インドネシア共和国
インドネシア国泥炭地回復緊急支援
に係る委託業務
業務完了報告書

List of Contents

1. はじめに

1.1. 背景

インドネシアの温室効果ガス排出量は土地利用（生態部門）も含めると、アメリカ、中国に次いで世界第三位であり、泥炭地由来の CO_2 排出量は総排出量の約 38%と見積もられ、気候変動問題への対処としての泥炭地の適正管理を含めた森林減少・劣化対策は喫緊の課題となっている。また、インドネシアは約 9,400 万 ha の森林面積（日本の国土面積の約 2.5 倍）を有し、ブラジル、コンゴ民主共和国に次ぐ世界第三位の熱帯林保有国である。しかしながら、1970 年代前半から森林開発、木材生産等が増加してきた結果、森林の減少が問題視されるようになり、現在の状況が続けば、2022 年までに巨大な泥炭湿地林を有する同国のスマトラ島、カリマンタン島の 98%の森林消失が予想される。

こうした課題に対応するため、インドネシア政府は、国連気候変動枠組み条約（UNFCCC）第 21 回締約国会議（COP21）のパリ協定合意を受けて、大統領直轄の泥炭地回復庁（以下 BRG）を 2016 年に新設し、泥炭水理単位（Hydrological Unit：主に河川や海岸を境界線とした地域で、泥炭ドームやマングローブを含む地域）を導入し、この泥炭水理単位で保全・回復活動を実施する等、泥炭湿地林の回復に本格的に乗り出した。

一方、泥炭地回復活動については、森林の保全および持続可能な森林管理ならびに森林の炭素ストックの向上を含めた取り組み（以下、REDD+：Reducing Emissions from Deforestation and Forest Degradation in developing countries）の文脈で、2008 年ごろから各国援助機関や国際 NGO によって取り組みが開始され、インドネシアが主導的役割を果たしてきた。国連気候変動枠組み条約（UNFCCC）に代表される国際的に最上位の気候変動対策の議論では、REDD＋による炭素ストックの保全の重要性が認識されつつある。

しかしながら、UNFCCC において、REDD＋の精度設計に関する各国間の議論は難航しつつあるものの、調整に向けた議論は継続されている。あわせて、自主的な取り組みも、選考的に実施されており、インドネシアでは、ノルウェー政府や国連開発計画（UNDP）の共同の取り組みである UN-REDD プログラム等から支援を受けた REDD＋戦略策定、炭素モニタリング（以下 MRV：Measurement, Reporting and Verification）体制構築、および資金メカニズム等について検討が進められている。

JICA は北海道大学とともに、科学技術協力（SATREPS）「インドネシアの泥炭・森林における火災と炭素管理プロジェクト」を 2010 年 2 月から 2014 年 3 月まで、中央カリマンタン州を対象に実施され、特に炭素蓄積量の多い泥炭地の炭素管理に係る研究、GHG 排出の提言につながる技術開発の成果を得たところであり、これらの成果を包括的に有機的に活用したインドネシアにおける REDD＋の推進が求められている。また、同大学は、2015 年 2 月から 2016 年 4 月まで、「日本インドネシア REDD+実施メカニズム構築プロジェクト（IJ-REDD+)」の一部業務を受託し、同国環境林業省をカウンターパート機関として

SATREPS 事業の成果を活用し、中央カリマンタン州の熱帯泥炭地からの CO2 排出量の算定と行政官向け CO2 排出量推定マニュアルの作成、本マニュアルを活用した現地関係者向けの技術研修を実施し、SATREPS の成果の定着と、環境林業省の能力強化全般に貢献した。

2016 年 1 月に設立された泥炭地回復庁は事業実施期間ではないが、インドネシアの荒廃した泥炭地 200 万 ha の回復・修復にかかわる全体的なプログラム形成を主導する役割を担う重要な調整機関である。この際、科学的、科学技術的観点を基本とした泥炭地回復・修復の手法や評価法が強く求められている。そこで、全日本的研究・技術支援体制を確率するため、20 年近い熱帯泥炭に関する豊かな研究成果と蓄積がある、北海道大学、京都大学、総合地球環境学研究所（以下、「日本学術連合」）が泥炭地回復庁（BRG）と 2016 年 11 月にモロッコ・マラケシュで開催された UNFCCC・COP22 再度イベントの場で泥炭地回復に係る情報収集調査実施に係る協議議事録（ミニッツ）を署名し、翌 12 月には、ジャカルタにて泥炭地回復のための民間投資促進にかかる共同声明文の署名、さらに 2017 年 5 月には、泥炭地回復緊急支援の実施に係る協議議事録（ミニッツ）を署名した。

インドネシアでは、泥炭地回復は危急の課題であるが、広大な面積について、短時間で実施するには、政治的要請と現実とのギャップが大きすぎるため、実現が極めて困難である。そこで、日本学術連合、BRG、国際泥炭地学会（以下、IPS）、日本泥炭地学会（以下、JPS）、JICA が中心となって、泥炭地回復事業を科学的見地から助言する「インドネシア泥炭地回復国際委員会（International Advisory Committee for Peatland Restoration in Indonesia）」を立ち上げるべく、準備を着手しつつある。これは泥炭地回復事業に取り組むステークホルダーが泥炭地生態系への理解不足によって起こしうる破壊的活動を防止し、適切な回復事業の実施を促進するため、科学的・専門的立場から、各ステークホルダーに対して助言する体制を作ろうというものである。

1.2. 本プロジェクトの目的

本業務は北海道大学が実施した、科学技術協力（SATREPS）「インドネシアの泥炭・森林における火災と炭素管理プロジェクト」及び「日本インドネシア REDD＋実施メカニズム構築プロジェクト（IJ-REDD+）」における業務委託契約の成果を踏まえ、①MRV 手法の提案、②モデルパイロットプロジェクトの提案、③泥炭地回復事業実施に係るキャパシティビルディング手法の提案、④インドネシア泥炭地回復国際委員会立ち上げ、⑤国際会議における泥炭地回復に係る協力活動と成果の情報発信の 5 点を実施するための基本的設計の提案を行うことを目的として実施した。

各基本設計の提案項目ごとの具体的な目的および、提案に際した留意事項を下表に整理した。

表 1　本プロジェクト業務の目的と留意事項の整理

No.	基本設計項目	目的	留意点
1.	MRV 手法の確立	既往の科学技術協力（SATREPS）で開発された科学的モデルを泥炭地からの GHG 排出算定手法の基礎とし、リアルタイムでの泥炭地の地下水位推定、GHG 放出評価、火災危険度予想マップ作成の実施体制の提案	科学的対応の妥当性、正確性確保 信頼性の高いデータの入手しやすさ 運用方法及びマニュアルのわかりやすさ
2.	モデルパイロットプロジェクトの提案	主にリアウ州と中部カリマンタン州を重点として現地調査ヲ実施し、BRG が地方政府で展開するプロジェクト実施体制・コンポーネントを明確化し、モデルパイロットプロジェクトを展開するためのガイドライン作成	BRG の予算契約や人材確保
3.	泥炭地回復事業実施に係るキャパシティビルディング手法の提案	インドネシアの大学等の研究機関に対するキャパシティビルディングセンター設置についての提案と設置に係る協議及び手続きを行うため研究機関の支援	大学・民間・行政・地域住民を対象とする各階層への異なる段階的なアプローチ手法の作成
4.	インドネシア泥炭地回復国際委員会立ち上げ	IPS/JPS を中核とし、BRG と JICA,日本学術連合が、相互に連携して「インドネシア泥炭地回復国際委員会」を新設するため、BRG 及び IPS 等の関係機関間の調整の実施	円卓会議（International Peatland Roundtable）の開催とそこでの本業務の提案内容の提示
5.	国際会議における泥炭地回復に係る協力活動と成果の情報発信	インドネシア泥炭地回復国際委員会の新設のために実施した円卓会議（(International Peatland Roundtable）の成果を本会期中に IPS（国際泥炭地学会）を含む国際機関の関係各者へ共有し、具体的な枠組み作りの助言を行う等、同委員会構築支援を実施	インドネシア国における泥炭地回復に係る協力活動とその成果を、第 23 回気候変動枠組条約締約国会議（UNFCCC・COP23、開催地：ドイツ）ジャパンパビリオン JICA-BRG（インドネシア国泥炭地回復庁）共催イベント等において発表

2. MRV 手法の確立

既往の科学技術協力（SATREPS）で開発された科学的モデルを泥炭地からの GHG 排出量算定手法の基礎とし、リアルタイムでの泥炭地下推計、GHG 放出評価、火災危険度予想マップ作成の実施体制を提案した。なお、業務の実施に際しては、科学的対応の妥当性・正確性を確保しつつ、信頼性の高いデータの入手しやすさや、運用方法およびマニュアルのわかりやすさについて留意した。具体的な支援事項として、地下水位推計モデルの作成支援（2.1）、地下水位推計モデルと地下水位と泥炭分解による GHG 排出量との関連モデルの構築支援（2.2）、地下水位推計モデルによる泥炭火災頻度予想モデルの構築（2.3）を実施した。

2.1. 地下水位推定モデルの作成

ここでは、衛星による気温や降水量データに基づき、泥炭地における地下水位を推計するためのモデルをインドネシア技術評価応用庁と協力の上、作成した。特に中部カリマンタン州をモデル地域とし、適用可能なパラメータを地下水位観測により補正し、特定するための技術支援を行った。

(1) 地下水位観測によるパラメータ補正

当該地下水位推計モデルを地下水位の観測値からパラメータを補正し、准リアルタイムの地下水位マップを作成に向けた技術支援を行った。

表 2 （参考）地下水位マップの開発内容

NCEP の 0.25 度グリッドの土壌水分データは、WRF モデルを用いて 1.7km×1.7km グリッドにスケールダウンした。中央カリマンタンとリアウの GWL 地図を推定するために、GWL と土壌水分との間の回帰分析を行った。中央カリマンタンとリアウの GWL 地図を推定するために、GWL と土壌水分との間の回帰分析を用いた。また、炭素フラックス推定は、平野モデルに基づいて計算した。主なデータは、0.25 度大域対流圏解析と予測グリッド（https://rda.ucar.edu/datasets/ds083.3/）から得られた土壌水分データを用いた。データは毎日更新され、通常は 12 時間毎に取得されるものである。土壌水分の 4 層は 6 時間ごとにダウンロードされ、フィールドで気象学的なオープンソースのメソスケール気象学の 1 つである気象研究予測モデル（WRF）を使用して処理を行った。物理法則モジュールを使用することで、1 km x 1 km のメッシュグリッドに 0.25 度のダウンスケーリングの結果を導出した。図は、WRF を使用したダウンスケーリング手順を示す。土壌水分と GWL との関係の経験的モデルを適用することで地下水位マップを作成し

た。この結果は、排水状況や火災の焼跡の泥炭の地図を用いてオーバーレイする必要がある。

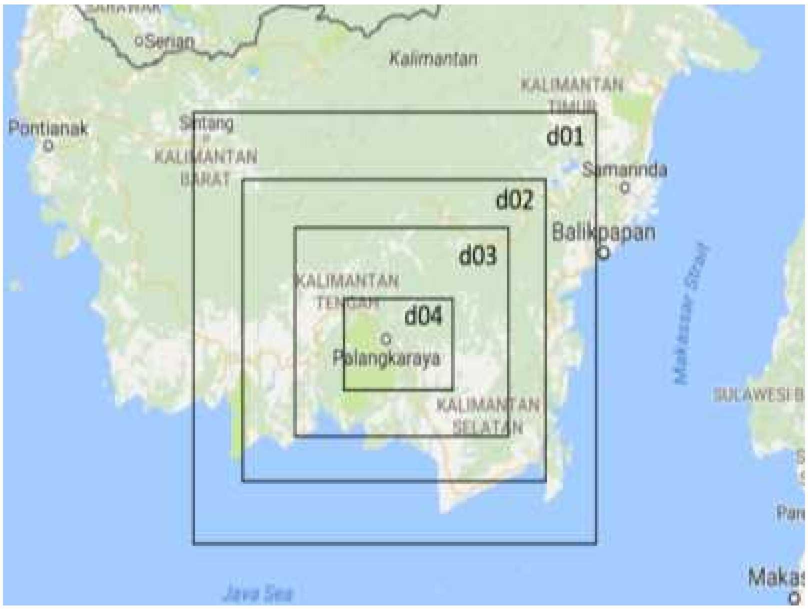


Fig-1. The domain of WRF simulation.

WRF シミュレーションの結果を図 2 に示す。図は 2017 年 1 月 3 日の土壌水分図を 1 km×1 km グリッドで示したものである。土壌水分は海岸線や河川に近い地域で高い傾向がある。また、伐採されていない森林でも土壌水分量は高いとの値を示し、排水された森林では低い値を示している。

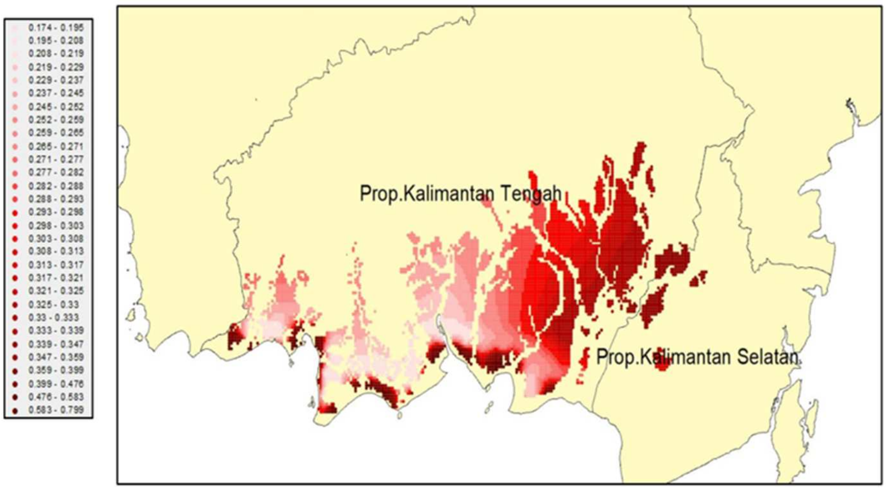


Fig. 2 中央カリマンタンの土壌水分量（1 km x 1 km グリッド）

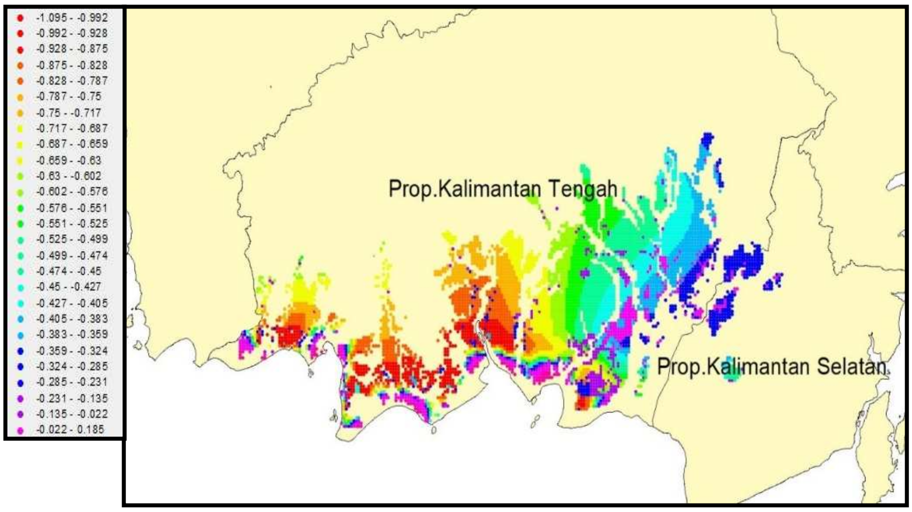


Fig.3. 中央カリマンタンの 1 km x 1 km の地下水位マップ

上図は中央カリマンタンの地下水位マップを示す。結果は、東部では高い値を持ち、西部では低い値が得られた。これは、GWL の増加に伴う土壌水分の増加の傾向と一致していることがわかる。

(4) 地下水位の観測データの開発

泥炭地からの地下水位データのリアルタイムデータは、 地下水位、土壌水分、雨量を 22 の地域において、GWL 測定装置（SESAME）により観測を実施している。西カリマンタン、中央カリマンタン、リアウ、ジャンビ、南スマトラを対象とする。利用者（自治体、関係者等）へのシステムの普及に向けて、インドネシア泥炭地からの地下水位データのリアルタイムデータ情報の開発ユーザーとして、地元の政府・ステークホルダーへのシステムの配布が行われている。GSM、USSD などのモバイル通信システムを介して計測器からデータセンターに送信されたデータを用いる。データは Web GIS の形式で表示されるので、ユーザーが直接簡単に使用することが可能である。

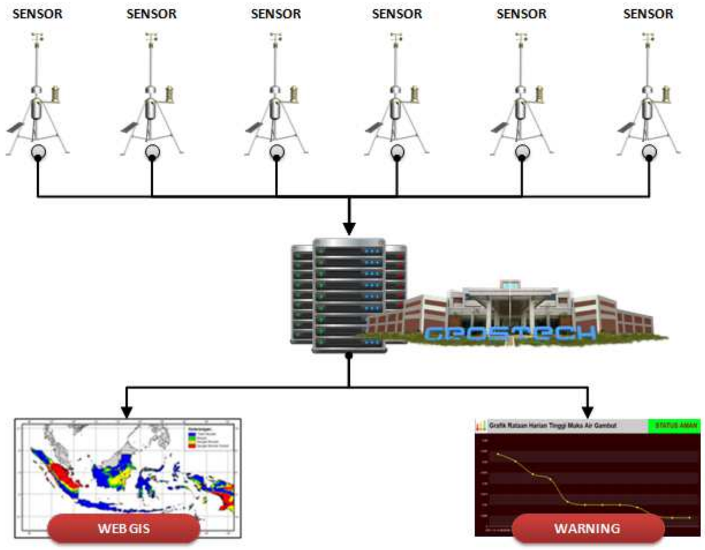


Fig.4.データ通信のスキーム

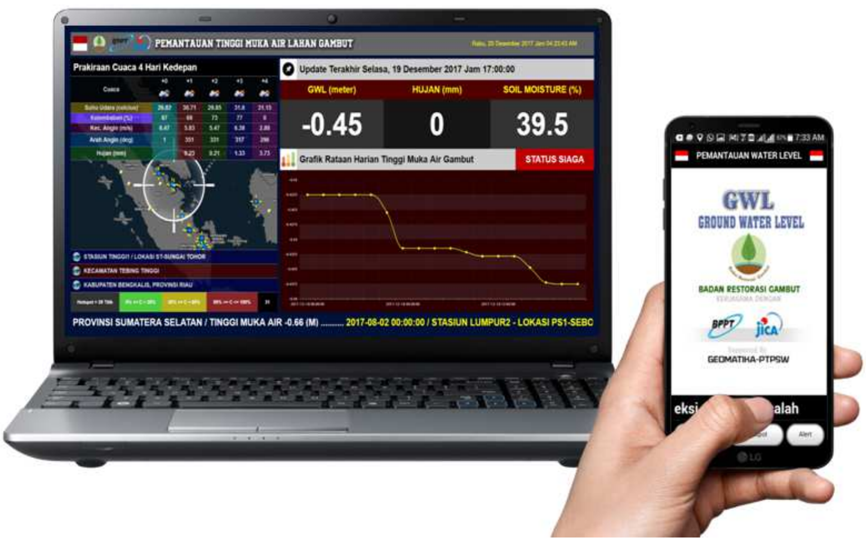


Fig.5. 地下水位のモニタリングシステム.

このウェブサイトから GWL および土壌水分情報を 10 分間隔で入手することが可能である。 このシステムの普及とテストは、パレンバン、ジャカルタ、パランカラヤなどのいくつかの場所でモデルパイロットとして行われている。

Fig.6. GWL モニタリングシステムに関する普及啓発活動

2018 年 1 月 15 日「International Workshop on “Forest Ecological Resources Security for Next Generation: Development and Routine Utilization of Forest Ecological Resources and their Domestication”」Sulaiman 氏・Awaluddin 氏の発表資料より抜粋

(2) マニュアルの作成

本研究の対象地域であるインドネシア国中部カリマンタン州パランカラヤ近郊の熱帯泥炭地においては、これまでの多くの研究成果に基づき、1）微生物による泥炭分解に伴う年間 CO_2 放出量（Hirano et al., 2016），ならびに 2）泥炭火災に伴う年間炭素排出量（Takahashi et al, 2013）の 2 つについて、いずれも月平均地下水位の年間最低値との関係式を用いて推定する手法が確立されている。この手法は，モニタリング機材の設置を含む実地研修や炭素排出量推計マニュアルの作成を通じて、現地において熱帯泥炭地の管理に携わる行政関係者への技術移転がなされている（濱田ほか，2017 a,b）。

本手法による推計精度の向上，ならびに他の地域の熱帯泥炭への適用を行うに当たり、モニタリング体制の中で強化すべき点として、（１）水分条件との関係の詳細把握、（2）地域による泥炭間隙水の化学性の時間変化把握、（３）実際の炭素蓄積量の変化を計測により把握、（４）多地点モニタリングが可能な安価な遠隔観測システムを開発・導入に着目し、現行 MRV システムの現状と課題を整理し、新たに開発するシステムの検討ならびに使用するセンサーの選定を行った。これらの成果は、具体的手順をプロトコルとする手順書をとりまとめた（別冊資料 01）。

表 3　（参考）MRV システムの現状に関する情報収集と改良に向けての検討

1.　現行 MRV システムの現状と課題

本研究の対象地域である，インドネシア国中部カリマンタン州パランカラヤ近郊の熱帯泥炭地においては，これまでの多くの研究成果に基づき，1）微生物による泥炭分解に伴う年間 CO2 放出量（Hirano et al., 2016），ならびに 2）泥炭火災に伴う年間炭素排出量（Takahashi et al, 2013），の 2 つについて，いずれも月平均地下水位の年間最低値との関係式を用いて推定する手法が確立されている。この手法は，モニタリング機材の設置を含む実地研修や，炭素排出量推計マニュアルの作成を通じて，現地において熱帯泥炭地の管理に携わる行政関係者への技術移転がなされている（濱田ほか，2017 a,b)。

本手法による推計精度の向上，ならびに他の地域の熱帯泥炭への適用を行うに当たり，モニタリング体制の中で強化すべき点としては，以下の 4 つが挙げられる。

（1）　水分条件との関係をより詳細に把握する

泥炭の分解および火災に伴う年間の炭素排出量は，地下水位によって一定程度の説明が可能である。他方，実際に泥炭火災が発生するためには，地表面付近の泥炭が極度に乾燥している必要があるが，この乾燥度合は直近の降雨量や植生密度，表層泥炭の物理特性などの影響を受けるため，土壌水分量を直接測定する方がより正確である。

泥炭の分解に伴う CO2 放出についても，一般に微生物活性が最大となる水分条件が存在し，それより乾燥しても湿潤であっても活性が低下することが知られている。このため，極度に乾燥した表層泥炭においては，泥炭の分解は頭打ち，もしくは抑制される可能性がある。加えて，濱田ほか（2017 b）で提示した泥炭分解に伴う CO2 排出量推計モデルでは，地下水位の地点データの広域化に際して衛星観測から得られた土壌水分量をパラメータとしており，これを直接計測することは推計モデルの精緻化に寄与するものである。

また，炭素の絶対量としては CO2 より小さいものの，同じ質量当たりの温室効果では CO2 の 25 倍に相当するメタンを考慮に入れる場合，微生物の影響はさらに複雑になる。メタンは，酸素の少ない還元的な環境で泥炭が分解される際に生成され，酸素の多い環境で CO2 に酸化される。このため，地下水面下で生成されたメタンは，そのまま大気中に放出されるものと泥炭表層で CO2 に酸化されるものに分かれ，その比は表層泥炭の乾燥度合に強く影響される。これまで一般に，熱帯泥炭地からのメタン放出量は北方泥炭のそれに比べて少ないとされてきたが（Couwenberg et al., 2010），対象地域における最近の研究では，熱帯泥炭地からのメタン放出が火災後に急増することが報告されている（Adji et al., 2014）。インドネシアの泥炭地のかなりの部分が火災の影響を受けていることを

考えると，気候変動への影響を考慮する上でメタンの排出量は無視できないと言える。

(2)　地域による泥炭間隙水の化学性の時間変化を把握する

既に得られている関係式のうち，泥炭分解に伴う年間 CO_2 放出量と月平均地下水位の年間最低値との関係については，自然林（2 地点）および火災跡地（1 地点）の両方において共に直線的な関係が得られている（Hirano et al., 2016）。観測を行った 3 地点は，最も離れた地点間で 15～16 km と近い距離にあるものの，排水条件や火災の有無の違いがその地点の泥炭地生態系に及ぼした影響（泥炭自体の変質や植生の違い）は大きいと思われる。このような条件の異なる地点間で共通に得られた「地下水位の最低値と直線的」という関係は，したがって，インドネシア国内の別の泥炭地域（例えばスマトラ，パプアなど）においても共通に見られる可能性が高いと予想される。

他方，直線の勾配や切片については自然林と火災跡地で異なっており，排水や火災の差異による影響が現れていると考えられる。このような観点から，対象地域で得られた炭素排出量の推計法を他の泥炭地域に適用する場合は，地下水位との直線関係を仮定しつつ，その勾配や切片に影響を及ぼす要因の違いを明らかにしてゆくアプローチが適切である。

地域による泥炭地生態系の炭素排出特性に影響する要因のうち，植生のタイプやバイオマス，泥炭自体の物理化学特性などは，現地調査や資料採取後の室内分析によって知ることができる。しかし，泥炭間隙に含まれる土壌水・地下水の化学性は，地下水位や土壌水分量によって変化する可能性があり，水分条件と並行してのモニタリングが必要となる。

このような化学性として，pH・電気伝導度（EC）・酸化還元電位（ORP）などがある。熱帯の泥炭が，高い温度にもかかわらず分解されない要因として，湿潤で還元的な条件に加え，pH の低い極めて酸化的な条件による微生物活動の抑制が考えられる。泥炭へのミネラル分の付加は pH の上昇につながる。泥炭の pH 上昇は，CO_2 やメタンの生成を増大させる（Ye et al., 2012）。その溶存ミネラル成分は EC として検知されるため，EC を測定することでミネラル分の影響を評価することができる。ORP は，(1）で述べたメタンの生成・酸化条件を評価する際の重要な指標である。

(3)　実際の炭素蓄積量の変化を計測により把握する

前述した炭素排出量と地下水位との関係のうち，火災による炭素排出量については，実際に焼失した泥炭の深さデータに基づいて評価したものである。これに対して分解による CO_2 放出量は，地上部植生と大気との境界を横切る CO_2 の差

分から推計したものであり，これには泥炭の分解のほか，植物による吸収や呼吸が含まれている。泥炭地生態系の挙動を長期的に推定するには，これらの各要素を分離して把握する必要がある。

分解による泥炭の消失は，泥炭土壌の不可逆的な沈下として検出することができる。泥炭地の地表面はまた，泥炭の湿潤化や乾燥に伴う膨張・収縮によっても上昇・下降する。このため，泥炭土壌の沈下から泥炭の分解量を精度よく評価するには，地下水位や土壌水分量のモニタリングを並行して行い，膨張・収縮による可逆的な変動成分を取り除く必要がある。

また，植物による正味の炭素吸収量は，植物バイオマスの生長として検出することができる。植物バイオマスの増減は，一般に胸高周囲長を計測して胸高直径を求めることで推定することができる。

(4) 多地点モニタリングが可能な安価な遠隔観測システムを開発・導入する

泥炭地は通常，泥炭ドームを基本的な構造としており，ドームの周縁部から中心部に向かって泥炭層厚・地下水位・植物種構成などが段階的に変化している。これに加え，対象とするインドネシアの泥炭地域では，以前より排水や火入れなどの人為的な撹乱が広範囲にわたって行われており，栽培されている種や水位の管理状態などを考慮すると，泥炭からの炭素排出量に影響を及ぼす因子の地域的な多様性は膨大なものとなっている。このような地域的な差異を地上観測によって把握するには，多くの地点に設置できる安価な観測システムが必要となる。

多くの地域で開発が進んでいるとは言え，インドネシア泥炭地の大半はいまだにアクセスが困難な地域であり，データ回収に要する手間を考えると，遠隔地のデータを無線で伝送するタイプのデータロガーの利用が現実的である。地下水位の低下が泥炭火災の予測に利用できるという観点からも，この点は特に重要である。データの伝送はまた，センサーの故障や太陽電池の盗難などに伴う欠測期間を最小化することにも役立つ。

インドネシアの熱帯泥炭地ではこれまで，みどり工学研究所が提供するフィールドデータ伝送システム「SESAME」が多くの地点で導入されており，泥炭地回復庁（BRG）によるモニタリングシステムに採用されるなど，高い評価を得ている。現行の SESAME システムは，ロガー1 台ごとに携帯通信端末を備えており，これを用いてデータの伝送を行っている。このため，1）携帯電話の電波が入らない地域では利用できない，2）ロガー1 台ごとに端末本体とデータ通信のコストが生じる，という制限がある。インドネシア泥炭地では，携帯電話がまったく通じない，あるいは電波がかなり不安定な地域が多く，また上記の地域的な多様性を把握するために多地点の設置を行う際，個別に携帯通信端末を備えるのは非効率かつ割高になるという欠点がある。これらの課題を解決する，新たなデータ伝

送システムの開発が望まれる。

2. 新しいMRVシステムの検討と使用するセンサーの選定

上記 1.で指摘した，現行 MRV システムの現状と課題を踏まえ，新たに開発するシステムの検討，ならびに使用するセンサーの選定を行った。センサー構成は，1.の（1）～（3）で指摘した項目ごとに組み合わせ，それらを 1.の（4）で指摘した新しいデータ伝送システムを用いたネットワークで結ぶこととした。(1）～（3）の観測システムの概要を図 1 に示す。また，（4）の概要を図 2 に示す。

（1） 水収支観測システム（図 1 a）

地下水位計測用の水位計に，雨量と土壌水分（＋地温；後述）を計測するセンサーを併置したシステム。SESAME システムにおいて，標準的なセンサー構成として想定しているのが圧力式水位計と転倒ます式雨量計の組み合わせであり，電圧出力の土壌水分計およびサーミスタ式の地温計の出力を受けるポートも備えているため，泥炭地での使用実績がある従来のロガーをそのまま使用することが可能である。このシステムはまた，BRG が泥炭地に設置しているシステムのセンサー構成と一致する。

水位計には，引き続き投げ込み型圧力式のセンサー（スイス・STS 社製）を採用した。現地調査において，観測井内の水位を超音波式のセンサーで計測している事例を確認したが，細い管内での超音波センサーの使用は壁面での反射の影響を受けること，音波速度が温度に依存するため別途温度計測が必要なこと，などの点から不適当である。

雨量計には，日本国内で標準的な仕様の転倒ます式雨量計（0.5 ミリ単位・大田計器社製）を採用した。ロガーボックスの背面にアングルを組み，雨量計と太陽電池を載せて 1 本の単管パイプに立てるという，泥炭地用の設置方式を開発しており，BRG 用のシステムなどに採用されている。このほか，より安価な雨量計として米デービス社製の 6463M（0.2 ミリ単位）を検討した。簡易な室内実験の結果，ある程度の精度は確認できたが，単管への固定方法が異なるほか，長期的な耐久性については監視を継続する必要がある。

土壌水分計には，価格と耐久性のバランスに鑑み，英デルタ社の SM150（現在は地温計付きの SM150T に置き換わっている）を採用した。このセンサーの出力は電圧であり，メーカーが提供する変換式を用いて概算の体積含水率に変換する。提供される式には鉱質土壌用と有機質土壌用とがあり，泥炭土壌であるため後者を採用したが，より正確な値を求めるには現地土壌を用いた校正が必要となる。

(2)　水質観測システム（図 1 b）

泥炭表層の ORP と地下水中の EC・pH を計測するシステム。SESAME システムのセンサーとしては使用実績がないため，従来のロガーの改良ないしは新しいロガーの開発が必要となる。以下に述べるように，適用可能なセンサーが確定していない pH を除けば，現行のロガーも利用可能である。

ORP は表層における値が重要であるため, 水中に投げ込むタイプではなく土壌間隙水中の計測が可能なセンサーが必要である。この条件を満たすセンサーとして，農研機構が藤原製作所と共同で開発した水田土壌における ORP を計測するセンサーがあり（農研機構ウェブサイト，2018)，装置を購入次第，現地において試験を行うこととした。

EC および pH については，泥炭にパイプを打ち込み地下水中の値を計測することとした。EC については比較的安価でメンテナンスが不要なセンサーが多く確認できたが，pH については定期的な校正と KCl 内部液の補充が必要なものが多く，引き続き調査することとした。

(3)　泥炭地バイオマス観測システム（図 1 c）

泥炭地生態系の炭素収支に直接関係する項目のうち，SESAME システムで計測実績のある地盤沈下と胸高周囲長を計測するシステム。現行のロガーを利用可能。

泥炭土壌の地盤沈下を計測するセンサーとしては，みどり工学研究所が自社製作した地位変動計を採用した。原理としては，泥炭層下の基盤層まで打ち込んだパイプに固定した基準高度と，地表面とともに上昇・下降する対象高度との距離を，レーザーを用いて精密に計測するというものである。

胸高周囲長を計測するセンサーは，一般にデンドロメーターと呼ばれる。原理としては，胸高付近の高さで対象木の周囲に回したワイヤーの伸縮を，プーリーの回転角度やバネの伸縮として検出するというものである。木が生長し，胸高周囲長が検出可能な範囲の上限まで達すると，再度現地に行ってプーリーやバネの位置を元に戻す再設定が必要になる。SESAME で採用実績のあるセンサーとしては，日本環境計測製のデンドロメーターがあり，主に北海道内で利用されている。本センサーは精密な計測が可能な反面，現地で再調整せずに測定可能な範囲が比較的狭い。インドネシア泥炭地での利用を考慮した場合，植物の生長は年間を通して速く，また頻繁に現地で再調整を行うことは困難である。このため，再調整せずに測定可能な範囲の広いセンサーについても引き続き調査することとした。

（4）　小電力無線と衛星通信回線を用いた新たなデータ伝送システム（図 2）

携帯電話が通じない地域でも展開可能な，衛星電話回線と小電力無線ネットワークを用いた新しいデータ伝送システム。（1）～（3）のセンサーを接続した個別のデータロガー（子機）は，計測したデータを一定の時間間隔で，衛星電話回線端末を持つゲートウェイ（親機）に送信する。親機は一定の時間間隔で，子機から集めたデータをまとめてサーバーに伝送する。

子機～親機間の通信には，小電力無線規格の一つである LoRa を用いる。LoRa は，近年急速に注目を集めている 920MHz 帯の低消費電力かつ広域の無線通信（Low Power Wide Area; LPWA）の規格の 1 つであり，LoRa 変調と呼ばれる特殊なスペクトラム拡散技術を用いて 10 km 以上の遠距離通信を可能としている。みどり工学研究所では以前より, ZigBee や WiSUN といった同様の無線通信技術の利用を検討していたが，従来の方式では理論上の通信距離を出せずにいた。国内の通信事業者が相次いで LoRa のサポートを表明する状況を受け，試験用の LoRa モジュールを入手してその性能を野外で検証したところ，見通しがよければ 10 km を越える距離の通信が可能な反面，森林内など見通しの悪い場所では 1 km に満たないことが分かった。このため，子機はロガー部と通信部を分離した上で通信ケーブルで接続し，見通しの悪い場所では通信部を高所に上げて用いることができる仕組みとした。

また，電波法上の制限から，届け出なしでの LoRa モジュールの利用は国内では 20 mW 以下の出力に制限されている。インドネシアにおいてはこの制限は 500 mW 以下と高い。国内の LoRa 通信モジュール製造業者の多くは 20 mW 以下の出力のモジュールしか提供していないが，インドネシアでより確実にデータを伝送するため，250 mW の出力が可能なアールエフリンク社製の LoRa モジュールを利用することとした。

親機で利用する衛星通信回線としては，インマルサット社が提供する BGAN M2M を採用した（通信速度・最大 448 kbps）。通信コストは通常の携帯回線より割高になるが，上述の小電力無線ネットワークと組み合わせることで，ロガー 1 台当たりの通信コストは逆に割安にすることも可能である。インマルサットの契約は利用国の代理店を通して行う必要があるため，利用の際には SESAME システムのインドネシアにおける代理店を通して契約を行う（みどり工学研究所以外のユーザーが契約する場合は，みどり工学研究所に代行を依頼できる）。

親機にはまた，カメラが 3 台まで接続可能である。カメラは親機がサーバーに計測データを伝送するタイミングで撮影を行い，計測データと同時にサーバーに送られる。画像ファイルの送信は計測データよりも通信量が多くなるが，国内で試験送信を行ったところ，通信上の支障は生じなかった。ただ，通信料金が高くなるため，撮影の頻度や画像のサイズ・画質の検討が必要である。

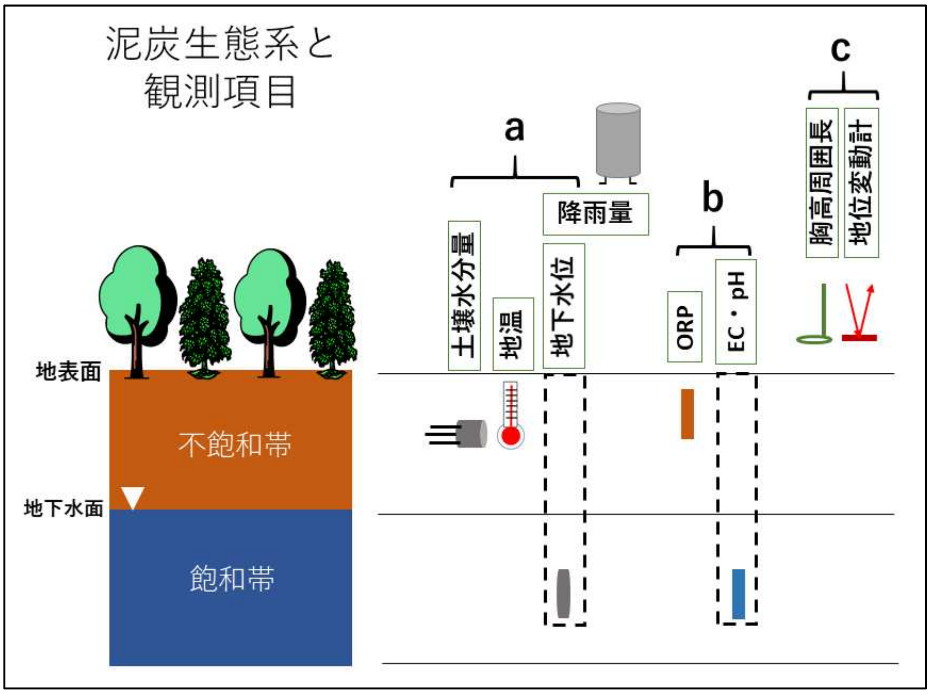


図１．新しい観測システム．a. 水収支観測システム，b. 水質観測システム，c. バイオマス観測システム

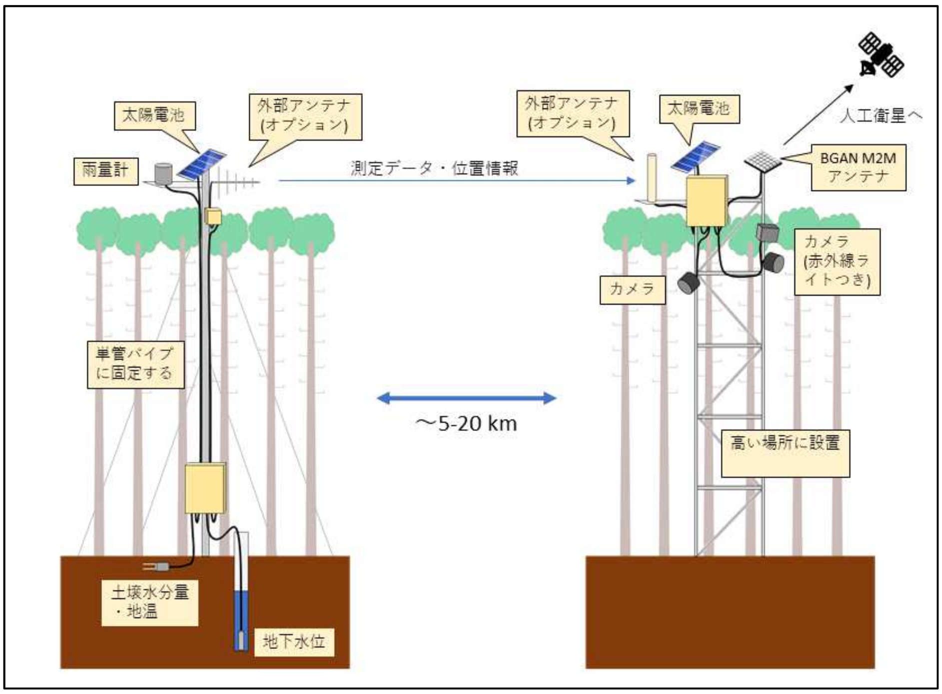


図２．小電力無線と衛星通信回線を用いた新たなデータ伝送システム

引用文献

Hirano T., Sundari S., and Yamada H. (2016): CO2 balance of tropical peatland ecosystems. In: Osaki M. and Tsuji N. (eds.), *Tropical Peatland Ecosystems*, Springer, Tokyo, Japan, 329-337.

Takahashi H., Jaya A., and Limin S.H. (2013): The scenario of carbon management by water management, fire fighting and forest recovery in tropical peatland. *Proceedings of International Symposium on Wild Fire and Carbon Management in Peat-Forest Indonesia*, 43-49, Palangka Raya, Indonesia.

濱田洋平・辻　宣行・高橋英紀・繁永幸久・内藤瑠美・小林　浩・高原　繁・大崎　満（2017a）：インドネシア・中部カリマンタン州における熱帯泥炭地からの炭素排出量評価のためのガイドブック作成と技術移転の取組み（その１）．水利科学，No. 355, 92-122.

濱田洋平・辻　宣行・高橋英紀・繁永幸久・内藤瑠美・小林　浩・高原　繁・大崎　満（2017b）：インドネシア・中部カリマンタン州における熱帯泥炭地からの炭素排出量評価のためのガイドブック作成と技術移転の取組み（その２）．水利科学，No. 356, 95-119.

Couwenberg J., Dommain R., and Joosten H. (2010): Greenhouse gas fluxes from tropical peatlands in South-East Asia. Global Change Biology, 16, 1715-1732.

Adji F.F., Hamada Y., Darung U., Limin S.H., and Hatano R. (2014): Effect of plant-mediated oxygen supply and drainage on greenhouse gas emission from a tropical peatland in Central Kalimantan, Indonesia. Soil Science and Plant Nutrition, 60, 216-230.

Ye R., Jin Q., Bohannan B., Keller J.K., McAllister S.A., Bridgham S.D. (2012): pH controls over anaerobic carbon mineralization, the efficiency of methane production, and methanogenic pathways in peatlands across an ombrotrophic-minerotrophic gradient. Soil Biology & Biochemistry, 54, 36-47.

農研機構ウェブサイト（2018）：安価な小型データロガーを用いた土壌酸化還元電位の自動経時計測方法.
http://www.naro.affrc.go.jp/project/results/laboratory/karc/2013/13_005.html（2018 年 2 月 27 日確認）

2.2.　地下水位推計モデルと地下水位と泥炭分解による GHG 排出量との連関モデルの構築支援

科学技術協力（SATREPS）の重要成果の一つである泥炭地の状態に応じた地下水位と泥炭分解による GHG 排出量との連関モデル（平野モデル）をベースとし、上記の地下水位推計モデルと衛星画像等による泥炭地の植生分布等の区分手法を組み合わせることによる、GHG 排出量を推計する手法開発に取り組んだ。

科学技術協力（SATREPS）の重要成果の一つである泥炭地の状態に応じた地下水位と泥炭分解による GHG 排出量との連関モデルの成果を活用し、統合 MRV システムとして、下記ア）～カ）の成果の統合と、それによる巨大な炭素プールである東南アジアの熱帯泥炭生態系の保全への適用を目指し検討を行った。

ア）長期的な圃場モニタリングによる排水や干ばつによる外乱による熱帯泥炭生態系からの CO2 排出量の定量化
イ）酸化的泥炭分解による CO2 排出量の地下水位（GWL）への影響解明
ウ）熱帯泥炭林からの渦流共分散法による生態系規模のメタン（CH4）排出量の定量化
エ）L－Band の PALSAR データを用いた GIS ベースの土地被覆変化と森林バイオマスの段階的評価システムの開発
オ）フィールドデータによるボルネオ島の森林全体の炭素収支のシミュレーション、熱帯雨林に多目的プロセスベースの地上生物圏モデル（VISIT）のカスタマイズ
カ）熱帯泥炭分布の地図情報これらの個々の結果は、ボルネオの熱帯生態系の炭素動態を評価

表 4 （参考）Developing an integrated system to evaluate the carbon dynamics of tropical peat ecosystems in Borneo

Integrated MRV System WS on 15 Jan. 2018 @ Kyoto Univ.

Developing an integrated system to evaluate the carbon dynamics of tropical peat ecosystems in Borneo

The Environment Research and Technology Development of the Ministry of the Environment, Japan (2015-2017)

- Hokkaido University
- National Institute for Environmental Studies (NIES)
- Japan Aerospace Exploration Agency (JAXA)
- Japan Space Systems

1

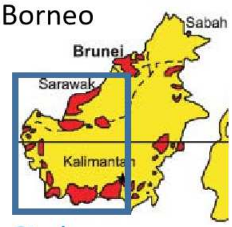
Final goals through three years (2015-17)

To scientifically contribute to the implementation of REDD+ and the evaluation of countermeasure techniques…

Goal #1: Development of an integrated system

An integrated system to evaluate the carbon dynamics and the GHGs balance of tropical peat ecosystems in Borneo will be developed.

Borneo



Study area

Goal #2: Evaluation of countermeasure techniques

Using the outcome of #1, countermeasure techniques to reduce GHGs emissions, such as damming up of degraded peat lands and forest conservation, will be evaluated.

Damming

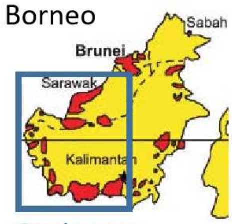
2

Final goals through three years (2015-17)

To scientifically contribute to the implementation of REDD+ and the evaluation of countermeasure techniques…

Goal #1: Development of an integrated system

An integrated system to evaluate the carbon dynamics and the GHGs balance of tropical peat ecosystems in Borneo will be developed.



Study area

Goal #2: Evaluation of countermeasure techniques

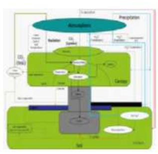
Using the outcome of #1, countermeasure techniques to reduce GHGs emissions, such as damming up of degraded peat lands and forest conservation, will be evaluated.

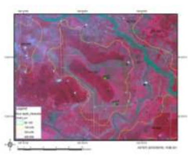
Damming

2

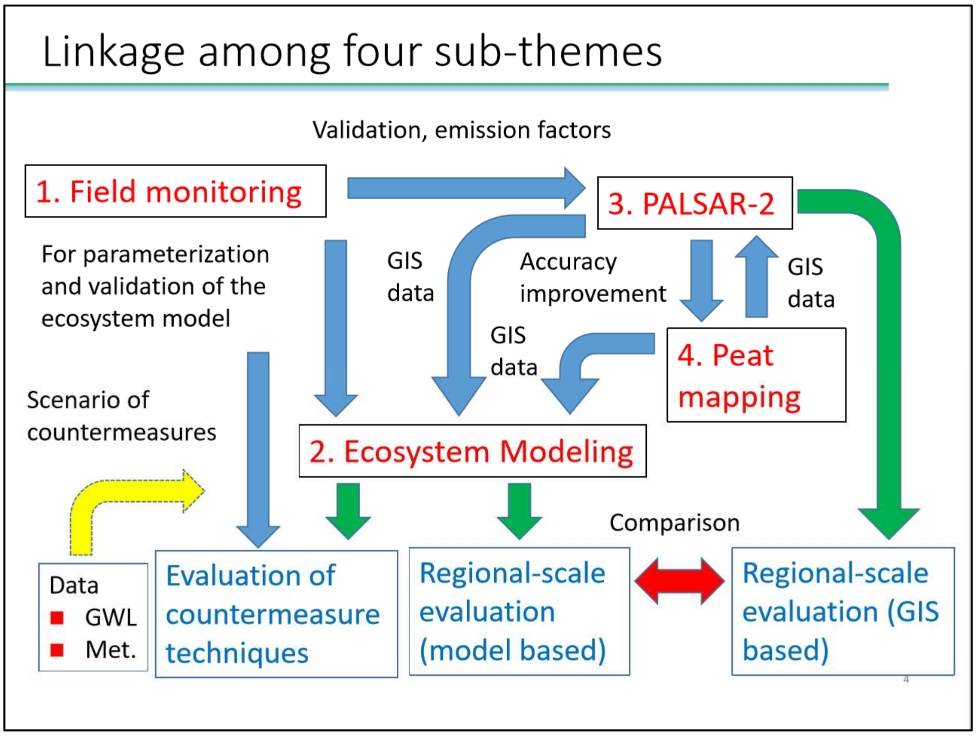
Four sub-themes by each institutes

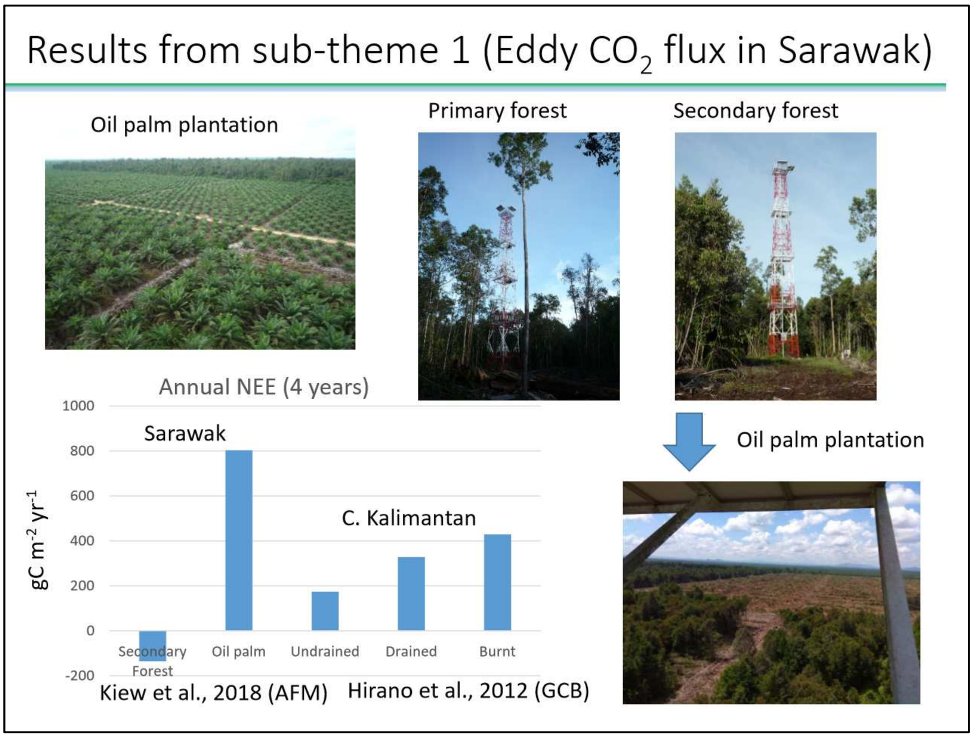
1. Field monitoring of GHGs fluxes: Hokkaido University
2. Development of an ecosystem model for carbon dynamics assessment: NIES
3. Development of an regional-scale evaluation system of carbon dynamics using satellite data (PALSAR-2): JAXA
4. High-precision mapping of peatlands: Japan Space System





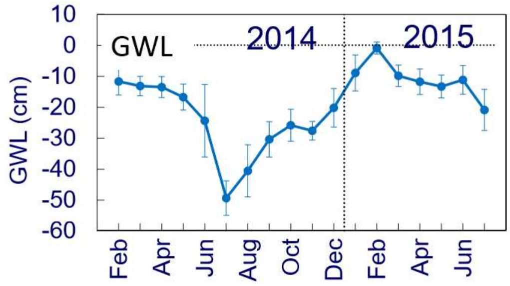
3

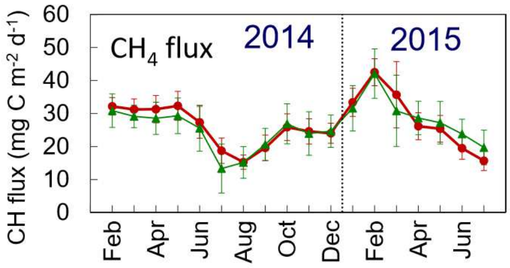

Linkage among four sub-themes
Validation, emission factors
1. Field monitoring
3. PALSAR-2
For parameterization and validation of the ecosystem model
GIS data
Accuracy improvement
GIS data
GIS data
4. Peat mapping
Scenario of countermeasures
2. Ecosystem Modeling
Comparison
Data
GWL
Met.
Evaluation of countermeasure techniques
Regional-scale evaluation (model based)
Regional-scale evaluation (GIS based)


Results from sub-theme 1 (Eddy CO2 flux in Sarawak)
Oil palm plantation
Primary forest
Secondary forest
Annual NEE (4 years)
1000
800
600
400
200
0
-200
gC m-2 yr-1
Sarawak
C. Kalimantan
Secondary Forest
Oil palm
Undrained
Drained
Burnt
Kiew et al., 2018 (AFM)
Hirano et al., 2012 (GCB)
Oil palm plantation

Results from sub-theme 1 (Eddy CH_4 flux in Sarawak)

Monthly mean





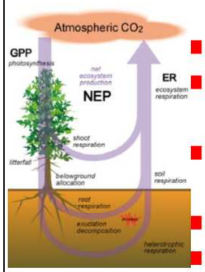
@ an primary forest in Sarawak

- CH_4 source throughout a year
- Positive relationship of CH_4 emissions with GWL
- Large discrepancy in annual emissions between the EC (9.2 g C m^{-2}) and chamber (<1.0 g C m^{-2}) method.

Xhuan et al., under revision (AFM)

Sub-theme 2 (Ecosystem modeling)

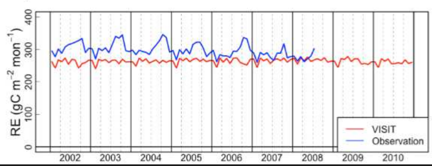
Ecosystem model: VISIT



- Simulation of GHGs
- Carbon dynamics of ecosystems
- Multiple scales: from site to globe
- Daily time steps
- Many applications

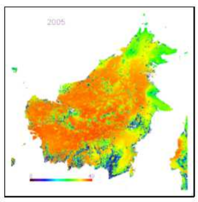
1. Development of a sub-model for tropical peat

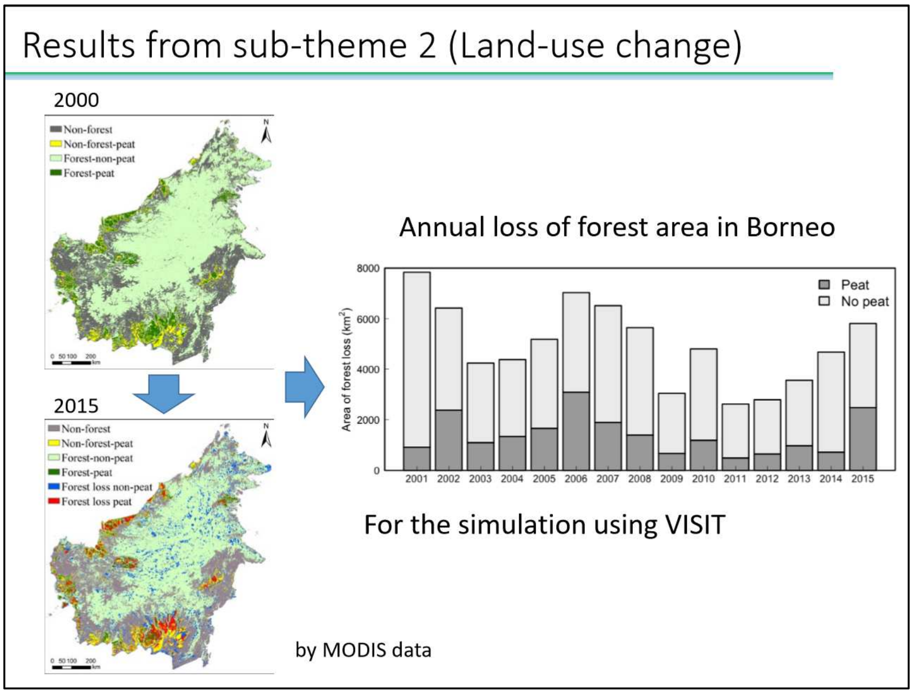
- Using field data from the sub-theme 1, the sub-model will be parameterized and validated.



2. Development of a regional-scale model

- Assessment of the carbon dyanamics and GHG fluxes in Borneo.
- Evaluation of countermeasure techniques.





2018年1月15日「International Workshop on “Forest Ecological Resources Security for Next Generation: Development and Routine Utilization of Forest Ecological Resources and their Domestication”」平野教授発表資料より抜粋

(1) マニュアルの作成

この推計プロトコルは、添付資料１に整理した。より詳細については、別添のガイドブックにおいてマニュアルとして整理した。

2.3.地下水位推計モデルによる火災危険度予想マップ作成

地下水位と火災発生の関係モデルはまだ構築されていない。しかしながら、これまでのプロジェクトの成果より、泥炭地下水位の増減は降水量が主要因子として働いていることも明らかになっている。さらにインドネシアを中心に実施された SATREPS「短期気候変K同励期限地域における海陸観測網最適化と高精度降雨予測」（代表者　山中大学）で蓄積された知見をもとに、インドネシアのスマトラとカリマンタンでの 3 か月程度の降雨予想モデルを開発する可能性について関係機関と検討を行った（1）。

また、泥炭火災は排水路密度やそれを覆う植生とも関係が深いため、これらの詳細マップの作成を試みた(2)。また、さらにこれらを統合した、火災頻度・強度予想マップの作製の概要を提示した(3)。具体的には、リアルタイム地下水位マップを基盤とした火災頻度・強

度の 3 か月予想マップを作成すべく関係機関を支援した。

(1) 3 か月程度の降雨予想モデルの開発検討

木村圭司(奈良大学)の研究チームは、数値データの気象シミュレーション WRF と NCEP の FNL データを初期データとして、Palangkaraya の SESAME 地点の土壌水分を推定した。WRF の結果を用いた地下水位を推定した結果、約 1 か月連続の推定は非常に高い成果が得られたが、他の期間と比べ異なるパラメータは異なるものとなったと報告した。

熱帯泥炭地の火災は、地下水位 (GWL) が 40cm 未満の場合に高頻度で発生するが、GWL を予測するには、数値気象シミュレーションの活用が適切である。小地域での気象や土壌水分量の予測によく使用される WRF(天気予報と予測モデル)を分析結果と、Palangkaraya の SESAME（(株) みどり工学支援の感性データ伝送サービス）の観測ポイントのデータを用いてで GWL と比較した。初期気象データとして NCEP FNL データを使用し、WRF を用いて 4 つの土壌層の土壌含水量を予測した。検証データは Palangkaraya の Kalteng での GWL 観測データを用いた。シミュレートされた領域は 4 つのドメインで構成した。第 1 のドメインは 31×31 メッシュで 27km グリッド、第 2 ドメインは 31×31 メッシュで 9 km グリッド、第 3 ドメインは 31×31 メッシュで 3 km グリッド、最小ドメインは 31×31 メッシュで 1 km グリッドとした。各ドメインの中心点は Kalteng SESAME 観測点の同じ地点とした。土壌タイプ、地形、土地利用などは、WRF ver.3.5.1 のデフォルトとして使用された。

2015 年 8 月、2017 年 2 月、2017 年 8 月にを対象に WRF シミュレーションの分析結果を得、GWL と土壌水分量の間の相関関係を相関分析によって評価した。結果は各月において非常によい相関が得られた。しかし、パラメータが異なるので、3 ヶ月間の相互相関の値は高くなかった。今後の展望としては、GWL と模擬土壌水分量の相関式を得るために、1 日の土壌含水量の 1 ヶ月間のシミュレーションを行う必要がある。ここで実施した GWL のシミュレーションは、1 ポイントのデータに基づいいたが、インドネシアでは、1 km メッシュの GWL の分布図と WRF シミュレーションを組み合わせてシミュレートする必要があることを示した。

表 5　（参考）数値気象モデル WRF による地下水位の推定

Estimation of the Ground Water Level
using numerical weather simulation
WRF (Weather Research and Forecasting Model)

KIMURA,K., N.TAKANO (Nara University),
A.Sulaiman, and S. Awaluddin(BPPT)

GEOG

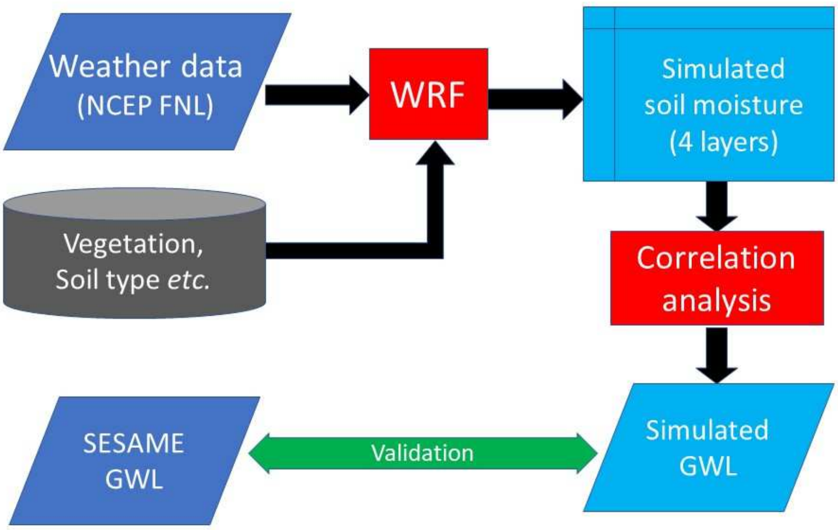
Introduction

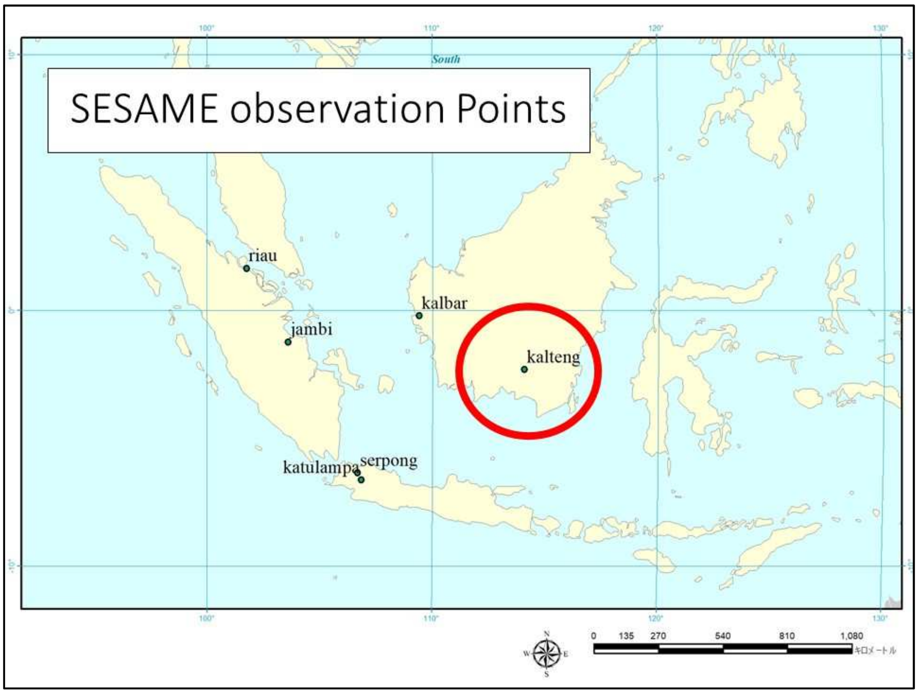
- Tropical peatland fire often occurs when the Ground Water Level (GWL) is under 40cm.
- In order to predict the GWL, the numerical weather simulation may be useful.
- WRF (Weather Research and Forecast Model) is often used for the local weather simulation.
- Now we analyze the WRF soil moisture and GWL of one SESAME point at Palangkaraya.

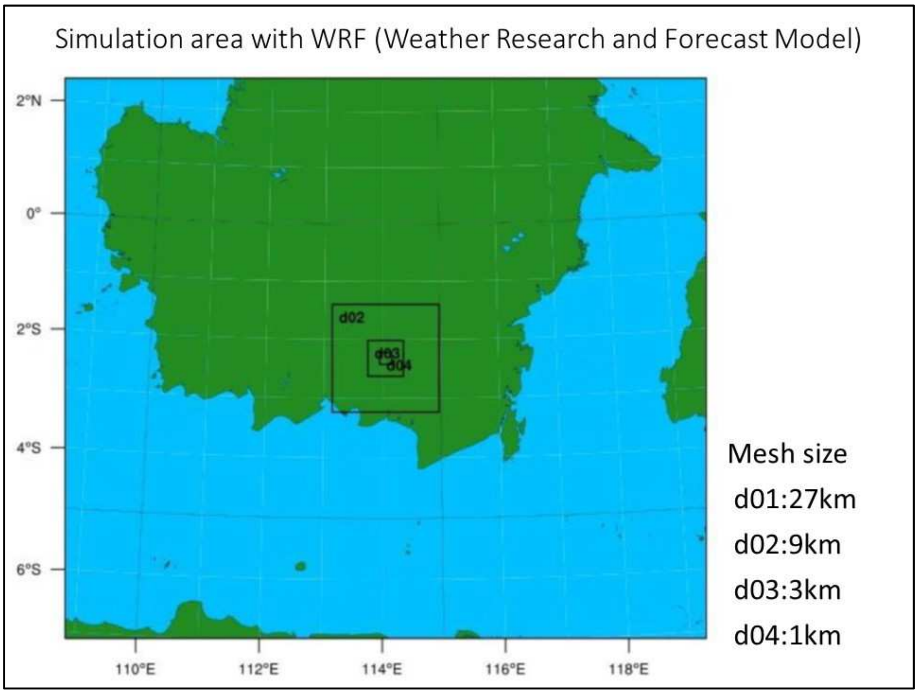
About numerical weather simulation

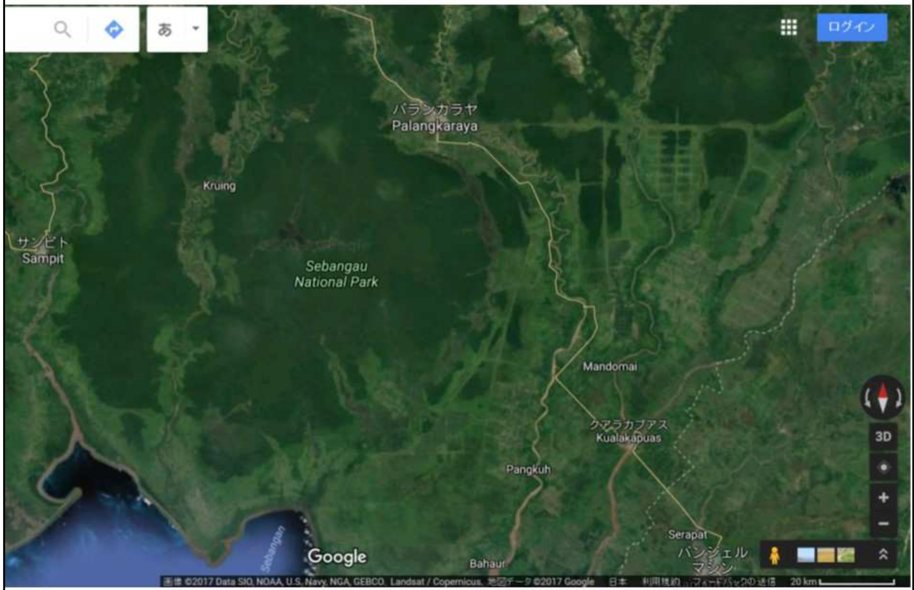
- We can use two simulation origines of the soil moisture.
  - ECMWF ERA-Interim (in Europe)
    - The precision and the resolution is better.
    - We can download only data more than three months ago.
      Today (on January 15, 2018), we can get the data until October, 2017.
    - As for the resolution, most detailed one is 0.125 degree.
    - We can use it for analysis and the variation.
  - NCAR FNL data (in U.S.A.)
    - We can download the data for a half day ago.
    - As the resolution, 1 degree.
    - We can use it for the simulation for forecast.
      Now, we can get the data until yesterday.

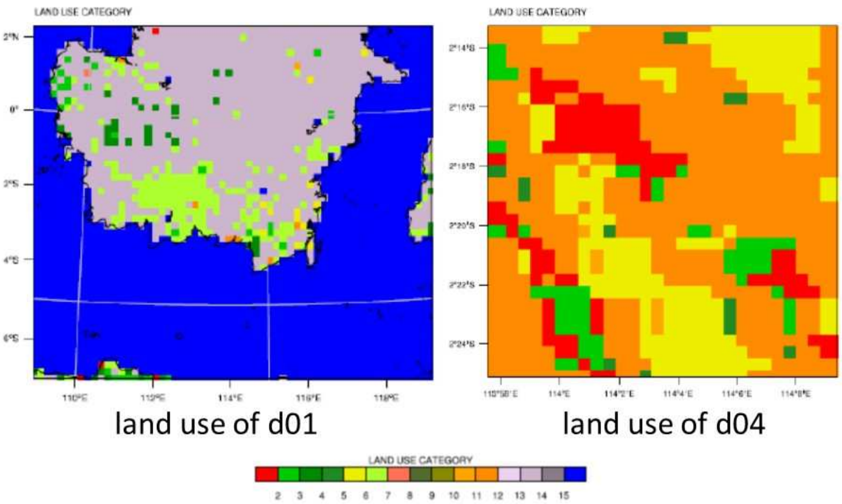
Ground water level prediction modelling



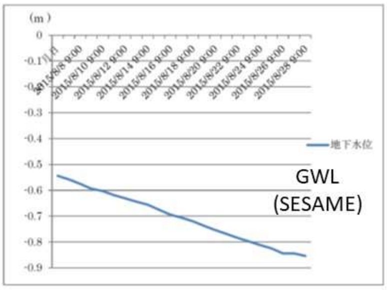

SESAME observation Points
South
riau
jambi
kalbar
kalteng
katulampa
serpong
0 135 270 540 810 1,080


Simulation area with WRF (Weather Research and Forecast Model)
2°N
0°
2°S
4°S
6°S
110°E
112°E
114°E
116°E
118°E
d02
d03
d04
Mesh size
d01:27km
d02:9km
d03:3km
d04:1km

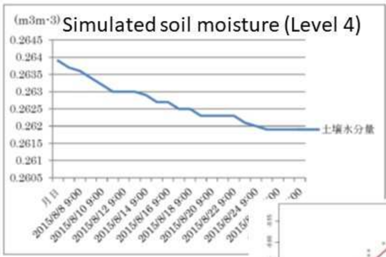


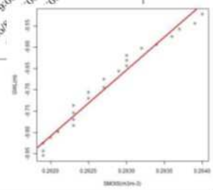


Legend		
1_Urban and Built-up	2_Dryland Cropland&Pasture	3_Irrigated Cropland&Pasture
4_Mixed Cropland&Pasture	5_Cropland/Grassland Mosaic	6_Cropland/Woodland Mosaic
7_Grassland	8_Shrubland	9_Mixed Shrubland/Grassland
10_Savanna	11_Deciduous Broadleaf	12_Deciduous Needleleaf
13_Evergreen Broadleaf	14_Evergreen Needleleaf	15_Mixed Forest
16_Water Bodies		



Multiple Regression Analysis (MRA)



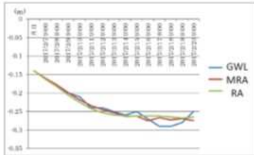


In August, 2015

(Dry season) at the point of SESAME

Correlation

variable	slope	intercept	t value	p value	judgement
Level1	-0.13646	-7.69361	-1.735	0.113	
Level2	0.3432		0.902	0.388	
Level3	-0.36807		-0.565	0.585	
Level4	25.31291		7.449	2.19E-05	***
Adjusted coefficient of determination	0.9187				
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1					

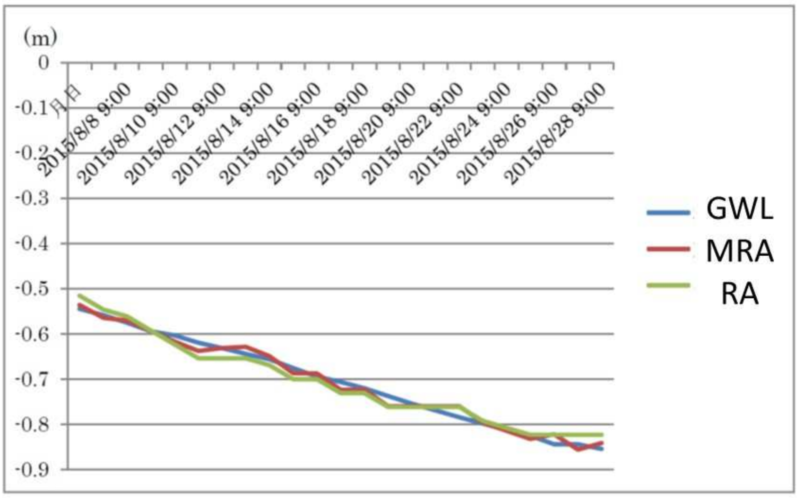


Ground Water Level(SESAME) and simulated soil moisture

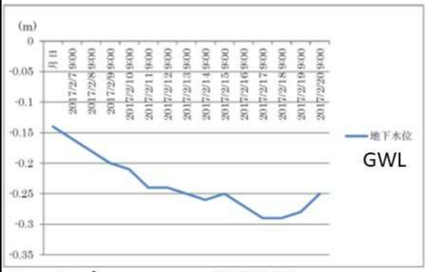
Multiple Regression Analysis (MRA)

variable	slope	intercept	t value	p value	judgement
Level1	0.5877	-54.4165	1.918	0.070251	*
Level2	-1.952		-2.99	0.007526	**
Level3	25.6019		3.898	0.000968	***
Level4	181.4307		19.931	3.39E-14	***
Adjusted coefficient of determination	0.9826				
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1					

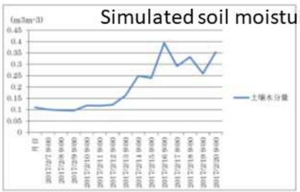
Comparation of the results (in August, 2015)

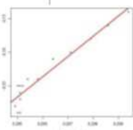


- Correlation is very good.



Multiple Regression Analysis(MRA)





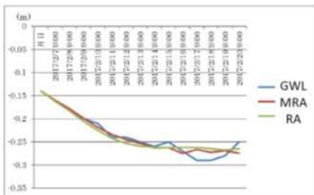
In February, 2017

(Wet season) at the point of SESAME

Correlation

variable	slope	intercept	t value	p value	judgement
Level1	-0.13646	-7.69361	-1.735	0.113	
Level2	0.3432		0.902	0.388	
Level3	-0.36807		-0.565	0.585	
Level4	25.31291		7.449	2.19E-05	***
Adjusted coefficient of determination	0.9187				

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1



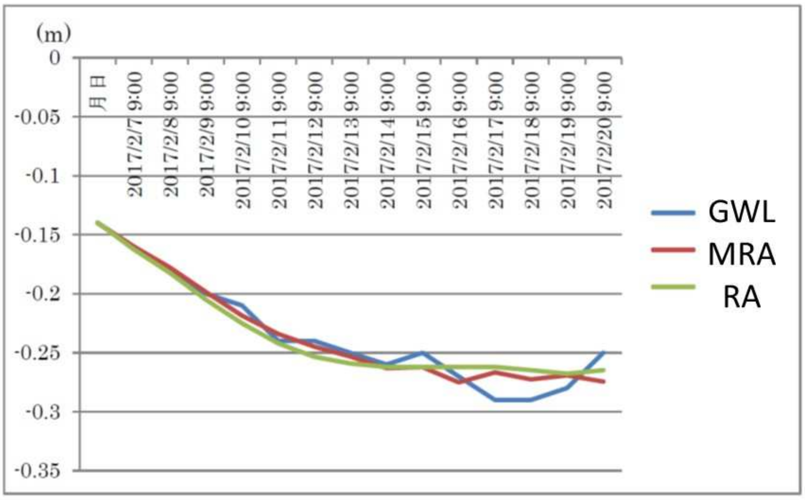
Multiple Regression Analysis (MRA)

variable	slope	intercept	t value	p value	judgement
Level1	-0.13646	-7.69361	-1.735	0.113	
Level2	0.3432		0.902	0.388	
Level3	-0.36807		-0.565	0.585	
Level4	25.31291		7.449	2.19E-05	***
Adjusted coefficient of determination	0.9187				

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

The result of MRA is better then that of RA.

Comparation of the results (in February, 2017)

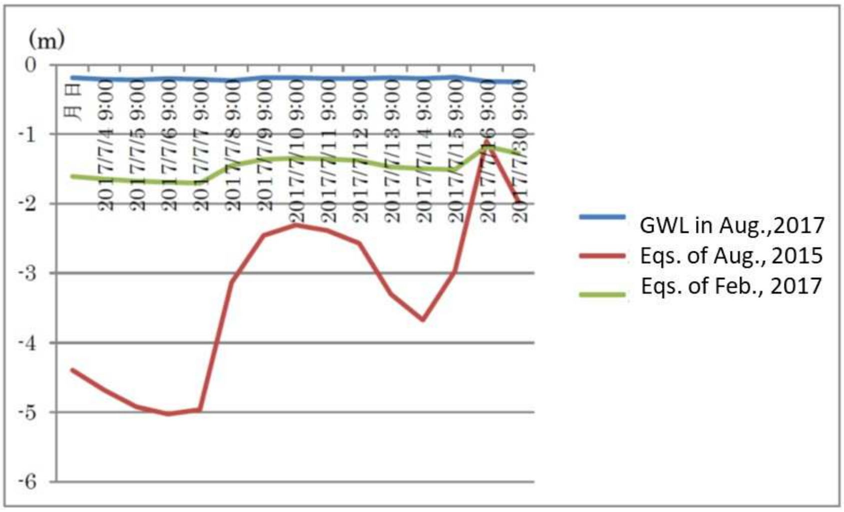


- Correlation is very good.

Discussion 1

- Each correction is very good.
- But… the values of slope and intercept are different.
- Is it the reason of the season or only that term?
  → Let's check!

Verification with another month



- Both equations are quite different!

Discussion 2

- Correction in short period is very good.
- The results fit to only short period.
- The results don't fit to other period:
  even if the month is the same of the different year.
- The reason why…
  the mechanism of the GWL change is not explained
  by the correlation of the soil moisture simulation.

Conclusion

- We can make the GWL prediction model with WRF (numerical weather simulation).
- The simulated results are very good for the real GWL at Palangkaraya.
- But, the parameters from the WRF results to the GWL change every time. It is not fix to even the season or the month.
- When we calculate the parameters and use them, the GWL is estimated very good, we found.
- We must compare as:
  - the GWL simulated with ECMWF data,
  - the different vegetation type (burnt forest and bare ground).
- In this study, the result is effective for only one point. We must make the simulated GWL map for whole Indonesia to predict the wild fire occurrence.

2018 年 1 月 15 日「International Workshop on "Forest Ecological Resources Security for Next Generation: Development and Routine Utilization of Forest Ecological Resources and their Domestication"」木村教授発表資料より抜粋

(2) 植生・微地形の詳細マップの作成

ここでは、植生および泥炭ドームの微地形の詳細評価のためドローン（Phantom 4Pro, DJI）をプラットフォームとする写真測量技術による現地調査を実施した。ここでは、調査地域の関心領域に重なるフライトプランを事前に計画し、オーバラップ率 80%にて、70 度のアングルで撮影し、重複画像を用いた写真測量技術によるモデル化により微地形モデルを生成した。この詳細な微地形 DSM およびオルソモザイク画像より水路の抽出および植生域のマッピングを行った。

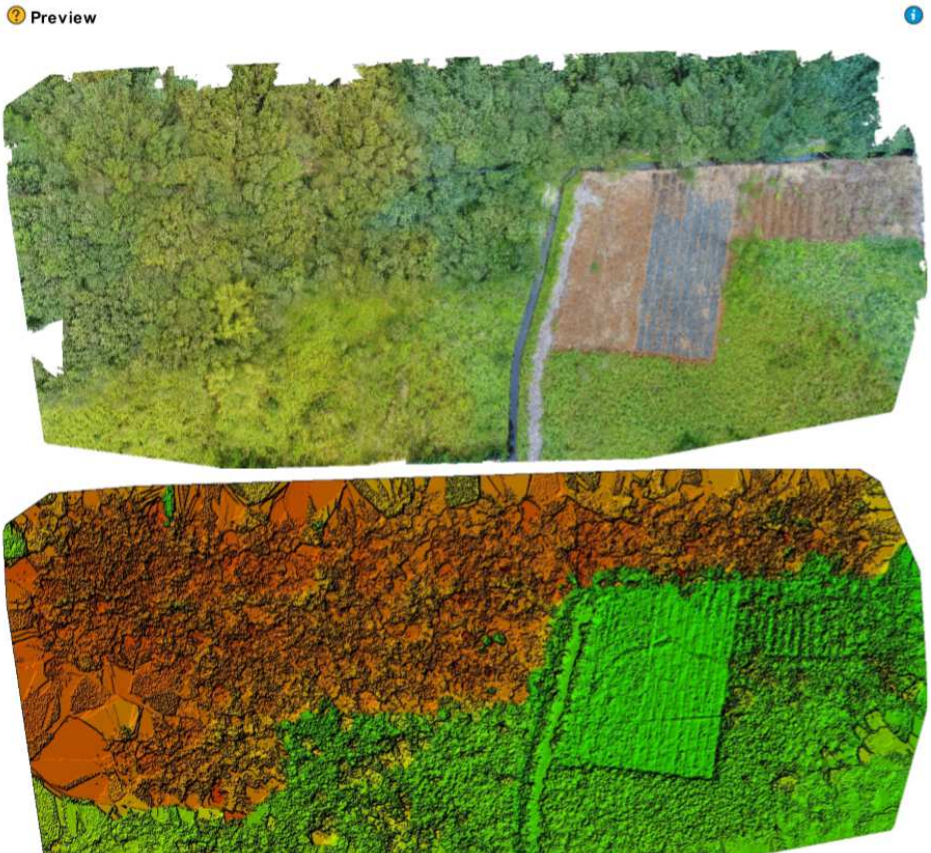


図 1　写真測量の結果抽出されたオルソモザイク画像とデジタルサーフェスモデル（DSM）

ドローンを用いた写真測量技術によるカメラデータからの 3D マッピングの精度は、飛行の精度やカメラのピクセルサイズ、焦点距離等に依存する。さらに詳細な微地形 LiDAR データを用いた検討を実施し、対象地域の経年変化を抽出する目的で、2011 年および 2014 年の同対象地域内の LiDAR データによる微地形図を入手した。

図 2　LiDAR – DSM and – DTM for Block C as overview.

（**Projected by Global Mapper: UTM,　Zone-49, WGS84, meters**）

(3) 火災頻度・強度予想マップ作成概要の提示

泥炭土壌の保全および適切な管理のためには、地域別の泥炭土壌の挙動を網羅的にかつ精細に把握する必要がある。原理上、泥炭地の土壌の分解状況は SAR(合成開口レーダ)の差分干渉波解析（DInSAR）による地表変動量として抽出可能である。ただし、干渉 SAR に用いるマイクロ波の特性上、現実には泥炭地の植被や地形が干渉の可否や精度に影響を与える。つまり、干渉 SAR に使用するマイクロ波の波長は短いほど地表変動検出の分解能がよいが同時に地表面の植生等の微小な変化による影響を受け干渉を得にくい。しかし、一方で短波長に比べて波長が長い場合には地表変動検出の分解能は小さいが、広域な干渉を得られるという性質をもつ。

ここでは、周波数の異なる SAR を用いて、それぞれの周波数特性に応じて検出される泥炭地の変化を整理し、土壌分解指標として差分干渉 SAR 解析の有効性を検証し、火災の発生頻度と強度を推定する方法論を提示する。

1) SAR 衛星の泥炭地管理への適用性

SAR の周波数特性ごとの検出可能な変化量の特定においては、差分干渉波解析(DInSAR)では、多時期の地表面の変動を面的に捉えることができるが、泥炭地管理への適用には運用や技術的観点に課題があることを指摘した。

表 6　SAR 衛星を使った解析の運用上の課題

	運用面	技術面
課 題	• 広大な泥炭地をカバーする多時期の SAR データの取得には高額な費用を要する	• マイクロ波の周波数に応じて検知可能な対象や変化量のスケールが異なり泥炭地空間の網羅的把握が困難
解決方策	• 無償配布 SAR 衛星データ（Sentinel）の活用	• 周波数の異なるセンサの組み合わせによる空間的網羅性の向上

2) 時系列比較による人為的影響の評価

泥炭の分解状況は地表面の沈降現象として顕在化する。また、地表面の時系列変動は降水量による季節トレンドと土地改変や火災等のイベント発生による長期変動が想定される。このことから、多時期の SAR のデータから泥炭土壌表面の変動量の検出（DInSAR 解析）と発生イベントの検出結果から人為的土地改変や火災の発生が泥炭土壌に及ぼす影響を検出することが可能である。

3) 地点別の泥炭地表の変動特性の比較

泥炭土壌の分解の反応は、火災発生後の植生遷移過程や微地形上の立地、開水路の有無や距離に応じて多様であり数点での実測値から泥炭管理の空間的代表性を担保することは難しい。したがって、適切な泥炭保全管理のためには、泥炭地の状況を①植生、②微地形、③水利の観点から網羅的に把握する必要がある。

事前に抽出された水路や植生のマッピング結果と SAR センサの解析結果を統合的に用いることにより、ハイドロロジカルユニットを包括する広域な面的解析により、植生・微地形・水利に応じた泥炭地表の変動特性を検出することが可能となる。

(4) マニュアルの作成

本章で触れた、地下水位推計モデルによる火災危険度予想マップ作成の関連項目については、別添のガイドブックにおいて詳細を整理した。

3. モデルパイロットプロジェクトの提案

泥炭地回復において最も困難な点は、泥炭地回復の総合的知見やモデルが存在しない点である。これまでの既往プロジェクトの対策、開発プログラムの下で排水路掘削を基盤として組み立てられている。このように従来の排水路採掘にとらわれない革新的な視点によるモデルパイロットプロジェクトの構築と実施が求められている。

なお、一部修復が成功している地域もあるが、これは、１）河川の氾濫原、２）海岸沿い（潮汐作用で海水（栄養と水）の供給がある）といった限られた地域であり、こういった地域は土壌の栄養条件が良く、良好な生物生産機能を維持できるためである。しかしながら、内陸や泥炭地水理単位の内部では、河川や潮汐の影響を受けないために、貧栄養の荒廃泥炭地であり、上記のモデルは全く適用できない。そのため、本業務において、BRG との共同により極めて困難な荒廃泥炭地の回復手法の提案を行った。

対象地域は、BRG と協議の上、リアウ州の Tebing Tinggi Island oyobi 中部カリマンタン州の Kahayan Sebangau Rivers、西カリマンタン州を対象とすることとした。

3.1. 現地調査

泥炭地火災や泥炭地開発に起因する温室効果ガス排出の地球規模のインパクトを鑑み、その適切な管理体制の確立は喫緊の課題である。本来泥炭が果たしている生態系機能を回復・保全し同時に経済的側面をサポートしながら持続的社会を目指すべきである。ここで報告する現地調査は、次期モデルパイロットプログラムを重点的に取り組むことができる地域を多角的視点で見極めることを目的として行われたものである。

(1) リアウ州

BRG の事業における拠点州の一つであるリアウ州ベンカリス島の、オイルパームプランテーション・泥炭復興拠点の試験場の二か所を視察した。前者はオイルパーム会社 PT Meskom Agro Sarimas の圃場、後者は Tanjung Leban 村内の農家で泥炭復興の試験場として様々な研究者、研究機関の試験・調査を受け入れている。（地図参照）

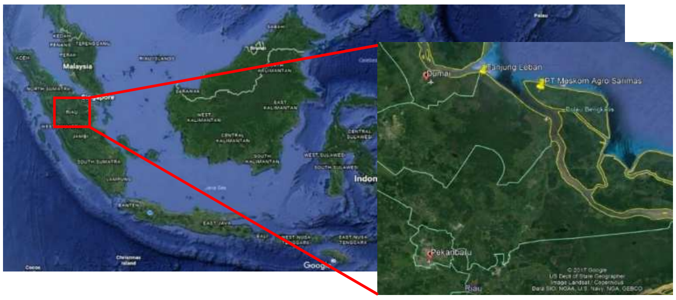


図 3　リアウ州ベンカリス島

(2) 調査行程

調査は 2017 年 8 月 29 日から 9 月 1 日の日程で行われた。詳細を以下の表にまとめる。

時間	活動内容	注釈
2017 年 8 月 29 日（火）		
08.35 – 10.20	Jakarta ― Pekanbaru	フライト移動
11.00 – 17.00	Pekanbaru ― Bengkalis	船移動・Bengkalis に滞在
2017 年 8 月 30 日（水）		
08.00 – 08.30	Bengkalis からオイルパーム会社 PT Meskom Agro Sarimas へ	車移動
08.30 – 12.00	PT Meskom Agro Sarimas にてミーティングの後、プランテーション現場にて施肥・水位管理の見学、泥炭水浄化施設の見学	
12.00 – 13.30	休憩・昼食の後、移動	車移動
13.30 – 15.00	Badan Lingkungan Hidup Kab. Bengkalis にてミーティング	
15.00 – 18.00	Bengkalis ― Dumai	船移動・Dumai に滞在
2017 年 8 月 31 日（木）		
07.30 – 09.00	Dumai ― Desa Tanjung Leban	車移動
09.00 – 09.30	Tanjung Leban 村役場でミーティング	
09.30 – 11.30	Desa Tanjung Leban の試験圃場を視察	
11.30 – 13.30	Break and lunch at Pak Ning	車移動
13.30 – 17.30	Desa Tanjung Leban ― Pekanbaru	Pekanbaru に滞在
2017 年 9 月 1 日（金）		
11.10 – 12.55	Pekanbaru ― Jakarta	フライト移動

(3) オイルパーム会社 PT Meskom Agro Sarimas（リアウ州　ベンカリス島）の視察

ここでは 8 月オイルパーム会社 PT Meskom Agro Sarimas 視察の詳細について記載する。

1) 規模・管理状況等

規模や管理状況は下記の通りである。

- 海岸からの距離：6.5km
- 泥炭の深さ：12 m　（ベンカリスの島の泥炭全体がこの深さ）
- 会社の敷地面積：3,705 ha
- プランテーション面積：1,000 ha
- オイルパーム生産量：面積 17-18 ha / day、重量 500t / day
- 施肥：
  - NPK 6kg/year/tree (N:P:K=7:6:36)
  - リン鉱石（P）1 kg/year/tree;
  - 尿素（N）1.7 kg/year/tree
  - 亜鉛（Zn）+銅（Cu）（混合）量不明
  - ホウ素　量不明
  - 灰 7 kg/year/tree （pH 調整のオイルパームの残渣由来の灰で pH11　※ディレクター情報）
  - ※追加 K 施肥→昨年 2016 年から K の施肥量を増やしているらしい
- 水位：40 cm に保つ努力をしている。
- 水位管理：二か月に一回測定・18 地点（※2016 年から開始）、降雨も測定
  - 水位 40cm の政府方針に対する会社見解：会社の経験では 50-70 cm の水位が最高収量を期待できるが、政府の 40 cm ルールに従うように努力している。しかし実際は水位を保つ管理は難しい（コストがかかる）。
- 別会社のプランテーションも訪問するよう勧められた：PT Tabung Haji Indo Plantation (@Tembilahan subdistric) ※82,147.22 Ha という広大な土地の泥炭地（土地の 98%に当たる）
- 精製されたオイルの取引先は別のオイルパームの大会社 PT Wilmar である
- 泥炭水を純化（蒸留・化学処理・濾過）してミネラルウォーターを生産。
  6,000 トン/日の泥炭水を処理。
  - 商品名 Leicos　として主にベンカリスで販売している（図 1）
  - 泥炭に純化した水を戻している

- オイルパームの残渣でバイオガス（メタン）を生産

➢ 工場のタービンを回す燃料に利用
➢ 残りは燃料として販売

2) オイルパームプランテーションの視察

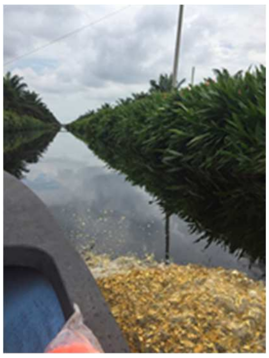


図 4　水路・水位測定法・土壌断面

- 1,200 m×250 m 区画間に通る水路（幅 8－12　m）をモーターボートで移動
  ※　1 区画 ＝30 Ha、水路幅は３種：12 m、8 m、4-6 m
- 今年設けられたという水位測定地点（計 18 地点）の一つ（図３）。当地点の水位は 40 ㎝。
- 土壌断面観察（図４）：オイルパーム根元から２m地点で作成。（0－40 ㎝）。

図 5　マウント切断面

- マウントの断面観察（図５）：根元に土が盛られ、内部に根が伸びている。
  ※マウントは近くの水路工事の時に出た泥炭を木の根元に積み上げたもので、全ての木に同様に作られているわけではなかった。マウントの断面は多くの根が侵入しており、ここから酸素と栄養を吸収していると思われる。偶然できたものだが、地表から木へ養分・酸素の供給を行う仕組みのモデルにできる可能性はある。
- 深刻ではないものの、オイルパームの葉に K 不足の症状が見られた。会社側もこれを

気にかけている様子で、今年からKとNの増加施用を開始しているそうだ。追加施肥をすれば数年後の収量増加は見込めるのではないか。

3) 訪問のまとめ

政府の40㎝水位の推奨を受け企業努力はしているものの、会社としてはこれによる収量減（「10%減」という数値情報に対して）は大きいと感じている。現在は経験的に高収量が見込める 50－70cm の水位での管理を希望している。一方、プランテーションの視察同行と大崎先生による泥炭地管理の説明後、Hirawan ディレクターが高水位栽培法のパイロットプロジェクトへの興味を示す場面があったが、訪問中の合意は引き出せなかった。当会社は水位調整の水門を設けており（図５）、40 ㎝水位に管理できる設備は整えられていた。生産利益の保証が明確になれば比較的スムーズに高水位栽培に移行できるサイトであるといえる。

図 6　水門

今後の協力体制について、訪問後に当会社から、パイロットプロジェクトへの協力に意欲的になっている旨の連絡があり、今後の BRG が率いる高水位栽培法のパイロットプロジェクトの参加企業として有力な候補である。

(3) 泥炭試験圃場の視察（Tanjung Leban 村、Nur さんの圃場）

当試験場は、海岸からの距離が近く、土壌に十分な栄養塩が供給されている可能性が非常に高い。泥炭復興プロジェクトにおいてはこのような、もとから成功が約束された土地でのモデルケースの確立は、適切ではないのではないかという見解を現地視察で結論付けた。ただし、泥炭土壌における栄養塩の海岸からの分布状況（水平・垂直方向）と地形・植生データとを合わせて示す目的の調査地としては適したサイトであることがわかった。

- オイルパームが植わっていたが 2008 年に消失。2009 年から別の樹種を植林
- 敷地面積：2.5 ha
- 泥炭深度：9 m から現在は 7 m
- 海岸からの距離：3 ㎞

  ※ 海岸から近いので海水の影響を受けている可能性が非常に高い

図 7　試験林と水路

3.2.モデルパイロットプロジェクトの提案

インドネシア泥炭復興庁は国内の 7 州を泥炭地保全事業の対象にしているが、本プロジェクトでは BRG と協議の上、リアウ州と中央カリマンタンに焦点を絞って取り組んだ。オイルパームプランテーションを経営する会社の視察からも分かる通り、泥炭地保全のための高水位は現在の栽培方式ではオイルパームの収量減を招くという理由から、採用されにくい現状がある。保全と経済の両立を可能にする新たな栽培システムの開発が望まれる。

(4) 高水位の維持法

ここでは、火災対策の手法も組み込んだ、カナルブロッキングと地下水のポンピングアップによる水位制御法のモデルパイロットプロジェクトの詳細を示す。ここでは、西カリマンタン州のクタパン地域のコミュニティ植林地を対象地とし、ペラン川泥炭地帯の栽培プロットデザインの詳細について記載する。プロットの準備については、地域政府との協議の上、パイロットサイトとして 2017 年 10 月より試験運用を開始した。開水路により排水の進む、地域であるが、この一部をカナルブロッキングによりせき止め、火災防止のトリートメントを行う部分と、従来通りの排水状況のまま乾燥させる部分に 2 分した。また、

さらに排水路のダム構築により湿潤になる場所の一部を、さらに井戸を掘削して地下水のポンピングアップを実施する試験地を設けた。栽培植物は水路で囲われたブロックごとに定義した。また、圃場に散乱した幼木や倒木等のバイオマスを集め、木炭の製造により有効活用することで一面に散布した。木炭は、保水・通期や微生物のマトリックスとして機能し、炭素貯留への貢献が期待されるため。さらに施肥の有無による生育の差を比較するために、一列ごとに施肥を行った。

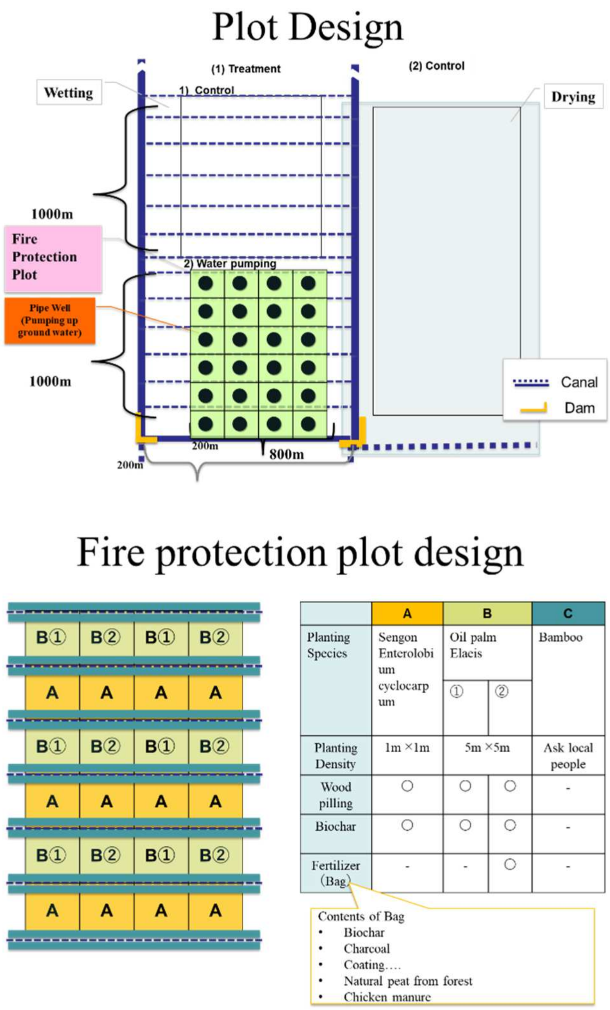


図 8　高水位維持法のプロットデザイン

(2) 高水位栽培法

高水位を保ちつつ土壌の表層で効率的な栽培を行う技術の確立と実証は、泥炭地保全と経済活動の両側面の要求を満たすための喫緊の課題である。化学肥料の泥炭土壌への直接投入は、高い酸性土壌の泥炭地では栄養塩が保持されないため、損失・流亡が大きく非効率的である。

高水位栽培法では、天然の堆肥と鶏糞（窒素に富む）の混合肥料を通気性の袋（土嚢

袋など）に入れたものを積み上げ、土壌表面に配置する。植物の根はこのバッグの内部に延ばされ、泥炭土壌を介さずに栄養が直接植物に効率的に供給されるシステムである。また緩効性肥料の試験も行われる。特に植物のあらゆる生物学的機能に要求されるカリウムイオンの供給効率の向上を目指す。この栽培システムの利点は以下のとおりであり、社会的インパクトが期待できる。

1. 泥炭地での作物栽培が高水位を維持しながら行うことができる。
2. 泥炭土壌へ直接施肥をしないため、養分の流亡を防ぎ植物が効率的に養分を利用できる。
3. 植物根が地表面に広がることで酸素の供給も十分に行える。
4. 肥料からの養分流出を最小限に抑え、自然土壌の汚染を防ぐことができる。

最初のパイロットプロジェクトはオイルパームのプランテーションで行われる。BRG の主導で以下の三地点が候補地に挙げられ、計画が進んでいる。

1) KHG Sungai Kampar – Sungai Gaung （リアウ）
2) KHG Sungai Sugihan – Sungai Lumpur （南スマトラ）
3) KHG Kubu Raya （西カリマンタン）

プロジェクト期間は 2 年間であり、初年度の半年間でオイルパームの植物体に見られるカリウム不足の症状の改善が期待される。収量の改善は一年を経過した時点で現れることが期待される。二年目からは、この栽培法の評価を行うための各種測定が行われる。現場での方法確率がなされれば、別の地点での応用も計画される。またオイルパーム以外の別の商品作物への高水位栽培法の適用試験が行われる計画である。
当パイロットプロジェクトでは以下の成果が期待されている。

- 熱帯泥炭保全の責任ある管理の行動計画としての‘革新的なオイルパーム栽培法’の提案
- 国内で展開してゆくパイロットプロジェクトにかかわる委員会の設立

(3) バイオマスの有効利用

泥炭地は通常乾季においても高い水保全機能を持ち、水供給により高い光合成能を維持することができる。したがって、高い乾物生産能を有する。そこで、泥炭地適応植物であるサゴヤシを中心に、サゴデンプンとバイオマスの生産系を確立し、泥炭地の保全と経済効果を著しく高める方策を提案した。

図 9　サゴのバイオマスポテンシャル

図 10　サゴの特性

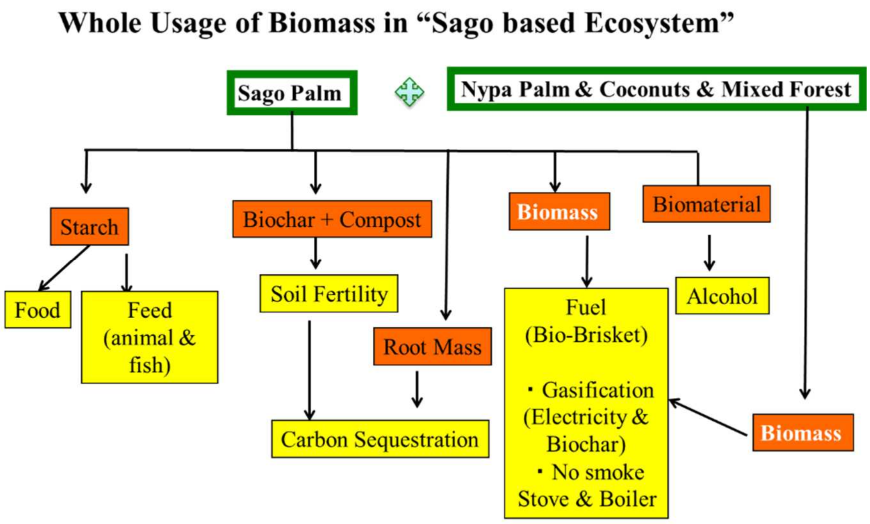


図 11　サゴを中心とするバイオマス生産系の提案

(4) 複合経済システム

泥炭地は非常にもろい生態系で、このような生態系では、本来プランテーションシステムは不向きである。そこで保全を核とした複合的管理システムの導入が求められる。そこで、住居や村の周りの食用の経済作物や果樹、家畜放牧用草地、バイオマス林、保全林の要素を 1 ユニットとした、Micro-Hydrological Unit のモデル構築を提案した。

本プロジェクトは、1）COP21 および SDG に関連する炭素/水問題、2）気候変動への緩和および適応への貢献、3）食糧危機の克服など自然資本の推定および利用を活用した経済価値向上のロードマップを作成する。飼料（デンプン利用率）とエネルギー（バイオマスエネルギーと再生可能エネルギー）の経済価値の向上は地域社会で展開されることにより、地域社会の社会経済的プログラムをカバーし、そのプログラムは修復、回復、泥炭地の保護の鍵となることが想定される。

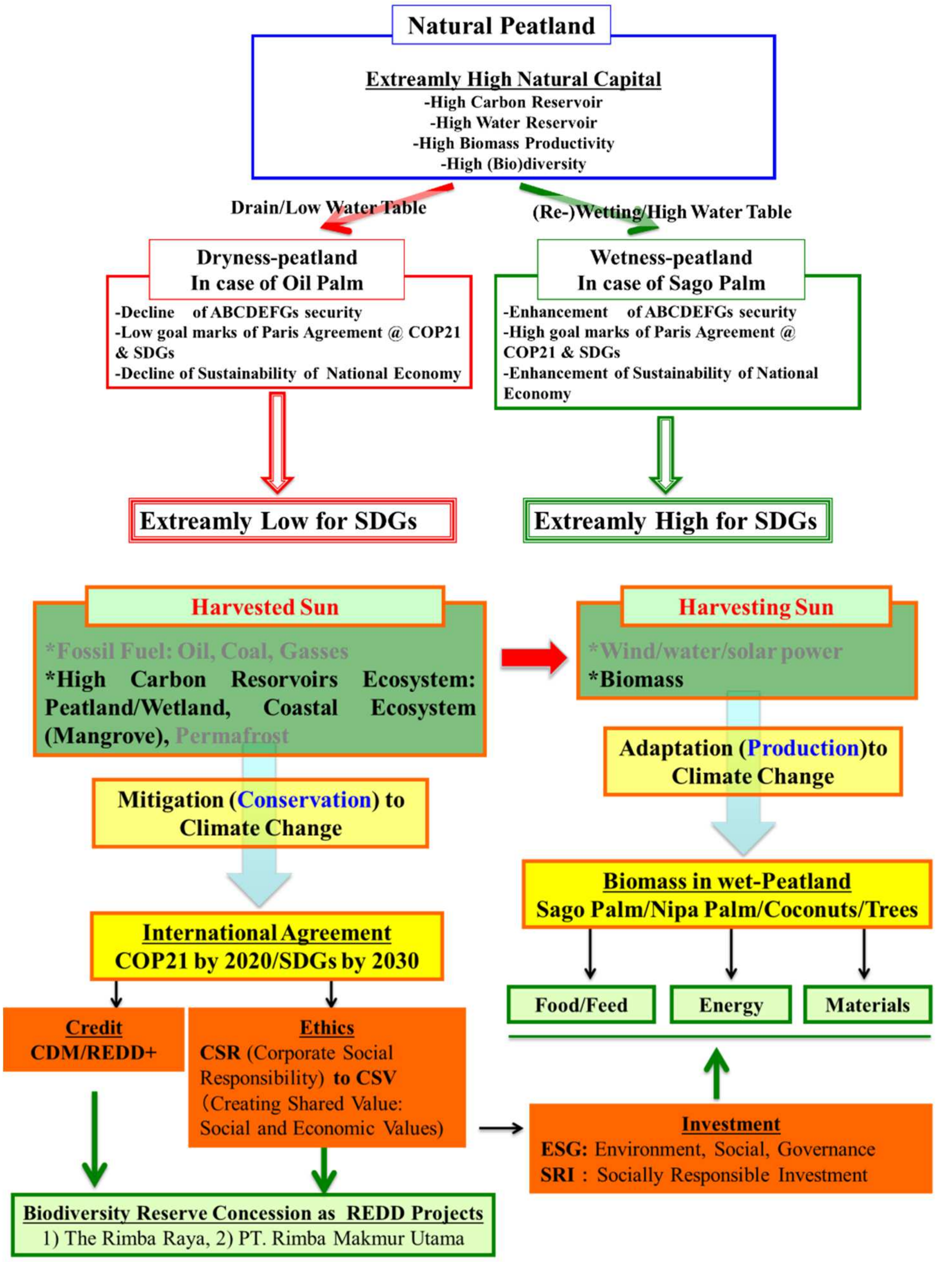


図 12　泥炭地の複合的生産システム

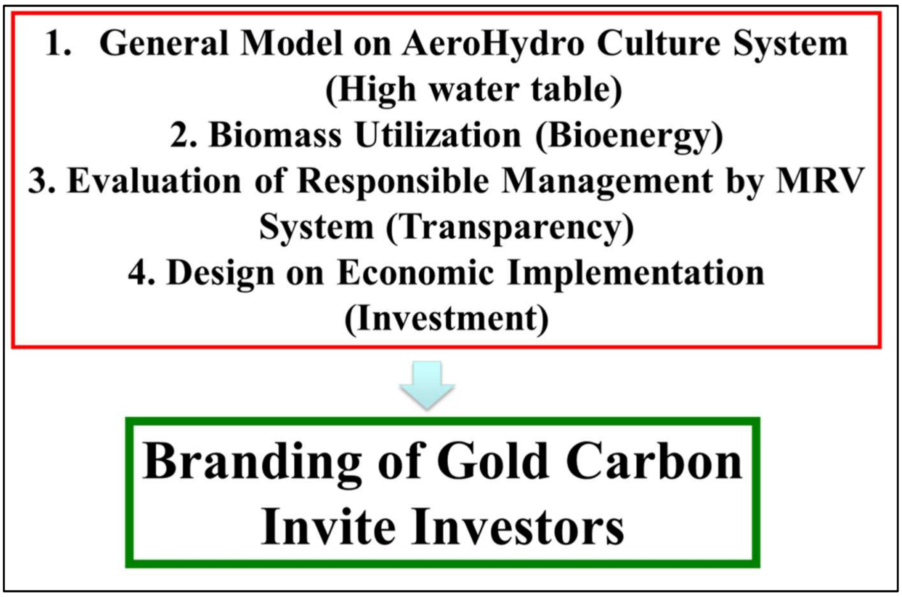


図 13　泥炭地の経済的評価手法の提案

(5) SDGs 指標の評価

泥炭地を高水位条件で保全すると、著しく高い SDGs の達成目標が得られることが期待される。そのための SDGs 指標の評価法の開発が必要である。下表の通り、泥炭地を取り巻く Security の観点から、以下の指標評価（ABCDEFs Security）を行う手法開発を BRG との協同により提案した。

表 7　評価指標の提案

項目	評価手法
Aquatic/Water reservoir ecosystem	Water security
Biodiversity security	High Biodiversity by mix planting and nature conservation around peat dome
Climate Change security	Mitigation as Carbon Emission Reduction and Adaptation as high Biomass Production against El Nino.
Disaster security	Fire and Haze protection
Energy security	Biomass energy from sago starch and residuals, and other biomass materials in sago based ecosystem
Food/Feed security	Sago starch for food and feed (animal husbandry and fish culture)
Social Security	PES and CSR and CSV by several credit(REDD+　JCM)

4. 泥炭地回復事業実施に係るキャパシティビルディング手法の提案

泥炭地の修復・回復・保全のためには、正しい科学的な知識を基盤とした、管理・維持の手法が必要となる。これを徹底するために、各種のトレーニング、実習、教育カリキュラムが必要である。また、そのために各レベルにおけるマニュアルやガイドラインを作成する必要がある。ここでは、そのキャパシティビルディングの母体となる組織構築を提案した。

4.1. 泥炭地回復大学コンソーシアム

カリマンタンでは 5 大学（カリマンタン大学コンソーシアム)、5 大学（スマトラ大学コンソーシアム）とスマトラで組織した。

大学ネットワークは、泥炭地の科学的な知見の集積に向けて、標準化された現地調査の方法論を確立することを目的とする。本プロジェクトでは、1 月 17 日～27 日に中央カリマンタン州にて合同調査を実施し、カリマンタン大学コンソーシアムのパランカラヤ大学、スマトラ大学コンソーシアムのリアウ大学の研究者とともに、泥炭地の調査手法の標準化に取り組んだ。また、成果として、別添の現地調査のマニュアルを作成し、これを教育・実習等のマニュアル及びガイドラインとして提案した。

4.2. 泥炭地回復センター(International) Tropical Peatland Center (tentative)

11 月に行われた第一回泥炭地円卓会議において、カリマンタン大学コンソーシアムおよびスマトラ大学コンソーシアムの組織化にあたりカリマンタンとスマトラにそれぞれ泥炭地研究の研修センターの設立を提案した。提案の特筆すべき点は、泥炭地回復における民間部門の事業参入の促進を前提としたことにある。ディスカッションペーパーの中では、研修センターの運営は BRG のみでなく、環境林業省（MoEF)、技術評価庁（BPPT）/インドネシア科学院（LIPI)、大学、地方自治体など様々な関連ステークホルダー間での協力関係構築に注意を払うべきであることについて協調した。

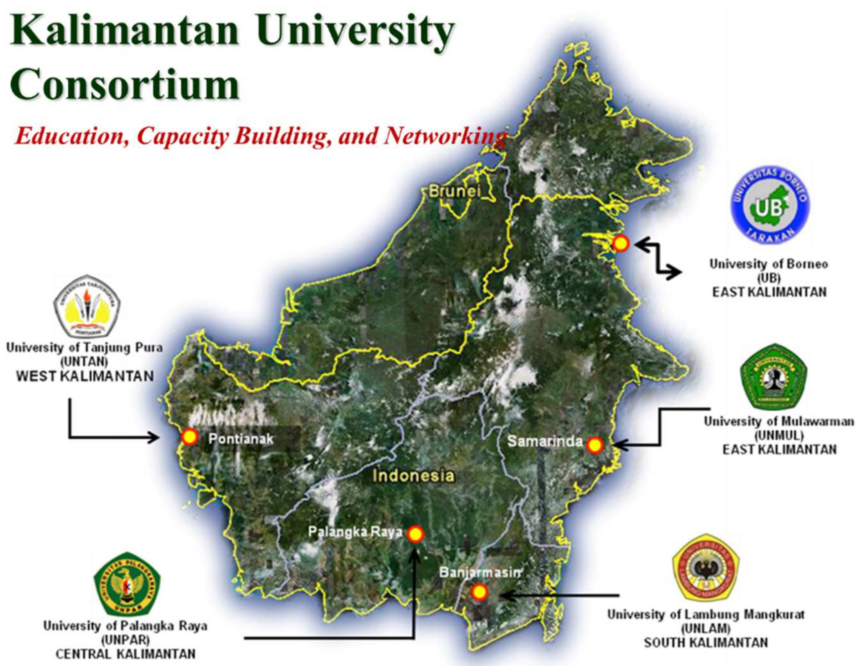


図 14　カリマンタン大学コンソーシアムの構成図

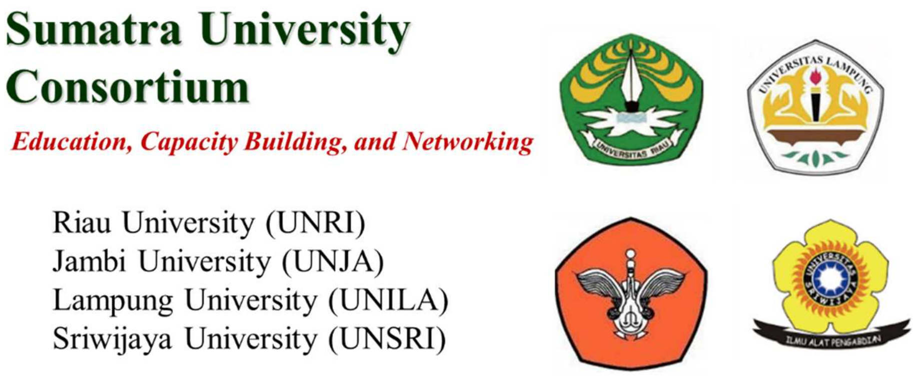


図 15　スマトラ大学コンソーシアムの構成図

5. インドネシア泥炭地回復国際委員会構築支援

インドネシアでの泥炭地回復・修復事業は多彩なステークホルダーが連携するために、利害関係の調整が泥炭地回復・修復プロジェクトの成否のカギを握るといっても過言ではない。そこで、IPS や JPS を核とし、BRG や JICA、日本学術連合が連携して、「インドネシア泥炭地回復国際委員会」の設立を支援した。。

受注者は、具体的には、同委員会の新設に際し、関係機関間の連絡、調整を行い、本業務において、委員会設立のための計画書案を作成し、関係機関の了承取得の支援を行った。なお、同委員会は、１）Executive Board、２）Implement Groups、３）Secretaries により構成することとし、同委員会の設立に際し、国際的な支援を得るために、関係ドナーへの参画の要請を支援した。

5.1.関係機関間の連絡・調整

本プロジェクトでは、「インドネシア泥炭地回復国際委員会」の立ち上げに向け、第一回泥炭地円卓会議を関係機関間の議論の場として設置した。またこの第一回泥炭地円卓会議の開催にあたり、BRG 関係者、JICA、IPS、JPS、日本学術連合等の関係機関との事前調整を進め、第一回円卓会議の開催の周知とプログラムの作成を、各関係者との協議の上進めた。開催に係る経費については、実施機関である BRG(泥炭地回復庁)と協議の上、経費負担額を決定した。また、同委員会の設立および円卓会議の開催に向けて、国際的な支援を得るために、日本学術連合と共同で、在インドネシア共和国ノルウェー大使館への援助要請をおこない、UNDP（United Nations Development Programme）を通じて、開催資金の一部援助を得ることができた。

5.2.委員会設立のための計画書案の作成

本プロジェクトでは、円卓会議の開催に向け、「インドネシア泥炭地回復国際委員会」の母体や運営組織についての提案書を円卓会議のディスカッションペーパーとして整備した。また、円卓会議においては、Jakarta Declaration on Responsible management of Tropical Peatland として BRG、IPS、JPS、日本学術連合を含む参加者間で共同声明をまとめた。その後、環境林業省（MoEF)、農業省（MoA)、技術評価庁（BPPT）/インドネシア科学院（LIPI)、大学、地方自治体、民間企業など様々な関連ステークホルダー間との複数のミーティングおよびワークショップを実施し、「インドネシア泥炭地回復国際委員会」および「国際泥炭地研究センター」設立における協力関係構築につとめ、関係機関の了承取得の支援をすることができた。

5.3.円卓会議の開催

2017 年 11 月 1 日～11 月 2 日の期間に 2 日間にわたって、第一回泥炭地円卓会議をジャカルタ市内のホテルにおいて開催した。これは、IPS,BRG,JPS の三者を主催元として、インドネシア国内外の泥炭地研究者および泥炭関係の実務者を招き、「インドネシア泥炭地回復国際委員会」の立ち上げや枠組みに関する議論を実施した。80 数名が参加し、協議を通じて得られた合意事項は、Jakarta　Declaration という共同声明に具体的なアクションをまとめた。また 11 月 3 日～5 日にかけて、参加希望者を中カリマンタン州パランカラヤに連れていき、フィールドエクスカージョンを行った。

(1) 開催要領

第一回泥炭地円卓会議およびフィールドエクスカージョンの開催要領を下記に示す。

1) 1st Tropical Peatland Roundtable

Date and Time
08:30~17:00 November 1st, 2017
09:00~14:30 November 2nd, 2017

Menara Peninsula Hotel, Jakarta, Jasmine 4 room, 3rd Floor
Jalan Letjen S. Parman Kav. 78, Jakarta
Telephone: (62-21) 535 0888
Fax: (62-21) 535 9838

Welcome dinner
Date and Time
18:30~20:00 November 1st, 2017

2) Field Excursion to Palangkaraya (Advanced registration is required)

Date and Time
November 3rd to 5th, 2017
Venue
(Refer to agenda for field trip)

(2) 開催スケジュール

開催スケジュールを下記に示す。

表 8　1st November: 1st Tropical Peatland Roundtable Day 1

Time	Agenda	PIC
08:30-09:00	Registration/Short movies about peatlands restoration will be played prior the opening	
09.00-09.05	Committee Report	Dr. Haris Gunawan (Deputy Research and Development of Peatland Restoration Agency
09:05-09:30	Opening Remarks	1) Ir. Nazir Foead MSc (The Head of the Peatland Restoration Agency) 2) Dipl.-Ing.Gerald Schmilewski (The president of International Peatland Society)
09.30-10.00	Press Conference and Coffee Break/ Photo session	
10.00-11.00	Panel Dialogue	Facilitator: Dr. Alue Dohong/ Dr. Abdul Wahib Situmorang 1) Prof. Azwar Maas : Situation of Indonesian Peatlands 2) Directorate General PPKL, KLHK: Sustainable Management of Indonesian Peatlands 3) Dr. Haris Gunawan: Restoring Degraded Peatland, The Potency of Promising Adaptive Crops.
11.00-11:45	Topics Presentation and Discussion 1 Restoration of Degraded Peatland in Different Land Uses	Facilitator : Hanni Adiati, MSc 1. Prof. Indratmo : Hydrological Restoration in Plantation Areas 2. Prof. Line Rochefort : The Development of Technology to Restoring Peatlands 3. Prof. Kosuke Mizuno : Restoration of Peatland in Community Lands
11:45 – 13:00	Lunch	
13.00 – 14.00	Topics Presentation and Discussion 2 Development	Facilitator: Dr. Budi Wardhana 1. Dr. Hidenori Takahashi: Developing System on Water Table Monitoring 2. Dr. Albertus Sulaiman: Building An Integrated Peatland Monitoring Through Modeling and Mapping Water Table 3. Bernd Hofer: Data collecting, data processing and peatland restoration

Time	Agenda	PIC
	Peatland Monitoring System	planning – experiences from Europe 4. Vähäkuopus Tuija: Geological Survey of Peatland
14.00–14.30	Coffee Break	
14:30-17:00	Roundtable Discussion	Chaired by Dr. Haris Gunawan and Dr. Bambang Setiadi 1) "Discussion Paper" explanation by Dr. Mitsuru Osaki (President of Japan Peatland Society) 2) Short comments/presentation from participants
18:30-20:00	Welcome dinner party	Supported by BRG

表 9　2nd November: 1st Tropical Peatland Roundtable Day 2

Time	Agenda	PIC
09:00-09.15	Registration and Coffee	
09.15-10.30	Topics Presentation and Discussion 3 Carbon Emission on Peatlands	Facilitator: Dr. Belinda Margono - Prof. Dr. Daniel Murdiyarso: Estimation of Carbon Emission on Tropical Peatland: Before and After Restoration Scenario - Prof. Dr. Eeva Stiina Tuittila: Ecology of Boreal Peatlands Including Methane and Carbon Dioxide Processes - Dr. Takashi Hirano: Long Term Monitoring of CO2 Flux in Tropical Peatlands
10:30-12:30	Action plan discussion	Chaired by Prof. Mitsuru Osaki, Prof. Azwar Maas - Proposing discussion points by Dr. Bambang Setiadi
12:30-13:30	Lunch	
13:30-15:00	Jakarta Declaration	- Discussion on draft of Jakarta Declaration - Signature with Gerald Schmilewski, Nazir Foead, Mitsuru Osaki (Witness by Haris Gunawan in the case of Nazir Foead) - Jakarta Declaration on Tropical Peatland by Gerald Schmilewski (The president of International Peatland Society)
15:00-15:15	Closing Remarks	Dr. Bambang Setiadi

1st Tropical Peatland Roundtable

International Peatland Society

Japan Peatland Society

2nd November 2017

"Jakarta Declaration" on

Responsible Management of Tropical Peatland

Truly effective Tropical Peatland Restoration in Indonesia will require substantial development of an integrated peatland management system based on scientific and technical knowledge and information. Achieving this requires the establishment of an International Committee for Technical Consultation to facilitate Tropical Peatland Restoration Action.

For this purpose, the IPS (International Peatland Society), BRG (Peatland Restoration Agency, Indonesia) and JPS (Japan Peatland Society) organized the 1st "Tropical Peatland Roundtable" on the 1st and 2nd November 2017 in Jakarta, supported by JICA (Japan International Cooperation Agency), Norwegian Embassy, UNDP (United Nations Development Programme), and BRG.

After two days of thorough discussion, a principal strategy of Responsible Management of Tropical Peatland was agreed. This includes five pillars of action:

- establish a "Tropical Peatland Center "
- organize an " International Committee for Technical Consultation"
- develop an "Integrated Monitoring System"
- conduct a "Model Project" for responsible management
- achieve capacity building

We release this "Jakarta Declaration" as a milestone for promoting action on "Responsible Management of Tropical Peatland", also as a basis for bridging Indonesian stakeholders and the international community.

Gerald Schmilewski	Nazir Foead	Mitsuru Osaki
The President of the International Peatland Society (IPS)	The Head of Peatland Restoration Agency (BRG)	The President of Japan Peatland Society (JPS)

図 16　Jakarta Declaration・ジャカルタ共同宣言

6. 国際会議における泥炭地回復に係る協力活動と成果の情報発信

インドネシア国における泥炭地回復に係る協力活動とその成果を、第 23 回気候変動枠組条約締約国会議（UNFCCC・COP23、開催地：ドイツ）ジャパンパビリオン JICA-BRG（インドネシア国泥炭地回復庁）共催イベント等において発表することで、国際社会への情報発信を支援した。これと併せ、インドネシア泥炭地回復国際委員会の新設のために 2017 年 11 月に実施した円卓会議（(1st Tropical Peatland Roundtable）の成果を本会期中に IPS（国際泥炭地学会）を含む国際機関の関係各者に共有すると共に、フィードバックを受け具体的な枠組み作りの助言を行う等の同委員会構築ための支援をおこなった。
本章では、その具体的な支援の内容として、第 23 回気候変動枠組条約締約国会議（UNFCCC・COP23、開催地：ドイツ）ジャパンパビリオン JICA-BRG（インドネシア国泥炭地回復庁）共催イベント等での発表内容（6.1.）、および、2017 年 10 月と 2018 年 4 月に開催された IPS の常任理事会における協議内容（6.2.）について記載する。

6.1. 第 23 回気候変動枠組条約締約国会議ジャパンパビリオン JICA-BRG 共催イベント等での発表

平成 29 年 11 月 6 日(月)から同 17 日(金)にかけてボン(ドイツ)にて開催された「国連気候変動枠組条約第 23 回締約国会議(COP23)」へ本プロジェクトより、大崎満氏および高橋英紀氏が出張し（11 月 8 日：日本発、同月 17 日帰着)、サイドイベント、ジャパンパビリオンで所定の報告を行うとともに、各国のパビリオンの内容からリアルタイムモニタリングシステムの活用が有効な課題についての情報を得た。9 日に行われたインドネシアパビリオンのイベントでは、Wahjudi Wardoyo (Senior Advisor to the Ministry of Environment and Forestry）氏, Nazir Foead (BRG 長官), Mr. Alue Dohong (BRG 次官)により、インドネシアの泥炭地回復に関する国家戦略が述べられた。BRG の要請により、大崎氏はおもに Monitoring System について述べ、Monitoring System が SDGs 等の環境評価に使用出来ると事を強調した。また、11 月 11 日に開催された日本パビリオンのサイドイベントでは、特に、BPPT の Sulaiman と Awaluddin により開発が進められている、地下水位推定マップの成果を披露した。これに基づき、１）泥炭の微生物分解による二酸化炭素放出モデル、２）火災の頻度と強度推定モデルの作成が可能で、さらに４）降水量予測モデルの作成により、４）火災の頻度と強度推定モデルの 3 ヶ月前の予想モデルの作成が可能であることも､述べた。

6.2. IPS の常任理事会における協議

(1) IPS 常任理事会（2017 年 10 月）

10 月 10 日～11 日の二日間にわたり、ポーランドの Poznan において開催された IPS の常任理事会に本プロジェクトリーダーの大崎氏が参加した。ここでは、11 月に開催を企画した円卓会議の開催について報告し、セッションの議題について協議を行った。また、具体的なセッションプログラムについても提案した。下記をセッションの主題として提案し、承認を得た。また、IPS からの参加者についても内諾を得ることができた。

Table 6-1　提案した議題

Agenda 1: Integrated MRV System（統合型モニタリングシステム）
Agenda 2. Model Pilot Project（モデルパイロットプロジェクト）
Agenda 3. Capacity Building（キャパシティビルディング）
Agenda 4. International Program（国際プログラム）

(2) IPS 常任理事会（2018 年 4 月）

2017 年 3 月 31 日～4 月 8 日にかけて、リトアニアの Vilnius において行われた IPS 常任理事会に参加し、第二回泥炭円卓会議のインドネシアの開催と協議事項について提案と協議を行った。その結果、IPS、JPS、インドネシア泥炭学会、BRG,、インドネシア環境林業省（MoEF）の 5 者により 2018 年 11 月の開催について同意が得られた。IPS からの責任者は、Jack Rieley 氏と大崎満氏とすることが決まった。

Figure 6-1　会議の様子

7. 最終提案

ここでは、本プロジェクトにおける提案をインドネシアの熱帯泥炭地の回復プロセスとして整理し、ジャカルタ共同宣言において採択した「Responsible Management of Tropical Peatland」の具体的なアクションとして提案する。

7.1.要旨

熱帯泥炭地は炭素と水の巨大ストックであり、したがって自然資本で評価すると、最もその価値が高い生態系の一つとなる可能性が高い。熱帯泥炭地は、開発に伴う排水路の掘削で水位が低下し、微生物分解と火災により膨大な量の炭素が放出されている。これは、地球規模での危機的状況で、別の言い方をすると、熱帯泥炭地の保全は地球規模での安全保障を達成する。つまり、１）水の安全保障（Aquatic /water　Security）と２）炭素の安全保障（Carbon Security）にも多大な貢献をする。これらの重要な安全保障は、SDGs の１７の目標でも鍵となる要因で、熱帯泥炭地の修復・回復･保全は、地球規模で SDGs にも貢献する。

キーワード：水耕栽培、窒素固定、バイマス生産、気根、マウンド根

7.2.はじめに

熱帯泥炭地には多量の炭素が蓄積されているが、世界の熱帯泥炭地の約 7 割が東南アジアに分布しており、そのうちの大部分がインドネシアに存在している。この熱帯泥炭は、20 世紀に入ってから開発圧に晒され、急速に水路掘削と熱帯泥炭林の伐採が進められ、オイルパームやパルプ材等のプランテーションが進出し、火災や微生物分解による多量の炭素放出がなされている。

UNFCCC workshop (UNFCC-SBSTA 38 Research Dialogue, 2012 と UNFCCC workshop,2013）で、高密度炭素生態"High Carbon Reservoir Ecosystem"について議論され、“Technical and scientific aspects of ecosystems with high-carbon reservoirs not covered by other agenda items under the Convention”（ UNFCCC においても高密度炭素生態の技術的、科学的な取り組みが不十分である）と認識された。以降、この問題に対して、各種の取り組みが急速に進みつつある。ちなみにここで議論となった、高密度炭素生態とは、

1) Peatlands/Wetlands　（泥炭地/湿地）
2) Costal Ecosystem (Mangrove/Sea grass/Coral)（沿岸生態系で、マングローブ、海藻、サンゴによる沿岸生態系）
3) Permafrost　（永久凍土）

である。最近、沿岸生態系と海洋の炭素は、ブルーカーボン(Blue carbon)と呼ばれてい

るが、これにならうと泥炭地/湿地の炭素は、良く保全された場合にはゴールドカーボン(Gold carbon)と呼ぶことができ、同様に永久凍土の炭素（おもにメタン）は、シルバーカーボン(Silver Carbon)と呼ぶことができる。一方、生態管理に失敗して、生態系から庞大な炭素が放出されると、その炭素をブラックカーボン(Black)と呼ことにする。つまり、熱帯泥炭地の回復(Restoration)や修復（Rehabilitaion)とは、ブラックカーボンをいかにゴールドカーボンに変換・評価するシステムの開発でもある。1997-8 年のスーパーのエルニーニョでは、地球規模で森林火災が大発生し、全世界の二酸化炭素排出量の 24~66 %以上の二酸化炭素排出があった（そのうち６０％程度は東南アジアと推計されている）と評価されているが、そのうち熱帯泥炭の消失の占める割合が極めて高かったと推計されている（Guido R. van der Werf, *et al.* 2004)。その間にも通常のエルニーニョが４～５年で頻発するようになり、熱帯泥炭火災が頻発し、ヘイズが多発し、周辺住民の呼吸器疾患の発生や死亡率が高まり、航空機や船舶の運航障害による経済的な損失も拡大している。またインドネシア隣国のマレーシアやシンガポールへの被害も著しく、訴訟や外交問題にも発展している。それは、インドネシアでは熱帯泥炭地の開発が 1990 年代より急速に進み、その開発はほとんど排水路の掘削とリンクしており、熱帯泥炭地の乾燥化が著しく進んでいるためであり、1990 年代以前にはエルニーニョが発生しても、1990 年代以降のようなひどい泥炭地火災は発生していない。このことから、「泥炭地の排水による乾燥化」により、「熱帯泥炭地火災（熱い燃焼）」と「熱帯泥炭地の微生物分解（冷たい燃焼）」が発生するのは、泥炭分解の科学的原理として議論の余地のないほど明瞭である。逆の言い方をすると、熱帯泥炭では水位が高く、また水に酸素がほとんど溶存しないため、酸素が欠乏し、微生物の活性も著しく抑えられ有機物が分解しないで熱帯でも泥炭の蓄積がおこるという、泥炭生成の科学的原理と表裏をなす。

こういった熱帯泥炭地の問題に対して、インドネシア政府（Joko Widodo 大統領）は、2015 年 11 月のパリにおける気候変動枠組条約第 21 回締約国会合（COP21/UNFCCC）において、森林火災予防及び温室効果ガス排出削減のために、泥炭地回復庁（Peatland Restoration Agency、BRG）の設置を発表し、2020 年までに約 200 万 ha 以上の泥炭荒廃地を水位維持や植林・経済作物の栽培などにより回復・有効利用する方針が打ち出され、BRG は 2016 年 1 月に設立された。これをうけて、北海道大学、京都大学、総合地球環境学研究所(RIHN)が BRG と研究協力協定を結び、それを支援するかたちで JICA も BRG と協定を締結して、プログラム支援(JICA-BRG Project、北海道大学受託）を進め、熱帯泥炭の革新的（innovative)な修復・管理のために、１）センシングとモニタリングシステムの構築とモデル化、２）モデルパイロットプロジェクトのデザインと推進、３）キャパビルシステムの構築、４）国際熱帯泥炭センター（仮称）の設立を推進している。とくに、計測評価、革新的栽培法等をマニュアル化して、国際標準化することが重要で、国際機関との連携も重要な鍵となる。

7.3. 自然資本としての熱帯泥炭地

熱帯泥炭地を、評価しようとすると極めて複雑な系で厖大な研究･調査が必要で、その維持・管理技術となるとさらに混迷を深める。しかし、一方では、熱帯泥炭地を自然資本の観点から把握すると、その生態はむしろ極めて単純である。つまり熱帯泥炭地とは、「高密度炭素・水集積系」("High Carbon/Water Reservoir Ecosystem")で、そこに植物が生育している。

地球規模での相互連関環境リスクのクラスター（A cluster of interconnected environment-related risks）解析によると、そのトップランキングに、１）水危機（“water crises”）と２）気候変動に対する緩和策と適応策の失敗（ “failure of climate change mitigation and adaptation”）が上げられる（The Global Risks Report 2017 12th Edition)。熱帯泥炭地とは、「高密度炭素・水集積系」で、地球規模の環境リスクの双璧因子を併せ持つ、極めて特異的な生態系であると認識されつつある。そこで、熱帯泥炭を、自然資本の観点から分析してみる。

荒廃熱帯泥炭地の回復により、自然資本の価値が著しく高まり、広大な荒廃泥炭地を持つインドネシアでは、国家の各種のセキュリティー(Security)が強化される可能性が高い。荒廃熱帯泥炭地の回復による強化されるセキュリティーを **ABCDEFGs** Security (安全保障）と呼び、以下のような構成要素から分析できる。

-**A**quatic /water security （水のセキュリティー）：水貯蔵生態系の機能

-**B**iodiversity security （生物多様性のセキュリティー）： 泥炭･湿地適応植物の多様性と機能

-**C**limate Change security（気候変動に対するセキュリティー）：気候変動に対する緩和策と適応策への地球規模の貢献

-**D**isaster security （火災に対するセキュリティー）：泥炭火災や煙害の軽減

-**E**nergy security （エネルギーのセキュリティー）：膨大なバイオマスのエネルギー利用

-**F**ood/**F**eed security（食糧･飼料のセキュリティー）：サゴヤシを中心としたデンプン供給

-**G**lobal Partnership as global security （地球規模課題に対するセキュリティーへの貢献）：熱帯泥炭地の計測標準化の国際貢献と泥炭地の保全･修復･回復プログラム開発の国際連携

-**s**ocial security: REDD+, PES, CSR&CSV、ESG&SRI を通した、自然資本の実体化・価値化

最近、陸域の水が世界的な各種の危機の中でも最も危機的要因であると、指摘されている（The Global Risks Report 2017 12th Edition)。熱帯泥炭地は、開発に伴う排水路の掘削で水位が低下し､微生物分解と火災により膨大量の炭素が放出されている。これは、地球規模での危機的状況で、逆の言い方をすると、熱帯泥炭地の保全は地球規模での安全保障を達成する。また、熱帯泥炭の **ABCDEFGs** Security (安全保障）を達成すること

により、多くの SDGs（Sustainable Development Goals)を達成できる可能性がある。ちなみに、SDGs の２は F、５は s、６はA、７は E、８は s、９は s、11 は s、12 は s、13 は A、C、D、14 は A、B、15 は B、17 は G を内包する。逆に熱帯泥炭を破壊すると、多くの ABCDEFGs Security (安全保障）が失われ、SDGs が極めて低い評価となる。SDGs は銀行や投資家が投資する際の指標となりつつあり、ESG （Environment, Social, Governance）や SRI (socially Responsible Investment)を通して、例えば、熱帯泥炭でオイルパームを低水位（排水条件下）栽培すると、熱帯泥炭の ABCDEFGs Security (安全保障）を著しく低下させ、企業への投資が著しく制限されるようになる。

7.4.熱帯泥炭地は「水耕培養系」

熱帯泥炭地とは、生態学的に言うと「高密度炭素・水集積系」であるが、栽培学的にもっと単純化すると、「水耕栽培系」である。水は水耕なので第一の基本要素で、炭素（泥炭素材）は水耕栽培での支持素材にすぎない。水耕栽培法は、基本的に水-栄養-酸素の三要素からなる。熱帯泥炭では、水位を下げてオールパーム等を栽培することが多いので、水があたかも毒のように錯覚している研究者も多いが、水が問題なのは、酸素の溶解度が極めて低く、水があると酸素欠乏に陥りやすいためである。養分吸収に多大なエネルギーを要するため、酸素が無いと吸収根から栄養が吸収できず、根が腐れてきて植物が枯死する。主根等支持根は、冠水した泥炭地で１０m程度の深さでも生育できるのは、養分吸収は行わず、維持呼吸のみを行っているので、地上部からの通道組織を通しての酸素の拡散だけでも十分に生育できるためである。一方、通道組織は発達しているイネでも、側根で多量に養分を吸収するために、水耕栽培でもアエレーション（空気のコンプレッサーによるバブリング）が不可欠である。したがって、熱帯泥炭地での植物の第一の制限要因は、「酸素」である。

熱帯泥炭地での植物の第二の制限要因は、「無機栄養」である。無機栄養の泥炭地への供給は、河川から主に粘土鉱物の供給、海洋からは海水の潮汐作用による無機栄養の供給があるが限定的である（図 1)。一方、水の供給も、河川や海洋からあるが、これも限定的である。泥炭地への水の供給はほとんど降雨によるもので、雨水はほとんど栄養分を含まず、酸性（pH5.6)であることから、カチオンが溶脱しやすい。特に、K^+とNa^+は化合物を作らずイオンの形態で存在するので最も溶脱しやすい。

熱帯泥炭地では、川と川や海に囲まれた島で泥炭が形成されるが、泥炭地の Hydrogical Unit と呼ばれ、中央部に向かって泥炭が深くなりドーム構造を作る（図 1)。この模式図から明らかなことは、無機栄養の供給が旺盛な河川や海岸沿いでは植物の生育が旺盛であるが、泥炭（有機物）の蓄積が少なく、一方、ドームの頂上では貧栄養で植物の生育が抑制されているが、泥炭の蓄積は多い。このことから、栄養が豊富なゾーンでは微生物の活性が旺盛で添加された有機物が活発に分解され、ほとんど蓄積しない

が、ドームの頂上付近においては貧栄養であるため、微生物の活性も抑制され有機物分解が進まず、有機物の蓄積がおこる。

以上のことから、熱帯泥炭の蓄積には、1）高水位と2）貧栄養の二つの要因が重要であることが理解できる。従って、水位を低下させ（酸素を供給し微生物を活性化）、肥料を施肥（微生物を活性化）するような、特に、オイルパームの栽培は泥炭地の保全からすると最低・最悪の栽培法である。

また、熱帯泥炭における、無機栄養、主にカチオンの溶脱能は、熱帯泥炭を貧栄養生態系に導く。泥炭（有機物）は、pH7 付近ではカチオンを吸着するが、pH４以下の酸性条件下では、カチオンを脱着するのが主要な機構である。ちなみに、熱帯泥炭ではpH は 3.5 付近のことが多く、基本的には養分は溶脱する生態系である。

以上のごとく、熱帯泥炭地では、1）養分供給システムがなく、2）養分は溶脱し、貧栄養生態系である。しかし、後述するようにバイオマス生産能は意外と高く、無機栄養の供給はどうなっているのだろうか。図１に模式的に示したが、３つの栄養循環機構が働いていると推定される。

1）表層リサイクル（a)：リター等表層で分解し、微生物や根に直ちに吸収され、養分は溶脱を最小限にし、

2）器官内リサイクル(b)：植物の古くなった器官から養分を回収し、

3）細胞内リサイクル(c)：細胞内で古くなった化合物を分解し、再利用することにより、養分低含有率耐性を高める。

表層栄養リサイクル系は、表層の可給性有機物と分解系微生物層よりなり、したがって、この表層が、乾燥化（排水や森林破壊）、火災、開発にともなう表層攪乱で、表層栄養リサイクル系の機能が著しく低下する。表層栄養リサイクル系が破壊されると、森林の自然更新には２０年以上かかる事例も観察している（未発表）。

7.5.酸素/無機栄養吸収系

熱帯泥炭地は、1）水の供給（雨水）と泥炭の養分脱着(pH４以下でカチオンの脱着）の性質から、貧栄養生態系で、2）水の豊富な生態系であることから、酸素が欠乏しやすく、それが養分吸収能をさらに低下させている。結局、泥炭とそれを取り巻く環境は、物理的、化学的性質として、無機栄養供給系に大きな問題を抱えている。この問題に、熱帯泥炭の自然生態系はどう対処しているのであろうか。基本的には、

1）気根の形成

2）マウンド（根）の形成

による。気根の形成により、大気から酸素を吸収し、マウンドの形成により酸素と養分

を吸収する。

7.6.熱帯泥炭地の自然林での高生産速度

中部カリマンタン州の泥炭林（PSF1, PSF2）とヒース林（浅い泥炭で下層は砂質土）（HF1, HF2）に設けた調査区（Rahajoe et al. 2003; Miyamoto et al. 2003; Nishimura et al. 2007; Atikah et al. 2014） と、西カリマンタン州の低地（鉱質土）混交フタバガキ林（MDF1, MDF2）（Kohyama et al. 2001, 2003）にそれぞれ２か所づつ設けた１ヘクタール調査区の幹直径追跡データを、各調査区の幹直径・樹高関係と各森林タイプの伐採調査による地上部器官の相対成長関係（Yamakura et al. 1986; Miyamoto et al. 2007, 2016）を用いて解析した。幹直径 5 cm 以上への幹数ベースの加入速度と枯死率、および地上部現存量ベースの 個体成長による生産速度と個体枯死速度を、観測期間の違いに影響されない瞬間速度推定（Kohyama, Kohyama & Sheil 2017）によって計算した。

泥炭湿地林とヒース林は混交フタバガキ林と比較して、樹木種数・最大樹高・地上部現存量が小さいことが知られており、私たちの調査区データでも明らかだった（図 3）。追跡調査のデータから、地上部現存量の樹木個体成長・加入による生産速度と、死亡による枯死速度を計算した（下図参照）。樹木個体成長による生産速度は、個体より短命の葉などの生産速度を併せた地上部純一次生産速度のおよそ４割程度であることが知られている（Malhi et al. 2004; Takyu et a. 2005）。その結果、低湿地のふたつの森林タイプが、混交フタバガキ林の 1.5〜2 倍の現存量回転率を示すことが明らかになった。個体数の回転率も、混交フタバガキ林よりも高かった。低湿地では、貧栄養な立地が林冠木の高枯死率をもたらす一方、更新個体への光・栄養供給をもたらし、結果として高い現存量生産速度をもたらすと考えられる。

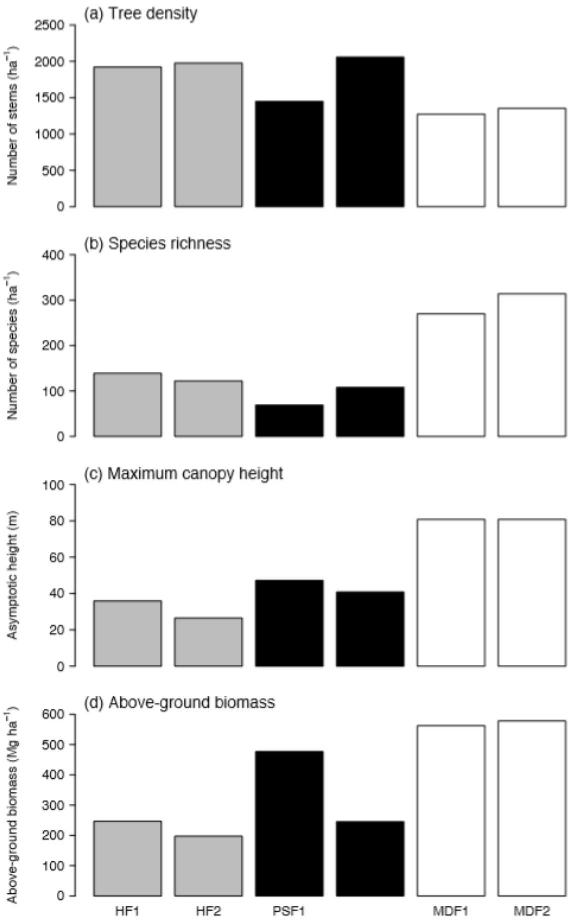


図 17　カリマンタンのヒース林 (HF)、泥炭湿地林 (PSF)､混交フタバガキ林 (MDF) に各 2 か所づつ設けた 1-ha 調査区の構造。幹胸高直径 5 cm 以上の全個体センサスから。最大林冠高は、拡張相対成長式の上限樹高を示している。

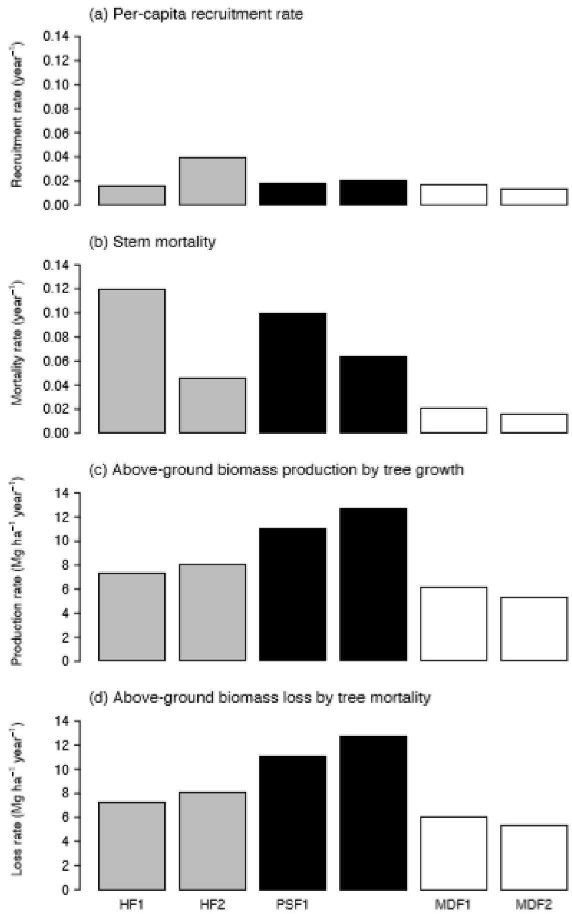


図 18　カリマンタンのヒース林 (HF)、泥炭湿地林 (PSF)、混交フタバガキ林 (MDF) の 1-ha 調査区の個体数と現存量動態　幹胸高直径 5 cm 以上の個体の加入・成長・死亡データから。

各調査区において推定した樹木の幹直径–樹高アロメトリー関係から、小径木ではヒース林が細長い樹形を、林冠木では混交フタバガキ林が細長い樹幹形を示すことが判る（Miyamoto et al. 2016)。泥炭湿地林とヒース林では地上部現存量が 200〜300 t/ha と、混交フタバガキ林の半分〜1/3 であるのに対して、樹木成長による生産速度が 10〜15 t/ha/年と混交フタバガキ林のそれを上回り、現存量当たり３倍以上の回転速度を示していた。林冠での速い枯死率が速やかな小径個体の更新を促すという熱帯泥炭地生態系の潜在的な生産特性が明らかとなった。速い林冠個体の枯死速度は、泥炭湿地林では木質泥炭の素材供給速度が高いことを意味する。

人為的に排水され、森林火災による撹乱を受けた泥炭地のフラックス観測（Hirano et al. 2012）では、純生態系炭素交換速度（NEE）で 5 t/ha/年の炭素放出であった。この値は、撹乱・灌漑泥炭地の地表沈降速度 1 cm/年に相当する、6 t/ha/年の炭素放出（H. Takahashi et al., 2018）と概ね一致する。こうした放出は、樹木の成長と枯死による乾燥

重量ベースの現存量回転速度とも合致する。高水位で撹乱を受けない泥炭林では、速い木質炭素の生産と地表への供給により、地表の表層有機物が保持されていることが明らかになった。熱帯泥炭の修復と管理には、高地表水位の維持とともに、地表への大型の木質炭素供給のために森林性植被の維持が必要である。

7.7.熱帯泥炭地での窒素固定能

熱帯泥炭の自然林では、高水位下でも旺盛な生育をすることが明らかとなった。つまり、気根とマウンドを形成して、酸素と栄養を吸収している。さらに、驚くべき事であるが、熱帯泥炭は空気中窒素の固定能が極めて高い生態系である。

タイ南部のナラチワット県のト・デンの熱帯泥炭地における、δ ^{15}N を調査した(Yanbuaban, M, et al, 2007)。土壌のδ ^{15}N（パーミル）は 3.0 値以上で、各種植物の葉のδ ^{15}N は 3.0 値以下であった。このことは、植物は軽い ^{14}N を優先的に使っていることから、気体の代謝が盛んで、空気中窒素が主要な窒素供給源であることを示している。また、窒素固定した窒素化合物が、地上にリターとして供給され、分解されて脱窒等が起きると、軽い ^{14}N が優先的に消失し、長年の間に土壌のδ ^{15}N の値は大きくなると解釈される。いずれにしても、熱帯泥炭地では土壌由来の窒素吸収はすくなく、空気中窒素の固定が盛んな生態系と推定される。

このような傾向は、インドネシアの中部カリマンタンの熱帯泥炭地でも確認されている（Takeshi MATSUBARA, et al, 2002)。ここでは、土壌のδ ^{15}N は 1.0 以上であり、各種植物のδ ^{15}N は 1.0 以下であり、タイの熱帯泥炭地と同様に空気中窒素を固定して、窒素栄養を獲得している生態系である。

空気中窒素の固定はマメ科等、根粒菌を形成する植物が主要であるが、熱帯泥炭林にはマメ科植物は少なく、また根粒菌は水（酸素欠乏）に極めて敏感で在り、高水位の熱帯泥炭地では窒素固定は困難である（ただ、マウンドでは根粒を形成して窒素固定をおこなう可能性があるが)。δ ^{15}N の低い植物（窒素固定植物）では、１）根粒菌を形成せず、２）内生菌はほとんど認められず、３）気根を形成することが多く、その先端にはゲル状の物質が分泌されて多数の窒素固定微生物が単離できることから、熱帯泥炭における窒素固定は、気根において活発と推定される。

7.8.革新的熱帯泥炭回復･修復法

熱帯泥炭地では、水が高水位で存在することから、１）酸素の供給が第一の制限要因となり、２）無機栄養の供給がほとんど無く、泥炭（有機物）の特性として低 pH 条件下では無機栄養は脱着して流亡することから、栄養が第二の制限要因となる。つまりこのような条件下では、植物の生育が抑制されるのみならず、微生物の活性も抑制され、したがって、有機物が分解されにくく有機物の蓄積が起きる。このようなことから、熱

帯泥炭地でオイルパームの栽培をするためには、一般的に、排水をし、厖大な量の化学肥料を投入する必要があると考えられて、熱帯泥炭の排水が急速に進んだ。水位を低下させると、酸素が供給され、さらに化学肥料の大量投与で、微生物の活性が著しく高まり、熱帯泥炭の急激な分解が起き（冷たい燃焼＝ゆっくりした酸化）、さらに乾燥化が進むために火災が頻発し(熱い燃焼＝急激な酸化)、熱帯泥炭の消失が加速されてきた。

このような熱帯泥炭地では、生物生産生態系としては極めて貧弱なバイマス生産能しかないように考えられるが、実際には極めて高いバイオマス生産能を示す(図 4 参照)。実際、自然の熱帯泥炭林では、高水位下でも、気根とマウンドにより、泥炭地表層より酸素と栄養を吸収している生態系である。このように、熱帯泥炭地では、表層の機能維持が極めて重要で、この表層機能が維持されると、乾期でも水の供給が十分で光合成能の低下が少なく、鉱質土壌のように低 pH で溶解するアルミニュウムの毒性害（Al^{3+}自体の毒性と Al-P 化合物の生成によるリンの不可給化）もなく、理想的なバイオマス生産系となる。

また、δ ^{15}N の値の土壌と植物葉の解析から、熱帯泥炭地では空気中の窒素を固定している系である。マメ科植物は少なく、根粒･茎粒も見当たらず、一方、気根の先端は根分泌物のムシゲルで覆われ、多数の窒素固定バクテリアが棲息していることから、気根が酸素のみならず窒素固定も行っていると推察される。

以上のことから、熱帯泥炭地は極めて特徴的な生産生態体系であり、一種の水耕栽培系とも言える。そこで、高水位の熱帯泥炭地は、１）表層から酸素と栄養を供給する AeroHydro Culture (水気耕栽培）系で、２）植物栄養で最も多量に必要な窒素は、空中窒素固定により供給する空中窒素固定系と定義できる。この系では、リン栄養は植物の要求量も少なく溶脱しにくいので表層のリサイクル系で回り、カリの溶脱が大きいのでカリが長期的には制限要因と成り、窒素固定に必要な微量要素はもともと泥炭で少ないので制限要因となっている可能性がある。

これらを考慮して、熱帯泥炭地の理想的回復･修復の技術として、１）高水位にした AeroHydro Culture (水気耕栽培)で表層より酸素と栄養を供給(気根形成植物の導入、マウンド形成植物の導入)、２）空中窒素固定系の強化（気根形成植物の導入と幼苗時に窒素固定菌の接種）を基盤とすると良い。具体的技術として、荒廃した泥炭地では、特に表層機能が失われているので、１）まず水位の回復、２）気根やマウンド形成植物の導入、３）マウンドの人工的形成、４）緩効性肥料やコンポストにより泥炭表層からの栄養供給（特にカリ）、５）窒素固定系の強化として微量要素の供給（火山灰が良い資材)、６）菌根菌の接種による、生育促進効果とリン吸収能の強化、等が推奨される。これらの技術は、泥炭地のオイルパームにも適応出来来、高水位下でも表層より無機栄養（特にカリ）を供給することにより、効率的にカリを吸収させることにより、むしろ生産力を高める可能性すらある。

7.9.おわりに

熱帯泥炭地を自然資本で評価すると、最もその価値が高い生態系の一つとなる可能性が高い。熱帯泥炭地は、開発に伴う排水路の掘削で水位が低下し、微生物分解と火災により膨大量の炭素が放出されている。これは、地球規模での危機的状況で、逆の言い方をすると、熱帯泥炭地の保全は地球規模での安全保障を達成する。特に、熱帯泥炭地でのサゴヤシ栽培は、１）多量のバイオマスのエネルギー変換でエネルギーの安全保障（Energy security）と２）多量のサゴデンプンの食糧と飼料への利用で食糧･飼料の安全保障（Food/Feed security）を同時に 達成できる極めて有望な植物である。また、サゴヤシは同時に水位の高い状態（水貯留生態）が生育に適していることから、１）水の安全保障（Aquatic /water security）と２）炭素の安全保障（carbon Security）にも多大な貢献をする。これらの重要な安全保障は、SDGs の１７の目標でも鍵となる要因で、熱帯泥炭地の修復・回復･保全は、地球規模で SDGs に貢献する。

また、SDGs は銀行や投資家が投資する際の指標となりつつ有り、ESG（Environment, Social, Governance）や SRI (socially Responsible Investment)を通して、例えば､熱帯泥炭でオイルパームを栽培して､熱帯泥炭の ABCDEFGs Security (安全保障）を著しく低下させている企業への投資が著しく制限されるようになる。

また、食糧とエネルギーの地方での自給は、これまで大都市中心のエネルギー効率を重視した食料の高度加工システムを変換し､地方にその拠点を移す可能性を秘めている。食糧とエネルギーのフットプリントが今後一層重要になるなってくるが､熱帯泥炭はその新しい、生産システムを構築しうる可能性を秘めている。

8. 謝辞

本業務は、JICA-BRG (Peatland Restoration Agency, Indonesia) Project（代表井上京）の委託調査研究業務として実施した。また、JST-JICA の SATREPS（代表大崎満）、 環境省の環境研究総合推進費 (4-1506: 代表小林繁男と 2-1504: 代表平野高司）との部分的な連携のもとで実施した。

引用文献

Atikah, T. D., Rahajoe, J. S., & Kohyama, T. S. (2014). Differentiation in architectural properties and functional traits of forest-floor saplings among heath, peat swamp, and mixed dipterocarp forests. Tropics, 22(4), 157-167.

Guido R. van der Werf, *et al.*: Continental-Scale Partitioning of Fire Emissions During the 1997 to 2001 El Niño/La Niña Period. *Science* 303, 73-76 (2004) DOI:

10.1126/science.1090753

Hirano, T., Segah, H., Kusin, K., Limin, S., Takahashi, H., & Osaki, M. (2012). Effects of disturbances on the carbon balance of tropical peat swamp forests. Global Change Biology, 18(11), 3410-3422.

Kohyama, T., Suzuki, E., Partomihardjo, T., & Yamada, T. (2001). Dynamic steady state of patch‐mosaic tree size structure of a mixed dipterocarp forest regulated by local crowding. Ecological research, 16(1), 85-98.

Kohyama, T., Suzuki, E., Partomihardjo, T., Yamada, T., & Kubo, T. (2003). Tree species differentiation in growth, recruitment and allometry in relation to maximum height in a Bornean mixed dipterocarp forest. Journal of Ecology, 91(5), 797-806.

Kohyama, T. S., Kohyama, T. I., & Sheil, D. (2017; Online First). Definition and estimation of vital rates from repeated censuses: choices, comparisons and bias corrections focusing on trees. Methods in Ecology and Evolution. https://doi.org/10.1111/2041-210X.12929

Malhi, Y., & Wright, J. (2004). Spatial patterns and recent trends in the climate of tropical rainforest regions. Philosophical Transactions of the Royal Society B: Biological Sciences, 359(1443), 311-329.

Miyamoto, K., Suzuki, E., Kohyama, T., Seino, T., Mirmanto, E., & Simbolon, H. (2003). Habitat differentiation among tree species with small-scale variation of humus depth and topography in a tropical heath forest of Central Kalimantan, Indonesia. Journal of Tropical Ecology, 19(1), 43-54.

Miyamoto, K., Rahajoe, J. S., Kohyama, T., & Mirmanto, E. (2007). Forest structure and primary productivity in a Bornean heath forest. Biotropica, 39(1), 35-42.

Miyamoto, K., Kohyama, T. S., Rahajoe, J. S., Mirmanto, E., & Simbolon, H. (2016). Forest Structure and Productivity of Tropical Heath and Peatland Forests. In Tropical Peatland Ecosystems (pp. 151-166). Springer, Tokyo.

Nishimua, T. B., Suzuki, E., Kohyama, T., & Tsuyuzaki, S. (2007). Mortality and growth of trees in peat-swamp and heath forests in Central Kalimantan after severe drought. Plant Ecology, 188(2), 165-177.

Rahajoe, J. S., & Kohyama, T. (2003). The relationship between N, P returned via litter production and nutrient use efficiency of heath and peat swamp forests in central Kalimantan. Tropics, 13(1), 1-8.

Sundari, S., Hirano, T., Yamada, H., Kusin, K., & Limin, S. (2012). Effect of groundwater level on soil respiration in tropical peat swamp forests. Journal of Agricultural Meteorology, 68(2), 121-134.

Takahashi, H., Shigenaga, Y., Hamada, Y., Osaki, M., & Setiadi, B. (2018). Near-real time remote monitoring of ground-water/surface levels and warning to carbon loss from tropical peatlands in Indonesia. n: *The Proceedings of the International Workshop on Forest Ecological Resources Security for Next Generation: Development and Routine Utilization of Forest Ecological Resources and their Domestication* (eds. Shiodera, S., Fujita, M., & Kobayashi, S., pp. 80-90. Center for Southeast Asian Studies. Research Center, Kyoto University, Kyoto.

Takeshi Matsubara, Sehat J. Tuah, Suwido H. Limin & Mitsuru Osaki: Nitrogen source for common tree species in peat swamp forests, Central Kalimantan inferred from δ15N analysis, In Proceedings of the International Symposium on LAND MANAGEMENT AND BIODIVERSITY IN SOUTHEAST ASIA, Eds. by Mitsuru OSAKI et al., p.59-64, Bali, Indonesia, 17-20 September 2002

Takyu, M., Kubota, Y., Aiba, S. I., Seino, T., & Nishimura, T. (2005). Pattern of changes in species diversity, structure and dynamics of forest ecosystems along latitudinal gradients in East Asia. Ecological Research, 20(3), 287-296.

Yamakura, T., Hagihara, A., Sukardjo, S., & Ogawa, H. (1986). Aboveground biomass of tropical rain forest stands in Indonesian Borneo. Vegetatio, 68(2), 71-82.

Yanbuaban, M., Nuyim, T., Matsubara, T., Watanabe, T. and Osaki, M.: Nutritional ecology of plants grown in a tropical peat swamp. *TROPICS*, **16**, 31-39 (2007)

UNFCC-SBSTA 38 Research Dialogue : Plenary II: Emerging scientific findings: Ecosystems and GHG emissions and removals from sources, sinks and reservoirs, including from terrestrial ecosystems, In Developments in research activities relevant to the needs of the Convention, 4 June 2012, Maritim Hotel, Bonn, Germany

UNFCCC Workshop: 24-25 October 2013, Bonn, Germany

Annex.01

GUIDEBOOK FOR ESTIMATING TROPICAL PEATLAND ECOSYSTEM

- Carbon and Water Dynamics-

2nd Edition

BRG-JICA PROJECT
Peatland Restoration Agency – Japan International Cooperation Agency Project for The Elaboration of Peatland Restoration
JICA

IJ-REDD+ PROJECT
Indonesia-Japan Project for Development of REDD+ Implementation Mechanism
JICA

GUIDEBOOK FOR ESTIMATING TROPICAL PEATLAND ECOSYSTEM
- Carbon and Water Dynamics-
2nd Edition

Authors:
Mitsuru Osaki
Ayako Oide
Kayo Matsui
Rahmawati Ihsani Wetadewi
Haris Gunawan
Albertus Sulaiman
Awaldin
Keiji Kimura
Takashi Hirano
Hidenori Takahashi
Yohei Hamada

Published by:
JICA-BRG Project between Peatland Restoration Agency, Indonesia (BRG) and Japan International Cooperation Agency (JICA)

Published Date 20 March 2018

Information of 1st Edition "GUIDEBOOK FOR ESTIMATING CARBON EMISSION FROM TROPICAL PEATLAND IN INDONESIA". 2nd Edition is revised from this 1st Edition.

This publication was produced in its first version by the Indonesia−Japan Project for the Development of the REDD+ Implementation Mechanism (IJ-REDD+ Project) in collaboration with the Ministry of Environment and Forestry Indonesia (KLHK), Hokkaido University, the Environment Agency of Central Kalimantan Province (BLH Provinsi Kalimantan Tengah), the Agency for the Assessment and Application of Technology (BPPT), the Agency for Research and Development of Environment and Forestry (BPPLHK) Banjarbaru, the Sebangau National Park Office, the University of Palangka Raya, and Starling Resources. The first version of the publication was funded by the Japan International Cooperation Agency (JICA). The second version was produced by the Indonesia-Japan Project for Peatland Restoration (BRG-JICA Project) in collaboration with the Peatland Restoration Agency Indonesia (BRG), Hokkaido University, Kyoto University, the Research Institute of Humanity and Nature (RIHN), the National Agency for the Assessment and Application of Technology (BPPT), and the Ministry of Environment and Forestry Indonesia (KLHK). The second version of the publication was funded by the Japan International Cooperation Agency (JICA).

PREFACE

Hokkaido University and Palangka Raya University have a long history of cooperation in research on tropical peatland ecosystems dating back to 1997. The Japan International Cooperation Agency (JICA) and the Japan Science and Technology Agency (JST) have also supported this cooperation through the Science and Technology Research Partnership for Sustainable Development (SATREPS) program, a Japanese government program that promoted international joint research with the title "Wild Fire and Carbon Management in Peat-Forests in Indonesia" from 2009 to 2014. These cooperative programs have generated important research on tropical peatland ecosystems in Central Kalimantan and many outcomes of this cooperation have been included in a recently published book edited by M. Osaki & N. Tsuji (2016), "Tropical Peatland Ecosystems", 651 p. This is the world's first complete book on this topic and it contains 41 scholarly articles that describe various aspects of tropical peatland ecosystems.

In line with these research advances, one of the recommendations that emerged from a joint workshop between the SATREPS program and the IJ-REDD+ Project in January 2014 was to develop methodologies to mitigate climate change due to carbon emissions. To this end, translating research results into a guide that can be easily understood by all stakeholders at the provincial government level was necessary. The IJ-REDD+ Project has coordinated and facilitated with stakeholders the preparation of this guidebook on estimating carbon emissions from peatlands in Indonesia, particularly with stakeholders from Central Kalimantan.

After these projects and the first version of the guidebook, Mr. Joko Widodo, the president of Indonesia, issued a presidential regulation in early 2016 to establish the Peatland Restoration Agency (BRG) which bears the mandate of peatland ecosystem restoration for two million hectares in five years. This is the evidence of genuine concern that peatland restoration is an urgent task in Indonesia. Many stakeholders are involved in peatland management, such as oil palm and fast-wood plantation companies, local communities, and agro-industries which grow sago, nipa, coconut, coffee, cacao, and native species for food and feed production and biomass production as a source of bioenergy. In addition to coordinating the interests of multiple stakeholders, multiple elements in peatland ecosystems need to be managed including water levels, nutrient status in soil and water, vegetation, topography, and the economic system.

The Peatland Restoration Agency (BRG) must restore disturbed, degraded, and damaged peatlands over a period of five years. Hence further collaborations between Japanese and Indonesian scientists are urgently required to implement the conservation and sustainable management of peatlands in Indonesia. The BRG-JICA Project was conducted from October 2017 to March 2018 in collaboration with Hokkaido University and founded by the JICA. The BRG-JICA Project has updated its methodologies so the second vesion of the guidebook that is published here.

We wish to express our appreciation to all parties who have supported this cooperation.

31 March 2018

Mitsuru Osaki
Leader of the JICA-BRG Project

ACRONYMS

AVHRR	Advanced Very High Resolution Radiometer
BIG	Geospatial Information Bureau of Indonesia
C	Carbon
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon dioxide
DB	Drained and Burned Land
DEM	Digital Elevation Model
DF	Drained Forest
DOC	Dissolve Organic Carbon
EC	Eddy Covariance
ECMWF	European Center for Medium-Range Weather Forecast
ER	Ecosystem Respiration
GHG	Greenhouse Gas
GIS	Geographic Information System
GOI	Government of Indonesia
GPS	Global Positioning System
GWL	Groundwater Level
GWP	Global Warming Potential
IJ-REDD+ Project	Indonesia-Japan Project for Development of REDD+ Implementation Mechanism
INDC	Intended Nationally Determined Contribution
JICA	Japanese International Cooperation Agency
LiDAR	Light detection and ranging (an optical remote sensing technology)
MODIS	Moderate Resolution Imaging Spectroradiometer
MRV	Monitoring, Reporting and Verifying
N_2O	Nitrous Oxide
NDVI	Normalized Difference Vegetation Index
NEE	Net Ecosystem Exchange
NEP	Net Ecosystem Production
NOAA	National Oceanic and Atmospheric Administration
OP IRGA	Open-Path CO_2 Infra-Red Gas Analyzer
PALSAR-2	Phased Array type L-band Synthetic Aperture Radar
PAR	Photosynthetically Active Radiation
PM	Particulate Matter
RAN-GRK	*Rencana Aksi Nasional Penurunan Emisi Gas Rumah Kaca* (National Action Plan for Reducing GHG Emissions)
REDD+	Reducing Emissions from Deforestation and Degradation Plus Carbon Stock Enhancement
SAR	Synthetic Aperture Radar
SAT	Ultra-Sonic Anemometer-Thermometer
SESAME	Sensory data transmission Service Assisted by Midori Engineering

SRTM	Shuttle Radar Topography Mission
UNFCCC	United Nations Framework Convention on Climate Change
WI	Wetlands International

I INTRODUCTION

1.1. Background

Indonesia holds approximately 15 million hectares of peat soil, which represents 50% of the world's total tropical peatland area (DNPI, 2014). Peatlands store a huge amount of carbon in the form of organic matter accumulated in waterlogged and anaerobic conditions. In natural conditions when peatland hydrology is intact, peatlands are capable of providing multiple environmental benefits including water regulation, carbon storage, and biodiversity maintenance.

Despite such ecological functions, peatlands have been utilized for economic development for decades. Peatland development often involves the construction of drainage canals, which inevitably lower water levels and put hydrological integrity at risk. Once peat soils are exposed to the air, they start to decompose and become dry and vulnerable to fires – which are major sources of greenhouse gas (GHG) emissions. In 2010, emissions from peat decomposition and burning contributed to 44 percent of Indonesia's total GHG emissions (DNPI, 2014).

For this reason, sustainable peatland management must be a central component in Indonesia's strategy to combat climate change and its devastating impacts on its land and people. The important role of peatlands is also reflected in the recent Ministry of Environment and Forestry decree (No S.661 /MenLHK-Setjen/Rokum/2015), as well as the national action plan for GHG (RAN-GRK). The decree not only bans the issuance of new business licenses on peatlands, but also requires concession holders to halt peatland clearing and maintain the minimum groundwater level (GWL) at 40cm.

Groundwater level is the most important environmental factor in peatland management (Shigenaga et al., 2016). This guidebook aims to provide practical methods for estimating carbon emissions from peat decomposition and burning by using real-time GWL data as a key parameter. It also provides a method for predicting GWLs for several days into the future. These models can be used for various purposes in practice, including developing science-based national and regional development strategies and early fire warning systems.

1.2. What is this guidebook about?

This guidebook provides step-by-step procedures to:

- Collect spatial information from remote sensing data sources
- Collect field sampling data of GWL and other parameters
- Estimate GWL distribution based on the field samples and remote sensing data
- Establish a linear relationship (model) between carbon emissions and GWLs
- Predict GWLs several days into the future based on field sampling data.

Although the methods outlined in this guidebook were initially developed in Central Kalimantan during the JICA-JST Project from 2010 to 2014 (see Preface for the project background), this guidebook provides general procedures which are replicable for peatlands throughout Indonesia.

1.3. Guidebook Organization

This guidebook is organized into four parts: **I.** Introduction, **II.** Field surveys, **III.** Ground Water Table, **IV.** Carbon Emissions, and **V.** Future Considerations.

Part I of this guidebook provides introductory information including information on guidebook structure.

Part II of this guidebook explains how to conduct field surveys to obtain basic information on peatlands.

Part III of this guidebook explains how to predict Ground Water Level (GWL) several days in advance based on daily average GWL data observed in the field. Figure 17 illustrates the framework of the GWL Prediction Model.

Part IV of this guidebook introduces a protocol to estimate the amount of carbon emissions from peatland due to microbial decomposition and peat burning. It is divided into four sections: 1) Data collection and processing, 2) Data analysis, 3) Carbon emission modeling from peat decomposition, and 4) Carbon emission modeling from peat burning. Based on the framework presented in Figure 1, each section provides step-by-step procedures in sub-sections.

Part V of this guidebook suggests further developments for an Integrated Sensing System to understand models introduced in Parts III and IV. Part V also discusses potential applications of these models.

1.4. Who is this guidebook for?

This guidebook is intended to be used by a wide range of stakeholders in Indonesia who wish to develop and implement sustainable management practices on peatland by knowing the amount of carbon emissions from land use and land use change, and by preventing peatland fires. These stakeholders include:

- Policy makers;
- Peatland managers (such as concession holders);
- Researchers; and
- Local authorities.

Peatlands can be classified into three zones based on the distance from the coast; coastal peatland, intermediate peatland and inland peatland. Coastal zone is affected by high salinity from the sea water and the tidal effect. On the other hand, inland peat is an oligotrophic environment. We need to apply an efficient cultivation system for restoration as well as agricultural demands. From the point of soil nutrient spatial conditions, zone-specific management is necessary. Different peat zones have different properties in water quality, soil and vegetation. Aiming at a large-scale application of zoning in the future, it is necessary to monitor several associate factors that determine the peatland properties, which leads establishment of an improved model system for tropical peatlands monitoring.

2.1. What needs to be measured for field survey

Soil properties and water quality and condition determine the types of vegetation. In field survey, these environmental factors related to each other are measured. There are established methodology and description methods for each measurement, which are introduced 2.3 Analytical items.

The general information is needed to record at each plot such as:

- date of measurement and sampling
- crew members present
- location of plot (e.g. management district, etc.)
- plot identification – name and/or number of the sampled plot or stand/GPS information and precision (± X m)
- plant community/site type: e.g. intact forest, logged forest, grassland, oil palm or other (if other, describe)
- geomorphic setting: river banks, peat dome, interior or basin, etc.
- ecological condition – evidence of any recent or past disturbances such as:
    - timber harvest
    - hydrological status (e.g. drained or undrained
    - recent wildfire and other disturbances such as natural (e.g. disease, insects, etc.) or anthropogenic (e.g. roads, trails, nontimber harvest or use, etc.)
    - plantations/restoration sites (e.g. age of planted trees)
- topography
- soil surface description: wet, dry, litter presence, etc.

In addition to descriptive data, it is valuable to establish permanent photo points in plots.

2.2. Survey Design

Survey plan can be designed by the following steps, which must be carried out in a transparent and consistent manner. Opinions and ideas from the crew members who are experienced in each survey need to be reflected and well-justified.

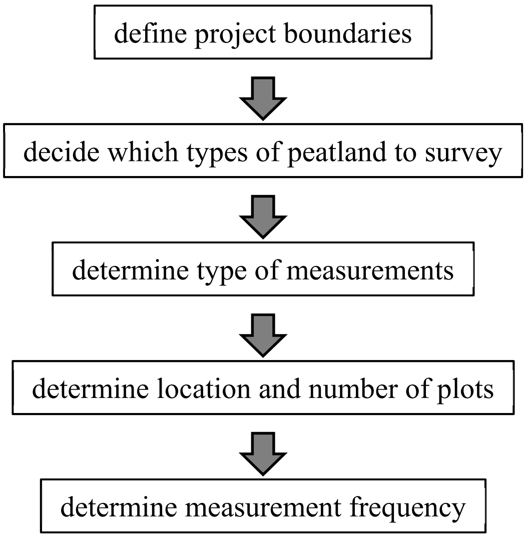


Figure1 Suggested steps in the preparation of measurement plan.

Based on the purpose of survey, site selection, types of survey (e.g. transect survey, area survey, etc.) and sampling design including analytical items (e.g. water quality, soil, vegetation, etc.) can be determined. Seasonal changes should also be considered in tropical peatlands, which has a big seasonal difference in water and soil condition.

2.3. Analytical items

Not all the analytical items are necessary or infeasible at field survey. Therefore, some of them will be selected based on the project purpose. The accuracy of measurement devices used at field also needs to be considered. The measurement values given by devices for outside use are usually less accurate than those analyzed under well-equipped condition in laboratory. If a high accuracy is required, sample collection as well as field measurement needs to be carried out for detail analysis in laboratory.
Following analytical items are useful to determine each plot.

- Soil physical properties
  - Soil texture (simple diagnosis at field / lab analysis)
- Soil chemical properties such as
  - EC (field measurement / lab analysis)
  - pH (field measurement / lab analysis)
  - Concentrations of exchangeable cations (K^+, Na^+, Ca^{2+}, Mg^{2+}) (lab analysis)
  - CEC (lab analysis)

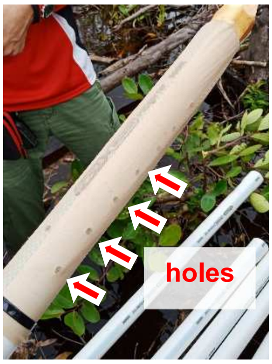
- Ground water
  - Water level (field measurement)
  - Water qualities such as:
    - pH (field measurement / lab analysis)
    - EC (field measurement / lab analysis)
    - Concentrations of cations and anions (K^+, Na^+, Ca^{2+}, Mg^{2+}, PO_4^{3-}, NH_4^+) (field measurement / lab analysis)
    - BOD, COD, DO (field measurement / lab analysis)

2.4. Specific measurements

2.2.1 WATER

Several measurements such as pH and EC etc. will be conducted at field by using portable devises for each analytical item. To obtain water samples to apply for measurement, firstly a well will be established in each sampling site.

A long plastic pole, an electric drill, tights and plastic cable ties are the main materials for establishment of a well. The pole should be cut according to the depth of water table at each site, which needs to be checked in advance. One end of the pole will be drilled to make some holes on the side. Two layers of tights will cover the end of the pole with holes (a). It must cover all holes and be tied with a rubber band so that ground water be filtrated through them into inside of the pole (a). The covered tights will be band with a plastic cable tie (b). Wood piece is processed to put into the end of the pole, which is useful to penetrate peat (c). The pole is penetrated straight to peat and ground water can be taken from inside of the pole. It is better to put a cap on the pole end to avoid contamination of ground water inside the pole (d).



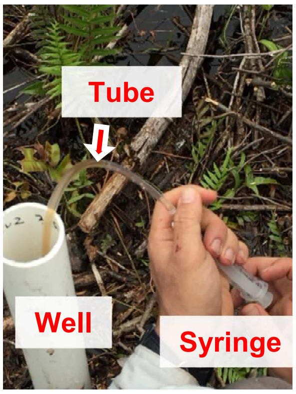
(a)

(b)

(c)

(d)

Using a tube and a syringe, ground water will be withdrawn into the syringe (e). Then, a filter is put on the syringe to collect water samples and apply to the measurement devices such as pH, EC and DO meters (f). Note that calibration must be done before measurement for each devise following the devises' manuals. When analyze a new sample, wash a residue adhering to the inner surface of a devise with a liquid to be analyzed next, then discard the liquid and dispense a new liquid to be analyzed. At least triplicate is necessary to obtain a data value.



(e)

(f)

2.2.2 SOIL

Soil samples will be collected by an auger at the points of determined intervals along a transect line. However, when a rapid change is expected on a transect, appropriate subdivisions should be set between the intervals. At field survey, observation of site and soil collected will be recorded.
Peat monitoring sheet is shown in appendix, which will be useful for recoding all the necessary information of sampling plot and survey area (see appendix. Peat Monitoring sheet).

For collecting soil samples, the depth of soil sampling will be decided based on the purposes of survey (i.e. 0-15 cm, 15-30 cm, 30-50 cm, 50-100 cm, 100-200 cm, 200-300 cm, 300-500 cm and > 500 cm). A soil sample is packed into a plastic bag. Air must be removed from the plastic bag before sealing as shown below. Also, peat soil water will be collected into plastic bottles by filtration at the depth of water level of each soil sampling points as explained in 2.4.3. WATER chapter.

Air is removed from a soil sampling bag.

2.2.3 VEGETATION

A tree survey contains all kinds of detailed information about the trees. The survey will reveal information such as species of the tree based on scientific name, physical measurements of the tree such as height and diameter, age of the tree etc.

Firstly, survey plot will be set by area measurement (a). The plots for tree survey should be representative, so the places that are specifically disturbed are not recommend to be set a survey plot. Three or four people are recommended to conduct tree survey in one square plot. At least one of them must be the experienced in identifying tree species. Each crew member is responsible for measurement, tree identification or recording.

(a) A survey plot is set by area measurement.

For the purposes of survey, the minimum size (cm) in stem diameter of mature trees to be measured will be decided. (i.e. trees with over 10-cm stem diameter). The main stem (trunk) diameter must be measured at 1.3 m above the soil surface (Kauffman et al., 2016). Within the individual plots, trees of each species are counted. All trees need to be tagged with special tags and numbers (b). These results are then expressed as percentages of the total for that area (i.e. Lithocarpus dasystachys makes up 15% of all the trees).

(b) A tree stem is measured and tagged with special tags and numbers

If possible, trees that are measured should be identified to the species or genus level. For the tallest tree of each species in an area, its height was measured using a clinometer. However, it is usually difficult in forests with a high tree density. The example of result table is shown in Table below.

Table 1 Results of tree survey

Species	Number of trees	Basal area (cm2)	Basal area (%)
Lithocarpus dasystachys	62	16157	15.32
Tetractomia tetrandra	36	8750	8.30
Combretocarpus rotundatus	4	6557	6.22
Xylopia fusca	8	5345	5.07
Cratoxylon glaucum	10	5083	4.82
Syzygium sp.	23	4849	4.60
Shorea teysmanniana	20	4446	4.22
Horsfieldia crassifolia	7	4195	3.98
Lithocarpus gracilis	1	4137	3.92
Mezzettia parvifolia	7	4130	3.92
Elaeocarpus mastersii	10	3529	3.35
Dactylocladus stenostachys	3	3513	3.33
Stemonurus secundiflorus	5	3426	3.25
Ilex hypoglauca	10	2767	2.62
Mezzettia umbelliflora	4	2757	2.61
Santiria griffithianum	11	2718	2.58
Neoscortechinia kingi	5	2652	2.51
Diospyros pseudomalabarica	8	2301	2.18
Gymnacranthera farquhariana	12	2209	2.09
Shorea balangeran	1	1304	1.24
Grewia sp.	10	1265	1.20
Garcinia sp.	3	1077	1.02
Others (35 sopecies)	67	12297	12
Total	**327**	**105466**	**100.00**

Reference

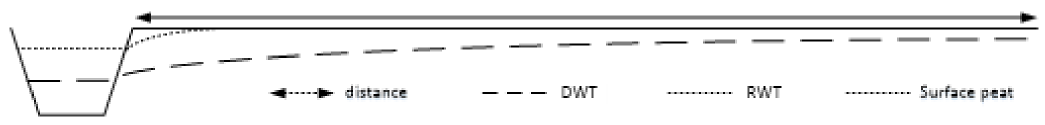
Kauffman et al. (2016) Protocols for the measurement, monitoring, and reporting of structure, biomass, carbon stocks and greenhouse gas emissions in tropical peat swamp forests. Working Paper 221.Center for International Forestry Research. DOI: 10.17528/cifor/006429

Annex.01

Appendix

	Name of surveyor		Peat profile
1	Date, Time		
2	Code / Number of sampling		
3	Administrative location		
4	GPS coordinate		
5	Peat maturity	Sapric/Hemic/fibric/Mineral/Charcoal(S/H/F/M/C) write in 'Peat profile'	
6	Peat thickness (cm)		
7	Depth of substratum (cm)		
8	Depth of charcoal (cm)		
9	Substratum soil type	Clay/sand	
10	Drainage pattern / type	natural/artificial (describe) . . .	
11	Distance for nearest canal (m)	primary/secondary/etc.	
12	Canal water table (WT) (cm) (Interview and/or observation)	Present ___ (cm); wet season ___ (cm); dry season ___ (cm)	
13	GWT of sampling point (cm) pH / EC (μS/cm)/DOC ※2		
14	Landuse		
	Year of canal construction		
	Previous landuse		
	Year of converting landuse		
15	Soil classification		
16	Number of samples	(total)	
	From auger		
	From core (undisturbed)		

Sketch:



Peat profile: Necessary information from soil observation, which are recorded in the tables will be drawn in the right space.
Sketch: in a transect survey, record general information in a visually understandable way such as site names, water level in dry season (DWT) and in rainy season (RWT), peat depth etc.

Reference of peat monitoring sheet

	Name of surveyor	Write the name who records
1	Date, Time	Write the date and time you conduct sampling in this point.
2	Code / Number of sampling	Write the code of sampling point.
3	Administrative location	Write administrative location. (Ex: name of village, district etc.)
4	GPS coordinate	Record GPS (X; Y) data at this point.
5	Peat maturity	Rapid assessment of peat maturity by squeezing amount of sample at field. For further explanation, see BBLSDP 2014(page 4, pdf page 9).
6	Peat thickness (cm)	The depth of mineral soil layer from the surface by auger measurement
7	Depth of substratum (cm)	Measure the depth where the mineral soil appeared
8	Depth of charcoal (cm)	Record the depths where charcoal is observed during collecting samples. Usually an artificial place has more charcoal layers than natural forests. Charcoal tents to appear in the upper layers in Natural forest due to the frequent fires in current decades.
9	Substratum soil type	Define mineral soil type. (Mineral Soil Classification: Clayey, Sandy, Loamy, etc.)
10	Drainage pattern / type	Describe drainage pattern / type (natural, artificially built, etc.)
11	Distance for nearest canal/stream (m or km)	Measure the sampling point to the nearest canal around, and recognize the canal (primary/secondary/branch etc.)
12	Canal water table (WT) (cm)	Measure the water table level from ground surface at the nearest canal. By interview (if possible). Difference between rainy season and dry season.
13	GWT of sampling point (cm)	Measure water table level at the sampling point using after you dig peat soil or make a well. Measure pH, EC and DOC as a site representative water quality)
14	Landuse	Describe present vegetation cover (forest, bare land, plantation etc.).
	Year of canal construction	Record when canal was built. (Interview)
	Previous landuse	Record the previous landuse / land cover. (Interview)
	Year of converting landuse	Record the year of converting land use to the present condition. (Interview)
15	Soil classification	Classify soil type of the samples using common soil taxonomy system or local taxonomy system (WRB,USDA, FAO, etc.)
16	Number of samples	Total number of samples taken from auger and cores
	From auger	The number of samples taken from auger.
	From core (undisturbed)	The number of core samples.

Peat profile: Necessary information from soil observation, which are recorded in the tables will be drawn in the right space.

Sketch: in a transect survey, record general information in a visually understandable way such as site names, water level in dry season (DWT) and in rainy season (RWT), peat depth etc.

Annex.01

2.5. Peat Thickness Estimation with a Phenology Classification Method

Hypothesis

According to studies of Central Kalimantan peatlands (Shimada et al. 2017), peat thickness is predictable by forest phenology type above the peat layer. Peat swamp forest (PSF) phenology type in Central Kalimantan was classified into eight major types (PHIL, W1, W2, W2D-A, W2D-Z, W1D, PHOB-Z, PHOB-V) using multi-temporal (1992−1993) monthly National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Radiometer (AVHRR) data. Specifically, fluctuation patterns of the vegetation index among three seasonal periods (i.e., the former half of the five-month rainy season, the latter half of the five-month rainy season, and the two-month dry season) were classified.

Tropical peatlands are characterized by high groundwater levels and their seasonal fluctuations. High groundwater level usually leads to a decrease in vegetation activity owing to anoxic stress to plant roots. Considering the hydrological buffer function of the peat layer, we focused on phonological difference due to the hydro-periodical difference of PSF and its relation to peat thickness. Riverine PSF and PSF fringing on shallow peat layers have greater water flow and seasonal groundwater level fluctuations in comparison to inner forests on deeper peat layers which tend to have permanently high groundwater levels that moderately fluctuate. Since the hydroperiod is a seasonal characteristic of peatlands in Southeast Asia, PSF phenology was hypothesized to be a predictor of underlying peat thickness. The result of the association of ombrophobous PSF phenology types (PHOB-Z and PHOB-V [Remark 1]) with significantly shallower peat layers (Table X. 1) indicates the influence of flooding stress due to a waterlogging in the rainy season. This supports a part of the hypothesis (Figure 2-1).

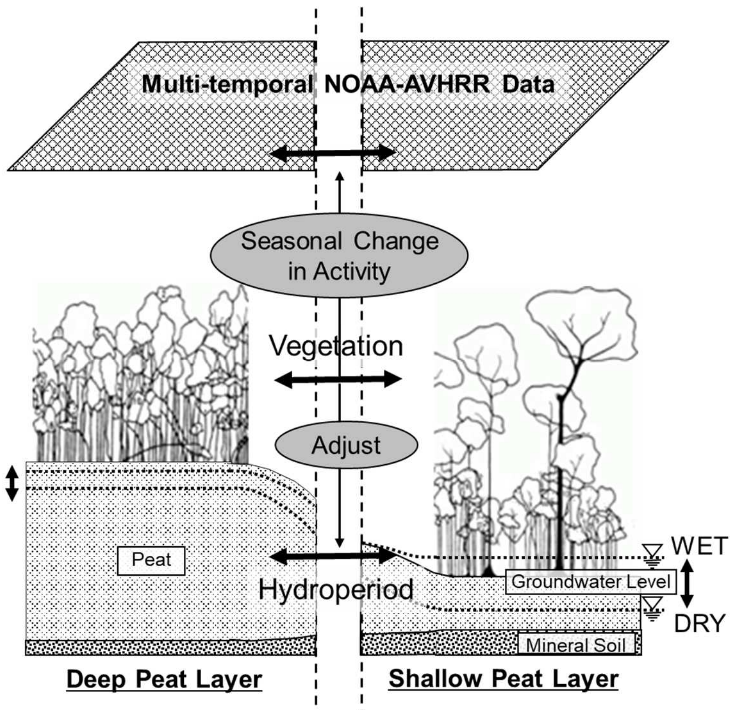


Figure 2-1: Phenological pattern, mean peat thickness, and percentage of areal extent among eight peat swamp forest types in Central Kalimantan (cited from Shimada et al. 2017)

PSF phenology types that have maximum vegetative activity during the latter rainy season (i.e., W2 and W2D-A) occur on relatively deeper peat layers (Table X. 1). The root mean square error (RMSE) for the peat thickness estimation map was derived by assigning each associated mean peat thickness value (Table X. 1 and Figure X. 6) to PSF types in Central Kalimantan and was found to be 2.49 m. Individually, the phenology types on deeper peat layers (i.e., W2, W2D-A, and W2D-Z) tend to have greater errors (RMSE = 2.33 m, RMSE = 3.17 m, and RMSE = 2.77 m, respectively) in peat thickness estimation.

Table 2-1: Phenological pattern, mean peat thickness, and percentage of areal extent among eight peat swamp forest types in Central Kalimantan (cited from Shimada et al. 2017).

Phenology type	Phenological pattern*					Mean peat thickness (m)	Percentage of areal extent (%)
	WET1	→	WET2	→	DRY		
PHIL	1	(+) (−)	1	(−)	0	0.75	0.5
W1	1	(−)	0	(+)(−)	0	–	0.8
W1D	1	(−)	0	(+)	1	1.56 [bc]	9.1
W2	0	(+)	1	()	0	4.70 [ab]	6.4
W2D-A	0	(+)	1	(-)	1	4.59 [a]	13.6
W2D-Z	0	(+)	1	(+)	1	2.64 [b]	47.2
PHOB-Z	0	(+)	0	(+)	1	1.35 [c]	13.3
PHOB-V	0	(−)	0	(+)	1	0.84 [c]	9.1

*WET1: former half of the rainy season (September 1992 to January 1993)
WET2: latter half of the rainy season (February to June 1993)
DRY: dry season (July to August 1993)
0: Normalized Difference Vegetation Index (NDVI) during a seasonal period < annual mean NDVI
1: NDVI during seasonal period > annual mean NDVI
(+): positive gradient between seasonal periods
(-): negative gradient between seasonal periods
a > b > c: values followed by the same letter are not significantly different at a significance level of $P < 0.05$ (Sheffé's test)

2.2.2. Peat Thickness Estimation Method

Here, we explain the steps involved in the derivation of the phenological classification map (i.e., the prediction map for peat thickness).

Step 1. Preparation of time-series satellite imagery data

- Acquisition of time-series vegetation index data product or raw reflectance imagery data which are to be calculated into a vegetation index. High temporal resolution image data such as Terra/Aqua-Moderate Resolution Imagery Spectroradiometer (MODIS) and NOAA-AVHRR are preferable since the elimination of contamination from noise or clouds can be more easily achieved.

- Vegetation index time-series imagery products can be freely acquired through various web archive data center portals, e.g., United States Geological Survey (USGS) Global Visualization Viewer (GloVis: https://glovis.usgs.gov/), USGS EarthExplorer (https://earthexplorer.usgs.gov/), National Aeronautics and Space Administration (NASA) Earthdata Search (https://search.earthdata.nasa.gov/search), and Global Land Cover Facility (GLCF: http://www.landcover.org/).

- A dataset of more than one year is required for analysis.

- The vegetation index can be the NDVI (eq (1)), the Enhanced Vegetation Index (EVI: eq (2)), or the Temperature Adjusted Vegetation Index (TAVI: eq (3) and eq (4)). TAVI, which includes not only vegetation chlorophyll activity but also vegetation transpiration activity, can be a more sensitive indicator than NDVI in the tropics (Foody et al. 1996).

$$\text{NDVI} = \frac{NIR-Red}{NIR+Red} \qquad \textbf{eq (1)}$$

$$\text{EVI} = \text{G} \times \frac{NIR-Red}{NIR+C_1 \cdot Red-C_2 \cdot Blue+L} \qquad \textbf{eq (2)}$$

$$\text{TAVI} = \frac{NDVI}{T_s} \times 100 \qquad \textbf{eq (3)}$$

Where,
NIR: reflectance in the wavelength of near-infrared,
RED: reflectance in visible red,
Blue: reflectance in visible blue,
L: canopy background adjustment,
G: gain factor,
C_1, C_2: the coefficients of the aerosol resistance term,
T_s: surface radiation temperature calculated by the split window algorithm using two thermal bands (Price 1990) [eq (4)].

$$T_s = \frac{[T_x+3.3(T_x-T_y)](5.5-\varepsilon_x)}{4.5-0.75T_x(\varepsilon_x-\varepsilon_y)} \qquad \textbf{eq (4)}$$

Where,
T_x, T_y: brightness temperature (K) at thermal bands *x* and *y*,
ε_x, ε_y: emissivity at the wavelength bands *x* and *y*.

In the estimation case of Shimada (2001), datasets of 10-day composite NOAA-AVHRR data products on NDVI and channel-4 and channel-5 radiation temperature (T_x and T_y, respectively) over the Sumatra-Kalimantan area were collected from the Earth Resources Observations Systems (EROS) Data Center (Shimada et al. 2001). T_S was calculated using eq (4) by assuming the surface emissivity (ε_x, ε_y) to be 0.96 (Nemani et al. 1993). The image data period was set as April 1992 to September 1993 to avoid the effects of the large-scale forest fire in 1994
.

Step 2. Preprocessing of time-series satellite imagery data

- Monthly composite imagery data (e.g., NDVI, EVI, T_S, and other indices) should be prepared from shorter time period composites such as eight-day, 10-day, or 16-day composite data by maximum filter so as to reduce the effects of cloud contamination.

- Monthly composite data should be smoothed by the three-month moving median filter to eliminate remaining contamination due to clouds and noise (Fig. X. 2).

- TAVI, if adopted for the phenological classification, should be calculated using median-smoothed monthly images.

- The monthly vegetation index imagery dataset which was trimmed into a one-year period should be aggregated into three seasonal index images with a one-year mean image. The concept of the discrimination method of the seasonal period within a year is shown in the next step (Step 3).

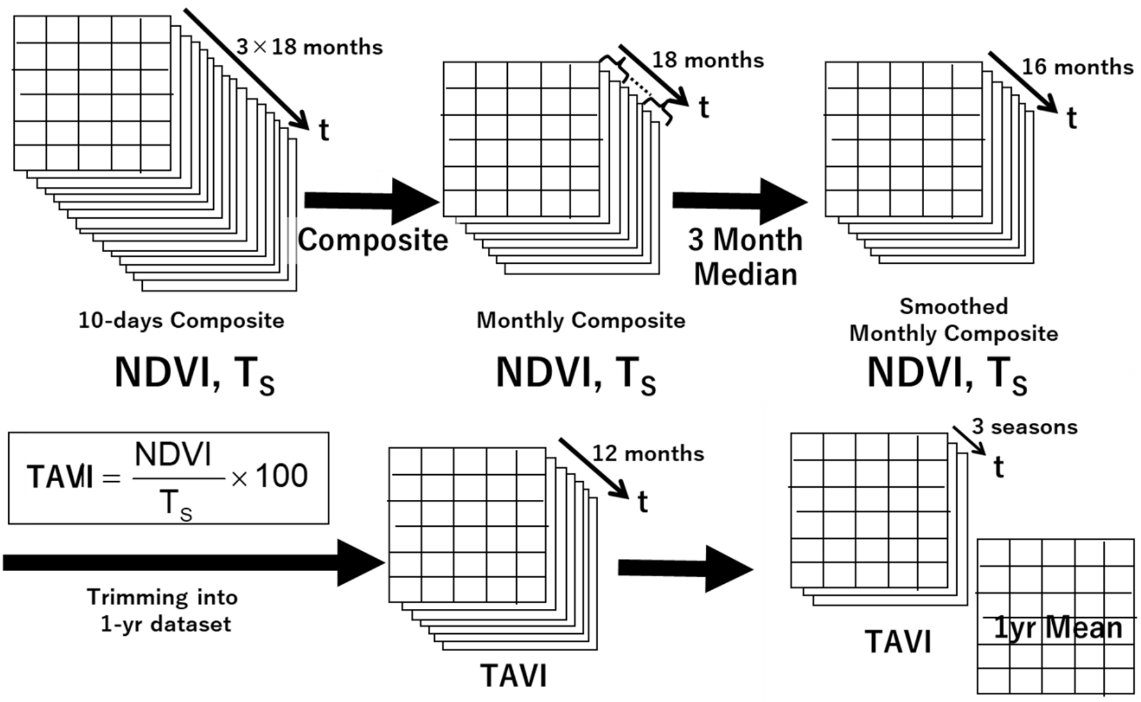


Figure 2-2: Image preprocessing scheme example of deriving one-year mean and seasonal Temperature Adjusted Vegetation Index (TAVI) data from the 10-day composite National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Radiometer (AVHRR) and T_S time-series data.

Step 3. Seasonal period discrimination

- A year of the tropical region can be divided into two seasonal periods, i.e., the wet (rainy) season and the dry season. Each region has its own unique seasonal distribution, e.g., the wet season typically occurs in Central Kalimantan from June to October, with the remaining months constituting the dry season (~ two months) and intermediate months. To reflect vegetative responses resulting from regional and real-time micrometeorology, data corresponding to the region and time of imagery acquisition should be used. Since extraction of vegetation seasonal characteristics is important and the wet season is longer than the dry season, the wet season is divided into two seasonal periods, i.e., the former and latter wet periods (WET1 and WET2, respectively).

Including the dry seasonal period (DRY), three seasonal periods are discriminated (Fig. X. 3).

- Monthly precipitation data and evapotranspiration rate data at the target area and time period are needed to set the ranges of the seasonal periods.

- Identify the month of the year when monthly evapotranspiration exceeds monthly precipitation. Classify these consecutive months as the dry period and the remaining months as the wet period. The wet period should be split in half and the first half of the period classified as WET1 and the second half classified asWET2.

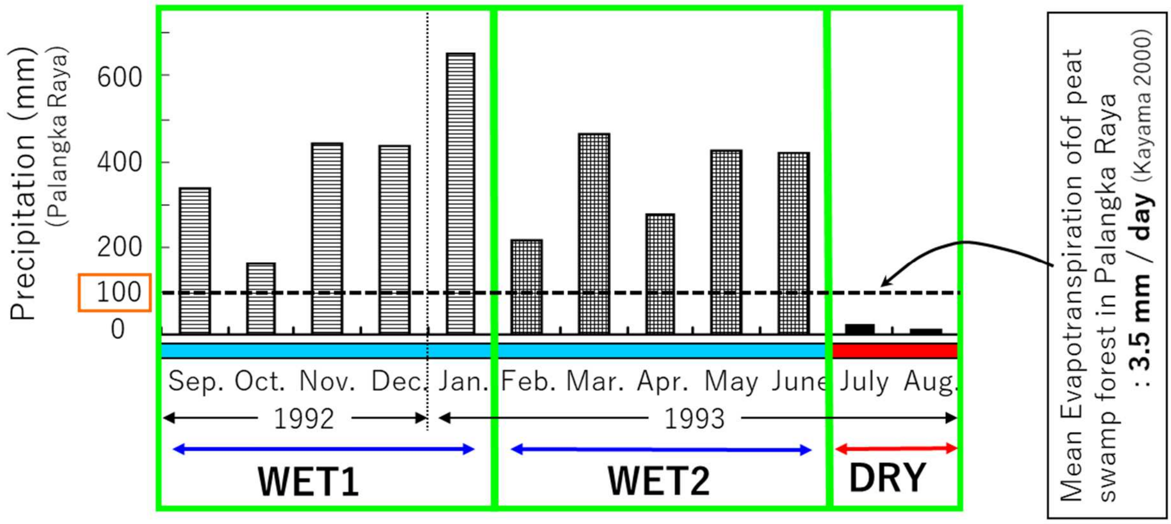


Figure 2-3: Discrimination of three seasonal periods in a target year (September 1992 to August 1993) in a peat swamp forest near Palangka Raya, Central Kalimantan

Step 4. Phenological type classification

- The pixel value of each seasonal vegetation index (e.g., $\overline{\mathrm{TAVI}_{\mathrm{WET1}}}$, $\overline{\mathrm{TAVI}_{\mathrm{WET2}}}$, and $\overline{\mathrm{TAVI}_{\mathrm{DRY}}}$) is to be compared to the corresponding one-year mean vegetation index value (e.g., $\overline{\mathrm{TAVI}_{\mathrm{1yr}}}$) to assess vegetative activity during different seasonal periods (Fig. X. 4).

- If a value of the seasonal vegetation index exceeds the annual mean value, the vegetation at the corresponding pixel for the seasonal period is considered active, while pixel values below the annual mean value are considered inactive (Table X. 1). All combinations of active and inactive vegetation among the three seasonal periods create six patterns (i.e., in the following order, WET1:WET2:DRY = +:+:–, +:–:–, +:–:+, –:+:+, –:–:+, –:+:–).

- The gradient of vegetation index values between consecutive seasonal periods (i.e., between WET1–WET2 and WET2–DRY) can be analyzed. The total number of possible phenology patterns is 10.

- Each vegetation phenology type can be named, e.g., the ombrophilous type as PHIL and the ombrobobous type as PHOB (Fig. 4, Table X. 1).

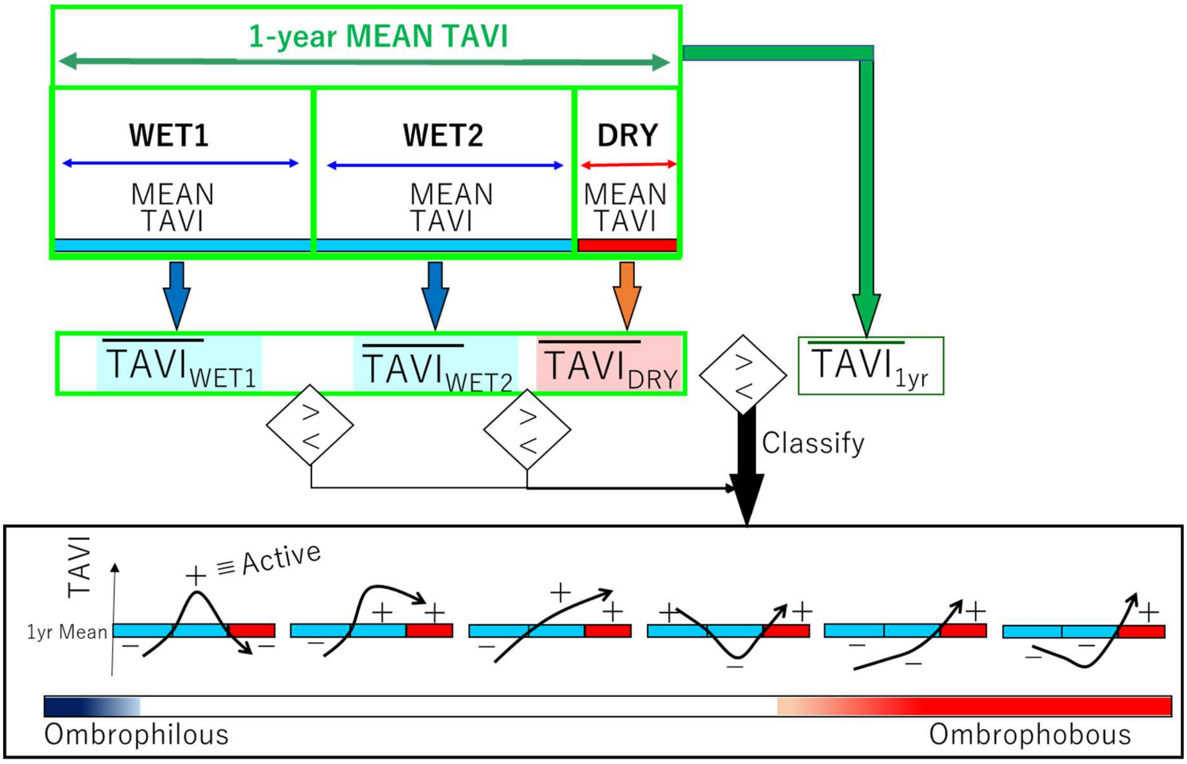


Figure 2-4: Schematic figure on phenology type classification using the Temperature Adjusted Vegetation Index (TAVI) among three seasonal periods in a target year (September 1992 to August 1993) in a peat swamp forest near Palangka Raya, Central Kalimantan.

Figure 2-5: Output map of the phenological schematic figure on discriminating three seasonal periods in a target year (September 1992 to August 1993) in a peat swamp forest near Palangka Raya, Central Kalimantan.

Step 5. Assigning phenological type to peat thickness

As vegetation phenology relates to peat thickness (Fig. X. 1, Table X. 1), the mean thickness value for each phenology type (Table X. 1) can be used to derive an estimated peat thickness map (Fig. X. 6).

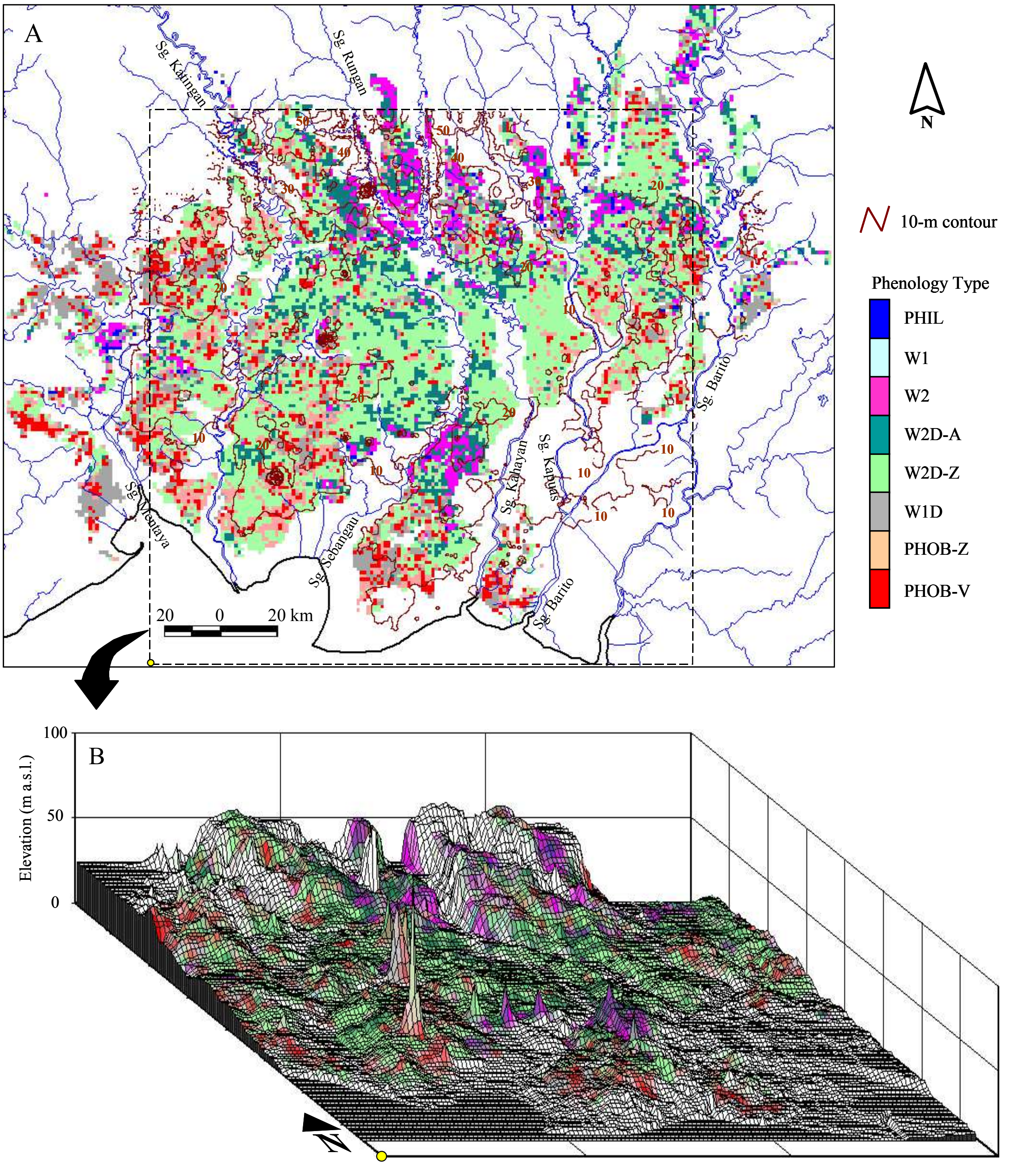


Figure 2-6: Phenology classified map of a peat swamp forest in Central Kalimantan derived using the Temperature Adjusted Vegetation Index derived from National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Radiometer (AVHRR) (September 1992 to August 1993) data. Each phenology type corresponds to a phenological pattern and a specific peat thickness (Table X. 1; cited from Shimada 2001).

REFERENCES

Shimada S. (2001). Distribution of Carbon in Peat Layer and Estimation of Carbon Mass using Satellite Data in a Tropical Peatland, Central Kalimantan, Indonesia, Hokkaido University Ph.D. thesis.

Shimada S., Takada, M., Takahasi, H. (2017) Peat Mapping, In: Tropical Peatland Ecosystems (Osaki & Tsuji Eds.) Chapter 31, Springer Japan.

Annex.01

3.1. Ground Water Table (GWL) Monitoring

Groundwater level measurements

GWL is a key parameter for estimating carbon emissions from peat decomposition and burning. Therefore, it is important that GWL is measured in every type of peatland identified based on distinctive land use and land cover characteristics in the study area (see Sub-section 2.2.1). GWL data are collected through the steps described below.

Step 1. Prepare equipment for field measurements

A minimum list of equipment needed for the field measurement of GWL is provided below, and should be adjusted based on the field condition. This guidebook suggests that GWL be monitored and recorded by using the SESAME system[1], which comes with water level, temperature and precipitation sensors (see Figure 3).

- SESAME system
- SIM card for mobile network
- Laptop computer with a modem
- Iron pipe
- PVC pipe
- Eijkelkamp[2] peat auger
- Cleaver
- GPS receiver
- Compass
- Measuring tape

Activate the SIM card. Top up the card (if it is prepaid) before it expires for seamless data transmission.

Obtain a server access license (user ID and

[1] SESAME system SESAME 01-II: http://www.midori-eng.com/english/image/sesame-01-2_pamph.pdf

[2] The Eijkelkamp auger is a peat sampler used for soil profile description and classification. The details about the Eijkelkamp auger are available at https://en.eijkelkamp.com/products/augering-soil-sampling-equipment/peat-sampler.html.

password) for data acquisition[3].

Set up the modem on a laptop computer for data transmission.

Figure 3-1. SESAME system

Test the Internet connection.

Step 2. Select locations for field measurements

Select field measurement locations based on the following conditions:

- The locations must be physically accessible and legally permissible for the installation of the SESAME system and its maintenance.
- GSM/GPRS/Q-CDMA network coverage is available (because the SESAME system transmits data through the mobile network).
  - If the network coverage is not available at the ground surface level, an antenna may be mounted above the vegetation canopy to catch the signal.
- The locations are representative of distinctive peatland types identified by the remote sensing imagery (see Sub-section 2.2.1 on Peatland Type).
  - The SESAME system should be installed at every distinctive type of peatland, as the Carbon Emission Model will be developed per peatland type.
  - The SESAME system should be installed at the CO_2 flux observation sites as well (see Sub-subsection 2.1.2.2).
- The location is safe from potential thefts of instruments.

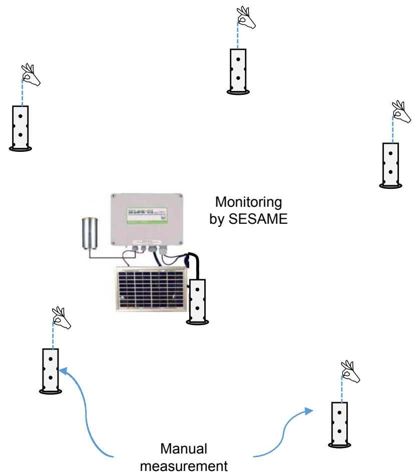
[3] The server is currently maintained by Midori Engineering Laboratory in Japan. Contact Mr. Yukihisa Shigenaga (email: shigenaga@midori-eng.co.jp; Telephone: +81-11-555-5000; URL: http://www.midori-eng.co.jp) for details.

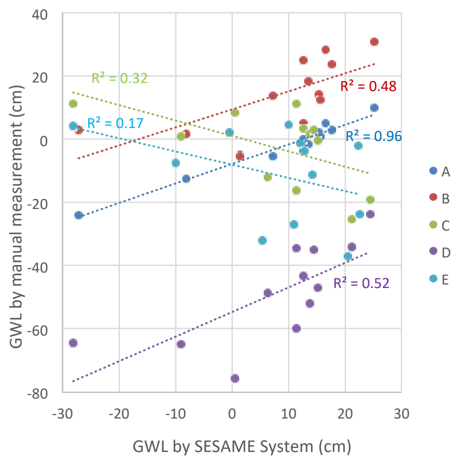
Box 2. How many units of the SESAME system should be installed in the area of interest?

Because GWL is affected by a number of factors including precipitation, vegetation types, land cover, slope of the land, peat depths and water channels (i.e., rivers and canals), there is no single answer to which how many units of the SESAME system are needed in order to represent GWLs over a certain area of peatland. The following method can be adopted to determine the number of SESAME system units to be installed in the study area.

- Install one SESAME system at a sampling location representative of a peatland type based on distinctive land use and land cover characteristics (e.g., drained forest or DF) found in the study area, and measure and record GWL at the location.

- Additionally, set up PVC pipes for manual GWL monitoring randomly in several locations within the same peatland type (DF) in the area. Measure and record GWLs manually at these locations once a month at least for one year. 12 GWL data from each monitoring pipe will be obtained. Then plot GWL data from the SESAME system on the X axis and manual GWL data on the Y axis to obtain their relationships.





- Examine the correlation of each regression line. If the correlation is strong, the data obtained by the SESAME system can be used to represent GWLs at the manual monitoring location. Consider to install another SESAME system at the manual monitoring location which showed a weak correlation.

- Caution needs to be taken for areas in which GWLs tend to change considerably within a short distance and/or short time interval (e.g., areas close to a drainage canal).

Step 3. Install a SESAME system in the selected location

Measure peat depths at the selected location to install the SESAME system.

Install an iron pipe all the way into the mineral soil through the peat layer so that the pipe stays stable (①).

Build a metal platform to hold a rain gauge sensor and the SESAME instrument cabinet. The metal platform must be placed high enough to be free from potential flood damage (②).

Make 0.5 cm diameter holes in a PVC pipe to serve as a water gauge (③).

Install the SESAME instrument cabinet on the iron pipe (④). There is a solar panel on the box. Therefore, the installation must be directed into the sunlight.

Install the rain gauge sensor on the metal platform (⑤).

Install the water logger sensor into the PVC pipe (⑥).

Install an iron pipe all the way into the mineral soil through the peat layer. It must be placed several meters away from the SESAME system (⑦).

Install a ground surface elevation laser sensor into the PVC casing. The laser sensor must be placed high enough to be free from potential flood damages (⑧).

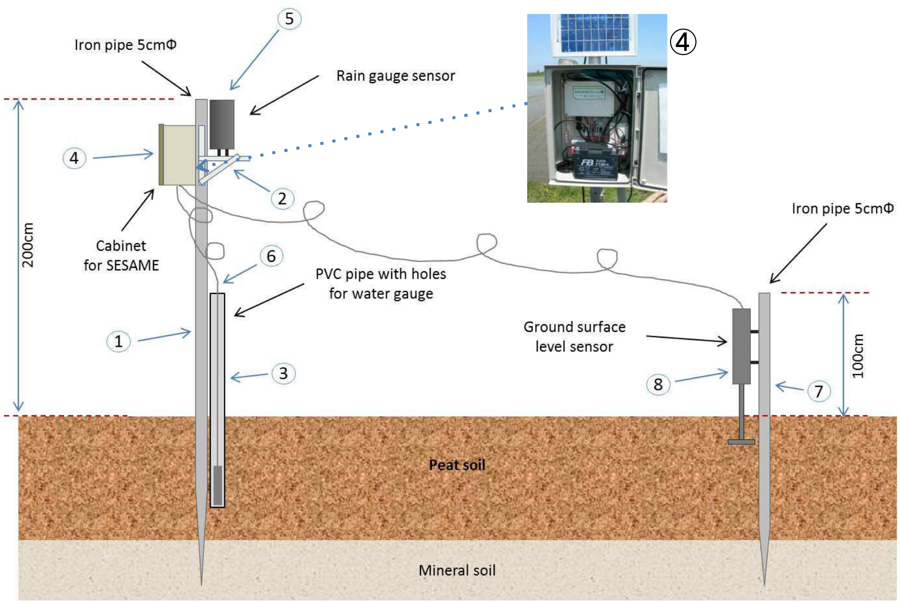


Figure 3-2. Illustration of SESAME system installation

Step 4. Activate the SESAME system and start recording GWL and other microclimate parameters

Check that all components (GWL sensor, rain gauge, temperature sensor and ground surface elevation sensor) are working properly.

Activate the SESAME system and start recording GWL at the interval of 10 minutes and other microclimate parameters (i.e., precipitation and air temperature).

Check that the data from the SESAME system are transmitted to the server without any errors. If there are errors, you must check whether the SESAME system is properly installed in the field.

3.2. Soil Moisture Mapping with a Remote-Sensing Dataset

Step 1. Download an existing peatland map

A peatland map of the study area is needed to delineate peatland from non-peat areas. Indonesia has several peatland maps developed by various institutions and organizations, including the Ministry of Agriculture (MoA) and Wetlands International (WI) (see Figure 2). These are the most frequently cited maps in Indonesia. Peatland maps (in ESRI shape file) from these sources may be obtained by sending a formal letter of request.

Ministry of Agriculture
http://www.pertanian.go.id

Wetlands International
http://indonesia.wetlands.org/Infolahanbasah/PetaSebaranGambut/tabid/2834/language/id-ID/Default.aspx

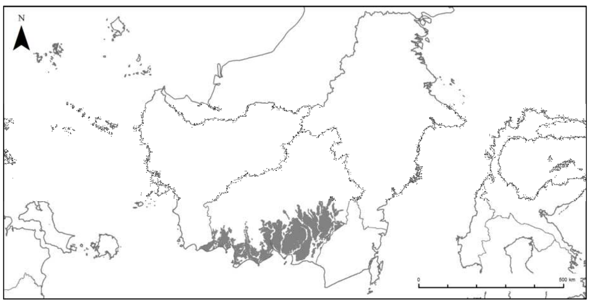


Figure 2. Peatland map of Central Kalimantan by Wahyunto, et al. (2004)

Box 1. An alternative approach: Create a new peatland map

A new peatland map be developed by using a spatial model. There are various methodologies to create a new peatland map, and the following is an example.

- Obtain and pre-process satellite imagery of the study area. In order to reduce data gaps and improve interpretation, it is recommended to use a combination of medium- to high-resolution optical satellite images as well as Synthetic Aperture Radar (SAR) data.
- Obtain BIG (Badan Informasi Geospasial) topography maps at the 1:50,000 scale and SRTM digital elevation model data. These data are used to determine geomorphological features such as peat dome structures and hydrological networks of the study area.
- Obtain NOAA Advanced Very High Resolution Radiometer (AVHRR) data of selected years from the USGS Global Land 1-km AVHRR Project, and evaluate vegetation activities by normalized difference vegetation index (NDVI). In order to estimate accurate peatland distribution in the study area, it is recommended that the NDVI analysis be based on the land cover of the past (e.g., 1990), when peatland was relatively undisturbed and its original condition and distribution could be assessed.
- Conduct ground-truthing to verify peat and non-peat areas in the study area.
- Manually delineate peat boundaries on a GIS platform based on the NDVI values, slope raster data, and morphological and hydrological network information obtained through remote sensing analyses. Peatlands generally occur on gentle slope areas with slope angles of less than or equal to 0.2°, and manual delineation should be conducted in reference to such areas.
- Conduct a geo-statistical analysis to estimate peat thickness distribution within the study area.
- Based on the distribution of peat thickness, filter out areas with peat thickness less than 50 cm (according to the definition of peatland), and develop the final peatland map of the study area.

Step 2. Download soil moisture data

Download soil moisture data from an available source to be used to estimate the spatial distribution of GWLs in the study area.
One source of global soil moisture data available for free of charge is the volumetric soil water layer product of the European Center for Medium-Range Weather Forecast (ECMWF). It is available at http://apps.ecmwf.int/datasets/data/interim-full-daily/.

Before downloading the data, you must select the applicable time-series (i.e., daily), coordinate system (e.g., WGS 84), coordinates, and grid size (e.g., 0.5 degrees). They must match those applied in Step 2 of Sub-section 2.2.1 (Peatland Type).

Step 3. Download NCAR/NCEP soil moisture data

Another source of global soil moisture data that is freely available and can be used to estimate the spatial distribution of GWL in the study area is the volumetric soil water layer product of NCEP (https://rda.ucar.edu/datasets/ds083.2/). After registration, a Gribs2 six-hourly file of soil moisture data can be obtained. These data have a resolution of ~ 0.25° × 0.25° and can be downscaled to 1 km × 1 km by using NOAH land surface models that have been installed in the Weather Research and Forecasting (WRF) software.

Step 4. Download forest cover change data

Download a forest cover change data product from an available source to be used to identify forest and non-forest areas in the study area.

One source of forest cover change data is the Global Forest Change product developed by NASA, available at https://earthenginepartners.appspot.com.

Step 5. Download surface reflectance data

Download a surface reflectance data product from an available source to be used to identify undrained and drained areas in the study area.

One source of surface reflectance data is the MODIS surface reflectance product (MOD09A1), available at http://modis.gsfc.nasa.gov/data/dataprod/mod09.php.
This MODIS surface reflectance product allows you to identify these areas based on plant physiological responses to different degrees of dryness on vegetated land surfaces.

Step 6. Download burned area data

Download a burned area data product from an available source to be used to estimate the spatial distribution of burned areas in the study area.

One of the burned area products available globally is MODIS burned area product (MCD45A1). It is available at http://modis.gsfc.nasa.gov/data/dataprod/mod45.php.

Original imagery data obtained by aerial photography may be used in combination with the MODIS burned area product to improve the accuracy.

Advanced techniques such as LiDAR (Light Detection and Ranging) and PALSAR-2 (Phased Array type L-band Synthetic Aperture Radar) may be used if they are available and applicable. They are high resolution and can determine ground surface levels with an accuracy of several centimeters. However, even if these high-resolution remote sensing techniques are adopted, field measurements must still be conducted for ground-truthing purposes (see Sub-subsection 2.1.2.3 on Burn Scar Measurements).

3.3. Groundwater level (GWL) analysis

The SESAME system records real-time GWL data at a 10-minute interval (see Sub-subsection 2.1.2.1). The data must be downloaded from the server and analyzed to obtain the lowest monthly average GWL(s) in the study year(s). This value will be used as a key parameter for the Carbon Emission Models explained in Sections 2.3 and 2.4. Obtain at least several lowest monthly average GWL values in the study years (i.e., several continuous years of GWL observation) in order to improve the accuracy of the models.

Step 1. Download raw data from the SESAME server

Access the SESAME server and download raw GWL data for the selected time and location via the procedures described in Annex 2.

You must install the SESAME software on your computer first to be able to access the server. To obtain this software, contact Midori Engineering Laboratory.

Step 2. Organize the raw data into observation data

Make a .csv file (e.g., Excel), and add field names to the spreadsheet.
Organize the downloaded raw data as observation data for each variable (i.e., GWL, precipitation, and ground surface level) via the procedures described in Annex 3.

Repeat this for all downloaded raw data collected at each type of peatland.

Check to see if data are complete.

If there are missing data for a short time period, make an interpolation and fill the data gaps.

If data gaps are caused by mobile network failure, the missing data can also be obtained directly from the SESAME system (data logger). The SESAME system stores data in a memory card for three months.

Step 3. Convert the observation data into daily average values for each parameter

Take the daily average of each observation data recorded at a 10-minute interval.

Add the daily average values for each variable in a new column on the spreadsheet (see Figure 12).

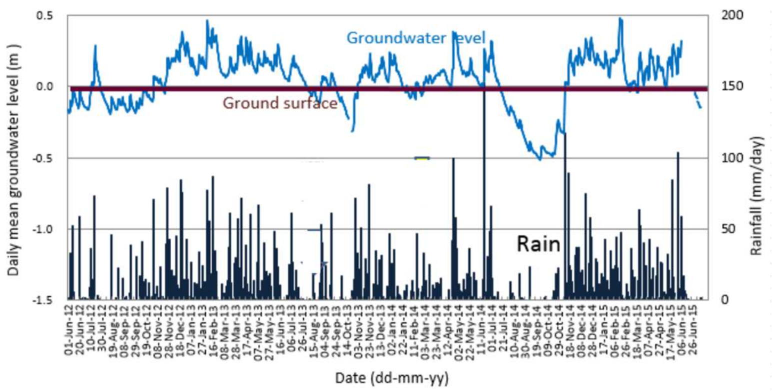


Figure 12. Example for time-series daily average GWLs with other parameters

Step 4. Obtain a linear relationship between daily soil moisture and daily average GWL for each type of peatland

Draw a scatter graph by plotting the observed (measured) daily average GWLs on the Y-axis and the remote-sensing based daily soil moisture data of all grid cells on the X-axis.

Soil moisture data can be obtained in the procedure explained in Step 2 of Sub-section 2.1.1, and daily average GWL values obtained in Step 3 above.

Obtain a linear regression equation between the daily soil moisture and the daily average GWL.

Repeat this for all peatland types (see Figure 13). The equations obtained for the regression lines will be used to simulate daily average GWLs at each peatland type in all other grids throughout the study area.

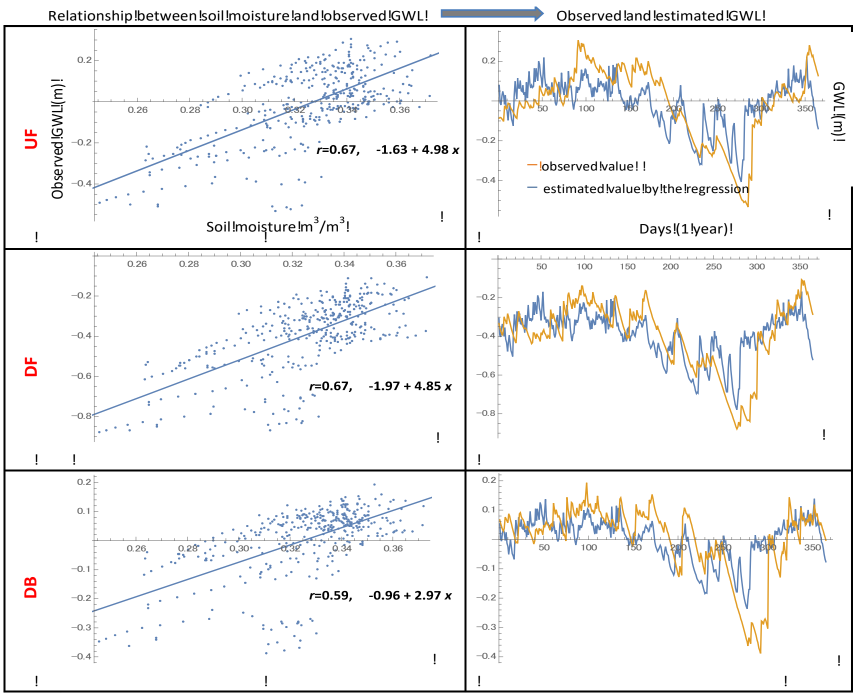


Figure 13. Example of GWL estimations for each peatland type based on the relationship between soil moisture and observed GWL data

Step 5. Estimate daily average GWL values in all other grid cells

Estimate daily average GWL at each peatland type in all other grid cells, using the equations obtained in Step 4 above and daily soil moisture data in each grid.

Step 6. Obtain the estimated monthly average GWL values in all other grid cells

Calculate monthly average GWL at each peatland type in all other grid cells based on the estimated daily average GWL values obtained in Step 5 above.

Step 7. Find the lowest value of the estimated monthly average GWLs for each peatland type in every grid cell

Find the lowest value from the estimated monthly average GWLs of the selected year obtained in Step 6 above.

Repeat this for each peatland type in every grid cell. These values are the **lowest monthly average GWLs in the study year** used as a key parameter for estimating annual average carbon emissions as described in Sections 2.3 (Carbon Emission Model from Peat Decomposition) and 2.4 (Carbon Emission Model from Peat Burning).

3.4. Ground Water Level Mapping

The GWL instrument (such as SESAME) results suggest a strong relationship between GWL and soil moisture in peatlands. This fact can be used to create a GWL map based on the soil moisture map. Required steps are described as follow:

1. Select the area of interest and download soil moisture data from https://rda.ucar.edu/datasets/ds083.2/. The data contain 52 layers of atmospheric moisture and four layers of soil moisture collected every six hours. The data can be downloaded from other sources such as ECMWS but in the Gribs file format. The data typically have a resolution of 0.25° × 0.25°.

2. Downscale the grid resolution into a 1 km × 1 km mesh with a land surface model. The most powerful model is called the Weather Research and Forecasting (WRF) model. The WRF model is a numerical weather prediction and atmospheric simulation system designed for both research and operational applications. WRF is run in the Linux environment so Linux Ubuntu, HDF5, NetCDF, WRF v. 9, and NCL software should be installed. First, initial data from NCEP are processed by the preprocessing procedure using the WPS module. Make the grid by using the geogrid, ungrib, and met grid. Then process the initial data by running WFR. For three days of simulation, the system requires six hours of processing. WRF have four numerical domain D01 (largest area), D01, D02, and D04 (the smallest area). The WRF result of soil moisture map with the D0 domain is depicted in Figure 14.

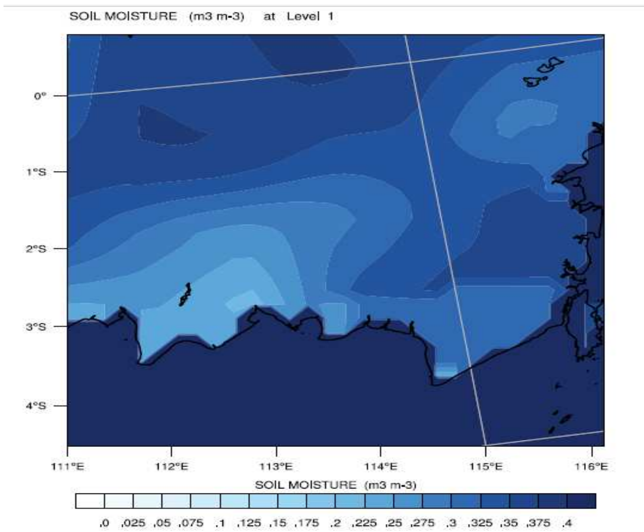


Figure 14: Soil moisture map from WRF output in the D01 domain.

3. Overlay the map with the peatland map to obtain the soil moisture map of the peatland area

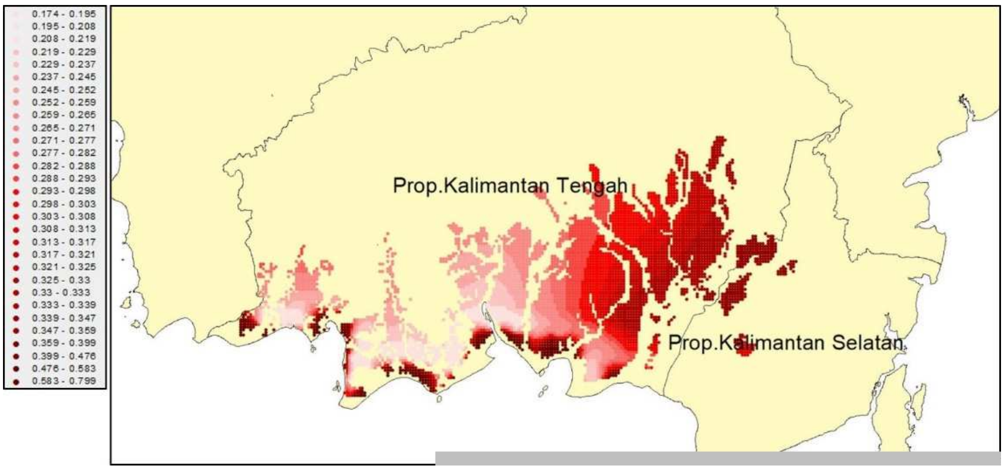


Figure 15: Soil moisture map of peatlands in Central Kalimantan.

4. Apply the empirical formula between soil moisture and GWL (Fig. 13) with three catagories (i.e., UF, DF, and DB) to obtain the GWL map as follows (Fig. 16);l

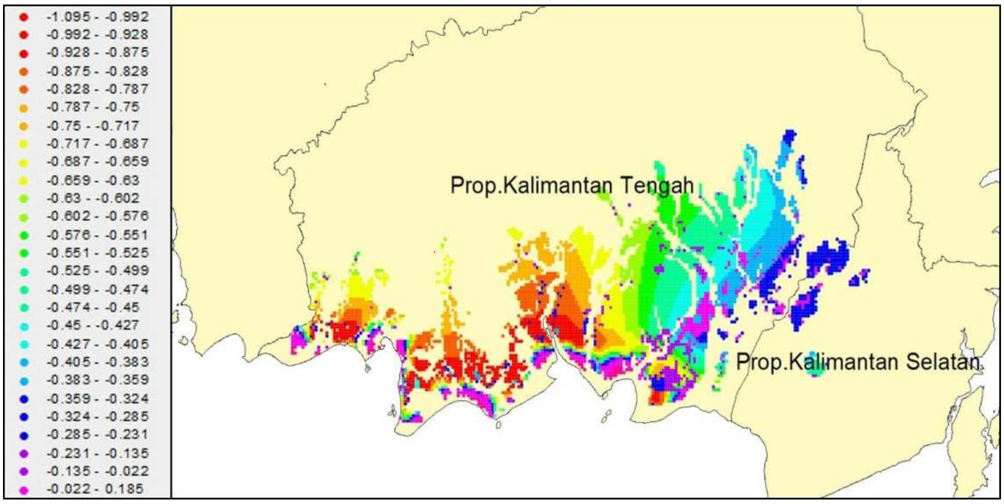


Figure 16: Ground Water Level map of peatlands in Central Kalimantan

4.1.3. Carbon Emission Model from Peat Decomposition

4.1.3.1. Carbon Emission Mapping

Box 1: What is a Carbon Emission Model from Peat Decomposition?

The Carbon Emission Model from Peat Decomposition is based on the assumption that there is a linear relationship between NEE and GWL. Based on this relationship, the model allows the estimation of the annual NEE of the study area using the lowest monthly mean GWL in the study year(s) as a key parameter.

NEE is the difference between the amount of CO_2 that is emitted by ecosystem respiration (RE) and absorbed by photosynthesis (gross primary production). Therefore, the relationship between net ecosystem production (NEP) and NEE is given by:

$$NEE = -NEP$$

$$NEP = GPP - RE$$

RE is found to increase with soil temperature and decrease as GWL (or soil moisture) rises. In forest ecosystems, CO_2 exchange between biomass and atmosphere usually occupies most of the carbon flow. If other carbon sources are negligible, the carbon balance of the forest ecosystem can be determined by NEE as follows:

- NEE > 0: carbon source (emission)
- NEE = 0: carbon neutral
- NEE < 0: carbon sink

Step 1. Obtain a linear relationship between the observed lowest monthly mean GWL in the study year(s) and annual NEE

Use the lowest monthly average GWL value for each peatland type selected from the observed monthly average GWL in the study years as described in Step 7 of sub-section 2.2.2.Use the annual NEE values for each peatland type obtained in sub-section 2.2.3.

Draw a linear regression line between the observed lowest monthly mean GWL in the study year(s) on the *x*-axis and observed annual NEE on the *y*-axis and obtain a relationship for each peatland type (Fig. 14) in the study area. Each regression equation obtained in this step will be used to estimate annual NEE values throughout the study area. The equation can be used to estimate NEE or CO_2 emissions for different years or other locations in the study area based on the estimated spatial distribution of GWL.

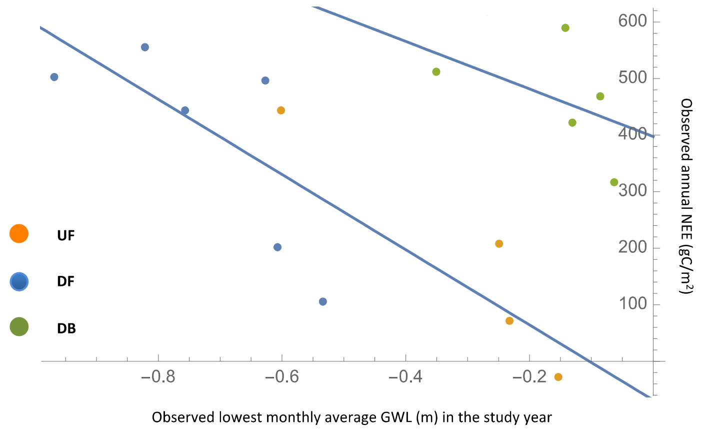


Figure 14: Example of relationships between the lowest monthly mean GWL (m) in the study years and annual NEE (g C m^{-2} $year^{-1}$) observed in Central Kalimantan (Hirano et al., 2012)

Step 2. Estimate annual NEE using the estimated lowest monthly mean GWL in the study year(s) in all other grid cells

Estimate annual NEE for each peatland type in all other grid cells (i.e., areas beyond the observation points) using the equations obtained in Step 1. Use the estimated lowest monthly mean GWL value in the study year obtained in Step 7 of sub-section 2.2.2. Calculate the total NEE from the study area by summing up NEE values from each grid cell using the following equation:

$$T = \sum_{i=1}^{N} A_i \left[\alpha_i X_i + \beta_i Y_i + \gamma_i Z_i + ... \right] \quad \textbf{eq (13)}$$

Where,
T: total NEE,
A_i: peatland area in grid cell i,
α_i: the ratio of peatland type X area in grid cell i,
β_i: the ratio of peatland type Y area in grid cell i,
γ_i: the ratio of peatland type Z area in grid cell i,
X_i: NEE value of peatland type X area in grid cell i,
Y_i: NEE value of peatland type Y area in grid cell i,
Z_i: NEE value of peatland type Z area in grid cell i,
N: the number of grid cells.

Step 3. Generate a map of estimated annual CO_2 emissions

Generate a map of estimated annual CO_2 emissions (positive NEE values) based on the grid file created in Step 2 of sub-section 2.2.1. and the NEE values obtained in Step 2. Fig. 15 shows an example of annual NEE maps for 2012 in Central Kalimantan created on a 0.5° grid file.

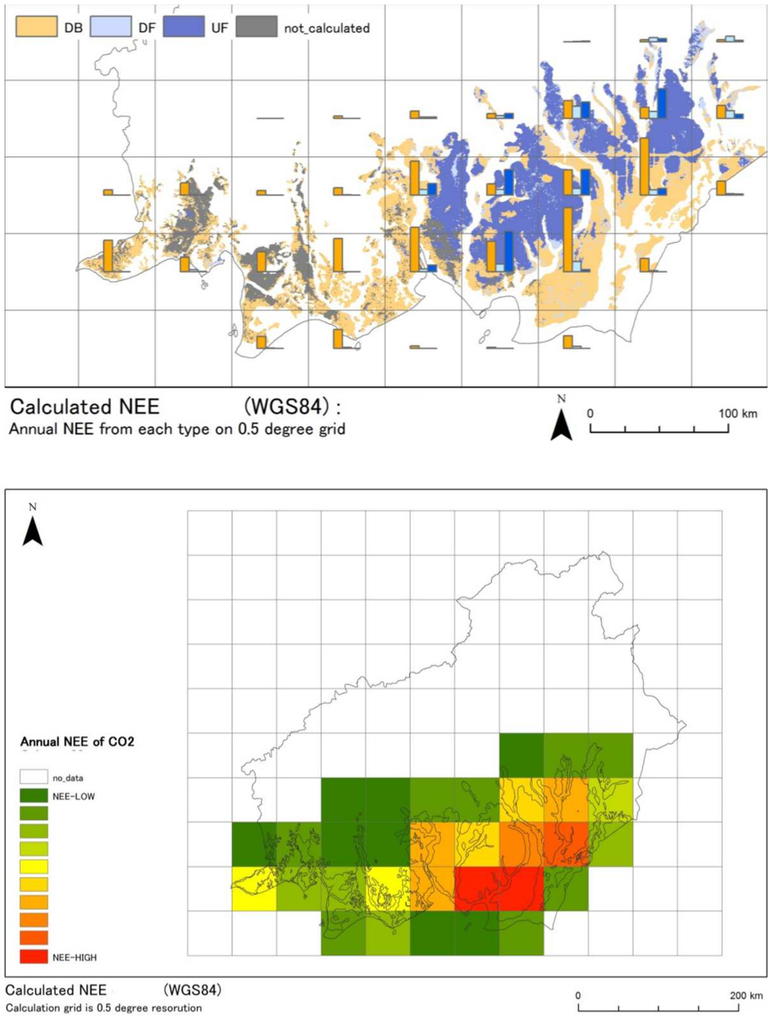


Figure 15: Map of estimated annual NEE values for each peatland type (top) and for total NEE (bottom) in 2012 on grid files for Central Kalimantan

4.1.3.2. Carbon Emission from Time Series Data

Time-series data of GWL can be used to estimate a time series of carbon emission of peat decomposition by applying the Hirano model. We describe the procedure as follows.

Step 1: Obtain time-series data with a daily time interval from the SESAME instrument

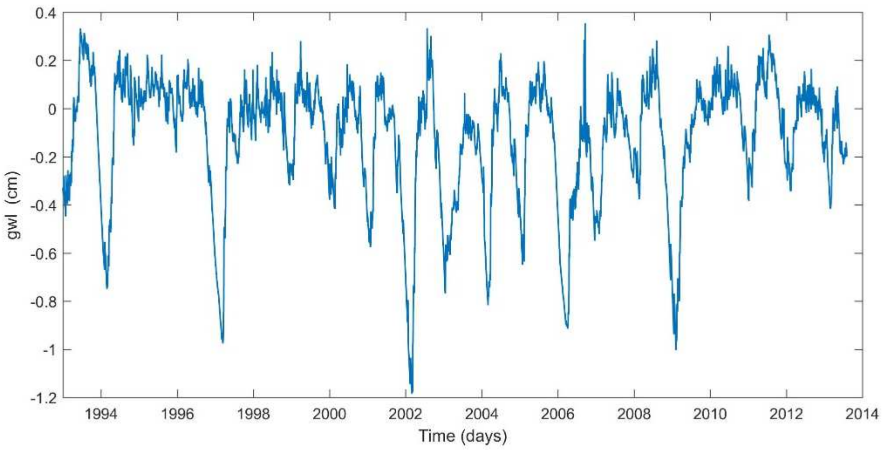


Figure 16: Time series of Ground Water Level in Central Kalimantan

Step 2: Apply the Fast Fourier Transform to obtain the GWL spectrum

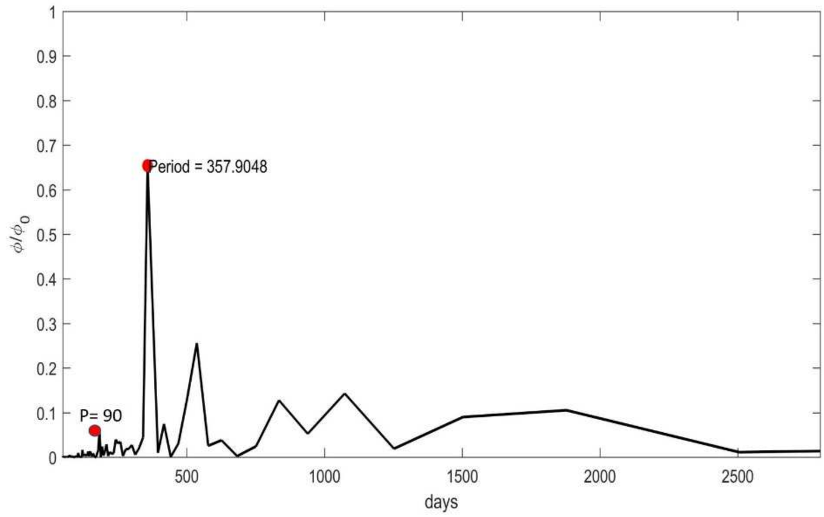


Figure 17: Normalized Ground Water Level power spectrum

Step 3: Due to the significance of the power spectrum over more than 90 days, this should be used as a cut-off frequency in a lowpass filter (Fig. 18)

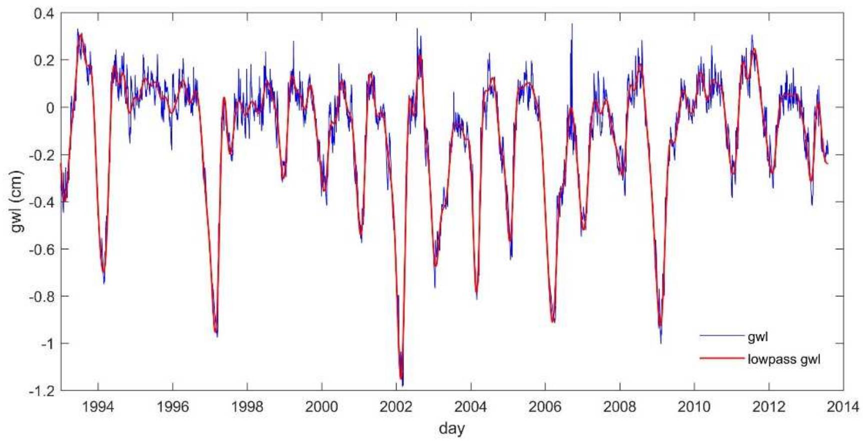


Figure 18: Ground Water Level time series with the lowpass filter with a cutoff period of 90 days

Step 4: Apply the Hirano model to obtain a time series of carbon emission (Fig. 19)

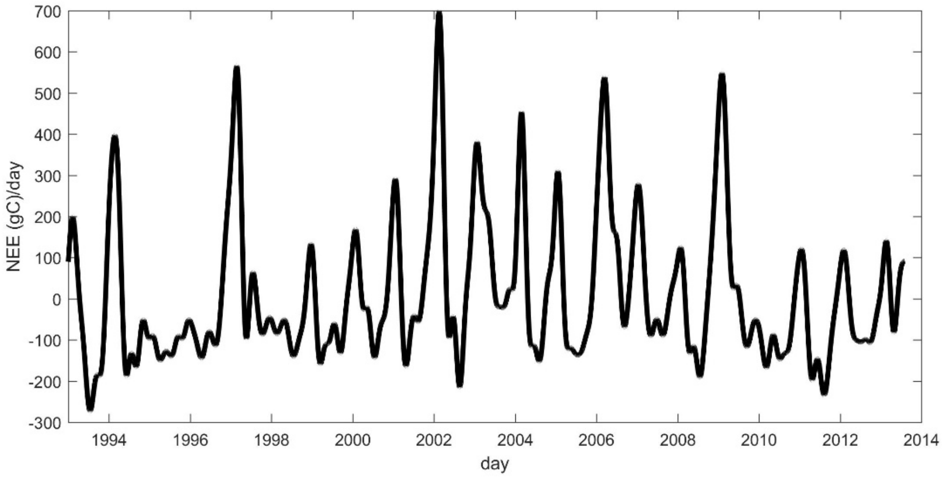


Figure 19: Time series of carbon emission of peat decomposition
A positive value indicates carbon emission and a negative value indicates a carbon sink.

3.5. Ground Water Level Prediction

L

❖ What will you learn in Part III? ❖

- How to predict daily groundwater level (GWL) for several days ahead
  - ✓ Key points to understand:
    - The GWL Prediction Model uses the Kalman Filter technique introduced by Rudolf E. Kalman.
    - The Kalman filter is an algorithm or mathematical calculation which uses time-series values observed over time and returns estimates of uncertain variables in a linear system. It separates time-series noise, and can be used to estimate the past, present and future state of the variables (i.e., GWL).
    - The GWL Prediction Model takes a linear model based on the observed GWL values. This means that the future state of the variables (i.e., predicted GWL) has a proportional value to the current average value and statistical noise.
    - The model reduces the noise from the observed GWL values. In this model, the slope is assumed constant.
    - It is useful to apply the GWL Prediction Model in practice. **40 cm below the ground surface** is the threshold of GWL not only for preventing peatland fires but also for keeping peat carbon stored belowground.

Groundwater level can be used as an ecological indicator for peatland management. Lowering GWL causes various ecological disturbances such as carbon emissions, damages to faunal and floral species, loss of ecosystem services, and devastating peatland fires. Early information about the condition of GWLs will help local authorities, land managers and local communities prevent the occurrence of such disturbances and act upon them in a timely manner. The GWL Prediction Model forecasts GWLs for several days ahead.

Surface peat fires tend to start when the GWL drops to about 20 cm below the ground surface, and expand to the surrounding area when it becomes lower than 40 to 50 cm (Putra et al., 2008). Similarly, it is necessary to maintain the GWL higher than 40 cm below the ground surface in order to make replanting successful and minimize fire risks (Wösten et al., 2006).

Figure 17 shows the framework of the GWL Prediction Model. It only uses observed daily average GWLs obtained in Step 3 of Sub-section 2.2.2 (GWL analysis). Therefore, the data collection and analysis procedures can be seen in the relevant sections above (see 2.1.2.1 on GWL measurements and 2.2.2 on GWL analysis), and will not be repeated in this section.

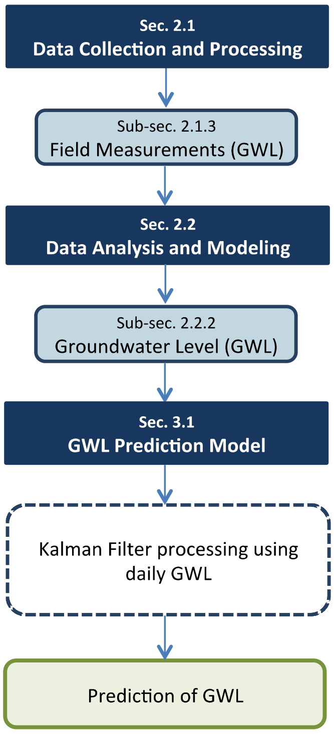


Figure 17. Framework for the GWL prediction

3.5.1. Takahashi Model on Groundwater Level Prediction

Step 1. General understanding of water balance in peatland ecosystem

Term definition and dimension in this section

Groundwater level, GWL, [m]: the height of groundwater table on the basis of ground surface level

Daily mean GWL: Average of hourly GWL from 0 o'clock to 24 o'clock.

Daily change of GWL, dGWL: Difference of GWL between at 0 o'clock and 24 o'clock.

Daily total rainfall, [mm day^{-1}]: Total amount of rainfall from 0 o'clock to 24 o'clock.

For GWL prediction, a general and correct understanding of water balance in peatland ecosystem is necessary. The peatland ecosystem is generally consisted from three basic layers, vegetation, peat and mineral soil layers (Fig. 3.5.2-1). The permeability of the mineral soil layer is generally low, so then the surface groundwater is held in peat layer. The peat layer is divided into the saturated and the unsaturated layers, below and above the groundwater table.

The main water resource to the peatland is rainfall in tropical area. Some part of rainfall is intercepted by vegetation and evaporated to the atmosphere directly. The most of rainfall reaches to the peat layer and increases the volume of unsaturated layer and the moisture of unsaturated layer.

The water in the peat layer uses for evapotranspiration, evaporation from ground surface and transpiration through vegetation, and horizontal outflow of groundwater through peat layer, actually the difference of in- and outflow of groundwater from the upper section and to the lower section. The amount of water loss through the mineral soil layer is not so large because of the low permeability of the mineral soil layer.

In the case of a tropical peat swamp forest in the Sebangau River catchment, the 51% of rainfall was used for evapotranspiration and the remains was used for outflow and change of ground water level (Kayama, M. et al., 2000).

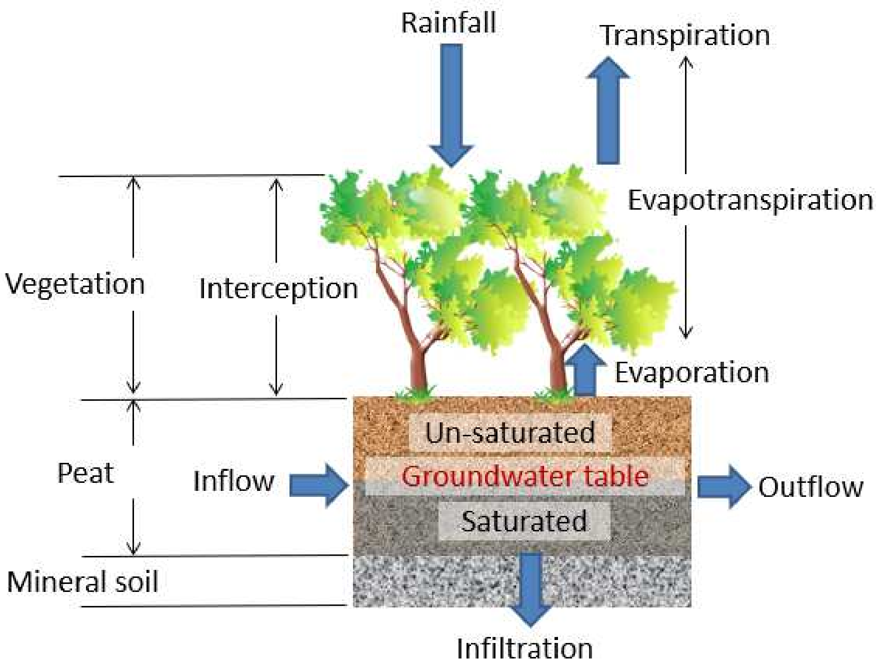


Fig. 3.5.2-1. Water balance of peatland ecosystem

Step 2. Water balance model for prediction of GWL in peatland ecosystem

Water balance in a peat layer is shown in Eq. 3.5.2-1 with several hypothesis as follows, The interception of rainfall by vegetation is zero, the change of water content in the unsaturated peat layer is zero, the infiltration through the mineral soil layer is zero, and the runoff is a difference of inflow and outflow in saturated layer of peat.

$$\mathrm{d}W = \mathrm{d}W_{rain} - \mathrm{d}W_{loss} \qquad \text{Eq. 3.5.2-1}$$

Where $\mathrm{d}W$: Daily change of GWL,

$\mathrm{d}W_{rain}$: Daily change of GWL by daily rainfall,

$\mathrm{d}W_{loss}$: Daily loss of GWL by horizontal runoff and evapotranspiration

In the case of the tropical peat swamp forest, the evapotranspiration has no big difference through a year with 3-4 mm day^{-1} (Takahashi, H., 1999). So then, daily changes of GWL by horizontal runoff and evapotranspiration are combined to daily change of GWL as $\mathrm{d}W_{loss}$.

Daily horizontal runoff in a peatland, which was estimated from the change of GWL during night, was shown as a function of GWL (Takahashi, H. et al, 2000). The $\mathrm{d}W_{loss}$ is also shown as a function of GWL as follows in this section.

$$\mathrm{d}W_{loss} = f_1(W) \qquad \text{Eq. 3.5.2-2}$$

where W: Distance of GWL from the ground surface.

The daily change of GWL, dW_{rain} by daily rainfall is calculated by following equation which is drown from Eq. 3.5.2-1.

$$\mathrm{d}W_{rain} = \mathrm{d}W + \mathrm{d}W_{loss} \quad \text{Eq. 3.5.2-1'}$$

The value of dW_{rain} has a linear relation with the amount of the daily rainfall (Umeda, Y. and Inoue T., 1985, Takahashi H. and Yonetani Y., 1997). But the relationship between the daily amount of rainfall, R, and the daily change of GWL, dW_{rain} is shown in following equation,

$$\mathrm{d}W_{rain} = f_2(R) \quad \text{Eq.3.5.2-3}$$

where R: daily amount of rainfall.

The $f_2(R)$ is decided by data of field observation in the site in this section.

Step 3. Procedure for GWL prediction

Definition of daily GWL is the height of groundwater table on the basis of ground surface level at 0 o'clock of the day, and the definition of daily rainfall is the accumulated rainfall from 0 o'clock to 24 o'clock of the day.

Determination process of Eq. 3.5.2-2 and Eq. 3.5.2-3, which are the key equations for GWL prediction, is described using the data measured in the peatland of Central Kalimantan.

Procedure-1. Determine $f_1(W)$ in Eq. 3.5.2-2

Data-1: Daily GWL [m] at 0 o'clock ----------- Column S in Fig. 3.5.2-2.
Data-2: Daily total rainfall [mm day^{-1}] ----------- Column W in Fig. 3.5.2-2.
Data-3: Daily mean GWL [m] ----------- Column Y in Fig. 3.5.2-2.
Data-3: Daily change of GWL [m] ----------- Column AA in Fig. 3.5.2-2.

One day after rainfall does not use for analysis.

Data without rain are used for analysis.

AA2 =S3-S2

	A	B	C	D	S	W	Y	AA
1	y	m	d	h	GWL (m)	Daily total rain (mm /day)	Daily mean GWL (m)	dGWL /day (m)
2	2016	5	14	0	−0.15	7.5	−0.161	−0.014
3	2016	5	15	0	−0.164	43	−0.12	0.052
4	2016	5	16	0	−0.112	1	−0.096	0.012
5	2016	5	17	0	−0.1	17.5	−0.104	−0.006
6	2016	5	18	0	−0.106	0	−0.125	−0.038
7	2016	5	19	0	−0.144	0	−0.158	−0.031
8	2016	5	20	0	−0.175	0	−0.189	−0.03
9	2016	5	21	0	−0.205	0	−0.219	−0.032
10	2016	5	22	0	−0.237	0	−0.242	−0.014
11	2016	5	23	0	−0.251	29	−0.238	0.039
12	2016	5	24	0	−0.212	4.5	−0.225	−0.025
13	2016	5	25	0	−0.237	3.5	−0.238	0
14	2016	5	26	0	−0.237	0	−0.248	−0.025
15	2016	5	27	0	−0.262	0	−0.27	−0.025
16	2016	5	28	0	−0.287	0	−0.292	−0.016
17	2016	5	29	0	−0.303	54.5	−0.281	0.134
18	2016	5	30	0	−0.169	0	−0.193	−0.031
19	2016	5	31	0	−0.2	11	−0.181	0.028
20	2016	6	1	0	−0.172	0	−0.179	−0.015
21	2016	6	2	0	−0.187	0	−0.2	−0.025
22	2016	6	3	0	−0.212	106.5	−0.197	0.156

Fig. 3.5.2-2. Sheet-1: Daily total rainfall [mm day^{-1}] and Daily change of GWL [m]

x(-1)

x(-1)

G2 =E2*-1

	A	B	C	D	E	F	G	H	I
1	y	m	d	daily total rain (mm/da	Daily mean GWL (m)	dGWL /day (m)	−mean GWL (m)	−mean GWL (m)+0.4	− dGWL/day (m)
2	2016	5	19	0	−0.158	−0.031	0.158	0.558	0.03
3	2016	5	20	0	−0.189	−0.03	0.189	0.489	0.0
4	2016	5	21	0	−0.219	−0.032	0.219	0.519	0.03
5	2016	5	22	0	−0.242	−0.014	0.242	0.542	0.01
6	2016	5	27	0	−0.27	−0.025	0.27	0.57	0.02
7	2016	5	28	0	−0.292	−0.016	0.292	0.692	0.01
8	2016	6	2	0	−0.2	−0.025	0.2	0.6	0.02
9	2016	6	6	0	−0.052	−0.038	0.052	0.452	0.03
10	2016	6	7	0	−0.098	−0.044	0.098	0.498	0.04
11	2016	6	8	0	−0.14	−0.043	0.14	0.54	0.04
12	2016	6	9	0	−0.174	−0.029	0.174	0.574	0.02
13	2016	6	21	0	−0.275	−0.02	0.275	0.675	0.0
14	2016	6	22	0	−0.292	−0.014	0.292	0.692	0.01
15	2016	6	23	0	−0.31	−0.022	0.31	0.71	0.02
16	2016	6	24	0	−0.33	−0.018	0.33	0.73	0.01
17	2016	6	30	0	−0.393	−0.018	0.393	0.793	0.01
18	2016	7	5	0	−0.442	−0.013	0.442	0.842	0.01
19	2016	7	6	0	−0.455	−0.014	0.455	0.855	0.01
20	2016	7	7	0	−0.471	−0.016	0.471	0.871	0.01
21	2016	7	11	0	−0.486	−0.019	0.486	0.886	0.01
22	2016	7	12	0	−0.502	−0.014	0.502	0.902	0.01
23	2016	7	15	0	−0.517	−0.013	0.517	0.917	0.01
24	2016	8	7	0	−0.421	−0.025	0.421	0.821	0.02
25	2016	8	8	0	−0.44	−0.013	0.44	0.84	0.01
26	2016	8	9	0	−0.454	−0.012	0.454	0.854	0.01
27	2016	8	10	0	−0.472	−0.025	0.472	0.872	0.02
28	2016	8	11	0	−0.491	−0.013	0.491	0.891	0.01

Fig. 3.5.2-3. Sheet-2: Selected Daily total rainfall [mm day^{-1}] and Daily change of GWL [m]

#1. Prepare Data-1 (Daily GWL [m] at 0 o'clock). Data-2 (Daily total rainfall [mm day^{-1}]) and in Sheet-1.

#2. Calculate Data-3 (Daily change of GWL [m]) which is the difference of Daily GWL and it of next day in Sheet-1.
#3. Select the day without rainfall excepting next day of rainfall in Sheet-1. The green color column are selected days.
#4. Selected days are listed in Sheet-2.
#5. Signs of Daily mean GWL and Daily change of GWL in columns E and F are changed from minus to plus and enter columns G and I for easy search of functional relationship together. The values of the columns G and I mean the distance of the groundwater table from the ground surface and the amount of daily loss of groundwater level.
#6. Add an experimental factor α =0.4 in this case, to column G and enter column H.
#7. Determine the suitable function for Eq. 3.5.2-4 using the approximate curve system of the Excel. The logarithmic function is the most suitable one for relationship between GWL and the daily loss of GWL in this case. But if the experimental factor α is not used in the equation, the loss of GWL will approach to the infinity as GWL approach to ground surface as shown in Fig. 3.5.1-4a. The experimental factor α = 0.2 is used in this analysis, Fig. 3.5.2-4a.
Finally, Eq. 3.5.2-2 is decided as next equation.

$$dW_{loss} = -0.028\ln(W - 0.2) + 0.012 \qquad \text{Eq. 3.5.2-4}$$

where dW_{loss}: Daily loss of GWL by horizontal runoff and evapotranspiration
W: Distance of GWL from the ground surface.

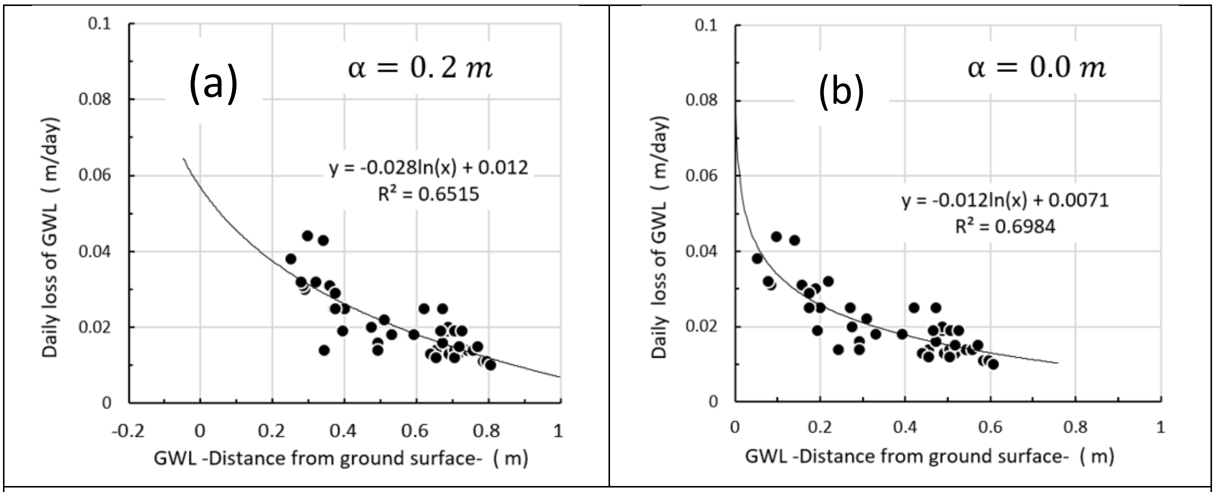


Fig. 3.5.2-4. Relationship between GWL and the daily loss of GWL with (a) and without (b) the experimental factor α = 0.2.

Procedure-2. Determine $f_2(R)$ in Eq. 3.5.2-3
Data-1: Daily GWL [m] at 0 o'clock ----------- Column S in Fig. 3.5.2-5.
Data-2: Daily total rainfall [mm day^{-1}] ----------- Column W in Fig. 3.5.2-5.
Data-3: Daily mean GWL [m] ----------- Column Y in Fig. 3.5.2-5.
Data-3: Daily change of GWL [m] ----------- Column AA in Fig. 3.5.2-5.

#1. Calculate the daily loss of GWL using Eq. 3.5.2-4 and enter the result in the column AB in the Sheet-1 (Fig. 3.5.2-5).
#2. Calculate the real change of GWL by rainfall by adding the daily loss of GWL(Column AB) to the observed change of GWL(Column AA) and enter the results to Column AC).
#3. Select the day when rain fell more than 2.0 mm day-1 and list up the amount of rainfall and the real change of GWL (Column AC in Sheet-1) by rainfall on the Sheet-3 (Fig. 3.5.2-6).

#4. Determine the suitable function for Eq. 3.5.2-5 using the approximate curve system of the Excel. The quadric function is the most suitable one for relationship between the daily total rainfall and the raise of GWL by rainfall in this case with the determination index 0.828 (Fig. 3.5.2-6a). The liner function is not suitable one with the smaller determination index 0.7787 (Fig. 3.5.2-6b).

Finally, Eq. 3.5.2-3 is decided as next equation.

$$dW_{rain} = -12.335R^2 + 2.970R + 0.0062 \qquad \text{Eq. 3.5.2-4}$$

where dW_{rain} : Daily change of GWL by daily rainfall

R: Daily total amount of rainfall

AC2 | f_x =AA2+AB2

	A	B	C	S	W	Y	AA	AB	AC
1	y	m	d	GWL at 0 o'clock (m)	Daily total rain (mm /day)	Daily mean GWL (m)	dGWL (m/day)	loss GWL (m/day)	dGWL by rain (m/day)
2	2016	5	14	−0.15	7.5	−0.161	−0.014	0.0174	0.0034
3	2016	5	15	−0.164	43	−0.12	0.052	0.0195	0.0715
4	2016	5	16	−0.112	1	−0.096	0.012	0.0208	0.0328
5	2016	5	17	−0.1	17.5	−0.104	−0.006	0.0204	0.0144
6	2016	5	18	−0.106	0	−0.125	−0.038	0.0192	−0.0188
7	2016	5	19	−0.144	0	−0.158	−0.031	0.0175	−0.0135
8	2016	5	20	−0.175	0	−0.189	−0.03	0.016	−0.014
9	2016	5	21	−0.205	0	−0.219	−0.032	0.0146	−0.0174
10	2016	5	22	−0.237	0	−0.242	−0.014	0.0136	−0.0004
11	2016	5	23	−0.251	29	−0.238	0.039	0.0138	0.0528
12	2016	5	24	−0.212	4.5	−0.225	−0.025	0.0144	−0.0106
13	2016	5	25	−0.237	3.5	−0.238	0	0.0138	0.0138
14	2016	5	26	−0.237	0	−0.248	−0.025	0.0133	−0.0117
15	2016	5	27	−0.262	0	−0.27	−0.025	0.0124	−0.0126
16	2016	5	28	−0.287	0	−0.292	−0.016	0.0115	−0.0045
17	2016	5	29	−0.303	54.5	−0.281	0.134	0.012	0.146
18	2016	5	30	−0.169	0	−0.193	−0.031	0.0158	−0.0152
19	2016	5	31	−0.2	11	−0.181	0.028	0.0164	0.0444
20	2016	6	1	−0.172	0	−0.179	−0.015	0.0165	0.0015
21	2016	6	2	−0.187	0	−0.2	−0.025	0.0155	−0.0095
22	2016	6	3	−0.212	106.5	−0.197	0.156	0.0156	0.1716
23	2016	6	4	−0.056	41	−0.008	0.069	0.0263	0.0953
24	2016	6	5	0.013	0	−0.005	−0.05	0.0265	−0.0235
25	2016	6	6	−0.037	0	−0.052	−0.038	0.0234	−0.0146
26	2016	6	7	−0.075	0	−0.098	−0.044	0.0207	−0.0233
27	2016	6	8	−0.119	0	−0.14	−0.043	0.0185	−0.0245
28	2016	6	9	−0.162	0	−0.174	−0.029	0.0167	−0.0123
29	2016	6	10	−0.191	26.5	−0.195	0.029	0.0157	0.0447

Fig. 3.5.2-5. Sheet-1: Daily GWL [m] at 0 o'clock etc.

F2 | f_x =E2/1000

	A	B	C	E	F	H	I
1	y	m	d	total rainfall mm/day	total rainfall m/day	dGWL by rain (m/day)	
2	2016	5	14	7.5	0.0075	0.0034	
3	2016	5	15	43	0.043	0.0715	
4	2016	5	17	17.5	0.0175	0.0144	
5	2016	5	23	29	0.029	0.0528	
6	2016	5	24	4.5	0.0045	−0.0106	
7	2016	5	25	3.5	0.0035	0.0138	
8	2016	5	29	54.5	0.0545	0.146	
9	2016	5	31	11	0.011	0.0444	
10	2016	6	3	106.5	0.1065	0.1716	
11	2016	6	4	41	0.041	0.0953	
12	2016	6	10	26.5	0.0265	0.0447	
13	2016	6	11	2	0.002	−0.0216	
14	2016	6	13	20.5	0.0205	0.0395	
15	2016	6	17	3.5	0.0035	0.0067	
16	2016	6	18	13.5	0.0135	0.0203	
17	2016	6	19	3.5	0.0035	0.0037	
18	2016	6	26	2.5	0.0025	0.0001	
19	2016	6	28	8.5	0.0085	0.022	
20	2016	7	1	2	0.002	1E−04	
21	2016	7	3	9	0.009	0.0274	
22	2016	7	8	2	0.002	−0.0074	
23	2016	7	9	10	0.01	0.0353	
24	2016	7	13	6	0.006	0.0182	
25	2016	7	17	10.5	0.0105	0.0161	
26	2016	7	18	27	0.027	0.0947	

Fig. 3.5.2-6. Sheet-3: Selected days for analysis of $f_2(R)$

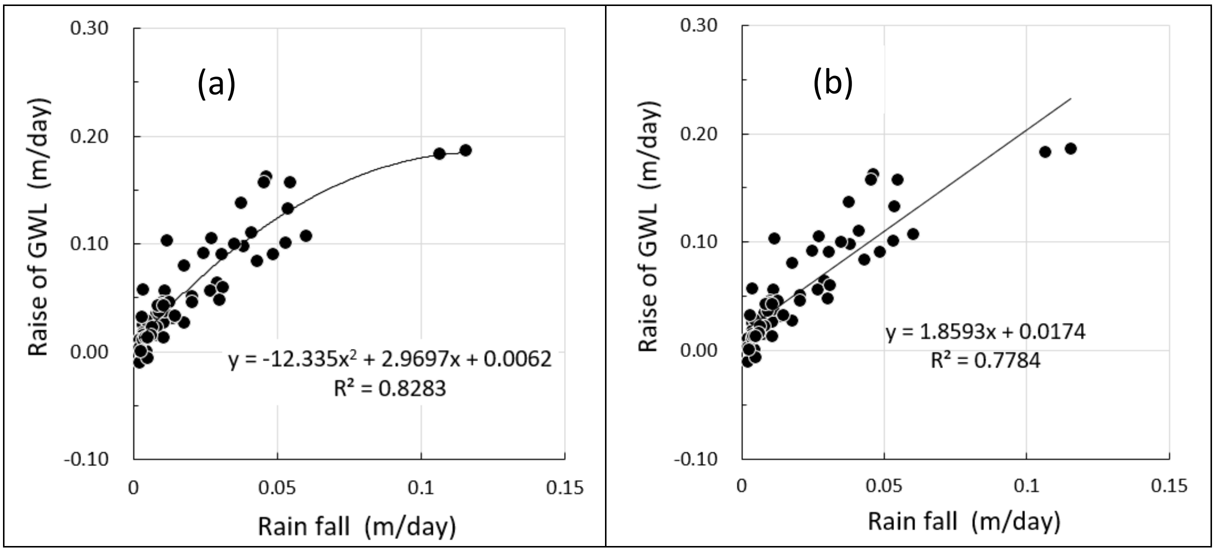


Fig. 3.5.2-7. Regression formulas for $f_2(R)$, the quadric (a) and linear (b) functions

Procedure-3. Estimate daily change of GWL by using the determined equations of dW_{loss} and dW_{rain}:

Data-2: Daily total rainfall [mm day^{-1}] ----------- Column W in Fig. 3.5.2-8.

Data-3: Daily mean GWL [m] ----------- Column Y in Fig. 3.5.2-8.

Data-4: Daily total rainfall [mm day^{-1}] for test with no rain from 7th Sept. to 31st Oct., 2016. ------------- Column Y in Fig. 3.5.2-9.

#1. Select the first day for GWL estimation. The 3rd Sept., 2016 is selected in this estimation.

#2. Copy the measured daily mean GWL on 3rd Sept., 2016 in Column Y to Column AE.

#3. Calculate GWL of next day by using the equation, which is combined $f_1(W)$ and $f_2(R)$.

#4. Compare the estimated GWL with the measured one (Fig.3.5.2-10).

#5. Estimate the GWL using the rainfall data in which it was no rainfall from 7th Sept. to 31st Oct., 2016 (Fig. 3.5.2-11).

AE115 | =AE114-(-0.022*LN(-1*AE114+0.2)+0.0071)+(-12.335*(W115/1000)^2+2.9697*(W115/1000)+0.0062)

	A	B	C	W	Y	AE	AK	AL
1	y	m	d	Daily total rain (mm /day)	Daily mean GWL (m)	EST GWL (m)		
113	2016	9	2	46	-0.49			
114	2016	9	3	0	-0.418	-0.4180		
115	2016	9	4	10	-0.421	-0.4010		
116	2016	9	5	0	-0.411	-0.4131		
117	2016	9	6	1	-0.43	-0.4218		
118	2016	9	7	0	-0.445	-0.4332		
119	2016	9	8	0	-0.466	-0.4441		
120	2016	9	9	0.5	-0.479	-0.4532		
121	2016	9	10	0	-0.491	-0.4635		
122	2016	9	11	0	-0.505	-0.4734		
123	2016	9	12	0	-0.518	-0.4830		
124	2016	9	13	1.5	-0.532	-0.4879		
125	2016	9	14	0	-0.54	-0.4970		
126	2016	9	15	12.5	-0.538	-0.4707		
127	2016	9	16	0	-0.513	-0.4803		
128	2016	9	17	45.5	-0.49	-0.3801		
129	2016	9	18	5	-0.384	-0.3785		
130	2016	9	19	20.5	-0.373	-0.3357		

Estimated GWL using GWL one day before and daily rainfall.

Fig. 3.5.2-8. Sheet-1: Estimation of daily GWL using measured daily rainfall data.

AP164

	F	W	Y	Z	AF	AL
1	Date Time	Daily total rain (mm /day)	Daily total rain (mm /day)	Daily mean GWL (m)	EST GWL (m)	EST GWL (m) no rain
113	2016/9/2 0:00	46	46	-0.49		
114	2016/9/3 0:00	0	0	-0.418	-0.4180	-0.4180
115	2016/9/4 0:00	10	10	-0.421	-0.4010	-0.4010
116	2016/9/5 0:00	0	0	-0.411	-0.4131	-0.4131
117	2016/9/6 0:00	1	1	-0.43	-0.4218	-0.4218
118	2016/9/7 0:00	0	0	-0.445	-0.4332	-0.4332
119	2016/9/8 0:00	0	0	-0.466	-0.4441	-0.4441
120	2016/9/9 0:00	0.5	0	-0.479	-0.4532	-0.4547
121	2016/9/10 0:00	0	0	-0.491	-0.4635	-0.4649
122	2016/9/11 0:00	0	0	-0.505	-0.4734	-0.4748
123	2016/9/12 0:00	0	0	-0.518	-0.4830	-0.4844
124	2016/9/13 0:00	1.5	0	-0.532	-0.4879	-0.4936
125	2016/9/14 0:00	0	0	-0.54	-0.4970	-0.5026
126	2016/9/15 0:00	12.5	0	-0.538	-0.4707	-0.5112
127	2016/9/16 0:00	0	0	-0.513	-0.4803	-0.5196
128	2016/9/17 0:00	45.5	0	-0.49	-0.3801	-0.5278
129	2016/9/18 0:00	5	0	-0.384	-0.3785	-0.5356
130	2016/9/19 0:00	20.5	0	-0.373	-0.3357	-0.5433
131	2016/9/20 0:00	14.5	0	-0.354	-0.3099	-0.5507
132	2016/9/21 0:00	38	0	-0.281	-0.2306	-0.5579
133	2016/9/22 0:00	8	0	-0.279	-0.2270	-0.5649
134	2016/9/23 0:00	3.5	0	-0.282	-0.2364	-0.5717
135	2016/9/24 0:00	6.5	0	-0.281	-0.2368	-0.5783
136	2016/9/25 0:00	0	0	-0.303	-0.2559	-0.5847
137	2016/9/26 0:00	8	0	-0.318	-0.2511	-0.5910

Fig. 3.5.2-9. Sheet-1: Estimation of daily GWL using rainfall data with no rain from 7th Sept. to 31st Oct., 2016.

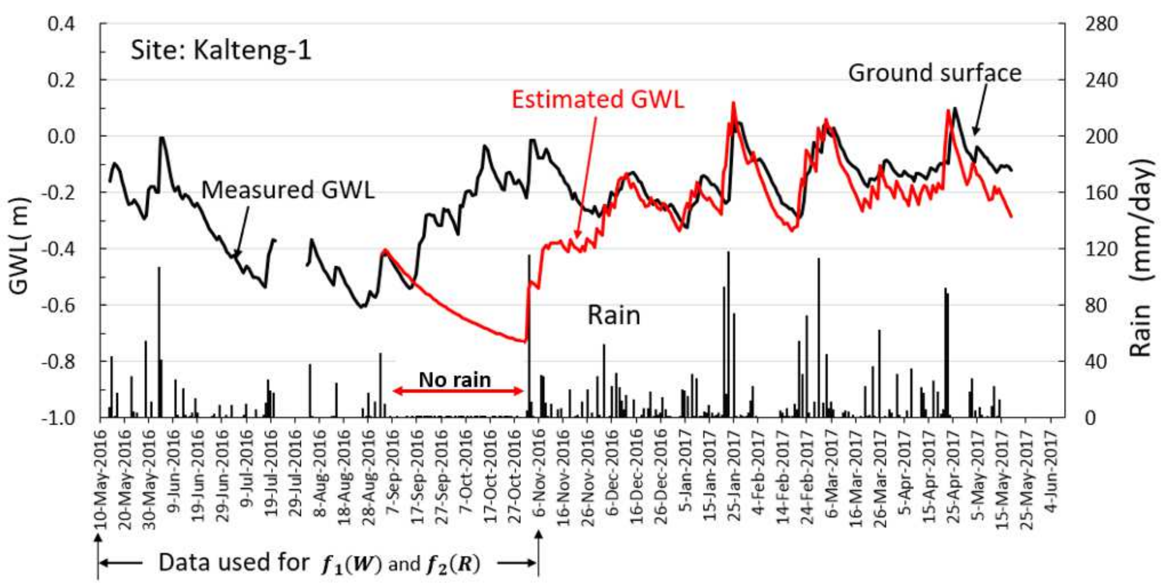


Fig. 3.5.2-11. The estimated GWL using the rainfall data in which it was no rainfall from 7th Sept. to 31st Oct., 2016.

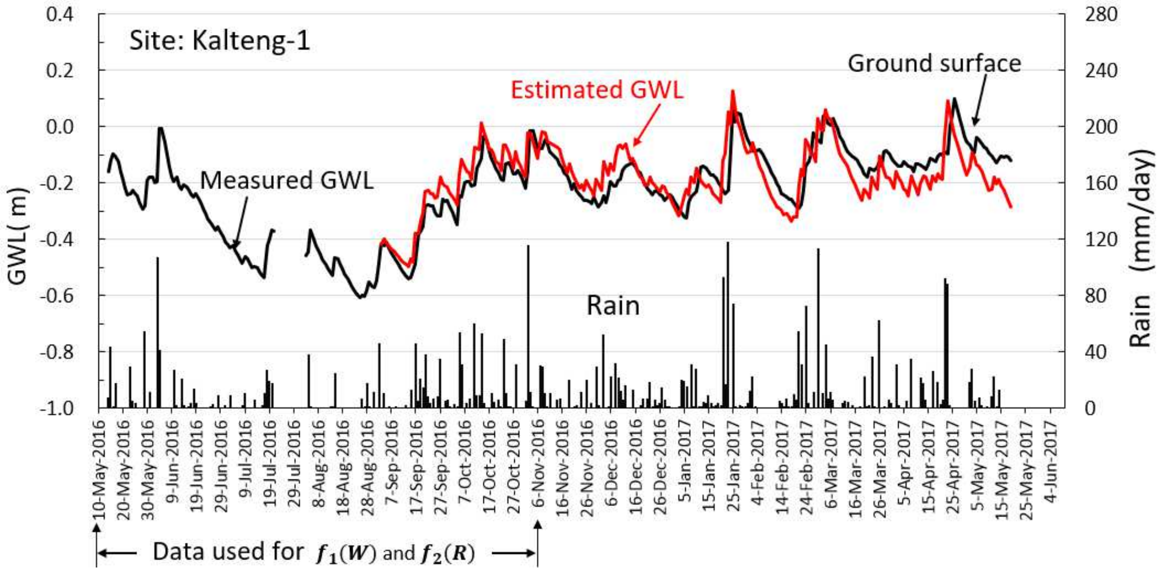


Fig. 3.5.2-10. Measured rainfall and GWL, and the estimated GWL

References

Kayama M., Takahashi H. and Limin H. S., 2000, Water Balance of a Peat Swamp Forest in the Upper Catchment of the Sebangau River, Central Kalimantan, Proceedings of the International Symposium on Tropical Peatlands, Bogor, 299-306.

Takahashi H. and Yonetani Y., 1997, Studies on Microclimate and Hydrology of Peat Swamp Forest in Central Kalimantan, Indonesia. Rieley J.O. and Page S.E. eds, Biodiversity and Sustainability of Tropical Peatlands, Sawara Publishing Ltd., 179-187.

Umeda Y. and Inoue T., 1985, The influence of evapotranspiration on the groundwater table in peatland. Jour. Faculty of Agriculture, Hokkaido University, 62(2), 167-181.

4.1. CO_2 flux measurements

4.1.1. Methodology of CO_2 flux measurements

CO_2 movement or CO_2 flux between the soil and the atmosphere is the primary function of soil respiration. Soil respiration returns substantial amounts of carbon to the atmosphere and is a major component of CO_2 emissions or NEE. Ecosystem disturbances, including climate change, deforestation, peatland drainage, forest and peatland fires, and land conversion, provoke changes in soil respiration and the resulting carbon balance, as the ecosystem loses important soil carbon storage due to such disturbances. Therefore, direct measurements of CO_2 fluxes should be conducted at various sites which include both intact peatland and other peatland areas characterized by varying degrees of ecosystem disturbances (see Sub-section 2.2.1 on Peatland Type). The results of these CO_2 flux measurements are used for the NEE analysis as described in Sub-section 2.2.3.

There are various methods to measure CO_2 fluxes, each with its own advantages and limitations. This guidebook recommends a micrometeorological method using a flux tower. Secondary CO_2 flux data may also be used, if such data are available for the study area.

Box 2. Alternative approaches to flux measurements

If it is not feasible to measure CO_2 fluxes with a flux tower, there are some alternative methods available, as presented below.

Incubation method: This method uses undisturbed sample soil columns stored in containers and incubated over a period of time. CO_2 fluxes are measured using a chamber which is attachable to the top of the container. Undisturbed peat samples from each peatland type should be used to avoid measurement errors. CO_2 fluxes should be measured repeatedly with different GWLs, which can be changed by supplying or draining the groundwater inside the containers. The groundwater used for this method should be drawn from the soil sampling locations.

Closed chamber method: Small chambers are used to directly measure CO_2 fluxes over a small surface area in the closed headspace for a short period of time. Chambers should be set up at each peatland type. The advantage of using this method is that it is relatively low in cost and simple to operate. However, it is easily affected by various environmental conditions in the field, and tends to create errors and biases in gas sampling.

Step 1. Prepare equipment for field measurements

A list of key instruments necessary for measuring CO_2 fluxes using a flux tower is provided below (see Figure 5).

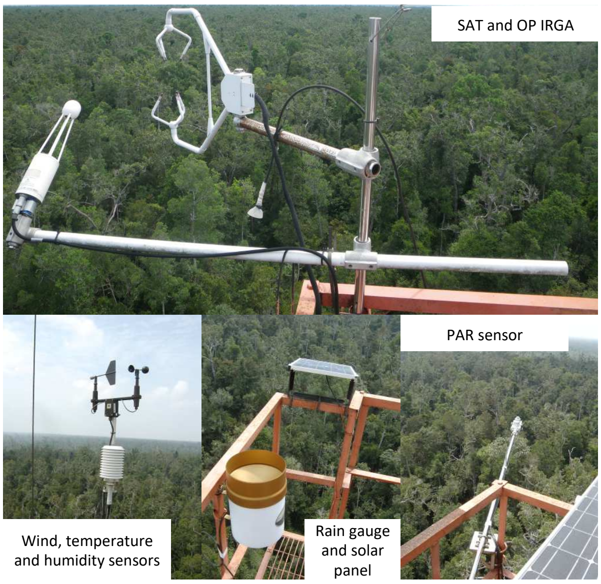


Figure 5. Flux tower instruments

Ultra-Sonic Anemometer-Thermometer (SAT):

Measures the sound speed in air in three-dimensions (especially vertical direction) in order to determine sonic virtual temperature and wind velocity in three-dimensions.

Must be settled exactly horizontally (or perpendicularly to the incline of the slope); otherwise, systematic errors will be included in the vertical wind velocity.

Open-Path CO_2 Infra-Red Gas Analyzer (OP IRGA):

Measures the attenuation of infrared radiation absorbed by CO_2 molecules intervening in the open path of the radiation in order to determine CO_2 concentration.

Recommended to be settled with 10–15 degrees slant from the vertical position in order to minimize the influences of wind distortion and raindrops sticking on the lens located at the end of the open path.

The surface of the lens should be kept clean. Ideally it should be gently wiped every ten days to every month. Application of water repellent on the surface of the lens is recommended.

Most of the commercially available OP IRGAs can simultaneously measure water vapor density. CO_2 and H_2O are individually determined using the infrared radiations with different wavelengths. Based on the same eddy covariance theory, H_2O flux (i.e., evapotranspiration) from the ecosystem into the atmosphere above can be determined.

Data logger:

Stores CO_2 flux data.

The specifications required:

Performance high enough to capture signals from several instruments at least ten times per second (>10 Hz)

Memory capacity high enough to temporarily store the huge amount of eddy covariance data for several days

Connections between the data logger and each sensor without noise and delay of signals

Power source:

Supplies power to run the equipment.

Recommended to use a stable commercial power supply with sufficient capacitance.

Recommended to use solar cells with rechargeable batteries.

In this system, the power generated by the solar cells is used both to drive the instruments and to charge the batteries during the daytime. In the nighttime, the power charged to the batteries is then consumed to drive the instruments.

The number of solar cells and batteries should be determined based on the power required by each instrument. It should also be taken into account that the power generation will be decreased on cloudy days and in the rainy season.

If the flux observation tower is covered by dense canopy, a solar cell panel should be placed on top of the tower. Make sure that the panel does not disturb the flow of the wind.

GPS receiver

Other microclimate measurement instruments:

Microclimate measurements are needed not only to record general weather conditions at the observation tower, but also to detect and correct invalid values in CO_2 fluxes.

Key microclimate parameters controlling rates of CO_2 fluxes should be recorded (temperatures, precipitation and GWL should be recorded with the SESAME system as described in Sub-subsection 2.1.2.1):

Photosynthetically active radiation (PAR) as the main variable, since it strongly affects CO_2 uptake rate during photosynthesis.

Air and soil temperatures

Precipitation

GWL

Step 2. Select locations for field measurements

Select CO_2 flux observation locations which satisfy the following conditions:

General wind direction in the area is known.

Land surface condition in the upwind area should be generally uniform and representative of the distinctive peatland types (see Sub-section 2.2.1 on Peatland Types).

Ideally, the length of the surface area from the observation tower toward the upwind direction, also known as the fetch length, should be 100 times greater than the height of the observation tower.

Permission for building of an observation tower must be available.

There must be accessible paths for the construction of the observation tower and its maintenance.

The location is safe from potential thefts of instruments.

Step 3. Build an observation tower at the selected location

Build CO_2 flux observation towers at the locations selected in Step 2.

The tower must be taller than the surrounding vegetation.

Ideally, the height of the tower is one and a half times to twice of the height of the canopy.

For a long-term observation, the growth of vegetation should be taken into account.

The tower must be strong enough to withstand the weight of instruments and strong wind. A weak tower swaying in the wind makes the observations erroneous.

A lightning rod should be mounted on top of the tower to protect the instruments in the event of lighting strike. Working around the tower during a thunderstorm is strictly prohibited.

Step 4. Install and activate the instruments, and start recording CO_2 fluxes and other microclimate parameters

Install SAT and OP IRGA in the upwind direction from the flux tower to avoid wind distortion effects.

If the prevailing wind direction changes seasonally, the direction of SAT and OP IRGA should be also adjusted toward the upwind direction.

The distance between SAT and OP IRGA should be between 15 and 30 cm.

If <15 cm, the airflow will be disturbed.

If >30 cm, the synchronicity of both sensors will be reduced.

Activate the data logger, and start recording time-series data.

Obtain the data from the data logger every 2 – 3 months.

4.1.2. Net ecosystem exchange (NEE) analysis

The Carbon Emission Model from Peat Decomposition, described in Section 2.3, uses the eddy covariance (EC) technique to estimate NEE. Raw EC data recorded at 10 Hz (see Sub-section 2.1.2.2 CO_2 flux measurements) are used to calculate physical parameters such as three-dimensional wind velocity, air and soil temperatures and CO_2 fluxes at the interval of 30 minutes to one hour. In this calculation process, many kinds of data correction, quality control and gap filling must be conducted.

Box 3. What is Eddy Covariance?

Eddy Covariance (EC) is a method for evaluating vertical transport of energy, water vapor and gases in the near-ground atmosphere. Near the ground surface, wind blows as a turbulent flow, meaning there are many "eddies" with wide ranges in size and duration. These eddies exchange the energy and gases between the upper and the lower atmospheric layers. According to the turbulent flow theory, these vertical fluxes can be given as a function of covariance of vertical wind velocity and gas concentration. Therefore, this method is called "eddy covariance".

Step 1. Conduct quality control on raw data

Check the raw data obtained in Sub-subsection 2.1.2.2 (CO_2 flux measurements), and make corrections if necessary.

Step 2. Calculate NEE values for the selected time interval

Organize the sequential raw data into a specific time interval (also known as averaging time). Averaging time is usually 30 minutes or 1 hour.

Calculate NEE values for each type of peatland by using the following equation.

$$NEE = \overline{w'c'} \tag{1}$$

Where:
W = vertical wind velocity (m/s)
C = CO_2 concentration (mg/m^3)
$'$ = fluctuating component
$\overline{}$ = mean value

Step 3. Conduct quality control on calculated NEE values

Check the calculated NEE values, and remove all erroneous data.

Certain climatic conditions, such as heavy rain and irregular wind direction, may cause errors in NEE calculation.

If necessary, correct the erroneous NEE values with some parameters obtained in the same time interval.

Step 4. Fill data gaps in calculated NEE values

Find data gaps, and estimate missing NEE values using several techniques such as regression, lookup table, or mean daily variation.

Step 5. Calculate annual NEE values

Calculate annual NEE for each type of peatland by accumulating all values of the observation year as expressed in the following equation.

$$Annual\ NEE = \sum_{Year}(NEE\ value\ at\ each\ time\ int\square rval) \quad (2)$$

4.1.3. Carbon Emission Model from Peat Decomposition

❖ What is a Carbon Emission Model from Peat Decomposition? ❖

The Carbon Emission Model from Peat Decomposition is based on the assumption that there is a linear relationship between NEE and GWL. Based on this relationship, this model allows you to estimate an annual NEE of the study area by using the lowest monthly average GWL(s) in the study year(s) as a key parameter.

NEE means the difference between CO_2 amount which is 1) emitted by ecosystem respiration (RE) and 2) absorbed by photosynthesis (gross primary production; GPP). Therefore, the relationship between net ecosystem production (NEP) and NEE is given by:

$$NEE = -NEP$$

$$NEP = GPP - RE$$

RE is found to increase with soil temperature, and decrease as GWL (or soil moisture) rises. In forest ecosystems, CO_2 exchange between biomass and the atmosphere usually occupies most of the carbon flow. If other carbon sources are negligible, the carbon balance of forest ecosystems can be determined by NEE as follows:

- NEE > 0: carbon source (emission)
- NEE = 0: carbon neutral
- NEE < 0: carbon sink

Step 1. Obtain a linear relationship between the observed lowest monthly average GWL(s) in the study year(s) and annual NEE

Use the lowest monthly average GWL value for each peatland type selected from the observed monthly average GWLs in the study years as described in Step 7 of Sub-section 2.2.2.

Use the annual NEE values for each peatland type obtained in Sub-section 2.2.3.

Draw a linear regression line between the observed lowest monthly average GWL(s) in the study year(s) on the *x* axis and observed annual NEE on the *y* axis, and obtain a relationship for each peatland type (see Figure 14) identified for the study area. Each regression equation obtained in this step will be used to estimate annual NEE values throughout the study area.

You can use the equation to estimate NEE (or CO_2 emissions) for different years, or other areas throughout the study area based on the estimated spatial distribution of GWL.

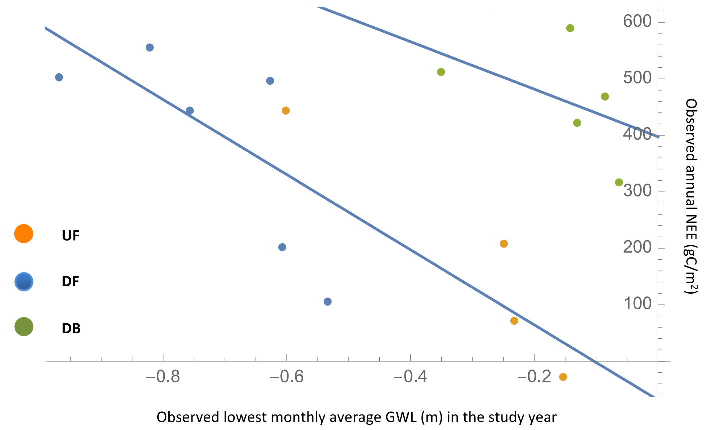


Figure 14. Example of relationships between the lowest monthly average GWLs (m) in the study years and annual NEE (gC/m^2/year) observed in Central Kalimantan (Hirano et al., 2012)

Step 2. Estimate annual NEE using the estimated lowest monthly average GWL(s) in the study year(s) in all other grid cells

Estimate annual NEE for each peatland type in all other grid cells (areas beyond the observation points), using the equations obtained in Step 1 above. Use the estimated lowest monthly average GWL value in the study year obtained in Step 7 of Sub-section 2.2.2 (Groundwater level analysis).

Calculate the total NEE from the study area by summing up NEE values from each grid cell by using the following equation.

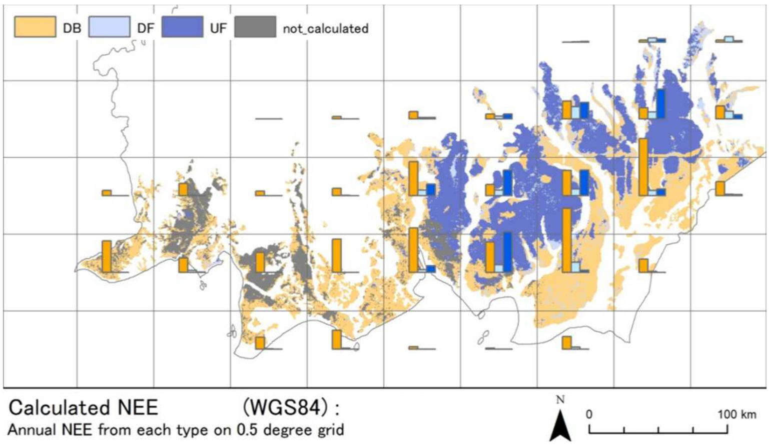
$$T = \sum_{i=1}^{N} A_i \left[\alpha_i X_i + \beta_i Y_i + \gamma_i Z_i + ... \right] \quad (13)$$

Where:
T = total NEE
A_i = peatland area in grid cell i
α_i = the ratio of peatland type X area in grid cell i
β_i = the ratio of peatland type Y area in grid cell i
γ_i = the ratio of peatland type Z area in grid cell i
X_i = NEE value of peatland type X area in grid cell i
Y_i = NEE value of peatland type Y area in grid cell i
Z_i = NEE value of peatland type Z area in grid cell i
N = the number of grid cells

Step 3. Generate a map of estimated annual CO_2 emissions

Generate a map of estimated annual CO_2 emissions (positive NEE values) based on the grid file created in Step 2 of Sub-section 2.2.1 (Peatland Type) and the NEE values obtained in

Step 2 above. Figure 15 shows an example of annual NEE maps of 2012 for Central Kalimantan created on a 0.5-degree grid file.



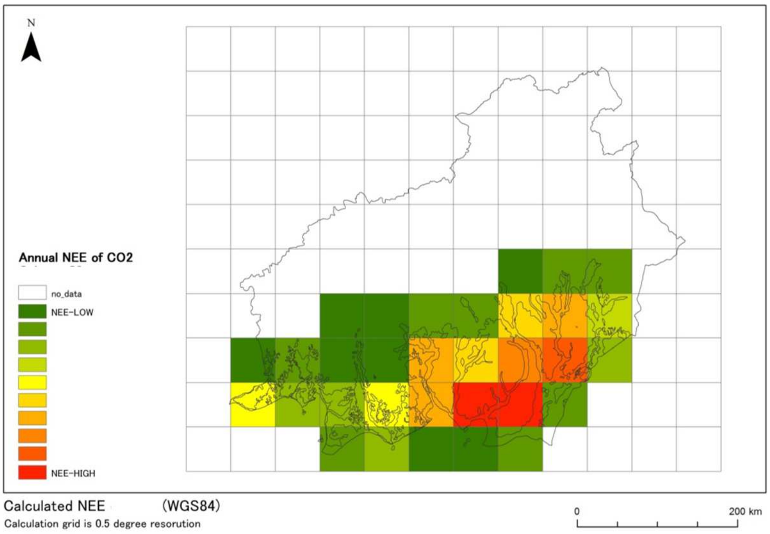


Figure 15. Map of estimated annual NEE values for each peatland type (top) and for total NEE (bottom) of 2012 on grid files for Central Kalimantan

5.1. GWL Prediction Model

Figure 18 is a graphical representation of the model described through the following steps. Detailed procedures of this model are provided in Annex 4.

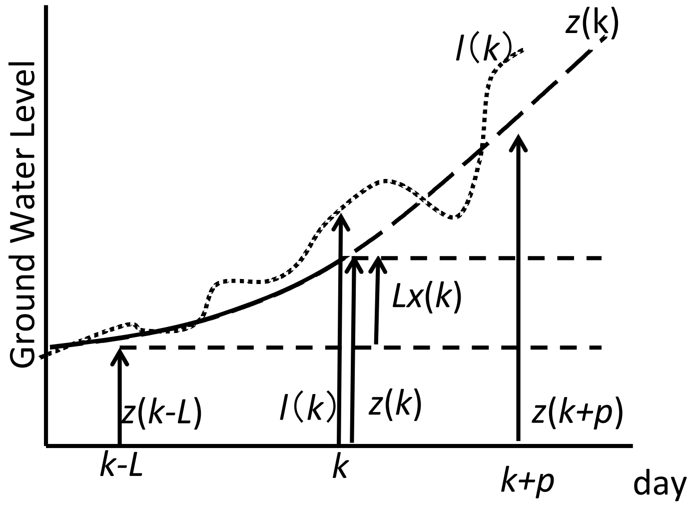


Figure 18. Illustration of the GWL prediction model based on the Kalman Filter technique

N = the number of daily average GWL observation data
k = current date - N
p = the number of days ahead for the prediction of GWL
$z(k)$ = moving average of the observed GWL data at day k
$l(k)$ = observed GWL from the SESAME system data at day k
$(2N+1)$ = range of moving average
$x(k)$ = a changing rate in GWL value per day (state variable)
L = time step width of the slope between the past and present data

Step 1. Select the daily average GWL observation data

Select the daily average GWL observation data which is to be used as an initial value for the calculation of predicted GWL values. The data may be selected arbitrarily, but must be larger than $(2N+1)$.

Determine the value of parameters as follows.

N = the number of daily average GWL observation data
p = the number of days ahead for the prediction of GWL

Step 2. Calculate a moving average of the daily average GWL observation data

Calculate a moving average of the GWL observation data value based on the N value determined in Step 1.

$$z(k) = \sum_{i=-N}^{N} l(k+i) / (2N+1) \quad (14)$$

Where:
$z(k)$ = moving average
$l(k)$ = observed GWL from the SESAME system

Step 3. Calculate a state variable

Calculate a state variable as defined below.

$$x(k) = [z(k) - z(k - L)] / L \quad (15)$$

Where:
$x(k)$ = the rate of change (slope) in GWL value per day (state variable)
L = time step width of the slope between the past and present data

Step 4. Apply the Kalman Filter

Apply the Kalman Filter as expressed in the following equations. The equation (16) is based on the assumption that the slope changing rate is constant.

$$x(k+1) = x(k) + w(k) \quad (16)$$

$$y(k) = Lx(k) + v(k) \quad (17)$$

Where:
$w(k), v(k)$ = white Gaussian noise
$y(k)$ = observed data at day k (observed state variable)

Calculate the observed state variable, using the following expression.

$$y(k) = l(k) - z(k - L) = Lx(k) + v(k) \quad (18)$$

Calculate $w(k)$ and $v(k)$, using the following expression.

$$w(k) = x(k) - x(k-1) \; (k = N + L + 2, \ldots.., q - N) \quad (19)$$
$$v(k) = l(k) - z(k) \; (k = N + L, \ldots.., q - N) \quad (20)$$

Run the Kalman Filter, using the following iteration.

$$\begin{aligned} x(k|k) &= x(k|k\text{-}1) + K(k)\,[y(k) - Lx(k|k\text{-}1)] \\ x(k+1|k) &= x(k|k) \\ C(k|k) &= C(k|k\text{-}1) - LK(k)\,C(k|k\text{-}1) \\ C(k+1|k) &= C(k|k) + W(k) \\ K(k) &= LC(k|k\text{-}1) / [L^2C(k|k\text{-}1)+V(k)] \end{aligned} \quad (21)$$

Where:
$C(k|k)$ = Variance of $x(k|k)$
$C(k+1|k)$ =Variance of $x(k+1|k)$
$W(k)$ = Variance of $w(k)$
$V(k)$ = Variance of $v(k)$

Step 5. Make a prediction of the GWL for p days ahead

Use the following model (equation) to estimate predicted values of the GWL.

$$z(k+p|k) = z(k) + px(k|k) \quad (22)$$

This equation can also be expressed as:

Forecasted GWL at day *p*+*k* = *moving average* + day *p* × (*forecasted value at day- k*)

The predicted daily GWL values may be applied to the surrounding areas of SESAME GWL observation points, if there are no environmental factors affecting the GWL in those areas. In other words:

Peatland depth is even.
There are no drainage canals or rivers nearby the SESAME observation point.
Peatland type is uniform.

Figure 19 shows an example of GWL prediction for 3 days ahead.

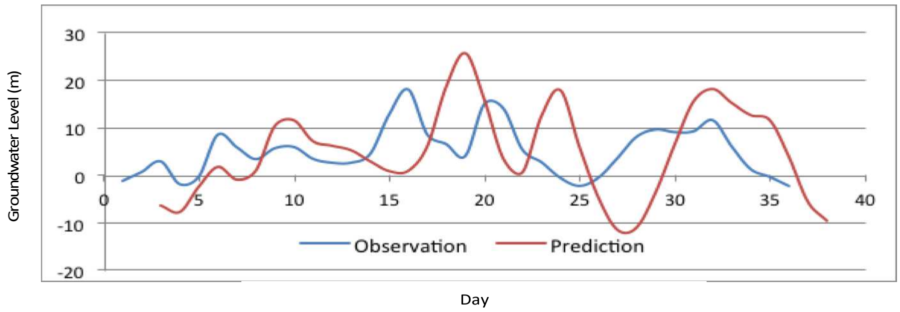


Figure 19. Illustration of GWL prediction for 3 days ahead

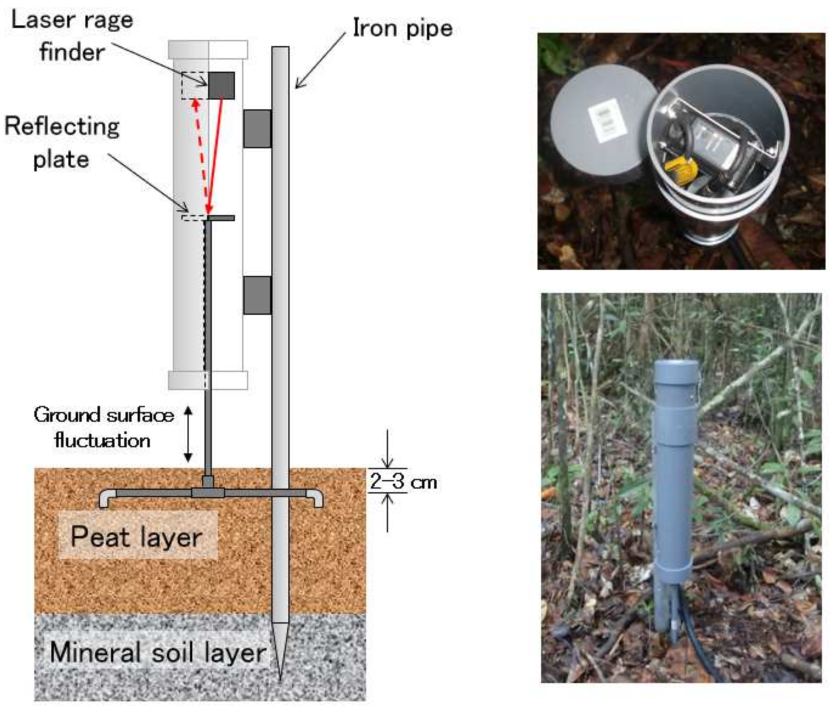
4.2. CO_2 Emission Estimation from Peat Subsidence

The subsidence of ground surface of peatland is mainly caused by biological decomposition, physical decomposition, chemical decomposition, compression by load, shrinkage, loss of matrix by water, and loss of matrix by fire (a type of chemical decomposition).Oxidation is the most important trigger of the subsidence of the peatland surface. Consequently, monitoring the ground surface level is a simple and useful way to assess decomposition and degradation of peatlands.Fluctuation of the ground surface in peatlands is affected by GWL. Monitoring of GWL should be combined with monitoring of ground surface level.

4.2.1. Instruments

Daily fluctuation of the ground surface is affected by changes in GWL. The amount of the fluctuation is usually smaller than a few millimeters. A laser distance sensor is the most suitable sensor for this purpose. The potentiometer is also suitable but the resolution is less than that of the laser distance sensor. The structure of the laser sensor and the layout of the sensor in the field are shown in Fig. 4.2.1. The laser sensor is fixed to the iron pipe which is fixed to the mineral soil layer below the peat layer. The movement of the ground surface transfers to the reflection plate through the plastic pipe which is connected to the plastic frame buried in the peat surface layer. Monitoring GWL should be done within 5 m of the ground surface level monitoring. The method of GWL monitoring is described in section 3.1. The control system of the laser distance sensor is incorporated in the same control box as GWL monitoring. Data of the ground surface level and GWL are sent simultaneously and in real time to the user through the SESAME system.

Figure 4.2.1: Schematic diagram of the laser distance meter and layout of the instrument in



the field (left), the inside of the sensor (right-top), and the full view of the sensor in the field (right-bottom)

4.2.2. Relationship between Ground Surface Level and GWL fluctuations

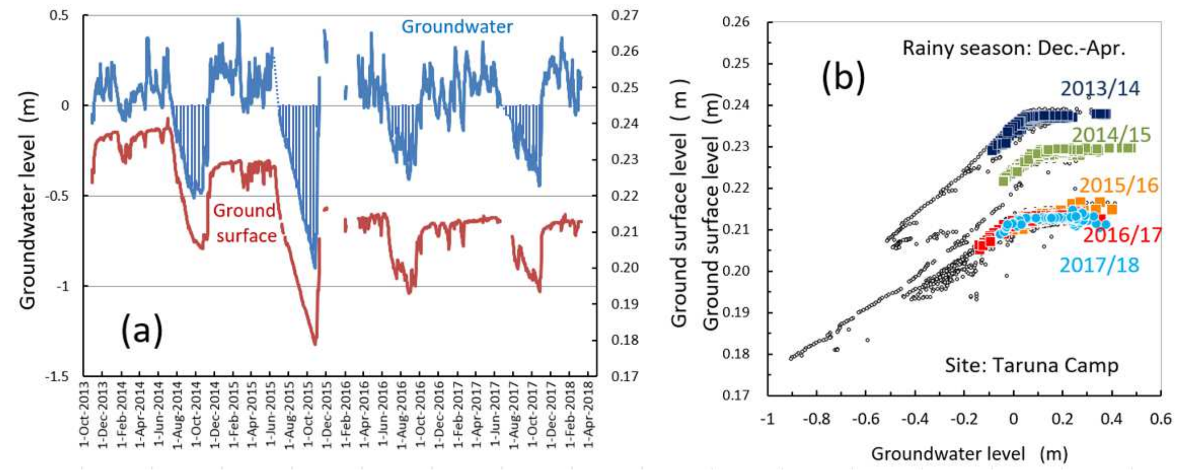
Results for ground surface level and GWL in a peatland in Central Kalimantan are shown in Fig. 4.2.2. The ground surface level changed following the change in GWL during the dry season from June to September (Fig. 4.2.2a). The change in ground water level was small despite the large change in GWL during the wet season from December to April. This means that the ground surface level during the rainy season indicates the standard level for this site.

The relationship between ground surface level and GWL is shown in Fig. 4.2.2b. There is little increase in ground surface level against the rise in GWL when GWL > 0.1 m. In addition, ground surface levels during the rainy season decrease year-by-year. The largest decrease was observed during the rainy season of 2015/16 and a small decrease was observed during the rainy season of 2014/2015. Conversely, decreases were small in 2016/17 and 2017/18. Differences in decreases of ground surface levels can be explained by the length and intensity of the dry season.

4.2.3. . Intensity of Drought Effects on Subsidence of GWL and Carbon Loss

The intensity of drought during a dry season can be represented by accumulated low

Figure 4.2.2: Four-year records of ground surface level and GWL in a peatland in Central



Kalimantan (a) and the relationship between ground surface level and GWL (b).

GWL below the reference water level throughout the dry season.

$$GWL_{day} = \sum_{i=1}^{n}(|G_i - G_0|) \qquad \textbf{eq (4.2.1)}$$

Where,

GWL_{day}: accumulated low GWL (m/day),

G_i: daily mean GWL in the dry season (m),

G_0: reference GWL (m) with $G_i < G_0$.

GWL_{day} in Fig. 4.2.3. was calculated from June 1 to October 31 with the reference GWL (G_i = 0). The average ground surface level during the wet season was obtained from the ground surface level when GWL > 0.2 m from December to April in the following year. The amount of ground surface subsidence is the difference between the ground surface level during the wet season and of the level in the previous wet season.

The volumetric carbon density of young ombrogeneous peat is ~ 50 kg m^{-3} (Shimada, 2001, 2016). The annual amount of subsidence of GSL in peatland (0.01 m) corresponds to ~ 500 g C m^{-2} yr^{-1}. This amount of carbon loss from the surface peat layer is close to the annual sum of NEE in drained and burned former forests (Hirano et al., 2012). The amount of NEE in tropical PSF shows a linear relationship with the lowest monthly GWL (Hirano et al., 2016)

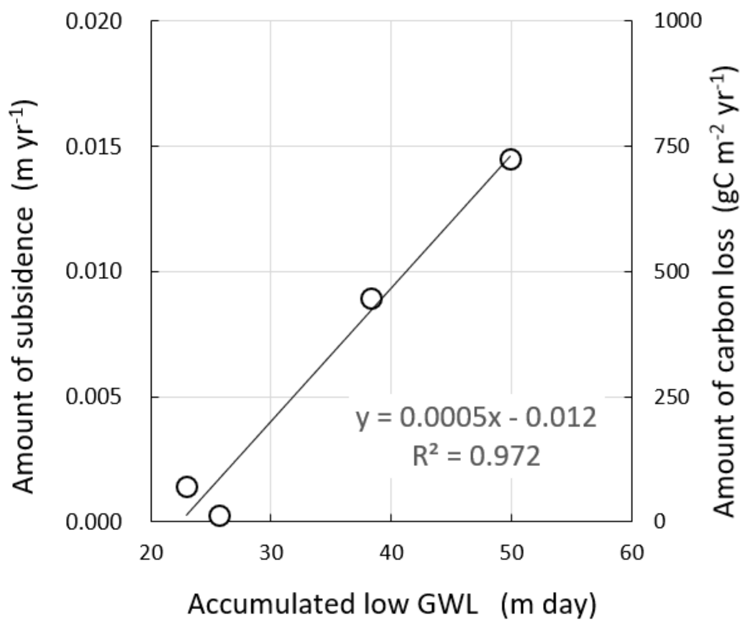


Figure 4.2.3: Relationships between accumulated low GWL (GWL_{day}), ground surface subsidence per year, and estimated carbon loss due to peat subsidence

References

Hirano T., Segah H., Kusin K., Limin S.H., Takahashi H. and Osaki M., 2012, Effects of disturbances on the carbon balance of tropical peat swamp forests, Global Change Biology 18, 3410–3422.

Hirano T., Sundari S. and Yamada H., 2016, CO2 Balance of Tropical Peat Ecosystem, Tropical Peatland Ecosystems (Eds, Osaki M. & Tsuji N.), 329-337.

Shimada S., Takahashi H., Haraguchi A. and Kaneko M., 2001, The carbon content characteristics of tropical peats in Central Kalimantan, Indonesia: Estimating their spatial variability in density, Geochemistry, 53: 249–267.

Shimada S., Takahashi H. and Osaki M., 2016, Carbon Stock Estimate, Tropical Peatland Ecosystems (Eds, Osaki M. & Tsuji N.), 353-365.

Takahashi H., 1999, Hydrological and Meteorological Environments of Inland Peat Swamp Forest in Central Kalimantan, Indonesia with Special Reference to the Effects of Forest Fire, TROPICS, 9, 17-25, Written in Japanese with English Abstract.

4.3. Methane Flux Estimation

CH_4 is the second most important greenhouse emission gas after CO_2. Tropical peatlands have a potential to be a large CH_4 source to the atmosphere because of high temperature, high GWL, and rich soil carbon which are all favorable to CH_4 production in peat. However, field studies using manual chamber systems have so far reported that soil CH_4 efflux in tropical peatlands is small (< 0.5 g C m^{-2} yr^{-1}) compared to that in temperate and boreal peatlands (Melling et al., 2005; Jauhiainen et al., 2008; Hirano et al., 2009). In contrast, CH_4 efflux measured by the eddy covariance technique with an open-path CH_4 analyzer (LI7700, Licor) above a protected tropical peat swamp forest in Sarawak was considerable (Wong et al., 2018). Annual CH_4

emission from the entire peat forest ecosystem was ~ 8 g C m^{-2} yr^{-1}. The large discrepancy between soil efflux and ecosystem-scale efflux is attributable to CH_4 emissions from tree stems (Pangala et al., 2013) and termites nesting aboveground (Martius et al., 1993). Obviously, the soil chamber method cannot measure aboveground CH_4 emissions and consequently underestimates CH_4 emissions. The eddy covariance technique that can measure ecosystem-scale flux is therefore preferable.

Figure 4.4: An eddy covariance system installed above a peat swamp forest. The front white system is an open-path CH_4 analyzer (LI7700)

References

Hirano, T., Jauhiainen, J., Inoue, T., Takahashi, H., 2009. Controls on the carbon balance of tropical peatlands. Ecosystems, 12, 873–887.

Jauhiainen, J., Limin, S., Silvennoinen, H., Vasander, H., 2008. Carbon dioxide and methane fluxes in drained tropical peat before and after hydrological restoration. Ecology, 89, 3503–3514.

Martius, C., Wassmann, R., Thein, U., Bandeira, A., Rennenberg, H., Junk, W., Seiler, W., 1993. Methane emission from wood-feeding termites in Amazonia. Chemosphere, 26, 623–632.

Melling, L., Hatano, R., Goh, K.J., 2005. Methane fluxes from three ecosystems in tropical peatland of Sarawak, Malaysia. Soil Biology and Biochemistry, 37, 1445–1453.

Pangala, S.R., Moore, S., Hornibrook, E.R., Gauci, V., 2013. Trees are major conduits for methane egress from tropical forested wetlands. New Phytologist, 197, 524–531.

Wong, G.X., Hirano, R., Hirano, T., Kiew, F., Aeries, E.B., Musin, K.K., Waili, J.W., Lo, K.L., Melling, L., Micrometeorological measurement of methane flux above a tropical peat swamp forest. Agricultural and Forest Meteorology, accepted.

4.4. CO_2 Emission from Burn scar measurements

4.4.1. Methodology of Burn scar measurements

The area and depth of burn scar in the study area are needed when estimating carbon emissions from peat burning, as the volume of burn scar is given by the burned peat area and burned peat depth (see Section 2.4). The area of burn scar can be detected with remote sensing data (e.g., MODIS burned area product) and/or original images taken by aerial photography (see Sub-section 2.1.1 on Remote Sensing Data Set). Burned peat depths in selected sampling plots can be measured through the steps described below (see Figure 6).

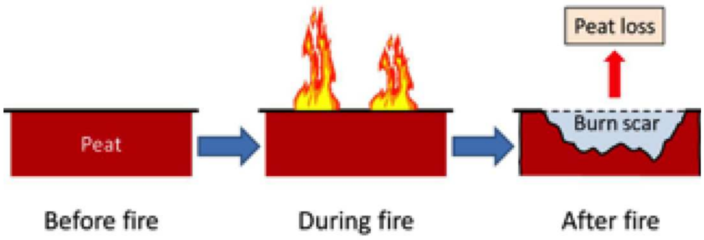


Figure 6. Illustration of burn scar measurement

Step 1. Make a burn scar map

Make a burn scar map of the study area just after a fire event, using the data prepared in the procedures described in Sub-section 2.1.1 (Remote Sensing Data Set).

Determine the burned area by a geometric analysis on the map on GIS.

Step 2. Prepare equipment for field survey

A minimum list of equipment necessary for burn scar field survey is provided below. This list should be adjusted based on the field condition.

- Eijkelkamp peat auger
- Aluminum cups and plastic bags
- Measuring tape and a rope
- Compass
- Measuring pole
- Theodolite
- GPS receiver

Step 3. Select sampling plots for field survey based on the burn scar map

Select sampling plots for field survey. The selected locations must represent the general condition of the burned area as shown in Figure 7.

- The total area of plots should cover at least 15% – 20% of the total burned area.
- If the number of plots is large, the locations can be randomly determined.

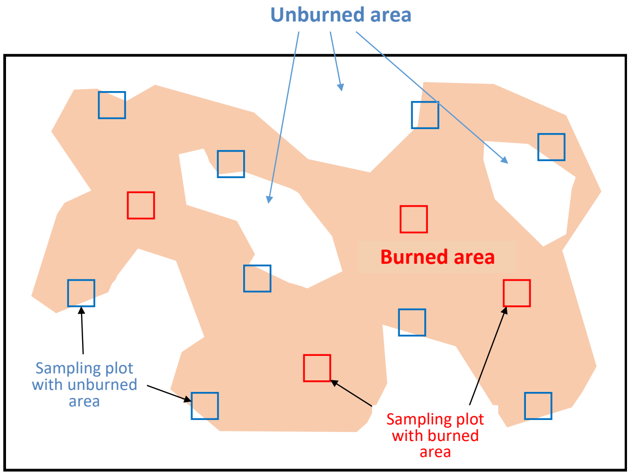


Figure 7. An example of burn scar sampling design

Step 4. Measure and record burned peat depths at the selected plots

Measure burned peat depths at several places in the sampling plots, and record them on a datasheet.

Once the rainy season begins, the burn scar gradually starts to fill in from the ingression of peat from the surrounding unburned area. Therefore, the survey should be conducted as soon as fires are out.

A measurement basis which indicates the level of ground surface before peat burning must be determined. The following objects can be used as the basis (also see Figure 8).

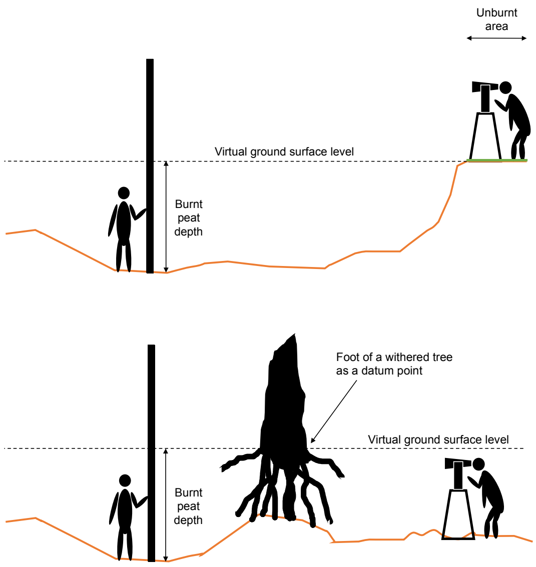


Figure 8. Illustration of burned peat depth measurements using an iron rod and a small unburned area (top) and a withered tree stand (bottom)

A small area which remains unburned: This is the most reliable basis, provided that the study area is generally flat and the ground surface level before burning can be assumed to be almost the same as the level in the surrounding area. If the plot contains an unburned area, its level can be used as the virtual ground surface level in the burned area before peat burning. If the size of each plot is large and the distribution of burned area is patchy, it is recommended to set up sampling plots at locations where plots can contain both burned and unburned areas.

An iron rod penetrated to the mineral soil underlying the peat layer: If the plot does not contain an unburned area, an iron rod may be used as the measurement basis. However, the iron rod must be installed before peat burning occurs (i.e., the beginning of the dry season). After the installation of an iron rod, scratch a line on the rod at the ground surface level. After the peat burning, measure the distance between from the scratched line and the burn scar surface (the new ground surface). This is the depth of burned peat layer.

Withered tree stand: If the plot does not contain an unburned area, a tree trunk may be used as the measurement basis. The level of withered tree foot suggests the ground surface level before peat burning. If the area suffers from peat fires repeatedly, however, this level may suggest the ground surface level from several years ago and may not reflect the peat depth burned by the latest fire.

Step 5. Collect peat samples in an unburned area near burn scar survey plots

Determine peat-boring points at an unburned area surrounding the burned peat depth plots measured in Step 4 above. The selected unburned area should be representative of land surface conditions of the burned area. It is recommended that at least 5 boring holes be made for each plot.

Collect peat samples in 50 cm segments with an auger (see Figure 9). Take 5 cm (50 cm^3) from each sample and place it into an aluminum cup before sealing it into a plastic bag. The number of samples to be collected at each boring point depends on the peat depth there.

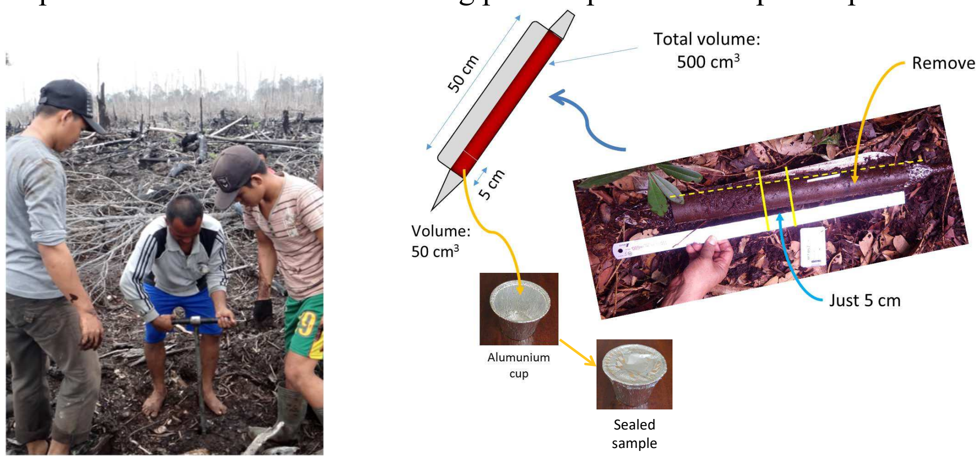


Figure 9. Procedure of peat sampling

Step 6 (Optional). Use advanced techniques for burned peat depth measurements

Select which advanced techniques to use (see Sub-section 2.1.1 on Remote Sensing Data Set).

Measure burned peat depths using the selected advanced techniques, and record data on the datasheet.

Verify the recorded data through ground-truthing.

Advanced techniques such as LiDAR and PALSAR-2 can replace the field measurement of burned peat depths. However, the analysis results should always be ground-truthed.

Data Analysis

❖ What data do you need to analyze? ❖

You will need to analyze raw data collected in field measurements in order to obtain linear relationships between GWL and remote sensing based soil moisture data (Figure 13), between GWL and NEE (Figure 14), and between GWL and carbon emissions from peat burning (Figure 16). These regression models are used to estimate carbon emissions from peat decomposition and burning, as explained at the end of the Part II of this guidebook. Therefore, the following data must be analyzed and each parameter must be calculated.

- ✓ Peatland types classified on a grid file covering the entire study area
- ✓ Lowest monthly average GWL(s) in the study year(s)
- ✓ Annual NEE in the study year
- ✓ The mass of carbon loss (or carbon emission) due to peat burning

Peatland type analysis

Peatland in the study area may consist of a variety of land use and land cover types with different degrees of ecosystem disturbances. The Carbon Emission Model from Peat Decomposition estimates the amount of CO_2 emissions from each type of peatland found in the study area. If land use and land cover characteristics were different, GWLs would be different as well; hence, the amount of CO_2 emissions from peat decomposition would vary, because the NEE is affected by the GWL. Therefore, it is important to classify the study area into different peatland types which represent distinctive characteristics of land use and land cover. Each peatland type must be clearly defined first. Detailed classification procedures are provided in Annex 1.

Step 1. Classify the study area into distinctive peatland types

Classify the study area into distinctive types of peatland by using remote sensing data set as described in Sub-section 2.1.1.

Peatland types may include:

Undrained (intact) forest (UF)
Drained (degraded) forest (DF)
Drained and burned land or non-forest area (DB)
Cropland
Oil palm plantation
Acacia plantation

Define forest and non-forest areas in the study area (if both areas exist).

Canopy loss areas may be classified as a drained and burned land (DB).

Define drained and undrained forest areas in the study area (if both areas exist).

Drained and undrained forest areas can be identified based on the relative dry tendency of dense forest surface. Lower dry classes can be classified as undrained forest (UF), and higher dry classes as drained forest (DF).

Step 2. Create a grid file, and extract pixel values of each peatland type into the grids

The classified study area must be prepared on a grid file, because the amount of CO_2 emissions from each peatland type will be calculated per grid cell.

Create a grid file on WGS 84 on GIS. NEE values are calculated based on a grid file on WGS 84. Therefore, it is necessary to cover the entire area of interest and to fit each grid to the pixel placement of ECMWF soil moisture data (the same grid size) described in Sub-section 2.1.1. Figure 10 shows an example of a grid file on 0.5-degree for Central Kalimantan. It shows the boundary of Central Kalimantan (blue line), new grids (black line) and ECMWF soil moisture data (gray scale).

Extract the pixel number of each peatland type from Step 1 above into every grid cell.

Calculate the area of each peatland type in each grid cell as illustrated in Figure 11. This will be used for NEE calculation in Section 2.3.

Upload the spreadsheet as an attribute table of the grid file on GIS.

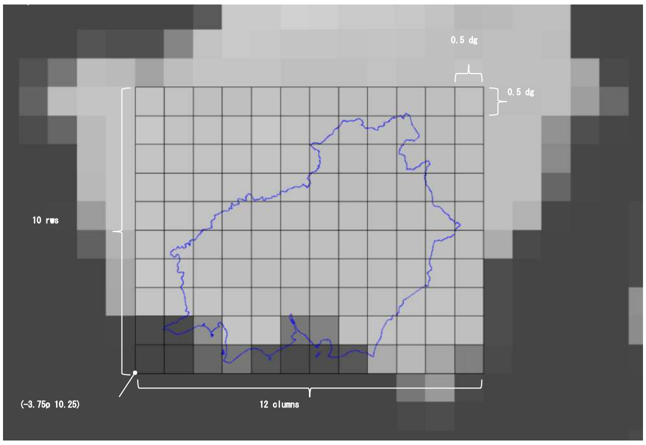


Figure 10. A grid file for Central Kalimantan

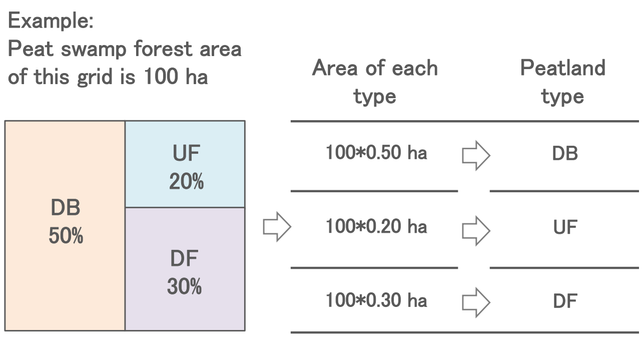


Figure 11. Example for the calculation of areas based on peatland types in a grid cell

4.4.2. Burn scar analysis

Step 1. Calculate the mean and standard deviation of burned peat depths

Calculate the mean and standard deviation of burned peat depths collected inside each plot as described in Step 5 of Sub-subsection 2.1.2.3.

Step 2. Take the average of burned peat depths among all sampling plots

Take the average of burned peat depths among all sampling plots with a standard error as given by:

$$\bar{d} = \frac{\sum_{i=1}^{N} d_i}{N}, \quad \Delta\bar{d} = \frac{\sqrt{\sum (\Delta d_i)^2}}{N} \tag{3}$$

Where:
N = the number of sampling plots
$\bar{d}$ = average burned peat depth among all sampling plots
= the standard error of average burned peat depth
d_i = average burned peat depth in Plot i
Δd_i = standard deviation of burned peat depth in Plot i

Step 3. Calculate burn scar volume

Calculate the volume of burn scar as given by:

$$\textit{Burn scar volume } (m^3) = \textit{Burn scar area } (m^2) \times \textit{Average burn peat depth } (m) \tag{4}$$

If the burn scar area contains an error ($A \pm \Delta A$), burn scar volume V and its standard error ΔV is given as follows. If there is no error, ΔA is assumed to be zero.

$$V = A \times \bar{d}, \quad \Delta V = \sqrt{(A \times \Delta\bar{d})^2 + (\bar{d} \times \Delta A)^2} \tag{5}$$

Step 4. Calculate bulk density of peat samples

Dry peat samples collected in Step 6 of Sub-subsection 2.1.2.3 (Burn scar measurements) in an oven at 105°C for 24 hours or longer until the constant weight is achieved.

Measure the dry weight of peat (W_p) and the weight of aluminum cup (W_c).

Determine the volume of peat samples (V). It is 50 cm^3, if samples are collected according to Step 6 of Sub-subsection 2.1.2.3 (Burn scar measurements).

Calculate the bulk density of peat samples as expressed in the following equation.

$$BD = \frac{(Wp + Wc) - Wc}{V} \tag{6}$$

Step 5. Calculate carbon content of peat samples

The following procedures are based on the loss on ignition (LOI) method. Carbon content can also be calculated by using an elemental analyzer.

Take a tablespoon of peat sample oven-dried as in Step 4 above, grind it, and measure the weight (M_p).

Measure the weight of a small, heat-resistant porcelain cup (M_c).

Place the peat sample into the porcelain cup, and measure the weight ($M_p + M_c$).
Burn the peat sample in a muffle furnace at a temperature >900 °C for 5 to 6 hours.

Cool the burned peat sample (ash) to room temperature in a desiccator, and measure the weight of the ash (M_a) with the porcelain cup.

Calculate the ash content (C_a) of the peat sample as:

$$Ca = \frac{(Ma + Mc) - Mc}{Mp + Mc - Mc} \times 100 \tag{7}$$

Calculate the content of organic matter in the peat sample (Co, %) as:

$$Co = 100 - Ca \tag{8}$$

Calculate the carbon content of peat samples (C, %), using the following equation.

$$C = Co \times 0.58 \tag{9}$$

Step 6. Calculate total peat carbon loss (emissions) from peat burning

Calculate the total amount of peat carbon loss due to peat burning by:

$$\textit{Peat carbon loss (kgC)} = \textit{Burn scar volume } (m^3) \times \textit{Bulk density } (kg/m^3) \times \textit{Carbon content (\% of dry weight peat)} \tag{10}$$

If the bulk density and carbon content contain errors ($BD \pm \Delta BD$ and $C\% \pm \Delta C\%$, respectively), calculate carbon content ($C \pm \Delta C$, kgC/m^3) first as follows. If there are no errors, ΔBD and/or $\Delta C\%$ are assumed to be zero.

$$C = BD \times C_{\%}, \quad \Delta C = \sqrt{(BD \times C_{\%})^2 + (\Delta BD \times C_{\%})^2} \tag{11}$$

Where:
C = carbon content
BD = bulk density

After this, calculate the total peat carbon loss ($F_b \pm \Delta F_b$) given as follows. The value, F_b, will be used as the amount of carbon emissions in Section 2.4 (Carbon Emission Model from Peat Burning).

$$F_b = V \times C, \quad \Delta F_b = \sqrt{(V \times \Delta C)^2 + (C \times \Delta V)^2} \tag{12}$$

Where:

F_b = carbon loss (emission)

4.4.3. Carbon Emission Model by Burn scar analysis

❖ What is a Carbon Emission Model from Peat Burning? ❖

Similar to the Carbon Emission Model from Peat Decomposition explained in Section **Error! Reference source not found.**, this model is based on the assumption that there is a linear relationship between the mass of carbon loss from peat burning and GWL. Based on this relationship, the Carbon Emission Model from Peat Burning allows you to estimate the amount of annual carbon emissions by using the lowest monthly average GWL(s) in the study year(s) as a parameter

Step 1. Obtain a linear relationship between the amount of annual carbon emission from peat burning and observed lowest monthly average GWL(s) in the study year(s)

Draw a linear regression line between the lowest monthly average GWL(s) in the study year(s) observed at a location representative of the characteristic of the burned area on the *x* axis, and observed annual carbon emission from peat burning obtained in Step 6 of Sub-section 2.2.4 on the *y* axis (see Figure 16).

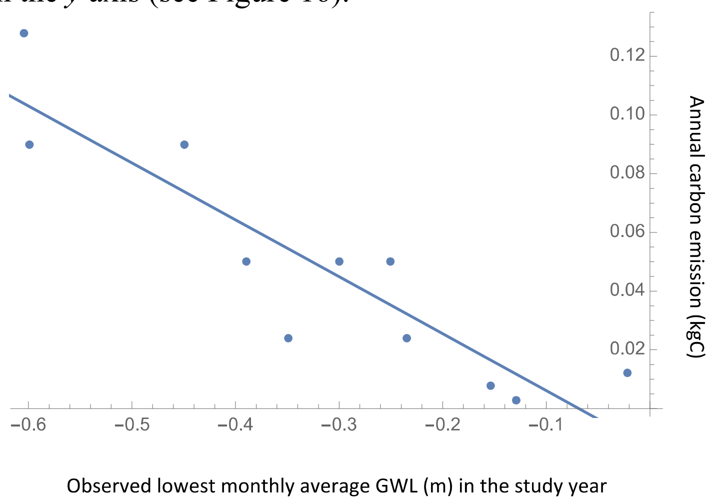


Figure 16. Example of a linear relationship between the lowest monthly average GWL(s) in the study year(s) and annual carbon emission from peat burning observed in the ex-Mega Rice area in Central Kalimantan (Putra et al., 2009)

Step 2. Estimate annual carbon emission from peat burning

Estimate annual carbon emissions from peat burning for other areas of interest. The equation obtained in Step 1 above can only be applied to other areas which indicate similar characteristics of the observed burned area.

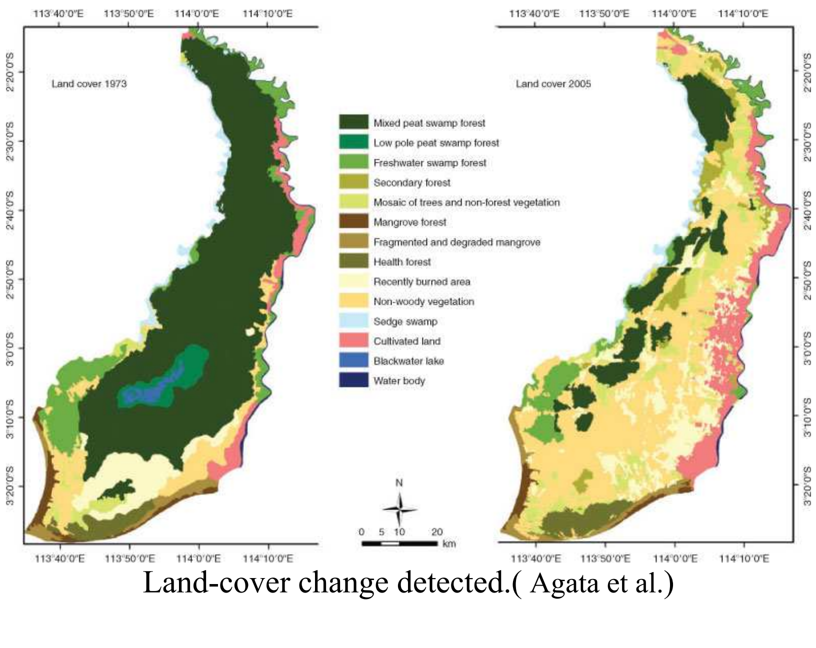
You can use the equation to estimate the amount of carbon emissions from peat burning for different years, or in other areas beyond sampling locations as long as those areas show similar characteristics to the burned area.

4.5. Estimation of Carbon Emission by Remote Sensing Analysis of Burn Scars

Forest fires in tropical peatlands cause deforestation and reduction of carbon density. The detection of burn scars is an important index for the carbon emission estimation. In this section, several remote sensing technologies used to detect burn scars in previous researches are reviewed.

4.5.1. Burn Scar Estimation

In Central Kalimantan, Indonesia, extensive forest fires have been occurring repeatedly in the peatlands after the rapid environmental change caused by the Mega Rice Project.
Prior studies revealed a rising trend in the rate of deforestation and identified fire as the principal factor influencing the subsequent vegetation succession. Agata et al. have analyzed a time series of satellite images of the peatlands of Central Kalimantan for the period 1973–2005. They identified a step change in fire regime, with increased burned areas and fire frequency following the peatland drainage; i.e., while peat swamp forest was the most extensive land-cover class and fires were of relatively limited extent and rarely repeated during the 23-year pre-Mega Rice Project period (1973–1996), in the 9-year post-Mega Rice Project period (1997–2005) there was a 72% fire-related loss in area of the peat swamp forest, mostly converted to non-woody vegetation rather than cultivated land and dominated by ferns or mosaics of trees . Fire is an important factor for land-cover dynamics and forest loss in the peatlands. Hence, there are high expectations on fire burn scar estimation by remote sensing technologies.



Land-cover change detected.(Agata et al.)

- Hoscilo Agata, Page Susan E., Tansey Kevin J., Rieley John O. (2011) Effect of repeated fires on land-cover change on peatland in southern Central Kalimantan, Indonesia, from 1973 to 2005. *International Journal of Wildland Fire* **20**, 578-588

4.5.2. Applicability of Synthetic Aperture Radar Analysis

Synthetic aperture radar (SAR) satellites can cover great areas and they are nearly independent of clouds. Using SAR data, the peat surface variations depending on vegetation, microtopography, and irrigation can be detected by wide-area analysis, including hydrological units.

To properly conserve and manage peat soil, it is necessary to comprehensively and precisely understand its behavior in each area. In principle, the decomposition situation of peat soil can be estimated as the amount of ground surface displacement by SAR differential interferometry (DInSAR) analysis. However, due to the characteristics of the microwaves used for this technique, intensity of interference and data accuracy are affected by the planting and topography of the peatland.

By performing DinSAR analysis with different frequencies by satellites and comparing the results, the amount and type of changes in peatland can be detected according to the respective frequency characteristics. The frequency determines where, what, and how much of the change can be detected in the peatland and the validation of the effectiveness of DInSAR analysis in peatland management. SAR data taken at different times allows the detection of the movement of peat soil surface and occurrence event detection reveals the influence of artificial land alteration and events as fire on the peat soil.

Step 1: Selection of SAR Data

This section focuses on the effectiveness of DInSAR analysis as soil decomposition index by organizing the detected peatland changes according to their frequency characteristics.

The L-band ALOS-2 satellite has been launched by JAXA as a successor to ALOS. ALOS-2 has higher resolution, wider observable area, and better data transfer capacity than ALOS. It will greatly contribute to the efficient management of land and conservation of the environment. TerraSAR-X is a X-band SAR providing consistent and high repetitive coverage thanks to time- and weather-independent acquisitions. It can detect subtle changes in the forest canopy due to high resolution and radiometric stability.

To select the suitable sensor for the research target, it is necessary to understand the characteristics of each sensor. That is, the shorter the wavelength of the microwave used for the interference SAR, the better the resolution of the ground change detection. However, in this case the analysis would be influenced by minute changes, such as vegetation on the ground surface, and is difficult to obtain interference. On the other hand, when the wavelength is longer, the resolution of the surface change detection gets worse but a wide range interference can be obtained.

SARs with different frequencies.

		TerraSAR-X	Sentinel-1	PALSAR-2
Frequency (ν)		9.65GHz (X-Band)	5.405GHz (C-Band)	1,257.5MHz (L-Band)
wavelength (λ)		3.1cm	5.6cm	22.9cm
Polarized wave	Single polarization	HH VV HV VH	VV HH	HH HV VH VV
	Dual polarized wave	HH+VV HH+HV VV+VH	HH+HV VV+VH	HH+HV VV+VH
Maximum resolution		0.25 m	5 m	3 m
Observation period		11days	12days	14days
Operation period		2007～	2014～	2014～

Step2: Burn Scar Estimation by PALSAR-2

This section describes the method of DInSAR analysis by using the actual application of PALSAR-2 sensor.

1) Data Mode Selection

To choose the mode of the data, their specifications, such as frequency, band width, spatial resolution, incidence angle, swath width, and polarization and noise levels (See Table), must be clarified according to the targeted research interest.

PALSAR-2 sensor observation mode and specification

<table>
<tr><th rowspan="2">Mode</th><th rowspan="2">Spot light</th><th colspan="5">Fine-beam</th><th colspan="3">Wide-beam</th></tr>
<tr><th>3m (SM1)</th><th colspan="2">6m (SM2)</th><th colspan="2">10m (SM3)</th><th colspan="2">ScanSAR (WD1)</th><th>Scan SAR (WD2)</th></tr>
<tr><td>Freq. (MHz)</td><td colspan="2">1,257.5</td><td colspan="7">1,236.5/1,257.5/1,278.5</td></tr>
<tr><td>Band width (MHz)</td><td colspan="2">84</td><td colspan="2">42</td><td colspan="2">28</td><td>14</td><td>28</td><td>14</td></tr>
<tr><td>Spatial resolution (m)</td><td>3*1 Rg*Az</td><td>3</td><td colspan="2">6</td><td colspan="2">10</td><td colspan="2">100 (3 looks)</td><td>40</td></tr>
<tr><td>Incidence angle (deg.)</td><td colspan="3">8-70</td><td>20-40</td><td>8-70</td><td>23.7</td><td colspan="3">8-70</td></tr>
<tr><td>Swath width (km)</td><td>25</td><td>50</td><td>50</td><td>40</td><td>70</td><td>30</td><td colspan="2">350 (5 scans)</td><td>490 (7 scans)</td></tr>
<tr><td>Polari-zation(*1)</td><td>SP</td><td>SP DP</td><td>SP DP CP</td><td>FP</td><td>SP DP CP</td><td>FP</td><td colspan="2">Sp DP</td><td>SP DP</td></tr>
<tr><td>Noise level (dB)</td><td>-24</td><td>-24</td><td>-28</td><td>-25</td><td>-26</td><td>-23</td><td>-26</td><td>-23</td><td>-26</td></tr>
</table>

*SP: HH or VV.
DP: HH+HV or VV+VH.
FP: HH+HV+VH+VV.
CP: Compact polarization (Circular or 45 degree linear polarization).

Step3: Master-Slave Data Pair Images

After clarifying the research interest in terms of multi-temporal analysis, interval of data, data pair acquisition for the multi-temporal analysis, and targeted site, the master and slave data pairs of the DinSAR analysis must be ensured.

As described above, a necessary condition for securing a high interference degree in DinSAR analysis is the selection of an interference pair having a short interorbital distance. In addition, it is important to consider the specifications of the sensors and the time intervals of the interference pairs. However, to objectively evaluate the coherence from the observation parameters, the critical baseline length *Bc*, which described by the following and often applied equation, must be considered.

$$B_c = \frac{\lambda\rho \cdot tan\theta}{2R_{rg}} \quad (1)$$

Where λ is the wavelength of the microwave, ρ is the range distance in the line of sight direction, θ is the incident angle, R_{rg} is the range resolution, and the critical baseline lengths of WD1 and SM3 (Table) are considered as 4,672 m and 9,974 m, respectively. The degree of interference of the DInSAR analysis decreases as the interorbital distance increases with a gradient of approximately 1/critical baseline length. As shown in Table 1, the WD1 and SM3 images by PALSAR-2 have the same wavelength, range length, and incident angle, but WD1 has lower spatial resolution than SM3. Since the critical baseline length of WD1 is shorter, even if all the other observation conditions are the same, its degree of interference inevitably tends to decrease. In the case of SM3, a pair whose interorbital distance is as close to zero as possible and whose time interval is within one year would be preferentially selected.

The figure shows the dependence of the coherence value of the entire image on the time interval. The coherence value rapidly decreases until the time interval reaches about 100 days, and then it gently decreases. Finally, it converges to the smallest value (0.3-0.35) around 200 days.

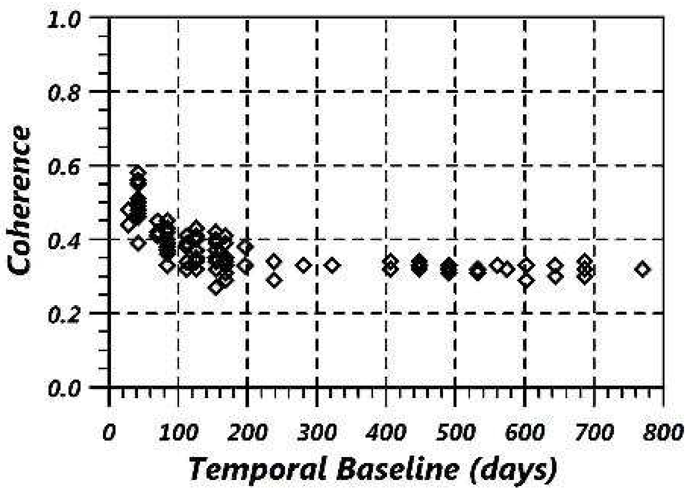


Figure Dependence of coherence value on the time interval of the interference pair.

Step4: Coherence Generation

The interference image is an image obtained by calculating the phase difference between the master image and the slave image and visualizing the change in the distance between the sensor and the ground surface in terms of radian angle. Since the interference image depends on the relative distance change, it indicates how much the ground surface approaches or gets away from the sensor.

In the differential interference analysis, the phase information of the component from which the microwave scatters backward is used. Therefore, the measurement accuracy of the analysis depends on the phase stability of this component. A previous research [11] reports that the phase stability decreases as the interorbital distance of the interference pair increases, and hence it is necessary to position the pairs so that their interorbital distance is as close to zero as possible.

In addition, since the state changes of the water vapor layer and the ionosphere between the sensor and the ground are factors lowering the measurement accuracy of the DInSAR analysis, a process for correcting their influence is necessary.

Since the process of differential interference analysis passes through an image averaging processing called multi-look processing, it is necessary to determine which are the optimal settings that likely cause interference in both the range direction and the azimuth direction.

Rodriguez et al. (1992) describes the relationship between coherence and interference phase by the following equation.

$$\phi = \sqrt{\frac{1}{2N}} \times \sqrt{\frac{1-\gamma^2}{\gamma^2}}$$

Here, φ is the standard deviation of the phase difference obtained by differential interference analysis, N is the number of looks, and γ is the coherence value. In the analysis using the data of WD1, since the number of looks in the range and azimuth directions are fixed to 2 and 8, respectively, the standard deviation of the phase given by a coherence value of 0.3 is 0.56 radians, with a displacement amount of about 1 cm.urthermore, it is good to visually confirm the actual differential interference analysis results in the analysis target range and adopt the combination that obtained sufficient interference.

Step5: Interpretation of Results

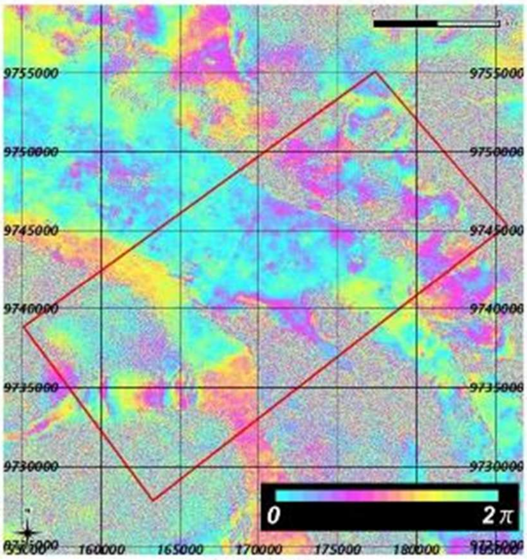
The key to interpret the results is that a change of the color tone from blue to red to yellow to green indicates that the ground surface is displaced away from the sensor, while a change from blue to green to yellow to red corresponds to a ground surface displaced toward the sensor.

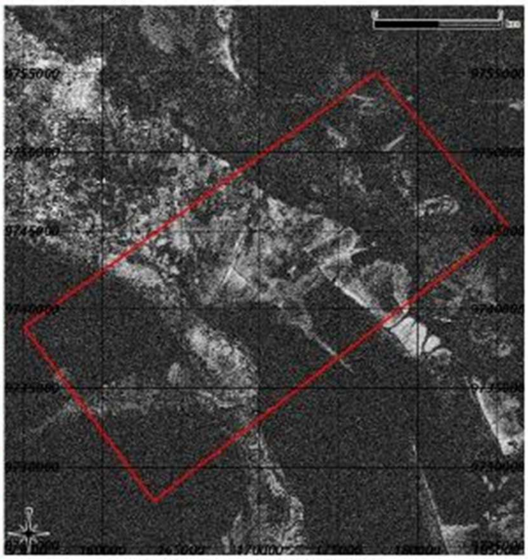
Usually, it is necessary to eliminate the 2π uncertainty by applying the phase unwrapping process. However, in the target area of this work, the phase change in a short period of time is intense and, especially in water systems, many phase discontinuous lines are observed and the phase unwrapping process does not function properly. Therefore, we decided to not apply the phase unwrapping process in this work and to interpret the results with the phase indication as it is.

The coherence image is obtained by indexing the similarity between the master image and the slave image from 0 to 1. Higher coherence values result in a higher correlation (white in the image), and vice versa (black in the image). For example, if the water is submerged or dried due to the difference between the rain precipitation rates of the rainy and the dry season, the coherence decreases.

Coherence decreases even if the surface covering form changes due to forest fires or logging. The coherence value is a synonymous of the degree of interference in the differential interference analysis and is often used for objectively evaluating the measurement accuracy of the ground surface displacement.

Red and blue arrows are shown in each interference images to assist the interpretation of major phase anomalies. A red arrow indicates that the subsidence phenomenon of the earth surface increases toward the tip and a blue arrow means that the tendency of the uplift phenomenon is to increase toward the tip.





In order to proceed with further detailed consideration, it is necessary to analyze fore and aft fires at short time intervals.

Several points should be considered to improve and apply the Water Table Models and Carbon Emission Models presented in this guidebook. To improve these models further, an Integrated Sensing System is necessary for the next program. It is distributed here to develop the concept of a model for an Integrated Sensing System.

5.1. Integrated Sensing System

Peatlands are dynamic ecosystems in relation to groundwater at both vertical and horizontal scales. Thus, each component of interest such as biomass, fire impact, ground subsidence, and landslide must be measured relative to ground movement. In addition to peatlands' significant movement and our index for peatland condition, sensing data lack suitable time-series intervals to monitor dynamic situations. Previously, sensed geospatial information was treated as static data. However, given the dynamics of peatland ecosystem, a new observation system that captures overall spatial dynamics in peatlands is necessary. In this section, we describe the specification of each sensor which can be applied to peatland ground surface measurement (5.1.1.) and illustrate the key concept of an Integrated Sensing System which can monitor the spatial dynamics of peatlands (5.1.2.).

5.1.1. Sensing Systems

In this section, we describe various sensing systems applied to conduct ground surface measurements in peatlands.

(1) Needs for Precise Measurement of Peatland Dynamics
The detection target in peatland ground surface can be summarized as follows (Fig. X).

- Biomass changes
- Fire impacts
- Ground subsidence
- Landslides

The various sensing methods such as the Synthetic Aperture Radar (SAR), Light Detection and Ranging (LiDAR), and camera have been applied to investigate the spatial dynamics of peatlands. To precisely measure field conditions, it is necessary to choose the most suitable sensor.

Annex.01

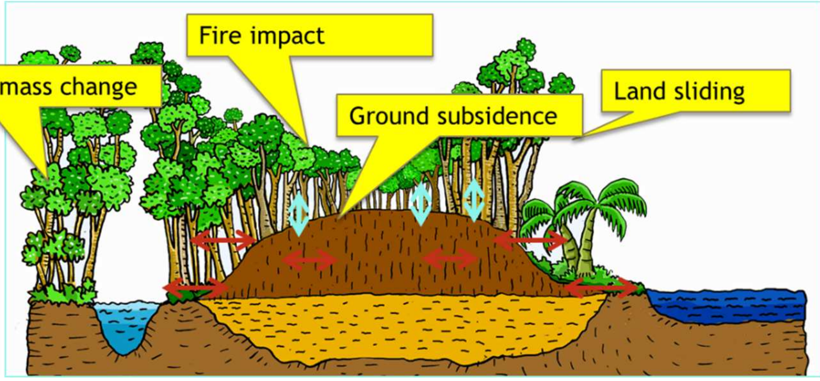


Figure 1:

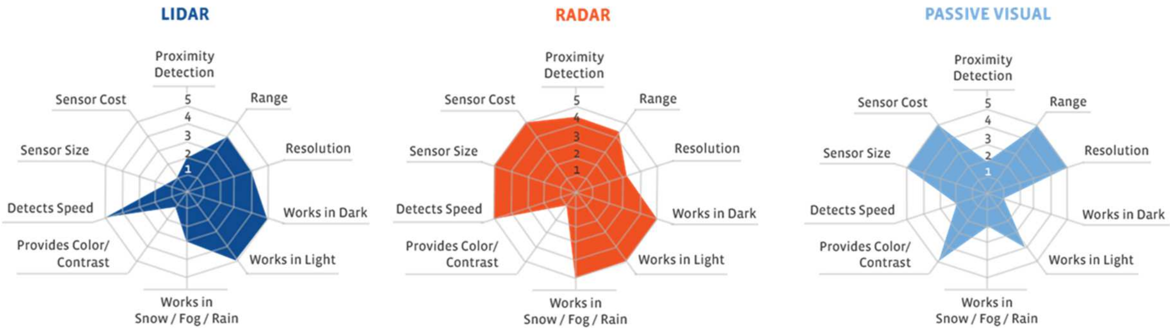


Figure 2: Derived from https://www.unitedlex.com/news-and-insights/blog/2017/google-tesla-it%E2%80%99s-war-lidar-or-radarF

Table X. Advantages and disadvantages of Light Detection and Ranging (LiDAR), RADAR, and camera sensors

	LiDAR	RADAR	Camera
Advantages	- Possible to detect objects with low reflectivity of radio waves - Distance and direction can be detected with high spatial resolution - Fast detection	- Does not depend on light source and weather conditions - Accurately measures distance to a target object - Fast detection	- Objects can be identified from features
Disadvantages	- Because infrared light is used, the detection performance deteriorates in bad weather conditions	- Low spatial resolution - Difficult to detect objects with low reflectivity of radio waves	- Inspection ability is reduced in bad weather conditions

(2) Hyperspectral sensor
Hyperspectral imaging collects and processes information from across the electromagnetic spectrum. The goal of hyperspectral imaging is to obtain the spectrum for each pixel in the image of a scene with the purpose of finding objects, identifying materials, or detecting processes. Hyperspectral images are suitable for analyzing specific crops by Normalized Vegetation Index (NVI) and in specific climates. The use of hyperspectral remote sensing is increasing for monitoring the development and health of crops.

(3) LiDAR
The LiDAR system can rapidly transmit laser pulses during the day and night. The result is therefore a reflection of both landscape and man-made features. The known speed of light as well as the measured time interval of the laser pulses from transmission to return allows the determination of distances. An aerial survey of a zoning area can be performed either by a fixed-wing airplane, helicopter, or in parts by a drone with LiDAR equipment including an Inertial Navigation System with a GPS. The result is an innovative tool for analyzing the ground and surface. Applications are possible for hydrology, measurements of peat domes, extraction of tree height, estimation of above-ground biomass, the design of infrastructure such as roads, water canals, plantations, etc.

The eye-safe laser in the system has a very narrow beam called a small-footprint LiDAR that can penetrate gaps in vegetation to reach the ground through trees and other elements. This penetration allows for an accurate determination of ground levels in vegetated areas. Due to the instrumentation in the LiDAR system that provides accurate position and altitude information for the laser points as well as an installed camera, very few ground control points are required, which means that accurate surveys are possible for inaccessible areas. These include quarries, wetlands, flood plains, etc. LiDAR data produce a Digital Surface model (DSM) with infrastructure, trees, canopy, and a Digital Terrain Model (DTM) of the topography of the landscape.

Tree height (h) can be obtained as follows:

$$h = DSM - DTM$$

The accuracy of the surface generated is ~ 15 cm in elevation (z), ideal for agricultural planning, peatland research, river catchments surveys, and flood mapping. Eroded areas can be accurately surveyed even through long grass layers.

The main objective was to map changes in the vertical structure of trees and vegetation with the multi-temporal LiDAR technology to identify both sources and sinks of carbon across peat dome-shaped gradients.

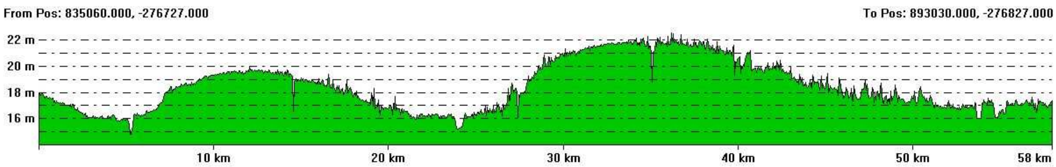


Figure 3: Peat profile with a Digital Terrain Model covering the rivers Sebangau (left), Kahayan (middle), and Kapuas (right)

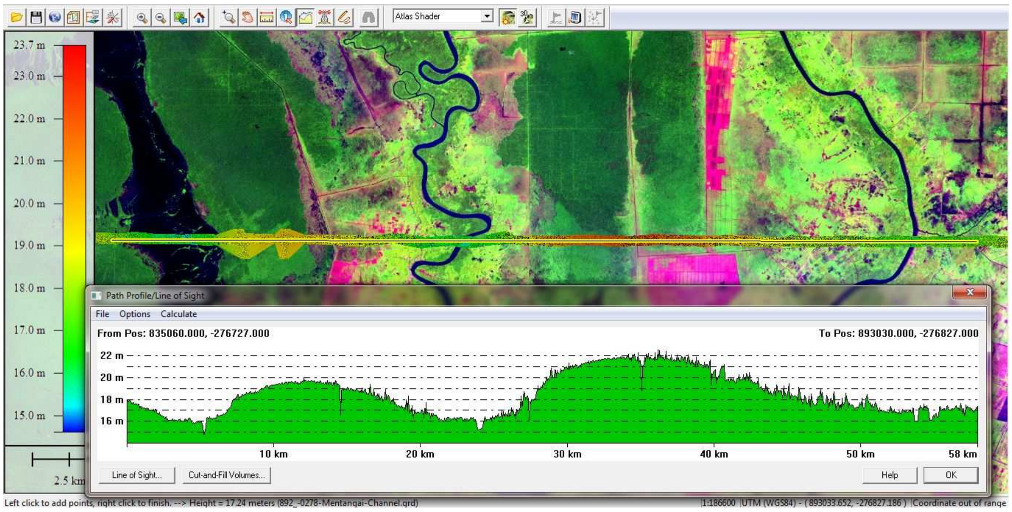


Figure 4: Light Detection and Ranging Digital Terrain Model and peat profile in the Pulang Pisau Province

(4) Radar

To conserve and manage peat soil properly, it is necessary to comprehensively and precisely understand the behavior of peat soil in each area. In principle, the decomposition rate of peat soil can be extracted as the amount of ground surface displacement by SAR differential interferometry analysis (DInSAR). SAR-satellites can cover a greater area and they are nearly independent of clouds. The L-Band ALOS-2 was launched by JAXA as a successor to ALOS. ALOS-2 has higher resolution, wider observable area, and better data transfer capacity than ALOS. ALOS-2 is expected to positively contribute to the efficient management of land and environment conservation. TerraSAR-X is a X-band SAR providing consistent and high repetitive coverage due to time- and weather-independent acquisitions. Subtle changes in the forest canopy are detected with TerraSAR-X due to its high resolution and radiometric stability.

(5) Ortho Photo

Photogrammetry is the process of authoring a digital surface model using multiple photos of the objects based on the principle of triangulation. A high-quality three-dimensional surface model of objects is modeled in a broad-scale application of photogrammetry to photos acquired by drones or unmanned aerial vehicles (UAVs). By taking multiple photos in at least two locations, "lines of sight" (LOS) can be developed from each camera to point to objects. These LOS are mathematically intersected to produce three-dimensional coordinates of points of interest.

Figure 5: Example of the Ortho-Photo method in Palangkaraya-Pahandut Habour on the Kahayan river

5.1.2. Key Concept of an Integrated Sensing System

In this section, we highlight two key concepts in an Integrated Sensing System considering the accuracy and reliability of sensing data.

(1) Sensor fusion technology

In the near future, large amounts of data will become available using drones, UAVs, helicopters, and satellites. To enhance the utility of such data, it is necessary to develop not only individual sensing technologies but also sensor fusion technologies using LiDAR, RADAR, camera, thermal and hyper-spectrum sensors. The combination of such data acquired by different sensor types will be useful for monitoring the rewetting of peatlands and for analyzing peatland deformation.

(2) Ground Control Network

To enable precise field measurements, careful design of a Ground Control Network is necessary. The Ground Control Network determines locations and deformations with improved precision everywhere and anytime on earth to satisfy societal and science requirements (United Nations Global Geospatial Information Management resolution).

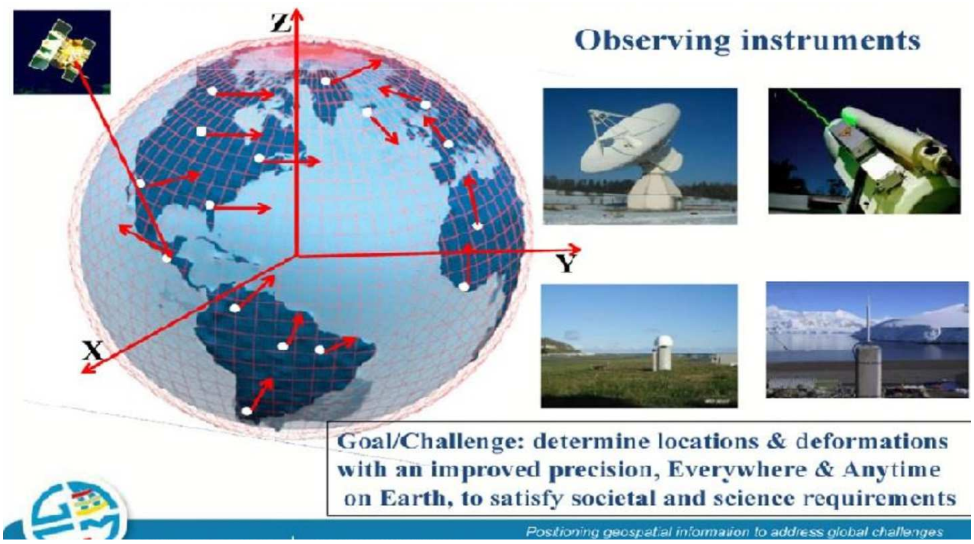


Figure 6:

Implementation of the Geodetic Control Network would contribute to increased application of geospatial data. It will also help observe the spatial dynamics of peatlands. For example, real-time location data would be applied to DInSAR analysis and used to verify the results of the analysis. The points to implement the Geodetic Control Station should be occupied by humans, located in stable ground, and should not be affected by construction activities. The site for setting the Geodetic Control station needs to be selected at a stable point, avoiding swampy or loose-soil areas.

5.2. Mapping Platform

To enable responsible management, it is important to monitor the spatial dynamics of peatlands. Such dynamic information on peatlands should be managed and operated on the integrated mapping platform to contribute to the decision-making process of policy makers. To ensure the high usability of the peatland mapping platform, ensuring the reliability of data will be the crucial for the system operators.

To create a reliable system, data to be uploaded to the system need to pass a screening test to check the accuracy of the contents and attributes of geospatial information. All data should therefore be automatically screened by the system. The mapped secondary data should include accuracy-validation information which is to be used for screening. To ensure the reliability of the material contents, it would be effective to ensure data are public. In addition, timely updating of the system is also important to improve operability. Timely updating would be achieved by the data server which manages data obtained from each SESAME system in Indonesia using a network connection. Improvement of network connection between the server and each SESAME system installed in the field would contribute to real-time updating of metadata by reducing the number of data gaps. Considering the high reliability of the system, the operational cost would be the crucial factor for operationalization. Thus, data processing, collection, evaluation, screening, and updating should be automated in the future.

REFERENCES

DNPI. (2014). Updating Indonesia's Greenhouse Gas Abatement Cost Curve. Dewan National Perbahaan Iklim. Jakarta, Indonesia.

Hirano, T., Segah, H., Kusin, K., Limin, S., Takahashi, H., and Osaki, M. (2012): Effects of disturbances on the carbon balance of tropical peat swamp forests. Global Change Biology, 18, 3410-3422.

ICCC. (2012): Peatland Definition: From Uncertainty to Certainty. Policy Memo, Indonesia Climate Change Center, Jakarta, Indonesia, 27 p.

Putra E.I., Hayasaka H., Takahashi H., and Usup A. (2008): Recent peat fire activity in the Mega Rice Project Area, Central Kalimantan, Indonesia. Journal of Disaster Research, 3(5), 334-341.

Putra E.I. and Hayasaka H. (2009): Carbon emission from severe peat fires in Mega Rice Project area, Indonesia. Proceedings of Japan Association for Fire Science and Engineering (JAFSE) Annual Symposium 2009, pp.226-227, Tokyo.

Shigenaga, Y., Saito, H., Takahashi, H., Teguh, R., Kencana, W., Jaya, A., and Setiadi, B. (2016): Field data transmission system by universal mobile telecommunication network. In: Osaki, M. and Tsuji, N. (eds.), Tropical Peatland Ecosystems, Springer, 479-489.

Wahyunto, Ritung, S., and Subagjo, H. (2004) Peta Sebaran Lahan Gambut, Luas dan Kandungan Karbon di Kalimantan (Map of Peatland Distribution Area and Carbon Content in Kalimantan) 2000-2002. Wetlands International-Indonesia Programme (WI-IP) & Wildlife Habitat Canada (WHC), Bogor, Indonesia.

Wösten JHM, van den Berg J, van Eijk P, Gevers GJM, Giesen WBJT, Hooijer A, Idris A, Leenman PH, Rais DS, Siderius C, Silvius MJ, Suryadiputra N, Wibisono IT. (2006): Interrelationships between hydrology and ecology in fire degraded tropical peat swamp forests. International Journal of Water Resources Development 22(1), 157–174.

ACRONYMS

APHI	The Indonesian Forest Concessionaires Association (Asosiasi Pengusaha Hutan Indonesia)
APRIL	Asia Pacific Resources International Holdings Ltd
BAPPEDA	Regional Development Planning Agency (Badan Perencanaan Pembangunan Daerah)
BAPPENAS	Ministry of National Development (Kementerian Perencanaan Pembangunan Nasional)
BBSDLP	Indonesian Center for Agricultural Land Resources Research and Development (Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian)
BIG	Indonesian Agency of Geospatial Information (Badan Informasi Geospasial)
BPPT	Agency for the Assessment and Application of Technology (Badan Pengkajian dan Penerapan Teknologi)
BRG	Peatland Restoration Agency (Badan Restorasi Gambut)
CEH	Centre for Ecology & Hydrology
CIMTROP	Center for International Cooperation in Sustainable Management of Tropical Peatland
DG	Directorate General
DPR	People's Representative Council (Dewan Perwakilan Rakyat)
DRN	Indonesian National Research Council (Dewan Riset Nasional)
FOERDIA	Forest Research and Development Centre
GAPKI	Indonesian Palm Oil Association (Gabungan Pengusaha Kelapa Sawit Indonesia)
GVL	Geomatic Ventures Limited
GWL	Ground Water Level
HITI	Indonesia Soil Science Society (Himpunan Ilmu Tanah Indonesia)
ICRAF	World Agroforestry Centre
IPB	Bogor Agricultural University (Institut Pertanian Bogor)
IPS	International Peatland Society
ISCC	Indonesia Sustainable Coffee Cooperative
ISRI	Indonesian Soil Research Institute
JICA	Japan International Cooperation Agency
JPS	Japan Peatland Society
KHDTK	Forest Area for the Special Purpose (Kawasan Hutan Dengan Tujuan Khusus)
LAPAN	Indonesian National Institute of Aeronautics and Space (Lembaga Penerbangan dan Antariksa Nasional)
NCEP	National Centers for Environmental Prediction
PASSES	Peatland Assessment in South East Asia by Satellite
SATREPS	Science and Technology Research Partnership for Sustainable Development
SDG	Sustainable Development Goals
WRI	World Resources Institutes

I ACTIVITY LIST

Based on Minutes of Meeting, BRG-JICA Project has done so many activities and attend so many meeting or conference. Those activities summarize as follow:

Table 1 Activity list

No.	Year	Date and Time	Held By	Meeting and Discussion
1.	2017	July 21	LAPAN	Focus Group Discussion on Remote Sensing Applications for Peatland Mapping and Environmental Issue
2.	2017	July 27	University of Nottingham, University of Leicester, Liverpool John Moores University, CEH, GVL, CGI	Workshop for the PASSES Project
3.	2017	July 31	BRG-JICA Project	Meeting with BBSDLP
4.	2017	August 4	BRG-JICA Project	Meeting with Deputy of BRG
5.	2017	August 4	BRG-JICA Project	Trial Demonstration of Real Time Groundwater Level Monitoring Meeting
6.	2017	August 14	BRG-JICA Project	Accelerated Real Time Groundwater Level Monitoring Meeting
7.	2017	August 24	BPPT	SATREPS Meeting: Hydrological Unit Management Based on SDGs Criteria in Tropical Coastal Peatland in Riau Province, Indonesia
8.	2017	August 25	BBSDLP	Seminar of Technology for Oil Palm Utilization in Peatland and National Organic Carbon Map
9.	2017	September 4	BRG-JICA Project	Kick-off Meeting BRG-JICA Project
10.	2017	September 6	BRG	Donor Coordination Meeting
11.	2017	September 20	BRG-JICA Project	Meeting with Head of BRG
12.	2017	September 22	BRG	Launching Joint Action of Central Kalimantan Peatland Restoration

13.	2017	September 23	Palangka Raya University	General Lecture on Gold Peatland
14.	2017	September 25	BRG-JICA Project	Meeting with CIMTROP
15.	2017	September 26	BRG-JICA Project	Field Survey at Palangka Raya
16.	2017	September 27	BRG-JICA Project	Meeting with CIMTROP
17.	2017	September 29	BRG-JICA Project	Meeting with Norwegian Embassy
18.	2017	October 2	IJ-REDD JICA	Field Survey at Ketapang
19.	2017	October 3	IJ-REDD JICA	Meeting at Ketapang
20.	2017	October 4	BRG-JICA Project	Demonstration of Ground Water Level Monitoring
21.	2017	October 31	BRG-JICA Project	SESAME and Modeling Workshop
22.	2017	November 1-5	IPS, BRG, JPS, JICA, UNDP	1st Tropical Peatland Roundtable
23.	2017	November 8-17	UNFCCC	COP 23
24.	2017	November 17	BRG	Sitroom Meeting
25.	2017	November 22	BRG-JICA Project	Meeting with ICRAF
26.	2017	November 27	BRG-JICA Project	Meeting with BBSDLP
27.	2017	November 27	BRG-JICA Project	Meeting with Head of BRG
28.	2018	January 15	BRG-JICA Project	Meeting on MRV Integration
29.	2018	January 18-27	BRG-JICA Project	Joint Survey with Kyoto University
30	2018	January 23	BRG-JICA Project	Meeting with Head of BRG
31	2018	January 23	BRG-JICA Project	Meeting with DG Plantation, Ministry of Agriculture
32	2018	January 26	BRG	Development Partner Coordination Meeting
33	2018	January 29	BRG-JICA Project	Meeting with ICRAF
34	2018	January 29	BRG-JICA Project	Meeting with ISCC
35	2018	January 31	BRG-JICA Project	Meeting with Deputy BRG
36	2018	February 1	BRG-JICA Project	Demonstration of Integrated Monitoring System
37	2018	February 2	BRG-JICA Project	Meeting with Head of BRG
38	2018	February 5	BRG-JICA Project	Meeting with Indonesia Special Envoy on Climate Change
39	2018	February 6	BRG-JICA Project	Meeting with Director of Peat Damage Control, Ministry of Environment and Forestry
40	2018	February 9	BRG-JICA Project	Meeting with Deputy of BRG
41	2018	February 9	BRG-JICA Project	Meeting with FOERDIA
42	2018	February 22	RIHN, Kyoto University, BRG-JICA Project	Joint Symposium on Tropical Peatland Restoration
43	2018	March 19	BRG-JICA Project	Meeting with PT SMART
44	2018	March 20	BRG-JICA Project	Meeting with FOERDIA

45	2018	March 22	BRG-JICA Project	Meeting with Head of BRG & Indonesia Special Envoy on Climate Change
46	2018	March 26	BRG-JICA Project	Meeting with GAPKI
47	2018	March 28	BRG-JICA Project	Meeting with APHI
48	2018	March 31 – April 8	University of Science, Ho Chi Minh National University	Inspection in Peatland and Wetland in Mekong Delta of Southern Vietnam
49	2018	April 14-19	IPS	IPS Executive Board Meeting at Vilnius, Lithuania

Annex.02

1. Focus Group Discussion on Remote Sensing Applications for Peatland Mapping and Environmental Issue

Date	:	21st July 2017
Time	:	10.00 – end
Place	:	LAPAN Office, East Jakarta, Indonesia
Held By	:	LAPAN
Aim	:	to increase the role of data and remote sensing technology in peatland in Indonesia
Participants	:	Dr. Rokhis Khomarudin (LAPAN); Syarif Budhiman, M.Sc. (LAPAN); Ir. Ita Carolita, M.Si (LAPAN); Dr. Haris Gunawan (BRG); Dr. Mitsuru Osaki (Hokkaido University); Dr. Stephen Hagen (Applied Geosolutions); Dr Mathew Warren (USFS); Dr. Aritta Suwarno (Wageningen University); Dr. Agus Kristiyanto (BPPT); Wetadewi (JICA-BRG Project)
Key Points	:	- Satellite data can be used to monitor agriculture, forest, water quality, and land use change - Peatland mapping is really crucial for peatland management, both course scale and very detail map for different purposes - Requirements of peatland mapping and monitoring: accurate surface topography data across wide areas, accurate peat depth for model development and evaluation - Collaboration between LAPAN and BRG, BIG, JAXA are important to provide a better resolution data
Subject of Discussion	:	Remote Sensing for Forest and Peatland Mapping, #01 Automated Detection and Classification of Logging Features with LiDAR, #02 Development of Remote Sensing Application for Peatland Monitoring, #03 Hydrological Restoration to Solve Basic Problems of Tropical Peatland, #04 ERI Data Interpretation: 2D Depth Assessment of Peat-swamp Landscape, #05
Photos	:	 

2. Workshop for the PASSES Project

Date	:	27th July 2017
Time	:	10.00 – 15.30
Place	:	Pullman Hotel, Jakarta, Indonesia
Held By	:	University of Nottingham, University of Leicester, Liverpool John Moores University, CEH, GVL, CGI

Aim	:	to develop and demonstrate cost effective, robust and operational monitoring capabilities for the remote assessment of peatland condition at regional and national scales
Participants	:	Prof. Susan Page (University of Laicester); Dr. Andrew Sowter (GVL); Andrew Groom BSc (Hons), MSc (CGI); Dr. Haris Gunawan (BRG); Dr. Mitsuru Osaki (Hokkaido University); Muhammad Haidar (BIG); Yudi Setiawan Ph.D, M.Sc (IPB); Dr. Surya Tarigan, MSc, M.Kom (IPB); Surahman Putra (WRI); Almo Pradana (WRI); Taufan M. Chrisna (APRIL); Vivik (BIG); Wetadewi (JICA-BRG Project)
Key Points	:	-The passes monitoring concept is focused around a transformative new satellite capability for the routine monitoring of peatland condition -The idea of the project will be done in 2 years followed with 3 phases: 1) a proof concept; 2) a ramp up phase which is scale up the monitoring of wide areas; 3) an operations phase that demonstrate how the system worked operationally -The monitoring solution is focusing on three things: 1) trying to identify where the priorities areas are; 2) provide the implementation of the success area; 3) vegetation is to help characterizing the peatland (indication of peat health). Peat depth is not included -In the next discussion will input detail instructions
Photos	:	 

3. Meeting with BBSDLP

Date	:	31st July 2017
Time	:	08.00 – 10.00
Place	:	BBSDLP Office, Bogor, Indonesia
Held By	:	BRG-JICA Project
Aim	:	to discuss about the next upcoming project with BRG and concept of oil palm cultivation under high water level in peatland
Participants	:	Dr. Mitsuru Osaki (Hokkaido University); Dr. Hideyuki Kubo (IJ-REDD+); Prof. Dedi Nursyamsi (BBSDLP); Prof. Dr. Fahmuddin Agus (BBSDLP); Dr. Yiyi Sulaeman, M.Sc. (BBSDLP); Dr. I. Wayan (BBSDLP); Dr. Woro Estiningtyas (BBSDLP); Dr. Budi Kartiwa (BBSDLP); Dr. Ir. Kusumo Nugroho, MSc., Dipl. AS. (BBSDLP); Dr. Maswar (BBSDLP); Dr. Husnain, M.Sc. (BBSDLP); Wetadewi (JICA-BRG Project)
Key Points	:	-Key factors of oil palm cultivation under high water level: oxygen, nutrients, water -Supply nutrients from the surface by combining conventional fertilizer, natural compost, biochar. -Will conduct further discussion with soil experts

Photos	:	 

4. **Meeting with Deputy of BRG**

Date	:	4th August 2017
Time	:	10.00 – 11.00
Place	:	BRG Office (Graha Mandiri Building 21st Floor), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	to briefly introduce the main idea of JICA's project
Participants	:	Dr. Mitsuru Osaki (Hokkaido University); Dr. Alue Dohong (BRG); Dr. Eli Nur Nirmala Sari (BRG); Wetadewi (JICA-BRG Project)
Key Points	:	- Decided to cooperate to make some action to support peatland restoration. - Need to convince oil palm companies to increase the groundwater table. - It is better if JICA do a pilot research and cooperate with two oil palm companies that want to manage their own water management system.

5. **Trial Demonstration of Real Time Groundwater Level Monitoring Meeting**

Date	:	4th August 2017
Time	:	15.30 – end
Place	:	BRG Office (Graha Mandiri Building 21st Floor), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To demonstrate the development of real time groundwater level monitoring
Participants	:	Dr. Haris Gunawan (BRG); Abdul Karim Mukharomah, S.E., M.E. (BRG); Dr. Mitsuru Osaki (Hokkaido University); Dr. Hideyuki Kubo (IJ-REDD+); Dr. Albertus Sulaiman (BPPT); Awaluddin, S.Pi., M.Sc. (BPPT); Prabu Kresna, S.T. (BPPT); Wetadewi (JICA-BRG Project)
Key Points	:	- SESAME tools that belongs to BRG are 23 (18 on peatland; 3 on non-peatland area; 2 will be installed soon) - All the real time data stored in BPPT's server. This data is not a public domain. It is belong to BRG. It depends on BRG authority - Next step will integrate with hotspot data from LAPAN, weather animation from NCEP, temperature and moisture data to predict groundwater level for the next three days - Will be develop android-based system

Photos	:	 

6. Accelerated Real Time Groundwater Level Monitoring Meeting

Date	:	14th August 2017
Time	:	10.30 – 12.00
Place	:	BRG Office (Graha Mandiri Building 21st Floor), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To follow up the development of real time groundwater level monitoring
Participants	:	Dr. Haris Gunawan (BRG); Abdul Karim Mukharomah, S.E., M.E. (BRG); Thomas Rinuwat (BRG); Rizki Aulia (BRG); Dr. Hideyuki Kubo (IJ-REDD+); Dr. Albertus Sulaiman (BPPT); Awaluddin, S.Pi., M.Sc. (BPPT); Prabu Kresna, S.T. (BPPT); Wetadewi (JICA-BRG Project)
Key Points	:	- BRG requested the assistance of BPPT team to build a monitoring system that could be integrated between several tools that already put in the field and satellite data. - It is recommended that during the field visit the President is provided with a satellite-based peatland monitoring system in the form of android.
Photos	:	 

7. SATREPS Meeting: Hydrological Unit Management Based on SDGs Criteria in Tropical Coastal Peatland in Riau Province, Indonesia

Date	:	24th August 2017
Time	:	09.00 – end
Place	:	BPPT Office, Serpong, Indonesia
Held By	:	BPPT
Aim	:	to discuss about the next upcoming SATREPS program "Assessment of Water Resource Management in Peatland"
Participants	:	Dr. Mitsuru Osaki (Hokkaido University); Prof. Koichi Yamamoto (Yamaguchi University); Ir. C. Nugroho S. P., M.Sc. (BRG); Dr. Albertus Sulaiman (BPPT); Dr. Reni Sulistyowati (BPPT); Dr. Fiolenta Marpaung (BPPT); Hiroshi Kobayashi (IJ-REDD+); Kayo Matsui, M.Sc. (Hokkaido University); Dr. Bambang Setiadi (DRN); Dr. Sigit

		Sutikno (Riau University); Dr. Muhammad Yusa (Riau University); Susialita (BPPT); Wetadewi (JICA-BRG Project)
Key Points	:	Decided who will involve in the research, fixing content of proposal and technical administration to submit to DIKTI.
Photos	:	 

8. Seminar of Technology for Oil Palm Utilization in Peatland and National Organic Carbon Map

Date	:	25th August 2017
Time	:	08.30 – end
Place	:	BBSDLP Office, Bogor, Indonesia
Held By	:	BBSDLP
Aim	:	to discuss about the possibility of oil palm to grow in high water table
Participants	:	Dr. Mitsuru Osaki (Hokkaido University); Prof. Dedi Nursyamsi (BBSDLP); Prof. Dr. Fahmuddin Agus (BBSDLP); Dr. Yiyi Sulaeman, M.Sc. (BBSDLP); Dr. Ir. Kusumo Nugroho, MSc., Dipl. AS. (BBSDLP); Dr. Husnain, M.Sc. (BBSDLP); Kayo Matsui, M.Sc. (Hokkaido University); Wetadewi (JICA-BRG Project); staff of BBSDLP
Key Points	:	-Nutrient application from the surface: for small stakeholder use natural compost and chicken manure, for big company use biochar and manure to balance the cost because mineral compost is expensive
Subject of Discussion	:	Breakthrough of Oil Palm Cultivation in High Watertable, #06 Water Table, CO2 Emissions and Oil Palm Performance on Peatland, #07 Monitoring Water Table in Peatland between Theory and Practice, #08 Cultivation of Oil Palm Plantation in the Peatland, #09
Photos	:	 

9. Kick-off Meeting BRG-JICA Project

Date	:	4th September 2017
Time	:	09.00 – end
Place	:	BRG Office (Graha Mandiri Building 21st Floor), Jakarta, Indonesia
Held By	:	BRG-JICA Project

Aim	:	To share current issues and challenges facing peatland restoration in Indonesia and come up with a short term action plan to address them by March 2018
Participants	:	Dr. Haris Gunawan (BRG); Ir. C. Nugroho S. P., M.Sc. (BRG); Dr. Mitsuru Osaki (Hokkaido University); Dr. Bambang Setiadi (DRN); Prof. Yukihiro Takahashi (Hokkaido University); Dr. Hideyuki Kubo (IJ-REDD); Dr. Albertus Sulaiman (BPPT); Awaluddin, S.Pi., M.Sc. (BPPT); Prabu Kresna Putra, S.T. (BPPT); Dr. Ayako Oide (Hokkaido University); Dr. Kusumo Nugroho (BBSDLP); Kayo Matsui, M.Sc. (Hokkaido University); Wetadewi (JICA-BRG Project)
Key Points	:	- Four agendas of the project: 1) Satellite based model on ground water level monitoring; 2) Peatland restoration actions; 3) Capacity building of Indonesian officials and universities; 4) Knowledge inputs nationally and internationally - Tentative sites (Tebing Tinggi Island & Kahayan-Sebangau River) was proposed as the better demonstration site to establish the field activities and develop models
Subject of Discussion	:	Action Plan for Minutes of Meetings (MoM) between BRG and JICA on the Elaboration of Peatland Restoration, #10 Gold Carbon Mechanism, #11
Photos	:	

10. Donor Coordination Meeting

Date	:	6th September 2017
Time	:	08.00 – 13.00
Place	:	Jakarta, Indonesia
Held By	:	BRG
Aim	:	- To present an overview of the current state of affairs with respect to peatland restoration (planning and implementation) - To ensure synchronization and coordination among donors and with BRG of external support for peatland restoration - To inventory and update on going , planned and potential donor support to peatland restoration
Participants	:	Dr. Hideyuki Kubo (IJ-REDD)
Subject of Discussion	:	Building the Technical Capacity for Peatland Monitoring and Restoration: JICA's support for peatlands, #12

11. Meeting with Head of BRG

Date	:	20th September 2017
Time	:	12.00 – 13.00

Place	:	BRG Office (Teuku Umar 10), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To discuss about idea and strategy of Tropical Peatland Roundtable and COP 23
Participants	:	Ir. Nazir Foead, M.Sc. (BRG); Dr. Mitsuru Osaki (Hokkaido University); Hitoshi Iriyama (JICA); Dr. Ayako Oide (Hokkaido University); Wetadewi (JICA-BRG Project)
Key Points	:	- BRG has high expectation with ground water level monitoring system (SESAME) - Standardize zoning method in peatland is necessary and need to collaborate with scientist from universities
Subject of Discussion	:	Gold Carbon Mechanism, #11
Photos	:	 

12. Launching Joint Action of Central Kalimantan Peatland Restoration

Date	:	22nd September 2017
Time	:	09.30 – 16.00
Place	:	Palangka Raya, Central Kalimantan, Indonesia
Held By	:	BRG
Aim	:	To demonstrate the rewetting system
Participants	:	Ir. Nazir Foead, M.Sc. (BRG); Dr. Alue Dohong (BRG); Dr. Myrna A. Safitri (BRG); Vegard Kaale (Norway's Ambassador to Indonesia); Ida Suriany (UK Embassy); Ir. Medrilzam, M.Prof.Econ, Ph.D. (Ministry of National Development); H. Hamdani, S.I.P. (DPR Commission IV); Dr. Mitsuru Osaki (Hokkaido University); Dr. Ayako Oide (Hokkaido University); Wetadewi (JICA-BRG Project); Doctoral students of forestry and agriculture faculty of Palangka Raya University; Masyarakat Peduli Api (MPA)
Key Points	:	- Incentives are increasing in Tanjung taruna in the context of restoration and handling of fire prevention - To maintain the development infrastructure, especially the canal blocking, all parties must be involved and help each other - Quick response system needs to be applied not only in local communities (Masyarakat Peduli Api/MPA) but also in the central government.

Photos	:	 

13. General Lecture on Gold Peatland

Date	:	23rd September 2017
Time	:	10.00 – 12.00
Place	:	Palangka Raya University, Central Kalimantan, Indonesia
Held By	:	Palangka Raya University
Aim	:	To give general lecture about peatland to doctoral students
Participants	:	Dr. Mitsuru Osaki (Hokkaido University); Prof. Dr. Ir. Salampak, M.S. (Palangka Raya University); Dr. Nina Yulianti (Palangka Raya University); Dr. Ayako Oide (Hokkaido University); Wetadewi (JICA-BRG Project)
Photos	:	 

14. Meeting with CIMTROP

Date	:	25th September 2017
Time	:	09.00 – 12.00
Place	:	CIMTROP, Palangka Raya, Central Kalimantan, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop zoning method in peatland
Participants	:	Dr. Mitsuru Osaki (Hokkaido University); Dr. Ir. Ici Piter Kulu (CIMTROP); Drs. Tampung N. Saman, M.Lib (CIMTROP); Erna Shinta, S.Hut., M.Agr., Ph.D. (CIMTROP); Kitso Kusin, S.P., M.Si. (CIMTROP); Dr. Ayako Oide (Hokkaido University); Wetadewi (JICA-BRG Project)
Key Points	:	- Mr. Kitso selected as a representative of Palangka University to join the survey - Survey selection target: DAM, oil palm cultivation, Sengon plantation, Sago plantation, KHDTK site, several research sites

Photos	:	 

15. Field Survey at Palangka Raya

Date	:	26th September 2017
Time	:	09.00 – 16.00
Place	:	Palangka Raya, Central Kalimantan, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To select several sites for field trip of 1st Tropical Peatland Roundtable
Participants	:	Dr. Mitsuru Osaki (Hokkaido University); Dr. Ir. Ici Piter Kulu (CIMTROP); Drs. Tampung N. Saman, M.Lib (CIMTROP); Erna Shinta, S.Hut., M.Agr., Ph.D. (CIMTROP); Kitso Kusin, S.P., M.Si. (CIMTROP); Dr. Ayako Oide (Hokkaido University); Wetadewi (JICA-BRG Project)
Key Points	:	- Six sites selected for field trip of 1st Tropical Peatland Roundtable: CIMTROP camp (DAM construction site); paludiculture research site at Kalampangan; integrated research site at Kalampangan; canal blocking site at Taruna Jaya; deep well site at Taruna Jaya; KHDTK Tumbang Nusa
Photos	:	 

16. Meeting with CIMTROP

Date	:	27th September 2017
Time	:	08.00 – 14.30
Place	:	CIMTROP, Palangka Raya, Central Kalimantan, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To organize field trip of 1st Tropical Peatland Roundtable
Participants	:	Dr. Mitsuru Osaki (Hokkaido University); Dr. Ir. Ici Piter Kulu (CIMTROP); Drs. Tampung N. Saman, M.Lib (CIMTROP); Erna Shinta, S.Hut., M.Agr., Ph.D. (CIMTROP); Kitso Kusin, S.P., M.Si. (CIMTROP); Dr. Ayako Oide (Hokkaido University); Wetadewi (JICA-BRG Project)
Key Points	:	- CIMTROP agree as a committee to arrange field trip of 1st Tropical Peatland Roundtable

		- CIMTROP will join the survey to develop zoning method and will use line transect method & same location sites as before
Photos	:	

17. Meeting with Norwegian Embassy

Date	:	29th September 2017
Time	:	08.00 – end
Place	:	Norwegian Embassy of Indonesia, Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To propose a new concept of peatland management
Participants	:	Dr. Mitsuru Osaki (Hokkaido University); Dr. Hideyuki Kubo (IJ-REDD); Dr. Ayako Oide (Hokkaido University)
Subject of Discussion	:	Gold Carbon Mechanism, #11

18. Field Survey at Ketapang

Date	:	2nd October 2017
Time	:	11.00 – 14.00
Place	:	Pelang river, Ketapang, West Kalimantan, Indonesia
Held By	:	IJ-REDD JICA
Aim	:	To select site of fire protection project
Participants	:	Dr. Mitsuru Osaki (Hokkaido University); Dr. Hideyuki Kubo (IJ-REDD); Dr. Ayako Oide (Hokkaido University); Dicko Rossanda (IJ-REDD); Wetadewi (JICA-BRG Project)
Key Points	:	- Six sites selected for field trip of 1st Tropical Peatland Roundtable: CIMTROP camp (DAM construction site); paludiculture research site at Kalampangan; integrated research site at Kalampangan; canal blocking site at Taruna Jaya; deep well site at Taruna Jaya; KHDTK Tumbang Nusa
Photos	:	 

19. Meeting at Ketapang

Date	:	3rd October 2017

Time	:	09.00 – end
Place	:	Regional Development Planning Agency (Bappeda) Office, Ketapang District, West Kalimantan, Indonesia
Held By	:	IJ-REDD JICA
Aim	:	To discuss about plot design preparation of fire protection project
Participants	:	Ir. Sunaji (Bappeda); Gusti Indra Kusuma (Bappeda); Dr. Mitsuru Osaki (Hokkaido University); Dr. Hideyuki Kubo (IJ-REDD); Dr. Ayako Oide (Hokkaido University); Dicko Rossanda (IJ-REDD); Wetadewi (JICA-BRG Project); Razanah (Bappeda); Edi Prayitno (Bappeda); Head of Pelang River Village, Rahmat Rohendi (Head of South Matan Hilir District)
Key Points	:	- This project can begin in the second week of October adjusted to the time schedule that has already been made - Charcoal and compost will be added in the surface of the peat to increase the soil fertility - Sengon and Bamboo are suggested to plant as a barrier around the canal blocking site - This project are expected to be useful not only to prevent forest fire but also to maintain soil moisture during dry season
Photos	:	

20. Demonstration of Ground Water Level Monitoring

Date	:	4th October 2017
Time	:	10.00 – 12.00
Place	:	BRG Office (Graha Mandiri Building 21st Floor), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To demonstrate the development of real time groundwater level monitoring
Participants	:	Dr. Haris Gunawan (BRG); Ir. C. Nugroho S. P., M.Sc. (BRG); Wahyu Utami Tulis Wiyati, S.T. (KLHK); Dr. Mitsuru Osaki (Hokkaido University); Dr. Hideyuki Kubo (IJ-REDD+); Dr. Yudi Anantasena (BPPT); Dr. Albertus Sulaiman (BPPT); Awaluddin, S.Pi., M.Sc. (BPPT); Prabu Kresna, S.T. (BPPT); Dionysius Bryan Sencaki (BPPT); Wetadewi (JICA-BRG Project)
Photos	:	 

21. SESAME and Modeling Workshop

Date	:	31st October 2017
Time	:	10.00 – 12.00
Place	:	BRG Office (Graha Mandiri Building 21st Floor), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To share and discuss about technical issue of the development of real time groundwater level monitoring
Participants	:	Dr. Haris Gunawan (BRG); Dr. Mitsuru Osaki (Hokkaido University); Dr. Takashi Hirano (Hokkaido University); Dr. Hidenori Takahashi (NPO Hokkaido Institute of Hydro Climate); Dr. Yohei Hamada (Midori Engineering Inc.); Dr. Hideyuki Kubo (IJ-REDD+); Dr. Albertus Sulaiman (BPPT); Awaluddin, S.Pi., M.Sc. (BPPT); Fany Melieani, S.Pi. (BPPT); Wetadewi (JICA-BRG Project)

22. 1st Tropical Peatland Roundtable

Date	:	1st - 5th November 2017
Time	:	08.30 – 17.00
Place	:	Menara Peninsula Hotel, Jakarta, Indonesia
Held By	:	IPS, BRG, JPS, JICA, UNDP
Aim	:	To discuss "The Framework on Tropical Peatland Restoration" and propose an action plan called Jakarta Declaration
Participants	:	69 participants (Scientists, Policy Makers, and Academician, Corporates, Donor Agencies, and NGOs representatives) from Indonesia, Japan, Finland, Germany, Netherlands, Vietnam, Singapore, Malaysia, Mexico.
Key Points	:	A principal strategy of Responsible Management of Tropical Peatland was agreed as Jakarta Declaration that includes five pillars of action: - establish a "Tropical Peatland Center" - organize an "International Committee for Technical Consultation" - develop an "Integrated Monitoring System" - conduct a "Model Project" for responsible management - achieve capacity building
Subject of Discussion	:	"Jakarta Declaration" on Responsible Management of Tropical Peatland, #13
Photos	:	 

23. COP 23

Date	:	8-17th November 2017
Time	:	13.00
Place	:	Bonn, Germany
Held By	:	UNFCCC

Aim	:	To discussing how to follow up on the Paris agreement, which was the result of a previous COP summit
Key Points	:	- Demonstrated the results of the groundwater level estimation map being developed by BPPT. Based on this, 1) carbon dioxide release model by microbial decomposition of peat, 2) generation frequency and intensity estimation model of fire, 3) creation of prediction model of rainfall, 4) fire frequency and intensity estimation

24. Sitroom Meeting

Date	:	17th November 2017
Time	:	14.00
Place	:	BRG Office (Teuku Umar 10), Jakarta, Indonesia
Held By	:	BRG
Aim	:	To discuss about the progress of the monitoring system that has been built by BRG
Participants	:	Abdul Karim Mukharomah (BRG); Awaluddin, S.Pi., M.Sc. (BPPT); Ayako Oide (Hokkaido University); Rahmadi Dadi; Surahman Putra (WRI); Almo Pradana (WRI); Herni Ramdlaningrum (UNDP); Hening Parlan (UNDP)
Key Points	:	- BPPT has built the monitoring system from 21 points that supported by JICA - The system already running from November 2016 - WRI also built similar system that focused on what was BRG has planned and implemented

25. Meeting with ICRAF

Date	:	22nd November 2017
Time	:	10.00 – 12.00
Place	:	BRG Office (Graha Mandiri Building 21st Floor), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To collaborate in the context of peatland restoration in Indonesia
Participants	:	Prof. Mitsuru Osaki (Hokkaido University); Hideyuki Kubo, Ph.D (IJ-REDD+); Dr. Ayako Oide (Hokkaido University); Wetadewi (JICA-BRG); Dr. James Roshetko (ICRAF); Dr. Gerhard Manurung (ICRAF); Anisa Budi Erawati (ICRAF); Elok Mulyoutami (ICRAF)
Key Points	:	- The project should focus on sustainable management - The candidate to submit the proposal is to SATREPS - Will conduct a meeting in January to develop a concept
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14
Photos	:	

26. Meeting with BBSDLP

Date	:	27th November 2017
Time	:	08.00 – 09.30
Place	:	BRG Office (Graha Mandiri Building 21st Floor), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop an innovated oil palm cultivation under high water level in tropical peatland
Participants	:	Prof. Mitsuru Osaki (Hokkaido University); Dr. Ayako Oide (Hokkaido University); Wetadewi (JICA-BRG); Prof. Dedi Nursyamsi (BBSDLP); Prof. Fahmuddin Agus (BBSDLP); Dr. Kusumo Nugroho (BBSDLP); Dr. Yiyi Sulaeman (BBSDLP); Dr. Ai Dariah (BBSDLP); Dr. Budi Kartiwa (BBSDLP); Dr. Poppy R. (BBSDLP); Dr. Wiwik Hartatik (BBSDLP)
Key Points	:	- BBSDLP interest about this concept and the next meeting should invite Directorate General Plantation of Ministry of Agriculture to have a further discussion
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14
Photos	:	

27. Meeting with Head of BRG

Date	:	27th November 2017
Time	:	09.30 – 11.00
Place	:	BRG Office (Teuku Umar 10), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop an innovated oil palm cultivation under high water level in tropical peatland
Participants	:	Ir. Nazir Foead, M.Sc. (BRG); Dr. Mitsuru Osaki (Hokkaido University); Dr. Ayako Oide (Hokkaido University); Wetadewi (JICA-BRG Project)
Key Points	:	- Need to create a workshop inviting some researcher's companies and company managers and workers to introduce the system - Need to do some appliead research and testing - The Minister of Environment and Forestry suggested to have the Tropical Peatland Center in Bogor. Need to discuss with resource development part of forestry and agriculture.
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14

28. Meeting on MRV Integartion

Date	:	15th January 2018
Time	:	10.00 – 17.00

Place	:	BRG Office (Graha Mandiri Building 21st Floor), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To discuss about the progress of development MRV system for peatland and to exchange ideas on the significance of MRV system for peatland restoration
Participants	:	Dr. Haris Gunawan (BRG); Dr. Mitsuru Osaki (Hokkaido University); Dr. Albertus Sulaiman (BPPT); Awaluddin, S.Pi., M.Sc. (BPPT); Kayo Matsui (Hokkaido University);
Photos	:	

29. Joint Survey with Kyoto University

Date	:	18-27th January 2018
Time	:	08.00 – 17.00
Place	:	Palangka Raya, Central Kalimantan, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop zoning method of peatland
Participants	:	Dr. Mitsuru Osaki (Hokkaido University); Dr. Shimamura (Ehime University); Dr. Itoh (Kyoto University); Dr. Ayako Oide (Hokkaido University); Kayo Matsui, M.Sc. (Hokkaido University); Dr. Shiodera (Kyoto University); Wahyu (Kyoto University); Drs. Ahmad Muhammad (Riau University); Dr. Nurni Komar (Riau University); Wetadewi (JICA-BRG Project)
Photos	:	 

30. Meeting with Head of BRG

Date	:	23rd January 2018
Time	:	08.30 – 09.45
Place	:	BRG Office (Teuku Umar 10), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop an innovated oil palm cultivation under high water level in tropical peatland
Participants	:	Ir. Nazir Foead, M.Sc. (BRG); Dr. Mitsuru Osaki (Hokkaido University); Dr. Hideyuki Kubo (IJ-REDD); Dr. Ayako Oide (Hokkaido University); Wetadewi (JICA-BRG Project)
Key Points	:	- SIRAT or Sinar Mas willing to participate and pay it by themselves. Need to find area included some part of Sinar Mas concession area and

		some part of community or government's protected forest. They should be in one Hydrologycal Peatland Unit side by side. We will have one research model and several spot to measure the station. This could be anywhere as per BRG mandate - Should invite Indonesian Agency for Agricultural Research and Development Ministry of Agriculture
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14

31. Meeting with DG Plantation, Ministry of Agriculture

Date	:	23rd January 2018
Time	:	12.30 – 15.30
Place	:	Ministry of Agriculture Office, Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop an innovated oil palm cultivation under high water level in tropical peatland
Participants	:	Prof. Mitsuru Osaki (Hokkaido University); Dr. Hideyuki Kubo (IJ-REDD); Dr. Ayako Oide (Hokkaido University); Wetadewi (JICA-BRG); Ir. Bambang, MM (DG Plantation); Ir. Irmijati R. Nurbahar, M.Sc. (Director of Perennial and Beverage Crops); Drs. Dudi Gunadi, B.Sc., M.Si (Director of Plantation Protection); Prof. Dedi Nursyamsi, M. Agr (Director of BBSDLP); Dr. Ir. Kusumo Nugroho, M.Sc., Dipl. AS. (Soil Scientist/GIS BBSDLP); Maswar (BBSDLP); Yiyi Sulaeman, M.Sc (Deputy for Research Collaboration and Dissemination BBSDLP)
Key Points	:	- Need to conduct futher study to prove this concept - Ministry of Agriculture agree to collaborate with BRG to make demonstration research by using Mr. Osaki technology. The research should compare between GWL 40cm (Regulation number PP 57/2016) with GWL 60-80cm (Permentan 14/2009).
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14
Photos	:	

32. Development Partner Coordination Meeting

Date	:	26th January 2018
Time	:	09.00 – 15.30
Place	:	Pangeran Hotel Pekanbaru, Riau, Indonesia
Held By	:	BRG
Aim	:	To build coordination with development partners to support restoration in the province

Participants	:	Dr. Budi Wardhana (BRG); Ir. Soesilo Indrarto, M.Si (BRG); Dr. Ir. Suwignya Utama, M.B.A (BRG); Dr. Mitsuru Osaki (Hokkaido University); Wetadewi (JICA-BRG Project); Provincial Restoration Team
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14
Photos	:	 

33. Meeting with ICRAF

Date	:	29th January 2018
Time	:	10.00 – 12.00
Place	:	ICRAF Office, Bogor, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop a sustainable management project
Participants	:	Prof. Mitsuru Osaki (Hokkaido University); Dr. Ayako Oide (Hokkaido University); Wetadewi (JICA-BRG); Dr. Gerhard Manurung (ICRAF); Anisa Budi Erawati (ICRAF); Elok Mulyoutami (ICRAF)
Key Points	:	- ICRAF wants to develop "Sustainable Improved Paludiculture for Conservation Enhancement and Poverty Reduction in Indonesia" - Prof. Osaki has a new concept to develop "Fieldology on Land Surface Management for Earth Sustainability" - Will try to submit the proposal to Global Innovation Fund
Photos	:	

34. Meeting with ISCC

Date	:	29th January 2018
Time	:	15.30 – 16.30
Place	:	Kebun Raya Bogor, Bogor, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop an innovated coffee plantation in tropical peatland
Participants	:	Prof. Mitsuru Osaki (Hokkaido University); M. Akbar Fitri (ISCC); Muhamad Syarip Lambaga (ISCC); Wetadewi (JICA-BRG)
Key Points	:	- AeroHydro concept needs to be proven by conducting further studies that can be done in other types of land (not only peat) and for other commodities (not just oil palm). Maybe this technology is able to

		increase the productivity of coffee which can also be linked to climate change issues
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14
Photos	:	

35. Meeting with Deputy BRG

Date	:	31st January 2018
Time	:	15.00 – 16.00
Place	:	BRG Office (Graha Mandiri Building 21st Floor), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To discuss the preparation of Joint Symposium
Participants	:	Dr. Haris Gunawan (BRG); Dr. Mitsuru Osaki (Hokkaido University); Dr. Ayako Oide (Hokkaido University); Kayo Matsui, M.Sc. (Hokkaido University); Wetadewi (JICA-BRG Project); Lutfiah Surayah (RIHN); Festy Putri (BRG)
Key Points	:	- BRG and FORDA already have a discussion to establish Tropical Peatland Center (follow up Jakarta Declaration). FORDA provide a space in Gunung Batu, Bogor for the secretariat office. - RIHN will conduct a symposium on 21st February and JICA-BRG project on 22nd February. The title for both event will be "Responsible Management of Tropical Peatland." - Need to invite foreign colleagues such as Malaysia, Vietnam, Thailand
Photos	:	

36. Demonstration of Integrated Monitoring System

Date	:	1st February 2018
Time	:	09.30 – 11.00
Place	:	BRG Office (Graha Mandiri Building 21st Floor), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To demonstrate the development of real time groundwater level monitoring
Participants	:	Dr. Haris Gunawan (BRG); Dr. Mitsuru Osaki (Hokkaido University); Dr. Hideyuki Kubo (IJ-REDD+); Nakamura (Embassy of Japan in Indonesia); Suzuki (JICA); Hitoshi Iriyama (JICA); Dr. Albertus Sulaiman (BPPT); Awaluddin, S.Pi., M.Sc. (BPPT); Adam Gerrand

		(FAO); Bambang Arifatmi (FAO); Dr. Osamu Kozan (Kyoto University); Dr. Ayako Oide (Hokkaido University); Kayo Matsui, M.Sc. (Hokkaido University); Kazuo Watanabe (Hokkaido University); Koshiyama (Hokkaido University); Daikobu (Hokkaido University); Wetadewi (JICA-BRG Project)
Key Points	:	- There's a high correlation between soil moisture and water level. Water level prediction is performed with the precision of the grid of 1 km × 1 km. WPS domain configuration. Carbon dioxide emissions can also be predicted using Hirano model (good correlation between CO2 emissions and water level)
Photos	:	 

37. Meeting with Head of BRG

Date	:	2nd January 2018
Time	:	11.30 – 12.00
Place	:	Pulman Thamrin, Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop an innovated oil palm cultivation under high water level in tropical peatland
Participants	:	Ir. Nazir Foead, M.Sc. (BRG); Dr. Budi Wardhana (BRG); Dr. Mitsuru Osaki (Hokkaido University); Dr. Ayako Oide (Hokkaido University); Kayo Matsui, M.Sc. (Hokkaido University); Wetadewi (JICA-BRG Project)
Key Points	:	- BRG already choose 3 landscape areas for pilot project: 1) KHG Sungai Gaung – Sungai Kampar. In this area there are a lot of types of land use. There's a wildlife sanctuary in the middle part (Jamrud National Park), plantation, HTI, RAPP Sinarmas; 2) 70% of the land licensed to Sinarmas including HTI and palm oil plantation in Ogan Komering Ilir, South Sumatera; 3) Kuburaya, West Kalimantan KHG Sugian Lumpur
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14

38. Meeting with Indonesia Special Envoy on Climate Change

Date	:	5th February 2018
Time	:	12.00 – 13.00
Place	:	Aromanis Restaurant, Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop an innovated oil palm cultivation under high water level in tropical peatland
Participants	:	Prof. Ir. Rachmat Witoelar; Dr. Mitsuru Osaki (Hokkaido University); Kayo Matsui, M.Sc. (Hokkaido University); Wetadewi (JICA-BRG Project); Lia Zakiyyah; Titi Pandjaitan

Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14
Photos	:	 

39. Meeting with Director of Peat Damage Control, Ministry of Environment and Forestry

Date	:	6th February 2018
Time	:	09.00 – 10.30
Place	:	Ministry of Environment and Forestry Office Kebon Nanas, Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop high water table cultivation and Gold Carbon mechanism
Participants	:	Ir. Wahyu Indraningsih, M.Sc.; Dr. Mitsuru Osaki (Hokkaido University); Dr. Hideyuki Kubo (IJ-REDD); Kayo Matsui, M.Sc. (Hokkaido University); Wetadewi (JICA-BRG Project)
Key Points	:	- Need to have pilot project in several location of private sector and community and need to design the criteria of the area and compare the result - Need to cooperate with Ministry of Agriculture
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14
Photos	:	 

40. Meeting with Deputy BRG

Date	:	9th February 2018
Time	:	13.30 – 14.30
Place	:	BRG Office (Teuku Umar 17), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop an innovated oil palm cultivation under high water level in tropical peatland
Participants	:	Dr. Budi Wardhana (BRG); Dr. Haris Gunawan (BRG); Dr. Mitsuru Osaki (Hokkaido University); Dr. Hideyuki Kubo (IJ-REDD); Dr. Ayako Oide (Hokkaido University); Kayo Matsui, M.Sc. (Hokkaido University); Wetadewi (JICA-BRG Project); Velanie Adiwijaya (BRG); Edison (BRG)
Key Points	:	- Period of research: Intensive activity in one year and the second year is monitoring

		- The team consists of: BRG (Deputy I and IV); JICA; BPPT; and operator manager
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14
Photos	:	

41. Meeting with FOERDIA

Date	:	9th February 2018
Time	:	14.30 – 15.00
Place	:	BRG Office (Graha Mandiri Building 21st Floor), Jakarta, Indonesia
Held By	:	BRG
Aim	:	To develop Tropical Peatland Center
Participants	:	Ir. C. Nugroho S. P., M.Sc. (BRG); Dr. Hesty Lestari Tata (FOERDIA); Dr. Yayuk Siswiyanti (FOERDIA); Dr. Mitsuru Osaki (Hokkaido University); Dr. Hideyuki Kubo (IJ-REDD); Nuri Luthfiana (BRG); Dede Hendry Tryanto (BRG): Nugroho Adi Utomo (BRG)
Key Points	:	- FOERDIA will be the secretary office that has duty to manage activities. BRG will participate during event management. - For networking not only representing state but also institution. International committee needs to consider NGO - Other European countries that concern with peat need to invite as well - Some flyer of dissemination and publication has been prepared - It is better to determine the topic research. The title of the research will be specify by whoever who proceed the research.
Subject of Discussion	:	Global Tropical Peatland Center, #16

42. Joint Symposium on Tropical Peatland Restoration

Date	:	22nd February 2018
Time	:	11.30 – 12.00
Place	:	Manara Peninsula Hotel, Jakarta, Indonesia
Held By	:	RIHN, Kyoto University, BRG-JICA Project
Aim	:	To demonstrate the establishment of an Integrated Monitoring System
Participants	:	60 participants (Scientists, Policy Makers, and Academician, Corporates, Donor Agencies, and NGOs representatives) from Indonesia, Japan, Germany, Russia, Vietnam
Key Points	:	- Suggestions for updating the system: consider better data sets such as soil moisture radar data due to the many aspects that can affect the soil moisture (i.e. porosity) & to pay attention to the positioning of the sensor (how much away from the canal and surface)
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14 & #15

		Global Tropical Peatland Center, #16 Action Plan on Tropical Peatland Center, #17
Photos	:	 

43. Meeting with PT SMART

Date	:	19th March 2018
Time	:	17.30 – 19.00
Place	:	Chatterbox, Plaza Senayan, Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop an innovated oil palm cultivation under high water level in tropical peatland
Participants	:	Ir. Nazir Foead, M.Sc. (BRG); Dr. Mitsuru Osaki (Hokkaido University); J.P. Caliman (PT SMART); Melanie Camaro (BRG); Wetadewi (JICA-BRG Project)
Key Points	:	- Ministry of Environment and Forestry allow BRG to do the research in the concession area. The result or the report of the research should be submitted by the end of the year to the President - Should make MoU between BRG, Ministry of Agriculture and Ministry of Environment and Forestry for this project - There will be two slots for BRG to present paper on ICOPE at the end of April (25-27 April) at Nusa Dua, Bali. Prof. Osaki will be presenting AeroHydro Culture System (the whole concept for the upcoming project) to engage company to apply this technology to their concession area - PT SMART has done so many research that related to subsidence and water table in Riau, North Sumatera, South Sumatera, Lampung, Jambi, Central Kalimantan
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14 & #15
Photos	:	

44. Meeting with FOERDIA

Date	:	20th March 2018
Time	:	09.00 – 12.00
Place	:	Forest Research and Development Centre Office, Bogor, Indonesia
Held By	:	BRG-JICA Project

Aim	:	To develop an innovated oil palm cultivation under high water level in tropical peatland and develop Tropical Peatland Center
Participants	:	Ir. C. Nugroho S. P., M.Sc. (BRG); Dr. Ir. Kirsfianti L. Ginoga, M.Sc. (FOERDIA); Dr. Mitsuru Osaki (Hokkaido University); Wetadewi (JICA-BRG Project); Staffs of Deputy IV BRG; Researchers from FOERDIA
Key Points	:	- Main idea of Tropical Peatland Center: - International advisor - Model peatland management - Networking - Capacity building: to educate communities not only by training - The Minister of Environmental and Forestry selected Bogor to be the host of Tropical Peatland Center.
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14 & #15 Action Plan on Tropical Peatland Center, #17
Photos	:	 

45. Meeting with Head of BRG and Indonesia Special Envoy on Climate Change

Date	:	22nd March 2018
Time	:	10.30 – 11.30
Place	:	Indonesia Special Envoy on Climate Change Office (Teuku Umar 10), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop an innovated oil palm cultivation under high water level in tropical peatland
Participants	:	Ir. Nazir Foead, M.Sc. (BRG); Prof. Ir. Rachmat Witoelar; Dr. Mitsuru Osaki (Hokkaido University); Wetadewi (JICA-BRG Project)
Key Points	:	- The tentative result should be submitted by the end of the year. - From the research it is better to have a rough calculation of the carbon emission. - Need to held a stake holders meeting with the company probably on 21st April 2018
Photos	:	

46. Meeting with GAPKI

Date	:	26th March 2018
Time	:	10.00 – 11.00
Place	:	BRG Office (Teuku Umar 17), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop an innovated oil palm cultivation under high water level in tropical peatland
Participants	:	Ir. Nazir Foead, M.Sc. (BRG); Dr. Mitsuru Osaki (Hokkaido University); Rapolo Hutabarat (Musimmas); Ermin (Musimmas); Melanie Camaro (BRG); Wetadewi (JICA-BRG Project)
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14 & #15
Photos	:	

47. Meeting with APHI

Date	:	28th March 2018
Time	:	15.30 – 17.00
Place	:	BRG Office (Teuku Umar 17), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop an innovated oil palm cultivation under high water level in tropical peatland
Participants	:	Ir. Nazir Foead, M.Sc. (BRG); Dr. Mitsuru Osaki (Hokkaido University); Melanie Camaro (BRG); Wetadewi (JICA-BRG Project); Colleagues from APHI
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14 & #15
Photos	:	

48. Inspection in Peatland and Wetland in Mekong Delta of Southern Vietnam

Date	:	31st March - 8th April 2018
Place	:	Uminh Ha Park (Peatland), Vietnam
Held By	:	Ho Chi Minh National University
Aim	:	Southern Vietnam locate Mekong Delta area, covering many ecosystems such 1) Mekong River, 2) Wetland and Swamp/lake, 3) Paddy field, 4) Mangrove (Costal Ecosystem), and 5) Peatland. Mekong Delta Ecosystem is very high food productivity, however Mekong Delta Ecosystem is recently suffering by human impact (intensive land use,

	international and domestic poor water management) and by climate change impact (doughtiness/wetness by climate change, sea water affection on coastal and inland). Thus, as Mekong Delta Ecosystem issues are overlapping with issues in lowland/wetland/peatland in Indonesia, it is very important and useful to understand Mekong Delta Ecosystem Management for Responsible Management of Tropical Peatland in Indonesia.
Participants :	Professor Lê Thuyên Xuân (University of Science, Ho Chi Minh National University
Key Points :	- Peatland Management after big fire in 2002 (completely control of high water table and reforestation) - Soil subsidence monitoring by SET system (subsiding in coastal zone of Mekong Delta by wrong water management) - Biomass production program (Biomass of Mangrove and Nipa palm and Coconuts palm will contribute to protection costal, give economic benefit of products and bio-fuel) - Develop and Propose Asian Program on Costal Ecosystem Management
Subject of Discussion :	Fieldology" for Mekong Delta Sustainability, #18
Photos :	   

49. IPS Executive Board Meeting at Vilnius, Lithuania

Date :	14-19th April 2018
Place :	Vilnius, Lithuania
Held By :	International Peatland Society
Aim :	Propose and discuss with 2nd Tropical Peatland Table in Indonesia
Participants :	Gerald Schmilewski (President), Guus van Berckel (1st Vice-President), Samu Valpola (2nd Vice President), Moritz Böcking, Donal Clarke, Erki Niitlaan, Jack Rieley, Meng Xianmin, Mitsuru Osaki, Lulie Melling, Susann Warnecke (Communications Manager, IPS)
Key Points :	- Discussing for 2nd Tropical Peatland Table in Indonesia, and agree to organize 2nd Tropical Peatland Table by IPS, JPS, Indonesia Peatland Society, BRG, and MoEF (Ministry of Environment and Forest, Indonesia) on November 2018 at Bogor. Responsible person of IPS are Jack Rieley and Mitsuru Osaki

		- (International) Tropical Peatland Center (tentative) will be establish at FORDA under MoEF (Ministry of Environment and Forest, Indonesia)
Subject of Discussion	:	EB Meeting 96, #19 Short Agenda for 2nd Tropical Peatland Roundtable, #20 Managing Peatlands to Cope with Climate Change: Indonesia's Experience, #21
Photos	: