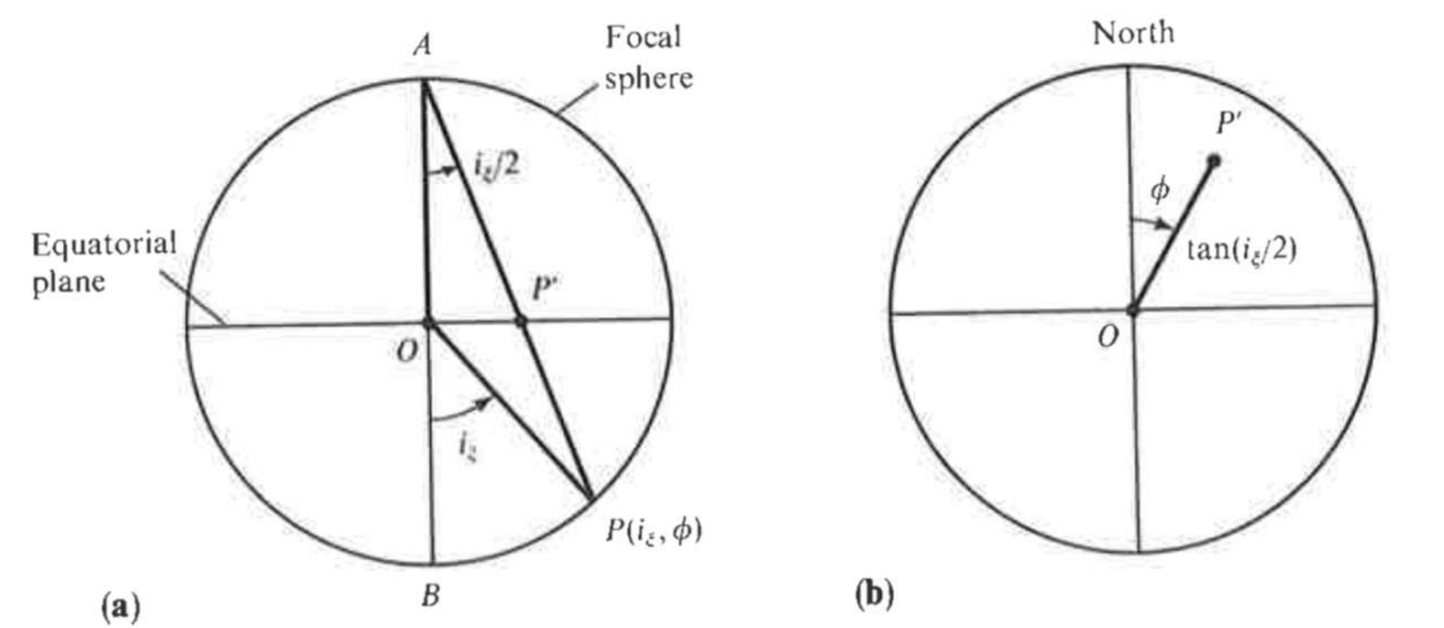


FIGURE 4.16

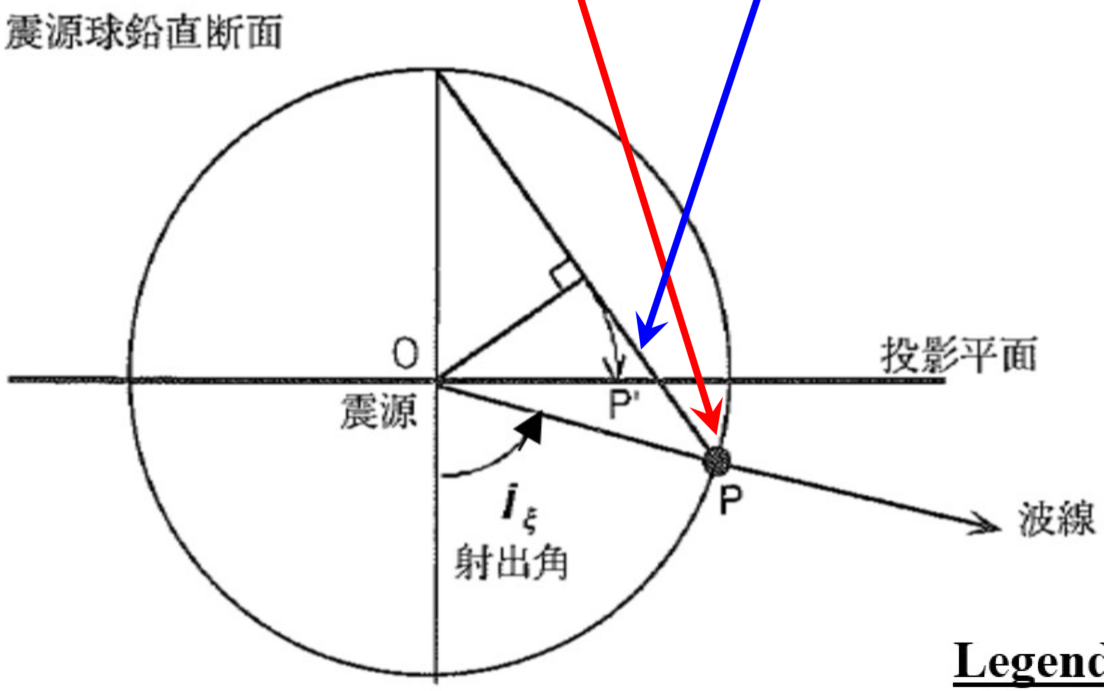
Note: The stereographic projection had been used mainly until 1957. Currently the equal area projection has been normally used.

Legend

O-P': $\tan(i_\xi/2)$ according to the stereographic projection

Step2 Drawing a focal sphere 2/3

Mapping the point P to the point P' equal area projection



Cross section of focal sphere

Mapping point P (i_ξ , ϕ) in the lower hemisphere to the point P' by **the (Lambert) equal area projection** of the focal sphere in the equatoria (projection) plane of the foc sphere

(After Seno 1995)

Legend

震源：Hypocenter

投影面：the projection plain on the equatorial one

射出角：Take-off angle

波線: Seismic Ray

O-P': $\sin(i_\xi/2)$

Equal-Area-Projection = Lambert-Equal-Area-Projection = Schmidt-Lambert-Projection

Step2 Drawing a focal sphere 3/3

Note: As for the Lambert equal area projection

Put dS as an infinitesimal size area on the focal sphere, with 1 as its radius, at the angular ray coordinates (i_ξ, φ).

$dS = \sin i_\xi \ d\phi * d i_\xi$

Put dS' as the projection of dS on the projection plain in the equatorial one.

$dS' = \sin(i_\xi/2)\, d\phi * d(\sin(i_\xi/2))$

$= \sin(i_\xi/2)\, d\phi * (1/2) \cos(i_\xi/2)\, d i_\xi$

$= (1/2) \sin(i_\xi/2) * \cos(i_\xi/2)\, d\phi\, d i_\xi$

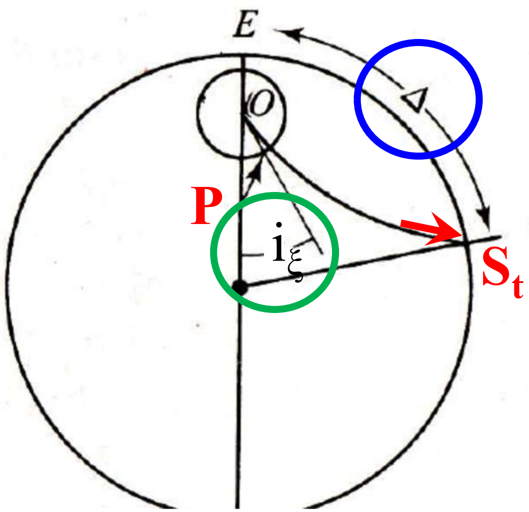
$= (1/2)^2 \sin(i_\xi)\, d\phi\, d i_\xi$

$dS' / dS = \sin i_\xi \ d\phi * d i = (1/2)^2$

So, dS area can be mapped into the new area, dS', with a reduction by the constant factor 1/4.

Step3 **Plotting the initial motion data on the plain 1/6**

Let us surround the focus with a unit sphere, **the focal sphere.** A seismic ray reaching the station S_t takes off the sphere with a taking-off angle, i_ξ, which is a function of the epicentral distance Δ. We assign P on the focal sphere with the polarity of the initial P-phase as observed at the S_t, then the P represents the data at S_t.

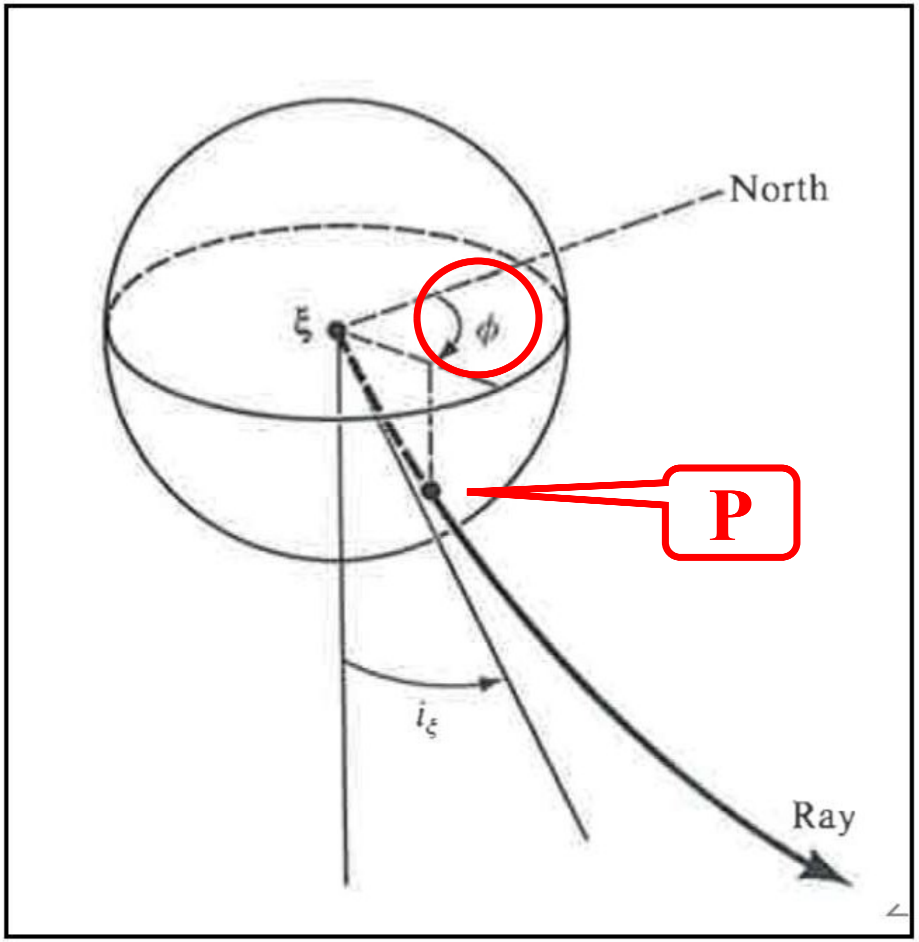


Left figure: Seismic ray in the earth (from O to S_t) and a focal sphere (small circle). O is the hypocenter, E is the epicenter, and P represents the projection of S_t on the surface of the focal sphere. Note that a seismic ray is drawn as concave rather than as a straight line, because the velocity of seismic waves generally increase with depth in the earth. (After Kasahara 1981)

Step3 Plotting the initial motion data on the plain 2/6

Below figure shows angular ray coordinates of **the point P** for displaying radiation.

Figure 2 Focal sphere for a seismic point source



The sphere is centered on the source and having arbitrarily small radius. The focal sphere is a convenient device for displaying radiation patterns, since information recorded by seismometers may be transferred to the focal sphere; this involves tracing the ray back from receiver to source and seeing where it intersects the focal sphere.

Equivalently one may specify a point on the focal sphere by angular ray coordinates (i_ξ, ϕ). **P**

Legend

i_ξ, measured up from the downward; $0 \leqq i_\xi < \pi/2$

ϕ, measured clockwise round from north; $0 \leqq \phi < 2\pi$

(After Aki & Richard 1980)

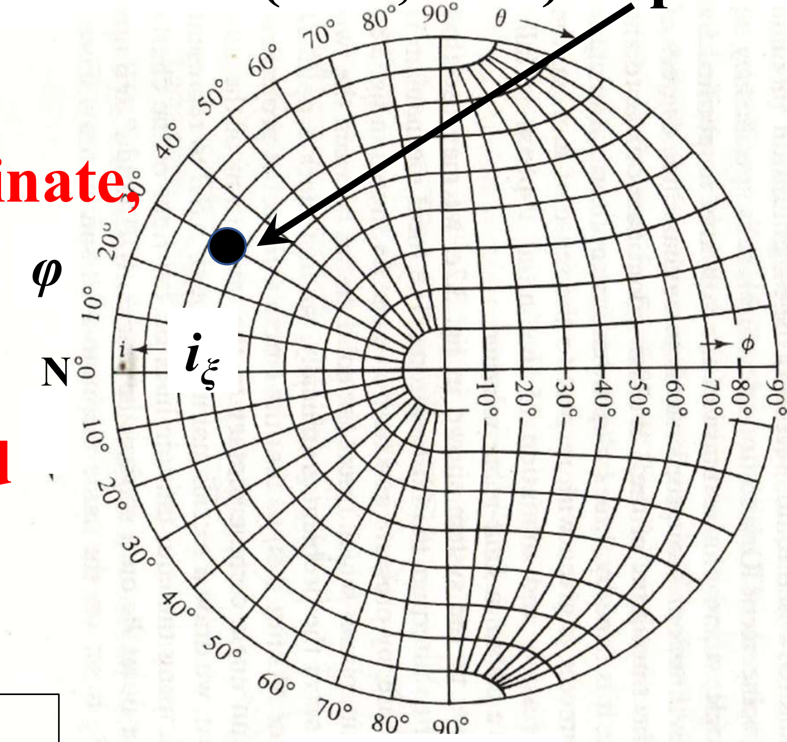
Step3 Plotting the initial motion data on the plain 3/6

In order to plot the data of a station on the projection plain on the equatorial one, we

1. **determine the azimuth φ and the epicentral distance Δ of the station**.
2. **use Δ and the focus depth h** and **determine the take-off angle i_ξ** from the focus for the initial P-phase through preparing the i_ξ-Δ-h relation.

4. **Plot each station datum at the appropriate coordinate, P (i_ξ,φ)** through using the left half of the Schmidt net. If a datum should appear in the other hemisphere, plot the datum at its antipode. The datum should be **plotted with solid black or with solid white**.

Ex. P (73.0, 30.0) "up"



Schmidt net

Note that the i_ξ-Δ-h relation can usually be found in **the travel time table.**

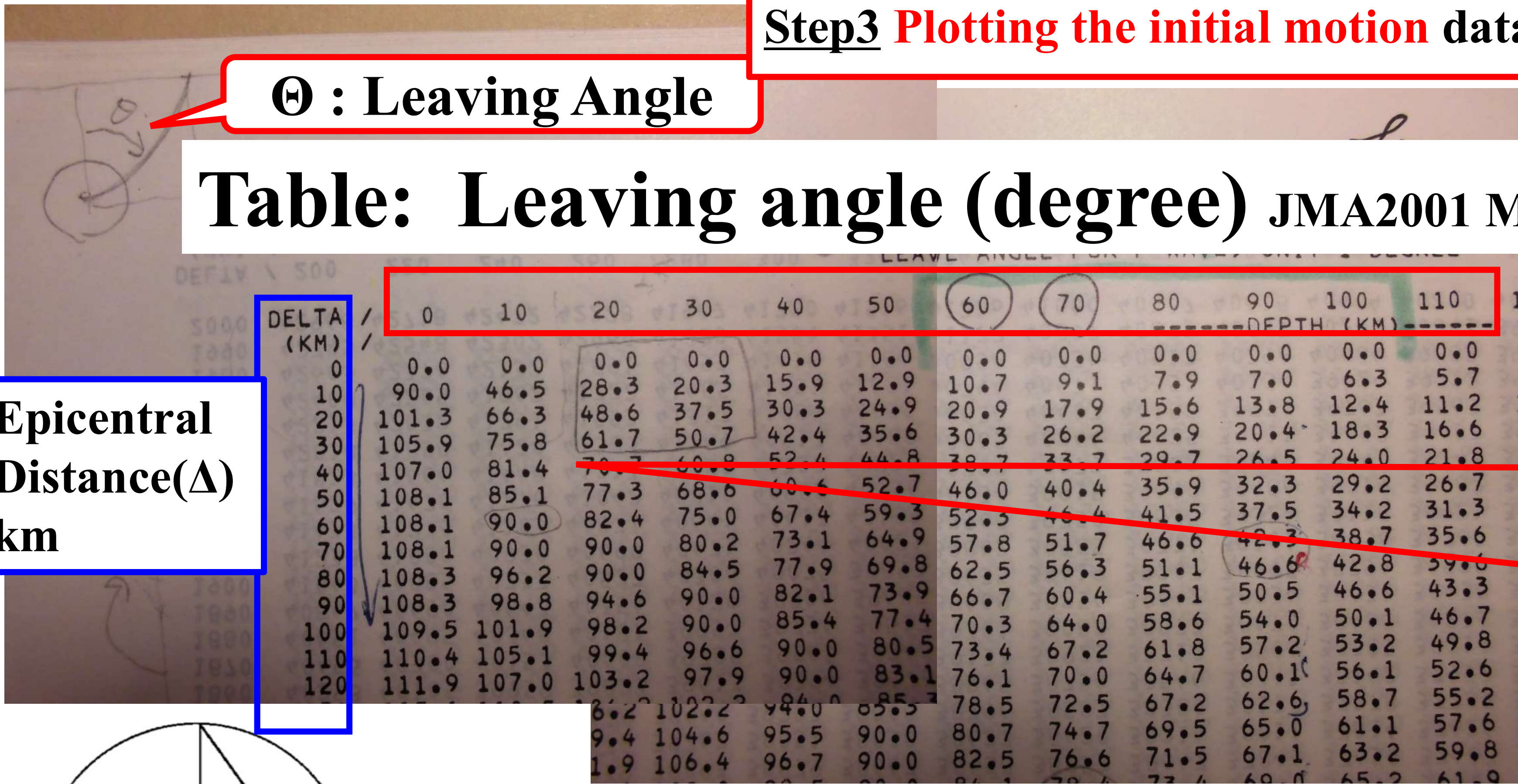
Step3 Plotting the initial motion data on the plain 4/6

Θ : Leaving Angle

Table: Leaving angle (degree) JMA2001 Model

Epicentral Distance(Δ) km

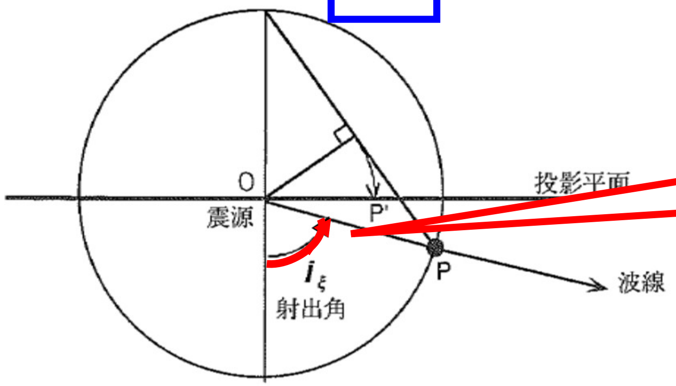
Depth km



LEAVE ANGLE FOR P WAVE, UNIT : DEGREE

DELTA (KM) /	0	10	20	30	40	50	60	70	80	90	100	110
						DEPTH (KM)						
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	90.0	46.5	28.3	20.3	15.9	12.9	10.7	9.1	7.9	7.0	6.3	5.7
20	101.3	66.3	48.6	37.5	30.3	24.9	20.9	17.9	15.6	13.8	12.4	11.2
30	105.9	75.8	61.7	50.7	42.4	35.6	30.3	26.2	22.9	20.4	18.3	16.6
40	107.0	81.4	70.7	60.8	52.4	44.8	38.7	33.7	29.7	26.5	24.0	21.8
50	108.1	85.1	77.3	68.6	60.6	52.7	46.0	40.4	35.9	32.3	29.2	26.7
60	108.1	90.0	82.4	75.0	67.4	59.3	52.3	46.4	41.5	37.5	34.2	31.3
70	108.1	90.0	90.0	80.2	73.1	64.9	57.8	51.7	46.6	42.3	38.7	35.6
80	108.3	96.2	90.0	84.5	77.9	69.8	62.5	56.3	51.1	46.6	42.8	39.6
90	108.3	98.8	94.6	90.0	82.1	73.9	66.7	60.4	55.1	50.5	46.6	43.3
100	109.5	101.9	98.2	90.0	85.4	77.4	70.3	64.0	58.6	54.0	50.1	46.7
110	110.4	105.1	99.4	96.6	90.0	80.5	73.4	67.2	61.8	57.2	53.2	49.8
120	111.9	107.0	103.2	97.9	90.0	83.1	76.1	70.0	64.7	60.1	56.1	52.6
	[illegible]	[illegible]	6.2	102.2	94.0	85.3	78.5	72.5	67.2	62.6	58.7	55.2
	[illegible]	[illegible]	9.4	104.6	95.5	90.0	80.7	74.7	69.5	65.0	61.1	57.6
	[illegible]	[illegible]	1.9	106.4	96.7	90.0	82.5	76.6	71.5	67.1	63.2	59.8

Ex. Δ 40km and Depth 10km give the leaving angle 81.4 degrees.



i_ξ: Take-0ff Angle

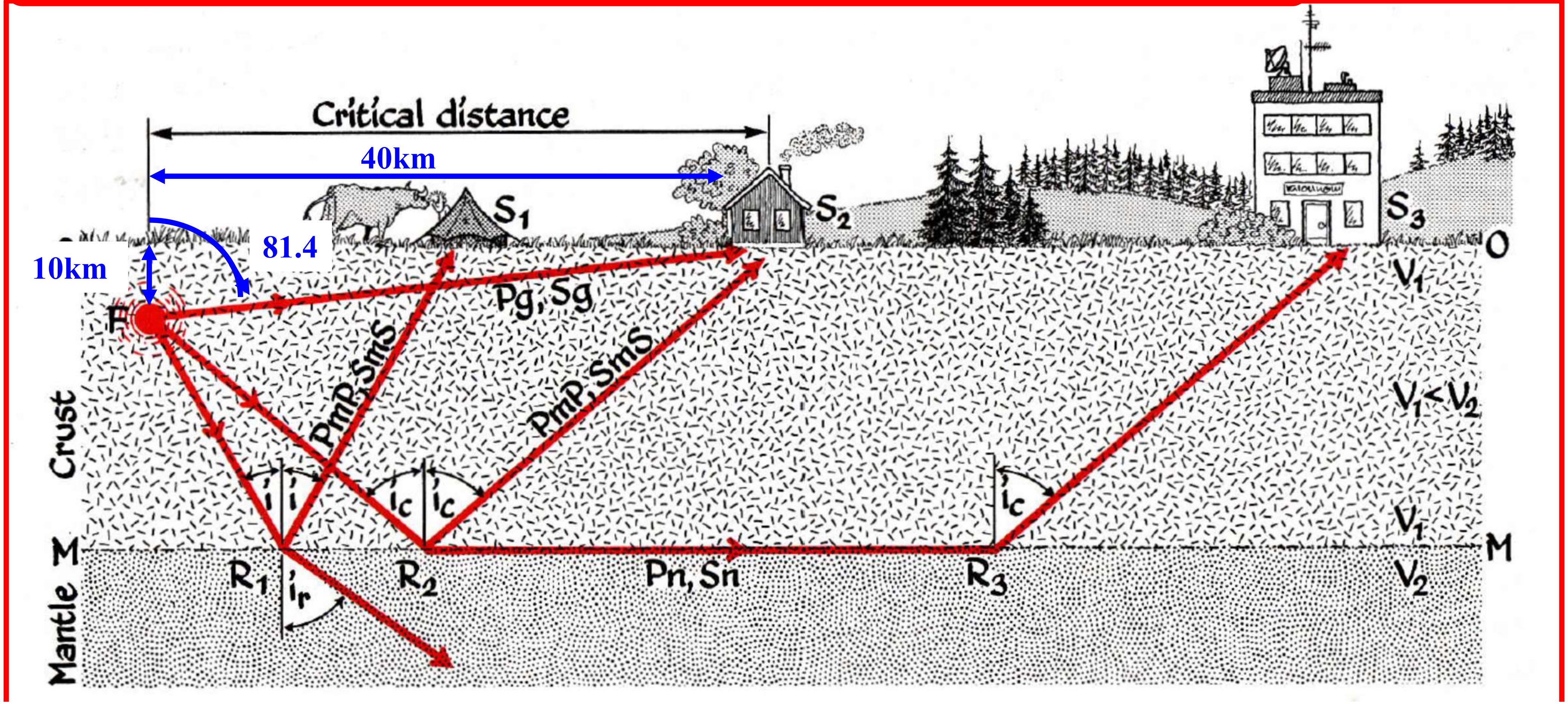
Take-off angle, i_ξ, or leaving one, Θ, is given with the hypocenter (the depth) and the station location (the distance).

Step3 Plotting the initial motion data on the plain 5/6

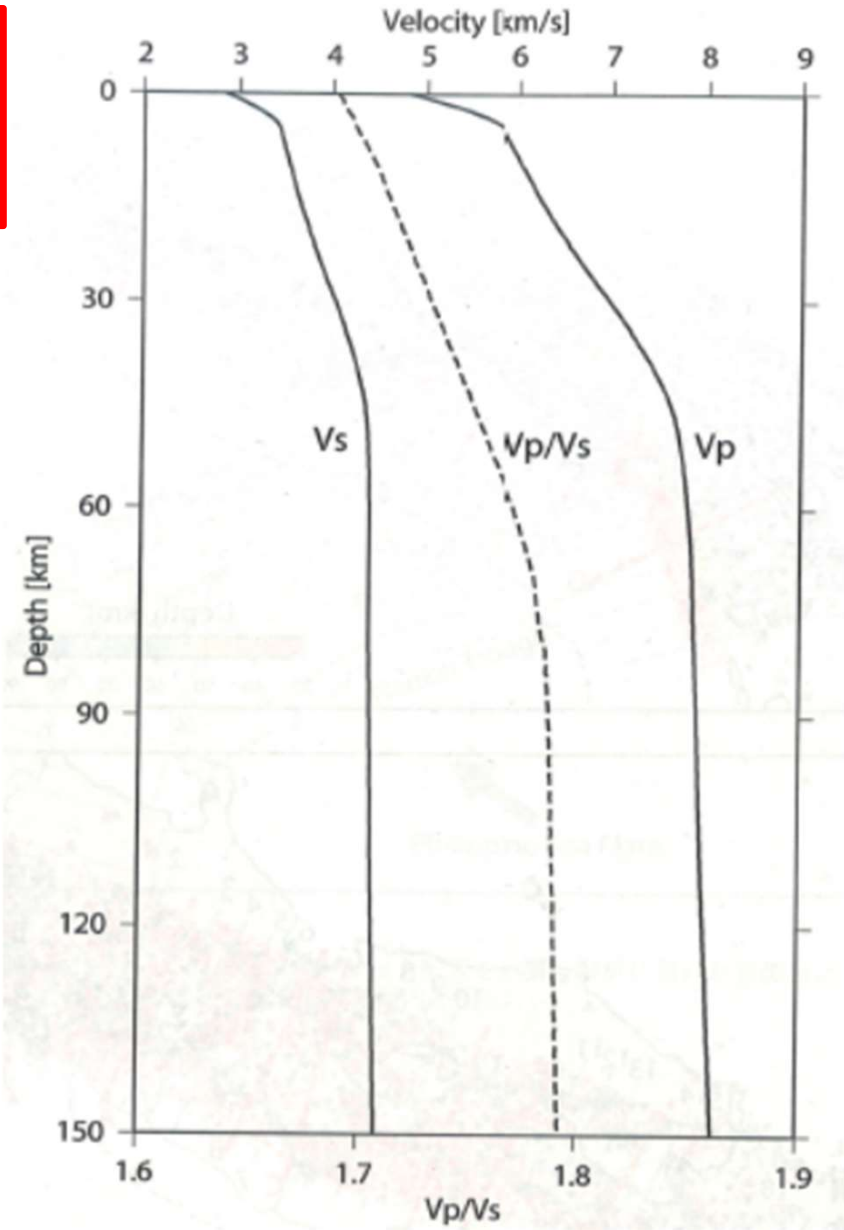
Wave propagation through a one-layer curst

(After Kulhánek 1990)

Ex. Δ 40km and Depth 10km give the leaving angle 81.4 degrees.



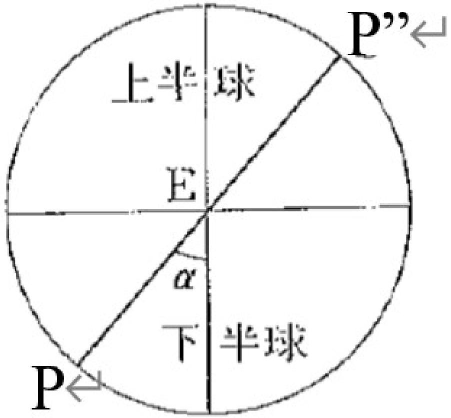
<u>Step3</u> Plotting the initial motion data on the plain 6/6

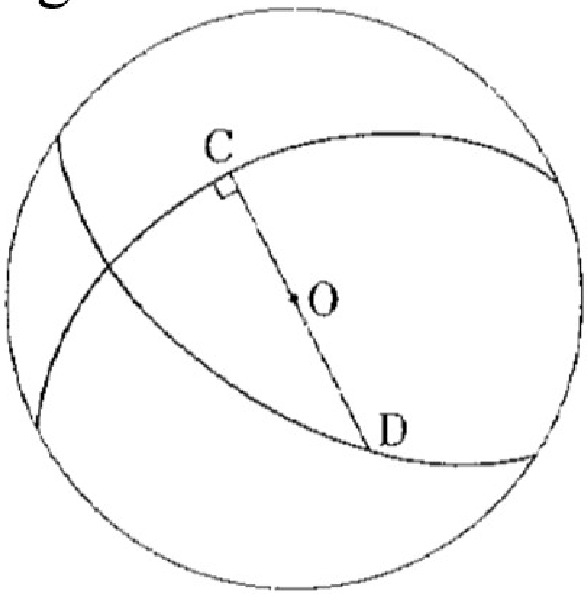


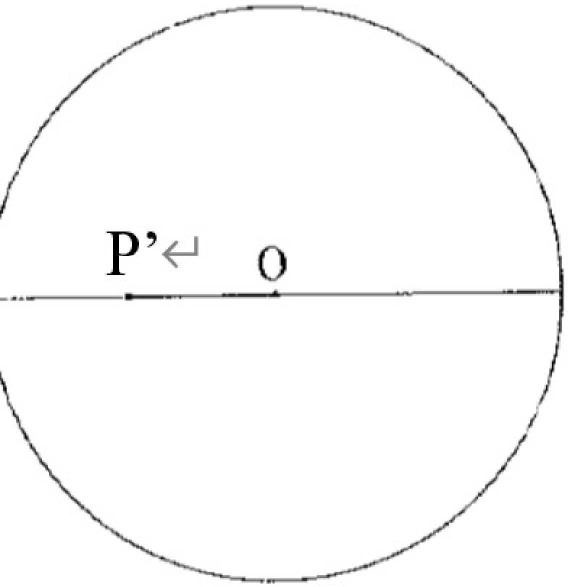
JMA2001 Model

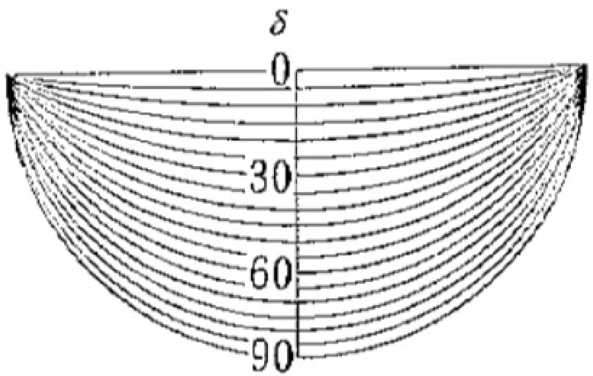
Step4 Drawing the nodal lines based on the push (black) & pull (white) distribution 1/5

$\alpha = i_\xi$ in Figure 2









See the next slide.

Left upper figure: the vertical plane through the center, E, of the focal sphere and the points. P is the same as the one in the figure 3.

Left lower figure: the projection plain. P' is the projection of P on the projection plain.

Right upper figure: the nodal lines depicted in the projection plain. The line with C should be one (δ=x radian) of the curbs in the right lower figure. Then D must be put on the curb of the δ of "π/2 – x" radian.

Right lower figure: the nodal lines to be selected according to the fault dip angle δ. (See the Step 1.) (After Utsu 2001)

Step4 Drawing the nodal lines 2/5

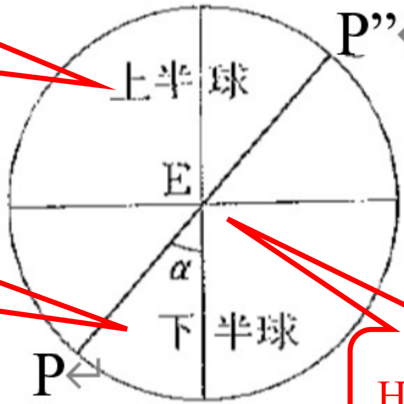
$\alpha = i_\xi$ in Figure 2

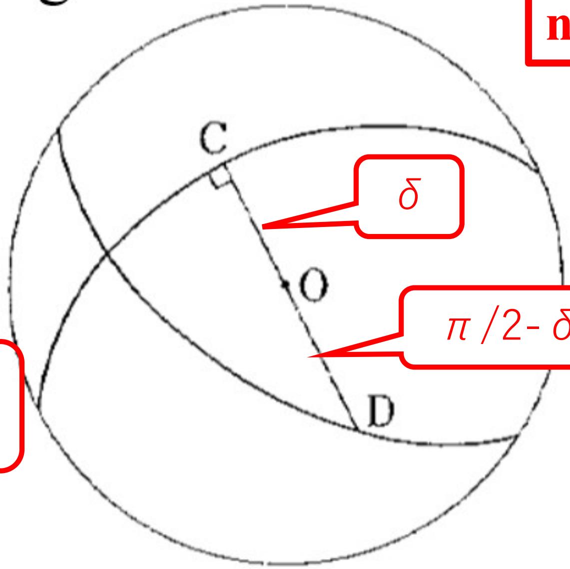
Cross section of focal sphere

Upper hemisphere

Lower hemisphere

Hypocenter



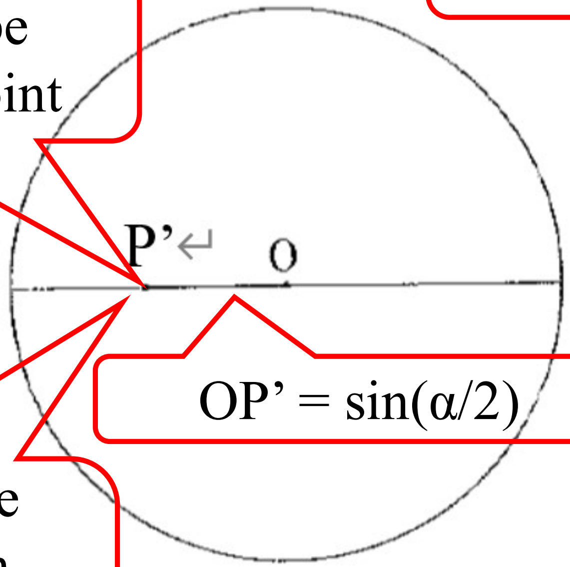


δ

$\pi/2-\delta$

One of the nodal planes is the fault plain, and the other is the auxiliary plane. In the left case, the plane with C is adopted as the former.

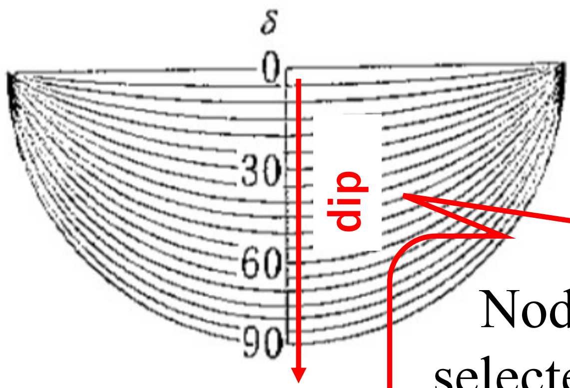
P point should be projected to P' point



OP' = sin(α/2)

P'' point should be projected through moving to the mirror point about E or P point.

Equal area projection



After Utsu, 2001

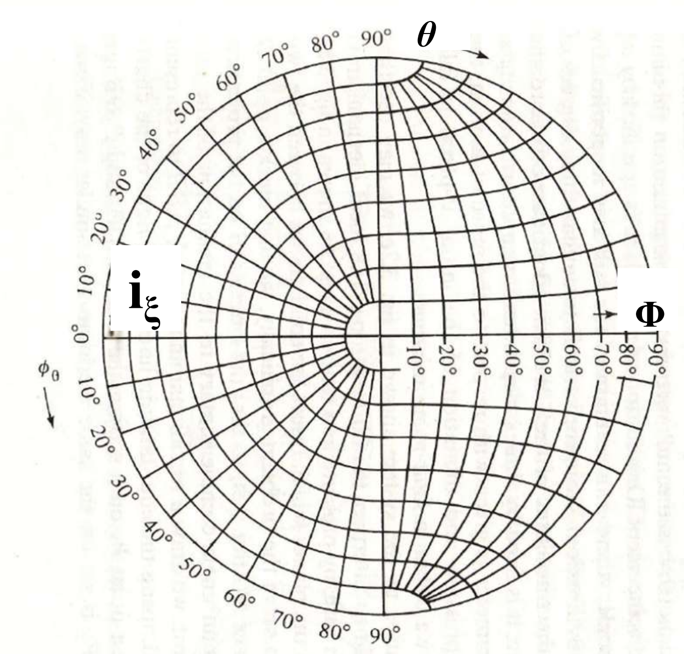
Nodal lines should be selected from these curbs. δ can be the dip of the fault.

Step4 **Drawing the nodal lines 3/5**

1. Through using the right half of the **Schmidt net**, trace the chosen meridian for one of the planes like the plane A in the figures (a) & (c) in **the next slide**. **The dip angle, θ_A, of plane A** from the **vertical** may now be read from the projection chart. Mark the middle point of the arc C and extend a line CO beyond O as shown in the figure (a).

2. Plot the point A on this extension so that the length of OA represents $90° - \theta_A$ from the vertical as shown in the figure (b) & (c) **in the next slide**. Then point A represents the pole of plane A.

3. Draw the second meridian passing through the pole A as a candidate of the nodal line B as shown in the figure (d) in **the next slide**.



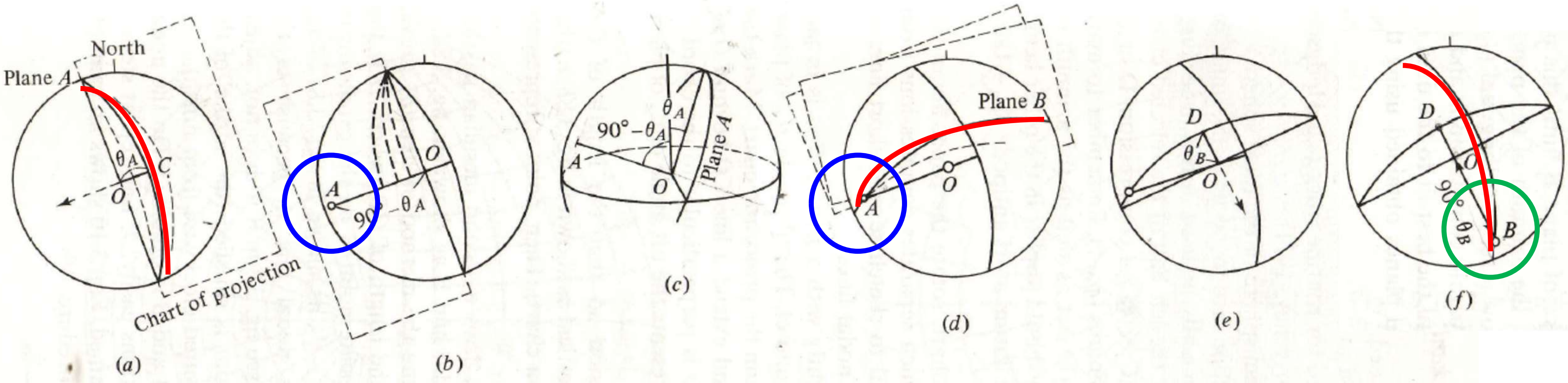
(a) Schmidt

Step4 **Drawing the nodal lines 4/5**

The procedure for mapping a fault plane diagram

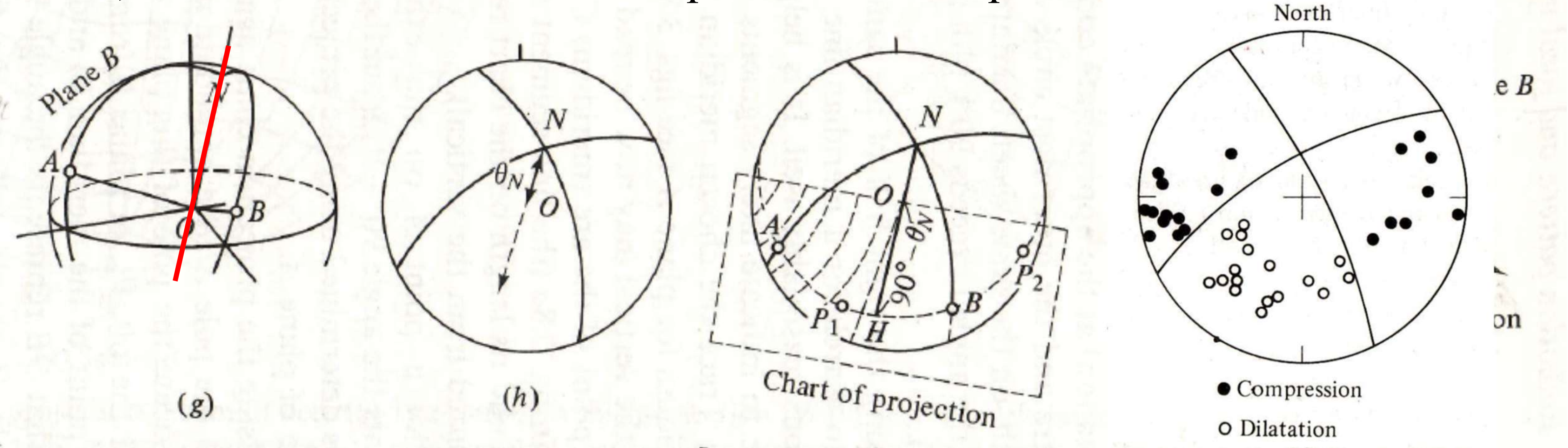
(After Kasahara 1981)

The basic rules for mapping the nodal lines (planes) are as follows:
1) They must lie on meridians of the projection net
2) If one of the planes is given like A in the figure (a), another plane like B in the figure (d) must contain the pole A, and vice versa, and must reasonably explain the observed polarities.



<u>Step4</u> Drawing the nodal lines 5/5

Locate the pole of this plane using the above method as shown in the figures (e) & (f) in **the previous slide**. **The pole B should fall on the first nodal line A**, because of the orthogonal relation of the two planes **(fig. (g)).** If it does not, adjust the strike of the of plane B until this constraint is satisfied. The line ON, where the two plane cross one another, is called the **Null Axis**, as the medium on this line experiences no displacement.



(i) (j) (After Kasahara 1981)

Contents of the self-training materials

1) **Observed results**,
2) Meaning of getting the **stress change** caused by the earthquake in the stress field,
3) **Nodal plane of the earthquake** obtained from the push-pull distribution of the P-wave initial motion,
4) **Initial motion focal mechanism** explaining the released force at the point of the hypocenter,
5) **Double couple forces** (quadrant type of focal mechanism).

4) Initial motion focal mechanism explaining the released force at the point of the hypocenter

Essential issues

for considering the relation between

focal mechanism & the stress field

1) Directions of maximum, minimum & intermediate stresses,

2) Internal Friction,

3) Not intact rocks like existence of active-faults,

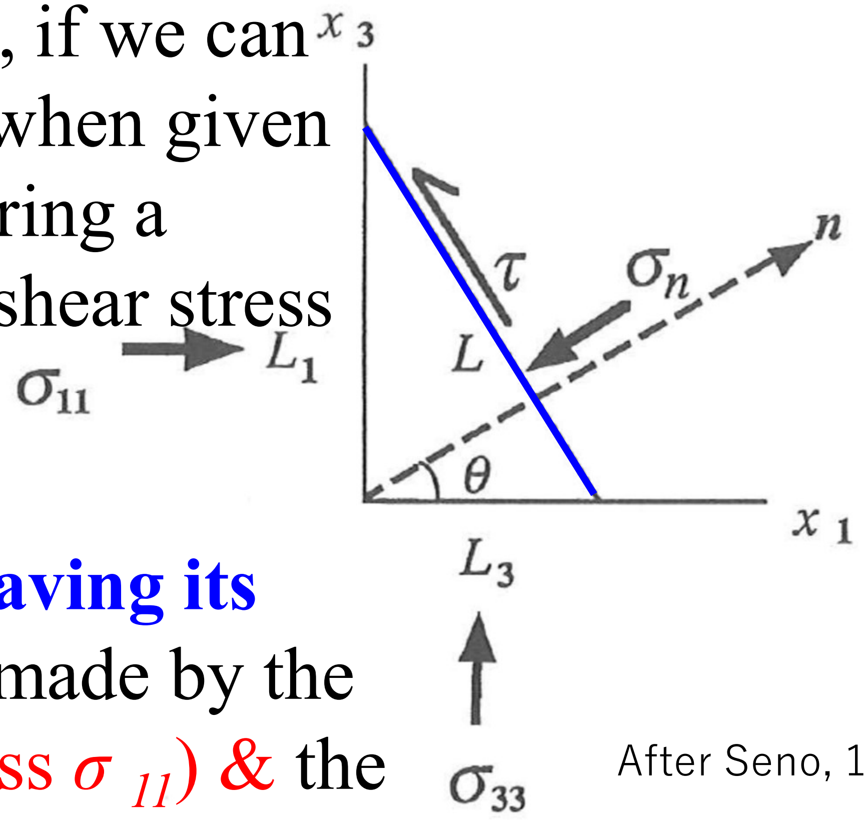
4) Existence of pore pressure,

5) Effect of occurrence of any near-distance-large-event (Thrust type and inland shallow type; Coulomb Failure Function (ΔCFF), induced earthquakes, temporal stress field changes).

Relation between Seismotectonics & the faulting

Earthquake is **a <u>shear</u> fracture or dislocation or** is generated by any **<u>shear stress</u> working on a plane or a fault <u>to break</u>**.

We can thus identify the plane to fracture, if we can calculate the shear stresses on any plane when given **three principal stresses** through considering a finite volume in rocks enduring until the shear stress becomes larger to achieve any critical amount like τ_s.



After Seno, 1995

In the figure, we **<u>consider the plane *L* having</u> its normal vector *n* direction** on the plane made by the maximum pressure axis x_1 (principal stress σ_{11}) & the minimum one x_3 (σ_{33}).

The three surface elements, ***L***, ***L_1***, and ***L_3*** get stresses that are balanced together.

The x_1 component of the balanced stresses have the below relation among them.

$$\sigma_{11}L_1 = \sigma_{11}L\cos\theta = \sigma_n\cos\theta L + \tau\sin\theta L$$

The x_3 component of the balanced stresses have the below relation among them.

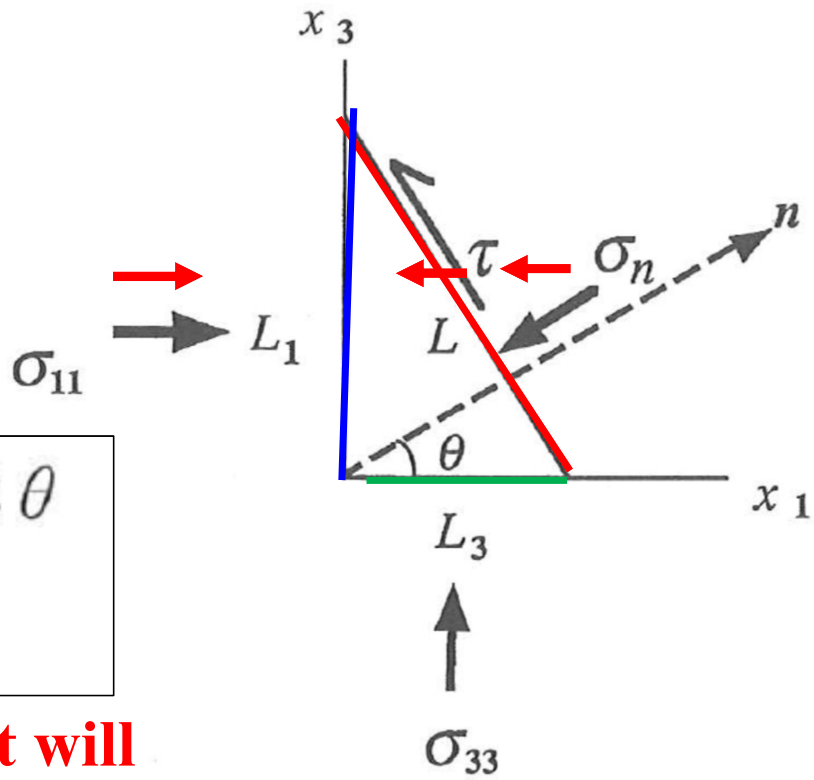
$$\sigma_{33}L_3 = \sigma_{33}L\sin\theta = \sigma_n\sin\theta L - \tau\cos\theta L$$

From the above formulae, we get the below:

$$\sigma_n = 1/2\cdot(\sigma_{11}+\sigma_{33}) + 1/2\cdot(\sigma_{11}-\sigma_{33})\cos 2\theta$$

$$\tau = 1/2\cdot(\sigma_{11}-\sigma_{33})\sin 2\theta$$

The formula for the shear stress *τ* shows that it will become maximum when *θ* is 45 degrees.



After Seno, 1995

Relation between the principal stress and the faulting

If there is no friction on the surface *L*, it will fracture when $\boldsymbol{\tau}$ becomes larger and reaches $\boldsymbol{\tau_s}$. But actual earth rocks usually have some **Internal Friction $\boldsymbol{\mu}$.** Then, we should consider the below formula for estimating the fracture condition.

$$\tau = \tau_0 + \mu\sigma_n$$

, where τ_0 is **the Coulomb Failure Function (CFF)** or the strength of the rock (sometimes called Cohesion) ,whch should be considered instead of $\boldsymbol{\tau_s}$.

$$\sigma_n = 1/2 \cdot (\sigma_{11} + \sigma_{33}) + 1/2 \cdot (\sigma_{11} - \sigma_{33}) \cos 2\theta$$

$$\tau = 1/2 \cdot (\sigma_{11} - \sigma_{33}) \sin 2\theta$$

$$(\sigma_n - \tfrac{1}{2} \cdot (\sigma_{11} + \sigma_{33}))^2 + \tau^2 = (\tfrac{1}{2} \cdot (\sigma_{11} - \sigma_{33}))^2$$

For the inland area of Japan, as the Coefficient of Internal Friction, 0.5-0.7 would be proper (by Odaka et al. 1997).

We should consider that $\boldsymbol{\tau}$ becomes larger according to $\boldsymbol{\sigma_n}$ enlargement with the **Internal Friction $\boldsymbol{\mu}$.** Then, we should consider the below figure. (Note that if $\boldsymbol{\mu}$ is zero, $\boldsymbol{\theta_s}$ is 45 degrees in the figure.) The red $\boldsymbol{\sigma_{11}}$ becomes larger and reaches the blue $\boldsymbol{\sigma_{11}}$; then the Circle does **the green line**, and a fracturing occurs in the rock.

$$(\sigma_n - \tfrac{1}{2} \cdot (\sigma_{11} + \sigma_{33}))^2 + \tau^2 = (\tfrac{1}{2} \cdot (\sigma_{11} - \sigma_{33}))^2$$

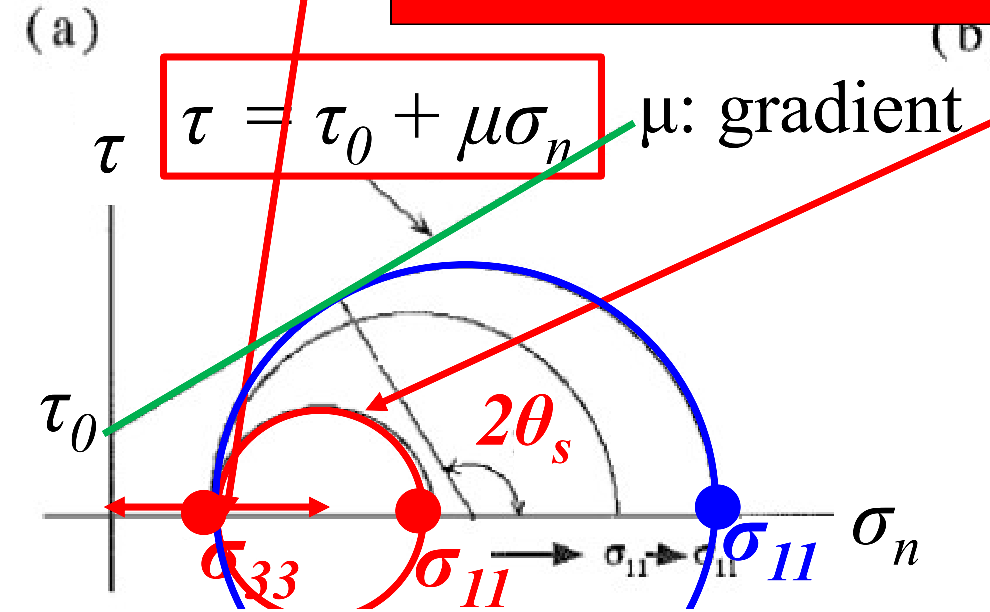
Mohr's Circle

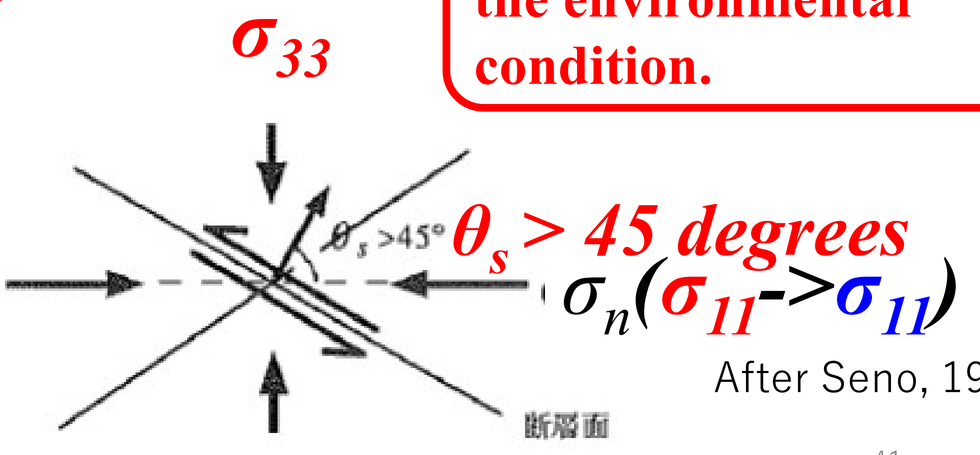
Mohr-Coulomb Failure

$$\tau = \tau_0 + \mu\sigma_n$$

μ: gradient

τ_0 and μ are given as the environmental condition.



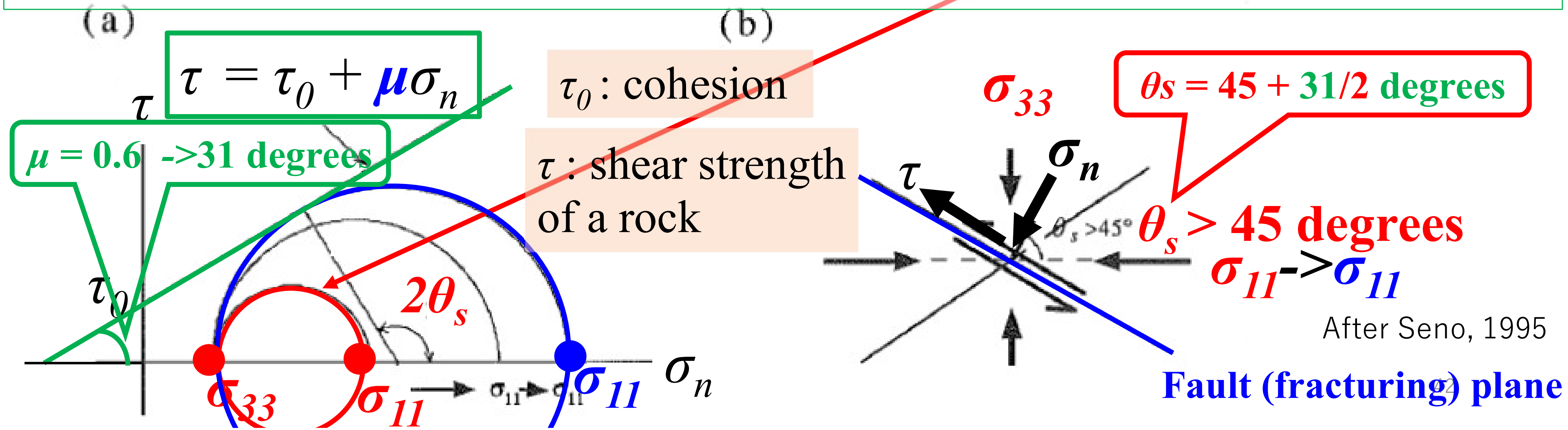


After Seno, 1995

Suppose that shear stress $\boldsymbol{\tau}$ becomes larger according to normal stress $\boldsymbol{\sigma_n}$ enlargement in the rock with **cohesion $\boldsymbol{\tau_0}$** & **internal friction $\boldsymbol{\mu}$** due to enlargement of stress difference (σ_{11}- σ_{33}). **Namely,** $\boldsymbol{\sigma_n}$ becomes gradually larger **from** the red $\boldsymbol{\sigma_{11}}$ to the blue $\boldsymbol{\sigma_{11}}$. Then the red circle becomes the blue circle. And the circle reaches and touches with **the green line**, which makes a fracturing in the rock.

Mohr's Circle

Mohr-Coulomb failure, Coulomb failure criterion, or Amonton Coulomb failure condition



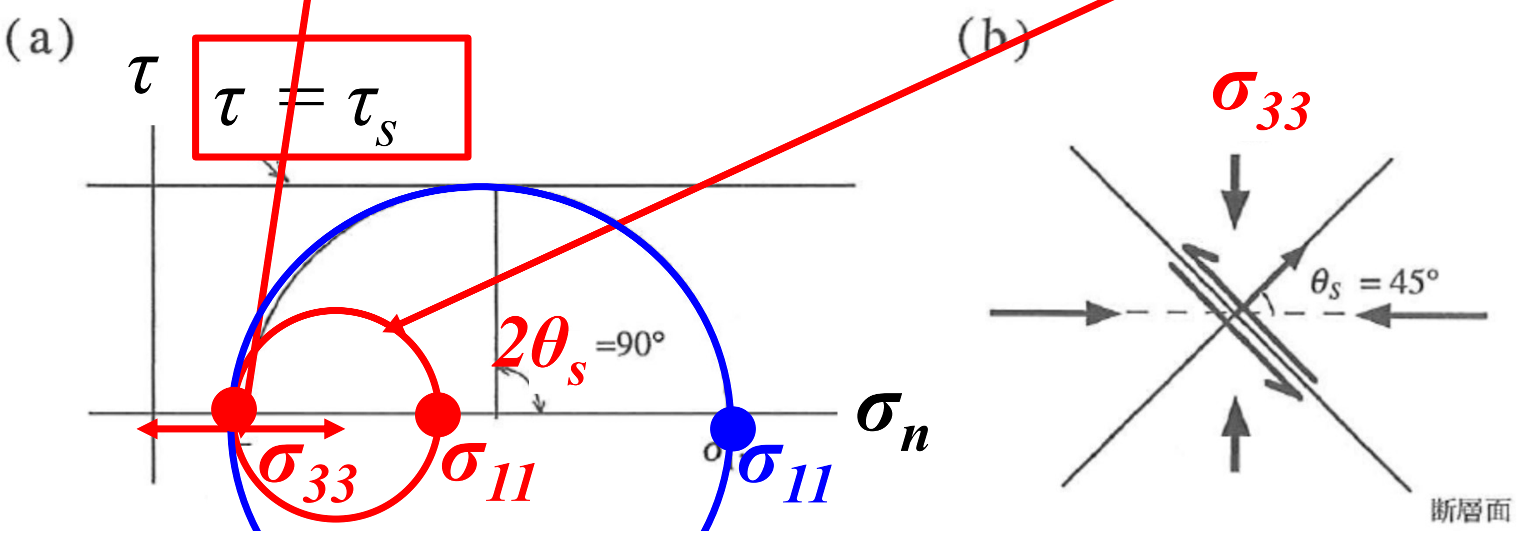
After Seno, 1995

In the case of no **Internal Friction or $\mu=0$**, we should consider the τ becomes larger and is getting at τ_s. Then, we should consider the below figure.

$$(\sigma_n - \tfrac{1}{2} \cdot (\sigma_{11} + \sigma_{33}))^2 + \tau^2 = (\tfrac{1}{2} \cdot (\sigma_{11} - \sigma_{33}))^2$$

Mohr's Circle

τ_s is given as the environmental condition.



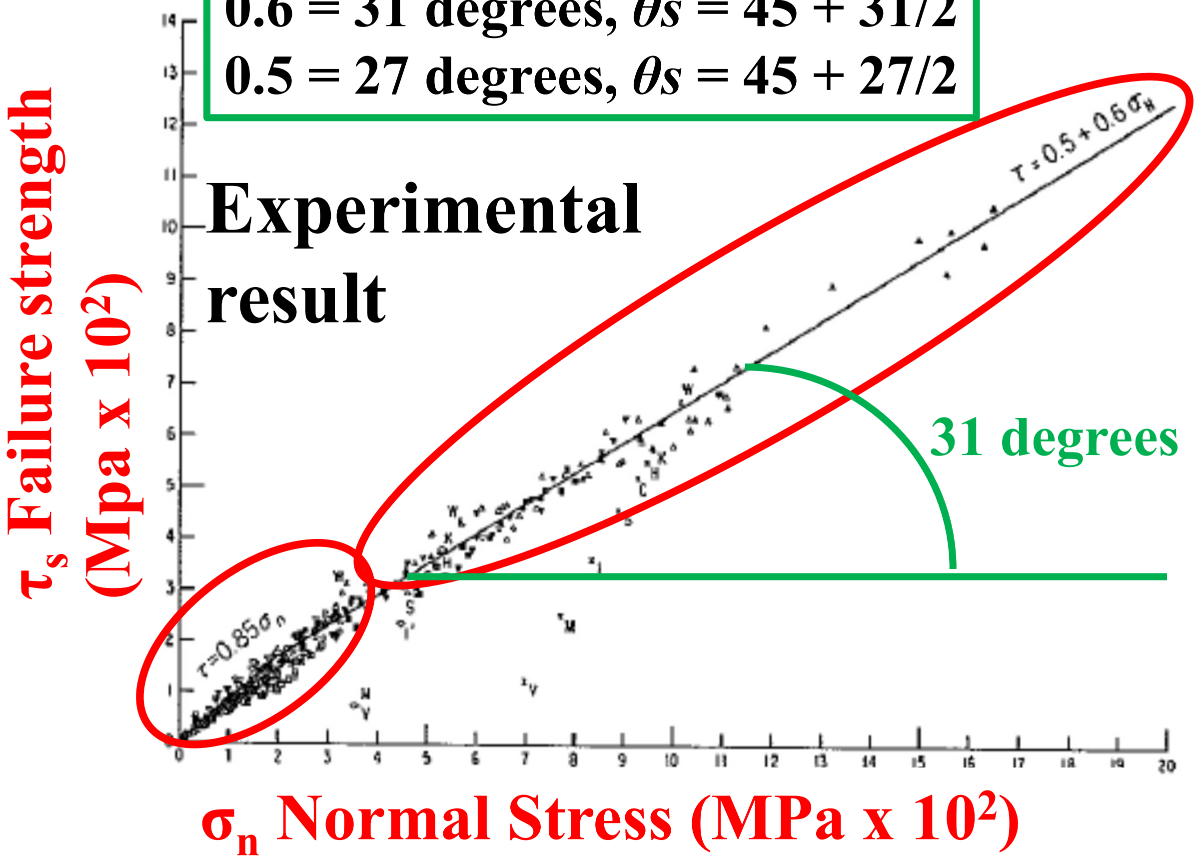
$\theta_s = 45$ ***degrees***

σ_n (σ_{11}->σ_{11})

After Seno, 1995

Coefficient of Internal Friction μ

Gradient μ
0.7 = 35 degrees, $\theta s = 45 + 35/2$
0.6 = 31 degrees, $\theta s = 45 + 31/2$
0.5 = 27 degrees, $\theta s = 45 + 27/2$



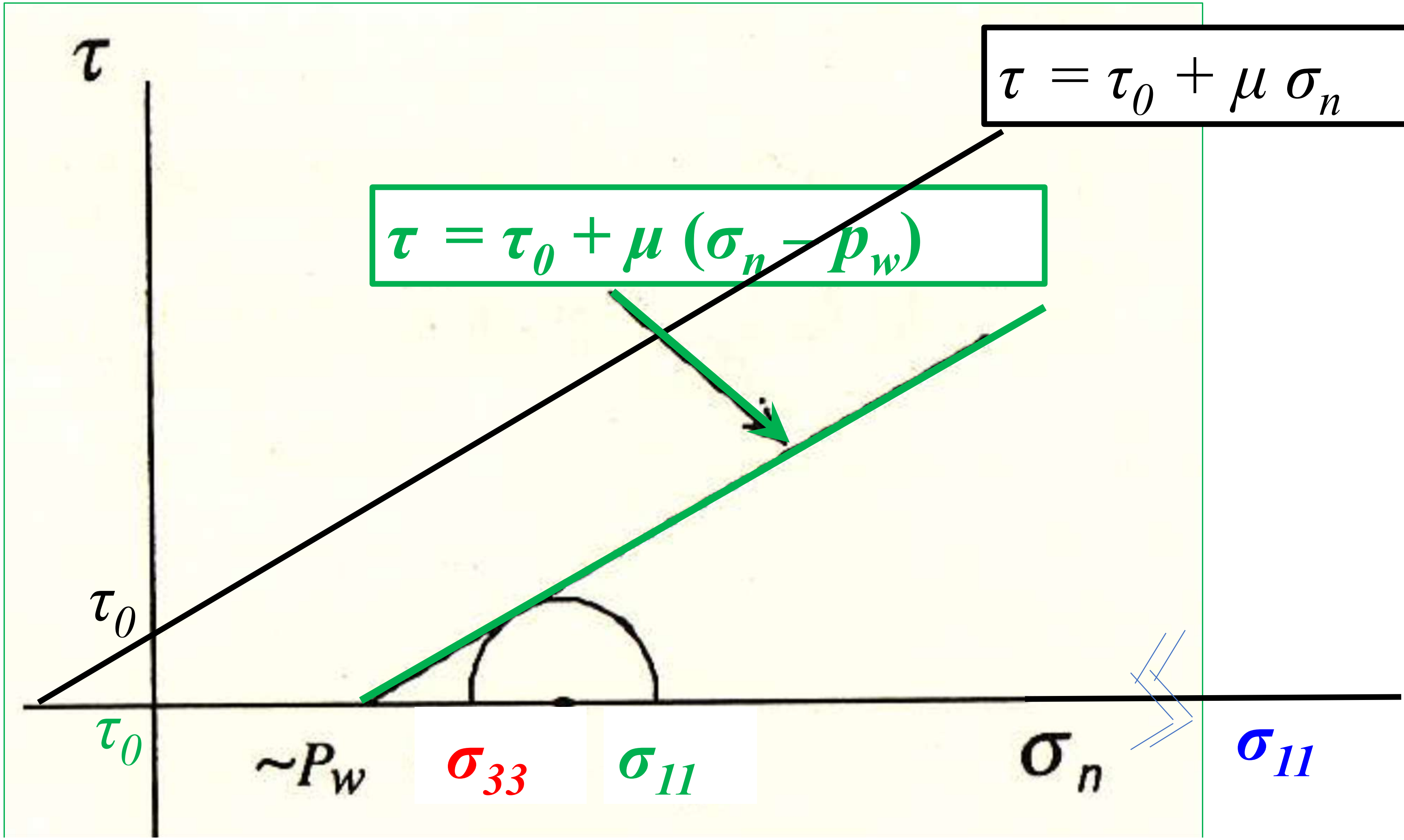
If $\sigma_n > 2 \times 10^2$ MPa,
$|\tau| = 0.5 + 0.6\sigma_n$ (10^2 x MPa)
If $\sigma_n < 2 \times 10^2$ MPa,
$|\tau| = 0.85\sigma_n$
Byerlee's law: If σ_n is approximately equal to the overburden pressure, the upper equation is valid for all depths greater than about 6 km.
(After Byerlee 1978 shown in Lay & Wallace 1995)

As for the inland area of Japan, the μ would be 0.5-0.7 (by Odaka et al. 1997).

After Seno 1995

https://www.jstage.jst.go.jp/article/mripapers/48/2/48_2_41/_article

In the case of existence of pore pressure p_w, we should consider the below figure.

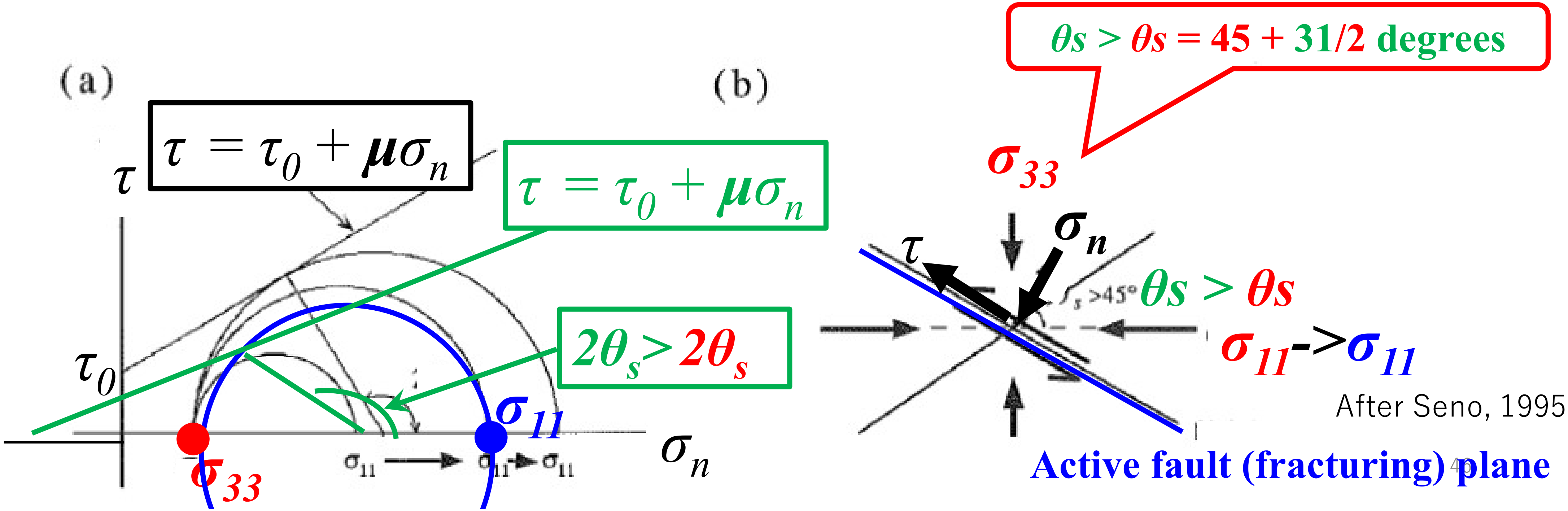


After Seno, 1995

In the case that

a) most of the area has **cohesion τ_0** & **internal friction μ** & **additionally**

b) the area has an **active-fault" with smaller "τ_0 & μ"** ***and large θ_s of the existing "fracturing" plane.*** Then, we should consider the below figure.



Consider an area, where

Most of the area

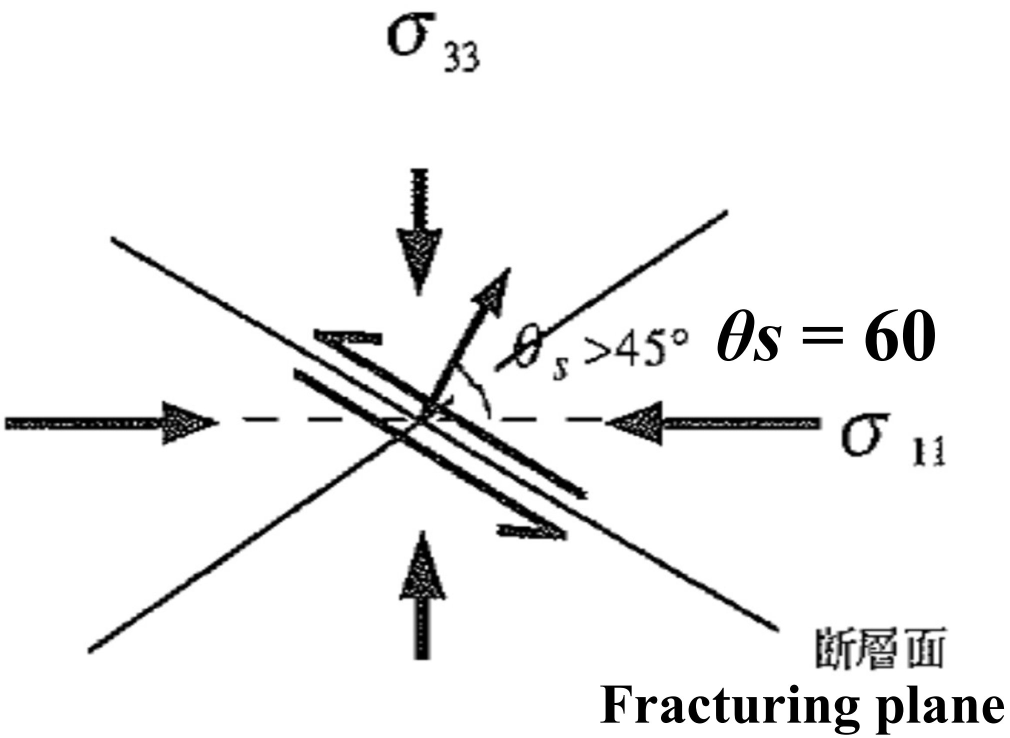
cohesion τ_0

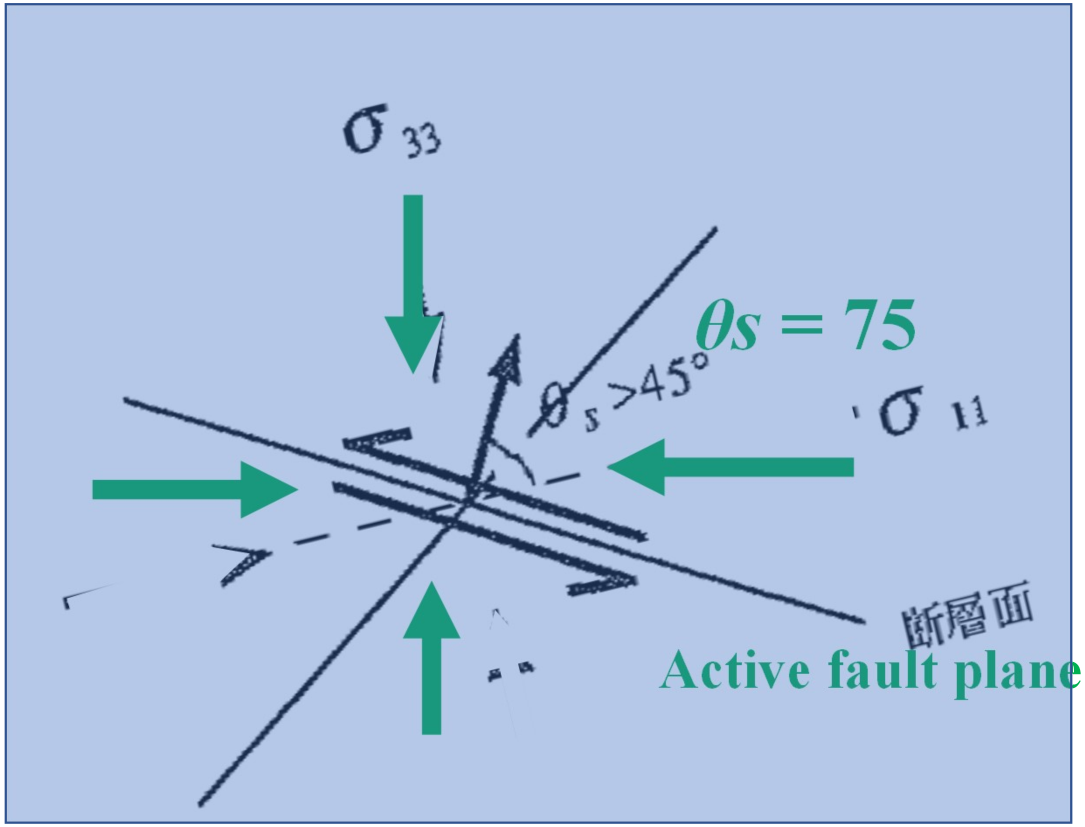
internal friction $\mu = 0.6$

$\theta s = 45 + 31/2$ degrees = 60

An existing active-fault with smaller "τ_0 & μ" and large θ_s of the existing "fracturing" plane

$\theta s = 45 + 60/2$ degrees =75



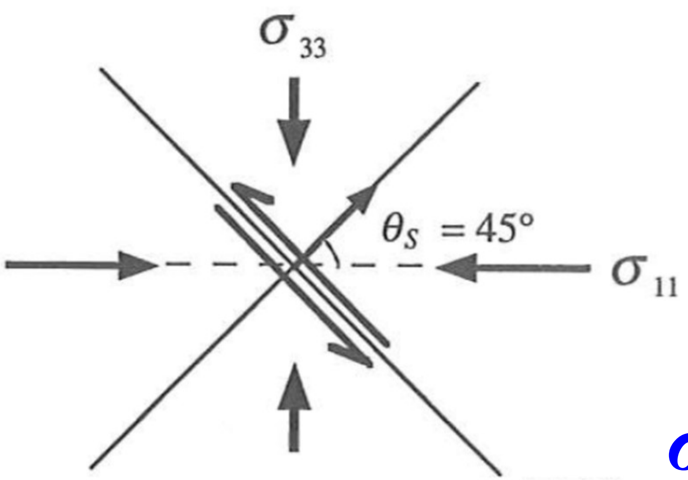


Released stress directions (rough view)

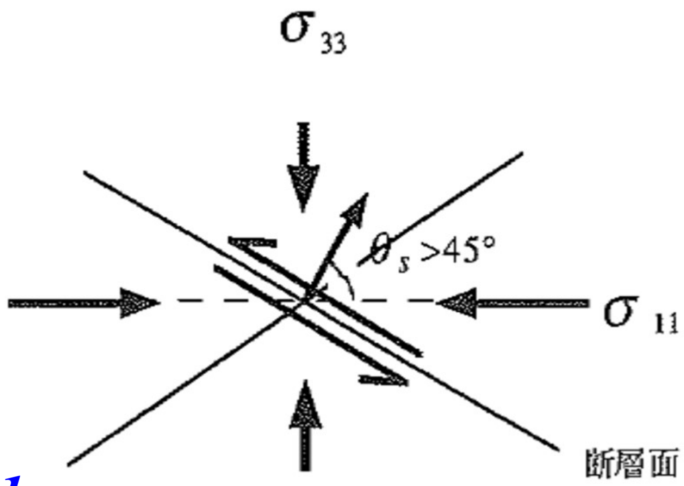
Cohesion: smaller τ_0
Internal friction: $\mu \approx 0$
$\theta_s = 45$
Same as the stress field
$\boldsymbol{\sigma_{11}}$ completely diminish
$\boldsymbol{\sigma_{33}}$ kept as it is

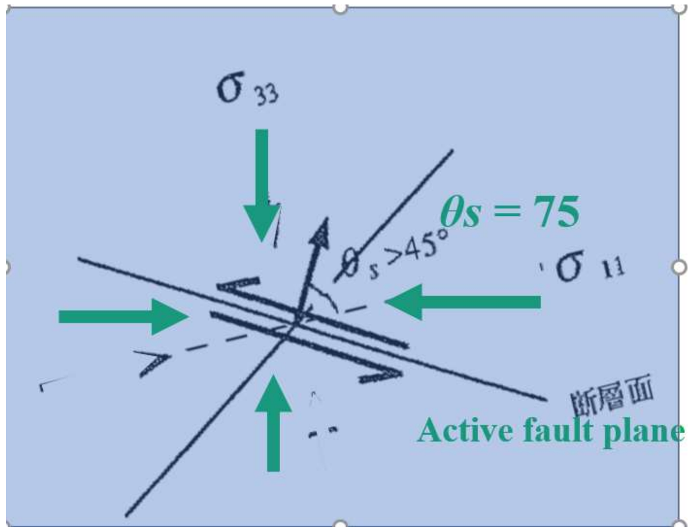
Standard τ_0 & $\mu = 0.6$
$\theta_s = 45 + 31/2$ degrees
15.5 difference from the stress field
$\boldsymbol{\sigma_{11}}$ considerably diminish
$\boldsymbol{\sigma_{33}}$ somewhat varies

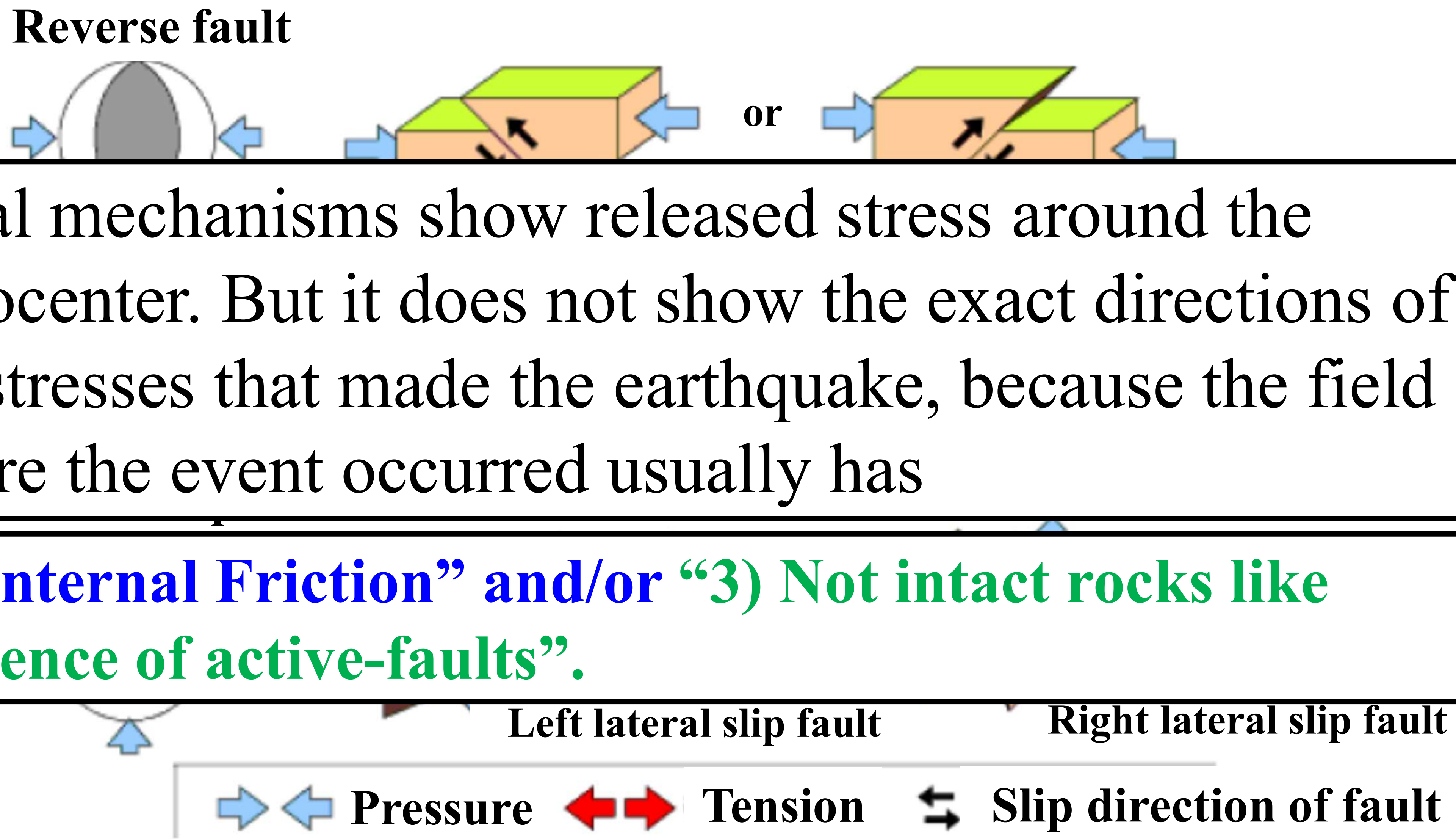
An active-fault
Smaller τ_0 and μ
θ_s = Fault plane =75
30 degrees difference from the stress field
Depends on the θ_s



$\boldsymbol{\sigma_{11}}$





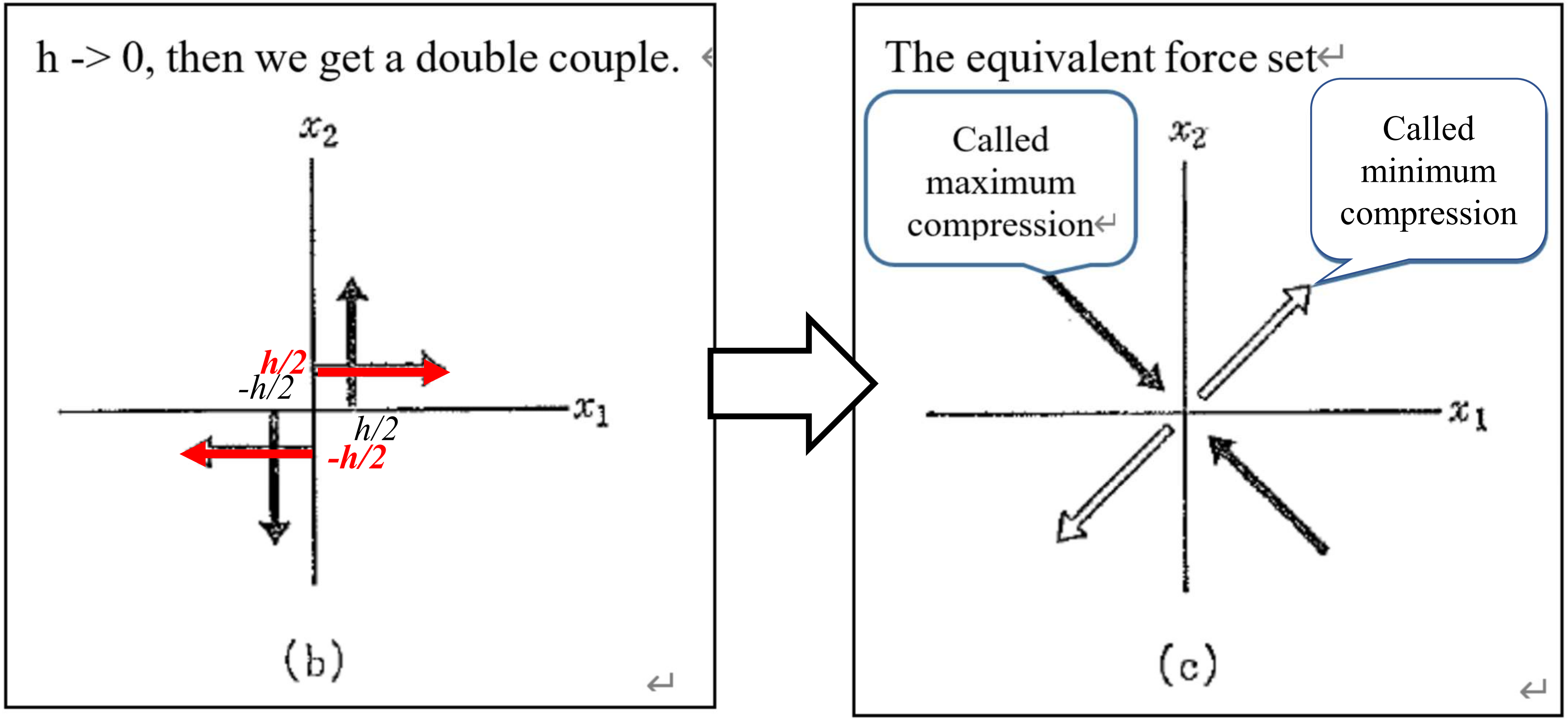


Focal mechanisms show released stress around the hypocenter. But it does not show the exact directions of the stresses that made the earthquake, because the field where the event occurred usually has

“2) Internal Friction” and/or **“3) Not intact rocks like existence of active-faults”.**

Double couple equivalent to the Stress field

The double couple in (b) is equivalent to the stress in (c).



After Fukao 1978

Contents of the self-training materials

1) **Observed results**,
2) Meaning of getting the **stress change** caused by the earthquake in the stress field,
3) **Nodal plane of the earthquake** obtained from the push-pull distribution of the P-wave initial motion,
4) **Initial motion focal mechanism** explaining the released force at the point of the hypocenter,
5) **Double couple forces** (quadrant type of focal mechanism).

Background issues

The earth: **elastic body** when considering the propagation of seismic waves that is the phenomenon in the **short time scale**

The earthquake: **a breaking-phenomenon generated when the strain in the crust achieves the amount of 10^{-4}–10^{-5}**.

-> **The strain** due to the seismic waves should be no more that **10^{-4}–10^{-5}** as well.

When considering the seismic wave generation & its propagation, **the infinitesimal strain theory** can be the base.

(Note: The descriptions from now on are following 1. "Aki & Richards, 1980, p.19-25, p.66, p.70" and 2. "Fukao, p.19-23, p.26, p.60 in Kanamori, 1978". The equation numbers are following those in Fukao 1978.)

The point force *F* 1/2

From now, it is explained with the below slides **how to get the displacement *u(x, t)* at each point in the elastic body occupying infinite space by a body force *f* for a unit mass**. The "*f*", which works on a micro volume V, has its amount $X_0(t)$ and is applied at the time "t" in the the direction of working force indicated by the vector $\boldsymbol{l} = (l_x, l_y, l_z)$. (Note: $\delta(\mathbf{x})$ is Dirac's Delta function working at **x**.)

$$\boldsymbol{f} = X_0(t)\,\delta(\mathbf{x})\,\boldsymbol{l}$$

Then, the **"point force *F*"** can be defined from that **a small volume, Δx · Δy · Δz or "V" should be made infinitesimal until reaching limit.** It is shown below, where the "*ρ*" is the density of the elastic body.

$$\boldsymbol{F} = \lim_{V \to 0} \int_V \rho \boldsymbol{f} \, dv$$

The solution ***u(x, t)*** will be shown at the last stage of this explanation in the formulae 2.94 and 2.95.

The point force *F* 2/2

From now we select the following as the |***f***| (or instead of δ(**x**)), which works on the origin of the coordinate axes.

$$f(x,y,z,t) = -\frac{1}{4\pi}\frac{F(t)}{\rho}\boldsymbol{l}\nabla^2\left(\frac{1}{r}\right) \quad (2.88)$$

$$r^2 = x^2+y^2+z^2$$

because $\lim_{V\to 0}\iiint_V \nabla^2(1/r)\,dV = -4\pi.$

$\boldsymbol{f} = X_0(t)\,\delta(\mathbf{x})\,\boldsymbol{l}$

$\delta(\mathbf{x}) = (-1/4\pi)\,\nabla^2(1/r)$

$X_0(t) = F(t)/\rho$

, where we set a sphere having volume “v”, and use Gaussian theory.

Then we can get the following from the above formulae:

$$\boldsymbol{F} = F(t)\boldsymbol{l} \quad (2.89)$$

, where unit vector $\boldsymbol{l} = (l_x, l_y, l_z)$ indicates the direction of working force.

The selection tells that the ***F*** is defined as the force directed to ***l*** and having *F(t)* as the time function.

Introduction of potentials 1/2

Based on the Helmholtz's theorem (Morse & Feshbach, 1953, p.53), any vectors such as the $\boldsymbol{u}\ (\boldsymbol{x}, t)$ and the $\boldsymbol{f}$ can be generally written as follows:

$$\boldsymbol{u}\ (\boldsymbol{x}, t) = \mathrm{grad}\ \varphi + \mathrm{rot}\ \boldsymbol{A}, \quad \mathrm{div}\ \boldsymbol{A} = 0 \qquad (2.10)$$

$$\boldsymbol{f} = \mathrm{grad}\ \Phi + \mathrm{rot}\ \boldsymbol{P}, \quad \mathrm{div}\ \boldsymbol{P} = 0 \qquad (2.17)$$

The φ & the Φ and the $\boldsymbol{A}$ & the $\boldsymbol{P}$ are called scalar potentials and vector potentials. The φ & the $\boldsymbol{A}$ are potential displacements as well.

Introduction of potentials　2/2

The below formula can be proved:

$$-\boldsymbol{l}\,\nabla^2(1/\mathrm{r}) = -grad\ div\ (\boldsymbol{l}/\mathrm{r}) + rot\ rot\ (\boldsymbol{l}/\mathrm{r})$$

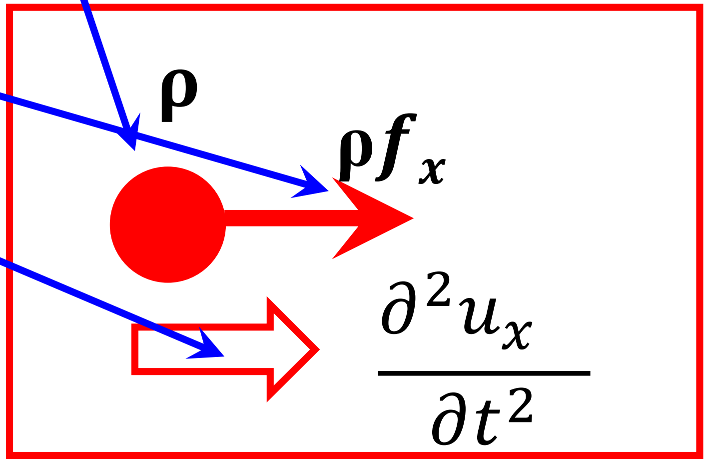
Then, referring the formulae 2.88 and 2.17 shows as follows:

$$\Phi(x, y, z, t) = -\frac{F(t)}{4\pi\rho}\mathrm{div}\left(\frac{\boldsymbol{l}}{r}\right)$$
$$\boldsymbol{P}(x, y, z, t) = \frac{F(t)}{4\pi\rho}\mathrm{rot}\left(\frac{\boldsymbol{l}}{r}\right) \quad (2.90)$$

The Equation of Motion 1/4

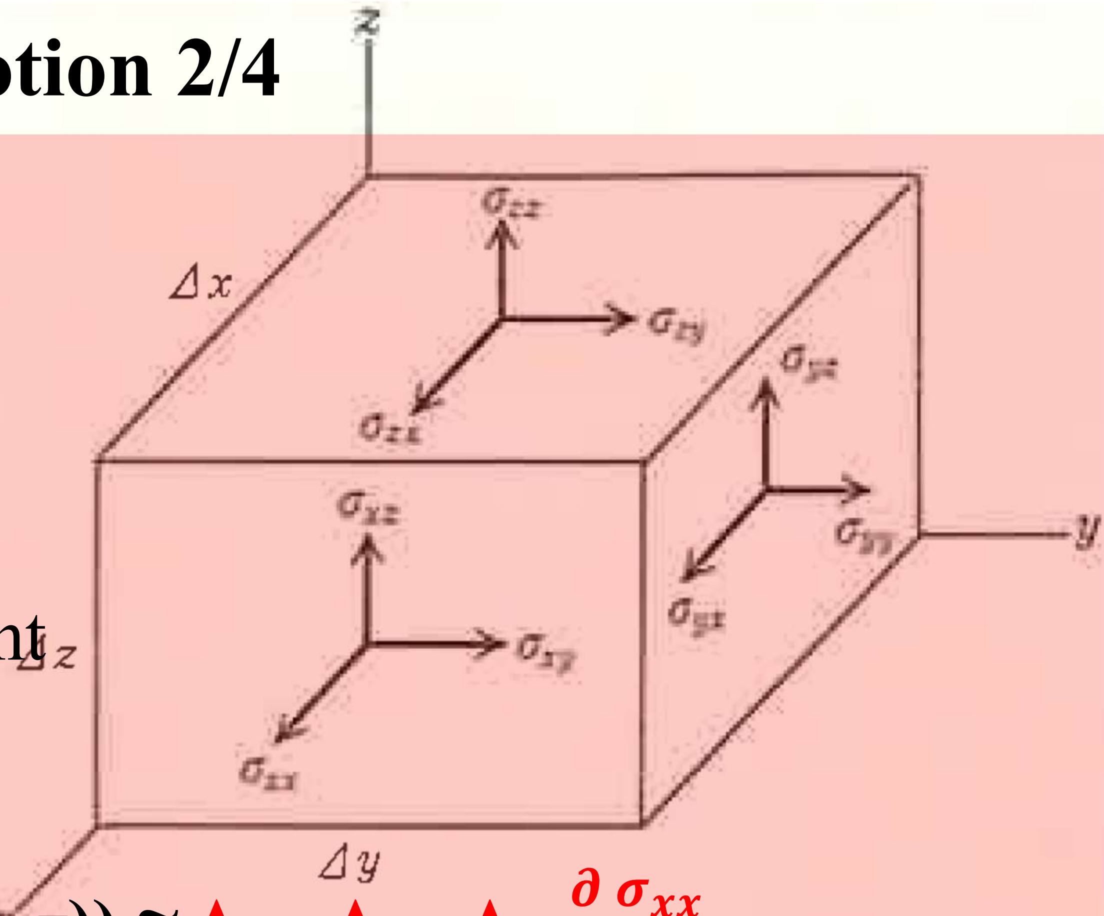
We consider that there is **a point having "unit mass" ρ**, which gets **a point force ρf_x, whose direction is x**. Then the point should **move with the acceleration $\frac{\partial^2 u_x}{\partial t^2}$ to the x direction**. The equation of motion can be as shown below:

$$\rho \frac{\partial^2 u_x}{\partial t^2} = \rho f_x$$



When we consider a small volume, V ($= \Delta x \cdot \Delta y \cdot \Delta z$), having a unit mass **in an elastic body occupying infinite space**, we should additionally consider **the surroundings that induce a surface force on the small volume. The surface force per unit size is called stress.**

The Equation of Motion 2/4



The right figure shows the "small volume", $\Delta x \cdot \Delta y \cdot \Delta z$, having "unit mass" **in the elastic body occupying infinite space.** The **surroundings induce the below amount stresses** for the x component of the surface force on the surface orthogonal to the *x*-axis:

$$\boldsymbol{\Delta y \cdot \Delta z \cdot (\sigma_{xx}(x+\Delta x, y, z) - \sigma_{xx}(x, y, z)) \approx \Delta y \cdot \Delta z \cdot \Delta x \frac{\partial \sigma_{xx}}{\partial x}},$$

similarly on the surface orthogonal to the *y* & *z*-axes are

$$\boldsymbol{\Delta z \cdot \Delta x \cdot \Delta y \frac{\partial \sigma_{yx}}{\partial y}} \text{ and } \boldsymbol{\Delta x \cdot \Delta y \cdot \Delta z \frac{\partial \sigma_{zx}}{\partial z}}.$$

Normal stress: $\sigma_{xx}\ \sigma_{yy}\ \sigma_{zz}$

Shear stress: $\sigma_{zx} (= \sigma_{xz})$, $\sigma_{zy} (= \sigma_{yz})$, $\sigma_{xy}\ (= \sigma_{yx})$

The Equation of Motion 3/4

We assume that there exists the force balance between the "body forces and surface forces acting throughout a volume V with surface S" and the inertia forces. The elasticity theory handles the ***u***'s gradient as small. Then, for the x-component, the balance should be formulated as below.

$$\rho \frac{D^2 u_x}{Dt^2} \approx \rho \frac{\partial^2 u_x}{\partial t^2} = \frac{\partial \sigma_{xx}}{\partial x} + \frac{\partial \sigma_{yx}}{\partial y} + \frac{\partial \sigma_{zx}}{\partial z} + \rho f_x \quad (2.3),$$

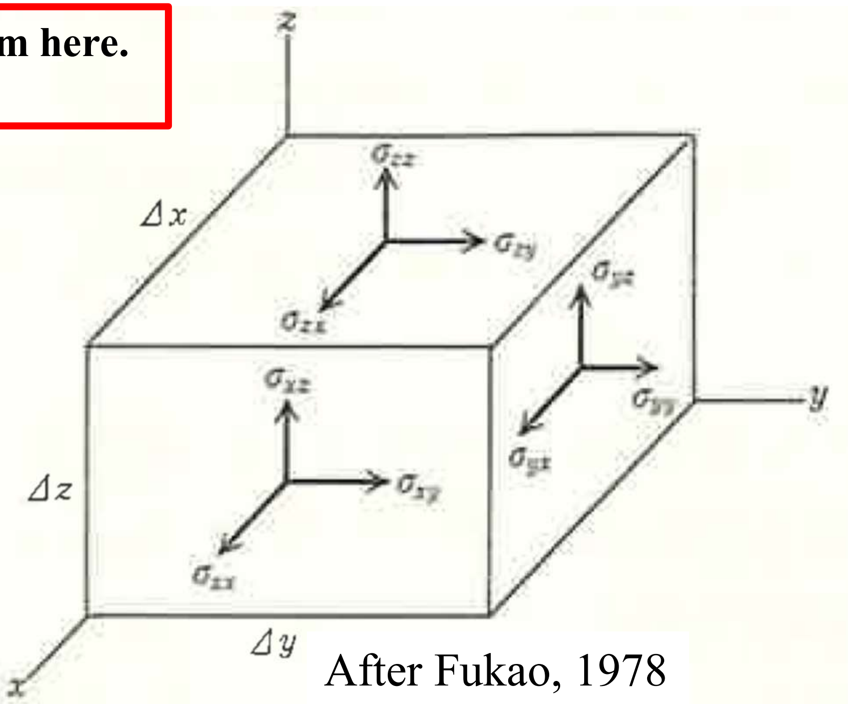
where σ_{xx}, σ_{yx}, and σ_{zx} are stress tensors defined as shown in the below figure.

We should note that the block with V & S is taken as the coordinate system here. Namely the coordinates of the general space are subject variables here.

Because of the followings:

$$\frac{D^2 u_x}{Dt^2} = \frac{\partial^2 u_x}{\partial t^2} + u_x \frac{\partial u_x}{\partial x} + u_y \frac{\partial u_x}{\partial y} + u_z \frac{\partial u_x}{\partial z}$$

$$\frac{\partial u_x}{\partial x} \approx 0, \quad \frac{\partial u_x}{\partial y} \approx 0, \quad \frac{\partial u_x}{\partial z} \approx 0$$



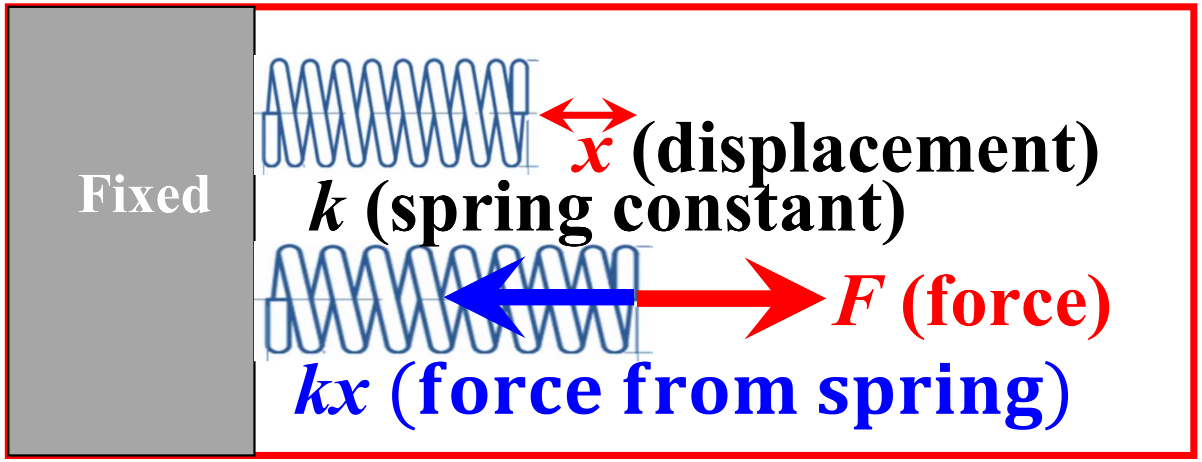
After Fukao, 1978

The Hooke's law 1/3

When a spring with **k as its spring constant** **extends** by ***x***, the spring has **the force *kx***. In order to keep the displacement *x*, a **force *F*** should operates on the spring. Namely,

$$F = k\,x$$

This is the Hooke's law.
Or the displacement is linearly proportional to the given force.



For isotropic elastic body, transformation of surfaces in it should be handled. So **strains on a surface** in the body with λ and μ as its elastic constants should be considered instead of displacement.

The Hooke's law 2/3

For isotropic elastic body, the generalized Hooke's law can be expressed as follows. Namely, the **stresses, σ_{xx}** and others, are **linearly proportional** to the **strains, ε_{xx}** and others. (Note: Stress & strain are a kind of tensor.)

$$\left.\begin{aligned} \sigma_{xx} &= \lambda\theta + 2\mu\varepsilon_{xx},\ \sigma_{xy} = 2\mu\varepsilon_{xy} \\ \sigma_{yy} &= \lambda\theta + 2\mu\varepsilon_{yy},\ \sigma_{yz} = 2\mu\varepsilon_{yz} \\ \sigma_{zz} &= \lambda\theta + 2\mu\varepsilon_{zz},\ \sigma_{zx} = 2\mu\varepsilon_{zx} \end{aligned}\right\} \quad (2.12)$$

λ and μ are called Lamé's constants. They are similar to the spring constant.

, where ε_{xx}, ε_{yy}, and ε_{zz} are $\frac{\partial u_x}{\partial x}$, $\frac{\partial u_y}{\partial y}$, and $\frac{\partial u_z}{\partial z}$ respectively;

and ε_{xy}, ε_{yz}, and ε_{zx} are as follows respectively:

$$\frac{1}{2}\left(\frac{\partial u_y}{\partial x} + \frac{\partial u_x}{\partial y}\right) = \varepsilon xy,\ \frac{1}{2}\left(\frac{\partial u_z}{\partial y} + \frac{\partial u_y}{\partial z}\right) = \varepsilon yz, \text{ and } \frac{1}{2}\left(\frac{\partial u_x}{\partial z} + \frac{\partial u_z}{\partial x}\right) = \varepsilon zx;$$

$$\theta = \varepsilon xx + \varepsilon yy + \varepsilon zz$$

After Fukao, 1978

The Hooke's law 3/3

In ε_{ij}, σ_{ij}, & δ_{ij}, *i* & *j* can be *x*, *y*, & *z* instead.

Kronecker's Delta
$\delta_{ij} = 1$ when $i = j$
$= 0$ when $i \neq j$

We can rewrite 2.12 as followings:

$\varepsilon_{ij} = (1/2\mu)\ \sigma_{ij} - (\lambda / (2\mu(3\lambda+2\mu)))\ \sigma_{ij}\delta_{ij}$, where ε_i & σ_{ij} are strain and stress tensors.

When a rod is **pulled** with $\boldsymbol{\sigma_{xx}}$ as shown in the figure, then

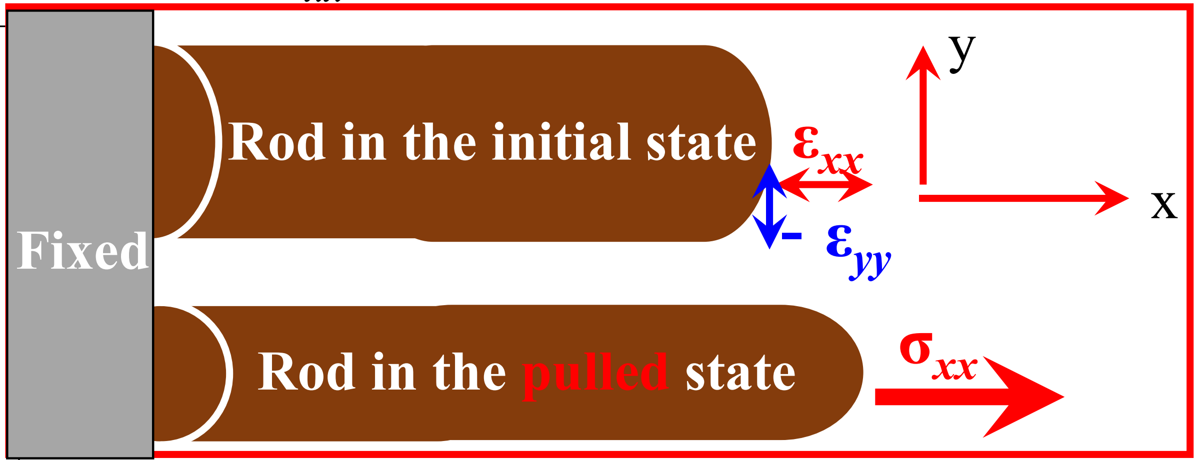
$\varepsilon_{xx} = ((\lambda+\mu)/(\mu(3\lambda+2\mu)))\ \sigma_{xx} = (1/\mathbf{Y})\ \sigma_{xx}$ = **Expansion**

$\varepsilon_{yy} = \varepsilon_{zz} = -\ (\lambda/(2\mu(3\lambda+2\mu))\ \sigma_{xx} = -\ (\boldsymbol{\sigma}/\mathbf{Y})\ \sigma_{xx}$ = **Contraction**

Y (Young's modulus)
σ (Poisson's ratio)

μ (Modulus of rigidity
= one of Lame's constants)
$\varepsilon_{ij} = (1/2\mu)\ \sigma_{ij}\ (i \neq j)$
Shearing Strain
k (Bulk modulus)
$\sigma_{ii} = -p\ \delta_{ij}$, where p is static pressure.
Then,
$\varepsilon_{ii} = -\ (1/(\lambda+(2/3)\mu))\ p = (1/k)\ p$
Shrinkage

After Kakutani, 1969



Young's Modulus Y, Poisson Ratio σ & the other physical constants can be expressed by Lamé's Constants, λ & μ, as shown here.

Equation of Motion 4/4

Rewritten the Equation of Motion 2.3 with the Hooke's law 2.12

$$\rho\frac{\partial^2 \mathbf{u}}{\partial t^2} = (\lambda + 2\mu)\text{grad div } \mathbf{u} - \boldsymbol{\mu}\text{rot rot } \mathbf{u} + \rho \boldsymbol{f}$$

Further, introduction of potentials in 2.10 & 2.17 make the following relations:

$$\left.\begin{aligned} &\frac{\partial^2 \varphi}{\partial t^2} - \alpha^2 \nabla^2 \varphi = \Phi, \text{ where } \alpha = \sqrt{\frac{\lambda + 2\mu}{\rho}} \\ &\frac{\partial^2 \boldsymbol{A}}{\partial t^2} - \beta^2 \nabla^2 \boldsymbol{A} = \boldsymbol{P}, \text{ where } \beta = \sqrt{\frac{\mu}{\rho}} \end{aligned}\right\} \quad (2.18)$$

Namely, **the velocities of P & S or α & β, which are shown abeve, are made from density and Lamé's constants, which are coefficients to link the stress and the strain.** The exact amount of them should be experimentally estimated.

The Particular Solution for the inhomogeneous Equation of Motion

$$\varphi(x, y, z, t) = \frac{1}{4\pi\alpha^2} \int_0^\infty \frac{\Phi(x', y', z', t - \frac{R}{\alpha})}{R} dx'dy'dz'$$

(2.86)

$$\boldsymbol{A}(x, y, z, t) = \frac{1}{4\pi\beta^2} \int_0^\infty \frac{\boldsymbol{P}(x', y', z', t - \frac{R}{\beta})}{R} dx'dy'dz'$$

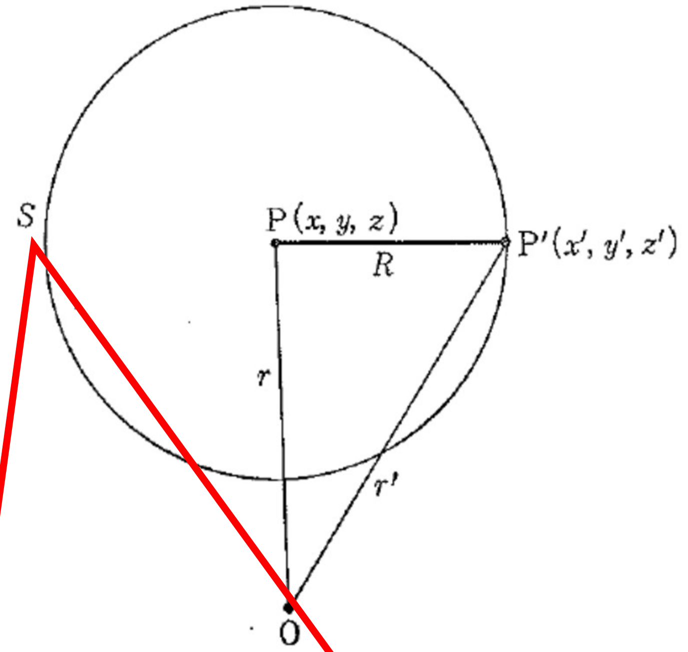
, where $R^2 = (x-x')^2+(y-y')^2+(z-z')^2$

Note that seismic displacements, ***u(x**, t)* (= grad φ+ rot ***A***), have P wave part, "grad φ", and S wave part, "rot ***A***".

Shown in Fukao 1978 after Morse & Feshbach, 1953, p.84

The potential displacements

The potential displacements, φ and ***A***, made by the force (2.89) working on the origin could be obtained by substituting 2.90 for 2.86. The integration of the formula 2.86 can be carried out through seeing the right figure as shown below:



$$\int \frac{\Phi(x', y', z', t-R/\alpha)}{R} \mathrm{d}x'\mathrm{d}y'\mathrm{d}z'$$

$$= -\frac{1}{4\pi\rho}\int_0^\infty F\left(t-\frac{R}{\alpha}\right)\frac{\mathrm{d}R}{R}\iint_S \left\{ l_x \frac{\partial}{\partial x'}\left(\frac{1}{r'}\right) + l_y \frac{\partial}{\partial y'}\left(\frac{1}{r'}\right) + l_z \frac{\partial}{\partial z'}\left(\frac{1}{r'}\right) \right\} \mathrm{d}S$$

$$r'^2 = x'^2 + y'^2 + z'^2$$

S is the surface of the sphere with P (x, y, z) as its center.

$$I = \iint_S \frac{\partial}{\partial x'}\left(\frac{1}{r'}\right)\mathrm{d}S = -\iint_S \frac{\partial}{\partial \xi}\left(\frac{1}{r'}\right)\mathrm{d}S = -\frac{\partial}{\partial \xi}\iint \frac{1}{r'}\mathrm{d}S$$

where we take a point Q (ξ, η, ζ) near to the origin; the " r' " should be the infinitesimal length between P&Q with moving Q toward the origin. The integration shown in the last formula will be 0 when $R > r$ and will be $4\pi R^2(1/r)$ when $R < r$ through considering the potential theorem. Then,

$$I = 4\pi R^2 \left(\frac{\partial}{\partial x}\right)(1/r).$$

The above consideration lead us to the formulae shown on the right.

$$\phi = -\frac{1}{4\pi\rho\alpha^2}\,\mathrm{div}\left(\frac{\boldsymbol{l}}{r}\right)\int_0^r RF\left(t-\frac{R}{\alpha}\right)\mathrm{d}R$$

$$= -\frac{1}{4\pi\rho}\,\mathrm{div}\left(\frac{\boldsymbol{l}}{r}\right)\int_0^{r/\alpha} \tau F(t-\tau)\mathrm{d}\tau \qquad (2.91)$$

$$\boldsymbol{A} = \frac{1}{4\pi\rho}\,\mathrm{rot}\left(\frac{\boldsymbol{l}}{r}\right)\int_0^{r/\beta} \tau F(t-\tau)\mathrm{d}\tau \qquad (2.92)$$

(2.91), (2.92) and (2.10) will give us as follows:

$$\boldsymbol{u}(\boldsymbol{x}, t) = \frac{1}{4\pi\rho} \operatorname{grad} \operatorname{div}\left(\frac{\boldsymbol{l}}{r}\right) \int_{r/\alpha}^{r/\beta} \tau F(t-\tau) d\tau - \frac{1}{4\pi\rho\alpha^2} \boldsymbol{r} \operatorname{div}\left(\frac{\boldsymbol{l}}{r}\right) F\left(t - \frac{r}{\alpha}\right) + \frac{1}{4\pi\rho\beta^2} \boldsymbol{r} \times \operatorname{rot}\left(\frac{\boldsymbol{l}}{r}\right) F\left(t - \frac{r}{\beta}\right) \quad (2.93)$$

We can replace x, y, and z with x_1, x_2, and x_3; then we can show the displacement u_i^k of the direction *i* with the force of the direction *k* as follows:

$$u_i^k(\boldsymbol{x}, t) = \frac{1}{4\pi\rho} \frac{\partial^2 r^{-1}}{\partial x_i \partial x_k} \int_{r/\alpha}^{r/\beta} \tau F(t-\tau) d\tau + \frac{1}{4\pi\rho\alpha^2 r} \frac{x_i x_k}{r^2} F\left(t - \frac{r}{\alpha}\right) + \frac{1}{4\pi\rho\beta^2 r} \left(\delta_{ik} - \frac{x_i x_k}{r^2}\right) F\left(t - \frac{r}{\beta}\right) \quad (2.94)$$

Near Field Term

Far Field Term of P wave

Far Field Term of S wave

,where δ_{ik} is the Kronecker's delta.

Dynamic displacement with the point force (Fig. 2.94 reappearance)

The dynamic displacement $u_i^k(x, t)$ of x_i component induced by the point force $F(t)$ operating to x_k direction can be obtained as follows:

$$u_i^k(\boldsymbol{x}, t) = \frac{1}{4\pi\rho}\frac{\partial^2 r^{-1}}{\partial x_i \partial x_k}\int_{r/\alpha}^{r/\beta}\tau F(t-\tau)\mathrm{d}\tau$$

$$+ \frac{1}{4\pi\rho\alpha^2 r}\frac{x_i x_k}{r^2}F\left(t-\frac{r}{\alpha}\right)$$

$$+ \frac{1}{4\pi\rho\beta^2 r}\left(\delta_{ik}-\frac{x_i x_k}{r^2}\right)F\left(t-\frac{r}{\beta}\right) \quad (2.94)$$

Near Field Term

Far Field Term of P wave

Far Field Term of S wave

$$\alpha = \sqrt{\frac{\lambda+2\mu}{\rho}}$$

$$\beta = \sqrt{\frac{\mu}{\rho}}$$

ρ *is* density. α is P-wave velocity. β is S-wave velocity. r is hypocenter distance.

Kronecker's Delta
$\delta_{ij} = 1$ when $i = j$
$= 0$ when $i \neq j$

If we put $t \rightarrow \infty$ and $F(t) \rightarrow F_0$, above equation gives us the following:

$$u_i^k(\boldsymbol{x}) = \frac{F_0}{8\pi\mu}\left(\frac{\lambda+3\mu}{\lambda+2\mu}\frac{\delta_{ik}}{r} + \frac{\lambda+\mu}{\lambda+2\mu}\frac{x_i x_k}{r^3}\right) \tag{2.95}$$

The formulae (2.94) and (2.95) show **the dynamic and static displacements** respectively when a force acting on the origin respectively in a **homogeneous isotropic elastic body** having finite space.

Single couple 1/3

When a force acting not on the origin but on the arbitrary point like $\boldsymbol{x'} = (x_1', x_2', x_3')$, the displacement made by it is given by replacing $\boldsymbol{x}$ with $\boldsymbol{x}-\boldsymbol{x'}$ and putting $|\boldsymbol{x}-\boldsymbol{x'}|$ for r in the formulae (2.94) and (2.95). For example, the forces acting at the same time on the points *(h/2, 0, 0)* and *(-h/2, 0, 0) with the direction of* x_2 and $-x_2$ respectively as shown in the Figure 2.24 (a), the displacement to be made by them should be as follows:

$$u_i^2 (x_1-h/2, x_2, x_3, t) - u_i^2 (x_1+h/2, x_2, x_3, t) \quad (2.96)$$

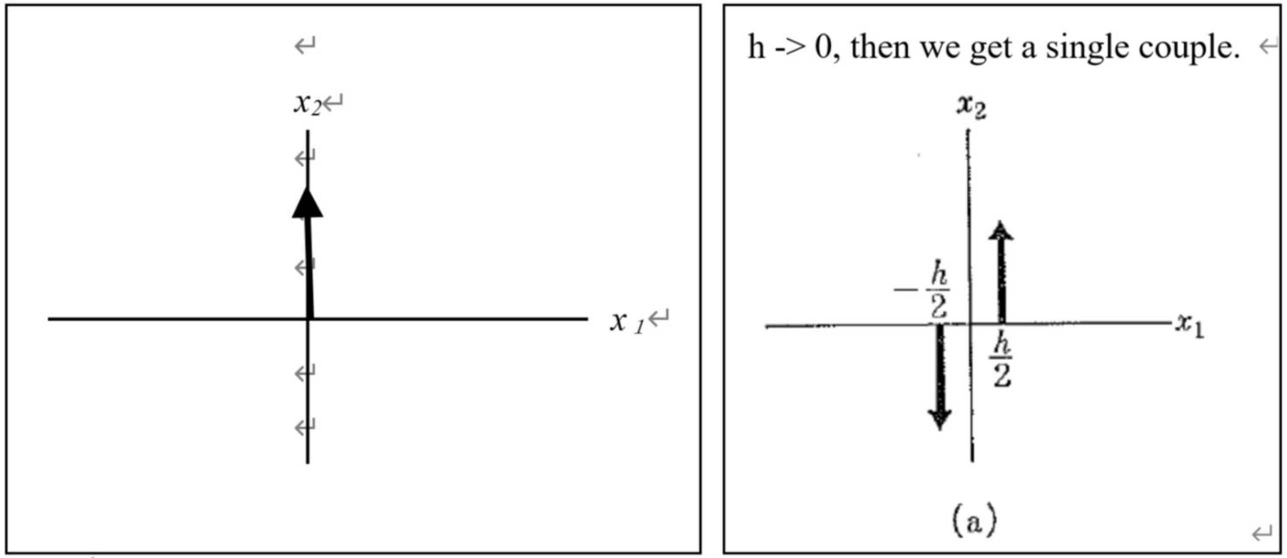


Figure 2.24. A point force acting to the x_2-direction, (a) Single couple.

Single couple 2/3

If we consider making "*h*" smaller to the limit through expressing these forces with *M(t)/h*, we can get the Single Couple having x_2 as the force direction and *M(t)* as the moment around x_3 pole when the "*h*" reaches to 0; and we can get from the (2.96) the displacement, v_i, made by the Single Couple; namely,

$$v_i = \lim_{h \to 0} u_i^2 (x_1 - h/2, x_2, x_3, t) - u_i^2 (x_1 + h/2, x_2, x_3, t)$$

whereas *F(t)* in the formulae (2.94) and (2.95) should be replaced by *M(t)/h*.

Finally, we get the followings:

$$v_i = -\frac{\partial}{\partial xi} u_i^2 \quad (2.97)$$

Whereas *F(t)* and F_0 in the formulae (2.94) and (2.95) should be replaced by *M(t)* and M_0.

Single couple 3/3

With the formula (2.97), we get far field approximation through neglecting the terms having the order of higher than 1/r through considering r >> 0 as follows:

As for the dynamic displacement in the far field, we get the below:

$$v_i = \frac{1}{4\pi\rho\alpha^3 r}\gamma_1\gamma_2\gamma_i M'\left(t - \frac{r}{\alpha}\right) + \frac{1}{4\pi\rho\beta^3 r}(\delta_{i2} - \gamma_2\gamma_i)\gamma_1 M'\left(t - \frac{r}{\beta}\right) \quad (2.98)$$

, where $\gamma_i = x_i/r$

As for the static displacement in the far field, we get the below:

$$V_i = \frac{M_0}{8\pi\mu r^2}\frac{\lambda+\mu}{\lambda+2\mu}\left(\frac{\lambda+3\mu}{\lambda+\mu}\delta_{i2}\gamma_1 - \delta_{i1}\gamma_2 + 3\gamma_1\gamma_2\gamma_i\right) \quad (2.99)$$

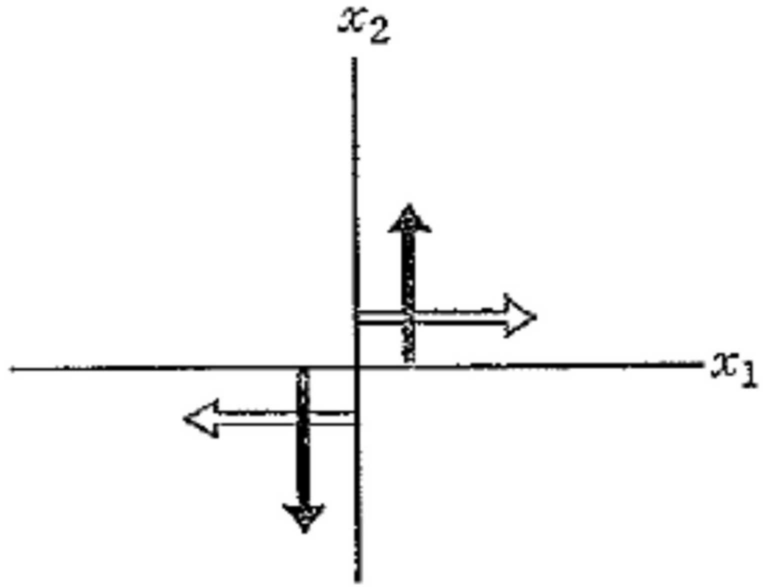
The formulae (2.98) and (2.99) show the dynamic and static displacements when a Single Couple acting with the force of x_2-direction and the moment of x_3-direction on the origin.

Double couple 1/3

In the same manner we can take an additional Single Couple acting with the force of x_1-direction and the moment of x_2-direction on the origin as shown in the below figure (b). In the case that the latter one acts together with the former one, we call the set of Single Couple as Double Couple. The displacement to be made by it should be as follows:

$$v_i = -\frac{\partial}{\partial x1} u_i^{2} - \frac{\partial}{\partial x2} u_i^{1} \quad (2.100)$$

Whereas $F(t)$ and F_0 in the formulae (2.94) and (2.95) should be replaced by $M(t)$ and M_0.



(b)

Double couple 2/3

With the formula (2.100), we get far field approximation through neglecting the terms having the order of higher than 1/r through considering r >> 0 as follows:

As for the dynamic displacement in the far field, we get the below:

$$v_i = \frac{1}{4\pi\rho\alpha^3 r} 2\gamma_1\gamma_2\gamma_i M'\left(t - \frac{r}{\alpha}\right) + \frac{1}{4\pi\rho\beta^3 r}(-2\gamma_1\gamma_2\gamma_i + \delta_{i1}\gamma_2 + \delta_{i2}\gamma_1) M'\left(t - \frac{r}{\beta}\right) \quad (2.101)$$

, where $\gamma_i = x_i/r$

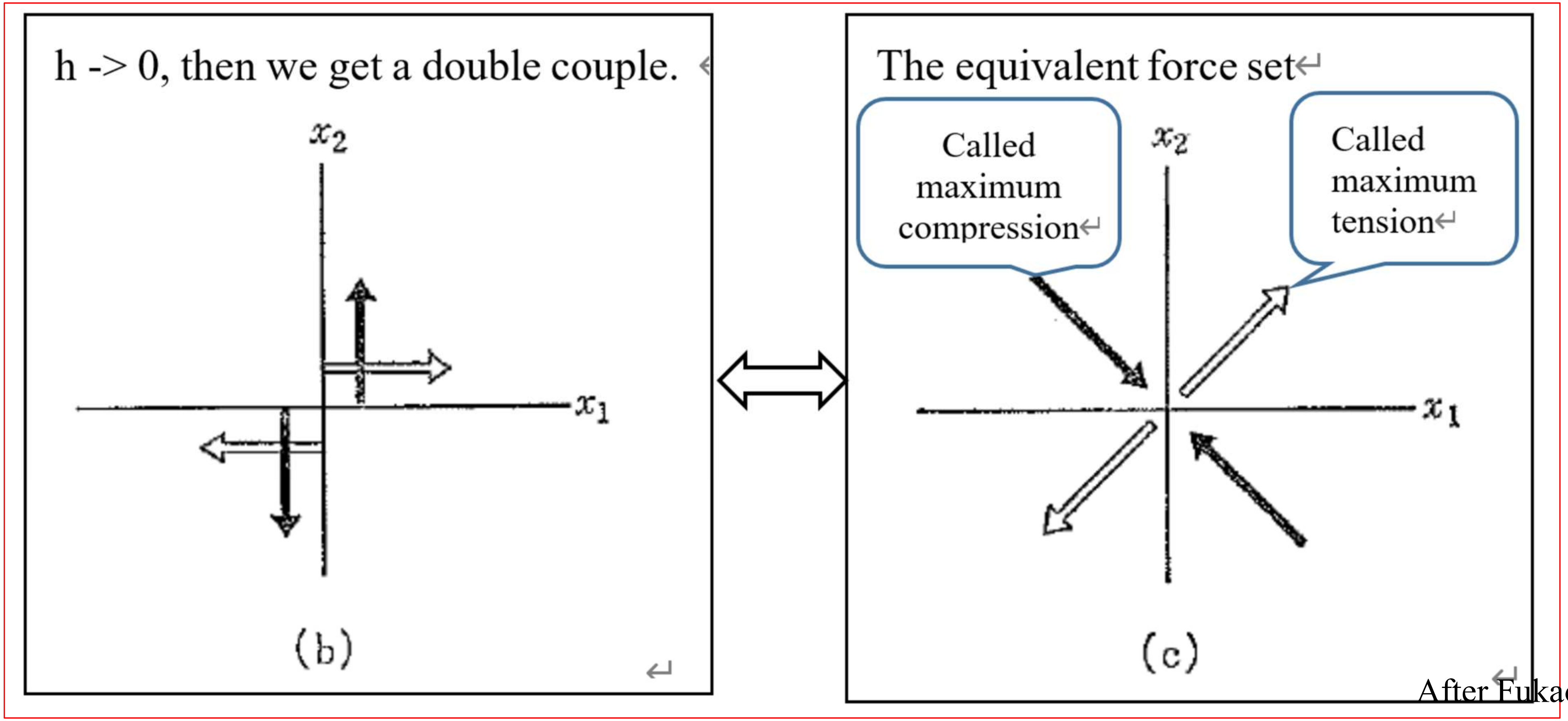
As for the static displacement in the far field, we get the below:

$$v_i = \frac{M_0}{4\pi\mu r^2} \frac{\lambda+\mu}{\lambda+2\mu} \left\{ \frac{\mu}{\lambda+\mu}(\delta_{i2}\gamma_1 + \delta_{i1}\gamma_2) + 3\gamma_1\gamma_2\gamma_i \right\} \quad (2.102)$$

The formulae (2.101) and (2.102) show the dynamic and static displacements when a Double Couple acting on the origin with the force of x_1 *and* x_2 directions in the x_1x_2 plane in a homogeneous isotropic elastic body having finite space.

Double couple 3/3

The below figures shows that a point force is acting as (b) Double couple and is equivalent force shown in (c) with double couple force.



After Fukao 1978

Coordinates transformation to the polar ones 1/2

$$\gamma_1 = x_1/r = \sin\theta\cos\phi$$
$$\gamma_2 = x_2/r = \sin\theta\sin\phi \qquad (2.103)$$
$$\gamma_3 = x_3/r = \cos\theta$$

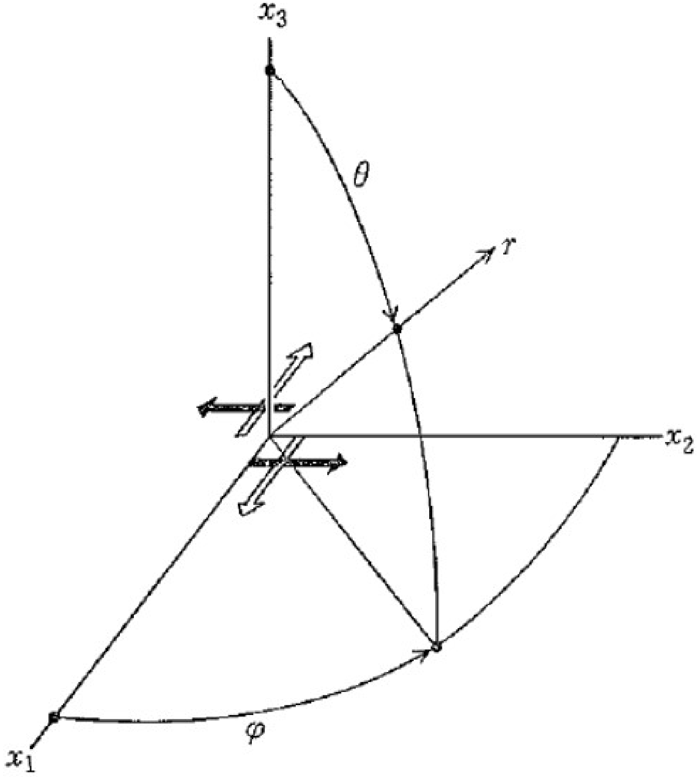


Figure 2.25 Definition of the polar coordinates

$$\begin{pmatrix} v_r \\ v_\theta \\ v_\varphi \end{pmatrix} = \begin{pmatrix} \sin\theta\cos\varphi & \sin\theta\sin\varphi & \cos\theta \\ \cos\theta\cos\varphi & \cos\theta\sin\varphi & -\sin\theta \\ -\sin\varphi & \cos\varphi & 0 \end{pmatrix} \begin{pmatrix} v_1 \\ v_2 \\ v_3 \end{pmatrix} \qquad (2.\,104)$$

After Fukao 1978

Coordinates transformation to the polar ones 2/2

By introducing 2.101 and 2.103 into 2.104, we get the below left formulae. V_r shows P-wave dynamic displacements and V_θ & V_φ show S-wave ones. Similarly, we get the below right formulae for the static displacements for P and S.

$$\left.\begin{aligned} v_r &= \frac{1}{4\pi\rho\alpha^3 r} M'\left(t - \frac{r}{\alpha}\right)\sin^2\theta \sin 2\varphi \\ v_\theta &= \frac{1}{4\pi\rho\beta^3 r} M'\left(t - \frac{r}{\beta}\right)\frac{1}{2}\sin 2\theta \sin 2\varphi \\ v_\varphi &= \frac{1}{4\pi\rho\beta^3 r} M'\left(t - \frac{r}{\beta}\right)\sin\theta \cos 2\varphi \end{aligned}\right\} \quad (2.105)$$

$$\left.\begin{aligned} v_r &= \frac{M_0}{4\pi\mu r^2}\frac{3\lambda+5\mu}{2(\lambda+2\mu)}\sin^2\theta \sin 2\varphi \\ v_\theta &= \frac{M_0}{4\pi\mu r^2}\frac{\mu}{\lambda+2\mu}\frac{1}{2}\sin 2\theta \sin 2\varphi \\ v_\varphi &= \frac{M_0}{4\pi\mu r^2}\frac{\mu}{\lambda+2\mu}\sin\theta \cos 2\varphi \end{aligned}\right\} \quad (2.106)$$

After Fukao 1978

Dynamic displacement with Double Couple force 1/2

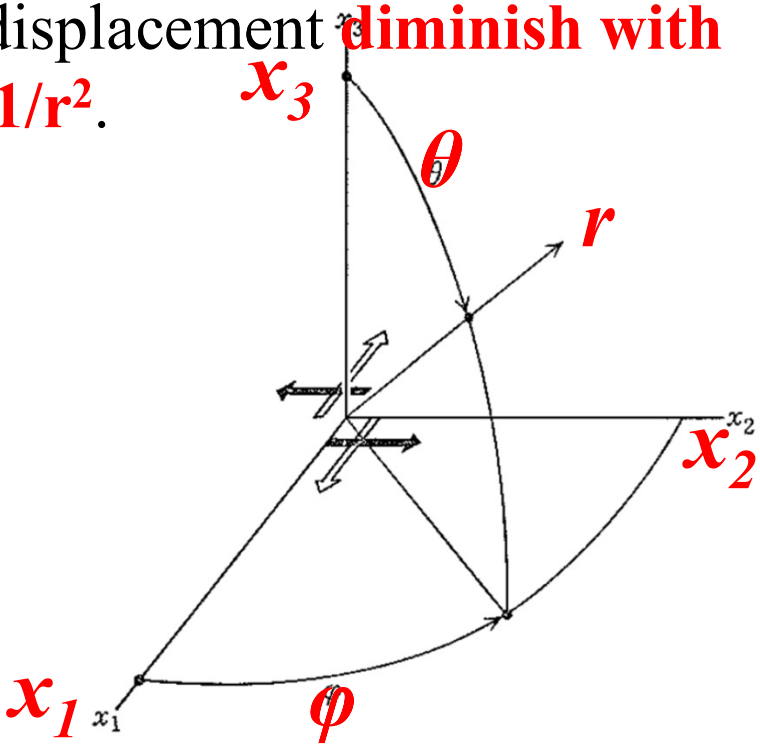
Because the v_r propagates to the same direction as the displacement direction, it shows the P wave displacement. On the other hand the v_θ and v_φ propagate to the orthogonal direction with the displacement direction, they show the S wave displacement.

The ratio of the maximum amplitude of v_r to v_θ and v_φ are $(\alpha/\beta)^3$, which roughly equals to 5. The amplitudes of the **dynamic** displacement **diminish with 1/r**; on the other hand, those of the **static** one do **with $1/r^2$**.

$$
\left.
\begin{aligned}
v_r &= \frac{1}{4\pi\rho\alpha^3 r} M'\left(t - \frac{r}{\alpha}\right) \sin^2\theta \sin 2\varphi \\
v_\theta &= \frac{1}{4\pi\rho\beta^3 r} M'\left(t - \frac{r}{\beta}\right) \frac{1}{2} \sin 2\theta \sin 2\varphi \\
v_\varphi &= \frac{1}{4\pi\rho\beta^3 r} M'\left(t - \frac{r}{\beta}\right) \sin\theta \cos 2\varphi
\end{aligned}
\right\}
$$

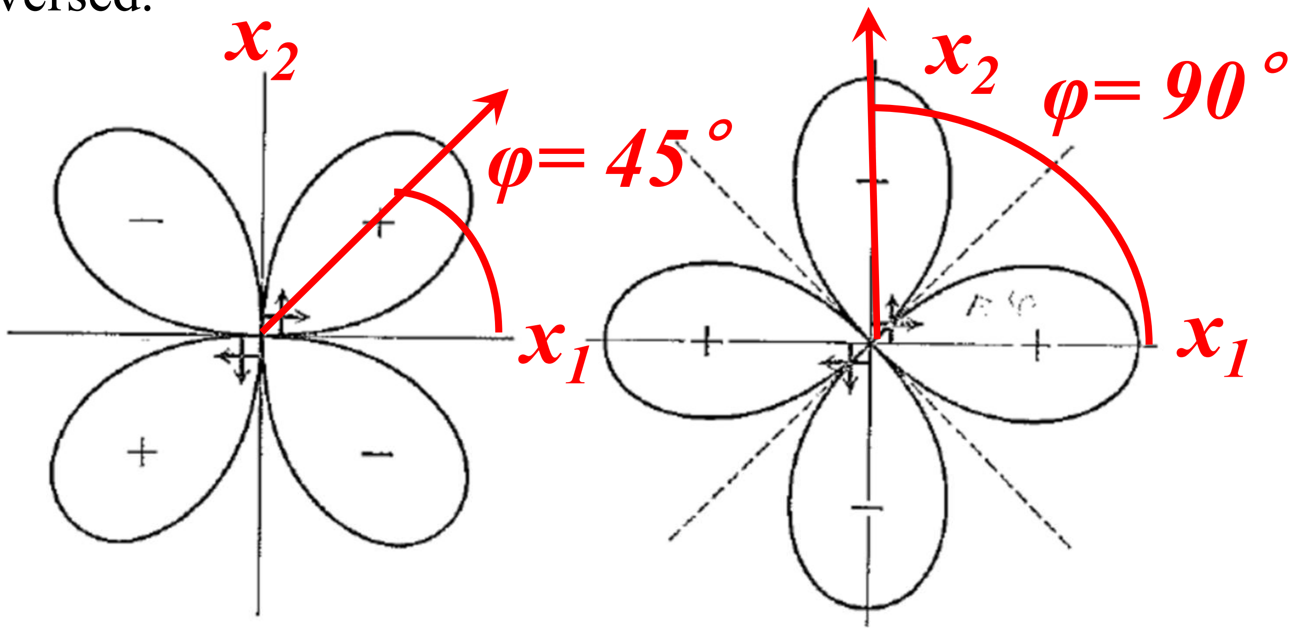
(2.105; reappearance)

ρ: density
α: P-velocity
β: S-velocity
r: hypocentral distance



Dynamic displacement with Double Couple force 2/2

The below figures are drawn with the formulae 2.105. Namely the amplitude distributions of P wave (v_r) and S wave (v_θ& v_φ) **for φ**. As for v_θ, the +/- sign is shown for θ< 90° . For θ> 90° , the sign should be reversed.



v_r (P wave) & v_θ(S wave) v_ϕ(S wave)

Note: The above figures are normalized with each maximum amplitude.

The v_r (P wave) shows zero on the two planes who are mutually orthogonal. The planes are $x_1 = 0$ and $x_2 = 0$, who are called "nodal planes". The v_θ (S wave) shows the three nodal planes; they are $x_1 = 0$, $x_2 = 0$ and $x_3 = 0$. The v_φ (S wave) shows the two nodal planes; they are $x_2 = x_1$ and $x_2 = -x_1$.

The v_r and the v_φ have the maximum at θ= 90° . The v_θ has maximum at θ= 45° & 135° . If we take "1 " as the maximum amplitude for v_r, those of v_θ and v_φ should be $(\alpha/\beta)^3/2$ and $(\alpha/\beta)^3$.

After Fukao 1978

Thank you!
¡Gracias!

Self-training System (Category 7; Element 1)

Prepared by Expert on 05Mar23

1. Introduction

Expert should develop any new and robust self-training system because the similar system developed by MARN after the Phase 1 was finished after conducting the series of mutual presentations.

2. General idea

The system should use the process of preparation of monthly seismic newsletters, which are prepared as internal documents now. The members of the monitoring shift officers should mutually contribute to enhance the contents of newsletters.

We should start to make "seasonal" seismic newsletters once during 3 months like March for Jan - Mar, June for Apr - Jun, September for Jul - Sep and December for Oct - Dec. Further the result should be uploaded to the MARN web site.

3. Purpose

The self-training is to brush up the monitoring skills of the monitoring officers constantly. And the system should support the training.

4. Detail of the system

4-1 Procedures

The below steps should be taken by the officer who should take the turn:

Step 1 To collect seismic data of the season from SeisComP.

Step 2-1 To analyze them according to the standard procedures to make the "monthly newsletter" (Boletín Mensual de Actividad Sísmica Marzo 2021) as can be found in the web site of MARN.

Step 2-2 To additionally analyze them with MT and MF diagrams with SeisPC.

Step 3 To evaluate the feature of the seismic activity in the season.

Step 4 To collect and analyze additional seismic data to understand the feature with old large events.

Step 5 To complete the draft seasonal newsletter and to get authorization from the supervisor and the Communications Department to publicize by uploading to the open web site of MARN.

4-2 Tools

1) The data format converter from SeisComP to SeisPC prepared by MARN.
2) SeisPC that was explained in the OJT held on 26Jan23.
3) MARN Guidebook 2023
4) Existing catalogue as of 10Feb23, which includes ISC catalogue.
5) Series of Scenarios as of 24Jan23
6) Tentative earthquake bulletin list as of 16Sep21, which has the information to be regularly or urgently issued to the public from MARN.

Appendix ISC

MARN was regularly providing data to ISC.

http://www.isc.ac.uk/ **About the International Seismological Centre**

ISC was set up in 1964 with the assistance of UNESCO as a successor to the International Seismological Summary to follow up the pioneering work of Prof. John Milne and Sir Harold Jeffreys in collecting, archiving and processing seismic station and network bulletins and preparing and distributing the definitive summary of world seismicity.

Under the umbrella of the IASPEI, ISC always played a role in setting up international standards such as the International Seismic bulletin Format, the IASPEI Standard Seismic Phase List and the IASPEI Manual of the Seismological Observatory Practice. **The ISC was always serving the scientific research**.

The current mission of the ISC is to maintain: 1) ISC Bulletin – the longest continuous definitive summary of World seismicity; 2) International Seismographic Station Registry (jointly with NEIC/USGS); 3) IASPEI Reference Event List (Ground Truth, jointly with IASPEI).

Scenarios of tsunami simulation exercises
for how to proceed with the Tsunami Monitoring Duty in El Salvador Ver.2

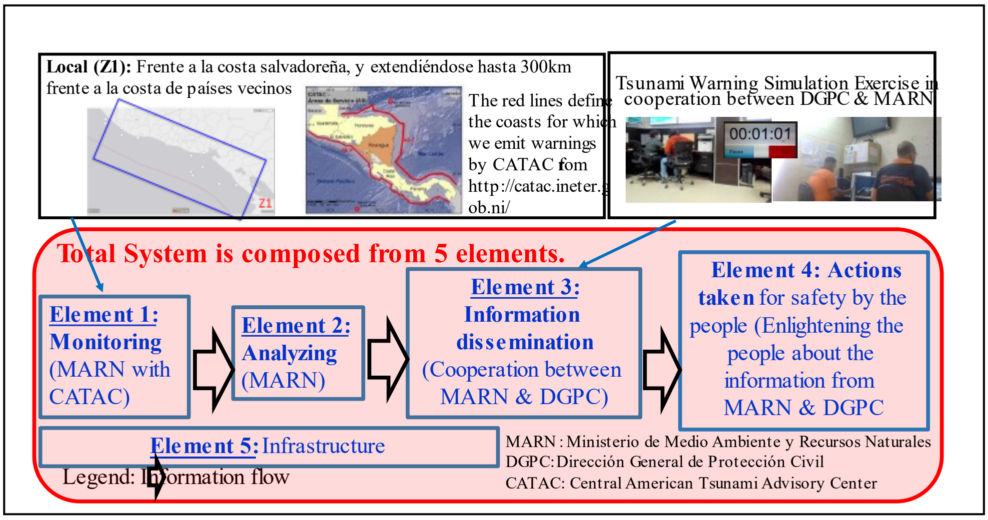
Prepared by Expert on 26Oct22

1. Introduction

MARN will implement the Tsunami warning Simulation Exercises according to **the exercise procedures** to be prepared based on **the scenario** selected from **series of them** (**See the appendix of this document.**) or developed through discussing **the purpose** and **the scope of the exercise** to be conducted.
This document will provide MANR with the series of scenarios mentioned above. Further this document additionally shows a) various exercise procedures, b) various purposes, and c) various scopes.

2. How to develop scenarios

A scenario should be developed with purpose and scope.
And the purpose should be decided through considering a) which elements (**See the below upper column.**) should be covered in the exercise and b) which zone (**See the below bottom column.**) should be handled.
Further, the scope should be decided through considering a) human resources issue, b) related projects issue (any additional enhancement), and c) actual events or disaster (any additional challenges).



Zone
Local (Z-1): Frente a las costas hasta 300km (aprox. hasta frontera Guatemala-México y frontera Nicaragua-Costa Rica).
Regional (Z-2): De 300km a 1000km (Desde las costas mexicanas hasta la costa de Colombia-Ecuador).
Distal (Z-3): Más de 1000km (toda la cuenca del Pacifico).

3. Purposes

3.1 As for Zone 1

3.1.1 Elements 1 and 2

To review the skill to handle urgent handling during 10 min with MARN internal drill.

3.1.2 Elements 1 and 2 and 3

1) To review the current tsunami warning official procedures in MARN
2) To brush up the skills for issuance of tsunami information to the public and for handling of communications between DGPC and MARN

3.1.3 Element 3

To review the status of cooperation procedures between MARN and DGPC

3.2 As for Zone 2

(To be filled according to our necessity.)

3.3 As for Zone 3

(To be filled according to our necessity.)

4. Scopes

4.1 Human resources

One drill will be handled by 2 officers from 21 officers. So, we can expect that 12 officers (= 2 offices x 6 drills) per year could experience a drill. We should consider more officers could experience drills to improve their ability from the drills. Further, we should expect the officers who should handle the drill planned would read the **guideline**[1] to review what to do in the emergency beforehand.

4.2 Related projects

We sometimes have any related projects like EEW, CATAC. So, we should consider the relation with those in the drills to get more “profits” from them.

4.3 Actual events/disasters

Scenarios should come from any events or from any disasters like historical ones and recent ones to find any challenges from them and resolve them through conducting drills.

5. Goal

To promote that the warnings/advisories and the information related to seismic and tsunami phenomena are properly issued from MARN/DGPC and used for the mitigation or prevention of concerned disasters by the users of the information accordingly.

6. Day and Time

To consider any anniversary like the 5th of November of the World Tsunami Awareness Day.

7. One idea on the detail of the exercise

1) To set the core exercise duration as 31 minutes. The Start, the End and the Stop announcements should be issued from MARN through Radio.

Its start time: XX:15 (Preparation should be initiated from XX:00)

Its end time: XX:46 (We should take the first “25 min” as “25 min”, but the last “5 min” as 2 hours and 40 min.)

2) To monitor the exercise somehow to efficiently review it.

3) Principal actions

3-1) Communications tools

Those would be used as shown in the below column.

---

[1] Guideline for how to proceed with the Tsunami Monitoring 02Oct22

Tools to be used to communicate between MARN and DGPC as of 01Nov21

	Feature	**Veraval, mutual, speedy Through human**	**Documentation Through human or automatic**	**Speedy, text only To many specific officers**	**Rich (Maps, Tables)**
Within	Messge type (depend)	Radio	Fax	WhatsApp	SNS
2 min	**CALM MESSAGE** Mensaje tranquilo	DGPC	None	MARN, DGPC	The public
3 min	**PRELIMINARY MESSAGES** Mensaje preliminar One of them has **a short table** of the preliminary arrivalt times.		DGPC		
15 min	**FINAL MESSAGE** Mensaje actualizado **With a Map**	DGPC without Map		MARN, DGPC without Map	
20 min	**Tsunami Message 1** Mensaje del tsunami **With a Table**	None	None	MARN, DGPC	The public
25 min	**Tsunami Message 2-1** Mensaje del tsunami 2-1 **With a Map** **Tsunami Message 2-2** Mensaje del tsunami 2-2 **With a Table**				
30 min	**Instrumental seismic intensity message** Mensaje de intensidad sísmica instrumental **With a Map**				
Depend	**Tsunami Observation message** Mensaje de observación de tsunamis				
Depend	**Tsunami Cancellation message 1** Mensaje de cancelación 1	DGPC	DGPC	DGPC	The public
Depend	**Tsunami Cancelation message 2** Mensaje de cancelación 2				

3-2) Sharing the actions

The actions like the below taken in issuing information to the public from MARN/DGPC should be known by both sides.

Procedures timeline

Table of actions against the event with Magnitude X.X off YYYYY at the drill on ZZNov22

(for "Aviso y Alerta de Tsunami" for LOCAL (Z1); the red actions should be acutually issued onlyt to DGPC.)

Elapsed time (min)	Status of the environment	Procedures to be started by the elapsed time	
		Actions taken by Seismic shift	Actione taken by Landslide shift
0	Detecting the event (starting the procedures)		
1	Given observed seismic waveforms of any stations		
2	Given automatic hypocenter & M	Issuing **Calm message (message 1)** via radio, fax and WhatsApp	
3		Selecting hypocenter & M according to the criteria based on data number & average RMS	Checking information in CISN
		Checking consistency with other information collected until the timing	
5		Issuing **Preliminary message (message 2-1)** with checked M, detection timing, indication of tsunami threat, and any term to tell what to do, via radio, fax and WhatsApp	Responding to supervisors and to the public
6		Disseminating Preliminary message via Twitter and web Disseminating Estimated tsunami arrival times (**ETA; message 2-2**) via radio, WhatsApp, Twitter and web	
7-15		Evaluating the latest hypocenter according to **the criteria** / Calculating manually seismic parameters / Selecting M according to **the criteria**	
		Issuing **Final message (message 3)** with degree of tsunami threat via radio, fax and WhatsApp	
		Disseminating **Final message** via Twitter and web	

(***Continuing***)

Procedures timeline (***Continued***)

10-20	Receiving seismic parameters and tsunami potential level from outside	Assesing the information from CATAC, PTWC, USGS and other outside organizations Judging necessity of updating the information	Issuing **tsunami bulletin (message 4)** with Seismic parameters, degree of tsunami threat, ETA via fax & WhatsApp / Disseminating **it** via
15-20	Getting Mw from CMT	Judging necessity of change of tsunami degree based on the Mw / If necessary, issuing message with updated information Disseminating **the ShakeMap (message 6)** with Twitter and web Locating aftershocks manually	Checking the information in the MARN web / Sea level gauges are monitored (arrival times and heights)/ Disseminating **the data (message 5-1 & 5-2)** via Twitter and web / **Informing authorities of the CMA** / Communicating with officials in the coastal zone / Monitoring the information in international agencies, media & Twitter and web
20-30		Addressing media	
40			Issueing **tsunai observation message (message 7)**
Beyond 3 hours		Issuing **Tsunami cancellation (message 8 & 9)** via radio & WhatsApp	

3-3) Remarks
a) Notification
We should add the word "Drill" on every message that should be sent to the outside of MARN and DGPC; and we should tell "this is a drill action" in radio and WhatsApp.
b) Public relations
If we have time, we should prepare and post a flyer on the homepages to introduce the joint tsunami exercise; or we should inform the mass media of it from their PR sections. The PR activities will enlighten the populations on the necessity of preparation against seismic or tsunami disasters.

8. Future

1) The tsunami simulation exercise cohosted by DGPC and MARN should be held on the regular basis for making people remind the experience on Tsunami events, like the "26th of August 2012" event.
2) The level of difficulty should be increased step by step, if necessary, like 1) being involved from more municipalities according to the selected scenario, 2) considering the timing of cancellation[2], 3) including any problem in communications tools[3], 4) considering the contents of information[4] according to the feature of the event selected as the scenario.

[2] The chapter 4 (Elaboration of cancellation procedures) of the "**Guideline for how to proceed with the Tsunami Monitoring 11Oct22**" tells that "The cancellation should be followed the Tsunami Protocol. In addition, we should take care of the arrival of larger tsunamis after diminishing of initial tsunamis. (Note: To talk DGPC to use only MARN's cancellation information.)"

[3] The Note in the "chapter 3" (Daily monitoring works - 1) Works just after taking over the shift duty) of the "**Guideline for how to proceed with the Tsunami Monitoring 11Oct22**" tells that "The inspection of communications tools could be practically carried out when MARN should handle small size seismic phenomena."

[4] The messages related to actions like "preparation", "evacuation" and "take actions", must be clearly understood as well by the officers of both of DGPC and MARN to be able to explain to the people or to the media. On the workshop for reviewing the exercise, this must be one of topics to be clarified through explained their own understandings by both of DGPC and MARN.

3) A workshop, to review the exercise, cohosted by MARN and DGPC should be held annually. The date should be just after implementation of the above exercise according to its purpose.

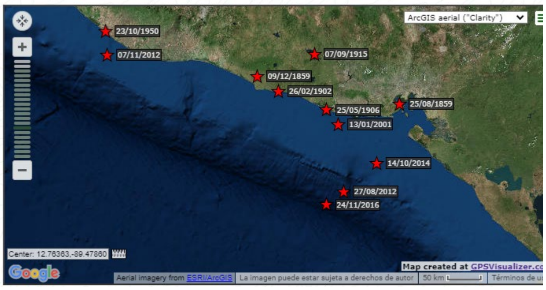
Appendix Series of Scenarios

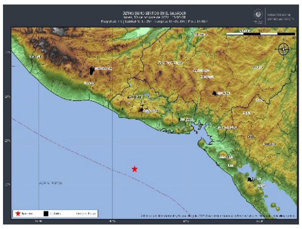
Scenarios of tsunami simulation exercises
for how to proceed with the Tsunami Monitoring Duty in El Salvador
Officers who has conducted drills until now: Favio & Cecilia (05Nov21), Marlon (07Jul22)

Purpose	Element	Zone	Long span purpose: Human resources issue	Long span purpose: Related projects issue (enhancement)	Long span purpose: Actual events or disasters (challenges)	Scenario		
To coordinate the understandings of DGPC and MARN shift officers about a) the current tsunami warning official procedures in DGPC and MARN b) the status of cooperation procedures between MARN and DGPC	3	Local (Z-1): Frente a las costas hasta 300km (aprox. hasta frontera Guatemala-México y frontera Nicaragua-Costa Rica).	To be considered	None	One of 24 tsunamis since 1859	1	Type	26Aug12 off Usultan
							Feature	Same as the previous one of 26Aug12
To brush up the skills for issuance of tsunami information to the public and for handling of communications between DGPC and MARN	1, 2, 3						Epicenter	Off Usultan
							Mw	7.3
To enhance the awareness of tsunami threar thropugh urging the populations at the coast of Usultan to have any tsunami evacuation drill, by chance	4						M	tsunami earthquake
							Origin Time	10:25 AM 10OctXX
To coordinate the understandings of DGPC and MARN shift officers about a) the current tsunami warning official procedures in DGPC and MARN b) the status of cooperation procedures between MARN and DGPC	3	Ditto	To be considered	Tsunami Ready	One of 24 tsunamis since 1859	2	Type	13Jan01 near coast
							Feature	M7.7 class and near to coast
To brush up the skills for issuance of tsunami information to the public and for handling of communications between DGPC and MARN	1, 2, 3						Epicenter	Off Rio Lempa
							Mw	7.7
To enhance the awareness of tsunami threar thropugh urging the populations at the coast of Usultan and La Libertad to have any tsunami evacuation drill, by chance	4						M	tsunami earthquake
							Origin Time	08:25 AM 05Nov22
To coordinate the understandings of DGPC and MARN shift officers about a) the current tsunami warning official procedures in DGPC and MARN b) the status of cooperation procedures between MARN and DGPC	3	Ditto	Officers who would conduct the drill with this senario	Tsunami Ready	Larger than the maximun size local earthquakes definitively having tsunami since 1859	3	Type	Fault length and slip amount should be twice of the "26Aug12 off Usultan".
							Feature	M7.9 class and off La Libertad
To brush up the skills for issuance of tsunami information to the public and for handling of communications between DGPC and MARN	1, 2, 3						Epicenter	118km off La Libertad; west of "26Aug12 off Usultan"
							Mw	7.9
To enhance the awareness of tsunami threar thropugh urging the populations at the coast of La Libertad to have any tsunami evacuation drill, by chance	4						M	Normal earthquake
							Origin Time	10:00 AM 22Nov22

# date	lat	lon	q	depth	q	mw	q
1915-09-07 01:20:49.10	14.126	-89.007	C	15	C	7.7	C
2001-01-13 17:33:32.16	13.06	-88.699	A	38	A	7.71	A
2012-08-27 04:37:20.05	12.189	-88.654	A	20	A	7.34	A

From The "ISC-GEM Catalogue" as of 10Oct22





Scenario 3

Period

Scenarios of tsunami simulation exercises
for how to proceed with the Tsunami Monitoring Duty in El Salvador

Purpose	Zone	Scope: Related projects issue	Scope: Actual events or disasters	Scenario		
Coordinar los entendimientos de los oficiales de turno de la DGPC y el MARN sobre a) los procedimientos oficiales actuales de alerta de tsunamis en DGPC y MARN, b) el estado de los procedimientos de cooperación entre el MARN y la DGPC	Local (Z-1): Frente a las costas hasta 300km (aprox. hasta frontera Guatemala-México y frontera Nicaragua-Costa Rica).	Ninguno	Uno de los 24 tsunamis desde 1859	**1**	Type	26Aug12 off Usultan
Repasar las habilidades para la emisión de información sobre tsunamis al público y para el manejo de las comunicaciones entre DGPC y MARN					Feature	Same as the previous one of 26Aug12
Aumentar la conciencia del tsunami a través de instando a las poblaciones de la costa de Usultan a tener cualquier simulacro de evacuación de tsunami, por casualidad					Epicenter	Off Usultan
					Mw	7.3
					M	tsunami earthquake
					Origin Time	10:25 AM 10OctXX
Igual que el escenario 1	Ditto	Tsunami Ready	Uno de los 24 tsunamis desde 1859	**2**	Type	13Jan01 near coast
Igual que el escenario 1					Feature	M7.7 class and near to coast
Aumentar la conciencia del tsunami a través de instando a las poblaciones de la costa de Usultan y La Libertad a tener cualquier simulacro de evacuación de tsunami, por casualidad					Epicenter	Off Rio Lempa
					Mw	7.7
					M	tsunami earthquake
					Origin Time	08:25 AM 05Nov22
Igual que el escenario 1	Ditto	Tsunami Ready	Terremotos locales más grandes que el tamaño máximo que definitivamente tienen tsunami desde 1859	**3**	Type	Fault length and slip amount should be twice of the "26Aug12 off Usultan".
Igual que el escenario 1					Feature	M7.9 class and off La Libertad
Aumentar la conciencia del tsunami a través de instando a las poblaciones de la costa de La Libertad a tener cualquier simulacro de evacuación de tsunami, por casualidad					Epicenter	118km off La Libertad; west of "26Aug12 off Usultan"
					Mw	7.9
					M	Normal earthquake
					Origin Time	10:00 AM 22Nov22

Scenarios of tsunami simulation exercises
for how to proceed with the Tsunami Monitoring Duty in El Salvador

Purpose	Zone	Scope: Related projects issue	Scope: Actual events or disasters	Scenario		
To coordinate the understandings of DGPC and MARN shift officers about a) the current tsunami warning official procedures in DGPC and MARN b) the status of cooperation procedures between MARN and DGPC	Local (Z-1): Frente a las costas hasta 300km (aprox. hasta frontera Guatemala-México y frontera Nicaragua-Costa Rica).	None	One of 24 tsunamis since 1859	**1**	Type	26Aug12 off Usultan
To brush up the skills for issuance of tsunami information to the public and for handling of communications between DGPC and MARN					Feature	Same as the previous one of 26Aug12
To enhance the awareness of tsunami threar thropugh urging the populations at the coast of Usultan to have any tsunami evacuation drill, by chance					Epicenter	Off Usultan
					Mw	7.3
					M	tsunami earthquake
					Origin Time	10:25 AM 10OctXX
Same as the scenario 1	Ditto	Tsunami Ready	One of 24 tsunamis since 1859	**2**	Type	13Jan01 near coast
Same as the scenario 1					Feature	M7.7 class and near to coast
To enhance the awareness of tsunami threar thropugh urging the populations at the coast of Usultan and La Libertad to have any tsunami evacuation drill, by chance					Epicenter	Off Rio Lempa
					Mw	7.7
					M	tsunami earthquake
					Origin Time	08:25 AM 05Nov22
Same as the scenario 1	Ditto	Tsunami Ready	Larger than the maximun size local earthquakes definitively having tsunami since 1859	**3**	Type	Fault length and slip amount should be twice of the "26Aug12 off Usultan".
Same as the scenario 1					Feature	M7.9 class and off La Libertad
To enhance the awareness of tsunami threar thropugh urging the populations at the coast of La Libertad to have any tsunami evacuation drill, by chance					Epicenter	118km off La Libertad; west of "26Aug12 off Usultan"
					Mw	7.9
					M	Normal earthquake
					Origin Time	10:00 AM 22Nov22

Scenarios of tsunami simulation exercises
for how to proceed with the Tsunami Monitoring Duty in El Salvador
Officers who has conducted drills until now: Favio & Cecilia (05Nov21), Marlon (07Jul22)

Purpose	Element	Zone	Long span purpose			Scenario		
			Human resources issue	Related projects issue (enhancement)	Actual events or disasters (challenges)			
To coordinate the understandings of DGPC and MARN shift officers about a) the current tsunami warning official procedures in DGPC and MARN b) the status of cooperation procedures between MARN and DGPC	3	Local (Z-1): Frente a las costas hasta 300km (aprox. hasta frontera Guatemala-México y frontera Nicaragua-Costa Rica).	To be considered	None	One of 24 tsunamis since 1859	1	Type	26Aug12 off Usultan
							Feature	Same as the previous one of 26Aug12
To brush up the skills for issuance of tsunami information to the public and for handling of communications between DGPC and MARN	1, 2, 3						Epicenter	Off Usultan
							Mw	7.3
To enhance the awareness of tsunami threar thropugh urging the populations at the coast of Usultan to have any tsunami evacuation drill, by chance	4						M	tsunami earthquake
							Origin Time	10:25 AM 10OctXX
To coordinate the understandings of DGPC and MARN shift officers about a) the current tsunami warning official procedures in DGPC and MARN b) the status of cooperation procedures between MARN and DGPC	3	Ditto	To be considered	Tsunami Ready	One of 24 tsunamis since 1859	2	Type	13Jan01 near coast
							Feature	M7.7 class and near to coast
To brush up the skills for issuance of tsunami information to the public and for handling of communications between DGPC and MARN	1, 2, 3						Epicenter	Off Rio Lempa
							Mw	7.7
To enhance the awareness of tsunami threar thropugh urging the populations at the coast of Usultan and La Libertad to have any tsunami evacuation drill, by chance	4						M	tsunami earthquake
							Origin Time	08:25 AM 05Nov22
To coordinate the understandings of DGPC and MARN shift officers about a) the current tsunami warning official procedures in DGPC and MARN b) the status of cooperation procedures between MARN and DGPC	3	Ditto	Officers who would conduct the drill with this senario	Tsunami Ready	Larger than the maximun size local earthquakes definitively having tsunami since 1859	3	Type	Fault length and slip amount should be twice of the "26Aug12 off Usultan".
							Feature	M7.9 class and off La Libertad
To brush up the skills for issuance of tsunami information to the public and for handling of communications between DGPC and MARN	1, 2, 3						Epicenter	118km off La Libertad; west of "26Aug12 off Usultan"
							Mw	7.9
To enhance the awareness of tsunami threar thropugh urging the populations at the coast of La Libertad to have any tsunami evacuation drill, by chance	4						M	Normal earthquake
							Origin Time	10:00 AM 22Nov22

Draft minutes of the seminar with CATAC on 07Feb23

Prepared by MORI on 12Feb23

Date & Time: 07Feb22 (Tus) 09:10 - 10:55 AM Central American Time

Attendance:

CATAC: Wilfried, Emilio

MARN: Manuel, Douglas, Griselda, and Luis

JICA: Shigeo (MORI; Expert); Ken (Uchimoto), Dera

Documents:

Memo for the seminar with CATAC on 07Feb23

Purpose of the cooperation

For MARN, to more properly share information related to the tsunami warning with CATAC to more properly handle the tsunami information issued from CATAC in the tsunami warning system of MARN

For CATAC, to maintain reliability of CATAC through preventing human errors with the information that can be referred to for handling tsunami advisories.

Results 1/4

1. Status of MARN (20 min including Q&A)

Regarding "Review the progress in MARN", Expert has explained the latest procedures and the timeline of tsunami warning of MARN with several slides.

CATAC issues two messages on earthquakes, having automatic results and checked ones. The checked one would be issued within 2 minutes after the issuance of the automatic one.

Regarding "Status of MARN on the items we should discuss", Expert has explained about 1) GPS sophistication, 2) tsunami database, 3) multiple events issue.

1) Nicaragua has 20 GPS real time observations; CATAC would consult the GPS issue with a university in US (Washington University?). MARN has consulted another university in US as well.

2) CATAC has made the tsunami simulation on the 2012 event; they can show the result in the planned webinar on 21Feb23.

3) The multiple events issue should be handled properly. The issue should be considered further.

Regarding "Status of MARN on the data available including the data from other countries", Expert has explained the tables that show the assumed data provided from the foreign organizations. (*Continuing*)

Results 2/4

Regarding "Status of MARN on the data available including the data from other countries", (*Continued*)
CATAC is getting data from many organizations in the CA *like ?Guatemala (??), ACP? (20?), UCR ?(40?), COPECO ?(40?), ?Ecuador (??),* and Caribbean stations additionally. But sometimes the communications status become wrong. But some Caribbean stations were affected by hurricanes. It would take some time and high cost to be recovered.
(MORI is sorry that he has not well described here what CATAC had explained in the seminar. So, Dr. Starch, would you please make comment on the above issue and on the below status.)

2. Status of CATAC (20 min including Q&A)

Regarding "review the progress in CATAC including international negotiations", *CATAC is working to get the official agreement to start its work officially from the Caribbean area team of IOC. After that CATAC should get it from the superior authority.*
Regarding "Status of CATAC on the items we should discuss", we have had no discussion on it.
Regarding "Status of CATAC on the data available including the data from other countries", it is as described in the previous agenda.

Results 3/4

20 min including Q&A

3. The items initially proposed from CATAC (MARN, CATAC)

Regarding "To define that MARN could be the backup of CATAC in case of impact of earthquake or other events at CATAC", MARN has proposed an idea as described in **the slide 32**. CATAC has accepted the idea. CATAC has mentioned that they are also discussing the same issue with Honduras.

Regarding "To exchange "seismic and tsunami processing results" in sub real time", CATAC has mentioned that we should discuss the issue further.

Regrading "To unify processing parameters and definition of common event bulletin in a short time after the occurrence of earthquakes", CATAC has mentioned that we should discuss this issue further.

Regarding "To install a permanent voice and video connection", it was done .

Results 4/4

4. Wrap up (20 min including Q&A and adaption of the resolution)

CATAC would have a tsunami warning drill in *June 2023 with Panama(?).*

We have discussed the draft resolution and have approved them.

CATAC has mentioned about the Starlink that handles satellite internet connection in the world. https://www.starlink.com/ It might become an economical connection in the future.

Agenda 1/2

1. Situación del MARN

1.1 Revisar los avances en el MARN

1.2 Situación del MARN sobre los temas que debemos discutir (GPS sophistication, tsunami database, multiple events issue)

1.3 Situación del MARN sobre los datos disponibles, incluidos los datos de otros países

2. Situación del CATAC

2.2 Revisar el progreso en CATAC, incluidas las negociaciones internacionales

2.3 Situación de CATAC sobre los temas que debemos discutir

2.4 Situación de CATAC sobre los datos disponibles, incluidos los datos de otros países

Agenda 2/2

3. Los ítems propuestos inicialmente desde el CATAC (MARN, CATAC)

3.1 Definir que el MARN podría ser el respaldo del CATAC en caso de impacto de terremoto u otros eventos en el CATAC.

3.2 Intercambiar "resultados de procesamiento sísmico y de tsunamis" en tiempo real

3.3 Unificar los parámetros de procesamiento y definición del boletín de eventos comunes en poco tiempo después de la ocurrencia de terremotos

3.4 Para instalar una conexión permanente de voz y vídeo

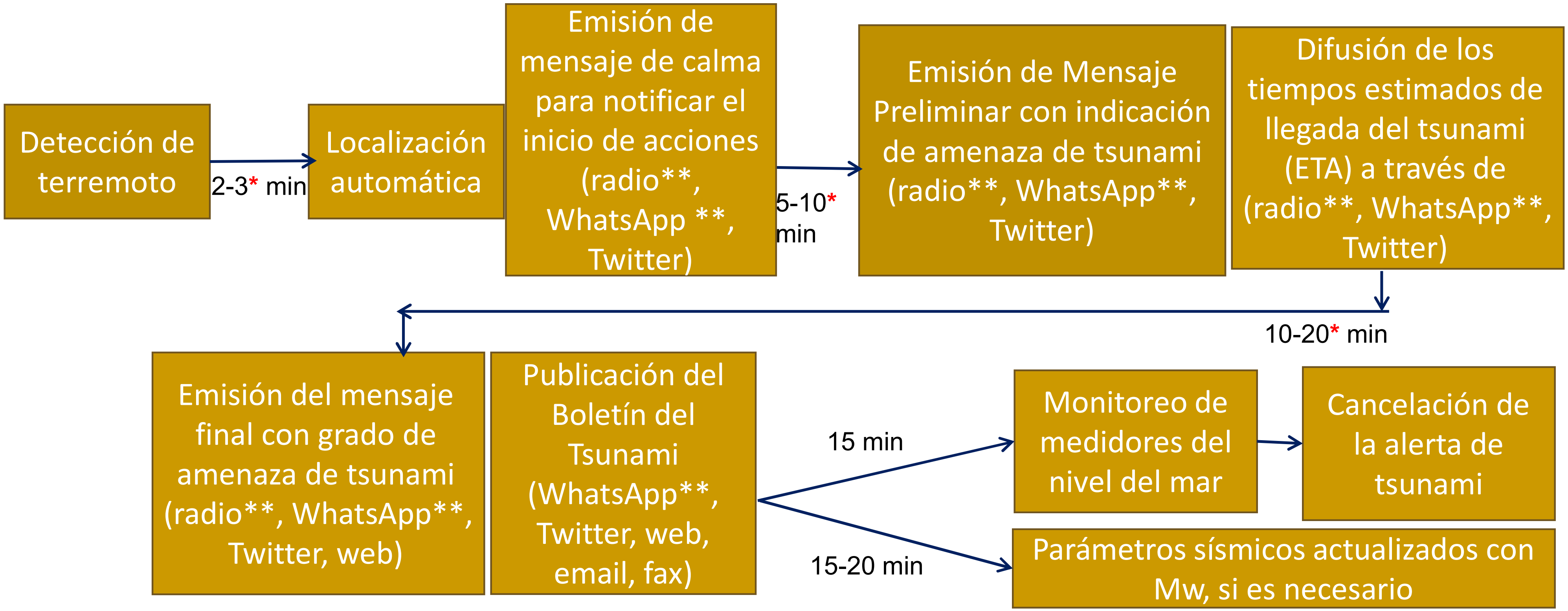
4. Concluye

4-1 Discusión sobre la **resolución** (MARN, CATAC)

4-2 Discusión sobre cómo hacer que la resolución funcione en consecuencia (MARN, CATAC)

1-1) Revisar los avances en el MARN

Resumen de acciones realizadas por el Observatorio Ambiental del MARN ante la amenaza de un tsunami



Los tsunamis locales llegan a la costa de El Salvador en menos de 1 hora, los tsunamis regionales entre 1 y 3 horas y los tsunamis distales en más de 3 horas

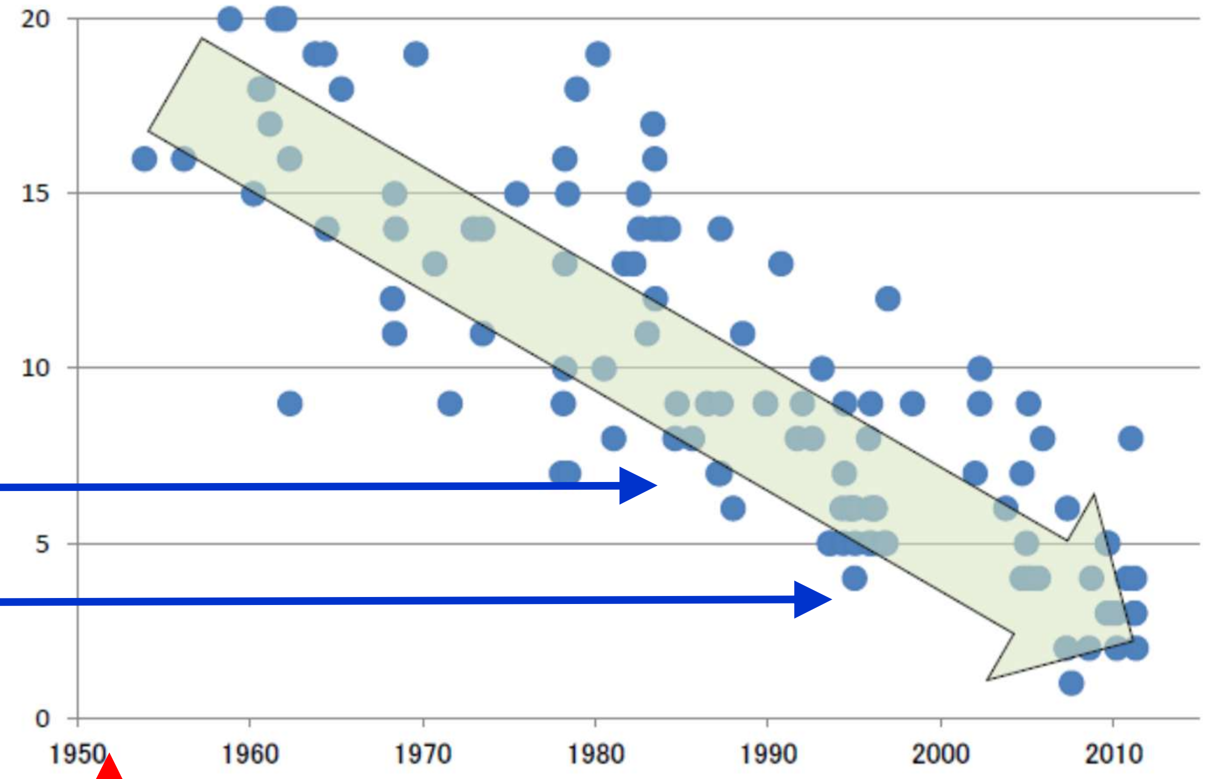
1-1) Revisar los avances en el MARN

Herramientas para comunicarse con DGPC y difundir la información al público

Tiempo transcurrido desde la detección del sismo		Herramientas	Radio	WhatsApp	Fax	Twitter	Web
	Procedures or actions	Hacia	DGPC y autoridadess locales	DGPC y autoridadess locales	DGPC	Público	Público
0 min	Detección de terremoto						
2-3 min	Localización automática						
	Emisión de mensaje de calma para notificar el inicio de acciones		Primero	Segundo	Copia de redundancia para WhatsApp	Segundo	
5-10 min	Emisión de Mensaje Preliminar con indicación de amenaza de tsunami						Tercero
	Difusión de los tiempos estimados de llegada del tsunami (ETA)						
10-20 min	Emisión del mensaje final con grado de amenaza de tsunami						
	Emisión y difusión del Boletín de Tsunami con parámetros sísmicos, grado de amenaza de tsunami, ETA, y de altura estimada de tsunami			Primero	Segundo (Junto con emal)	Tercero	
	Los datos potenciales de tsunami emitidos por PTWC y CATAC son evaluados y divulgados.				Copia de redundancia para WhatsApp		
15-20 min	Parámetros sísmicos actualizados con Mw, si es necesario						
	Difusión de mapas de intensidad instrumental (ShakeMap)						

Not so often occur Tsunami comes soon

Progress in Dissemination Timing of Tsunami Warning in Japan



1983 Arrival 7 min with an event in Japan Sea

1993 Arrival several min with an event at SW off Hokkaido

1952 Start of Tsunami Warning

1999 Quantitative Tsunami Warning

2006 introduction of Ergent Earthquake Warning technology

平成24年度 気象・地震等の情報に関する講習会 http://www.jma.go.jp/jma/kishou/minkan/koushu120518/shiryou4.pdf

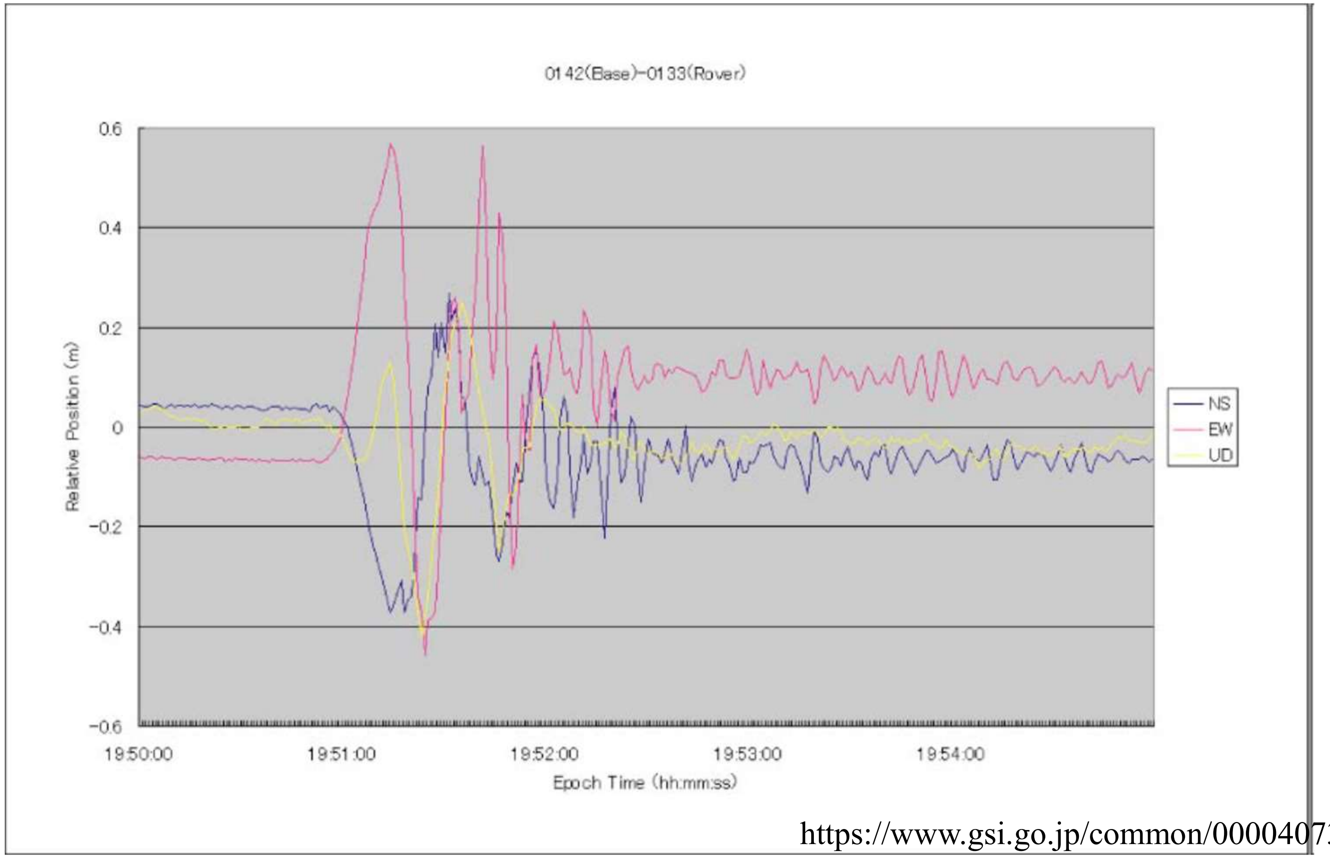
Real-time Monitoring of Ground Movement by Kinematic GPS and its Contribution to Tsunami Forecast

Seismometers and accelerometers measure ground velocity and acceleration, respectively. They are very sensitive to short-period seismic waves but less sensitive to longer-period ones. Contrast to them, GPS measures ground displacement in short- and long-period components, even in DC one. GPS is never saturated and measures the displacement in wide frequencies and dynamic ranges. The larger earthquakes occurred; the longer period seismic waves are radiated. Large events should demonstrate advantages of kinematic GPS as a sensor monitoring the ground motion.

The Geographical Survey Institute (GSI) is operating the GEONET consisting of 1200 continuous GPS stations in Japan. GEONET GPS data with 1 second sampling are transmitting to the analysis center of the GSI in real time. Moreover, the GSI constructed a system to analyze the transmitted data and to monitor the ground displacement in real time.

https://www.gsi.go.jp/common/000040737.pdf

Ground displacement of the 2003 M8.0
Tokachi-Oki earthquake on September 26, 2003, observed by kinematic GPS with 1Hz sampling. It clearly shows static crustal displacements (offsets between 19:50 and 19:52) as well as long-period seismic waves.



https://www.gsi.go.jp/common/000040737.pdf

GPS sophistication (a comment from one of GPS specialist)

1. Regarding warning tsunamis using CMT analysis or W-phase with GPS observation, he has no experience on the issue, but thinks it is quite a challenging issue because GPS is much less sensitive to ground motions than seismographs. Even if it is possible to estimate the epicenter process in real time, a network of observation points like GEONET is required, so he thinks it may be very difficult only with two observation points in El Salvador.

2. The Geospatial Information Authority of Japan (GSI) is developing a system called the "Real-time GEONET Analysis system for Rapid Deformation Monitoring (REGARD) ", which estimates focal mechanism in real time using GEONET's 1Hz sampling data. This uses inverse analysis from the ground surface displacement associated with the earthquake. With this, it seems that the magnitude of the epicenter and the amount of slippage can be estimated in real time or almost in real time even for an inland M7 class earthquake. (*Continuing*)

GPS sophistication

(*Continued*) In the case of El Salvador, he thinks the following is necessary:

1) The number of observation points should be increased to, preferably, several tens ~ 100 observation points,

2) For real-time analysis, Position estimation should be performed in real time by RTKLIB or by others that allows a real-time kinematic analysis using phase data of 1Hz sampling obtained from these observation points. Since precise position data of GPS satellites is required to obtain the highest accuracy, it is necessary to acquire the Precise Ephemeris of International GNSS Service (IGS) via the Internet separately and use it for analysis. "Our prioritized idea on the GPS data handling system (rough image)" is also good, because the receiver itself has a function that can obtain the Precise Ephemeris of the satellite, and you can get a precise positioning solution directly from the receiver (although the receiver is more expensive accordingly).

3. In any case, he thinks that considerable technical training is required to produce proper results.

Note on the terms 1/2

GEONET is the acronym for the GNSS Earth Observation Network System operated by the Geospatial Information Authority of Japan (GSI). That is an observation system that aims to establish a high-density and high-precision survey network consisting of electronic reference points installed at approximately 1,300 locations nationwide and the GEONET Central Station (Tsukuba City, Ibaraki Prefecture) and to monitor crustal movements over a wide area.
GNSS (Global Navigation Satellite System) is the general term for satellite positioning systems such as GPS in the United States, Quasi-Zenith Satellite (QZSS) in Japan, GLONASS in Russia, and Galileo in the European Union.
https://www.gsi.go.jp/denshi/denshi65009.html
The method was developed by Prof. Yusaku Ohta of Tohoku University, who is still actively challenging tsunami prediction by real-time analysis.
https://irides.tohoku.ac.jp/eng/organization/ohta_yusaku.html

Note on the terms 2/2

RTKLIB is that, for RTK (Real Time Kinematic)-GPS, a concise and highly portable RTK-GPS positioning calculation library written in C language, and a collection of application programs using it.

RTK is one of the measurement methods called "relative positioning". It is a technology that receives signals from four or more satellites with two receivers, a fixed station, and a mobile station, and by exchanging information between the two receivers and correcting the misalignment, it is possible to obtain position information with higher accuracy than single positioning. The biggest feature of RTK is that it can be kept to within a few centimeters, although there is some error.

The Precise Ephemeris is more accurate satellite orbit information than the broadcasted Ephemeris. Currently, the most used Precise Ephemeris is the IGS one created and provided by IGS.

Current GPS data handling system (rough image) as of 06Oct22

Unmanned:

Existing 2 GPS stations with Topcon NetG3A receiver & CR-5 antenna **in El Salvador** (Sampling rate: 1/30 Hz)

Radio communication through Internet with IP Address or private network with Top NET

Manned:

MARN monitoring center **in San Salvador**

MARN remotely, manually and regularly gets data from the station and analyzes them.

Our prioritized idea on the GPS data handling system (rough image)

Unmanned: (a "COR" & a "target")

Existing 2 GPS stations with existing NetG3A & CR-5 **in El Salvador** (1.0Hz or 5.0Hz; "with or without OAF" - should be checked)

Radio communication through Internet with IP Address or private network with Top NET

(communication test with the rate should be conducted.)

Manned:

MARN monitoring center **in San Salvador**

With new device, like "RTX system for Trimble", to make corrections in real time based on the information transmitted by the satellites without any corrections from Continuously Operating Reference Stations (CORS).

MARN remotely & automatically gets streamline data in real time from the station with new software 1 with dashboard made by 3rd party, Bruno, and analyzes them in the center with repository (100 Mb/day or larger),if necessary.

Another idea on the GPS data handling system (rough image)

Unmanned: (a COR & a "target")
Existing 2 GPS stations with existing new NetG5 & CR-5 **in El Salvador** (1.0Hz or 5.0Hz)

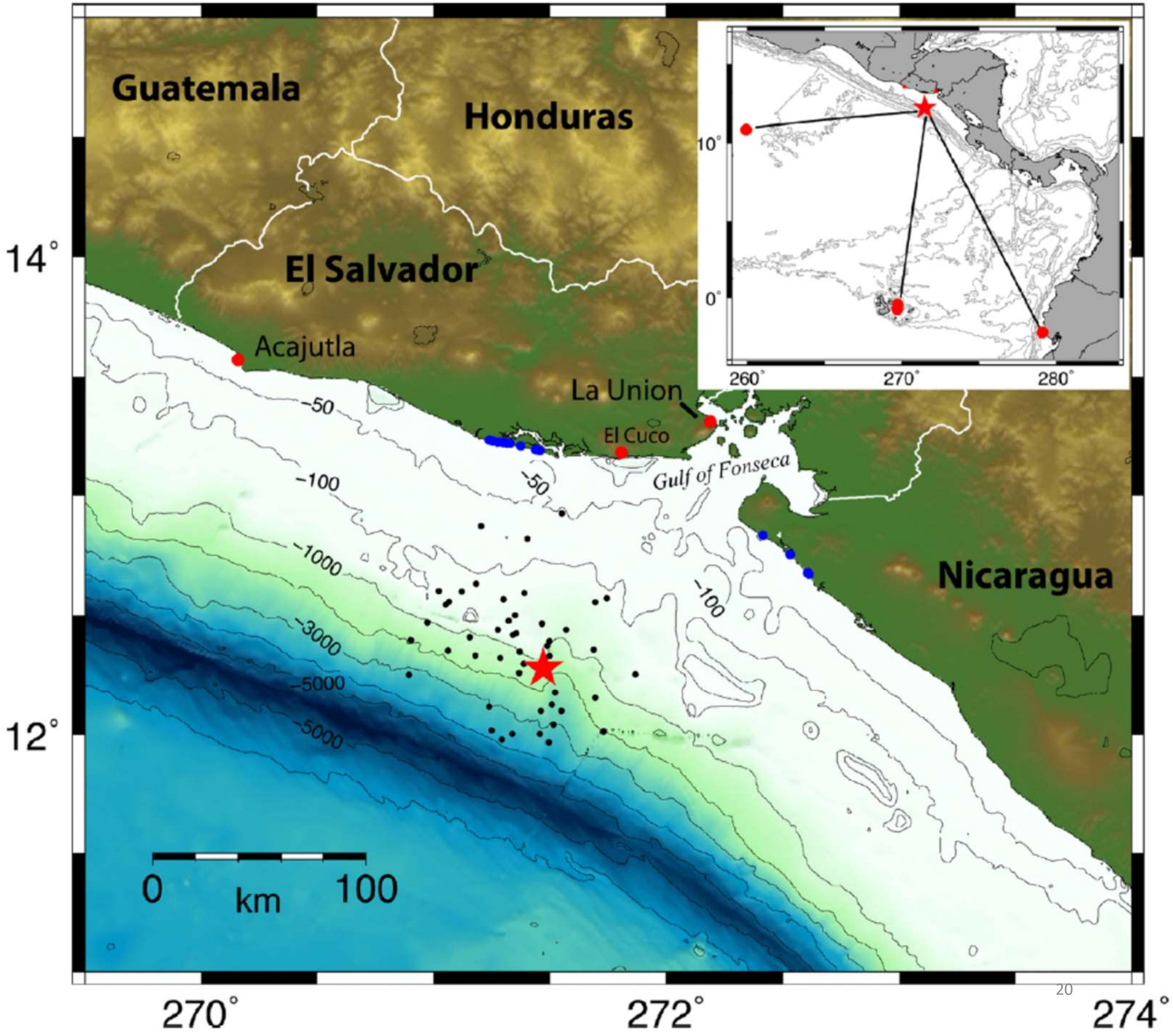
Radio communication through Internet with IP Address or private network with Top NET
(communication test with the rate should be conducted.)

Manned:
MARN monitoring center **in San Salvador**

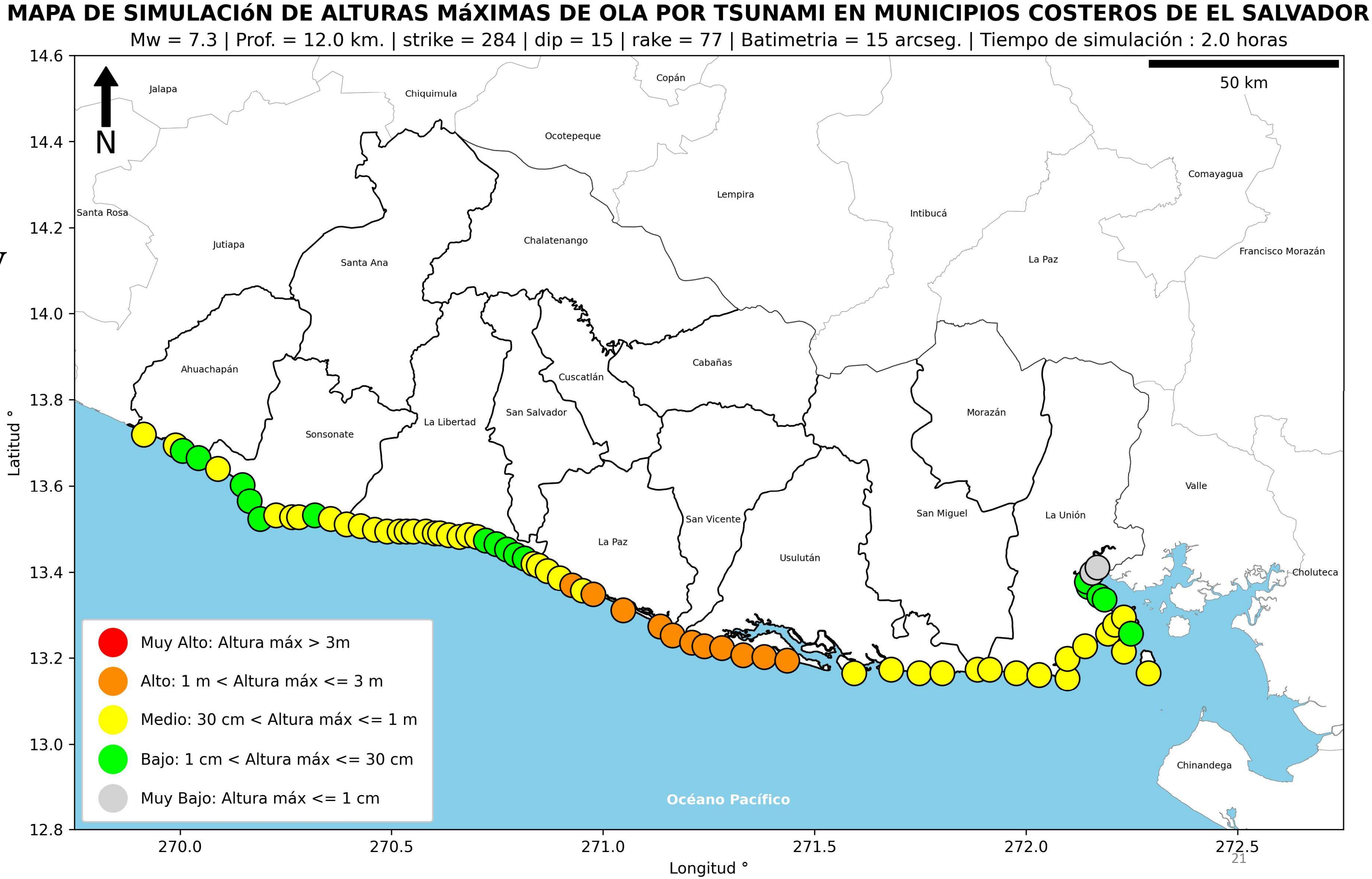
Receiver at the station automatically & continuously sends streamline data in real time with new software 2 (Topcon Receiver Utility to configure FTP push in TRU)

MARN remotely & automatically gets streamline data in real time from the station with new software 1 with dashboard made by 3rd party, Bruno, and analyzes them in the center with repository (100 Mb/day or larger), if necessary.

Simulations on the 2012 Usultan event after Borrero et al 2014 1/4



Simulation with the scaling law of Utsu 2001 by MARN



Simulations on the 2012 Usultan event after Borrero et al 2014 2/4

Table 3

General description and characteristics of the different source models

Source	Details
S1	USGS finite fault model, no scaling
S2	USGS finite fault model, 1.92 scale factor based on a slow rupture in mechanically softer material (see Newman *et al.* 2011 and "Appendix" section)
S3	USGS finite fault model, 2.55 scale factor to match amplitude of leading wave at DART 43413
S4	Moment magnitude-constrained custom inversion based on a least-squares regression between modeled tsunami waveforms produced by unit (1 m) slip on shallow subfaults in the source region and recorded data at DART 43413
S5	Same as 4, but magnitude is unconstrained
S6	Rectangular fault model. 60 × 30 km, 2.2 m slip, dip 15°, rake 81°, strike 287°, determined from macro-scale seismic parameters (Heidarzadeh and Satake 2014)
S7	Ye *et al.* (2013) finite fault model, no scaling ($V_r = 2.0$ km/s)
S8	Ye *et al.* (2014) finite fault model, with modified rupture velocity ($V_r = 1.5$ km/s)

Simulations on the 2012 Usultan event after Borrero et al 2014 3/4

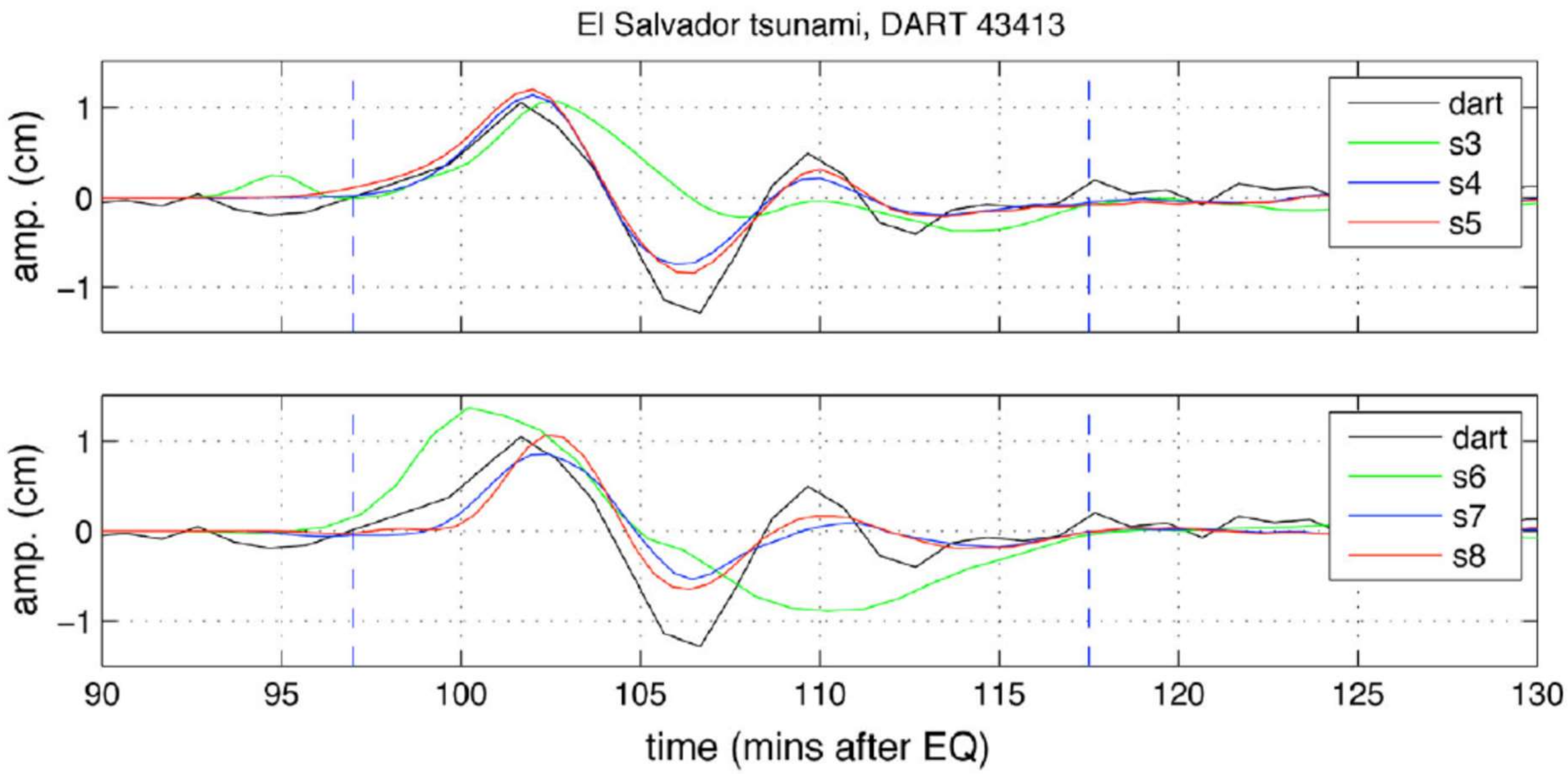


Figure 10
Recorded water level time series at DART 43414 compared to model results for six different tsunami sources. The *vertical dashed lines* denote the portion of the data record used to invert for tsunami sources *4* and *5*

Simulations on the 2012 Usultan event after Borrero et al 2014 4/4

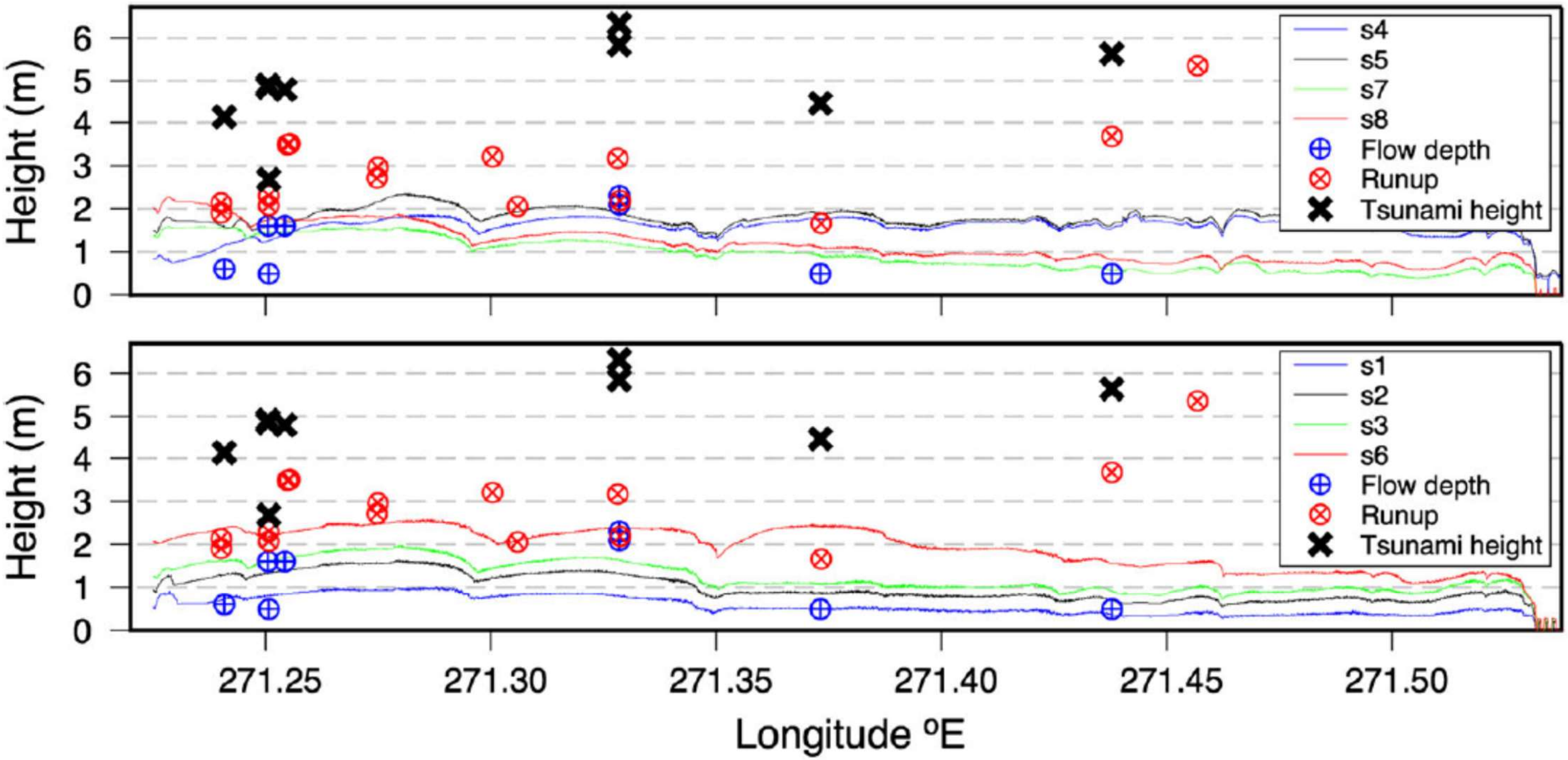


Figure 8
Tsunami heights modeled on land from the eight different sources compared to field measurements

Tsunami database 1.2 Status of MARN on the items we should discuss (tsunami database)

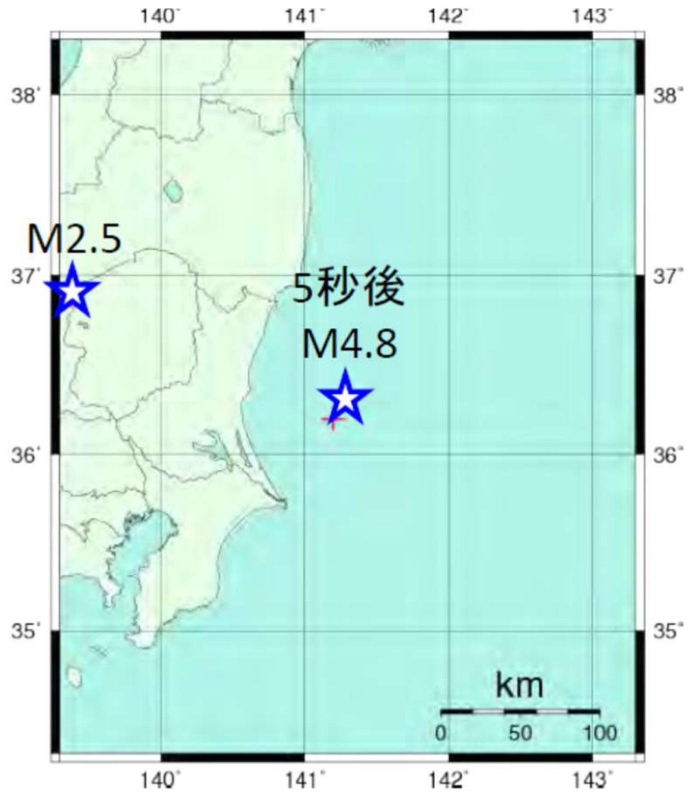
Regarding the database, based on the results from comparison with the observations in the 2012 Usultan event and from comparison with the estimated heights obtained from the standard scaling law like Blaser 2010 or Utsu 2001/1984, it should be reconsidered due to its under-estimation about the event.

	MARN Tsunami database			2012 event simulation Mw7.3			MARN Guidebook 2017			JMA		
Mw	Dislocación (metros) U	Ancho (km) W	Largo (km) L	Dislocación (metros) U	Ancho (km) W	Largo (km) L	Dislocación (metros) U	Ancho (km) W	Largo (km) L	Dislocación (metros) U	Ancho (km) W	Largo (km) L
7.0	0.2	50	100	1.2	22.9	41.7	2.5	22.4	44.7	2.0	20.0	39.8
7.1	0.3	50	100	1.3	25.5	47.5	2.8	25.1	50.1	2.2	22.4	44.7
7.2	0.4	50	100	1.5	28.3	54.2	3.2	28.2	56.2	2.5	25.1	50.1
7.3	0.5	50	100	1.6	31.5	61.8	3.5	31.6	63.1	2.8	28.2	56.2
7.4	0.7	50	100	1.8	35.0	70.5	4.0	35.5	70.8	3.2	31.6	63.1
7.5	1.0	50	100	2.0	38.9	80.4	4.5	39.8	79.4	3.5	35.5	70.8
7.6	1.4	50	100	2.3	43.3	91.6	5.0	44.7	89.1	4.0	39.8	79.4
7.7	2.0	50	100	2.5	48.1	104.5	5.6	50.1	100.0	4.5	44.7	89.1
7.8	2.8	50	100	2.8	53.5	119.1	6.3	56.2	112.2	5.0	50.1	100.0
7.9	4.0	50	100	3.2	59.4	135.8	7.1	63.1	125.9	5.6	56.2	112.2
8.0	5.6	50	100	3.5	66.1	154.9	7.9	70.8	141.3	6.3	63.1	125.9

Enhancement of hypocenter analysis against multi-occurrence of earthquakes

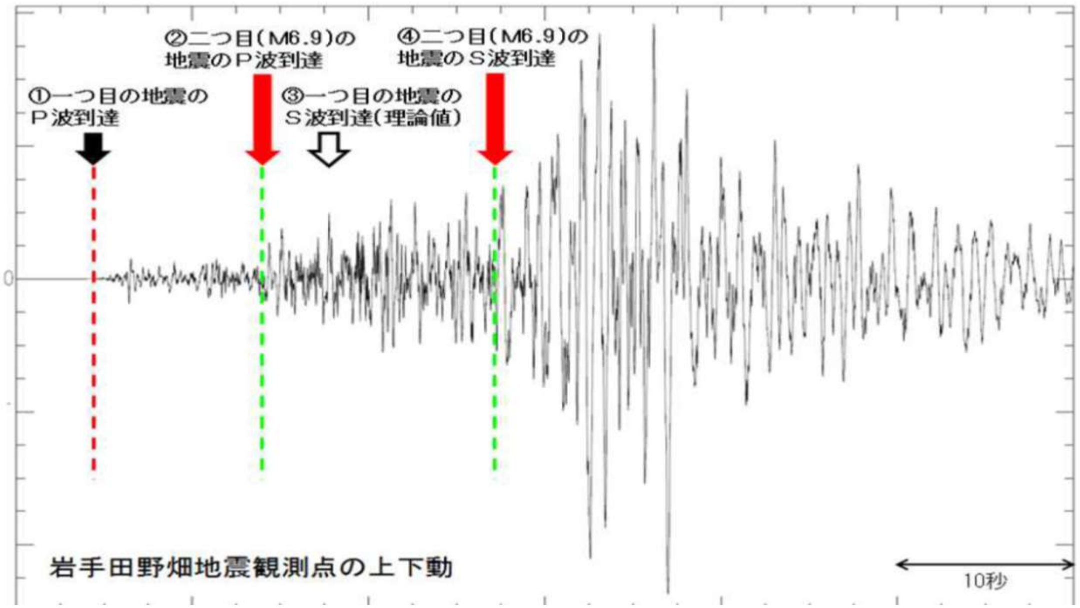
In the case that the hypocenter is not well calculated, the reason will come from the multi-occurrence. So, we should use only the P phases to understand the first event.

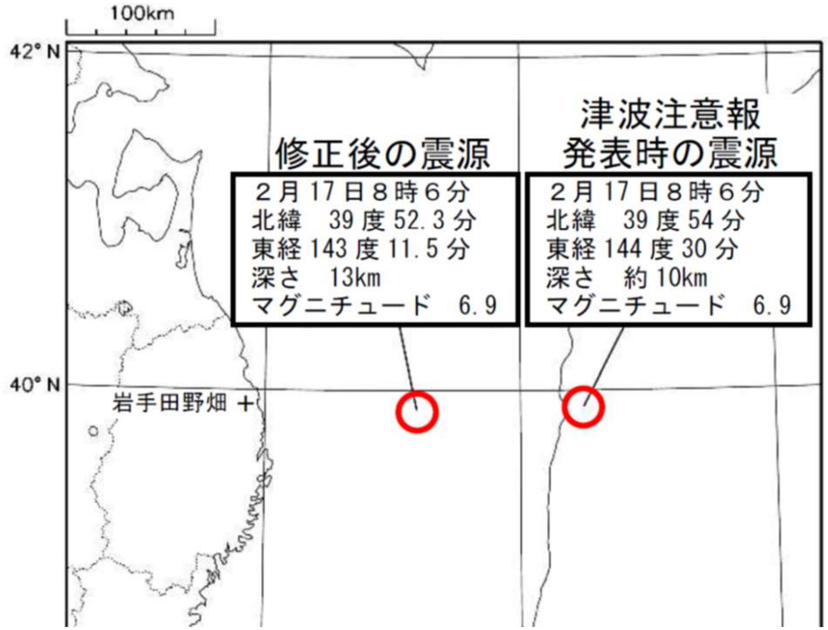
Note: For the purpose, Integrated Particle Filter (IPF) method could contribute somehow. The method uses 1) an algorithm that combines multiple data and methods with Bayesian inference, 2) an identification algorithm that considers the uncertainty of the hypocenter using trigger time and amplitude. The event shown **in the right figure** was well handled with the method.



Date	Time	Epicenter	Lat.	Lon.	Dep.	Mag.
2011/03/19	06:18:48	NW Gunma Pref.	36.9	139.4	10km	2.5
	06:18:53	E Off Ibaraki Pref.	36.2	141.2	40km	4.8

Desarrollo del manejo de un fenómeno accidental, **occurrencia de dos eventos casi al mismo tiempo**





Las ondas P y S del 1^er^ evento son ①&③; y las del 2^do^ evento son ②&④, respectivamente (*ver figura de la izquierda*). Sin embargo, en su momento, el JMA malinterpretó esta cuestión y considero a toda la traza como un solo evento, ① como su P, y ④ como su S. El JMA emitió a la poblacion el aviso de tsunami y su epicentro erroneamente localizado(el círculo rojo de la derecha en el mapa de la figura derecha); luego, el JMA reviso con detalle dicha traza y localizo el epicentro en una mejor ubicacion (círculo rojo de la izquierda en el mapa de la figura derecho).

1.3 Status of MARN on the data available including the data from other countries

Contributors

The contributors, seismological observatories, in Central America for MARN of data from seismic stations on real time basis					
Order #	Contributor		Country	Feature of the data BB, SP or SM	# of Stations 2015
1	INSIVUMEH	Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología	Guatemala	*BB?*	*10?*
2	MARN	Ministerio de Medio Ambiente y Recursos Naturales	El Salvador		
3	INETER	Instituto Nicaragüense de Estudios Territoriales	Nicaragua	*BB?*	*15?*
	IRIS				

The contributors, seismological observatories, in Central America for CATAC of data from seismic stations on real time basis

Order #	Contributor		Country	Feature of the data BB, SP or SM	# of Stations 2015
1	INSIVUMEH	Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología	Guatemala	*BB?*	*10?*
2	MARN	Ministerio de Medio Ambiente y Recursos Naturales	El Salvador		
3	COPECO	Comisión Permanente de Contingencias	Honduras	*BB?*	*2?*
4	INETER	Instituto Nicaragüense de Estudios Territoriales	Nicaragua		
5	OVSICORI (UNA)	Observatorio Vulcanológico y Sismológico de Costa Rica (Universidad Nacional de Costa Rica)	Costa Rica	*BB?*	*?*
6	RSN-UCR-ICE	Red Sismologica Nacional - Universidad de Costa Rica - Instituto Costarricense de Electricidad		*BB?*	*1?*
7	IGC-UPA	Universidad de Panamá, Instituto de Geociencias	Panama	*BB?*	*10*
8	ACP	Authoridad del Canal de Panamá			

Covering data

a) **As for seismic data**, the latest message issued from CATAC shows that "The parameters are calculated using data received in real time, with the contribution of seismic stations of seismological observatories in Central America (INSIVUHEH, MARN, COPECO, INETER, OVSICORI, ICG-UPA, ACP, RSN-UCR-ICE), and the global seismological network."

b) **As for tide gage data**, CATAC monitors the link of IOC. Data are coming in to its SeisComP system. CATAC is also monitoring the deep ocean sea gauges with Tidetool software. Sea gages are a big problem in Central America, we recently lost several sea gauges due to the impact of hurricanes and accident with a ship crashing at the station. As for the tide gauges managed by CATAC, CATAC is getting the data from the Nicaraguan sea gauges directly from the stations with a sampling rate of 16 samples per second, we decimate the data to 1 sample per minute and send them to the IOC site. Then CATAC downloads them from the IOC site together with data from many other stations.

Covering data

c) As for GPS data that might be used like broadband seismometer, CATAC is still in the process to include the GPS data to its system. Recently CATAC has installed a software to get the data in real time from the GPS/GNSS stations (about 20 in Nicaragua). The software serves the raw data to several clients, most importantly UNAVCO and University of Washington. Univ Washington will send us back the data converted into displacement. Displacement can be delt as for any seismic stations to compute the magnitude of the Earthquake much faster than data from seismic stations. CATAC hopes to finish these routines within a few months into its routine process.

3.1 To define that MARN could be the backup of CATAC in case of impact of earthquake or other events at CATAC.

How to handle becoming the backup for CATAC

Based on **the below challenges**, the below idea could be proposed.

Responsibility: INETER should be responsible for the issuance of the "CATAC tsunami advisories", even if they take the action with the backup from MARN.

Works to be covered: MARN should cover the works of CATAC that MARN can handle with the resources they have now. So, MARN would provide CATAC with the information issued from MARN and passively with the results obtained from the MARN's SeisComP4 by using the new feature in messaging system that handles exchanging parameter messages between different SeisComP modules during runtime.

Steps to become the backup:

Based on the above ideas, the below may be the practical steps:

Step 1 (Timing: soon) To install a permanent voice and video connection such as grouping in WhatsApp

Step 2 (Timing: after finishing the migration of SeisComP at CATAC) To try to exchange "seismic and tsunami processing results" in real time

Step 3 (Timing: after finishing Step 2) To try to cope with the information in the tsunami advisories

We should finish the Step 3 by the end of the Phase 2 project (at the end of March ,2023).

In the future beyond: To try to unify processing parameters and definition of common event bulletin in a short time after the occurrence of earthquake

Background

As for the "Cooperación entre CATAC y el MARN en el campo de sismología y tsunami", the below ideas from CATAC were shared among us:

To define that MARN could be the backup of CATAC in case of impact of earthquake or other events at CATAC

Item 1 Exchange of seismic and tsunami processing results in real time

Item 2 Unify processing parameters and definition of common event bulletin in a short time after the earthquake (not to have many different locations and magnitudes)

Item 3 Install a permanent voice and video connection (Whatsapp, Telegram, or ..)

Item 1 To exchange “seismic and tsunami processing results” in real time

We should consider the below challenges under the condition that SC3 of both sides has been migrated to SC4.

Note 1: CATAC confirmed that 1) the exchange would not induce any responsibility to MARN, 2) the action is just getting data, so the security won’t be affected.

Note 2: Merits for MARN to get them in real time should be a) that MARN could use them as backup information, and b) that MARN might be able to establish enhanced procedures for handling tsunamis and earthquakes.

Challenge 1: the “specifications” of “getting them from CATAC in real time” is not so clear.

(Note: Specifications = Contents, Timing, Stability, Method’s reliability, and its cost)

Challenge 2: the “specifications” of “providing them from MARN in real time” is not so clear.

Item 2 To unify processing parameters and definition of common event bulletin in a short time after the earthquakes

We should consider the below challenges.

Challenge: For MARN, it might be necessary to establish the procedure to unify seismic parameters.

How to Handle: To consider through seeing the full spec trial of CATAC

Note: CATAC mentioned as follows:

1) CATAC uses standard global velocity structure model. The model could be different according to the “area structure feature”.

2) The difference of the results from MARN and CATAC would come mainly from difference of data used in the calculation.

3) The data from Honduras is important for us to get reliable results. But currently those are not well collected.

4) CATAC is now considering developing the reginal velocity structure with Spanish researchers, Guatemala, and Costa Rica.

Item 3 To install a permanent voice and video connection

We have tested Skype and WhatsApp.

Note: CATAC mentioned that we could easily handle WhatsApp, and that monitoring officers thus could use them under handling tsunami advisories.

Challenge: For MARN, MARN should consider who, how, when, and where to use, and how to maintain the service.

How to Handle: To develop the procedures on how to use them.

Draft resolutions

1. Realizamos al menos una vez al año un ejercicio conjunto de simulación de tsunamis.
2. Todos los años después del ejercicio, se deben realizar talleres para confirmar los resultados del ejercicio y comprender los puntos de mejora de las operaciones de respuesta a tsunamis.
3. Debemos seguir considerando los desafíos actuales relacionados con la “colaboración entre CATAC y MARN”; y deberíamos obtener soluciones a los desafíos antes del próximo ejercicio de simulación de tsunami.

1. We conduct at least once a year joint tsunami simulation exercise.

2. Every year after the exercise, workshops should be held to confirm the results of exercise and to understand the improvement points of tsunami response operations.

3. We should continue to consider the current challenges related to "collaboration between CATAC and MARN"; and we should get solutions on the challenges before the next tsunami simulation exercise.

Draft minutes of the Workshop to review and plan the tsunami simulation exercise cohosted by DGPC and MARN

Prepared by MARN and Expert as of 12Feb23

1. Introduction

MARN and DGPC implemented a tsunami simulation exercise (called the "**Exercise**" hereinafter) on 22Nov22. Further, MARN and DGPC have expressed to do the exercises regularly beyond and to hold a "meeting cohosted by both to review the latest exercise" (called the "**Workshop**" hereinafter).

2. Purpose

1) **To review the latest exercise** to find any challenges in the tsunami handling function between DGPC and MARN and to get any hint to solve them,
2) **To make communications between DGPC and MARN become better** and to produce feelings of reliability between DGPC and MARN through exchanging technical information and knowing the procedures of both institutions to improve the performance of both in a hazardous event,
3) **To plan any outline of the next drill**.

3. Date

24th of January in 2023

4. Time

02:40-04:10 PM (1h 30min)

5. Venue

Online with Zoom due to the current pandemic. Zoom was provided from MARN.

6. Chair and Timekeeper

MARN

7. Attendance

MARN: 5 officers (Manuel Diaz, Douglas Hernández, Griselda Marroquín, Luis Mixco, Francisco Campos)
DGPC: 2 officers (Luis Montenegro, **Jose ???)**
JICA: Uchimoto, Cortes; MORI (Expert)

8. Results

8.1 Conclusions

8.1.1 Evaluation of the tsunami drill carried out on 22Nov22 (Tue)

1) Documents for the drill having the information on the planned and the actual

a) Planned actions for the total
The scenario, the total procedures and their timeline are described in the "**Guion Simulacro por Tsunami - 22 de noviembre de 2022**" (File name: "**2022-11-14-propuesta Guion-simulacro-2022_MARN**").

b) Planned actions for MARN
The procedures are described in the record of **the Appendix 3**.

c) Actual actions for the total
The procedures and their timeline are described in the document, "**Compilación de mensajería distribuida en grupos de whatsApp durante el simulacro por tsunami realizado el 22 de noviembre de 2022**." (File name: "**2022-11-22-Evaluacion-de-mensajeria-distribuida-durante-simulacro-por-tsunami**").

2) Evaluation of MARN's activity

The scenario, the procedures, and the timeline implemented have followed their initial plan as monitored[1] with the temporal WhatsApp grouping except the cancellation that was issued 10:36 instead of 10:37.

(Note: The procedures included "Issuance of tsunami warning & of the other information" and "Communications with DGPC & the other organizations".)

The challenges noticed in the drill are as follows (**See the below column**.):

- To the extent possible, we should improve information issuance times.

[1] The temporal grouping was organized by MARN, DGPC, Alcaldía de La Libertad and Plan Internacional.

- We should keep the action protocol in case of tsunamis and the procedures up to date and put it to the test by frequently carrying out drills.
- We should have continuous training of personnel involved in seismological monitoring.
- We should enlighten the population so that they understand the key terms (Watch, Prepare and Act), so that they can act appropriately in the event of a potential tsunamigenic event.
- We should have joint **training** between both MARN-DGPC institutions, for the proper understanding of protocols, messages and bulletins (**establishment of inter-institutional protocol?)**

> Excerpt from the "record".
>
> - En la medida de lo posible mejorar tiempos de emisión de la información.
> - Mantener actualizado el protocolo de actuación en caso de tsunamis y los procedimientos. Y ponerlo a prueba mediante la realización frecuente de simulacros.
> - Capacitación continúa del personal involucrado en el monitoreo sismológico.
> - Educar a la población para que comprendan las palabras claves (Vigilancia, Preparación y Tomar Acción), para que actúen apropiadamente ante un evento con potencial tsunamigénico.
> - Capacitación conjunta entre ambas instituciones MARN-DGPC, para la comprensión adecuada de los protocolos, mensajes y boletines (¿establecimiento de protocolo interinstitucional?).

3) Evaluation of activities of DGPC and local authorities[2]

The scenario, the procedures, and the timeline implemented have also followed their initial plan as monitored[3] with the temporal WhatsApp grouping as well.
(Note: Procedures included "handling tsunami warning received sent from MARN", "issuance of warning for evacuation" and "handling evacuation".)
The challenges noticed in the drill are as follows:
It might be better for us to ask schools to join the next tsunami evacuation drill.

4) Evaluation of the usage of the Tsunami Flags

We had prepared a document, "**How to use tsunami flag in the tsunami drill 22Nov22 ver10**" and had provided it to DGPC. But we had the procedures and the timeline for using them. This issue should be considered **in the section 8.1.3.**

5) Evaluation of the general issues

We have had evaluators at the drill as mentioned in the **Guion** and "**FORMATO DE EVALUACION SIMULACRO_22 DE NOVIEMBRE**". **See the below column.**

> Excerpt from the "**Guion Simulacro por Tsunami - 22 de noviembre de 202"2**
>
> **EVALUADORES**
>
> - Punto de reunión: Sala de Uso Múltiples de la Alcaldía de La Libertad
> - Hora: 7:00 am
> - Se socializarán la guía de evaluación.
> - Se proporcionará kit de evaluador (Hoja de evaluación, lapicero, tabla)
> - Se formará un grupo de WhatsApp únicamente para la recolección de fotografía.
> - Documentar en la hoja de evaluación con hora de teléfono
> - Inicio de ejercicio 09:50 am
>
> **CANTIDAD DE EVALUADORES**
> MARN_DOA: 2
> Plan Internacional: 2
> DGPC:
>
> OBSERVADORES

We should collect the sheets of evaluator and should analyze them.
Expert has noticed below issues (**see the below table**):
a) The planned procedures and the planned timeline of DGPC and MARN had several differences as follows:
- Regarding the source of the start time, DGPC used the arrival time of strong motion, but MARN used the Origin Time (OT) of the event,
- Information issuance timings are difference,
- "Calm message" and bulletin # 1, 2, 3 issued from MARN were not planned by DGPC to

[2] CCPC, CSSO, and GV in the community and Majahual Beach and urban area
[3] The temporal grouping was organized by MARN, DGPC, Alcaldía de La Libertad and Plan Internacional.

receive,

- The cancellation information and the finale report are separated in the plan of DGPC,
- The radio used by MARN was not planned by DGPC to get information issued from MARN.
- Not planned information like "reports on sea level variations recorded on tide gauges" was informed through WhatsApp.

b) The activations of sirens were carried out both with "attacking strong motion" and with "receiving calm message". (Note: The activations should be done with "receiving preliminary message" that mentions tsunami threat according to the plan.)

Planned Time	Planned actions: Actions of CCPC, CSSO, MITUR	Planned actions: GV	Planned actions: CMPC/DGPC	Planned procedures	Actual Time	Actual actions: Actions of CCPC, CSSO, MITUR	Actual actions: GV	CMPC/DGPC	Actual procedures	Tool: WhatsApp	Note
9:50	Awaiting the information issued by MARN & DGPC		Center be activated	Attacked by strong motions	9:55				Attacked by strong motions		OT
				Calm message	9:56				Calm message		
9:55					9:59	Siren activated					
9:55	Activation of siren Evacuation	Activation of whistle and tsunami flag	Actoins should be carrie out	Preliminary message	10:01			Indicating alamr activation	Preliminary message	DGPC, Grupos	
9:55					10:02	Evacuating			Bulletin #1	DGPC, Grupos	
					10:03	JPAC Evacuating					
10:00				Final message	10:08				Final message	DGPC, Grupos	
					10:08				Revised bulletin	DGPC, Grupos	
					10:12				Bulletin #2	DGPC, Grupos	
					10:16				Shakemap	DGPC, Grupos	
				Estimated tsunami height & ETA	10:20				Bulletin #3	DGPC, Grupos	
	Arrival at the meeting point				10:21	Bocana sector and San Antonio are already at the meeting point					
					10:22						
					10:25	A community is already at the meeting point are already at the meeting point			***Reports on sea level variations recorded on tide gauges***		
10:20					10:30		He reports that lifeguards have observed variations in sea level				
10:25	Receiving the cancellation information		DGPC: Issuance of the tsunami warning cancellation	Bulletin #4 cancellation (Final del comportamiento del evento)	10:36				Bulletin #4 cancellation (Final del comportamiento del evento)	DGPC, Grupos	
12:35					10:37						

8.1.2 The status of the challenges remained until the drill day

a) The idea on the **one voice for Tsunami warning cancellation** was followed in the drill.

b) The idea on the establishment of the new official communications tools between DGPC and MARN like WhatsApp was conducted.

c) The idea on establishing common procedures was considered but was not implemented somehow as mentioned in the "5) Evaluation of the general issues".

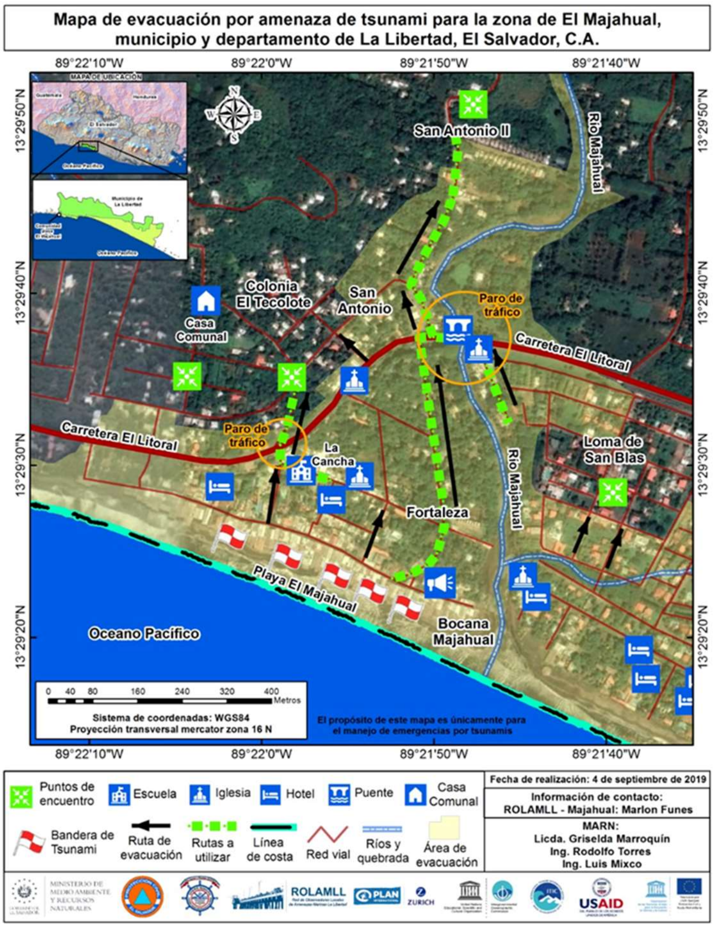
(Note 1: The idea on the regular inspection of the official communications tools has been understood in the workshop.)

(Note 2: The idea on always noticing the "Non-earthquake tsunami" has been understood in the workshop.)

(Note3: The idea on considering the usage of the term what to do in the Tsunami warning issued from MARN has been understood.)

8.1.3 Discussion on the introduction of Tsunami Flag

a) We have understood how to use the Tsunami Flag. We have noticed that one of the important functions of it can be to lead the populations to the safe area effectively. In the drill 5 tsunami flags have been activated according to the planned procedures. **See the right figure.**



Excerpt from "**Guion Simulacro por Tsunami - 22 de noviembre de 2022**"

b) The tower for the lifeguards look not so strong and no so high to save the lives from Tsunami as shown in the right bottom photos. So the tsunami flags should be hanged at the tower according to the "**flow of lifesaver's actions**" in the ppt file of "**How to use tsunami flag in the tsunami drill 22Nov22 ver10**".

c) We have understood that it should be useful for us to handle evacuation effectively. So, it should be authorized somehow accordingly.

d) Through the authorization, DGPC would consider its introduction to the whole coastal area.

e) The plan to make its promotion video would be useful.

Lifeguard Tower 1 at San Diego Beach

8.2 Adaption of the resolution

Based on the "**8.1conclusions**" in this workshop, **the below resolutions** have been understood and should be considered further for the future.

Resolutions

1. We conduct at least once a year joint tsunami simulation exercise.
(Note: DGPC has a plan to have a seismic evacuation drill in the coming March.
(Note: MARN thinks that it would be better for us to expand the above plan into tsunami warning drill.)
2. Every year after the exercise, workshops should be held to confirm the results of exercise and to understand the improvement points of tsunami response operations.
3. We should continue to consider the current challenges related to "collaboration between DGPC and MARN"; and we should get solutions on the challenges before the next tsunami simulation exercise. The latest challenges are as follows:
1) Tsunami warning cancellation should be handled accordingly.
2) Official communications tools should be established, and their inspection should be conducted regularly. The latest idea is to do so every Mondays, Wednesdays, and Fridays around 07:30 am with the inspection lists.
3) We should understand that we should expect non-earthquake tsunami.
4) Usage of the term what to do in the Tsunami warning issued from MARN should be considered among us.
5) We should take actions on the usage of the Tsunami Flag accordingly.
6) We should consider how to communicate with CATAC according to its progress.

Appendix 1: The actual programme of the workshop

Hora	Charla	Duracion (minutos)	Responsable	Tentative contents
2:40	Saludos, y explicación sobre el propósito y la agenda del taller, y sobre el estado de las herramientas y la asistencia / Greetings, and Explanation on the purpose & Agenda of Workshop, and on Status of tools & attendance	1	MARN	
2:41	Evaluación del simulacro de tsunami el 22nov22 (Martes) Evaluation of the tsunami drill carried out on 22Nov22 (Tue)	14	MARN	- Emisión de alerta de tsunami y de la otra información - Comunicaciones con DGPC y otras organizaciones - Issuance of tsunami warning & of the other information - Communications with DGPC & the other organizations
2:55		25 with Q&A	DGPC	- Manejo de alerta de tsunami recibida del MARN - Emisión de advertencia para evacuación - Manejo de evacuación - Manejo de la bandera del tsunami - Handling tsunami warning received from MARN - Issuance of warning for evacuation - Handling evacuation - Handling Tsunami Flag
3:20	El estado de los desafíos se mantuvo hasta el día del simulacro The status of the challenges remained until the drill day	20 with Q&A	MARN (Expert)	- Cancelación de la alerta de tsunami - Herramientas de comunicación y su inspección periódica - Tsunami no sísmico - Uso del término qué hacer en la alerta de tsunami emitida por el MARN - Tsunami warning cancellation - Communications tools and their regular inspection - Non-earthquake tsunami - Usage of the term what to do in the Tsunami warning issued from MARN
3:40	Discusión sobre la introducción de Tsunami Flag Discussion on the introduction of Tsunami Flag	15 with discussion	MARN (Expert)	- Cómo usar la bandera del tsunami - Evaluación sobre su necesidad y cómo autorizar - Planificación de su introducción en toda la zona costera, - Video promocional - How to use the Tsunami Flag - Evaluation on its necessity and how to authorize - Planning its introduction to the whole coastal area, - Promotion Video
3:55	Adaptación de la resolución Adaption of the resolution	14 with discussion	MARN (Expert) / DGPC	- Cómo comunicarse con CATAC - Discusión sobre la resolución incluido el próximo simulacro de tsunami - Discusión sobre cómo hacer que la resolución funcione en consecuencia - How to communicate with CATAC - Discussion on the resolution including the next tsunami drill - Discussion on how to make the resolution work accordingly
4:09	Wrapup y saludos Wrapup and greetings	1	MARN	

Appendix 2: The planned and actual scenarios of the simulation of tsunami and evacuation
(Note: The below description comes from the document, **"Guion Simulacro por Tsunami - 22 de noviembre de 2022**" and from the record in **the Appendix 3**.)
Event: Earthquake of M7.9, off the coast of La Libertad, with threat of "ALTA de tsunami".

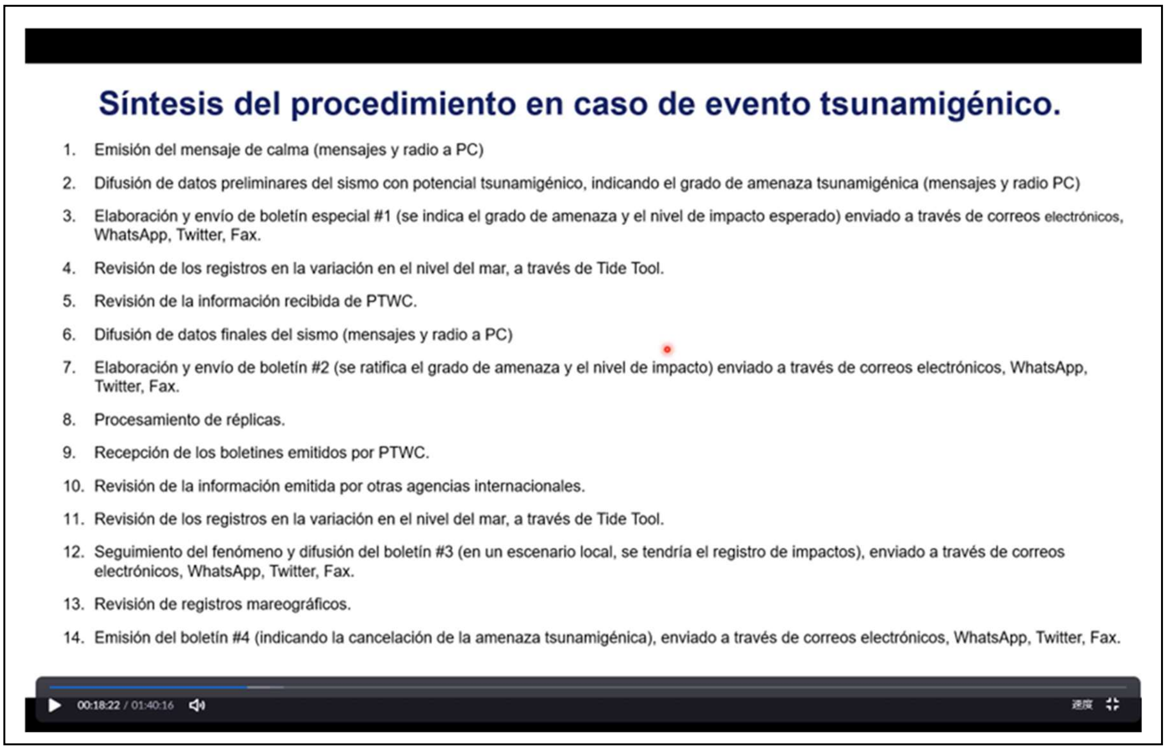
Preliminary message: M7.7, off the coast of La Libertad, OT 22Nov23 09:55, with threat of "ALTA de tsunami".

Final message: M7.9, off the coast of La Libertad, depth 15km, OT 22Nov23 09:55, with threat of "MUY ALTA de tsunami".

Objectives of the drill: To evaluate the response capacities in evacuation processes to the threat of earthquakes that generate tsunami, through the communal commissions of civil protection (CCPC), Occupational Health and Safety Committee (CSSO), and Lifeguards (GV) in the community and Majahual Beach and urban area.
Monitoring Media: VHF Radio, WhatsApp Groups, Phone Calls.

Appendix 3 Record of the workshop
https://us02web.zoom.us/rec/share/jOUGRqczZJ20-2cZkhmxZPuCX4kM4uSYYLDtmoe34Tm_UgGBP0VcreXYkEnCnn4v.dBN0A37PayIKeEfg
Código de acceso:

Appendix 4 Procedures
A4.1 MARN
1) Planned procedures
They come from **the record of the appendix 3**. **See the below column.**



2) Actual procedures
They come from the document, **"Compilación de mensajería distribuida en grupos de whatsApp durante el simulacro por tsunami realizado el 22 de noviembre de 2022**".

3) Actual Timeline
See the below column.

Tools used to communicate between MARN and DGPC

Time	Elapsed time from OT	Procedures	Tools	Radio	Twitter	WhatsApp	Telegram	Telephone call	Fax
9:55	0:00	OT							
9:56	0:01	Calm message		DGPC	Public	ROL, grupos internos IBF	DGPC?		
10:01	0:06	Preliminary message		DGPC	Public	ROL, grupos internos IBF	DGPC?	Personal geology availability	
10:03	0:08	Bulletin #1 ETA?		DGPC	Public	ROL, grupos internos IBF	DGPC?		DGPC
10:08	0:13	Final message		DGPC	Public	ROL, grupos internos IBF	DGPC?		DGPC
10:12	0:17	Bulletin #2 ETA?		DGPC	Public	ROL, grupos internos IBF	DGPC?	Personal geology availability	
10:20	0:25	Bulletin #3 estimated tsunami height & ETA			Public	ROL, grupos internos IBF			
10:17	0:22	ShakeMap			Public	ROL, grupos internos IBF	DGPC?		
10:37	0:42	Bulletin #4 cancellation			Public	ROL, grupos internos IBF			

A4.2 CCPC, CSSO, and GV in the community and Majahual Beach and urban area
Planned procedures and timeline
See the "Guion Simulacro por Tsunami - 22 de noviembre de 2022". And **see the below column.**

Timeline of evacuation drill planned in the tsunami drill

Time	Elapsed time from the attacked time	Procedures	Tools	Radio	WhatsApp	Pllaned / actual Time	Note
9:50	0:00	Attacked by strong motions				9:55	OT
9:55	0:05	Preliminary message		***DGPC***	DGPC, Grupos	10:01	6min behind
10:00	0:10	Final message		***DGPC***	DGPC, Grupos	10:08	8min behind
10:00	0:10	Bulletin #3 estimated tsunami height & ETA			DGPC, Grupos	10:20	20min behind
10:20	0:30					10:37	17min behind
10:25	0:35	Bulletin #4 cancellation			DGPC, Grupos		12min behind
12:35	2:45						

Appendix 5 Record of the Tsunami Drill in the MARN office
https://us02web.zoom.us/rec/share/PDq1LYTKLNi-lIi3X8DO5m01JJNq4q5ULMdtuPDMjob24o0a8lMbFHIcFWSvbPs.zanjrpicNjT1XkHZ?startTime=1669132258000
Código de acceso: 2DKU2T^&

Period

Borrador de actas del Taller para revisar y planificar el ejercicio de simulación de tsunami coorganizado por DGPC y MARN

Preparado por el MARN y Experto a partir del 30Jan23

1. Introducción

MARN y DGPC implementaron un ejercicio de simulación de tsunami (llamado el "**Ejercicio**" en adelante) el 22Nov22. Además, el MARN y la DGPC han expresado hacer los ejercicios regularmente más allá y celebrar una "reunión coorganizada por ambos para revisar el último ejercicio" (llamado el "**Taller**" en adelante).

2. Propósito

1) Revisar el último ejercicio para encontrar cualquier desafío en la función de manejo de tsunamis entre DGPC y MARN y obtener cualquier pista para resolverlos,

2) Mejorar las comunicaciones entre DGPC y MARN y producir sentimientos de confiabilidad entre DGPC y MARN a través del intercambio de información técnica y el conocimiento de los procedimientos de ambas instituciones para mejorar el desempeño de ambos en un evento peligroso,

3) Para planificar cualquier esquema del próximo simulacro.

3. Fecha

24 de enero de 2023

4. Tiempo

02:4 0-04:10 PM (1h 30min)

5. Lugar

En línea con Zoom debido a la pandemia actual. Zoom fue proporcionado por MARN.

6. Anfitrión y cronometrador

MARN

7. Asistentes

MARN: 5 oficiales (Manuel Díaz, Douglas Hernández, Griselda Marroquín, Luis Mixco, Francisco Campos)

DGPC: 2 oficiales (Luis Montenegro, **José ???)**

JICA: Uchimoto, Cortés; MORI (Experto)

8. Resultados

8.1 Conclusiones

8.1.1 Evaluación del simulacro de tsunami realizado el 22nov22 (Martes)

1) Documentos para el simulacro que tienen la información sobre el planificado y el real

a) Acciones previstas para el total

Se describen el escenario, el total de procedimientos y su cronograma el "**Guion Simulacro por Tsunami - 22 de noviembre de 2022**" (Nombre de archivo: "**2022-11-14-propuesta Guion-simulacro-2022_MARN** ").

b) Acciones previstas para el MARN

Los procedimientos se describen en el registro del **apéndice 3**.

c) Acciones reales para el total

Los procedimientos y su cronograma se describen en el documento, "**Compilación de mensajería distribuida en grupos de whatsApp durante el simulacro por tsunami realizado el 22 de noviembre de 2022**". (Nombre del fichero: "**2022-11-22-Evaluacion-de-mensajeria-distribuida-durante-simulacro-por-tsunami**").

2) Evaluación de la actividad del MARN

El escenario, los procedimientos y la línea de tiempo implementada han seguido su plan inicial como monitoreado con la agrupación temporal de WhatsApp[1], excepto la cancelación que se emitió 10:36 en lugar de 10:37.

(Nota: Los procedimientos incluyendo "Emisión de alerta de tsunami y de la otra información" y "Comunicaciones con DGPC y las otras organizaciones".)

Los desafíos observados en el simulacro son los siguientes (**consulte la columna a**

[1] Laagrupación temporal fue organizada por MARN, DGPC, Alcaldía de La Libertad y Plan Internacional.

continuación):

Excerpt del "registro".

- En la medida de lo posible mejorar tiempos de emisión de la información.
- Mantener actualizado el protocolo de actuación en caso de tsunamis y los procedimientos. Y ponerlo a prueba mediante la realización frecuente de simulacros.
- Capacitación continúa del personal involucrado en el monitoreo sismológico.
- Educar a la población para que comprendan las palabras claves (Vigilancia, Preparación y Tomar Acción), para que actúen apropiadamente ante un evento con potencial tsunamigénico.
- Capacitación conjunta entre ambas instituciones MARN-DGPC, para la comprensión adecuada de los protocolos, mensajes y boletines (¿establecimiento de protocolo interinstitucional?).

3) Evaluación de las actividades de la DGPC y las autoridades locales[2]

Elescenario, los procedimientos y el cronograma implementado también han seguido su plan inicial como se relacionócon la agrupación temporal de WhatsApp[3].

(Nota: Los procedimientos incluían "manejo de la alerta de tsunami recibida enviada por MARN", "emisión de advertencia para evacuación" y "manejo de evacuación").

Los desafíos observados en el simulacro son los siguientes:

Podría ser mejor para nosotros pedir a las escuelas que se unan al próximo simulacro de evacuación del tsunami.

4) Evaluación del uso de las banderas del tsunami

Habíamos preparado un documento, "**Cómo usar la bandera de tsunami en el simulacro de tsunami 22Nov22 ver10**" y se lo habíamos proporcionado a DGPC. Teníamos los procedimientos y el cronograma para usarlos. Esta cuestión debe considerarse **en la sección 8.1.3.**

5) Evaluación de las cuestiones generales

Hemos tenido evaluadores en el simulacro como se menciona en el **Guion** and "**FORMATO DE EVALUACION SIMULACRO_22 DE NOVIEMBRE**". **Consulte la columna siguiente.**

Excerpt from the "**Guion Simulacro por Tsunami - 22 de noviembre de 202"2**

EVALUADORES

- Punto de reunión: Sala de Uso Múltiples de la Alcaldía de La Libertad
- Hora: 7:00 am
- Se socializarán la guía de evaluación.
- Se proporcionará kit de evaluador (Hoja de evaluación, lapicero, tabla)
- Se formará un grupo de WhatsApp únicamente para la recolección de fotografía.
- Documentar en la hoja de evaluación con hora de teléfono
- Inicio de ejercicio 09:50 am

CANTIDAD DE EVALUADORES

MARN_DOA: 2

Plan Internacional: 2

DGPC:

OBSERVADORES

Debemosrecoger las hojas del evaluador y analizarlas.

Expert ha notado los siguientes problemas (**ver la tabla a continuación**):

a) Los procedimientos previstos y el cronograma previsto de DGPC y MARN tuvieron varias diferencias de la siguiente manera:

- con respecto a la fuente de la hora de inicio, DGPC utilizó la hora de llegada del movimiento fuerte, pero MARN utilizó la hora de origen del evento (OT),
- Los tiempos de emisión de información son diferentes,
- "Mensaje tranquilo" y boletín # 1, 2, 3 emitido por el MARN no fueron planeados por DGPC para recibir,
- La información de cancelación y el informe final están separados en el plan de DGPC,

[2] CCPC, CSSO y GV en la comunidad y Playa Majahual y área urbana

[3] Laagrupación temporal fue organizada por MARN, DGPC, Alcaldía de La Libertad y Plan Internacional.

- La radio utilizada por el MARN no fue planificada por la DGPC para obtener información emitida por el MARN.
- información no planificada como "informes sobre variaciones del nivel del mar registradas en mareógrafos" fue informada a través de WhatsApp.

b) Las activaciones de sirenas se llevaron a cabo tanto con "atacar un movimiento fuerte" como con "recibir un mensaje de calma". (Nota: Las activaciones deben hacerse con "recibir un mensaje preliminar" que mencione la amenaza de tsunami de acuerdo con el plan).

Planned Time	Planned actions: Actions of CCPC, CSSO, MITUR	Planned actions: GV	Planned actions: CMPC/DGPC	Planned procedures	Actual Time	Actual actions: Actions of CCPC, CSSO, MITUR	Actual actions: GV	CMPC/DGPC	Actual procedures	Tool: WhatsApp	Note
9:50	Awaiting the information issued by MARN & DGPC		Center be activated	Attacked by strong motions	9:55				Attacked by strong motions		OT
				Calm message	9:56				Calm message		
9:55					9:59	Siren activated					
9:55	Activation of siren Evacuation	Activation of whistle and tsunami flag	Actoins should be carrie out	Preliminary message	10:01			Indicating alamr activation	Preliminary message	DGPC, Grupos	
9:55					10:02	Evacuating			Bulletin #1	DGPC, Grupos	
					10:03	JPAC Evacuating					
10:00				Final message	10:08				Final message	DGPC, Grupos	
					10:08				Revised bulletin	DGPC, Grupos	
					10:12				Bulletin #2	DGPC, Grupos	
					10:16				Shakemap	DGPC, Grupos	
				Estimated tsunami height & ETA	10:20				Bulletin #3	DGPC, Grupos	
	Arrival at the meeting point				10:21	Bocana sector and San Antonio are already at the meeting point					
					10:22						
					10:25	A community is already at the meeting point are already at the meeting point			***Reports on sea level variations recorded on tide gauges***		
10:20					10:30			He reports that lifeguards have observed variations in sea level			
10:25	Receiving the cancellation information		DGPC: Issuance of the tsunami warning cancellation	Bulletin #4 cancellation (Final del comportamiento del evento)	10:36				Bulletin #4 cancellation (Final del comportamiento del evento)	DGPC, Grupos	
12:35					10:37						

8.1.2 El estado de los desafíos se mantuvo hasta el día del simulacro

a) La idea de **una sola voz para la cancelación de la alerta de tsunami** se siguió en el simulacro.

b) Se llevó a cabo la idea del establecimiento de las nuevas herramientas oficiales de comunicación entre DGPC y MARN como WhatsApp.

c) Se consideró la idea de establecer procedimientos comunes, pero no se implementó de alguna manera, como se menciona en la "5) Evaluación de las cuestiones generales".

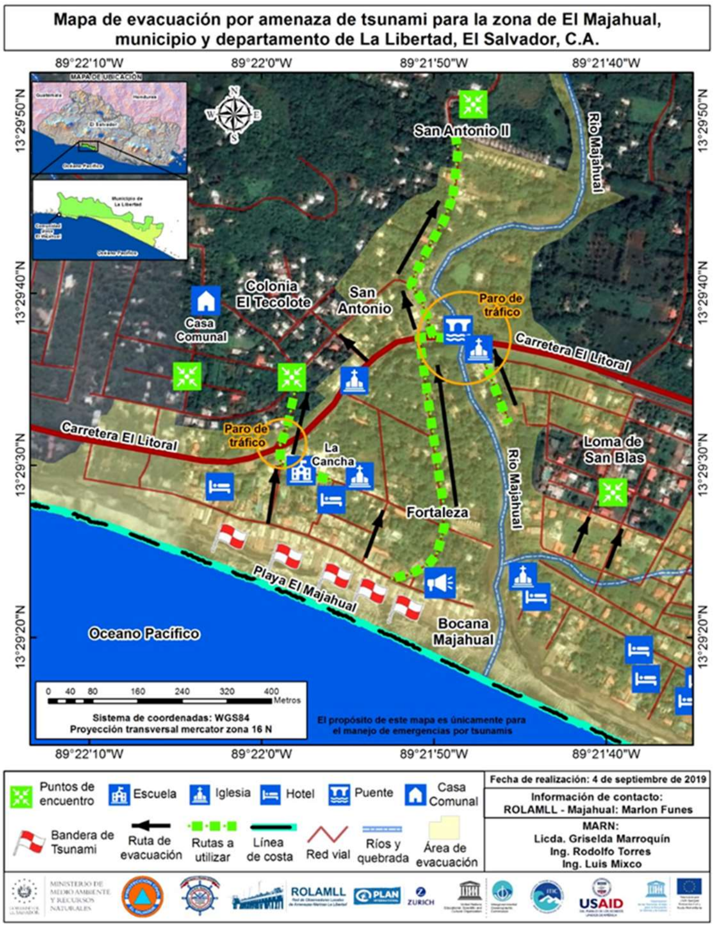
(Nota 1: La idea de la inspección periódica de los instrumentos oficiales de comunicación se ha entendido en el taller.)

(Nota 2: La idea de notar siempre el "tsunami no sísmico" se ha entendido en el taller.)

(Nota 3: Se ha entendido la idea de considerar el uso del término qué hacer en la alerta de tsunami emitida por el MARN).

8.1.3 Discusión sobre la introducción de la Bandera del Tsunami

a) Hemos entendido cómo usar la Bandera del Tsunami. Hemos notado que una de las funciones importantes de la misma puede ser llevar a las poblaciones al área seguro de manera efectiva. En el simulacro se han activado 5 banderas de tsunami de acuerdo con los procedimientos planificados. **Vea la figura en la derecha.**



Excerpt from "**Guion Simulacro por Tsunami - 22 de noviembre de 2022**"

b) La torre para los salvavidas no se ve tan fuerte y no tan alta para salvar las vidas del tsunami como se muestra en las fotos de la parte inferior derecha. Por lo tanto, las banderas del tsunami deben colgarse en la torre de acuerdo con el "**flujo de las acciones del salvavidas**" en el archivo ppt de "**Cómo usar la bandera del tsunami en el simulacro de tsunami 22Nov22 ver10**".

c) Hemos entendido que debería ser útil para nosotros manejar la evacuación de manera efectiva. Por lo tanto, debe autorizarse de alguna manera en consecuencia.

d) A través de la autorización, la DGPC consideraría su introducción en toda la zona costera.

e) El plan para realizar su video promocional sería útil.

Lifeguard Tower 1 at San Diego Beach

8.2 Adaptación de la resolución

Sobre la base de las "conclusiones 8.1" de este taller, se han entendido **las siguientes resoluciones** y deben examinarse más a fondo para el futuro.

<u>Resoluciones</u>

1. Realizamos al menos una vez al año ejercicios conjuntos de simulación de tsunami.
   (Nota: DGPC tiene un plan para tener un simulacro de evacuación sísmica en marzo próximo.
   (Nota: MARN piensa que sería mejor para nosotros expandir el plan anterior a un simulacro de alerta de tsunami).
2. Todos los años después del ejercicio, deberían celebrarse talleres para confirmar los resultados del ejercicio y comprender los puntos de mejora de las operaciones de respuesta al tsunami.
3. Debemos continuar considerando los desafíos actuales relacionados con la "colaboración entre DGPC y MARN"; Y deberíamos encontrar soluciones sobre los desafíos antes del próximo ejercicio de simulación de tsunamis. Los últimos desafíos son los siguientes:

1) La cancelación de la alerta de tsunami debe manejarse en consecuencia.
2) Deberían establecerse instrumentos oficiales de comunicación y su inspección debería realizarse periódicamente. La última idea es hacerlo todos los lunes, miércoles y viernes alrededor de las 07:30 am con las listas de inspección.
3) Debemos entender que debemos esperar un tsunami sin terremotos.
4) El uso del término qué hacer en la alerta de tsunami emitida desde el MARN debe ser considerado entre nosotros.
5) Debemos tomar medidas sobre el uso de la bandera del tsunami en consecuencia.
6) Debemos considerar cómo comunicarnos con CATAC de acuerdo con su progreso.

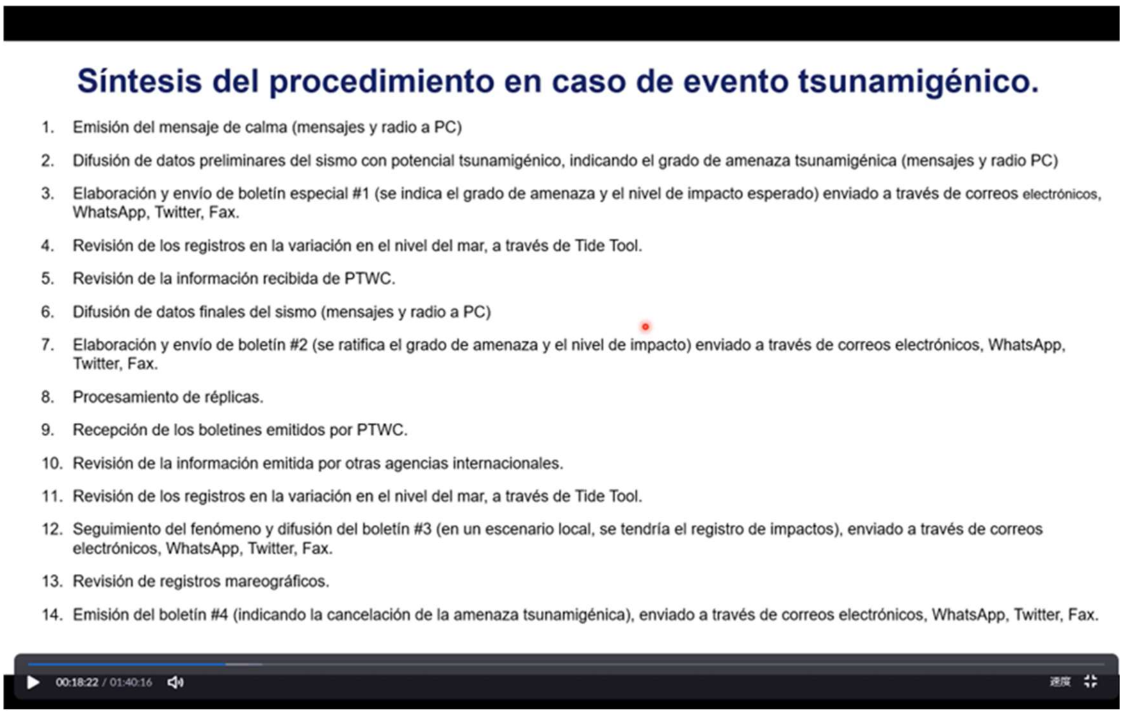
Apéndice 1: El programa real del taller

Hora	Charla	Duracion (minutos)	Responsable	Tentative contents
2:40	Saludos, y explicación sobre el propósito y la agenda del taller, y sobre el estado de las herramientas y la asistencia / Greetings, and Explanation on the purpose & Agenda of Workshop, and on Status of tools & attendance	1	MARN	
2:41	Evaluación del simulacro de tsunami el 22nov22 (Martes) Evaluation of the tsunami drill carried out on 22Nov22 (Tue)	14	MARN	- Emisión de alerta de tsunami y de la otra información - Comunicaciones con DGPC y otras organizaciones - Issuance of tsunami warning & of the other information - Communications with DGPC & the other organizations
2:55		25 with Q&A	DGPC	- Manejo de alerta de tsunami recibida del MARN - Emisión de advertencia para evacuación - Manejo de evacuación - Manejo de la bandera del tsunami - Handling tsunami warning received from MARN - Issuance of warning for evacuation - Handling evacuation - Handling Tsunami Flag
3:20	El estado de los desafíos se mantuvo hasta el día del simulacro The status of the challenges remained until the drill day	20 with Q&A	MARN (Expert)	- Cancelación de la alerta de tsunami - Herramientas de comunicación y su inspección periódica - Tsunami no sísmico - Uso del término qué hacer en la alerta de tsunami emitida por el MARN - Tsunami warning cancellation - Communications tools and their regular inspection - Non-earthquake tsunami - Usage of the term what to do in the Tsunami warning issued from MARN
3:40	Discusión sobre la introducción de Tsunami Flag Discussion on the introduction of Tsunami Flag	15 with discussion	MARN (Expert)	- Cómo usar la bandera del tsunami - Evaluación sobre su necesidad y cómo autorizar - Planificación de su introducción en toda la zona costera, - Video promocional - How to use the Tsunami Flag - Evaluation on its necessity and how to authorize - Planning its introduction to the whole coastal area, - Promotion Video
3:55	Adaptación de la resolución Adaption of the resolution	14 with discussion	MARN (Expert) / DGPC	- Cómo comunicarse con CATAC - Discusión sobre la resolución incluido el próximo simulacro de tsunami - Discusión sobre cómo hacer que la resolución funcione en consecuencia - How to communicate with CATAC - Discussion on the resolution including the next tsunami drill - Discussion on how to make the resolution work accordingly
4:09	Wrapup y saludos Wrapup and greetings	1	MARN	

Apéndice 2: Los escenarios previstos y reales de la simulación de tsunami y evacuación.
(Nota: La siguiente descripción proviene del documento, " **Guion Simulacro por Tsunami - 22 de noviembre de 2022"** y del registro en **el Apéndice 3**.)
Evento: Terremoto de M7.9, frente a la costa de La Libertad, con amenaza de "ALTA de tsunami".
Mensaje preliminar: M7.7, frente a la costa de La Libertad, OT 22Nov23 09:55, con amenaza de "ALTA de tsunami".
Mensaje final: M7.9, frente a la costa de La Libertad, profundidad 15km, OT 22Nov23 09:55, con amenaza de "MUY ALTA de tsunami".
Objetivos del simulacro: Evaluar las capacidades de respuesta en procesos de evacuación ante la amenaza de terremotos que generan tsunami, a través de las comisiones comunales de protección civil (CCPC), Comité de Seguridad y Salud Ocupacional (CSSO), y Salvavidas (GV) en la comunidad y Playa Majahual y área urbana.
Medios de monitoreo : radio VHF, grupos de WhatsApp, llamadas telefónicas.

Apéndice 3: Record of the workshop
https://us02web.zoom.us/rec/share/jOUGRqczZJ20-2cZkhmxZPuCX4kM4uSYYLDtmoe34Tm_UgGBP0VcreXYkEnCnn4v.dBN0A37PayIKeEfg
Código de acceso:

Apéndice 4: Procedimientos
A4.1 MARN
Procedimientos previstos
Provienen del registro del Apéndice 3. Vea la siguiente columna.



2) Procedimientos reales
Provienen del documento, **"Compilación de mensajería distribuida en grupos de whatsApp durante el simulacro por tsunami realizado el 22 de noviembre de 2022".**

3) Línea de tiempo real
Vea la siguiente columna.

Herramientas utilizadas para comunicarse entre MARN y DGPC

Time	Elapsed time from OT	Procedures	Tools	Radio	Twitter	WhatsApp	Telegram	Telephone call	Fax
9:55	0:00	OT							
9:56	0:01	Calm message		DGPC	Public	ROL, grupos internos IBF	DGPC?		
10:01	0:06	Preliminary message		DGPC	Public	ROL, grupos internos IBF	DGPC?	Personal geology availability	
10:03	0:08	Bulletin #1 ETA?		DGPC	Public	ROL, grupos internos IBF	DGPC?		DGPC
10:08	0:13	Final message		DGPC	Public	ROL, grupos internos IBF	DGPC?		DGPC
10:12	0:17	Bulletin #2 ETA?		DGPC	Public	ROL, grupos internos IBF	DGPC?	Personal geology availability	
10:20	0:25	Bulletin #3 estimated tsunami height & ETA			Public	ROL, grupos internos IBF			
10:17	0:22	ShakeMap			Public	ROL, grupos internos IBF	DGPC?		
10:37	0:42	Bulletin #4 cancellation			Public	ROL, grupos internos IBF			

A4.2 CCPC, CSSO y GV en la comunidad y Playa Majahual y área urbana
Procedimientos planificados y cronograma
Ver el **"Guion Simulacro por Tsunami - 22 de noviembre de 2022**". Y **vea la siguiente columna.**

Timeline of evacuation drill planned in the tsunami drill

Time	Elapsed time from the attacked time	Procedures	Tools	Radio	WhatsApp	Plland / actual Time	Note
9:50	0:00	Attacked by strong motions				9:55	OT
9:55	0:05	Preliminary message		***DGPC***	DGPC, Grupos	10:01	6min behind
10:00	0:10	Final message		***DGPC***	DGPC, Grupos	10:08	8min behind
10:00	0:10	Bulletin #3 estimated tsunami height & ETA			DGPC, Grupos	10:20	20min behind
10:20	0:30	Bulletin #4 cancellation			DGPC, Grupos	10:37	17min behind
10:25	0:35						12min behind
12:35	2:45						

Apéndice 5: Registro del Simulacro de Tsunami en la oficina del MARN
https://us02web.zoom.us/rec/share/PDq1LYTKLNi-lIi3X8DO5m01JJNq4q5ULMdtuPDMjob24o0a8lMbFHIcFWSvbPs.zanjrpicNjT1XkHZ?startTime=1669132258000
Código de accesso: 2DKU2T^&

Period