カンボジア国
土地管理及びインフラ開発のための
電子基準点整備プロジェクト
プロジェクト業務完了報告書
－ 概要版 －

2024 年 12 月

独立行政法人国際協力機構

株式会社パスコ

1. プロジェクトの概要

1.1. 背景

カンボジアでは、1992 年に土地法が制定され、土地の私的所有制度が導入された。2001 年の同法改正では、土地の私有に対する権利保護が強化された。これにより、土地保有に対する保証制度が強化され、不動産市場が活性化した。しかし、地籍測量の進捗は全土の 6 割程度にとどまっていたことから、測量を迅速化させるための高精度測位環境が求められていた。地籍測量は、国土管理・都市計画・建設省（Ministry of Land Management, Urban Planning and Construction：MLMUPC）の地籍地理総局（General Department of Cadastre and Geography：GDCG）が 2003 年から実施しており、2023 年までにカンボジア全土の土地登記を完了させることを目標としていた。

かかる背景を踏まえて、カンボジア政府は、地籍測量の迅速化と高精度な位置情報サービスの提供能力を向上させるため、電子基準点（Continuously Operating Reference Station：CORS）とデータセンター（Data Center：DC）の整備、運営維持管理のための能力強化、CORS データの利活用促進を目的とした技術協力を日本に要請した。

1.2. 目標

本プロジェクトの目標は、2024 年末までに 5 点の CORS と DC を整備し、地籍測量や工事測量で活用することである。また、プロジェクト終了 3 年後には、CORS が適切に管理・拡張され、地籍測量やインフラ整備に活用されることが期待されている（上位目標）。具体的には、CORS の整備、運営維持管理能力の強化、CORS データの利用促進を行うことで、カンボジアの長期目標である「Cambodia Vision」の実現に寄与することを目指している。

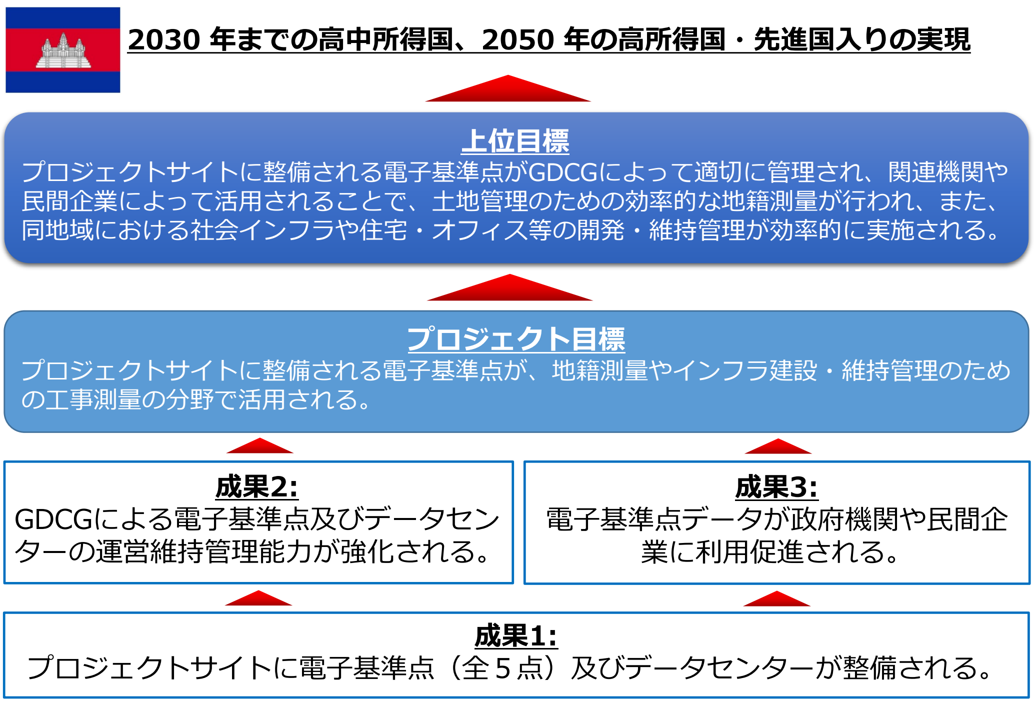


図 1　本プロジェクトの目標及び期待される成果（出典：JPT（Japan Project Team ））

2. 活動内容

2.1. プロジェクトフローチャート

プロジェクトの実施フローは以下のとおりである。

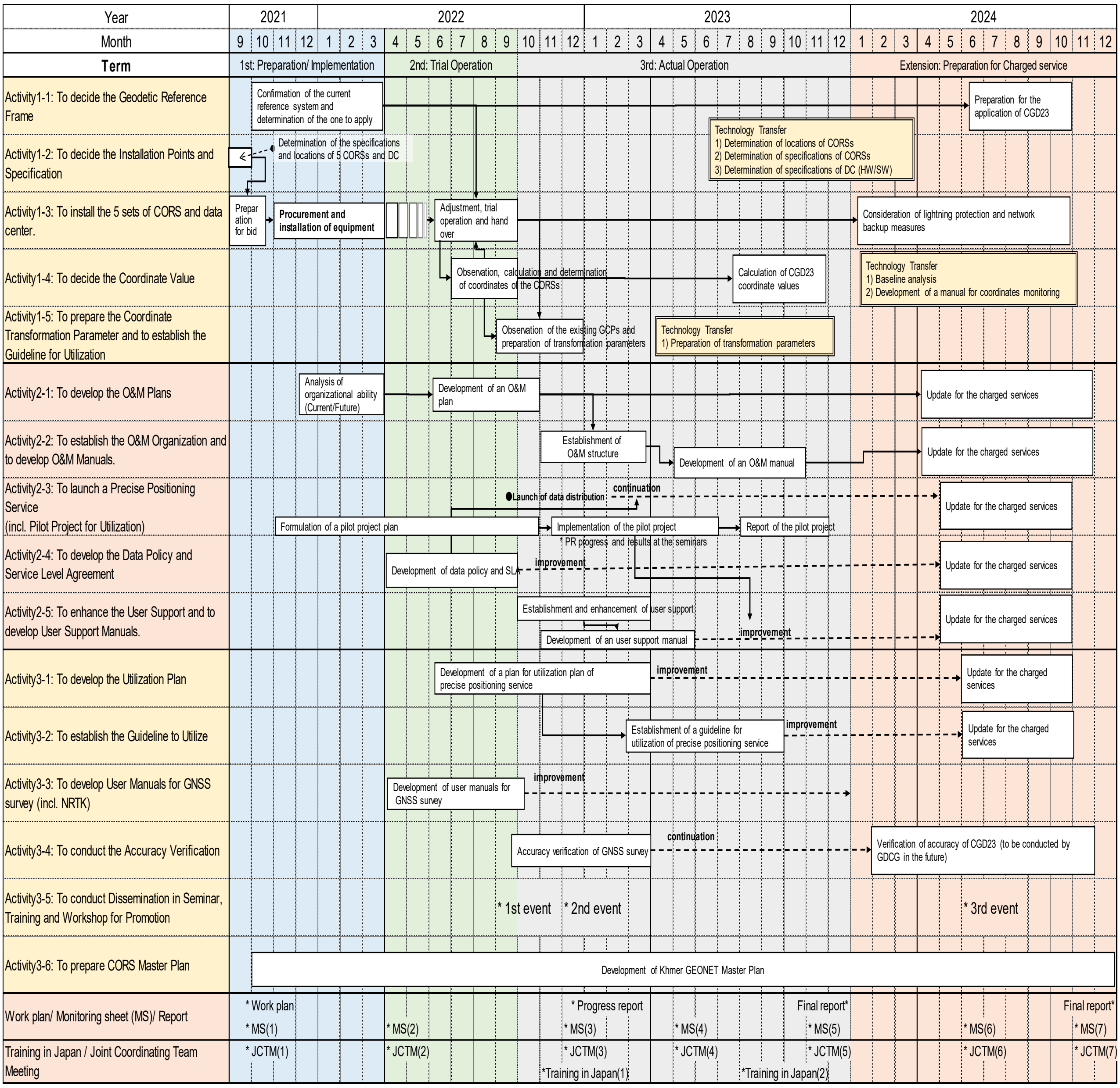


図 2　プロジェクト実施フロー（出典：JPT）

2.2. プロジェクト全体にかかる活動

- **本邦研修の実施**: CORS の運営維持管理や利活用促進に関する技術、知見を習得することを目的として、第 1 回本邦研修（2022 年 11 月 2 日～15 日）と第 2 回本邦研修（2023 年 8 月 21 日～9 月 2 日）を実施した。
- **Joint Coordinating Team Meeting（JCTM）の開催**: 約半年ごとに全 7 回の JCTM を開催し、各

活動の進捗確認と活動内容の報告、課題の整理と協議、今後の予定の確認、プロジェクトの評価などを行った。

国土地理院（2022/11/4）

日本測量協会（2022/11/4）

トプコン（2023/8/30）

情報通信研究機構（NICT）（2023/8/31）

図 3　本邦研修（撮影：JPT）

2.3. 成果 1: CORS 及び DC の整備にかかる活動

- **測地基準系の決定**: CORS に適用する測地基準系を、ITRF2020 を採用した CGD23 とした。ただし、CGD23 を適用するまでは、暫定的に従来の CGD09 の座標値で運用することとした。
- **設置場所と仕様の決定**: 5 点の CORS と DC の設置場所を決定し、仕様を確定した。また、設置場所の選定時に現地踏査を OJT で実施した。
- **設置工事**: Aruna 社への現地再委託によって CORS と DC の設置工事を実施し、検収を完了した。Aruna 社はその後の運営維持管理にも協力した。設置された CORS システムは、「Khmer GEONET」と命名された。
- **座標値の決定**: Bernese ソフトウェアを用いて CORS の座標値を計算した。これにより、高精度な測位を行うための環境が整備された。また、座標計算にかかる技術移転を実施した。
- **座標変換パラメータの策定**: CGD09 と CGD23 の座標変換パラメータを計算した。また、変換パラメータの計算にかかる技術移転を実施した。これにより、既存の測地基準系と CGD23 との互換性を確保した。

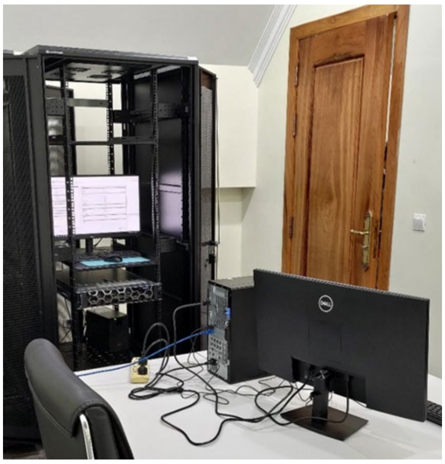
		
PNH100KHM	SIE100KHM	DC

図 4　完成した CORS と DC（撮影：JPT）

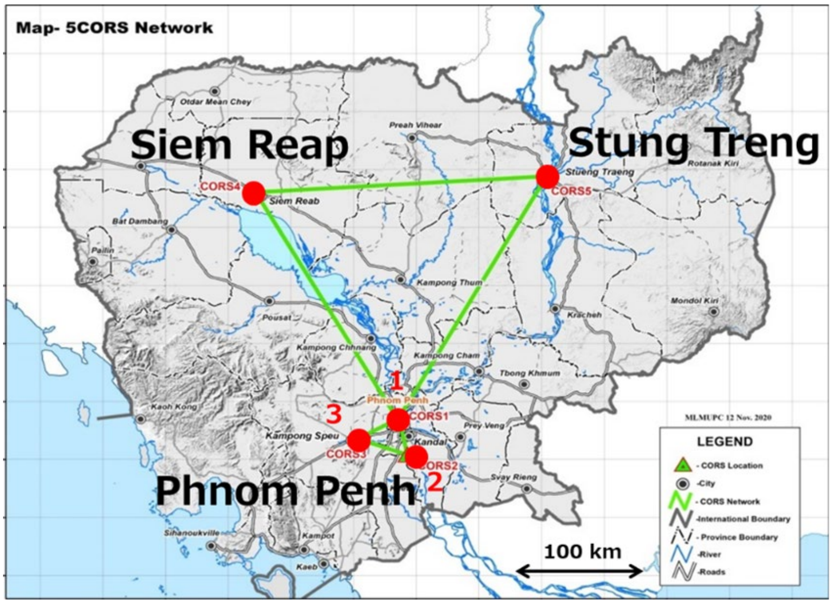


図 5　5 点の CORS の配置（出典：JPT）

2.4. 成果 2: 運営維持管理能力の強化にかかる活動

- **運営維持管理計画の策定**: Khmer GEONET の運営維持管理計画を策定した。計画には、運営維持管理の基本方針、組織体制、マニュアル、資機材保守、人材育成、予算、広報などが記述された。
- **運営維持管理体制の構築**: Khmer GEONET の運営維持管理マニュアルを整備した。マニュアルには、管理体制、通常時・緊急時のレポートラインの枠組み、日報・週報等報告手順及び報告ツールの概要、データバックアップ体制、有償配信サービスの料金体系案等が記述された。
- **データ配信の開始**: 2022 年 10 月に NRTK（Network-Real Time Kinematic）の補正データの配信とユーザー登録を開始した。また、配信データの品質管理にかかる技術移転を実施した。
- **実証事業の実施**: 測量、建設、農業、地籍調査分野で 5 件の実証プロジェクトを実施した。各プロジェクトの成果は、プロジェクトセミナーで発表された。実証事業の実施により、CORS データの有用性が確認された。

- **データポリシーと SLA の策定**: データ配信方法や利用制限などについて示したデータポリシーと、ユーザーにサービスの仕様を示すための SLA（Service Level Agreement）を策定した。
- **ユーザーサポートマニュアルの整備**: ユーザーサポートマニュアルを整備し、サポート体制を強化した。

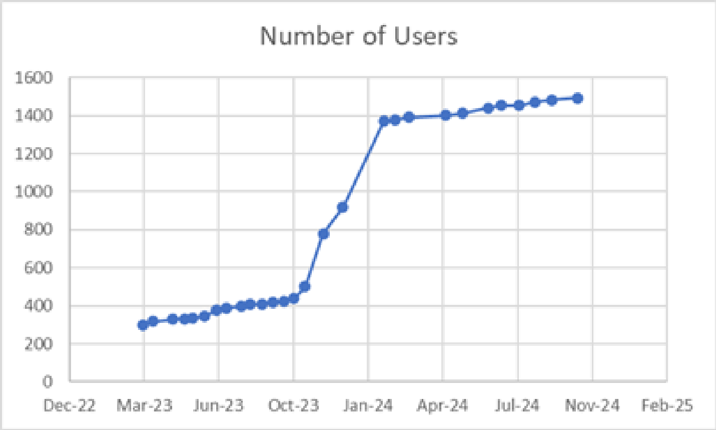


図 6　Khmer GEONET のユーザー登録数の推移（出典：JPT）

農業プロジェクト

測量プロジェクト

図 7　実証プロジェクトの活動（撮影：JPT、CPT（Cambodia Project Team ））

2.5. 成果 3: 利活用促進にかかる活動

- **利活用計画の策定**: Khmer GEONET の利活用促進計画を策定した。GDCG が本計画に記載された活動を具体化し実行することで、今後の CORS データの活用が促進される。
- **利活用ガイドラインの整備**: 利活用ガイドラインを作成した。ガイドラインは、ユーザーが CORS データを効果的に利用するための手引書になる。
- **GNSS 測量マニュアルの整備**: Khmer GEONET を用いたスタティック法及び NRTK 法の作業手順、基線解析や網平均計算の精度評価のための指標を記載した、GNSS 測量マニュアルを作成した。
- **精度検証**: スタティック法及び NRTK 法で Khmer GEONET から配信されるデータの精度検証を OJT で実施した。前述したとおり現時点の CORS は CGD09 に基づくものであるため、CGD23 が適用された後に改めて GDCG が精度検証を実施することとした。
- **セミナー等の開催**: セミナーの開催や展示会への出展を行うことで、Khmer GEONET の広報

と利活用促進を図った。セミナーでは GNSS 体験会や実証プロジェクトの成果発表を行うことで、Khmer GEONET が広く周知された。

- **マスタープランの策定**: カンボジアにおける将来の CORS の姿を見据えた Khmer GEONET マスタープランを策定した。

図 8（左）Khmer GEONET の Web サイト（出典：https://khmergeonet.xyz/）、（右）利活用事例のリーフレット（出典：CPT）

図 9　セミナーの様子（撮影：JPT）

3. プロジェクトの評価

3.1. 目標の達成度

プロジェクト目標は、地籍測量やインフラ整備で CORS が活用されることで達成された。Khmer GEONET のユーザー数の増加や、Khmer GEONET を利用した地籍調査の加速化が確認された。

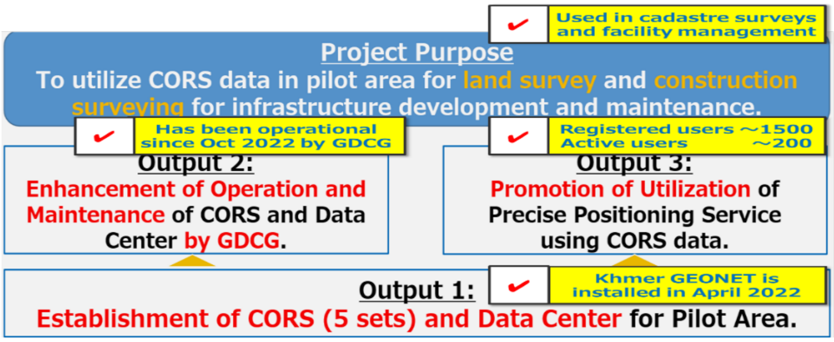


図 10　各成果とプロジェクト目標の達成（出典：JPT）

3.2. DAC 評価 6 基準に基づく自己評価

本プロジェクトの成果を、経済協力開発機構／開発援助委員会（OECD-DAC）の「DAC 評価 6 基準」に基づき、以下のように自己評価した。

- **妥当性（Relevance）**：5 点の CORS は、GDCG の地籍調査の迅速化に貢献した。また、実証プロジェクトにより、農業や建設分野での CORS の有用性が確認された。
- **整合性（Coherence）**：プロジェクト成果はカンボジアの開発協力政策の目標に合致している。また、本プロジェクトで得られた知見は日本の無償資金協力によって 2026 年までに実現予定の CORS 全土整備に役立てられている。加えて、Khmer GEONET によって日本の無償資金協力で供与された GNSS ローバーが有効活用されている。
- **有効性（Effectiveness）**：5 点の CORS と DC は計画どおり設置され、ユーザー数は 1,500 名（2024/11 時点）となった。実証プロジェクトの結果、Khmer GEONET が様々な分野における作業の効率化に役立つことが確認された。
- **インパクト（Impact）**：CORS の整備により、地籍調査が迅速化され、土地登記のための測量数が増加した。これにより、公正な社会の発展と国民の財産保全に寄与した。
- **効率性（Efficiency）**：オンライン会議を活用することで、COVID-19 の影響を最小化し、プロジェクトの活動を効率的に実施できた。
- **持続性（Sustainability）**：GDCG のスタッフは運営維持管理能力を獲得することができた。本プロジェクト終了後も、Khmer GEONET の運営維持管理にかかる予算と組織改編が承認されることで、プロジェクト成果の持続性が確保される見込みである。

これらの評価に基づき、プロジェクトは全体として成功し、今後の持続的な発展が期待できる。

4. 上位目標達成に向けて

4.1. 取り組むべき課題

1). CGD23 の適用と有償配信の開始

Khmer GEONET は 2022 年 10 月から試験運用を開始し、プロジェクト終了まで無償でサービスを提供した。新しい測地基準系 CGD23 の定義は決定され、プロジェクト期間中に CGD23 の座標計算や座標変換パラメータの技術移転は完了したが、CGD23 の正式な測地基準としての公表準備が整わなかったため、未だ CGD09 が使用されている。GDCG は CGD23 を 2024 年末までに公表し、2025 年 6 月までに適用すると同時に有償配信を開始することを計画している。このためには省令

公布、基準点の成果改定、セミナーやトレーニングの実施など多くの業務が必要となる。

2). 運営維持管理にかかる予算と組織の確保

CORS は国家の測地インフラとして、農業、建設、自動運転などに活用されることで、経済発展や生活向上のために重要な役割を果たす。CORS の運営維持管理に不可欠な予算と体制を確保するために、GDCG は上位省庁にその必要性を適切に説明する必要がある。2025 年度の予算は概ね確保されたが、2026 年度以降の予算確保と体制の確立が求められる。GDCG は、Khmer GEONET の運用セクションの設置により運営維持管理業務の一元化を図る必要がある。

3). 運営維持管理計画、利活用計画、マスタープランの更新と活用

本プロジェクトでは、GDCG が Khmer GEONET に関して実施すべき活動を定めた運営維持管理計画、利活用計画、Khmer GEONET マスタープランを整備した。運営維持管理計画は 5 点の CORS に焦点を当てたものであるため、今後の全土整備に合わせた計画の拡張・改訂が必要となる。利活用計画は、有償配信と全土整備に向けた周知・PR やと利用拡大のための活動と、今後 2 年間の活動スケジュールを含んでいる。この計画の具体化と活動の実施が求められる。Khmer GEONET マスタープランは 2034 年までのカンボジアにおける CORS 整備の方向性を示し、利活用分野、仕様、整備計画、予算確保などについて記述されている。プロジェクト終了後も GDCG が関係省庁と協力して精査・協議し、適宜更新していくことが期待される。

4.2.上位目標達成に向けた提言

1). 土地管理と土地行政のための効率的な地籍調査の実施に向けて

GDCG は 2002 年からカンボジア全土の地籍調査事業を推進しており、2023 年からの新政権による「デジタル経済・社会の発展」政策により、地籍調査の迅速化とデータ一元管理が実施された。Khmer GEONET の整備と運用もこれらに大きく貢献し、2025 年末までに筆界測量が完了する見込みとなっている。しかし、その後も土地の分合筆や取引が行われるごとに現地での測量作業が必要であり、CORS の活用がその効率化に継続的に寄与する。現在の測量成果には複数の測地基準系によるものが混在しているため、GDCG ができる限り早期に CGD23 を適用するとともに、既存の測地基準に準拠した測量成果を CGD23 に座標変換することで、測地基準系の統一を図ることを提言する。

2). 居住地、商業地での社会インフラの効率的な開発と維持管理の実現に向けて

本プロジェクト期間中、Khmer GEONET のユーザー数は約 1,500 に達し、主に地籍調査の測量作業に利用されている。土地の権利を明確化し、取引を円滑化するために地籍調査は重要であり、この意味で Khmer GEONET はインフラ開発の基盤として機能しているといえる。今後、配信サービスは有償になり、民間企業は利用料を支払ってサービスを利用することになる。ユーザーがコストメリットを感じるためには、安定した高精度の測位データ配信と適切なユーザーサポートが必要となる。これを実現するために、GDCG が運営維持管理マニュアルや GNSS 測量マニュアルに基づくメンテナンスと精度検証、ユーザー対応を確実に実施することを提言する。

3). GDCG による Khmer GEONET の適切な管理に向けて

Khmer GEONET の持続的な運用には、GDCG がシステム全体を適切に管理する必要がある。CORS の全土整備後は CORS の設置数の増加とユーザーの拡大に伴うトラブルの増加が予想されるため、GDCG は必要な予算と人員を確保し十分に備えておかなければならない。また、有償ユーザーを拡大して利用料を得るだけでなく、社会インフラとしての重要性を PR することで、政府内での Khmer GEONET の運営維持管理予算の優先度を上げる努力が必要となる。さらに、業務プロセスの改善による効率化を図ったうえで、増員要求や民間委託を進めることが求められる。その際、増員や民間委託の目的を明確にし、データに基づく根拠を上位省庁に提示することを提言する。

4). カンボジア全土への Khmer GEONET の拡張後に向けて

本プロジェクトでは CORS の全土整備後の運用や利活用促進に向けた活動を実施したが、実際に GDCG が経験したのは 5 点の CORS 設置と運営維持管理である。90 点を超える全土整備後の業務量増加に対応するため、民間企業への業務委託等によって不測の事態に備える体制を早期に構築すること及びそのための予算確保を提言する。また、将来において MADOCA-PPP（通信回線を必要としないで一定の精度でリアルタイム測位を実施できる技術）の併用を検討することも有効であろう。

以上

Site Photos and Description for CORS

CORS Site Name (Long Name):	
CORS Site Name (Short Name):	
CORS Site ID#:	
Location Map	Google Map (Image)
Sky Visibility or Fisheye Photo	Field Sketch
North East	South West
South West	North East
Entrance to The Site	Remarks

Site Selection Note for CORS (draft)

CORS Information	
CORS Site Name (Long Name)	
CORS Site Name (Short Name)	
CORS Site ID number	
Date of the site selection	
Name who selected the site	
Address	
Circumstance around the CORS	
Ground condition (strength, geology)	
Average temperature and humidity	
Flood frequency and flood depth	
Frequency of Lighting	
Nearby facility that transmits radio waves	
Availability of System Power Supply	
(if Yes) From where, and How far from	
Communication lines (Wired and/or Mobile)	
(Wired) From where, How far from, internet speed	
(Mobile) Which provider, signal condition	
Sky visibility (See Site Description)	
Security	
Others	
Route to the CORS	
Location where vehicles can reach	
Route from vihicles to the CORS	
Others, Remarks	
Land owner and manager information	
Institution name	
Name of the person in charge	
Address	
Phone No.	
Fax No.	
e-mail	
Other related Institutions information (Entry permission, Construction permission, Electric power company, etc.)	
Institution name 1	
Name of the person in charge	
Address	
Phone No.	
Fax No.	
e-mail	
Remarks	
Institution name 2	
Name of the person in charge	
Address	
Phone No.	
Fax No.	
e-mail	
Remarks	
Remarks	

Ver, 24th October 2024

Project on Establishment of Continuously Operating Reference Stations (CORS) for Land Management and Infrastructure Development

Post Processing Manual For Khmer GEONET

Bernese 5.4

1. INDEX

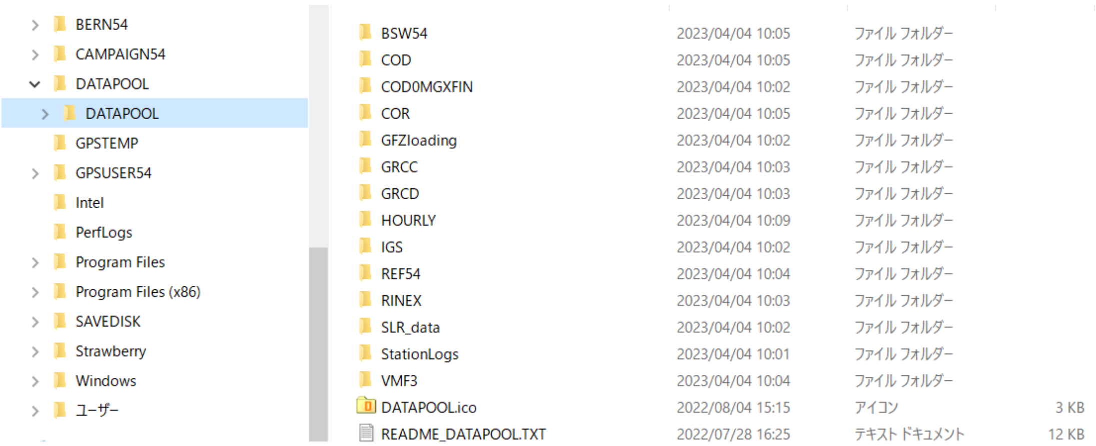
NOTE: The remaining issues are shown below. GDCG should discuss this issue and update this manual.

- You will need to edit the instructions for Bernese software updated to Bernese 5.4 or later.
- After CORS is installed throughout Cambodia, it is necessary to record the process of determining its coordinates and the survey network that was calculated.
- Once CORS has been installed throughout Cambodia, it is necessary to decide on the interval at which the coordinate values will be monitored and the observation date for the data used for monitoring. Then use Bernese software to monitor the coordinates at the determined time.

2. Folder structure

2.1. DATAPOOL Folder

The DATAPOOL folder is for placing external local copies.
See [README_DATAPOOL.TXT] for more information.



(1) BSW54

This folder is intended to store the ionosphere maps (ION file) and the differential code bias files (DCB file). These files are in Bernese specific formats. These files can be downloaded from the following sites.

Download site: http://ftp.aiub.unibe.ch/CODE/

Download site: Index of /CODE/2023/ (unibe.ch)

(2) COD

This folder is intended to store the Orbits files, the earth orientation parameters files (EOP file) and the satellite clock corrections files.

This folder is intended to store the files with the analysis center name COD.

These files can be downloaded from the following sites.

Download site of CODE: http://ftp.aiub.unibe.ch/CODE/

Download site of

Crustal dynamics data information system: http://ftp.aiub.unibe.ch/BSWUSER52/

These file names are [SSSWWWWD.XXX].

SSS: Analysis center name (e.g. COD, IGS)

WWWW: GPS week

D: Day of week (e.g. [0] is Sunday, [6] is Saturday)

XXX: Extension

EOP or ERP: Earth orientation parameters (Convert IERS format (EOP) to Bernese format (ERP))
SUM: Analysis report of GPS week
CLK: Clock correction information of satellite
PRE or SP3: Precise orbit files
[IGS] provides GPS and GLONASS of the precise orbit files in separate files.
The analysis center name of the precise orbit files of GLONASS is IGV.
GPS and GLONASS of the precise orbit files can be merged.

(3) COD0MGXFIN
CODE experimental Multi-GNSS Extension (MGEX) solution, containing GPS, GLONASS, Galileo, Bei Dou, and QZSS.

(4) COR
CODE operational rapid solution, containing GPS, GLONASS and Galileo

(5) GFZ loading
Grid files with crustal deformation corrections from the non-tidal loading models as provided by GFZ Potsdam for atmosphere, ocean and hydrology non-tidal loading effects.

(6) GRCC
These directories are intended to host files which are necessary for Low Earth Orbiter (LEO) data processing. For each LEO satellite a separate folder is foreseen.

(7) GRCD
These directories are intended to host files which are necessary for Low Earth Orbiter (LEO) data processing. For each LEO satellite a separate folder is foreseen.

(8) HOURLY
The same as the RINEX directory but dedicated to hourly RINEX data as used for RTK applications.

(9) IGS
Like the COD folder, this folder is intended to store the Orbits files, the earth orientation parameters files (EOP file) and the satellite clock corrections files in this folder.

This folder is intended to store the files with the analysis center name IGS.

(10) REF54

This folder is intended to store Bernese format files which are useful for several campaigns (e.g. Station coordinate information file (IGS20.CRD) and Velocity information file (IGS20.VEL)).

(11) RINEX

This folder is intended to store GNSS observation data files in RINEX format.
These file names are [TTTTDDDS.YYX].

TTTT: Station name (e.g. PHN1, SIE1)
DDD: Day of year (e.g. [176] is 25th June)
S: Session name (e.g. [0], [2])
YYX: Extension of year and file category
YY: Year (e.g. [22] is 2022)
X: File category
[o]: Observation data such as carrier phase
[n]: Broadcast orbits data of GPS satellites
[g]: Broadcast orbits data of GLONASS satellites

RINEX version 3.02 introduced a new file naming convention.
These file names are [cccc00CCC_R_yyyydddhhmm_lll_sss_MO.rnx].

cccc00CCC: 9 characters defining the receiver (proposed usage: four–character site/station code, one–digit number to indicate the monument/receiver at the site, and ISO country code).
R: data source: one of the three items (S from streams, R directly from the receiver, U unknown)
yyyydddhhmm: start epoch (specified for the minute)
lll: the intended (nominal) file period (e.g., 01D, 01H, 15M)
sss: the sampling rate of the observations (e.g., 30S, 01S)
MO: data type (indicating the GNSS or M for multi–GNSS) and content (O for observation, N for navigation)
rnx: extension to be used for all RINEX files

(12) SLR_data

This folder is intended to store Satellite Laser Ranging files

(13) Station logs

This folder is intended to store the information files of IGS station.

These files can be downloaded from the following sites.

Download site of the station information: https://files.igs.org/pub/station/log/

The coordinates of the observation point, receiver and antenna information can be downloaded from the following site. For example, [IGb14.SNX] is a file that contains information about [IGb14] reference frame.

Download site: https://files.igs.org/pub/station/coord/

(14) VMF3

This folder is intended to store the grid files needed for processing using Vienna Mapping Function (VMF3). The grid files can be downloaded from the following sites.

Download site: http://ggosatm.hg.tuwien.sc.at/DELAY/Grid/VMFG/

They are not used for the examples but it shall indicate that for other types of files other directories may be created.

2.2. CAMPAIGN Folder

When you create a campaign in Bernese, the campaign folder and subfolders are created.
The folder structure when the [INTRO] campaign is created is shown below.
These subfolders are for copying the files needed for analysis from the DATAPOOL folder and so on.

2.3. SAVEDISK Folder

The SVEDISK folder is for storing important analysis results.
See [README_SAVEDISK.TXT] for more information.

Create a subfolder in the SAVEDISK folder with the same name as the campaign folder.
Copy important files from [ATM, ORB, OUT, SOL, STA] subfolder in the campaign folder to the [ATM, ORB, OUT, SOL, STA] subfolder in the SVEDISK folder.

3. General files

3.1. A list of general files to be used

A list of General files is shown below.

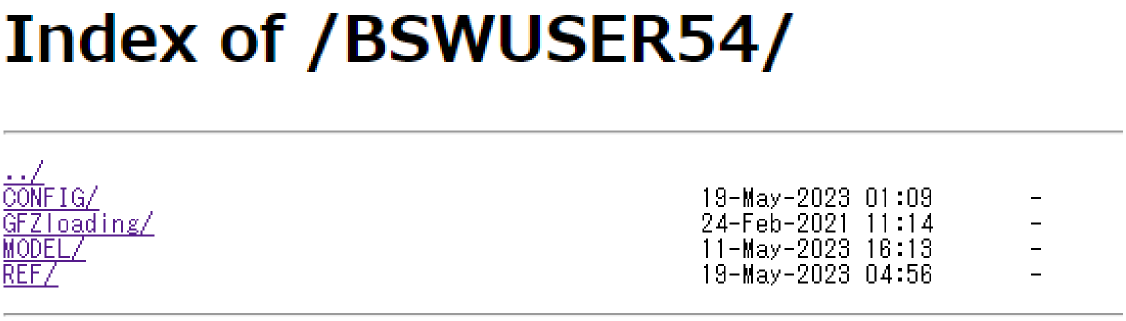
Filename	Content	Modification	Update from
CONST.BSW	All constants used in the *Bernese GNSS Software*	No	BSW aftp
IAU2000R06.NUT	Nutation model coefficients	No	—
IERS2010XY.SUB	Subdaily pole model coefficients	No	—
OT_FES2004.TID	Ocean tides coefficients	No	—
TIDE2000.TPO	Solid Earth tides coefficients	No	—
EGM2008_SMALL.GRV	Earth potential coefficients (reduced version, sufficient for GNSS and LEO orbit determination)	No	—
s1_s2_def_ce.dat	S1/S2 atmospheric tidal loading coefficients	No	—

Configuration files located in ${C}/GLOBAL/CONFIG

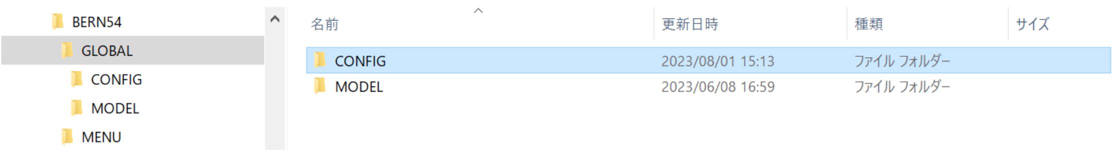
Filename	Content	Modification	Update from
DATUM.BSW	Definition of geodetic datum	Introducing new reference ellipsoid	BSW aftp
GPSUTC.BSW	Leap seconds	When a new leap second is announced by the IERS	BSW aftp
POLOFF.POL	Pole offset coefficients	Introducing new values from IERS annual report (until 1997)	—
SATELLIT_I14.SAT or SATELLIT_I20.SAT	Satellite information file	New launched satellites	BSW aftp
BOXWING.MAC	Definition of orbit model parameters	New launched satellites	BSW aftp
SAT_$Y+0.CRX	Satellite problems	Satellite maneuvers, bad data, ...	BSW aftp

The latest general files can be downloaded from the following sites.

Download site: Index of /BSWUSER54/ (unibe.ch)



Copy the downloaded General files to the [C:/BERN54/GLOVAL/GONFIG] or [C:/BERN54/GLOVAL/MODEL] folder.

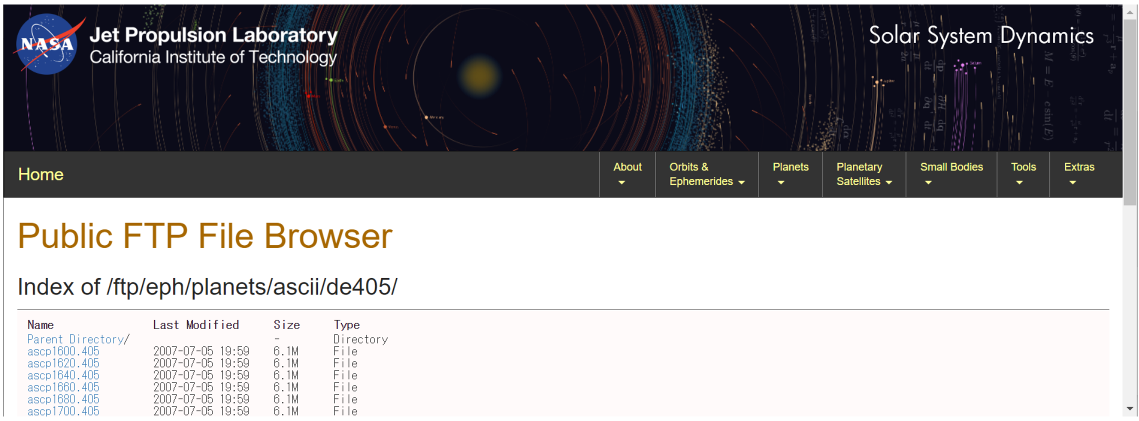


3.2. Installation of the JPL planetary and lunar ephemerides

Download the JPL planetary and lunar ephemerides from the download site.

See [JPL_EPH.TXT] for more information.

Download site: https://ssd.jpl.nasa.gov/ftp/eph/planets/ascii/de421/



Get the following files (in ASCII mode).

- ✓ header.421
- ✓ testpo.421
- ✓ ascp1900.421: covers the time interval between 1900 and 2050
- ✓ ascp2050.421: covers the time interval between 2050 and 2200

Concatenate the JPL planetary and lunar ephemerides files (ASCII files).

Merge [header.421] and [ascp1900.421, ascp2200.421] using a text editor or Windows Command Prompt.

Open a Windows Command Prompt.

[Copy header.421+ ascp1900.421+ ascp2050.421 temp.421]

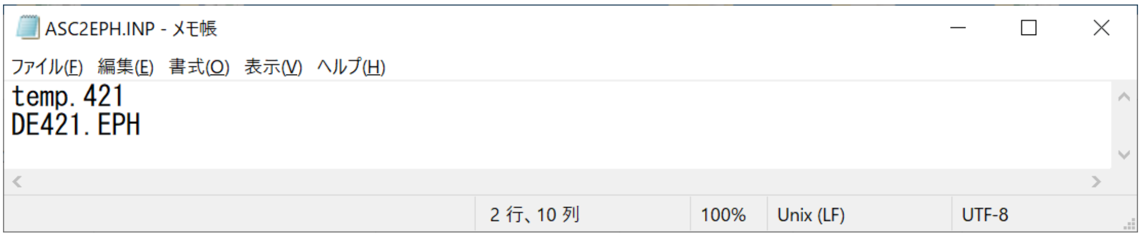
The merged file name is a temporary file name (e.g. temp.421).

Convert the file to binary.

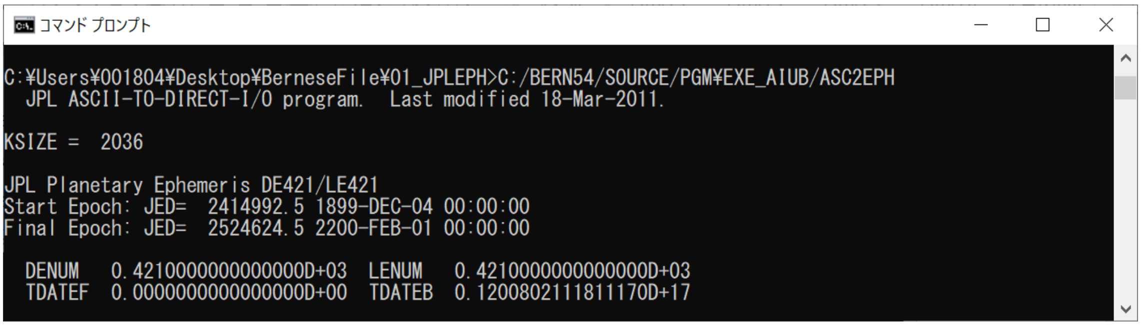
Create an input file [ASC2EPH.INP] using a text editor.

1st line: Filename of the concatenated ASCII file (temp.421),

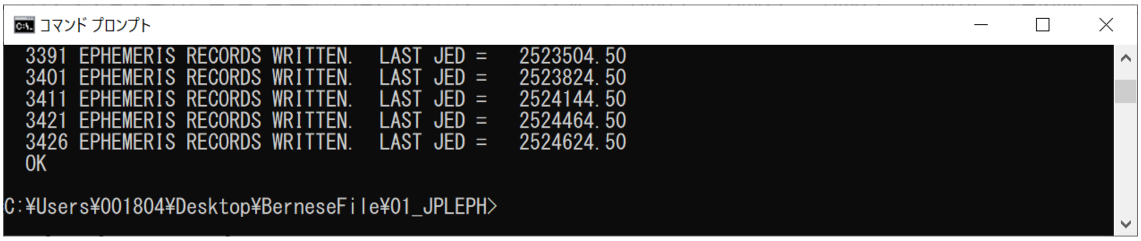
2nd line: Filename of the resulting binary file [DE421.EPH (JPLEPH)].



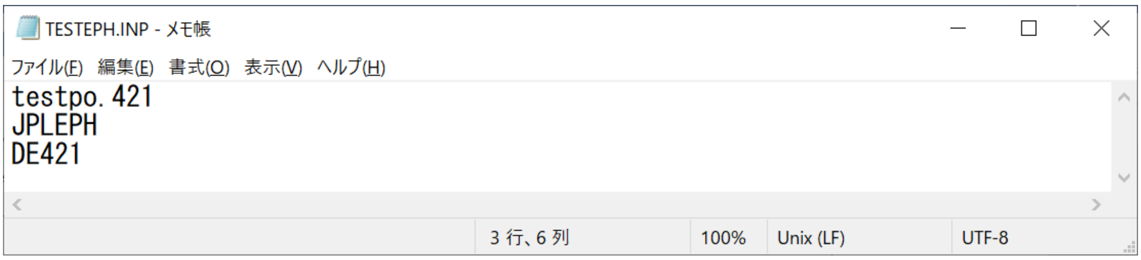
Open a Windows Command Prompt. Set the folder where the input file [ASC2EPH.INP] is saved as the current directory.
Execute [C:/BERN54/SOURCE/PGM/EXE_AIUB/ASC2EPH.exe]



Make sure there are no errors.



Check the integrity of the file and test the values.
Create an input file [TESTEPH.INP] using a text editor.
1st line: Name of the test-data file from JPL (testpo.421)
2nd line: Name of the binary file to be tested [JPLEPH]
3rd line: DE number of the ephemeris (421)



Set the folder where the input file [TESTEPH.INP] is saved as the current directory.
Execute [C:/BERN54/SOURCE/PGM/EXE_AIUB/TESTEPH.exe]

```
コマンド プロンプト

C:¥Users¥001804¥Desktop¥BerneseFile¥01_JPLEPH>C:/BERN54/SOURCE/PGM¥EXE_AIUB/TESTEPH
 JPL TEST-EPHEMERIS program.  Last modified March 2013.

   2414992.50     2524624.50          32.00
 DENUM    0.421000000000000D+03
 LENUM    0.421000000000000D+03
 TDATEF   0.000000000000000D+00
```

Make sure there are no errors.

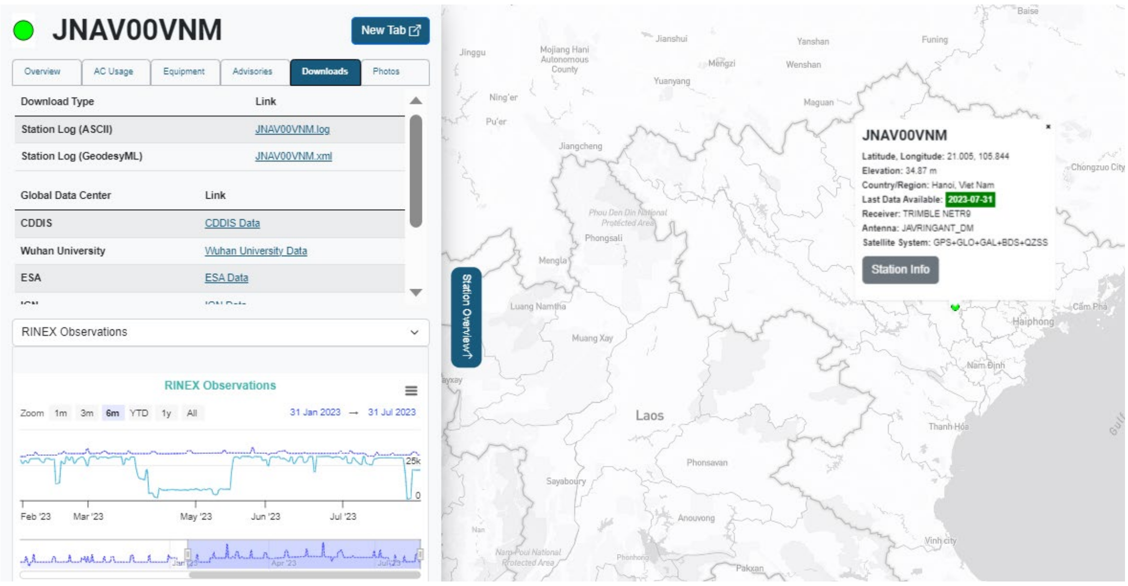
```
選択コマンド プロンプト
 2800 2500212.5    7   10    6          0.0050445003488           0.0050445003488  0.86736E-18
 2900 2503256.5   15    0    2          0.4125495806855           0.4125495806855  0.55511E-16
 3000 2506300.5   12    3    5         -0.0061446979927          -0.0061446979927  0.86736E-18
 3100 2509343.5    9   11    4         -0.0022391993211          -0.0022391993211  0.43368E-18
 3200 2512387.5    3   11    3         -0.3238173037952          -0.3238173037952  0.00000E+00
 3300 2515431.5   13    3    5          0.0000054558555           0.0000054558555  0.19566E-18
 3400 2518474.5    4    6    3         -2.3518118205103          -2.3518118205103  0.88818E-15
 3500 2521518.5    5    6    6          0.0014609478661           0.0014609478661  0.21684E-18
 3600 2524562.5    1    7    3         -7.8125572338720          -7.8125572338720  0.00000E+00

C:¥Users¥001804¥Desktop¥BerneseFile¥01_JPLEPH>
```

Copy JPLEPH file to the C:/BERN54/GLOBAL/MODEL folder.
Rename [JPLEPH] file to [DE421.EPH] file.

4. IGS Station

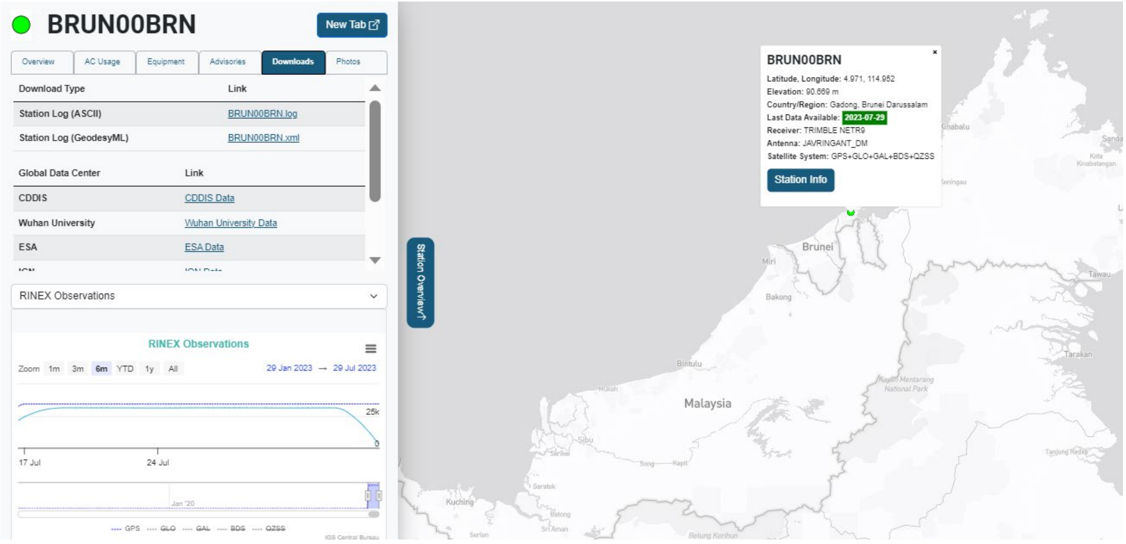
Six IGS stations were selected to determine the coordinates of the Khmer GEONET.

Vietnam's JNAV points could not be used due to missing coordinates in the IGS20.CRD file.



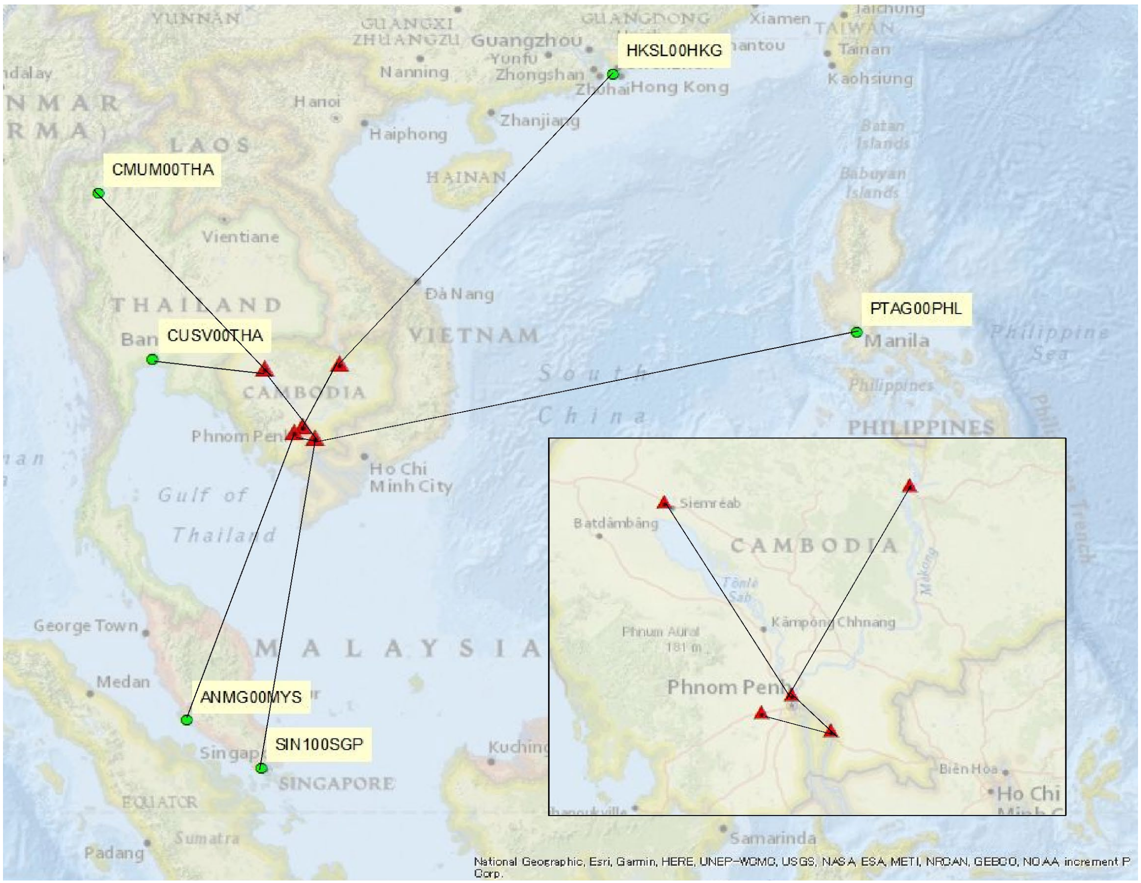
697	JERV	59923M001	-4237232.94673	4077485.01051	-2462642.27254	ITR20
698	JFNG	21602M006	-2279828.92233	5004706.50910	3219777.43653	IGS20
699	JIZN	20131M001	4533845.34033	4097166.23992	1820976.20420	PPP
700	JLCK	59928M001	-4687826.26867	3697044.33552	-2237232.43621	ITR20
701	JNU1	49519S001	-2354254.77619	-2388549.49660	5407042.74156	ITR20
702	JOEN	10512M001	2564138.90853	1486149.90360	5628951.53474	ITR20
703	JOG2	23109M002	-2200207.97520	5924895.55216	-855929.19342	ITR20

Brunei points have coordinates in the IGS20.CRD file.
However, I couldn't use it because the RINEX file was not archived.



BREW00USA_R_20231300000_01D_30S_MO.crx.gz	2023:05:11 00:11:56	2.67MB
BRMG00DEU_R_20231300000_01D_30S_MO.crx.gz	2023:05:11 05:51:46	5.22MB
BRST00FRA_R_20231300000_01D_30S_MO.crx.gz	2023:05:11 03:59:20	2.75MB
BRUX00BEL_R_20231300000_01D_30S_MO.crx.gz	2023:05:11 00:15:03	4.78MB
BSHM00ISR_R_20231300000_01D_30S_MO.crx.gz	2023:05:11 00:16:58	3.85MB
BUCU00ROU_R_20231300000_01D_30S_MO.crx.gz	2023:05:11 00:51:39	3.97MB
BZR200ITA_R_20231300000_01D_30S_MO.crx.gz	2023:05:11 00:10:21	2.53MB
CAS100ATA_R_20231300000_01D_30S_MO.crx.gz	2023:05:11 00:19:37	4.34MB
CCJ200JPN_R_20231300000_01D_30S_MO.crx.gz	2023:05:11 00:32:07	1.92MB

The network diagram is shown below.



Baseline combinations are shown below.

02:CMUM-10:SIE1

10:SIE1-03:CUSV

10:SIE1-09:PNH1

04:HKSL-11:STG1

11:STG1-09:PNH1

09:PHN1-07:KND1

07:KND1-05:PTAG

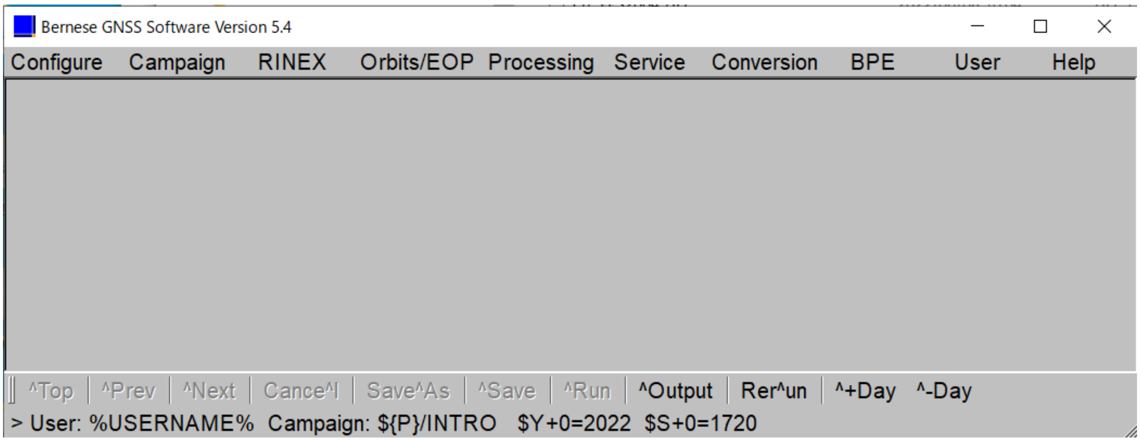
07:KND1-06:SIN1

07:KND1-08:KPS1

08:KSP1-01:ANMG

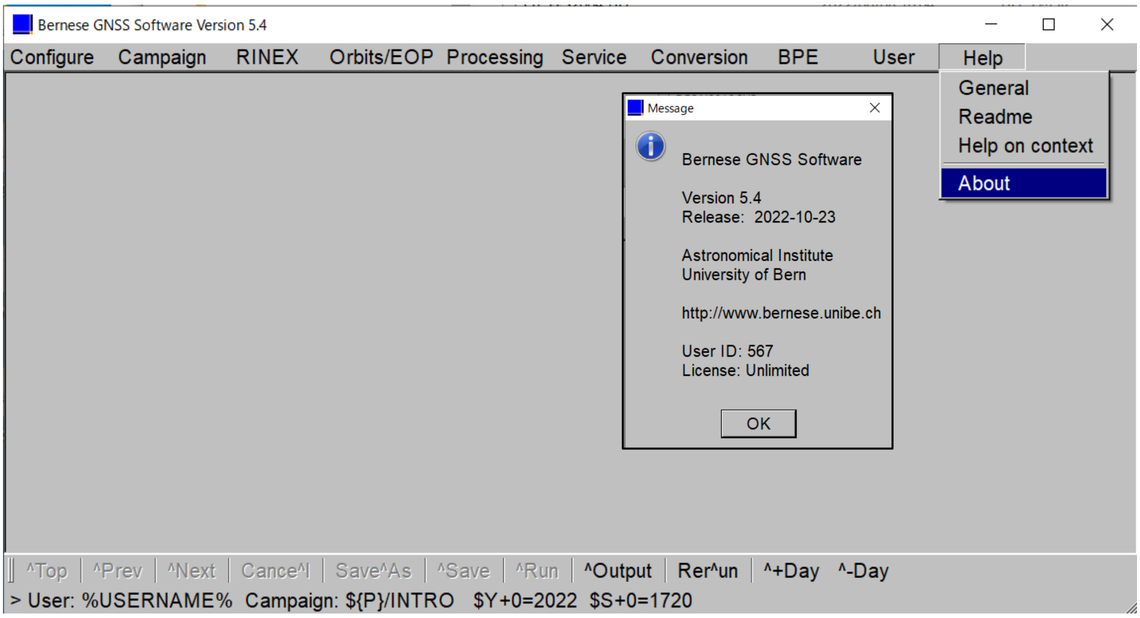
5. Menu

Click [Bernese 5.4 shortcut] to launch the menu program.



Check version and release date.

Bernese software purchased in October 2022 has a release date of 23th October 2022.

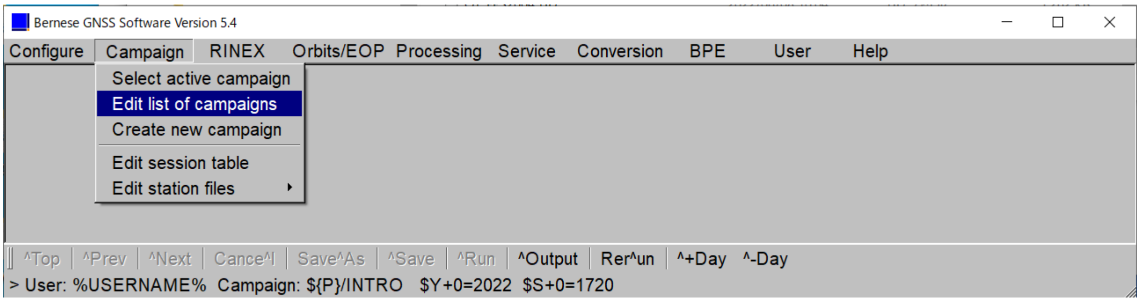


If the version is upgraded, refer to [C:/BERN54/GPS/DOC/README_UPDATE.TXT] and update the version.

6. Campaign setup

6.1. Edit list of campaigns

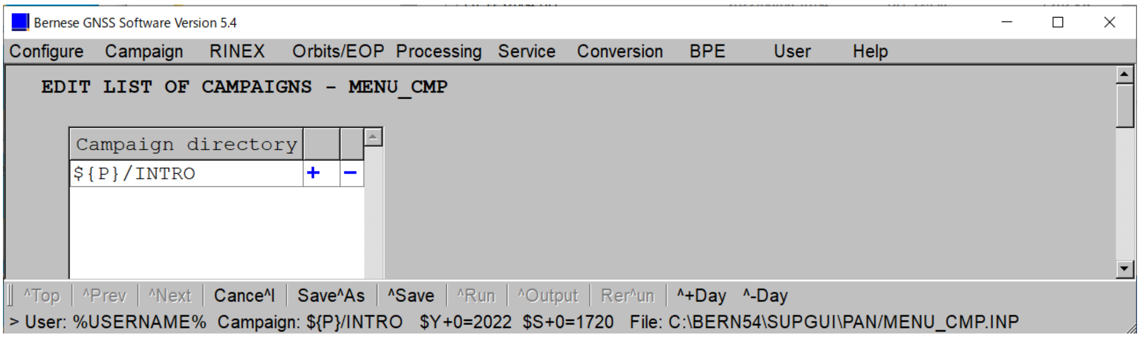
Click [Edit list of campaigns] to display the submenu.



Click [+] to copy the line. Click [-] to delete the line.

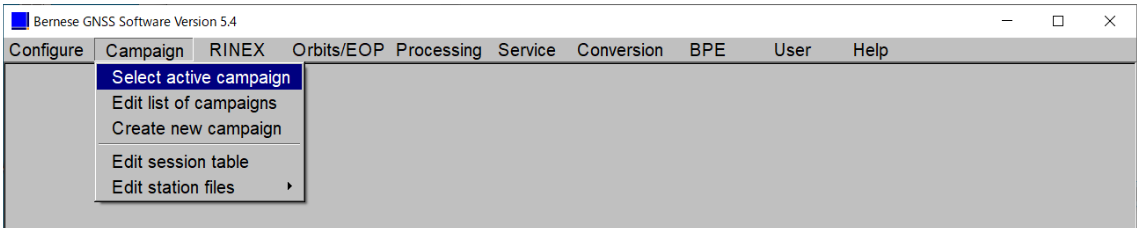
Rename the campaign directory to [${P}/XXXXX]. [XXXXX] can be named arbitrarily.

Click [^Save] to save your changes.

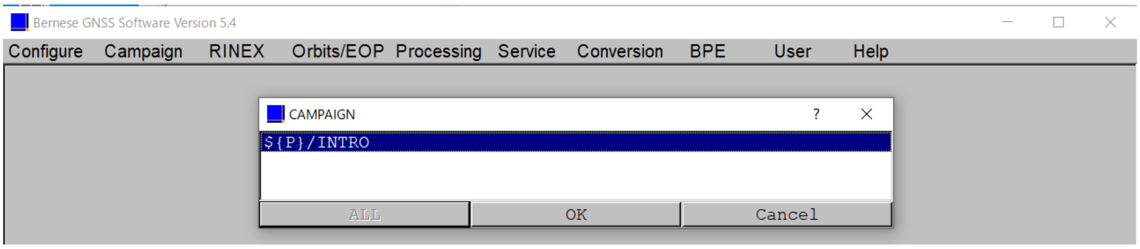


6.2. Select the active campaign

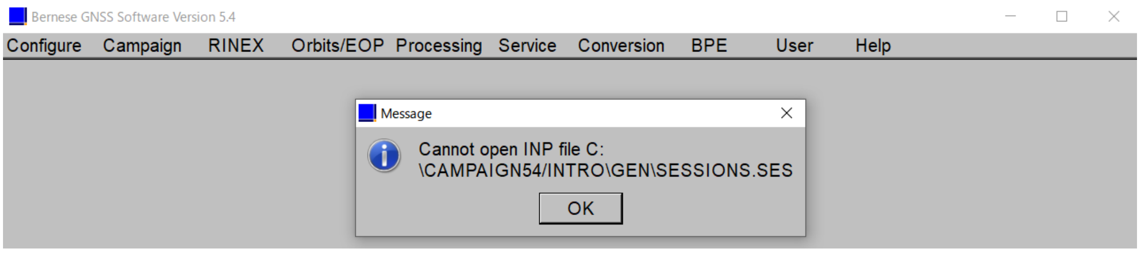
Click [Select active campaign] to display the registered campaign directory.

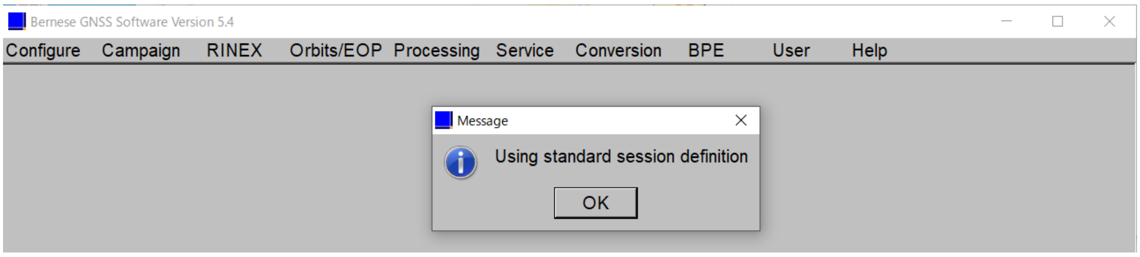


Select the campaign and click [OK].

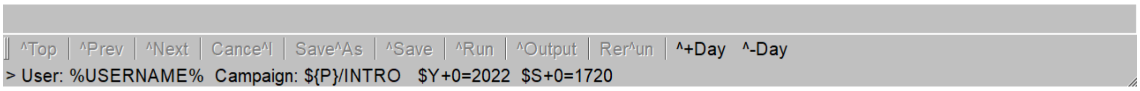


If the Directory is not created, Message will be displayed, but there is no problem. So press the [OK] button. Then, click [OK] for all.



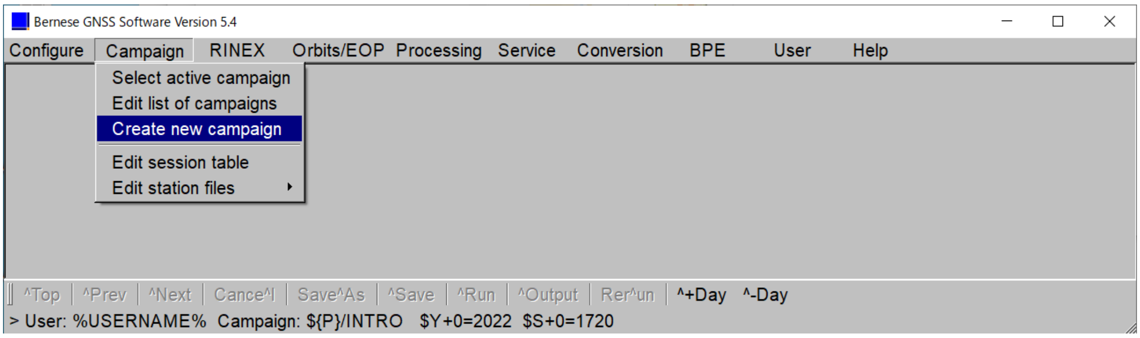


Make sure the selected campaign is displayed at the bottom of the menu screen.

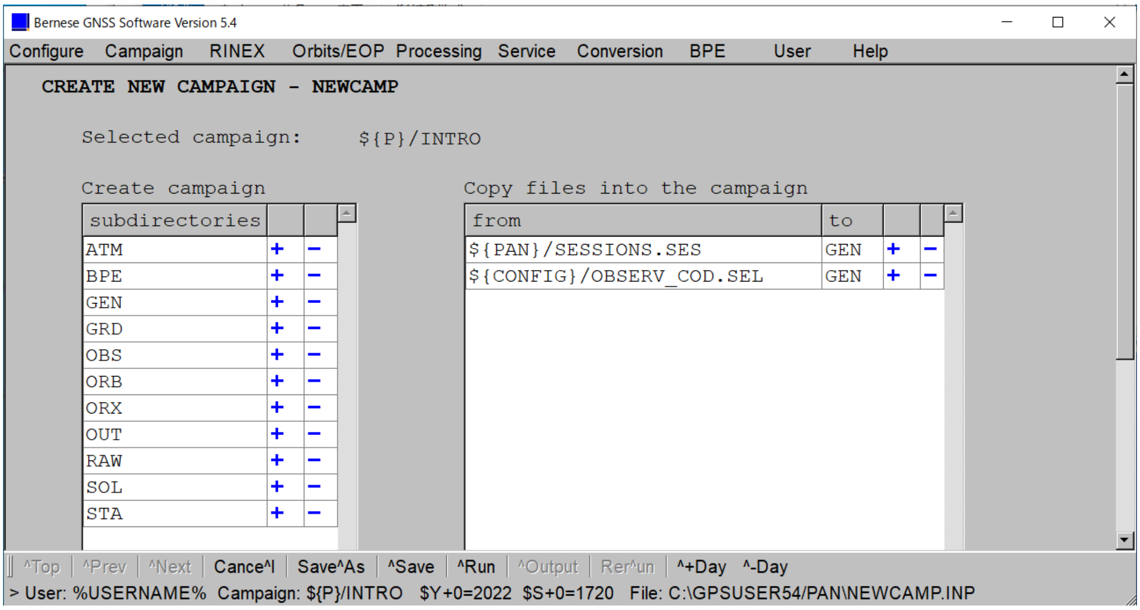


6.3. Create campaign folder

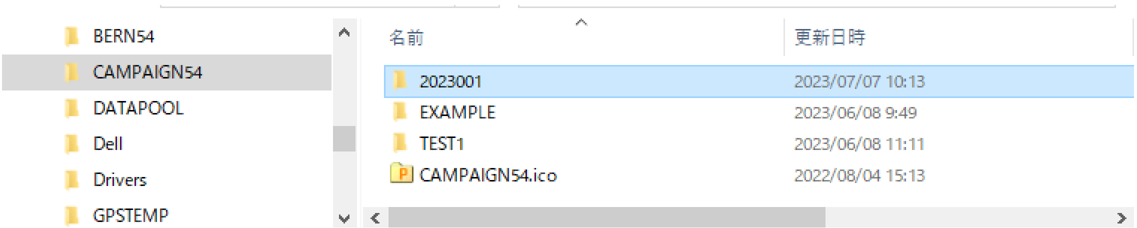
Click [Create new campaign] to display the submenu.



Click [^Run]

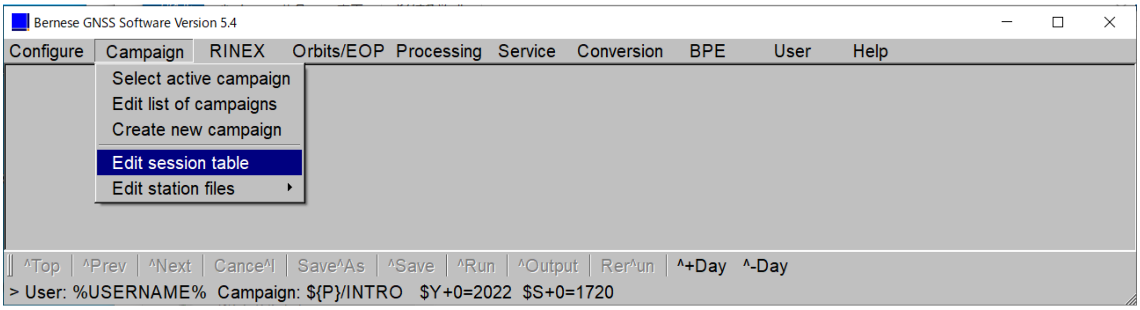


A folder with the campaign name will be created in the CAMPAIGN54 folder.



6.4. Select current session

Click [Edit session table] to display the registered Session table.

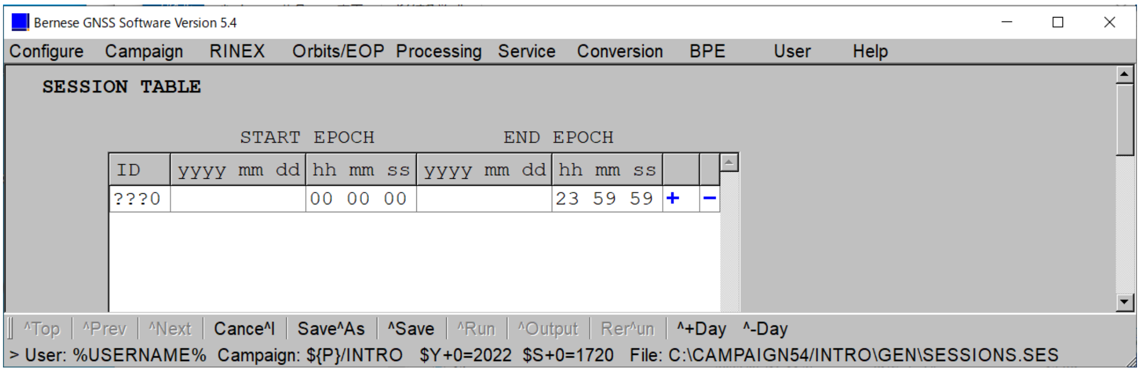


[???] is [Day of year]. It is a total day with 1st-Jan as 1. Set with wildcards.

START EPOCH and END EPOCH dates [yyyy mm dd] are blank.

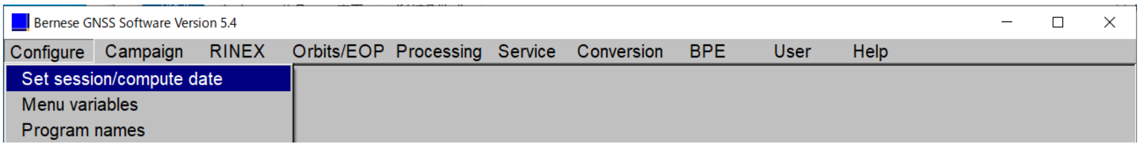
START EPOCH time is 00:00:00. END EPOCH time is 23:59:59.

Click [^Save].



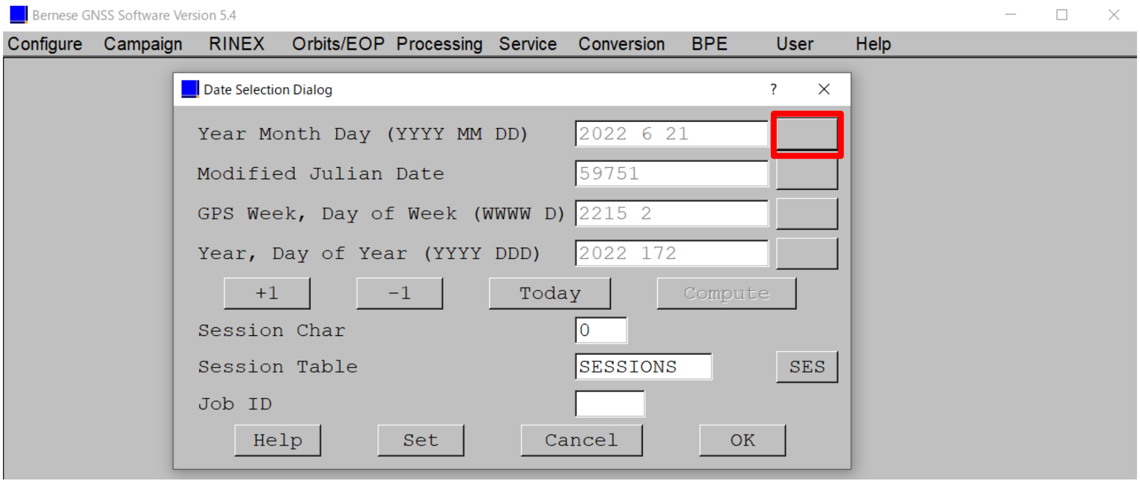
6.5. Baseline processing date setting

Click [Set session/compute date] to display the submenu

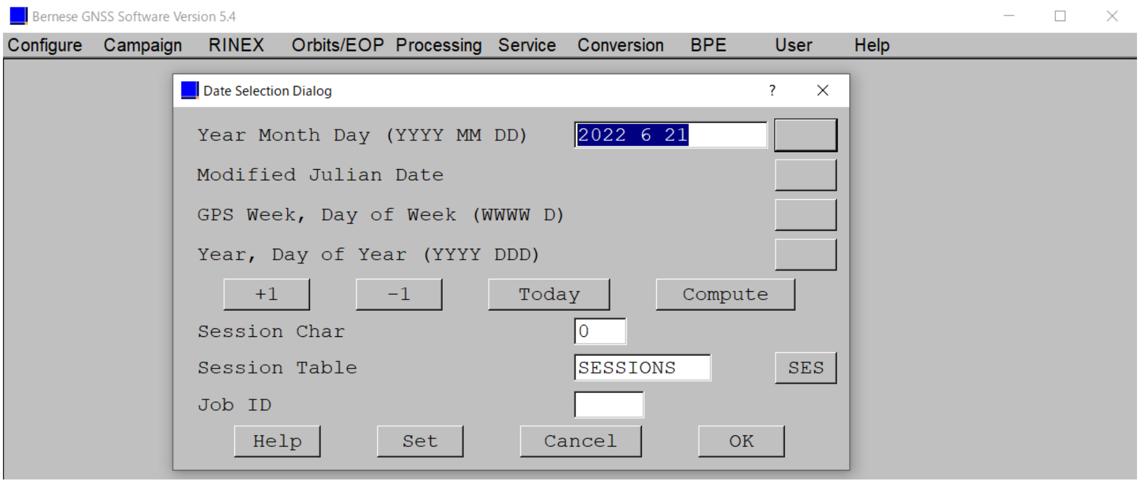


Set by [Year Month Day], [Modified Julian Date], [GPS Week and Day of Week] or [Year and Day of Year].

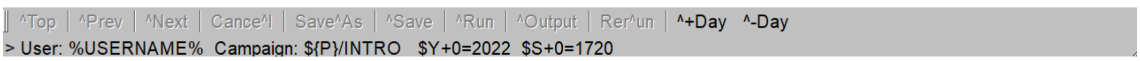
Click the red frame to set in [Year Month Day].



Enter the date and click [OK].



Make sure that the baseline processing date you set is displayed at the bottom of the menu screen.



7. Preparation of observation data, ephemeris data and observation point information

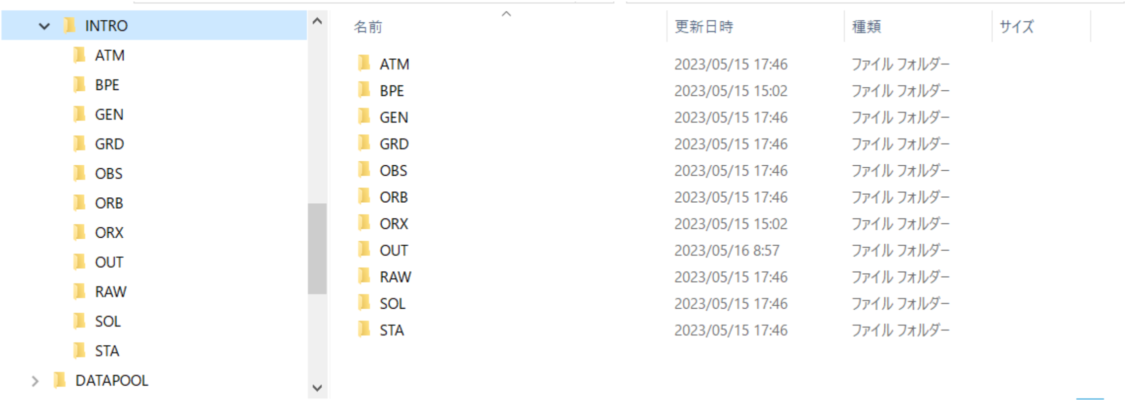
Download the data for analysis from the site of Bern University and Vienna University of Technology.

Download site of Bern University: http://www.bernese.unibe.ch/

Download site of Vienna University of Technology:

Index of /trop_products/GRID/1x1/VMF3/VMF3_OP (tuwien.ac.at)

Copy the downloaded data to subfolders of the campaign.



7.1. RINEX file (Khmer GEONET)

Copy the RINEX file archived by Pivot to [RAW] folder of the campaign.

[KND100KMRxxxxxxxxx_MO.crx]: Compact RINEX format file of the observation data

KND1_0414_MO.crx - メモ帳

ファイル(F) 編集(E) 書式(O) 表示(V) ヘルプ(H)

```
3.0                 COMPACT RINEX FORMAT                    CRINEX VERS   / TYPE
Alloy 5.45                              14-APR-22 00:00:00  CRINEX PROG / DATE
     3.04           OBSERVATION DATA    M (MIXED)           RINEX VERSION / TYPE
Alloy 5.45          Receiver Operator   20220414 000000 UTC PGM / RUN BY / DATE
KND100KHM                                                   MARKER NAME
KND100KHM                                                   MARKER NUMBER
GEODETIC                                                    MARKER TYPE
OBS                 AGENCY                                  OBSERVER / AGENCY
6135R40092          TRIMBLE ALLOY       5.45                REC # / TYPE / VERS
                    TRM159800.00    SCIS                    ANT # / TYPE
 -1619494.2095  6040719.2668  1247864.1215                  APPROX POSITION XYZ
        0.0000        0.0000        0.0000                  ANTENNA: DELTA H/E/N
G   15 C1C L1C S1C C1X L1X S1X C2W L2W S2W C2X L2X S2X C5X  SYS / # / OBS TYPES
       L5X S5X                                              SYS / # / OBS TYPES
R    9 C1C L1C S1C C2C L2C S2C C3X L3X S3X                  SYS / # / OBS TYPES
E   15 C1X L1X S1X C5X L5X S5X C7X L7X S7X C8X L8X S8X C6X  SYS / # / OBS TYPES
       L6X S6X                                              SYS / # / OBS TYPES
J   15 C1C L1C S1C C1X L1X S1X C1Z L1Z S1Z C2X L2X S2X C5X  SYS / # / OBS TYPES
       L5X S5X                                              SYS / # / OBS TYPES
C   15 C1X L1X S1X C5X L5X S5X C2I L2I S2I C7I L7I S7I C6I  SYS / # / OBS TYPES
       L6I S6I                                              SYS / # / OBS TYPES
    15.000                                                  INTERVAL
  2022     4    14     0     0    0.0000000     GPS         TIME OF FIRST OBS
G L2X -0.25000                                              SYS / PHASE SHIFT
R L1P  0.25000                                              SYS / PHASE SHIFT
R L2C -0.25000                                              SYS / PHASE SHIFT
J L2X  0.25000                                              SYS / PHASE SHIFT
DBHZ                                                        SIGNAL STRENGTH UNIT
 23 R01  1 R02 -4 R03  5 R04  6 R05  1 R06 -4 R07  5 R08  6 GLONASS SLOT / FRQ #
    R09 -2 R10 -7 R11  0 R12 -1 R13 -2 R14 -7 R15  0 R17  4 GLONASS SLOT / FRQ #
    R18 -3 R19  3 R20  2 R21  4 R22 -3 R23  3 R24  2        GLONASS SLOT / FRQ #
                                                            GLONASS COD/PHS/BIS
                                                            END OF HEADER
> 2022  4 14  0  0  0.0000000  0 54      C60C13C10C 5C 3C 2R 8G31G32C19C39R 2C21C59G 3G16R 1R13R11G27C45J 4G 4J 7J 3J 2C30C 4C 1C36C29C26C56G26R23C 7G22G 8C40C16C38R22C35C
3&4000
      3&36677968039 3&190991895234 3&45300    3&36677936598 3&155196468618 3&49600 &&&&&&&&&&&0707&&&&&&&&0808&&
      3&39726531102 3&206866527904 3&36900 3&39726524043 3&159962321308 3&37100 3&39726517789 3&168096019750 3&35400 &&&&&&&&&&&0606&&0606&&0505&&
      3&36220854453 3&188611585457 3&45600 3&36220840602 3&145846461992 3&47900 3&36220835176 3&153262401399 3&47900 &&&&&&&&&&&0707&&0707&&0707&&
```

Since the file name is long, change it to a short file name for BERNESE.

Examples are shown below.

KND11720.crx: Compact RINEX format file of the observation data

Compact RINEX format file is converted to RINEX file format. Use [CRX2RNX.exe] for format conversion.

Open a Windows command prompt. Set the [RAW] folder as the current directory.

Specify the compact RINEX format file to be converted and execute [CRX2RNX.exe].

In addition, specify the directory where [CRX2RNX.exe] was saved and execute it.

コマンド プロンプト

```
Microsoft Windows [Version 10.0.19043.1645]
(c) Microsoft Corporation. All rights reserved.

C:¥Users¥001804>cd C:¥GPSDATA¥CAMPAIGN52¥INTRO¥RAW

C:¥GPSDATA¥CAMPAIGN52¥INTRO¥RAW>C:¥Users¥001804¥Desktop¥RNXCMP_4.1.0_Windows_mingw_64bit¥bin¥CRX2RNX KND1_0414_MO.crx

C:¥GPSDATA¥CAMPAIGN52¥INTRO¥RAW>_
```

[KND11720.rnx]: RINEX format file of the observation data

KND1_0419_MO.rnx - メモ帳

ファイル(F) 編集(E) 書式(O) 表示(V) ヘルプ(H)

```
     3.04           OBSERVATION DATA    M (MIXED)           RINEX VERSION / TYPE
Alloy 5.45          Receiver Operator   20220419 000000 UTC PGM / RUN BY / DATE
KND100KHM                                                   MARKER NAME
KND100KHM                                                   MARKER NUMBER
GEODETIC                                                    MARKER TYPE
OBS                 AGENCY                                  OBSERVER / AGENCY
6135R40092          TRIMBLE ALLOY       5.45                REC # / TYPE / VERS
                    TRM159800.00    SCIS                    ANT # / TYPE
 -1619492.9440  6040715.0700  1247864.9000                  APPROX POSITION XYZ
        0.0000        0.0000        0.0000                  ANTENNA: DELTA H/E/N
G   15 C1C L1C S1C C1X L1X S1X C2W L2W S2W C2X L2X S2X C5X  SYS / # / OBS TYPES
       L5X S5X                                              SYS / # / OBS TYPES
R    9 C1C L1C S1C C2C L2C S2C C3X L3X S3X                  SYS / # / OBS TYPES
E   15 C1X L1X S1X C5X L5X S5X C7X L7X S7X C8X L8X S8X C6X  SYS / # / OBS TYPES
       L6X S6X                                              SYS / # / OBS TYPES
J   15 C1C L1C S1C C1X L1X S1X C1Z L1Z S1Z C2X L2X S2X C5X  SYS / # / OBS TYPES
       L5X S5X                                              SYS / # / OBS TYPES
C   15 C1X L1X S1X C5X L5X S5X C2I L2I S2I C7I L7I S7I C6I  SYS / # / OBS TYPES
       L6I S6I                                              SYS / # / OBS TYPES
    15.000                                                  INTERVAL
  2022     4    19     0     0    0.0000000     GPS         TIME OF FIRST OBS
G L2X -0.25000                                              SYS / PHASE SHIFT
R L1P  0.25000                                              SYS / PHASE SHIFT
R L2C -0.25000                                              SYS / PHASE SHIFT
J L2X  0.25000                                              SYS / PHASE SHIFT
DBHZ                                                        SIGNAL STRENGTH UNIT
 23 R01  1 R02 -4 R03  5 R04  6 R05  1 R06 -4 R07  5 R08  6 GLONASS SLOT / FRQ #
    R09 -2 R10 -7 R11  0 R12 -1 R13 -2 R14 -7 R15  0 R17  4 GLONASS SLOT / FRQ #
    R18 -3 R19  3 R20  2 R21  4 R22 -3 R23  3 R24  2        GLONASS SLOT / FRQ #
                                                            GLONASS COD/PHS/BIS
                                                            END OF HEADER
> 2022  4 19  0  0  0.0000000  0 56        .000000002000
C60                                                                           36676924.46107 190986448.77507        45.100
C13                                                                           39951995.54705 208040563.92005        32.400    39951989.86306 1608701
C10                                                                           36257146.44507 188800554.36307        45.100    36257132.97708 1459925
R 8  23796338.92206 127428334.40306        36.400    23796344.31306  99110944.74806        36.800
C43  26150543.69505 137422022.53805        35.800    26150545.37106 102620329.33906        37.500    26150550.30505 136172756.58105        35.400
C41  25785958.37905 135506140.45505        35.400    25785967.42206 101189662.40406        40.300    25785965.14106 134274277.98906        36.900
G 3  22583797.96106 118678570.85006        41.700                                                                                              22583804.75007  9247688
C 5                                                                           38320699.70305 199545919.94305        35.800    38320685.26606 1543015
```

Pivot also allows you to download the RINEX format files [KND11720.23o].

The [KND11720.23o] file can be used as is.

----- Supplementary Explanation ---

The RINEX file has the broadcast ephemeris data.

A description of the broadcast ephemeris data is shown below.

However, BERNESE uses the precise ephemeris data. As a general rule, the broadcast ephemeris data are not used.

[KND100KMRxxxxxxxxx_MN.rnx]: RINEX format file of the broadcast ephemeris data

KND1_0414_MN.rnx - メモ帳

ファイル(F) 編集(E) 書式(O) 表示(V) ヘルプ(H)

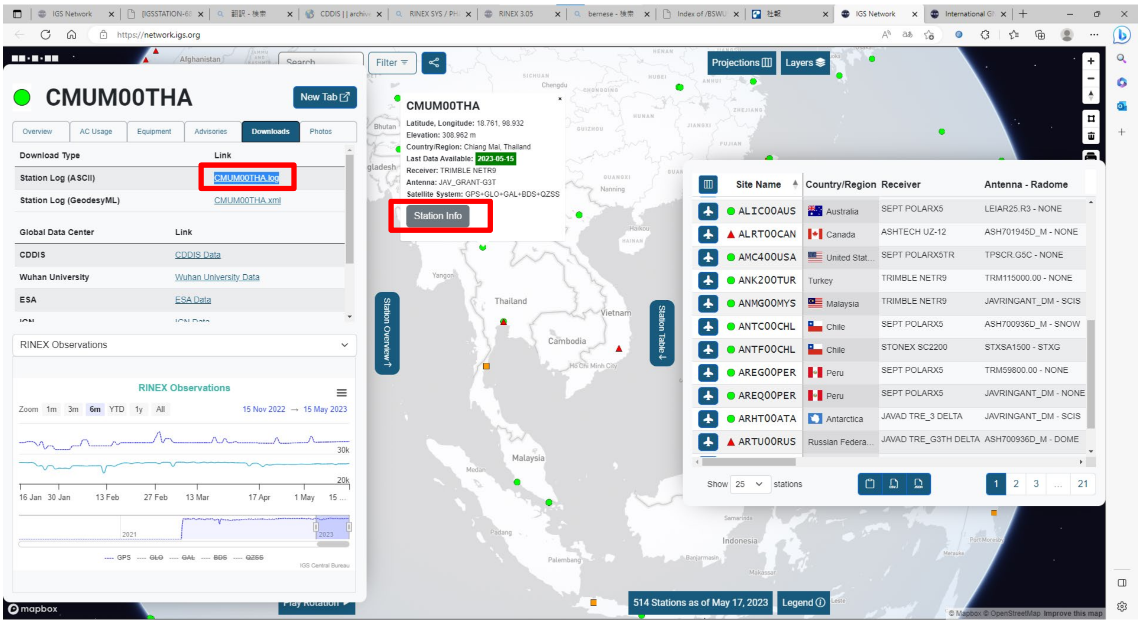
```
     3.04           N: GNSS NAV DATA    M: MIXED NAV DATA   RINEX VERSION / TYPE
Alloy 5.45          Receiver Operator   20220414 000000 UTC PGM / RUN BY / DATE
GPSA    .1583D-07   .1490D-07  -.1192D-06  -.1192D-06       IONOSPHERIC CORR
GPSB    .1065D+06   .6554D+05  -.1966D+06  -.1966D+06       IONOSPHERIC CORR
GAL     .7950D+02  -.1953D-01   .1309D-01   .0000D+00       IONOSPHERIC CORR
QZSA    .2328D-07  -.7451D-08  -.4172D-06  -.6557D-06       IONOSPHERIC CORR
QZSB    .1229D+06   .6554D+05  -.1180D+07  -.3146D+07       IONOSPHERIC CORR
BDSA    .2235D-07   .2906D-06  -.2086D-05   .3099D-05       IONOSPHERIC CORR
BDSB    .1700D+06  -.9667D+06   .4588D+07  -.2687D+07       IONOSPHERIC CORR
GPUT  -.6519258022D-08 -.168753900D-13 503808 2205          TIME SYSTEM CORR
GAUT  -.9313225746D-09  .888178420D-15 259200 2205          TIME SYSTEM CORR
BDUT   .0000000000D+00  .408562073D-13     14  849          TIME SYSTEM CORR
QZUT  -.2793967724D-08  .000000000D+00 528384 2205          TIME SYSTEM CORR
GAGP   .4220055416D-08  .577315973D-14 345600 2205          TIME SYSTEM CORR
    18    18  2185     7                                    LEAP SECONDS
                                                            END OF HEADER
C60 2022 04 13 23 00 00 -.447384081781D-06 -.150990331349D-12  .000000000000D+00
```

7.2. RINEX file (IGS Station)

7.2.1. Station Information

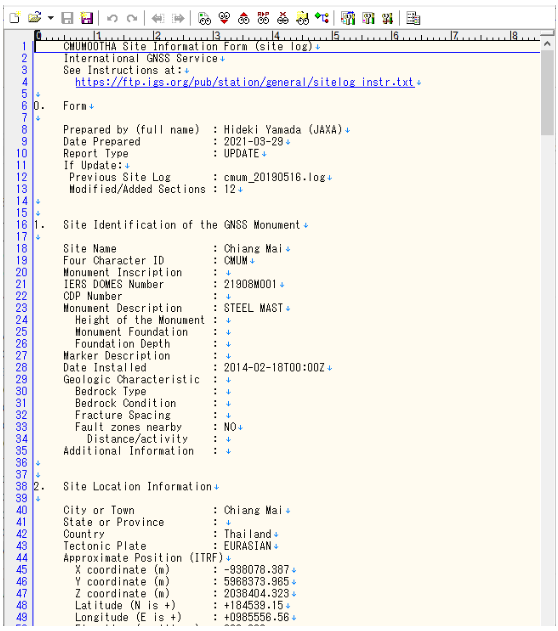
Connect to the IGS website.

IGS website: https://igs.org/network/



Select the IGS station mark (●, ▲) and click [Station Info]. ▲ is the point that is not working.

Then click [Station Log (AASCII)] to get information about the IGS station.



```
CMUM00THA Site Information Form (site log)
International GNSS Service
See Instructions at:
  https://ftp.igs.org/pub/station/general/sitelog_instr.txt

0.   Form

     Prepared by (full name)  : Hideki Yamada (JAXA)
     Date Prepared            : 2021-03-29
     Report Type              : UPDATE
     If Update:
      Previous Site Log       : cmum_20190516.log
      Modified/Added Sections : 12

1.   Site Identification of the GNSS Monument

     Site Name                : Chiang Mai
     Four Character ID        : CMUM
     Monument Inscription     :
     IERS DOMES Number        : 21908M001
     CDP Number               :
     Monument Description     : STEEL MAST
       Height of the Monument :
       Monument Foundation    :
       Foundation Depth       :
     Marker Description       :
     Date Installed           : 2014-02-18T00:00Z
     Geologic Characteristic  :
       Bedrock Type           :
       Bedrock Condition      :
       Fracture Spacing       :
       Fault zones nearby     : NO
         Distance/activity    :
     Additional Information   :

2.   Site Location Information

     City or Town             : Chiang Mai
     State or Province        :
     Country                  : Thailand
     Tectonic Plate           : EURASIAN
     Approximate Position (ITRF)
       X coordinate (m)       : -938078.387
       Y coordinate (m)       : 5968373.965
       Z coordinate (m)       : 2038404.323
       Latitude (N is +)      : +184539.15
       Longitude (E is +)     : +0985556.56
```

```
       Elevation (m,ellips.)  : 308.962
     Additional Information   :

3.   GNSS Receiver Information

3.1  Receiver Type            : JAVAD TRE_G3TH DELTA
     Satellite System         : GPS+GLO+GAL+QZSS
     Serial Number            : 00675
     Firmware Version         : 3.5.4
     Elevation Cutoff Setting : 0 deg
     Date Installed           : 2014-02-18T00:00Z
     Date Removed             : 2015-08-24T00:00Z
     Temperature Stabiliz.    :
     Additional Information   : Temperature-controlled room or cabinet

3.5  Receiver Type            : TRIMBLE NETR9
     Satellite System         : GPS+GLO+GAL+BDS+QZSS
     Serial Number            : 5423R48734
     Firmware Version         : 5.37
     Elevation Cutoff Setting : 0 deg
     Date Installed           : 2019-04-17T04:53Z
     Date Removed             : CCYY-MM-DDThh:mmZ
     Temperature Stabiliz.    : none
     Additional Information   : Temperature-controlled room or cabinet

4.   GNSS Antenna Information

4.1  Antenna Type             : JAV_GRANT-G3T    NONE
     Serial Number            : 01320
     Antenna Reference Point  : BAM
     Marker->ARP Up Ecc. (m)  : 0.0000
     Marker->ARP North Ecc(m) : 0.0000
     Marker->ARP East Ecc(m)  : 0.0000
     Alignment from True N    : 0.0 deg
     Antenna Radome Type      : NONE
     Radome Serial Number     :
     Antenna Cable Type       :
     Antenna Cable Length     :
     Date Installed           : 2014-02-18T00:00Z
     Date Removed             : CCYY-MM-DDThh:mmZ
     Additional Information   :

4.x  Antenna Type             : (A20, from rcvr_ant.tab; see instructions)
     Serial Number            : (A*, but note the first A5 is used in SINEX)
     Antenna Reference Point  : (BPA/BCR/XXX from "antenna.gra"; see instr.)
     Marker->ARP Up Ecc. (m)  : (F8.4)
     Marker->ARP North Ecc(m) : (F8.4)
     Marker->ARP East Ecc(m)  : (F8.4)
     Alignment from True N    : (deg; + is clockwise/east)
```

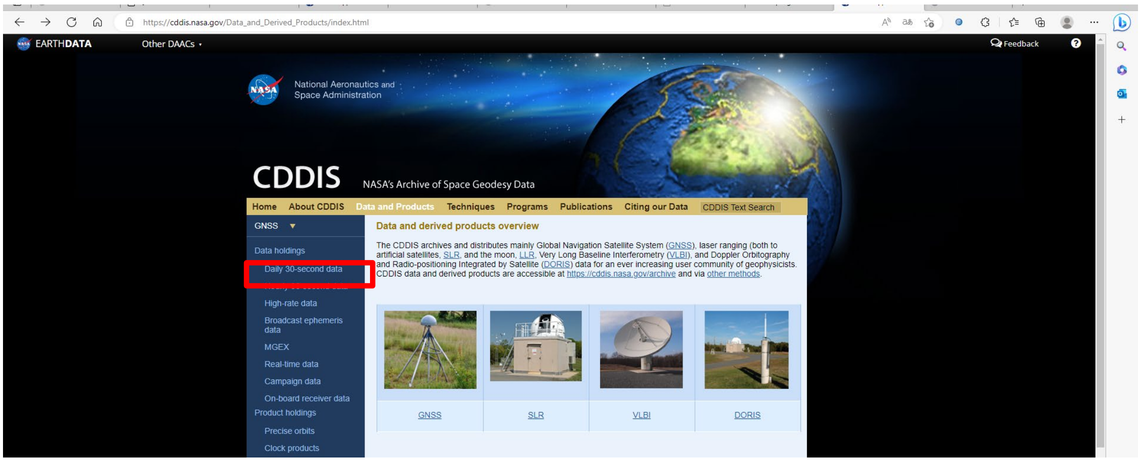
7.2.2. Download RINEX file

Connect to the NASA website.

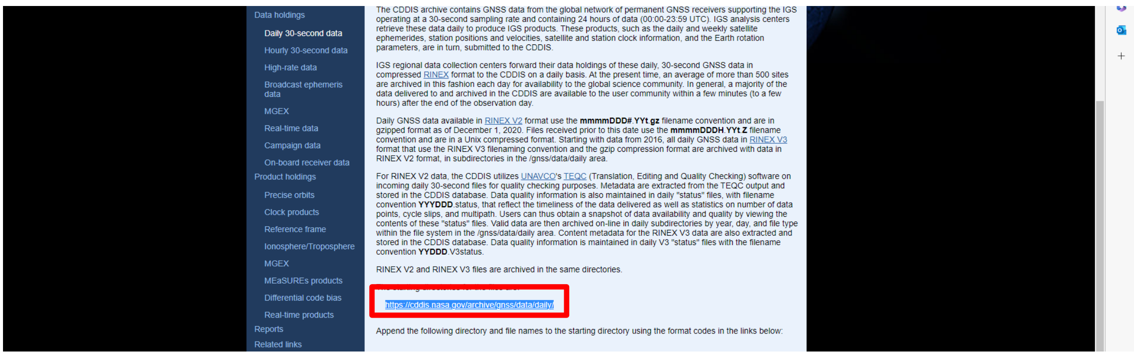
NASA's Archive of Space Geodesy Data: [CDDIS | (nasa.gov)]

Click [GNSS – Global Navigation Satellite System].

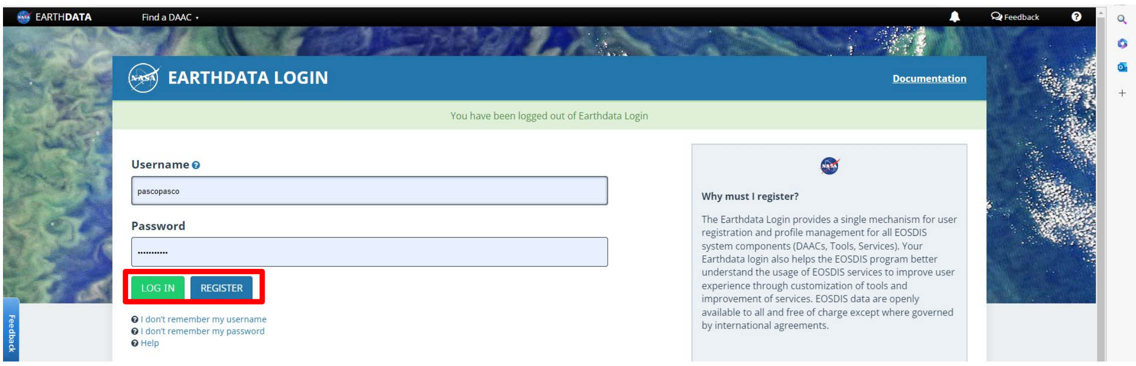
Click [Daily 30-second data].



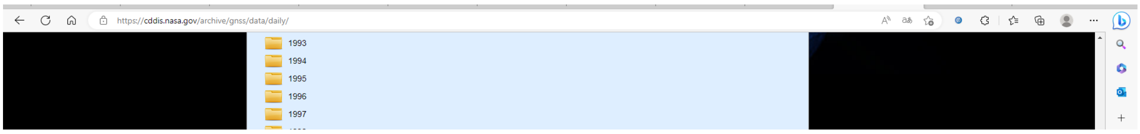
Click [https://cddis.nasa.gov/archive/gnss/data/daily/].



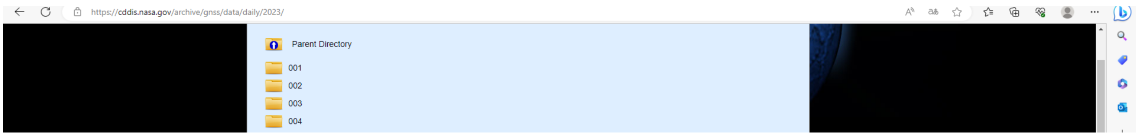
After registering as a user, log in.



Click the year folder of the RINEX file to be used.



Click the day of year folder of the RINEX file to be used.



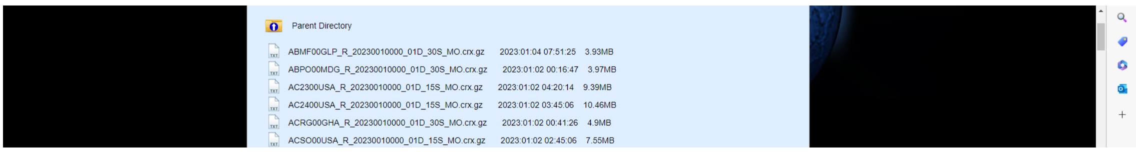
Click the folder of the RINEX file to be used.

[23d] is compact RINEX format of the observation data.

Download the RINEX file of the IGS station to be used.

Click [23d].

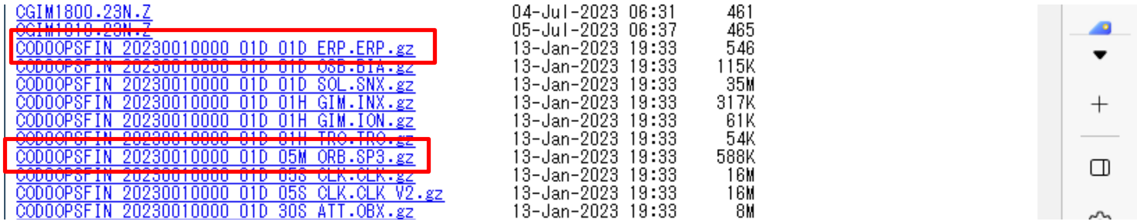
After downloading, convert the compact RINEX format file to RINEX file format.



7.3. Precise orbit files and IGS/IERS pole files

Download the precise orbit files and the IGS/IERS pole files from the download site.

Download site for 2023 data: http://ftp.aiub.unibe.ch/CODE/2023/



[COD0OPSFIN_20yyddd0000_01D_05M_ORB.SP3.gz]: Compressed file of the precise orbit file

[COD0OPSFIN_20yyddd0000_01D_01D_ERP.ERP.gz]: Compressed file of the IGS/IERS pole file

[yyyy]: year

[ddd]: Day of year

e.g. [COD0OPSFIN_20230010000_01D_05M_ORB.SP3.gz] is the compressed file of the precise orbit file at 1st January 2023

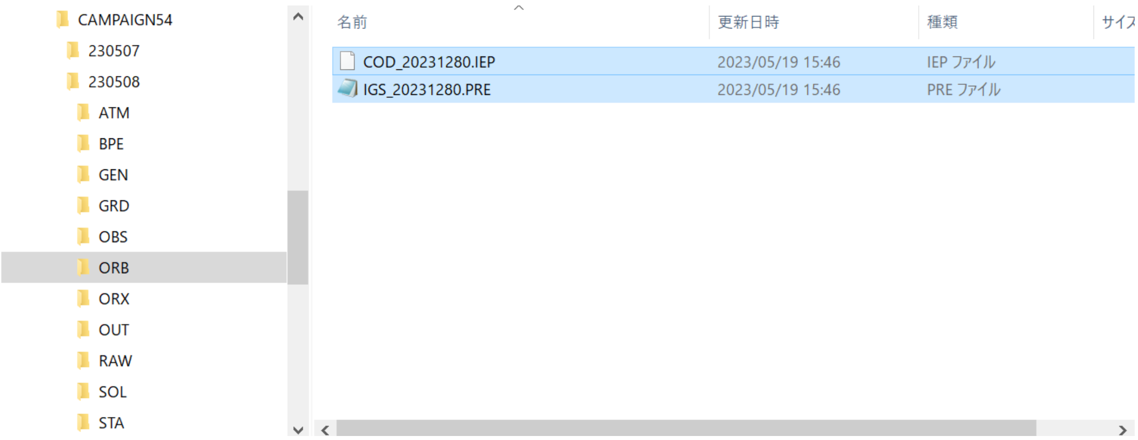
e.g. [COD0OPSFIN_20230010000_01D_01D_ERP.ERP.gz] is the compressed file of the IGS/IERS pole file at 1st January 2023

Unzip and rename the file.

From [COD0OPSFIN_20yyddd0000_01D_05M_ORB.SP3] to [IGS_yyyyddd0.PRE]

From [COD0OPSFIN_20yyddd0000_01D_01D_ERP.ERP] to [COD_yyyyddd0.IEP]

Copy the precise orbit files and the IGS/IERS pole files to [ORB] folder of the campaign.

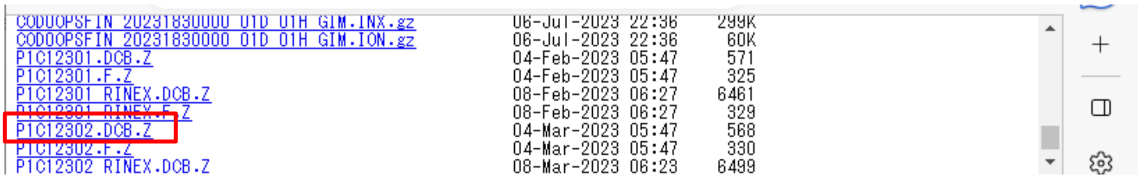


7.4. Code bias files

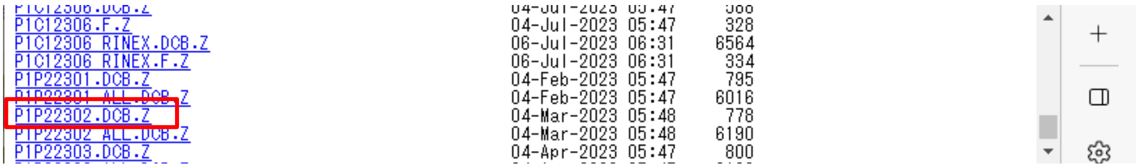
Download the code bias files from the download site.

Download site for 2023 data: http://ftp.aiub.unibe.ch/CODE/2023/

[P1C1yymm.DCB.Z]: Compressed file of the P1C1 code bias file



[P1P2yymm.DCB.Z]: Compressed file of the P1P2 code bias file



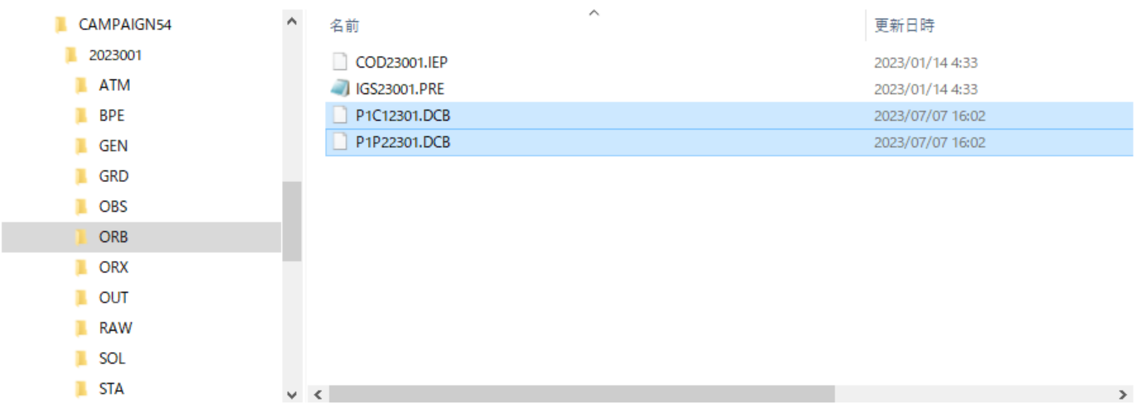
[yy]: Year (20yy)

[mm]: Month

e.g. [P1C12301.DCB.Z] is the compressed file of the P1C1 code bias file at January 2023

e.g. [P1P22301.DCB.Z] is the compressed file of the P1P2 code bias file at January 2023

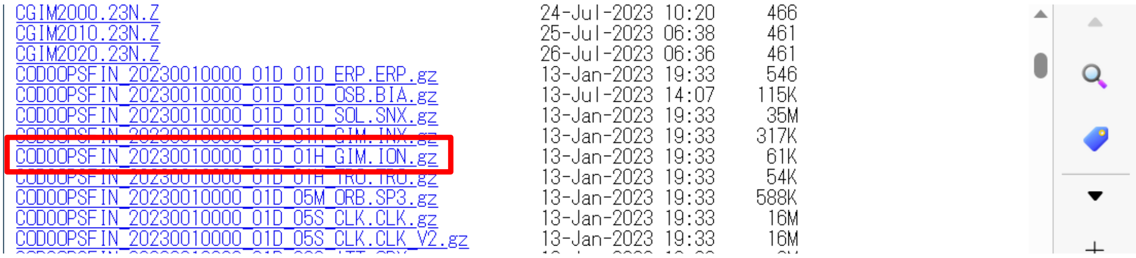
Unzip and copy the code bias files to [ORB] folder of the campaign.



7.5. Global ionosphere model file

Download the global ionosphere model files from the download site.

Download site for 2023 data: http://ftp.aiub.unibe.ch/CODE/2023/



[COD0OPSFIN_yyyyddd0000_01D_01H_GIM.ION.gz]: Compressed file of the global ionosphere model file

[yyyy]: year

[ddd]: Day of year

e.g. [COD0OPSFIN_20230010000_01D_01H_GIM.ION.gz] is the compressed file of the global ionosphere model file at 1st January 2023

Unzip and rename the file.

From [COD0OPSFIN_20yyddd0000_01D_01H_GIM.ION] to [COD_yyyyddd.ION]

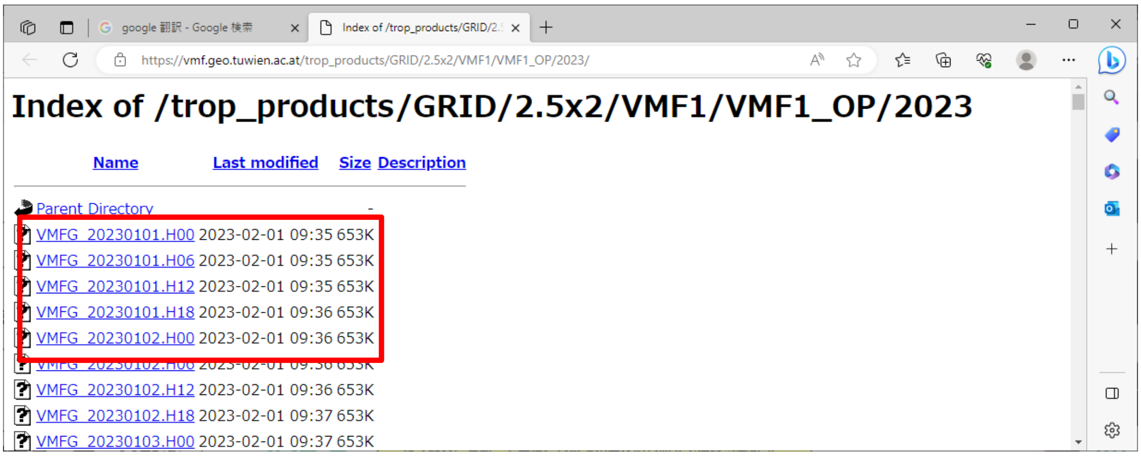
Copy the global ionosphere model files to [ATM] folder of the campaign.

7.6. Tropospheric delay model file (VMF grid data file)

Download the tropospheric delay model files (VMF grid data files) from the download site.

Download site for 2023 data:

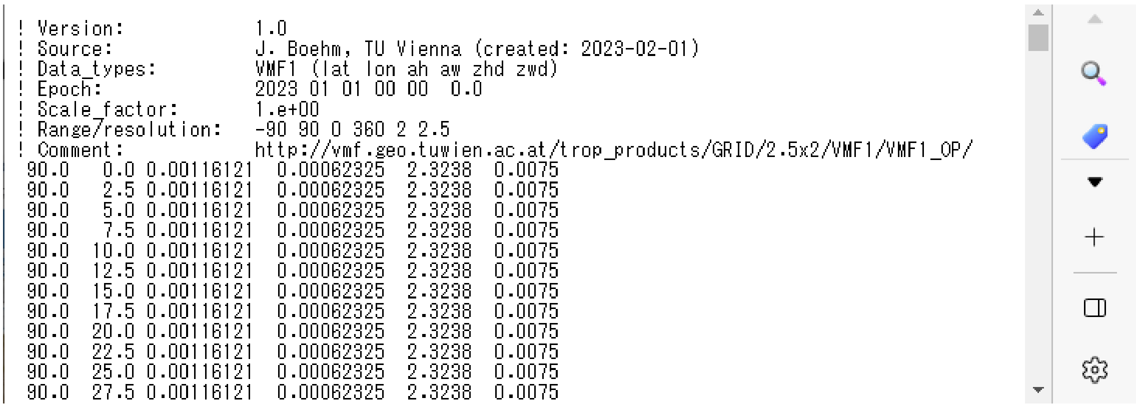
https://vmf.geo.tuwien.ac.at/trop_products/GRID/2.5x2/VMF1/VMF1_OP/2023/



The VMF grid data files are created every 6 hours.

Use 4 files of the day of baseline analysis and the first 1 file of the next day.

Click the file name to see the data.



```
! Version:            1.0
! Source:             J. Boehm, TU Vienna (created: 2023-02-01)
! Data_types:         VMF1 (lat lon ah aw zhd zwd)
! Epoch:              2023 01 01 00 00  0.0
! Scale_factor:       1.e+00
! Range/resolution:   -90 90 0 360 2 2.5
! Comment:            http://vmf.geo.tuwien.ac.at/trop_products/GRID/2.5x2/VMF1/VMF1_OP/
 90.0   0.0 0.00116121  0.00062325  2.3238  0.0075
 90.0   2.5 0.00116121  0.00062325  2.3238  0.0075
 90.0   5.0 0.00116121  0.00062325  2.3238  0.0075
 90.0   7.5 0.00116121  0.00062325  2.3238  0.0075
 90.0  10.0 0.00116121  0.00062325  2.3238  0.0075
 90.0  12.5 0.00116121  0.00062325  2.3238  0.0075
 90.0  15.0 0.00116121  0.00062325  2.3238  0.0075
 90.0  17.5 0.00116121  0.00062325  2.3238  0.0075
 90.0  20.0 0.00116121  0.00062325  2.3238  0.0075
 90.0  22.5 0.00116121  0.00062325  2.3238  0.0075
 90.0  25.0 0.00116121  0.00062325  2.3238  0.0075
 90.0  27.5 0.00116121  0.00062325  2.3238  0.0075
```

Merge 5 files using a text editor.

The file name is [VMF_yyyyddd.GRD].

[yyyy]: Year

[ddd]: Day of year

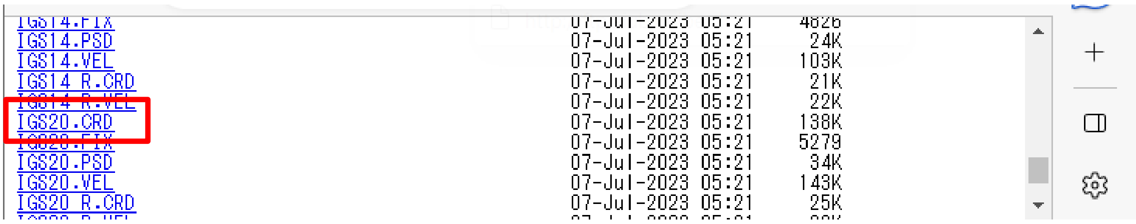
Copy VMF grid data file to [GRD] folder of the campaign.

7.7. Observation point coordinate file

7.7.1. Get Coordinate file of IGS Station

Download the IGS station coordinate file [IGS20.CRD] from the download site.

Download site: http://ftp.aiub.unibe.ch/BSWUSER54/REF/



7.7.2. Create Coordinate file

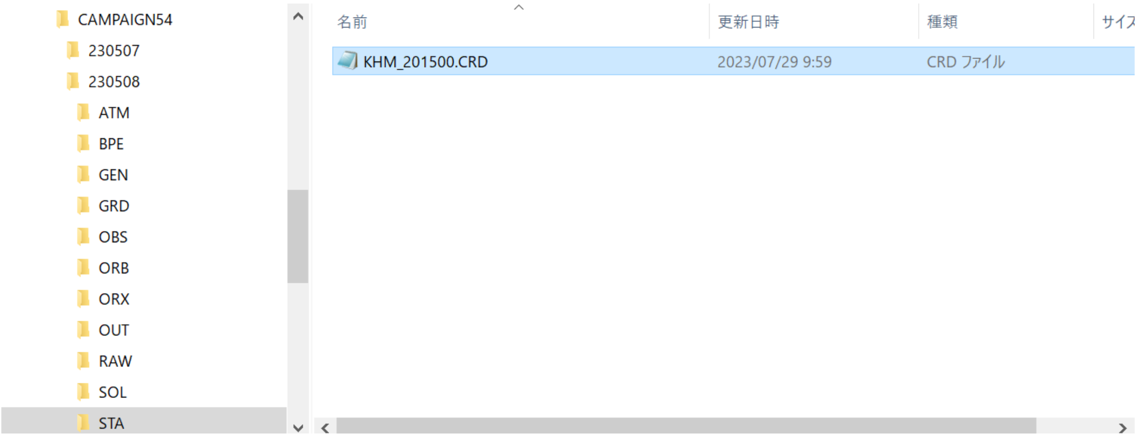
Create coordinate data for the IGS and Khmer GEONET stations using a text editor.
The coordinates of the IGS station are the values of [IGS20.CRD] file.
Coordinates of the Khmer GEONET station can be temporary values, but accurate values are better. For example, use the ITRF2014 values entered in Pivot.

LOCAL GEODETIC DATUM: IGS20 EPOCH: 2015-01-01 00:00:00

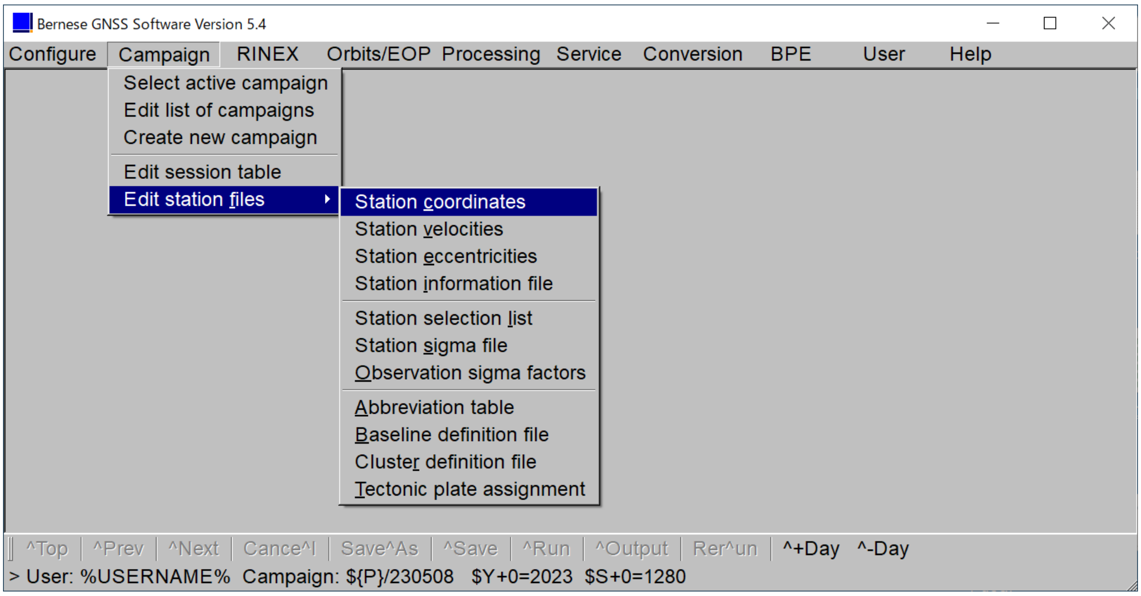
NUM	STATION NAME	X (M)	Y (M)	Z (M)	FLAG	SYSTEM
1	ANMG	-1270826.89380	6242631.33340	307792.42240	I	
2	CMUM	-938078.34810	5968373.98630	2038404.32190	I	
3	CUSV	-1132914.86460	6092528.56900	1504633.21270	I	
4	HKSL	-2393382.91750	5393860.99760	2412592.23210	I	
5	PTAG	-3184318.71050	5291065.49990	1590418.24380	I	
6	SIN1	-1507972.63360	6195613.86690	148488.03430	I	
7	KND1	-1619492.94400	6040715.07000	1247864.90000		
8	KSP1	-1572714.38600	6050448.84600	1260501.89200		
9	PNH1	-1603672.47300	6038739.32500	1277314.62100		
10	SIE1	-1490303.89300	6024644.81700	1465891.13600		
11	STG1	-1706798.61200	5963096.21200	1481479.65100		

7.7.3. Edit Coordinate file

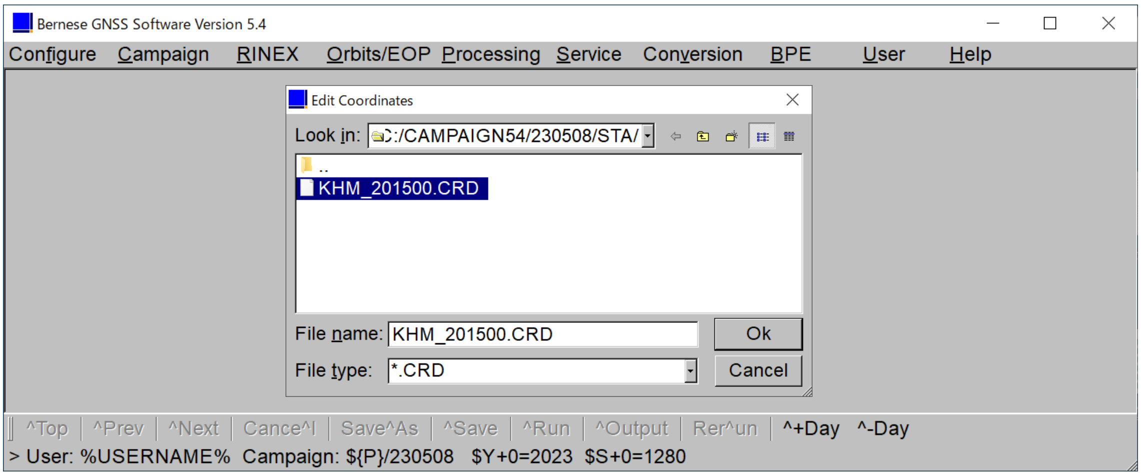
Copy the observation point coordinate file to [STA] folder of the campaign.



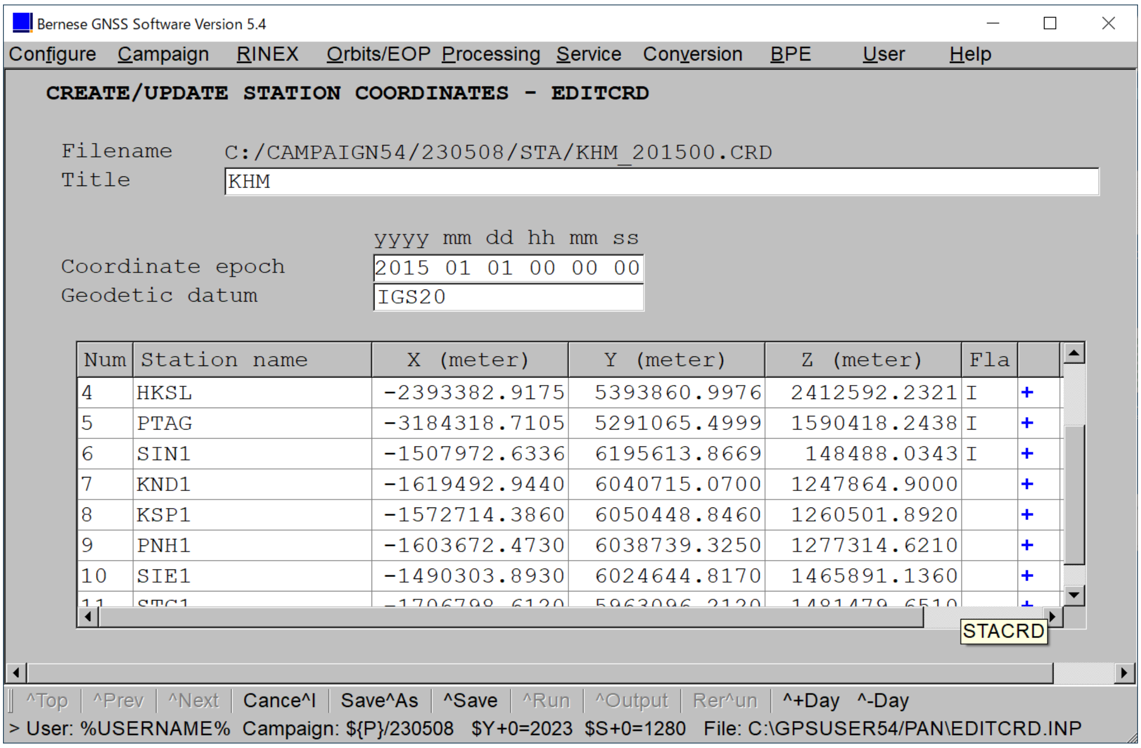
Click [Station Coordinates] to display the submenu.



Select the coordinate file and click [OK].



Enter Title, Coordinate epoch, Geodetic datum, Station name and the coordinate values. Click [^Save].



Title: Can be entered arbitrarily

Coordinate epoch: The year, month, day, hour, and second for which the coordinates were calculated.

Geodetic datum: e.g. IGS20

If you save, they will be sorted by the station name.

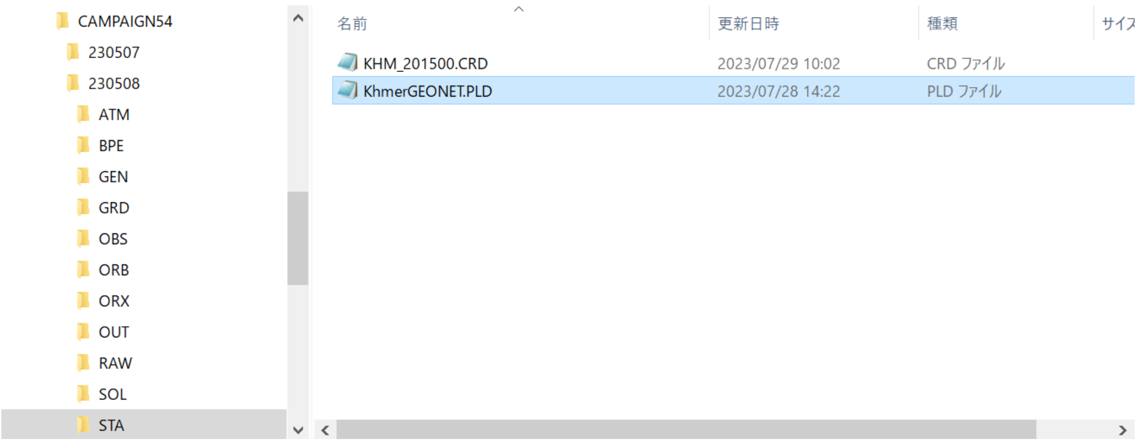
```
-------------------------------------------------------------------------------
LOCAL GEODETIC DATUM: IGS20             EPOCH: 2015-01-01 00:00:00

NUM  STATION NAME           X (M)          Y (M)          Z (M)     FLAG     SYSTEM

  1  ANMG              -1270826.89380  6242631.33340   307792.42240    I
  2  CMUM               -938078.34810  5968373.98630  2038404.32190    I
  3  CUSV              -1132914.86460  6092528.56900  1504633.21270    I
  4  HKSL              -2393382.91750  5393860.99760  2412592.23210    I
  7  KND1              -1619492.94400  6040715.07000  1247864.90000
  8  KSP1              -1572714.38600  6050448.84600  1260501.89200
  9  PNH1              -1603672.47300  6038739.32500  1277314.62100
  5  PTAG              -3184318.71050  5291065.49990  1590418.24380    I
 10  SIE1              -1490303.89300  6024644.81700  1465891.13600
  6  SIN1              -1507972.63360  6195613.86690   148488.03430    I
 11  STG1              -1706798.61200  5963096.21200  1481479.65100
```

7.8. Plate definition file

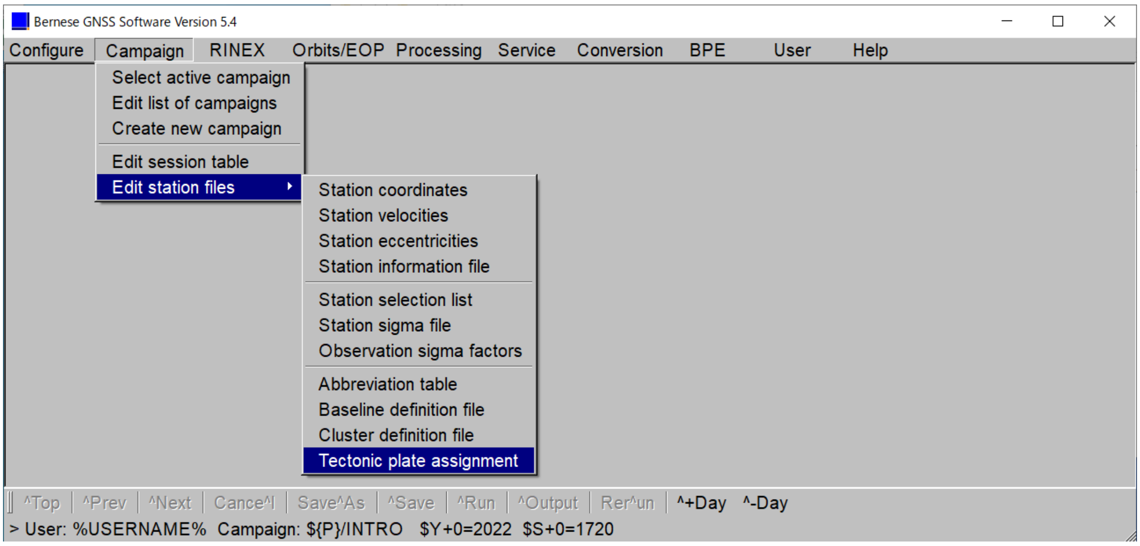
Create the plate definition file using a text editor.

```
--------------------------------------------------------------------------------
LOCAL GEODETIC DATUM: IGS20

NUM  STATION NAME           VX (M/Y)       VY (M/Y)       VZ (M/Y)  FLAG   PLATE

  1  ANMG                                                                  EURA
  2  CMUM                                                                  EURA
  3  CUSV                                                                  EURA
  4  HKSL                                                                  EURA
  7  KND1                                                                  EURA
  8  KSP1                                                                  EURA
  9  PNH1                                                                  EURA
  5  PTAG                                                                  PHIL
 10  SIE1                                                                  EURA
  6  SIN1                                                                  EURA
 11  STG1                                                                  EURA
```

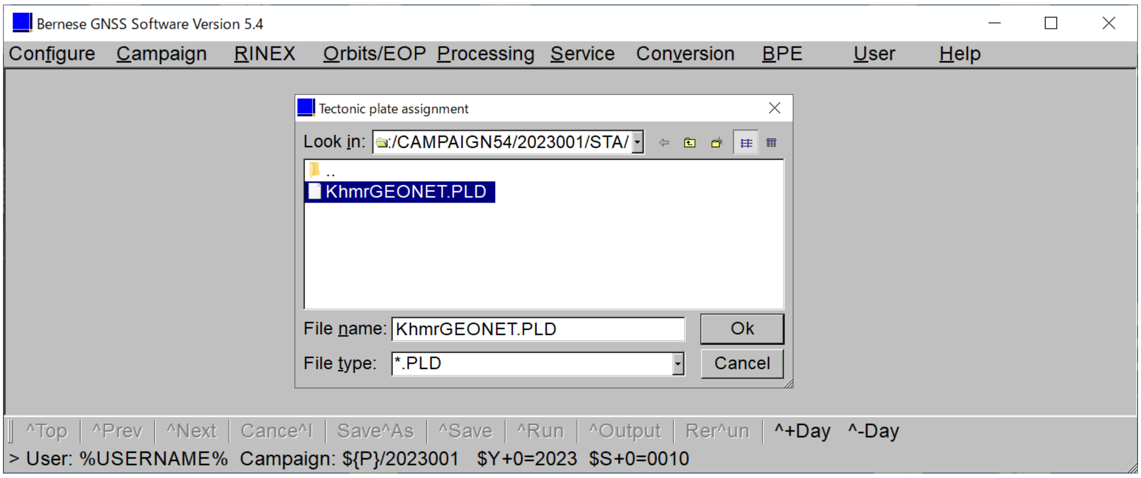
Copy the plate definition file (KhmrGEONET.PLD) to [STA] folder of the campaign.



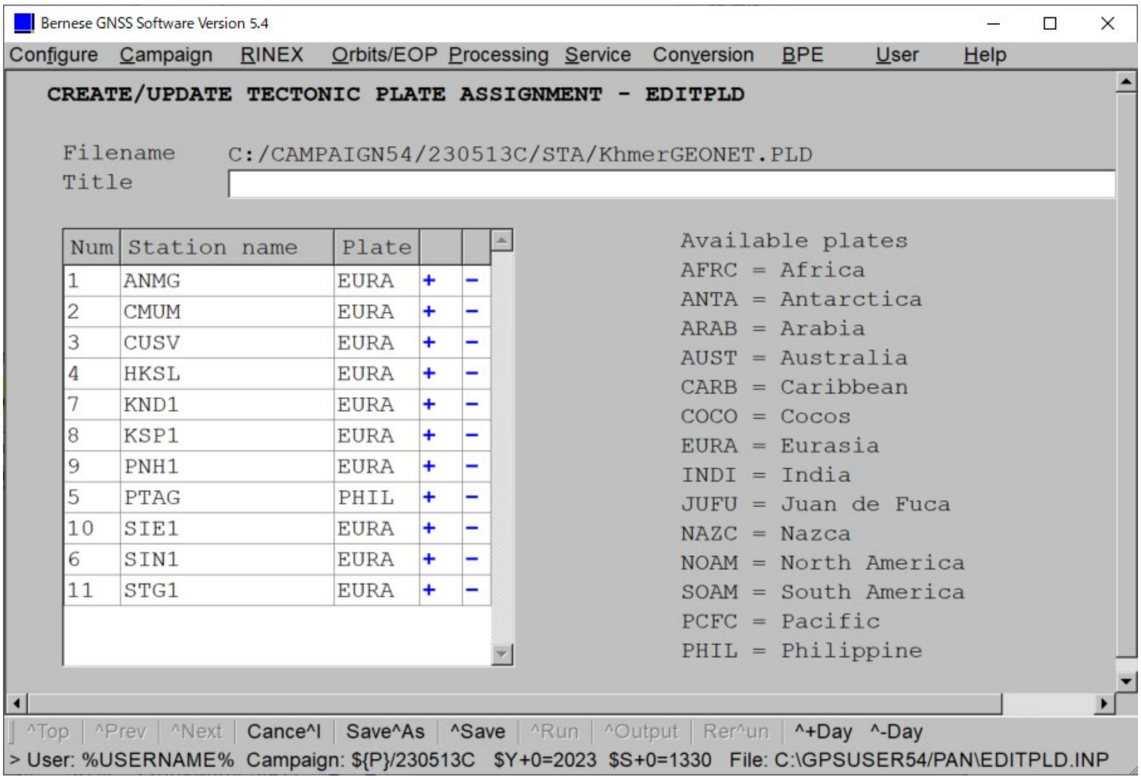
Click [Tectonic plate assignment] to display the submenu.



Select the plate definition file and click [OK].



Enter Title, Num, Station name and Plate.
Click [Save].



Cambodia is on the Sunda plate.

However, Bernese chooses the Eurasian plate.

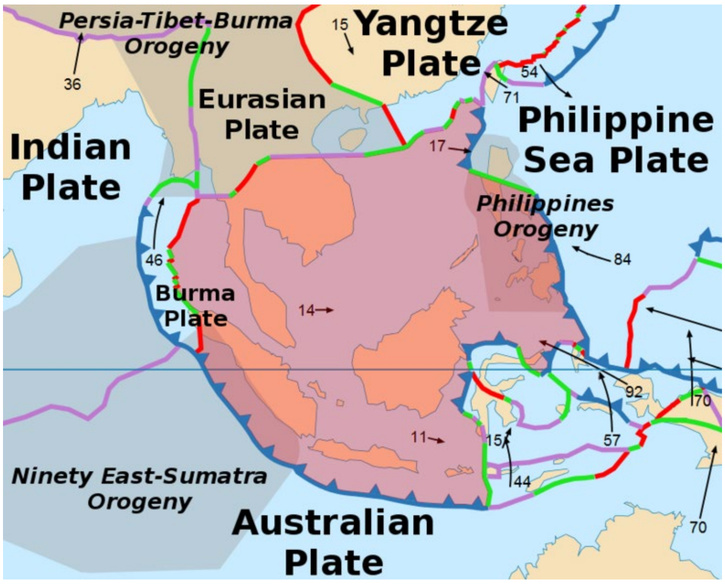


Fig.1 Sunda Plate

https://en.wikipedia.org/wiki/Sunda_Plate#:~:text=The%20Sunda%20Plate%20is%20a%20minor%20tectonic%20plate,movement%20at%2010%20mm%2Fyr%20eastward%20relative%20to%20Eurasia

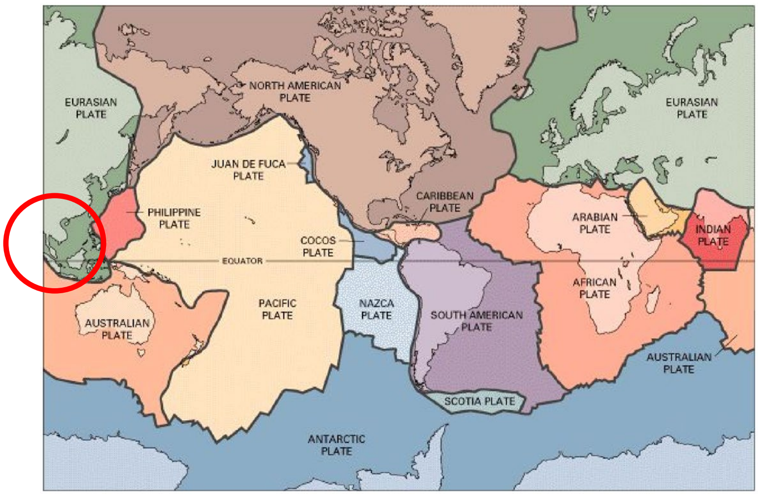
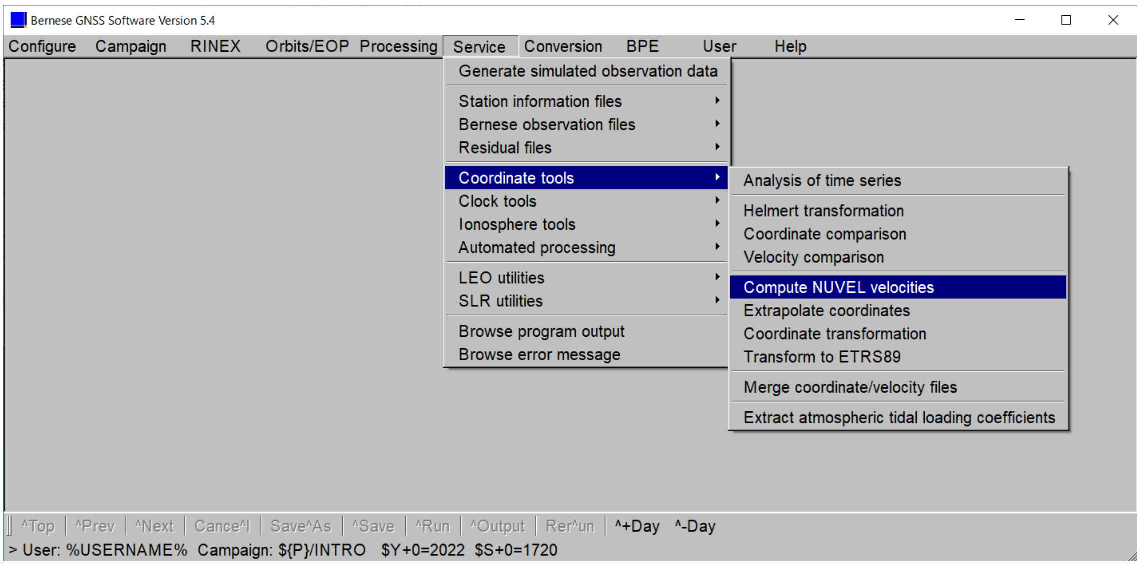


Fig.2 Plate for Bernese

http://ftp.aiub.unibe.ch/BSWUSER52/STA/plates.pdf

7.9. Observation point velocities file

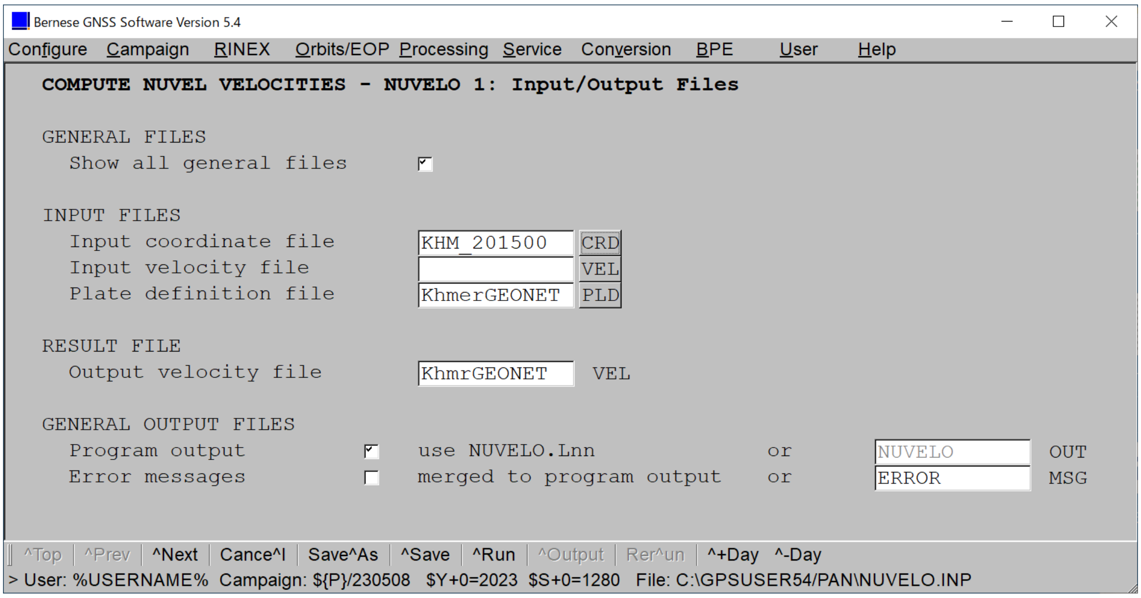
Click [Compute NUVEL velocities] to display the submenu.



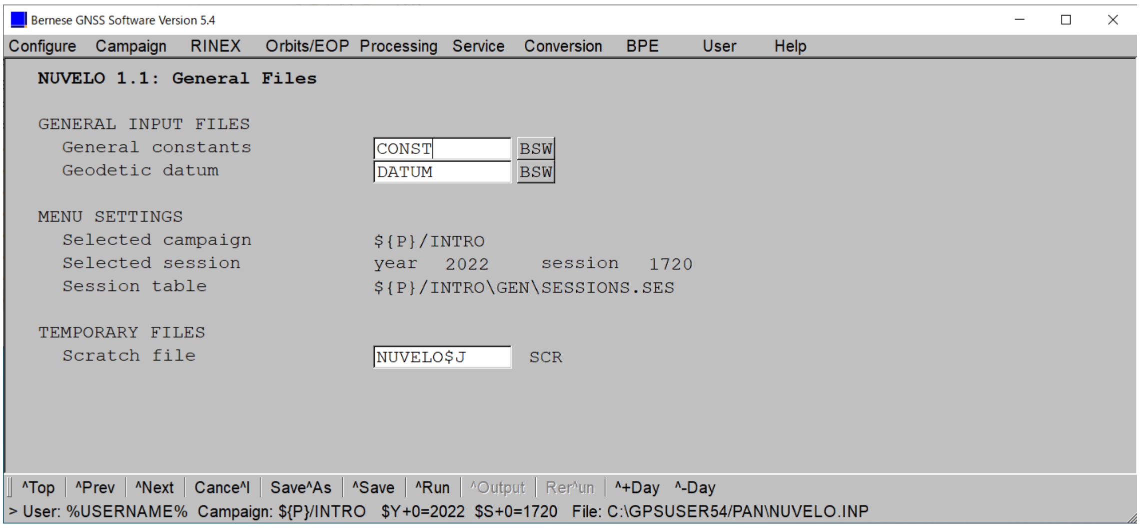
Select Input coordinate file and Plate definition file.

Enter the file name of the Output velocity file.

Click [^Next].

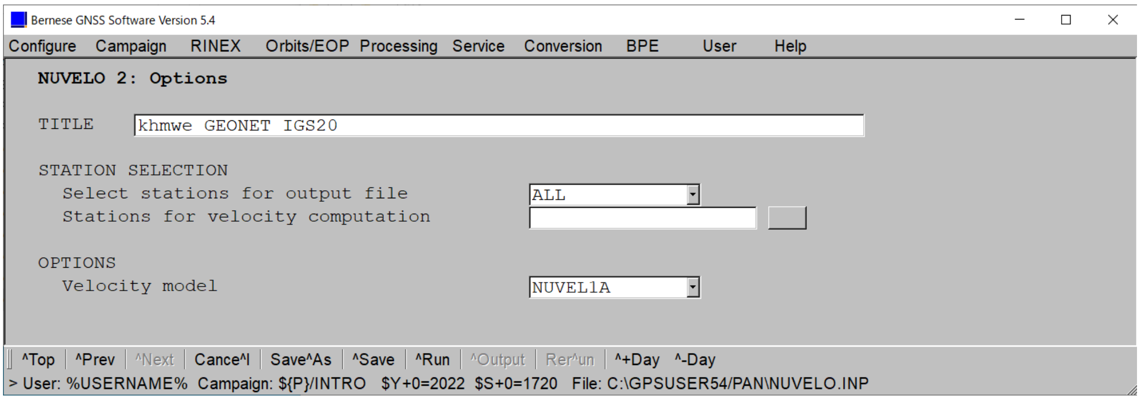


Click [^Next].



Enter Title and select [ALL] for Select station for output file.

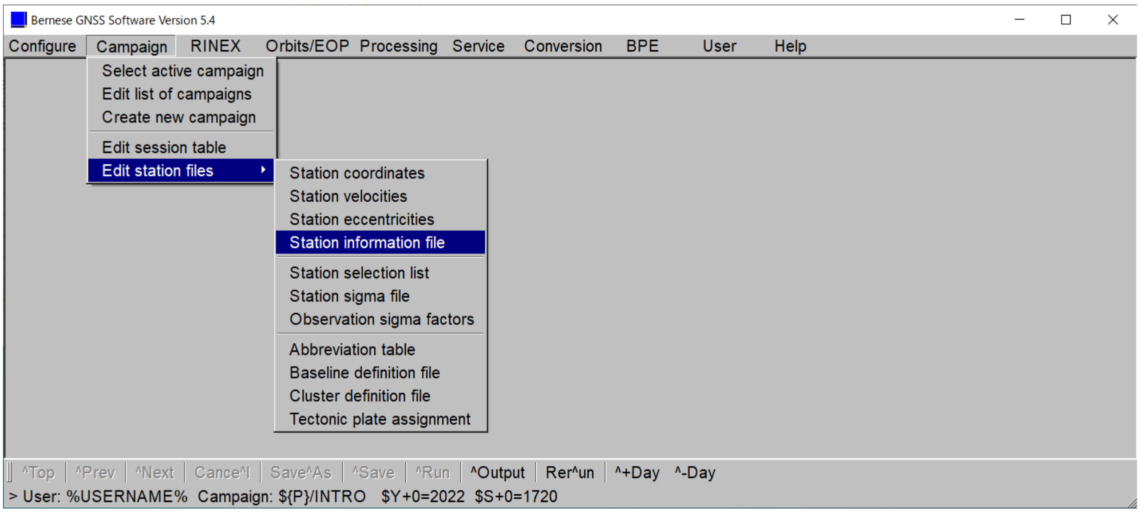
Click [^Run].



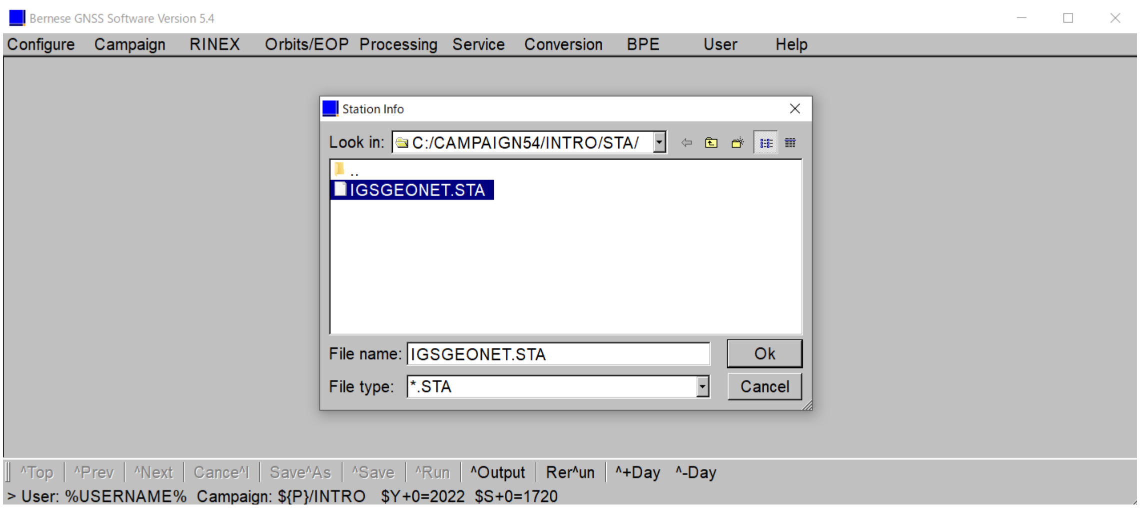
7.10. Station information file

Copy the sample file of the station information file (KHM_20231280.STA) to [STA] folder of the campaign.

Click [Station information file] to display the submenu.



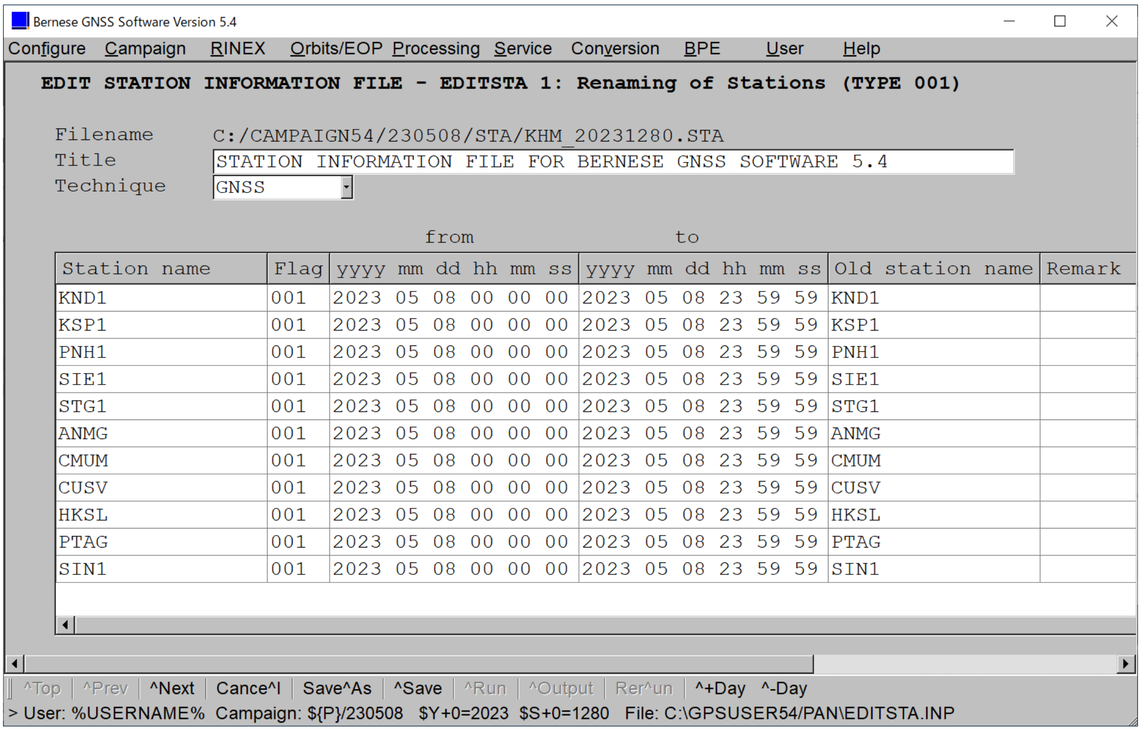
Select the sample file and click [OK].



(1) Type 001

Enter Title, Station name, From, To and Old station name.

Click [^Next].



Station name: Station name for Bernese

From: Start time of observation

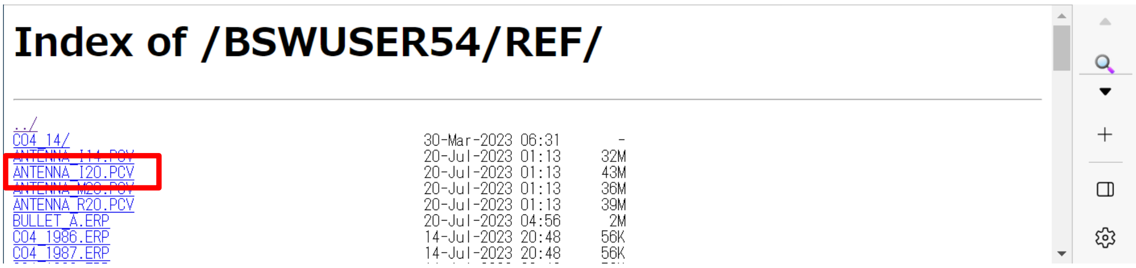
To: End time of observation

Old station name: Observation point name entered in [Marker Name] of RINEX file

(2) Type 002

Download PCV correction file from the download site.

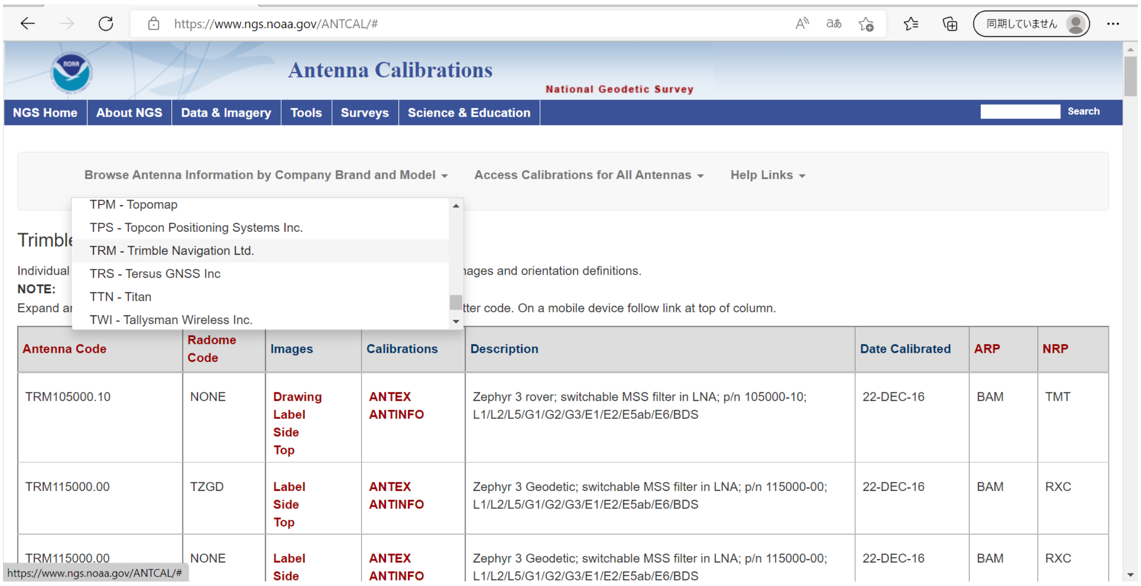
Download site: http://ftp.aiub.unibe.ch/BSWUSER54/REF/



Copy PCV correction file to the [C:/CAMPAIGN54/2023001/GEN] folder of the campaign.

Antenna information can be found on the NOAA website.

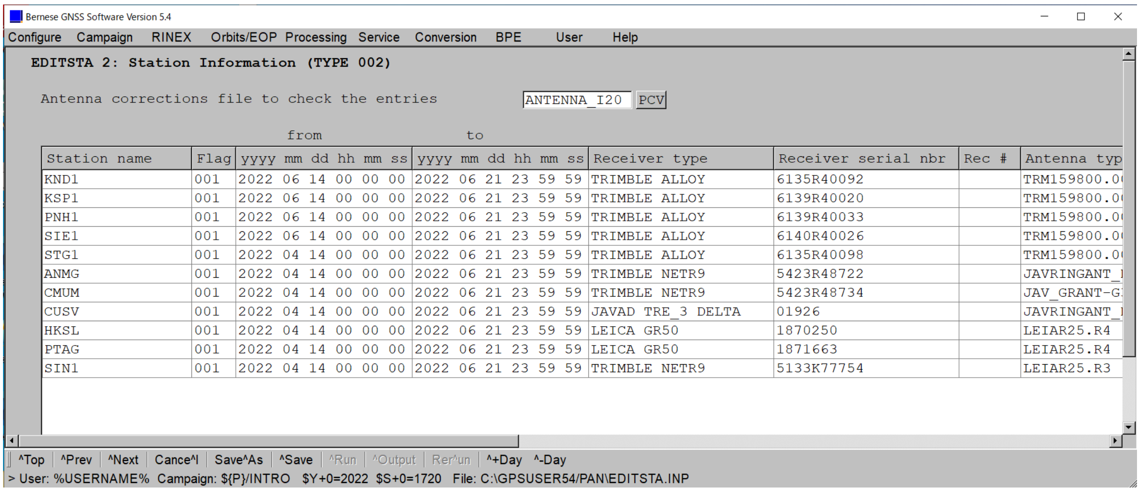
NOAA website: https://www.ngs.noaa.gov/ANTCAL/



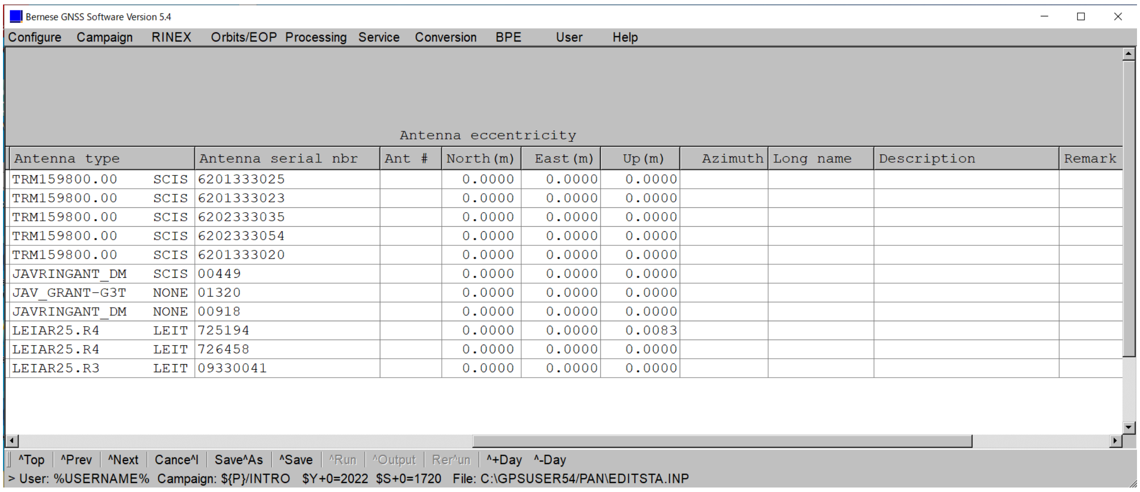
Select PCV correction file.

Enter Station name, From, To, Receiver type, Receiver serial number, Antenna type and Antenna serial number.

Click [^Next].



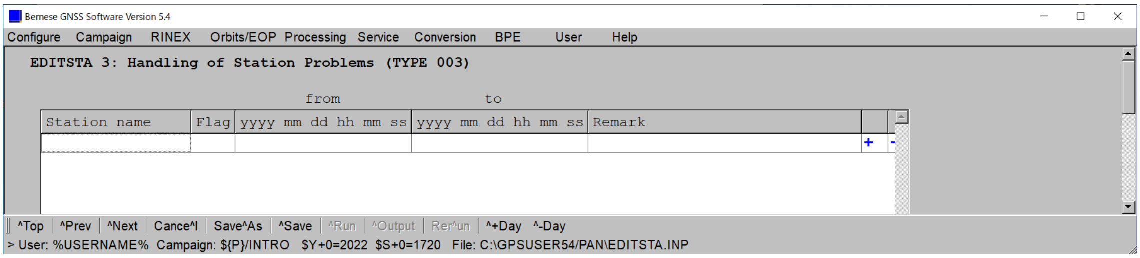
Station name	Flag	yyyy mm dd hh mm ss (from)	yyyy mm dd hh mm ss (to)	Receiver type	Receiver serial nbr	Rec #	Antenna typ
KND1	001	2022 06 14 00 00 00	2022 06 21 23 59 59	TRIMBLE ALLOY	6135R40092		TRM159800.0
KSP1	001	2022 06 14 00 00 00	2022 06 21 23 59 59	TRIMBLE ALLOY	6139R40020		TRM159800.0
PNH1	001	2022 06 14 00 00 00	2022 06 21 23 59 59	TRIMBLE ALLOY	6139R40033		TRM159800.0
SIE1	001	2022 06 14 00 00 00	2022 06 21 23 59 59	TRIMBLE ALLOY	6140R40026		TRM159800.0
STG1	001	2022 04 14 00 00 00	2022 06 21 23 59 59	TRIMBLE ALLOY	6135R40098		TRM159800.0
ANMG	001	2022 04 14 00 00 00	2022 06 21 23 59 59	TRIMBLE NETR9	5423R48722		JAVRINGANT_
CMUM	001	2022 04 14 00 00 00	2022 06 21 23 59 59	TRIMBLE NETR9	5423R48734		JAV_GRANT-G
CUSV	001	2022 04 14 00 00 00	2022 06 21 23 59 59	JAVAD TRE_3 DELTA	01926		JAVRINGANT_
HKSL	001	2022 04 14 00 00 00	2022 06 21 23 59 59	LEICA GR50	1870250		LEIAR25.R4
PTAG	001	2022 04 14 00 00 00	2022 06 21 23 59 59	LEICA GR50	1871663		LEIAR25.R4
SIN1	001	2022 04 14 00 00 00	2022 06 21 23 59 59	TRIMBLE NETR9	5133K77754		LEIAR25.R3



Antenna type	Antenna serial nbr	Ant #	North(m)	East(m)	Up(m)	Azimuth	Long name	Description	Remark
TRM159800.00 SCIS	6201333025		0.0000	0.0000	0.0000				
TRM159800.00 SCIS	6201333023		0.0000	0.0000	0.0000				
TRM159800.00 SCIS	6202333035		0.0000	0.0000	0.0000				
TRM159800.00 SCIS	6202333054		0.0000	0.0000	0.0000				
TRM159800.00 SCIS	6201333020		0.0000	0.0000	0.0000				
JAVRINGANT_DM SCIS	00449		0.0000	0.0000	0.0000				
JAV_GRANT-G3T NONE	01320		0.0000	0.0000	0.0000				
JAVRINGANT_DM NONE	00918		0.0000	0.0000	0.0000				
LEIAR25.R4 LEIT	725194		0.0000	0.0000	0.0083				
LEIAR25.R4 LEIT	726458		0.0000	0.0000	0.0000				
LEIAR25.R3 LEIT	09330041		0.0000	0.0000	0.0000				

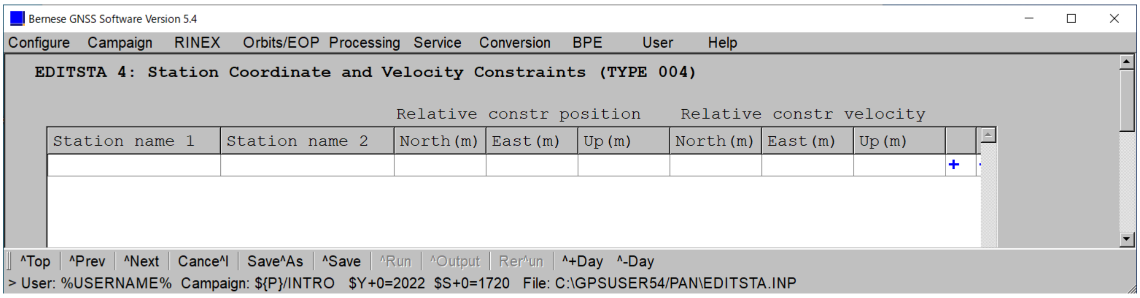
(3) Type 003

Click [^Next].



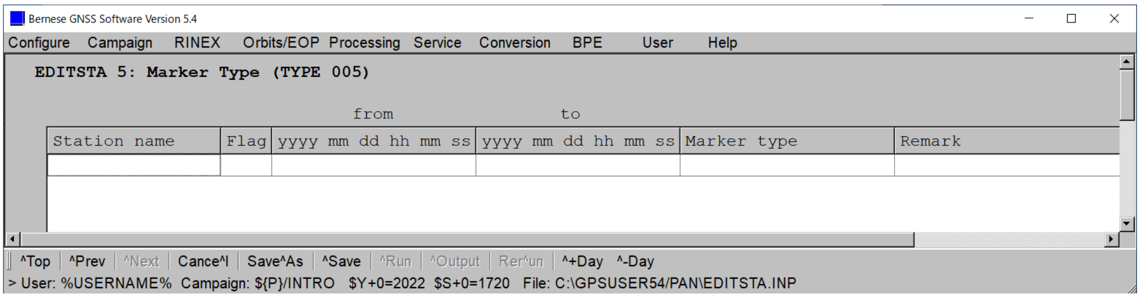
(4) Type 004

Click [^Next].



(5) Type 005

Click [^Save].



You can also create it using the text editor.

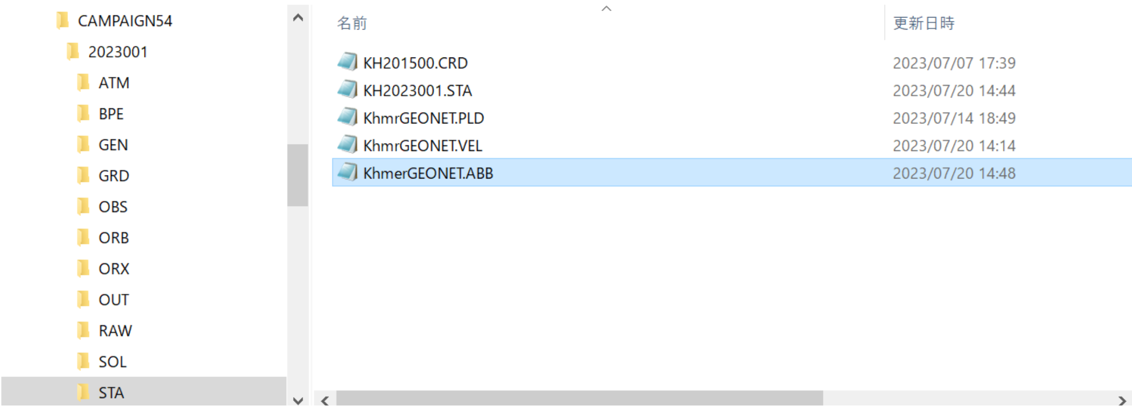
You can also use the existing file.

7.11. Observation point abbreviation file

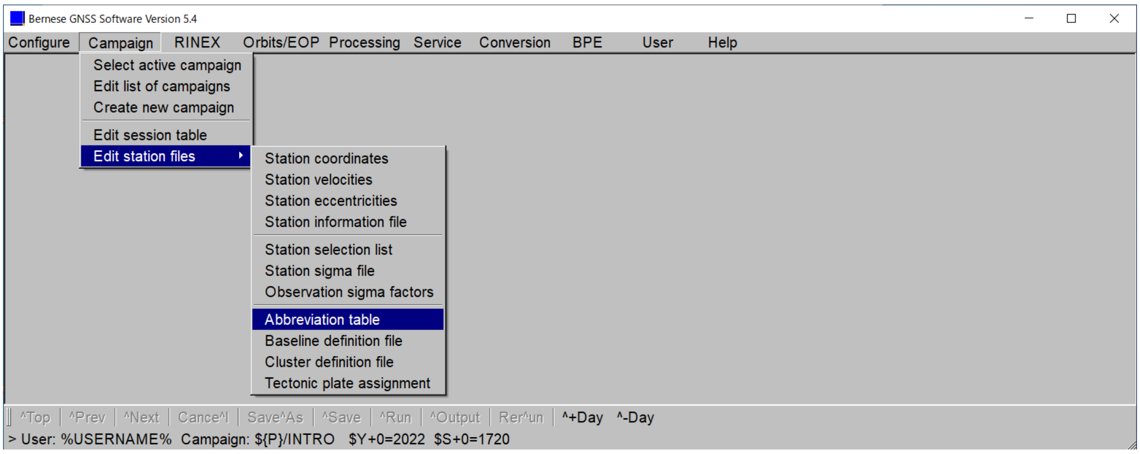
Create the observation point abbreviation file using a text editor.

```
Khmer GEONET IGS20                                               16-MAY-23 14:55
--------------------------------------------------------------------------------

Station name             4-ID    2-ID    Remark
****************         ****     **     ***************************************
ANMG                     0001     01
CMUM                     0002     02
CUSV                     0003     03
HKSL                     0004     04
PTAG                     0005     05
SIN1                     0006     06
KND1                     0007     07
KSP1                     0008     08
PNH1                     0009     09
SIE1                     0010     10
STG1                     0011     11
```

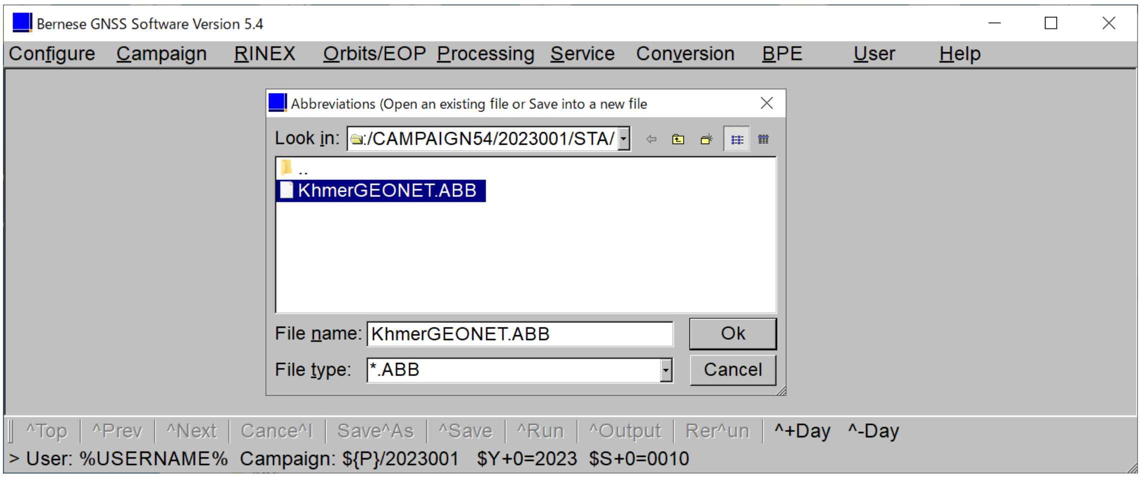
Copy the observation point abbreviation file [KhmerGEONET.ABB] to [STA] folder of the campaign.



Click [Abbreviation table] to display the submenu.

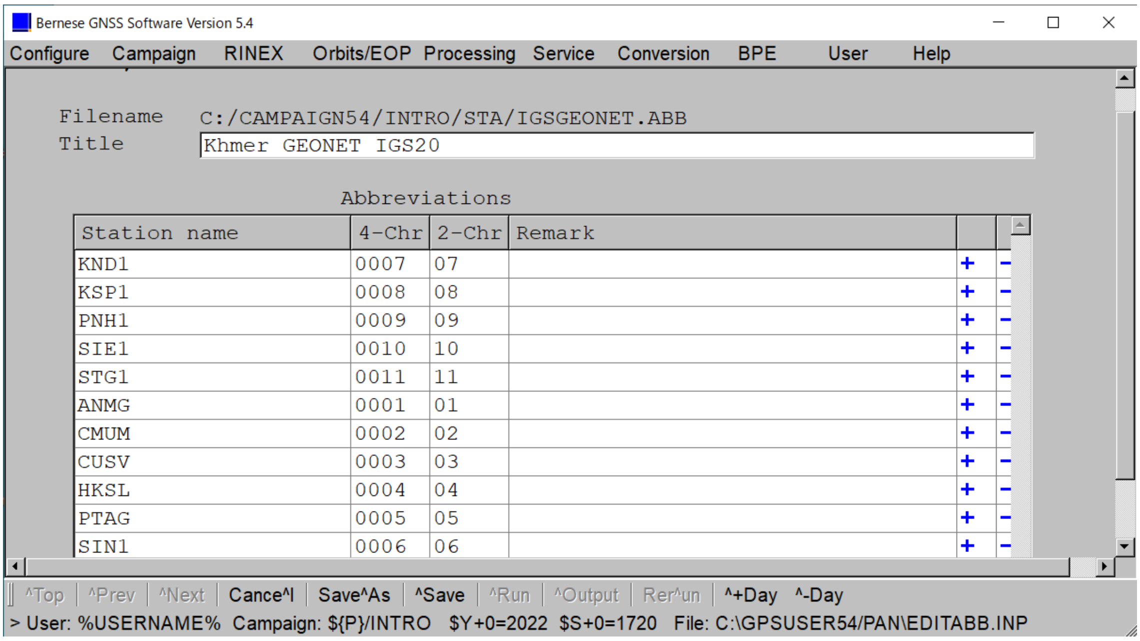


Select the sample file and click [OK].



Enter Title Station name, Abbreviation (4-Chr) and Abbreviation (2-Chr).

Click [^Save].



You can also create it using the text editor.

You can also use the existing file.

7.12. Ocean tide parameter file

Order the Ocean tide loading provider to calculate by email. You can receive the results by email.

Provider site: http://holt.oso.chalmers.se/loading/

Select ocean tide model

A brief description of the ocean tide models can be found here. **Note: Default model is a fake to bar spammers**

FES2014b

What type of loading phenomenon do you consider

◉ **vertical and horizontal displacements**

○ **gravity (nm/s^2) and tilt (nrad)**

using Greens function

◉ **elastic (Farrell, 1972)**

○ **visco-elastic (STW105)**

If you have selected vertical and horizontal displacements, you can correct for the centre of mass motion of the Earth due to the ocean tides .

(**NO** means your frame origin is in the solid earth centre,
YES that it is in the joint mass centre of solid earth and ocean.)

Do you want to correct your loading values for the motion?

◉ **NO**

○ **YES**

Want a plot? **Option is available for the ocean models with a grid constant ≥ (1/8)°**

The plots show the grid refinement in the near-field and also the resolution of the coastline.

They are generated for each site that involves the loading post-processor. Notice "`Computed by OLMPP`" in the result file.

◉ **NO**

○ **YES**

Fetch plot here after you received the results. Look for your user name: `name-olmpp1.png` `name-olmpp2.png` etc.

Also see the **Caption** common to all maps.

What kind of output format is required?

◉ **BLQ**(normal)

○ **HARPOS**(... RECENTLY ADDED FEATURE ...)

Gravity loading parameters for **TSOFT** and **g-Software** can be converted from BLQ with **olgt.pl**

Where are your stations?

In the following form, up to one hundred stations can be entered, each station on a separate line.

In the case of displacements, the height of the station above sea level is irrelevant; it is not necessary to specify this parameter at all.

```
Name of station_________||Longitude (deg)| Latitude (deg)| Height (m)    OR
Name of station_________|       X (m)           Y (m)          Z (m)
// Records starting with // are treated as comments
//ABCD                       4274689.360     2104509.140     4226072.801
//Onsala                       11.9264         57.3958         0.0000
//ruler.................b<...............<...............<...............
ANMG                    -1270826.89380  6242631.33340   307792.42240
CMUM                     -938078.34810  5968373.98630  2038404.32190
CUSV                    -1132914.86460  6092528.56900  1504633.21270
HKSL                    -2393382.91750  5393860.99760  2412592.23210
PTAG                    -3184318.71050  5291065.49990  1590418.24380
SIN1                    -1507972.63360  6195613.86690   148488.03430
KND1                    -1619492.94400  6040715.07000  1247864.90000
KSP1                    -1572714.38600  6050448.84600  1260501.89200
PNH1                    -1603672.47300  6038739.32500  1277314.62100
SIE1                    -1490303.89300  6024644.81700  1465891.13600
STG1                    -1706798.61200  5963096.21200  1481479.65100
```

Our fixed column layout: Show example

No blankspace to the left.

24 characters for the station, 25'th column blank, then three numerical fields with a width of 16 characters each, no TAB characters please! Each value MUST carry one floating-point dot followed by at least one decimal, but three decimal places (case XYZ) or five (case degrees) are more than sufficient.

On a UNIX/Linux system you can produce station lines for copy-and-paste with

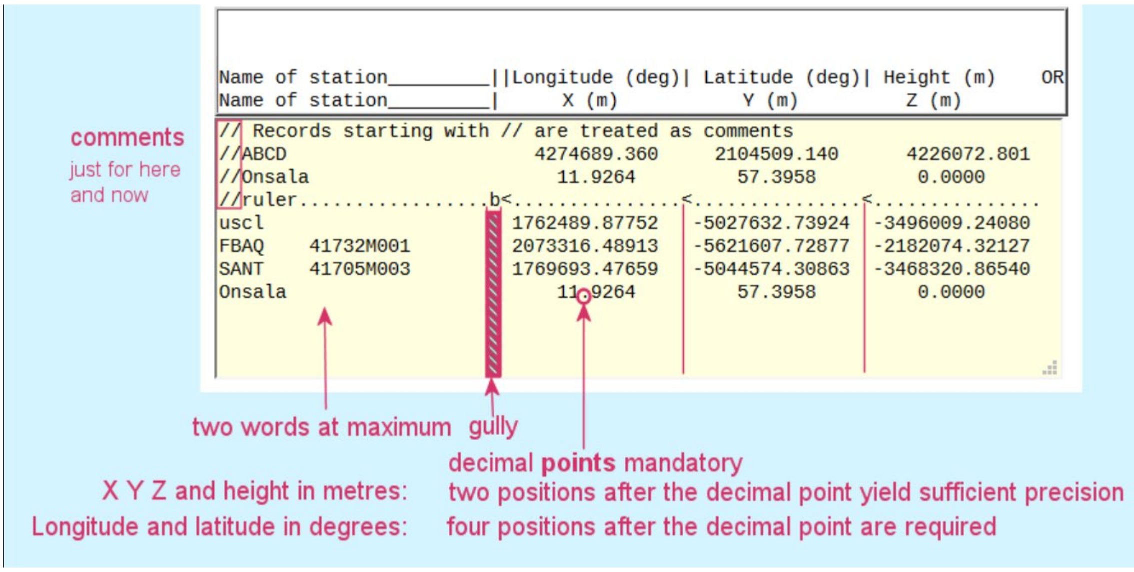
```
printf "%-24s  %15.3f %15.3f %15.3f¥n" $name $x $y $z
printf "%-24s  %15.5f %15.5f %15.3f¥n" $name $lon $lat $hgt
```

What is your e-mail address?

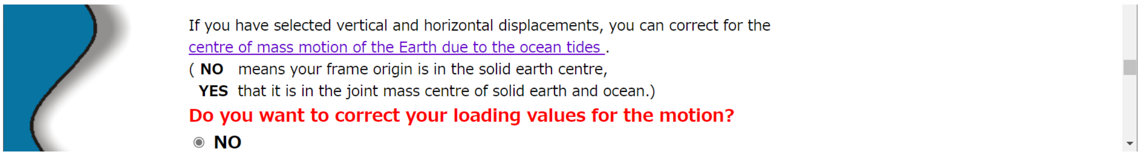
Note: Because of a large amount of misuse we deny requests with return addresses at a couple of notorious domains.

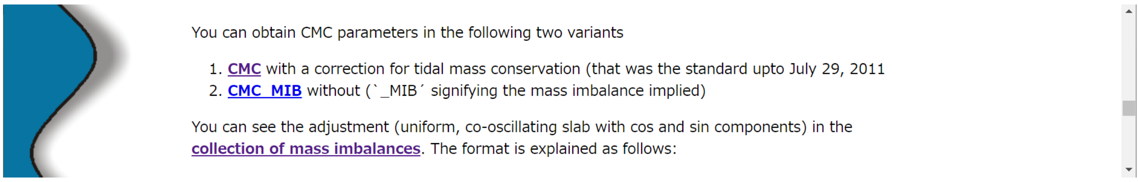
Submit Reset

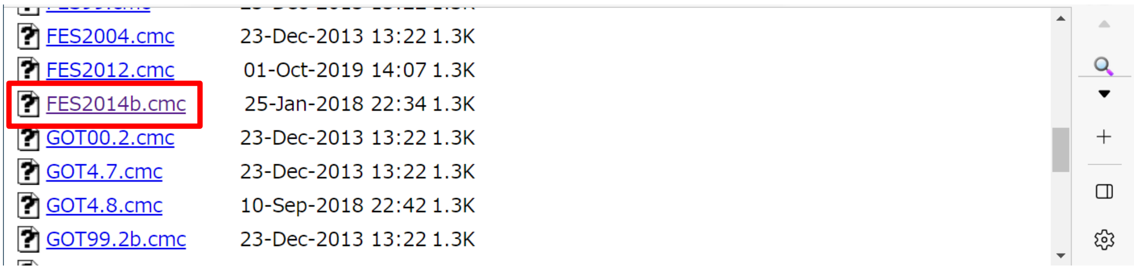
Drift messages, planned outages of service

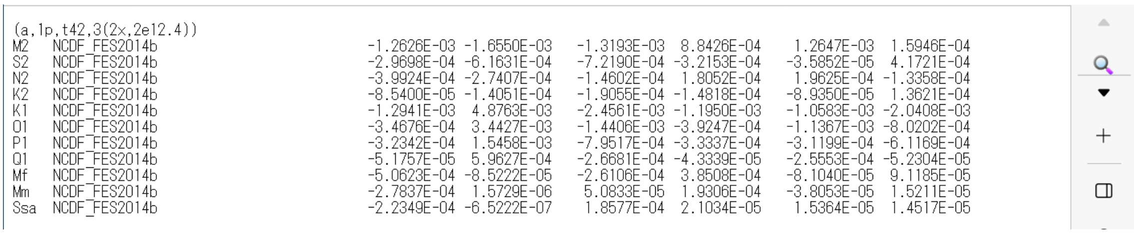


Create the ocean tide parameter file [XXXXX.BLQ] using a text editor (XXXXX can be named arbitrarily).
[CMC Value] is not entered in the result.
Follow the link below to display [CMC Value].
Enter [CMC Value] by referring to [EXAMPLE.BLQ].

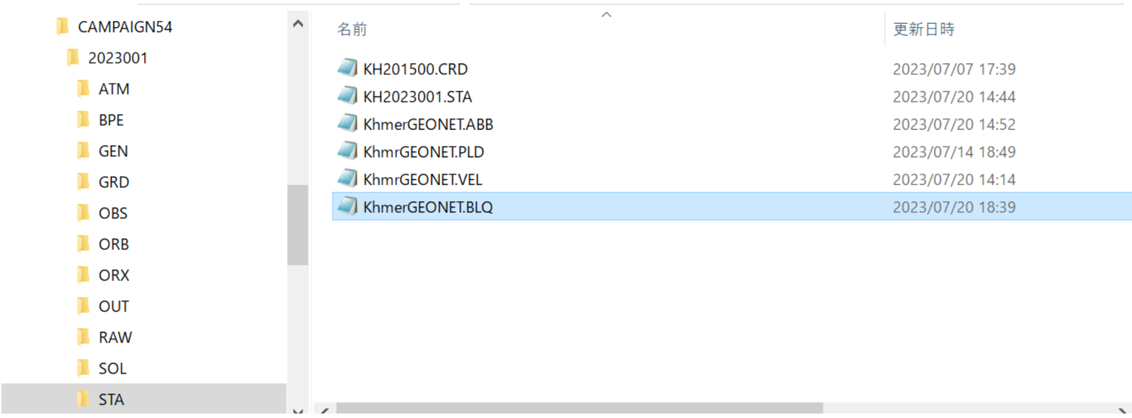






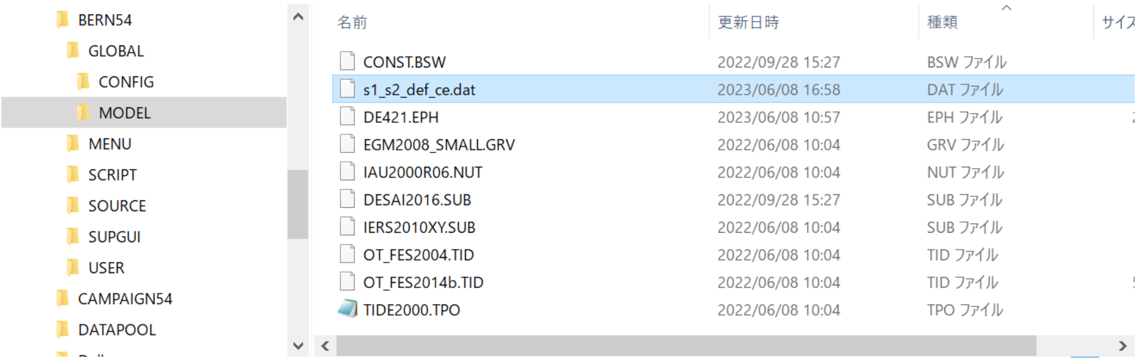


Copy the ocean tide parameter file to [STA] folder of the campaign.

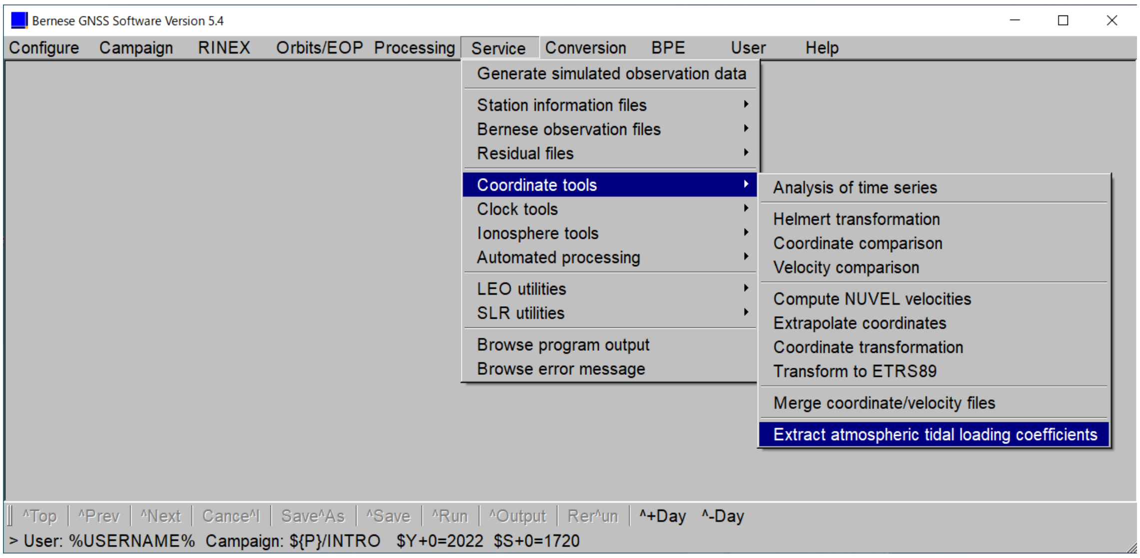


7.13. Atmospheric tide parameter file

Copy [S1_s2_def_ce.dat] file to [STA] folder of [C:/BERN54/GLOBAL/MODEL].



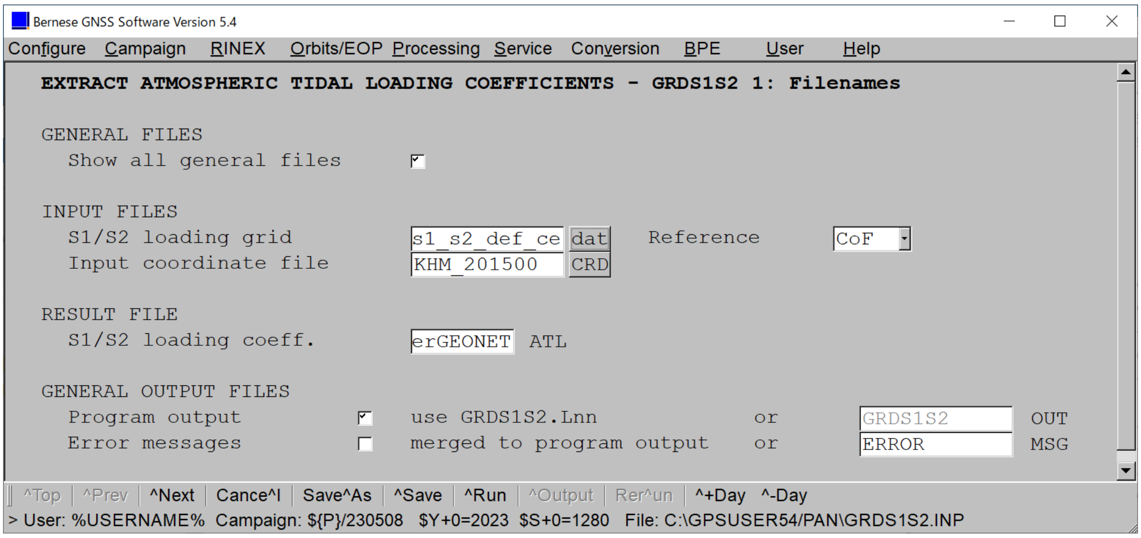
Click [Extract atmospheric tidal loading coefficients] to display the submenu.



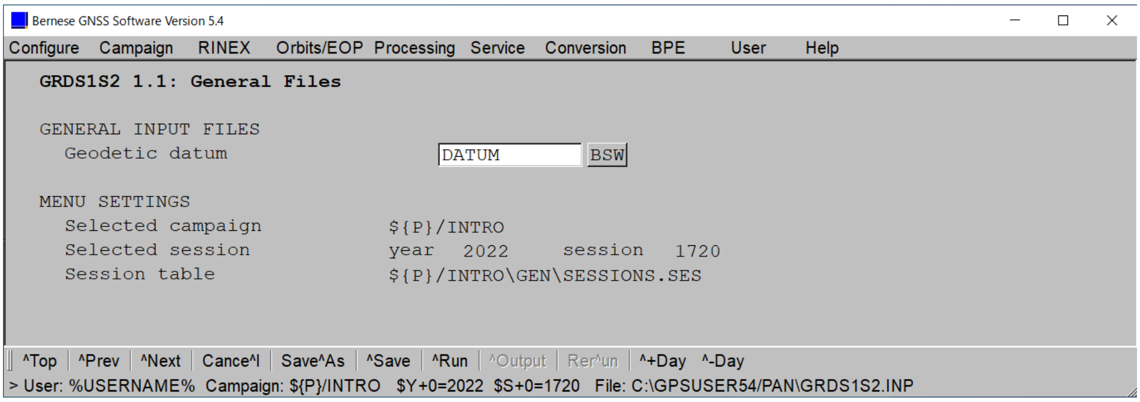
Select Input coordinate file.

Enter the file name of the Output S1/S2 loading coefficient file.

Click [^Next].

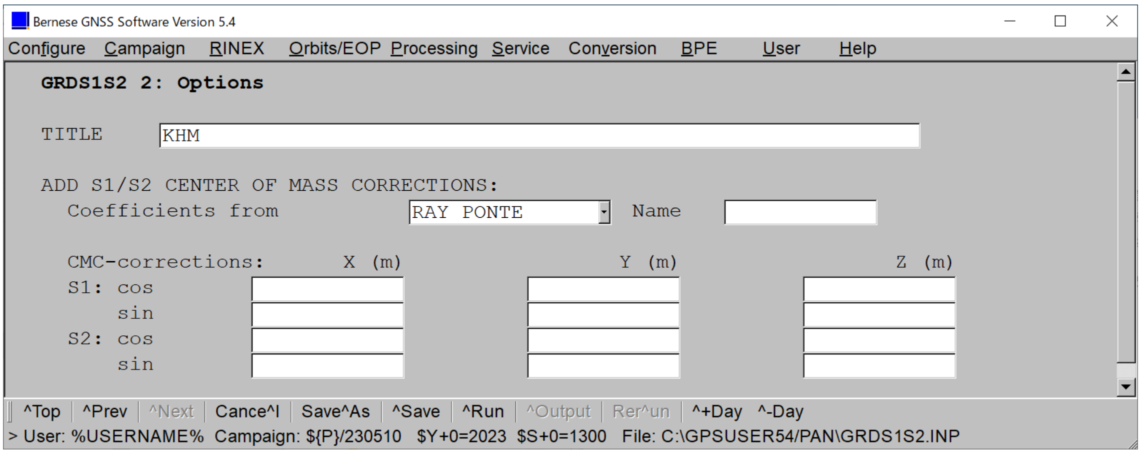


Click [^Next].



Enter Title and select [RAY PONTE] for Coefficients form.

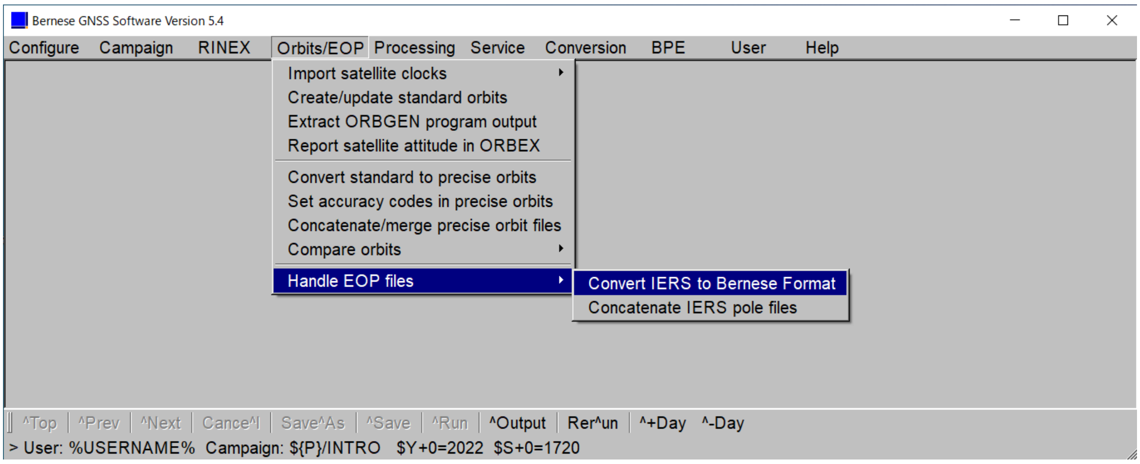
Click [^Run].



8. Pole and Orbit Preparation

8.1. Convert IGS/IERS pole file (POLUPD)

Click [Convert IERS to Bernese Format] to display the submenu.



Select Foreign formatted ERP files. Change the extension to [.IEP].

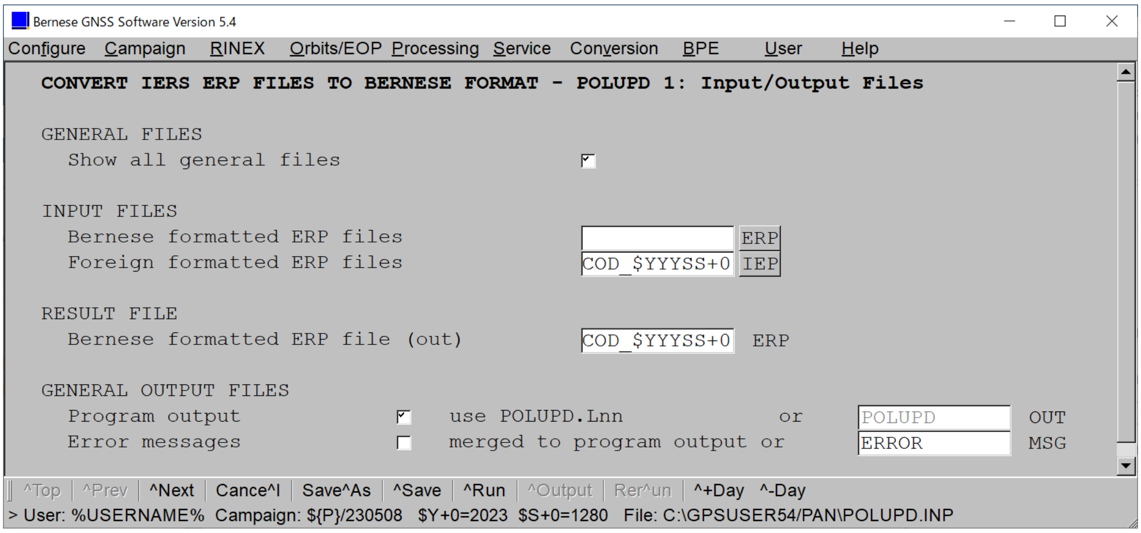
Enter the file name of Bernese formatted ERP file (out).

The name of the Bernese formatted ERP file is [COD_$YYYSS+0.ERP].

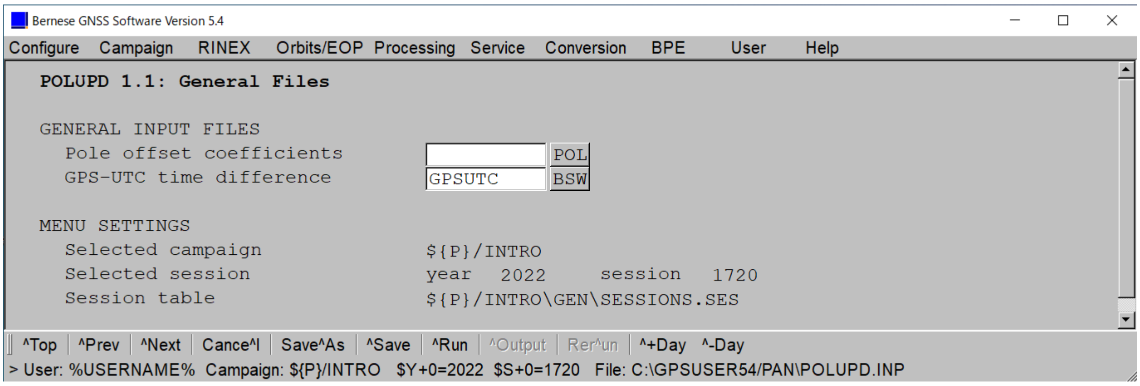
$YYY: Year

$SS+0: Day of year (e.g. [1760] is 25th June)

Click [^Next].



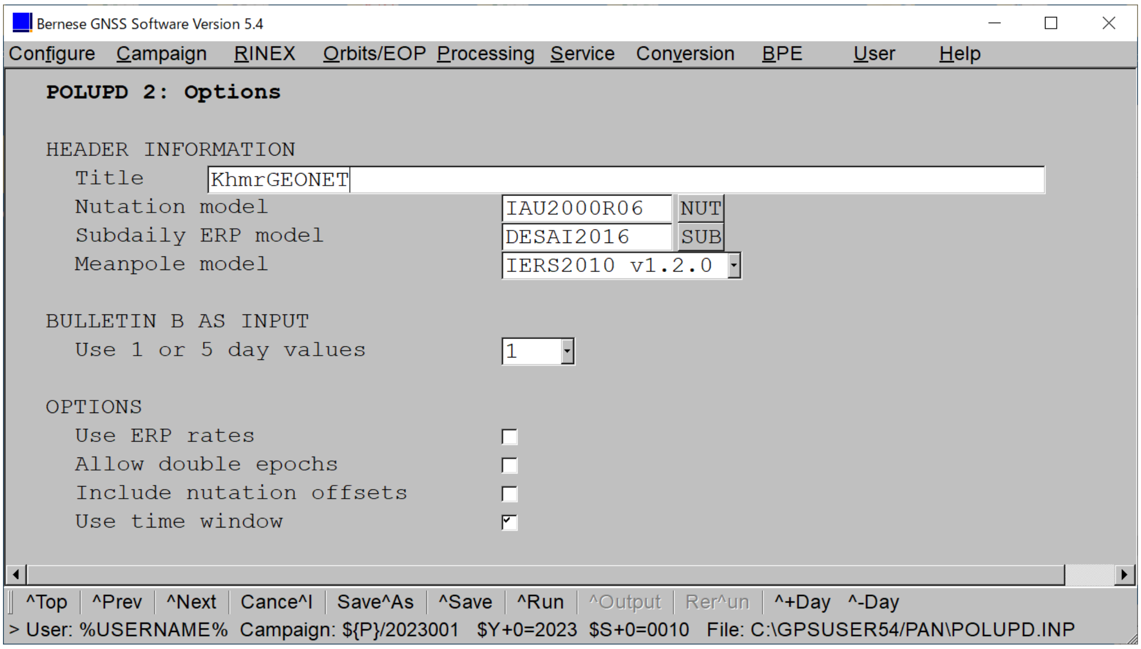
Click [^Next].



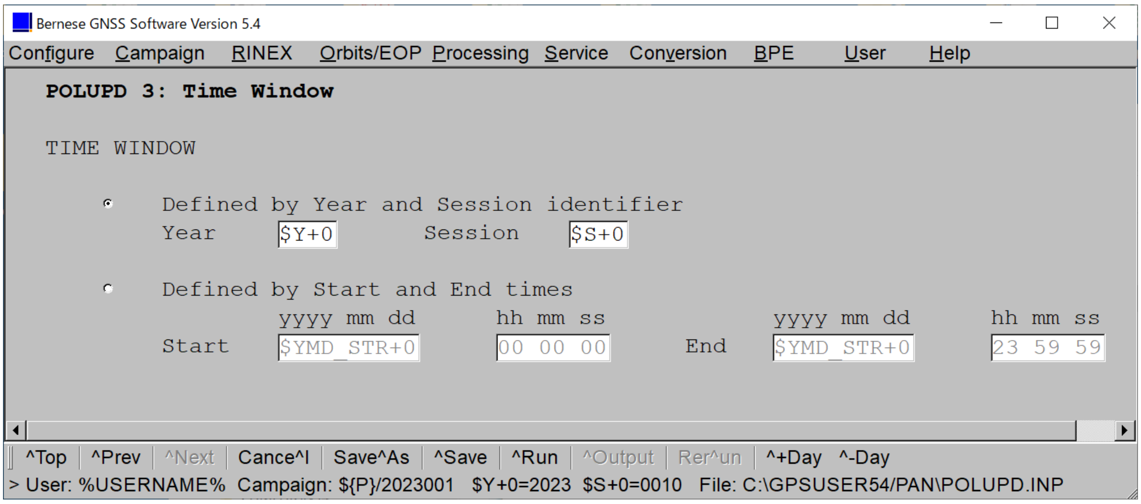
Enter Title.

Select Nutation mode [IAU2000R06], [DESA2016] and Sub daily pole mode [IERS2010 V1.2.0].

Click [^Next].



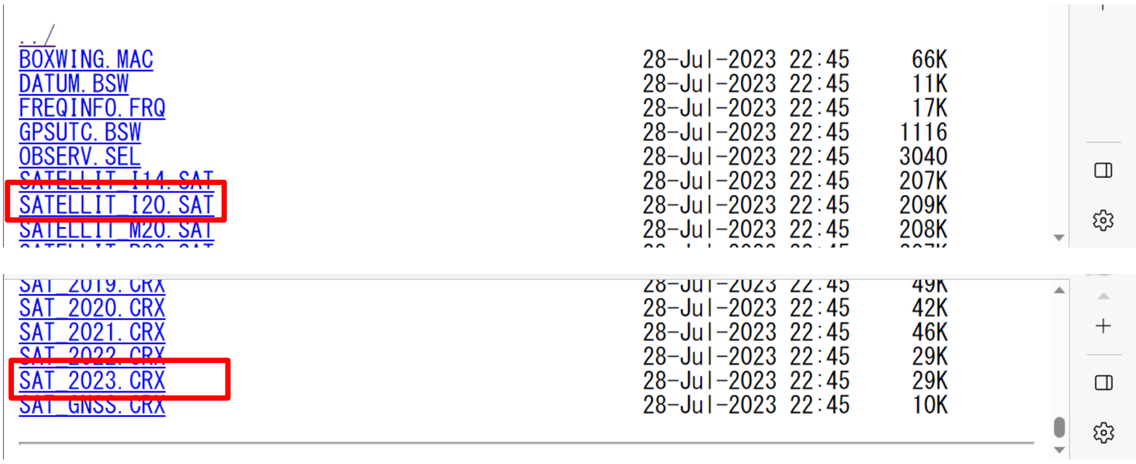
Click [^Run].


Bernese GNSS Software Version 5.4
Configure Campaign RINEX Orbits/EOP Processing Service Conversion BPE User Help
POLUPD 3: Time Window
TIME WINDOW
Defined by Year and Session identifier
Year $Y+0 Session $S+0
Defined by Start and End times
yyyy mm dd hh mm ss yyyy mm dd hh mm ss
Start $YMD_STR+0 00 00 00 End $YMD_STR+0 23 59 59
^Top ^Prev ^Next Cance^l Save^As ^Save ^Run ^Output Rer^un ^+Day ^-Day
> User: %USERNAME% Campaign: ${P}/2023001 $Y+0=2023 $S+0=0010 File: C:\GPSUSER54/PAN\POLUPD.INP

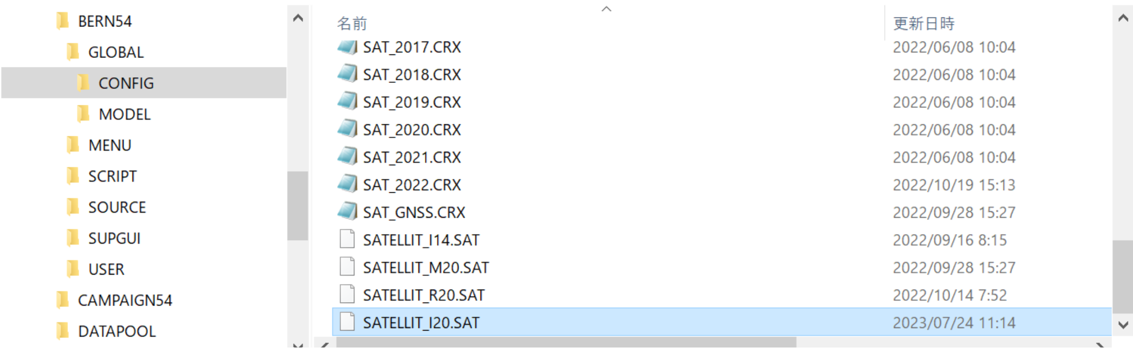
8.2. Generate Orbit Files (ORBGEN)

Download [SATELLIT_I20.SAT] file and [SAT_2023.CRX] file from the download site.

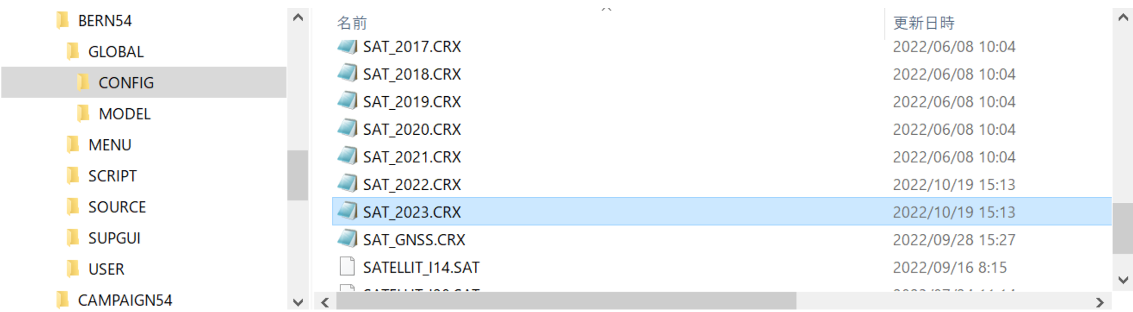
Download site: [Index of /BSWUSER54/CONFIG/ (unibe.ch)]



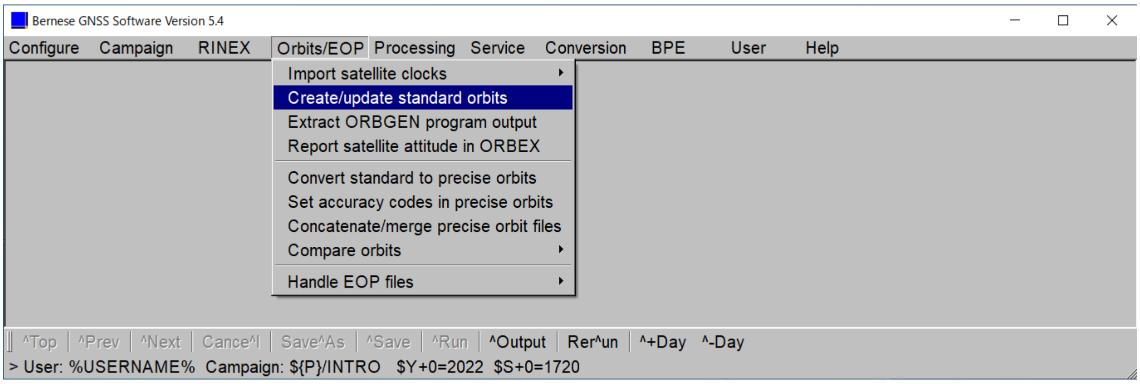
Copy [SATELLIT_I20.SAT] file to [C:/BERN54/GLOBAL/CONFIG] folder.



Copy [SAT_2023.CRX] file to [C:/BERN54/GLOBAL/CONFIG] folder.



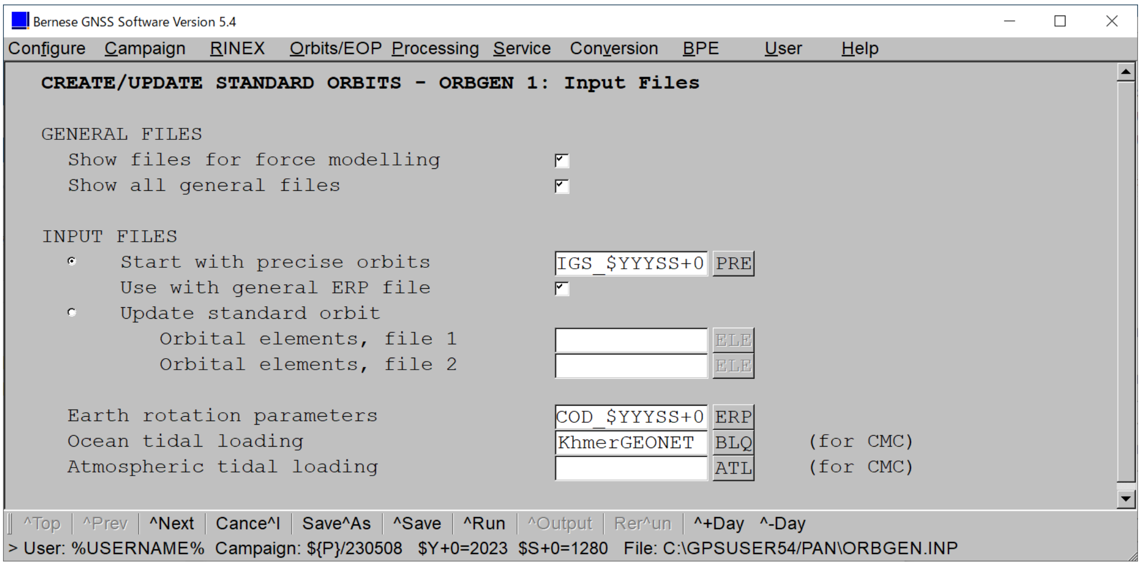
Click [Create/update standard orbits] to display the submenu.



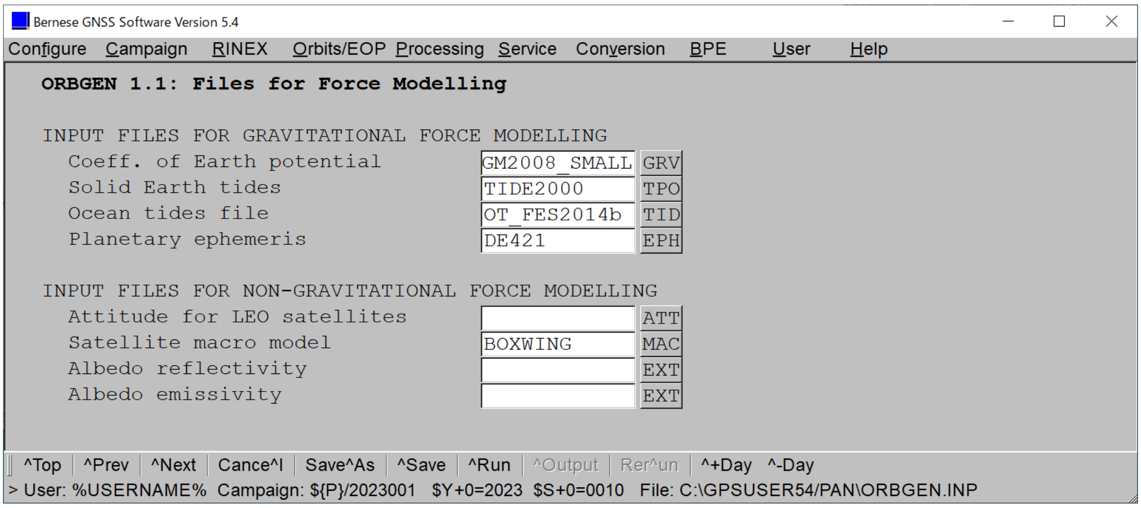
Select Input files.

For Earth rotation parameters file, specify the file created in section 8.1.

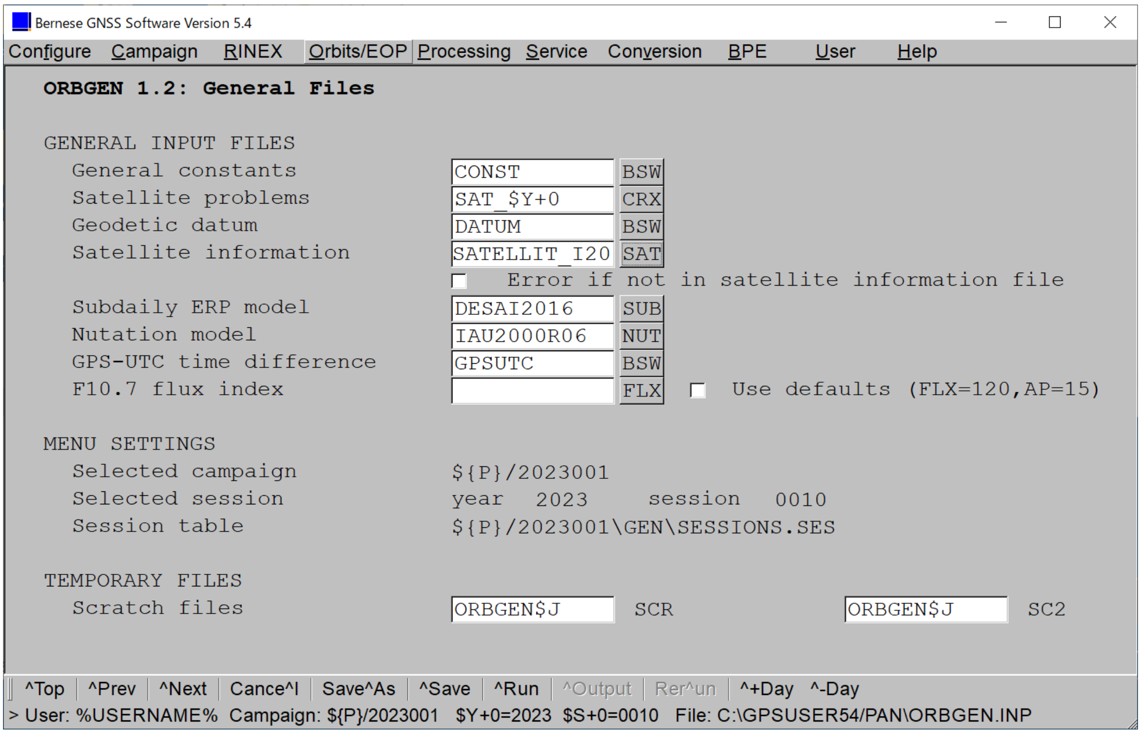
Click [^Next].



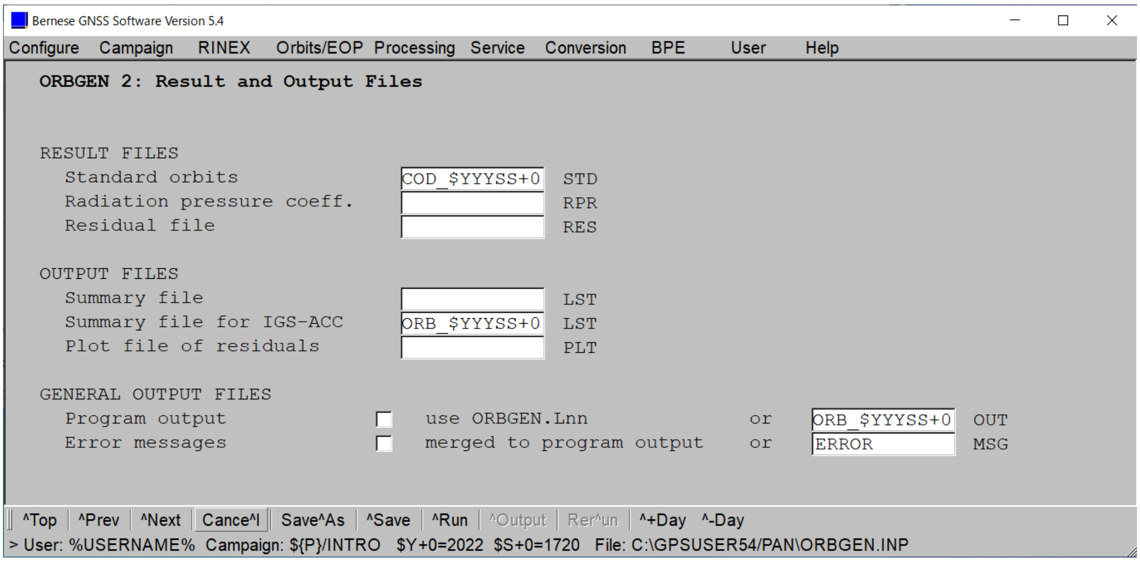
Click [^Next].



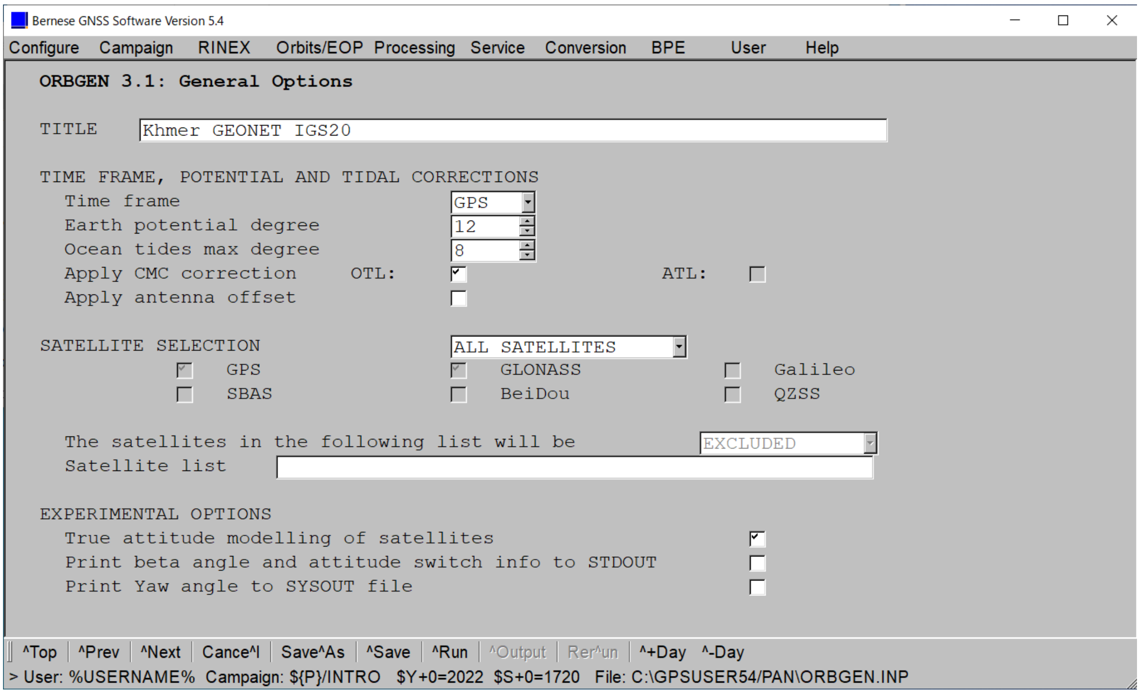
Click [^Next].



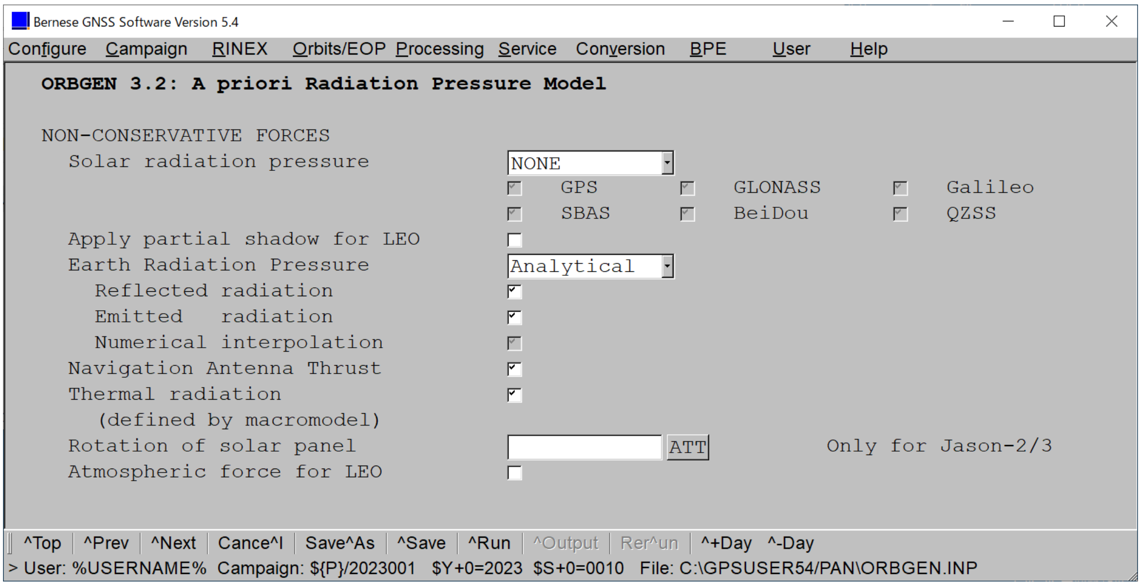
Click [^Next]



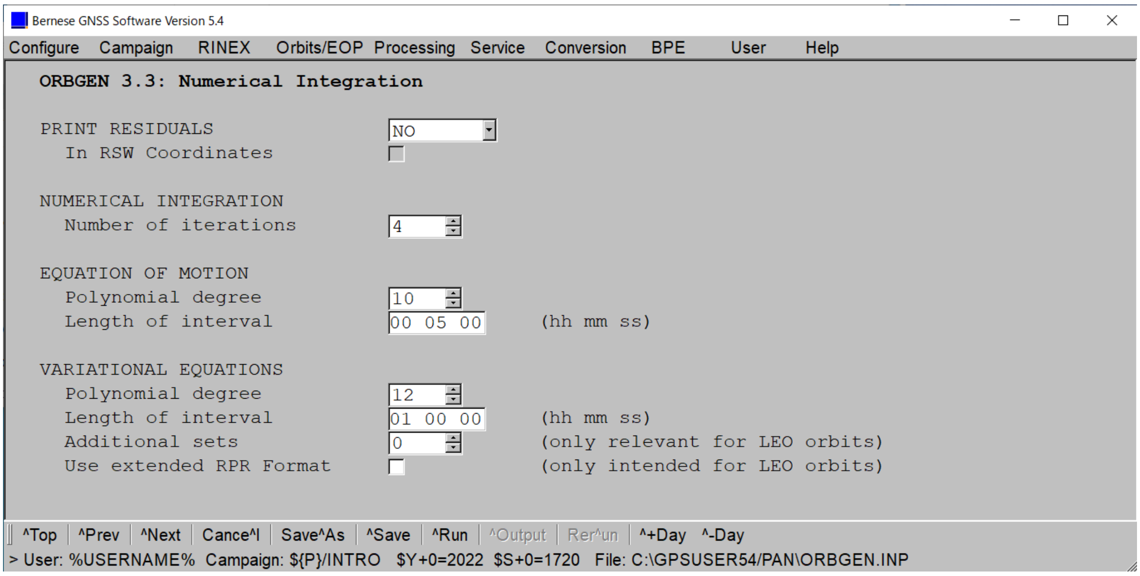
Click [^Next].



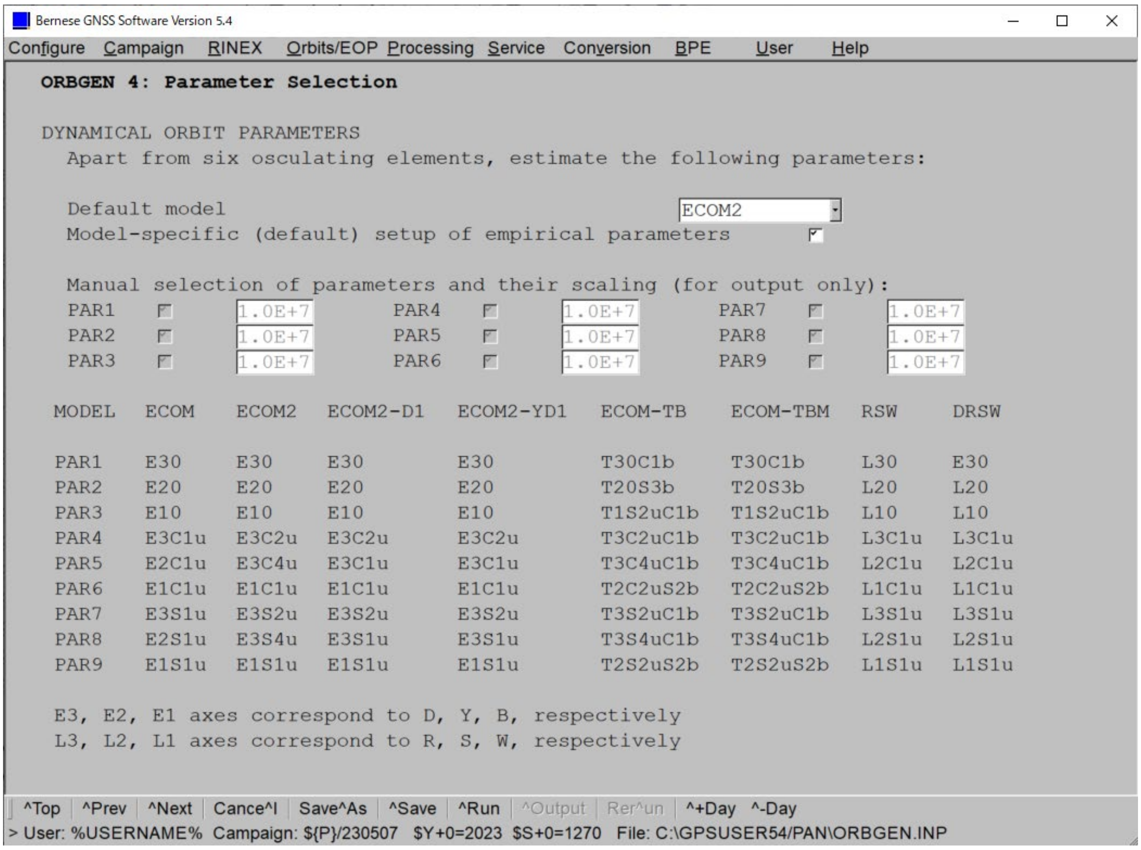
Click [^Next].



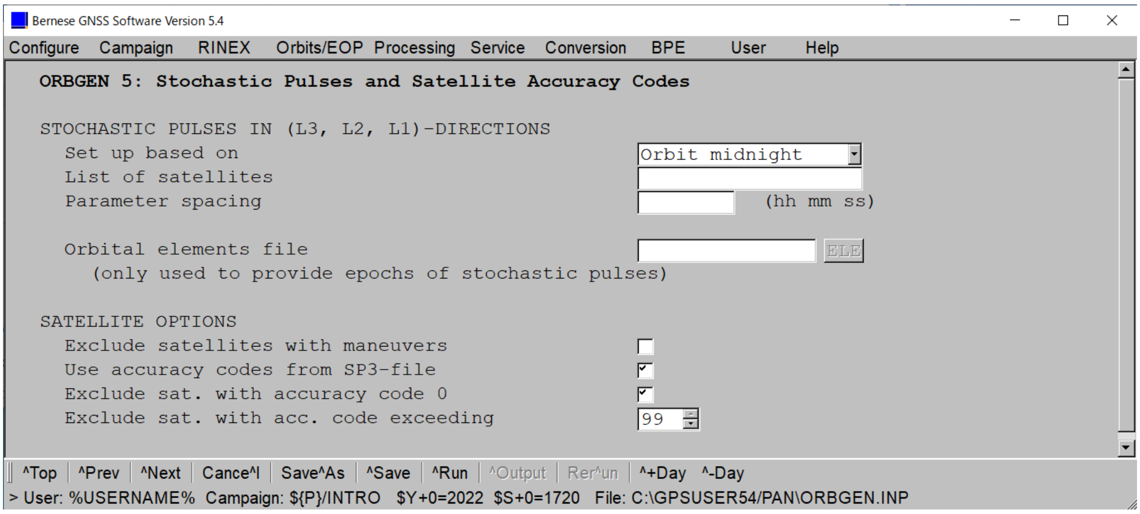
Click [^Next].



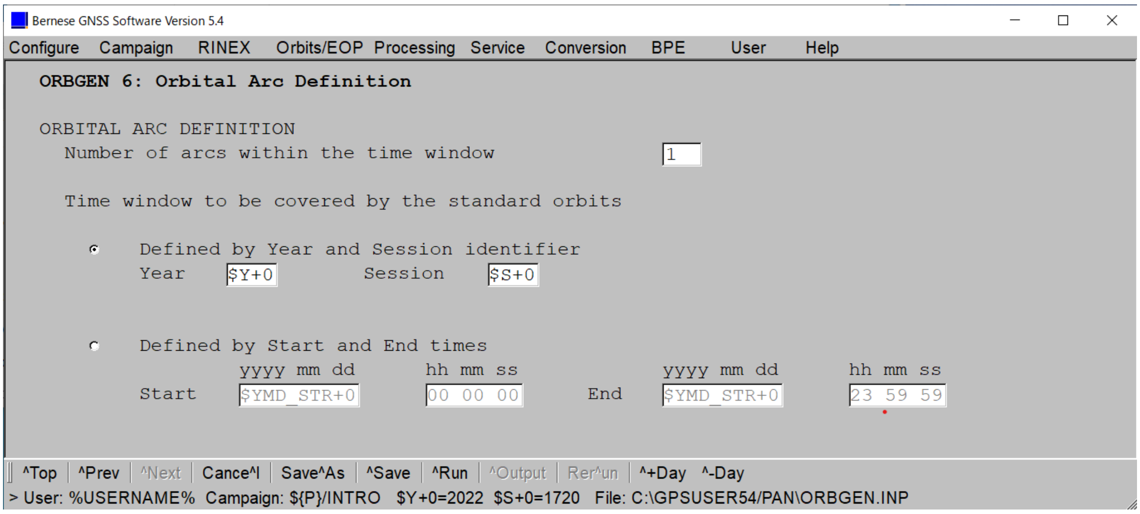
Click [^Next].



Click [^Next].

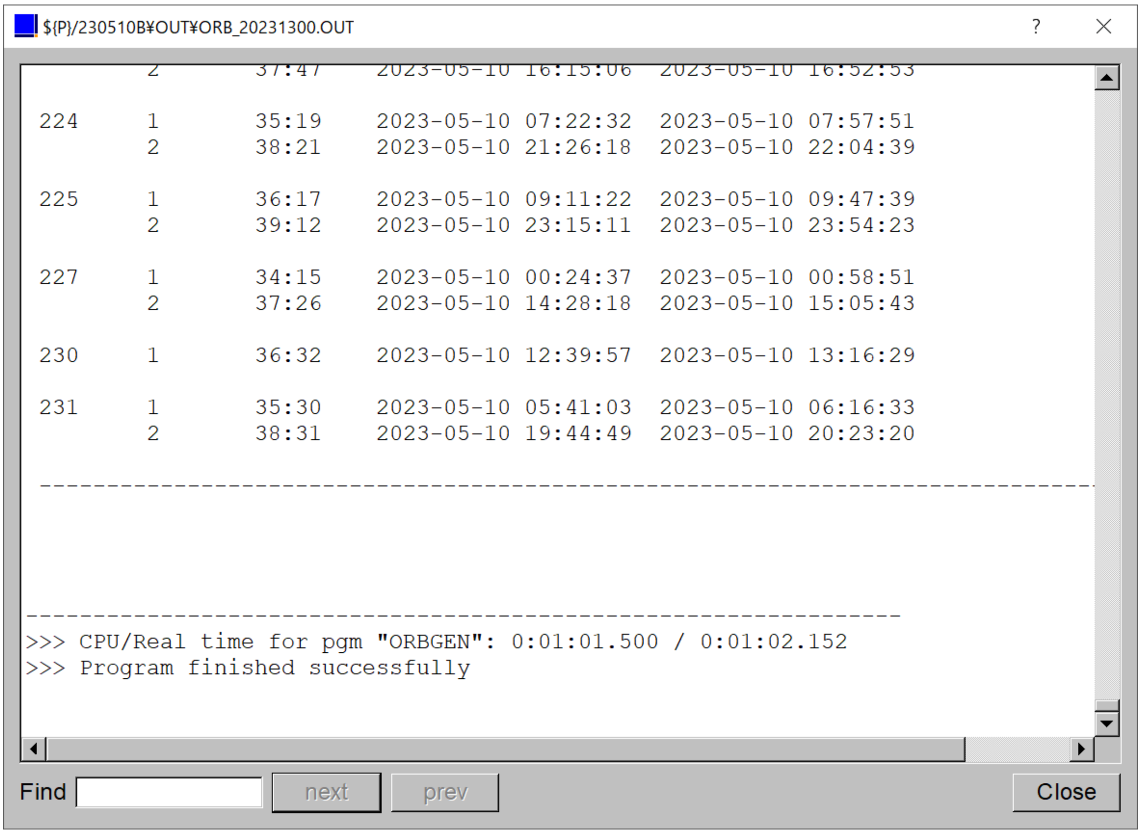


Click [^Run].



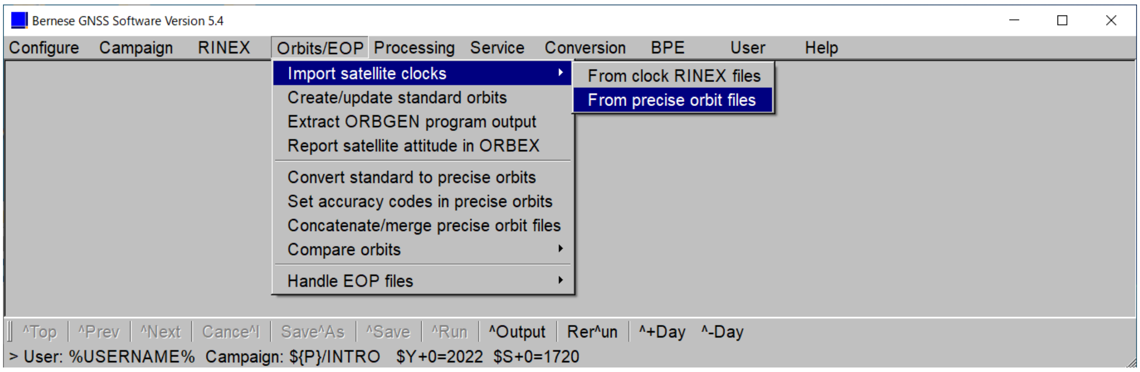
Click [^Output].

Check the results.

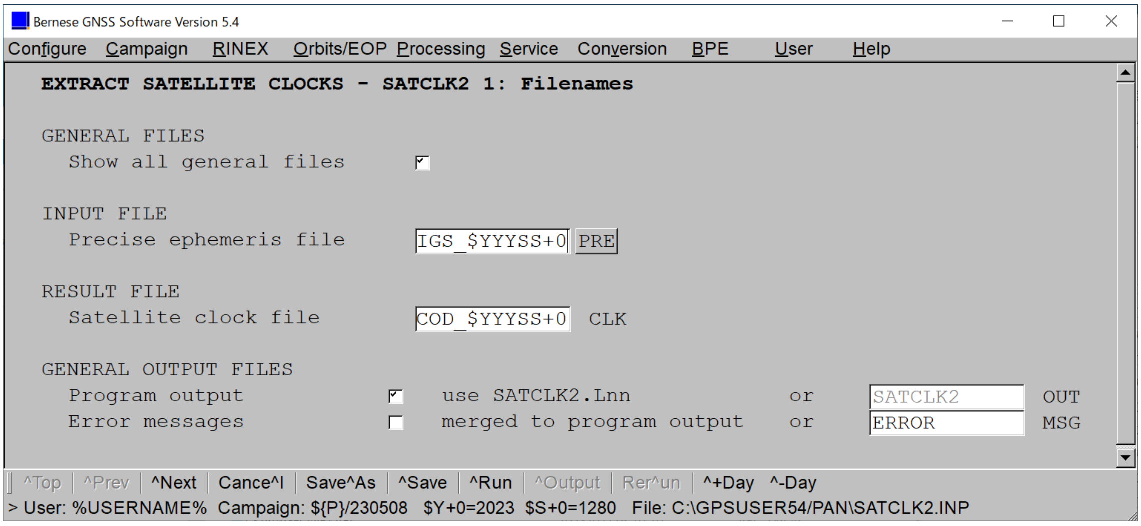


8.3. Extract satellite clock corrections

Click [From precise orbit files] to display the submenu.

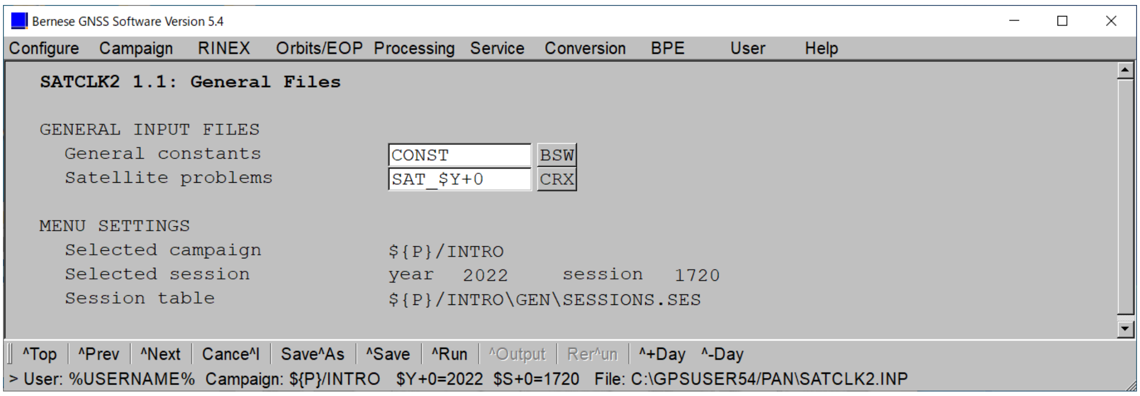


Click [^Next].

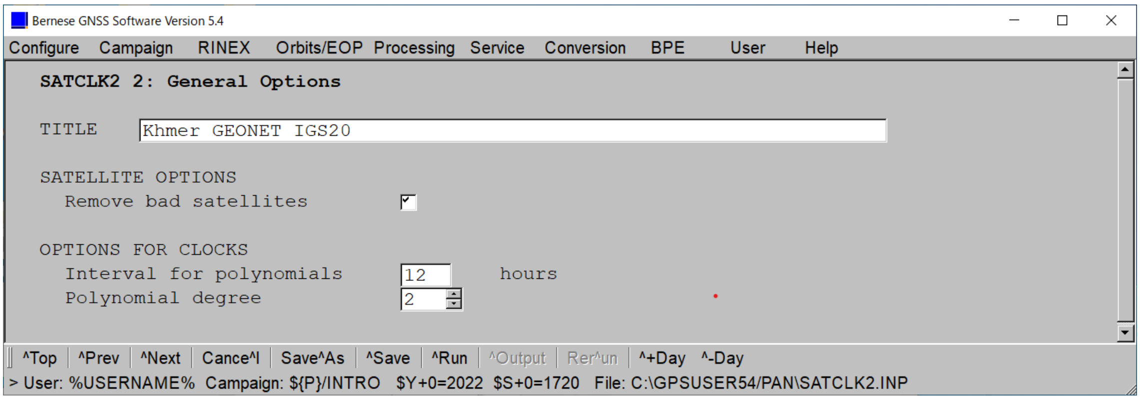


Select Satellite problems file.

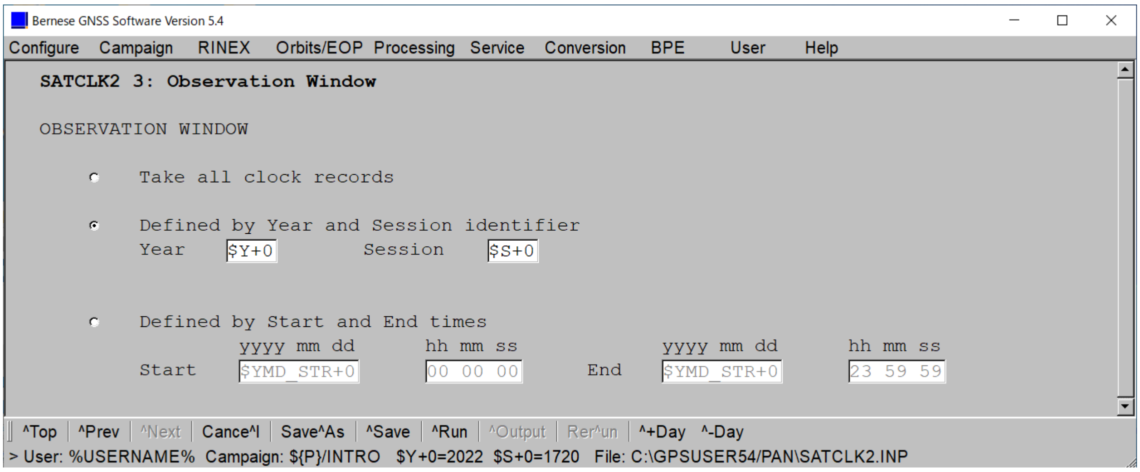
Click [^Next].



Click [^Next].

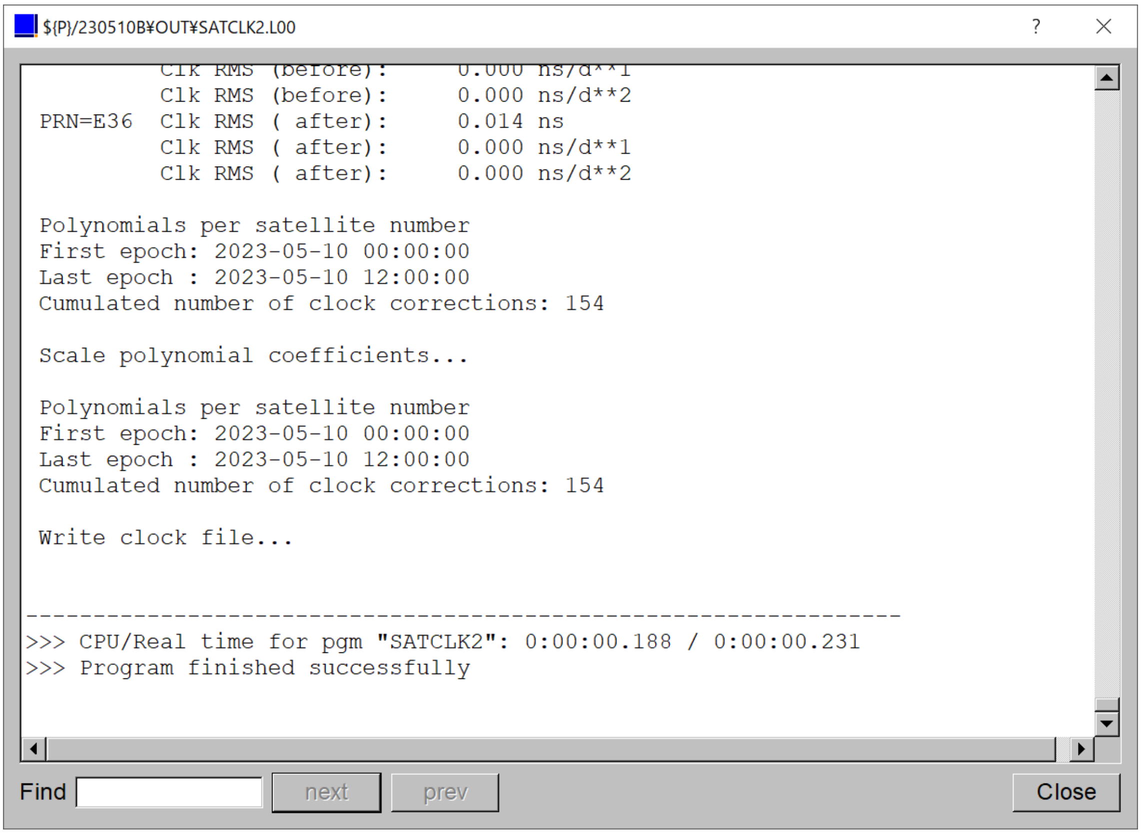


Click [^Run].



Click [^Output].

Check the results.

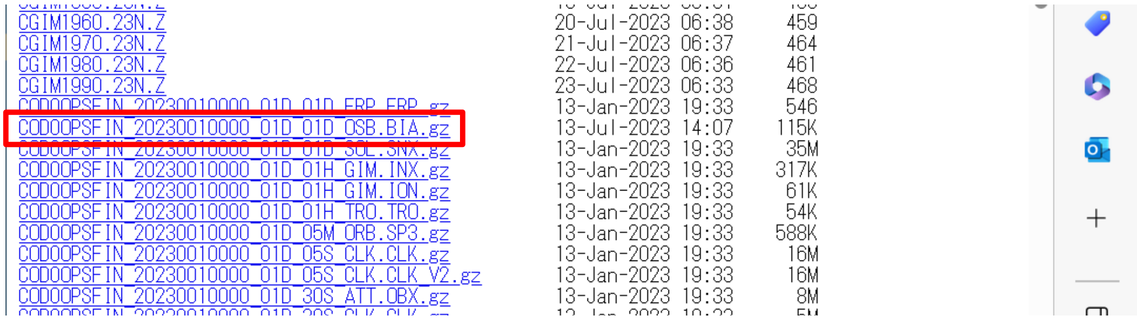


```
$(P)/230510B¥OUT¥SATCLK2.L00

            Clk RMS  (before):     0.000 ns/d**1
            Clk RMS  (before):     0.000 ns/d**2
 PRN=E36    Clk RMS  ( after):     0.014 ns
            Clk RMS  ( after):     0.000 ns/d**1
            Clk RMS  ( after):     0.000 ns/d**2

 Polynomials per satellite number
 First epoch: 2023-05-10 00:00:00
 Last epoch : 2023-05-10 12:00:00
 Cumulated number of clock corrections: 154

 Scale polynomial coefficients...

 Polynomials per satellite number
 First epoch: 2023-05-10 00:00:00
 Last epoch : 2023-05-10 12:00:00
 Cumulated number of clock corrections: 154

 Write clock file...


-----------------------------------------------------------------
>>> CPU/Real time for pgm "SATCLK2": 0:00:00.188 / 0:00:00.231
>>> Program finished successfully

Find [        ] next  prev                                  Close
```

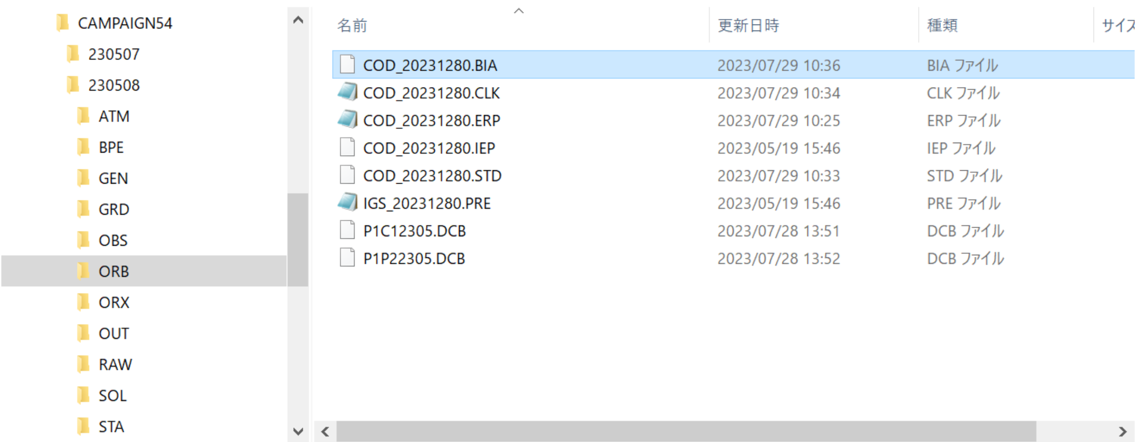
8.4. Convert Bias Corrections from Bias SINEX into Bernese bias Format

Download the Bias Corrections file from the download site.

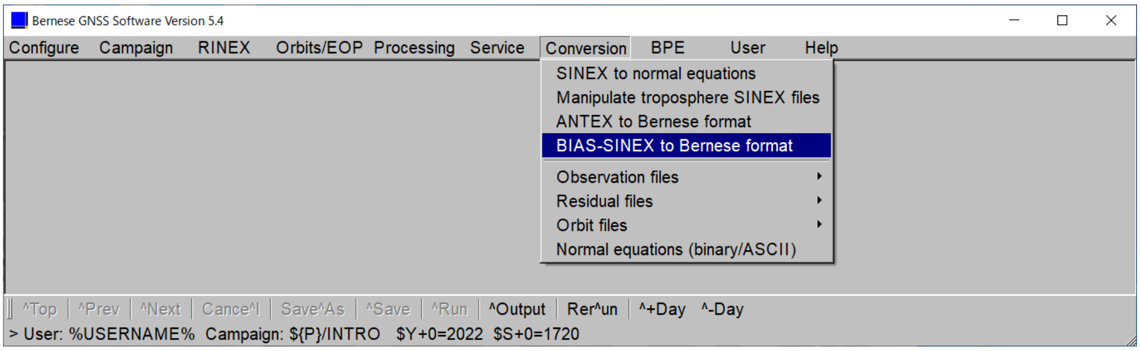
Download site: http://ftp.aiub.unibe.ch/CODE/2023/



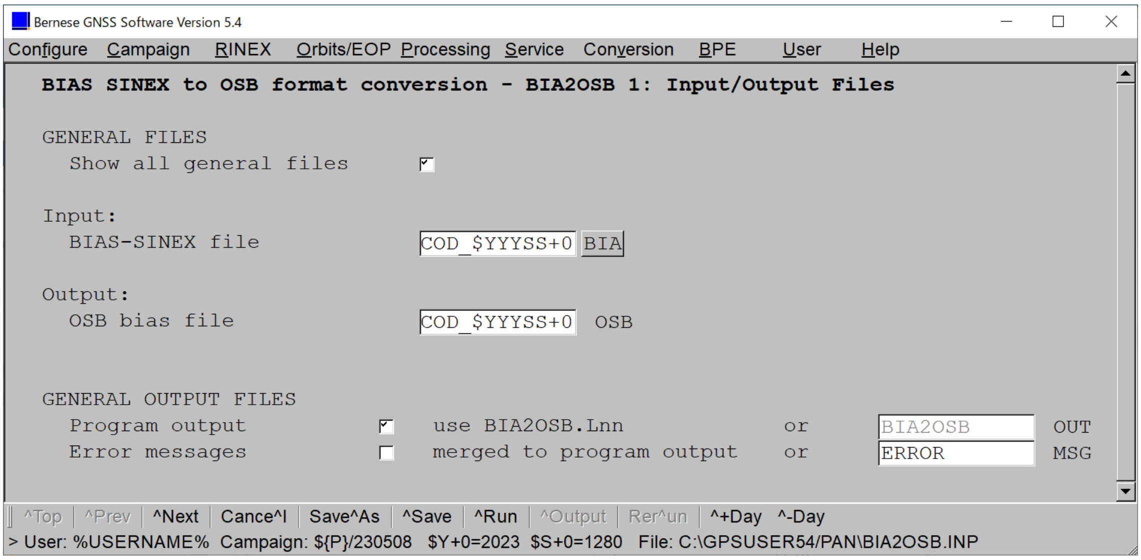
Copy the Bias Corrections file to [ORB] folder of the campaign.



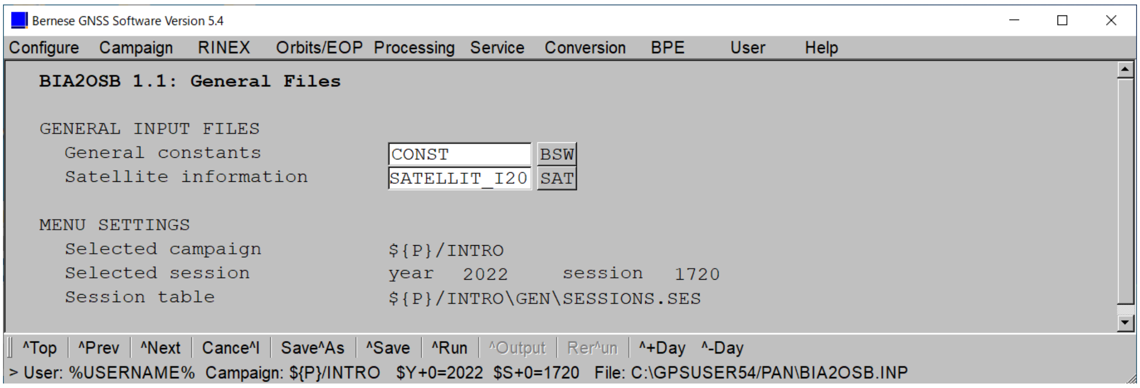
Click [Bias-SINEX to Bernese format] to display the submenu.



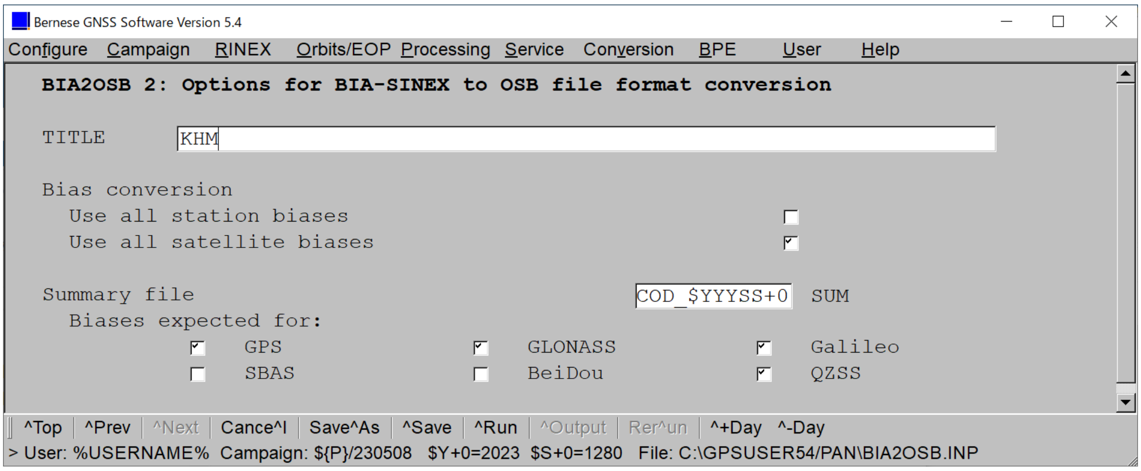
Click [^Next].



Click [^Next].

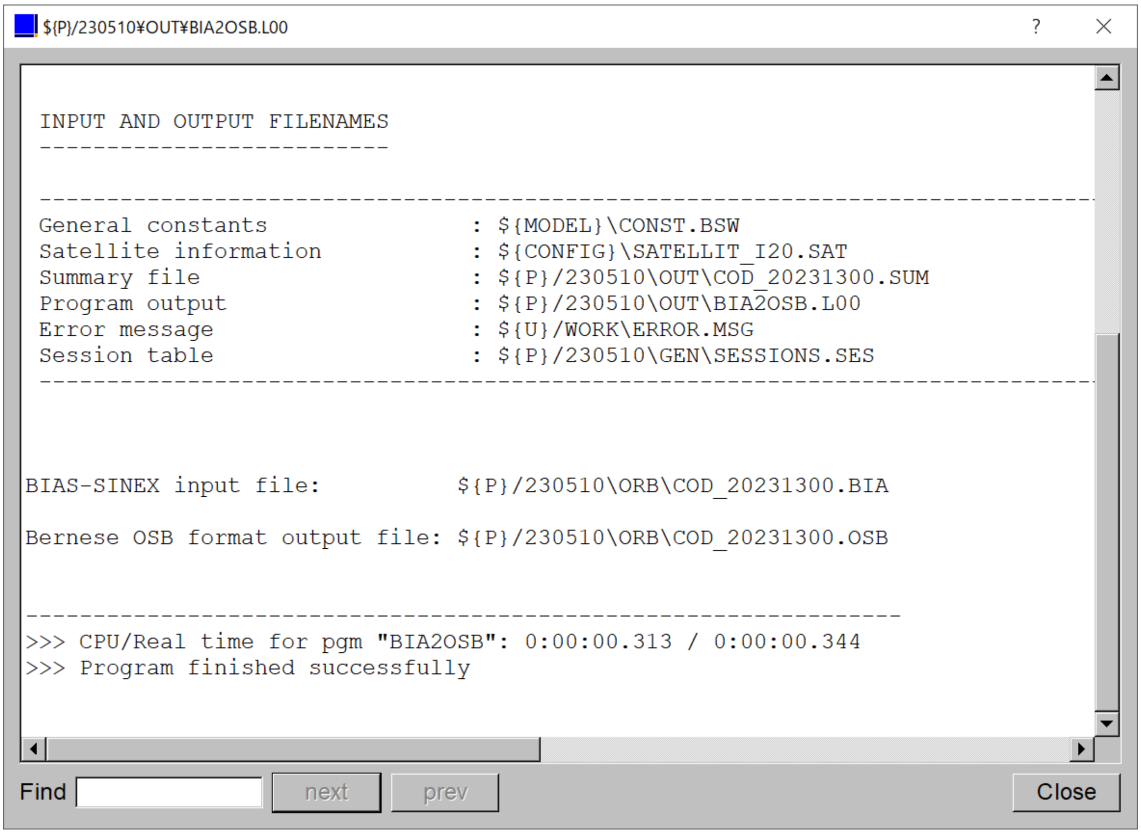


Click [^Run].



Click [^Output].

Check the results.

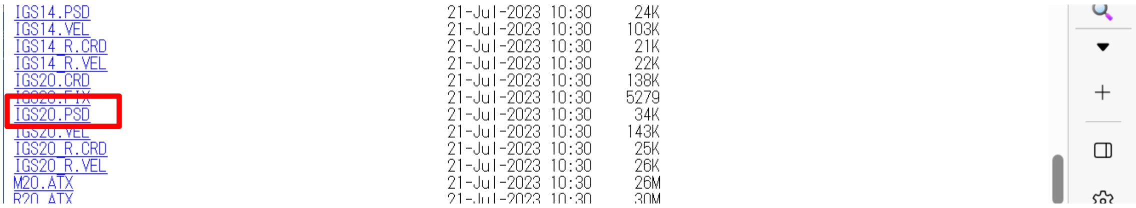


9. Baseline Processing

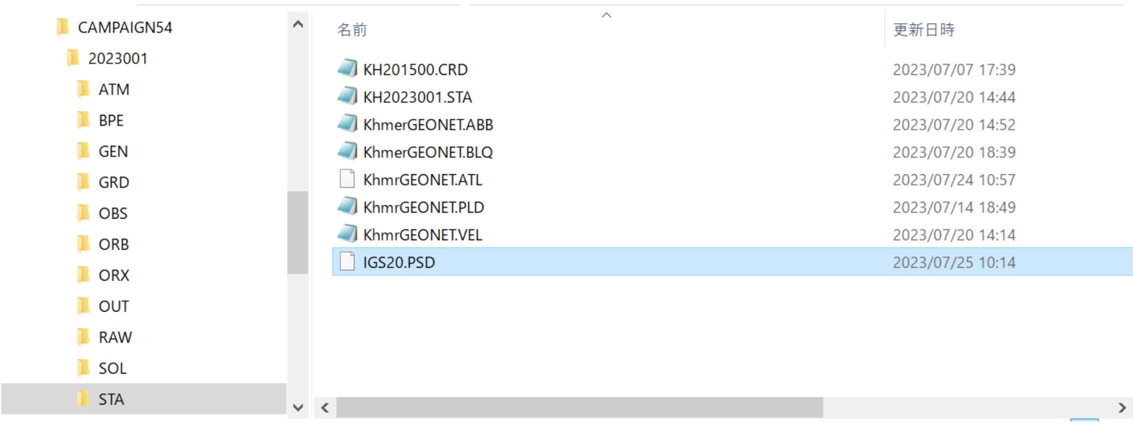
9.1. Extrapolate coordinate file (COOVEL)

Download Post Seismic Deformation corrections file [IGS20.PSD] from the download site.

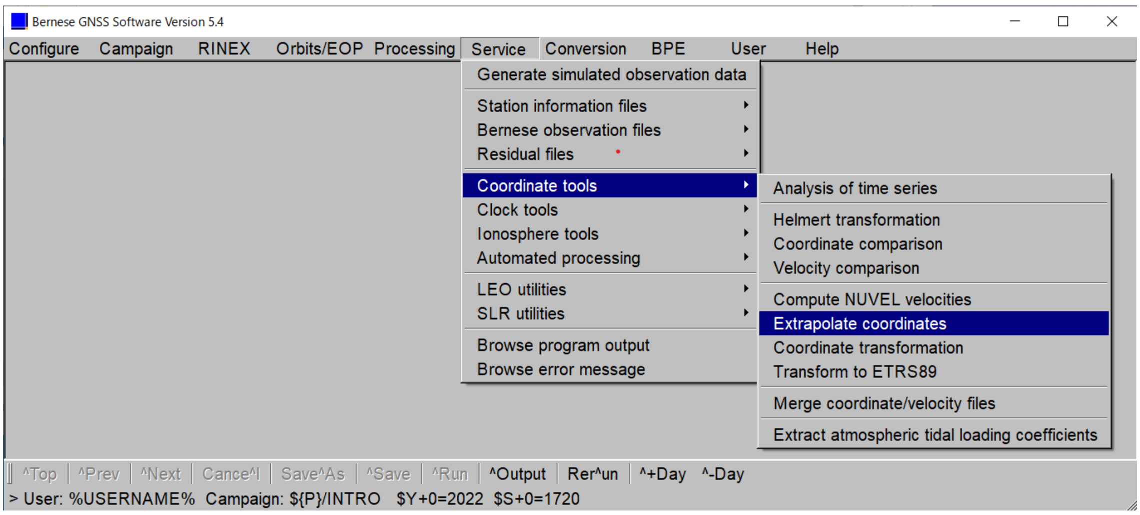
Download site: [Index of /BSWUSER54/REF/ (unibe.ch)]



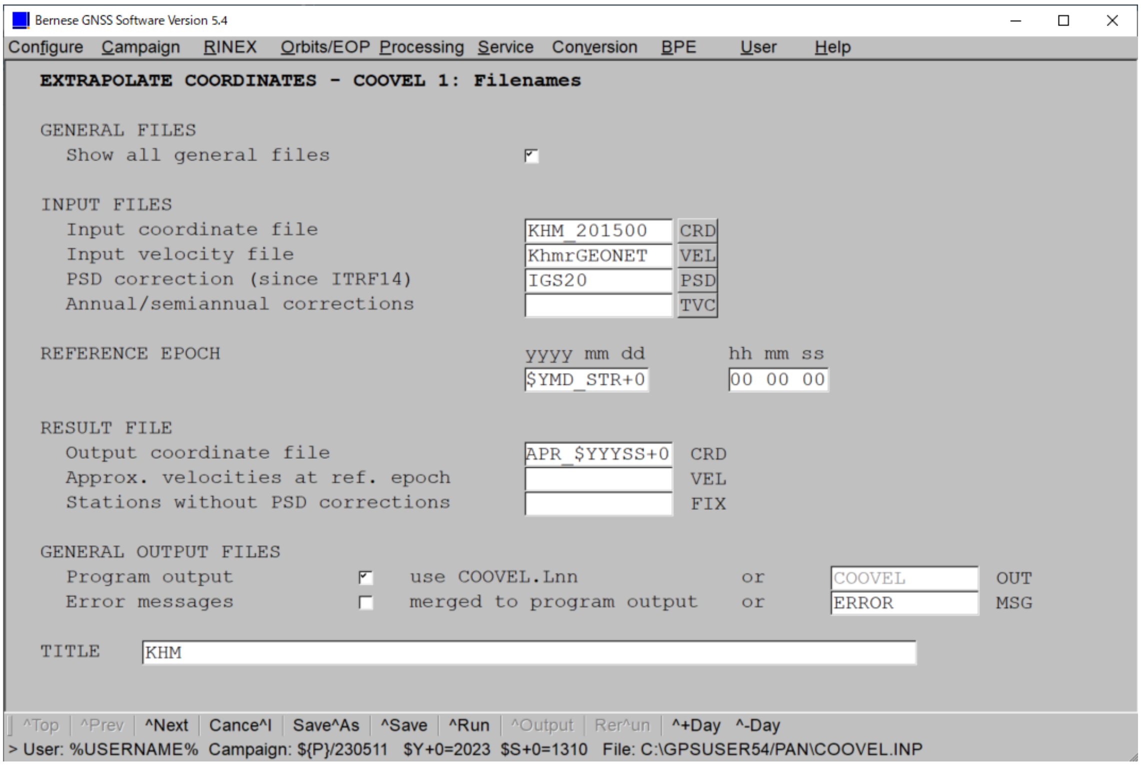
Copy Post Seismic Deformation corrections file to [STA] folder of the campaign.



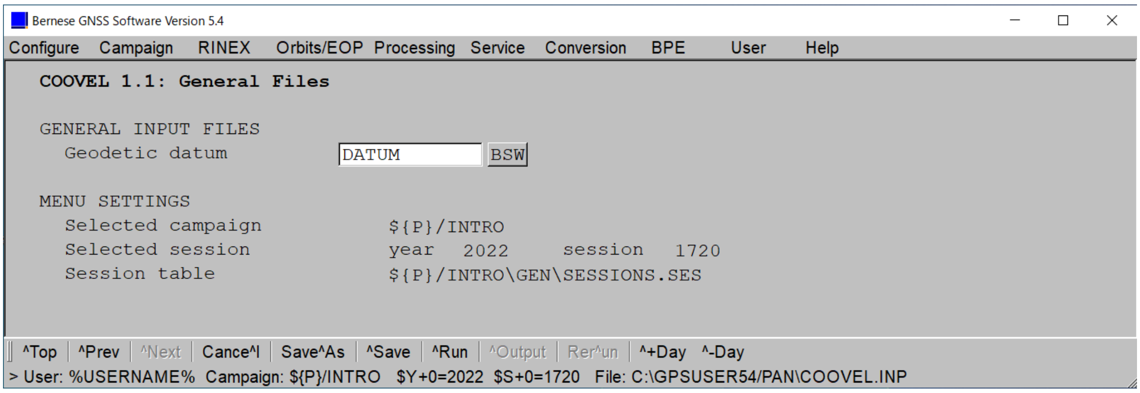
Click [Extrapolate coordinates] to display the submenu.



Select Input Coordinate file, Input velocity file and PSD correction.
Enter REFERENCE EPOCH, Output coordinate file and Title.
Click [^Next].



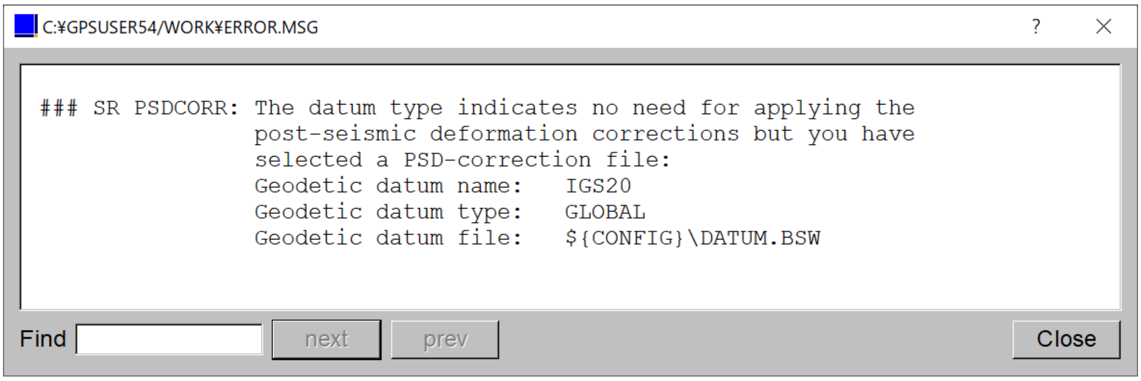
Click [^Run].

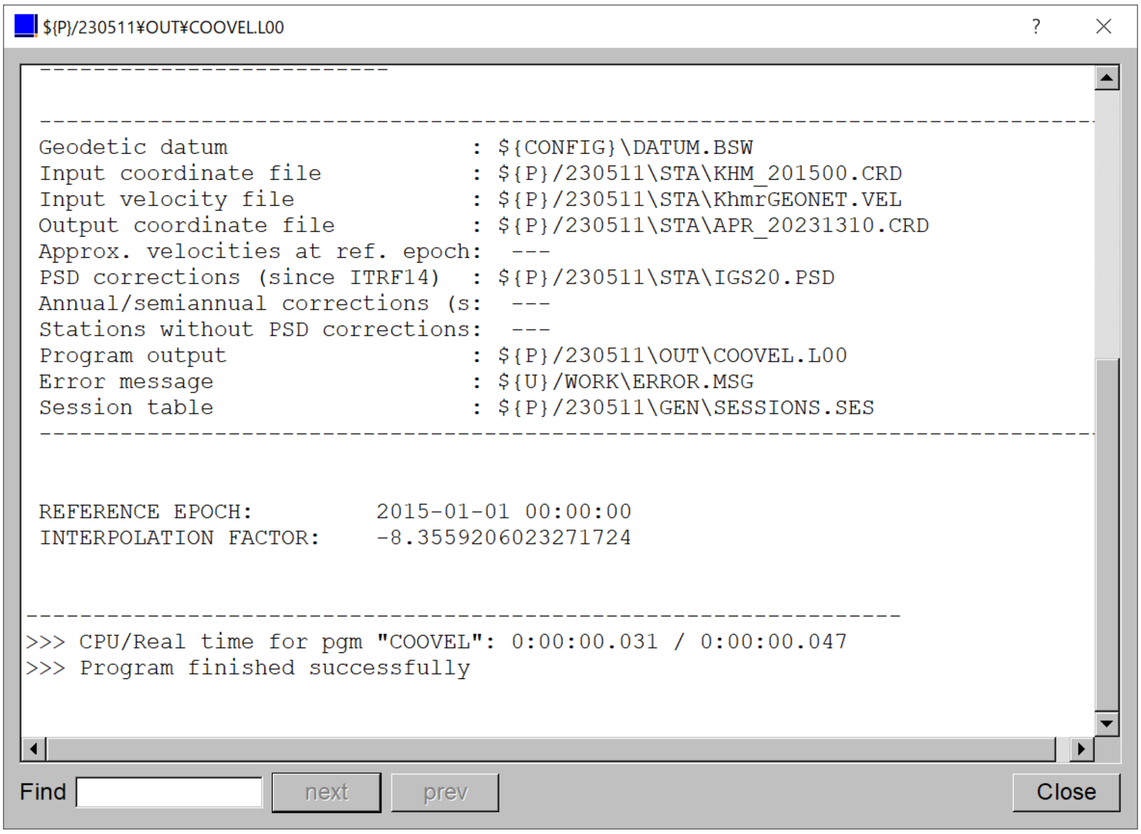


Click [^Output].

Check the results.

You can safely ignore this warning.





9.2. Inventory of the unput RINEX files (RNXGRA)

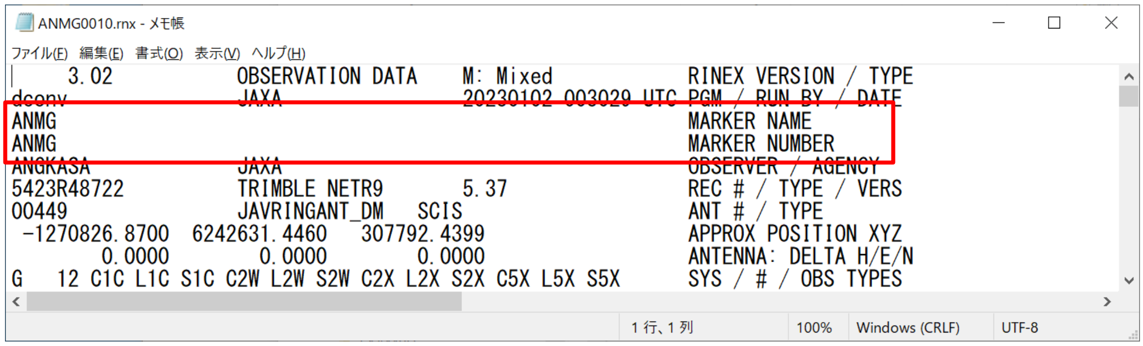
Check the RINEX file header.

Edit the header as shown below.

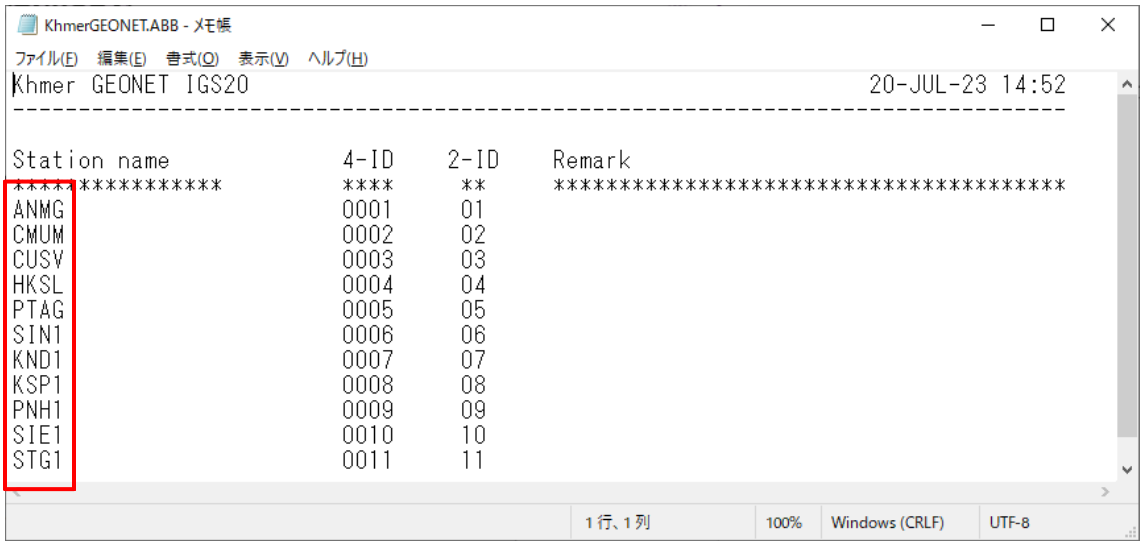
If you see a warning in the RINEX file during the calculation, it is most likely related to the header and you will need to edit the header.

Here are three examples: Other warnings may also occur.

A) The marker name and marker number should be 4 characters. Give it the same name as the [KhmerGEONET.ABB] file.

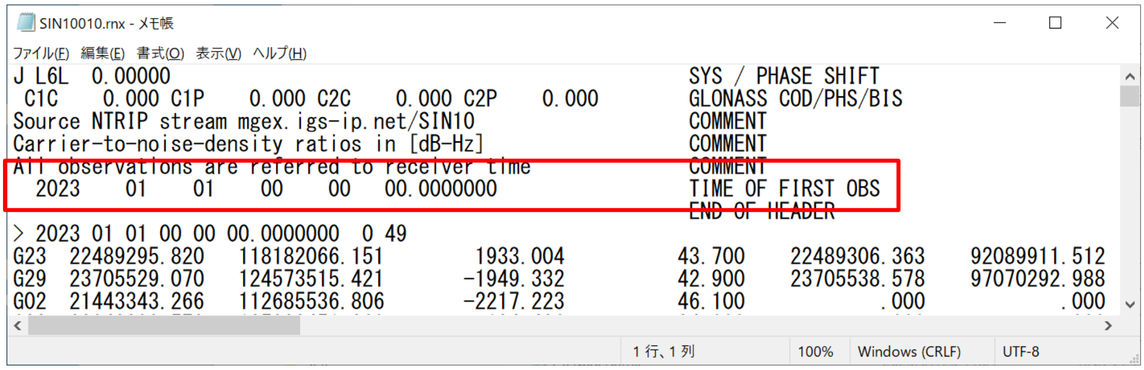


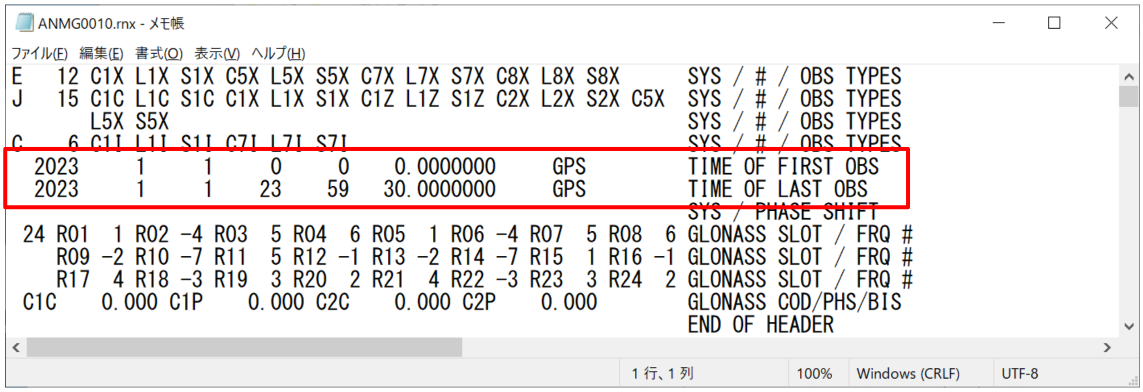
```
ANMG0010.rnx - メモ帳
ファイル(F) 編集(E) 書式(O) 表示(V) ヘルプ(H)
     3.02           OBSERVATION DATA    M: Mixed            RINEX VERSION / TYPE
dconv               JAXA                20230102 003029 UTC PGM / RUN BY / DATE
ANMG                                                        MARKER NAME
ANMG                                                        MARKER NUMBER
ANGKASA             JAXA                                    OBSERVER / AGENCY
5423R48722          TRIMBLE NETR9       5.37                REC # / TYPE / VERS
00449               JAVRINGANT_DM   SCIS                    ANT # / TYPE
 -1270826.8700  6242631.4460   307792.4399                  APPROX POSITION XYZ
        0.0000         0.0000         0.0000                ANTENNA: DELTA H/E/N
G   12 C1C L1C S1C C2W L2W S2W C2X L2X S2X C5X L5X S5X      SYS / # / OBS TYPES
1 行、1 列    100%    Windows (CRLF)    UTF-8
```



```
KhmerGEONET.ABB - メモ帳
ファイル(F) 編集(E) 書式(O) 表示(V) ヘルプ(H)
Khmer GEONET IGS20                                                20-JUL-23 14:52
---------------------------------------------------------------------------------

Station name          4-ID    2-ID    Remark
****************      ****     **     ****************************************
ANMG                  0001     01
CMUM                  0002     02
CUSV                  0003     03
HKSL                  0004     04
PTAG                  0005     05
SIN1                  0006     06
KND1                  0007     07
KSP1                  0008     08
PNH1                  0009     09
SIE1                  0010     10
STG1                  0011     11
1 行、1 列    100%    Windows (CRLF)    UTF-8
```

B) If GPS time is not listed in [TIME OF FIRST OBS] and [TIME OF LAST OBS], please edit it so that it is correct.





C) If there is no value in PHASE SHIFT, delete it. Do not edit if it contains a value.

ANMG0010.rnx - メモ帳

ファイル(F) 編集(E) 書式(O) 表示(V) ヘルプ(H)

```
E   12 C1X L1X S1X C5X L5X S5X C7X L7X S7X C8X L8X S8X      SYS / # / OBS TYPES
J   15 C1C L1C S1C C1X L1X S1X C1Z L1Z S1Z C2X L2X S2X C5X  SYS / # / OBS TYPES
       L5X S5X                                              SYS / # / OBS TYPES
C    6 C1I L1I S1I C7I L7I S7I                              SYS / # / OBS TYPES
  2023     1     1     0     0    0.0000000     GPS         TIME OF FIRST OBS
  2023     1     1    23    59   30.0000000     GPS         TIME OF LAST OBS
                                                            SYS / PHASE SHIFT
 24 R01  1 R02  4 R03  5 R04  6 R05  1 R06  4 R07  5 R08  6 GLONASS SLOT / FRQ #
    R09 -2 R10 -7 R11  5 R12 -1 R13 -2 R14 -7 R15  1 R16 -1 GLONASS SLOT / FRQ #
    R17  4 R18 -3 R19  3 R20  2 R21  4 R22 -3 R23  3 R24  2 GLONASS SLOT / FRQ #
 C1C    0.000 C1P    0.000 C2C    0.000 C2P    0.000        GLONASS COD/PHS/BIS
                                                            END OF HEADER
```

19 行、78 列 | 100% | Windows (CRLF) | UTF-8

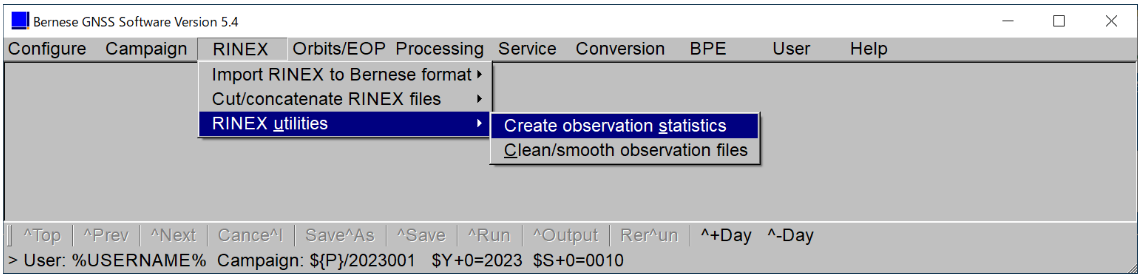
HKSL0010.rnx - メモ帳

ファイル(F) 編集(E) 書式(O) 表示(V) ヘルプ(H)

```
C    8 C1I L1I D1I S1I C7I L7I D7I S7I                      SYS / # / OBS TYPES
DBHZ                                                        SIGNAL STRENGTH UNIT
    30.000                                                  INTERVAL
  2023    01    01    00    00    0.0000000     GPS         TIME OF FIRST OBS
  2023    01    01    23    59   30.0000000     GPS         TIME OF LAST OBS
     0                                                      RCV CLOCK OFFS APPL
G L2S -0.25000                                              SYS / PHASE SHIFT
G L2X -0.25000                                              SYS / PHASE SHIFT
R L2P  0.25000                                              SYS / PHASE SHIFT
E L8Q -0.25000                                              SYS / PHASE SHIFT
 24 R01  1 R02  4 R03  5 R04  6 R05  1 R06  4 R07  5 R08  6 GLONASS SLOT / FRQ #
    R09 -2 R10 -7 R11  0 R12 -1 R13 -2 R14 -7 R15  0 R16 -1 GLONASS SLOT / FRQ #
    R17  4 R18 -3 R19  3 R20  2 R21  4 R22 -3 R23  3 R24  2 GLONASS SLOT / FRQ #
```

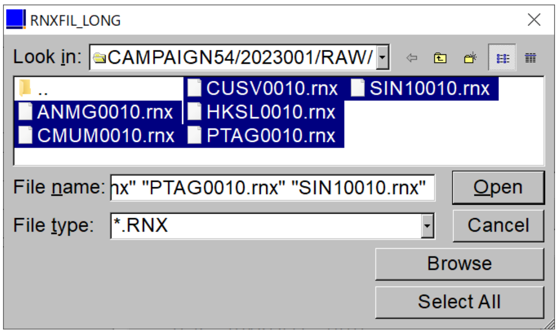
1 行、1 列 | 100% | Windows (CRLF) | UTF-8

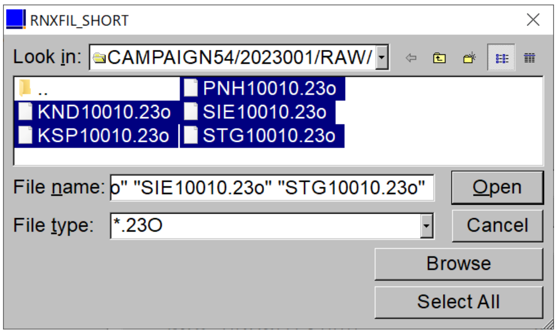
Click [Create observation statistics] to display the submenu.

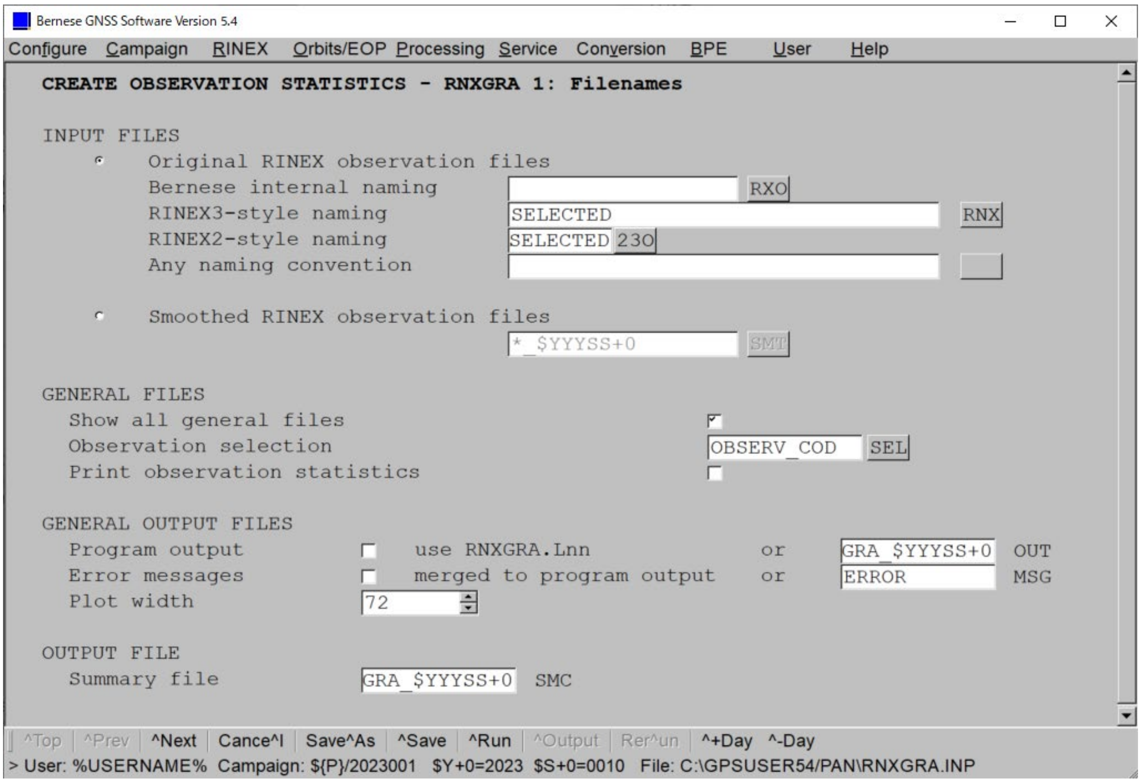


Select RINEX FILES.

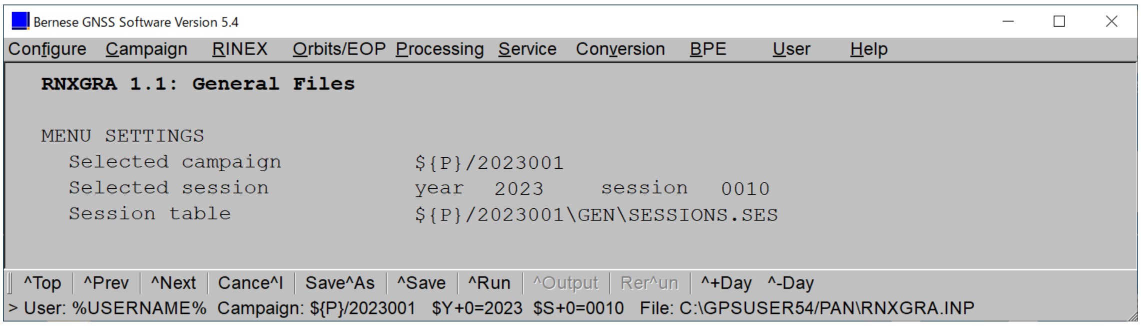
Click [^Next].



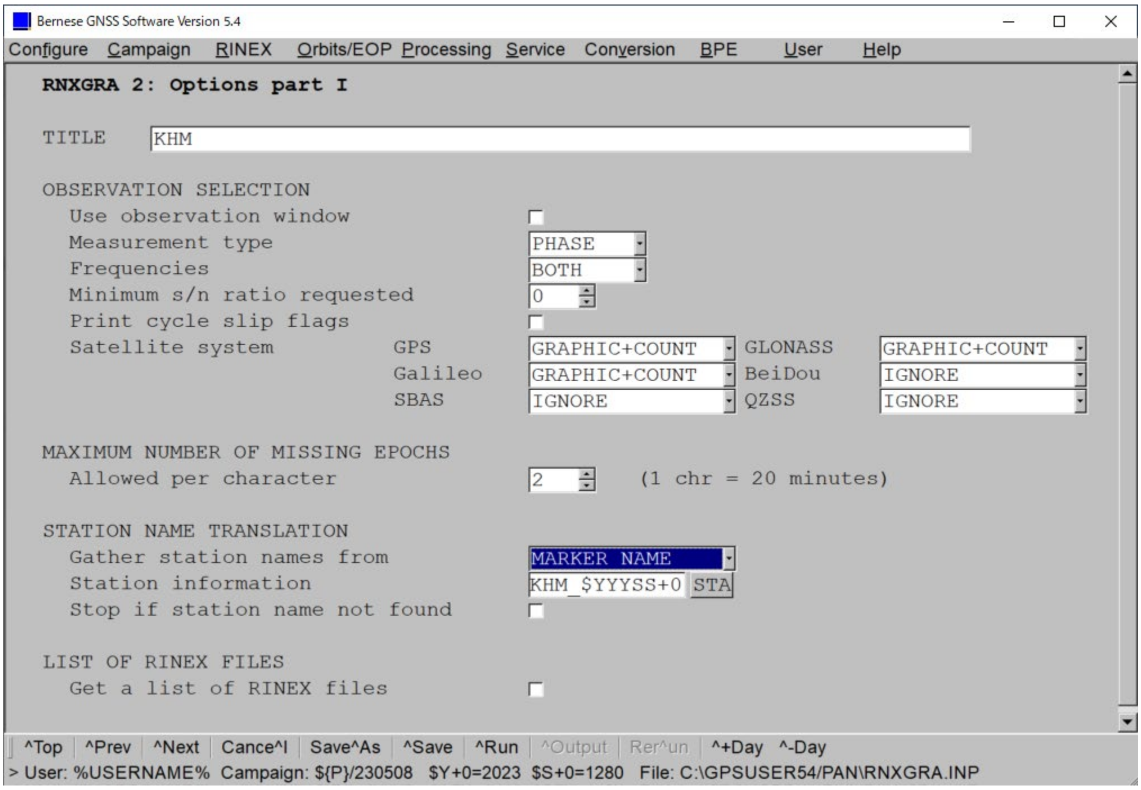




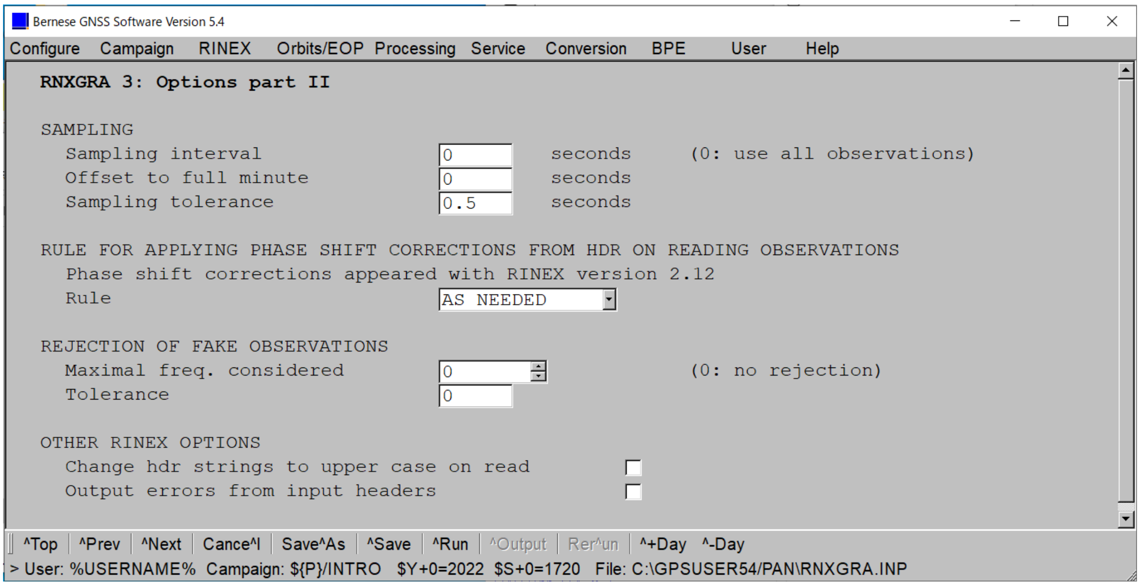
Click [^Next].



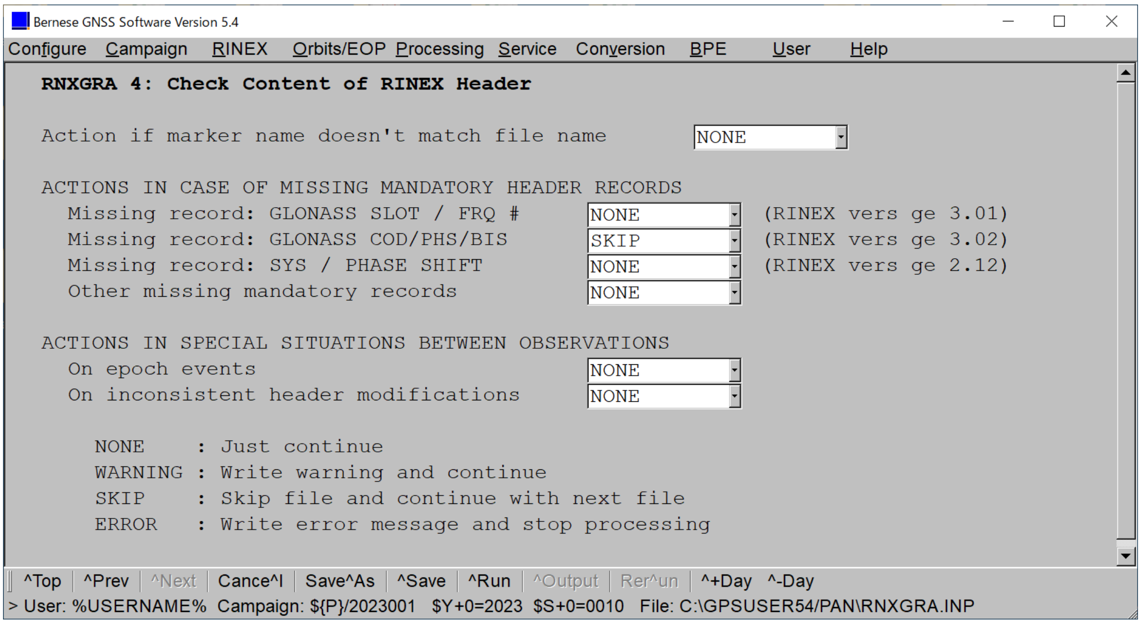
Click [^Next].



Click [^Next].



Click [^Run].



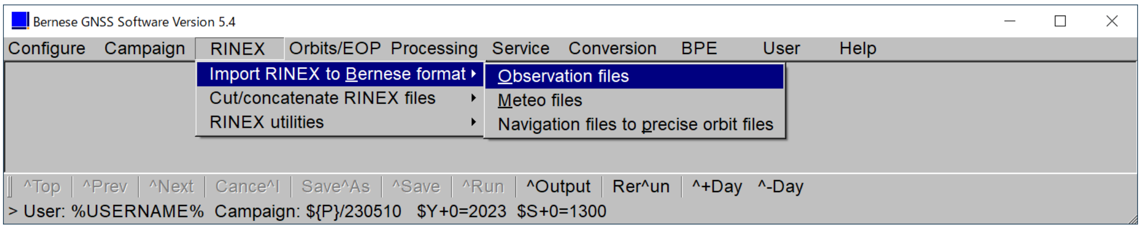
Click [^Output].

Check the results.


```
SATELLITE SYSTEM: GALILEO

KND1 |6665677777755666666777888897789*****8988888989***998877888888887778888898
KSP1 |77766777666656666677778888*9999999***688999999******988999999977888888888
PNH1 |77766777777656666667787777789999899998788999999889999*9977888878788888888
SIE1 |88767776666656666666666778888999989999*8888888889988*****887999999856777788778
STG1 |777666777766666666677767888889999****877889999889*****9999999886588888887
ANMG |788887777766676667577778999886-78888787788877788988*88877778767787766666
CMUM |644647776776665444455555455576667667766655545566666555545544544444444446
CUSV |66767777777666677777766679988*89****878988888887777766589*****98977777765
HKSL |777779776675666555667888878789998888878888888899999989899998887667777899899
PTAG |777777767777778766777887799898868888999886888999988999998777899987777789998
SIN1 |8987888889*889988999998*****9*******99**_****9**************988**998**99
-----+-----------------+-----------------+-----------------+-----------------+
     0                                   12                                   24

ANTI-SPOOFING :

 201 |   1222222222222222222222222222222222221
 202 |                                             111222222222222221  1222222
 203 |                                                      112222222222222222
 204 |           1112222222222222222222222111222222222222222222
 205 |                                  11           1122222222222222222222222
 207 |2222222222222211
 208 |111                                                           2212222222
 209 |                   1111222222222222222 11122222222222222222222222
 210 |       1                  222222222222222222222222222222222211
 211 |                              122222222222222222222222222222222211
 212 |    1111 211          1122222222222222222222222222    111
 213 |222111           111111                                              111
 215 |                                                             11222222222
 219 | 1112222222222222222222222211
 221 |222222222222222222222222221
 224 |                      11111112222222222222222222222222111      111 1222222
 225 |                                    1112222222222222222222111122222222222
 226 |22222222211111122222222222222221
 227 |222222222222222
 230 |2222222                                                    1
 231 |            222222222222222222222222222222222211
 233 |2222222222222211122222222222222222222222
 234 |                                                   111112222222222222222
 236 |                                     22222222222222222222222222222222211
-----+-----------------+-----------------+-----------------+-----------------+
     0                                   12                                   24


-----------------------------------------------------------------
>>> CPU/Real time for pgm "RNXGRA": 0:01:38.031 / 0:01:38.750
>>> Program finished successfully
```

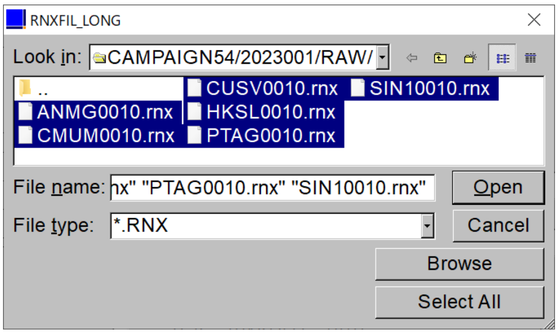
9.3. Converting the Observation from RINEX into Bernese format (RXOBV3)

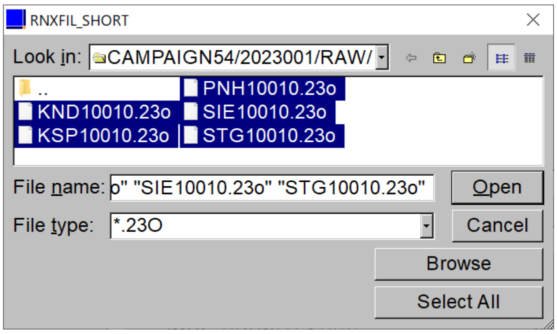
Click [Import RINEX to Bernese format>Observation files] to display the submenu.

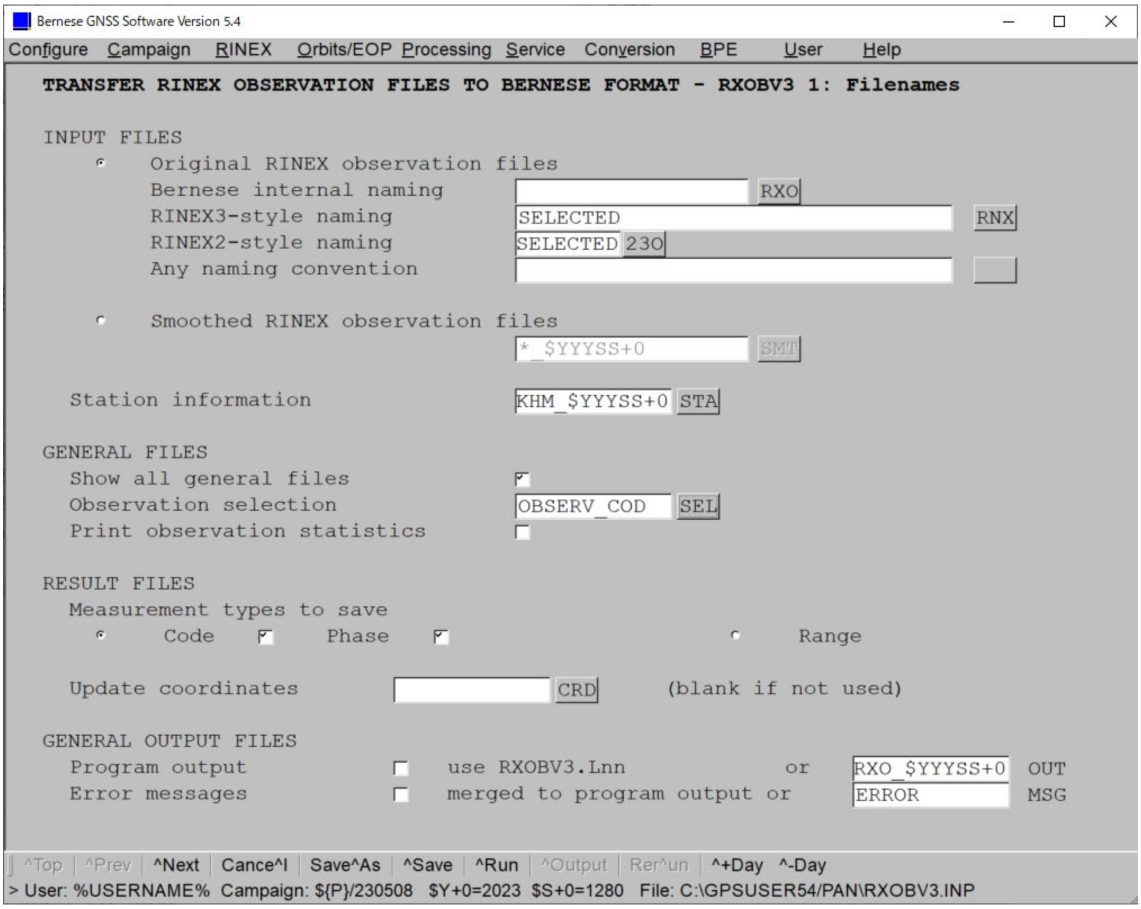


Select all of RINEX files.

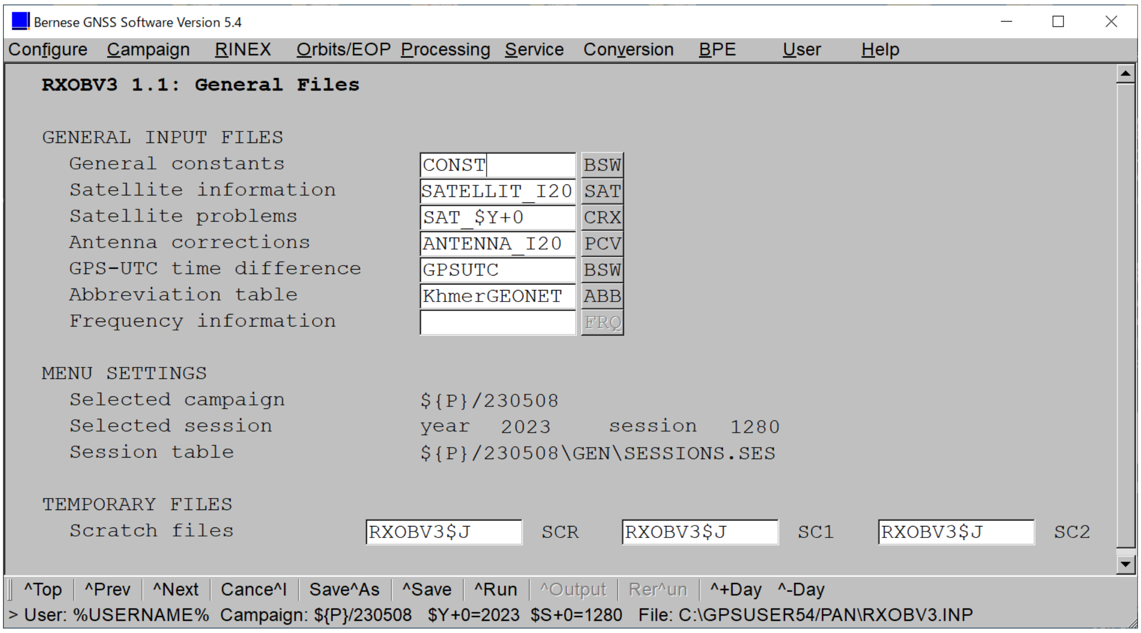
Click [^Next].



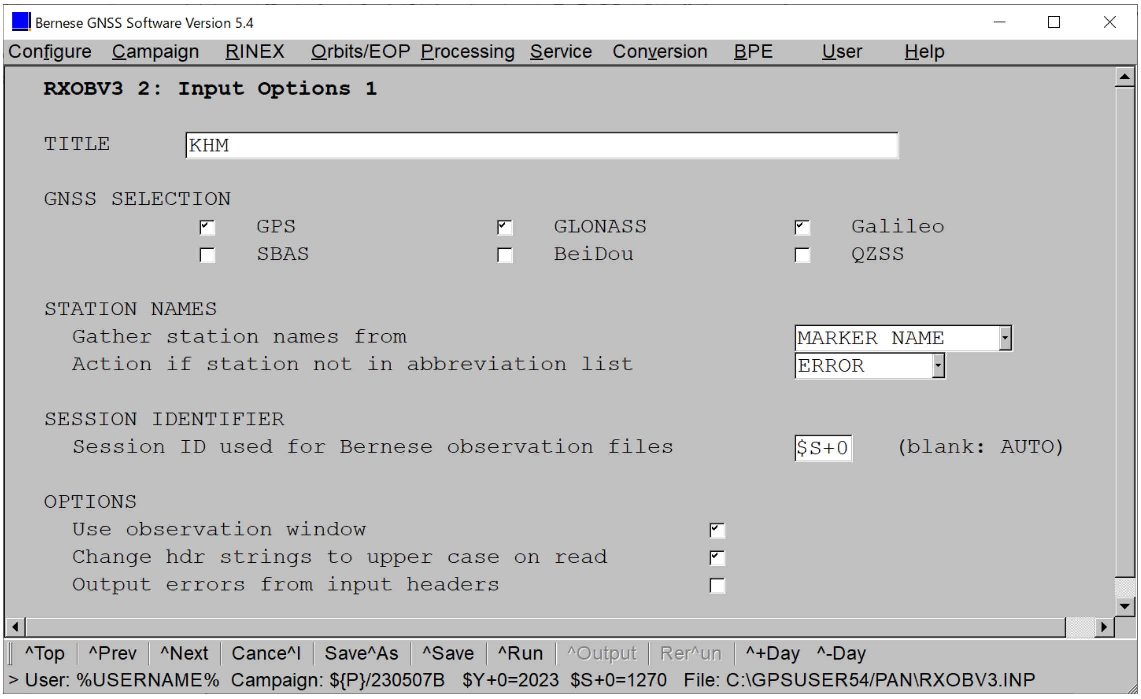




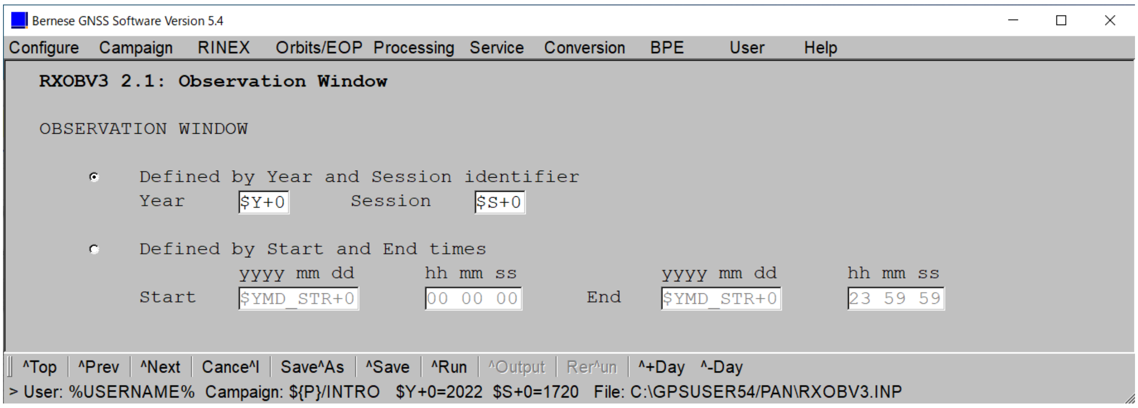
Click [^Next].



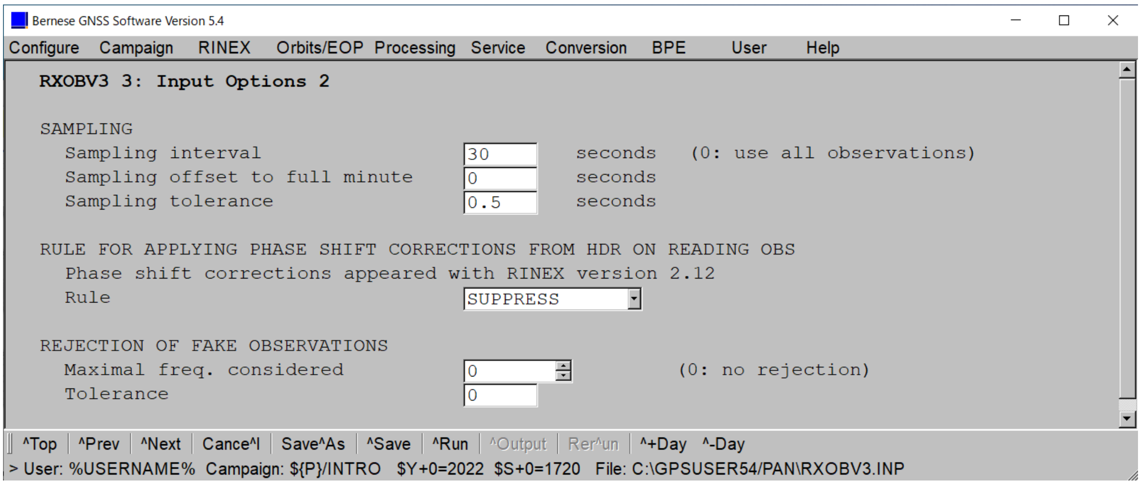
Click [^Next].



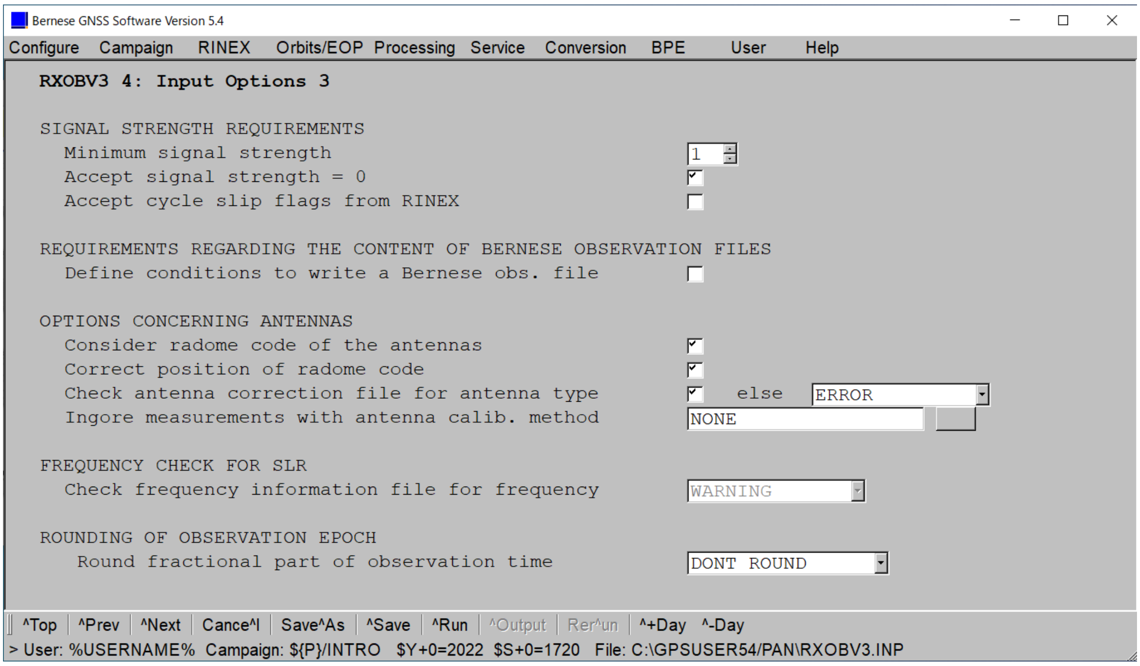
Click [^Next].



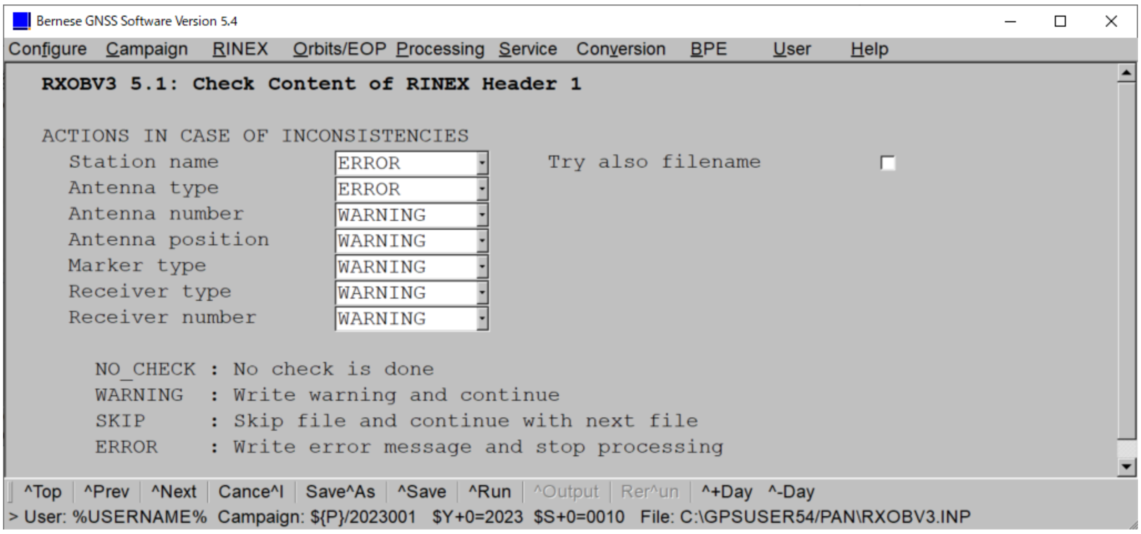
Click [^Next].



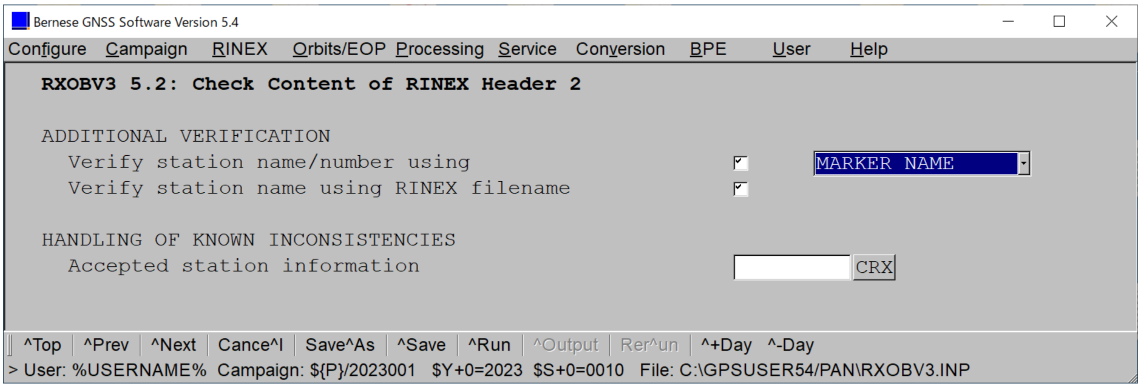
Click [^Next].



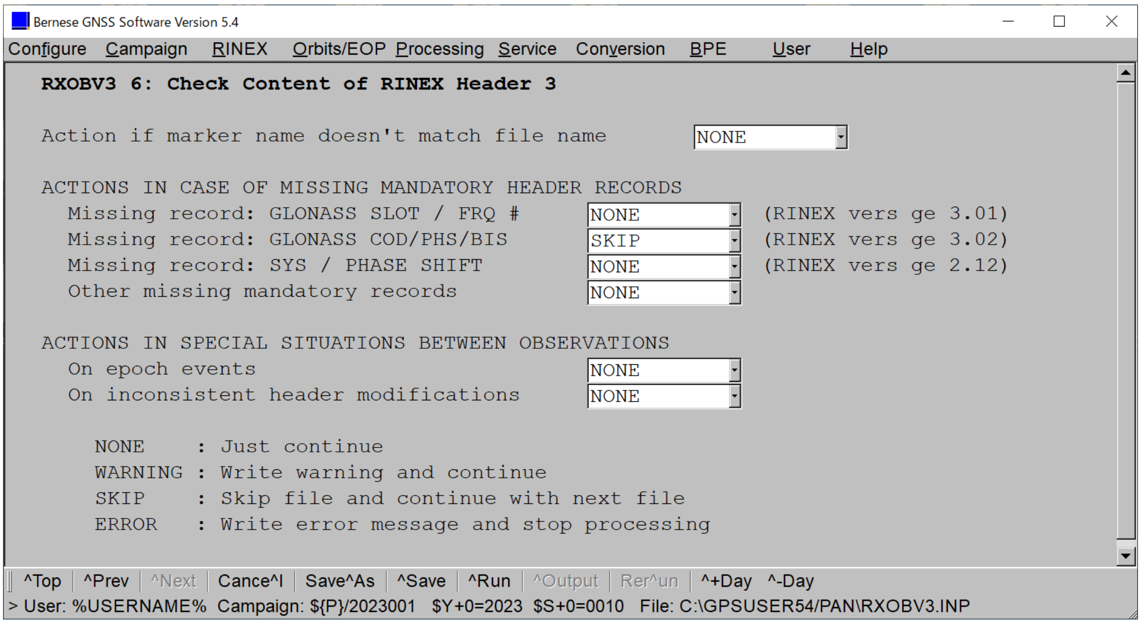
Click [^Next].



Click [^Next].



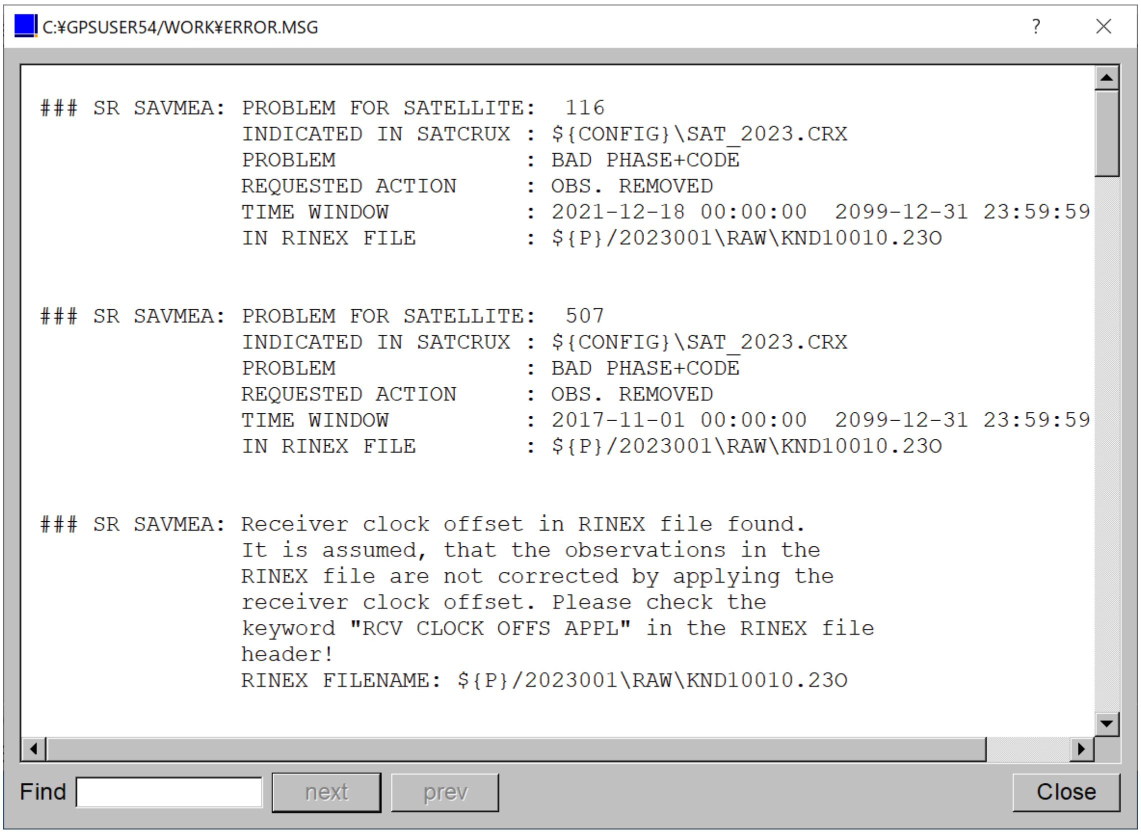
Click [^Run].



Click [^Output].

Check the results.

Satellite problem and receiver clock offset warnings are displayed. You can safely ignore this warning.


C:¥GPSUSER54/WORK¥ERROR.MSG

```
### SR SAVMEA: PROBLEM FOR SATELLITE:  116
              INDICATED IN SATCRUX : ${CONFIG}\SAT_2023.CRX
              PROBLEM              : BAD PHASE+CODE
              REQUESTED ACTION     : OBS. REMOVED
              TIME WINDOW          : 2021-12-18 00:00:00  2099-12-31 23:59:59
              IN RINEX FILE        : ${P}/2023001\RAW\KND10010.23O


### SR SAVMEA: PROBLEM FOR SATELLITE:  507
              INDICATED IN SATCRUX : ${CONFIG}\SAT_2023.CRX
              PROBLEM              : BAD PHASE+CODE
              REQUESTED ACTION     : OBS. REMOVED
              TIME WINDOW          : 2017-11-01 00:00:00  2099-12-31 23:59:59
              IN RINEX FILE        : ${P}/2023001\RAW\KND10010.23O


### SR SAVMEA: Receiver clock offset in RINEX file found.
              It is assumed, that the observations in the
              RINEX file are not corrected by applying the
              receiver clock offset. Please check the
              keyword "RCV CLOCK OFFS APPL" in the RINEX file
              header!
              RINEX FILENAME: ${P}/2023001\RAW\KND10010.23O
```

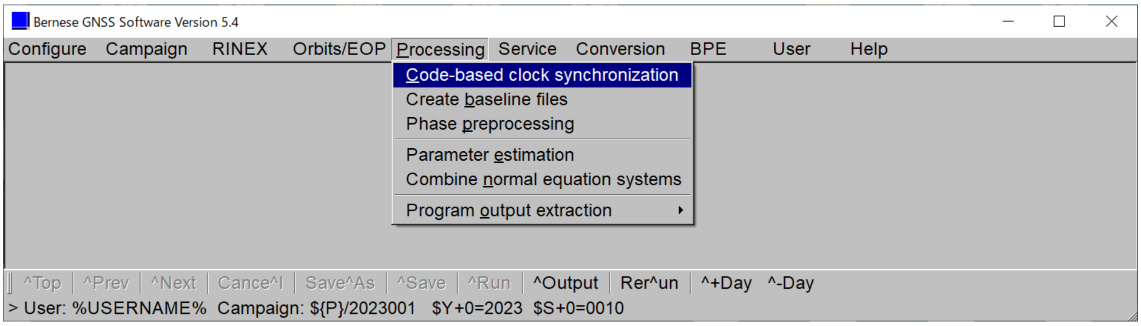
${P}/2023001¥OUT¥RXOBV3.L01

```
  3  ${P}/2023001\RAW\PNH10010.23O         ${P}/2023001\OBS\00090010.CZH    2880    75206   749
                                           ${P}/2023001\OBS\00090010.CZO
                                           ${P}/2023001\OBS\00090010.PZH    2880    75206   749
                                           ${P}/2023001\OBS\00090010.PZO

  4  ${P}/2023001\RAW\SIE10010.23O         ${P}/2023001\OBS\00100010.CZH    2879    66353   658
                                           ${P}/2023001\OBS\00100010.CZO
                                           ${P}/2023001\OBS\00100010.PZH    2879    66353   658
                                           ${P}/2023001\OBS\00100010.PZO

  5  ${P}/2023001\RAW\STG10010.23O         ${P}/2023001\OBS\00110010.CZH    2880    76122   758
                                           ${P}/2023001\OBS\00110010.CZO
                                           ${P}/2023001\OBS\00110010.PZH    2880    76122   757
                                           ${P}/2023001\OBS\00110010.PZO

  8  ${P}/2023001\RAW\CUSV0010.RNX         ${P}/2023001\OBS\00030010.CZH    2880    73795   737
                                           ${P}/2023001\OBS\00030010.CZO
                                           ${P}/2023001\OBS\00030010.PZH    2880    73795   737
                                           ${P}/2023001\OBS\00030010.PZO

  9  ${P}/2023001\RAW\HKSL0010.RNX         ${P}/2023001\OBS\00040010.CZH    2880    70770   703
                                           ${P}/2023001\OBS\00040010.CZO
                                           ${P}/2023001\OBS\00040010.PZH    2880    70559   701
                                           ${P}/2023001\OBS\00040010.PZO

 10  ${P}/2023001\RAW\PTAG0010.RNX         ${P}/2023001\OBS\00050010.CZH    2880    80361   795
                                           ${P}/2023001\OBS\00050010.CZO
                                           ${P}/2023001\OBS\00050010.PZH    2880    80051   793
                                           ${P}/2023001\OBS\00050010.PZO

 11  ${P}/2023001\RAW\SIN10010.RNX         ${P}/2023001\OBS\00060010.CZH    2874    89565   884
                                           ${P}/2023001\OBS\00060010.CZO
                                           ${P}/2023001\OBS\00060010.PZH    2874    87210   862
                                           ${P}/2023001\OBS\00060010.PZO


 RINEX files not converted to BERNESE observation format:
 -------------------------------------------------------
 Num  Rinex file name                  Reason
 -------------------------------------------------------------------------------------------


-----------------------------------------------------------------
>>> CPU/Real time for pgm "RXOBV3": 0:00:40.766 / 0:00:41.128
>>> Program finished successfully
```

Find next prev Close

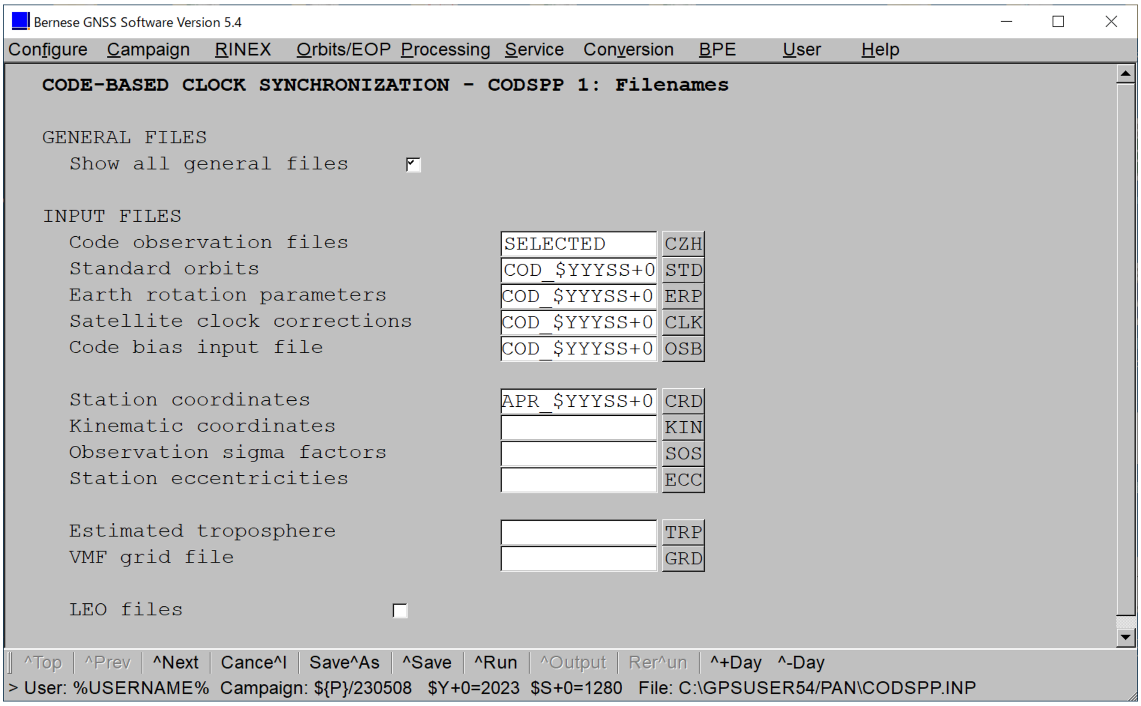
9.4. Receiver clock synchronization (CODSPP)

Click [Code-based clock synchronization] to display the submenu.

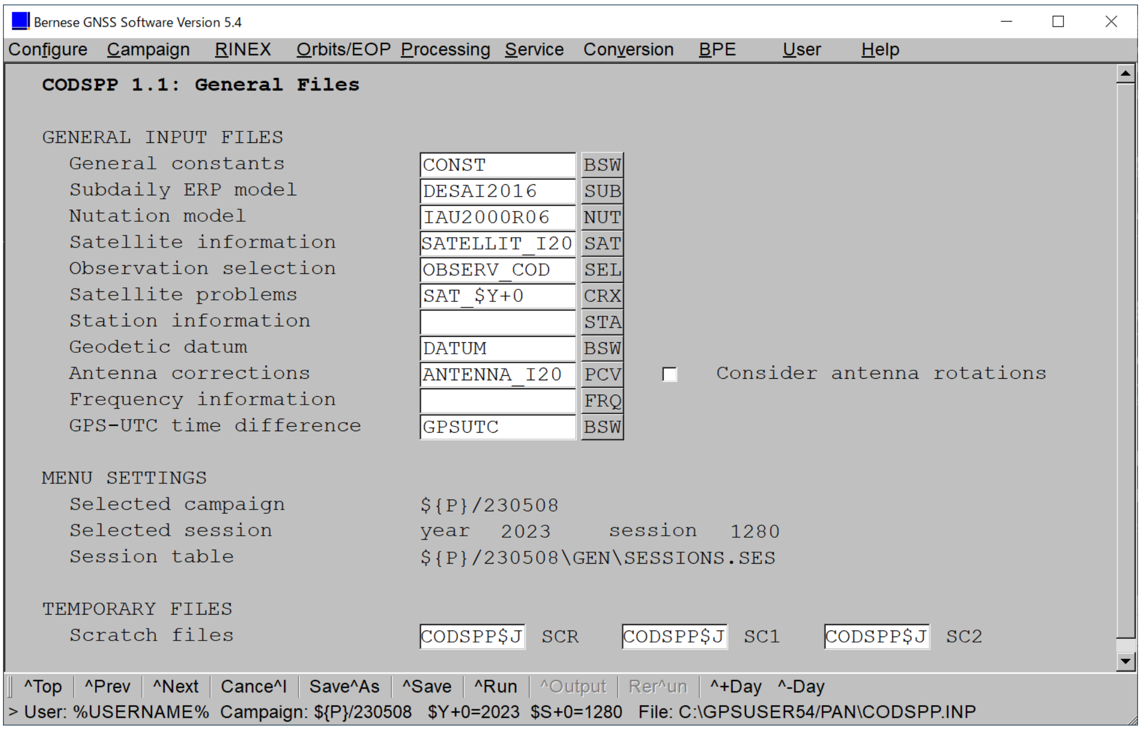


Select Standard orbits, Satellite clocks, Code observation files, A priori coordinates, Pole file and Code bias input files.

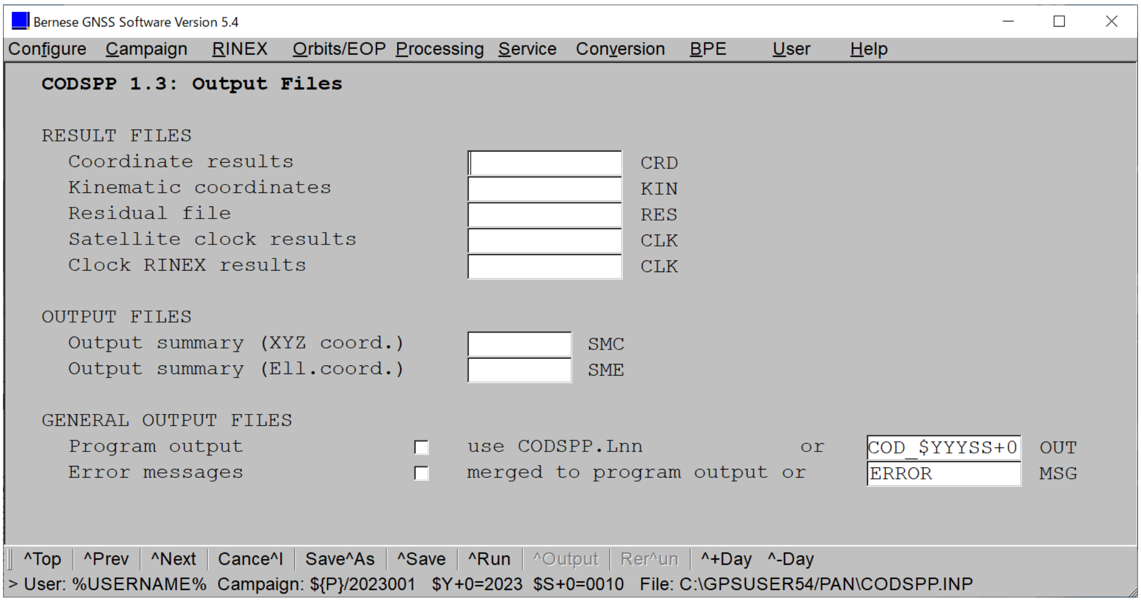
Click [^Next].



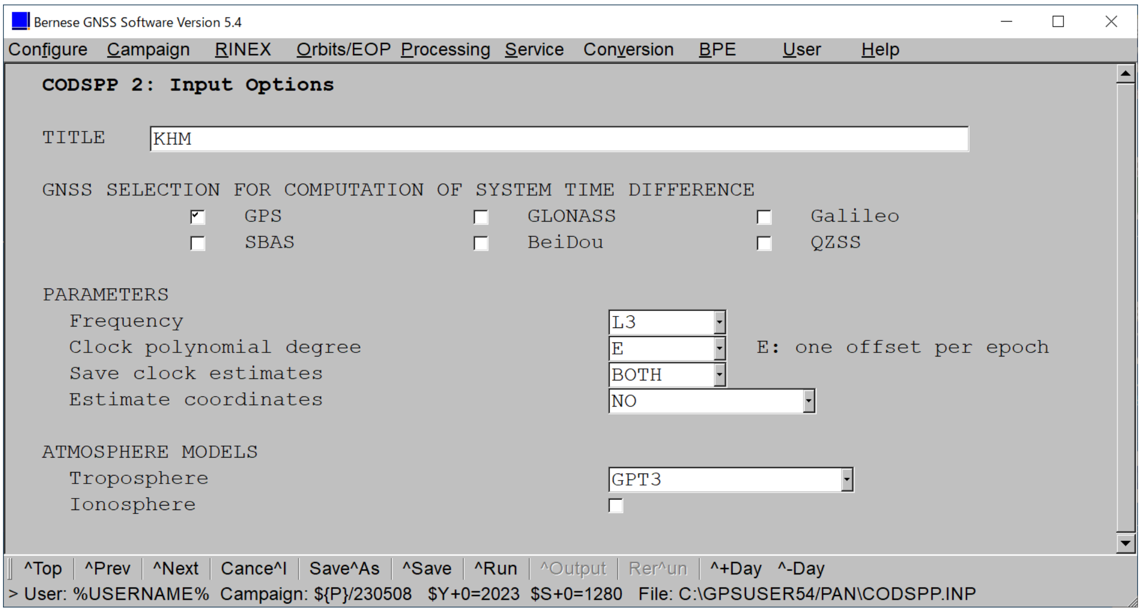
Click [^Next].



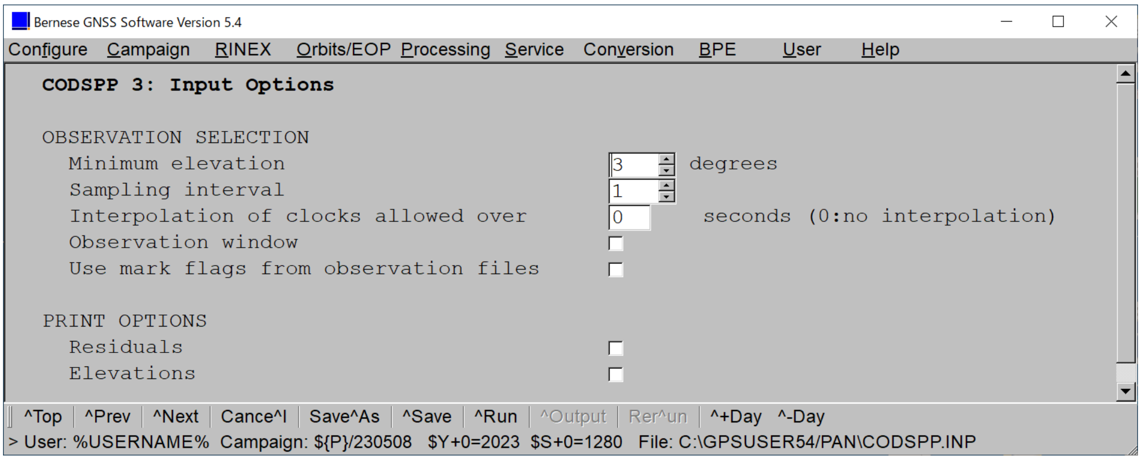
Click [^Next].



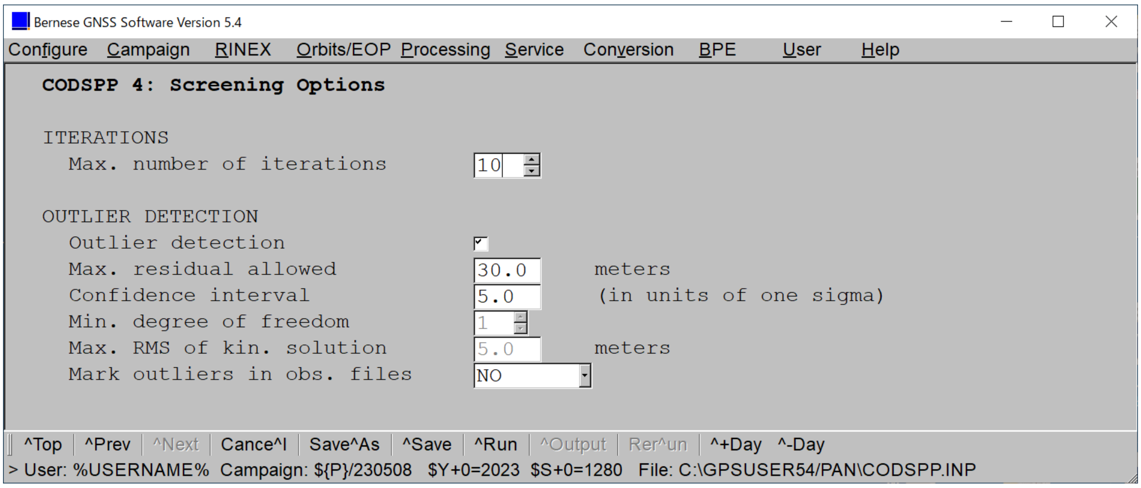
Click [^Next].



Click [^Next].

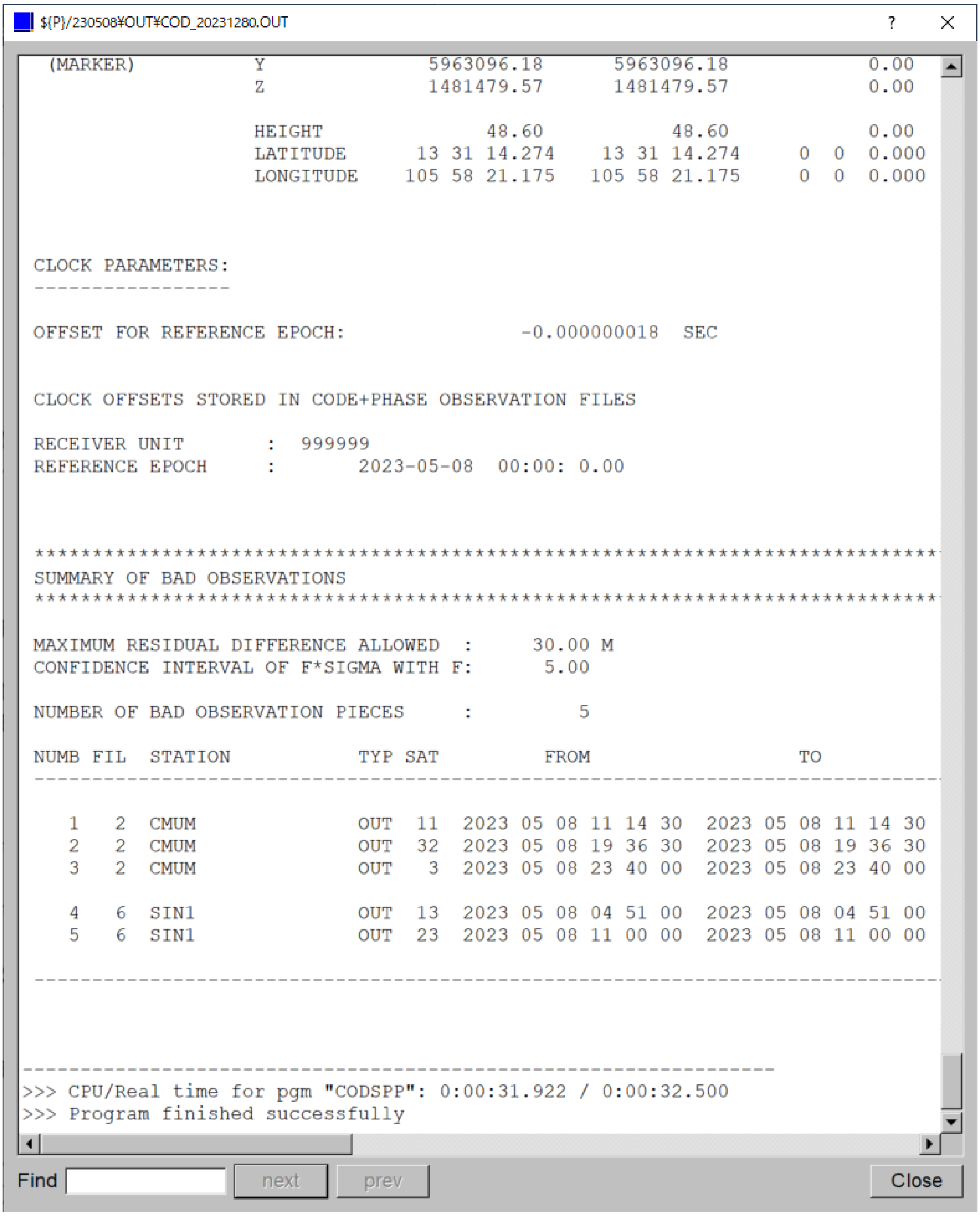


Click [^Run].


Bernese GNSS Software Version 5.4
Configure Campaign RINEX Orbits/EOP Processing Service Conversion BPE User Help
CODSPP 4: Screening Options
ITERATIONS
Max. number of iterations 10
OUTLIER DETECTION
Outlier detection
Max. residual allowed 30.0 meters
Confidence interval 5.0 (in units of one sigma)
Min. degree of freedom 1
Max. RMS of kin. solution 5.0 meters
Mark outliers in obs. files NO
^Top ^Prev ^Next Cance^l Save^As ^Save ^Run ^Output Rer^un ^+Day ^-Day
> User: %USERNAME% Campaign: ${P}/230508 $Y+0=2023 $S+0=1280 File: C:\GPSUSER54/PAN\CODSPP.INP

Click [^Output].

Check the results.



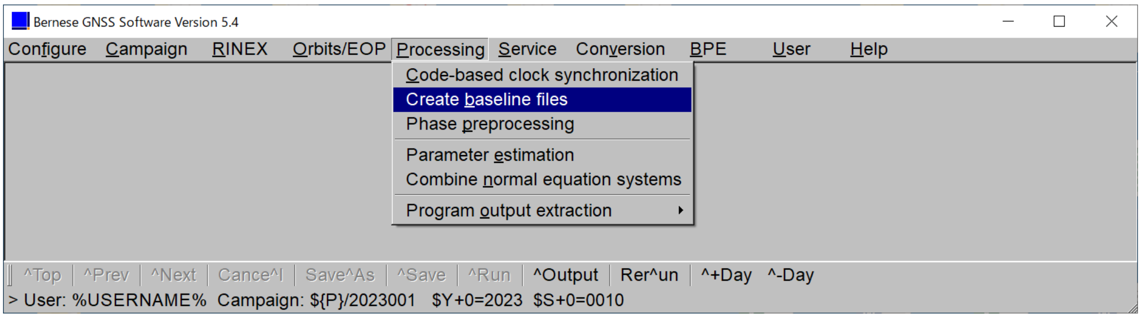
$(P)/230508¥OUT¥COD_20231280.OUT

```
  (MARKER)             Y             5963096.18      5963096.18                0.00
                       Z             1481479.57      1481479.57                0.00

                       HEIGHT             48.60           48.60                0.00
                       LATITUDE      13 31 14.274    13 31 14.274     0   0    0.000
                       LONGITUDE    105 58 21.175   105 58 21.175     0   0    0.000



 CLOCK PARAMETERS:
 -----------------

 OFFSET FOR REFERENCE EPOCH:                     -0.000000018   SEC


 CLOCK OFFSETS STORED IN CODE+PHASE OBSERVATION FILES

 RECEIVER UNIT          :  999999
 REFERENCE EPOCH        :       2023-05-08  00:00: 0.00



 ******************************************************************************
 SUMMARY OF BAD OBSERVATIONS
 ******************************************************************************

 MAXIMUM RESIDUAL DIFFERENCE ALLOWED  :      30.00 M
 CONFIDENCE INTERVAL OF F*SIGMA WITH F:       5.00

 NUMBER OF BAD OBSERVATION PIECES      :          5

 NUMB FIL  STATION            TYP SAT          FROM                    TO
 ------------------------------------------------------------------------------

    1   2  CMUM               OUT  11  2023 05 08 11 14 30  2023 05 08 11 14 30
    2   2  CMUM               OUT  32  2023 05 08 19 36 30  2023 05 08 19 36 30
    3   2  CMUM               OUT   3  2023 05 08 23 40 00  2023 05 08 23 40 00

    4   6  SIN1               OUT  13  2023 05 08 04 51 00  2023 05 08 04 51 00
    5   6  SIN1               OUT  23  2023 05 08 11 00 00  2023 05 08 11 00 00

 ------------------------------------------------------------------------------



-----------------------------------------------------------------
>>> CPU/Real time for pgm "CODSPP": 0:00:31.922 / 0:00:32.500
>>> Program finished successfully
```

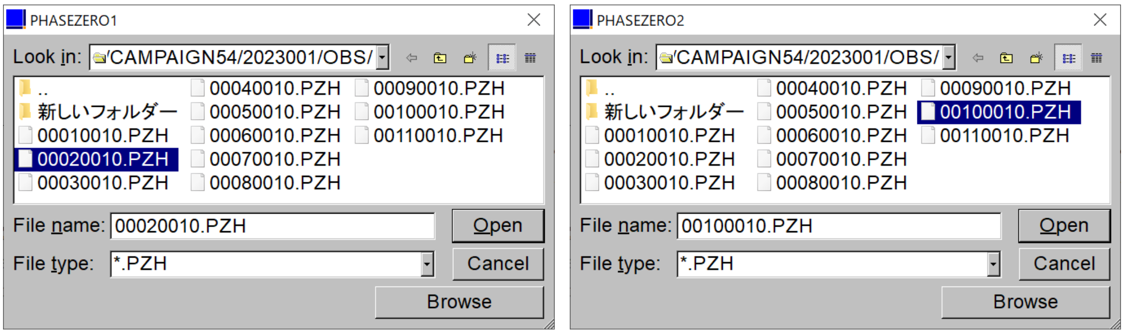
9.5. Single difference (SNGDIF)

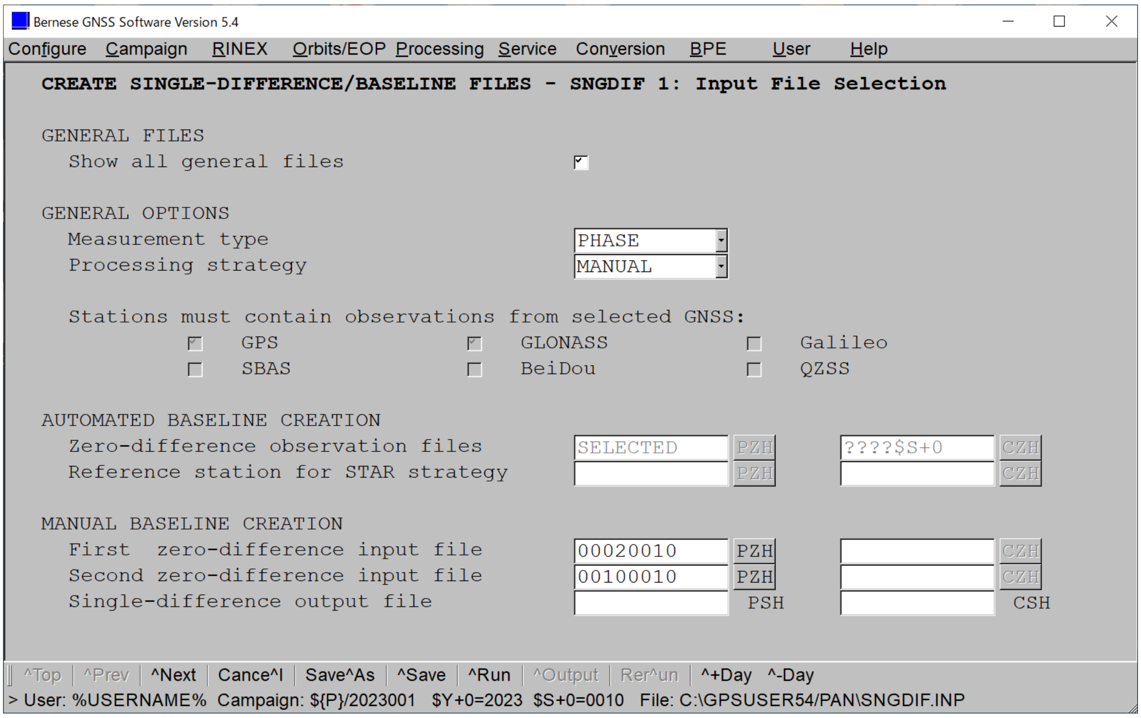
Calculate for each baseline.

Click [Create baseline files] to display the submenu.



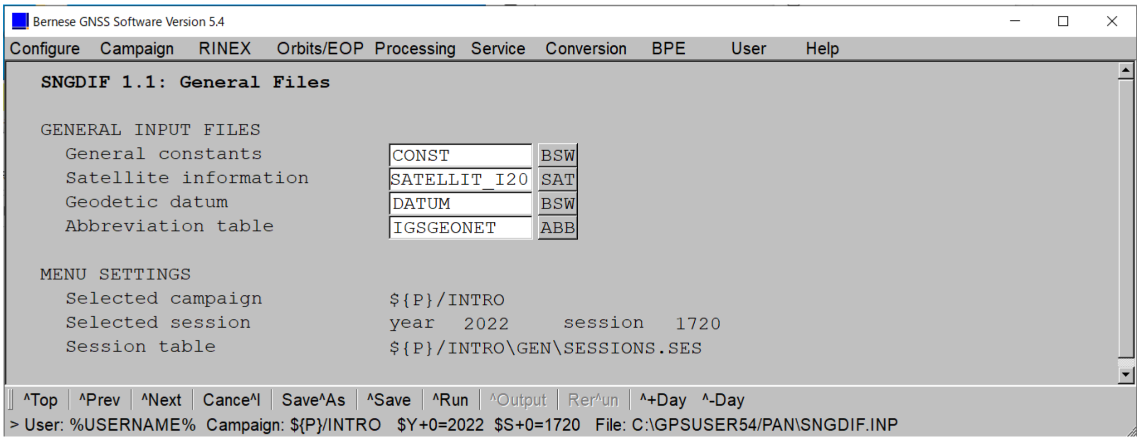
Click [^Next].



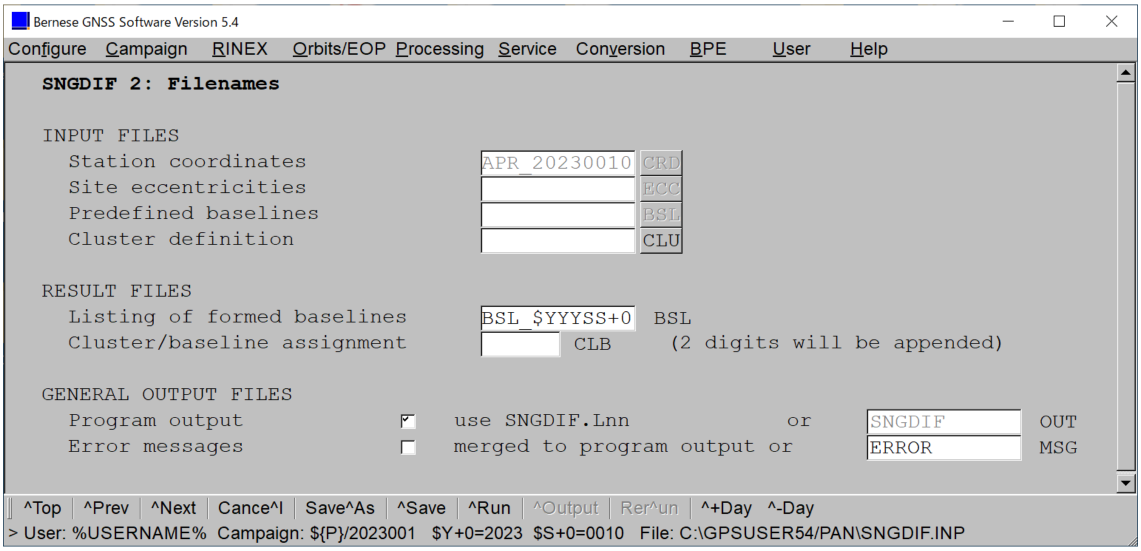


Select Abbreviation table.

Click [^Next].

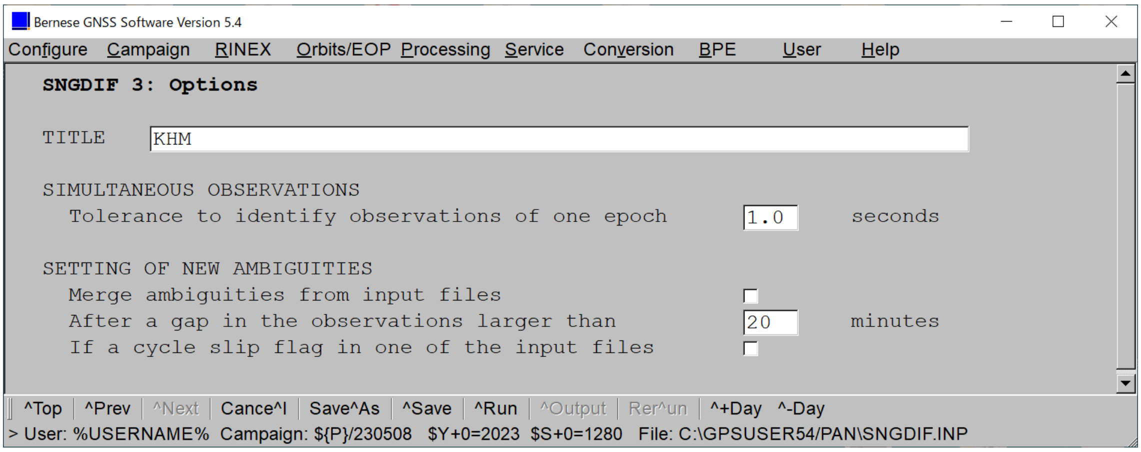


Click [^Next].



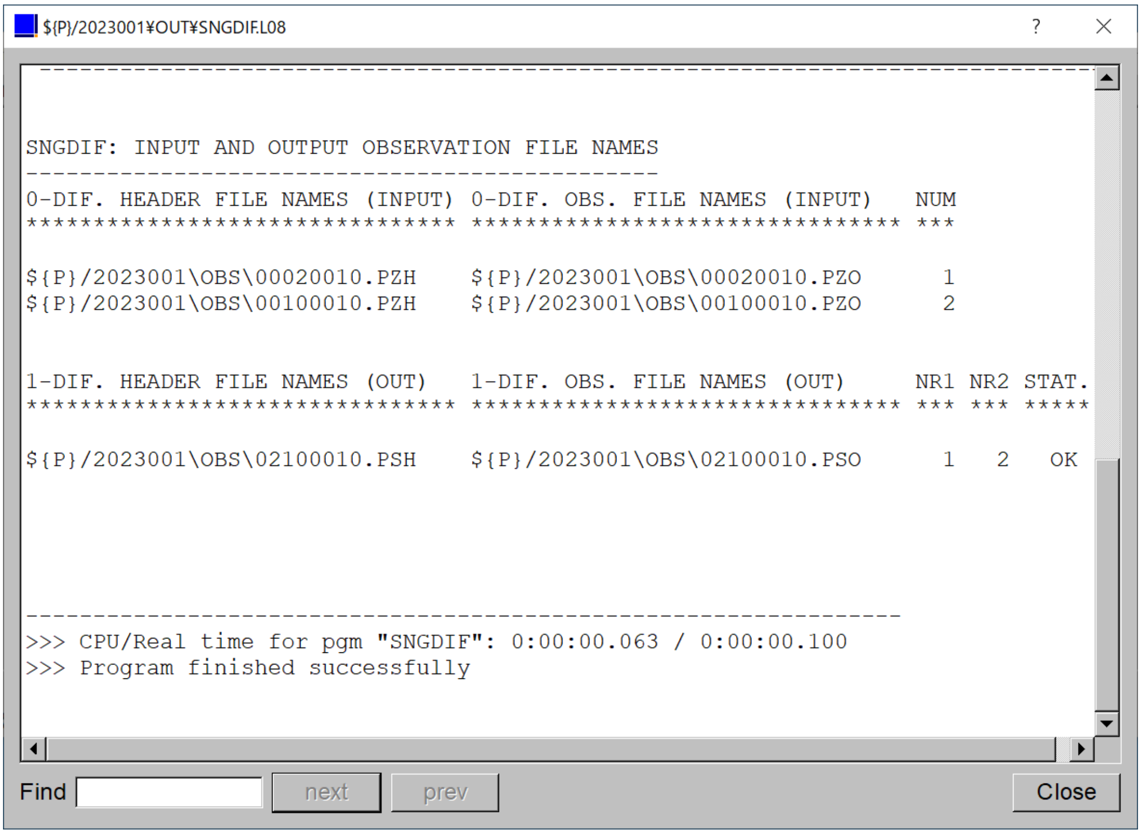
Enter TITLE.

Click [^Run].



Click [^Output].

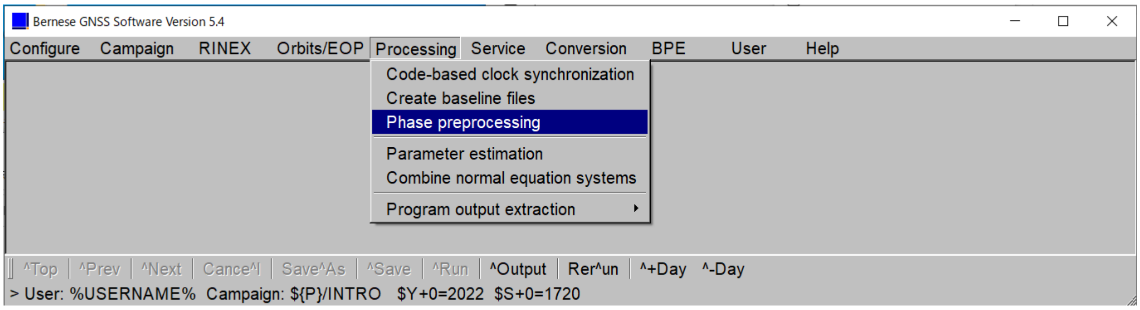
Check the results.



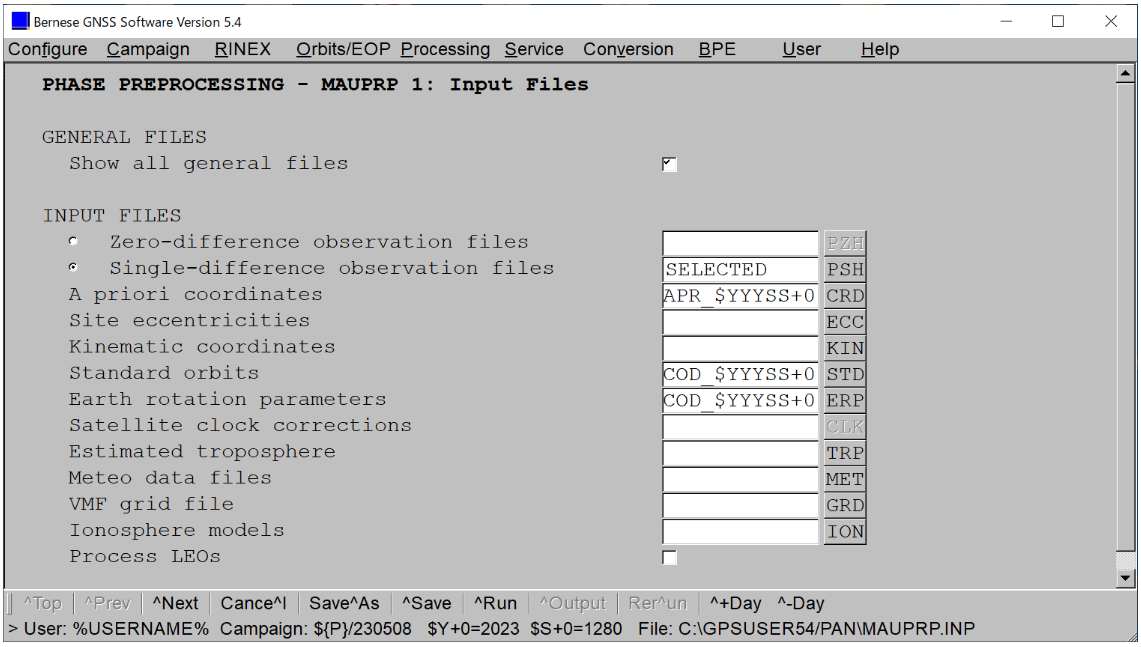
Repeat this calculation to create all required baselines.

9.6. Cycle slip, detection and correction of abnormal values (MAUPRP)

Click [Phase preprocessing] to display the submenu.

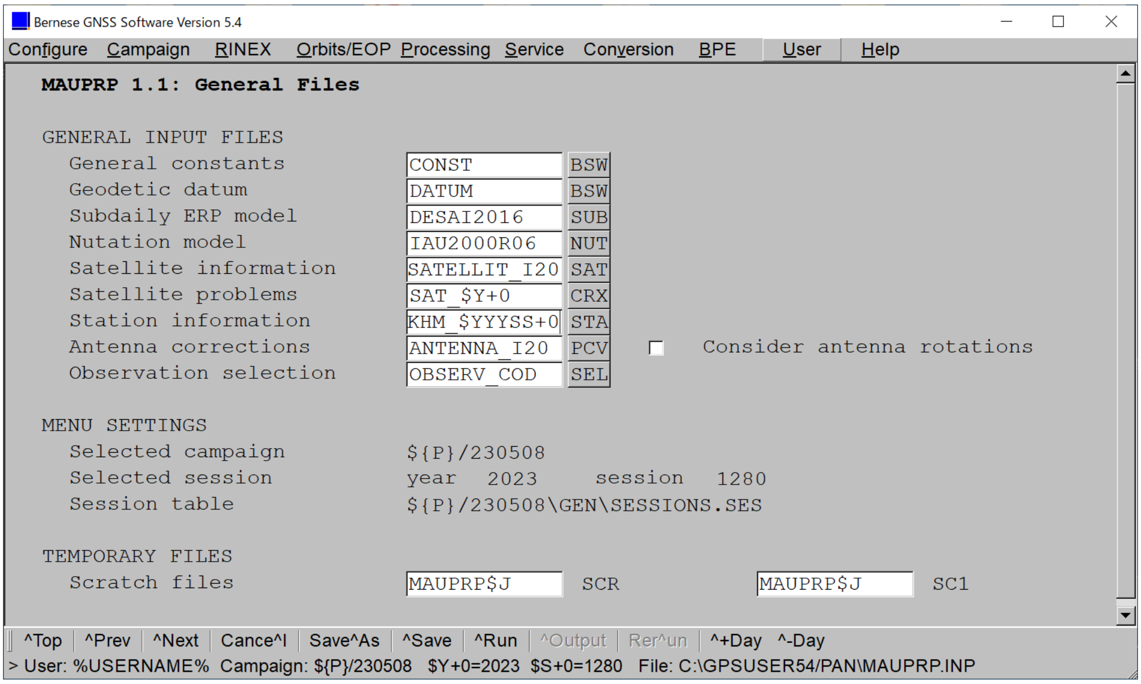


Click [^Next].



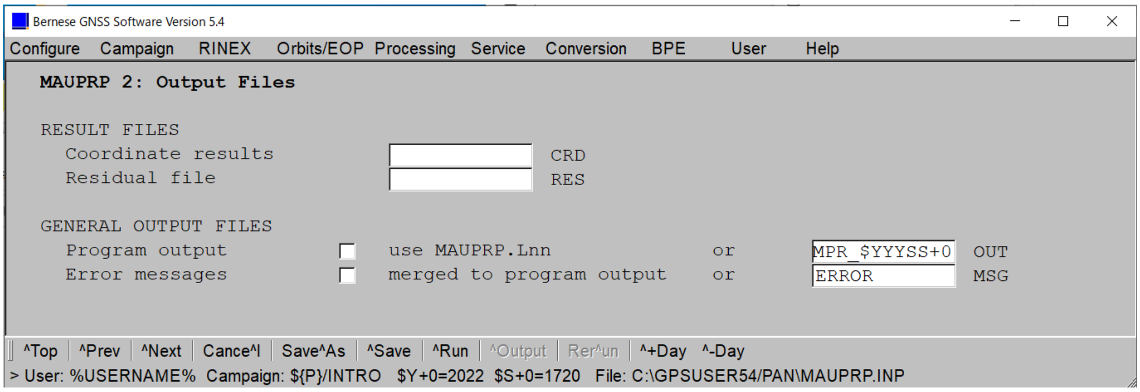
Select and Check GENERAL INPUT FILES.

Click [^Next].

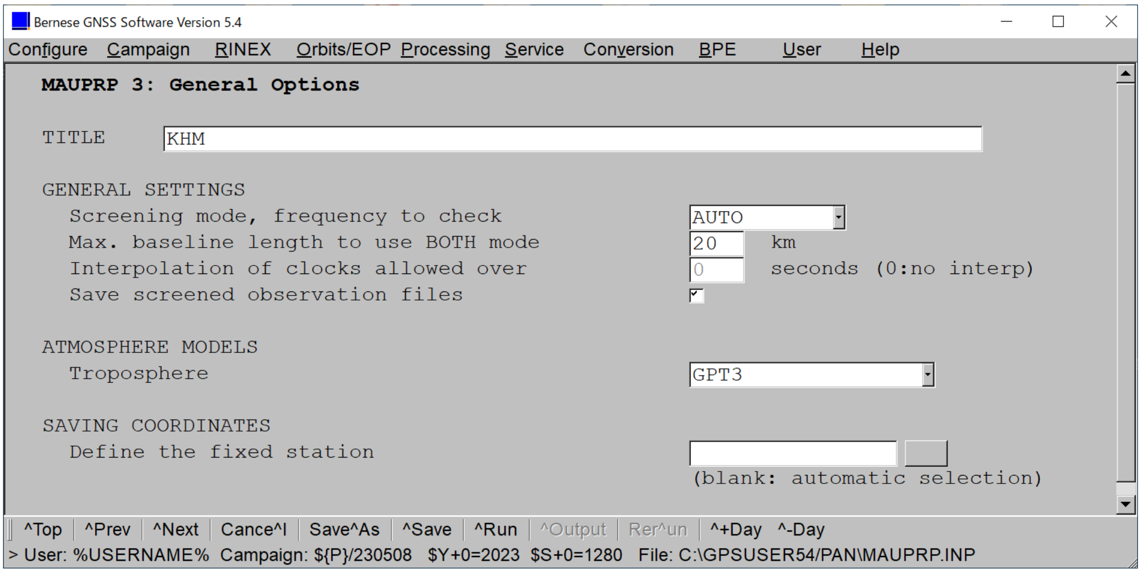


If you want to keep the result, enter RESULT FILES.

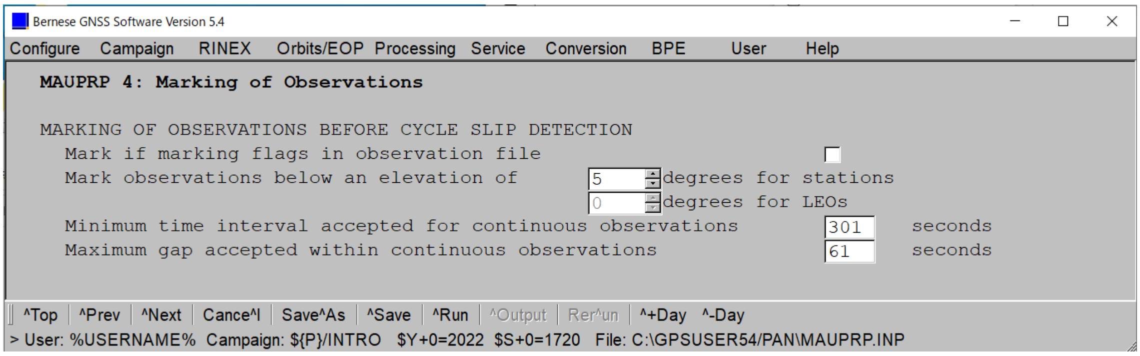
Click [^Next].



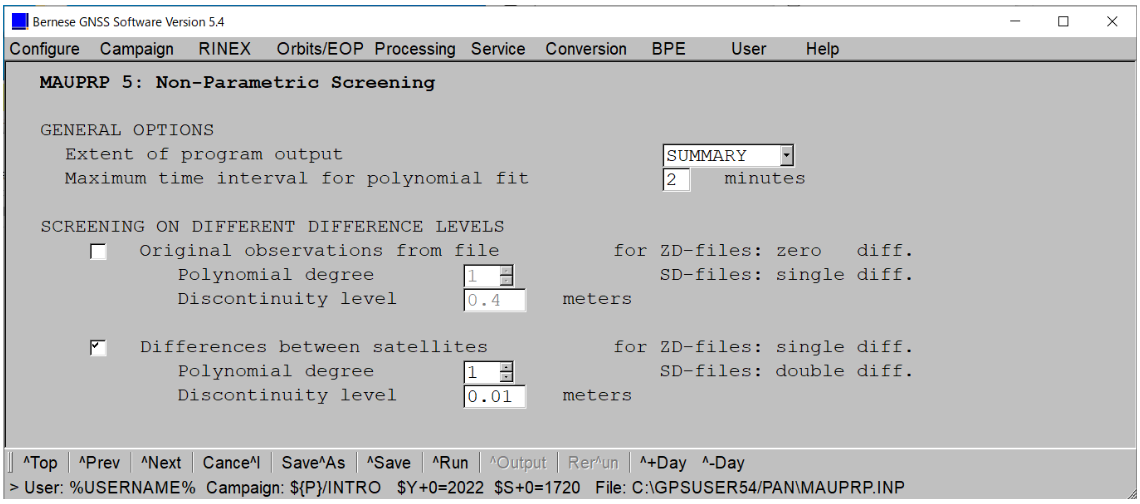
Click [^Next].



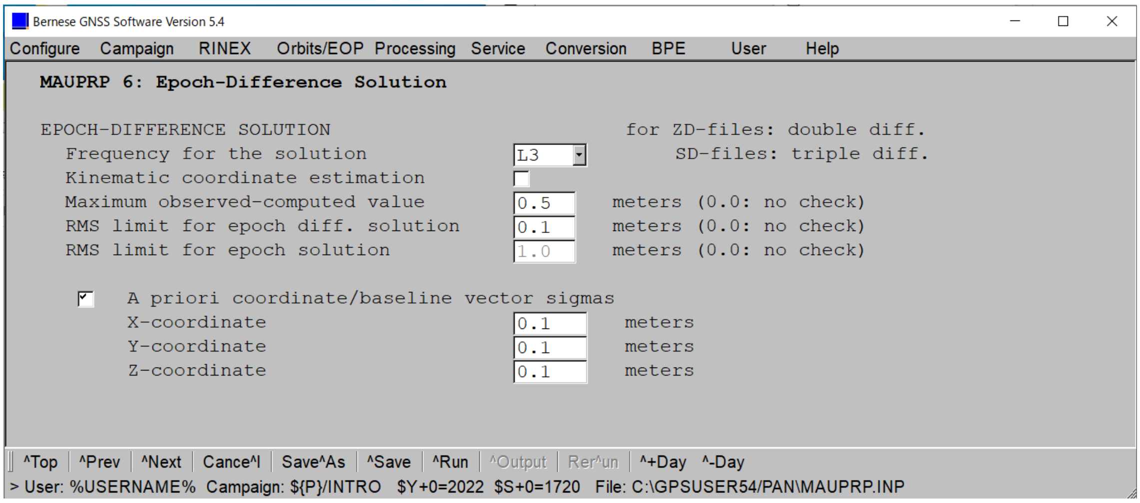
Click [^Next].



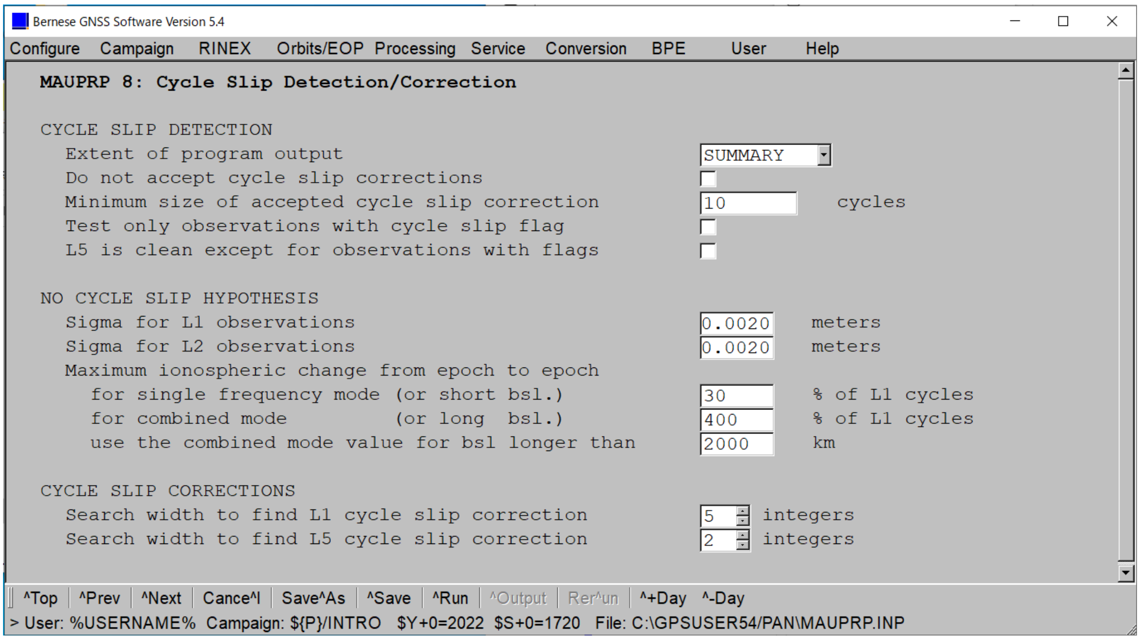
Click [^Next].



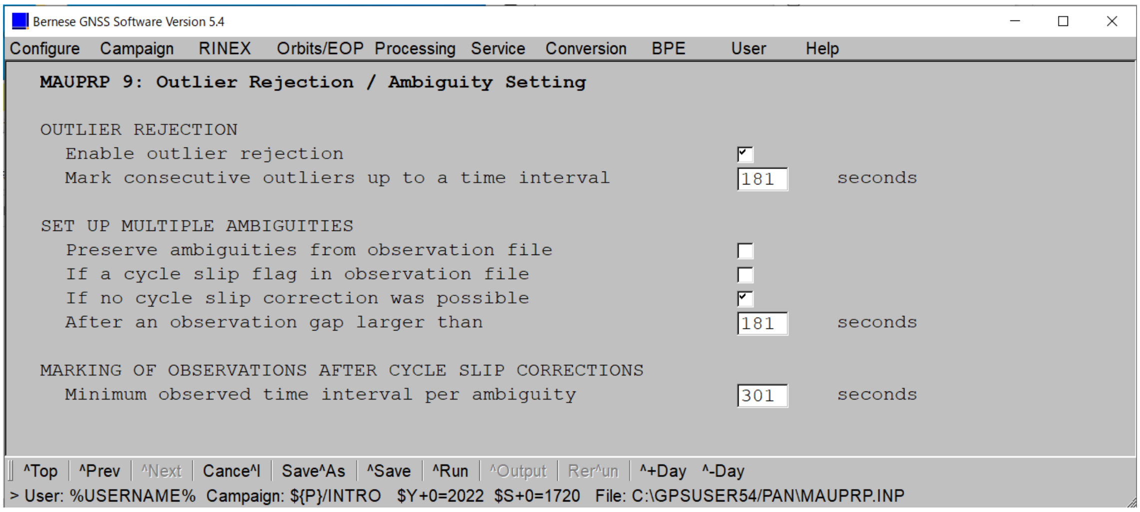
Click [^Next].



Click [^Next].



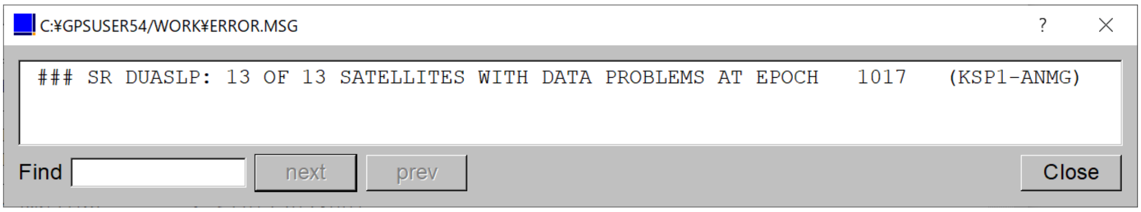
Click [^Run].

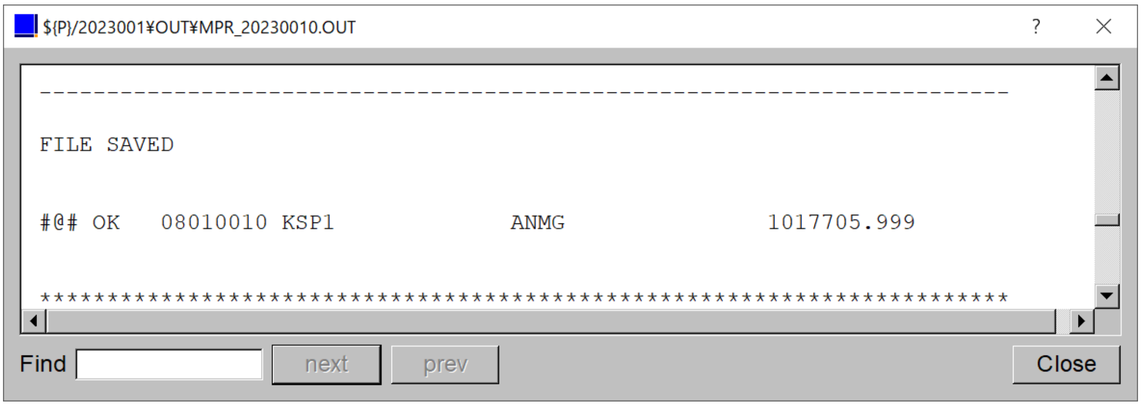


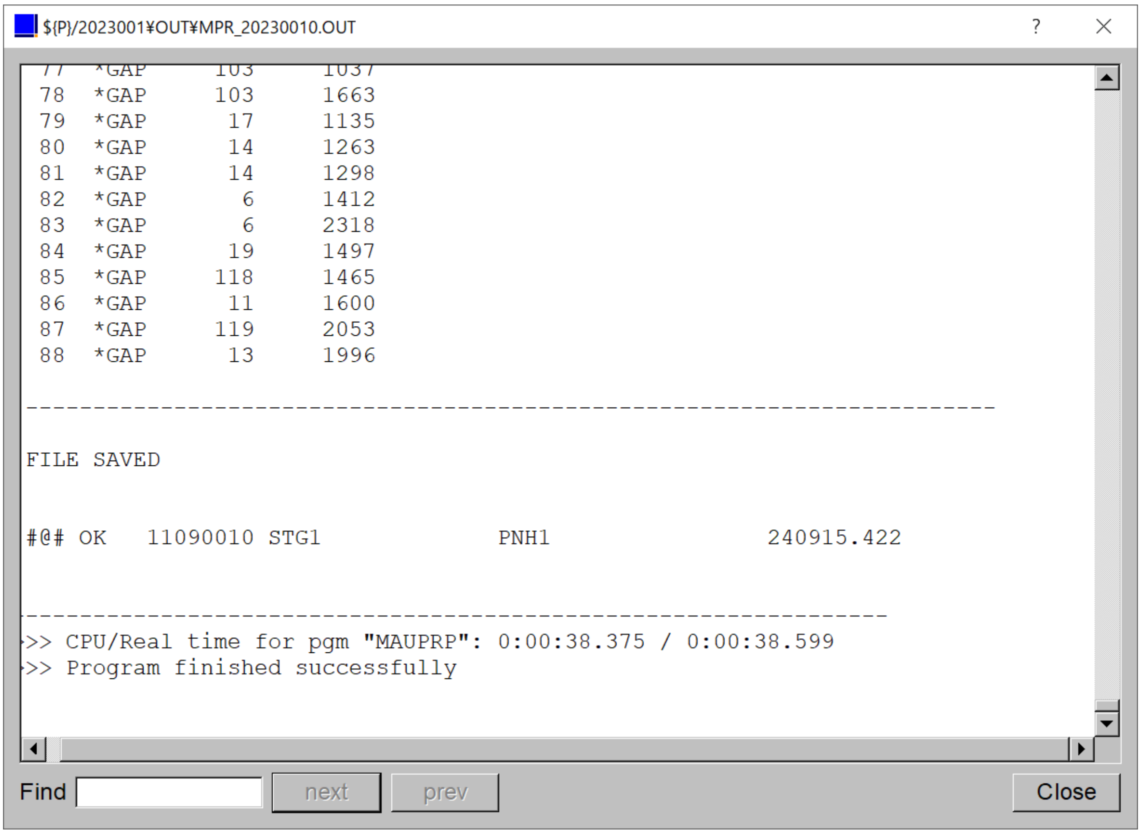
Click [^Output].

Check the results.

Ignore the following warnings.



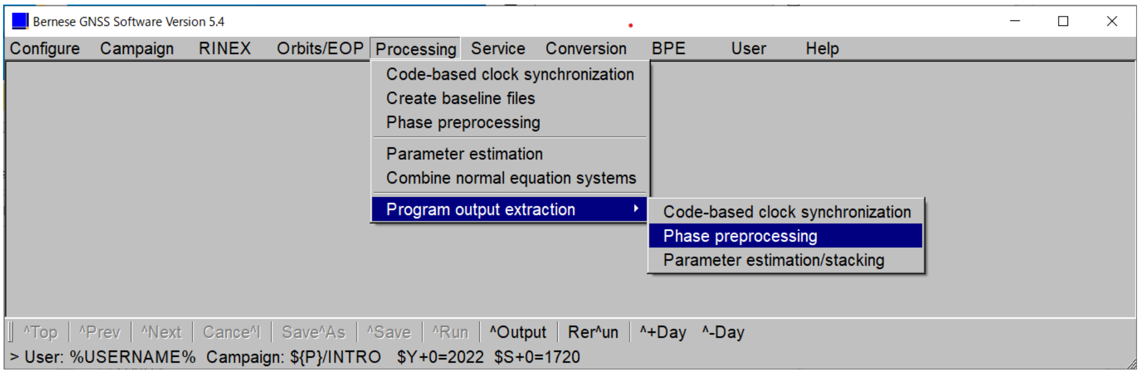




9.7. About Baseline length (MPRXTR)

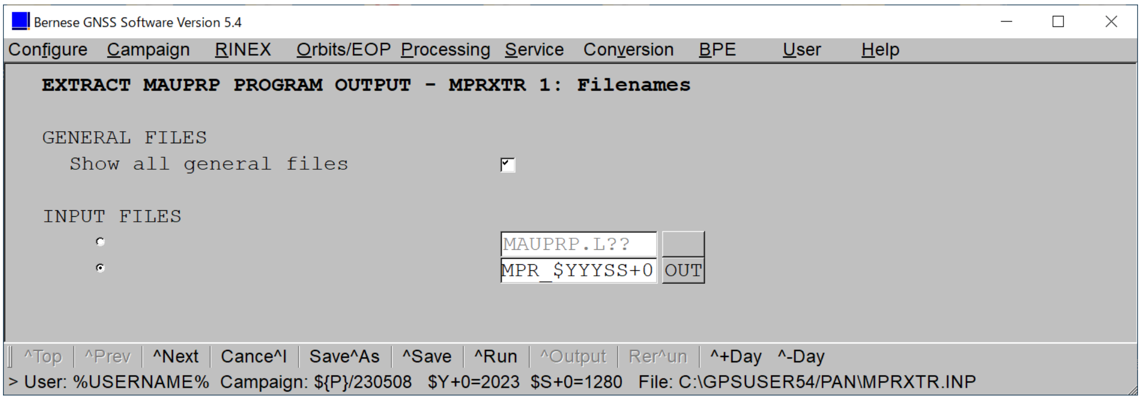
Sort the calculation results by baseline length.

Click [Phase preprocessing] to display the submenu.



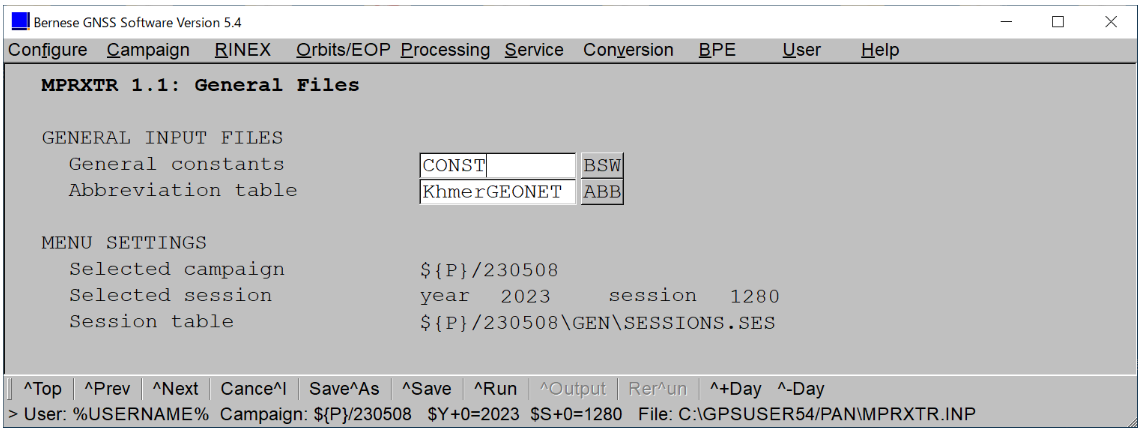
Select INPUT FILERS.

Click [^Next].



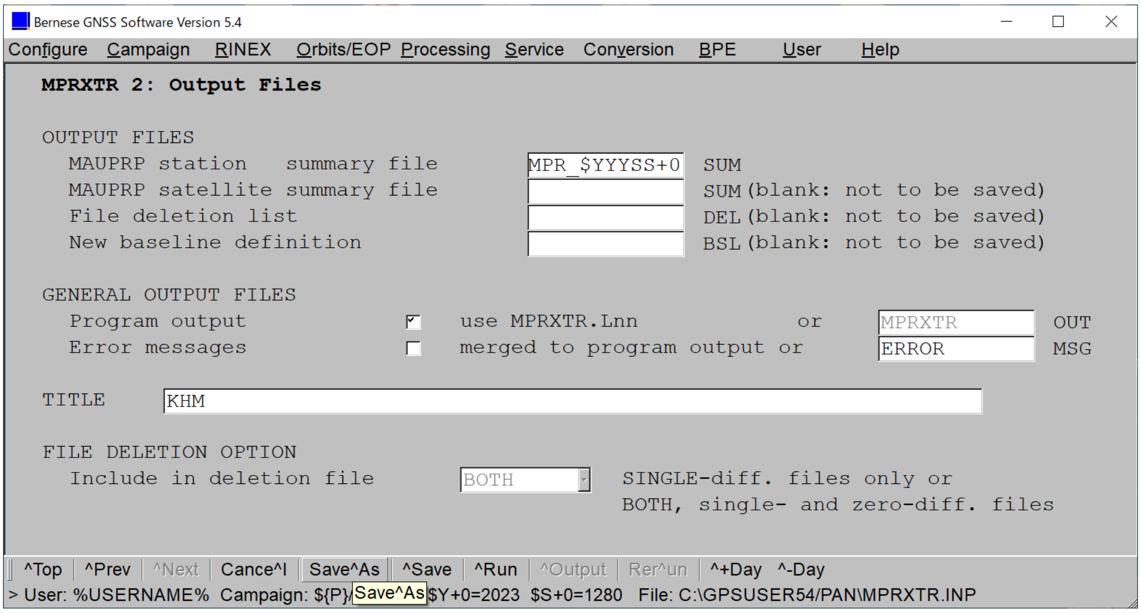
Select GENERAL INPUT FILERS.

Click [^Next].



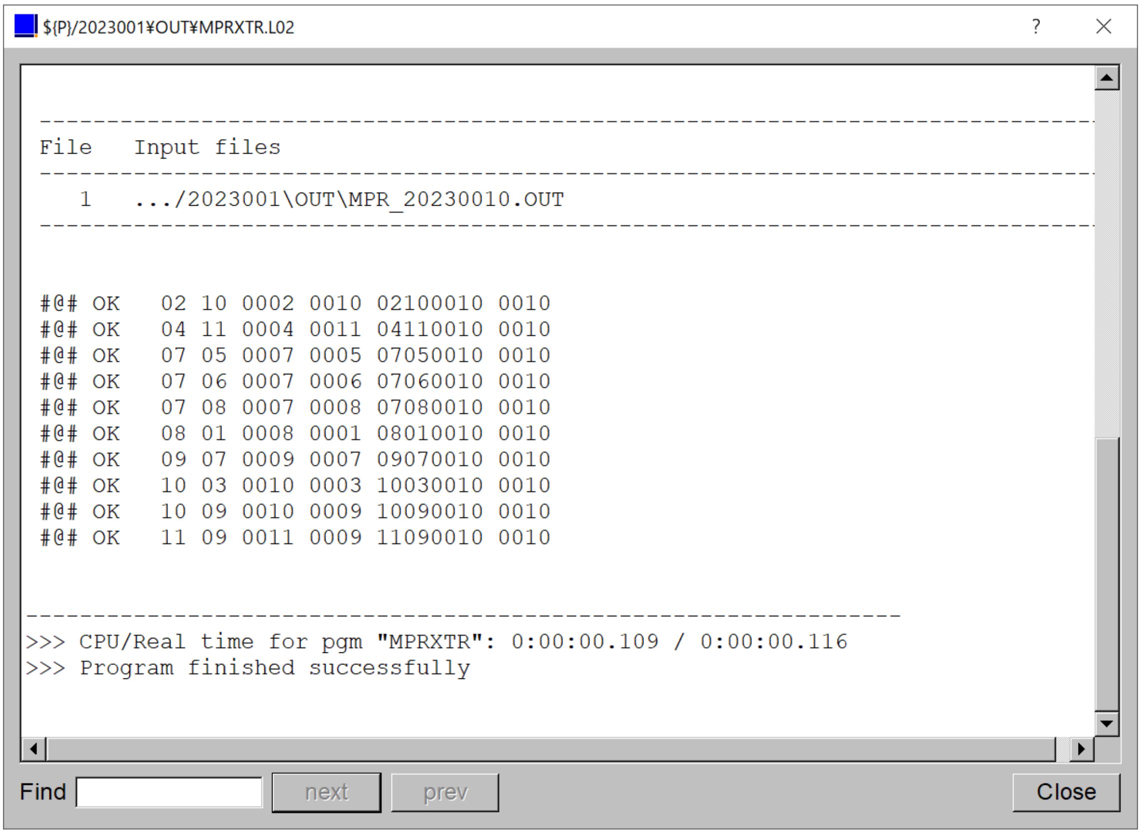
Enter MAUPRP summary file and TITLE.

Click [^Run].

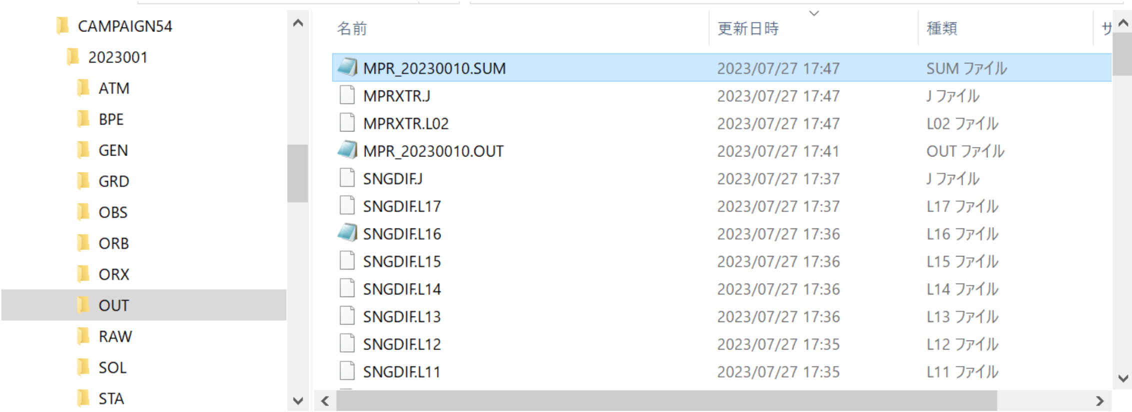


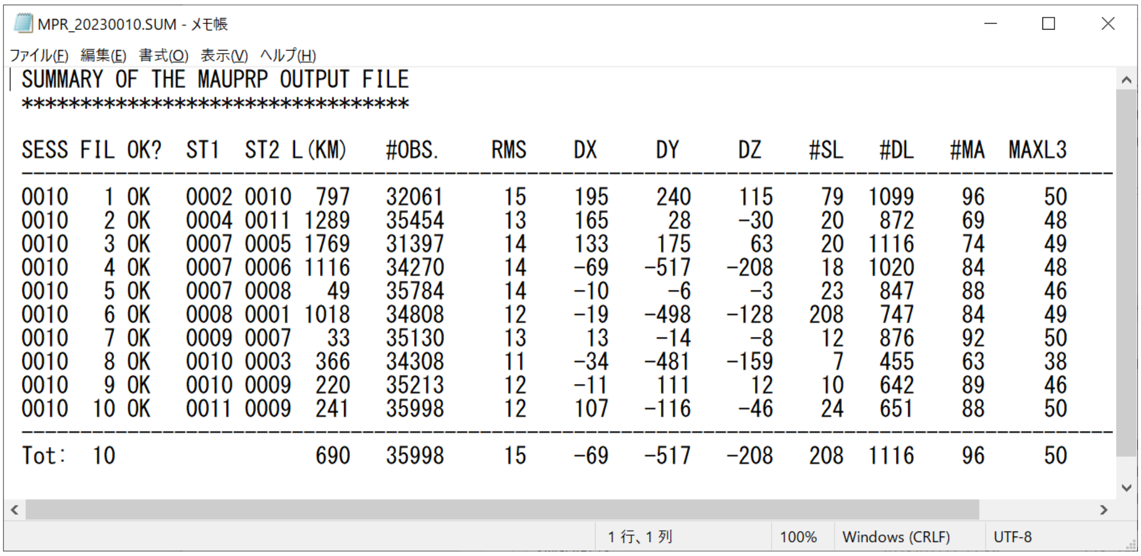
Click [^Output].

Check the results and the output file [ex. MPR_20230010.SUM].



Check the [MPR_20230010.SUM] file.





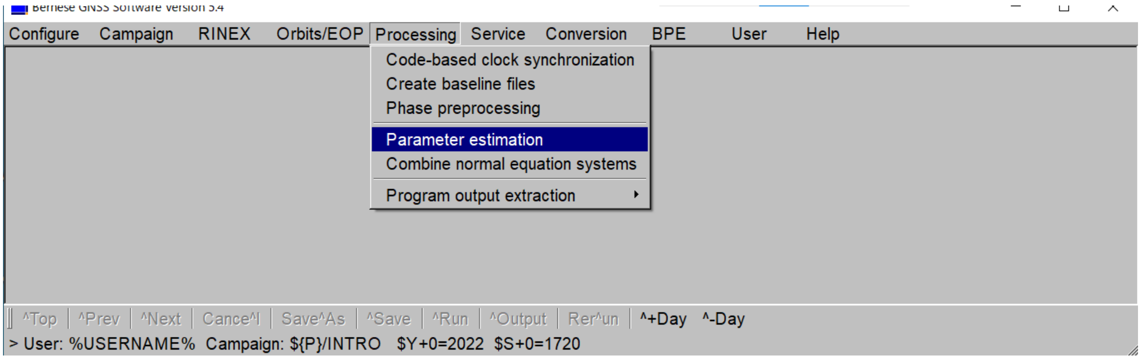

```
SUMMARY OF THE MAUPRP OUTPUT FILE
*********************************

SESS FIL OK? ST1  ST2  L(KM)  #OBS.   RMS   DX    DY    DZ   #SL   #DL   #MA  MAXL3
-------------------------------------------------------------------------------------
0010   1 OK  0002 0010  797   32061   15   195   240   115   79  1099   96    50
0010   2 OK  0004 0011 1289   35454   13   165    28   -30   20   872   69    48
0010   3 OK  0007 0005 1769   31397   14   133   175    63   20  1116   74    49
0010   4 OK  0007 0006 1116   34270   14   -69  -517  -208   18  1020   84    48
0010   5 OK  0007 0008   49   35784   14   -10    -6    -3   23   847   88    46
0010   6 OK  0008 0001 1018   34808   12   -19  -498  -128  208   747   84    49
0010   7 OK  0009 0007   33   35130   13    13   -14    -8   12   876   92    50
0010   8 OK  0010 0003  366   34308   11   -34  -481  -159    7   455   63    38
0010   9 OK  0010 0009  220   35213   12   -11   111    12   10   642   89    46
0010  10 OK  0011 0009  241   35998   12   107  -116   -46   24   651   88    50
-------------------------------------------------------------------------------------
Tot:  10                690   35998   15   -69  -517  -208  208  1116   96    50
```

9.8. Check the data (GPSEST, RMSCHK, SATMRK)

9.8.1. GPSEST

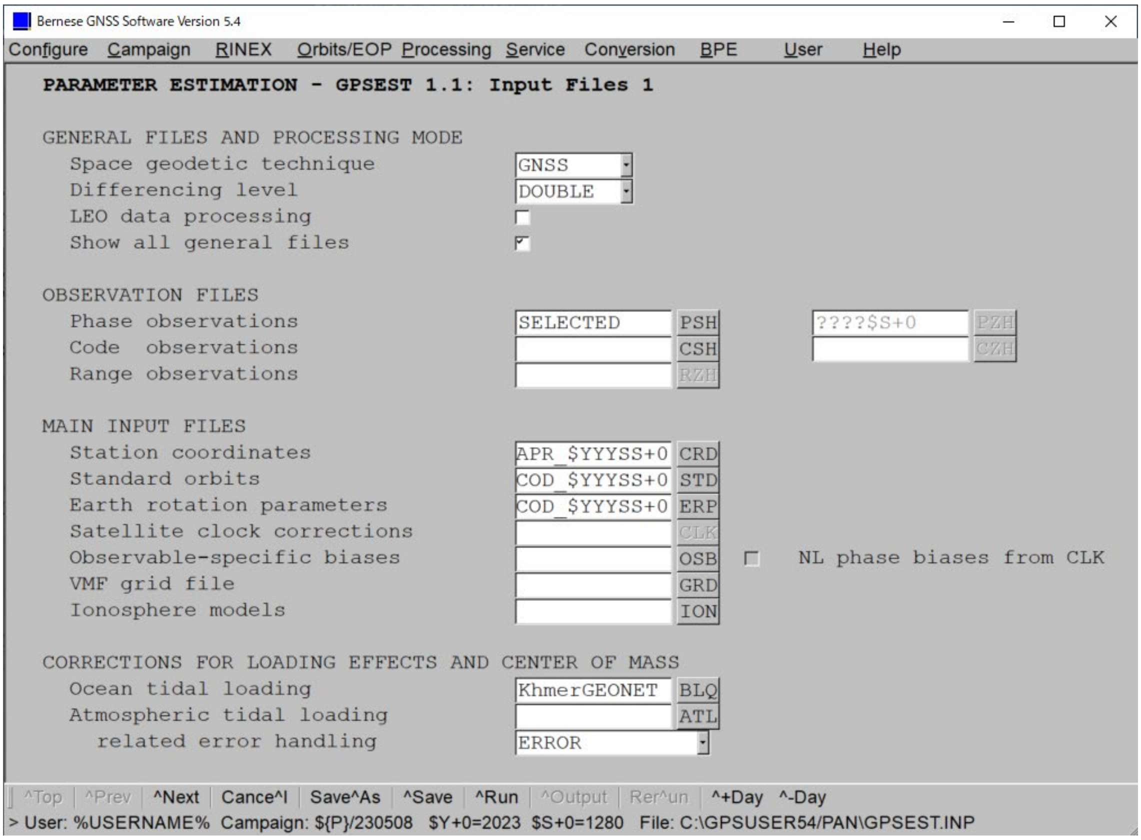
Check data quality.

Click [Parameter estimation] to display the submenu.

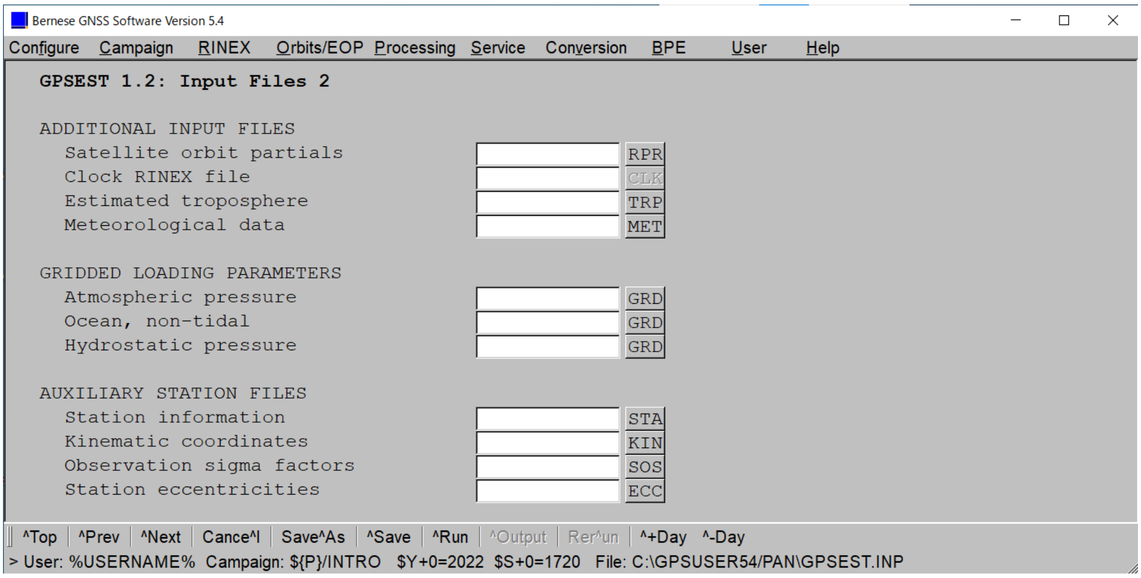


Select INPUT FILES

Click [^Next].

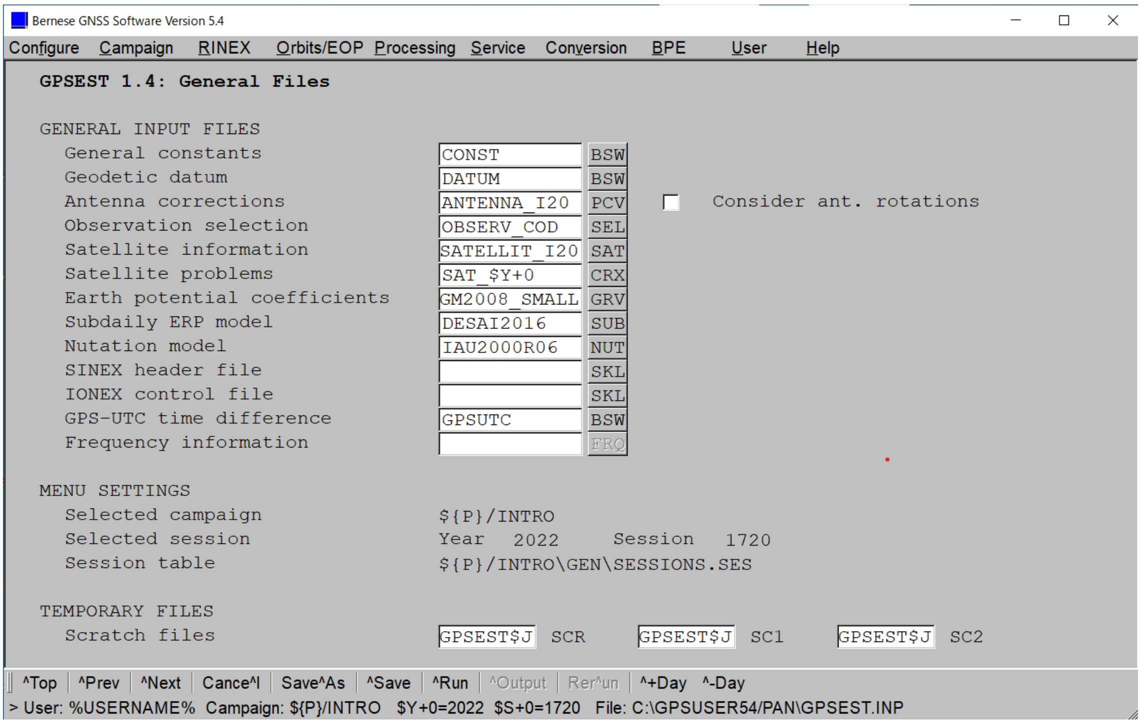


Click [^Next].

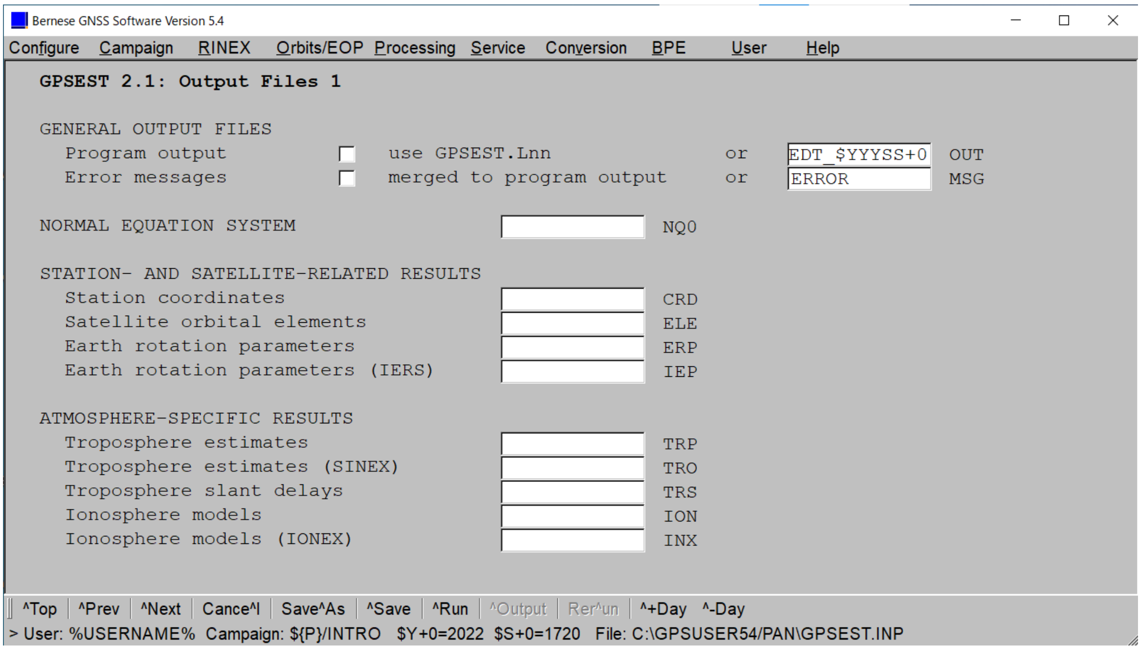


Select GENERAL INPUT FILES.

Click [^Next].

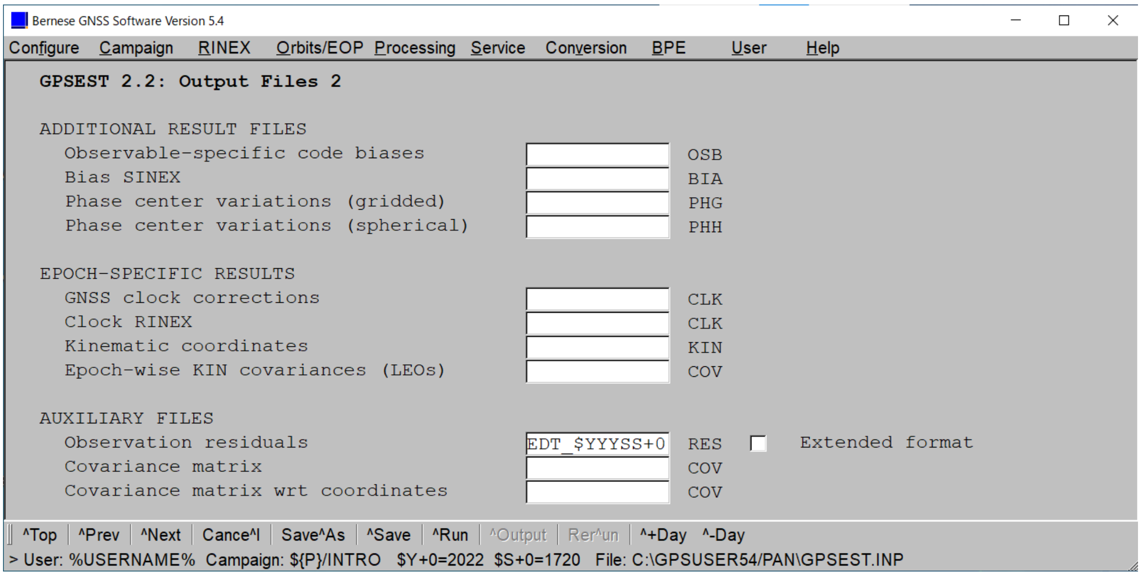


Click [^Next].

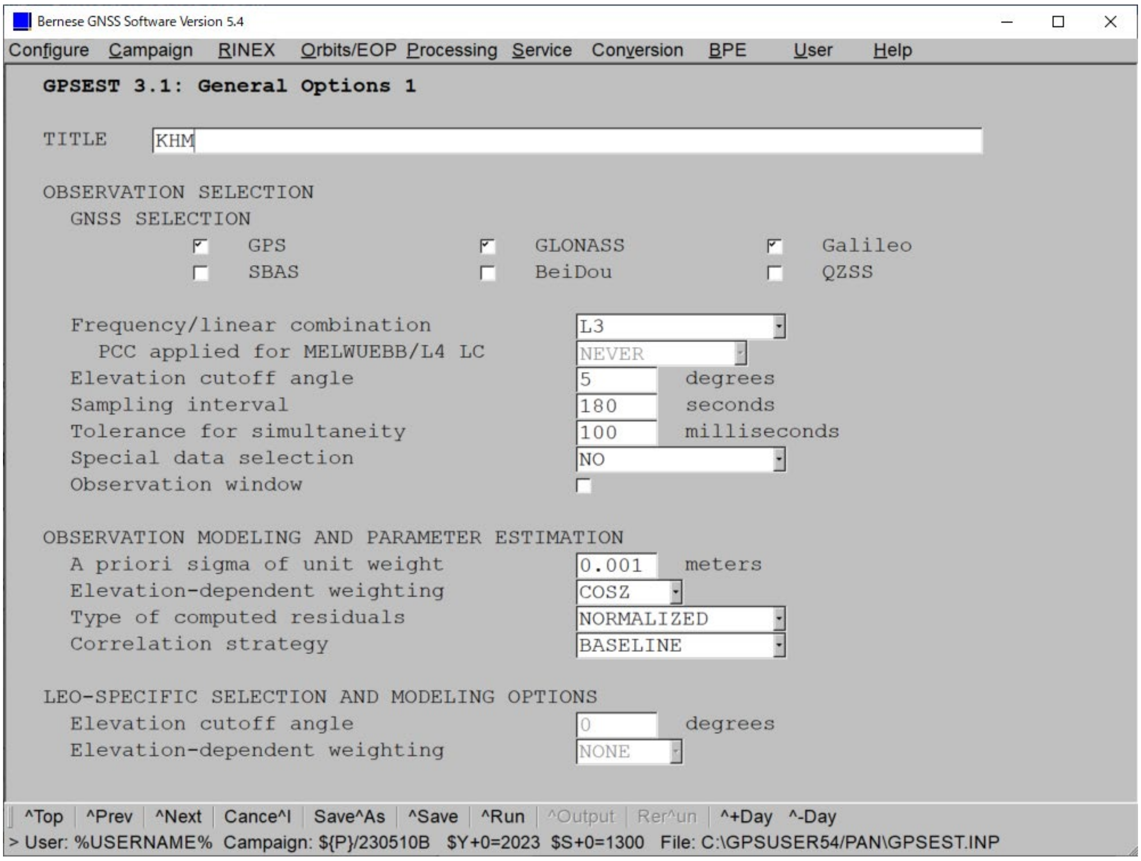


Enter Observation residuals.

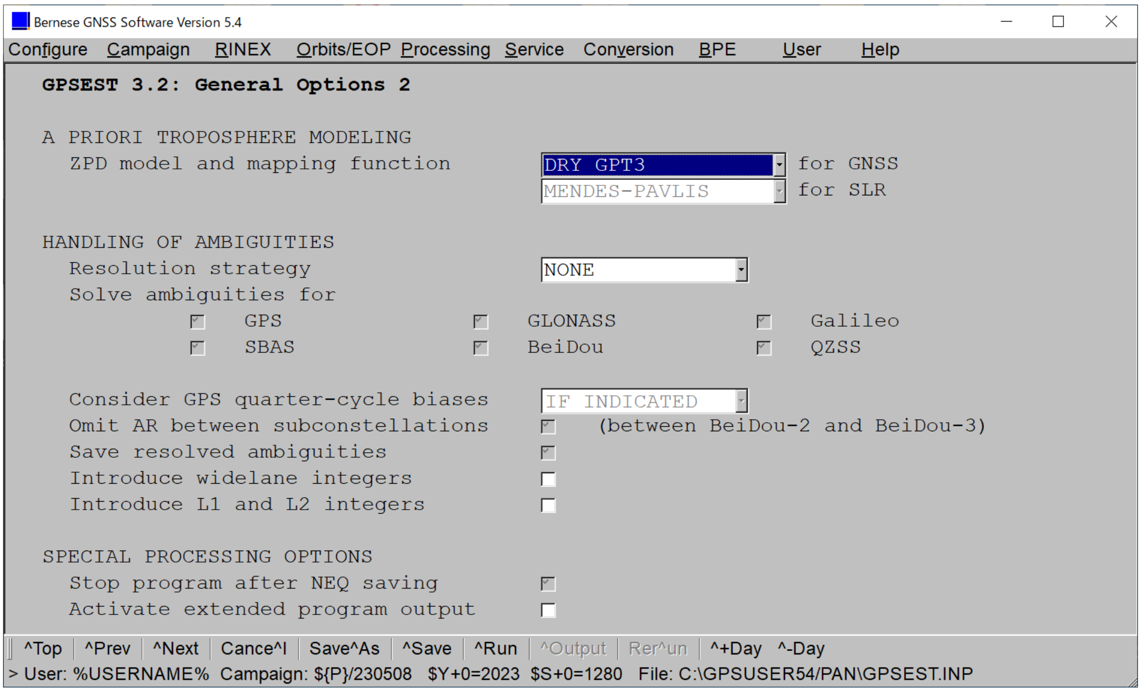
Click [^Next].



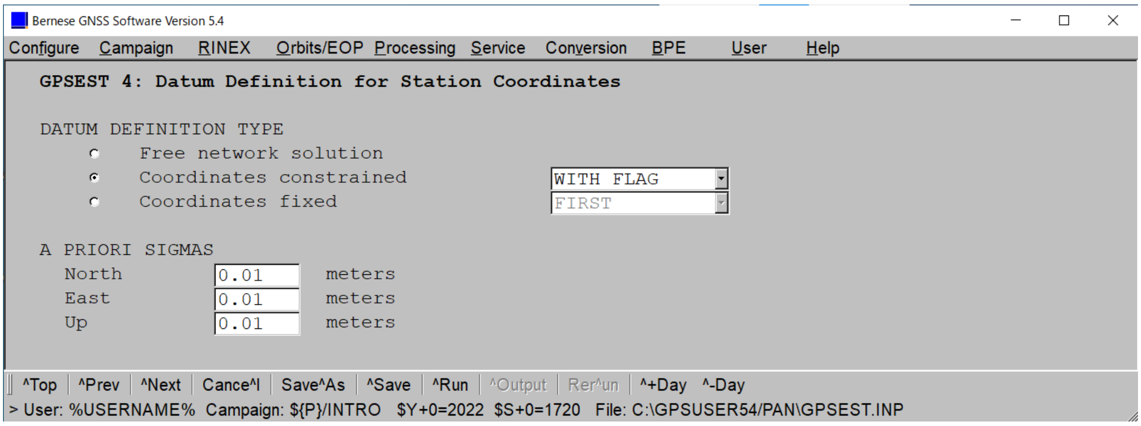
Click [^Next].



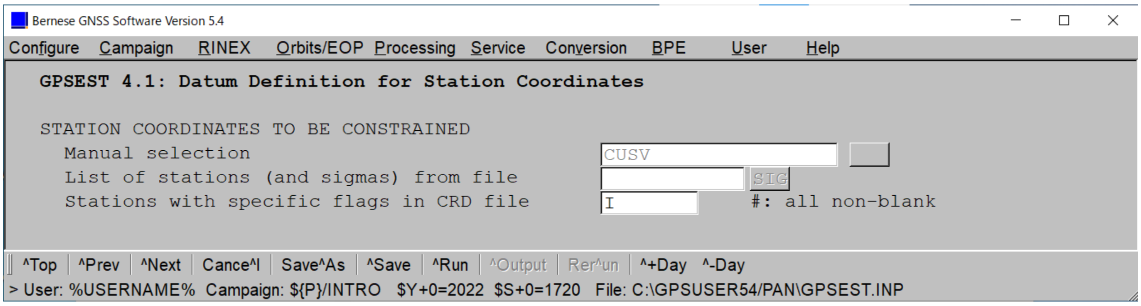
Click [^Next].



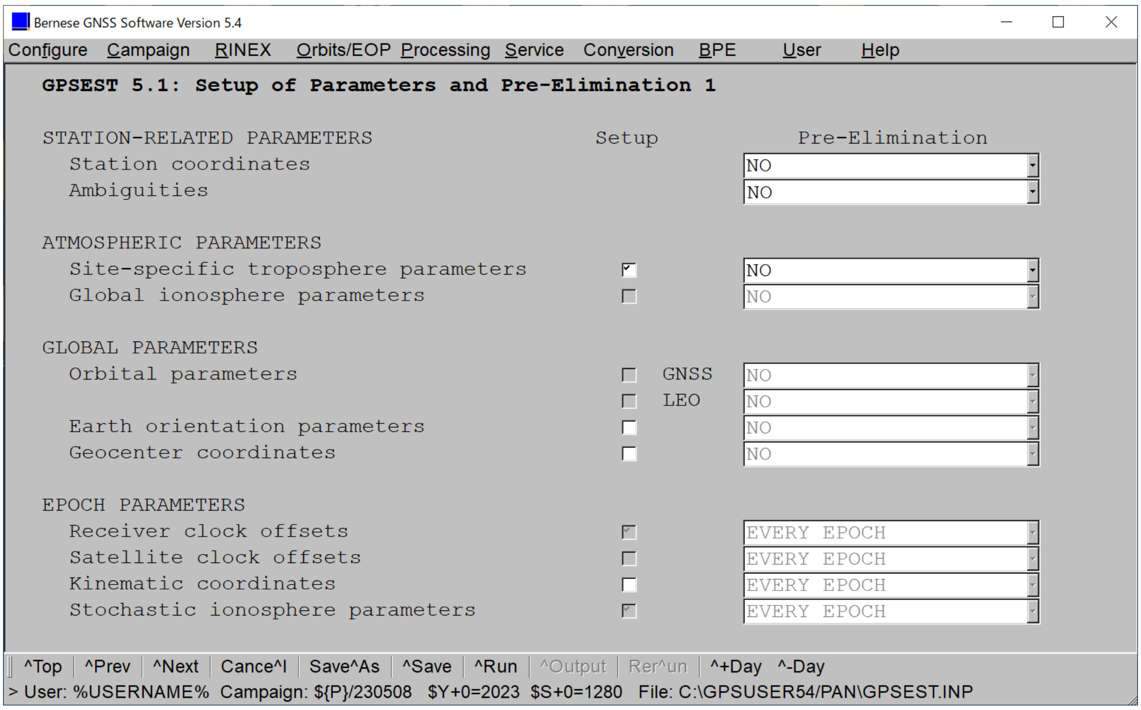
Click [^Next].



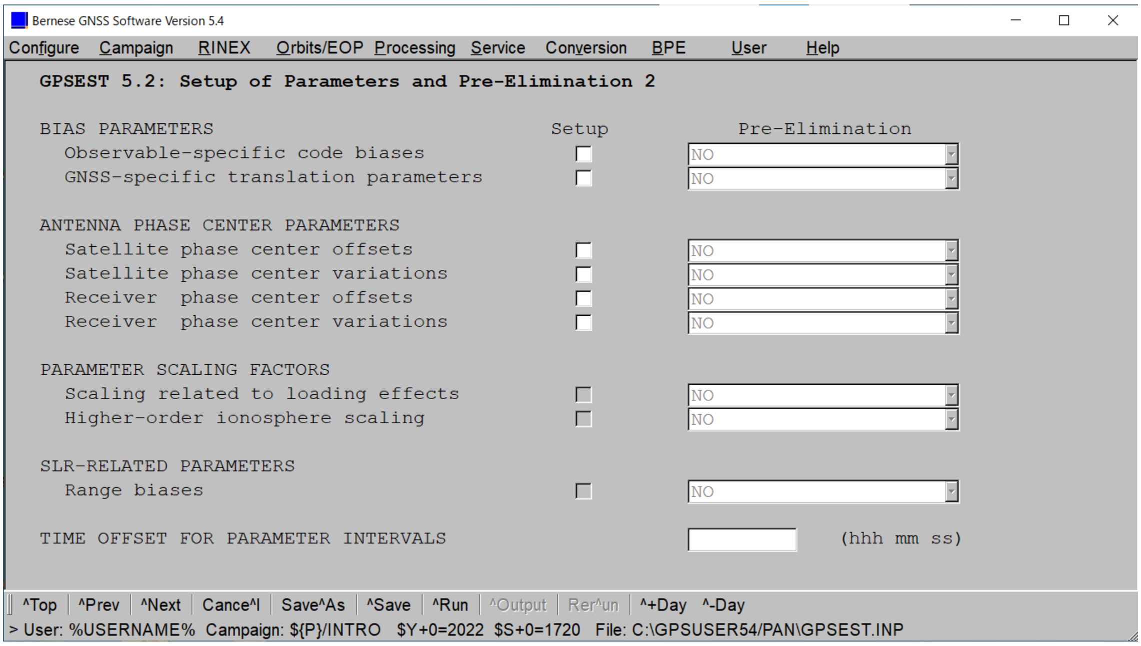
Click [^Next].



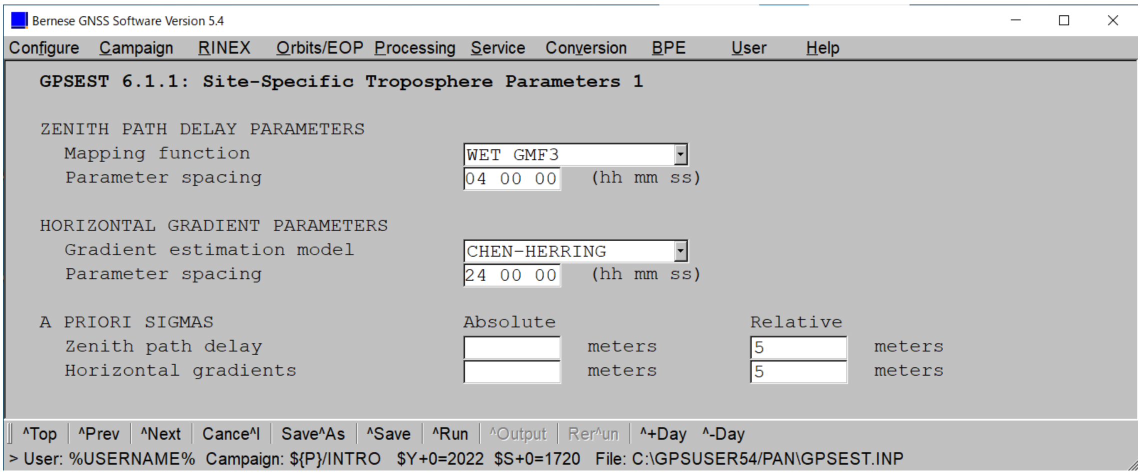
Click [^Next].



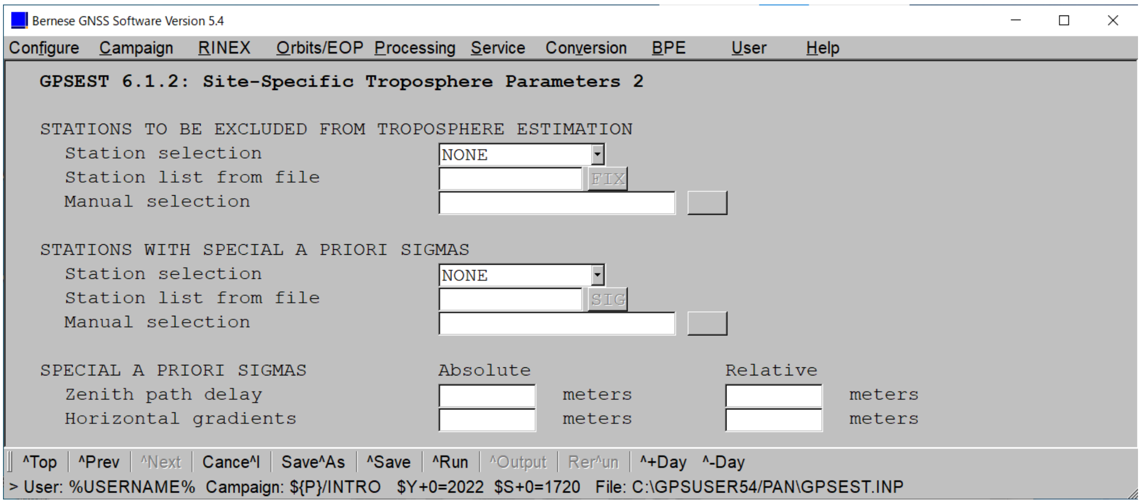
Click [^Next].



Click [^Next].

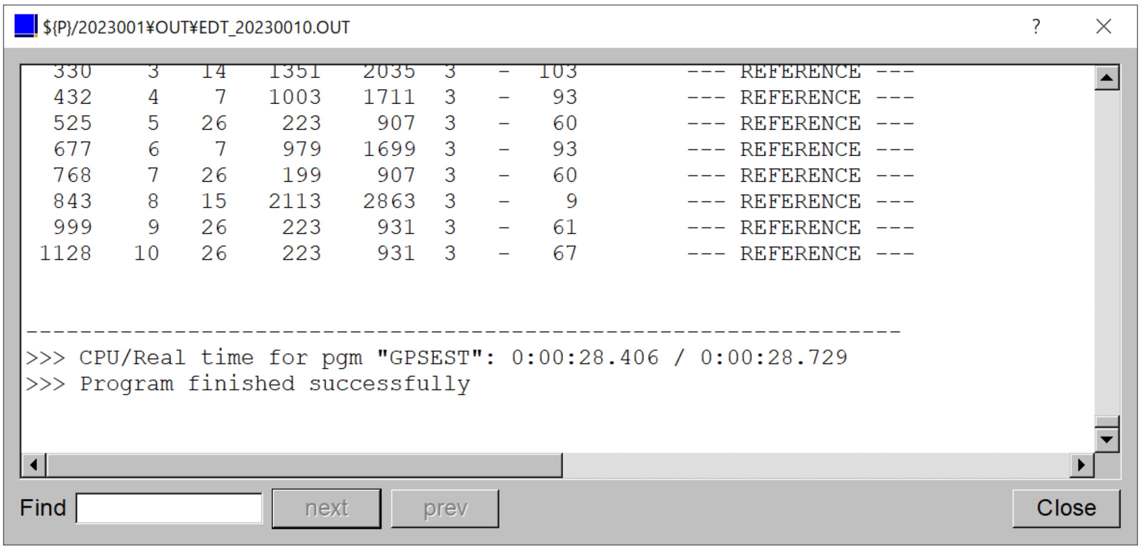


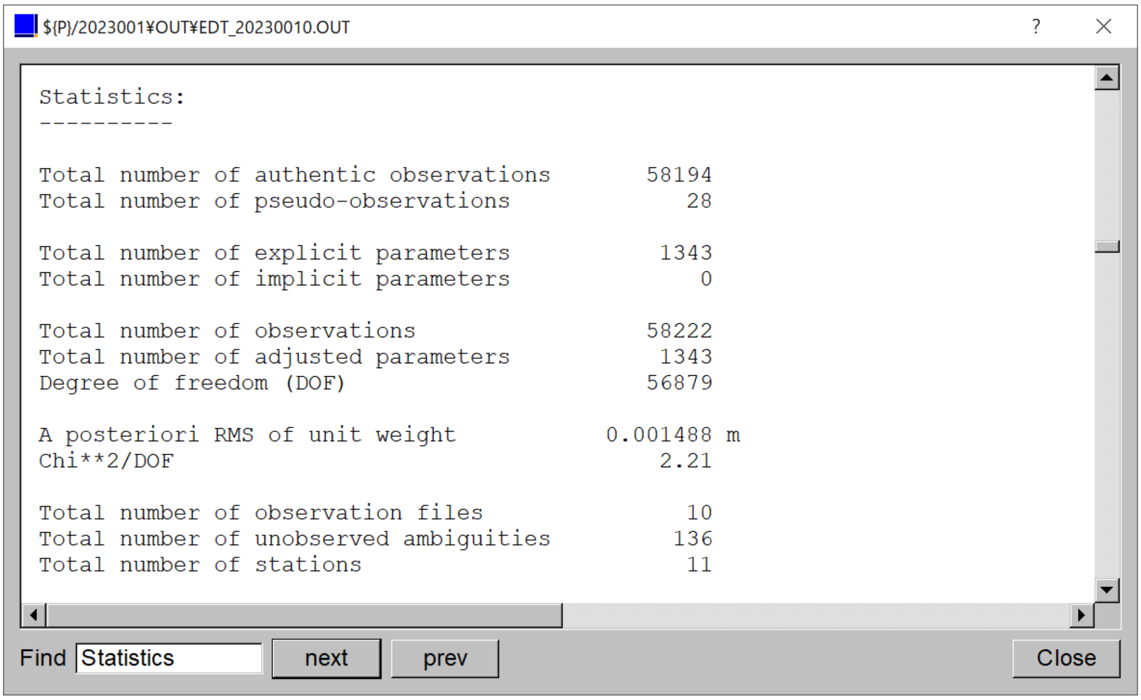
Click [^Run].



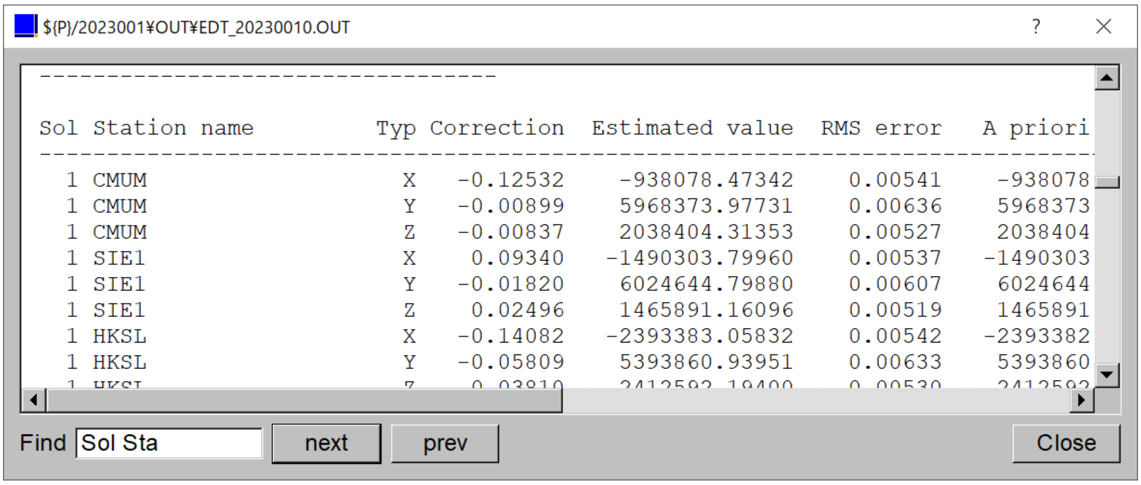
Click [^Output].

Check the results.




${P}/2023001¥OUT¥EDT_20230010.OUT
Statistics:

Total number of authentic observations 58194
Total number of pseudo-observations 28
Total number of explicit parameters 1343
Total number of implicit parameters 0
Total number of observations 58222
Total number of adjusted parameters 1343
Degree of freedom (DOF) 56879
A posteriori RMS of unit weight 0.001488 m
Chi**2/DOF 2.21
Total number of observation files 10
Total number of unobserved ambiguities 136
Total number of stations 11
Find Statistics
next
prev
Close

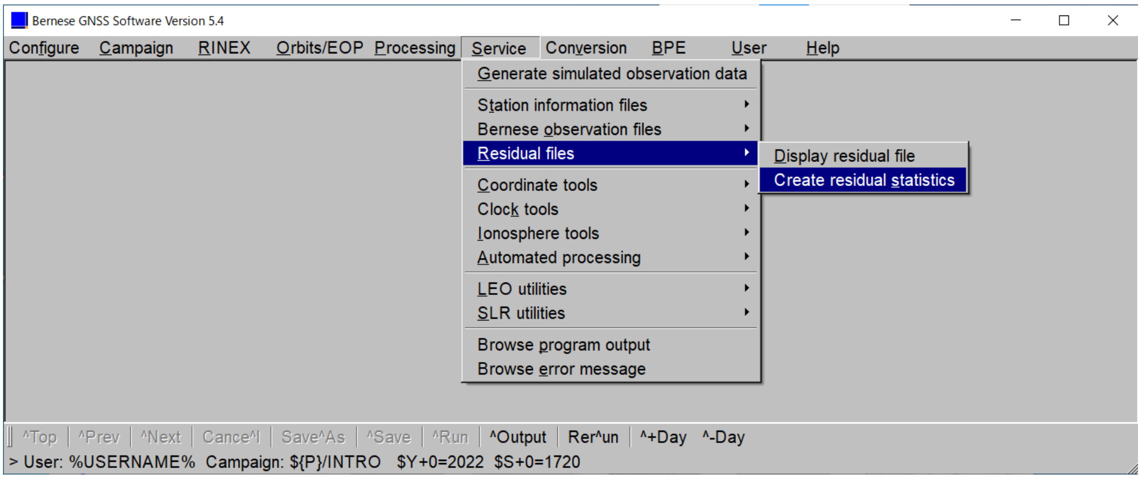

${P}/2023001¥OUT¥EDT_20230010.OUT
Sol Station name Typ Correction Estimated value RMS error A priori
1 CMUM X -0.12532 -938078.47342 0.00541 -938078
1 CMUM Y -0.00899 5968373.97731 0.00636 5968373
1 CMUM Z -0.00837 2038404.31353 0.00527 2038404
1 SIE1 X 0.09340 -1490303.79960 0.00537 -1490303
1 SIE1 Y -0.01820 6024644.79880 0.00607 6024644
1 SIE1 Z 0.02496 1465891.16096 0.00519 1465891
1 HKSL X -0.14082 -2393383.05832 0.00542 -2393382
1 HKSL Y -0.05809 5393860.93951 0.00633 5393860
Find Sol Sta
next
prev
Close

9.8.2. RMSCHK

Examine the residuals file.

Make a list of outliers.

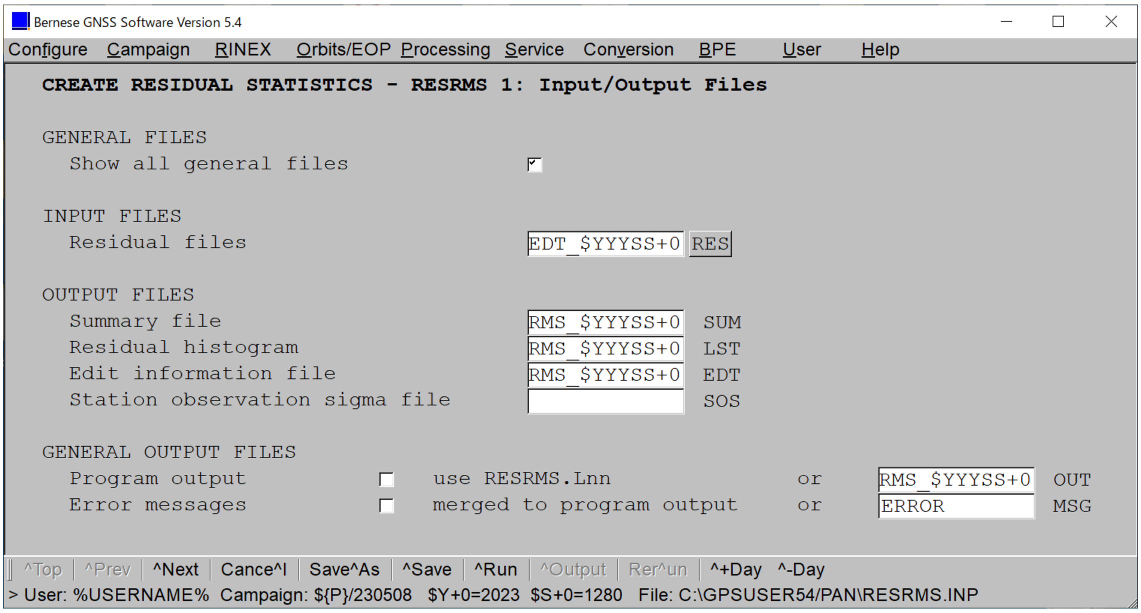
Click [Create residual statistics] to display the submenu.



Select INPUT FILE.

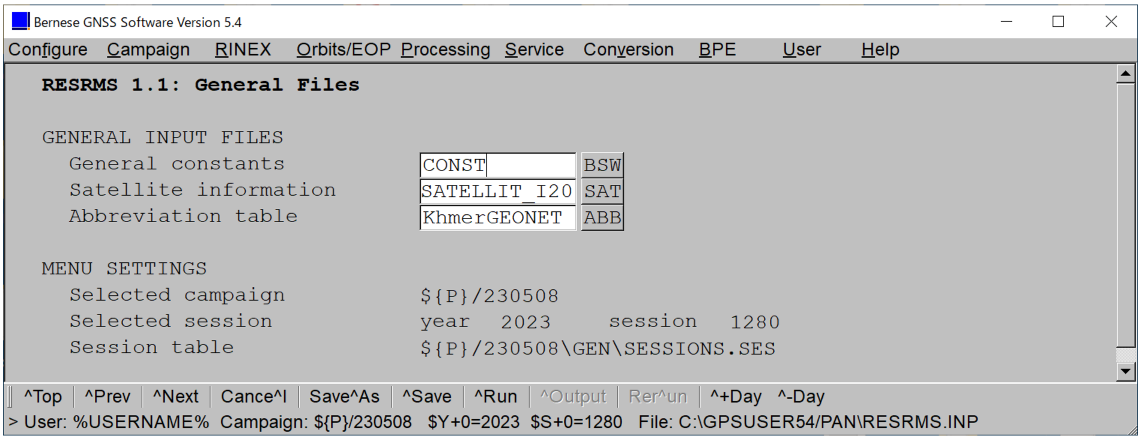
Enter OUTPUT FILE. The Edit information file is used by program SATMRK.

Click [^Next].



Select and Check GENERAL INPUT FILES.

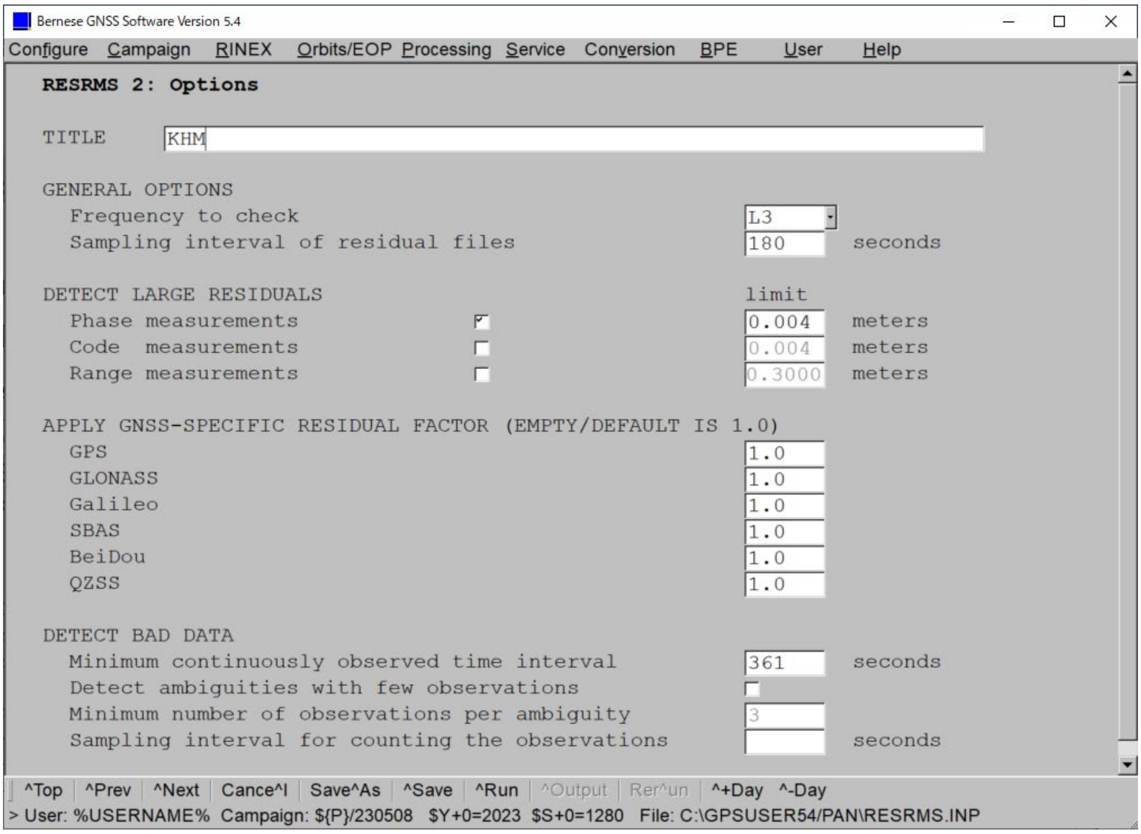
Click [^Next].



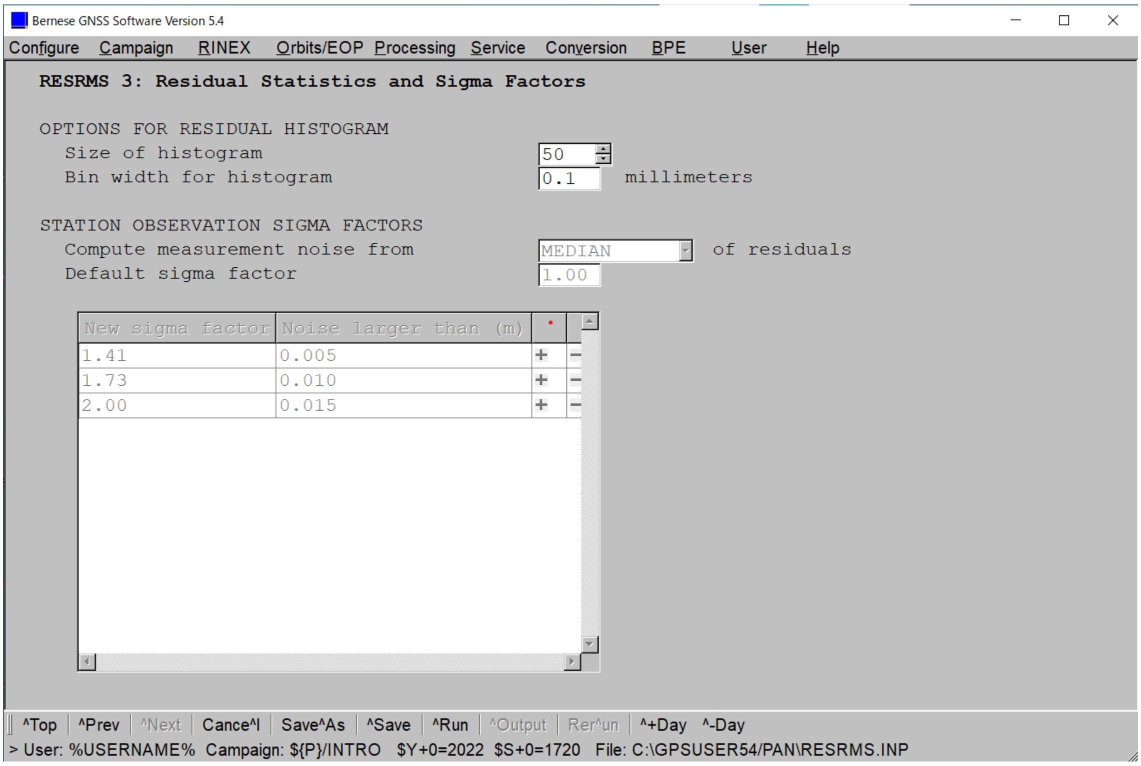
Sampling rate of residual files is 180 seconds.

Enter TITLE.

Click [^Next].

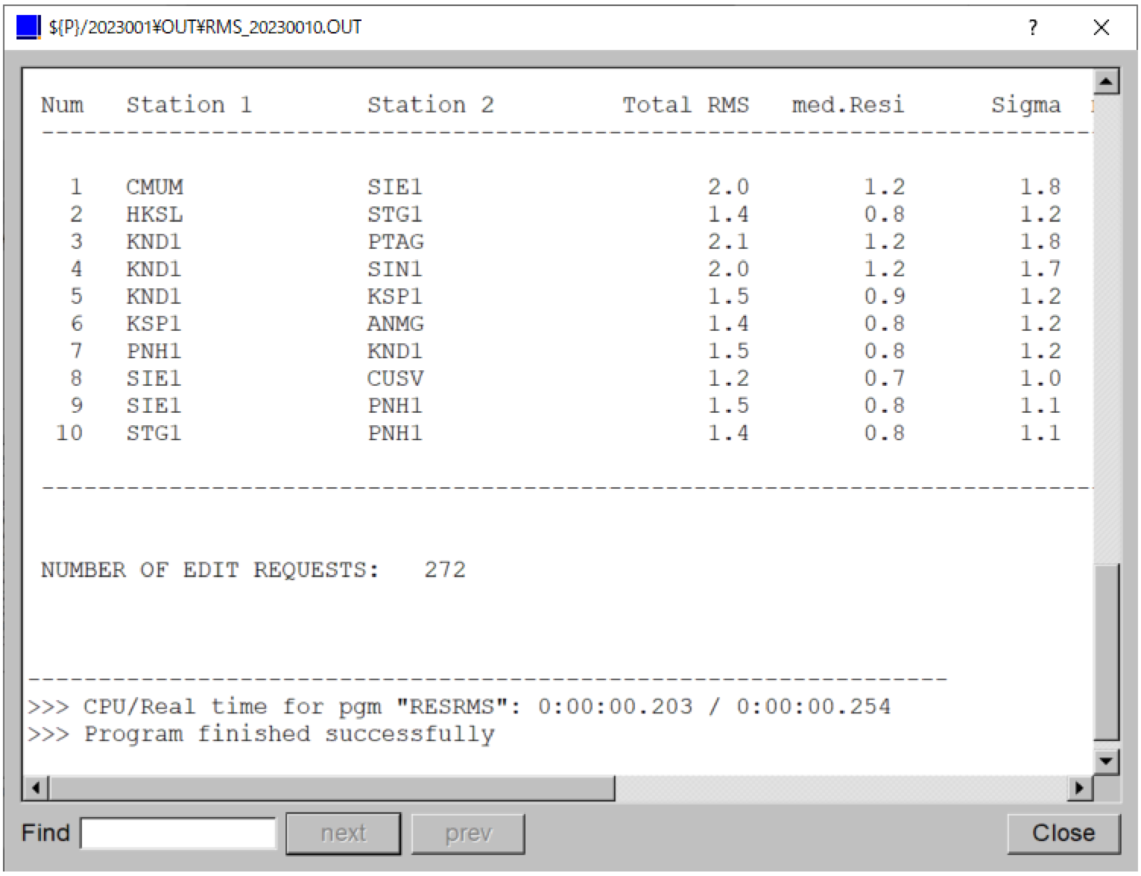


Click [^Run].


Bernese GNSS Software Version 5.4
Configure Campaign RINEX Orbits/EOP Processing Service Conversion BPE User Help
RESRMS 3: Residual Statistics and Sigma Factors
OPTIONS FOR RESIDUAL HISTOGRAM
Size of histogram 50
Bin width for histogram 0.1 millimeters
STATION OBSERVATION SIGMA FACTORS
Compute measurement noise from MEDIAN of residuals
Default sigma factor 1.00
New sigma factor | Noise larger than (m)
1.41 | 0.005
1.73 | 0.010
2.00 | 0.015
^Top ^Prev ^Next Cance^l Save^As ^Save ^Run ^Output Rer^un ^+Day ^-Day
> User: %USERNAME% Campaign: ${P}/INTRO $Y+0=2022 $S+0=1720 File: C:\GPSUSER54/PAN\RESRMS.INP

Click [^Output].

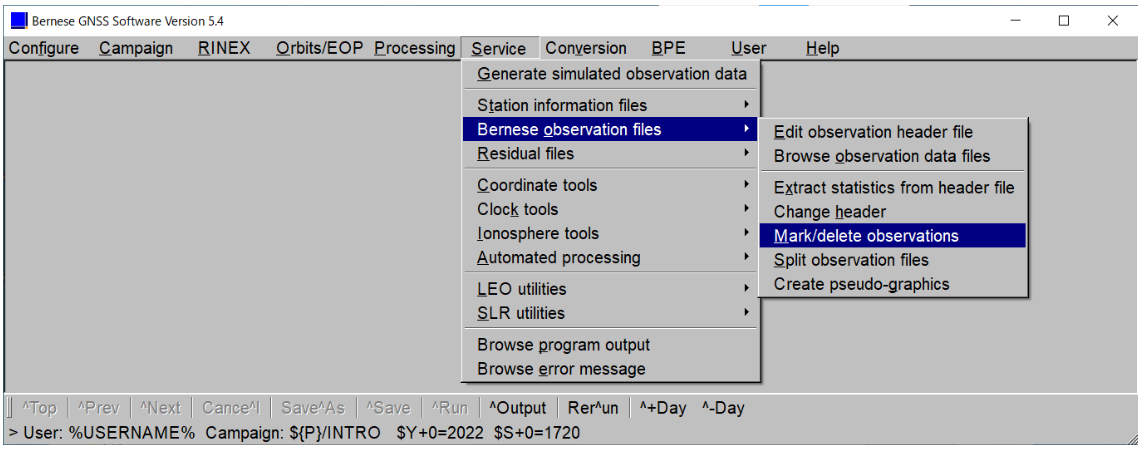
Check the result.




```
Num   Station 1        Station 2          Total RMS   med.Resi      Sigma
---------------------------------------------------------------------------

  1   CMUM             SIE1                     2.0        1.2        1.8
  2   HKSL             STG1                     1.4        0.8        1.2
  3   KND1             PTAG                     2.1        1.2        1.8
  4   KND1             SIN1                     2.0        1.2        1.7
  5   KND1             KSP1                     1.5        0.9        1.2
  6   KSP1             ANMG                     1.4        0.8        1.2
  7   PNH1             KND1                     1.5        0.8        1.2
  8   SIE1             CUSV                     1.2        0.7        1.0
  9   SIE1             PNH1                     1.5        0.8        1.1
 10   STG1             PNH1                     1.4        0.8        1.1

---------------------------------------------------------------------------


NUMBER OF EDIT REQUESTS:    272



-----------------------------------------------------------------
>>> CPU/Real time for pgm "RESRMS": 0:00:00.203 / 0:00:00.254
>>> Program finished successfully
```

9.8.3. SATMRK

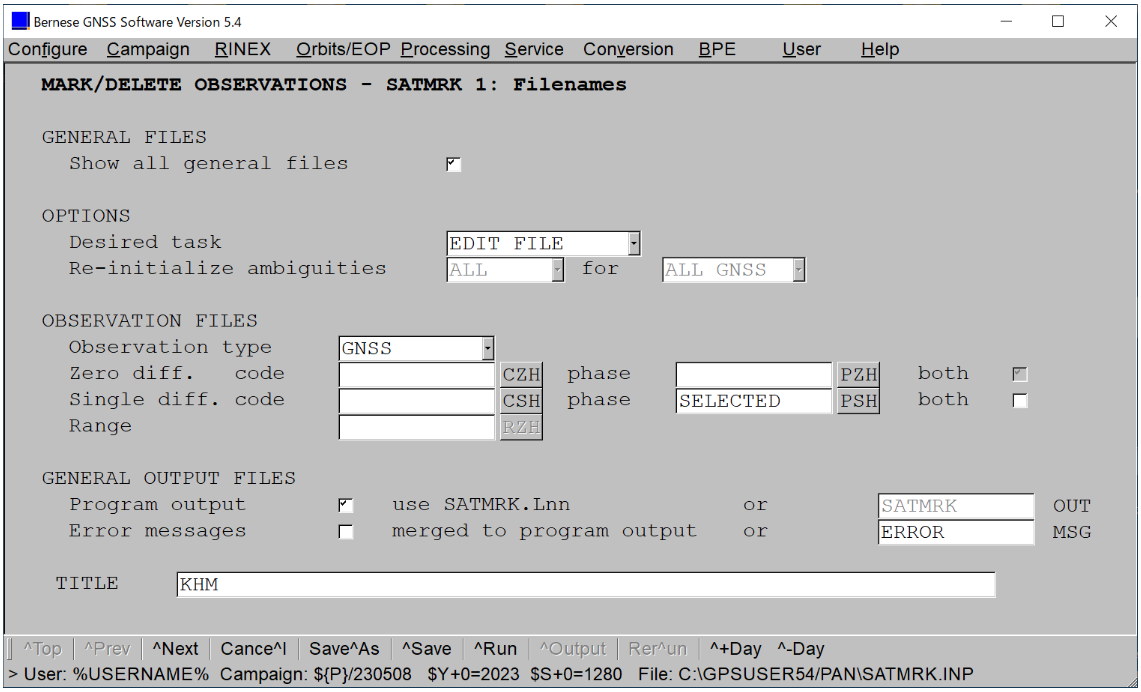
Use the outlier list to flag anomalous data. Data with flags are not used in calculations. Click [Mark/delete observations] to display the submenu.



Select Single Diff. phase file.

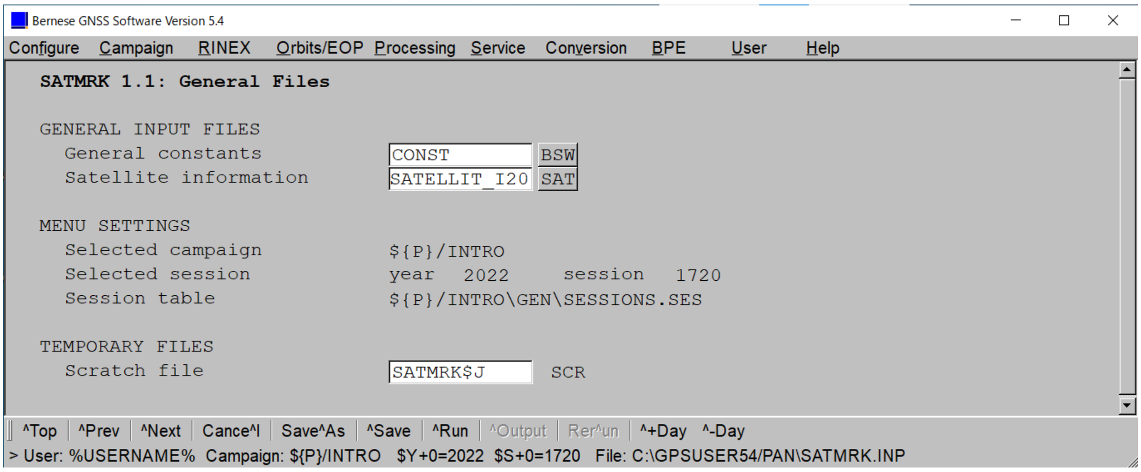
Enter TITLE.

Click [^Next].



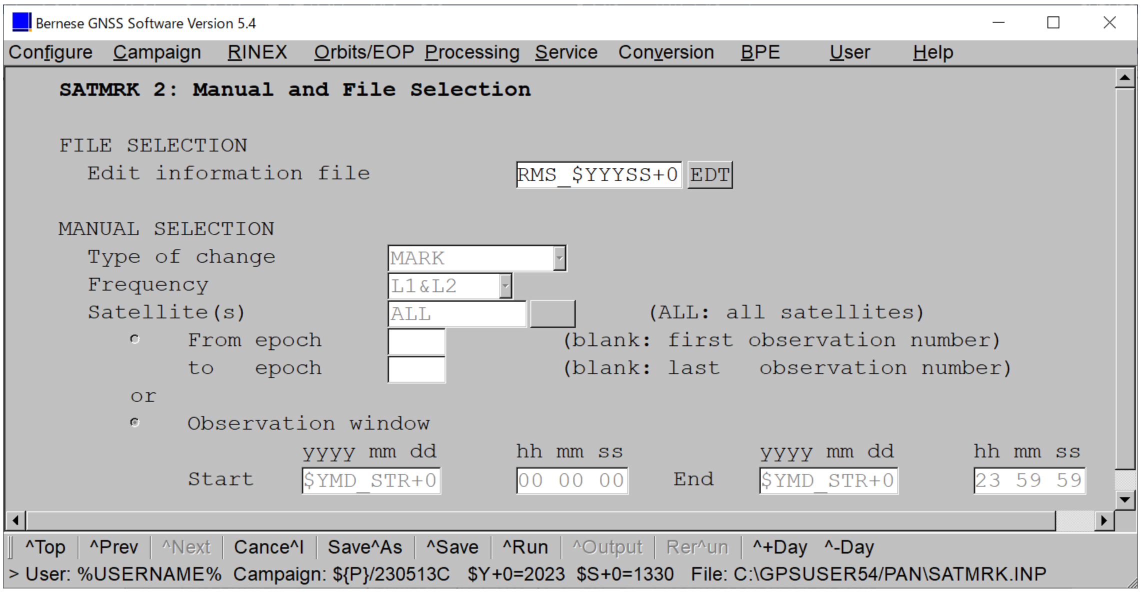
Select GENERAL INPUT FILES.

Click [^Next].



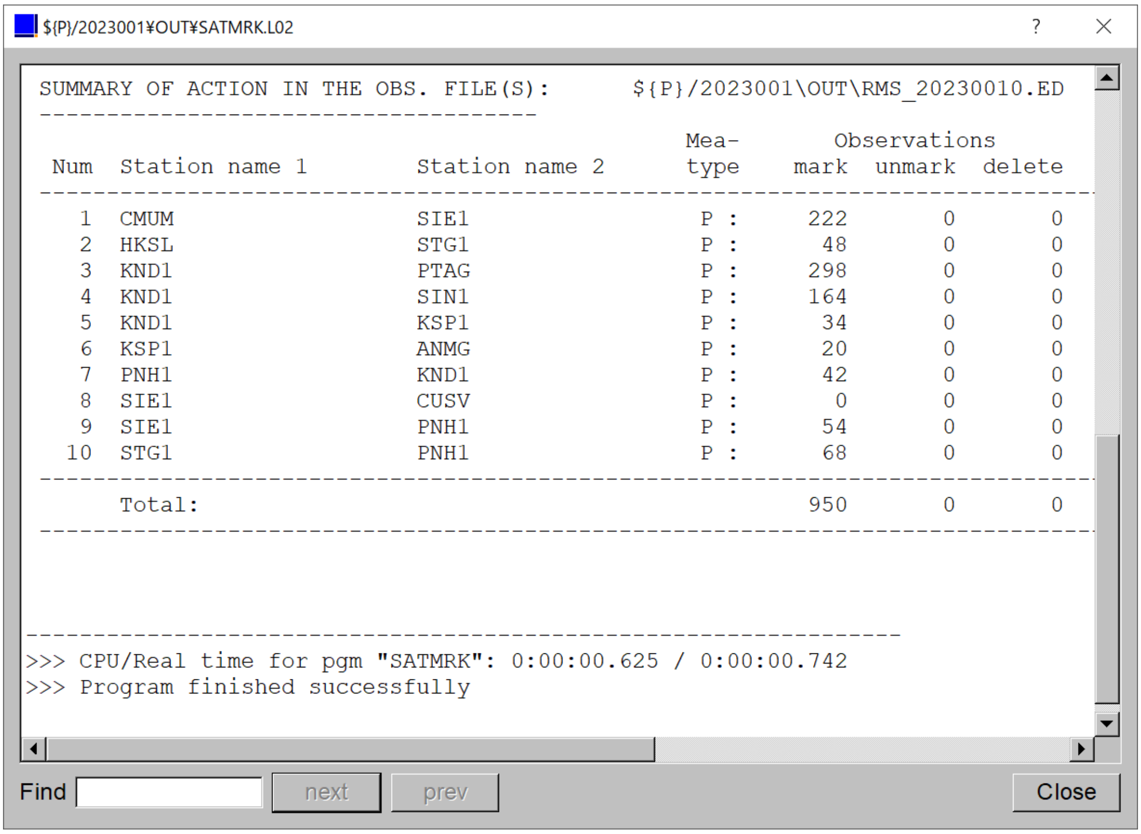
Select Edit information file.

Click [^Run].



Click [^Output].

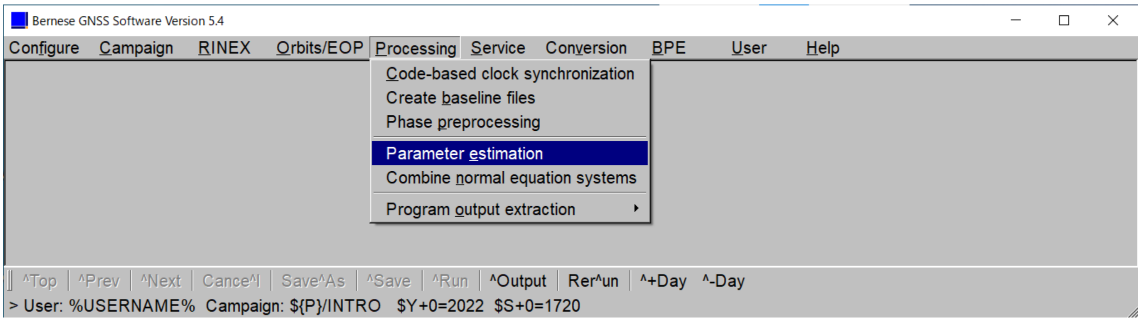
Check the results.




```
 Num  Station name 1       Station name 2       Mea-       Observations
                                                type    mark  unmark  delete
 ------------------------------------------------------------------------------
   1  CMUM                 SIE1                 P :      222       0       0
   2  HKSL                 STG1                 P :       48       0       0
   3  KND1                 PTAG                 P :      298       0       0
   4  KND1                 SIN1                 P :      164       0       0
   5  KND1                 KSP1                 P :       34       0       0
   6  KSP1                 ANMG                 P :       20       0       0
   7  PNH1                 KND1                 P :       42       0       0
   8  SIE1                 CUSV                 P :        0       0       0
   9  SIE1                 PNH1                 P :       54       0       0
  10  STG1                 PNH1                 P :       68       0       0
 ------------------------------------------------------------------------------
      Total:                                             950       0       0
 ------------------------------------------------------------------------------

>>> CPU/Real time for pgm "SATMRK": 0:00:00.625 / 0:00:00.742
>>> Program finished successfully
```

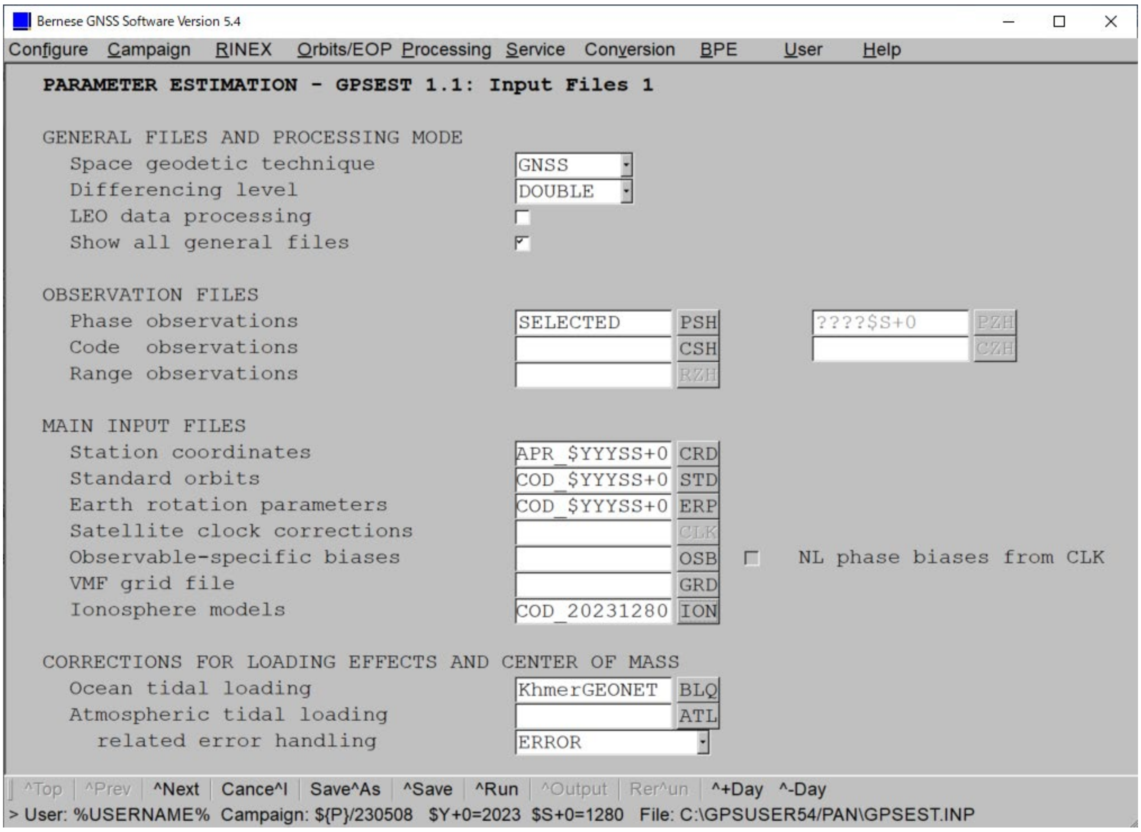
9.9. Coordinate values when Ambiguity is a real number and estimating the amount of atmospheric propagation delay (GPSEST)

Click [Parameter estimation] to display the submenu.

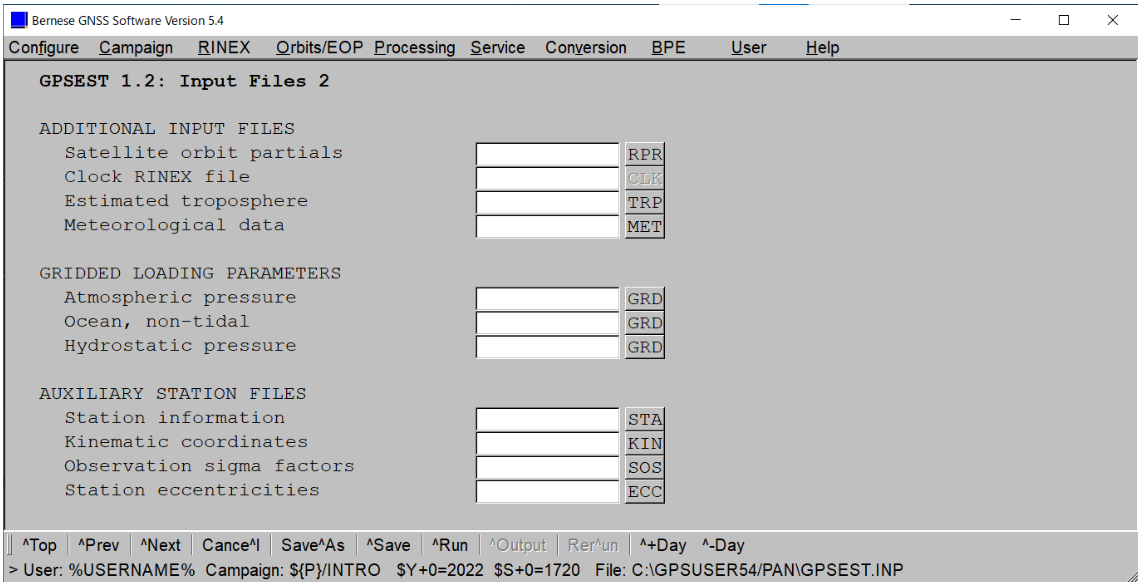


Select INPUT FILES.

Click [^Next].

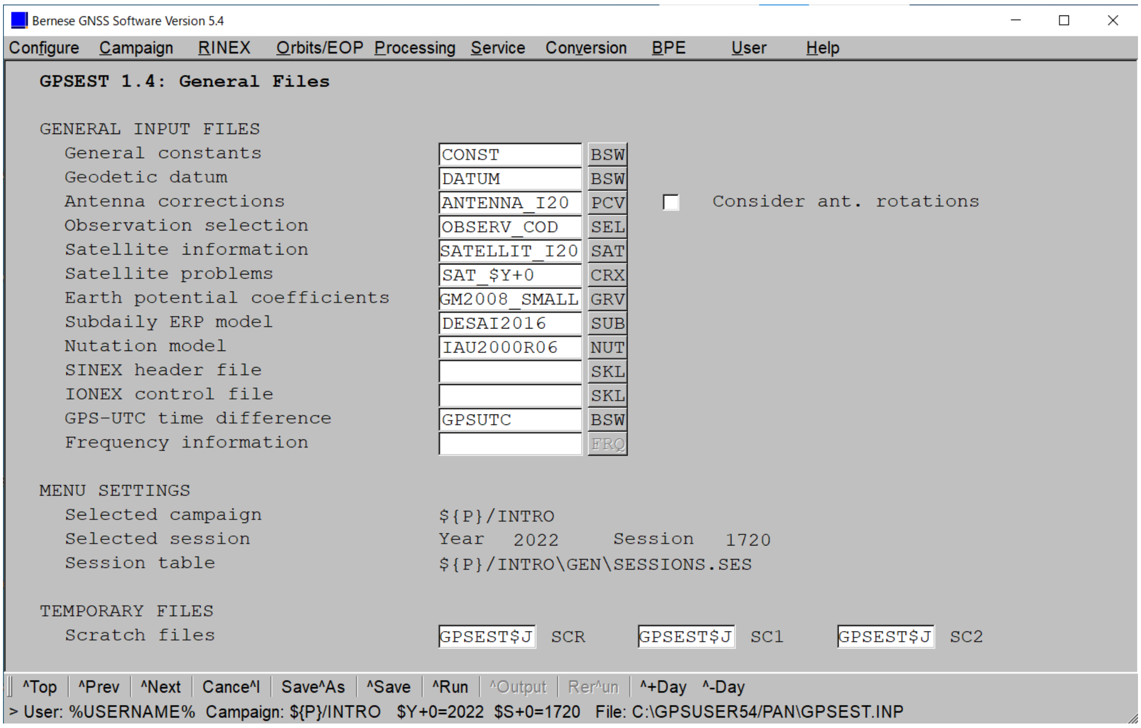


Click [^Next].



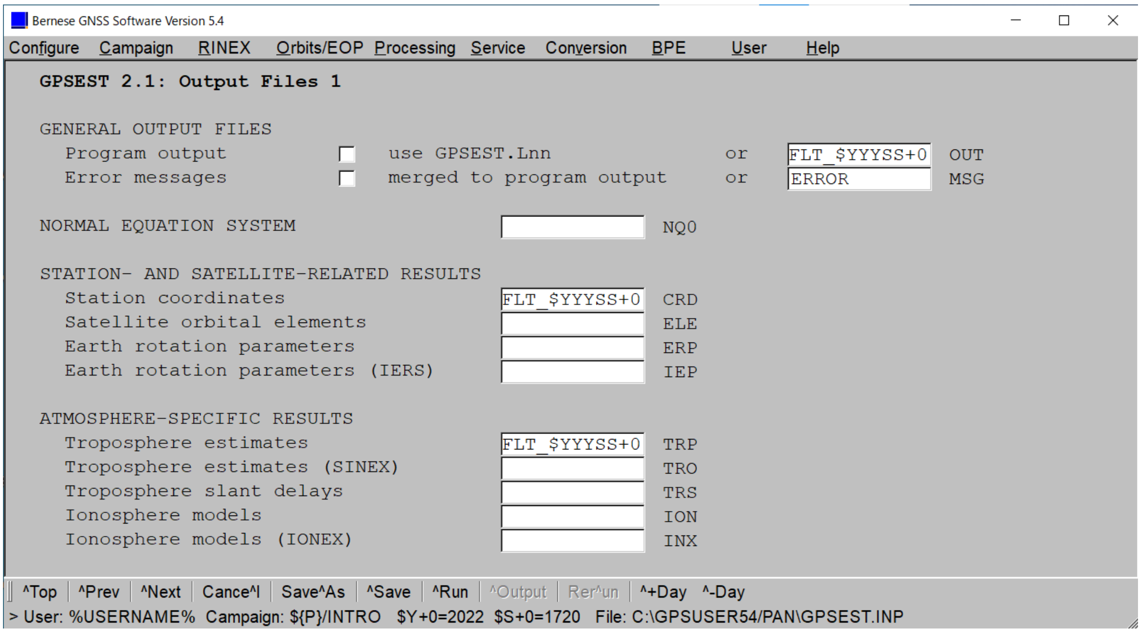
Select GENERAL INPUT FILES.

Click [^Next].



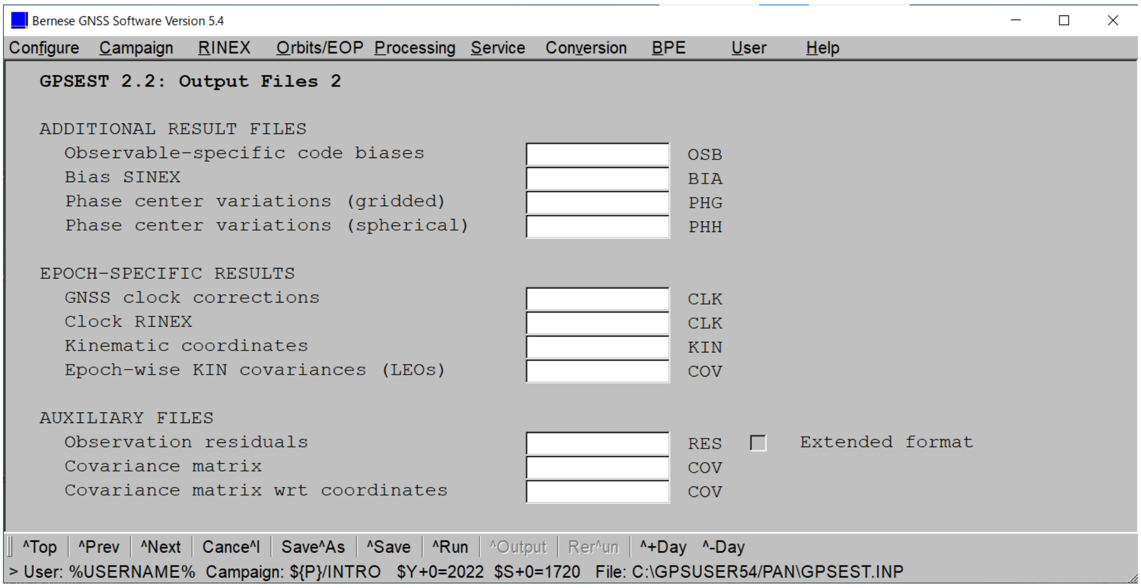
Enter Program output, Station coordinates and Troposphere estimate.

Click [^Next].



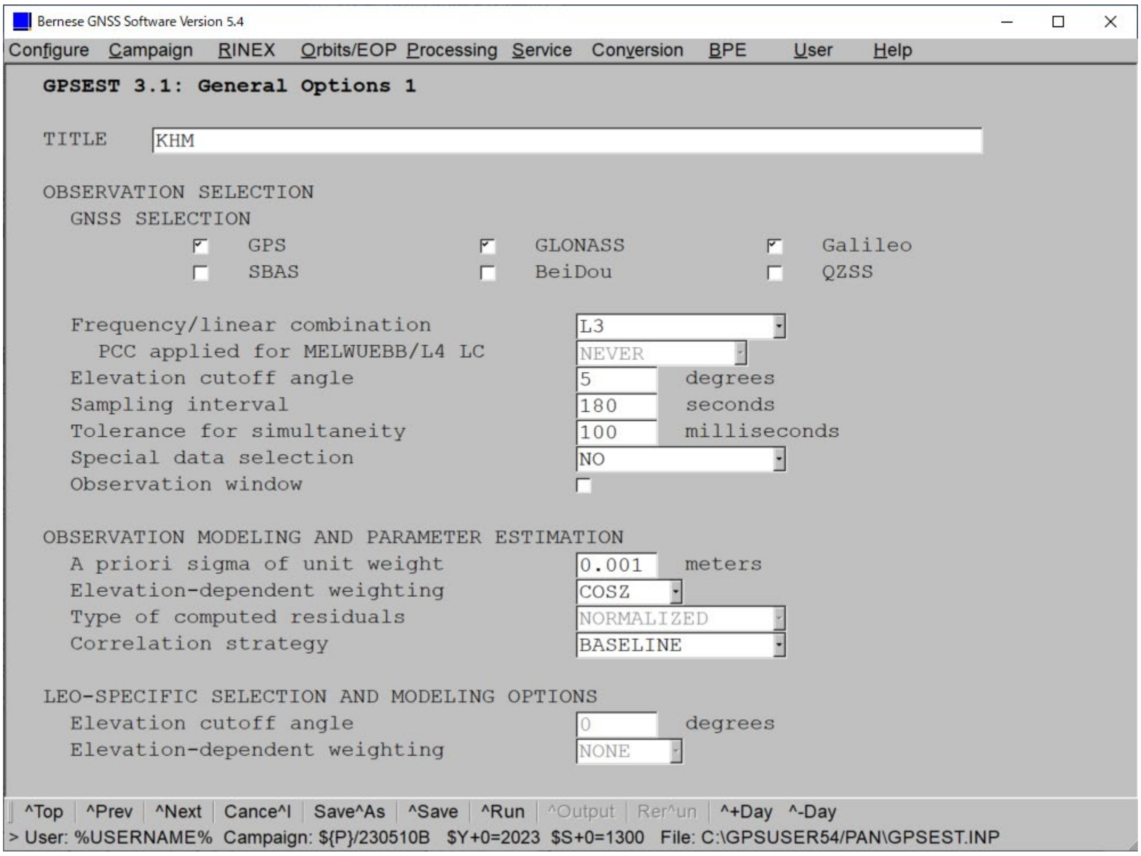
Enter Observation residuals.

Click [^Next].

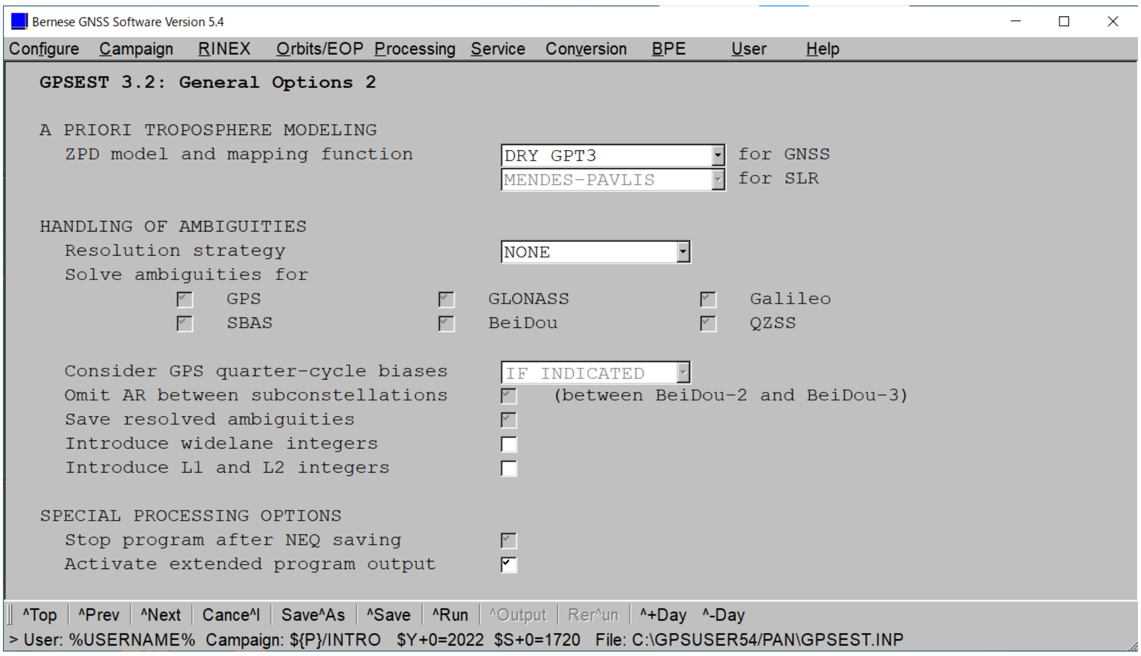


Sampling interval is 180 seconds.

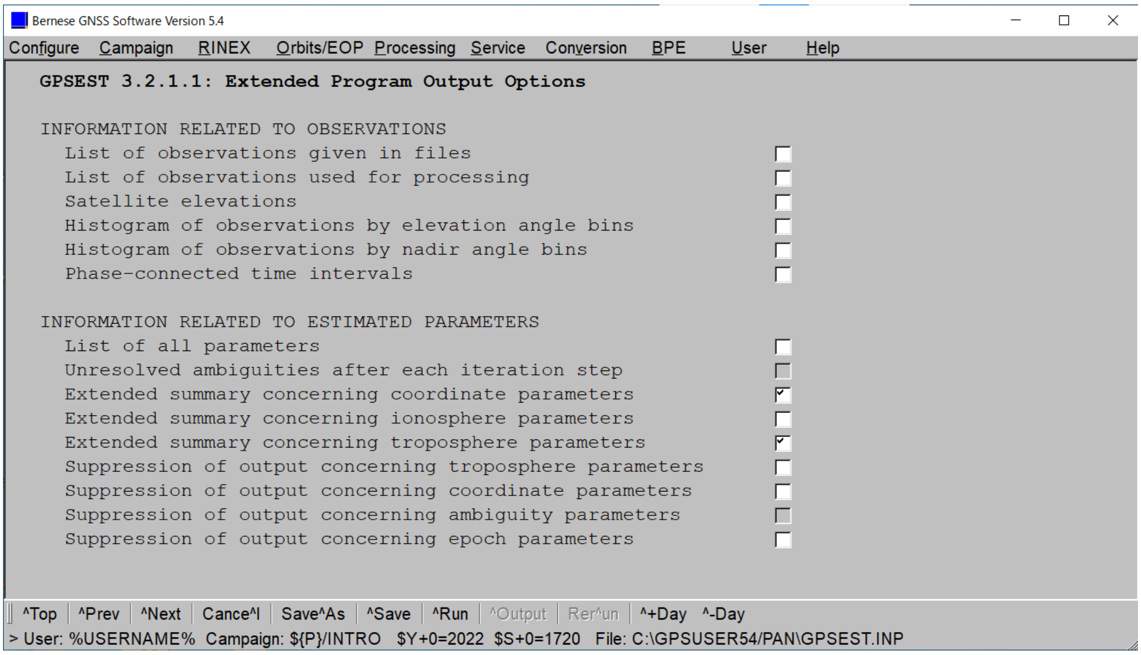
Click [^Next].



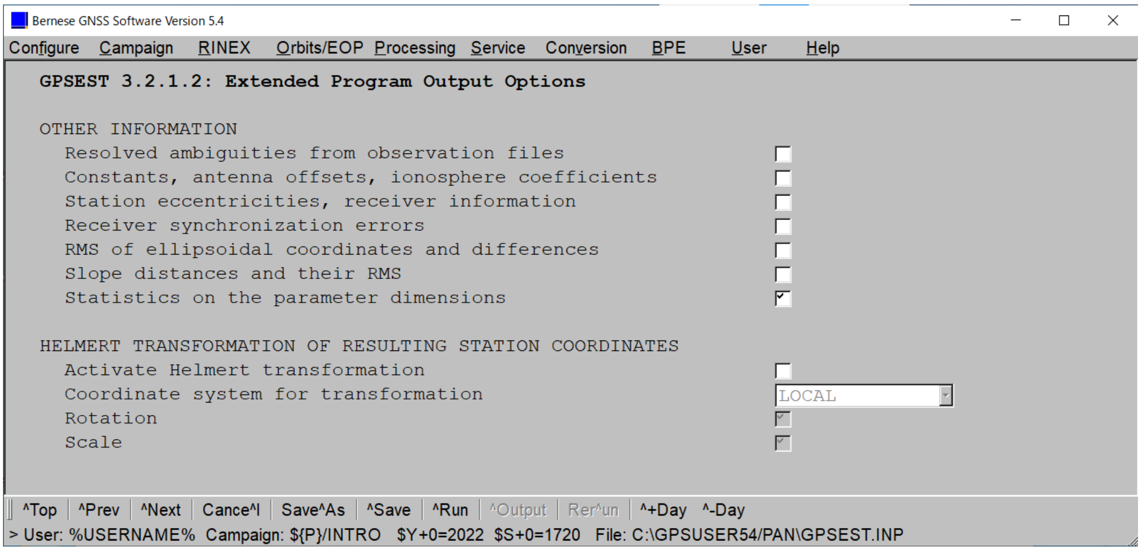
Click [^Next].



Click [^Next].

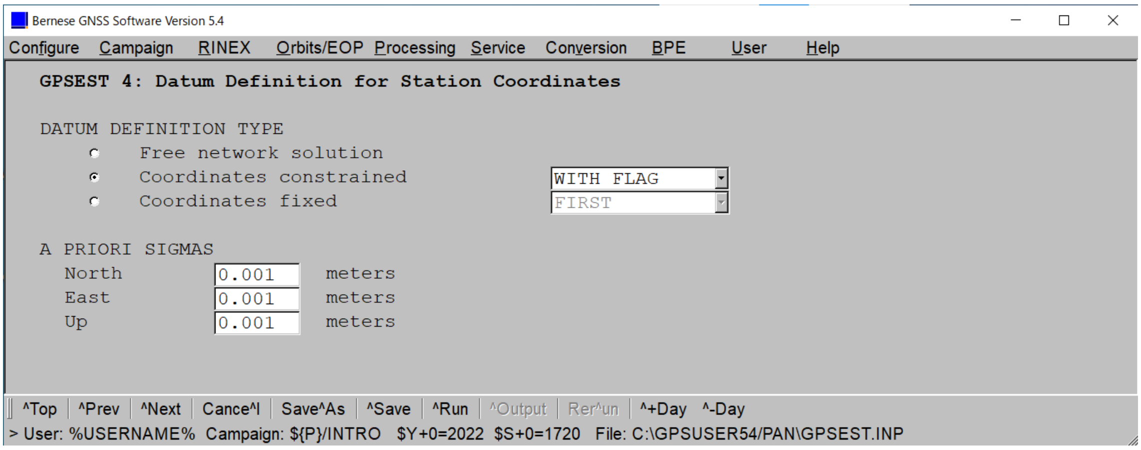


Click [^Next].



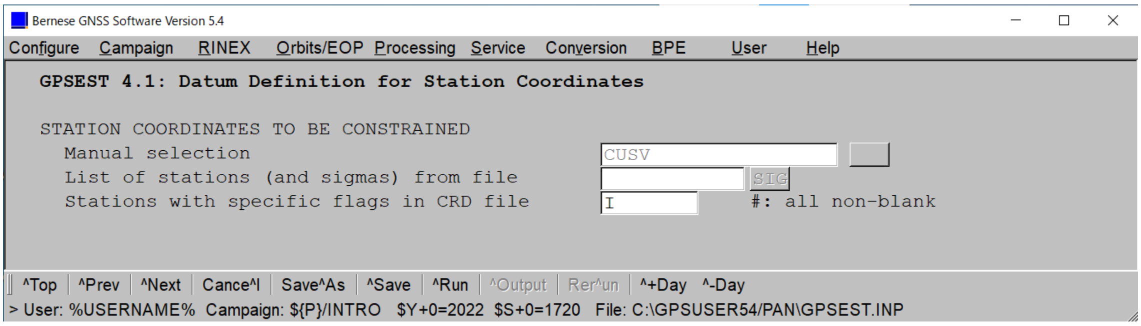
A PRIORI SIGMAS is [0.001] meters.

Click [^Next].

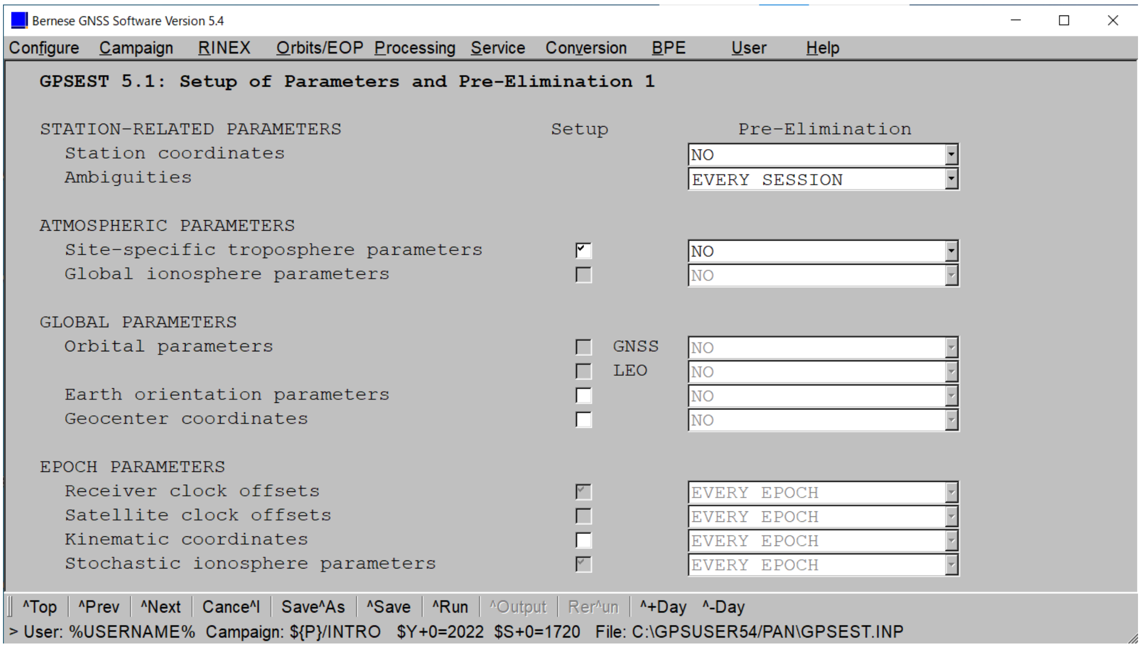


Enter flag in CRD file.

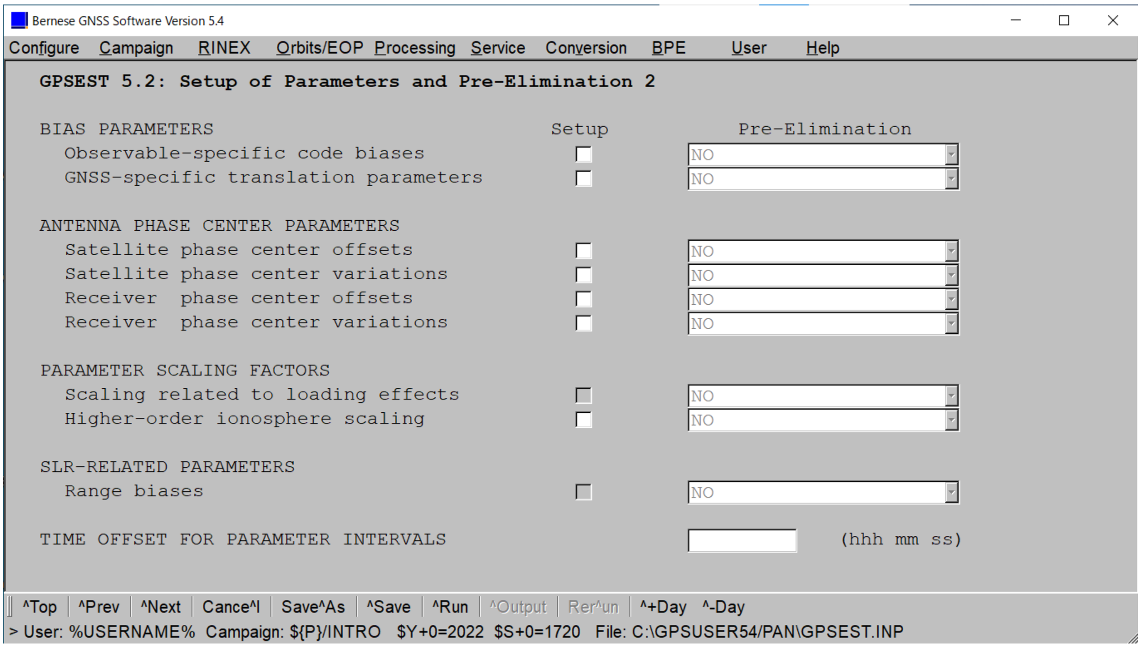
Click [^Next].



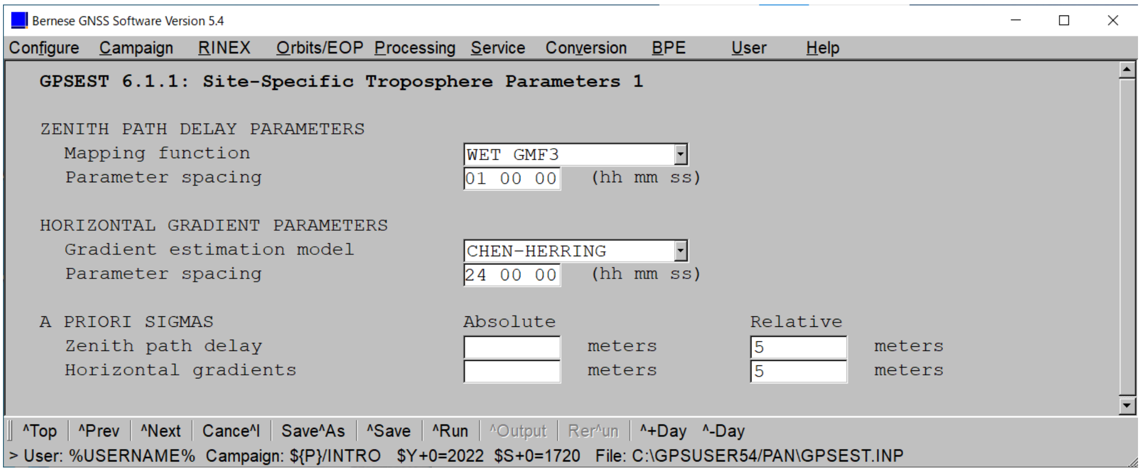
Click [^Next].



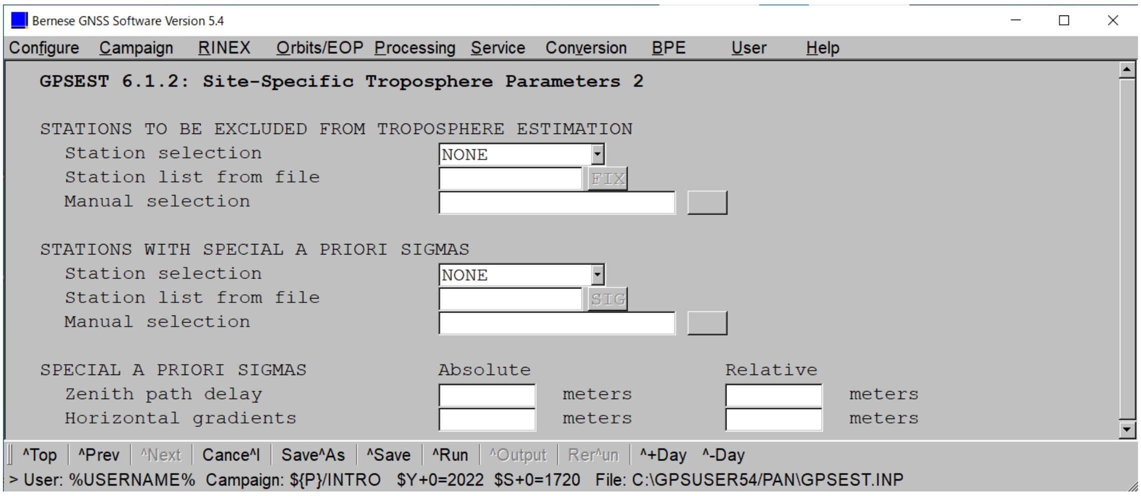
Click [^Next].



Click [^Next].

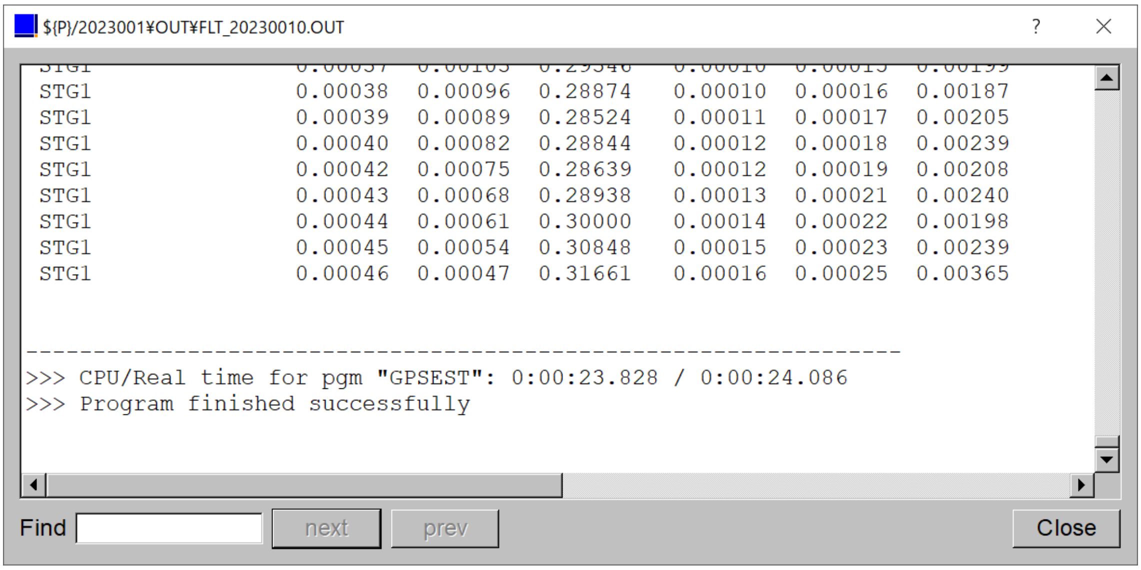


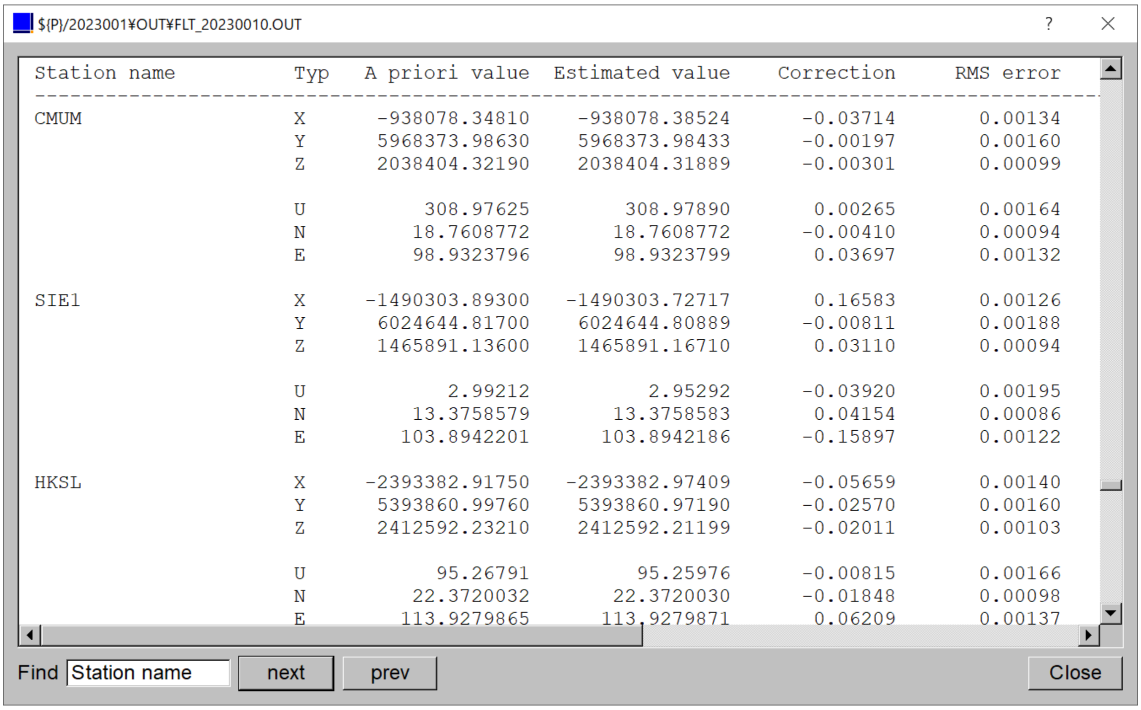
Click [^Run].



Click [^Output].

Check the results.



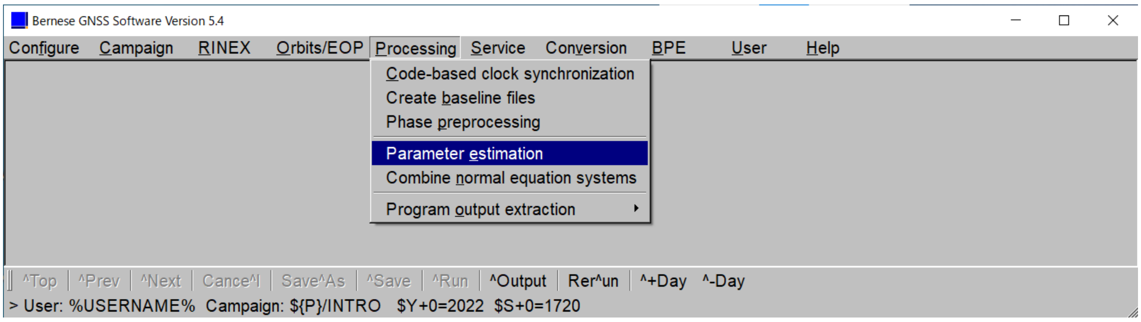


9.10. Ambiguity integerization (GPSEST)

QIF (Quasi Ionosphere Free)

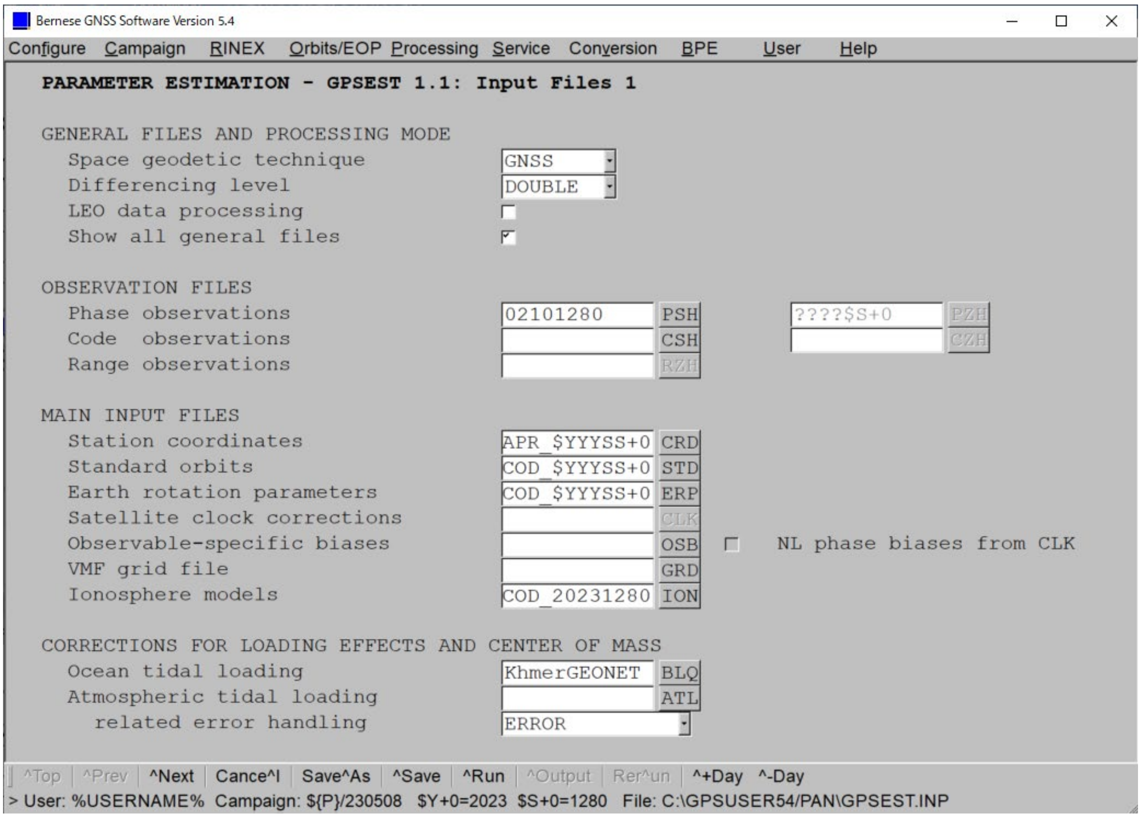
Calculate for each baseline.

Click [Parameter estimation] to display the submenu.



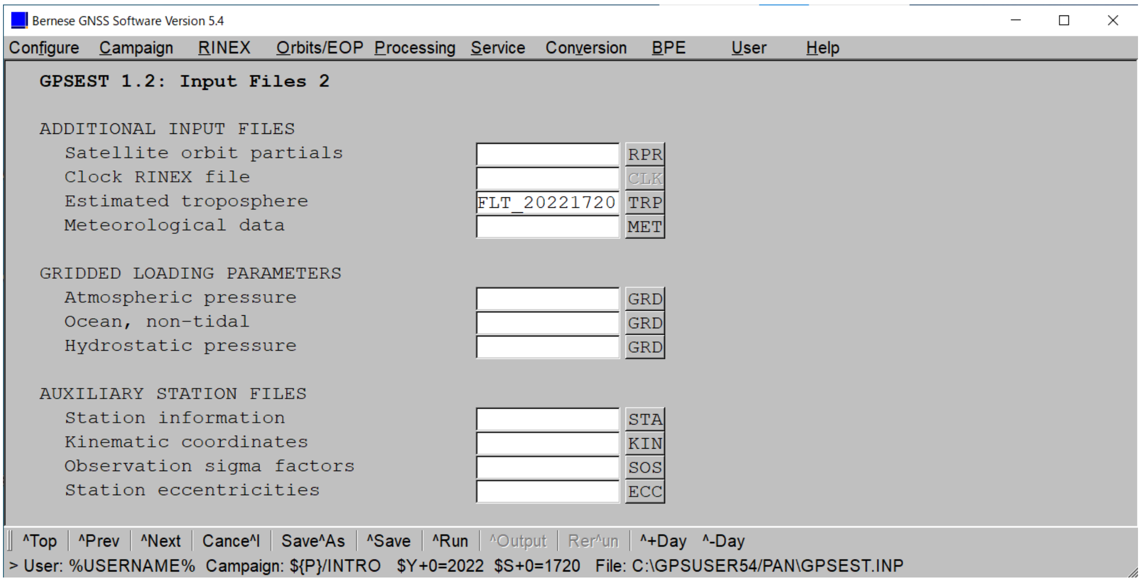
Select Input Files.

Click [^Next].



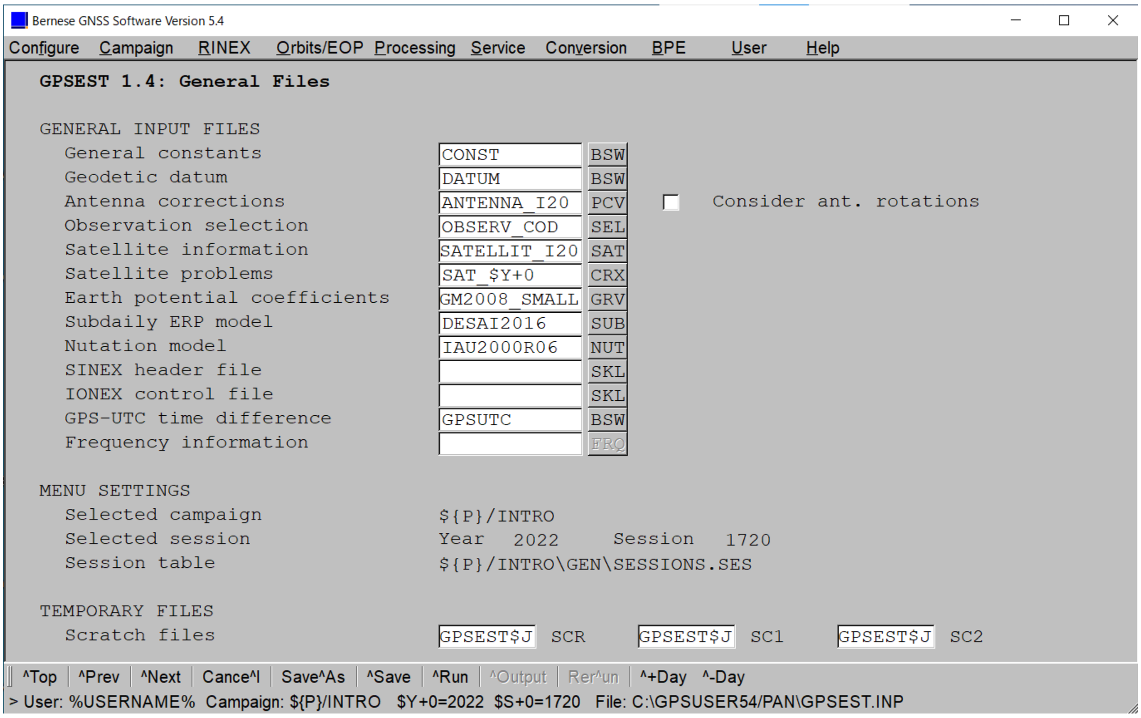
Select Troposphere estimates.

Click [^Next].



Select GENERAL INPUT FILES.

Click [^Next].



Program output is the filename of the result.

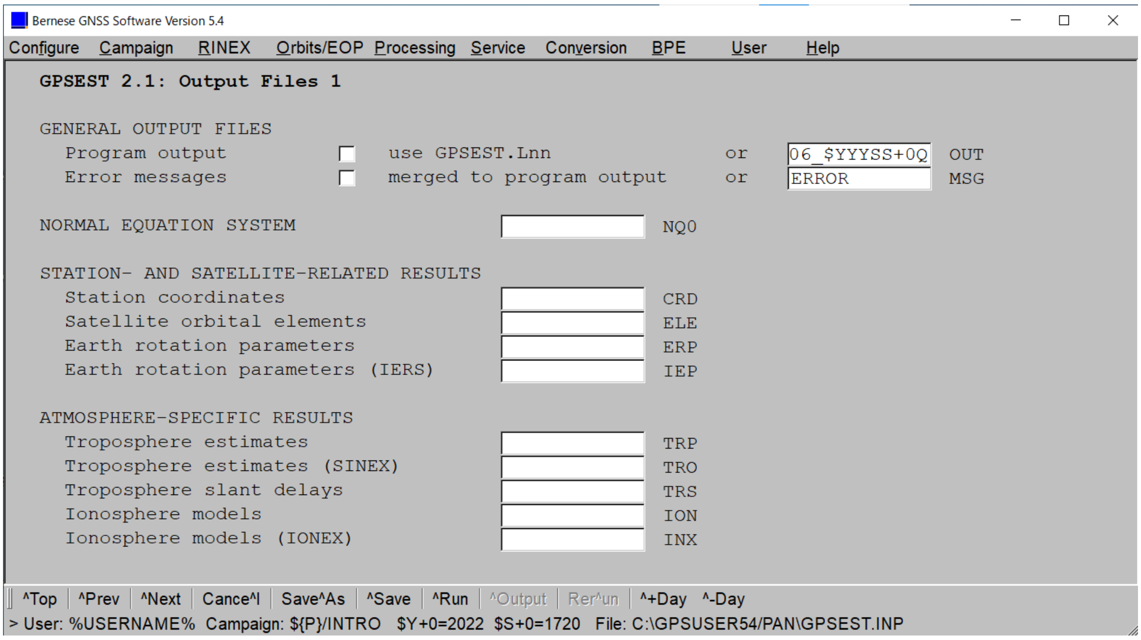
The file name is [QXXXX_$YYYSS+0.OUT].

[XXXX]: Base line

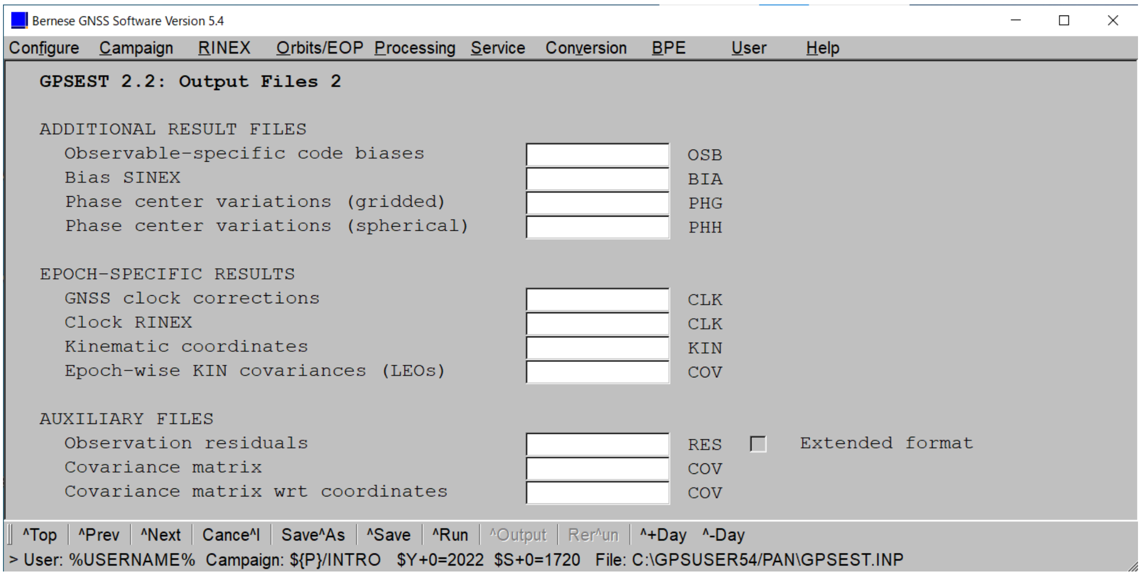
[$YYY]: Year

[SS]: Day of year

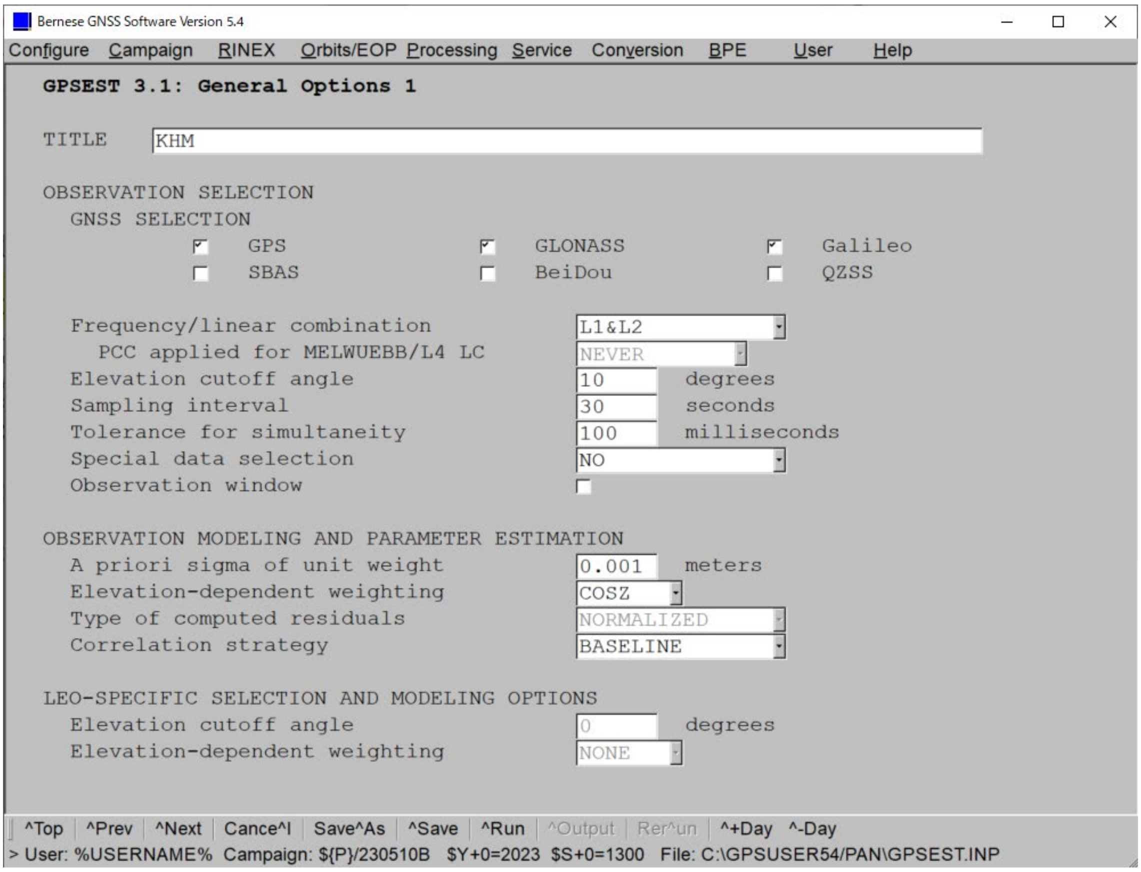
Click [^Next].



Click [^Next].

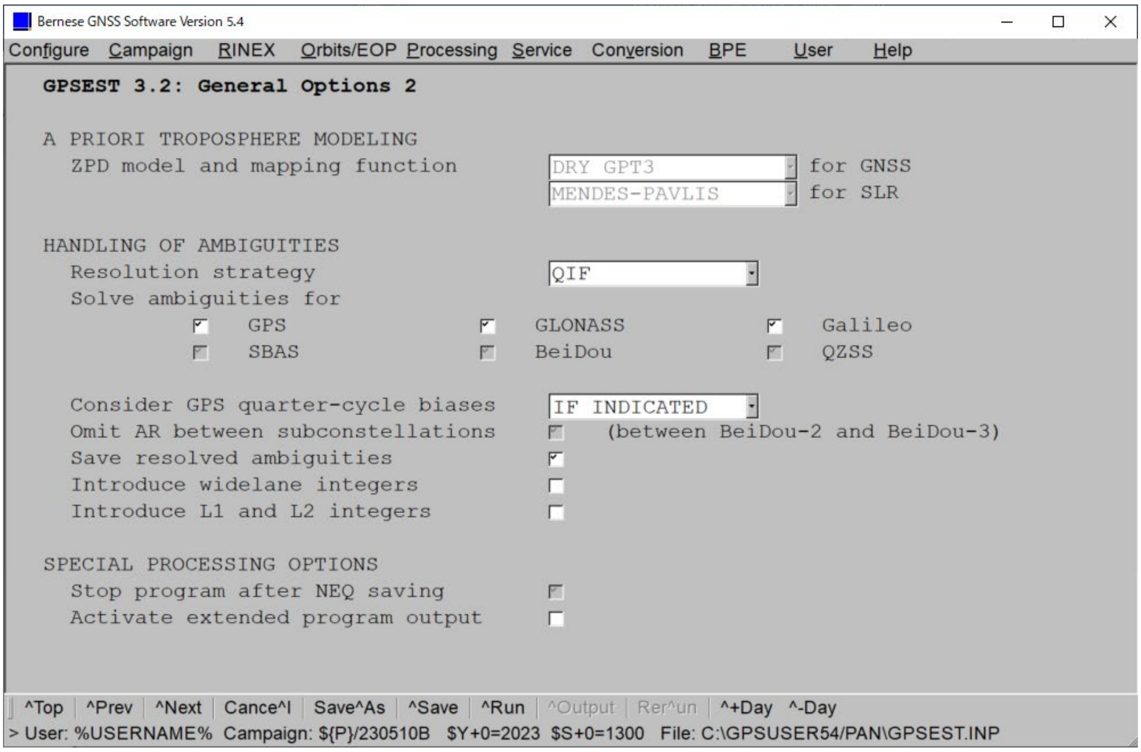


Click [^Next].

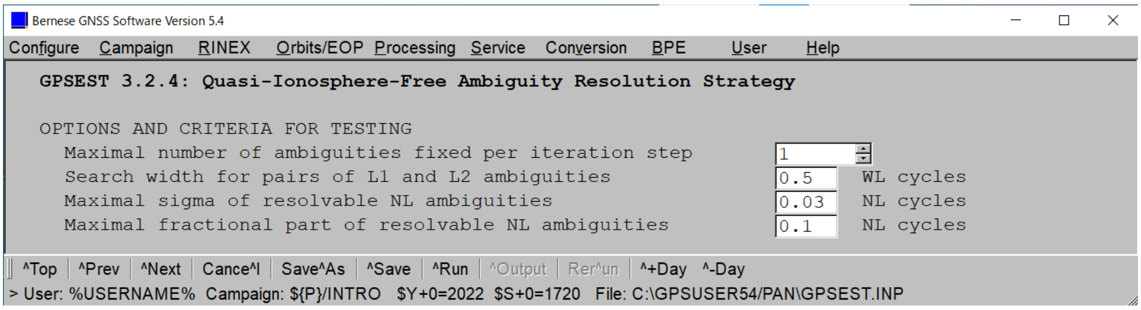


Bernese GNSS Software Version 5.4
Configure Campaign RINEX Orbits/EOP Processing Service Conversion BPE User Help
GPSEST 3.1: General Options 1
TITLE KHM
OBSERVATION SELECTION
GNSS SELECTION
GPS GLONASS Galileo
SBAS BeiDou QZSS
Frequency/linear combination L1&L2
PCC applied for MELWUEBB/L4 LC NEVER
Elevation cutoff angle 10 degrees
Sampling interval 30 seconds
Tolerance for simultaneity 100 milliseconds
Special data selection NO
Observation window
OBSERVATION MODELING AND PARAMETER ESTIMATION
A priori sigma of unit weight 0.001 meters
Elevation-dependent weighting COSZ
Type of computed residuals NORMALIZED
Correlation strategy BASELINE
LEO-SPECIFIC SELECTION AND MODELING OPTIONS
Elevation cutoff angle 0 degrees
Elevation-dependent weighting NONE
^Top ^Prev ^Next Cance^l Save^As ^Save ^Run ^Output Rer^un ^+Day ^-Day
> User: %USERNAME% Campaign: ${P}/230510B $Y+0=2023 $S+0=1300 File: C:\GPSUSER54/PAN\GPSEST.INP

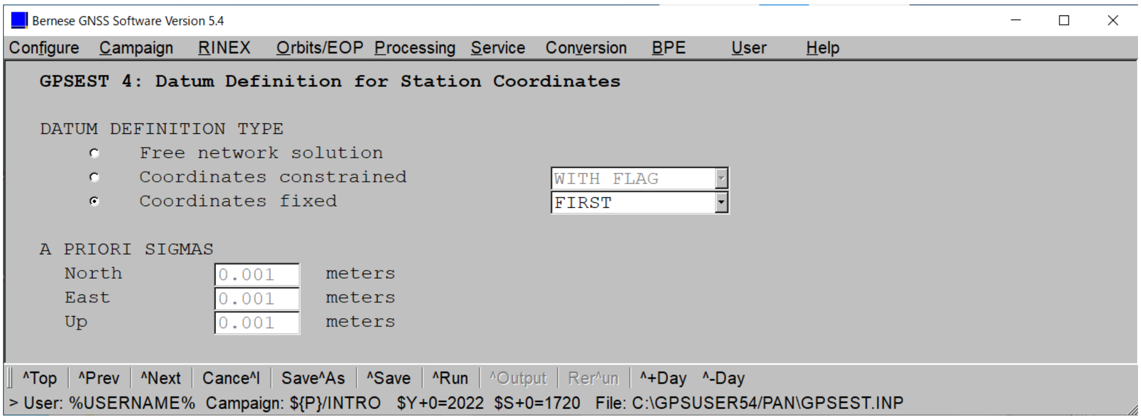
Click [^Next].



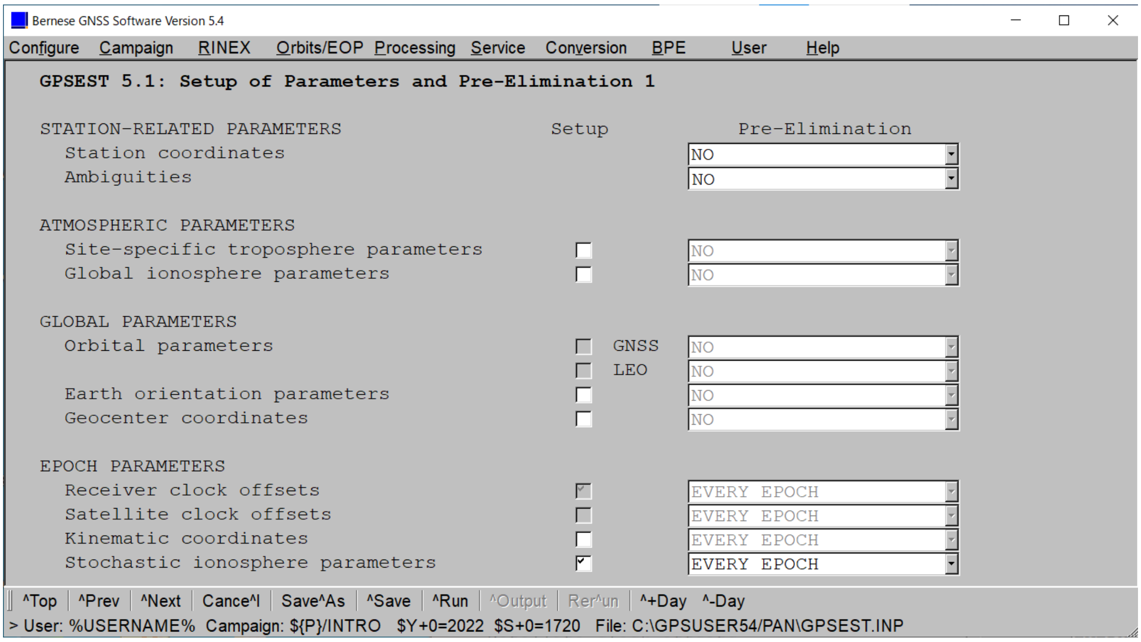
Click [^Next].



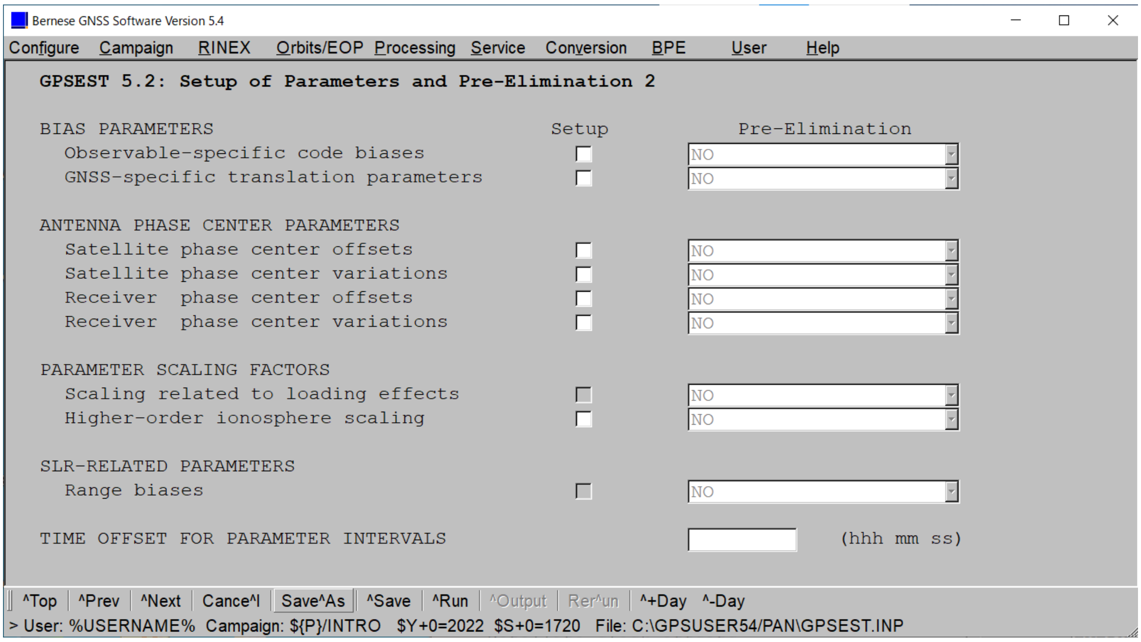
Click [^Next].



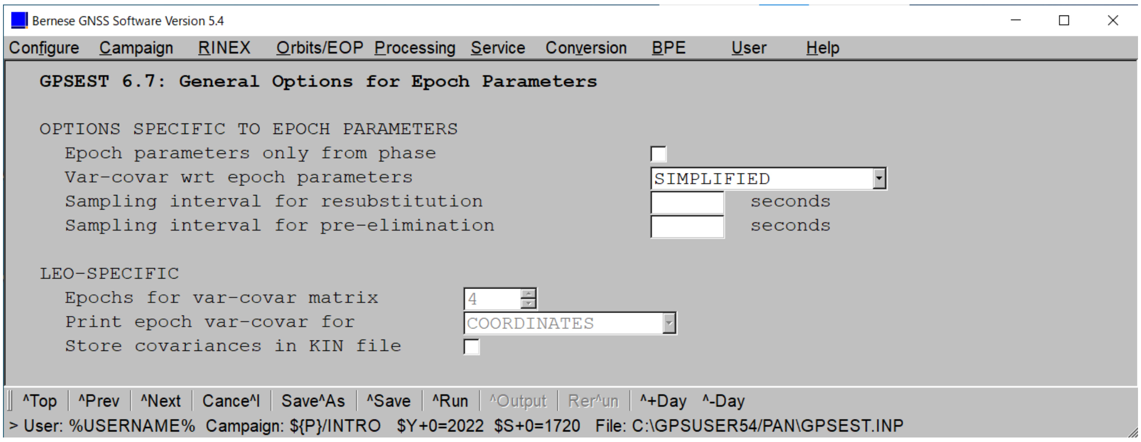
Click [^Next].



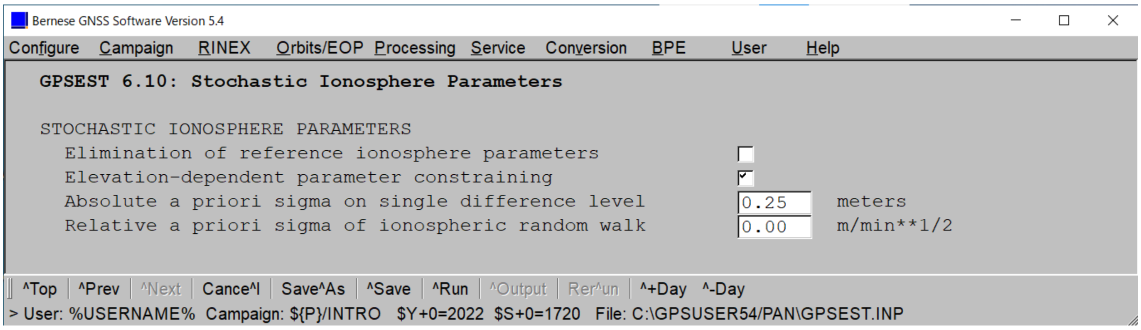
Click [^Next].



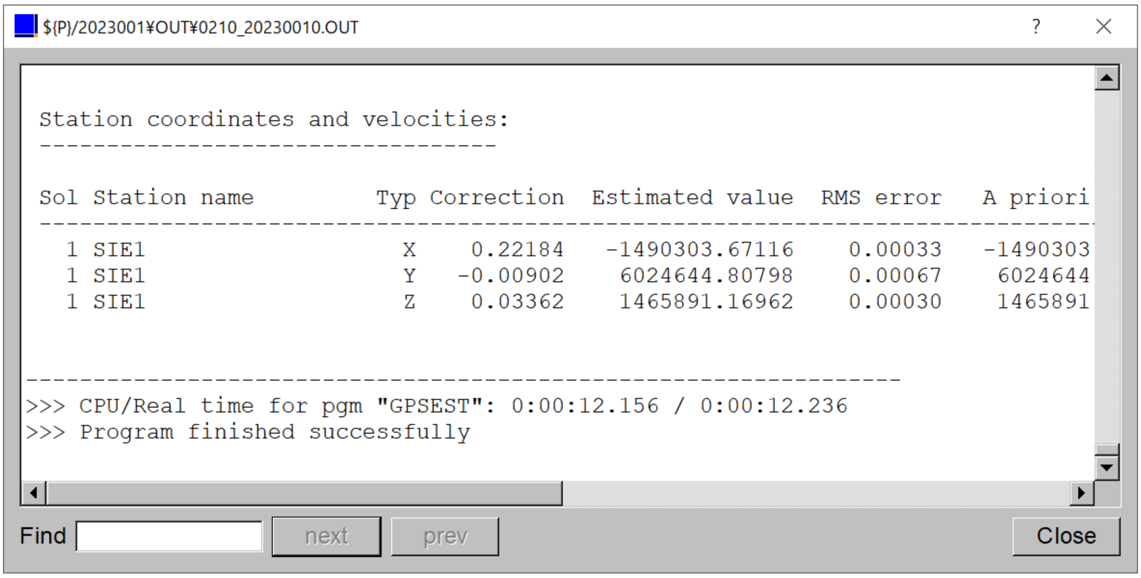
Click [^Next].



Click [^Next].



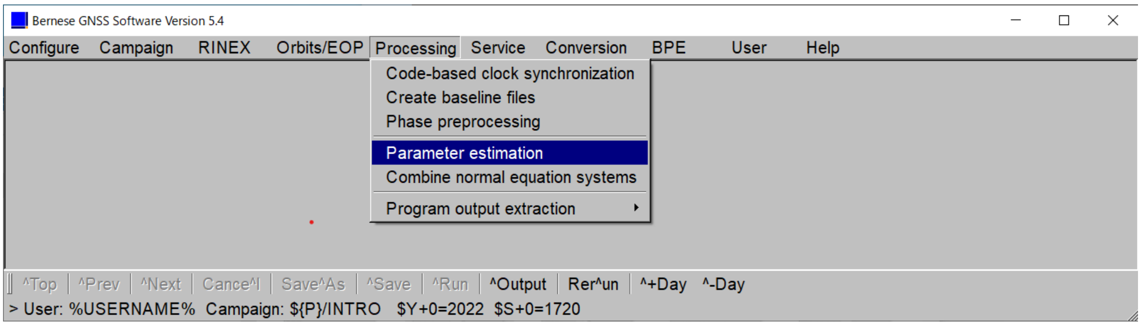
Check the results.



Repeat this calculation to create all required baselines.

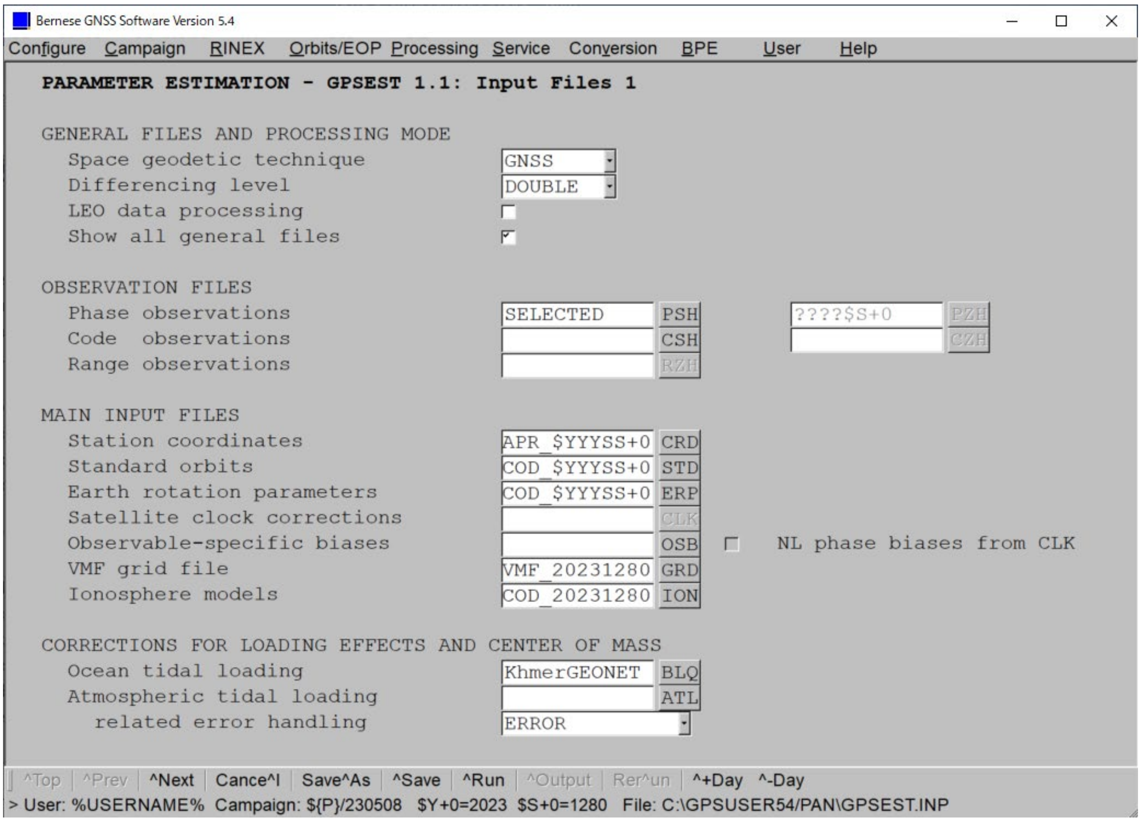
9.11. Creating a normal equation file (GPSEST)

Click [Parameter estimation] to display the submenu.

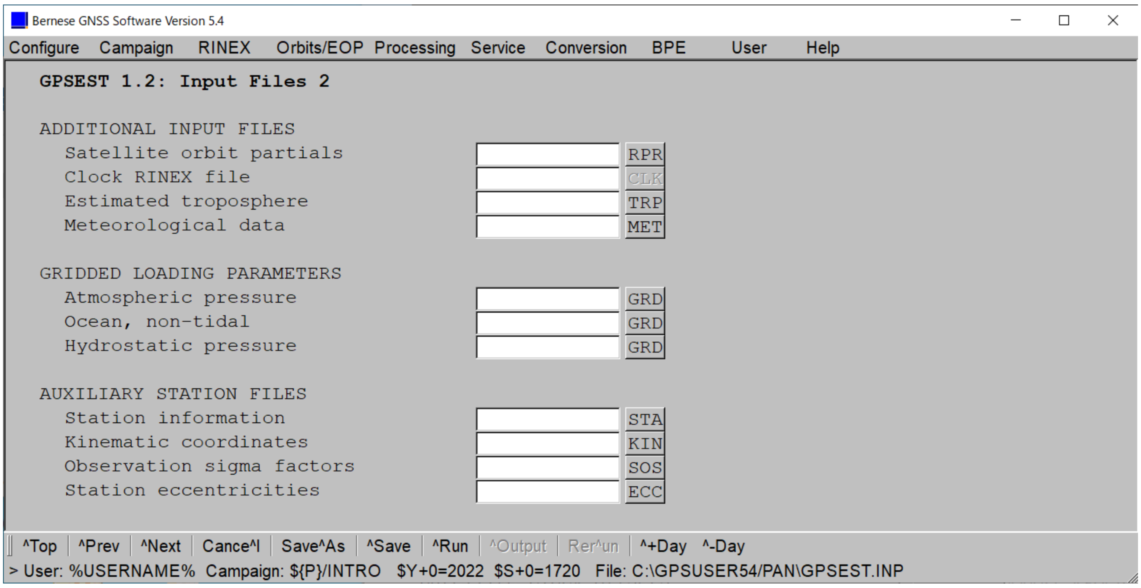


Select Input Files.

Click [^Next].

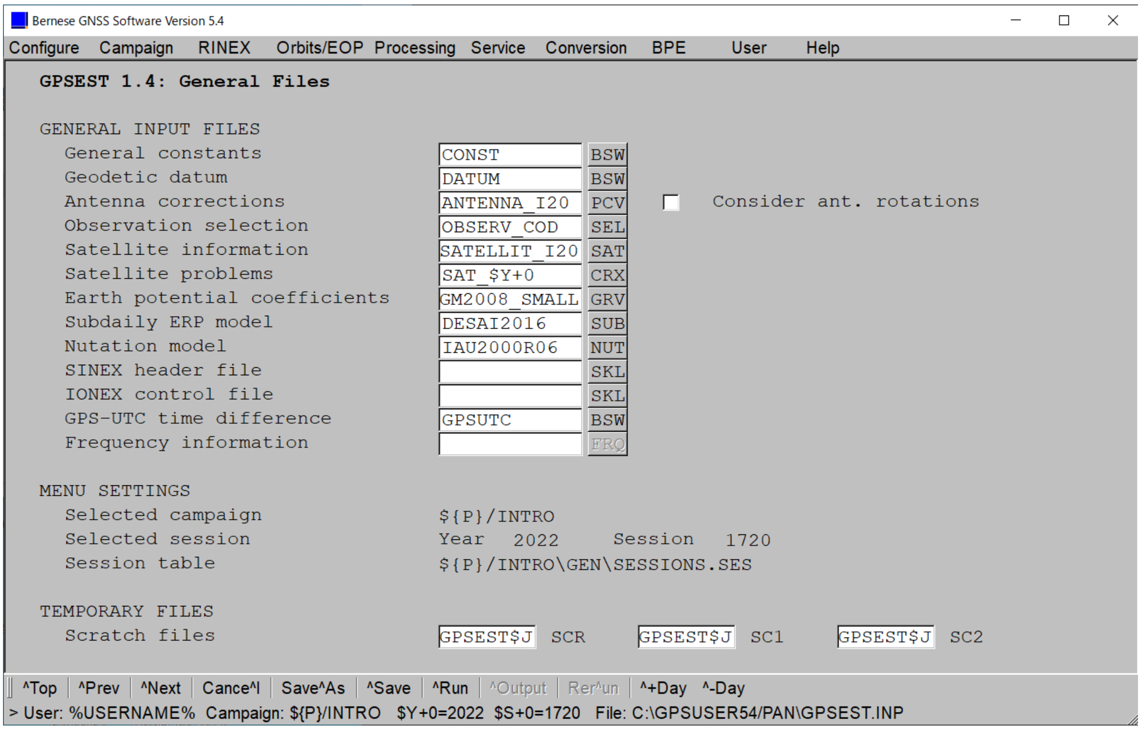


Click [^Next].

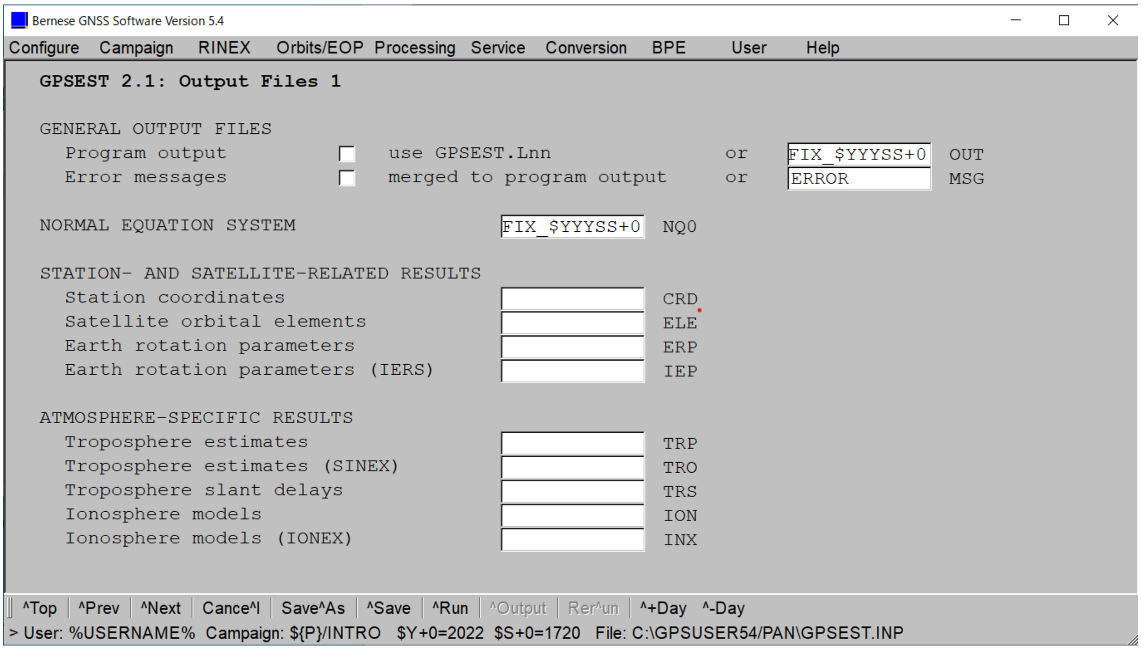


Select GENERAL INPUT FILES.

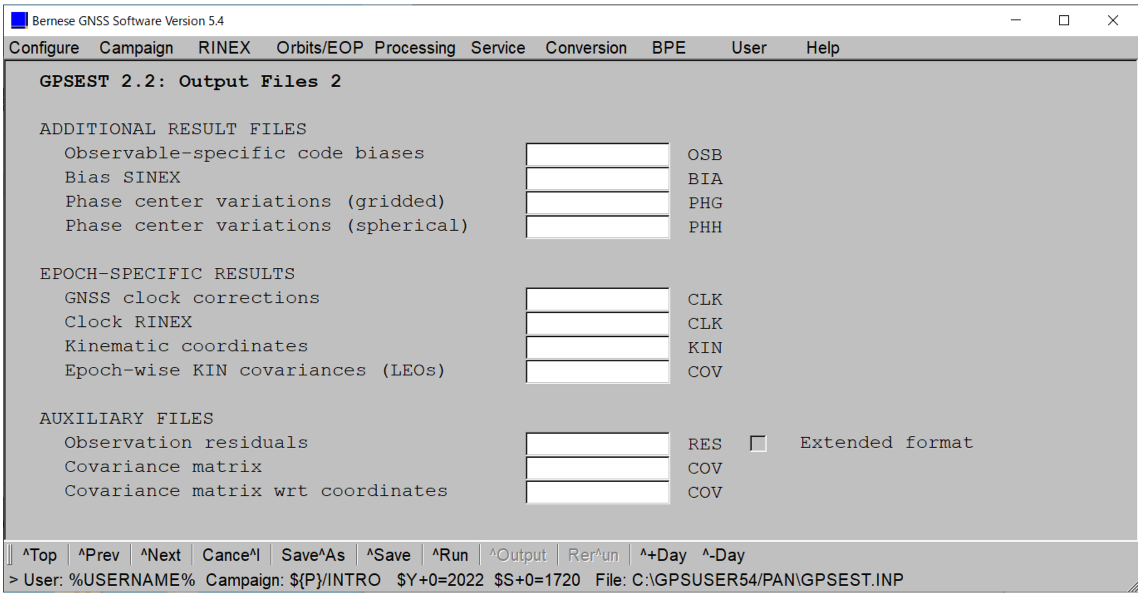
Click [^Next].



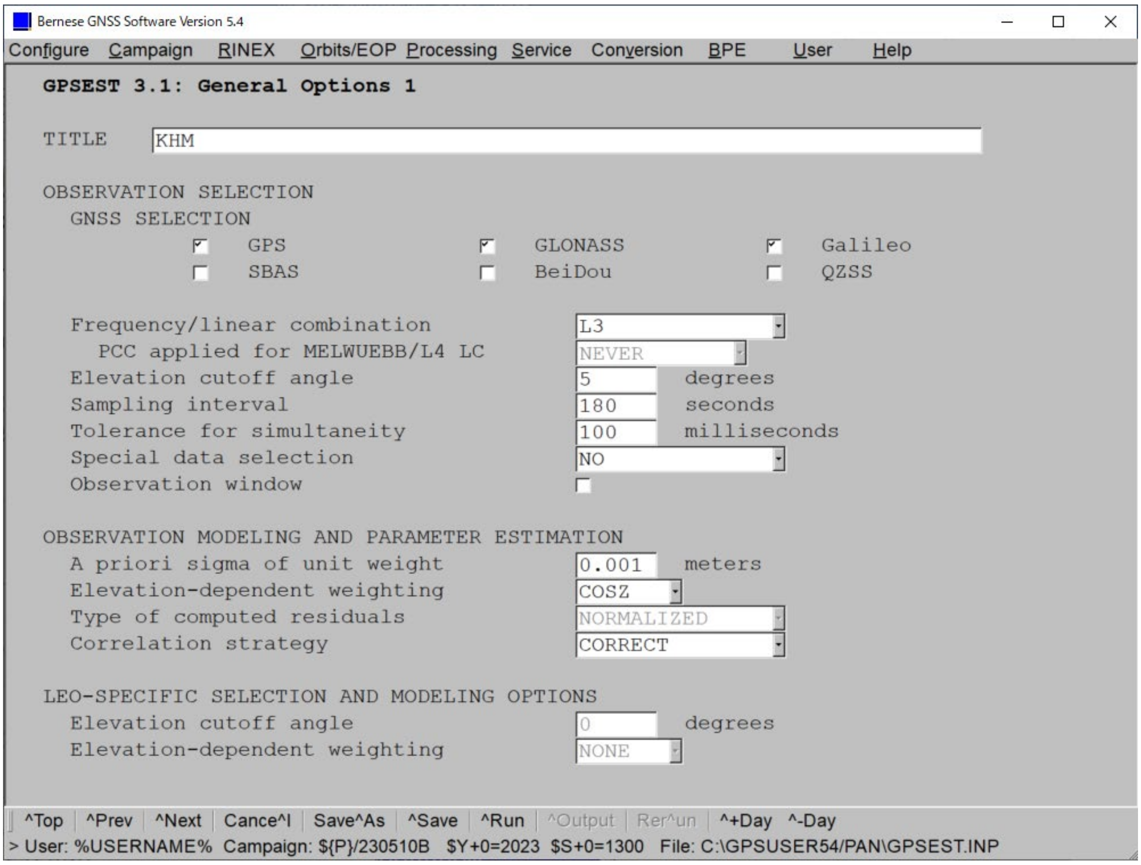
Click [^Next].



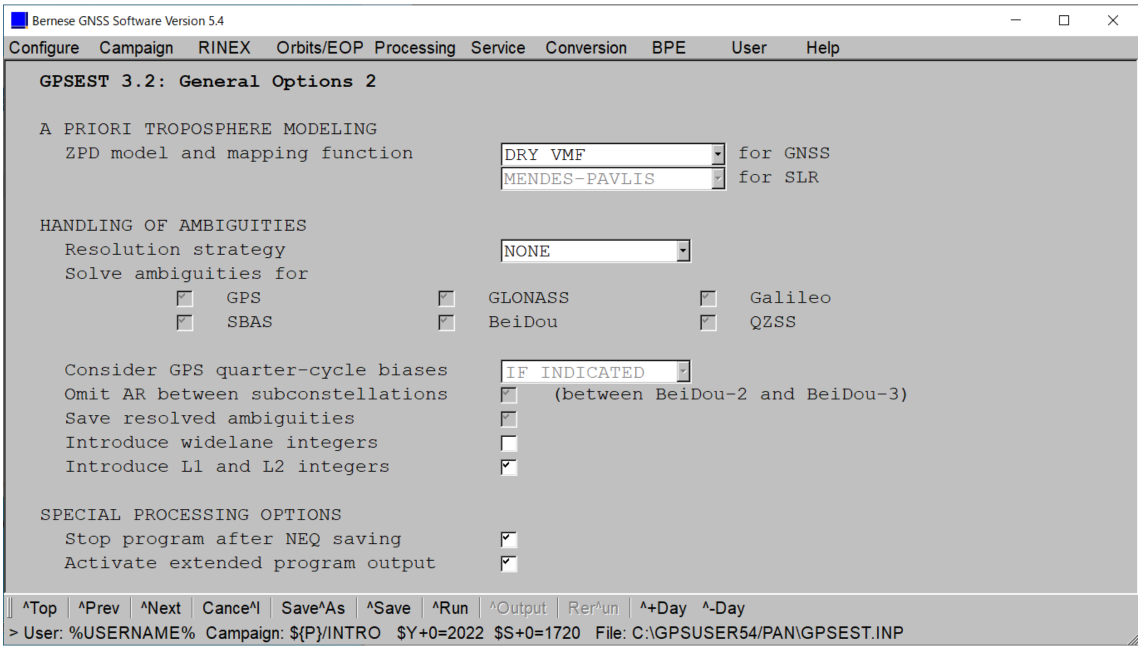
Click [^Next].



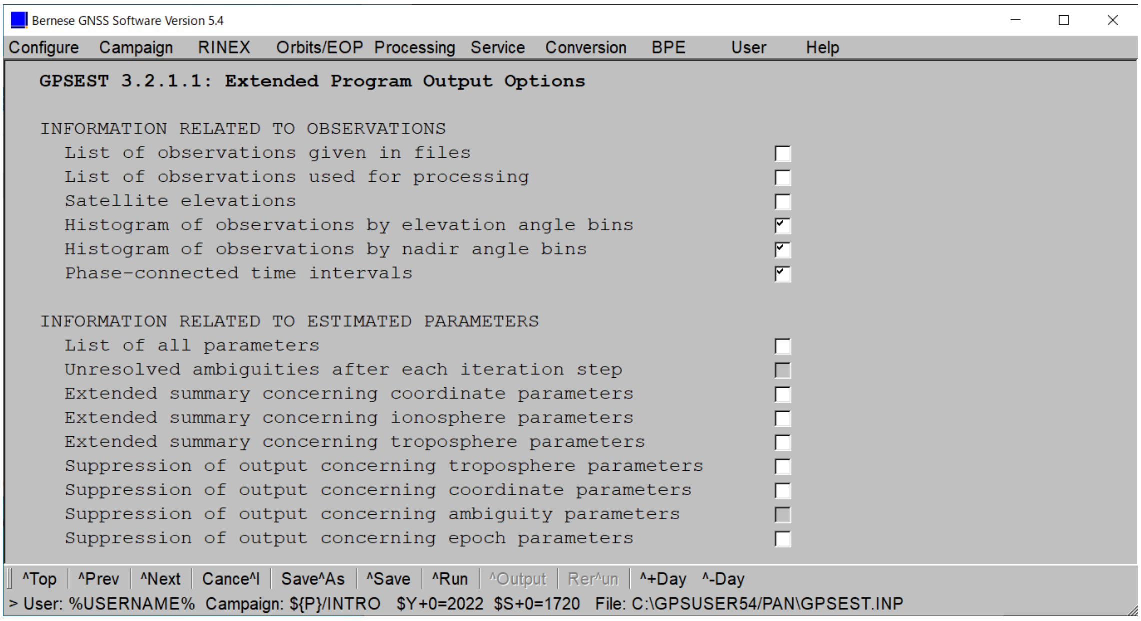
Click [^Next].



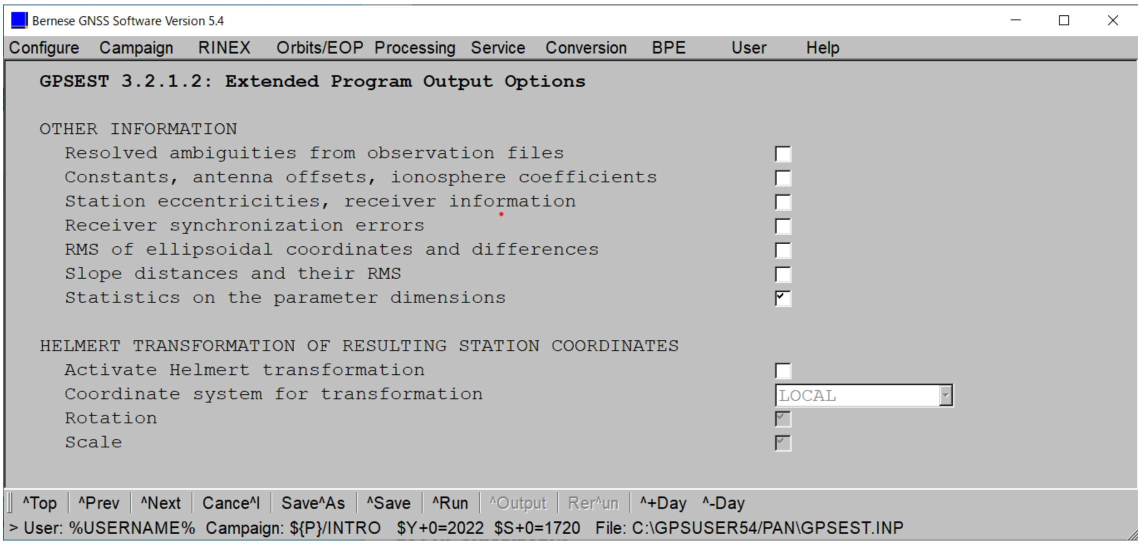
Click [^Next].



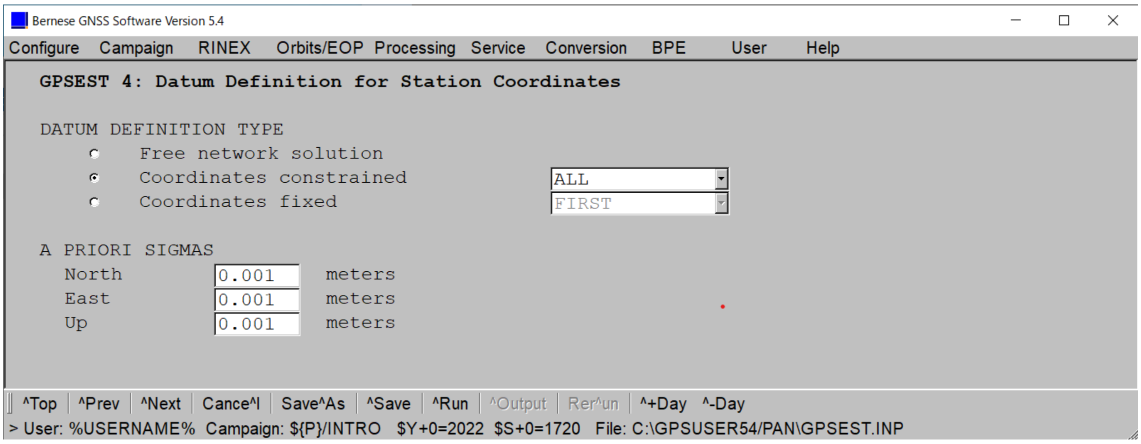
Click [^Next].



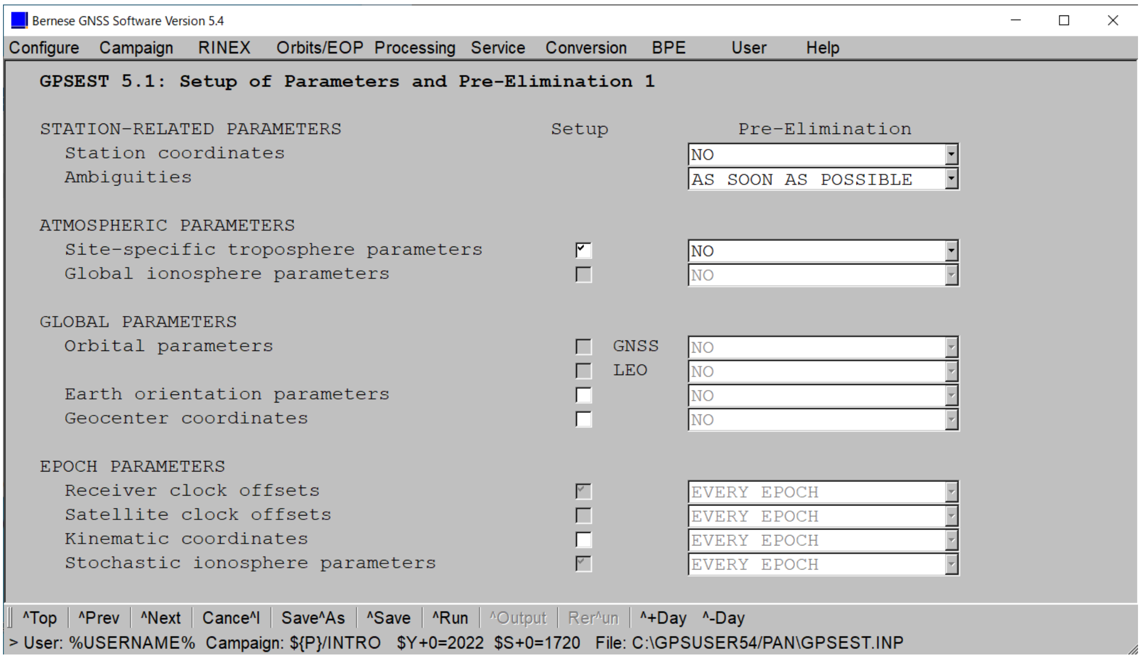
Click [^Next].



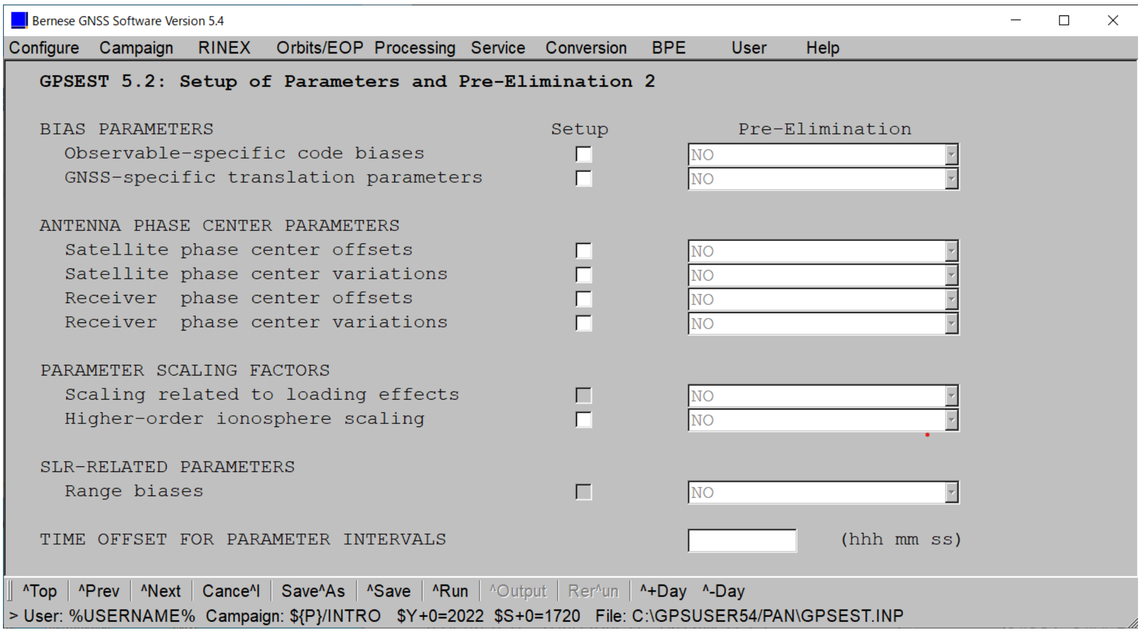
Click [^Next].



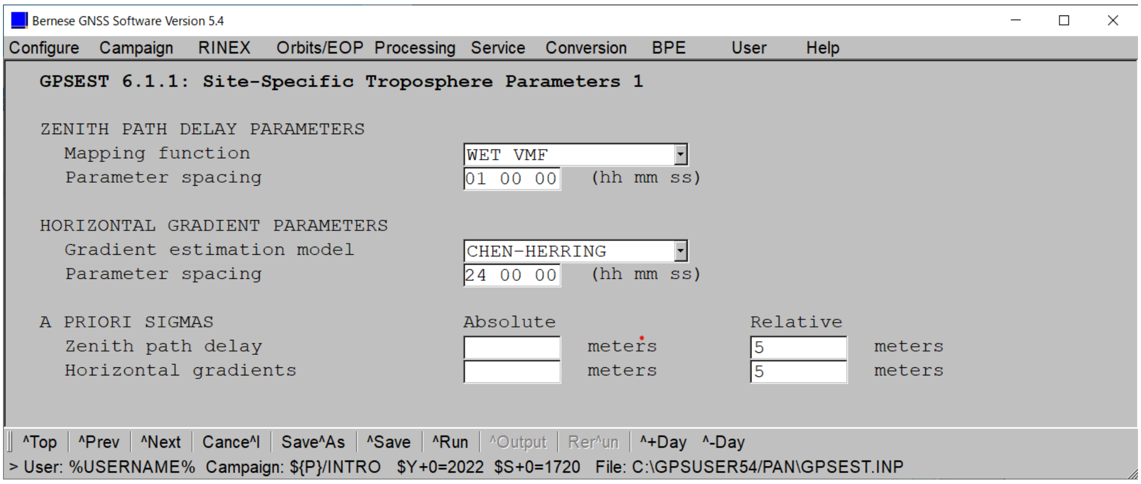
Click [^Next].



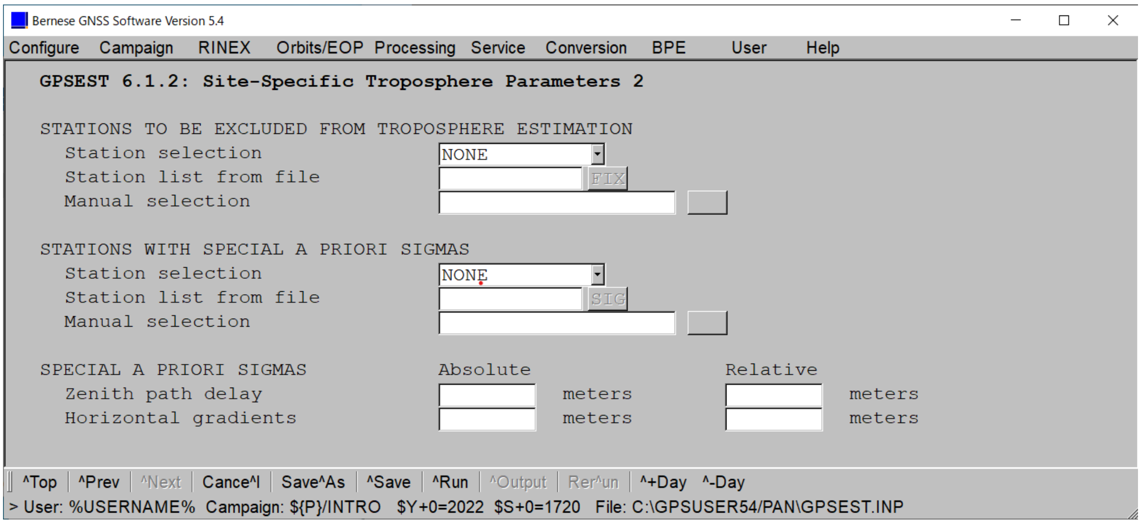
Click [^Next].



Click [^Next].



Click [^Run].


Bernese GNSS Software Version 5.4
Configure Campaign RINEX Orbits/EOP Processing Service Conversion BPE User Help
GPSEST 6.1.2: Site-Specific Troposphere Parameters 2
STATIONS TO BE EXCLUDED FROM TROPOSPHERE ESTIMATION
Station selection
NONE
Station list from file
FIX
Manual selection
STATIONS WITH SPECIAL A PRIORI SIGMAS
Station selection
NONE
Station list from file
SIG
Manual selection
SPECIAL A PRIORI SIGMAS
Absolute
Relative
Zenith path delay
meters
meters
Horizontal gradients
meters
meters
^Top ^Prev ^Next Cance^l Save^As ^Save ^Run ^Output Rer^un ^+Day ^-Day
> User: %USERNAME% Campaign: ${P}/INTRO $Y+0=2022 $S+0=1720 File: C:\GPSUSER54/PAN\GPSEST.INP

Click [^Output].

Check the results.

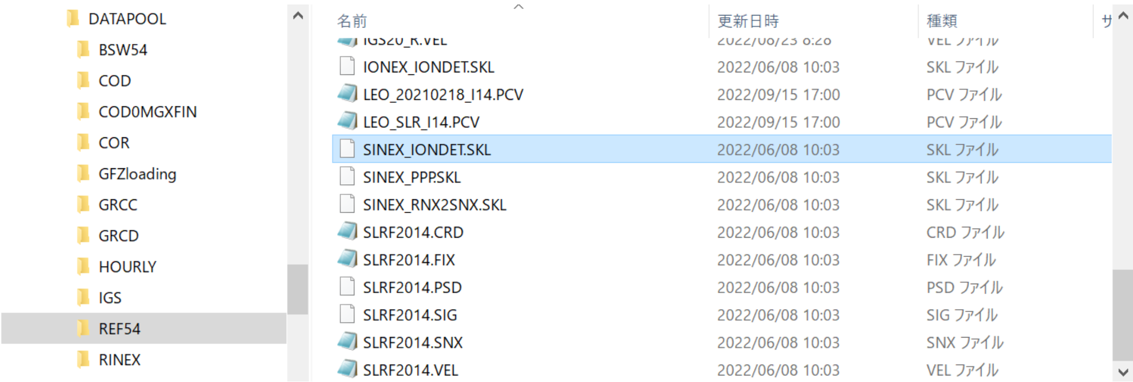
${P}/2023001¥OUT¥FIX_20230010.OUT

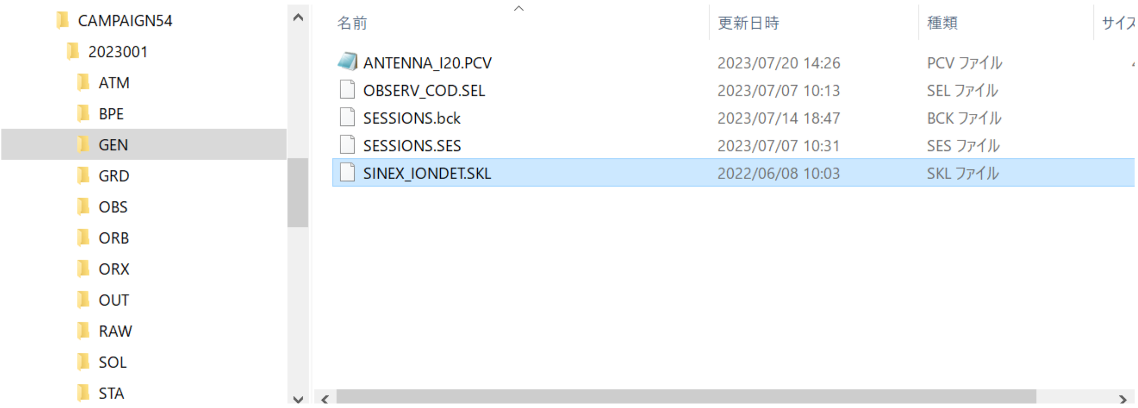
```
SUMMARY OF RESULTS
------------------

Number of parameters:
--------------------

Parameter type                              Adjusted   Explicitly   Implicitly
-------------------------------------------------------------------------------
Station coordinates / velocities                  33           33            0
Ambiguities                                      704            0          704
Site-specific troposphere parameters             319          319            0
-------------------------------------------------------------------------------
Total number                                    1046          352          694


*Abbreviation pre-elimination (elim): before stacking (bfst),  after stacking


Statistics:
----------

Total number of authentic observations      58672
Total number of pseudo-observations             0
Total number of observations                58672

Total number of explicit parameters           352
Total number of implicit parameters           694
Total number of parameters                   1046


Total number of observation files              10
Total number of stations                       11
Total number of satellites                      0



-----------------------------------------------------------------
>>> CPU/Real time for pgm "GPSEST": 0:00:17.344 / 0:00:17.427
>>> Program finished successfully
```

Find next prev Close

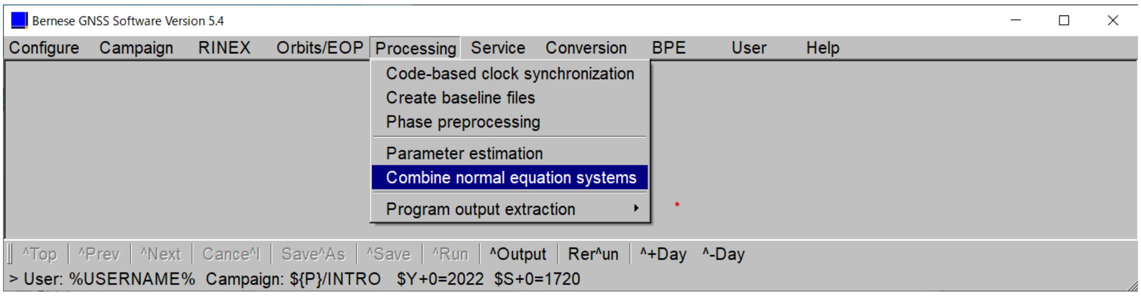
9.12. Calculation of coordinate values (ADDNEQ2)

Copy the [SINEX_IONDET.SKL] file of the DATAPOOL folder to [GEN] folder of the campaign.

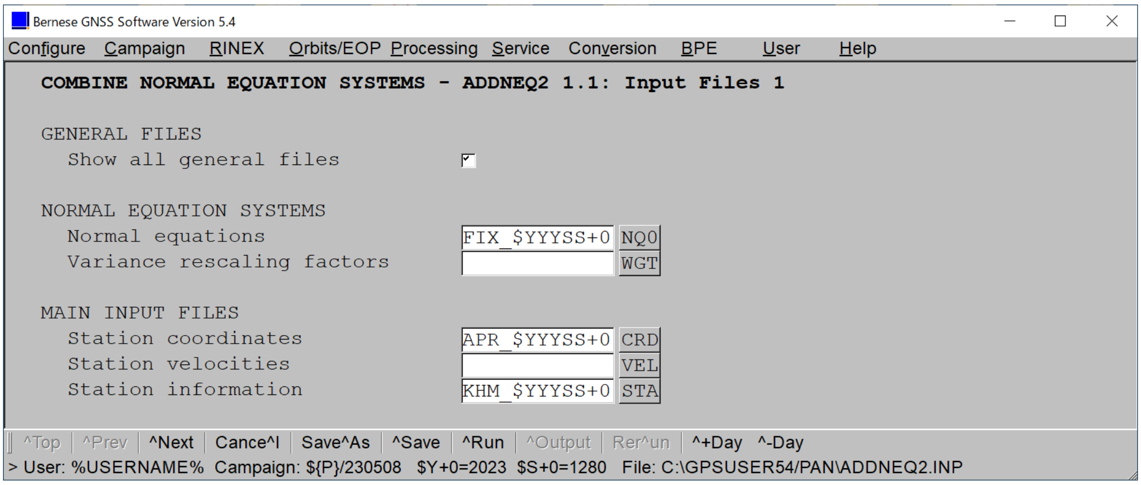




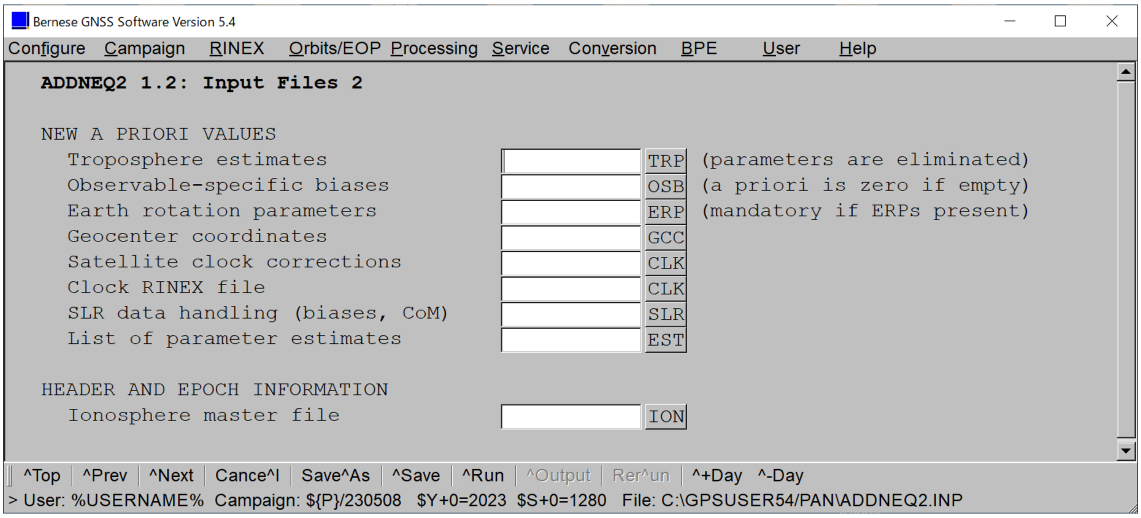
Click [Combine normal equation systems] to display the submenu.



Click [^Next].

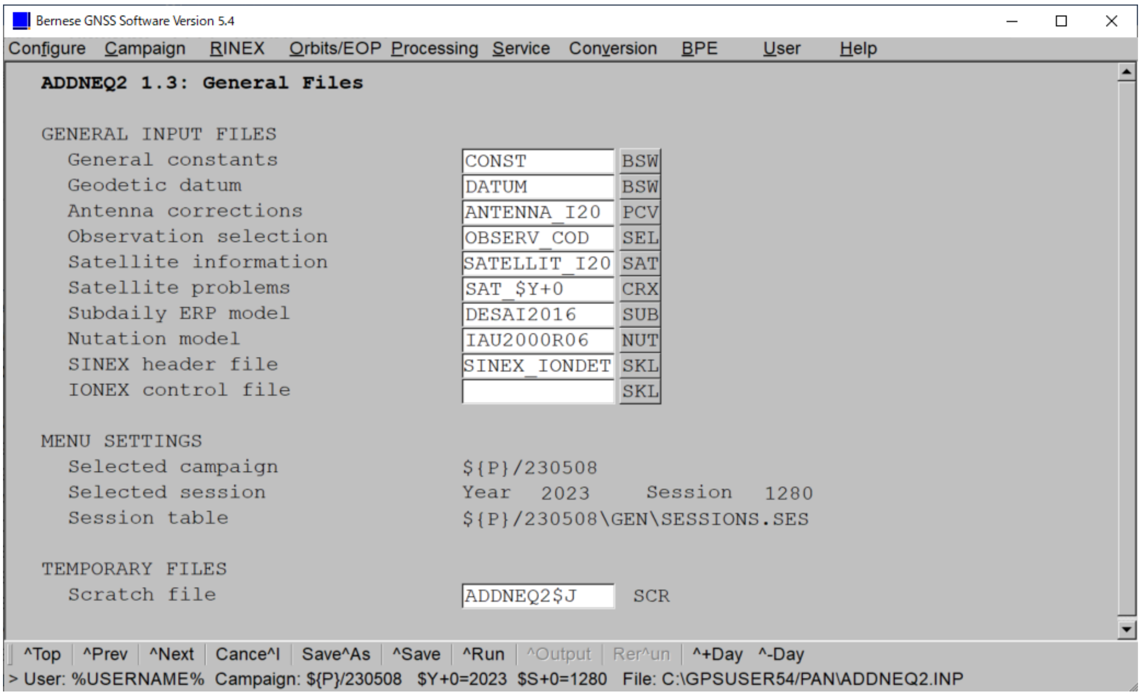


Click [^Next].

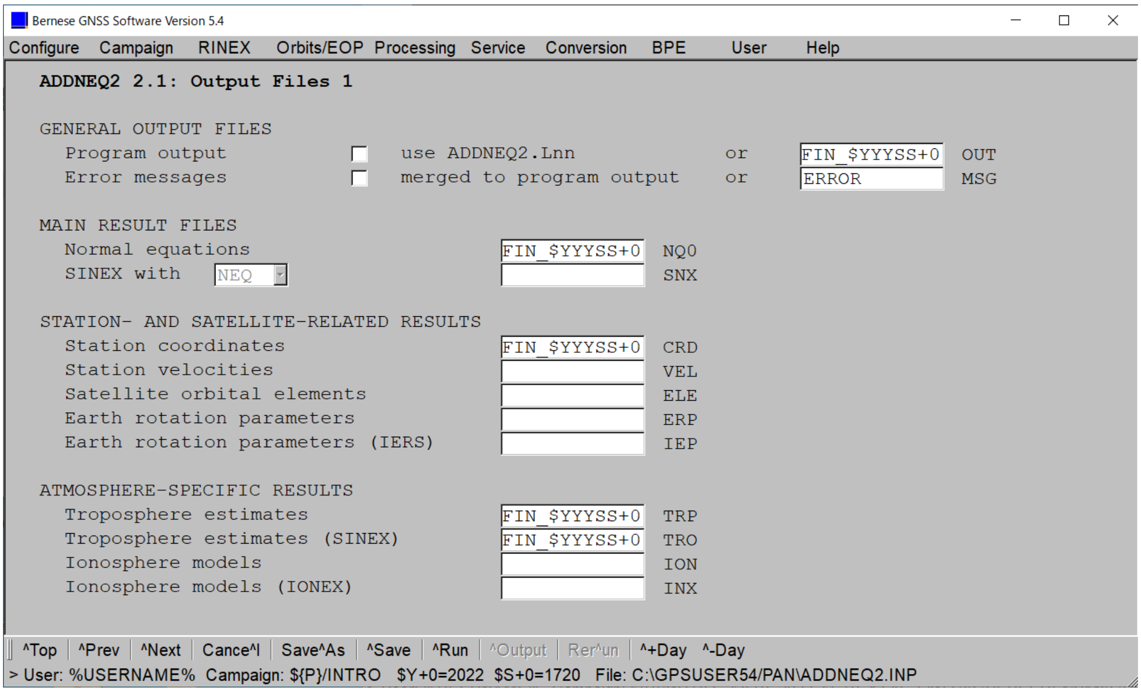


Select General Files.

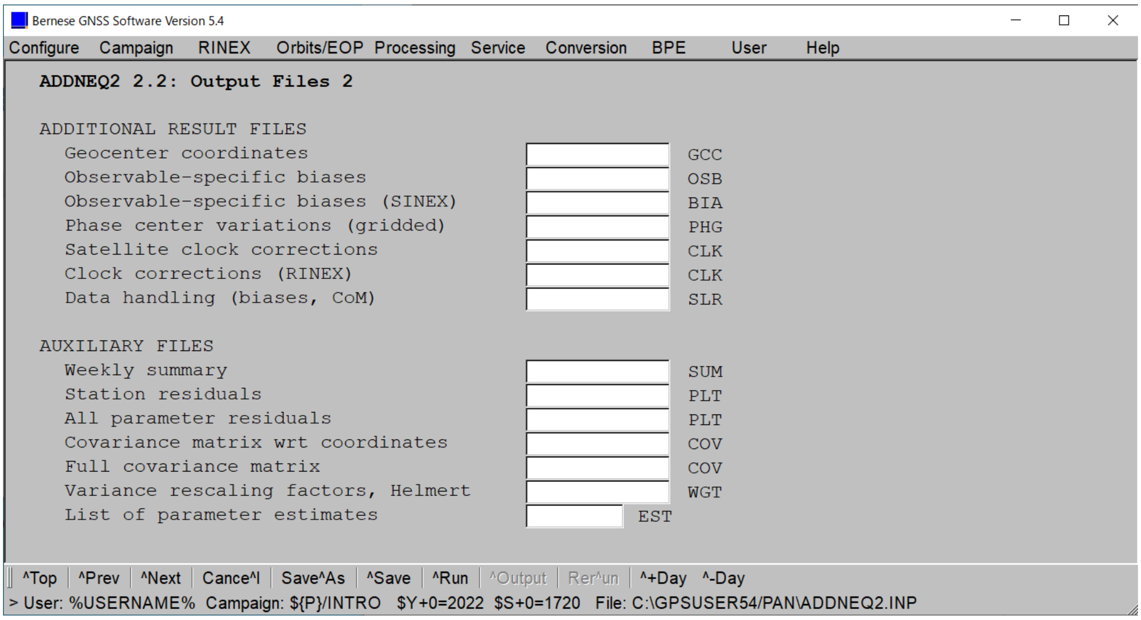
Click [^Next].



Click [^Next].

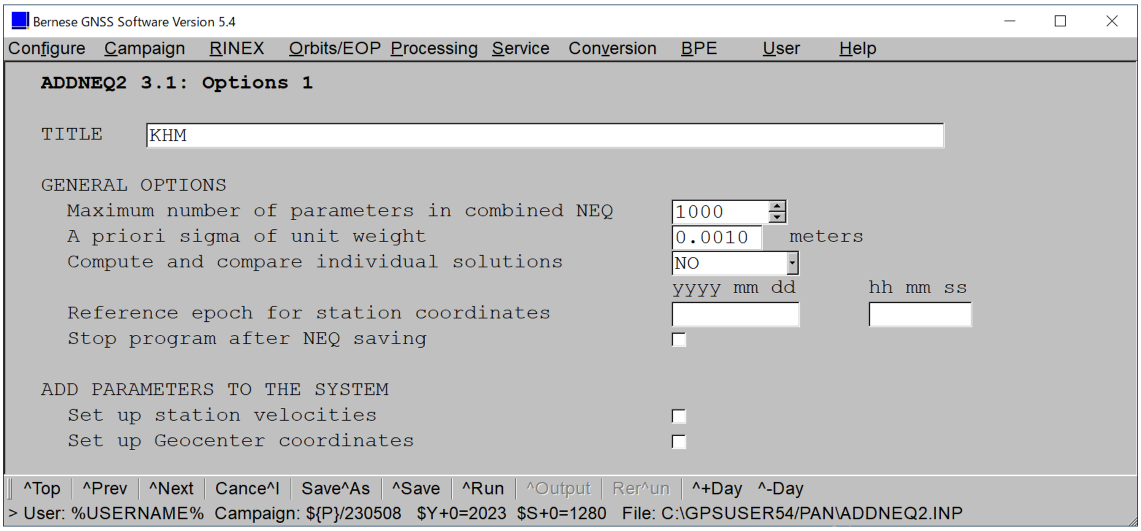


Click [^Next].

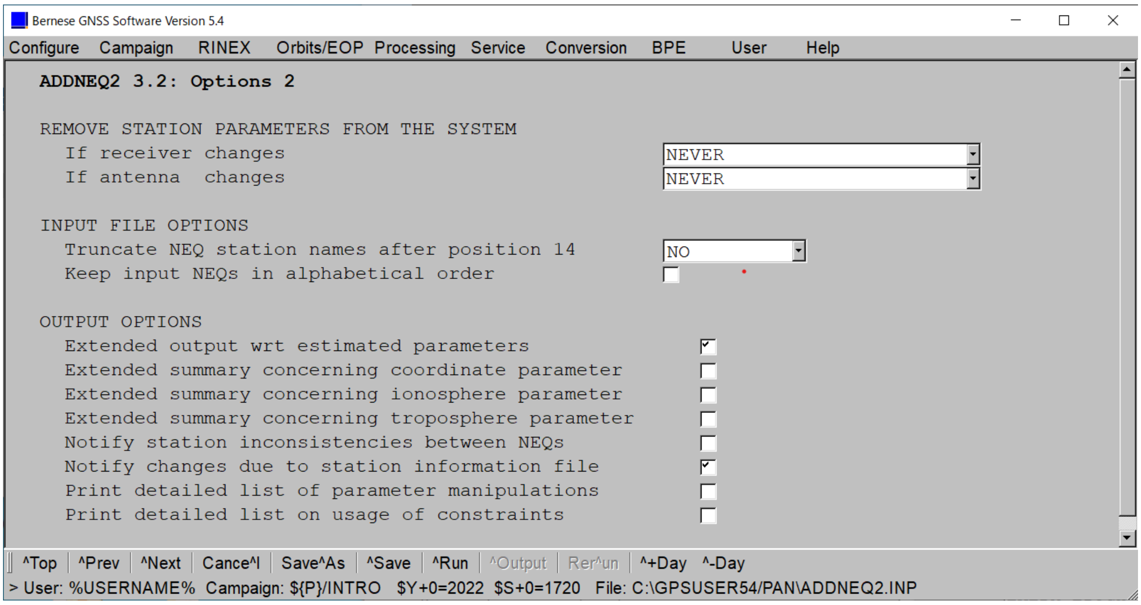


Enter TITLE.

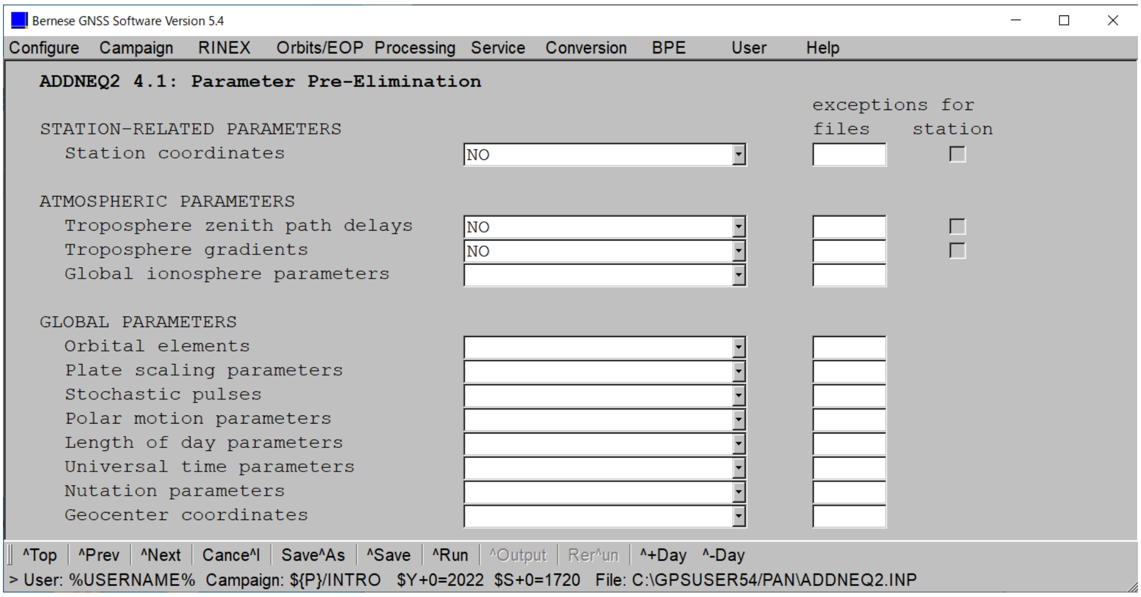
Click [^Next].



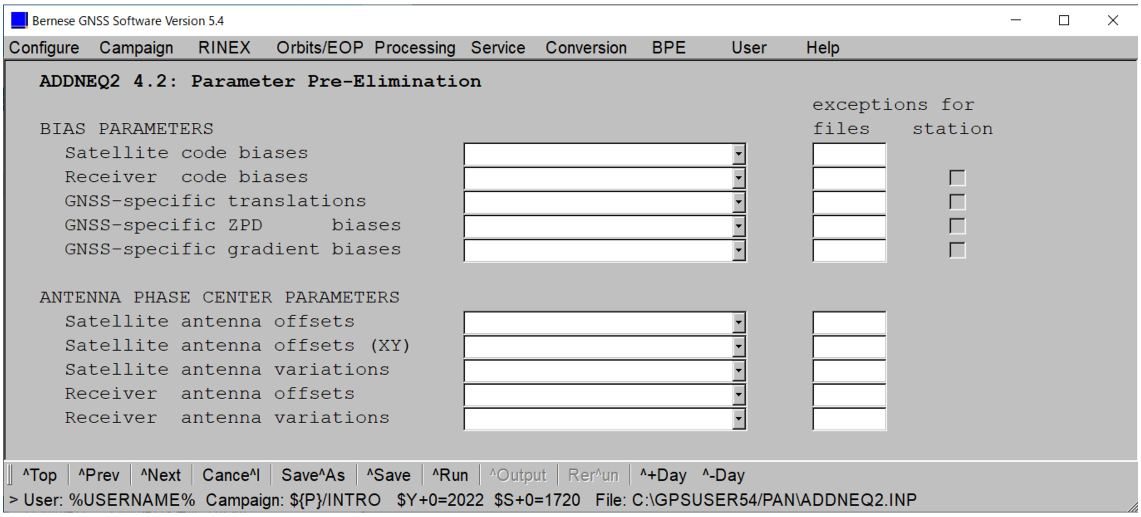
Click [^Next].



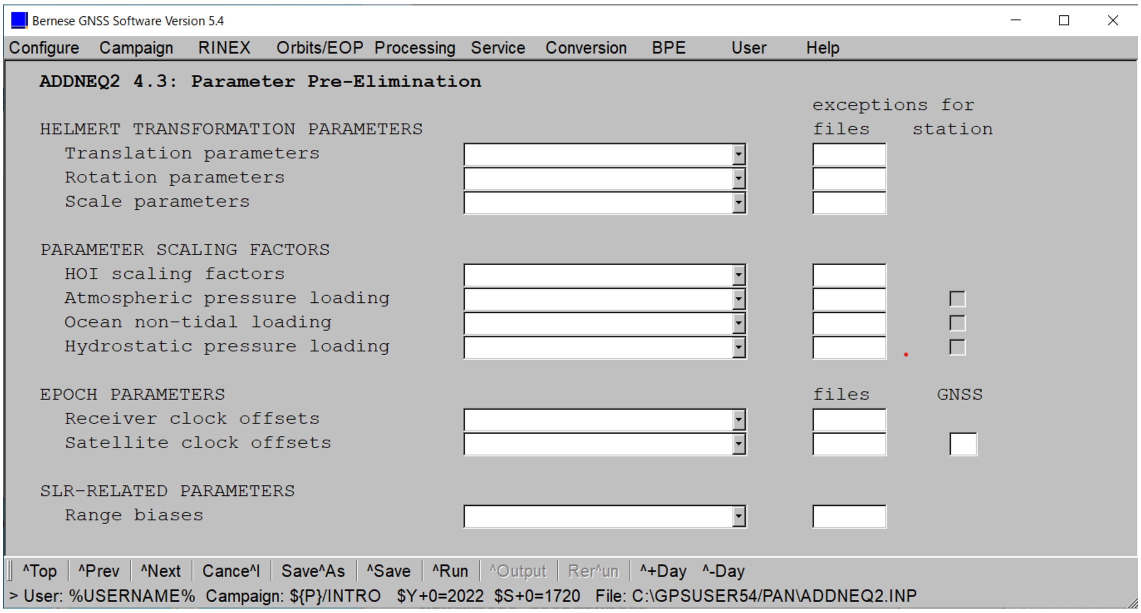
Click [^Next].



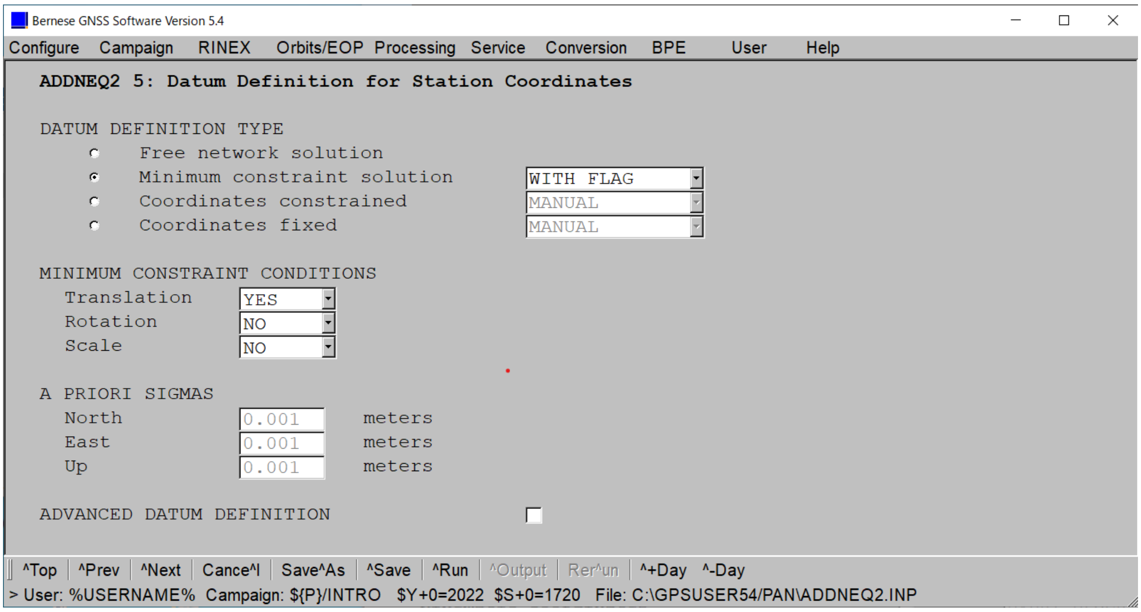
Click [^Next].



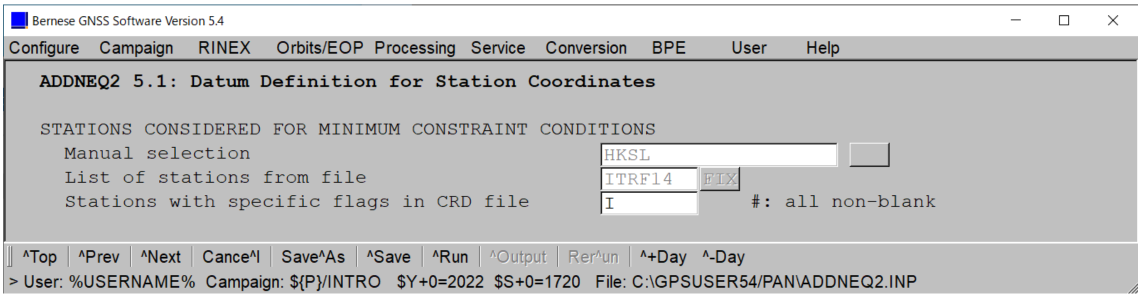
Click [^Next].



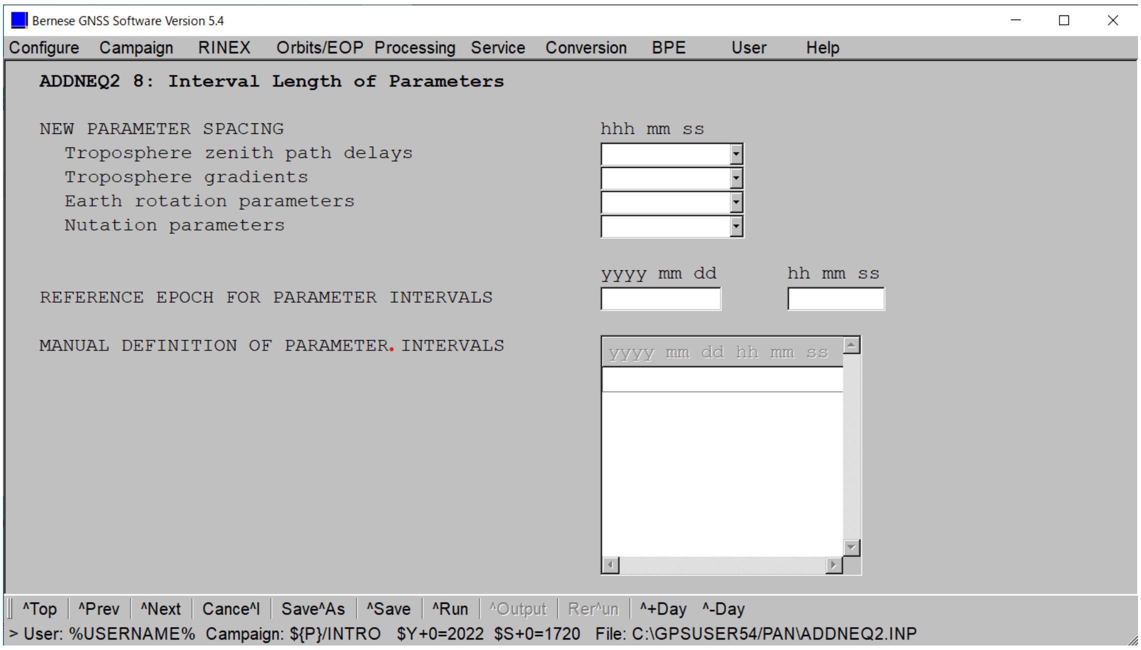
Click [^Next].



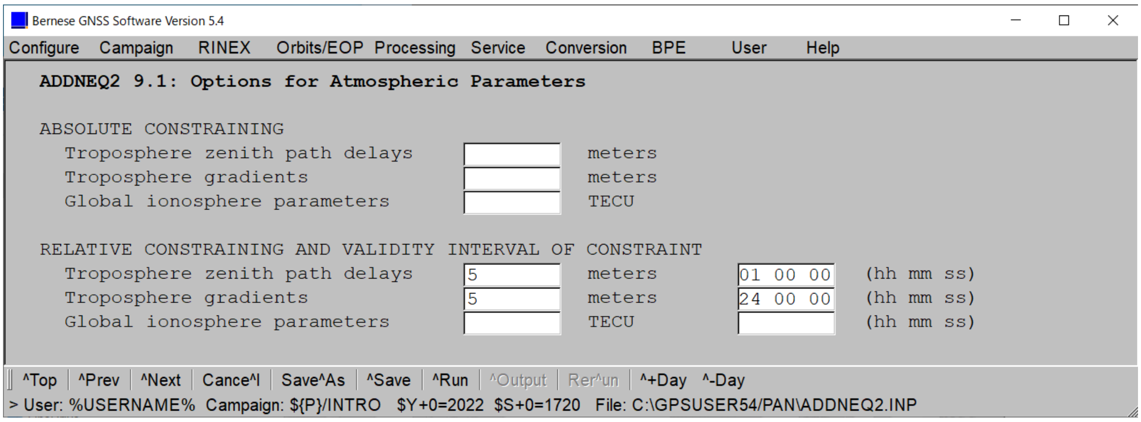
Click [^Next].



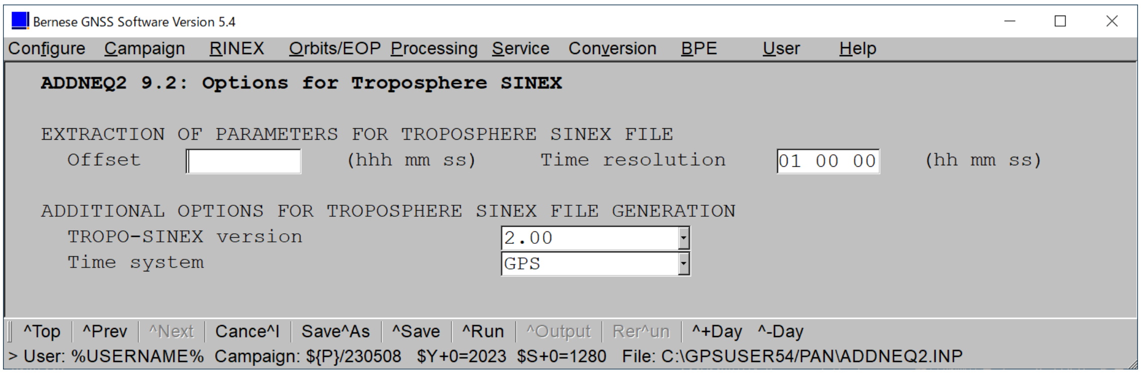
Click [^Next].



Click [^Next].



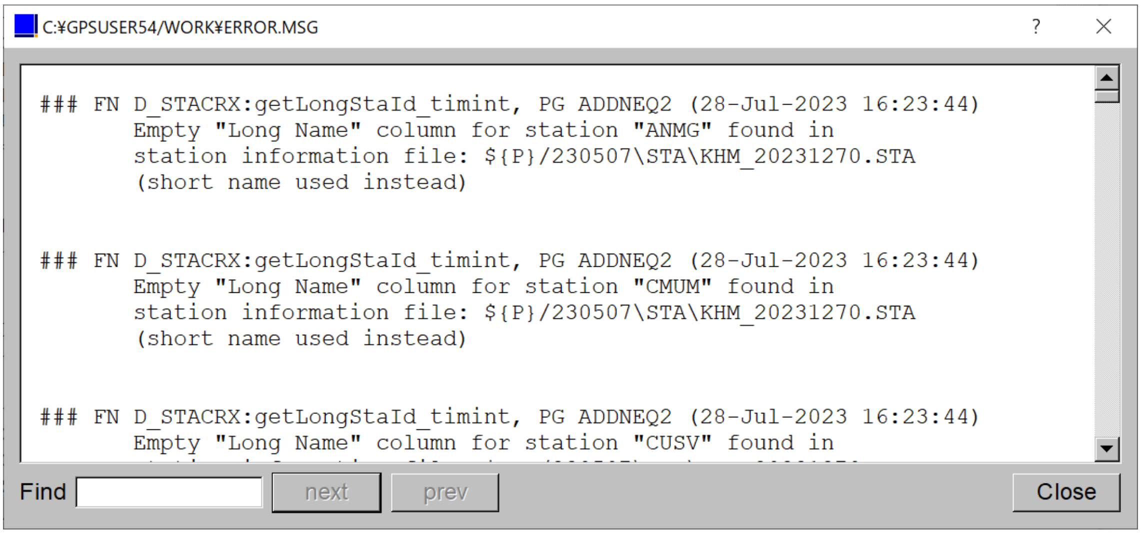
Click [^Run].



Click [^Output].

Check the results.

Ignore the following warnings.



${P}/INTRO¥OUT¥FIN_20221720.OUT

```
*Abbreviation pre-elimination (elim): before stacking (bfst),  after stacking


Statistics:
----------

Total number of authentic observations        57958
Total number of pseudo-observations             289

Total number of explicit parameters             352
Total number of implicit parameters             710

Total number of observations                  58247
Total number of adjusted parameters            1062
Degree of freedom (DOF)                       57185

A posteriori RMS of unit weight            0.001807 m
Chi**2/DOF                                     3.26

Total number of observation files                10
Total number of stations                         11
```

Find | next | prev | Close

${P}/INTRO¥OUT¥FIN_20221720.OUT

Station coordinates and velocities:

Sol	Station name	Typ	Correction	Estimated value	RMS error	A priori value
1	ANMG	X	-0.00989	-1270827.08669	0.00057	-1270827.07680
1	ANMG	Y	0.00325	6242631.29185	0.00154	6242631.28860
1	ANMG	Z	0.01524	307792.40554	0.00040	307792.39030
1	CMUM	X	-0.00222	-938078.58782	0.00062	-938078.58560
1	CMUM	Y	-0.01692	5968373.96568	0.00208	5968373.98260
1	CMUM	Z	0.00560	2038404.27900	0.00065	2038404.27340
1	CUSV	X	-0.00775	-1132915.05385	0.00061	-1132915.04610
1	CUSV	Y	0.00036	6092528.52756	0.00175	6092528.52720
1	CUSV	Z	0.02484	1504633.15904	0.00047	1504633.13420
1	HKSL	X	-0.00242	-2393383.15912	0.00072	-2393383.15670
1	HKSL	Y	0.00791	5393860.93981	0.00156	5393860.93190
1	HKSL	Z	0.01369	2412592.16829	0.00060	2412592.15460
1	KND1	X	-0.01712	-1619492.96932	0.00070	-1619492.95220
1	KND1	Y	0.06018	6040715.12878	0.00174	6040715.06860
1	KND1	Z	0.02380	1247864.92020	0.00054	1247864.89640
1	KSP1	X	-0.01870	-1572714.41290	0.00063	-1572714.39420
1	KSP1	Y	0.06651	6050448.91111	0.00159	6050448.84460
1	KSP1	Z	0.02204	1260501.91044	0.00049	1260501.88840
1	PNH1	X	-0.01686	-1603672.49806	0.00071	-1603672.48120
1	PNH1	Y	0.06448	6038739.38808	0.00171	6038739.32360

Find | next | prev | Close

10. Calculation result file

10.1. Coordinate file

The coordinate file is [FIN_$YYYSS+0.CRD].

```
KHM                                                              29-JUL-23 15:09
--------------------------------------------------------------------------------
LOCAL GEODETIC DATUM: IGS20           EPOCH: 2023-05-10 12:00:00

NUM  STATION NAME          X (M)          Y (M)          Z (M)     FLAG     SYSTEM

  1  ANMG            -1270827.02740  6242631.29501   307792.41238    W        GR
  2  CMUM             -938078.54770  5968373.98854  2038404.29516    W        GR
  3  CUSV            -1132915.00378  6092528.54503  1504633.16581    W        GR
  4  HKSL            -2393383.11602  5393860.93838  2412592.17135    W        GR
  7  KND1            -1619492.90963  6040715.07551  1247864.91456    A        GR
  8  KSP1            -1572714.34688  6050448.85813  1260501.90370    A        GR
  9  PNH1            -1603672.43390  6038739.33777  1277314.63722    A        GR
  5  PTAG            -3184318.48024  5291065.63736  1590418.30879    W        GR
 10  SIE1            -1490303.85527  6024644.81426  1465891.14335    A        GR
  6  SIN1            -1507972.76457  6195613.84510   148487.96335    W        GR
 11  STG1            -1706798.57348  5963096.21574  1481479.66509    A        GR
```

It is saved in the [STA] folder of the campaign.

230510
- ATM
- BPE
- GEN
- GRD
- OBS
- ORB
- ORX
- OUT
- RAW
- SOL
- STA

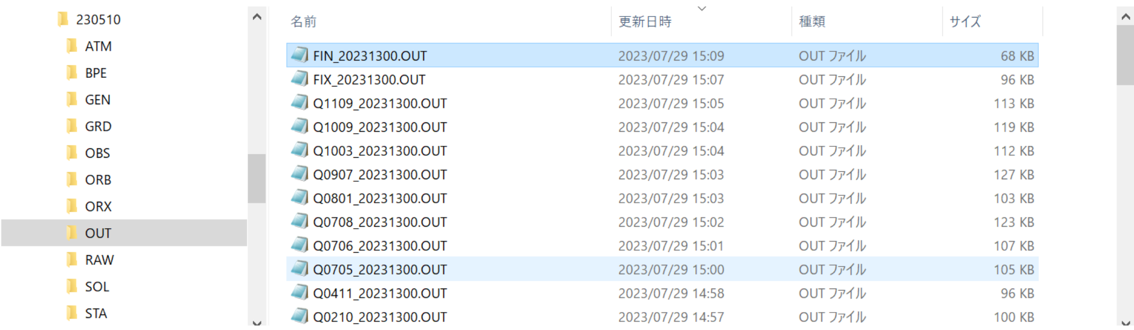
名前	更新日時	種類	サイズ
KhmerGEONET.BLQ	2023/07/20 18:39	BLQ ファイル	10 KB
IGS20.PSD	2023/07/25 10:14	PSD ファイル	34 KB
KhmerGEONET.PLD	2023/07/29 10:08	PLD ファイル	2 KB
KhmerGEONET.ABB	2023/07/29 10:19	ABB ファイル	2 KB
KHM_201500.CRD	2023/07/29 12:50	CRD ファイル	2 KB
KhmrGEONET.VEL	2023/07/29 14:14	VEL ファイル	2 KB
KHM_20231300.STA	2023/07/29 14:16	STA ファイル	6 KB
KhmerGEONET.ATL	2023/07/29 14:21	ATL ファイル	4 KB
APR_20231300.CRD	2023/07/29 14:30	CRD ファイル	2 KB
BSL_20231300.BSL	2023/07/29 14:43	BSL ファイル	1 KB
FLT_20231300.CRD	2023/07/29 14:54	CRD ファイル	2 KB
FIN_20231300.CRD	2023/07/29 15:09	CRD ファイル	2 KB

10.2. Calculation result file

The calculation result file that records RMS etc. is [FIN_$YYYSS+0.OUT].

```
Station coordinates and velocities:
-----------------------------------

Sol Station name        Typ Correction  Estimated value  RMS error   A priori value Unit    From                To
------------------------------------------------------------------------------------------------------------------------------

  1 ANMG                 X    0.03680   -1270827.02740    0.00062   -1270827.06420 meters  2023-05-10 00:00:00 2023-05-10 23:59:30
  1 ANMG                 Y   -0.00748    6242631.29501    0.00197    6242631.30249 meters  2023-05-10 00:00:00 2023-05-10 23:59:30
  1 ANMG                 Z    0.06675     307792.41238    0.00048     307792.34563 meters  2023-05-10 00:00:00 2023-05-10 23:59:30
  1 CMUM                 X   -0.00188    -938078.54770    0.00064    -938078.54582 meters  2023-05-10 00:00:00 2023-05-10 23:59:30
  1 CMUM                 Y    0.01018    5968373.98854    0.00196    5968373.97836 meters  2023-05-10 00:00:00 2023-05-10 23:59:30
  1 CMUM                 Z    0.04109    2038404.29516    0.00063    2038404.25407 meters  2023-05-10 00:00:00 2023-05-10 23:59:30
  1 CUSV                 X    0.05119   -1132915.00378    0.00062   -1132915.05497 meters  2023-05-10 00:00:00 2023-05-10 23:59:30
  1 CUSV                 Y   -0.00651    6092528.54503    0.00160    6092528.55154 meters  2023-05-10 00:00:00 2023-05-10 23:59:30
  1 CUSV                 Z    0.02587    1504633.16581    0.00051    1504633.13994 meters  2023-05-10 00:00:00 2023-05-10 23:59:30
  1 HKSL                 X   -0.00840   -2393383.11602    0.00077   -2393383.10762 meters  2023-05-10 00:00:00 2023-05-10 23:59:30
  1 HKSL                 Y   -0.01612    5393860.93838    0.00180    5393860.95450 meters  2023-05-10 00:00:00 2023-05-10 23:59:30
  1 HKSL                 Z    0.03147    2412592.17135    0.00066    2412592.13988 meters  2023-05-10 00:00:00 2023-05-10 23:59:30
  1 KND1                 X    0.21822   -1619492.90963    0.00064   -1619493.12785 meters  2023-05-10 00:00:00 2023-05-10 23:59:30
  1 KND1                 Y    0.03784    6040715.07551    0.00172    6040715.03767 meters  2023-05-10 00:00:00 2023-05-10 23:59:30
  1 KND1                 Z    0.09659    1247864.91456    0.00053    1247864.81797 meters  2023-05-10 00:00:00 2023-05-10 23:59:30
  1 KSP1                 X    0.22347   -1572714.34688    0.00065   -1572714.57035 meters  2023-05-10 00:00:00 2023-05-10 23:59:30
  1 KSP1                 Y    0.04312    6050448.85813    0.00171    6050448.81501 meters  2023-05-10 00:00:00 2023-05-10 23:59:30
  1 KSP1                 Z    0.09289    1260501.90370    0.00049    1260501.81081 meters  2023-05-10 00:00:00 2023-05-10 23:59:30
  1 PNH1                 X    0.22345   -1603672.43390    0.00065   -1603672.65735 meters  2023-05-10 00:00:00 2023-05-10 23:59:30
  1 PNH1                 Y    0.04443    6038739.33777    0.00165    6038739.29334 meters  2023-05-10 00:00:00 2023-05-10 23:59:30
  1 PNH1                 Z    0.09791    1277314.63722    0.00053    1277314.53931 meters  2023-05-10 00:00:00 2023-05-10 23:59:30
```

It is saved in the [OUT] folder of the campaign.



10.3. Calculate latitude, longitude, ellipsoidal height, UTM coordinates, elevation and geoid height

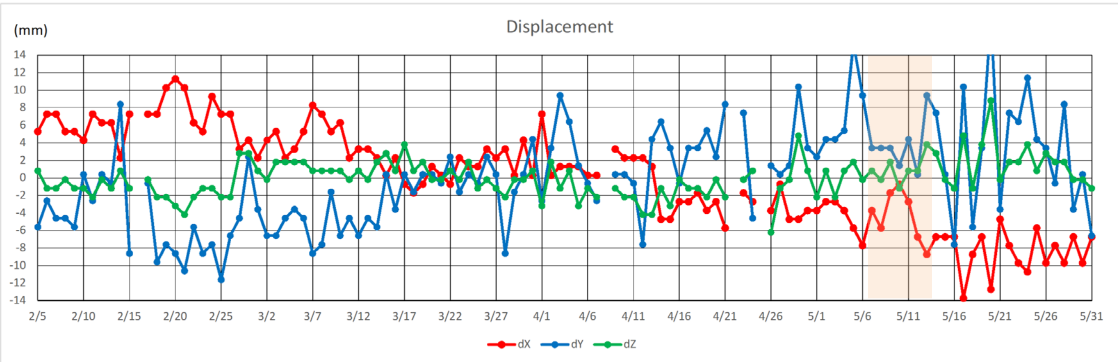
Bernese software cannot calculate latitude, longitude, ellipsoidal height, UTM coordinates, elevation and geoid height.

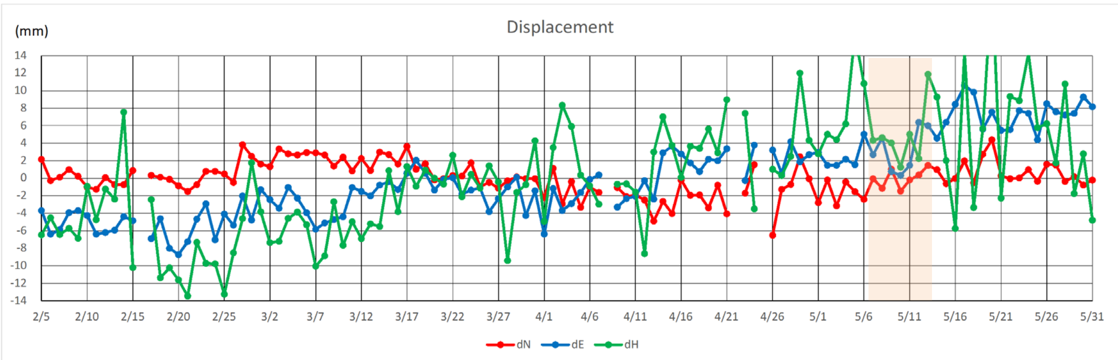
Therefore, use other coordinate calculation software.

11. Determination of CGD23 coordinates

11.1. Survey to determine CGD23 coordinates

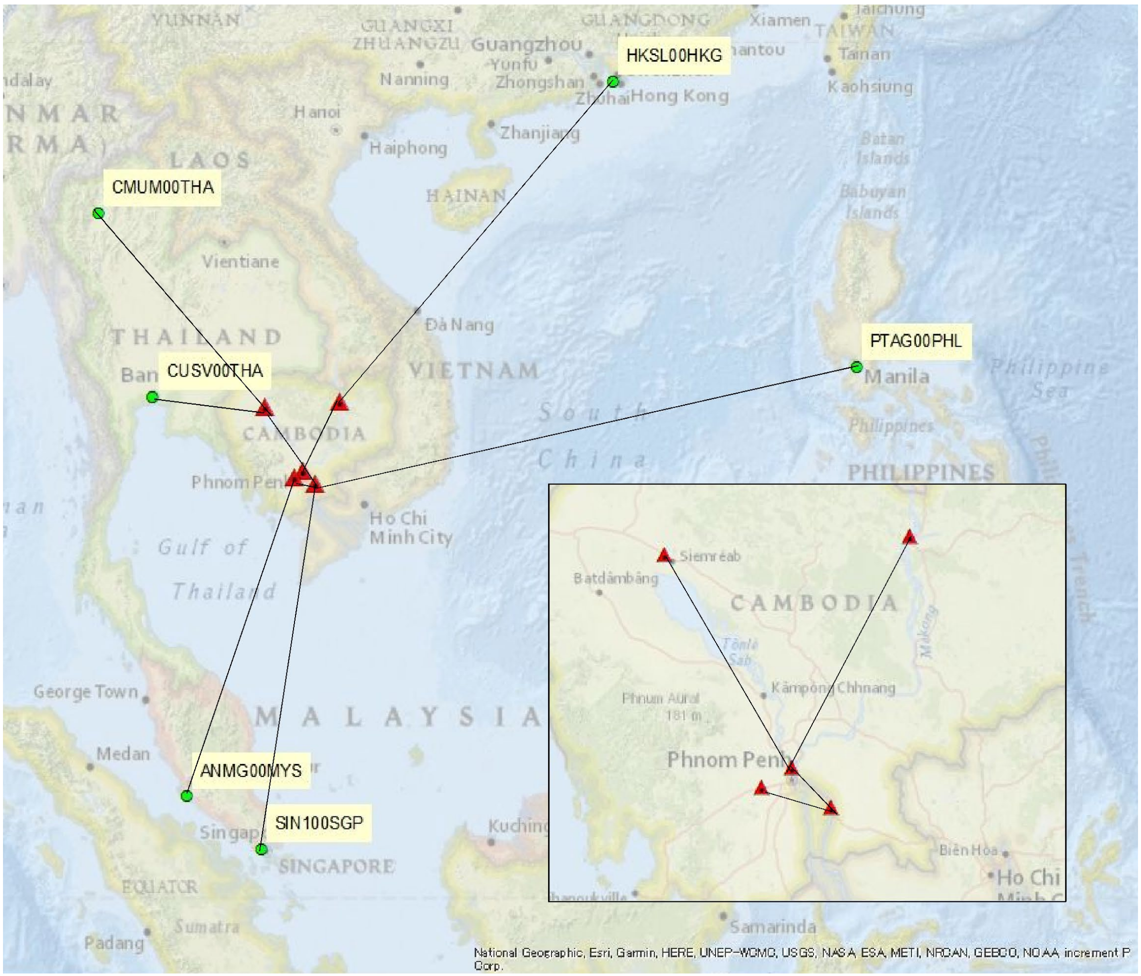
A preliminary calculation of the coordinates of PNH100KHM was performed.
RTX (ITRF2014) was used.
The purpose is to confirm when the coordinate values are stable.
This is to confirm the period when the influence of the ionosphere is small.
The figure below shows the change in coordinate values from 2/5 to 5/31.
The height component is not stable. It also appears to be on the rise.
It tends to change towards the east. This is roughly consistent with the velocity of crustal movement.
Based on the above, we decided to select the most stable 7-day period, which is the newest period possible.
In other words, the average value of the calculation results from 5/7 (Sun) to 5/13 (Sat) is adopted as the CGD23 coordinates.





11.2. Survey Network for CGD23

As a result of discussion, CGD23 coordinates are decided by the survey network shown below.



11.3. Geodetic Reference System and Map Projection

Let the average value of the results from 5/7 to 5/13 be the CGD23 coordinate of 5-CORS. The median value from 5/7 to 5/13 is 5/10. The epoch is 5/10 at noon (12:00). Since noon (12 o'clock) on May 10th is 129.5 days of the year, calculating the epoch using the following formula yields 2023.355.

$$Epoch = \frac{129.5}{365} = 0.355$$

The Geodetic Reference System and Map Projection is shown below.

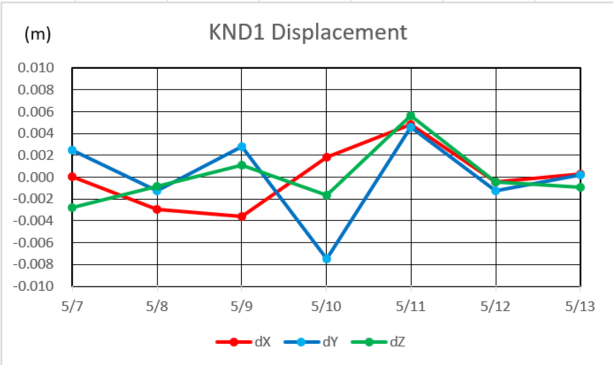
Item	Element
Geocentric Cartesian Coordinate System	ITRF2020 (Epoch 2023.355)
Reference Ellipsoid	GRS 80
Vertical Datum	Mean Sea Level (Haiphong, Vietnam)
Geoid Model	EGM2008
Plane Cartesian Coordinate System	UTM Zone 48 Central Meridian: 105° 00' 00" E Latitude of Origin: 0° 00' 00" N False Easting: 500,000.000 m False Northing: 0.000 m Scale Factor at Central Meridian: 0.9996

11.4. Calculation results from 5/7 to 5/13

11.4.1. KND100KHM

The calculation results for KND100KHM are shown below.

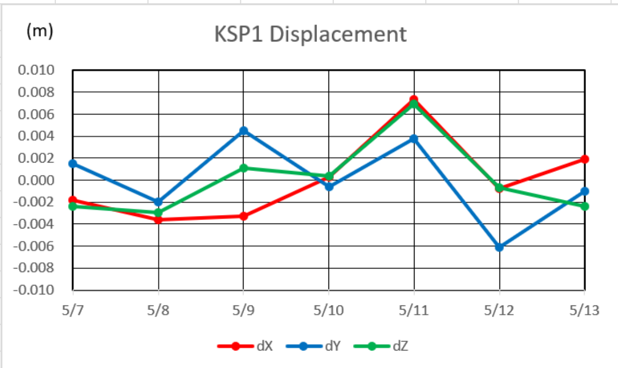
CGD23/ITRF2020 (Epoch2023.355, 2023/05/10)					RMS				Difference from average value		
Name	Date	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	REMARKS	dX (m)	dY (m)	dZ (m)
KND100KHM	2023/5/7	-1,619,492.911	6,040,715.085	1,247,864.913	0.001	0.002	0.001		0.000	0.002	-0.003
KND100KHM	2023/5/8	-1,619,492.914	6,040,715.082	1,247,864.915	0.001	0.002	0.001		-0.003	-0.001	-0.001
KND100KHM	2023/5/9	-1,619,492.915	6,040,715.086	1,247,864.917	0.001	0.002	0.000		-0.004	0.003	0.001
KND100KHM	2023/5/10	-1,619,492.910	6,040,715.076	1,247,864.915	0.001	0.002	0.001		0.002	-0.007	-0.002
KND100KHM	2023/5/11	-1,619,492.907	6,040,715.088	1,247,864.922	0.001	0.002	0.001	CUSV: No RINEX	0.005	0.005	0.006
KND100KHM	2023/5/12	-1,619,492.912	6,040,715.082	1,247,864.916	0.001	0.002	0.001		0.000	-0.001	0.000
KND100KHM	2023/5/13	-1,619,492.911	6,040,715.083	1,247,864.915	0.001	0.002	0.001		0.000	0.000	-0.001
AVERAGE		-1,619,492.911	6,040,715.083	1,247,864.916							



11.4.2. KSP100KHM

The calculation results for KSP100KHM are shown below.

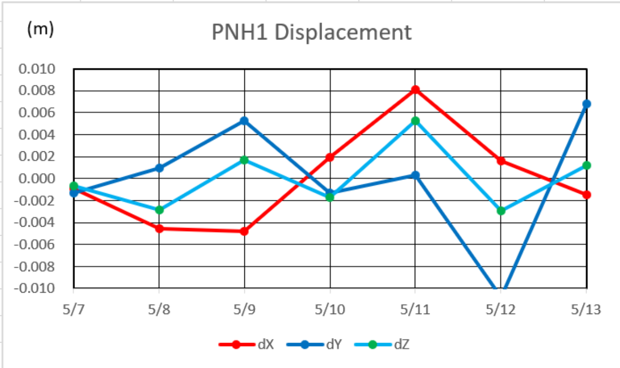
CGD23/ITRF2020 (Epoch2023.355, 2023/05/10)					RMS				Difference from average value		
Name	Date	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	REMARKS	dX (m)	dY (m)	dZ (m)
KSP100KHM	2023/5/7	-1,572,714.349	6,050,448.860	1,260,501.901	0.001	0.002	0.001		-0.002	0.001	-0.002
KSP100KHM	2023/5/8	-1,572,714.351	6,050,448.857	1,260,501.900	0.001	0.002	0.001		-0.004	-0.002	-0.003
KSP100KHM	2023/5/9	-1,572,714.350	6,050,448.863	1,260,501.904	0.001	0.002	0.000		-0.003	0.004	0.001
KSP100KHM	2023/5/10	-1,572,714.347	6,050,448.858	1,260,501.904	0.001	0.002	0.000		0.000	-0.001	0.000
KSP100KHM	2023/5/11	-1,572,714.340	6,050,448.862	1,260,501.910	0.001	0.002	0.001	CUSV: No RINEX	0.007	0.004	0.007
KSP100KHM	2023/5/12	-1,572,714.348	6,050,448.853	1,260,501.903	0.001	0.002	0.001		-0.001	-0.006	-0.001
KSP100KHM	2023/5/13	-1,572,714.345	6,050,448.858	1,260,501.901	0.001	0.002	0.001		0.002	-0.001	-0.002
AVERAGE		-1,572,714.347	6,050,448.859	1,260,501.903							



11.4.3. PNH100KHM

The calculation results for PNH100KHM are shown below.

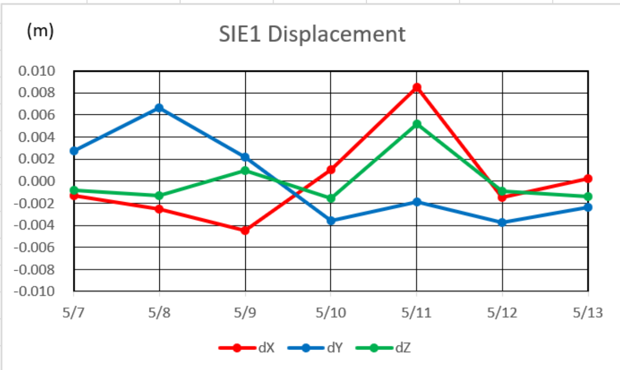
CGD23/ITRF2020 (Epoch2023.355, 2023/05/10)					RMS				Difference from average value		
Name	Date	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	REMARKS	dX (m)	dY (m)	dZ (m)
PNH100KHM	2023/5/7	-1,603,672.437	6,038,739.338	1,277,314.638	0.001	0.002	0.001		-0.001	-0.001	-0.001
PNH100KHM	2023/5/8	-1,603,672.440	6,038,739.340	1,277,314.636	0.001	0.002	0.001		-0.005	0.001	-0.003
PNH100KHM	2023/5/9	-1,603,672.441	6,038,739.344	1,277,314.641	0.001	0.002	0.000		-0.005	0.005	0.002
PNH100KHM	2023/5/10	-1,603,672.434	6,038,739.338	1,277,314.637	0.001	0.002	0.001		0.002	-0.001	-0.002
PNH100KHM	2023/5/11	-1,603,672.428	6,038,739.339	1,277,314.644	0.001	0.002	0.001	CUSV: No RINEX	0.008	0.000	0.005
PNH100KHM	2023/5/12	-1,603,672.434	6,038,739.328	1,277,314.636	0.001	0.002	0.001		0.002	-0.011	-0.003
PNH100KHM	2023/5/13	-1,603,672.437	6,038,739.346	1,277,314.640	0.001	0.002	0.001		-0.001	0.007	0.001
AVERAGE		-1,603,672.436	6,038,739.339	1,277,314.639							



11.4.4. SIE100KHM

The calculation results for SIE100KHM are shown below.

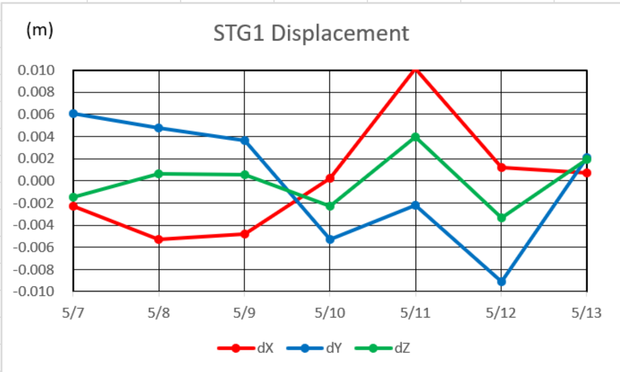
CGD23/ITRF2020 (Epoch2023.355, 2023/05/10)					RMS				Difference from average value		
Name	Date	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	REMARKS	dX (m)	dY (m)	dZ (m)
SIE100KHM	2023/5/7	-1,490,303.858	6,024,644.821	1,465,891.144	0.001	0.002	0.001		-0.001	0.003	-0.001
SIE100KHM	2023/5/8	-1,490,303.859	6,024,644.824	1,465,891.144	0.001	0.002	0.001		-0.003	0.007	-0.001
SIE100KHM	2023/5/9	-1,490,303.861	6,024,644.820	1,465,891.146	0.001	0.002	0.001		-0.004	0.002	0.001
SIE100KHM	2023/5/10	-1,490,303.855	6,024,644.814	1,465,891.143	0.001	0.002	0.001		0.001	-0.004	-0.002
SIE100KHM	2023/5/11	-1,490,303.848	6,024,644.816	1,465,891.150	0.001	0.002	0.001	CUSV: No RINEX	0.008	-0.002	0.005
SIE100KHM	2023/5/12	-1,490,303.858	6,024,644.814	1,465,891.144	0.001	0.002	0.001		-0.002	-0.004	-0.001
SIE100KHM	2023/5/13	-1,490,303.856	6,024,644.816	1,465,891.143	0.001	0.002	0.001		0.000	-0.002	-0.001
AVERAGE		-1,490,303.856	6,024,644.818	1,465,891.145							



11.4.5. STG100KHM

The calculation results for STG100KHM are shown below.

CGD23/ITRF2020 (Epoch2023.355, 2023/05/10)					RMS				Difference from average value		
Name	Date	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	REMARKS	dX (m)	dY (m)	dZ (m)
STG100KHM	2023/5/7	-1,706,798.576	5,963,096.227	1,481,479.666	0.001	0.002	0.001		-0.002	0.006	-0.001
STG100KHM	2023/5/8	-1,706,798.579	5,963,096.226	1,481,479.668	0.001	0.002	0.001		-0.005	0.005	0.001
STG100KHM	2023/5/9	-1,706,798.579	5,963,096.225	1,481,479.668	0.001	0.002	0.000		-0.005	0.004	0.001
STG100KHM	2023/5/10	-1,706,798.573	5,963,096.216	1,481,479.665	0.001	0.002	0.001		0.000	-0.005	-0.002
STG100KHM	2023/5/11	-1,706,798.564	5,963,096.219	1,481,479.671	0.001	0.002	0.001	CUSV: No RINEX	0.010	-0.002	0.004
STG100KHM	2023/5/12	-1,706,798.573	5,963,096.212	1,481,479.664	0.001	0.002	0.001		0.001	-0.009	-0.003
STG100KHM	2023/5/13	-1,706,798.573	5,963,096.223	1,481,479.669	0.001	0.002	0.001		0.001	0.002	0.002
AVERAGE		-1,706,798.574	5,963,096.221	1,481,479.667							



11.4.6. Conclusion

Since the RMS of the results calculated using Bernese software is approximately 2 mm, the daily coordinate values were determined with high accuracy.

The difference from the average value of the daily coordinates is 11 mm in the Y coordinate for PNH100KHM on 5/12, but it is less than 10 mm for other CORS.

Therefore, the CGD23 (Epoch 2023.355) coordinate value, which is the average value from 5/7 to 5/13, was determined with high accuracy.

11.5. 5-CORS CGD23 coordinates

The determined coordinates are shown below.

Name	X (m)	Y (m)	Z (m)
KND100KHM	-1,619,492.911	6,040,715.083	1,247,864.916
KSP100KHM	-1,572,714.347	6,050,448.859	1,260,501.903
PNH100KHM	-1,603,672.436	6,038,739.339	1,277,314.639
SIE100KHM	-1,490,303.856	6,024,644.818	1,465,891.145
STG100KHM	-1,706,798.574	5,963,096.221	1,481,479.667

Name	B (DD MM SS.SSSSS)	L (DDD MM SS.SSSSS)	H (m)
KND100KHM	11 21 29.10724N	105 00 28.29508E	2.021
KSP100KHM	11 28 28.52899N	104 34 14.32999E	23.783
PNH100KHM	11 37 47.13795N	104 52 20.72324E	2.735
SIE100KHM	13 22 33.08881N	103 53 39.19100E	2.986
STG100KHM	13 31 14.27708N	105 58 21.16724E	48.599

Name	N (m)	E (m)	h (m)	Geoid (m)
KND100KHM	1,255,573.579	500,857.576	14.064	-12.043
KSP100KHM	1,268,490.958	453,172.078	37.598	-13.815
PNH100KHM	1,285,616.938	486,093.422	15.770	-13.035
SIE100KHM	1,478,968.366	380,264.014	23.535	-20.549
STG100KHM	1,494,920.523	605,244.625	60.813	-12.214

11.6. Guessing how to obtain Nationwide-CORS coordinates

In a grant aid project, a method for calculating CGD23 coordinates of Nationwide-CORS will be studied.
Let's try to make a guess here.

(A) Consider that the CGD23 coordinate of Nationwide-CORS is calculated based on the 5-CORS coordinate. It may be possible to consider adding an IGS station to the survey network, but basically the 5-CORS coordinate values will be calculated as known coordinate values.

(B) Perform resurvey of 0-1st order control point. This is a necessary survey to check the accuracy of Nationwide-CORS coordinate values and coordinate transformation parameters.

(C) Calculate 0-1st order control point coordinates based on Nationwide-CORS coordinates.

(D) Check the accuracy of Nationwide-CORS coordinate values. In this project, CGD23 coordinates are calculated by resurveying at several 0-1st order control points. Therefore, check the accuracy of the Nationwide-CORS coordinate values by comparing them with the results in (C). If the difference is large, the following causes may be considered, so it is necessary to check the survey data to determine the cause and eliminate the error.

- ✓ Are there any abnormalities in the Nationwide-CORS RINEX data used for calculations?
- ✓ Are there any abnormalities in the survey data for the 0-1st order control point that was resurveyed?
- ✓ Especially in the resurvey data, are there any problems with the input values of the antenna type and antenna bottom height?

(E) Check the coordinate transformation parameters calculated in this project by comparing the CGD09 coordinate of the 0-1st order control point and the CGD23 coordinate that is the result of (C). If the displacement trend is not uniform, it is necessary to create coordinate transformation parameters suitable for the area.
Please refer to the [Coordinate_Transformation_Manual] for the coordinate conversion parameters suitable for each region.

12. Regular monitoring of CORS coordinate values

12.1. Crustal deformation in Cambodia

When we confirmed the crustal deformation in Cambodia over a 14-year period (from 2009 to 2023) using the results of verifying the accuracy of GNSS surveying using CORS data, we found that it was approximately 0.34 m in the east-southeast direction. The displacement rate is approximately 24mm/year.

2023 - 2009	dX (m)	dY (m)	dZ (m)	dN (m)	dE (m)	dU (m)
Max	-0.231	0.004	-0.045	-0.050	0.402	0.082
Min	-0.406	-0.138	-0.143	-0.154	0.224	-0.062
Average	-0.322	-0.034	-0.086	-0.095	0.319	0.030

The crustal deformation of the Sunda plate is 14mm/year in the eastward direction (Fig.1).

Considering the errors in the GNSS measurement of the 0-1st order control point, the results can be considered to be generally consistent with the crustal deformation research of the Sunda plate.

12.2. CORS coordinate values and social activities considering crustal deformation

The CGD23 coordinate value was Epoch2023.355.

In the future, if CORS is installed throughout Cambodia and its operation begins in 2025, the earth's crust will have moved approximately 50 mm east-southeast direction at that point.

If all of Cambodia were to move uniformly in parallel, there would be no problem in continuing to use CGD23. However, if the crust is shifting non-uniformly, it is necessary to revise the coordinate values to CGDxx at some point in time.

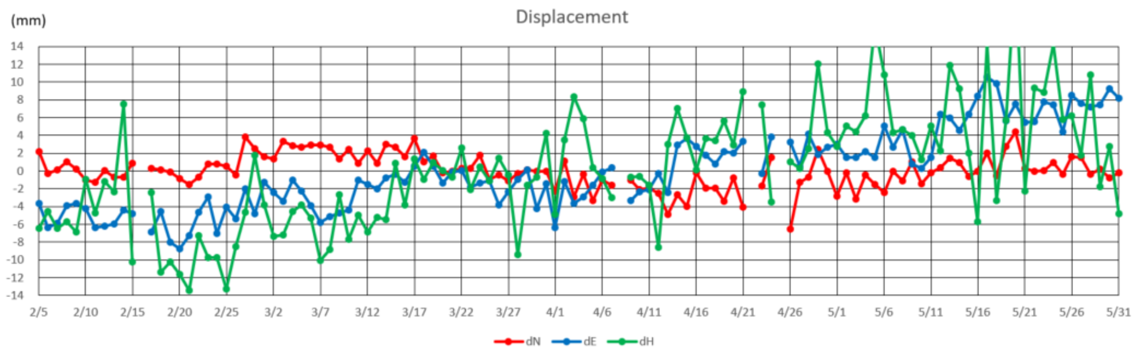
On the other hand, if the revision interval is short, the coordinate values and area will fluctuate in a short period of time, causing a problem of confusion in social activities. Therefore, it is better to avoid revising coordinate values in a short period of time.

12.3. Regular monitoring of CORS coordinate values

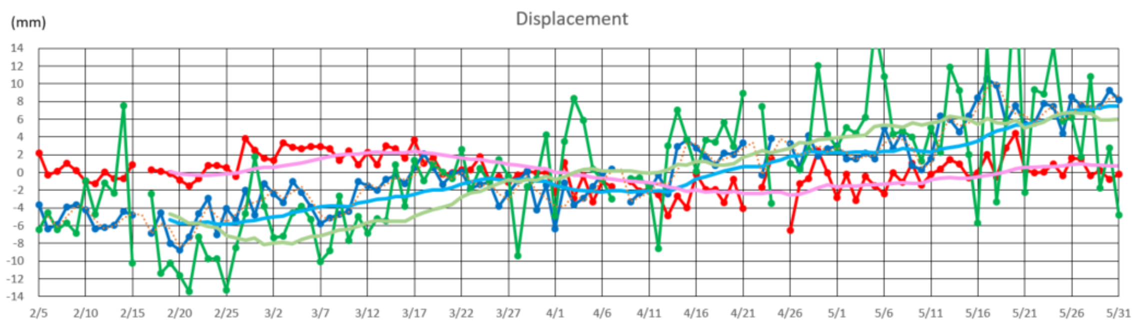
It is important to regularly monitor CORS coordinate values and understand the displacement status of CORS placed throughout Cambodia.

When calculating CORS coordinate values using the Bernese manual, they are calculated at the epoch of the GNSS observation date. We will call these coordinate values ``daily coordinates."
If the displacement direction and displacement rate of crustal deformation throughout Cambodia are uniform, it is not necessary to carry out monitoring every day, and it may be possible to monitor it every month. We recommend monitoring at least once a year.
At this time, it is better to unify the epoch to January 1st, so calculate the average value for several days before and after so that January 1st is the center.

For example, it is recommended to use the monitoring results calculated every day in a graph like the one shown below for analysis.



The daily difference is about 20 mm due to errors caused by water vapor, the ionosphere, solar activity, etc. Therefore, by analyzing the displacement trend using techniques such as regression calculation and moving average, it is possible to calculate a curve like the one shown below from the above figure.



Then, look at this curve and decide when to revise the coordinates to CGDxx.
As mentioned above, if the interval between revisions is short, there is a risk of

disrupting social activities, so it is basically preferable to use CGD23 coordinate values. The timing to revise the coordinate values is when a large displacement is observed in a short period of time, and when the displacement is uneven depending on the region.
For example, in a country like Japan, where the earth's crust is intricately intertwined and earthquakes occur frequently, it is necessary to repeat revisions every time there is a large earthquake.
Cambodia is located on one plate, the Sunda Plate, so we cannot expect large displacement in the short term. If the displacement is uniform at a constant rate, we may consider a proposal to revise it once every quarter century. For this reason, it is necessary to periodically check that the displacement is uniform at a constant rate.

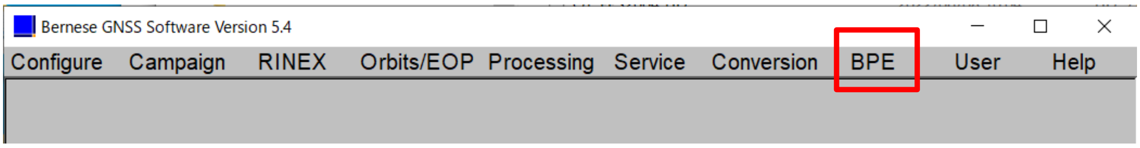
12.4. Future Goals

Manually performing calculations with Bernese software requires a lot of effort and time. Therefore, our future goal is to automate the calculations of the Bernese software and regularly monitor the daily coordinate values.
Below are the steps required to automate calculations in Bernese software.

(A) First, understand the process of baseline analysis and coordinate determination in GNSS surveying. After that, learn to calculate coordinate values manually according to this manual. We are currently at this stage in 2023.

(B) The second step is to automate the calculations of the Bernese software. However, the data required for the calculations (such as the precise orbit files available on the University of Bern's website) must be manually downloaded and stored in the designated folder by hand.

We will explain the automatic analysis of Bernese software.
Bernese Software has an automatic analysis function called Bernese Processing Engine (hereinafter referred to as [BPE]).



By defining the analysis procedure etc. in advance in the Processing Control File (hereinafter referred to as "PCF") and starting it, calculations can be performed

automatically. This means that the final solution can be calculated without repeatedly clicking [Run] on the menu screen.
Describe the SCRIPT name that will be executed in the PCF, and BPE executes the SCRIPT files in the order written in the PCF. In the SCRIPT, in addition to commands to run Bernese programs, you can also write commands to change file names and change menu screens. In addition, the PCF can be also described the variable names defined in the PCF, as well as the values and characters set for those variables.
To create CFCs and SCRIPTs, you must know how to run Bernese Software manually.
In other words, as explained in the previous section (A), you first need to improve your skills to be able to find the final solution according to the Bernese Software manual.
Next, the second step is to improve your skills by learning how to create PCFs and SCRIPTs for BPE.

(C) Create a program that automatically collects the data (such as the precise porbit files available on the University of Bern's website) and parameters necessary to find the final solution, and also a program that periodically executes BPE. The final goal is to use this program to build a tool to monitor daily coordinates.
In addition, in order to build the tool, it is necessary to form a team of GNNS survey engineers, IT engineers, system engineers, etc.

Ver. 24th October 2024

Project on Establishment of Continuously Operating Reference Stations (CORS) for Land Management and Infrastructure Development

Coordinate Transformation Manual for CGD23

Contents

NOTE: The remaining issues are shown below. GDCG should discuss this issue and update this manual.

- After the CGD23 coordinates are registered in Pivot, it is necessary to perform a check survey using NRTK. Please compare the CGD23 coordinate values, which were converted from CGD09 using the coordinate conversion parameters, with the coordinate values obtained by NRTK surveying. If the difference is within an acceptable range, there is no problem with the accuracy of the data being distributed from CORS.
- It is necessary to conduct a check survey after the CORS coordinate values for the entire Cambodia area have been calculated. Calculate the CGD09 coordinate values of CORS across Cambodia using the check survey data. This calculation can be done using TBC software. Next, use CORS for all of Cambodia to calculate the coordinate transformation parameters from CGD09 to CGD23. 5-Compare the coordinate transformation parameters calculated from CORS and the coordinate transformation parameters calculated from CORS for all of Cambodia. If this difference is within an acceptable range, only the coordinate transformation parameters calculated with 5-CORS can be used.
- If there are differences between regions, please refer to this manual and create coordinate transformation parameters suitable for each region. Then, for areas that are not compatible, use the new coordinate conversion parameters to convert CGD09 to CGD23.

1. Introduction

1.1. Introduction

This manual describes the transformation from CGD09 coordinates to CGD23 coordinates. As a reference, it describes how to transform coordinates to CGD23 coordinates from survey results with coordinates older than CGD09 coordinates.

1.2. Structure of the Manual

This manual describes the following items.

1. Geodetic reference system specification
2. Calculation procedure of coordinate transformation parameters
3. Introduction of coordinate transformation methods
4. Calculation methods of coordinate transformation parameters by Helmert transformation using Bernese5.4
5. Procedure of coordinate transformation by Helmert transformation using Bernese5.4
6. Coordinate transformation parameter from CGD09 to CGD23
7. Appendix
    1) Study of Coordinate transformation parameters using Khmer GEONET
    2) Coordinate transformation method from CGD03 to CGD23
    3) Coordinate transformation method of Cadastral survey boundary points
    4) Coordinate transformation method from Indian 19XX to CGD23

1.3. Scope of Application

The scope of this manual applies to the following survey results, which are points having CGD09 coordinates.

1. 0 order and 1st order Control Point
2. 2nd and 3rd Order Control Point
3. Cadastral survey boundary points

2. Geodetic Reference System and Map Projection

2.1. CGD23

Table 1 CGD23

Item	Element
Geocentric Cartesian Coordinate System	ITRF2020 (Epoch 2023.355, 10th May 2023)
Reference Ellipsoid	GRS 80
Vertical Datum	Mean Sea Level (Haiphong, Vietnam)
Geoid Model	EGM2008
Plane Cartesian Coordinate System	UTM Zone 48 - Central Meridian: 105º 00' 00" E - Latitude of Origin: 0º 00' 00" N - False Easting: 500,000.000 m - False Northing: 0.000 m - Scale Factor at Central Meridian: 0.9996
Unit and Notation	Meters, 0,001m

2.2. CGD09

Table 2 CGD09

Item	Element
Geocentric Cartesian Coordinate System	ITRF2005 (Epoch 2009.56, 23rd July 2009)
Reference Ellipsoid	GRS 80
Vertical Datum	Mean Sea Level (Ha Tien, Vietnam)
Geoid Model	EGM2008
Plane Cartesian Coordinate System	UTM Zone 48 - Central Meridian: 105º 00' 00" E - Latitude of Origin: 0º 00' 00" N - False Easting: 500,000.000 m - False Northing: 0.000 m - Scale Factor at Central Meridian: 0.9996
Unit and Notation	Meters, 0,001m

3. Calculation procedure of coordinate transformation parameters

3.1. Requirements for Calculating Coordinate Transformation Parameters

The requirements for calculating the coordinate transformation parameters are listed below.

- ✓ A point having both CGD09 coordinate values (old coordinate values) and CGD23 coordinate values (new coordinate values) is required.
- ✓ Points with CGD09 coordinate values (old coordinate values) must have no change to the current status and the status at the time of CGD23 coordinate values (new coordinate values) calculation.
- ✓ In addition to the points for calculating the coordinate transformation parameters, a verification point shall be prepared.
- ✓ The point for calculating the coordinate transformation parameters and the verification point shall be re-surveyed to calculate the CGD23 coordinate values (new coordinate values).

3.2. Procedure for Calculating Coordinate Transformation Parameters

A flowchart for calculating the coordinate transformation parameters is shown below.

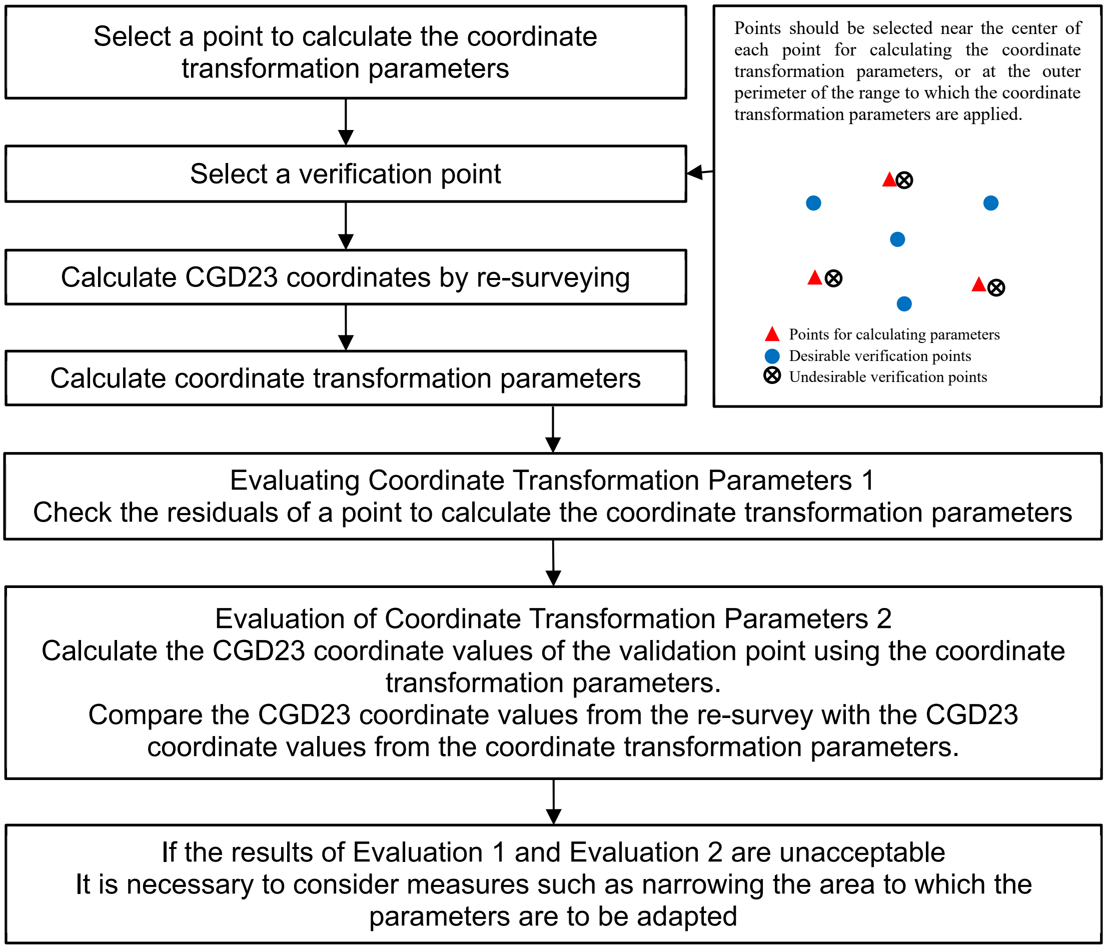


Figure 1 Flowchart

4. Introduction to common coordinate transformation methods

4.1. Helmert Transform

4.1.1. Helmert Transform (3D)

This method should be used when transforming the coordinates of a region with a large area of application, such as a global scale. Using points with both CGD09 coordinate values (old coordinate values) and CGD23 coordinate values (new coordinate values), it estimates the amount of translation from origin, rotation around each axis, and scale factor by the least-squares method. The coordinate transformation parameters from CGD09 to CGD23 coordinate values were calculated by this method. The conversion equations are shown below.

$$\begin{bmatrix} X_{CDG23} \\ Y_{CDG23} \\ Z_{CDG23} \end{bmatrix} = \begin{bmatrix} dx \\ dy \\ dz \end{bmatrix} + (1+s) \cdot \begin{bmatrix} 1 & -r_z & r_y \\ r_z & 1 & -r_x \\ -r_y & r_x & 1 \end{bmatrix} \cdot \begin{bmatrix} x_{CDG09} \\ y_{CDG09} \\ z_{CDG09} \end{bmatrix}$$

X_{CGD23}: $X\ value\ of\ CGD23\ coordinate$

Y_{CGD23}: $Y\ value\ of\ CGD23\ coordinate$

Z_{CGD23}: $Z\ value\ of\ CGD23\ coordinate$

dx: $Amount\ of\ translation\ from\ origon\ in\ x - axis\ direction$

dy: $Amount\ of\ translation\ from\ origon\ in\ y - axis\ direction$

dz: $Amount\ of\ translation\ from\ origon\ in\ z - axis\ direction$

s: $Scale\ factor$

r_x: $Amount\ of\ rotation\ around\ x -\ axis$

r_y: $Amount\ of\ rotation\ around\ y -\ axis$

r_z: $Amount\ of\ rotation\ around\ z -\ axis$

X_{CGD09}: $X\ value\ of\ CGD09\ coordinate$

Y_{CGD09}: $Y\ value\ of\ CGD09\ coordinate$

Z_{CGD09}: $Z\ value\ of\ CGD09\ coordinate$

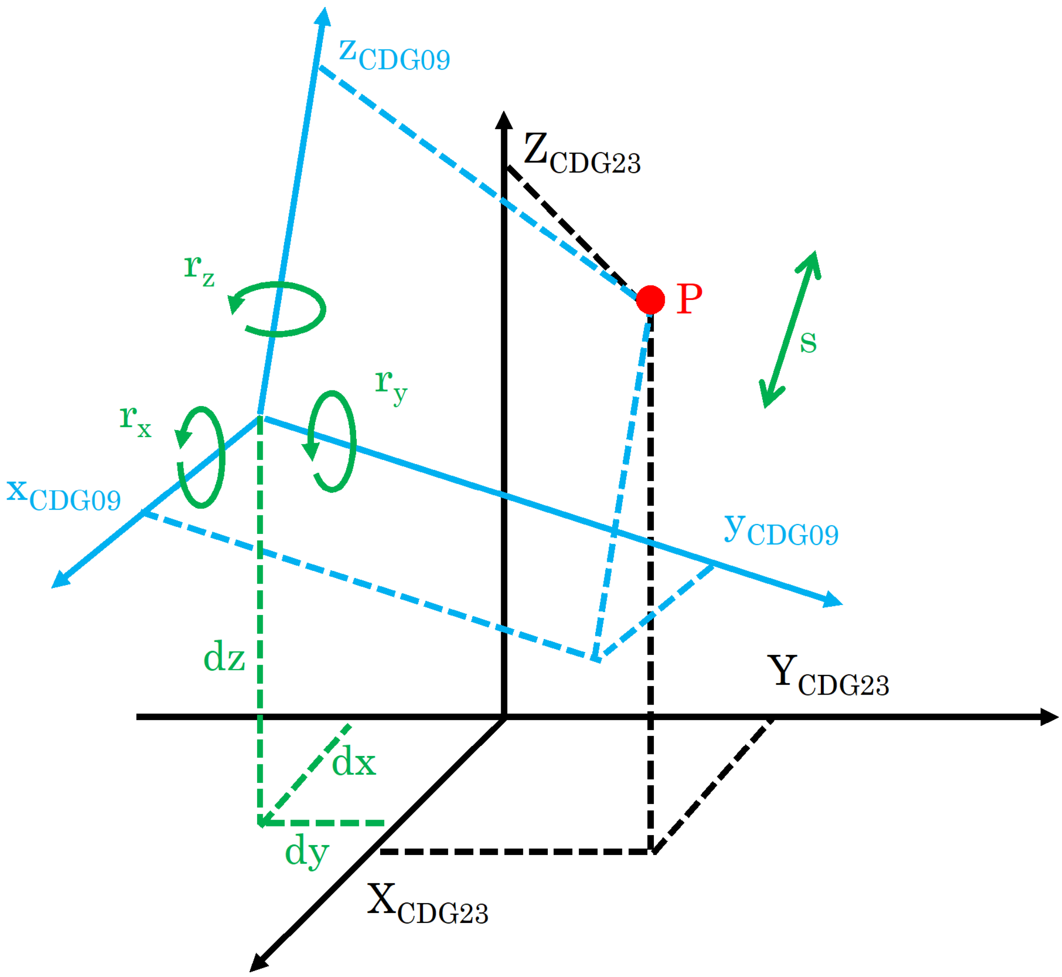


Figure 2 Helmert Transform (3D)

4.1.1. Helmert Transformation (2D)

In general, when transforming the coordinates of an area with a small area of application, the coordinates are transformed by dividing them into horizontal position coordinates and elevation coordinates. The Helmert transformation (two-dimensional) is a method of transforming coordinates for horizontal position coordinates using the amount of translation from origin, rotation, and scale factor. Using points with both CGD09 coordinate values (old coordinate values) and CGD23 coordinate values (new coordinate values), the amount translation from origin, rotation, and scale factor are estimated by the least-squares method. The transformation formula is shown below.

$$\begin{bmatrix} X_{CGD23} \\ Y_{CGD23} \end{bmatrix} = \begin{bmatrix} dx \\ dy \end{bmatrix} + s \cdot \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \cdot \begin{bmatrix} x_{CGD09} \\ y_{CGD09} \end{bmatrix}$$

$X_{CGD23}: X(N)\ value\ of\ CGD23\ coordinate$

$Y_{CGD23}: Y(E)\ value\ of\ CGD23\ coordinate$

$dx:\ Amount\ of\ translation\ from\ origon\ \ in\ x(N) - axis\ direction$

$dy: Amount\ of\ translation\ from\ origon\ \ in\ y(E) - axis\ direction$

$s: Scale\ factor$

$\theta: Amount\ of\ rotation$

$X_{CGD09}: X(N)\ value\ of\ CGD09\ coordinate$

$Y_{CGD09}: Y(E)\ value\ of\ CGD09\ coordinate$

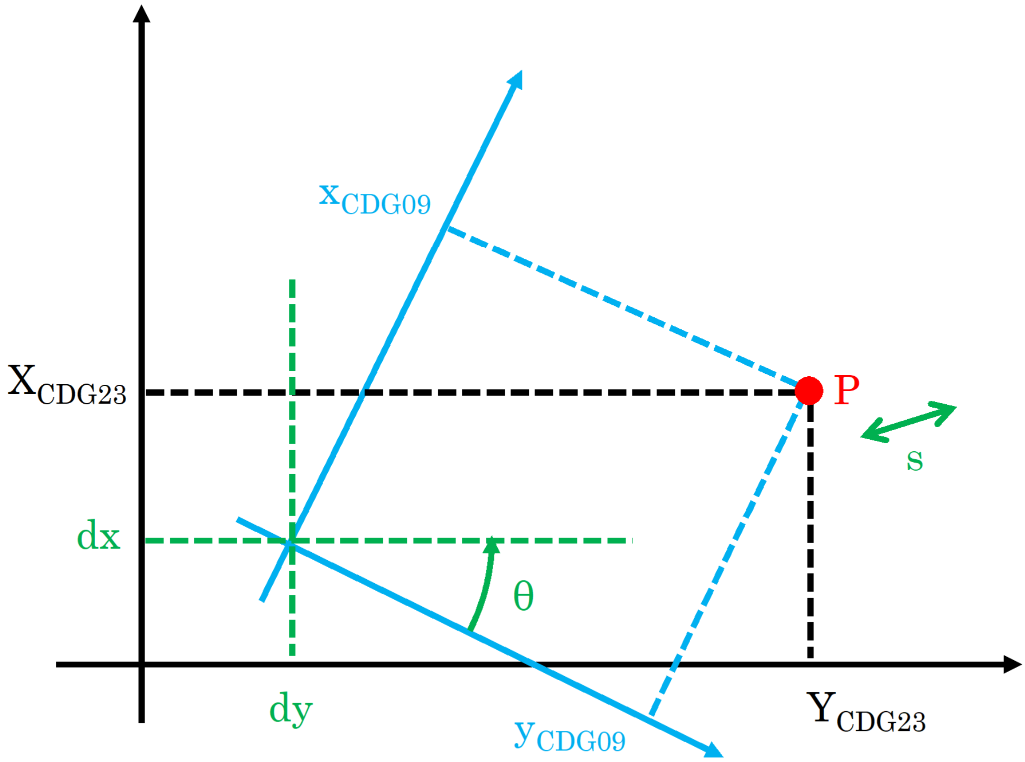


Figure 3 Helmert Transformation (2D)

4.2. Affine Transformation

In general, when transforming the coordinates of an area with a small area of application, the coordinates are transformed by dividing them into horizontal position coordinates and elevation coordinates.

The affine transformation is a method of transforming coordinates for horizontal position coordinates using the amount of translation from origin, rotation of each axis, and scale factor. Using points with both CGD09 coordinate values (old coordinate values) and CGD23 coordinate values (new coordinate values), the amount translation from origin, rotation of each axis, and scale factor are estimated by the least-squares method.

The transformation formula is shown below.

$$\begin{bmatrix} X_{CGD23} \\ Y_{CGD23} \end{bmatrix} = \begin{bmatrix} dx \\ dy \end{bmatrix} + \begin{bmatrix} s_x \cdot \cos\theta_x & -s_y \cdot \sin\theta_y \\ s_x \cdot \sin\theta_x & s_y \cdot \cos\theta_y \end{bmatrix} \cdot \begin{bmatrix} x_{CGD09} \\ y_{CGD09} \end{bmatrix}$$

$X_{CGD23}: X(N)\ value\ of\ CGD23\ coordinate$

$Y_{CGD23}: Y(E)\ value\ of\ CGD23\ coordinate$

$dx: Amount\ of\ translation\ from\ origon\ \ in\ \ x(N) - axis\ direction$

$dy: Amount\ of\ translation\ from\ origon\ \ in\ \ y(E) - axis\ direction$

$s_x: Scale\ factor\ of\ x - axis$

$s_y: Scale\ factor\ of\ y - axis$

$\theta_x: Amount\ of\ x - axis\ rotation$

$\theta_y: Amount\ of\ y - axis\ rotation$

$X_{CGD09}: X(N)\ value\ of\ CGD09\ coordinate$

$Y_{CGD09}: Y(E)\ value\ of\ CGD09\ coordinate$

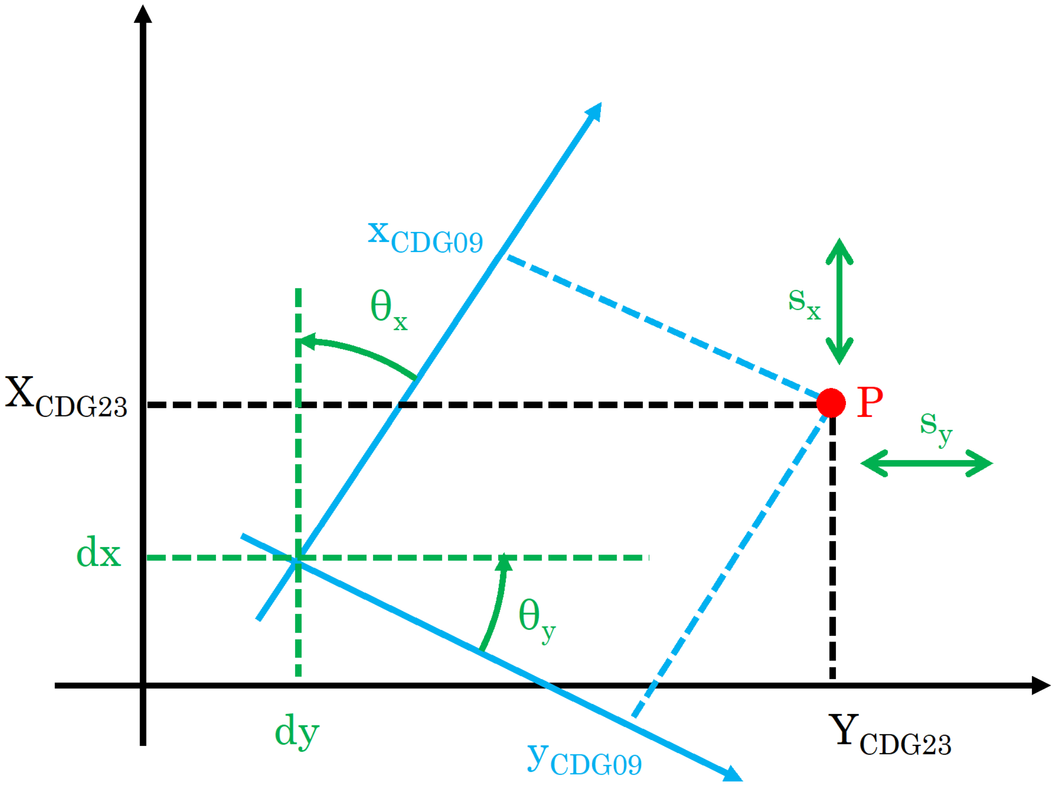


Figure 4 Affine Transformation

4.3. Method by weighted interpolation

The weighted interpolation is a method for conducting the coordinate transformation to calculate the correction amount for coordinate transformation by weighting the reciprocal of the distance between the point with both CGD09 coordinate values (old coordinate values) and CGD23 coordinate values (new coordinate values) and the point for which the coordinate transformation is performed. This method is used to calculate coordinate transformation parameters adapted to each region.
The calculation formula is shown below.

$$X_{CGD23} = X_{CGD09} + \frac{\sum_{i=1}^{n} dx_i \cdot P_i}{\sum_{i=1}^{n} P_i} \qquad Y_{CGD23} = Y_{CGD09} + \frac{\sum_{i=1}^{n} dy_i \cdot P_i}{\sum_{i=1}^{n} P_i}$$

$$H_{CGD23} = H_{CGD09} + \frac{\sum_{i=1}^{n} dh_i \cdot P_i}{\sum_{i=1}^{n} P_i}$$

$X_{CGD23}: X(N)\ value\ of\ CGD23\ coordinate\ of\ point\ A$

$Y_{CGD23}: Y(E)\ value\ of\ CGD23\ coordinate\ of\ point\ A$

$H_{CGD23}: Elevation\ value\ of\ CGD23\ coordinates\ at\ point\ A$

$X_{CGD09}: X(N)\ value\ of\ CGD09\ coordinate\ of\ point\ A$

$Y_{CGD09}: Y(E)\ value\ of\ CGD09\ coordinate\ of\ point\ A$

$H_{CGD09}: Elevation\ value\ of\ CGD09\ coordinates\ at\ point\ A$

$dx_i = x_{Bi\ CGD09} - x_{Bi\ CGD23}$:

$Correction\ amount\ for\ coordinate\ transformation\ of\ X(N)\ coordinate\ of\ point\ B_i$

$dy_i = y_{Bi\ CGD09} - y_{Bi\ CGD23}$:

$Correction\ amount\ for\ coordinate\ transformation\ of\ Y(E)\ coordinate\ of\ point\ B_i$

$dh_i = h_{Bi\ CGD09} - h_{Bi\ CGD23}$:

$Correction\ amount\ for\ coordinate\ transformation\ of\ elevation\ value\ of\ point\ B_i$

$$P_i = \frac{1}{S_i} = \frac{1}{\sqrt{(X_{Bi\ CGD09} - X_{CGD09})^2 + (Y_{Bi\ CGD09} - Y_{CGD09})^2}} : weight$$

$S_i: Horizontal\ distance\ between\ point\ B_i\ and\ point\ A$

$X_{Bi\ CGD23}: X(N)\ value\ of\ CGD09\ coordinate\ of\ point\ B_i$

$Y_{Bi\ CGD09}: Y(E)\ value\ of\ CGD09\ coordinate\ of\ point\ B_i$

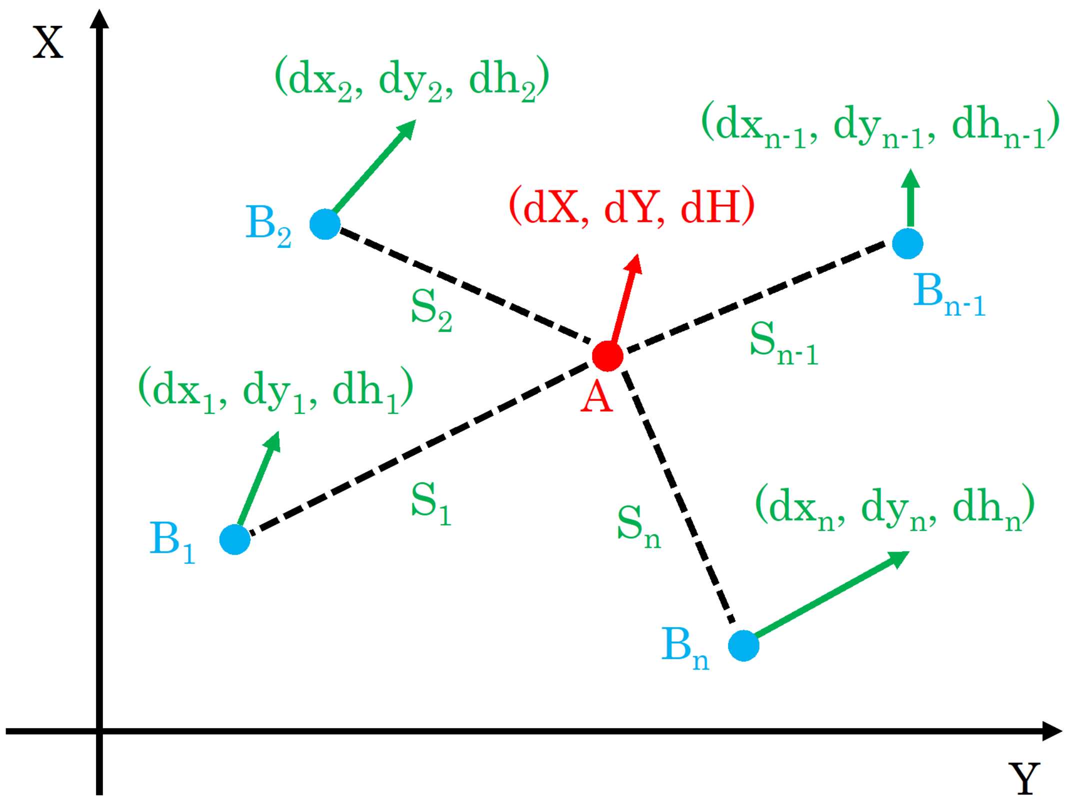


Figure 5 Method by weighted interpolation

4.4. Bilinear transformation method with linear interpolation

Coordinate transformation correction amount calculated from points having both CGD09 coordinate values (old coordinate values) and CGD23 coordinate values (new coordinate values) are distributed on a mesh. The method, which is calculating the coordinate transformation correction amount for an arbitrary point in a mesh by linear interpolation and then transforming the coordinates of that point, is called the bilinear transformation method. This method is used to calculate coordinate transformation parameters adapted to each region. And this method is also suitable for providing users with regionally adapted coordinate transformation parameters and for creating program of calculation formula.

The calculation formula is shown below.

$$\begin{bmatrix} X_{CGD23} \\ Y_{CGD23} \\ H_{CGD23} \end{bmatrix} = \begin{bmatrix} X_{CGD09} \\ Y_{CGD09} \\ H_{CGD09} \end{bmatrix} + \begin{bmatrix} \frac{y_2 - Y_{CGD09}}{y_2 - y_1}\left(\frac{x_2 - X_{CGD09}}{x_2 - x_1}\cdot dx_{11} + \frac{X_{CGD09} - x_1}{x_2 - x_1}\cdot dx_{21}\right) + \frac{Y_{CGD09} - y_1}{y_2 - y_1}\left(\frac{x_2 - X_{CGD09}}{x_2 - x_1}\cdot dx_{12} + \frac{X_{CGD09} - x_1}{x_2 - x_1}\cdot dx_{22}\right) \\ \frac{y_2 - Y_{CGD09}}{y_2 - y_1}\left(\frac{x_2 - X_{CGD09}}{x_2 - x_1}\cdot dy_{11} + \frac{X_{CGD09} - x_1}{x_2 - x_1}\cdot dy_{21}\right) + \frac{Y_{CGD09} - y_1}{y_2 - y_1}\left(\frac{x_2 - X_{CGD09}}{x_2 - x_1}\cdot dy_{12} + \frac{X_{CGD09} - x_1}{x_2 - x_1}\cdot dy_{22}\right) \\ \frac{y_2 - Y_{CGD09}}{y_2 - y_1}\left(\frac{x_2 - X_{CGD09}}{x_2 - x_1}\cdot dh_{11} + \frac{X_{CGD09} - x_1}{x_2 - x_1}\cdot dh_{21}\right) + \frac{Y_{CGD09} - y_1}{y_2 - y_1}\left(\frac{x_2 - X_{CGD09}}{x_2 - x_1}\cdot dh_{12} + \frac{X_{CGD09} - x_1}{x_2 - x_1}\cdot dh_{22}\right) \end{bmatrix}$$

$X_{CGD23}: X(N) value\ of\ CGD23\ coordinates\ of\ point\ A$

$Y_{CGD23}: Y(E)\ value\ of\ CGD23\ coordinates\ of\ point\ A$

$H_{CGD23}: Elevation\ value\ of\ CGD23\ coordinates\ at\ point\ A$

$X_{CGD09}: X(N) value\ of\ CGD09\ coordinates\ of\ point\ A$

$Y_{CGD09}: Y(E)\ value\ of\ CGD09\ coordinates\ of\ point\ A$

$H_{CGD09}: Elevation\ value\ of\ CGD09\ coordinates\ at\ point\ A$

$dx_{ij} = x_{Bij\ CGD09} - x_{Bij\ CGD23}: Correction\ amount\ for\ coordinate\ transformation\ of\ X(N) coordinate\ of\ point\ B_{ij}$

$dy_{ij} = y_{Bij\ CGD09} - y_{Bij\ CGD23}: Correction\ amount\ for\ coordinate\ transformation\ of\ Y(E) coordinate\ of\ point\ B_{ij}$

$dh_{ij} = h_{Bij\ CGD09} - h_{Bij\ CGD23}: Correction\ amount\ for\ coordinate\ transformation\ of\ elevation\ value\ of\ point\ B_{ij}$

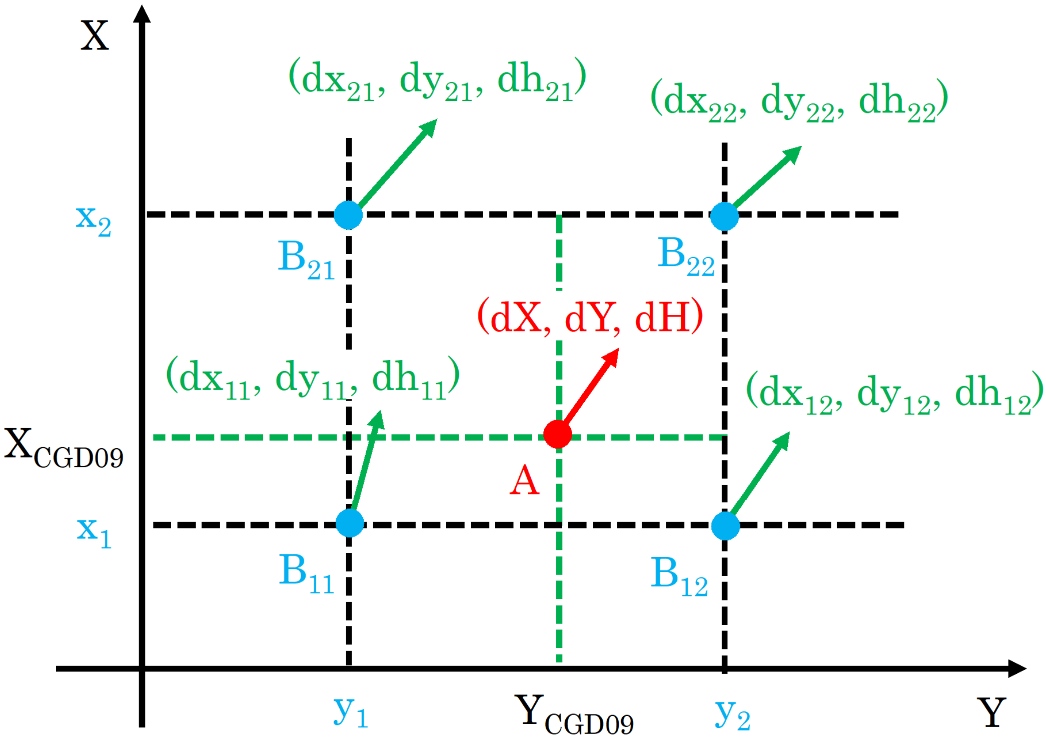


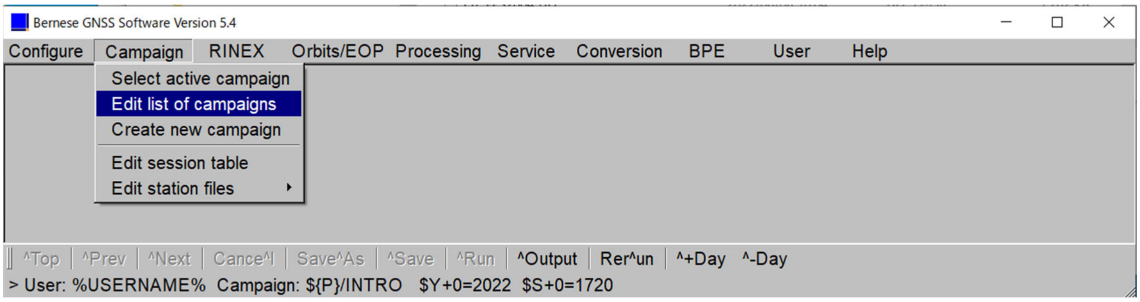
Figure 6 Bilinear transformation method with linear interpolation

5. Coordinate Transformation

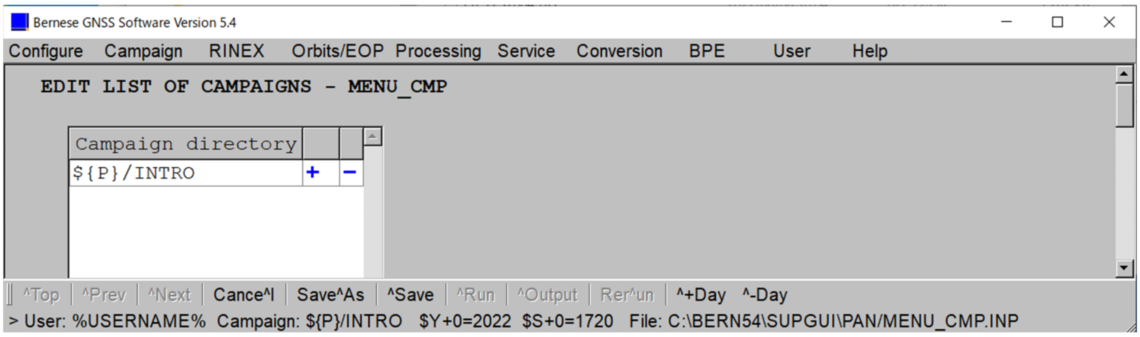
5.1. Create a campaign and the point coordinate files

5.1.1. Edit list of campaigns

Click [Edit list of campaigns] to display the submenu.

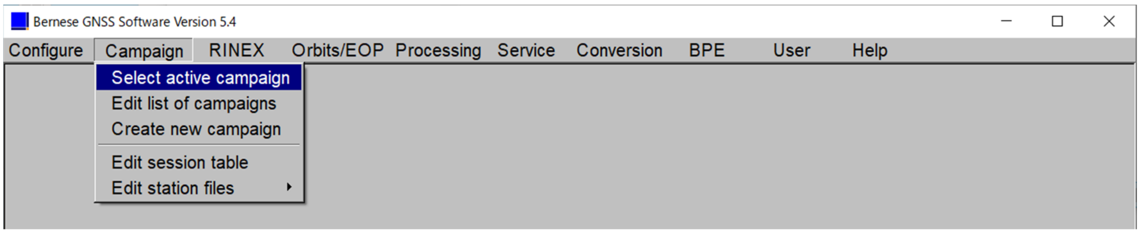


Click [+] to copy the line. Click [-] to delete the line.
Rename the campaign directory to [${P}/XXXXX]. [XXXXX] can be named arbitrarily.
Click [^Save] to save your changes.

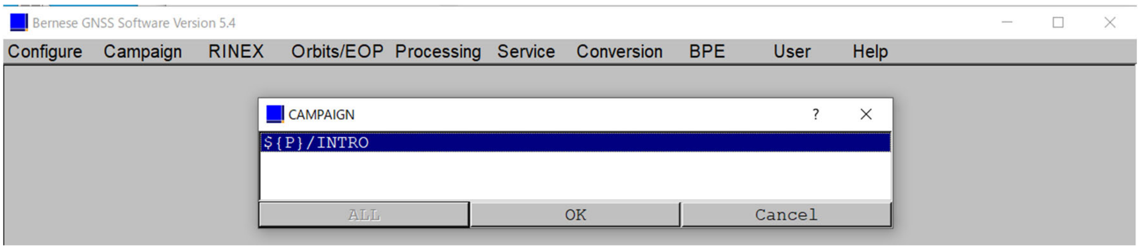


5.1.2. Select the active campaign

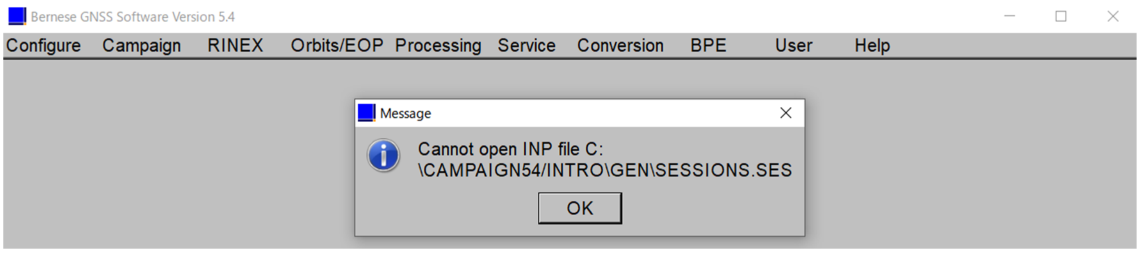
Click [Select active campaign] to display the registered campaign directory.

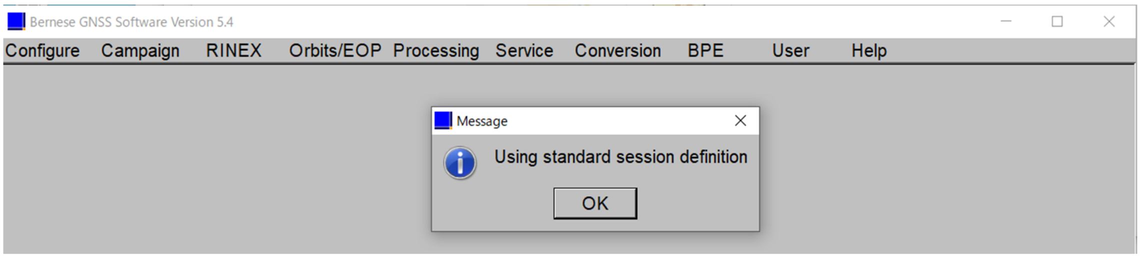


Select the campaign and click [OK].

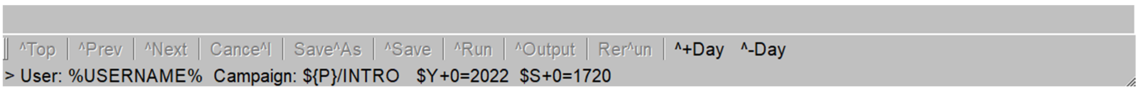


If the Directory is not created, Message will be displayed, but there is no problem. So press the [OK] button. Then, click [OK] for all.



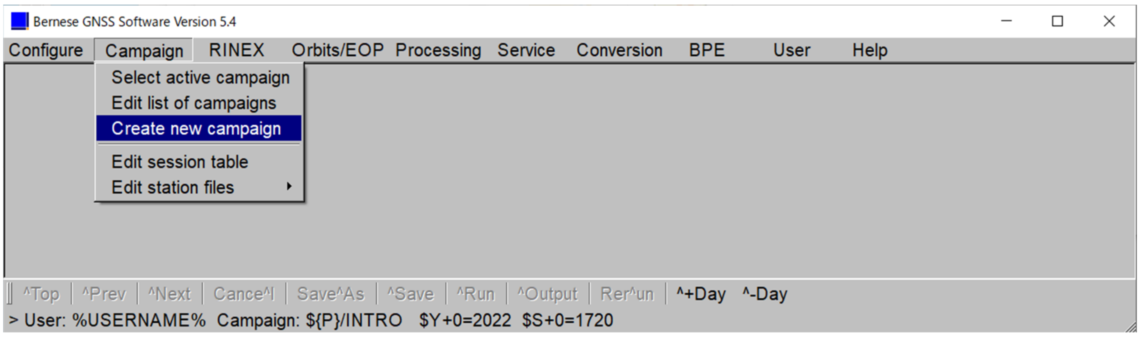


Make sure the selected campaign is displayed at the bottom of the menu screen.

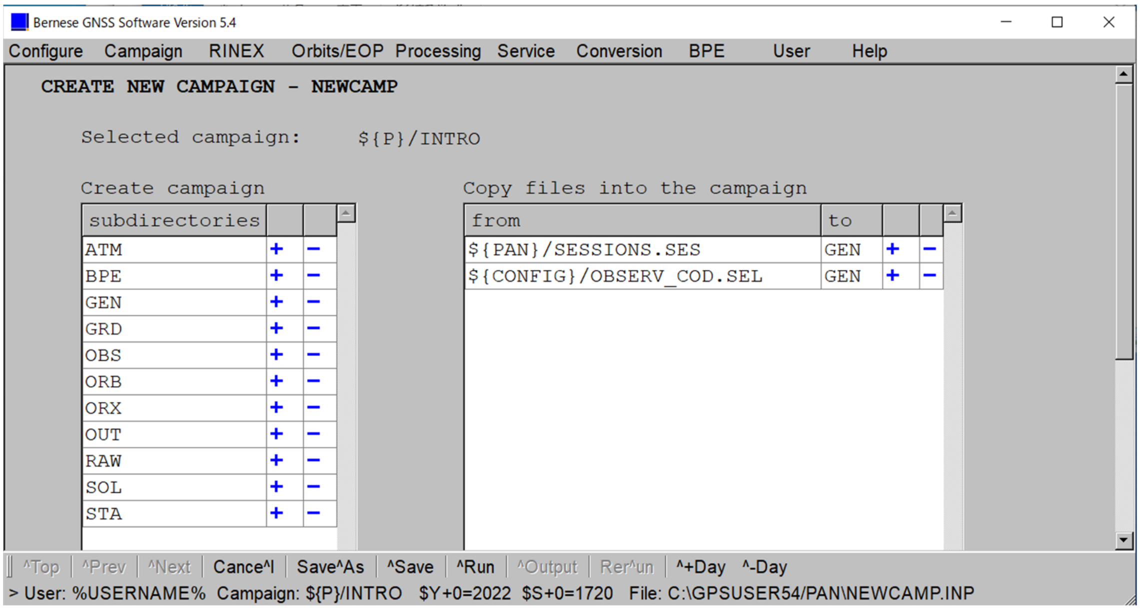


5.1.3. Create campaign folder

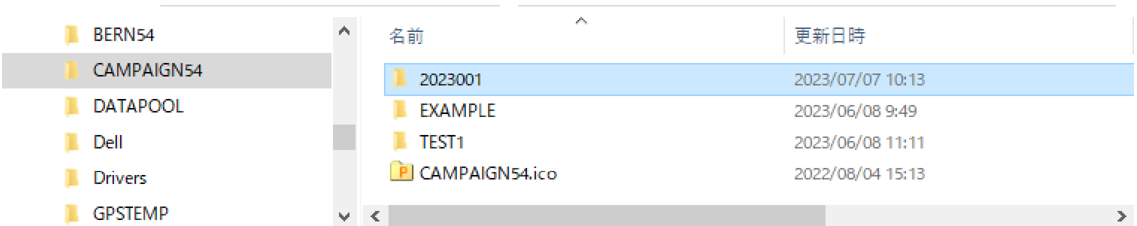
Click [Create new campaign] to display the submenu.



Click [^Run]

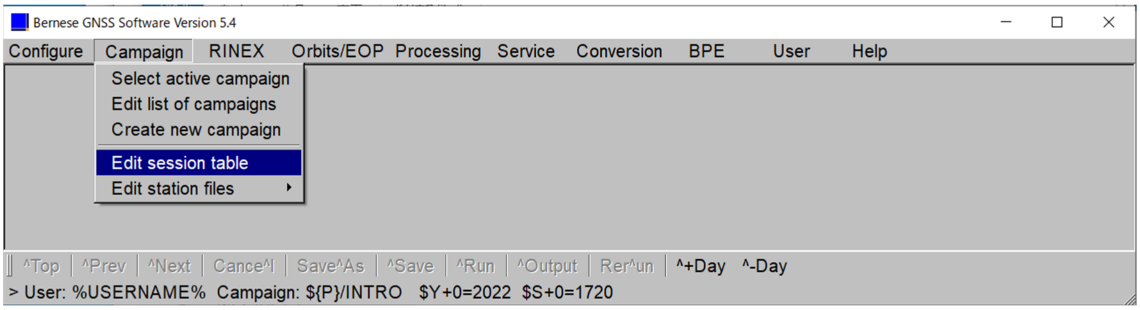


A folder with the campaign name will be created in the CAMPAIGN54 folder.



5.1.4. Select current session

Click [Edit session table] to display the registered Session table.

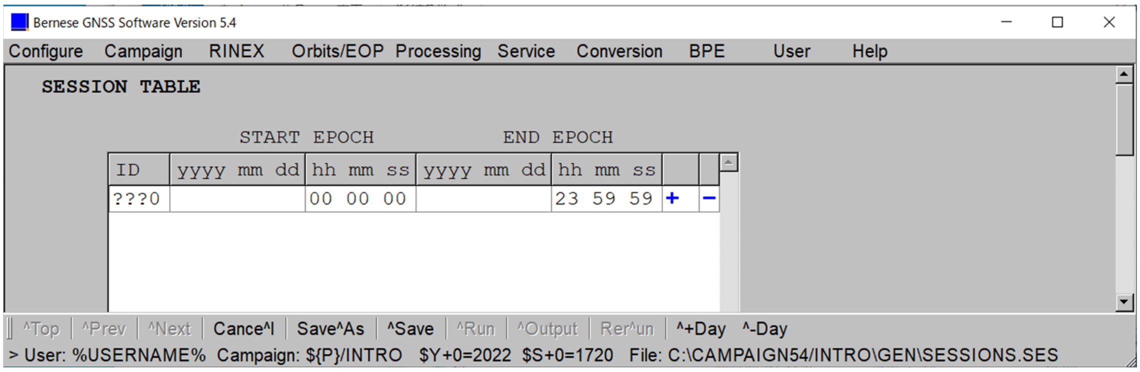


[???] is [Day of year]. It is a total day with 1st-Jan as 1. Set with wildcards.

START EPOCH and END EPOCH dates [yyyy mm dd] are blank.

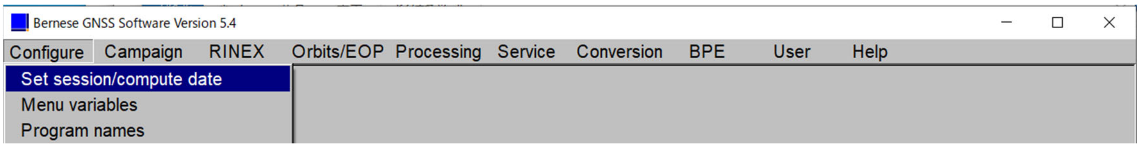
START EPOCH time is 00:00:00. END EPOCH time is 23:59:59.

Click [^Save].



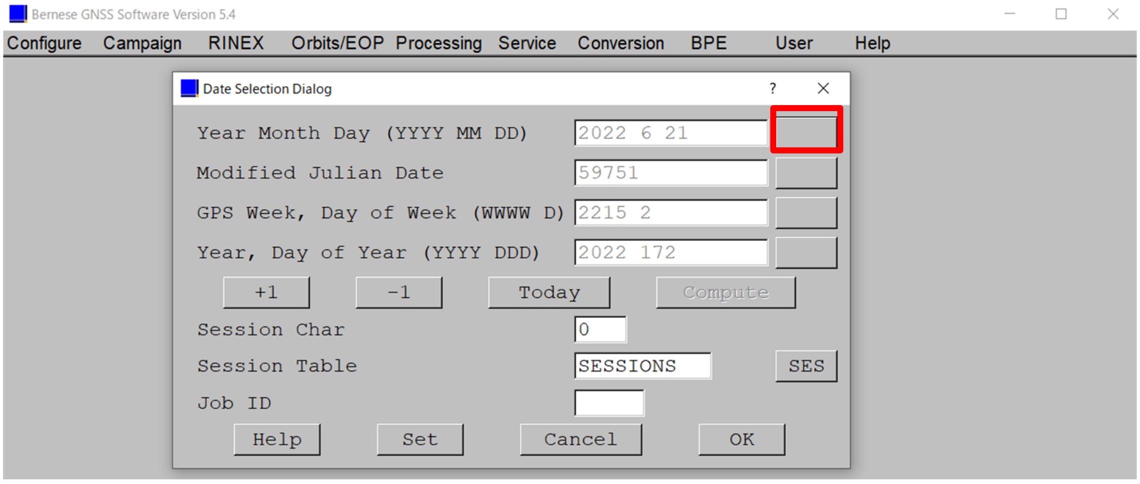
5.1.5. Calculation date setting

Click [Set session/compute date] to display the submenu

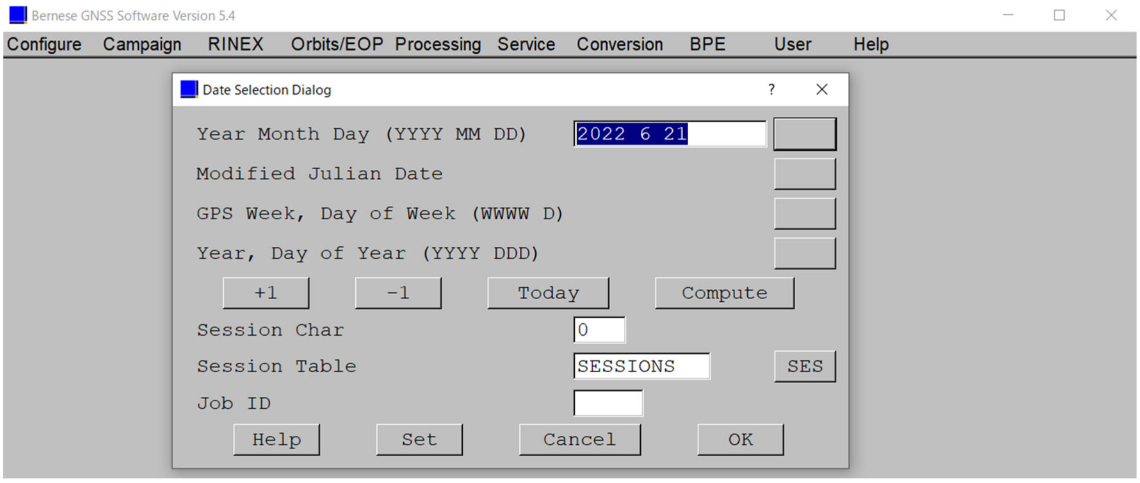


Set by [Year Month Day], [Modified Julian Date], [GPS Week and Day of Week] or [Year and Day of Year].

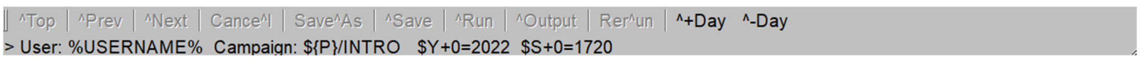
Click the red frame to set in [Year Month Day].



Enter the date and click [OK].



Make sure that the baseline processing date you set is displayed at the bottom of the menu screen.



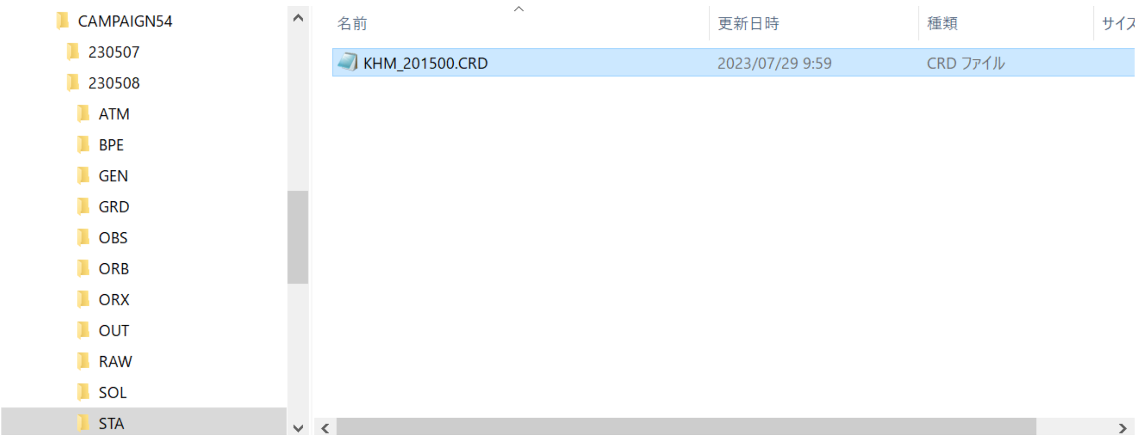
5.1.6. Create the point coordinate file

Create the point coordinate files using a text editor. (e.g. CGD23.CRD and CGD09.CRD)

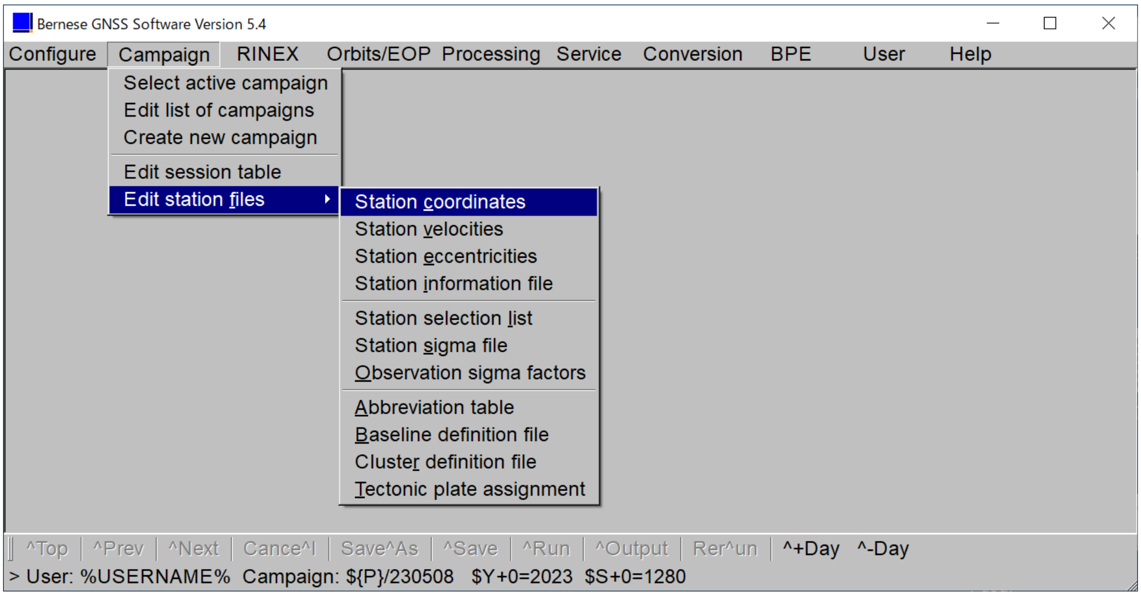
```
-------------------------------------------------------------------------------
LOCAL GEODETIC DATUM: IGS20           EPOCH: 2015-01-01 00:00:00

NUM  STATION NAME           X (M)          Y (M)          Z (M)     FLAG     SYSTEM

  1  ANMG             -1270826.89380  6242631.33340   307792.42240    I
  2  CMUM              -938078.34810  5968373.98630  2038404.32190    I
  3  CUSV             -1132914.86460  6092528.56900  1504633.21270    I
  4  HKSL             -2393382.91750  5393860.99760  2412592.23210    I
  5  PTAG             -3184318.71050  5291065.49990  1590418.24380    I
  6  SIN1             -1507972.63360  6195613.86690   148488.03430    I
  7  KND1             -1619492.94400  6040715.07000  1247864.90000
  8  KSP1             -1572714.38600  6050448.84600  1260501.89200
  9  PNH1             -1603672.47300  6038739.32500  1277314.62100
 10  SIE1             -1490303.89300  6024644.81700  1465891.13600
 11  STG1             -1706798.61200  5963096.21200  1481479.65100
```

5.1.7. Edit Coordinate file

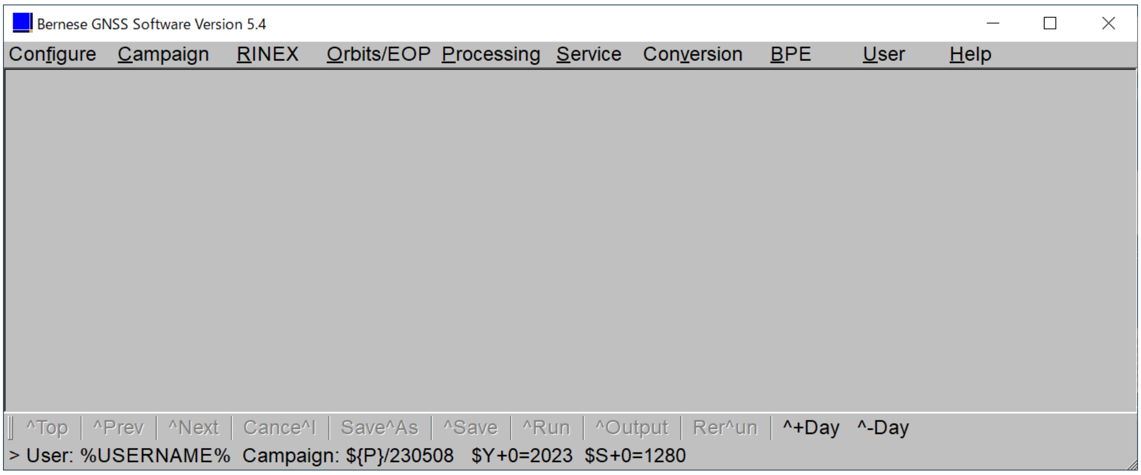
Copy the point coordinate files to [STA] folder of the campaign.



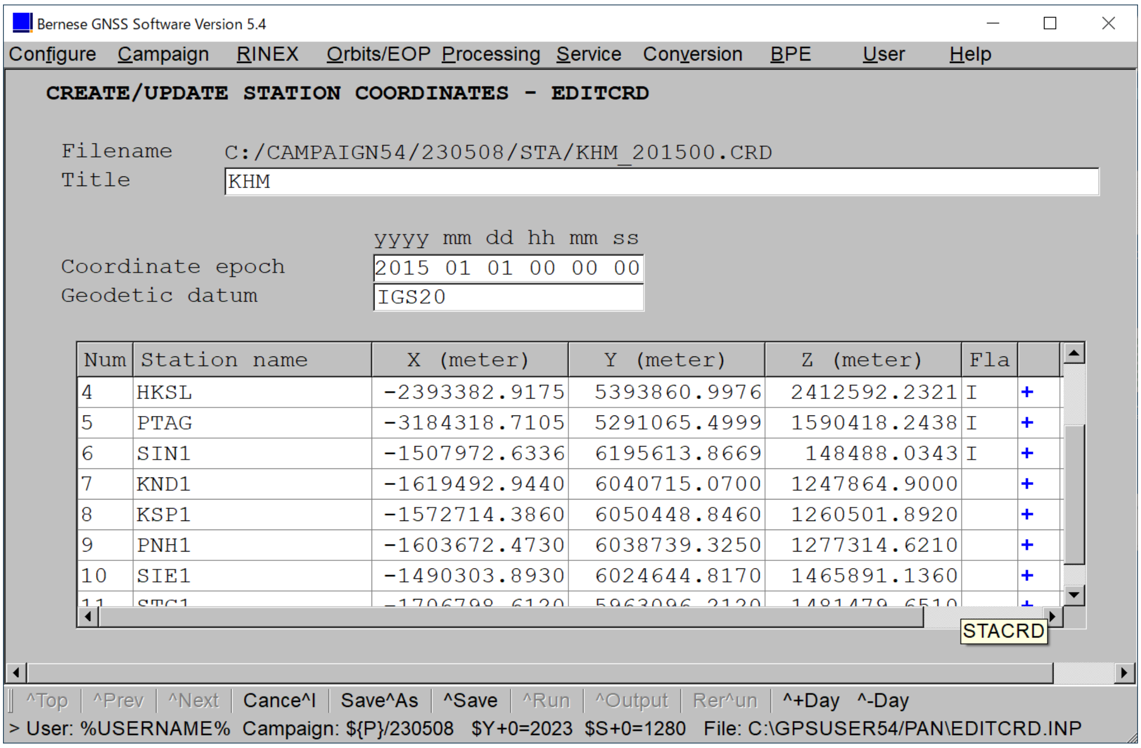
Click [Station Coordinates] to display the submenu.



Select the coordinate file and click [OK].



Enter Title, Coordinate epoch, Geodetic datum, Station name and the coordinate values. Click [^Save].



Title: Can be entered arbitrarily

Coordinate epoch: The year, month, day, hour, and second for which the coordinates were calculated.

Geodetic datum: e.g. IGS20

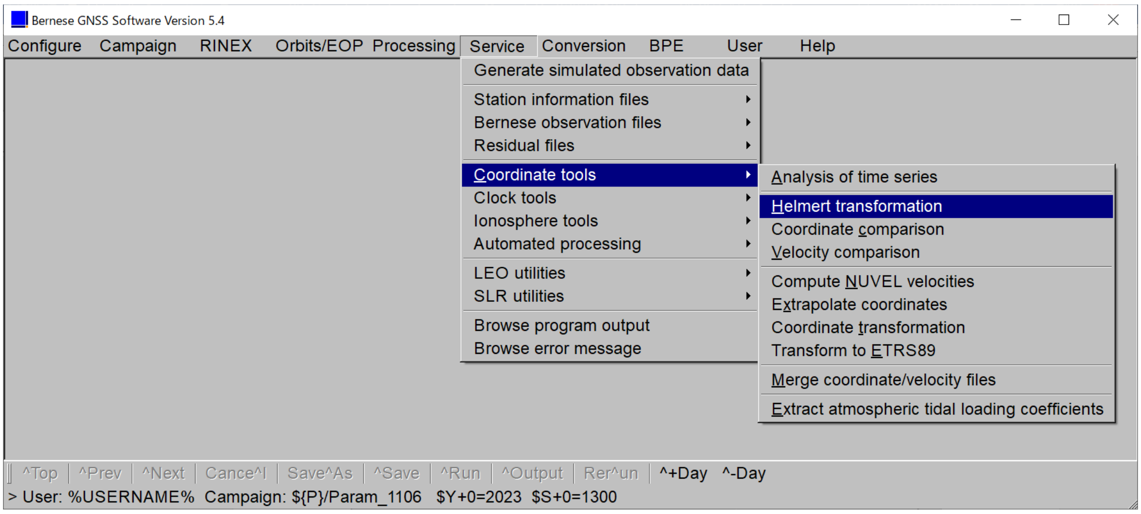
Refer to the following website for Transformation Parameters between ITRF Solutions.

Transformation Parameters between ITRF Solutions website:

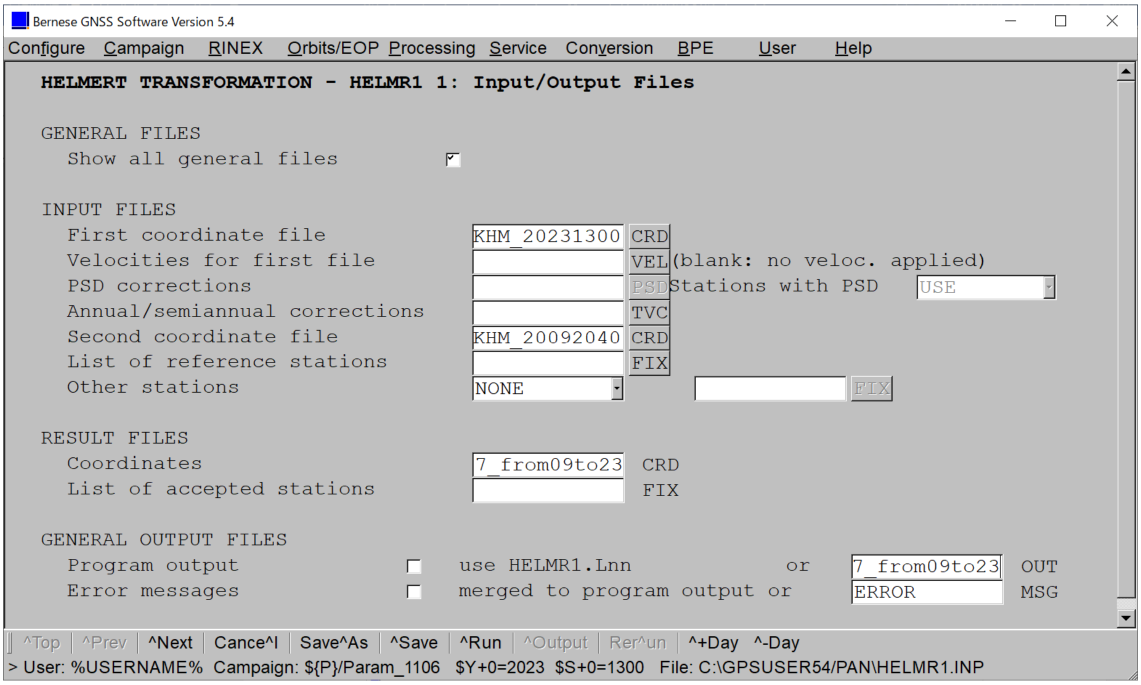
https://itrf.ign.fr/en/solutions/transformations

5.2. Helmert transformation (HELMR1)

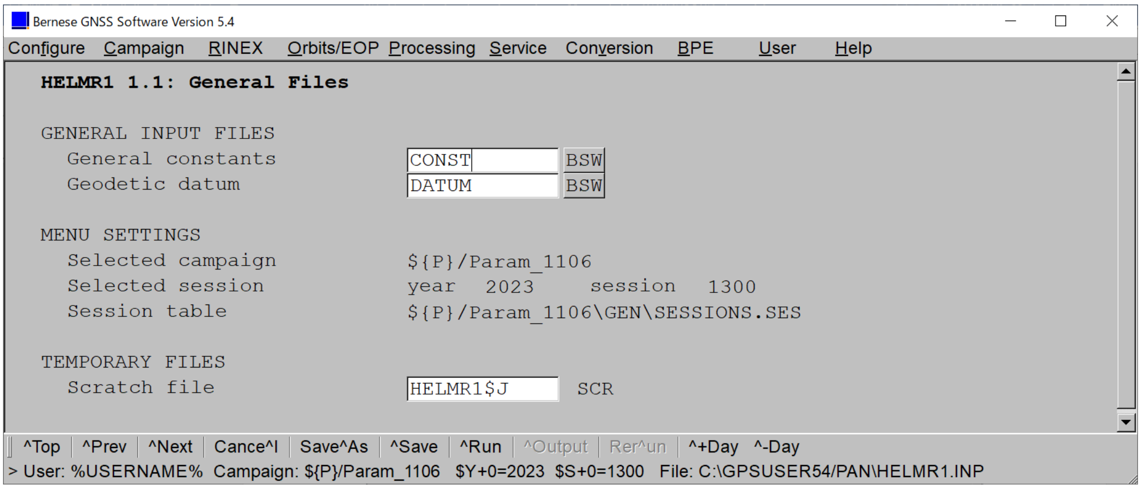
Calculation of transformation parameters from CGD09 to CGD23 is shown below.
Click [Helmert transformation] to display the submenu.



Select Input files ([First] is [To], [Second] is [From]).
Enter the file name of Result coordinates file and Output file.
Click [^Next].



Click [^Next].



Enter Title.

Select [STATION SELECTION].

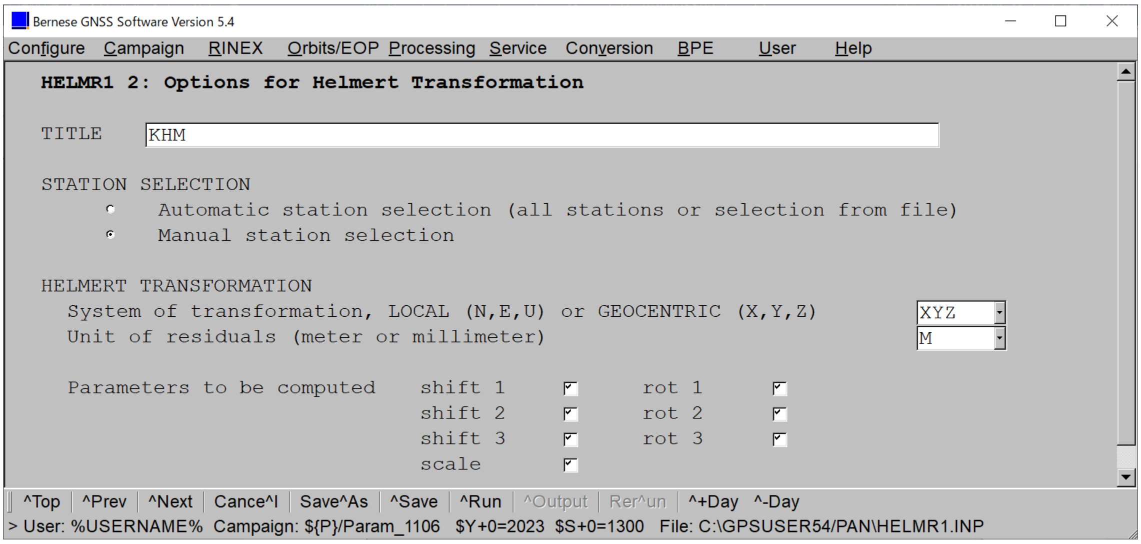
✓ Manual station selection

Select [HELMERT TRANSFORMATION].

✓ System of transformation: LOCAL (N, E, U) or GEOCENTRIC (X, Y, Z)

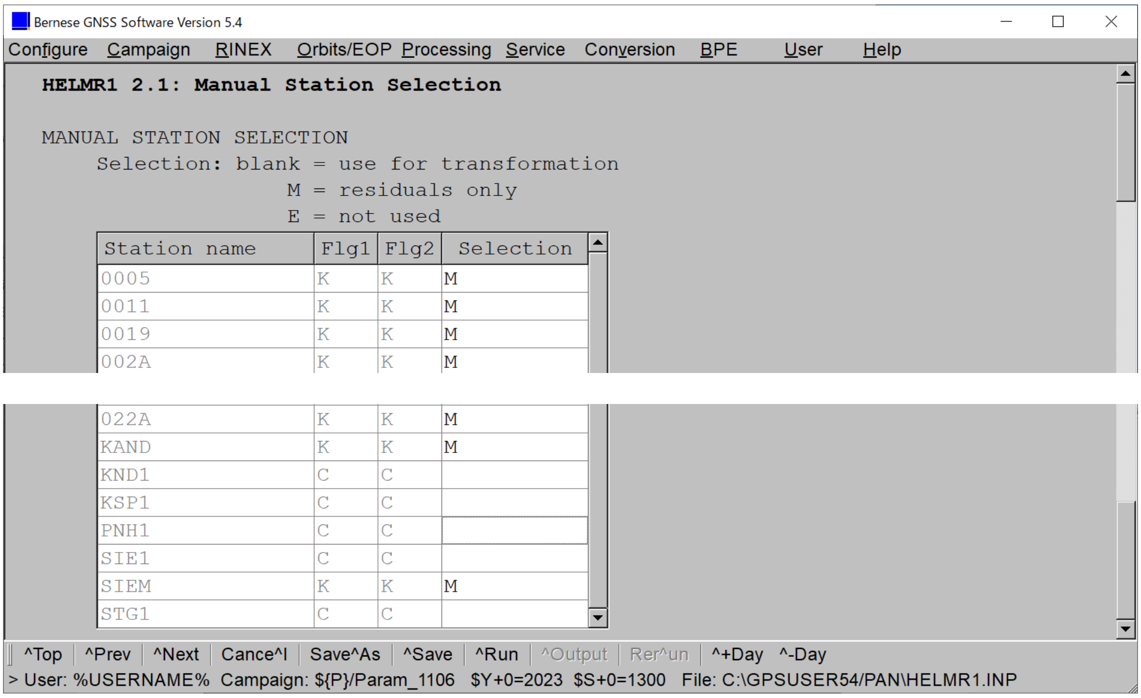
✓ Parameters to be computed: 3 parameters or 7 parameters

Click [^Next].

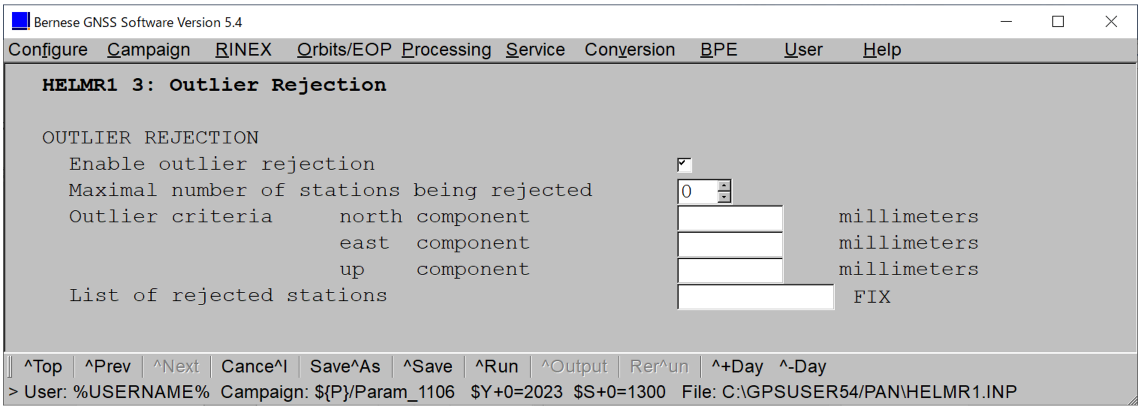


Input [STATION SELECTION].

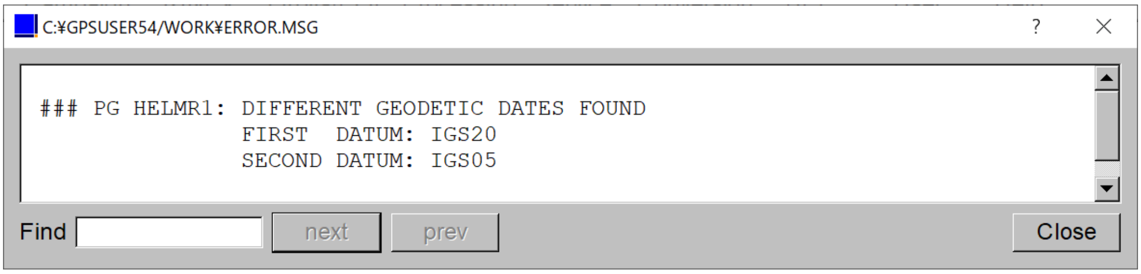
- ✓ [Blank], [M] or [E]
- ✓ Click [^Next].



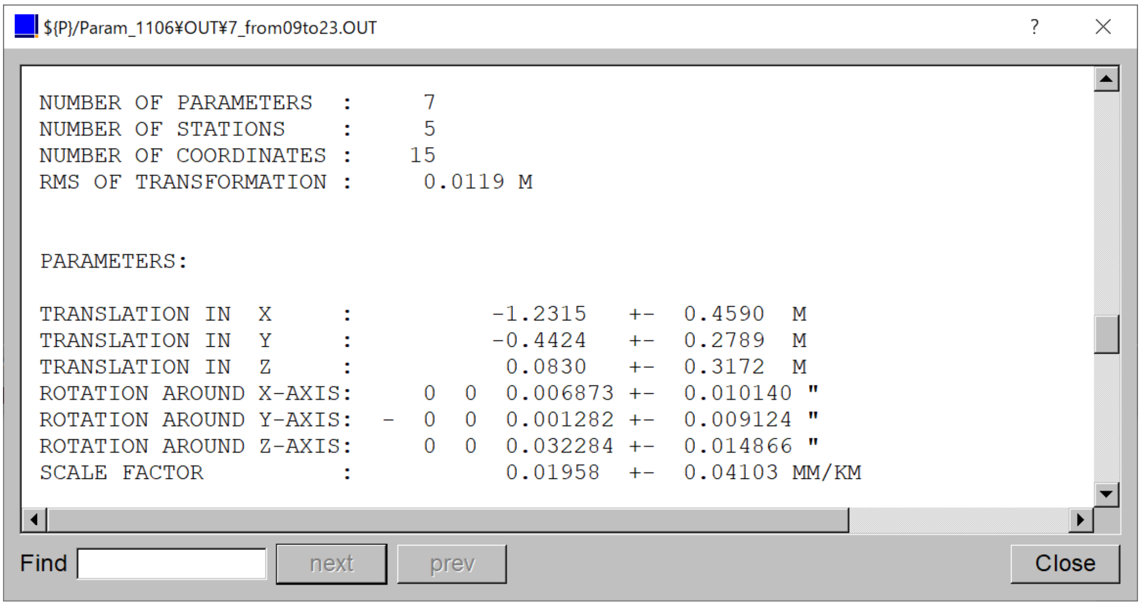
Click [^Run].



You can safely ignore this warning.



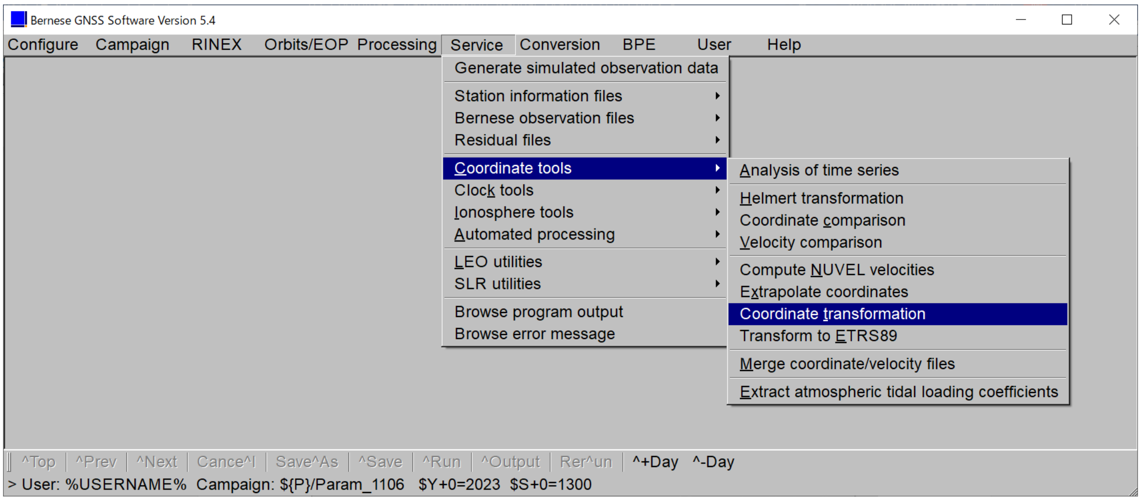
You can see the calculation result by clicking [^Output].
Also, the calculation result is saved in [OUT] of the campaign.



5.3. Coordinate transformation

Transform the coordinates using the parameters obtained in section [5.2.].

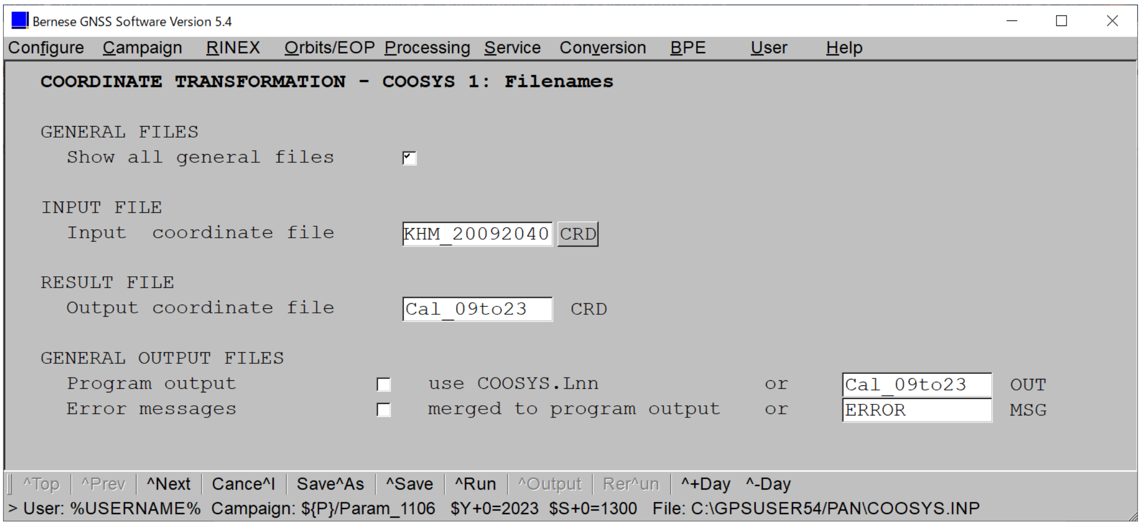
Click [Coordinate transformation] to display the submenu.



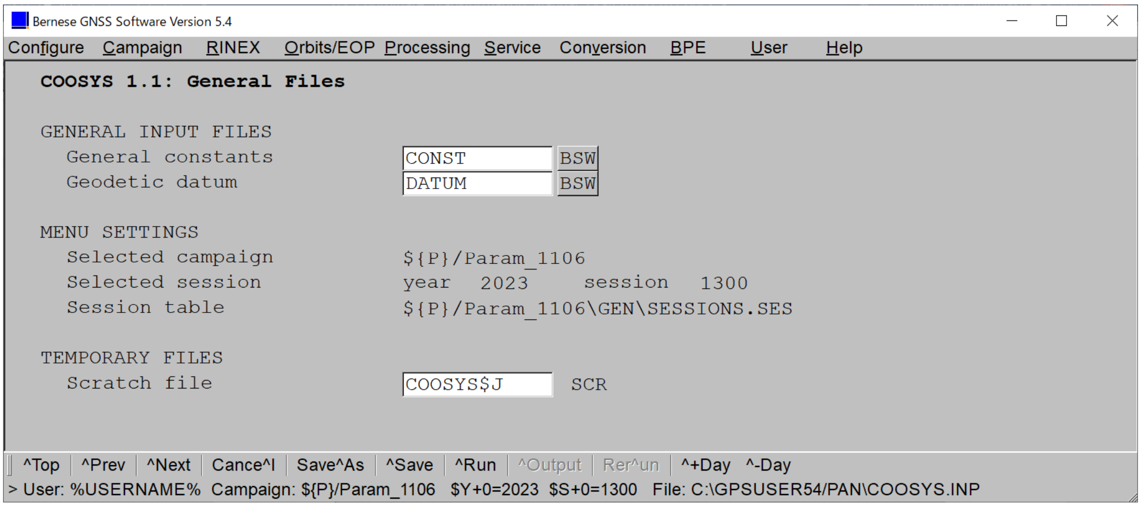
Select Input file [From].

Enter the file name of Result file [To] and Output file.

Click [^Next].



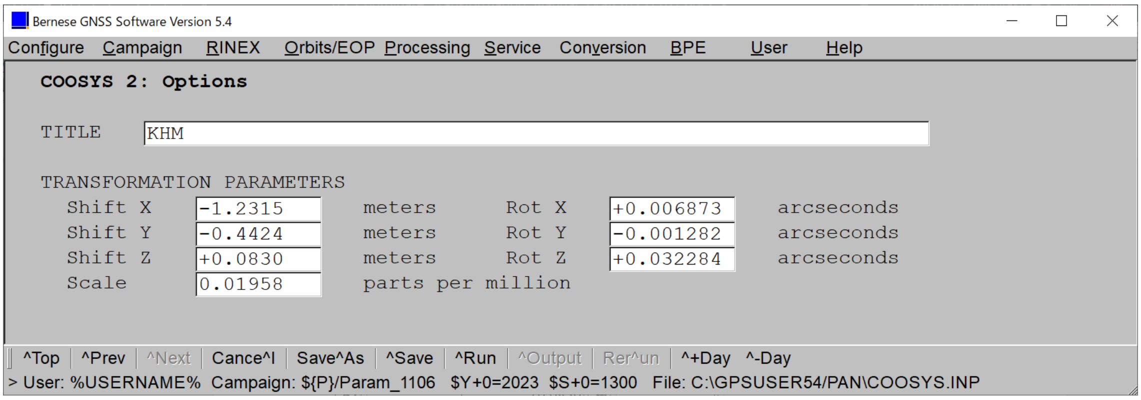
Click [^Next].



Enter Title and 7 parameters.

For scale, input [s] of (1+s).

Click [^Run].



Click [^Output].

Check the results.

The calculation result is saved in [STA] of the campaign.

6. Coordinate transformation parameter

6.1. Coordinate transformation parameters from CGD09 to CGD23 (7 parameters)

Coordinate transformation parameters were calculated using CGD09 and CGD23 coordinates of Khmer GEONET (5 points). 7 parameters of dX, dY, dZ, Rx, Ry, Rz and Scale are calculated.

6.1.1. 7 parameters

(A) Geocentric (X, Y, Z)

Element	Parameter	Unit
dX	-1.2315	m
dY	-0.4424	m
dZ	+0.0830	m
R_X	+0.006873	arc second
R_Y	-0.001282	arc second
R_Z	+0.032284	arc second
Scale	0.01958	mm/km (ppm), [s] of (1+s)

(B) Local (N, E, U)

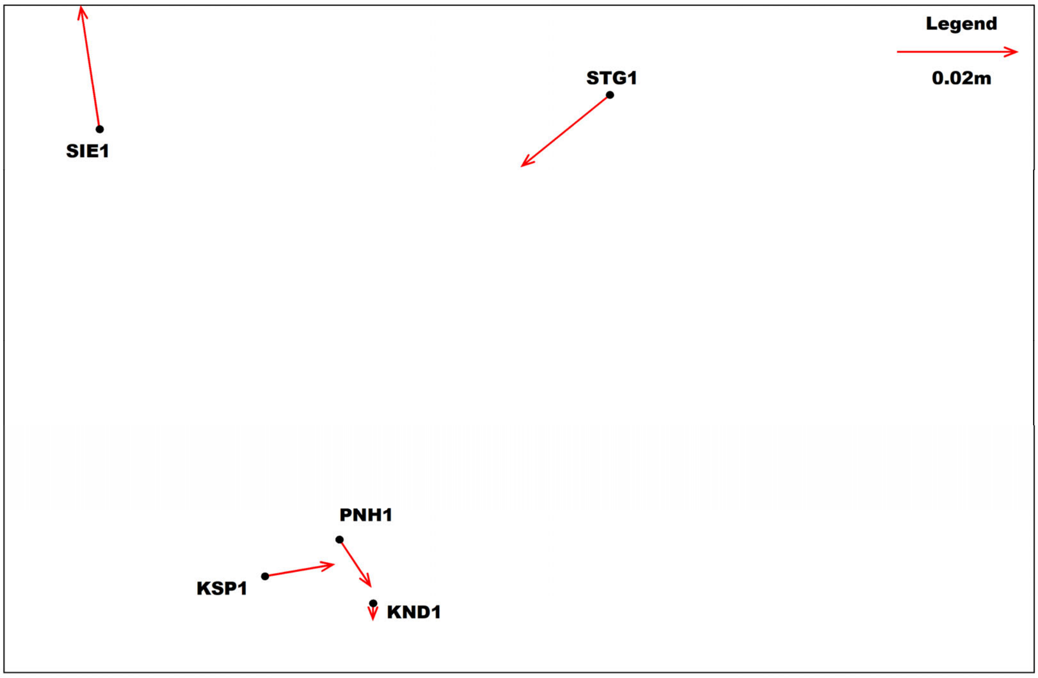
Element	Parameter	Unit
dN	-0.0905	m
dE	+0.3087	m
dU	+0.0330	m
R_N	-0.032184	arc second
R_E	+0.006314	arc second
R_U	-0.003929	arc second
Scale	0.01958	mm/km (ppm), [s] of (1+s)

6.1.2. Evaluating Coordinate Transformation Parameters (Residual check)

(1) Table of residual

Name	Residual					
	dX (m)	dY (m)	dZ (m)	dN (m)	dE (m)	dU (m)
KND1	0.001	-0.007	-0.005	-0.003	0.000	-0.008
KSP1	-0.012	0.002	0.003	0.002	0.011	0.005
PNH1	-0.006	0.004	-0.007	-0.008	0.005	0.004
SIE1	0.005	-0.005	0.020	0.021	-0.003	-0.001
STG1	0.012	0.007	-0.011	-0.012	-0.014	0.000

(2) Vector of residual (dN, dE)



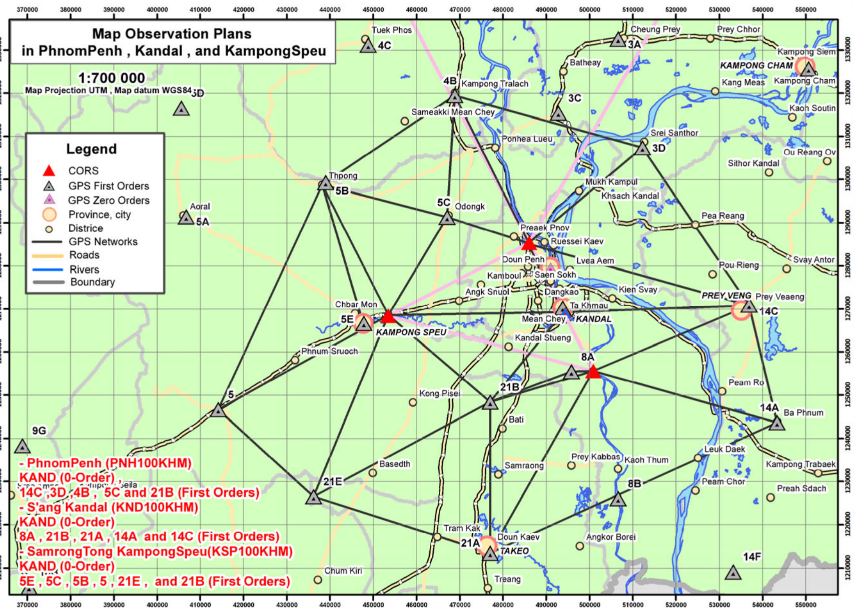
(3) Evaluation

The maximum value is the residuals in the north direction (21 mm) at SIE1, which is sufficiently small. Therefore, the calculated coordinate transformation parameters can be used as the adopted values.

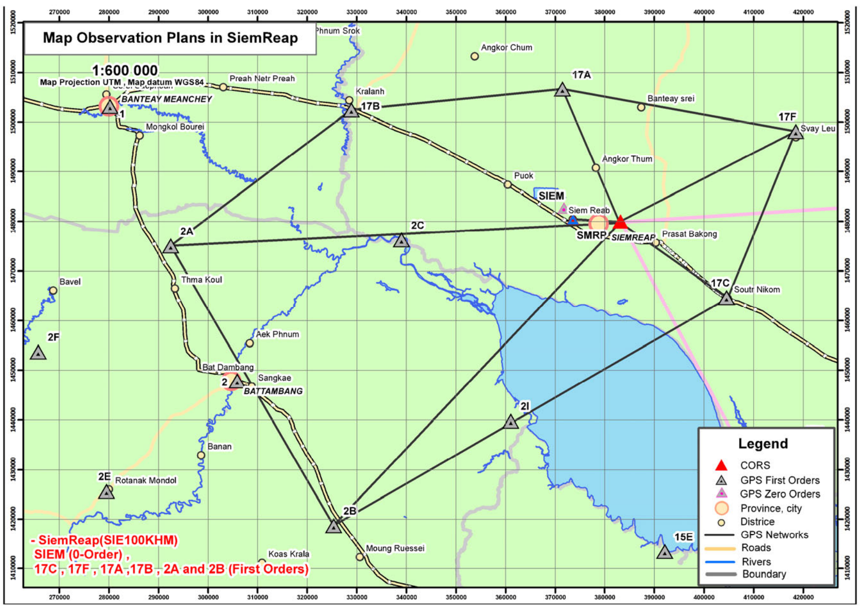
6.1.3. Evaluating Coordinate Transformation Parameters (Compare the coordinate values from the re-survey with the coordinate values from the coordinate transformation parameters)

(1) Re-survey network

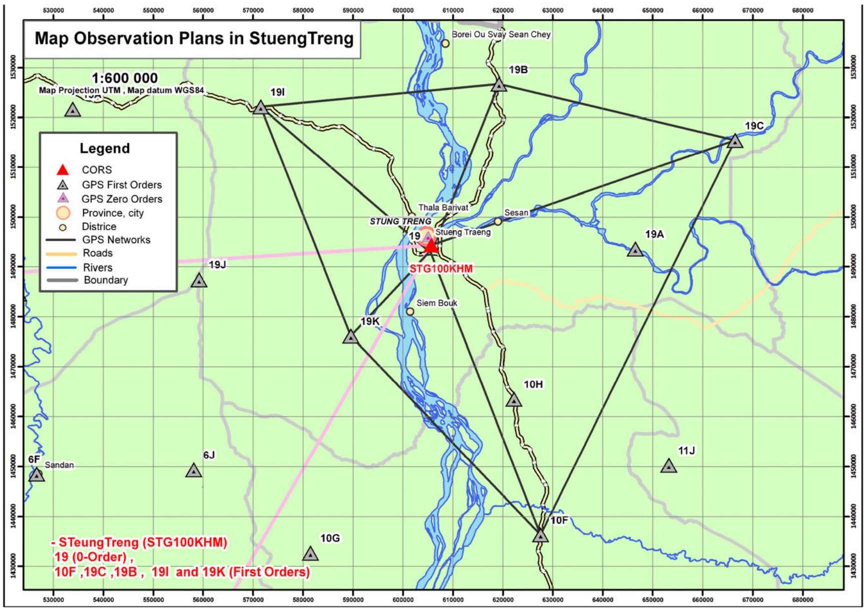
(A) Phnom Penh, Kandal and Kampong Speu (Re-survey was conducted in June 2022)



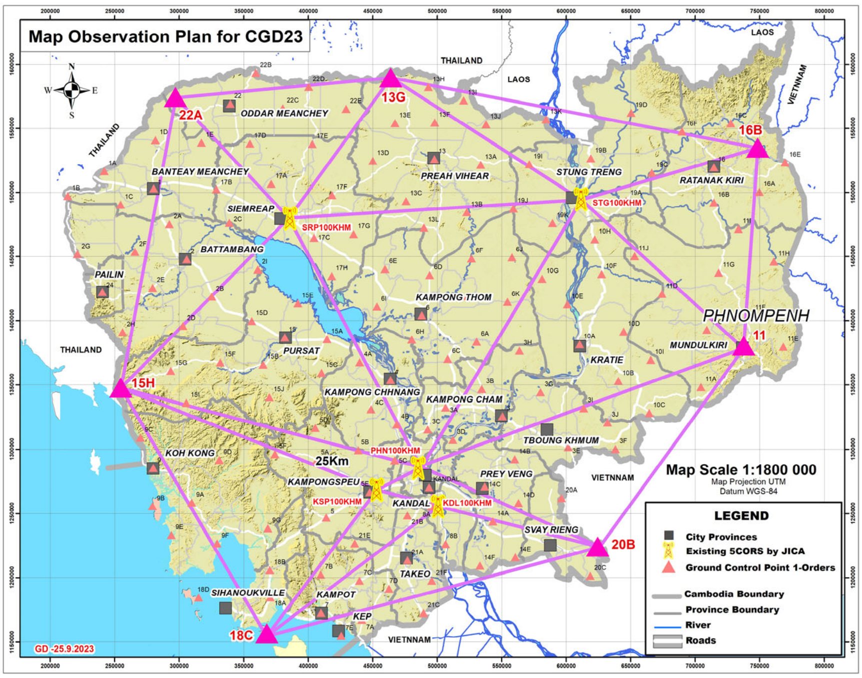
(B) Siem Reap (Re-survey was conducted in June 2022)



(C) Stueng Treng (Re-survey was conducted in June 2022)



(D) Near the national boundary (Re-survey was conducted in September 2023)

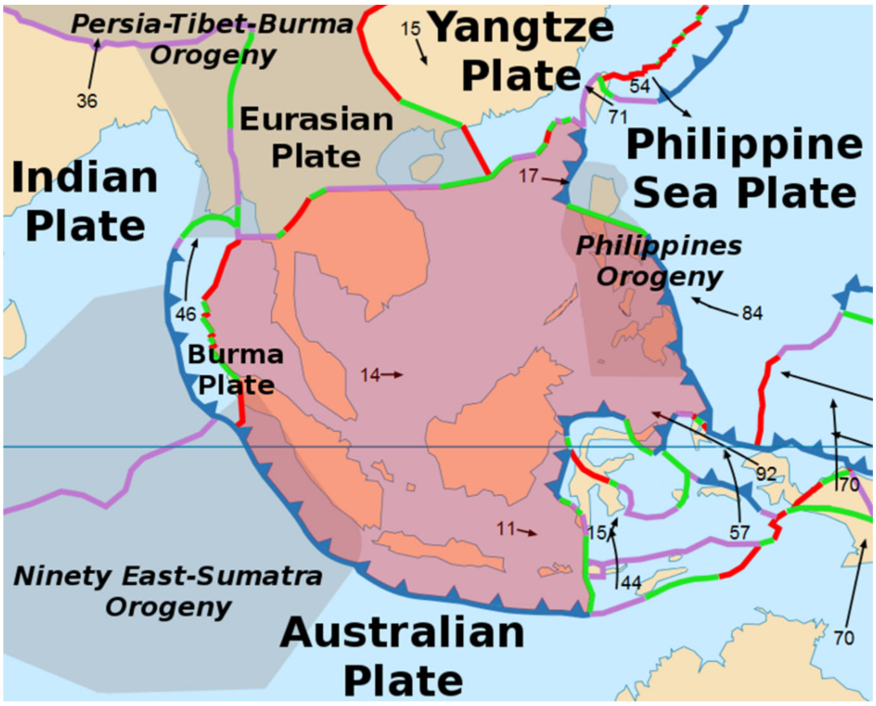


(2) Displacement amount from CGD09 to CGD23

(A) Displacement amount

The difference between the CGD09 and CGD23 coordinates is shown in the table below. Since the transformation parameters between geodetic reference systems (between ITRF2005 (CGD09) and ITRF2020 (CGD23)) are minute, the values shown in the table below are the displacements generated from survey errors and crustal deformation.

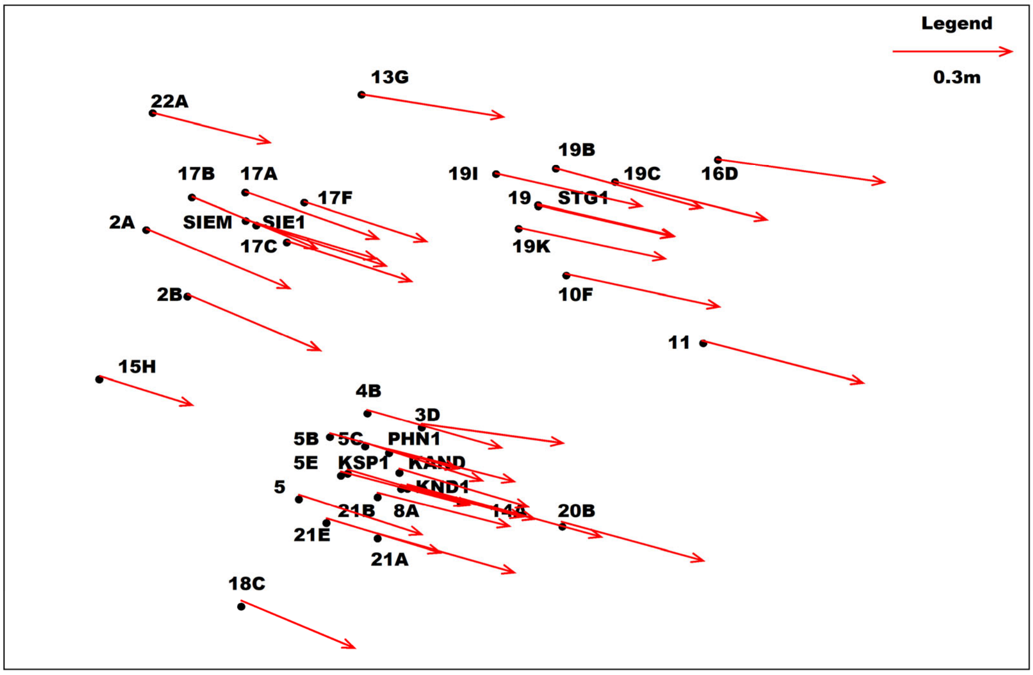
During the 14 years period, the land was displaced approximately 0.1m to the south and 0.3m to the east, resulting in a displacement of approximately 0.3m in the east-southeast direction. The height is about 0.03m, and there is a tendency toward micro uplift. The displacement rate of horizontal displacement is about 0.02m/year. According to the figure below, the displacement of the Sonde plate is in the east direction and its displacement speed is 0.014m/year, which is consistent with the plate motion.



https://en.wikipedia.org/wiki/Sunda_Plate#:~:text=The%20Sunda%20Plate%20is%20a%20minor%20tectonic%20plate,movement%20at%2010%20mm%2Fyr%20eastward%20relative%20to%20Eurasia

Name	CGD23 - CGD09 dX (m)	dY (m)	dZ (m)	dN (m)	dE (m)	dU (m)
(A) Phnom Penh, Kandal and Kampong Speu						
000500KHM	-0.303	-0.011	-0.092	-0.103	0.296	0.044
003D00KHM	-0.316	-0.138	-0.062	-0.050	0.341	-0.062
004B00KHM	-0.334	-0.002	-0.082	-0.098	0.323	0.064
005B00KHM	-0.306	-0.051	-0.087	-0.091	0.308	0.009
005C00KHM	-0.292	-0.002	-0.085	-0.098	0.283	0.053
005E00KHM	-0.296	-0.066	-0.085	-0.086	0.303	-0.005
008A00KHM	-0.301	-0.007	-0.072	-0.084	0.293	0.056
014A00KHM	-0.344	-0.028	-0.090	-0.100	0.339	0.045
021A00KHM	-0.328	-0.043	-0.093	-0.100	0.329	0.024
021B00KHM	-0.319	-0.035	-0.079	-0.087	0.318	0.031
021E00KHM	-0.284	-0.003	-0.077	-0.089	0.275	0.051
KAND00KHM	-0.300	-0.081	-0.101	-0.099	0.310	-0.021
(B) Siem Reap						
002A00KHM	-0.346	-0.031	-0.143	-0.154	0.343	0.015
002B00KHM	-0.323	-0.019	-0.135	-0.145	0.318	0.025
017A00KHM	-0.326	-0.014	-0.107	-0.121	0.320	0.038
017B00KHM	-0.303	-0.028	-0.125	-0.133	0.300	0.013
017C00KHM	-0.294	-0.064	-0.104	-0.105	0.300	-0.014
017F00KHM	-0.290	-0.054	-0.099	-0.102	0.294	-0.003
SIEM00KHM	-0.315	-0.035	-0.092	-0.101	0.314	0.018
(C) Stueng Treng						
001900KHM	-0.338	-0.016	-0.067	-0.082	0.329	0.059
010F00KHM	-0.374	-0.035	-0.073	-0.085	0.369	0.050
019B00KHM	-0.354	-0.041	-0.092	-0.102	0.353	0.035
019C00KHM	-0.358	-0.080	-0.097	-0.098	0.366	0.002
019I00KHM	-0.360	-0.016	-0.067	-0.084	0.351	0.064
019K00KHM	-0.357	-0.035	-0.069	-0.081	0.354	0.047
(D) Near the national boundary						
01100KHM	-0.398	-0.014	-0.091	-0.109	0.386	0.082
13G00KHM	-0.344	-0.031	-0.045	-0.058	0.341	0.044
15H00KHM	-0.231	0.004	-0.062	-0.075	0.224	0.040
16D00KHM	-0.406	-0.045	-0.046	-0.060	0.402	0.065
18C00KHM	-0.273	-0.033	-0.115	-0.121	0.273	0.011
20B00KHM	-0.336	-0.061	-0.096	-0.100	0.341	0.016
22A00KHM	-0.289	-0.007	-0.062	-0.076	0.282	0.042
Khmer GEONET						
KND100KHM	-0.311	-0.022	-0.079	-0.090	0.307	0.043
KSP100KHM	-0.295	-0.037	-0.087	-0.093	0.295	0.020
PNH100KHM	-0.304	-0.035	-0.076	-0.083	0.302	0.027
SIE100KHM	-0.313	-0.037	-0.100	-0.108	0.312	0.015
STG100KHM	-0.335	-0.016	-0.065	-0.080	0.326	0.060
Max	-0.231	0.004	-0.045	-0.050	0.402	0.082
Min	-0.406	-0.138	-0.143	-0.154	0.224	-0.062
Average	-0.322	-0.034	-0.086	-0.095	0.319	0.030

(B) Displacement vector (dN, dE)



(3) Comparison between re-survey and transformation results using parameters

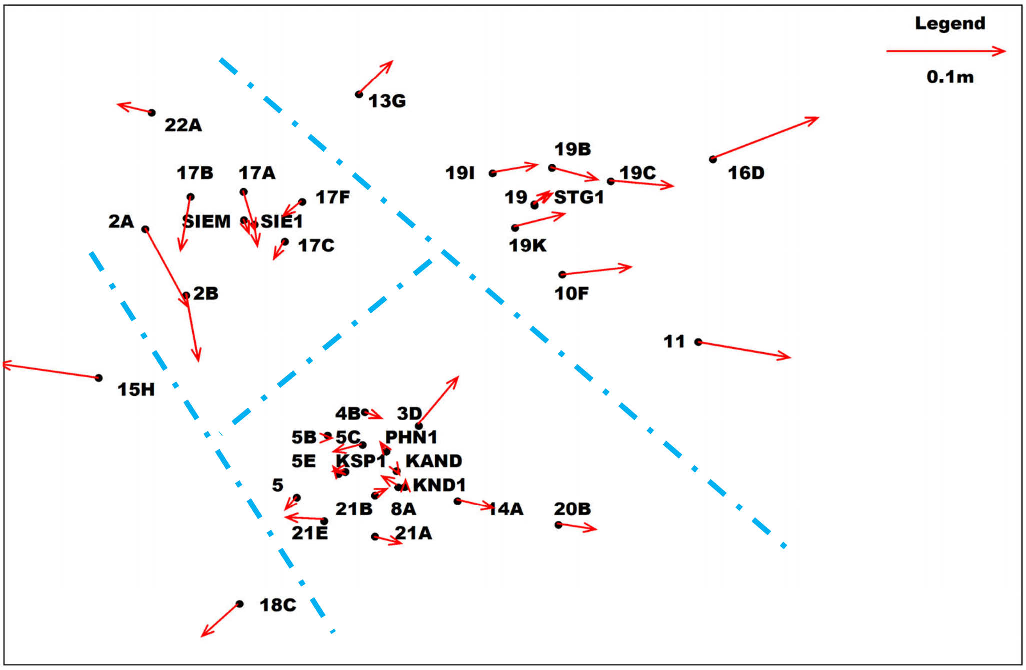
(A) Comparison of tables

Having compared the results of the Re-survey and the parameter-based transformations, the following characteristics were found.

- 2A, 3D, 11, 15H, 16D, 19C are singular points because their differences are larger than the other points. It is recommended to conduct further inspection survey after CORS is installed throughout Cambodia.
- Except for the above points, the difference is less than about 50 mm.
- In the Phnom Penh, Kandal and Kampong Speu region, the difference between the Re-survey and transformation results is small.
- In the Siem Reap region, the Re-survey results are located to the south.
- In the Stueng Treng region, Re-survey results are located to the eastern.
- Near the western coast area, the Re-survey results are located on the west side, but cannot be determined because 15H is a singularity.

Name	ReSurv. - Param. dX (m)	dY (m)	dZ (m)	dN (m)	dE (m)	dU (m)
(A) Phnom Penh, Kandal and Kampong Speu						
000500KHM	0.002	0.031	-0.007	-0.013	-0.010	0.027
003D00KHM	-0.004	-0.112	0.020	0.041	0.033	-0.100
004B00KHM	-0.024	0.030	0.001	-0.006	0.015	0.034
005B00KHM	0.001	-0.014	-0.003	0.000	0.002	-0.014
005C00KHM	0.017	0.031	-0.002	-0.007	-0.024	0.024
005E00KHM	0.011	-0.029	-0.001	0.005	-0.003	-0.030
008A00KHM	0.009	0.023	0.012	0.008	-0.014	0.023
014A00KHM	-0.032	-0.005	-0.007	-0.007	0.031	0.002
021A00KHM	-0.020	-0.010	-0.008	-0.007	0.023	-0.006
021B00KHM	-0.011	-0.002	0.005	0.005	0.012	0.002
021E00KHM	0.022	0.036	0.008	0.002	-0.031	0.030
KAND00KHM	0.010	-0.051	-0.017	-0.006	0.003	-0.054
(B) Siem Reap						
002A00KHM	-0.042	0.024	-0.062	-0.069	0.035	0.019
002B00KHM	-0.019	0.033	-0.053	-0.059	0.010	0.024
017A00KHM	-0.017	0.029	-0.028	-0.035	0.010	0.025
017B00KHM	0.003	0.021	-0.045	-0.048	-0.008	0.008
017C00KHM	0.016	-0.025	-0.024	-0.018	-0.009	-0.033
017F00KHM	0.021	-0.018	-0.020	-0.014	-0.016	-0.026
SIEM00KHM	-0.007	0.009	-0.012	-0.014	0.005	0.007
(C) Stueng Treng						
001900KHM	-0.016	-0.007	0.009	0.009	0.017	0.000
010F00KHM	-0.052	-0.028	0.004	0.007	0.057	-0.012
019B00KHM	-0.030	-0.034	-0.017	-0.011	0.039	-0.028
019C00KHM	-0.031	-0.080	-0.022	-0.005	0.052	-0.071
019I00KHM	-0.039	-0.002	0.009	0.007	0.038	0.011
019K00KHM	-0.036	-0.023	0.008	0.011	0.042	-0.010
(D) Near the national boundary						
01100KHM	-0.070	-0.022	-0.014	-0.013	0.074	-0.003
13G00KHM	-0.027	-0.003	0.031	0.029	0.028	0.012
15H00KHM	0.067	0.067	0.023	0.012	-0.080	0.054
16D00KHM	-0.073	-0.057	0.027	0.035	0.086	-0.025
18C00KHM	0.027	0.018	-0.027	-0.029	-0.030	0.006
20B00KHM	-0.019	-0.049	-0.013	-0.005	0.032	-0.044
22A00KHM	0.018	0.046	0.016	0.007	-0.028	0.044
Khmer GEONET						
KND100KHM	-0.001	0.007	0.005	0.003	0.000	0.008
KSP100KHM	0.012	-0.002	-0.003	-0.002	-0.011	-0.005
PNH100KHM	0.006	-0.004	0.007	0.008	-0.005	-0.004
SIE100KHM	-0.005	0.005	-0.020	-0.021	0.003	0.001
STG100KHM	-0.012	-0.007	0.011	0.012	0.014	0.000
Max	0.067	0.067	0.031	0.041	0.086	0.054
Min	-0.073	-0.112	-0.062	-0.069	-0.080	-0.100
Average	-0.009	-0.005	-0.006	-0.005	0.011	-0.003

(B) Difference vector (dN, dE)



(4) Evaluation

Except for the singular points (2A, 3D, 11, 15H, 16D, 19C), the difference between the Re-survey and parameter-based transformation results is about 50 mm, which is within the range of no practical influence. Therefore, the calculated coordinate transformation parameters can be used as the adopted values.

6.2. Coordinate transformation parameters from CGD09 to CGD23 (3 parameters)

Coordinate transformation parameters were calculated using CGD09 and CGD23 coordinates of Khmer GEONET (5 points). 3 parameters of dX, dY and dZ are calculated. The difference between the value calculated by the coordinate transformation using 7 parameters and using 3 parameters is about 30 mm. If the GDCG can accept the difference, it would be possible to perform coordinate transformations using 3 parameters for such as cadastral survey boundary points.

6.2.1. 3 parameters

(A) Geocentric (X, Y, Z)

Element	Parameter	Unit
dX	-0.3116	m
dY	-0.0294	m
dZ	-0.0814	m
R_X	0.000000	arc second
R_Y	0.000000	arc second
R_Z	0.000000	arc second
Scale	0.00000	mm/km (ppm), [s] of (1+s)

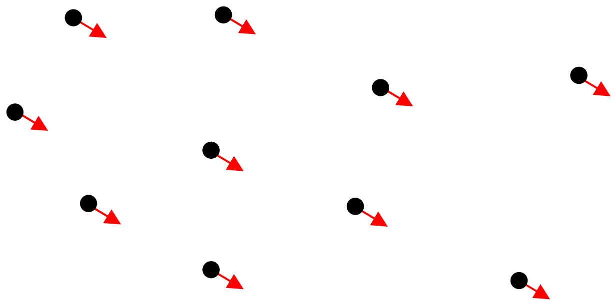
(B) Local (N, E, U)

Element	Parameter	Unit
dN	-0.0905	m
dE	+0.3087	m
dU	+0.0330	m
R_N	0.000000	arc second
R_E	0.000000	arc second
R_U	0.000000	arc second
Scale	0.00000	mm/km (ppm), [s] of (1+s)

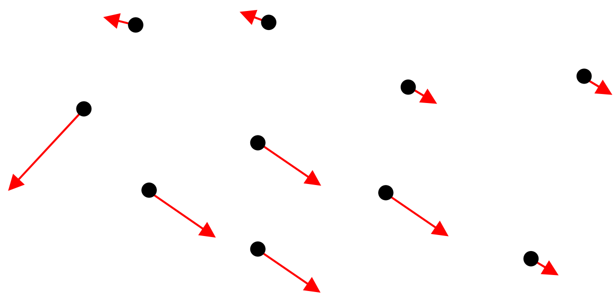
7. Coordinate transformation parameters adapted for each region

7.1. Cases where coordinate transformation parameters adapted to each region are required

Compare the old and new coordinate values of CGD09 and CGD23 of 0-1st order control point (or Nationwide-CORS). As shown in the figure below, if the size of difference vector is small and the results are in the same direction, you only need to apply one coordinate transformation parameter.

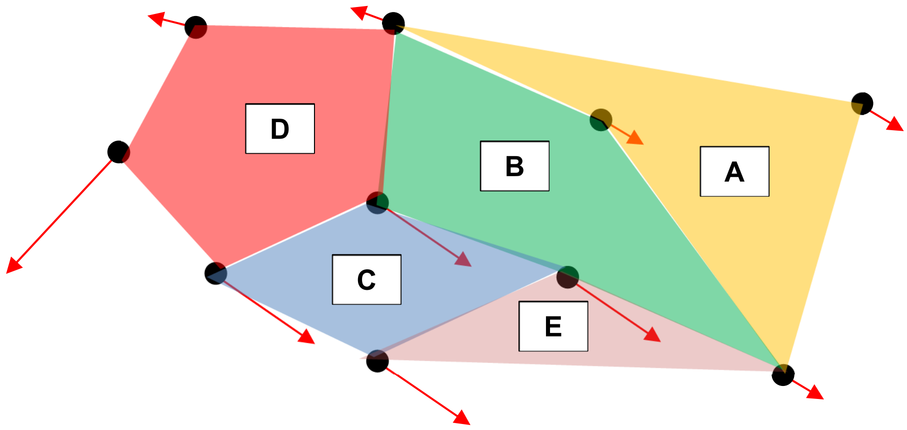


As shown in the figure below, if the size of the difference vector is large or if there is a region facing in a different direction, it is necessary to calculate coordinate transformation parameters adapted to that region.



7.2. Determine the region for calculating coordinate transformation parameters

For example, in the case of the figure below, the area for calculating the coordinate transformation parameters is determined as A to E.



(A) Although some vectors have different directions, the size of the vectors is within the error range, so it can be determined that the area is already compatible.

(B) Since it is adjacent to an area where the vector size is large, this area is treated as one block.

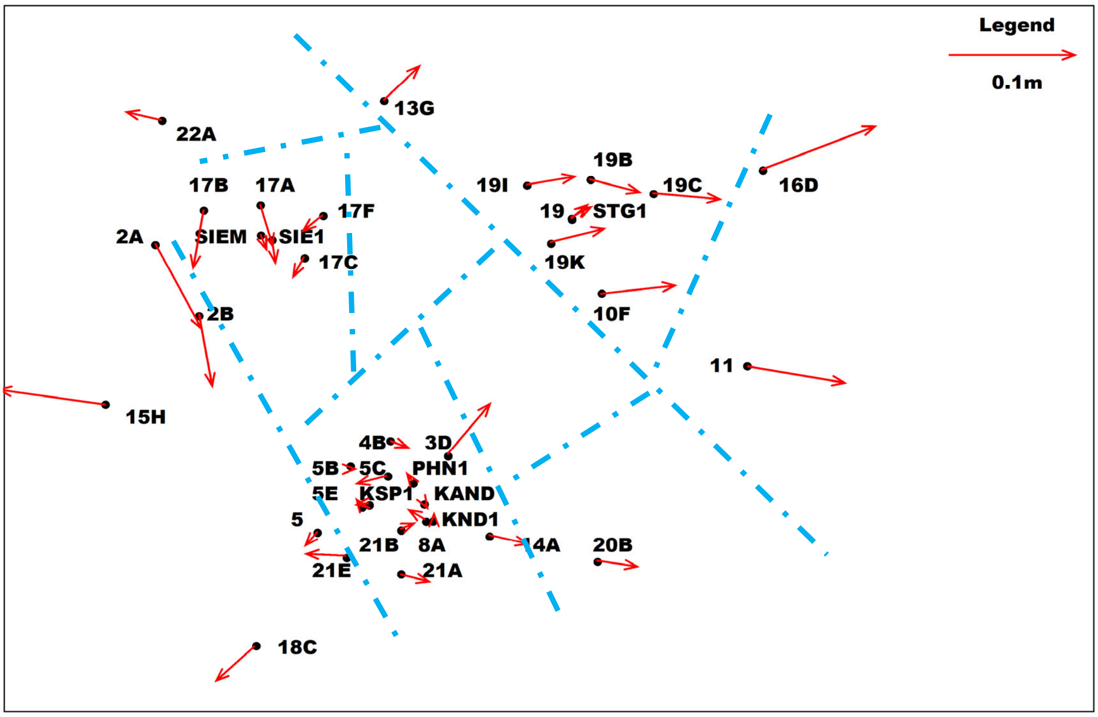
(C) Since the direction of the vectors is the same and the size of the vector is large, this area is treated as one block.

(D) The direction of the vectors is different, the size of the vector is large, and it is adjacent to an area where the size of the vector is small, so this area is treated as one block.

(E) This area has the same tendency as B. However, the point on the southwest side is expected to have a negative effect on block B, so the block is divided.

7.3. Reference example of region for calculating coordinate transformation parameters

The figure below is a simulation based on the results when calculating 5-CORS. The Nationwide-CORS calculation results are expected to be even more accurate, so they are used as a reference example. The light blue dotted line shows the divided areas.



7.4. How to calculate coordinate transformation parameters

(A) Helmert Transform (3D)

Please use software such as Bernese, TBC, MAGNET, etc.

(2) Helmert Transformation (2D)

This is explained in Appendix 3 at the end of this manual.

8. Appendix 1

8.1. Study of Coordinate transformation parameters using Khmer GEONET

The following two patterns were studied and the calculation method for the coordinate transformation parameters was determined. The requirements for the determined calculations were shown below.

(1) As a result of the study, it was determined to use the five Khmer GEONET points.

(2) As a result of the study, it was determined that the coordinate transformation parameters shall be 7 parameters.

8.1.1. Comparison of the calculation of coordinate transformation parameters using Khmer GEONET (5 points) only and the using Khmer GEONET (5 points) and 0-1st Order Control Point (32 points)

(1) Calculating coordinate transformation parameters using Khmer GEONET (5 points)
Refer to section 6.1.

(2) Calculating coordinate transformation parameters using Khmer GEONET (5 points) and 0-1st Order Control Point (32 points)

(A) Geocentric (X, Y, Z)

Element	Parameter	Unit
dX	-0.2670	m
dY	-0.7998	m
dZ	+0.0160	m
R_X	+0.007466	arc second
R_Y	+0.004936	arc second
R_Z	+0.005373	arc second
Scale	0.11205	mm/km (ppm), [s] of (1+s)

(B) Local (N, E, U)

Element	Parameter	Unit
dN	-0.0950	m
dE	+0.3196	m
dU	+0.0292	m
R_N	-0.004626	arc second
R_E	+0.008481	arc second
R_U	-0.003957	arc second
Scale	0.11205	mm/km (ppm), [s] of (1+s)

(3) Comparison table

The table below shows the comparison results of coordinate transformation using parameters calculated by Khmer GEONET (5 points) only and the parameters calculated by Khmer GEONET (5 points) and 0-1st Order Control Point (32 points).

Name	7 parameter (37 Point) - 7 parameter (5 Point) dX (m)	dY (m)	dZ (m)	dN (m)	dE (m)	dh (m)
(A) Phnom Penh, Kandal and Kampong Speu						
000500KHM	-0.006	0.007	-0.016	-0.018	0.004	0.005
003D00KHM	-0.011	-0.009	-0.014	-0.013	0.013	-0.009
004B00KHM	-0.009	-0.003	-0.011	-0.010	0.009	-0.003
005B00KHM	-0.008	0.002	-0.012	-0.012	0.007	0.001
005C00KHM	-0.009	-0.002	-0.014	-0.014	0.009	-0.003
005E00KHM	-0.008	0.002	-0.016	-0.017	0.007	0.001
008A00KHM	-0.010	-0.006	-0.018	-0.017	0.012	-0.006
014A00KHM	-0.014	-0.013	-0.021	-0.019	0.016	-0.013
021A00KHM	-0.009	-0.003	-0.021	-0.020	0.010	-0.004
021B00KHM	-0.010	-0.003	-0.018	-0.017	0.011	-0.004
021E00KHM	-0.007	0.003	-0.019	-0.020	0.006	0.001
KAND00KHM	-0.011	-0.005	-0.016	-0.015	0.012	-0.005
(B) Siem Reap						
002A00KHM	0.002	0.022	0.008	0.003	-0.007	0.023
002B00KHM	0.000	0.019	0.002	-0.002	-0.005	0.018
017A00KHM	-0.003	0.010	0.009	0.007	0.001	0.013
017B00KHM	-0.001	0.016	0.010	0.006	-0.002	0.018
017C00KHM	-0.005	0.006	0.004	0.002	0.004	0.007
017F00KHM	-0.006	0.003	0.007	0.006	0.005	0.006
SIEM00KHM	-0.003	0.011	0.007	0.005	0.001	0.013
(C) Stueng Treng						
001900KHM	-0.016	-0.025	0.001	0.005	0.022	-0.018
010F00KHM	-0.018	-0.027	-0.005	0.000	0.024	-0.021
019B00KHM	-0.017	-0.026	0.004	0.009	0.023	-0.019
019C00KHM	-0.019	-0.034	0.002	0.008	0.028	-0.026
019I00KHM	-0.014	-0.019	0.005	0.009	0.019	-0.012
019K00KHM	-0.015	-0.022	0.000	0.004	0.021	-0.016
(D) Near the national boundary						
01100KHM	-0.023	-0.043	-0.013	-0.005	0.035	-0.036
13G00KHM	-0.007	-0.004	0.014	0.014	0.008	0.002
15H00KHM	0.003	0.029	-0.002	-0.008	-0.009	0.027
16D00KHM	-0.023	-0.046	0.001	0.010	0.035	-0.036
18C00KHM	-0.003	0.014	-0.023	-0.025	0.000	0.010
20B00KHM	-0.017	-0.025	-0.024	-0.020	0.023	-0.024
22A00KHM	0.002	0.021	0.017	0.012	-0.006	0.024
Khmer GEONET						
KND100KHM	-0.011	-0.007	-0.018	-0.017	0.013	-0.008
KSP100KHM	-0.009	0.001	-0.015	-0.015	0.008	0.000
PNH100KHM	-0.010	-0.004	-0.015	-0.014	0.011	-0.004
SIE100KHM	-0.003	0.009	0.007	0.005	0.001	0.011
STG100KHM	-0.016	-0.025	0.001	0.006	0.023	-0.018
Max	0.014	0.014	0.014	0.014	0.035	0.027
Min	-0.025	-0.025	-0.025	-0.025	-0.009	-0.036
Average	-0.005	-0.005	-0.005	-0.005	0.011	-0.003

(4) Results of consideration

The difference between the results using parameters calculated by Khmer GEONET (5 points) only and the parameters calculated by Khmer GEONET (5 points) and 0-1st Order Control Point (32 points) in the east-west direction is about 35 mm, and the maximum difference between those two in the height direction is about 35 mm. Therefore, whether the calculation is performed with 5 points or 37 points, the difference is only about 35 mm. Although characteristic trends were observed depending on the regions (Phnom Penh, Siem Reap, Stung Treng, and coastal areas), the values are so small that there is no practical problem.

Therefore, it was determined to use Khmer GEONET (5 points) for the coordinate transformation parameters, since there was no difference to calculate the coordinate transformation parameters between using Khmer GEONET (5 points) only and using Khmer GEONET (5 points) and 0-1st Order Control Point (32 points).

8.1.2. Comparison of coordinate transformation parameters calculated using Khmer GEONET (5 points) (7 parameters) and using Khmer GEONET (5 points) (3 parameters)

(1) Coordinate transformation parameters calculated using Khmer GEONET (5 points) (7 parameters)

Refer to section 6.1.

(2) Coordinate transformation parameters calculated using Khmer GEONET (5 points) (3 parameters)

Refer to section 6.2.

(3) Comparison table

The table below shows the comparison results of coordinate transformation using parameters calculated by Khmer GEONET (5 points) (7 parameters) and Khmer GEONET (5 points) (3 parameters).

Name	dX (m)	dY (m)	dZ (m)	dN (m)	dE (m)	dh (m)
	3 parameter (5 Point) - 7 parameter (5 Point)					
(A) Phnom Penh, Kandal and Kampong Speu						
000500KHM	-0.007	0.013	0.004	0.001	0.003	0.014
003D00KHM	0.000	-0.003	0.001	0.001	0.000	-0.003
004B00KHM	-0.002	0.003	0.002	0.002	0.001	0.003
005B00KHM	-0.005	0.008	0.003	0.001	0.003	0.009
005C00KHM	-0.003	0.004	0.002	0.001	0.002	0.005
005E00KHM	-0.005	0.008	0.003	0.001	0.003	0.010
008A00KHM	-0.002	0.001	0.003	0.003	0.002	0.002
014A00KHM	0.000	-0.006	0.002	0.003	0.001	-0.005
021A00KHM	-0.004	0.004	0.004	0.003	0.003	0.006
021B00KHM	-0.004	0.004	0.003	0.002	0.003	0.005
021E00KHM	-0.006	0.010	0.004	0.001	0.003	0.012
KAND00KHM	-0.002	0.001	0.003	0.003	0.001	0.002
(B) Siem Reap						
002A00KHM	-0.008	0.026	0.000	-0.006	0.002	0.027
002B00KHM	-0.008	0.023	0.001	-0.004	0.002	0.024
017A00KHM	-0.003	0.014	-0.002	-0.005	0.000	0.014
017B00KHM	-0.006	0.020	-0.001	-0.006	0.002	0.020
017C00KHM	-0.002	0.010	-0.001	-0.004	0.000	0.009
017F00KHM	-0.001	0.007	-0.002	-0.003	-0.001	0.007
SIEM00KHM	-0.004	0.015	-0.001	-0.004	0.001	0.015
(C) Stueng Treng						
001900KHM	0.010	-0.020	-0.005	0.000	-0.004	-0.022
010F00KHM	0.010	-0.022	-0.004	0.002	-0.004	-0.024
019B00KHM	0.012	-0.022	-0.006	0.000	-0.005	-0.025
019C00KHM	0.015	-0.029	-0.006	0.002	-0.006	-0.033
019I00KHM	0.009	-0.015	-0.005	0.000	-0.005	-0.017
019K00KHM	0.009	-0.017	-0.004	0.001	-0.004	-0.019
(D) Near the national boundary						
01100KHM	0.016	-0.037	-0.004	0.005	-0.004	-0.040
13G00KHM	0.005	-0.001	-0.005	-0.004	-0.004	-0.003
15H00KHM	-0.014	0.034	0.004	-0.004	0.006	0.036
16D00KHM	0.021	-0.041	-0.008	0.003	-0.008	-0.046
18C00KHM	-0.012	0.022	0.007	0.002	0.007	0.025
20B00KHM	0.005	-0.017	0.002	0.005	-0.001	-0.017
22A00KHM	-0.005	0.024	-0.003	-0.008	0.000	0.023
Khmer GEONET						
KND100KHM	-0.002	0.000	0.003	0.002	0.002	0.001
KSP100KHM	-0.005	0.007	0.003	0.001	0.003	0.008
PNH100KHM	-0.002	0.002	0.002	0.001	0.001	0.003
SIE100KHM	-0.003	0.013	-0.001	-0.004	0.000	0.013
STG100KHM	0.010	-0.020	-0.005	0.001	-0.004	-0.022
Max	0.021	0.034	0.007	0.005	0.007	0.036
Min	-0.014	-0.041	-0.008	-0.008	-0.008	-0.046
Average	0.000	0.001	0.000	0.000	0.000	0.000

(4) Results of consideration

The difference between the east-west and north-south directions is less than 8 mm. The maximum difference in both height directions near the border is about 40 mm. And the difference between in both height direction at Stung Treng is about 30 mm. Thus, whether 7 or 3 parameters are used, the difference in the horizontal direction is only about 10 mm, and the difference in the height direction is only about 40 mm.

Although the characteristic trend was observed depending on the regions (Phnom Penh, Siem Reap, Stung Treng, and coastal areas), these values are so small that there is no practical problem.

Therefore, it was judged that there is no difference between the results of the coordinate transformation using 7 parameters calculated using Khmer GEONET (5 points) and the results of the transformation using 3 parameters calculated using Khmer GEONET (5 points), and it was determined to use 7 parameters calculated by the Khmer GEONET (5 points) as the transformation parameter.

In the case of transforming survey results without elevation information from CGD09 to CGD23, it can be said that 3 parameters can work without causing any practical problems.

8.2. Transformation parameter from CGD03 to CGD23

The coordinate transformation method from CGD03 to CGD23 is shown below.

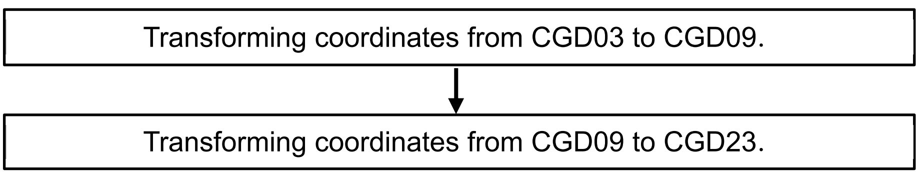
8.2.1. Content of CGD03

Item	Element
Geocentric Cartesian Coordinate System	ITRF2000 (Epoch 1998.90, 24th October 1998)
Reference Ellipsoid	GRS 80
Vertical Datum	Mean Sea Level (Vietnam)
Geoid Model	EGM2008
Plane Cartesian Coordinate System	UTM Zone 48 - Central Meridian: 105º 00’ 00” E - Latitude of Origin: 0º 00’ 00” N - False Easting: 500,000.000 m - False Northing: 0.000 m - Scale Factor at Central Meridian: 0.9996
Unit and Notation	Meters, 0,001m

8.2.2. Transformation parameter from CGD03 to CGD23

Calculate using one of the methods below.

(A) The coordinate transformation parameters from CGD03 to CGD09 were already calculated in 2005. Therefore, as shown in the flowchart below, it is recommended to perform the coordinate transformation from CGD03 coordinate values to CGD09 coordinate values using the above coordinate transformation parameters, and then calculate the CGD23 coordinate values using the transformation parameters from CGD09 coordinate values to CGD23 coordinate values.



Below are the coordinate transformation parameters from CGD03 to CGD09.

Element	Parameter	Unit
dX	-0.231	m
dY	-0.040	m
dZ	-0.114	m
R_X	-0.00722	arc second
R_Y	+0.02434	arc second
R_Z	-0.03011	arc second
Scale	+0.034	mm/km (ppm), [s] of (1+s)

(B) When calculating the coordinate transformation parameters from CGD03 to CGD23
First, prepare the CGD03 and CGD23 coordinate values for the 0-1st Order Control Point (32 points). Note that the CGD03 coordinate value for Khmer GEONET (5 points) has not been calculated. Next, the coordinate transformation parameters are calculated using Bernese software, etc. It is desirable to evaluate the accuracy of the calculation results by using several of the 32 points as verification points.

8.3. Transformation for Boundary points

Boundary points do not have elevation values. Therefore, it is not possible to calculate the coordinate values of CGD23 using the Helmert transformation (3D) method.
Therefore, the coordinate values of CGD23 should be calculated using one of the methods shown below.

(1) Prepare the CGD09 (or CGD03) and CGD23 coordinates of 0-2nd order control points installed around the Boundary points.

(2) Calculate coordinate transformation parameters using one of the following methods from these control points.

- ✓ Calculate using Helmert Transformation (2D). This is the method shown in section 4.1.1.
- ✓ Calculate using Affine Transformation. This is the method shown in section 4.2.
- ✓ Calculate using Method by weighted interpolation. This is the method shown in

section 4.3.

- ✓ A method of creating mesh-like (grid-like) coordinate transformation parameters using Method by weighted interpolation, etc., and calculate using Bilinear transformation method with linear interpolation. This is the method shown in section 4.4.
- ✓ If the parameters used to calculate the CGD23 coordinate values of 0-2nd order control points are 3 parameters, you can use the parameters dN and dE to perform parallel translation.

(3) Calculate the CGD23 coordinate values of the Boundary points using the coordinate transformation parameters obtained above.

8.4. Transformation parameter from Indian 19XX to CGD23

8.4.1. Control points

The coordinate transformation parameters from Indian1916 to CGD03 and from Indian1954 to CGD03 were already calculated in 1998.

(A) From Indian 1916 to CGD03

✓ 3 parameters

Element	Parameter	Unit
dX	+202.548	m
dY	+877.524	m
dZ	+320.787	m
R_X	0.00000	arc second
R_Y	0.00000	arc second
R_Z	0.00000	arc second
Scale	0.000	mm/km (ppm), [s] of (1+s)

✓ 10 parameters

Element	Parameter	Unit
dX	+202.177	m
dY	+876.634	m
dZ	+320.511	m
R_X	-10.33655	arc second
R_Y	-6.94679	arc second
R_Z	+20.75746	arc second
Scale	-18.364	mm/km (ppm), [s] of (1+s)
Centroid X	-1620202.016	m
Centroid Y	+6037591.585	m
Centroid Z	+1257548.565	m

(B) From Indian 1954 to CGD03

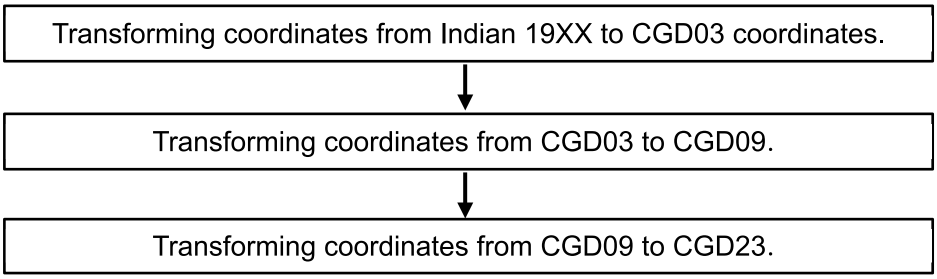
✓ 3 parameters

Element	Parameter	Unit
dX	+179.237	m
dY	+874.349	m
dZ	+308.080	m
R_X	0.00000	arc second
R_Y	0.00000	arc second
R_Z	0.00000	arc second
Scale	0.000	mm/km (ppm), [s] of (1+s)

✓ 10 parameters

Element	Parameter	Unit
dX	+179.237	m
dY	+874.349	m
dZ	+308.080	m
R_X	-4.75420	arc second
R_Y	-27.60029	arc second
R_Z	+15.65364	arc second
Scale	+93.654	mm/km (ppm), [s] of (1+s)
Centroid X	-1623986.360	m
Centroid Y	+6040009.771	m
Centroid Z	+1241333.247	m

Therefore, as shown in the flowchart below, coordinate transformation is firstly performed from Indian19XX coordinate values to CGD03 coordinate values using the following coordinate transformation parameters. Next, it is recommended to perform a coordinate transformation from CGD03 coordinate values to CGD09 coordinate values and then calculate the CGD23 coordinate values using the coordinate transformation parameters from CGD09 to CGD23 coordinate values.



Firstly, prepare the Indian19XX and CGD23 coordinate values of the 0-2nd Order Control Point, when you calculate the coordinate transformation parameters from Indian19XX to CGD23 or in case the coordinate transformation parameters from Indian19XX to CGD03 have not been calculated. Note that the Indian19XX coordinate values for Khmer GEONET (5 points) are not calculated. Next, coordinate transformation parameters are calculated using Bernese software. It is desirable to evaluate the accuracy of the calculation results by using several points as verification points.

8.4.2. Topographic map

Topographic maps created using a geodetic reference system such as Indian 19XX are small-scale topographic maps, so they do not require high-precision coordinate transformation.

In the Japanese survey manual, the accuracy of topographic maps (at map information level 5,000) is defined as follows.

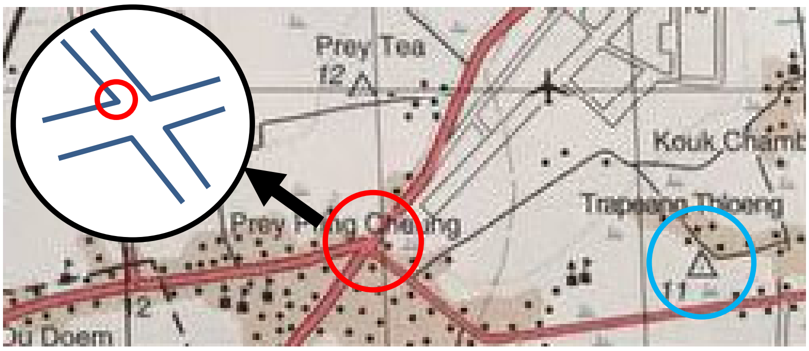
- ✓ Standard deviation of horizontal position: 3.5m or less (1- σ)
- ✓ Standard deviation of spot height elevation: 1.66m or less (1- σ)
- ✓ Standard deviation of contour line elevation: 2.5m or less (1- σ)

Therefore, the coordinate transformation parameters may be the amount of translation (dN, dE, dU), and an accuracy of about 1m-2m is considered sufficient.

The method for determining the coordinate transformation parameters is shown below.

(1) Select points for calculating the coordinate transformation parameters.

- ✓ For horizontal measurement positions, we recommend the corners of road intersections.
- ✓ Choose a location that hasn't changed from the old road.
- ✓ For the height measurement position, measure at a point where the elevation value is known.



- ✓ Select multiple points within the target area of the coordinate transformation. An example is shown below.
  - (a) Phnom Penh area: Horizontal (2 points) and height (2 points)
  - (b) Siem Reap: Horizontal (2 points) and height (2 points)
  - (c) Stueng Treng: Horizontal (2 points) and height (2 points)

(2) Use the NRTK or Single RTK methods to measure the coordinates of clear features.

(3) Read the coordinates of Indian19XX from the topographic map.

(4) Compare the coordinates of Indian19XX with the coordinates of CGD23. The average value of these differences is the coordinate transformation parameter (the amount of parallel displacement).

9. Appendix 2

9.1. Error Theory

Measured values always include errors. The value obtained by subtracting the true value Lo from the measured value L is the error ε.

$$\varepsilon = L - Lo$$

9.1.1. Type of error

Errors are classified into three types.

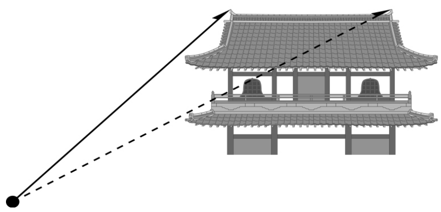
(A) Large error (negligence)

(B) Systematic error

(C) Random error

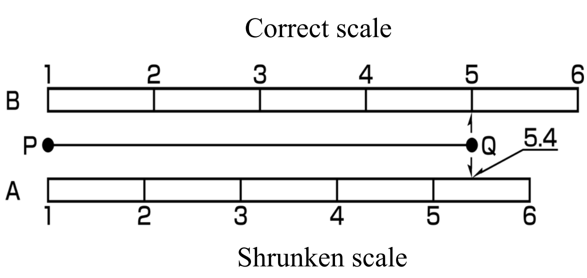
(A) Large error (negligence)

For example, human errors include measuring the wrong target or recording an angle of ``124°'' as ``214°'' by mistake. These are extremely large and can be found immediately.



(B) Systematic error

For example, if you measure distance using a shrunken scale, the distance will be measured to be longer than the actual length. In the example shown in the figure, when the distance between PQ is measured using a shrunken scale A, the measured distance is 5.4. The distance measured on the correct scale B is 5.0, so it is 0.4 longer.

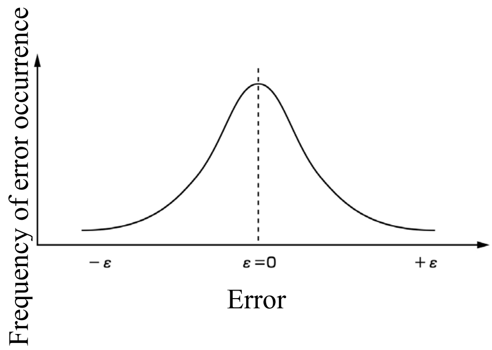


Since the cause of systematic errors is known, correct values can be determined by correction.

(C) Random error

Even after excluding large errors (negligence) and systematic errors, errors still remain. This is called a random error. The random errors are relatively small, and each value appears to be irregular, but there are some regularities as shown below.

- ✓ The number of small errors is greater than the number of large errors.
- ✓ The number of errors with equal amounts and opposite signs is equal
- ✓ Very large errors rarely occur



In other words, the size of random errors and their frequency of occurrence are normally distributed. First, discover and eliminate large errors (negligence). Next, correction is performed to eliminate systematic errors. Finally, analyze the random errors and calculate the most probable value.

One method for analyzing random errors is the least squares method. The least squares method is a method of calculating the most probable value so that the sum of squared errors is minimized.

$$\varepsilon_1^2 + \varepsilon_2^2 + \varepsilon_3^2 \cdots = \text{Minimum}$$

9.1.2. Precision and Accuracy

(A) Precision

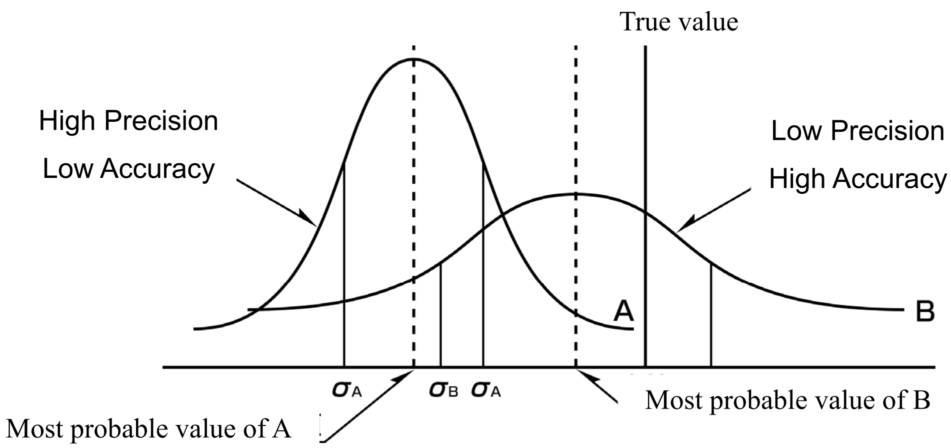
Represents the degree of dispersion of observed values.

The smaller the standard deviation σ, the better the precision.

(B) Accuracy

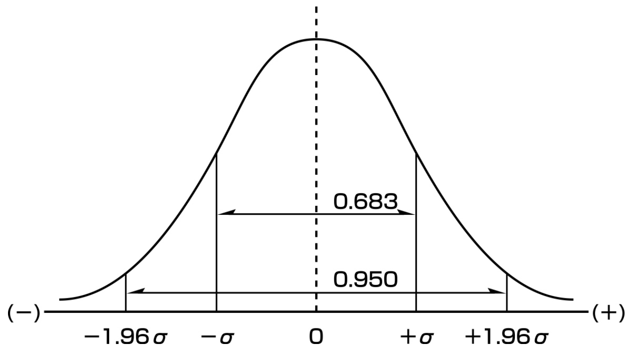
Represents the difference between the observed value and the true value.

Even if the precision is high, observed values with low accuracy cannot be used.



9.1.3. Degree of reliability

When the error is normally distributed as shown in the figure below, the probability of a measured value falling within the standard deviation σ is approximately 68%.



The relationship between range and probability is shown below.

1.00×σ (standard deviation)	Approximately 68%
1.96×σ (sometimes called 2σ)	Approximately 95%
	International standards often use 95% probability
2.58×σ (sometimes called 3σ)	Approximately 99%

10. Appendix 3

10.1. Calculate Helmert Transformation (2D) in Excel

10.1.1. Least Squares Method

The principle of the least squares method is [a method for estimating the most probable value that minimizes the sum of the squares of errors (residuals)].

10.1.2. Least Squares Method Using Observation Equations

(A) Observation Equation

It is theoretically known that a certain relational equation holds between m unknown quantities $X_1, X_2, \cdots X_m$ and n measured values $l_1, l_2, \cdots l_m$. The equation that expresses this kind of relationship is called the observation equation. Here, $n > m$ must be satisfied.

$$\left.\begin{aligned} l_1 &= f_1(X_1, X_2, \cdots X_m) \\ l_2 &= f_2(X_1, X_2, \cdots X_m) \\ &\vdots \\ l_n &= f_n(X_1, X_2, \cdots X_m) \end{aligned}\right\} \cdots \text{(1) Observation Equation}$$

When the relationship in equation (1) holds, equation (2) is called a mathematical model.

$$l_i = f_n(X_1, X_2, \cdots X_m) \cdots (2)$$

Before calculating with the least squares method, each mathematical model must be given.

However, since there are always errors in observations and measurements, equation (1) does not hold true strictly.

Here, let l_n^b be the value obtained by observing l_n.

l_n^b includes observation errors (random errors).

If we can obtain the most probable value l_n^a (adjusted value, most probable value) by adding an unknown correction amount v_j to the observed value, the following formula holds.

$$l_n^a = l_n^b + v_j \cdots (3)$$

Since equation (2) is generally nonlinear with respect to the unknown quantity x_j, it is linearized using Taylor's expansion formula.

Therefore, let x_i^o be the approximate value of x_j. x_i^o is calculated or estimated in advance by some method.

x_i^a is the most probable value of x_j determined by the least squares method, and if the unknown correction amount to be added to x_i^o is Δx_j, the following formula holds true.

$$x_i^a = x_i^o + \Delta x_j \quad (j = 1, 2, \cdots, m) \quad \cdots \ (4)$$

Δx_j is assumed to be a small amount. If we perform Taylor expansion on the right side of equation (2) and find the first term, we get the following equation.

$$f_i(x_1^a, x_2^a, \cdots, x_m^a) = f_i(x_1^o, x_2^o, \cdots, x_m^o) + \left(\frac{\partial f_i}{\partial x_1}\right)_o \Delta x_1 + \left(\frac{\partial f_i}{\partial x_2}\right)_o \Delta x_2 + \cdots + \left(\frac{\partial f_i}{\partial x_m}\right)_o \Delta x_m \quad \cdots \ (5)$$

Here, equation (6) is calculated by partially differentiating f_i and using the approximate value x_j^o as the value of x_j, and will be expressed as equation (7).

$$\left(\frac{\partial f_i}{\partial x_1}\right)_o \quad (j = 1, 2, \cdots, m) \quad \cdots \ (6)$$

$$\left(\frac{\partial f_i}{\partial x_1}\right)_o = a_{ij} \quad \cdots \ (7)$$

And we will express equation (2) as equation (8) or equation (9).

$$l_i^a = l_i^b + v_i = f_i(x_1^o, x_2^o, \cdots, x_m^o) + \sum_{j=1}^{m} a_{ij} \Delta x_j \quad \cdots \ (8)$$

$$l_i^o = f_i(x_1^o, x_2^o, \cdots, x_m^o) \quad \cdots \ (9)$$

Then, the correction amount v_j to be added to the observed value is given by equation (10).

$$v_i = \sum_{j=1}^{m} a_{ij} \Delta x_j + \left(l_i^o - l_i^b\right) \quad \cdots \ (10)$$

As shown in the above equation, the equation that holds true between the correction amount v_j to be added to the observed value and the unknown parameter Δx_j included in the mathematical model is called the observation equation.

Here, the unknown quantities are v_j and Δx_j, and the known quantities are a_{ij}, l_j^o, and l_j^b. Also, if Δx_j is expressed as x_j, the entire observation equation becomes the following equation.

$$\left.\begin{aligned} a_{11}x_1 + a_{12}x_2 + \cdots + a_{1m}x_m + \left(l_1^o - l_1^b\right) = V_1 \\ a_{11}x_1 + a_{12}x_2 + \cdots + a_{1m}x_m + \left(l_1^o - l_1^b\right) = V_1 \\ \vdots \qquad\qquad \\ a_{n1}x_1 + a_{n2}x_2 + \cdots + a_{nm}x_m + (l_n^o - l_n^b) = V_n \end{aligned}\right\} \cdots \ (11)$$

(B) Representation of observation equation by matrix

It is convenient to use matrices to find solutions to these equations and to examine the standard deviation of the solution functions. To do this, we rewrite equation (10) into a vector or matrix representation.

First, let us express the collection of observed quantities and unknown quantities as a column vector using the following equation.

$$L_b = \begin{pmatrix} l_1^b \\ l_2^b \\ \vdots \\ l_n^b \end{pmatrix},\ L_a = \begin{pmatrix} l_1^a \\ l_2^a \\ \vdots \\ l_n^a \end{pmatrix}, X_o = \begin{pmatrix} X_1^o \\ X_2^o \\ \vdots \\ X_n^o \end{pmatrix}, X_a = \begin{pmatrix} X_1^a \\ X_2^a \\ \vdots \\ X_n^a \end{pmatrix}, V = \begin{pmatrix} V_1 \\ V_2 \\ \vdots \\ V_n \end{pmatrix} \cdots \ (12)$$

Here, the symbol a means adjusted value. b is the observable quantity, and uses the initials of the German word Beobachtung. v and V are correction values, using the initial letters of the German word Verbesserung. These are commonly used symbols.

In order to find the most probable value of the unknown quantity X_a, the correction value X added to the approximate value X_o is expressed by the following formula.

$$X = X_a - X_o \ \cdots \ (13)$$

Let $L_o = (l_1^o, l_2^o, \cdots, l_n^o)$ represent the vector whose elements are equation (9) calculated from the approximate value of X. Also, it is expressed as $L_o - L_b = L$.

Here, if equation (11) is expressed as a matrix, it becomes the following equation.

$$L_a = F(X) \ \cdots \ (14)$$

On the other hand, since $L_a = L_b + V, X_a = X_o + V$, equation (14) becomes equation (15).

$$L_b + V = F(X_o + X) \quad \cdots \quad (15)$$

X is the unknown correction amount that we ultimately want to find. Generally, if the approximate value of X_o is close to the most probable value, the amount of correction is small. Therefore, using up to the first-order terms of the Taylor expansion, it can be expressed as the following equation.

$$L_b + V = F(X_o) + AX \quad \cdots \quad (16)$$

However, A is a matrix called a coefficient matrix or a design matrix. Its elements are as follows.

$$a_{ij} = \frac{\partial l_i^o}{\partial X_j^o}, \quad or \quad A = \frac{\partial L}{\partial X} = \frac{\partial F}{\partial X} \quad \cdots \quad (17)$$

Here. Since $F(X_o) = L_o, L = L_o - L_b$, equation (16) becomes the following equation.

$$V = AX + (L_o - L_b) = AX - L \quad \cdots \quad (18)$$

Equation (18) is an observation equation that expresses equation (11) in a matrix.

Observation Equation Model $V = AX - L$

(D) Weights

The previous formulas are for the case where n observations are mutually independent, and all observation precision is equal.

Here, consider the case where the variances of observed values $\sigma_1^2, \sigma_2^2, \cdots, \sigma_n^2$ are generally different. First, using the variance σ_o^2 of the unknown unit weights (also called unit weight variance) and the weights P_i, equation is expressed as follows.

$$\sigma_i^2 = \frac{\sigma_o^2}{P_i} \quad (i = 1, 2, \cdots, n) \cdots \quad (19)$$

Multiplying both sides of equation (11) by $\sqrt{P_i}$ yields the following equation.

$$v_i^o = \sum_{j=1}^{m} \sqrt{P_i}\, a_{ij} X_j + \sqrt{P_i}\left(l_i^o - l_i^b\right) \ \cdots \ (20)$$

However, if equation (21) holds true, the variance of $\sqrt{P_i}\left(l_i^o - l_i^b\right)$ is all equal to σ_o^2.

$$v_i^o = \sqrt{P_i} v_i \ \cdots \ (21)$$

In other words, equation (21) is an observation equation with equal precision.

(D) Matrix representation of weights

When expressing weights as a matrix, if the observations are mutually independent, the weight matrix P becomes a diagonal matrix with $P_i = P_{ii}$ as the diagonal elements, as shown below.

$$P = \begin{pmatrix} P_{11} & 0 & \cdots & 0 \\ 0 & P_{22} & & 0 \\ \vdots & & \ddots & \vdots \\ 0 & 0 & \cdots & P_{nn} \end{pmatrix}, \quad and\ P^{\frac{1}{2}} = \begin{pmatrix} \sqrt{P_{11}} & 0 & \cdots & 0 \\ 0 & \sqrt{P_{22}} & & 0 \\ \vdots & & \ddots & \vdots \\ 0 & 0 & \cdots & \sqrt{P_{nn}} \end{pmatrix} \ \cdots \ (22)$$

(E) Observation equation considering weights

Considering the weight from the above results, both sides of the observation equation (18) are multiplied by $P^{\frac{1}{2}}$, and it is expressed as the following equation.

$$P^{\frac{1}{2}} AX + P^{\frac{1}{2}} L = P^{\frac{1}{2}} V = V_o \ \cdots \ (23)$$

(F) Once again, about the least squares method

In the discussion so far, the diagonal matrix of the product of a matrix and its transposed matrix is the sum of squares.

As mentioned above, the least squares method is a method for estimating the most probable value that minimizes the sum of squared errors.

Therefore, the product of the error (residual) matrix and its transposed matrix can be differentiated and set to 0.

(G) Sum of squared errors (residuals)

V is the residual vector (matrix). To find the sum of the squares of each element of this vector (matrix), multiply the residual matrix V by its transposed matrix (matrix) V^T.

Since P is a diagonal matrix, keeping in mind that $P^T = P$, the following equation holds.

$$\left(P^{\frac{1}{2}}V\right)^T P^{\frac{1}{2}}V = V_o^T V_o = V^T \left(P^{\frac{1}{2}}\right)^T P^{\frac{1}{2}}V = V^T PV \quad \cdots \quad (24)$$

Therefore, using the observation equation (18), the sum of squared errors (residuals) can be expressed as follows.

$$\begin{aligned} V^T PV &= (AX + L)^T P(AX + L) = (L^T + X^T A^T)P(AX + L) \\ &= X^T A^T PAX + X^T A^T PL + L^T PAX + L^T PL \end{aligned}$$

Here, since $P^T = P$, $L^T PAX = (X^T A^T P^T L)^T = (X^T A^T PL)^T$.

Continuing the previous equation, we can transform it into the following equation.

$$\begin{aligned} V^T PV &= (AX + L)^T P(AX + L) = X^T A^T PAX + 2X^T A^T PL + L^T PL \\ &= X^T NX + 2X^T U + L^T PL \quad \cdots \quad (25) \end{aligned}$$

However, N and U are as follows.

$$\left.\begin{aligned} N &= A^T PA \\ U &= A^T PL \end{aligned}\right\} \cdots \quad (26)$$

(H) Derive a normal equation by minimizing the sum of squared errors (residuals)

$V^T PV$ is the sum of the squares of the residuals. To minimize this, [The derivative with respect to the elements of X is equal to 0].

Therefore, keeping in mind that $L^T PL$ does not include the most probable value vector X, differentiating equation (25) with respect to X yields the following equation.

$$\frac{1}{2} \cdot \frac{\partial(V^T PV)}{\partial X} = \frac{1}{2} \cdot \frac{\partial(X^T NX)}{\partial X} + \frac{\partial(X^T U)}{\partial X} + \frac{1}{2} \cdot \frac{\partial(L^T PL)}{\partial X} = 0 \quad \cdots \quad (27)$$

Here, using the matrix differential formula, we get the following.

$$\frac{1}{2}\cdot\frac{\partial(X^TNX)}{\partial X}=X^TN,\ \frac{\partial(X^TU)}{\partial X}=U^T\quad\cdots\quad(28)$$

Therefore, the following equation holds.

$$NX+U=0\quad\cdots\quad(29)$$

Or

$$A^TPAX+A^TPL=0\quad\cdots\quad(30)$$

Equations (29) and (30) are called [Normal equations].

(I) Find the most probable value

The most probable value is calculated using equation (29).

$$NX+U=0$$
$$NX=-U$$

Multiplying both sides by the inverse matrix N^{-1} of N yields the following.

$$N^{-1}NX=-N^{-1}U$$
$$X=-N^{-1}U\quad\cdots\quad(31)$$

In other words, with the matrix solution method, you can obtain a solution as if you were solving a linear equation.

Alternatively, use equation (30) to calculate as follows.

$$A^TPAX+A^TPL=0$$
$$A^TPAX=-A^TPL$$
$$X=-(A^TPA)^{-1}A^TPL\quad\cdots\quad(32)$$

10.1.3. Calculate Helmert Transformation (2D) in Excel

(A) Helmert Transformation (2D) calculation formula

$$\begin{bmatrix} X_{CGD23} \\ Y_{CGD23} \end{bmatrix} = \begin{bmatrix} dx \\ dy \end{bmatrix} + s \cdot \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \cdot \begin{bmatrix} x_{CGD09} \\ y_{CGD09} \end{bmatrix} \quad \cdots \ (33)$$

$X_{CGD23}: X(N)\ value\ of\ CGD23\ coordinate$

$Y_{CGD23}: Y(E)\ value\ of\ CGD23\ coordinate$

$dx:\ Amount\ of\ translation\ from\ origon\ \ in\ \ x(N) - axis\ direction$

$dy: Amount\ of\ translation\ from\ origon\ \ in\ \ y(E) - axis\ direction$

$s: Scale\ factor$

$\theta: Amount\ of\ rotation$

$X_{CGD09}: X(N)\ value\ of\ CGD09\ coordinate$

$Y_{CGD09}: Y(E)\ value\ of\ CGD09\ coordinate$

To simplify the explanation, equation (1) is expressed as follows.

$$\begin{bmatrix} X_a \\ Y_a \end{bmatrix} = \begin{bmatrix} C \\ D \end{bmatrix} + \begin{bmatrix} A & B \\ -B & A \end{bmatrix} \cdot \begin{bmatrix} x_b \\ y_b \end{bmatrix} \quad \cdots \ (34)$$

$A = s \cdot cos\theta$

$B = -s \cdot sin\theta$

$C = dx$

$D = dy$

(B) Observation equation

The observation equation is as follows.

$$V = AX - L$$

First, transform the Helmert Transformation (2D) formula to create each matrix such as design matrix A.

Equation (34) can be transformed as follows.

$$X_a = Ax_b + By_b + C$$
$$Y_a = -Bx_b + Ay_b + D \quad \cdots \ (35)$$

The most probable values of X_a and Y_a include errors (residuals) VX_a and VY_a, so equation (35) becomes as follows.

$$X_a + VX_a = Ax_b + By_b + C$$
$$Y_a + VY_a = -Bx_b + Ay_b + D \quad \cdots \ (36)$$

$$VX_a = Ax_b + By_b + C - X_a$$
$$VY_a = -Bx_b + Ay_b + D - Y_a \quad \cdots \ (37)$$

Rearrange equation (37) to make it easier to understand.

$$VX_a = Ax_b + By_b + C \qquad - X_a$$
$$VY_a = Ay_b - Bx_b \qquad + D - Y_a \quad \cdots \ (38)$$

The unknown quantities we want to calculate are A, B, C, and D.

Therefore, the unknown quantity matrix X is as follows.

$$X = \begin{bmatrix} A \\ B \\ C \\ D \end{bmatrix} \quad \cdots \ (39)$$

Since there are no unknown quantities in the terms X_a and Y_a, this becomes the matrix L, which is expressed by the following equation.

$$L = \begin{bmatrix} X_a \\ Y_a \end{bmatrix} \quad \cdots \ (40)$$

Since there are n pieces of data to be given, the matrix L is as follows.

$$L = \begin{bmatrix} X_{a1} \\ Y_{a1} \\ X_{a2} \\ Y_{a2} \\ \vdots \\ X_{an} \\ Y_{an} \end{bmatrix} \quad \cdots \ (41)$$

Equation (38) is expressed as the following equation using the error (residual) vector V and the unknown quantity vector X.

$$V = F(X) \quad \cdots \ (42)$$

Also, the elements of design matrix A are equation (17).

$$¥a_{ij} = \frac{\partial l_i^o}{\partial X_j^o}, \quad or \quad A = \frac{\partial L}{\partial X} = \frac{\partial F}{\partial X} \quad \cdots \ (17)$$

Create a design matrix A from equations (6) and (10) using the following equation.

$$A = \frac{\partial F}{\partial X} \quad \cdots \ (43)$$

$$A = \frac{\partial F(X)}{\partial A} + \frac{\partial F(X)}{\partial B} + \frac{\partial F(X)}{\partial C} + \frac{\partial F(X)}{\partial D} \quad \cdots \ (44)$$

$$A = \begin{bmatrix} x_b & y_b & 1 & 0 \\ y_b & -x_b & 0 & 1 \end{bmatrix} \quad \cdots \ (45)$$

Since there are n pieces of data to be given, the design matrix A is as follows.

$$A = \begin{bmatrix} x_{b1} & y_{b1} & 1 & 0 \\ y_{b1} & -x_{b1} & 0 & 1 \\ x_{b2} & y_{b2} & 1 & 0 \\ y_{b2} & -x_{b2} & 0 & 1 \\ \vdots & \vdots & \vdots & \vdots \\ x_{bn} & y_{bn} & 1 & 0 \\ y_{bn} & -x_{bn} & 0 & 1 \end{bmatrix} \quad \cdots \ (46)$$

Expressing the observation equation using equations (39), (41), and (46), it becomes the following equation.

$$V = AX + L = \begin{bmatrix} x_{b1} & y_{b1} & 1 & 0 \\ y_{b1} & -x_{b1} & 0 & 1 \\ x_{b2} & y_{b2} & 1 & 0 \\ y_{b2} & -x_{b2} & 0 & 1 \\ \vdots & \vdots & \vdots & \vdots \\ x_{bn} & y_{bn} & 1 & 0 \\ y_{bn} & -x_{bn} & 0 & 1 \end{bmatrix} \begin{bmatrix} A \\ B \\ C \\ D \end{bmatrix} + \begin{bmatrix} X_{a1} \\ Y_{a1} \\ X_{a2} \\ Y_{a2} \\ \vdots \\ X_{an} \\ Y_{an} \end{bmatrix} \quad \cdots \ (47)$$

(C) Calculation of unknown quantity

The unknown quantity is calculated using the normal equation (32).

$$A^TPAX + A^TPL = 0$$
$$A^TPAX = -A^TPL$$
$$X = -(A^TPA)^{-1}A^TPL \quad \cdots \quad (32)$$

To make the explanation easier to understand, we will consider the weight matrix P as a unit matrix as shown below. In other words, assume that all input data has equal precision.

$$P = \begin{bmatrix} 1 & 0 & \cdots & 0 & 0 \\ 0 & 1 & \cdots & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \cdots & 1 & 0 \\ 0 & 0 & \cdots & 0 & 1 \end{bmatrix} \quad \cdots \quad (48)$$

Expressing equation (32) using equations (39), (41), (46), and (48) yields the following equation. Note that equation (32) is transformed on the condition that the weight matrix P is a unit matrix.

$$\begin{bmatrix} A \\ B \\ C \\ D \end{bmatrix} = -\left(\begin{bmatrix} x_{b1} & y_{b1} & x_{b2} & y_{b2} & \cdots & x_{bn} & y_{bn} \\ y_{b1} & -x_{b1} & y_{b2} & -x_{b2} & \cdots & y_{bn} & -x_{bn} \\ 1 & 0 & 1 & 0 & \cdots & 1 & 0 \\ 0 & 1 & 0 & 1 & \cdots & 0 & 1 \end{bmatrix} P \begin{bmatrix} x_{b1} & y_{b1} & 1 & 0 \\ y_{b1} & -x_{b1} & 0 & 1 \\ x_{b2} & y_{b2} & 1 & 0 \\ y_{b2} & -x_{b2} & 0 & 1 \\ \vdots & \vdots & \vdots & \vdots \\ x_{bn} & y_{bn} & 1 & 0 \\ y_{bn} & -x_{bn} & 0 & 1 \end{bmatrix} \right)^{-1}$$
$$+ \begin{bmatrix} x_{b1} & y_{b1} & x_{b2} & y_{b2} & \cdots & x_{bn} & y_{bn} \\ y_{b1} & -x_{b1} & y_{b2} & -x_{b2} & \cdots & y_{bn} & -x_{bn} \\ 1 & 0 & 1 & 0 & \cdots & 1 & 0 \\ 0 & 1 & 0 & 1 & \cdots & 0 & 1 \end{bmatrix} P \begin{bmatrix} X_{a1} \\ Y_{a1} \\ X_{a2} \\ Y_{a2} \\ \vdots \\ X_{an} \\ Y_{an} \end{bmatrix} \quad \cdots \quad (47)$$

Create a Helmert Transformation (2D) calculation tool using equation (49).

If the number of points to be calculated is small, Excel may be used, but if there are many points to be calculated, we recommend creating an application using programming.

(D) Explanation of Excel VBA macros

Matrix calculations were created using Excel functions.

The routine to assign values to cells was created using VBA macros.

(i) Main routine

This is the main routine that erases previous calculations and executes each subroutine.

```
Sub HelmSimple()
    Sheets(Array("P", "A", "AT", "L", "PL", "ATPL", "PA", "ATPA")).Select
    Cells.Select
    Selection.ClearContents

    Call INdat
    Call make_P
    Call make_A
    Call cal_AT
    Call make_L
    Call cal_PL
    Call cal_ATPL
    Call cal_PA
    Call cal_ATPA
    Sheets("OUTPUT").Select
End Sub
```

Delete the previous calculation.

Execute the subroutines in order and display the OUTPUT sheet at the end.

(ii) Create INPUT data

Enter the point name, coordinates before transformation, coordinates after transformation, and weight (variance) on the INPUT sheet. However, since the condition is that they all have equal precision, the input value of the weight is set to 1. These are entered manually. Also, the explanation of the weight matrix will be omitted from now on.

	A	B	C	D	E	F	G
1	Name	From		To		Weight	
2		Xb	Yb	Xa	Ya	sigma Xb	sigma Yb
3	5	1246699.207	414116.026	1246699.104	414116.322	1.000	1.000
4	3D	1307397.722	512230.914	1307397.672	512231.255	1.000	1.000
5	4B	1319439.481	468822.901	1319439.383	468823.224	1.000	1.000
6	5B	1299339.345	438998.827	1299339.254	438999.135	1.000	1.000
7	5C	1291290.984	467060.518	1291290.886	467060.801	1.000	1.000
8	5E	1266636.714	447804.803	1266636.628	447805.106	1.000	1.000
9	8A	1255466.622	495800.431	1255466.538	495800.724	1.000	1.000

OUTPUT | INPUT | P | A | AT | L | PL | ATPL | PA | ATPA | ATPA-1 | X

Read the input data from the INPUT sheet and write it to the OUTPUT sheet.

```
Sub INdat()
    Dim ID(4999)
    Dim Xa(4999) As Double
    Dim Ya(4999) As Double
    Dim Xb(4999) As Double
    Dim Yb(4999) As Double

    i = 1
    Do While Not Sheets("INPUT").Cells(i + 2, 1).Value = 0
        ID(i) = Sheets("INPUT").Cells(i + 2, 1).Value
        Xb(i) = Sheets("INPUT").Cells(i + 2, 2).Value
        Yb(i) = Sheets("INPUT").Cells(i + 2, 3).Value
        Xa(i) = Sheets("INPUT").Cells(i + 2, 4).Value
        Ya(i) = Sheets("INPUT").Cells(i + 2, 5).Value
        i = i + 1
    Loop
    N = i - 1


    Sheets("OUTPUT").Cells(2, 9).Value = N
    For i = 1 To N
        Sheets("OUTPUT").Cells(i + 5, 1).Value = ID(i)
        Sheets("OUTPUT").Cells(i + 5, 2).Value = Xb(i)
        Sheets("OUTPUT").Cells(i + 5, 3).Value = Yb(i)
        Sheets("OUTPUT").Cells(i + 5, 4).Value = Xa(i)
        Sheets("OUTPUT").Cells(i + 5, 5).Value = Ya(i)
    Next i
End Sub
```

Read the input value from the INPUT sheet.

Count the number of data and write it to the OUTPUT sheet.

Write the input values to the OUTPUT sheet.

	A	B	C	D	E	F	G	H	I
1	Parameter	A	B	C	D	S	θ		data
2		1.000000033	0.000000003	-0.146	0.310	1.0000000328	0.00000		25
3									
4	Name	From		To		To (cal)			
5		Xb	Yb	Xa	Ya	Xa	Ya	dX	dY
6	5	1246699.207	414116.026	1246699.104	414116.322	1246699.103	414116.346	-1	24
7	3D	1307397.722	512230.914	1307397.672	512231.255	1307397.621	512231.237	-51	-18
8	4B	1319439.481	468822.901	1319439.383	468823.224	1319439.380	468823.222	-3	-2
9	5B	1299339.345	438998.827	1299339.254	438999.135	1299339.243	438999.147	-11	12
10	5C	1291290.984	467060.518	1291290.886	467060.801	1291290.882	467060.839	-4	38
11	5E	1266636.714	447804.803	1266636.628	447805.106	1266636.611	447805.124	-17	18
12	8A	1255466.622	495800.431	1255466.538	495800.724	1255466.519	495800.753	-19	29
13	14A	1243671.556	543377.087	1243671.456	543377.426	1243671.453	543377.411	-3	-15

OUTPUT | INPUT | P | A | AT | L | PL | ATPL | PA | ATPA | ATPA-1 | X

(iii) Create weight matrix P

Matrix P is a unit matrix, so its explanation will be omitted.

```
Sub make_P()
    Dim Wx(5000) As Double
    Dim Wy(5000) As Double
    Dim P(5000, 5000) As Double

    i = 1
    Do While Not Sheets("INPUT").Cells(i + 2, 1).Value = 0
        Wx(i) = Sheets("INPUT").Cells(i + 2, 6).Value
        Wy(i) = Sheets("INPUT").Cells(i + 2, 7).Value
        i = i + 1
    Loop
    N = i - 1

    For i = 1 To (N * 2) Step 2
        P(i, i) = 1 / Wx((i + 1) / 2) ^ 2
        P(i + 1, i + 1) = 1 / Wy((i + 1) / 2) ^ 2
    Next i
    For i = 1 To N * 2
        For j = 1 To N * 2
            If i = j Then
                Sheets("P").Cells(i, j).Value = P(i, j)
            Else
                Sheets("P").Cells(i, j).Value = 0
            End If
        Next j
    Next i
End Sub
```

	A	B	C	D	E	F	G	H	I
1	1.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
2	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
3	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
4	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
5	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
6	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
7	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00
8	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00
9	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00
10	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
11	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
12	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
13	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

OUTPUT | INPUT | P | A | AT | L | PL | ATPL | PA | ATPA | ATPA-1 | X

(iv) Create design matrix A

Create a design matrix of equation (46) and write it on sheet A.

$$A = \begin{bmatrix} x_{b1} & y_{b1} & 1 & 0 \\ y_{b1} & -x_{b1} & 0 & 1 \\ x_{b2} & y_{b2} & 1 & 0 \\ y_{b2} & -x_{b2} & 0 & 1 \\ \vdots & \vdots & \vdots & \vdots \\ x_{bn} & y_{bn} & 1 & 0 \\ y_{bn} & -x_{bn} & 0 & 1 \end{bmatrix} \quad \cdots \ (46)$$

```
Sub make_A()
  Dim Xb(4999) As Double
  Dim Yb(4999) As Double

  i = 1
  Do While Not Sheets("INPUT").Cells(i + 2, 1).Value = 0
    Xb(i) = Sheets("INPUT").Cells(i + 2, 2).Value
    Yb(i) = Sheets("INPUT").Cells(i + 2, 3).Value
    i = i + 1
  Loop
  N = i - 1
```

Read the elements of the design matrix from the INPUT sheet.

```
  For i = 1 To N
    j = 2 * i - 1
    Sheets("A").Cells(j, 1).Value = Xb(i)
    Sheets("A").Cells(j, 2).Value = Yb(i)
    Sheets("A").Cells(j, 3).Value = 1
    Sheets("A").Cells(j, 4).Value = 0
    Sheets("A").Cells(j + 1, 1).Value = Yb(i)
    Sheets("A").Cells(j + 1, 2).Value = -Xb(i)
    Sheets("A").Cells(j + 1, 3).Value = 0
    Sheets("A").Cells(j + 1, 4).Value = 1
  Next i
End Sub
```

Rearrange the elements of the design matrix and write them on sheet A.

	A	B	C	D	E	F	G	H
1	1246699.207	414116.026	1	0				
2	414116.026	-1246699.207	0	1				
3	1307397.722	512230.914	1	0				
4	512230.914	-1307397.722	0	1				
5	1319439.481	468822.901	1	0				
6	468822.901	-1319439.481	0	1				
7	1299339.345	438998.827	1	0				
8	438998.827	-1299339.345	0	1				
9	1291290.984	467060.518	1	0				
10	467060.518	-1291290.984	0	1				
11	1266636.714	447804.803	1	0				
12	447804.803	-1266636.714	0	1				
13	1255466.622	495800.431	1	0				

OUTPUT | INPUT | P | A | AT | L | PL | ATPL | PA | ATPA | ATPA-1 | X

(v) Create a transposed matrix of design matrix A

Create the transposed matrix A^T of the design matrix in equation (46) and write it on the A^T sheet.

$$A^T = \begin{bmatrix} x_{b1} & y_{b1} & x_{b2} & y_{b2} & \cdots & x_{bn} & y_{bn} \\ y_{b1} & -x_{b1} & y_{b2} & -x_{b2} & \cdots & y_{bn} & -x_{bn} \\ 1 & 0 & 1 & 0 & \cdots & 1 & 0 \\ 0 & 1 & 0 & 1 & \cdots & 0 & 1 \end{bmatrix}$$

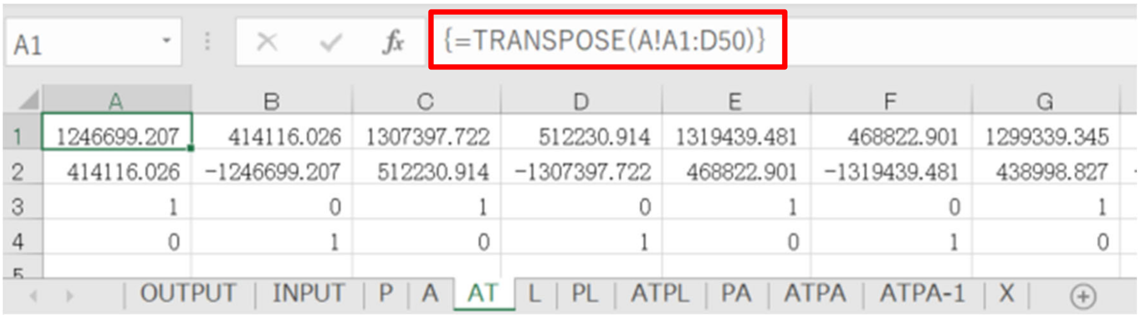
```
Sub cal_AT()
  N = 2 * Sheets("OUTPUT").Cells(2, 9).Value
```

Read the number of data N from the OUTPUT sheet.
Since the number of rows of design matrix A is twice the number of data N, the number of columns of the transposed matrix is 2×N.

```
  Sheets("AT").Select
  Range(Cells(1, 1), Cells(4, N)).Select
  NN$ = Trim(Str(N - 1))

  at$ = "=TRANSPOSE(A!RC:R[" & NN$ & "]C[3])"
```

Calculate the transposed matrix at$ of design matrix A using the Excel function TRANSPOSE and write it on the AT sheet.

```
  Selection.FormulaArray = at$
End Sub
```



	A	B	C	D	E	F	G
1	1246699.207	414116.026	1307397.722	512230.914	1319439.481	468822.901	1299339.345
2	414116.026	-1246699.207	512230.914	-1307397.722	468822.901	-1319439.481	438998.827
3	1	0	1	0	1	0	1
4	0	1	0	1	0	1	0

(vi) Create matrix L

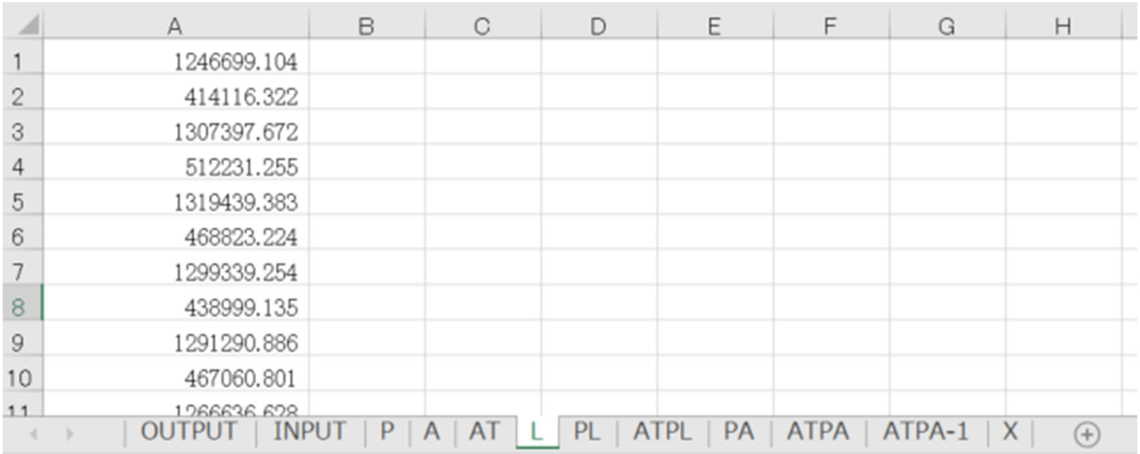
Create a matrix L and write it to the L sheet.

$$L = \begin{bmatrix} X_{a1} \\ Y_{a1} \\ X_{a2} \\ Y_{a2} \\ \vdots \\ X_{an} \\ Y_{an} \end{bmatrix} \quad \cdots \ (41)$$

```
Sub make_L()
  Dim Xa(4999) As Double
  Dim Ya(4999) As Double

  i = 1
  Do While Not Sheets("INPUT").Cells(i + 2, 1).Value = 0
    Xa(i) = Sheets("INPUT").Cells(i + 2, 4).Value
    Ya(i) = Sheets("INPUT").Cells(i + 2, 5).Value
    i = i + 1
  Loop
  N = i - 1

  For i = 1 To N
    j = 2 * i - 1
    Sheets("L").Cells(j, 1).Value = Xa(i)
    Sheets("L").Cells(j + 1, 1).Value = Ya(i)
  Next i
End Sub
```

Read the elements of matrix L from the INPUT sheet.

Write the elements of matrix L in order on sheet L.



(vii) Compute the product of matrix P and matrix L

Matrix P is a unit matrix, so its explanation will be omitted.

```
Sub cal_PL()
   N = 2 * Sheets("OUTPUT").Cells(2, 9).Value
   Sheets("PL").Select
   Range(Cells(1, 1), Cells(N, 1)).Select
   NN$ = Trim(Str(N - 1))
   pl$ = "=MMULT(P!RC:R[" & NN$ & "]C[" & NN$ & "],L!RC:R[" & NN$ & "]C)"
   Selection.FormulaArray = pl$
End Sub
```

(viii) Compute the product of matrix A^T and matrix PL

The matrix $A^T PL$ is as follows.

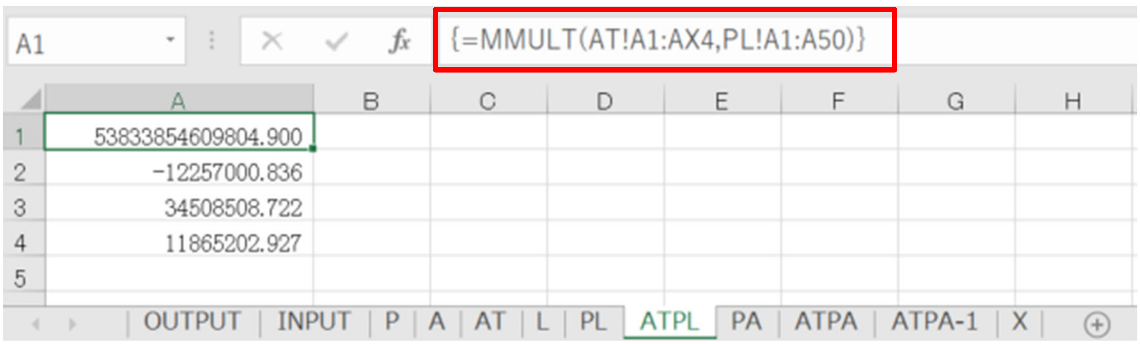
$$A^T PL = \begin{bmatrix} x_{b1} & y_{b1} & x_{b2} & y_{b2} & \cdots & x_{bn} & y_{bn} \\ y_{b1} & -x_{b1} & y_{b2} & -x_{b2} & \cdots & y_{bn} & -x_{bn} \\ 1 & 0 & 1 & 0 & \cdots & 1 & 0 \\ 0 & 1 & 0 & 1 & \cdots & 0 & 1 \end{bmatrix} P \begin{bmatrix} X_{a1} \\ Y_{a1} \\ X_{a2} \\ Y_{a2} \\ \vdots \\ X_{an} \\ Y_{an} \end{bmatrix}$$

```
Sub cal_ATPL()
   N = 2 * Sheets("OUTPUT").Cells(2, 9).Value
```

Read the number of data N from the OUTPUT sheet.
The number of rows in the matrix $A^T PL$ is twice the number of data N.

```
   Sheets("ATPL").Select
   Range(Cells(1, 1), Cells(4, 1)).Select
   NN$ = Trim(Str(N - 1))
   atpl$ = "=MMULT(AT!RC:R[3]C[" & NN$ & "],PL!RC:R[" & NN$ & "]C)"
   Selection.FormulaArray = atpl$
End Sub
```

Calculate the product atpl$ of matrix AT and matrix PL using the Excel function MMULT. Write on the ATPL sheet.



(ix) Compute the product of matrix P and matrix A

Matrix P is a unit matrix, so its explanation will be omitted.

```
Sub cal_PA()
    N = 2 * Sheets("OUTPUT").Cells(2, 9).Value
    Sheets("PA").Select
    Range(Cells(1, 1), Cells(N, 4)).Select
    NN$ = Trim(Str(N - 1))
    pa$ = "=MMULT(P!RC:R[" & NN$ & "]C[" & NN$ & "],A!RC:R[" & NN$ & "]C[3])"
    Selection.FormulaArray = pa$
End Sub
```

(x) Compute the product of matrix A^T and matrix PA

The matrix A^TPA is as follows.

$$A^TPA = \begin{bmatrix} x_{b1} & y_{b1} & x_{b2} & y_{b2} & \cdots & x_{bn} & y_{bn} \\ y_{b1} & -x_{b1} & y_{b2} & -x_{b2} & \cdots & y_{bn} & -x_{bn} \\ 1 & 0 & 1 & 0 & \cdots & 1 & 0 \\ 0 & 1 & 0 & 1 & \cdots & 0 & 1 \end{bmatrix} P \begin{bmatrix} x_{b1} & y_{b1} & 1 & 0 \\ y_{b1} & -x_{b1} & 0 & 1 \\ x_{b2} & y_{b2} & 1 & 0 \\ y_{b2} & -x_{b2} & 0 & 1 \\ \vdots & \vdots & \vdots & \vdots \\ x_{bn} & y_{bn} & 1 & 0 \\ y_{bn} & -x_{bn} & 0 & 1 \end{bmatrix}$$

```
Sub cal_ATPA()
    N = 2 * Sheets("OUTPUT").Cells(2, 9).Value
    Sheets("ATPA").Select
    Range(Cells(1, 1), Cells(4, 4)).Select
```

Since Helmert Transformation (2D) has 4 unknown quantities, the matrix A^TPA has 4 rows and 4 columns.

```
    NN$ = Trim(Str(N - 1))
    atpa$ = "=MMULT(AT!RC:R[3]C[" & NN$ & "],PA!RC:R[" & NN$ & "]C[3])"
    Selection.FormulaArray = atpa$
End Sub
```

Calculate the product atpa$ of matrix AT and matrix PA using the Excel function MMULT. Write on the ATPA sheet.

A1 {=MMULT(AT!A1:AX4,PA!A1:D50)}

	A	B	C	D	E	F
1	5.383E+13	0.000E+00	3.451E+07	1.187E+07		
2	0.000E+00	5.383E+13	1.187E+07	-3.451E+07		
3	3.451E+07	1.187E+07	2.500E+01	0.000E+00		
4	1.187E+07	-3.451E+07	0.000E+00	2.500E+01		
5						

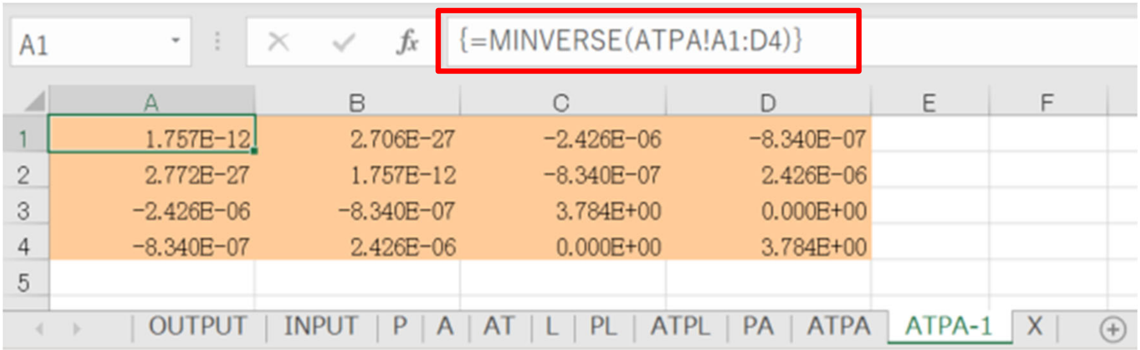
OUTPUT | INPUT | P | A | AT | L | PL | ATPL | PA | ATPA | ATPA-1 | X

(xi) Compute the inverse of $A^{T}PA$

The inverse matrix of matrix $A^{T}PA$ is as follows.

$$(A^T PA)^{-1} = \left(\begin{bmatrix} x_{b1} & y_{b1} & x_{b2} & y_{b2} & \cdots & x_{bn} & y_{bn} \\ y_{b1} & -x_{b1} & y_{b2} & -x_{b2} & \cdots & y_{bn} & -x_{bn} \\ 1 & 0 & 1 & 0 & \cdots & 1 & 0 \\ 0 & 1 & 0 & 1 & \cdots & 0 & 1 \end{bmatrix} P \begin{bmatrix} x_{b1} & y_{b1} & 1 & 0 \\ y_{b1} & -x_{b1} & 0 & 1 \\ x_{b2} & y_{b2} & 1 & 0 \\ y_{b2} & -x_{b2} & 0 & 1 \\ \vdots & \vdots & \vdots & \vdots \\ x_{bn} & y_{bn} & 1 & 0 \\ y_{bn} & -x_{bn} & 0 & 1 \end{bmatrix} \right)^{-1}$$

Calculate the inverse matrix from the matrix $A^{T}PA$ using the Excel function MINVERSE and write it on the ATPA-1 sheet.



	A	B	C	D	E	F
1	1.757E-12	2.706E-27	-2.426E-06	-8.340E-07		
2	2.772E-27	1.757E-12	-8.340E-07	2.426E-06		
3	-2.426E-06	-8.340E-07	3.784E+00	0.000E+00		
4	-8.340E-07	2.426E-06	0.000E+00	3.784E+00		
5						

(xii) Calculate the unknown quantity matrix X

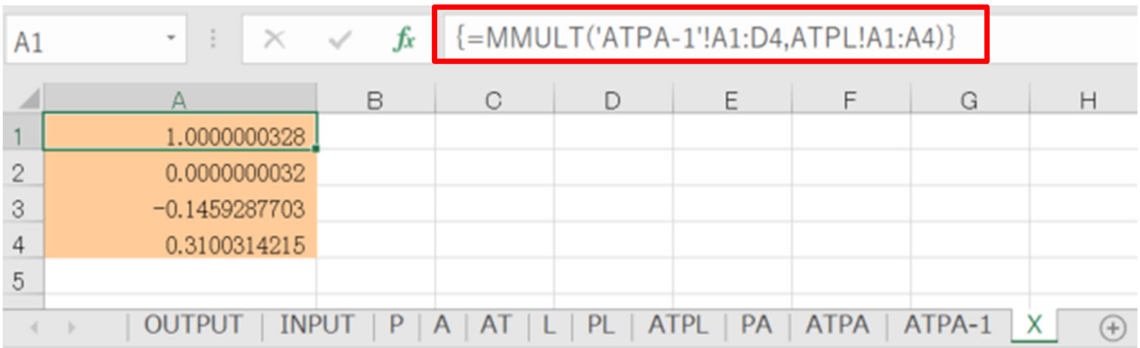
Parameters A, B, C, and D of Helmert Transformation (2D) are unknown quantity matrix X, which is expressed by the following equation.

$$X = \begin{bmatrix} A \\ B \\ C \\ D \end{bmatrix} \quad \cdots \ (39)$$

Matrix X is the product of the inverse of matrix A^TPA $(ATPA)^{-1}$ and matrix A^TPL.

$$X = -(A^T PA)^{-1} A^T PL$$

Calculate the product using the Excel function MINVERSE and write it on the ATPA-1 sheet.



(xiv) Create an OUTPUT sheet

A formula is written in the cell so that each element (coordinate transformation parameter) of the calculated unknown quantity matrix X is assigned from the X sheet to the OUTPUT sheet.

B2 =X!A1

	A	B	C	D	E	F	G	H	I
1	Parameter	A	B	C	D	S	θ		data
2		1.000000033	0.000000003	-0.146	0.310	1.0000000328	0.00000		25
3									
4	Name	From		To		To (cal)			
5		Xb	Yb	Xa	Ya	Xa	Ya	dX	dY
6	5	1246699.207	414116.026	1246699.104	414116.322	1246699.103	414116.346	-1	24
7	3D	1307397.722	512230.914	1307397.672	512231.255	1307397.621	512231.237	-51	-18
8	4B	1319439.481	468822.901	1319439.383	468823.224	1319439.380	468823.222	-3	-2
9	5B	1299339.345	438998.827	1299339.254	438999.135	1299339.243	438999.147	-11	12
10	5C	1291290.984	467060.518	1291290.886	467060.801	1291290.882	467060.839	-4	38
11	5E	1266636.714	447804.803	1266636.628	447805.106	1266636.611	447805.124	-17	18
12	8A	1255466.622	495800.431	1255466.538	495800.724	1255466.519	495800.753	-19	29

OUTPUT | INPUT | P | A | AT | L | PL | ATPL | PA | ATPA | ATPA-1 | X

A formula is written in the cell to coordinate transform the input value using the calculated coordinate transformation parameters.

F6 =$B$2*B6+$C$2*C6+$D$2

	A	B	C	D	E	F	G	H	I
1	Parameter	A	B	C	D	S	θ		data
2		1.000000033	0.000000003	-0.146	0.310	1.0000000328	0.00000		25
3									
4	Name	From		To		To (cal)			
5		Xb	Yb	Xa	Ya	Xa	Ya	dX	dY
6	5	1246699.207	414116.026	1246699.104	414116.322	1246699.103	414116.346	-1	24
7	3D	1307397.722	512230.914	1307397.672	512231.255	1307397.621	512231.237	-51	-18
8	4B	1319439.481	468822.901	1319439.383	468823.224	1319439.380	468823.222	-3	-2
9	5B	1299339.345	438998.827	1299339.254	438999.135	1299339.243	438999.147	-11	12
10	5C	1291290.984	467060.518	1291290.886	467060.801	1291290.882	467060.839	-4	38
11	5E	1266636.714	447804.803	1266636.628	447805.106	1266636.611	447805.124	-17	18
12	8A	1255466.622	495800.431	1255466.538	495800.724	1255466.519	495800.753	-19	29

OUTPUT | INPUT | P | A | AT | L | PL | ATPL | PA | ATPA | ATPA-1 | X

A formula is written in the cell to calculate the difference (residual) between the input value and the calculated value.

H6 =(F6-D6)*1000

	A	B	C	D	E	F	G	H	I
1	Parameter	A	B	C	D	S	θ		data
2		1.000000033	0.000000003	-0.146	0.310	1.0000000328	0.00000		25
3									
4	Name	From		To		To (cal)			
5		Xb	Yb	Xa	Ya	Xa	Ya	dX	dY
6	5	1246699.207	414116.026	1246699.104	414116.322	1246699.103	414116.346	-1	24
7	3D	1307397.722	512230.914	1307397.672	512231.255	1307397.621	512231.237	-51	-18
8	4B	1319439.481	468822.901	1319439.383	468823.224	1319439.380	468823.222	-3	-2
9	5B	1299339.345	438998.827	1299339.254	438999.135	1299339.243	438999.147	-11	12
10	5C	1291290.984	467060.518	1291290.886	467060.801	1291290.882	467060.839	-4	38
11	5E	1266636.714	447804.803	1266636.628	447805.106	1266636.611	447805.124	-17	18
12	8A	1255466.622	495800.431	1255466.538	495800.724	1255466.519	495800.753	-19	29

OUTPUT | INPUT | P | A | AT | L | PL | ATPL | PA | ATPA | ATPA-1 | X

(E) How to use Excel

(i) Activate the INPUT sheet.

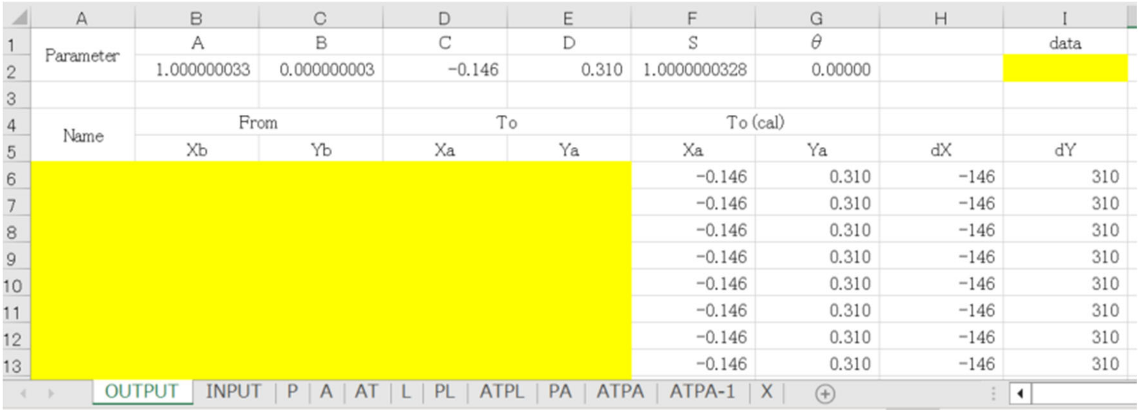
Enter [Name], [From] coordinates, and [To] coordinates. Weight is set to 1.

	A	B	C	D	E	F	G
1	Name	From		To		Weight	
2		Xb	Yb	Xa	Ya	sigma Xb	sigma Yb
3	5	1246699.207	414116.026	1246699.104	414116.322	1.000	1.000
4	3D	1307397.722	512230.914	1307397.672	512231.255	1.000	1.000
5	4B	1319439.481	468822.901	1319439.383	468823.224	1.000	1.000
6	5B	1299339.345	438998.827	1299339.254	438999.135	1.000	1.000
7	5C	1291290.984	467060.518	1291290.886	467060.801	1.000	1.000

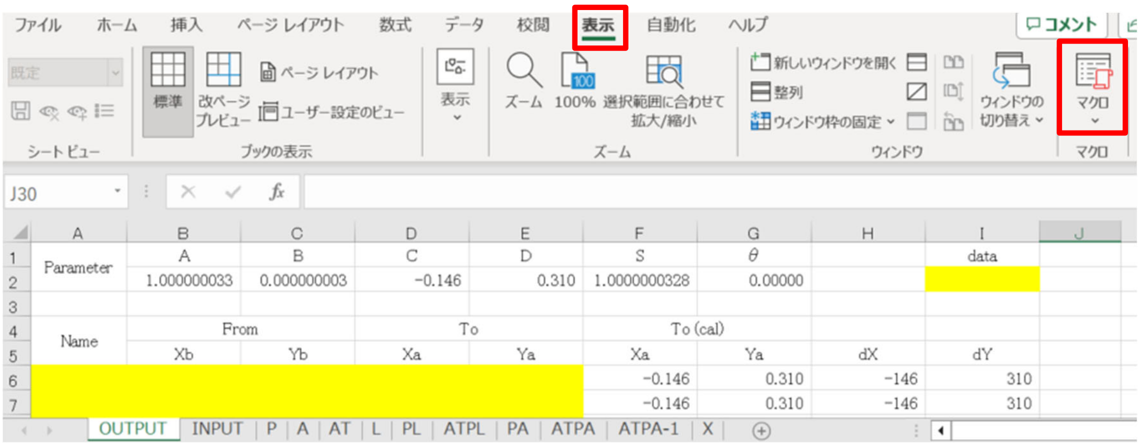
OUTPUT | INPUT | P | A | AT | L | PL | ATPL | PA | ATPA | ATPA-1 | X

(ii) Activate the OUTPUT sheet.

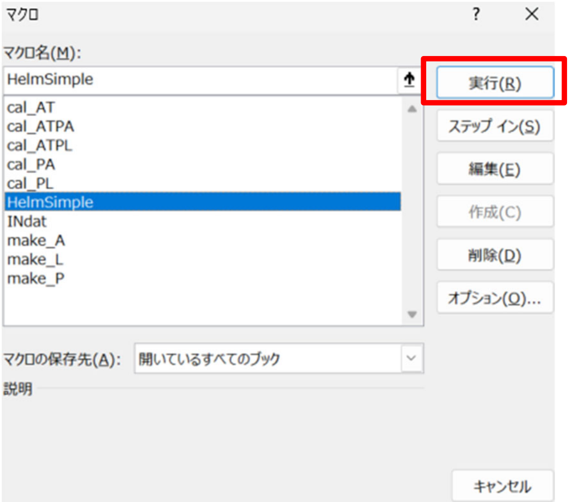
If there are numbers in the yellow cells, delete them.



(iii) Please display the macro.



(iv) Run the [HelmSimple] macro.

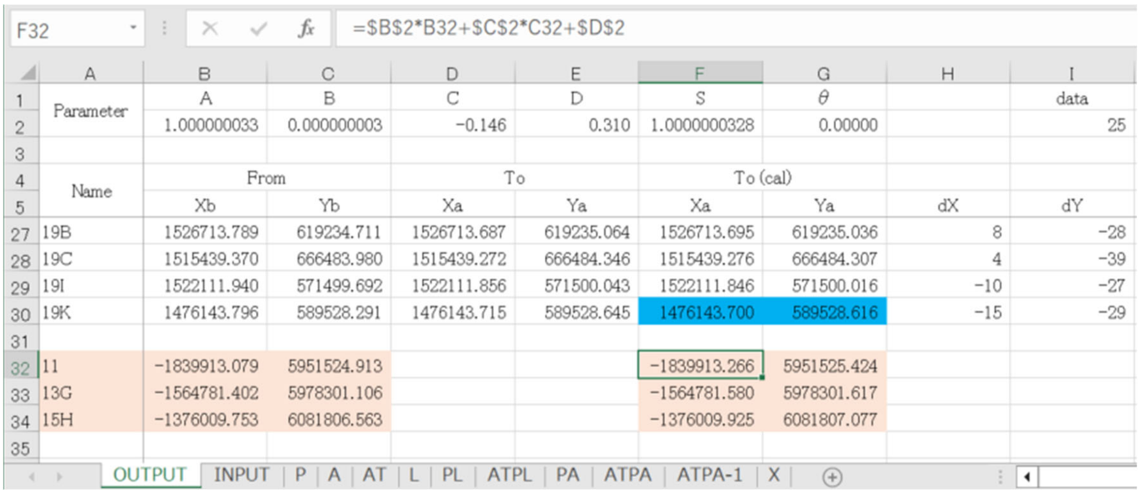


(v) Please check the residuals.

	A	B	C	D	E	F	G	H	I
1	Parameter	A	B	C	D	S	θ		data
2		1.000000033	0.000000003	-0.146	0.310	1.0000000328	0.00000		25
3									
4	Name	From		To		To (cal)			
5		Xb	Yb	Xa	Ya	Xa	Ya	dX	dY
6	5	1246699.207	414116.026	1246699.104	414116.322	1246699.103	414116.346	-1	24
7	3D	1307397.722	512230.914	1307397.672	512231.255	1307397.621	512231.237	-51	-18
8	4B	1319439.481	468822.901	1319439.383	468823.224	1319439.380	468823.222	-3	-2
9	5B	1299339.345	438998.827	1299339.254	438999.135	1299339.243	438999.147	-11	12
10	5C	1291290.984	467060.518	1291290.886	467060.801	1291290.882	467060.839	-4	38

OUTPUT | INPUT | P | A | AT | L | PL | ATPL | PA | ATPA | ATPA-1 | X

(vi) Enter the [Name] and [From] coordinates of the point you want to calculate in the blank line. The F and G columns of To(cal) contain function expressions. Please copy and paste.

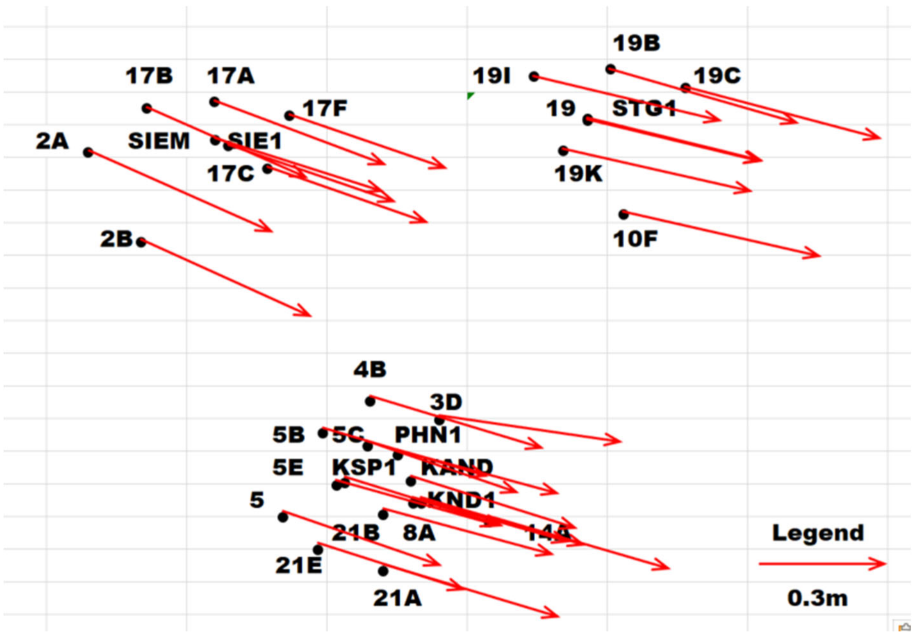

F32 =$B$2*B32+$C$2*C32+$D$2

	A	B	C	D	E	F	G	H	I
1	Parameter	A	B	C	D	S	θ		data
2		1.000000033	0.000000003	-0.146	0.310	1.0000000328	0.00000		25
3									
4	Name	From		To		To (cal)			
5		Xb	Yb	Xa	Ya	Xa	Ya	dX	dY
27	19B	1526713.789	619234.711	1526713.687	619235.064	1526713.695	619235.036	8	-28
28	19C	1515439.370	666483.980	1515439.272	666484.346	1515439.276	666484.307	4	-39
29	19I	1522111.940	571499.692	1522111.856	571500.043	1522111.846	571500.016	-10	-27
30	19K	1476143.796	589528.291	1476143.715	589528.645	1476143.700	589528.616	-15	-29
31									
32	11	-1839913.079	5951524.913			-1839913.266	5951525.424		
33	13G	-1564781.402	5978301.106			-1564781.580	5978301.617		
34	15H	-1376009.753	6081806.563			-1376009.925	6081807.077		
35									

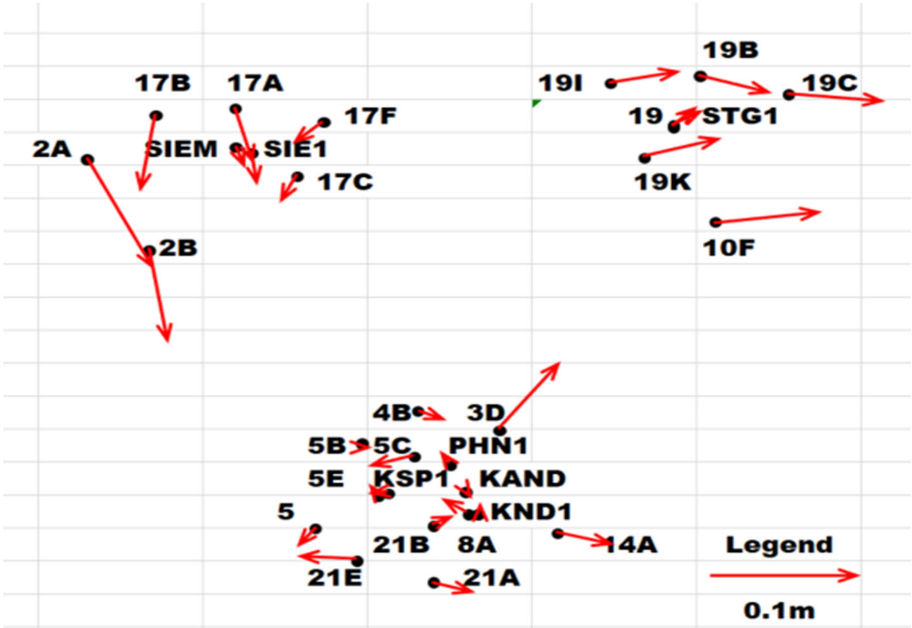
OUTPUT | INPUT | P | A | AT | L | PL | ATPL | PA | ATPA | ATPA-1 | X

10.1.4. Example of calculating parameters adapted to each region

The figure below shows the displacement vector from CGD09 to CGD23.



The figure above looks like the same displacement vector because the amount of displacement is large. Therefore, the figure below shows the characteristics of the displacement trend at each point by excluding the average value of the displacement vector from the figure above.



It can be seen that the characteristics are different in each region of Phnom Penh, Siem Reap, and Stung Treng.

Therefore, coordinate transformation parameters are calculated for each region of Phnom Penh, Siem Reap, and Stung Treng.

(A) Phnom Penh

Name	Whole Area Helmert2D Residual dN (mm)	Whole Area Helmert2D Residual dE (mm)	Each Region Helmert2D Residual dN (mm)	Each Region Helmert2D Residual dE (mm)
5	-1	24	7	-2
3D	-51	-18	-28	-21
4B	-3	-2	22	-15
5B	-11	12	10	-8
5C	-4	38	15	25
5E	-17	18	-4	0
8A	-19	29	-9	23
14A	-3	-15	4	-9
21A	-5	-7	-5	-17
21B	-16	4	-8	-7
21E	-15	45	-13	25
KAND	-4	12	10	6

(B) Siem Reap

Name	Whole Area Helmert2D Residual dN (mm)	Whole Area Helmert2D Residual dE (mm)	Each Region Helmert2D Residual dN (mm)	Each Region Helmert2D Residual dE (mm)
2A	57	-28	8	-22
2B	47	-2	17	19
17A	26	-3	-1	-18
17B	37	16	-3	8
17C	8	19	-1	13
17F	7	25	-3	6
SIEM	5	3	-18	-4

(C) Stung Treng.

Name	Whole Area Helmert2D Residual dN (mm)	Whole Area Helmert2D Residual dE (mm)	Each Region Helmert2D Residual dN (mm)	Each Region Helmert2D Residual dE (mm)
19	-13	-4	-7	24
10F	-12	-43	-6	-16
19B	8	-28	14	1
19C	4	-39	9	-10
19I	-10	-27	-3	2
19K	-15	-29	-8	-1

The residual error when calculated for each region is smaller than when calculated for the whole area. In other words, the parameters are adapted to each region by the amount of the reduced residual.

Project on Establishment of Continuously Operating Reference Stations (CORS) for Land Management and Infrastructure Development

Operation and Maintenance Plan for the Khmer GEONET

18 November 2024

GENERAL DEPARTMENT OF CADASTRE AND GEOGRAPHY OF MINISTRY OF LAND MANAGEMENT, URBAN PLANNING AND CONSTRUCTION OF KINGDOM OF CAMBODIA

JAPAN INTERNATIONAL COOPERATION AGENCY

PASCO CORPORATION

Record of Updating

25 September 2023	Version 0.1 the first draft
2 November 2023	Version 0.2 the second draft
3 May 2024	Version 1.0 towards the Paid-Service
18 November 2024	Version 1.1 End of the Project

Table of Contents

Acronyms and Abbreviations

No.	Abbreviation	Official Name
1	CORS	Continuously Operating Reference Stations
2	DPM	Deputy Prime Minister
3	GDCG	General Department of Cadastre and Geography
4	GNSS	Global Navigation Satellite System
5	GPS	Global Positioning System
6	JICA	Japan International Cooperation Agency
7	Khmer GEONET	Khmer GNSS Earth Observation Network System
8	MEF	Ministry of Economy and Finance
9	MLMUPC	Ministry of Land Management, Urban Planning and Construction
10	RGC	Royal Government of Cambodia

CHAPTER 1. Planning of Operation and Maintenance for the Khmer GEONET

1.1. Outline of establishment of the Khmer GEONET

The Khmer GEONET <https://khmergeonet.xyz> has been established under the "Project on Establishment of Continuously Operating Reference Stations (CORS) for Land Management and Infrastructure Development" between the Ministry of Land Management, Urban Planning and Construction (MLMUPC) and Japan International Corporation Agency (JICA). This is a JICA Technical Transfer Project with the period from August 2021 to December 2024.

The General Department of Cadastre and Geography (GDCG) under MLMUPC is the responsible agency in Cambodia for whole operation and maintenance for the Khmer GEONET. The construction of five stations and establishment of the Data Center have generally completed in April 2022. All equipment has been handed over from JICA to MLMUPC / GDCG on 6th December 2022.

The Khmer GEONET will start the Paid-Service on Wednesday, 25th June 2025.

1.2. Objective of the O & M Plan for the Khmer GEONET

This document describes the essential plan for the operation and maintenance (O & M) of hardware / software, organization and partnerships for the Khmer GEONET, which consists of five (5) stations and one (1) Data Center (as of November 2024).

1.3. Overview of the O & M Plan for the Khmer GEONET

The plan is separated into the mainly three phases: Phase 1 Towards Stable Paid-Service, Phase 2 Smooth Expansion to Whole Country, and Phase 3 Sustainable O & M of the Khmer GEONET.
Phase 1 is targeting the establishment of stable service of the Khmer GEONET until the end of the JICA Technical Transfer Project, December 2024.
Phase 2 is targeting the smooth integration with the JICA Grant Aid Project for the nationwide CORS network which will be completed in March 2026.

Phase 3 is targeting the sustainable activities of the Khmer GEONET since April 2026, after the completion of the JICA Grant Aid Project.

Please see the attached “Roadmap of the Operation and Maintenance Plan for the Khmer GEONET” for the summary of the progress.

CHAPTER 2. Tasks of the O & M Plan for the Khmer GEONET

2.1. Tasks of Phase 1 Towards Stable Paid-Service

The task list of Phase 1 is shown as below.

Table 2-1 Task List of Phase 1 Towards Stable Paid-Service

#	Tasks
1-1	Management Policy
1-2	Organizational Structure
1-2-1	Organizational Structure: O & M Office
1-2-2	Organizational Structure: Registration Service Office
1-2-3	Organizational Structure: Technical Inspection Office
1-2-4	Organizational Structure: Staff of the O & M Office
1-3	O & M Manuals and Reporting App for Data Center Operators
1-4	O & M Manuals and Reporting App for On-site Station Staff
1-5	Public-Private Partnership
1-6	Human Resources Development
1-7	Equipment Planning & Updating for 5 Stations and the Data Center
1-7-1	Equipment Planning for 5 Stations and 1 Data Center
1-7-2	Updating of Batteries for 5 Stations
1-8	Budget Planning for Fiscal Year 2024 & 2025
1-8-1	Budget Planning for Fiscal Year 2024
1-8-2	Budget Planning for Fiscal Year 2025
1-9	Start of the Paid-Service
1-10	Public Relations

2.1.1. Task 1-1 Management Policy

This task is the establishment of a basic policies including the Paid-Service for Khmer GEONET. The expected users are Government/International Project, Academia, Private Company, and so on.

The DRAFT Paid-Service Plan (Price List, User Category, Service Type) has been submitted to MLMUPC and MEF in June 2023. It will be approved by MEF and other line ministries in advance of the start of the Paid-Service.

2.1.2. Task 1-2 Organizational Structure

This task is the establishment of the official Section / Office with staff as the responsible flamework for the Khmer GEONET services.

2.1.2.1. Task 1-2-1 Organizational structure: O & M Office

GDCG has proposed a new O & M Office for Khmer GEONET.
It will be reviewed in the fiscal year 2025.

2.1.2.2. Task 1-2-2 Organizational Structure: Registration Service Office

GDCG has proposed a new Registration Service Office for Khmer GEONET.
It will be reviewed in the fiscal year 2025.
Registration of Surveyors has been announced and started in March 2024. The qualification test of surveyor will be conducted after consideration of the registration.
Licensing of Survey Company will be announced and started after the preparation of the qualification test. The survey company must have the registered and licensed (qualified) surveyors.

2.1.2.3. Task 1-2-3 Organizational Structure: Technical Inspection Office

GDCG has proposed a new Technical Inspection Office for Technical Inspection for Surveying Equipment.
It will be reviewed in the fiscal year 2025.

2.1.2.4. Task 1-2-4 Organizational Structure: Staff of the O & M Office

GDCG has proposed the staff of the new O & M Office for Khmer GEONET. The organizational structure would have the three categories of official staff:

1. Manager (High level decision making)
2. Supervisor (Department)
3. DC Operator (Data Center & 1 Station)

Besides, the on-site level (4 Stations) has one category of official staff:

1. Station Staff (District/Provincial Offices)

This proposal of the organizational structure has already been submitted. The approval line is: Department -> GDCG -> Under Secretary of State -> Secretary of State -> Minister of MLMUPC (= Deputy Prime Minister, as of November 2024).

The organization is provisionally named "Khmer GEONET Data Center" under the Geography Department of GDCG.)
It will be reviewed in the fiscal year 2025.

2.1.3. Task 1-3 O & M Manuals for Data Center Operators

The Japanese Project Team (JPT) and Aruna Technology Ltd. (Aruna) has been consulted with Cambodian Project Team (CPT, that is, GDCG) about the O & M manuals for Data Center Operators: GNSS-Receiver, Software (Trimble Pivot Platform, Bernese GNSS Software, etc.), Communication / Network / Power Supply. Moreover, Daily/Monthly/Yearly Tasks (storage and backup of data, calculation of coordinates, etc.) are also considered. All the documents should be shared on-line (Telegram, Private Google Drive, Data Center Server).
The O & M Manual has been translated from English to Khmer.
These documents and report formats will be updated based on experiences.

2.1.4. Task 1-4 O & M Check List & Report Format for On-site Maintenance

The reporting tool for station maintenance should be shared on-line. GDCG has developed a smartphone app based on ArcGIS Survey123, ArcGIS Field Maps and ArcGIS Dashboards for information management. All the report should be shared trough Telegram and archived in the GDCG Server (Synology NAS). Backup tape is also stored at the other building in case of contingency situation (once in a month).
The O & M Manual has been translated from English to Khmer.
The tools will be updated based on experiences.

2.1.5. Task 1-5 Public-Private Partnership

Outsourcing of a part of O & M activities from GDCG to the private company (ex. Aruna) is important. The contract between GDCG and private company for hardware maintenance and necessary support will be processed in fiscal year 2025.
The budget for O & M for the fiscal year 2025 will be finally approved by the Parliament by December 2024.

2.1.6. Task 1-6 Human Resources Development

Capacity development of engineers for the O & M of 5 CORS should be conducted after the approval of the Paid-Service plan / the organizational structure, and before the start of the Paid-

Service.

2.1.7. Task 1-7 Equipment Planning & Updating for 5 Stations and the Data Center

2.1.7.1. Task 1-7-1 Equipment Planning for 5 Stations and 1 Data Center

In case of machine troubles, an equipment plan should be prepared for operation continuity, update of hardware/software, and others for the 5 Stations and the Data Center. **(Completed)**

2.1.7.2. Task 1-7-2 Updating of Batteries for 5 Stations

Each Station has three units of battery. The batteries should be checked after two years (from April 2022) to see if it is necessary to change them at that time or their life can be extended.

Example: The maximum cost might be:

(USD150/unit) x (3 units/station) x 5 stations = USD 2,250

The unit price USD 150 includes transportation fees.

2.1.8. Task 1-8 Budget Planning for Fiscal Year 2024 & 2025

2.1.8.1. Task 1-8-1 Budget Planning for Fiscal Year 2024

The budget for the Khmer GEONET in the fiscal year 2024 (January - December 2024) have been submitted to MLMUPC from GDCG in March/April 2023. It has been discussed and approved in July/August 2023 at MEF. After that, it has been finally approved by the Parliament by December 2023. **(Completed)**

2.1.8.2. Task 1-8-2 Budget Planning for Fiscal Year 2025

GDCG have prepared a draft budget plan for the Khmer GEONET in the fiscal year 2025 (January - December 2025) by March/April 2024 to submit as a part of the Annual National Budget in 2025. It has been discussed by MLMUPC and MEF at the meeting on 5th July 2024 and after. The budget for O & M for the Khmer GEONET in the fiscal year 2025 will be finally approved by the Parliament by December 2024.

2.1.9. Task 1-9 Start of the Paid-Service

The Khmer GEONET will start the Paid-Service on 25th June 2025 (re-changed from 26 June 2024). Khmer GEONET Website has already been developed. The collaboration with Cambodia Data Exchange Platform (CamDX) will be added for payment method.

2.1.10. Task 1-10 Public Relations

For value adding and sustainability of the Khmer GEONET, number of users is an important monitoring index. Promotion activities are necessary.

The results of the pilot projects can be used as the PR materials for the current / future users of the Khmer GEONET.

The 3rd Seminar has successfully been conducted on 5th June 2024. The materials (agenda, leaflet for the Khmer GEONET, presentations, etc.) are shared among participants. **(Completed)**

2.2. Tasks of Phase 2 Smooth Expansion to Whole Country

The task list of Phase 2 is shown as below.

Table 2-2 Task List of Phase 2 Smooth Expansion to Whole Country

#	Tasks
2-0	Start of the Paid-Service
2-1	JICA Grant Aid for the Nationwide CORS Network
2-2	Updating of Batteries for the Nationwide CORS Network
2-3	Updating of Software
2-4	Public-Private Partnership
2-5	Human Resources Development
2-6	Equipment Planning
2-7	Budget Planning
2-8	Public Relations
2-9	Registration as the International GNSS Service (IGS) Station

2.2.1. Task 2-1 JICA Grant Aid for the Nationwide CORS Network

The contract has been concluded on 14th March 2024.

The construction will complete by March 2026 (planned two years from the contract).

(Total number of stations are under adjustment (as of November 2024).)

2.2.2. Task 2-2 Updating of Batteries for the Nationwide CORS Network

Each Station has three units of battery. Basically, the batteries should be checked after two years (from the set-up at the station) to see if it is necessary to change them at that time or their life can be extended.

Because of the variety of each on-site situation, the lifetimes of batteries may be different from each other.

2.2.3. Task 2-3 Updating of Software

Updating of software should be considered well in advance of the expiration.
For example:
Pivot (expire on 31 May 2027),
Bernese,
Network software,
Internet Security (Anti-Virus software, Firewall, etc.),
Microsoft Operation Software (Windows),
Microsoft Office (Excel, Word),
ArcGIS, etc.

2.2.4. Task 2-4 Public-Private Partnership

Outsourcing of a part of O & M activities from GDCG to the private company should be prepared.

2.2.5. Task 2-5 Human Resources Development

Capacity development of engineers for O & M of Nationwide CORS Network with the Data Center should be conducted.

2.2.6. Task 2-6 Equipment Planning

In case of machine troubles, an equipment plan should be prepared for operation continuity, update of hardware/software, and others for the Nationwide CORS Network with the Data Center. For reasonable planning, the evidence/experience, such as past accident records, should be considered.

2.2.7. Task 2-7 Budget Planning

Every year, GDCG shall prepare a draft budget plan by March/April to submit as Annual National Budget on the next fiscal year (January - December) for the Nationwide CORS Network with the Data Center.

2.2.8. Task 2-8 Public Relations

Goal setting (how many users are registered until when?) is important for promotion.
For example, increase users up to 1,000 registrations at the end of 2026, hopefully.

2.2.9. Task 2-9 Registration as the International GNSS Service (IGS) Station

It should be considered that how many stations of the Khmer GEONET might be aiming to register as International GNSS Service (IGS) stations. The target year should be also considered.

2.3. Tasks of Phase 3 Sustainable O & M of the Khmer GEONET

The task list of Phase 3 is shown as below.

Table 2-3 Task List of Phase 3 Sustainable O & M of the Khmer GEONET

#	Tasks
3-1	Updating of Hardware (GNSS Receiver, Antenna, UPS, etc.)
3-2	Updating of Storage, Server, etc.
3-3	Updating of Software
3-4	Human Resources Development
3-5	Future expansion of the Khmer GEONET

2.3.1. Task 3-1 Updating of Hardware (GNSS Receiver, Antenna, UPS, etc.)

Lifetime of hardware expects 10 years or more. The plan and budget for updating of the Nationwide CORS Network should be prepared well in advance.
Hopefully, the updating of each Stations might be one by one, not simultaneously.

2.3.2. Task 3-2 Updating of Storage, Server, etc.

Lifetime of PC at the Data Center will be expected around 3 years or more. The plan and budget for updating of the PCs at the Data Center should be prepared well in advance.

2.3.3. Task 3-3 Updating of Software

Lifetime of Software at the Data Center will be expected around 3 years or more. The plan and budget for updating of the software at the Data Center should be prepared well in advance.

2.3.4. Task 3-4 Human Resources Development

Capacity development of engineers for O & M of the Nationwide CORS Network with the Data Center is inevitable.

Hardware/software are progressed and changed. The Khmer GEONET should catch up and adapt the latest technology as needed.

2.3.5. Task 3-5 Future expansion of the Khmer GEONET

In future, the additional deployment of Stations for the Khmer GEONET will be considered. Demand and use case for the Khmer GEONET should be developed, adding to the cadastral survey.

[End of the Document]

Roadmap of the Operation and Maintenance Plan for the Khmer GEONET

Phase		Contents	Responsible Organization	Progress	2024												2025				2026				Remark
					1	2	3	4	5	6	7	8	9	10	11	12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	
Phase 1: Towards Stable Paid-Service (The Project completion in December 2024)																									
1-1	Management Policy	Establishment of a basic policies including the paid-services for Khmer GEONET (users: Government / International Project, Academia, Private Company, etc.) The DRAFT Paid Service Plan (Price List, User Category, Service Type) has been submitted to MLMUPC and MEF in June 2023. It will be approved by MEF and other line ministries in advance of the start of the paid-service.	CPT, MLMUPC, MEF	80%																					
1-2-1	Organizational Structure: O & M Office	GDCG has proposed a new O & M Office for Khmer GEONET. It will be reviewed in the fiscal year 2025.	CPT, MLMUPC	50%																					
1-2-2	Organizational Structure: Registration Service Office	GDCG has proposed a new Registration Service Office for Khmer GEONET. It will be reviewed in the fiscal year 2025. Registration of Surveyors has been announced and started in March 2024. (The qualification test of surveyor will be conducted after consideration of registration.) Licensing of Survey Company will be announced and started after the preparation of the qualification test. (The survey company must have the registered and licensed (qualified) surveyors).	CPT, MLMUPC	50%																					
1-2-3	Organizational Structure: Technical Inspection Office	GDCG has proposed a new Technical Inspection Office for Technical Inspection for Surveying Equipment. It will be reviewed in the fiscal year 2025.	CPT, MLMUPC	50%																					
1-2-4	Organizational Structure: Staff of the O & M Office	GDCG has proposed the staff of the new O & M Office for Khmer GEONET: 1. Manager (High level decision making) 2. Supervisor (Department) 3. DC Operator (Data Center & 1 Station) On-site Level (4 Stations): 1. Station Staff (District/Provincial Offices) It will be reviewed in the fiscal year 2025.	CPT, MLMUPC	80%																					
1-3	O & M Manuals and Reporting App for Data Center Operators	GDCG: Operation records/archives are shared on-line (Smartphone App developed by GDCG based on ArcGIS Survey123 and ArcGIS Dashboards, Telegram) JPT: The O & M Manual has been translated from English to Khmer. Aruna: Manuals for GNSS-Receiver, Software (Pivot, etc.), Communication/Network, Power Supply.	CPT, JPT, Private Company	90%																					
1-4	O & M Manuals and Reporting App for On-site Station Staff	GDCG: Operation records/archives are shared on-line (Smartphone App developed by GDCG based on ArcGIS Survey123 and ArcGIS Dashboards, Telegram). JPT: The O & M Manual has been translated from English to Khmer.	CPT, JPT	90%																					
1-5	Public-Private Partnership	Outsourcing of a part of O & M activities from GDCG to the private company (e.g. Aruna) The contract between GDCG and private company for hardware maintenance and necessary support will be processed in fiscal year 2025.	CPT, Private Company	70%																					
1-6	Human Resources Development	Capacity development of engineers (at District / Provincial office) for the O & M of 4 CORS (except PNH1 (MLMUPC)).	CPT	70%																					
1-7-1	Equipment Planning for 5 Stations and 1 Data Center	In case of machine troubles, operation continuity, update of hardware/software, and others	CPT, JPT	100%																					
1-7-2	Updating of Batteries for 5 Stations	(USD150/unit) x (3 units/station) x 5 stations - Test the batteries after two years (from April 2022) to see if it is necessary to change them at that time or their life can be extended. - The unit price includes transportation fees.	GDCG, Private Company	0%																					
1-8-1	Budget Planning for Fiscal Year 2024	GDCG shall prepare a draft budget plan by March/April 2023 to submit as Annual National Budget.	CPT, JPT, Private Company	100%																					
1-8-2	Budget Planning for Fiscal Year 2025	GDCG have prepared a draft budget plan by March/April 2024 to submit as Annual National Budget in 2025. It has been discussed by MLMUPC and MEF at the meeting on 5th July 2024 and after. The budget for O & M for the Khmer GEONET in the fiscal year 2025 will be finally approved by the Parliament by December 2024.	CPT, Private Company	90%																					
1-9	Start of the Paid-Service	It is re-planned to start on 25th June 2025. Khmer GEONET Website has been developed. The collaboration with Cambodia Data Exchange Platform (CamDX) will be added for payment method.	CPT	60%																					
1-10	Public Relations	The 3rd Seminar has been completed as scheduled on 5 June 2024. Explanatory materials (leaflet) have been distributed.	CPT, JPT	100%																					
Phase 2: Smooth Expansion to Whole Country (Grant Aid Project completion in March 2026)																									
2-0	Start of the Paid-Service	It is re-planned to start on 25th June 2025. Khmer GEONET Website has been developed. The collaboration with Cambodia Data Exchange Platform (CamDX) will be added for payment method.	GDCG	60%																					

	Phase		Contents	Responsible Organization	Progress	2024												2025				2026				Remark
						1	2	3	4	5	6	7	8	9	10	11	12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	
	2-1	JICA Grant Aid for Nationwide CORS Network	The contract has been concluded in March 2024. The construction will complete by March 2026 (planned two years from the contract).	GDCG, Joint Venture (JV)	10%																					
	2-2	Updating of Batteries for Nationwide CORS Network	3 batteries for each Station (every 2 years?)	GDCG	0%																					
	2-3	Updating of Software	Pivot (expire on 31 May 2027), Bernese, Network software, Internet Security (Anti-Virus software, Firewall, etc.), Microsoft Operation Software (Windows), Microsoft Office (Excel, Word), ArcGIS, etc.	GDCG, Private Company	0%																					
	2-4	Public-Private Partnership	Outsourcing of a part of O & M activities from GDCG to the private company	GDCG	0%																					
	2-5	Human Resources Development	Capacity development of engineers for O & M of the Nationwide CORS Network	GDCG	0%																					
	2-6	Equipment Planning	In case of machine troubles, operation continuity, update of hardware/software, and others	GDCG	0%																					
	2-7	Budget Planning	Every year, O & M for the Nationwide CORS Network.	GDCG	0%																					
	2-8	Public Relations	Goal Setting: How many users are registered until when?	GDCG	0%																					
	2-9	Registration as the International GNSS Service (IGS) Station	Goal Setting: How many stations of Khmer GEONET are registered as IGS stations until when?	GDCG	0%																					
	Phase 3: Sustainable O & M of Khmer GEONET (the Nationwide CORS Network from April 2026)																									
	3-1	Updating of Hardware (GNSS Receiver, Antenna, UPS, etc.)	Lifetime of Hardware expects 10 years or more. Plan and prepare budget in advance. Hopefully the updating of the Nationwide CORS Network might be one by one, not simultaneously.	GDCG	0%																					
	3-2	Updating of Storage, Server, etc.	Lifetime of PC expects 3 years or more. Plan and prepare budget in advance.	GDCG	0%																					
	3-3	Updating of Software	Lifetime of Software expects 3 years or more. Plan and prepare budget in advance.	GDCG	0%																					
	3-4	Human Resources Development	Capacity development of engineers for O & M of the Nationwide CORS Network	GDCG	0%																					
	3-5	Future expansion of the Khmer GEONET	Next stage after the JICA Grant Aid for Nationwide CORS Network	GDCG	0%																					