インドネシア国
環境林業省

インドネシア国
日本インドネシア REDD+
実施メカニズム構築プロジェクト
「泥炭地炭素排出量評価」

業務完了報告書

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１．業務の背景

　インドネシアは約 9,400 万ヘクタールの森林面積を有し、ブラジル、コンゴ民主共和国に次ぐ世界第 3 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 年までに巨大な森林地域を擁するスマトラ島、カリマンタン島の 98%の森林が消失すると予想されている。また、インドネシアの温室効果ガス排出量は、土地利用変化も含めるとアメリカ、中国に次いで世界第 3 位であり、泥炭地（泥炭林を含む、以下同じ）由来の CO_2 排出量は総排出量の約 38%と見積もられており、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。しかしながら、これまでの推定には一般に IPCC デフォルトの推奨値が使用されており、炭素蓄積量が多く水位変動の影響が大きい泥炭地からの排出量の推定には依然として大きな不確実性が含まれている。

　また、国連気候変動枠組条約（United Nations Framework Convention on Climate Change；UNFCCC）に代表される国際的な気候変動対策の議論では、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組み（Reducing Emissions from Deforestation and Forest Degradation (REDD) including the role of conservation, sustainable management of forests and enhancement of forest carbon stocks；REDD+）の重要性が認識されつつあり、UNFCCC では REDD+の制度設計に関する議論が各国間の調整などで難航しつつも継続されている。こうした中、自主的取組みも先行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、国連環境計画（United Nations Environment Programme；UNEP）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（Measurement, Reporting, Verification；MRV）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。

　このような状況の中、JICA-JST による地球規模課題対応国際科学技術協力プログラム（SATREPS）「泥炭・森林における火災と炭素管理プロジェクト（以下 JICA-JST SATREPS プロジェクト）」（2009 年～2014 年 3 月）が中部カリマンタン州をフィールドに実施され、特に炭素蓄積量の多い泥炭地の炭素管理に係る研究、技術開発に成果を得たところであり、これらの成果のインドネシアにおける REDD+の推進等への活用が求められている。

　また、JICA プロジェクト「日本インドネシア REDD+実施メカニズム構築プロジェクト（以下 IJ-REDD+プロジェクト）」がインドネシア環境林業省（旧 林業省）をカウンターパートとして、2013 年 6 月より実施されているところである。本プロジェクトの活動の一つとして、上記 JICA-JST SATREPS プロジェクトとの連携の下に、中部カリマンタン州における州レベルの MRV 能力向上を図るとともに、その成果を国レベルの REDD+メカニズム構築に資することとしている。

２．業務の目的

　本業務は、IJ-REDD+プロジェクトの投入の一環として、中部カリマンタン州における JICA-JST SATREPS プロジェクトの成果等に基づき、熱帯泥炭地からの CO_2 排出量の算定に関する以下のタスクを遂行することを目的として、2015 年 2 月 2 日～2016 年 3 月 31 日にかけて実施された。

① インドネシアにおける REDD+ や温室効果ガス削減州別行動計画（Rencana Aksi Daerah Penurunan Emisi Gas Rumah Kaca；Local Action Plan for GHG Emission Reduction, RAD-GRK）に携わる行政関係者が利用可能な、CO_2 排出量推定マニュアル（guidebook）の作成

② 上記マニュアルに基づき、中部カリマンタンにおける州レベル（準国レベル）の泥炭地からの CO_2 排出量について試算し、レポートを作成

③ マニュアルに記載された算定手法について、現地関係者に技術移転

また、業務を円滑に遂行するため、以下の点を考慮した。

（1）本業務においては、インドネシアにおける実情を踏まえて、行政レベルで利用可能なマニュアルを作成することを主たる目的の 1 つとした。この点に鑑み、科学的妥当性・正確性を確保しつつ、データ入手の容易さ、マニュアルの分かりやすさなどに留意した。

（2）インドネシア現地関係者・関係機関への技術移転を効果的に行う観点から、マニュアルおよび CO_2 排出量試算レポートの作成過程に関係者を積極的に関与させた。

（3）インドネシア国内における関係者・関係機関の調整、ワークショップや研修等の企画・実施、インドネシア国内向けのマニュアルやドキュメントの編集等については、本プロジェクトに関して JICA インドネシア事務所と契約を締結した現地コンサルタントである Starling Resources と連携しながら進めた。

（4）本業務は IJ-REDD+ プロジェクトの投入の一環として、同プロジェクトの全体的な調整の下に行われるものであるため、同プロジェクト専門家やナショナルスタッフと密に連絡を取りつつ業務を遂行した。

３．プロジェクト成果物の概要

(1) SESAME システムによる地下水位の自動連続観測体制の確立

　遠隔地における地下水位・降水量・地盤変位量等を自動連続観測するため、初級トレーニングコース（4.(3)参照）の際に実施された野外作業において、我が国で開発された野外データ伝送システムである SESAME システム（Fig. 1）を設置した。2 日間にわたって 2 台の設置を行い、1 台目は旧メガライスプロジェクトのブロック C 地区内に位置するトゥンバン・ヌサ研究林（SESAME-IJ1）、2 台目はセバンガウ川右岸に位置するセバンガウ国立公園内に設置した。

　SESAME システムは記録したデータを、アクセスポイント名（APNs）とインターネットを経由して日本に設置されているデータサーバーに自動的に転送する（Fig. 2）。しかし 2015 年は、現地で多発した森林・泥炭火災により発生した濃い煙霧によって日射が遮られ、太陽電池の発電効率が低下した結果、トゥンバン・ヌサ研究林内の SESAME-IJ1 のデータ転送が何度も失敗した。これに対してセバンガウ国立公園内では、排水路の効果的な閉塞が行われ地下水位が比較的高く維持された結果、大規模な火災の発生は生じず、公園内に設置された SESAME-IJ2 のデータ転送への影響は生じなかった。

　SESAME システムの設置方法、データの取得ならびに補正方法、設置する台数を最適化する

方法等について整理し、マニュアルにとりまとめた。また、集中トレーニングコース（4.(4)参照）および上級トレーニングコース（4.(5)参照）の中で、現地関係者に対してこれらの手法に関する技術移転を行った。
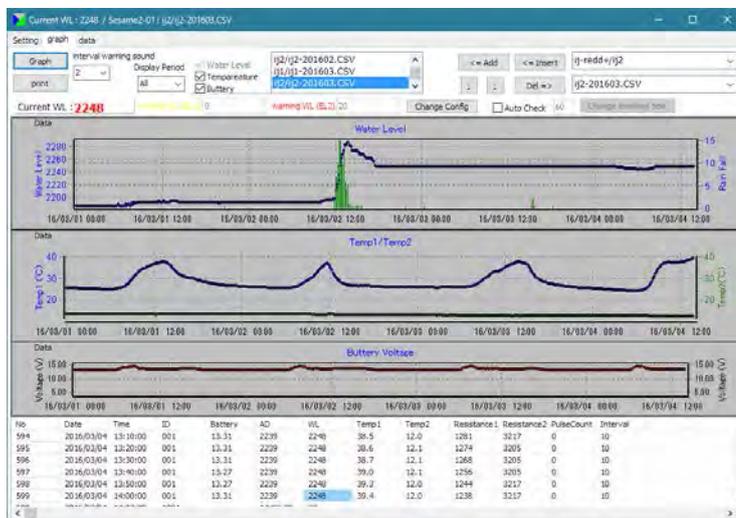

Fig. 1　SESAME システムの概要.

Fig. 2　SESAME システム用データ閲覧ソフトの画面.

(2)　地下水位分布推定モデルの開発

　　中部カリマンタン州内に分布する熱帯泥炭地の地下水位分布を求めるため、一次回帰式をベースとする簡易な推定モデルを作成した。地下水位の実測値の代わりとして、ヨーロッパ中期予報センター（European Centre for Medium-Range Weather Forecast, ECMWF）が提供している土壌水分量の日データ（0.5 度×0.5 度グリッド）を利用した。

　　中部カリマンタン州の泥炭地に見られる代表的な地表面条件の中から、3 つの泥炭地タイプを選定した（未排水の泥炭林 UF・排水された泥炭林 DF・排水された火災跡地 DB）。これら 3 つの泥炭地タイプに設置された観測地点で実測された地下水位と、それぞれの場所を含むグリッド内の ECMWF 土壌水分データと間で直線回帰を行ったところ、すべてのタイプで高い相関が得られた（$r = 0.59$〜0.67; Fig. 3 左）。これらの回帰式を用いることにより、土壌水分データから地下水位を推定することが可能となった（Fig. 3 右）。

　　ECMWF が提供する土壌水分データの処理方法ならびに関連情報を整理し、マニュアルにとりまとめた。また、集中トレーニングコース（4.(4)参照）および上級トレーニングコース（4.(5)参照）の中で、現地関係者に対してこれらの手法に関する技術移転を行った。
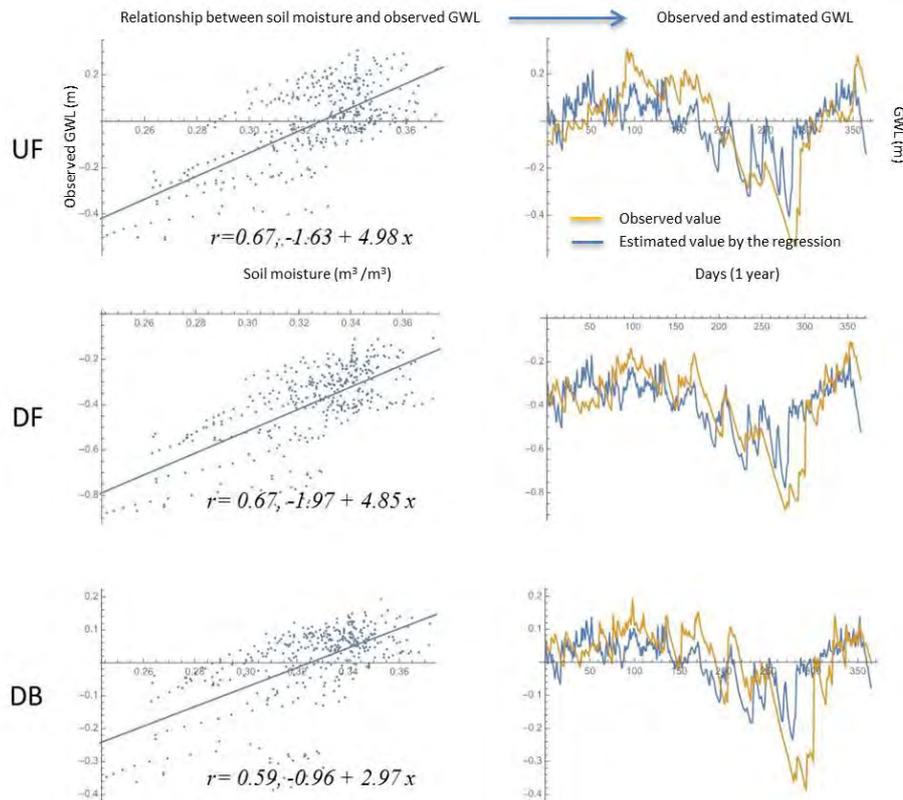
Fig. 3 左：ECMWF 土壌水分データと地下水位の実測データとの相関、右：左で得られた直線回帰式と土壌水分データに基づく地下水位の推定値と実測値との比較（2012 年）.

(3) 泥炭分解に伴う CO_2 排出量の推定

　　JICA-JST SATREPS プロジェクトにおける重要な発見の 1 つとして、平野ほか（2016）による泥炭分解に伴う年間 CO_2 排出量と地下水位との関係（平野モデル）がある。彼らは、前述した 3 つの泥炭地タイプにおいて、1 年間の正味 CO_2 交換量（Net Ecosystem Exchange, NEE）―年間の光合成による CO_2 吸収と、生態系呼吸（植物呼吸＋泥炭の好気的分解）による CO_2 放出との差し引き―が、地下水位の年間月平均最低値と高い相関関係にあることを示した。この発見によって、 3.(2)で開発したモデルを用いて推定した地下水位の分布から、中部カリマンタン州内の泥炭地における泥炭分解に伴う CO_2 排出量を推定することが可能となった。

　　本業務における試算では、2012 年における排出量を 0.5 度×0.5 度グリッドで推定した。各グリッドにおける地下水位と年間 NEE を推定する前に、グリッド内での 3 つの泥炭地タイプの面積を以下の手順で算出した。まず、泥炭地以外の面積を今回の推定の対象外として除いた。次に、平野モデルで対象とした泥炭地はすべて森林であるため、森林以外の面積を除いた。続いて、2000 年～2012 年の間に森林植生が失われた面積を画像解析から検出し、DB タイプとして割り当てられた。最後に、残りの面積を乾燥頻度によって UF タイプと DF タイプに割り当てた。乾燥頻度が高い領域（0.5～1）を DF、低い領域（0～0.5）を UF とした（Fig. 4）。

　　平野ほか（2016）による年間 NEE と、NEE の観測地点を含むグリッドの各泥炭地タイプについて推定した地下水位（Fig. 3 右）の年間月平均最低値との間で回帰分析を行った結果、2 本の

回帰直線が得られた。1 つは UF と DF、もう 1 つは DB についてのものである（Fig. 5）。これらの回帰式を用いて、各グリッドについて推定した地下水位の年間月平均最低値から年間 NEE を算出した。試算の結果、泥炭分解に伴う 2012 年の年間 CO_2 排出量の分布は Fig. 6 のようになり、総排出量は 5.37 MtC/年であった。

　泥炭地タイプを分類するためのデータソースおよびデータの取得方法、回帰分析の手順、GIS ソフトウェアを用いたグリッドとマップの作成方法等について整理し、マニュアルにとりまとめた。また、集中トレーニングコース（4.(4)参照）および上級トレーニングコース（4.(5)参照）の中で、現地関係者に対してこれらの手法に関する技術移転を行った。
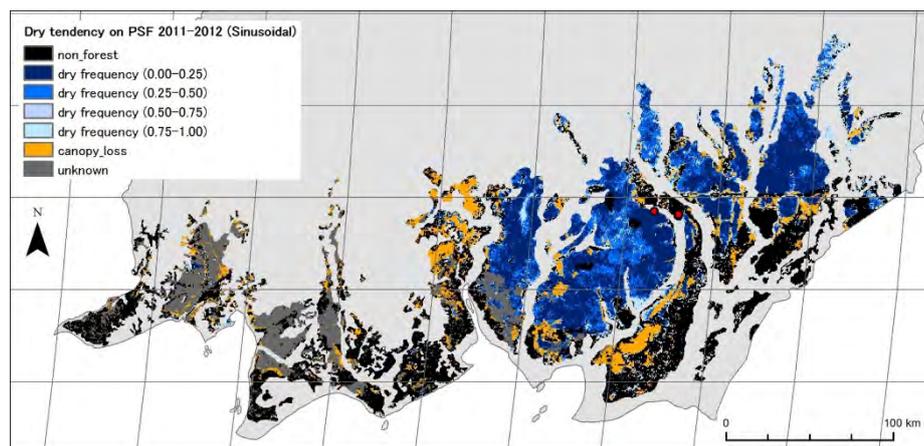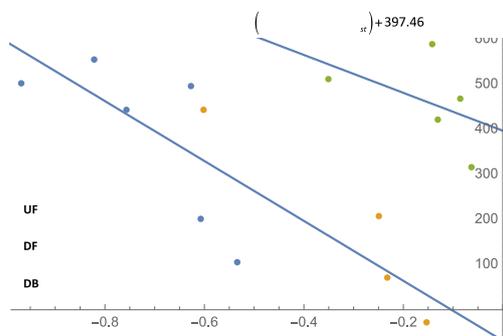

Fig. 4　2012 年の中部カリマンタン州における泥炭地タイプの分布.

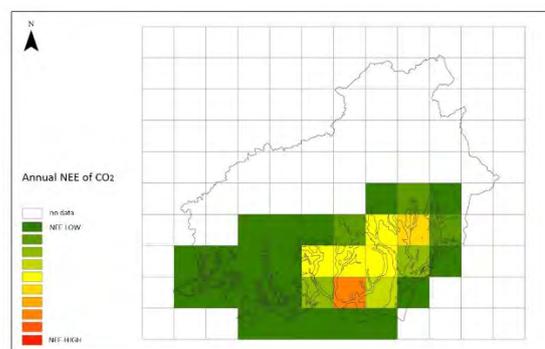Fig. 5　平野ほか（2016）による年間 NEE と土壌水分データから推定された地下水位の年間月平均最低値との関係.

Fig. 6　2012 年における年間 NEE の分布. 森林以外および泥炭地タイプが不明な領域は計算から除外した.

(4)　泥炭火災に伴う CO_2 排出量の推定

　JICA-JST SATREPS プロジェクトにおけるもう 1 つの重要な成果として、高橋ほか（2013）による泥炭火災に伴う CO_2 排出量を推定するためのモデルがある。彼らは、旧メガライスプロジェクト地域において、火災による年間 CO_2 排出量が地下水位の年間月平均最低値と強い相関を持つことを示した。この発見によって、 3.(2)にて開発したモデルから推定した地下水位を用い

て、中部カリマンタン州（現時点では旧メガライスプロジェクト地域のみ）の泥炭地火災に伴うCO₂排出量を推定することが可能となった。

Putra・早坂（2009; 高橋ほか（2013）で引用）によって推定された、1997年〜2007年における泥炭火災に伴う年間CO₂排出量と、UFタイプについて推定した各年の地下水位の年間月平均最低値との間で回帰分析を行った結果、大変強い相関が得られた（$r = 0.90$）。この回帰式を用いて、推定した地下水位を泥炭火災に伴う年間CO₂排出量に換算した（Fig. 7）。2012年の年間月平均最低値は –0.2856 m であり、これに基づいて推定した旧メガライスプロジェクト地域からの2012年の泥炭火災に伴う年間CO₂排出量は 0.0421 GtC であった。

泥炭火災による炭素損失量測定のためのデータの取得方法、焼け跡の観測を含む野外調査の手法、LiDAR や PALSAR-2 等の高度なテクノロジーに関する情報を整理し、マニュアルに取りまとめた。また、集中トレーニングコース（4.(4)参照）および上級トレーニングコース（4.(5)参照）の中で、現地関係者に対してこれらの手法に関する技術移転を行った。

Fig. 7　Putra・早坂（2009）による旧メガライスプロジェクト地域からの泥炭火災に伴う年間CO₂排出量（GtC/年、1997〜2007年）と推定された地下水位の年間月平均最低値との関係.
回帰式：$y = –0.194\, x – 0.0133$（$n = 11, r = 0.90$）
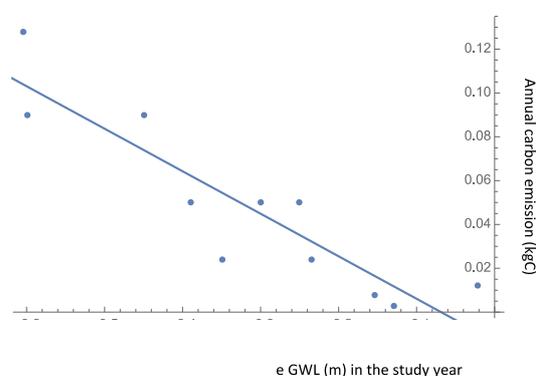
(5)　その他の関連技術

カルマンフィルターを用いた地下水位の予測モデルが開発され、3.(1)で設置した SESAME システム（SESAME-IJ1 および IJ2）から得られた地下水位データを使用したトライアル予測が行われた。3日後、7日後、11日後の予測結果を比較すると、より近い日の予測値の方が実際のデータの変動に近づく傾向が見られた（Fig. 8）。モデルにかけるためのデータの調整方法および計算ステップの進め方について整理し、マニュアルに取りまとめた。また、集中トレーニングコース（4.(4)参照）および上級トレーニングコース（4.(5)参照）の中で、現地関係者に対してこれらの手法に関する技術移転を行った。

右上: 3 日後

中段: 7 日後

下段: 11 日後
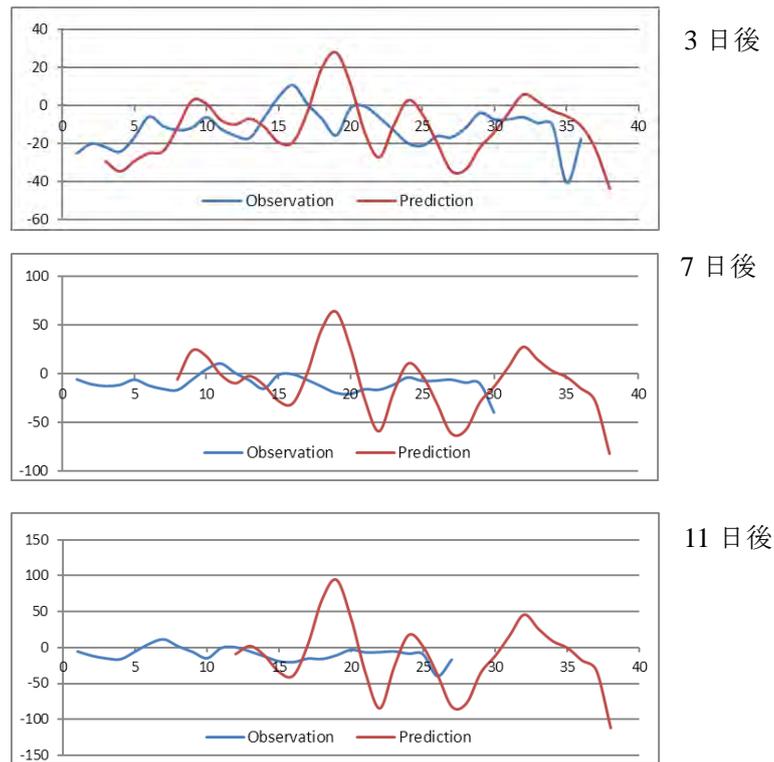
Fig. 8　地下水位のトライアル予測の結果．インドネシア・中部カリマンタン州内セバンガウ国立公園内で、2015 年 7 月〜9 月にかけて観測された SESAME データを用いた．

４．会議・ワークショップ・実地研修等の概要

(1)　国内キックオフミーティング（2015 年 3 月 13 日；北海道大学、札幌）
➤ 北大のプロジェクト担当者と国内のプロジェクト協力者との間で、プロジェクトの目的と概要がシェアされた。
➤ 高橋英紀博士（北海道水文気候研究所）および繁永幸久氏（みどり工学研究所）から、SESAME システムの設置と管理について協力する旨の同意が得られた。
➤ 木村圭司博士（奈良大学）から、地下水位の代理として ECMWF の土壌水分データを利用することが提案された。

(2)　現地キックオフワークショップ（2015 年 4 月 7 日；アクアリウスホテル、パランカラヤ：参加者 49 名）
➤ インドネシアのプロジェクト担当者との間で、プロジェクトの目的と概要がシェアされた。
➤ 現地関係者に対して、トレーニングコースの仮プランとスケジュールを説明した。その後、ワークショップ内での議論に基づき、詳細なプランを決定した。
➤ 初級トレーニングコースの中で、2 台の SESAME システムを設置することとした。
➤ 参加者から選抜されたメンバー（コアチーム）を日本に招聘し、集中トレーニングコースを実

施することが、現地コンサルタント Starling Resources から提案され、了承された。

➢ SESAME システムの設置候補地の視察のため、翌日の 4 月 8 日に野外調査を行った（Fig. 10）。いくつかのゴムプランテーションの植生状態と管理体制、およびトゥンバン・ヌサ研究林の視察を行った。

Fig. 9　現地キックオフワークショップ.

Fig. 10　SESAME システム設置候補地の視察.

(3)　初級トレーニングコース（2015 年 8 月 3 日～7 日；KOMDA REDD+トレーニングセンター・パランカラヤ大学・トゥンバン・ヌサ研究林・セバンガウ国立公園、パランカラヤ：16 名にトレーニングを実施）

➢ 初級トレーニングコース開始前の 8 月 1 日に、新たに SESAME システムの設置候補地となったセバンガウ国立公園の視察を行った。

➢ 初日（8 月 3 日）は、北大より派遣された専門家により総合的な講義が行われた（Fig. 11）。研修生は、REDD+に関する知識とインドネシアの熱帯泥炭地に関する知識について復習した。

➢ 2 日目（8 月 4 日）は、UF タイプの NEE 観測ステーションを訪問し、泥炭の採取実習を行った（Fig. 12）。研修生は、定容量の不撹乱泥炭試料を採取する方法、および渦相関法を用いた NEE の観測方法について学んだ。

➢ 3 日目（8 月 5 日）および 4 日目（8 月 6 日）は、それぞれトゥンバン・ヌサ研究林およびセバンガウ国立公園内に SESAME システムを設置した（Figs. 13・14）。これと並行して、2 日目に採取した泥炭試料の乾燥密度および灰分量分析のための室内実験を行った。

➢ 5 日目は（8 月 7 日）、SESAME データサーバーからのデータ取得を試みたが、講義室のインターネット環境の不備により、多くの研修生がデータを得ることができなかった。また、泥炭試料のデータについてのまとめを行った。

Fig. 11 熱帯泥炭地に関する講義.

Fig. 12 不攪乱泥炭試料の採取.

Fig. 13 トゥンバン・ヌサ研究林に SESAME シ
ステムを設置.

Fig. 14 セバンガウ国立公園に SESAME システ
ムを設置.

(4) 集中トレーニングコース（JICA 国別研修；2015 年 10 月 9 日〜16 日；北海道大学、札幌）

➤ 初級トレーニングコース参加者から 5 人のコアチームメンバーが選ばれ、JICA 研修員として北
海道大学に招聘された。

➤ メンバー全員に、ArcGIS・R・Excel などトレーニングコースに必要なソフトウェアがインスト
ールされたノート PC を配布した。

➤ 初日（10 月 9 日）は、ArcGIS の操作法に関する授業を行った。研修員は、泥炭地の境界線の地
図を描く方法や中部カリマンタン州を収めるグリッドセルの作り方を学んだ。

➤ 2 日目（10 月 10 日）は、北方泥炭地を学ぶための巡検を行った。研修員は当別町の篠津中央土
地改良区にある泥炭資料館、ならびに北海道農業研究センター内の美唄湿原を見学した。

➤ 1 日の休日を挟んだ後、泥炭分解および泥炭火災に伴う CO_2 排出量を推定する方法に関する PC
実習を、10 月 12 日〜14 日にかけて行った（Fig. 17）。研修員は、土壌水分データから地下水位
分布を推定する方法、推定した地下水位と CO_2 排出量の間の回帰式の出し方、およびそれらを
地図化して表示する方法について学んだ。

➤ 10 月 15 日には、高橋英紀博士および繁永幸久氏による指導の下、初級トレーニングコースで多
くの研修生が得られなかった SESAME サーバーからのデータ取得を再度試みた。今回はすべて
の研修員がデータを得ることができ、データの修正および変換方法について学んだ（Fig. 18）。

➤ 最終日（10 月 16 日）に、研修員、Starling Resources スタッフおよび北大のプロジェクト関係者

で話し合いを行い、上級トレーニングコースおよびマニュアルや試算レポートの作成における、コアチームメンバーの役割について議論した。その結果、これらのプロセスにおいてコアチームメンバーがより強く関わることで合意した。

Fig. 15　泥炭資料館（当別町）.

Fig. 16　美唄湿原.

Fig. 17　地下水位の推定手法の実習.
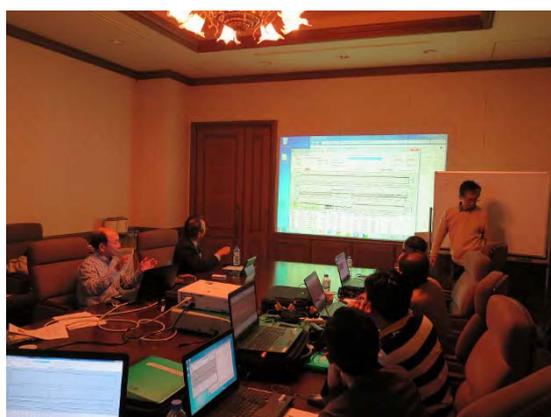
Fig. 18　SESAME データの取得.

(5) 上級トレーニングコース（2015 年 12 月 14 日〜18 日；ルワンサホテル、パランカラヤ；コアメンバーを含めた 14 名が参加）

➢ 上級トレーニングコース実施に先立ち、コアチームメンバーと Starling Resources のスタッフが、インドネシア語の PC 作業マニュアルを準備した。集中トレーニングコースで使用された英語マニュアルを訳すことにとどまらず、より理解しやすくなるよう追加・修正が加えられた。

➢ 原則として、8 月に行われた初級トレーニングコースに参加したメンバーを再度招聘した。コアチームメンバーは、ティーチングアシスタントとしての役割を担当した。

➢ トレーニングコースにおいて使用する ArcGIS・R・Excel などがインストールされたノート PC を 5 台用意した。

➢ 上級トレーニングコースでは、10 月に日本で実施した集中トレーニングコースと同様の内容を、コアチームメンバーの援助を受けながら再度実施した。研修生は、その日のはじめに当日の作業に関する大まかな説明を受けた後、グループに分かれて PC 実習に取り組んだ（Fig. 19）。イ

ンドネシア語のマニュアルを含めたコアチームメンバーの援助は、研修内容の理解とスムーズな進行に大いに役立った。

➢ 最終日（12 月 18 日）に、プロジェクト統括の大崎より、3 回に渡るトレーニングコースの締めの講義を行った（Fig. 20）。

Fig. 19　研修生による PC 実習.

Fig. 20　トレーニングコースの最終講義.

(6) プロジェクト成果物の取りまとめ会議（2016 年 1 月 25 日〜29 日；タクスホテル、バリ）

➢ 本プロジェクトの成果物（マニュアルおよび CO_2 排出量試算レポート）の取りまとめに向けて打合せを行うため、北大のプロジェクト関係者およびコアチームメンバーが、Starling Resources のメインオフィスがあるバリに集まった。

➢ コアチームメンバーと Starling Resources より、成果物のドラフトが提示された。北大のプロジェクト関係者は、そのドラフトに対してコメントおよび提案を行った。

Fig. 21　北大関係者・Starling Resources・コアチーム
　　　　メンバーによるプロジェクト成果物取りまと
　　　　めのための打合せ.

(7) 現地公開ワークショップ（2016 年 2 月 24 日；アクアリウスホテル、パランカラヤ；参加者 67 名）

➢ プロジェクトの成果を現地関係者へ伝えるための公開ワークショップを、キックオフワークショップと同じ場所で開催した。

➢ ワークショップに先立ち、前日の 2 月 23 日に巡検が行われた。41 名の参加者が、SESAME-IJ2

が設置されているセバンガウ 国立公園を訪れた（Figs. 22・23）。

➢ CO_2 排出量推定のための暫定版のマニュアルを、ワークショップ参加者に配布した（Fig. 24）。これに基づき、最終バージョンのためのコメントや提案を得ることができた。

➢ コアチームメンバーが、3 回のトレーニングコースで学んだことに基づいて、マニュアルおよび試算レポートの内容を発表した（Fig. 25）。

Fig. 22　セバンガウ国立公園についての説明.

Fig. 23　設置から半年経過した SESAME-IJ2 の状態.
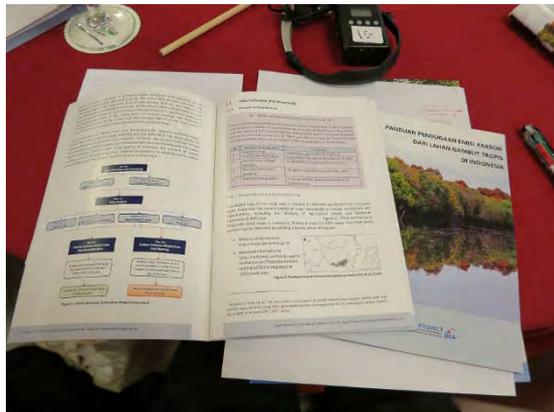
Fig. 24　インドネシア熱帯泥炭地からの炭素排出量の推定に関するマニュアル（暫定版）.

Fig. 25　マニュアルおよび試算レポートの内容を発表するコアチームメンバー.

５．プロジェクトに関する自己評価および将来への提言

● 本プロジェクトでは、インドネシア熱帯泥炭地からの主要な CO_2 排出量—泥炭分解および泥炭火災に伴うもの—を、ともに地下水位に基づいて推定した。地下水位に基づくこのモデルは、①熱帯泥炭地を含む湿原生態系の応答は、地下水位に強く影響を受けること、②地下水位は降水量や土壌水分量といった水文学的パラメータの 1 つであるが、これらのパ

ラメータについては将来の予報値が提供され始めていること、の 2 点から、CO_2 排出量の将来予測にまで活用できる見込みが高いモデルである。

● 現地関係者の間で最も関心が高かったのは SESAME システムであった。SESAME システムでは遠隔地の地下水位をほぼリアルタイムでモニタリングすることができるため、泥炭火災の早期警戒システムとしての利用に適している。

● コアチームメンバーは、上級トレーニングコースにおけるティーチングアシスタントとしての役割だけでなく、マニュアルおよび CO_2 排出量試算レポートの作成においても大きな役割を果たしてくれた。国際協力プログラムにおいては、日本人指導員と途上国の研修生との間でコミュニケーション不足が生じやすいが、本プロジェクトにおいては、コアチームメンバーや現地のコンサルタントである Starling Resources のスタッフが効果的に橋渡しを行ってくれた。技術移転の観点から見ると、現地からの参加者をどのような形で主体的に動くように巻き込んでいくかが極めて重要である。

● 生態系の炭素や水の挙動を再現する数値モデルは、これまで数多く発表されてきている。その多くはモデル内の計算手順を学術論文として明示しているが、内容を理解し実務レベルで用いるには、それらの多くは難解で複雑すぎる。本プロジェクトで採用した地下水位との直線回帰を主とするアプローチは、他の手法と比較して非常に単純であり、精度の面で改善の余地は多くある。しかしながら、上級トレーニングコースでは、研修生全員がすべての計算ステップをたどり、彼ら自身の手で CO_2 排出量を推定することに成功した。この経験は、実務レベルでのモデルの使用や、将来におけるモデルの改良のための大きな一歩であると確信する。

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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, 226-227, Tokyo.

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 in Indonesia, 43-49, Palangka Raya.

資料 1

Guidebook for Estimating Carbon Emissions from

Tropical Peatlands in Indonesia

インドネシア熱帯泥炭地からの
炭素排出量推定マニュアル

GUIDEBOOK FOR ESTIMATING CARBON EMISSIONS FROM TROPICAL PEATLANDS IN INDONESIA

GUIDEBOOK FOR ESTIMATING CARBON EMISSIONS FROM TROPICAL PEATLANDS IN INDONESIA

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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 promotes international joint research, with the title "Wild Fire and Carbon Management in Peat-Forests in Indonesia" for five years since 2009. These cooperation programs have generated much 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". This book, containing 651 pages and 41 scholarly articles, describes various aspects of tropical peatland ecosystems, and is the world's first complete book on this topic.

In line with these research developments, 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, an effort was needed to translate the research results into a guide that can be easily understood by all stakeholders who need it at the provincial govenrment level. For this purpose, the IJ-REDD+ Project has coordinated and facilitated the preparation of this guidebook on estimating carbon emissions from peatlands in Indonesia with stakeholders particularly from Central Kalimantan.

To prepare this guidebook, the IJ-REDD+ Project has cooperated with a team from Hokkaido University as technical consultants, Starling Resources as the local consultant, and members of the Core Team from 5 Indonesian insitutions – Environment Agency of Central Kalimantan Province (BLH Provinsi Kalimantan Tengah), Agency for the Assessment and Application of Technology (BPPT), Agency for Research and Development of Environment and Forestry (BPPLHK) Banjarbaru, and Sebangau National Park Office. We would like to express our appreciation to all parties who have supported this cooperation.

15 March 2016

Hiroshi Kobayashi
Acting Chief Advisor
IJ-REDD+ Project

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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
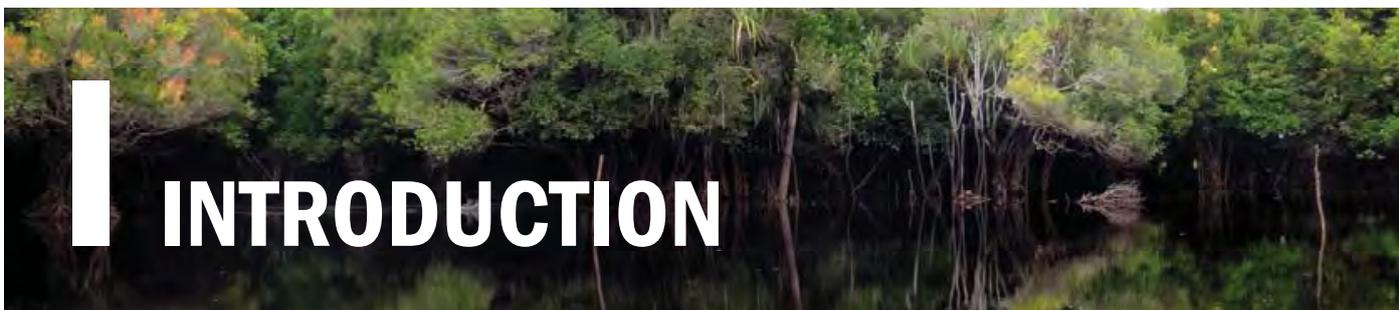
INTRODUCTION

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.   How is this guidebook organized?

This guidebook is organized into four parts – **I.** Introduction; **II.** Carbon Emission Model; **III.** GWL Prediction Model; and **IV.** Future Considerations.

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

Part II of this guidebook explains how 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 III of this guidebook explains how to predict GWLs several days into the future based on daily average GWL data observed in the field. Figure 17 shows the framework of the GWL Prediction Model.

Part IV of this guidebook suggests areas of improvements for the models explained in Part II and Part III. It also discusses the potential application of these models in practice.

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.

II CARBON EMISSION MODEL

❖ What will you learn in Part II? ❖

➢ How to estimate **CO₂ emissions from peat decomposition**

✓ Key points to understand:

- Real-time GWL measured at a study area is used as a key parameter to estimate CO_2 emissions from peat decomposition.
- The study area should be classified into different types of peatland based on distinctive land use and land cover characteristics (hereinafter, collectively termed "peatland types"). This is because CO_2 emissions are to be estimated by each peatland type.
- CO_2 flux measured at the study area is used to obtain net ecosystem exchange (NEE) values. A positive NEE value (>0) means the area is a source of CO_2 emissions.
- A linear relationship (regression line) between NEE and GWL values must be obtained. This is the most important part of this model.
- There is a strong correlation between GWL and soil moisture. Therefore, the spatial distribution of GWL in the study area can be estimated by using remote-sensing-based soil moisture data.
- This model allows you 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.

➢ How to estimate **carbon emissions from peat burning**

✓ Key points to understand:

- Real-time GWL measured at a study area is used as a key parameter to estimate CO_2 emissions from peat burning.
- Burn scar volume must be estimated by field sampling. Bulk density and carbon content can be determined by laboratory analyses on peat soil samples collected near the burned area. They are used to estimate the amount of carbon loss (emissions) due to peat burning.
- A linear relationship (regression line) between carbon loss and GWL values must be obtained. This is the most important part of this model.
- This model allows you to estimate the amount of carbon emissions for different years, or at other areas beyond sampling locations as long as those areas show similar characteristics to the burned area.

Figure 1 illustrates the steps to estimate carbon emissions from peatland due to microbial decomposition and peat burning. The initial step of data collection and processing involves the acquisition of a remote sensing data set and field sample data. These data are analyzed to estimate: 1) the classifications of peatland present based on distinctive land use and land cover characteristics (i.e., peatland types) and their spatial distribution in the study area; 2) annual average net ecosystem exchange (NEE) values; 3) the lowest monthly average GWL(s) in the study year(s); and 4) the amount of annual carbon emissions from peat burning.

The Carbon Emission Model from Peat Decomposition requires peatland types, annual NEE values and the lowest monthly average GWL(s) in the study year(s) to estimate the amount of annual CO_2 emissions. Similarly, the Carbon Emission Model from Peat Burning uses the amount of annual carbon loss (emissions) and the lowest monthly average GWL(s) in the study year(s) to estimate the amount of annual carbon emissions from peat burning. Detailed procedures to develop these models are provided under the relevant sections and/or sub-sections.
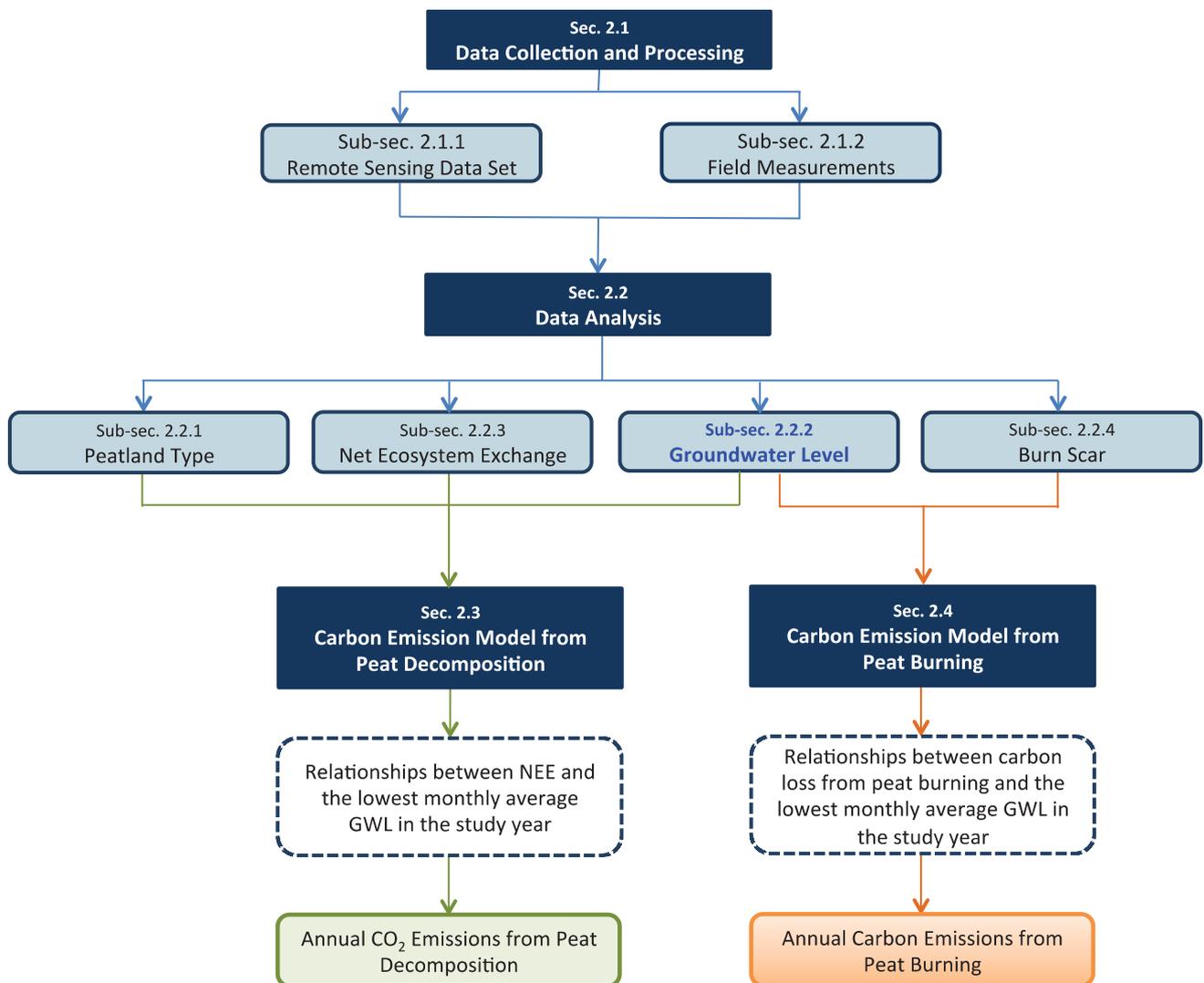
Figure 1. Carbon Emission Estimation Model framework

2.1 Data Collection and processing

2.1.1 Remote sensing data set

❖ What remote sensing data will you need? ❖

The Carbon Emission Models are based on remote sensing data. A set of remote sensing data is needed to classify the study area into different types of peatland (see Sub-section 2.2.1), to estimate the spatial distribution of GWL, and to detect burn scars (see Sub-section 2.2.3). There are different types of secondary data sources available which can be used to fulfill each purpose, as listed below.

No.	Remote sensing data	Purpose
1	Peatland map	To estimate the extent of peatland
2	Soil moisture product	To estimate the spatial distribution of GWL
3	Forest cover change product	To define forest and non-forest areas
4	Surface reflectance product	To define undrained and drained areas
5	Burned area product	To estimate the spatial distribution of burned areas

Step 1. Download an existing peatland map

A peatland map of the study area is needed to delineate peatland[1] 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)

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[1] Peatland is defined as "an area with accumulation of partly decomposed organic matter with ash content equal to or less than 35%, peat depth equal to or deeper than 50 cm, and organic carbon content (by weight) of at least 12%" (Purnomo et al., 2012).

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 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 4. 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). It is 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 5. 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).

2.1.2 Field measurements

❖   What sample data do you need to collect in the field?   ❖

You will need sample data in order to develop the Carbon Emission Models as explained in Sections 2.3 and 2.4. The greater the sample size is, the more accurate these models become. Therefore, it is recommended to set up observation points at various locations representing the distinctive characteristics of land use and land cover types in the study area. The following sample data must be collected in the field.

✓   GWL
✓ CO_2 flux
✓   Burn scar

2.1.2.1 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[2], 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

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

- Eijkelkamp[3] 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.

Figure 3. SESAME system

➢ Obtain a server access license (user ID and password) for data acquisition[4].

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

➢ 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).
  o 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).
  o The SESAME system should be installed at every distinctive type of peatland, as the Carbon Emission Model will be developed per peatland type.
  o 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.

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[3] 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.

[4] 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.
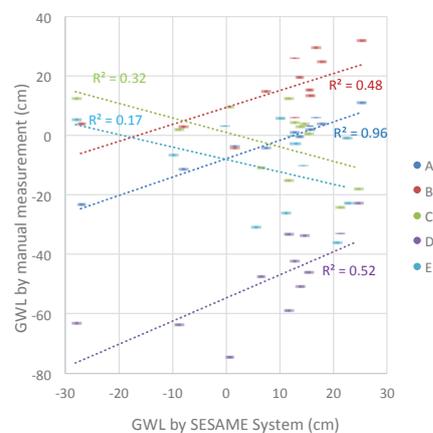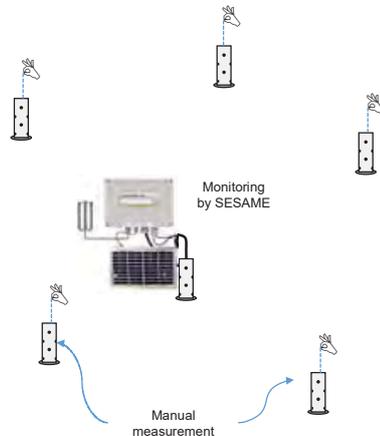
➢ Examine the correlation of each regression line. If the correlation is strong, the data obtained by the SESAME system can be used to represent GWLs at the manual monitoring location. Consider to install another SESAME system at the manual monitoring location which showed a weak correlation.

➢ 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).
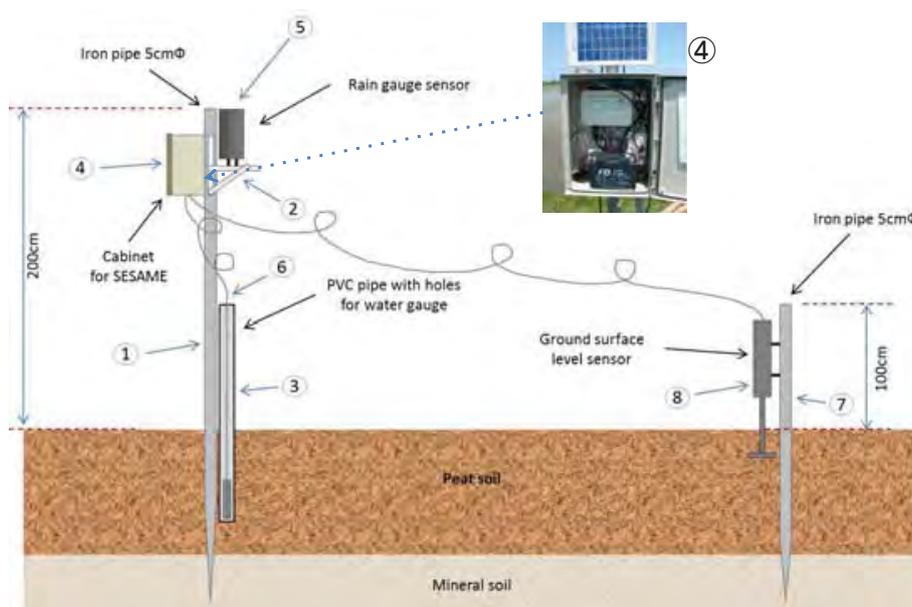
Figure 4. Illustration of SESAME system installation

- ➢ 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.

2.1.2.2 *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 3. 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).
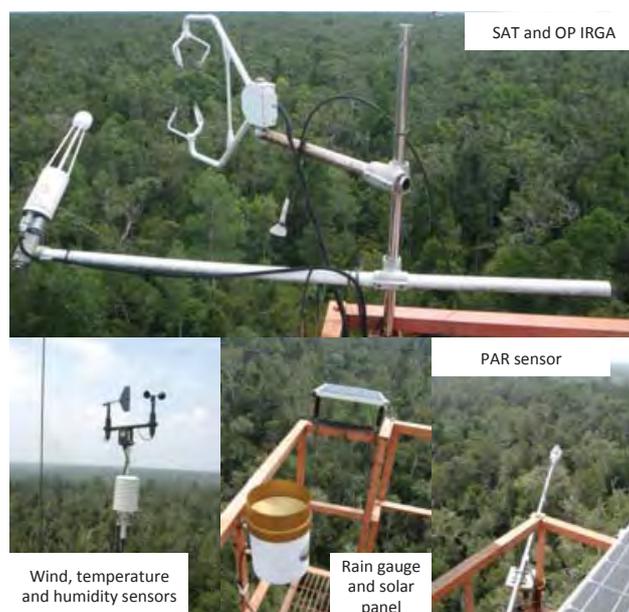
Figure 5. Flux tower instruments

- Ultra-Sonic Anemometer-Thermometer (SAT):
  - o 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.
  - o 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):
  - o 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.
  - o 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.
  - o 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.
  - o 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:
  - o Stores CO_2 flux data.
  - o 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:
  - o Supplies power to run the equipment.
  - o Recommended to use a stable commercial power supply with sufficient capacitance.
  - o 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.
  - o If <15 cm, the airflow will be disturbed.
  - o 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.

2.1.2.3 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).
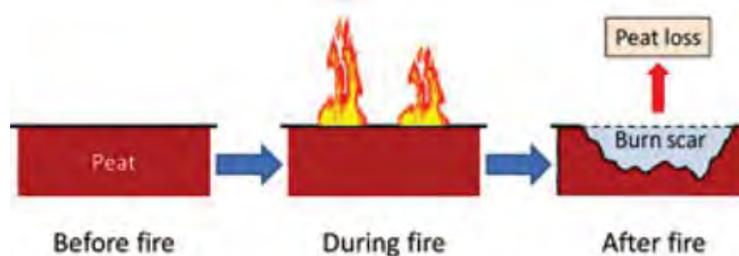
Figure 6. Illustration of burn scar measurement

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.
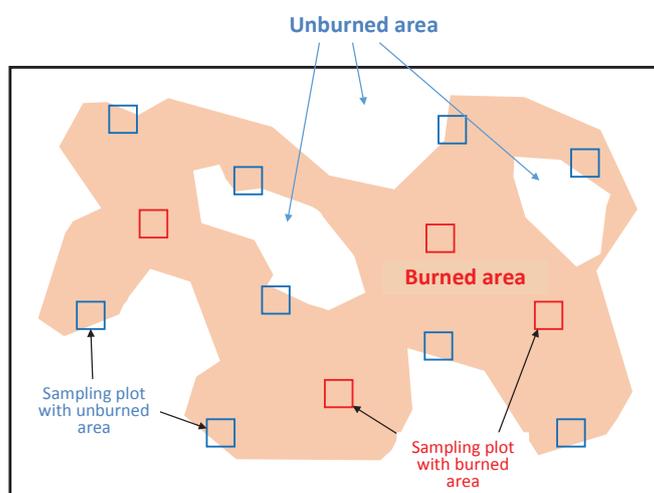
Figure 7. An example of burn scar sampling design

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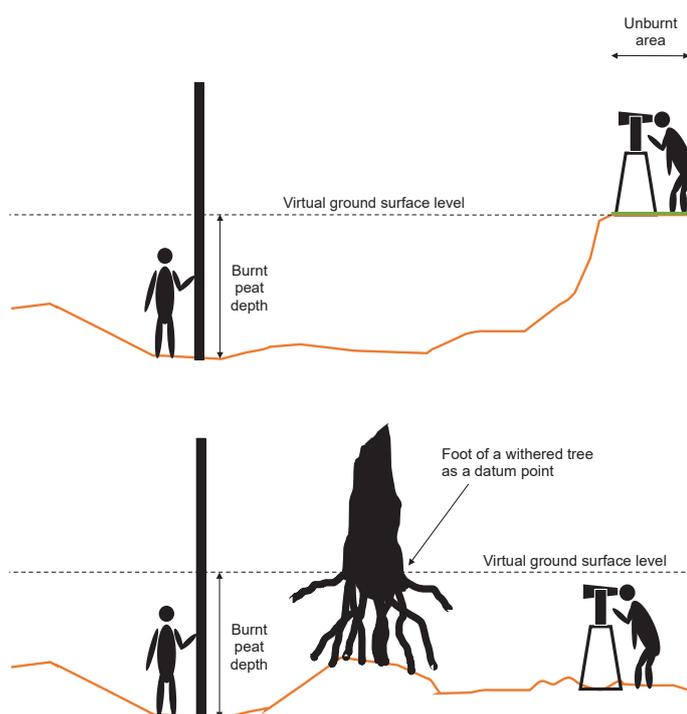
Figure 8. Illustration of burned peat depth measurements using an iron rod and a small unburned area (top) and a withered tree stand (bottom)

o **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.

o **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.

o **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 cm³) 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.
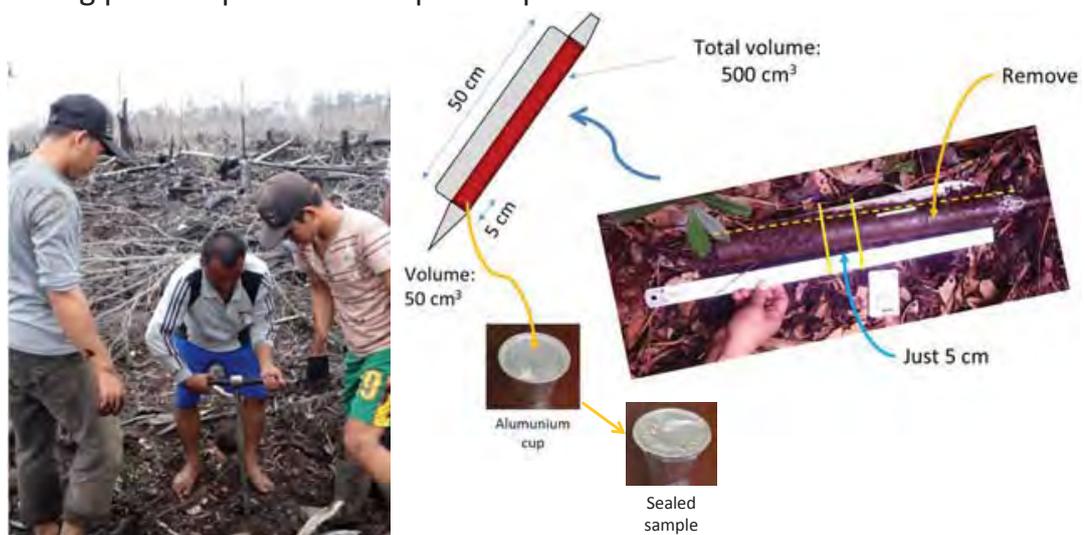
Figure 9. Procedure of peat sampling

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.

2.2 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

2.2.1 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.

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

o   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.
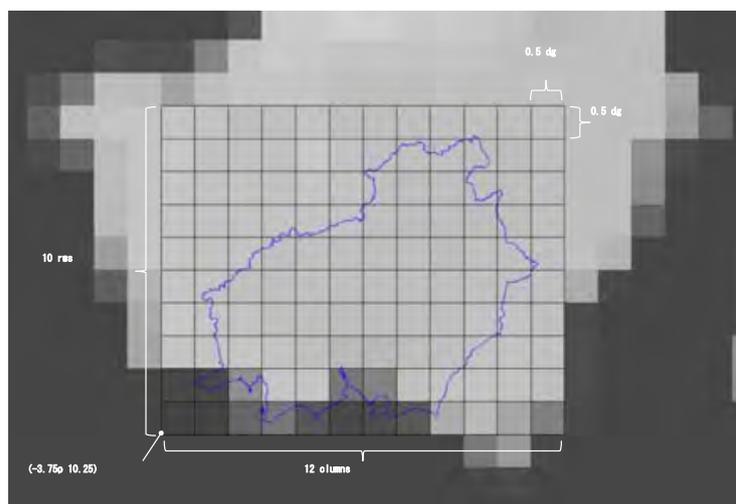
Figure 10. A grid file for Central Kalimantan
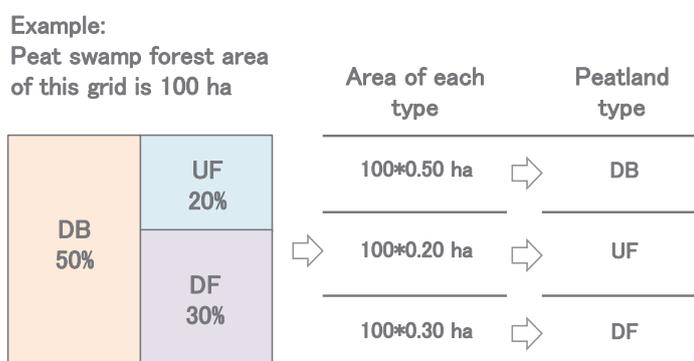
Figure 11. Example for the calculation of areas based on peatland types in a grid cell

2.2.2 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.

- 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).

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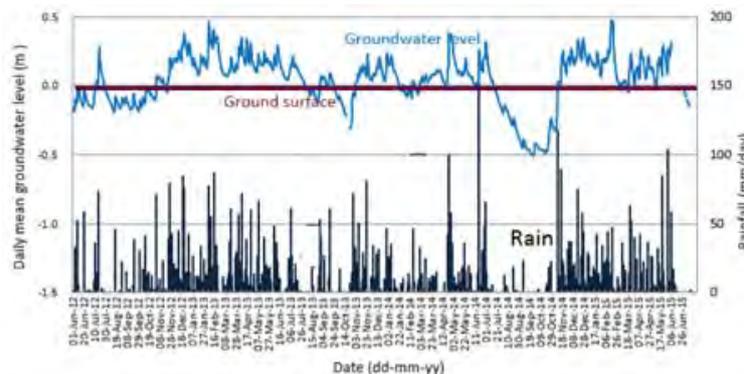
Figure 12. Example for time-series daily average GWLs with other parameters

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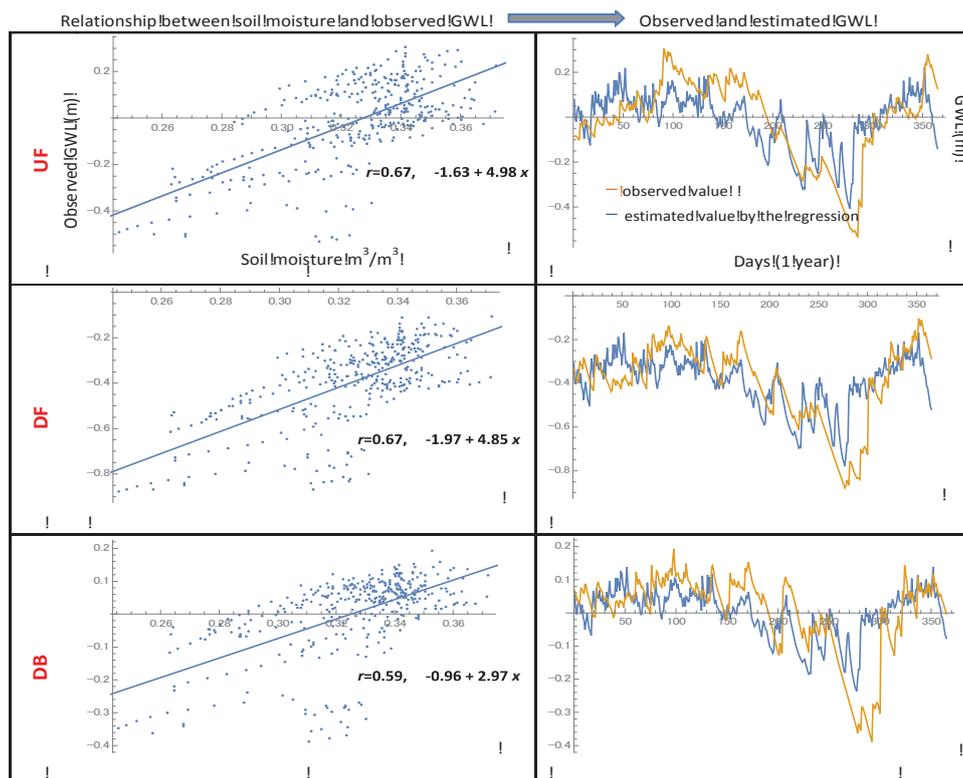
Figure 13. Example of GWL estimations for each peatland type based on the relationship between soil moisture and observed GWL data

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).

2.2.3 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 4. 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/m³)
′ = fluctuating component
⁻ = 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.

$$Annual\ NEE = \sum_{Year}(NEE\ value\ at\ each\ time\ interval) \qquad (2)$$

2.2.4 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:

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

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

Step 3. Calculate burn scar volume

> Calculate the volume of burn scar as given by:

$$Burn\ scar\ volume\ (m^3) = Burn\ scar\ area\ (m^2) \times Average\ burn\ peat \qquad (4)$$
$$depth\ (m)$$

- 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:

$$Co = 100 - Ca \qquad (8)$$

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

$$C = Co \times 0.58 \qquad (9)$$

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

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

Peat carbon loss (kgC) = Burn scar volume (m^3) × $\qquad (10)$
Bulk density (kg/m^3) × Carbon content (% of dry weight peat)

- If the bulk density and carbon content contain errors ($BD\pm\varDelta BD$ and $C\%\pm\varDelta C\%$, respectively), calculate carbon content ($C\pm\varDelta C$, kgC/m³) first as follows. If there are no errors, $\varDelta BD$ and/or $\varDelta C\%$ are assumed to be zero.

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

Where:
C = carbon content
BD = bulk density

➢ After this, calculate the total peat carbon loss ($F_b \pm \varDelta F_b$) 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).

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

Where:
F_b = carbon loss (emission)

2.3 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.
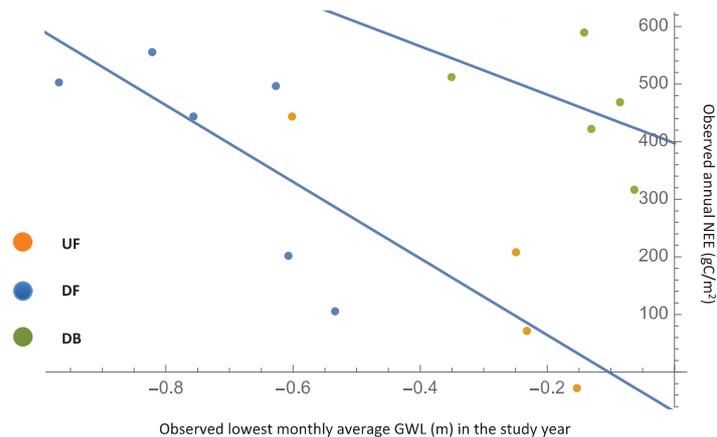
Figure 14. Example of relationships between the lowest monthly average GWLs (m) in the study years and annual NEE (gC/m² /year) observed in Central Kalimantan (Hirano et al., 2012)

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.

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

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 CO₂ 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.
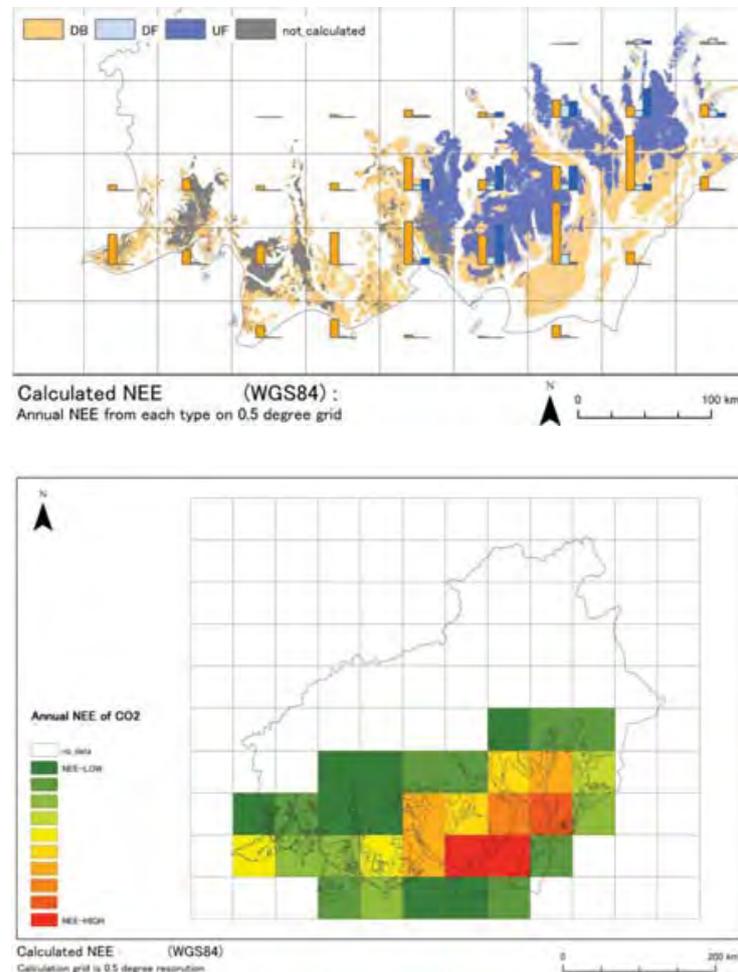
Figure 15. Map of estimated annual NEE values for each peatland type (top) and for total NEE (bottom) of 2012 on grid files for Central Kalimantan

2.4 Carbon Emission Model from Peat Burning

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

Similar to the Carbon Emission Model from Peat Decomposition explained in Section 2.3, 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).

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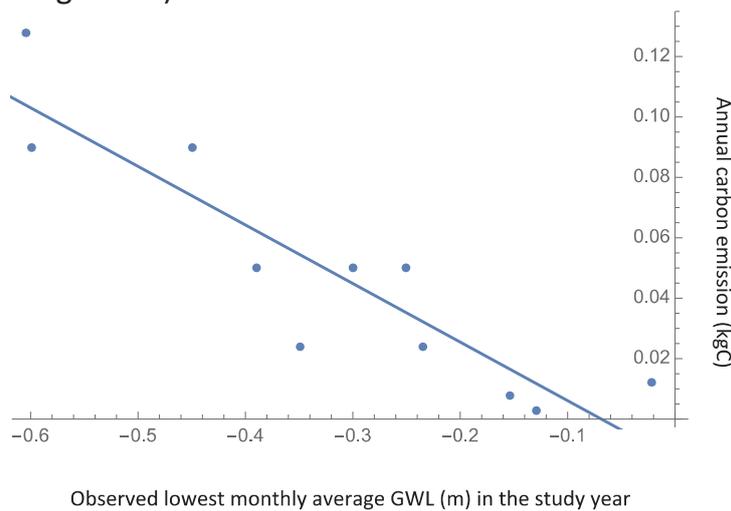
Figure 16. Example of a linear relationship between the lowest monthly average GWL(s) in the study year(s) and annual carbon emission from peat burning observed in the ex-Mega Rice area in Central Kalimantan (Putra et al., 2009)

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.

III GWL PREDICTION MODEL

❖ **What will you learn in Part III?** ❖

➢ How to predict daily groundwater level (GWL) for several days ahead

✓ Key points to understand:

- o The GWL Prediction Model uses the Kalman Filter technique introduced by Rudolf E. Kalman.

- o 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).

- o 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.

- o The model reduces the noise from the observed GWL values. In this model, the slope is assumed constant.

- o 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.

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┌─────────────────────────────────┐
│           Sec. 2.1              │
│  Data Collection and Processing │
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│        Sub-sec. 2.1.3           │
│     Field Measurements (GWL)    │
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│           Sec. 2.2              │
│    Data Analysis and Modeling   │
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│        Sub-sec. 2.2.2           │
│     Groundwater Level (GWL)     │
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│           Sec. 3.1              │
│      GWL Prediction Model       │
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   Kalman Filter processing using
            daily GWL
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│        Prediction of GWL        │
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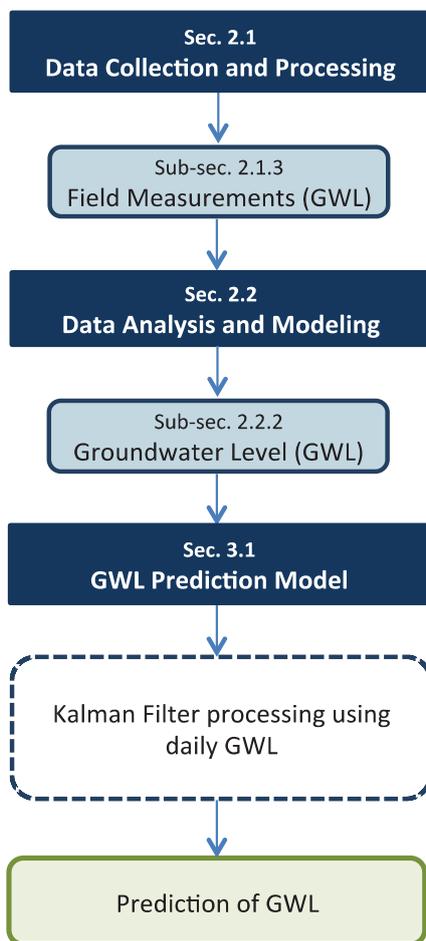
Figure 17. Framework for the GWL prediction

3.1   GWL Prediction Model

Figure 18 is a graphical representation of the model described through the following steps.
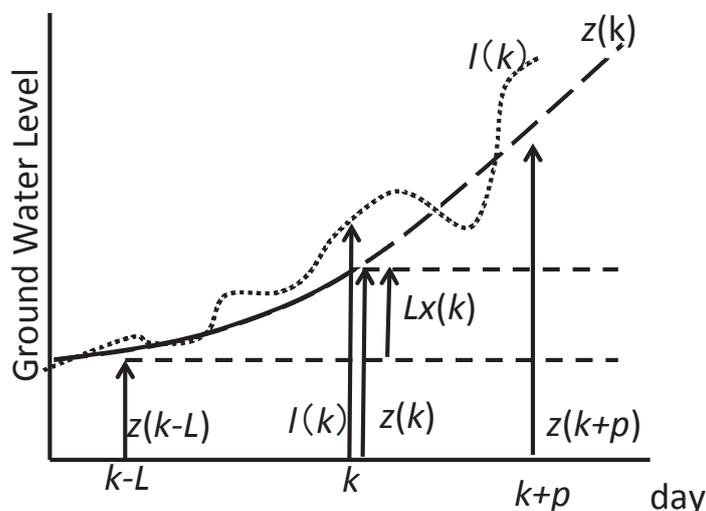
Figure 18. Illustration of the GWL prediction model based on the Kalman Filter technique

- 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.

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

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.

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

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.

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

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

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.

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

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

$$w(k) = x(k) - x(k-1) \ (k = N + L + 2, \ ....., q - N) \qquad (19)$$

$$v(k) = l(k) - z(k) \ (k = N + L, \ ....., q - N) \qquad (20)$$

> Run the Kalman Filter, using the following iteration.

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

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.

$$z(k+p/k) = z(k) + px(k/k) \qquad (22)$$

• 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:

o Peatland depth is even.

o There are no drainage canals or rivers nearby the SESAME observation point.

o Peatland type is uniform.

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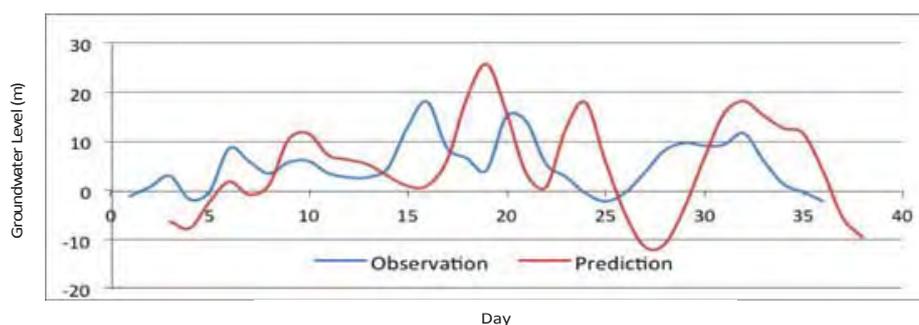
Figure 19. Illustration of GWL prediction for 3 days ahead

IV FUTURE CONSIDERATIONS

There are several important points that should be considered in order to improve and apply the Carbon Emission Models presented in this guidebook.

On data management:

- Develop a SESAME server and manage all data obtained from each SESAME system in Indonesia. This is likely to improve the network connection between the server and each SESAME system installed in the field in Indonesia, and thus reduce the number of data gaps. This is also likely to reduce the server maintenance cost.

On greenhouse gas sources:

- Expand carbon flux measurement including methane (CH_4), nitrous oxide (N_2O) and desorbed organic carbon (DOC).
  - CH_4-C emission is usually smaller than CO_2-C emission even in peatland ecosystems; however, CH_4 has a Global Warming Potential (GWP) value 25 times higher than CO_2.
  - In general, CH_4 emission from tropical peatland is much smaller than that in northern peatland (Couwenberg et al., 2010). However, large CH_4 fluxes were actually observed especially in burned areas (Adji et al. 2014), because of low O_2 transportation into peat layer via plant roots.
  - N_2O emissions from natural tropical peatland are negligible due to its nutrient-poor condition. In croplands and plantations, however, the application of N-fertilizers will cause considerable amount of N_2O emissions, which have a GWP value 298 times higher than CO_2.
  - Organic carbon outflow in water should be taken into account when evaluating the carbon balance in tropical peatland ecosystems.

- Evaluate the composition of gaseous carbon emitted from peat burning.
  - Peat burning emits many kinds of gaseous carbon. Usually CO_2 is dominant, but other gaseous carbons such as CO, CH_4 and PM are also present. These gases have different impacts on climate change, environment, and human health. It will be meaningful to assess the impact of peat burning more precisely, not only by estimating total peat carbon loss but also by evaluating the composition of fire-generating gaseous carbon sources.

On the application of the models:

- Use the GWL Prediction Model as an early fire warning system.
  - Work with relevant local institutions to develop and implement practical and user-friendly information communication systems (e.g., Android-based platform). These systems must be tailored to meet the needs of different user groups at the local level (e.g., communities, firefighting teams, companies, and government agencies).
  - Develop a central information communication system at the national level, and work with relevant institutions at all levels (i.e., national and regional) to integrate the system.
  - Use the Carbon Emission Models to estimate the amount of emissions in land use change as part of constructing regional development plans.

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資料２

Trial Calculation of Carbon Emissions Estimation from

Peatlands in Central Kalimantan

中部カリマンタン州泥炭地からの

炭素排出量推定結果報告書

TRIAL CALCULATION OF CARBON EMISSIONS ESTIMATION FROM PEATLANDS IN CENTRAL KALIMANTAN

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March 15, 2016

Table of Contents

ACRONYMS

CH_4	Methane
CO_2	Carbon dioxide
DB	Drained and Burned Land
DF	Drained Forest
DOC	Dissolve Organic Carbon
EC	Eddy Covariance
ECMWF	European Centre for Medium-Range Weather Forecast
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	Japan 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
NOAA	National Oceanic and Atmospheric Administration
PAR	Photosynthetically Active Radiation
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
SESAME	Sensory data transmission Service Assisted by Midori Engineering
WI	Wetlands International

INTRODUCTION

Central Kalimantan province encompasses 3,010,640 hectares (ha) of peatland along the southern coastal area of Kalimantan Island (Wahyunto and Suryadiputra, 2008). This is equivalent to 17.4% of the total area of the province, and 52.2% of the total peatland area in Kalimantan. 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 these environmental benefits, peatlands in Central Kalimantan have been exposed to various ecological threats such as peat oxidation and fires due to economic development. Peat oxidation and fires are major sources of Indonesia's greenhouse gas (GHG) emissions. A 2010 report suggests that 85% of Indonesia's GHG emissions stem from land use activities, with 37% due to deforestation and 27% due to peat fires (National Council on Climate Change, 2010), and therefore, the sustainable management of peatland has become a priority for Indonesia in addressing climate change and land use issues.

Central Kalimantan province is one of the pilot provinces to demonstrate sustainable peatland management and GHG emission reduction activities, collectively known as reducing emissions from deforestation and forest degradation plus conservation and enhancement of forest carbon stocks (REDD+). Various initiatives have been developed in the past decade, one of which is the JICA-JST Project[1]. During the period between 2009 and 2014, the JICA-JST Project developed an integrated methodology for estimating carbon emissions from peatland in Central Kalimantan.

Based on this methodology, this report presents a trial calculation of annual carbon emissions from peat decomposition and burning in Central Kalimantan for 2012. Furthermore, it presents an estimation of groundwater level (GWL) at two locations in Central Kalimantan predicted for several days into the future. This report is organized into three parts: 1) Carbon emissions from peat decomposition; 2) Carbon emissions from peat burning; and 3) Groundwater level (GWL) prediction.

I. Carbon Emissions from Peat Decomposition

1.1. Background

One factor that influences the decomposition rate of peat is groundwater level (GWL). When GWL decreases, the surface layer of peat will be exposed to the air, which creates opportunities for peat decomposition. This will increase the carbon emissions into the air. Previous studies have suggested that the GWL affects CO_2 emissions (Limpens et al., 2008; Page et al., 2009). When the GWL declines, CO_2 emissions will increase (Etik, 2009; Couwenberg et al., 2010; Dommain et al., 2012).

Hirano et al. (2012) showed a correlation between the lowest monthly average GWL and Net Ecosystem Exchange (NEE) on peatlands in Central Kalimantan. NEE values in a forest ecosystem

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[1] The JICA-JST Project on 'Wild Fire and Carbon Management in Peat-Forest in Indonesia' is a project which was implemented from 2009 to 2014 by the Japanese and Indonesian governments through the Science and Technology Research Partnership for Sustainable Development (SATREPS) cooperation. Implementing organizations in Indonesia included the National Standardization Agency (BSN), the Agency for the Assessment and Application of Technology (BPPT), the National Institute of Aeronautics and Space (LAPAN), the Indonesian Institute of Sciences (LIPI), the Forestry Research and Development Agency (FORDA), and the University of Palangka Raya (UNPAR). Meanwhile, the supporting organizations from Japan consisted of Hokkaido University, the Japan Science and Technology Agency (JST), and the Japan International Cooperation Agency (JICA).

suggest whether the forest is a carbon sink or a carbon source. If plant biomass in a peatland is not in a degeneration process, positive NEE values result from a peat decomposition process. Therefore, the GWL data can be used to estimate the CO_2 emissions from peat decomposition. The GWL is a key parameter in this study.

1.2. Objective

The objective of Part I of this report is to present an estimation of the annual CO_2 emission from peatlands in Central Kalimantan for 2012 based on a linear relationship between annual NEE and lowest annual average GWL values.

1.3. Study Site

The study site is the entire peatland area in Central Kalimantan province. In this study, to estimate the annual CO_2 emission from peatlands in Central Kalimantan, we used the observation data from three location points shown in the Figure 1. These three sites represent three different types of peatland: 1) Undrained Forest (UF); 2) Drained Forest (DF); and 3) Drained Burned Forest (DB), as described in Table 1.

Peatlands in Central Kalimantan (Wetlands International, 2005 and 2006)

Location (latitude, longitude)

DB : 2° 20′ 26.87″ S, 114° 02′ 16.45″ E

DF : 2° 20′ 45.86″ S, 114° 02′ 11.07″ E

UF : 2° 19′ 25.01″ S, 113° 54′ 15.69″ E

Observation points of Hirano Tower: UF, DF, and DB

Figure 1: The study site in Central Kalimantan Province peatland area

Table 1: The definition of each category of peatland type

No.	Peatland Type	Image	Definition
1	Undrained Forest (UF)		Intact or less disturbed forest which occurs on peatland with no traces of drainage network and no history of peat fires.
2	Drained Forest (DF)		Disturbed forest which occurs on peatland with traces of drainage network and trenches, but no history of peat fires.
3	Drained Burnt Forest (DB)		A non-vegetated and drained area which occurs on peatland with a history of drainage network, trenches and peat fires. This type of peatland is typically occupied with ferns, *kelakai* grasses and shrubs.

1.4.   Methods

In order to measure the amount of carbon emitted into the atmosphere (CO_2 flux) by tropical peat (including peat and forest stands on peat), three observation towers were installed at the three peatland types: Undrained Forest (UF), Drained Forest (DF), and Drained Burnt Forest (DB). Using micrometeorological techniques of eddy covariance, these towers were used to perform continuous measurements of net ecosystem exchange (NEE), which indicates the amount of CO_2 exchanged between the atmosphere and ecosystems, and the data were collected and analyzed. GWLs were measured at the interval of 10 minutes at each UF, DF, and DB observation site using the SESAME system[2].

1.4.1.   Classification of peatland types

Peatlands in the study area were classified into three distinctive land use and land cover types as defined in Table 1. Table 2 shows remote sensing data used to classify the area.

Table 2. Remote sensing data set used to classify the study area into distinctive peatland types

Remote sensing data	Source	Purpose
Wetlands International Peatland Map of 2005 and 2006	http://indonesia.wetlands.org/Infolahanbasah/PetaSebaranGambut/tabid/2834/language/id-ID/Default.aspx	To estimate the extent of peatland
Global Forest Change data, 2012	https://earthenginepartners.appspot.com	To define forest and non-forest areas
MODIS surface reflectance product (MOD09A1), 2012	http://modis.gsfc.nasa.gov/data/dataprod/mod09.php	To define undrained and drained areas
ECMWF volumetric soil water layer (soil moisture) product, 2012	http://apps.ecmwf.int/datasets/data/interim-full-daily/	To estimate the spatial distribution of GWL

The steps to identify the peatland type are as follows:
1.   We identified peatland and non-peatland areas in the study area based on the Peatland Map (Wetlands International, 2005 and 2006);
2.   We identified forest and non-forest areas in the study area based on the Global Forest Change data. The canopy loss areas were classified as a drained and burned land (DB);
3.   We identified drained and undrained areas based on the relative dry tendency of dense forest surface by using the MODIS surface reflectance product. Lower dry classes were classified as undrained forest (UF), and higher dry classes as drained forest (DF).

1.4.2.   Gridding of the study area

Since the spatial distribution of GWL and NEE values was to be estimated on grid, the study area was first divided into grid cells with a size of 0.5 x 0.5 degree on the WGS84 coordinate system. Then the pixel value of each peatland type was extracted into each cell. The distribution of peatlands in Central Kalimantan was obtained from the peatland map developed by Wetlands International (2005 and 2006). Of the 74 grid cells which covered the area of Central Kalimantan province, only 32 cells contained peatland areas (see Figure 2)

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[2] SESAME system comes with water level, temperature, precipitation and ground level sensors. More information is available at: http://www.midori-eng.com/english/image/sesame-01-2_pamph.pdf.

Calculation grid for NEE calculation
Calculation grid is 0.5 degree resolution
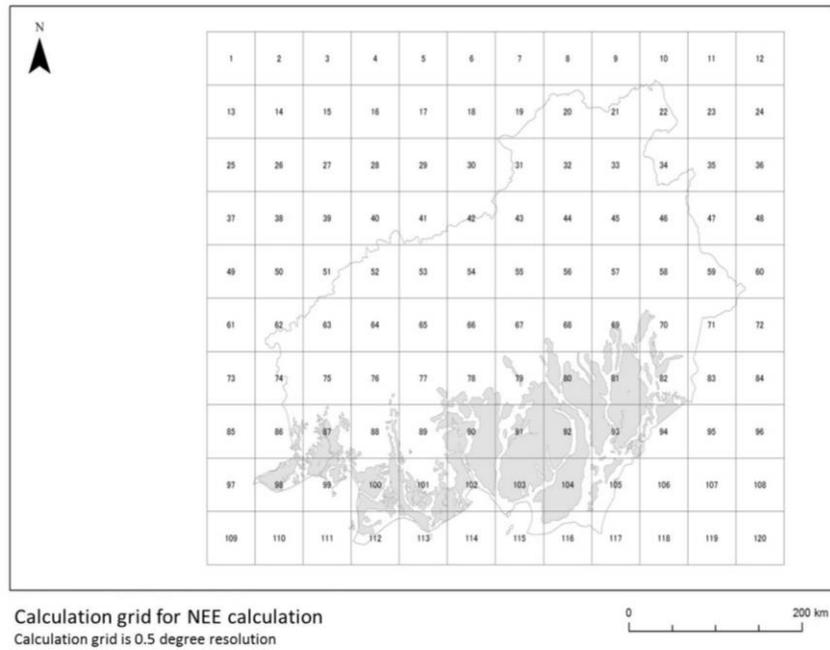
Figure 2: Distribution of tropical peatland in Central Kalimantan Province (Wetlands International, 2005 and 2006) and the cell numbers given to 0.5 x 0.5-degree grid

1.5. Results and Discussion

The result suggested that a considerable area of the western part could not be classified because of the high frequency of blocking by clouds in the satellite images. In the eastern part, most of the peatland in the ex-Mega Rice Project[3] area was classified as non-forest, since these areas were mainly developed and deforested during the ex-MRP (1997-1998) and devastated after the big peat fire in the following year. Therefore, most of the area in the western part and the MRP area were excluded from the carbon emission calculation in this study. Areas with lower dry frequencies were generally distributed in the upstream area of the big canal.

Grid cells with large peatland areas were generally occupied by UF. The areas of DF and DB were quite small in all cells. Cells in the eastern part were generally occupied by UF. The result of the classification of peatland type is presented in Figure 3. In this study, the non-forest area was excluded from the calculation, and the result suggests that the total area of peat swamp forest was 15,826 km^2. Nearly two-thirds of that area was classified as UF (64%). The remaining area was categorized as DB (19%) and DF (17%).

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[3] The Mega Rice Project was initiated in 1996 in the southern sections of Kalimantan, Indonesia. The government made a large investment in constructing irrigation canals and removing trees to turn one million hectares of unproductive and sparsely populated peat swamp forest into rice paddies in an effort to alleviate Indonesia's growing food shortage. The project did not succeed, and was eventually abandoned after causing considerable damage to the environment.
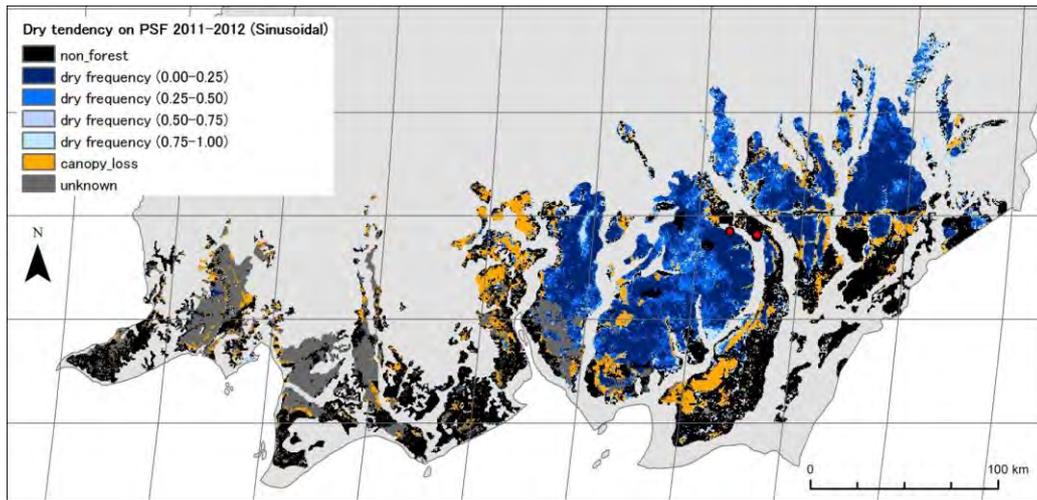
Figure 3: Distribution of forest type and dry frequency of peat swamp forest in the tropical peatland of Central Kalimantan in 2012

1.5.1. Estimation of the lowest monthly average GWL in 2012

The observed GWL data only covered the GWL in three grid cells: one for UF, one for DF, and one for DB. To estimate the GWL data for other grid cells, we used soil moisture data which was obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF) (see Table 2). The relationship between soil moisture data and GWL in the three different peatland types was determined by linear regression analysis. These relationships are presented in Figure 4.
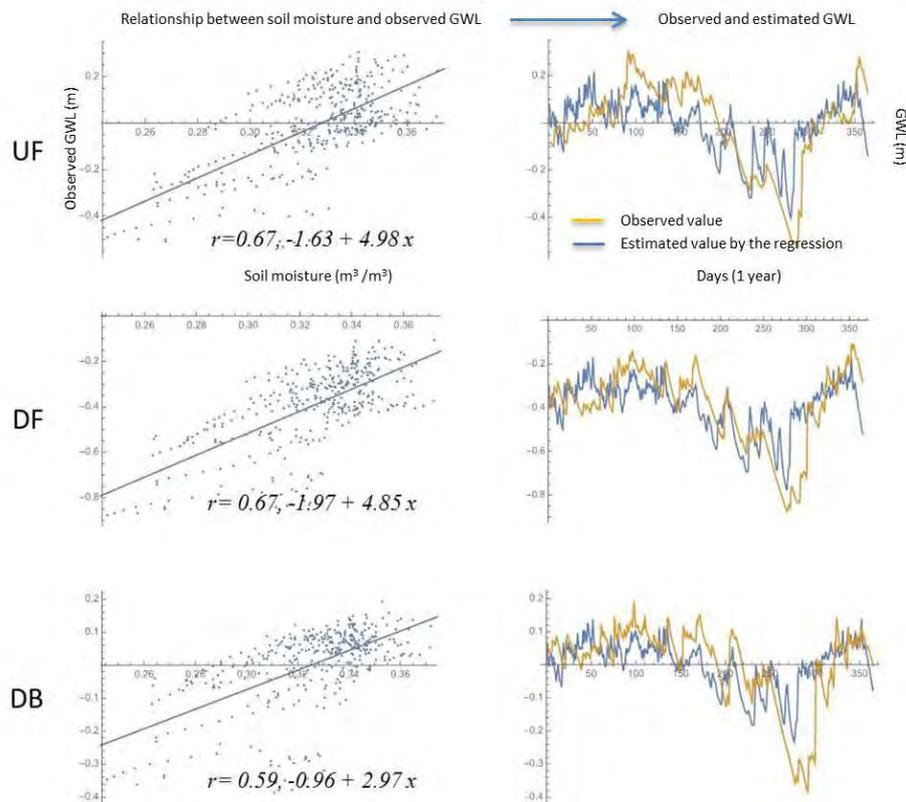
Figure 4: Left side: Linear relationships between soil moisture and observed groundwater level. Right side: estimated groundwater level by regression equation and observed value.

We estimated monthly GWL for each peatland type for each grid cell based on the soil moisture data by using the regression equation obtained in Figure 4 as follows:

Undrained Forest (UF): $y = -1.63 + 4.98 x$
Drained Forest (DF): $y = -1.97 + 4.85 x$
Drained Burnt Forest (DB): $y = -0.96 + 2.97 x$

The relationships between observed GWL and soil moisture data presented by ECMWF showed generally good positive correlations (r = 0.59-0.67). As a result, estimated GWL patterns were generally similar to observed GWLs (Figure 4).

1.5.2. Calculation of the lowest monthly average GWL in 2012 to annual NEE

Based on the relationship between the lowest monthly average GWL in 2012 and annual NEE presented in Hirano et al. (2012), linear regression lines were obtained for each peatland type 1) UF and DF, and 2) DB (Figure 5).

$y = -665.00 x - 68.74$ for UF and DF;
$y = -420.56 x + 397.46$ for DB;

Where:
y = Annual NEE (gC/m^2).
x = Lowest monthly average GWL (m) in the study year

Although the mean values of the lowest annual average GWL in UF and DF were largely different (the lowest annual average GWL in UF is larger than in DF), the slope and intercept were similar. Therefore, the data in both sites were merged in order to obtain an unified regression equation. The results of the regression on DB showed a slightly gentler slope and a much higher intercept relative to UF and DF.
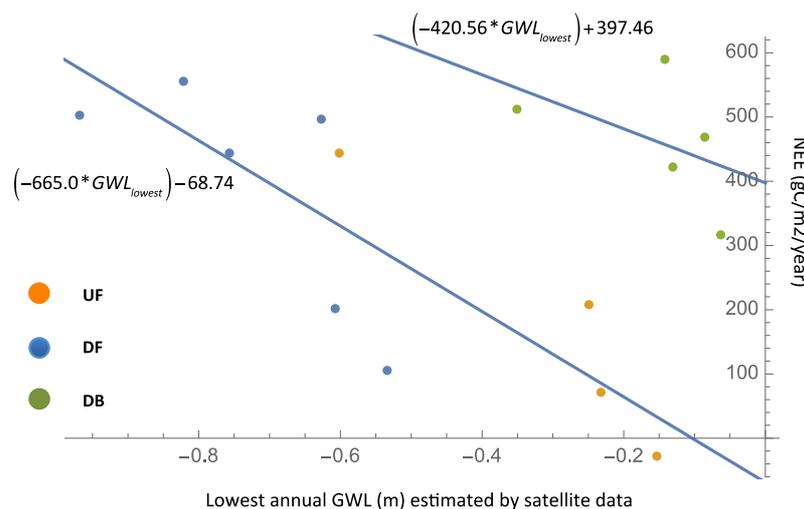
Figure 5: Relationships between the lowest monthly average GWL in 2012 estimated by satellite data and annual NEE observed in Hirano et al. (2012)

Assuming that these relationships are applicable to the other grid cells, the total NEE from peatlands in Central Kalimantan was calculated using the following formula:

$$T = \sum_{i=1}^{N} A_i \times \left[\alpha_i UF_i + \beta_i DF_i + \gamma_i DB_i \right]$$

Where:

T = total annual NEE
A_i = total peatland area in Cell i
α_i = the ratio of UF area in Cell i
β_i = the ratio of DF area in Cell i
γ_i = the ratio of DB area in Cell i
UF_i = NEE value of UF area in Cell i
DF_i = NEE value of DF area in Cell i
DB_i = NEE value of DB area in Cell i
N = the number of cells

The distribution of estimated annual NEE of tropical peatlands in Central Kalimantan was presented in Figure 6, which shows that the total annual NEE emitted from peatland area was 5.37 MtC/year (= 339 tC/km²/year).

Nearly half of the NEE was attributed to UF (47%) because the UF area was the largest area in the study site. The remaining NEE was bisected by DB (29%) and DF (24%).
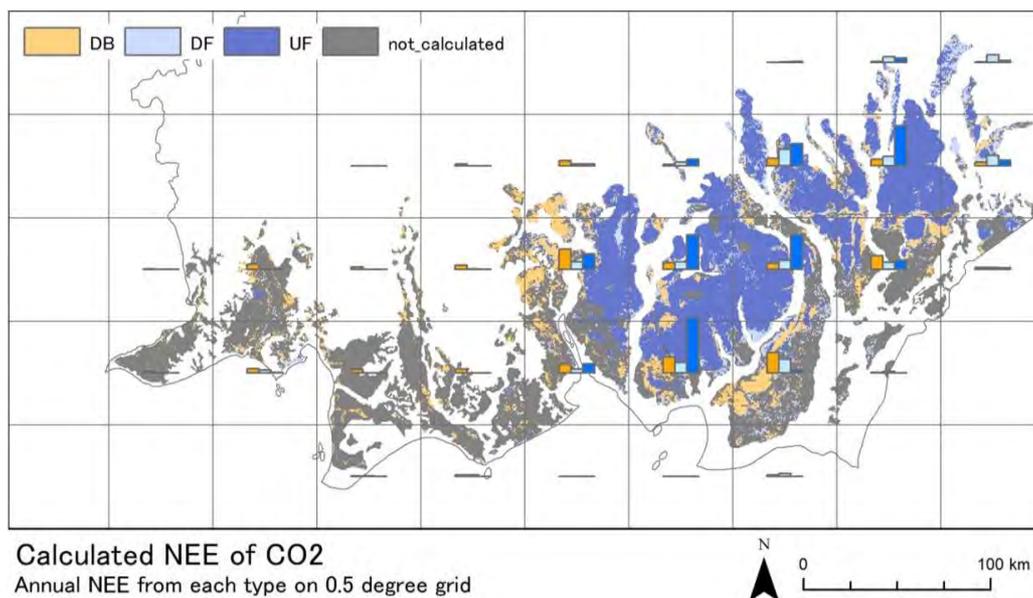
Figure 6: Distribution of annual NEE for each peatland type in each cell. Non-forest areas were excluded

In Figure 6, most of the grid cells in the western part and the ex-MRP showed the lowest NEE due to the exclusion of these areas. All grid cells showed CO_2 emission, and no grid cells showed CO_2 absorption. This means that the tropical peatland in Central Kalimantan in 2012 acted not as a CO_2 sink but as a CO_2 source in almost all the areas. The calculation must underestimate annual NEE, since the non-forest area was simply excluded. The non-forest area was equivalent to nearly two-thirds of the total area for the calculation, so excluding the non-forest area had a large influence on the results of the calculation.

Based on the discussion above, we consider the results in Figure 6 as the minimum value of the estimate, as we excluded non-forest area in this estimation. If we included non-forest area as DB, it

might overestimate the annual NEE, since the CO_2 emission from each unit area in DB was much larger than that in UF and DF (Figure 5).

The total NEE map in Central Kalimantan is shown in Figure 7 below.
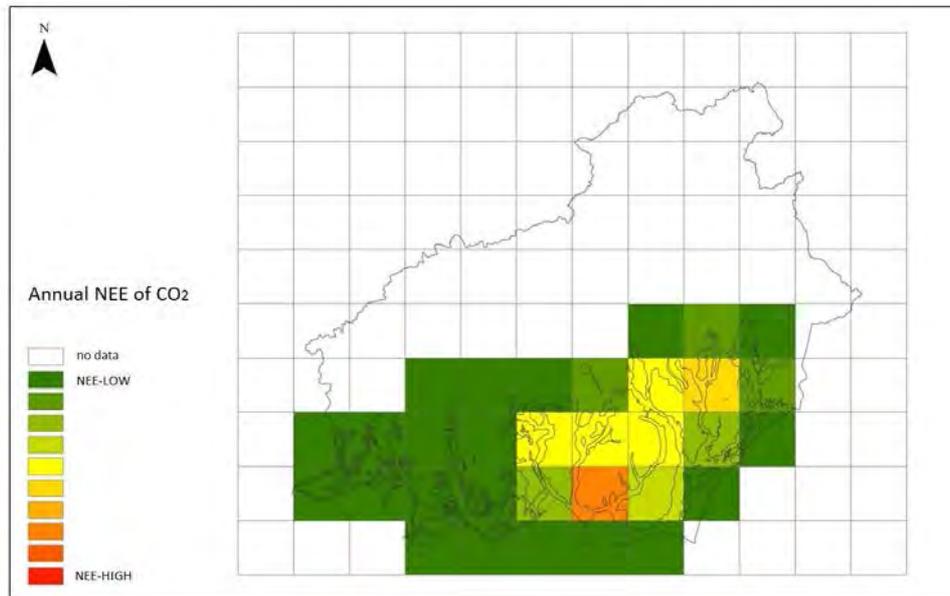
Figure 7: Distribution of annual NEE of 2012 in each cell. Non-forest area was excluded from the calculation

1.6. Future Consideration

In this Trial Calculation, there are several points that need to be done to improve the methodology in estimating carbon emissions from peat decomposition. Some important points to note are as follows.

- Related to the dry tendency, in this Trial Calculation we estimated them based on only two naming rules: "the [UF] point is low dry tendency" and "the [DF] point is high dry tendency". But the rules have no clear definition, no statistical threshold, and no numeric background data to divide them. The number of sampling points is too few to cover such a large area. It is very difficult to predict something stably in a large area with so little data. Therefore, after constructing the database on peatland measurement, these points (especially the parameters of the discriminate line) need to be increased.

- Related to non-forest peatland area, we identified dense forest peatland and non-forest peatland of 2000 based on the GFC dataset. The current non-forest peatland area contains peatland forest area burnt before 2000 and permanent swamp grass land. In this Trial Calculation, we treated the non-forest peatland as out of interest for our calculation. However, we should consider whether not-forest area is contained to [DB] or not when we estimate the carbon emissions in the future.

- Related to the GFC dataset, this dataset gives us the forest cover information on a global scale, and this is very useful for our operation. However, the current version of this data supports only from 2000 through 2013.

- In this Trial Calculation, we applied a cell size of 0.5x0.5 and a 12x10 grid with the total number of 32 cells that cover peatlands. If we change the cell size, e.g. 0.125x0.125, this will produce a larger number of cells with more accurate results.

II. Carbon Emission from Peat Burning

2.1. Background

In Indonesia, peat burning is a major source of GHG emissions, and contributed 28 percent of Indonesia's total GHG emissions in 2010 (DNPI, 2014). Peat fires typically occur during the dry season on almost an annual basis when precipitation is low. Peatland is highly susceptible to fire hazards when it becomes dry, and fires can burn peat layers for months at a time and spread below the surface very quickly. Furthermore, peat fires are likely to occur at an increased intensity and frequency when the *El Niño* phenomenon is in effect. Previous studies suggested a correlation between the groundwater level (GWL) and the vulnerability of peatland to fire hazards. When the GWL is high above the surface, peatland is inundated and there are no fire risks. However, 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), and peatland becomes vulnerable to fire hazards.

2.2. Objective

The objective of Part II of this report is to estimate carbon emission from peat burning in the Ex-MRP area in Central Kalimantan, in 2012.

2.3. Study Site and Methods

The study was conducted with about 1,457,100 ha of peatland in Ex-MRP area as a target. In this area, Putra and Hayasaka (2009) estimated annual peat carbon loss by peat fire from 1997 to 2007 based on satellite data (hotspot) analysis. In addition, Hayasaka et al. (2016) found linear relationships between Peat Fire Index (PFI), which was derived from a simple water balance equation, and annual lowest GWL as well as number of hotspots in Central Kalimantan.

Based on this knowledge and available data presented in the previous studies, we established a linear relationship between annual carbon emission from peat burning in Ex-MRP area and the lowest monthly average GWL estimated from satellite data. After that, carbon emission from peat burning in 2012 was estimated by extrapolating the regression equation to the year of 2012.

2.4. Results and Discussion

The relationship between the estimated lowest monthly average GWL and carbon emission from peat burning in 1997-2007 cited from Putra and Hayasaka (2009) is shown in Figure 8. Based on the data from 1997-2007, there were many changes in land surface type and drainage conditions in DF and DB, and therefore, we estimated the GWL in the UF type only to obtain a regression equation to estimate carbon emission from peat fire.

Observed lowest monthly average GWL (m) in the study year
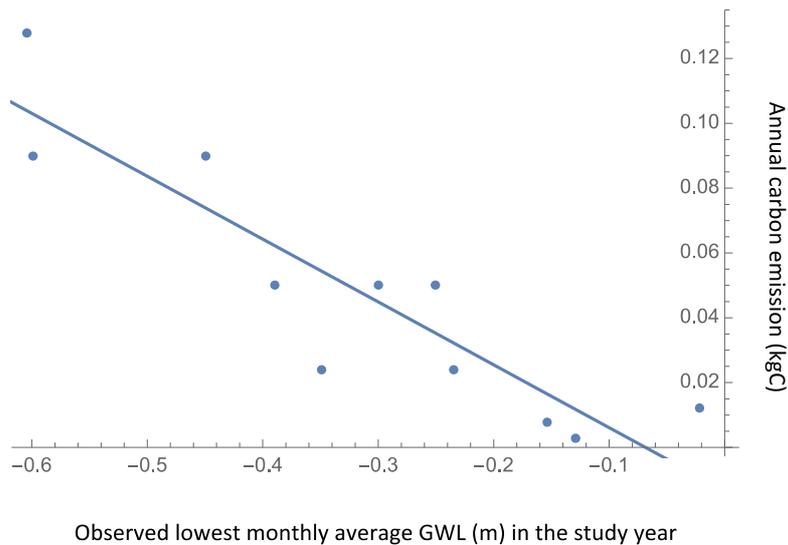
Figure 8: Relationship between the estimated lowest monthly average GWL (m) and carbon emissions from peat fire (GtC/year) at Ex- MRP area presented by Putra and Hayasaka (2009); (y=-0.194x - 0.0133 (n=11, r=0.90))

Based on the regression analysis (Figure 8), a regression equation was obtained as follows:

C (GtC/year) = -0.194 x Lowest monthly average GWL (m) – 0.0133

Where:
C = annual carbon emission from peat fire

The estimated lowest monthly average GWL in 2012 was –0.2856 m. Using this value and the regression equation above, the carbon emission from peat burning in 2012 in the Ex-MRP area was estimated as 0.0421 GtC.

Carbon emissions from peat and biomass burning estimated by previous studies which include the study area are summarized in Table 3. Page et al. (2002) estimated carbon emissions from peat burning during the severe 1997- 1998 fire in peatlands in the ex-MRP area as 0.12-0.15 GtC. Based on the LiDAR technique, Ballhorn et al. (2009) estimated carbon emissions from peat burning during the 2006 fire as 0.049 GtC. The estimated value in this study (0.0421 GtC) was within similar orders of magnitude to these previous estimations.

Table 3: Carbon emissions from peat and/or biomass burning from a part of southern Kalimantan areas estimated in previous studies

| | Page et al. (2002) | | van der Werf et al. (2008) | Ballhorn et al. (2009) | Putra et al. (2010) |
	Entire MRP	Study area[*1]	Southern Borneo[*2]	Study area[*1]	MRP
Year(s) of peat burning	1997-1998		2000-2006	2006	1997-2009
Total area (ha)	988,568	2,491,619	19×10^6	2.79×10^6	1,457,100
Peatland area (ha)	854,809	2,153,304	—	1,651,805	—
Percentage vs. total area	86.5%	86.4%	—	—	—
Burnt area (ha)	474,009	729,500	—	256,783	—
Percentage vs. total area	47.9%	29.3%	—	—	—
Percentage vs. peatland area	55.5%	33.9%	—	15.5%	—
Mean burnt peat depth (m)	0.51±0.05		—	0.33±0.18	0.51 (1997-2001)[*3]
					0.39 (2002-2009)[*4]
Carbon emission (GtC)	0.12-0.15	0.19-0.23	0.007-0.236	0.04915±0.02681	0.002-0.087
In 2006	—	—	0.236±0.106	↑	0.059

*1 The study area is defined by the coverage of a single image of Landsat TM. In this case the northern part of Block B in MRP is excluded.
*2 All the area of Kalimantan island south of 1°S.
*3 Cited from Page et al. (2002).
*4 Cited from Usup et al. (2004).

It is well known that the intensity of El Niño strongly affects rainfall pattern in the study area, and therefore affects fire occurrence and carbon emission from peat burning. Considering the time series of the intensity of El Niño, which was shown by the annual highest anomaly in sea surface temperature (SST) in NINO.3 area (Figure 9), in 1997-1998, in which most intensive El Niño in the 20th century was observed (> +3°C), estimated carbon emission was quite large (Page et al., 2002). In 2006, a small scale El Niño was observed (+1.1°C), and estimated carbon emission was relatively small (Ballhorn et al., 2009). In 2012, the target year of this study, the intensity of El Niño (+0.8°C) is slightly lower than that in 2006, while the estimated carbon emission was also slightly lower than that in 2006 estimated by Ballhorn et al. (2009). Judging from the relationship between the intensity of El Niño and carbon emission by peat burning from the study area, the estimated value of this study would be reasonable.
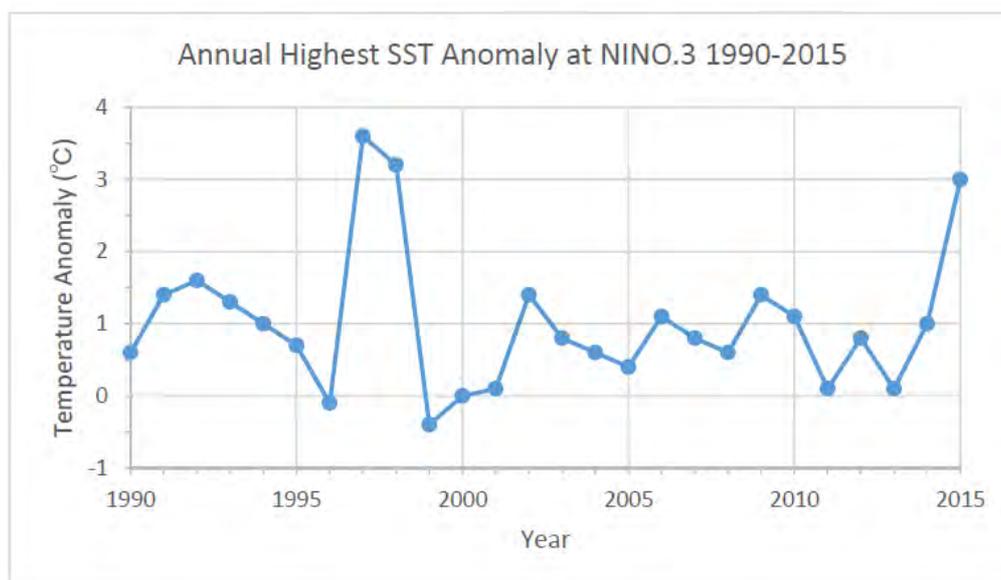
Figure 9: Time series of the intensity of El Niño 1990-2015. (Data source: Website of Japan Meteorological Agency, 02-02-2016; http://www.data.jma.go.jp/gmd/cpd/db/elnino/index/nino3idx.html)

Van der Werf et al. (2008) estimated carbon emission by total biomass burning from the southern part of Kalimantan. According to this estimate, carbon emission in 2006 was 0.236±0.106 GtC from that region. Carbon emission by peat burning from the ex-MRP area in the same year (Ballhorn et al.

2009) reached 20.8% of the total biomass burning emission from the Southern Kalimantan, although the peatland in the Ex-MRP area only covered 8.7% of the total area of the Southern Kalimantan region. These results quantitatively suggested that the peatland in the Ex-MRP area is an important hotspot of carbon emission by biomass (=including peat) burning.

2.5. Future Consideration

In this Trial Calculation, we estimated carbon emission from peat fire. However, we calculated it only in Ex-MRP area. In order to estimate carbon emissions from peat fires in Central Kalimantan, we need to get peat fire information from places other than the Ex-MRP area and conduct a field survey of burn scars outside of the ex-MRP area, especially burnt peat depth.

III. GWL Prediction Model

3.1. Background

The GWL can be used as an ecological indicator for peatland management. Early information about the condition of GWLs will help local authorities, land managers and local communities prevent the occurrence of ecological disturbances, prepare for possible peatland fires, and choose the most appropriate measures. Lowering GWL causes various ecological disturbances such as carbon emissions, damage to faunal and floral species, loss of ecosystem services, and devastating peatland fires. This is why it is crucial that the GWL is maintained at a sustainable level throughout the year.

This Trial Calculation presents how to predict daily GWLs for several days ahead by using 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 shown in this Trial Calculation takes a linear model based on the observed GWL values, which 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 to be constant.

3.2. Objective

To estimate the GWL for several days ahead based on the available observed GWL data from SESAME system using the Kalman Filter technique.

3.3. Study Site and Methods

The GWL prediction can be made from satellite data and the observed data. However, both sources of this data must be converted into daily GWL data. In this study, data observed by the SESAME system in the Special Purpose Forest Zone (*Kawasan Hutan Dengan Tujuan Khusus,* KHDTK) Tumbang Nusa and Sebangau National Park, Central Kalimantan (Figure 10) recorded from July to September 2015 were used.
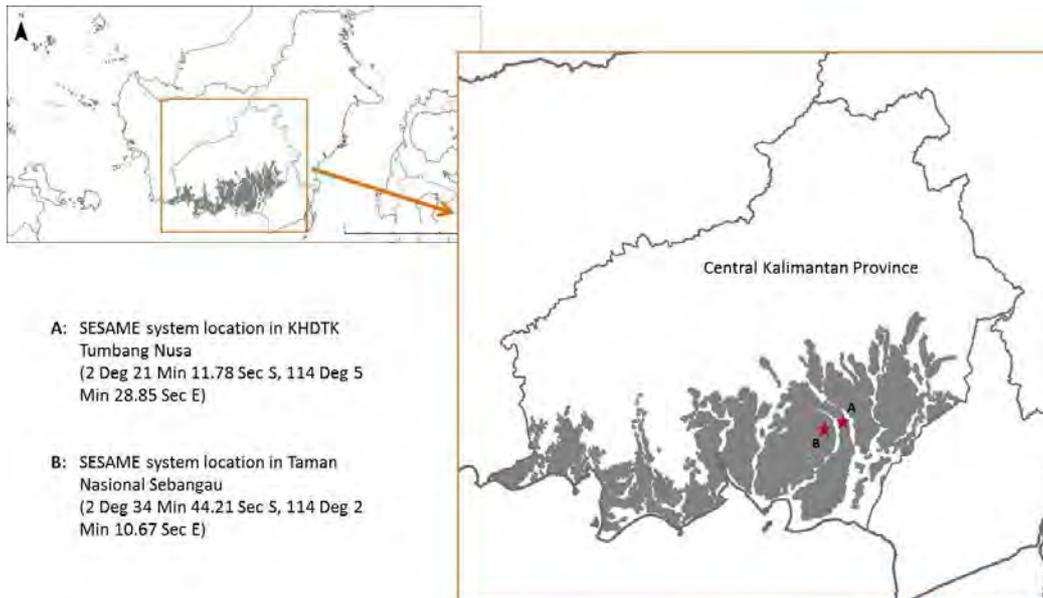
Figure 10: The location of SESAME system

The GWL prediction model uses observed GWL values as the main parameter. In this trial calculation, we used the Kalman Filter technique to predict GWL for several days ahead. The graphical representation of the model for GWL prediction is shown in Figure 11 as follows:
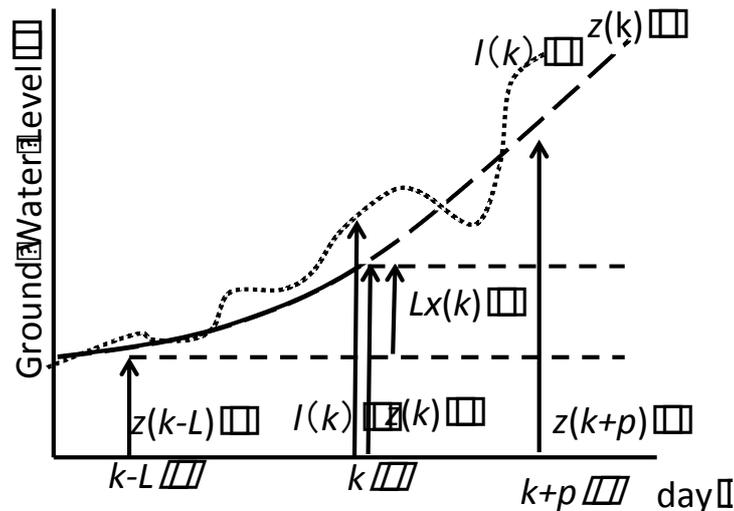
Figure 11: GWL delineation of the GWL prediction model based on Kalman Filter. The points of the curve state the GWL measurement data of SESAME system. The dotted line states the moving average

To make a GWL prediction for several days ahead using the Kalman Filter, we used the following equation:

$z(k+p|k) = z(k) + px(k|k)$

where $x(k|k)$ obtained from the Kalman Filter applied from the equations below:

$x(k+1)=x(k)+w(k)$ (1)
$y(k)=Lx(k)+v(k)$ (2)

where:
- $z(k)$ = moving average of the observed GWL data at day k
- k = current date − N

- p = the number of days ahead for the prediction of GWL;
  p indicates (p-N) days ahead prediction
- $l(k)$ = observed GWL from SESAME system data at day k
- $x(k)$ = a changing rate in GWL value per day (state variable)
- $w(k), v(k)$ = white Gaussian noise day-k;
- $y(k)$ = the observed data at day-k (observed state variable);
- N = the number of daily average GWL observation data. *(2N+1)* is range of moving average;
- L = time step width of the slope between the past and present data

Equation (1) and equation (2) are based on Kalman Filter containing an assumption that the slope is constant.

In applying the Kalman Filter technique, we used three important parameters: 1) number of days for moving average process (N); 2) information of number of days to be predicted (p); and 3) the slope (gradient) (L).

Data obtained from SESAME system is the GWL data with the interval of ten minutes, which then needs to be converted into daily GWL data. The data obtained has the length of three months, from July to September 2015.

In this Trial Calculation, the following five cases were calculated:
(1) GWL prediction using SESAME system data in Sebangau National Park with N=1, L=3, and p=3;
(2) GWL prediction using SESAME system data in Sebangau National Park with N=1, L=3, and p=8;
(3) GWL prediction using SESAME system data in Sebangau National Park with N=1, L=3, and p=12;
(4) GWL prediction using SESAME system data in KHDTK Tumbang Nusa with N=1, L=3, and p=3;
(5) GWL prediction using SESAME system data in KHDTK Tumbang Nusa with N=1, L=3, and p=8.

In this study, the 20 observed GWL data were used to calculate initial value of variance and state variable. For case (1), we predicted the GWL with N=1, L=3, and p=3. With N=1, we calculated moving average $2N+1=3$ days. As we started the calculation with 20 days of data, we obtained $20-2N=18$ days moving average. Based on this data, we determined $x(k)$ and variance. This result was used to predict two days ahead GWL (p=3), with the slope length at three days (L=3). This step was repeated to calculate the GWL prediction for cases (2), (3), (4), and (5).

3.4.   Results and Discussion

The detailed calculation results (Excel sheet) for case (1) until case (5) are presented in the Annexes. The results of GWL prediction in Sebangau National Park are presented in Figure 12, Figure 13, and Figure 14, while the calculation results are presented in Annex 1, Annex 2, and Annex 3, respectively. Based on the calculation results, the GWL prediction for p=3 has better accuracy than p=8, and the GWL prediction for p=8 has better accuracy than p=12. The shorter the predicted days, the more closely correlated a result was obtained.
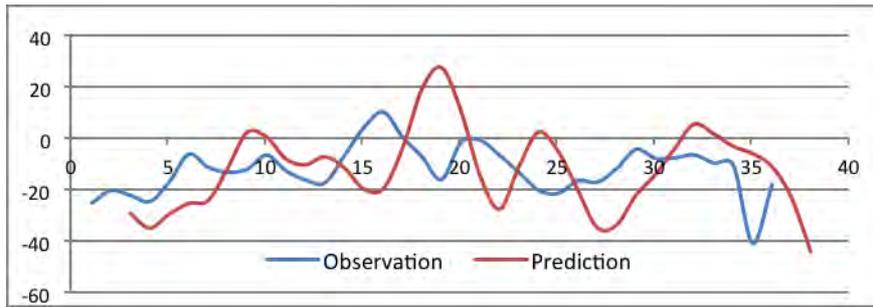
Figure 12. The results of 2 days ahead (_p_=3) estimation of GWL using observed SESAME system data of July to September 2015 in Sebangau National Park using Kalman Filter technique
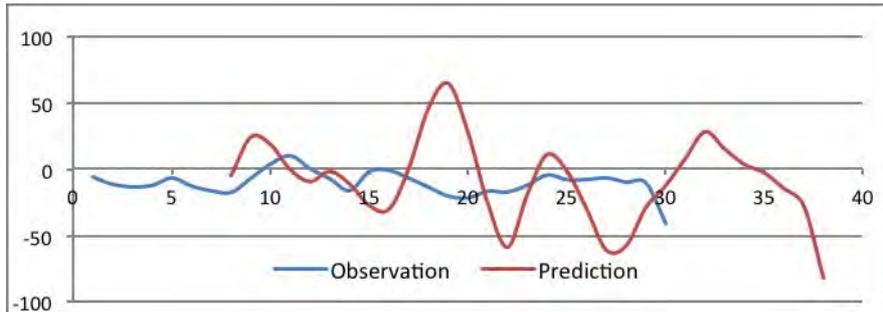
Figure 13. The results of 7 days ahead (_p_=8) estimation of GWL using observed SESAME system data of July to September 2015 in Sebangau National Park using Kalman Filter technique
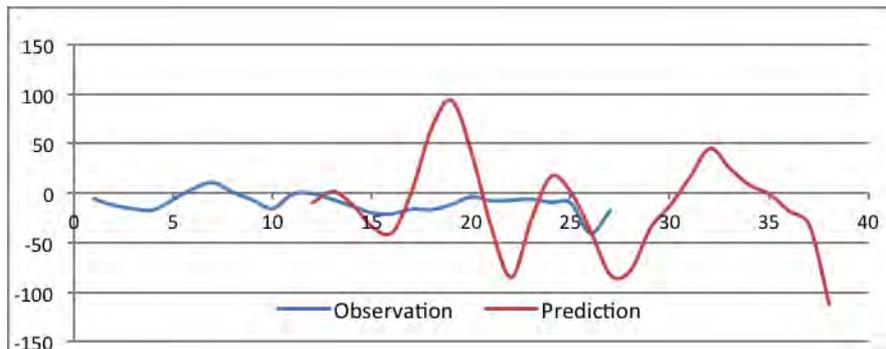
Figure 14. The results of 11 days ahead (_p_=12) estimation of GWL using observed SESAME system data of July to September 2015 in Sebangau National Park using Kalman Filter technique

The GWL prediction in KHDTK Tumbang Nusa is presented in Figure 15 and Figure 16, while the detailed calculation results are presented in Annex 4 and Annex 5. Similar to the calculation results in Sebangau National Park, the GWL prediction in KHDTK Tumbang Nusa for _p_=3 has better accuracy than _p_=8.
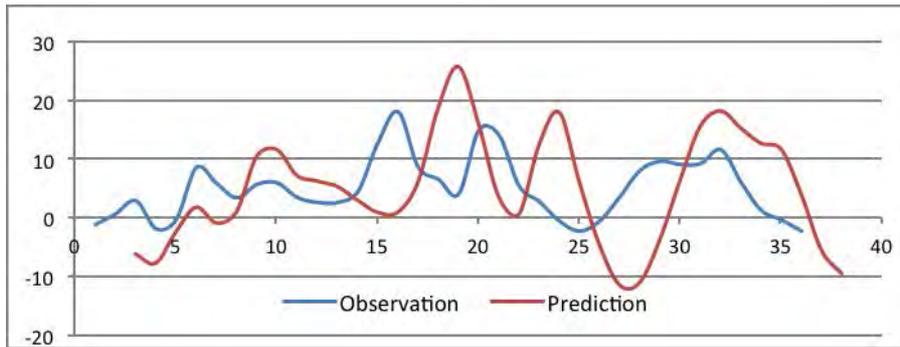
Figure 15. The results 2 days ahead (*p*=3) estimation of GWL using observed SESAME system data of July to September 2015 in KHDTK Tumbang Nusa using Kalman Filter technique
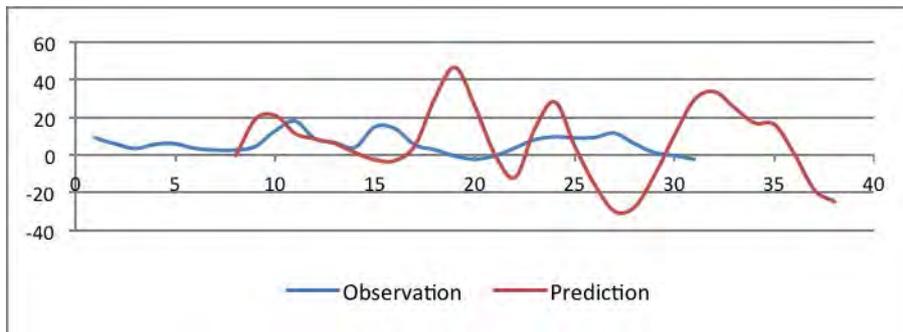
Figure 16. The results of 7 days ahead (*p*=8) estimation of GWL using observed SESAME system data of July to September 2015 in KHDTK Tumbang Nusa using Kalman Filter technique

The prediction of next four days GWL is more accurate than the prediction for longer days. These prediction results have similar patterns for both Sebangau National Park and KHDTK Tumbang Nusa.

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Annex 1: Calculation result of GWL prediction using SESAME system data in Sebangau National Park with N=1, L=3, and p=3 (the green highlight indicates the prediction result value)

Day	GWT (m)	N=1 z[k]	L=3 x[k]	w(k) x(k)-x(k-1)	v(k) l(k)-z(k)	l(k)-z(k-L) y[k]	K(k)	x(k/k)	x(k+1/k)	C(k/k)	C(k+1/k)	W(k)	V(k)	p=3 z(k+p/k)	GWT[cm]	
1	-10.7391															
2	-4.1	-19.7277				15.62769										
3	-44.3439	-20.613				-23.7309										
4	-13.3951	-24.5806				11.18548										
5	-16.0028	-15.1498	-1.52597		-0.85301	3.724912										
6	-16.0514	-17.5079	-1.03505	0.490922	1.456481	4.561637										
7	-20.4694	-20.0278	-1.51761	-0.48256	-0.44167	4.111174										
8	-23.5625	-21.8528	2.234336	3.75195	-1.70972	-8.41273										
9	-21.5264	-22.2498	1.580633	-0.6537	0.72338	-4.01852										
10	-21.6604	-20.1942	0.055478	-1.52515	-1.4662	-1.63264										
11	-17.3958	-20.3009	-0.51728	-0.57276	2.905093	4.456944										
12	-21.8465	-17.665	-1.52824	-1.01096	-4.18148	0.403241										
13	-13.7528	-15.9813	-1.40432	0.12392	2.228472	6.441435										
14	-12.3444	-15.4257	-1.62508	-0.22076	3.08125	7.956481										
15	-20.1799	-15.7861	-0.62631	0.998765	-4.39375	-2.51481										
16	-14.834	-15.9525	-0.00957	0.616744	1.118519	1.147222										
17	-12.8438	-11.9553	-1.15679	-1.14722	-0.88843	2.581944										
18	-8.18819	-8.43032	-2.45193	-1.29514	0.24213	7.597917										
19	-4.25903	-7.58403	-2.78951	-0.33758	3.325	11.69352			-2.78951		1000	1.776148758	59.58747			
20	-10.3049	-10.1442	-0.6037	2.185802	-0.16065	1.650463	0.3317	0.533596	0.533596	4.958023	6.214985	1.256961824	44.84455	-8.54342	-24.8125	1
21	-15.8688	-14.6972	2.088966	2.69267	-1.17153	-7.43843	0.2751	-1.95311	-1.95311	1.085716	2.8409	1.755183417	11.83978	-20.5566	-19.7319	2
22	-17.9181	-19.5331	3.983025	1.894059	1.615046	-10.334	0.2786	-3.1998	-3.1998	0.466409	2.401008	1.934598962	5.022215	-29.1325	-21.6125	3
23	-24.8125	-20.8208	3.558873	-0.42415	-3.99167	-14.6683	0.2617	-4.52638	-4.52638	0.515901	2.315142	1.799240998	5.913792	-34.4	-23.9444	4
24	-19.7319	-22.0523	2.451698	-1.10718	2.32037	-5.03472	0.2577	-2.32429	-2.32429	0.525148	2.545526	2.020378805	6.112935	-29.0252	-16.2951	5
25	-21.6125	-21.763	0.743287	-1.70841	0.150463	-2.0794	0.2632	-1.03634	-1.03634	0.535599	2.927151	2.39155148	6.10492	-24.872	-5.65556	6
26	-23.9444	-20.6174	-0.06782	-0.81111	-3.32708	-3.12361	0.2668	-1.04023	-1.04023	0.584491	2.990236	2.405745096	6.572886	-23.7381	-10.6792	7
27	-16.2951	-15.2984	-2.25131	-2.18349	-0.99676	5.757176	0.2679	1.338386	1.338386	0.586745	3.388365	2.801619572	6.569842	-11.2832	-12.6181	8
28	-5.65556	-10.8766	-3.62878	-1.37747	5.221065	16.10741	0.2637	4.526695	4.526695	0.70818	3.558063	2.84988324	8.057708	2.703465	-11.4181	9
29	-10.6792	-9.65093	-3.65548	-0.0267	-1.02824	9.938194	0.2690	3.54688	3.54688	0.686276	3.410876	2.724599743	7.65249	0.989713	-5.98333	10
30	-12.6181	-11.5718	-1.24221	2.413272	-1.0463	2.680324	0.2738	1.367267	1.367267	0.609081	3.896077	3.286995491	6.673404	-7.46996	-12.0417	11
31	-11.4181	-10.0065	-0.29005	0.95216	-1.41157	-0.54144	0.2811	0.061872	0.061872	0.610059	3.530812	2.920753702	6.509859	-9.82087	-15.6254	12
32	-5.98333	-9.81435	0.054475	0.344522	3.831019	3.667593	0.2744	1.01746	1.01746	0.62384	2.794682	2.170841889	6.819458	-6.76197	-16.6896	13
33	-12.0417	-11.2168	-0.11832	-0.1728	-0.82488	-0.46991	0.2718	0.06016	0.06016	0.516035	2.215827	1.69979196	5.696087	-11.0363	-6.12681	14
34	-15.6254	-14.7855	1.593019	1.711343	-0.83982	-5.61888	0.2593	-1.44386	-1.44386	0.491848	2.584305	2.092457021	5.689547	-19.1171	4.684722	15
35	-16.6896	-12.8139	0.999856	-0.59316	-3.87566	-6.87523	0.2604	-2.10616	-2.10616	0.565653	2.586681	2.02102776	6.51741	-19.1324	10.78403	16
36	-6.12681	-6.04389	-1.7243	-2.72415	-0.08292	5.089976	0.2605	0.86565	0.86565	0.565253	3.000324	2.4350708	6.509837	-3.44694	0.996528	17
37	4.684722	3.113979	-5.96651	-4.24221	1.570743	19.47026	0.2730	5.47198	5.47198	0.543103	4.451057	3.907953757	5.968277	19.52992	-6.66319	18
38	10.78403	5.488426	-6.10078	-0.13428	5.295602	23.59795	0.2798	7.481548	7.481548	0.71476	4.329355	3.614595159	7.663453	27.93307	-15.3681	19
39	0.996528	1.705787	-2.58323	3.517556	-0.70926	7.040419	0.2789	3.185555	3.185555	0.70719	5.494138	4.786947693	7.607358	11.26245	-1.05208	20
40	-6.66319	-7.01157	3.375185	5.95841	0.34838	-9.77717	0.2896	-2.41312	-2.41312	0.721177	8.618892	7.897714379	7.471303	-14.2509	-0.29375	21
41	-15.3681	-7.69444	4.39429	1.019106	-7.67361	-20.8565	0.2954	-6.4353	-6.4353	0.981442	8.561172	7.579730597	9.968046	-27.0003	-6.11806	22
42	-1.05208	-5.5713	2.425694	-1.9686	4.519213	-2.75787	0.2921	-1.60187	-1.60187	1.059406	9.157784	8.098377892	10.88115	-10.3769	-12.9146	23
43	-0.29375	-2.48796	-1.50787	-3.93356	2.194213	6.717824	0.2936	1.781154	1.781154	1.092219	10.77088	9.678569082	11.16112	2.855498	-19.6391	24
44	-6.11806	-6.44213	-0.41744	1.090432	0.324074	1.576389	0.3009	0.6476	0.6476	1.047653	10.86361	9.8159542	10.44481	-4.49933	-20.8333	25
45	-12.9146	-12.8906	2.439764	2.857203	-0.02399	-7.34329	0.3014	-2.15139	-2.15139	1.040161	11.3739	10.33374099	10.35269	-19.3448	-15.921	26
46	-19.6391	-17.7957	5.102573	2.662809	-1.84345	-17.1512	0.3062	-5.42733	-5.42733	0.924181	11.78529	10.86110892	9.053249	-34.0777	-16.4287	27
47	-20.8333	-18.7978	4.118565	-0.98401	-2.03551	-14.3912	0.3067	-4.84749	-4.84749	0.942803	11.0013	10.0584999	9.22306	-33.3403	-11.3036	28
48	-15.921	-17.7277	1.612361	-2.5062	1.806659	-3.03042	0.3045	-1.34179	-1.34179	0.950793	9.625947	8.675154486	9.36665	-21.753	-3.70833	29
49	-16.4287	-14.5511	-1.08153	-2.69389	-1.87758	1.367011	0.3005	0.278755	0.278755	0.947438	10.63964	9.692204481	9.457836	-13.7148	-7.22292	30
50	-11.3036	-10.4802	-2.77254	-1.69101	-0.8234	7.494229	0.3060	2.315832	2.315832	0.873695	9.843232	8.969537483	8.566725	-3.5327	-7.00694	31
51	-3.70833	-7.41162	-3.43869	-0.66614	3.703282	14.01934	0.3014	4.446957	4.446957	0.944353	5.986245	5.041892263	9.401113	5.929256	-5.91111	32
52	-7.22292	-5.9794	-2.85723	0.581454	-1.24352	7.328178	0.2836	2.741812	2.741812	0.893311	5.809193	4.915882159	9.449992	2.246037	-9.03958	33
53	-7.00694	-6.71366	-1.25551	1.601718	-0.29329	3.473256	0.2865	1.380156	1.380156	0.815619	5.955362	5.139743169	8.539529	-2.57319	-9.77113	34
54	-5.91111	-7.31921	-0.0308	1.224713	1.408102	1.500505	0.2872	0.622058	0.622058	0.824896	4.670698	3.84580194	8.61774	-5.45304	-40.0676	35
55	-9.03958	-8.24061	0.753737	0.784538	-0.79897	-3.06019	0.2769	-0.74214	-0.74214	0.790489	4.586302	3.795812101	8.563776	-10.467	-17.4069	36
56	-9.77113	-19.6261	4.30415	3.550413	9.854974	-3.05748	0.2559	-0.9548	-0.9548	1.065456	5.28635	4.22086473	12.49135	-22.4905		37
57	-40.0676	-22.4152	5.032005	0.727855	-17.6524	-32.7484	0.2028	-7.01627	-7.01627	2.069607	5.665948	3.59634115	30.61046	-43.464		38
58	-17.4069															39

Annex 2: Calculation result of GWL prediction using SESAME system data in Sebangau National Park with N=1, L=3, and p=8

Day	GWT (m)	N=1 z[k]	L=3 x[k]	w(k) x(k)-x(k-1)	v(k) l(k)-z(k)	l(k)-z(k-L) y[k]	K(k)	x(k/k)	x(k+1/k)	C(k/k)	C(k+1/k)	W(k)	V(k)	p=8 z(k+p/k)	GWT[cm]	
1	-10.7391															
2	-4.1	-19.7277			15.62769											
3	-44.3439	-20.613			-23.7309											
4	-13.3951	-24.5806			11.18548											
5	-16.0028	-15.1498	1.525974		-0.85301	3.724912										
6	-16.0514	-17.5079	1.035052	-0.49092	1.456481	4.561637										
7	-20.4694	-20.0278	1.517614	0.482562	-0.44167	4.111174										
8	-23.5625	-21.8528	-2.23434	-3.75195	-1.70972	-8.41273										
9	-21.5264	-22.2498	-1.58063	0.653704	0.72338	-4.01852										
10	-21.6604	-20.1942	-0.05548	1.525154	-1.4662	-1.63264										
11	-17.3958	-20.3009	0.517284	0.572762	2.905093	4.456944										
12	-21.8465	-17.665	1.528241	1.010957	-4.18148	0.403241										
13	-13.7528	-15.9813	1.404321	-0.12392	2.228472	6.441435										
14	-12.3444	-15.4257	1.625077	0.220756	3.08125	7.956481										
15	-20.1799	-15.7861	0.626312	-0.99877	-4.39375	-2.51481										
16	-14.834	-15.9525	0.009568	-0.61674	1.118519	1.147222										
17	-12.8438	-11.9553	1.15679	1.147222	-0.88843	2.581944										
18	-8.18819	-8.43032	2.451929	1.295139	0.24213	7.597917										
19	-4.25903	-7.58403	2.789506	0.337577	3.325	11.69352			2.789506		1000	1.776148758	59.58747			
20	-10.3049	-10.1442	0.603704	-2.1858	-0.16065	1.650463	0.3317	0.561257	0.561257	4.958023	7.090901	2.132877584	44.84455	-5.65416	-5.65556	1
21	-15.8688	-14.6972	-2.08897	-2.69267	-1.17153	-7.43843	0.2812	-2.00363	-2.00363	1.109662	3.711908	2.602246311	11.83978	-30.7262	-10.6792	2
22	-17.9181	-19.5331	-3.98302	-1.89406	1.615046	-10.334	0.2898	-3.25635	-3.25635	0.485098	2.335114	1.850016153	5.022215	-45.5839	-12.6181	3
23	-24.8125	-20.8208	-3.55887	0.424151	-3.99167	-14.6683	0.2601	-4.5308	-4.5308	0.512791	2.339074	1.826282827	5.913792	-57.0673	-11.4181	4
24	-19.7319	-22.0523	-2.4517	1.107176	2.32037	-5.03472	0.2583	-2.32016	-2.32016	0.526369	2.257971	1.731601342	6.112935	-40.6136	-5.98333	5
25	-21.6125	-21.763	-0.74329	1.70841	0.150463	-2.0794	0.2563	-1.069	-1.069	0.521622	2.475319	1.953696743	6.10492	-30.315	-12.0417	6
26	-23.9444	-20.6174	0.067824	0.811111	-3.32708	-3.12361	0.2574	-1.04754	-1.04754	0.563936	2.486635	1.922698769	6.572886	-28.9976	-15.6254	7
27	-16.2951	-15.2984	2.251312	2.183488	-0.99676	5.757176	0.2577	1.245817	1.245817	0.564319	2.860354	2.296034455	6.569842	-5.33185	-16.6896	8
28	-5.65556	-10.8766	3.628781	1.377469	5.221065	16.10741	0.2539	4.386188	4.386188	0.681872	3.101996	2.420123443	8.057708	24.21289	-6.12681	9
29	-10.6792	-9.65093	3.655478	0.026698	-1.02824	9.938194	0.2616	3.543671	3.543671	0.667351	2.982439	2.315087745	7.65249	18.69844	4.684722	10
30	-12.6181	-11.5718	1.242207	-2.41327	-1.0463	2.680324	0.2670	1.421141	1.421141	0.593848	3.369735	2.775887462	6.673404	-0.20263	10.78403	11
31	-11.4181	-10.0065	0.290046	-0.95216	-1.41157	-0.54144	0.2744	0.102557	0.102557	0.595494	3.344102	2.748607378	6.509859	-9.18602	0.996528	12
32	-5.98333	-9.81435	-0.05448	-0.34452	3.831019	3.667593	0.2718	1.015641	1.015641	0.617747	3.216066	2.598319069	6.819458	-1.68922	-6.66319	13
33	-12.0417	-11.2168	0.118324	0.172799	-0.82488	-0.46991	0.2785	0.036126	0.036126	0.528829	3.115991	2.587162286	5.696087	-10.9278	-15.3681	14
34	-15.6254	-14.7855	-1.59302	-1.71134	-0.83982	-5.61888	0.2771	-1.55097	-1.55097	0.525549	2.983167	2.457618769	5.689547	-27.1933	-1.05208	15
35	-16.6896	-12.8139	-0.99986	0.593163	-3.87566	-6.87523	0.2682	-2.14705	-2.14705	0.582706	2.529658	1.946951921	6.51741	-29.9903	-0.29375	16
36	-6.12681	-6.04389	1.724299	2.724155	-0.08292	5.089976	0.2592	0.841991	0.841991	0.562482	2.631865	2.069383022	6.509837	0.692037	-6.11806	17
37	4.684722	3.113979	5.966506	4.242207	1.570743	19.47026	0.2662	5.35337	5.35337	0.52968	3.65	3.120319801	5.968277	45.94094	-12.9146	18
38	10.78403	5.488426	6.100782	0.134276	5.295602	23.59795	0.2703	7.390701	7.390701	0.690428	3.814476	3.124048524	7.663453	64.61403	-19.6391	19
39	0.996528	1.705787	2.583226	-3.51756	-0.70926	7.040419	0.2729	3.261753	3.261753	0.691934	4.884349	4.192414756	7.607358	27.79981	-20.8333	20
40	-6.66319	-7.01157	-3.37518	-5.95841	0.34838	-9.77717	0.2849	-2.31178	-2.31178	0.70955	7.577997	6.868447405	7.471303	-25.5058	-15.921	21
41	-15.3681	-7.69444	-4.39429	-1.01911	-7.67361	-20.8565	0.2908	-6.36043	-6.36043	0.966327	7.370399	6.404072102	9.968046	-58.5779	-16.4287	22
42	-1.05208	-5.5713	-2.42569	1.968596	4.519213	-2.75787	0.2864	-1.68606	-1.68606	1.038641	7.636112	6.597471118	10.88115	-19.0598	-11.3036	23
43	-0.29375	-2.48796	1.50787	3.933565	2.194213	6.717824	0.2868	1.690855	1.690855	1.066863	9.030574	7.963710252	11.16112	11.03888	-3.70833	24
44	-6.11806	-6.44213	0.417438	-1.09043	0.324074	1.576389	0.2954	0.658174	0.658174	1.028376	8.657165	7.628788547	10.44481	-1.17673	-7.22292	25
45	-12.9146	-12.8906	-2.43976	-2.8572	-0.02399	-7.34329	0.2942	-2.08347	-2.08347	1.015383	9.165195	8.149812441	10.35269	-29.5584	-7.00694	26
46	-19.6391	-17.7957	-5.10257	-2.66281	-1.84345	-17.1512	0.3004	-5.3577	-5.3577	0.906432	9.493467	8.587035196	9.053249	-60.6573	-5.91111	27
47	-20.8333	-18.7978	-4.11857	0.984008	-2.03551	-14.3912	0.3009	-4.85169	-4.85169	0.924941	9.625546	8.700605637	9.22306	-57.6113	-9.03958	28
48	-15.921	-17.7277	-1.61236	2.506204	1.806659	-3.03042	0.3008	-1.38497	-1.38497	0.939191	9.996302	9.057111108	9.36665	-28.8074	-9.77113	29
49	-16.4287	-14.5511	1.081529	2.69389	-1.87758	1.367011	0.3016	0.280578	0.280578	0.950906	10.51539	9.564479564	9.457836	-12.3065	-40.0676	30
50	-11.3036	-10.4802	2.772542	1.691012	-0.8234	7.494229	0.3057	2.314009	2.314009	0.872848	10.10421	9.231360994	8.566725	8.031872	-17.4069	31
51	-3.70833	-7.41162	3.438686	0.666144	3.703282	14.01934	0.3021	4.45208	4.45208	0.946699	8.79879	7.852091492	9.401113	28.20503		32
52	-7.22292	-5.9794	2.857232	-0.58145	-1.24352	7.328178	0.2978	2.656947	2.656947	0.938057	8.792072	7.854014989	9.449992	15.27618		33
53	-7.00694	-6.71366	1.255514	-1.60172	-0.29329	3.473256	0.3009	1.303785	1.303785	0.856413	8.004109	7.147696396	8.539529	3.716621		34
54	-5.91111	-7.31921	0.030801	-1.22471	1.408102	1.500505	0.2977	0.586032	0.586032	0.855217	5.333265	4.47804709	8.61774	-2.63095		35
55	-9.03958	-8.24061	-0.75374	-0.78454	-0.79897	-3.06019	0.2829	-0.7769	-0.7769	0.807467	5.243888	4.436420947	8.563776	-14.4558		36
56	-9.77113	-19.6261	-4.30415	-3.55041	9.854974	-3.05748	0.2636	-0.96846	-0.96846	1.097458	6.258856	5.161398513	12.49135	-27.3738		37
57	-40.0676	-22.4152	-5.03201	-0.72785	-17.6524	-32.7484	0.2160	-7.41369	-7.41369	2.203659	5.999972	3.79631277	30.61046	-81.7247		38
58	-17.4069													0		39

Annex 3: Calculation result of GWL prediction using SESAME system data in Sebangau National Park with N=1, L=3, and p=12

Day	GWT (m)	N=1 z[k]	L=3 x[k]	w(k) x(k)-x(k-1)	v(k) l(k)-z(k)	l(k)-z(k-L) y[k]	K(k)	x(k/k)	x(k+1/k)	C(k/k)	C(k+1/k)	W(k)	V(k)	p=12 z(k+p/k)	GWT[cm]	
1	-10.7391															
2	-4.1	-19.7277			15.62769											
3	-44.3439	-20.613			-23.7309											
4	-13.3951	-24.5806			11.18548											
5	-16.0028	-15.1498	1.525974		-0.85301	3.724912										
6	-16.0514	-17.5079	1.035052	-0.49092	1.456481	4.561637										
7	-20.4694	-20.0278	1.517614	0.482562	-0.44167	4.111174										
8	-23.5625	-21.8528	-2.23434	-3.75195	-1.70972	-8.41273										
9	-21.5264	-22.2498	-1.58063	0.653704	0.72338	-4.01852										
10	-21.6604	-20.1942	-0.05548	1.525154	-1.4662	-1.63264										
11	-17.3958	-20.3009	0.517284	0.572762	2.905093	4.456944										
12	-21.8465	-17.665	1.528241	1.010957	-4.18148	0.403241										
13	-13.7528	-15.9813	1.404321	-0.12392	2.228472	6.441435										
14	-12.3444	-15.4257	1.625077	0.220756	3.08125	7.956481										
15	-20.1799	-15.7861	0.626312	-0.99877	-4.39375	-2.51481										
16	-14.834	-15.9525	0.009568	-0.61674	1.118519	1.147222										
17	-12.8438	-11.9553	1.15679	1.147222	-0.88843	2.581944										
18	-8.18819	-8.43032	2.451929	1.295139	0.24213	7.597917										
19	-4.25903	-7.58403	2.789506	0.337577	3.325	11.69352			2.789506		1000	1.776148758	59.58747			
20	-10.3049	-10.1442	0.603704	-2.1858	-0.16065	1.650463	0.3317	0.561257	0.561257	4.958023	7.090901	2.132877584	44.84455	-3.40913	-5.98333	1
21	-15.8688	-14.6972	-2.08897	-2.69267	-1.17153	-7.43843	0.2812	-2.00363	-2.00363	1.109662	3.711908	2.602246311	11.83978	-38.7408	-12.0417	2
22	-17.9181	-19.5331	-3.98302	-1.89406	1.615046	-10.334	0.2898	-3.25635	-3.25635	0.485098	2.335114	1.850016153	5.022215	-58.6093	-15.6254	3
23	-24.8125	-20.8208	-3.55887	0.424151	-3.99167	-14.6683	0.2601	-4.5308	-4.5308	0.512791	2.339074	1.826282827	5.913792	-75.1905	-16.6896	4
24	-19.7319	-22.0523	-2.4517	1.107176	2.32037	-5.03472	0.2583	-2.32016	-2.32016	0.526369	2.257971	1.731601342	6.112935	-49.8943	-6.12681	5
25	-21.6125	-21.763	-0.74329	1.70841	0.150463	-2.0794	0.2563	-1.069	-1.069	0.521622	2.475319	1.953696743	6.10492	-34.5909	4.684722	6
26	-23.9444	-20.6174	0.067824	0.811111	-3.32708	-3.12361	0.2574	-1.04754	-1.04754	0.563936	2.486635	1.922698769	6.572886	-33.1878	10.78403	7
27	-16.2951	-15.2984	2.251312	2.183488	-0.99676	5.757176	0.2577	1.245817	1.245817	0.564319	2.860354	2.296034455	6.569842	-0.34858	0.996528	8
28	-5.65556	-10.8766	3.628781	1.377469	5.221065	16.10741	0.2539	4.386188	4.386188	0.681872	3.101996	2.420123443	8.057708	41.75764	-6.66319	9
29	-10.6792	-9.65093	3.655478	0.026698	-1.02824	9.938194	0.2616	3.543671	3.543671	0.667351	2.982439	2.315087745	7.65249	32.87312	-15.3681	10
30	-12.6181	-11.5718	1.242207	-2.41327	-1.0463	2.680324	0.2670	1.421141	1.421141	0.593848	3.369735	2.775887462	6.673404	5.481937	-1.05208	11
31	-11.4181	-10.0065	0.290046	-0.95216	-1.41157	-0.54144	0.2744	0.102557	0.102557	0.595494	3.344102	2.748607378	6.509859	-8.77579	-0.29375	12
32	-5.98333	-9.81435	-0.05448	-0.34452	3.831019	3.667593	0.2718	1.015641	1.015641	0.617747	3.216066	2.598319069	6.819458	2.373343	-6.11806	13
33	-12.0417	-11.2168	0.118324	0.172799	-0.82488	-0.46991	0.2785	0.036126	0.036126	0.528829	3.115991	2.587162286	5.696087	-10.7833	-12.9146	14
34	-15.6254	-14.7855	-1.59302	-1.71134	-0.83982	-5.61888	0.2771	-1.55097	-1.55097	0.525549	2.983167	2.457618769	5.689547	-33.3972	-19.6391	15
35	-16.6896	-12.8139	-0.99986	0.593163	-3.87566	-6.87523	0.2682	-2.14705	-2.14705	0.582706	2.529658	1.946951921	6.51741	-38.5785	-20.8333	16
36	-6.12681	-6.04389	1.724299	2.724155	-0.08292	5.089976	0.2592	0.841991	0.841991	0.562482	2.631865	2.069383022	6.509837	4.06	-15.921	17
37	4.684722	3.113979	5.966506	4.242207	1.570743	19.47026	0.2662	5.35337	5.35337	0.52968	3.65	3.120319801	5.968277	67.35442	-16.4287	18
38	10.78403	5.488426	6.100782	0.134276	5.295602	23.59795	0.2703	7.390701	7.390701	0.690428	3.814476	3.124048524	7.663453	94.17684	-11.3036	19
39	0.996528	1.705787	2.583226	-3.51756	-0.70926	7.040419	0.2729	3.261753	3.261753	0.691934	4.884349	4.192414756	7.607358	40.84682	-3.70833	20
40	-6.66319	-7.01157	-3.37518	-5.95841	0.34838	-9.77717	0.2849	-2.31178	-2.31178	0.70955	7.577997	6.868447405	7.471303	-34.7529	-7.22292	21
41	-15.3681	-7.69444	-4.39429	-1.01911	-7.67361	-20.8565	0.2908	-6.36043	-6.36043	0.966327	7.370399	6.404072102	9.968046	-84.0196	-7.00694	22
42	-1.05208	-5.5713	-2.42569	1.968596	4.519213	-2.75787	0.2864	-1.68606	-1.68606	1.038641	7.636112	6.597471118	10.88115	-25.804	-5.91111	23
43	-0.29375	-2.48796	1.50787	3.933565	2.194213	6.717824	0.2868	1.690855	1.690855	1.066863	9.030574	7.963710252	11.16112	17.8023	-9.03958	24
44	-6.11806	-6.44213	0.417438	-1.09043	0.324074	1.576389	0.2954	0.658174	0.658174	1.028376	8.657165	7.628788547	10.44481	1.455964	-9.77113	25
45	-12.9146	-12.8906	-2.43976	-2.8572	-0.02399	-7.34329	0.2942	-2.08347	-2.08347	1.015383	9.165195	8.149812441	10.35269	-37.8923	-40.0676	26
46	-19.6391	-17.7957	-5.10257	-2.66281	-1.84345	-17.1512	0.3004	-5.3577	-5.3577	0.906432	9.493467	8.587035196	9.053249	-82.088	-17.4069	27
47	-20.8333	-18.7978	-4.11857	0.984008	-2.03551	-14.3912	0.3009	-4.85169	-4.85169	0.924941	9.625546	8.700605637	9.22306	-77.0181		28
48	-15.921	-17.7277	-1.61236	2.506204	1.806659	-3.03042	0.3008	-1.38497	-1.38497	0.939191	9.996302	9.057111108	9.36665	-34.3473		29
49	-16.4287	-14.5511	1.081529	2.69389	-1.87758	1.367011	0.3016	0.280578	0.280578	0.950906	10.51539	9.564479564	9.457836	-11.1842		30
50	-11.3036	-10.4802	2.772542	1.691012	-0.8234	7.494229	0.3057	2.314009	2.314009	0.872848	10.10421	9.231360994	8.566725	17.28791		31
51	-3.70833	-7.41162	3.438686	0.666144	3.703282	14.01934	0.3021	4.45208	4.45208	0.946699	8.79879	7.852091492	9.401113	46.01335		32
52	-7.22292	-5.9794	2.857232	-0.58145	-1.24352	7.328178	0.2978	2.656947	2.656947	0.938057	8.792072	7.854014989	9.449992	25.90397		33
53	-7.00694	-6.71366	1.255514	-1.60172	-0.29329	3.473256	0.3009	1.303785	1.303785	0.856413	8.004109	7.147696396	8.539529	8.93176		34
54	-5.91111	-7.31921	0.030801	-1.22471	1.408102	1.500505	0.2977	0.586032	0.586032	0.855217	5.333265	4.47804709	8.61774	-0.28682		35
55	-9.03958	-8.24061	-0.75374	-0.78454	-0.79897	-3.06019	0.2829	-0.7769	-0.7769	0.807467	5.243888	4.436420947	8.563776	-17.5634		36
56	-9.77113	-19.6261	-4.30415	-3.55041	9.854974	-3.05748	0.2636	-0.96846	-0.96846	1.097458	6.258856	5.161398513	12.49135	-31.2476		37
57	-40.0676	-22.4152	-5.03201	-0.72785	-17.6524	-32.7484	0.2160	-7.41369	-7.41369	2.203659	5.999972	3.79631277	30.61046	-111.379		38
58	-17.4069												0			

Day	GWT (m)	N=1 z[k]	L=3 x[k]	w(k) x(k)-x(k-1)	v(k) l(k)-z(k)	l(k)-z(k-L) y[k]	K(k)	x(k/k)	x(k+1/k)	C(k/k)	C(k+1/k)	W(k)	V(k)	p=3 z(k+p/k)	GWT[cm]	
1	1.558621															
2	-2.41333	2.208383			-4.62172											
3	7.479861	3.240694			4.239167											
4	4.655556	5.20463			-0.54907											
5	3.478472	3.539815	-0.44381		-0.06134	1.270089										
6	2.485417	1.491898	0.582932	1.026743	0.993519	-0.75528										
7	-1.48819	-0.27431	1.826312	1.24338	-1.21389	-6.69282										
8	-1.82014	-1.56898	1.702932	-0.12338	-0.25116	-5.35995										
9	-1.39861	-0.91204	0.801312	-0.90162	-0.48657	-2.89051										
10	0.482639	0.275	-0.1831	-0.98441	0.207639	0.756944										
11	1.740972	0.150694	-0.57323	-0.39012	1.590278	3.309954										
12	-1.77153	0.46412	-0.45872	0.114506	-2.23565	-0.85949										
13	1.422917	1.288657	-0.33789	0.120833	0.134259	1.147917										
14	4.214583	3.007639	-0.95231	-0.61443	1.206944	4.063889										
15	3.385417	3.647454	-1.06111	-0.1088	-0.26204	2.921296										
16	3.342361	4.397665	-1.03634	0.024775	-1.0553	2.053704										
17	6.465217	5.929378	-0.97391	0.062423	0.535839	3.457579										
18	7.980556	8.35785	-1.57013	-0.59622	-0.37729	4.333102										
19	10.62778	7.893287	-1.16521	0.404925	2.734491	6.230113			-1.16521		1000	0.419496407	3.559717			
20	5.071528	6.567361	-0.21266	0.952546	-1.49583	-0.85785	0.3332	-0.28618	-0.28618	0.265721	0.553338	0.287616733	2.392129	5.70881	-1.04444	1
21	4.002778	3.00162	1.78541	1.998071	1.001157	-4.35507	0.2587	-1.19068	-1.19068	0.123916	0.687974	0.5640576	1.437065	-0.57043	0.802778	2
22	-0.06944	0.962963	2.310108	0.524698	-1.03241	-7.96273	0.2689	-2.3715	-2.3715	0.132907	0.668925	0.536018117	1.48258	-6.15155	3.028472	3
23	-1.04444	-0.1037	2.223688	-0.08642	-0.94074	-7.61181	0.2657	-2.50365	-2.50365	0.135657	0.681277	0.545620167	1.531502	-7.61466	-1.76806	4
24	0.802778	0.928935	0.690895	-1.53279	-0.12616	-2.19884	0.2691	-1.07412	-1.07412	0.131266	0.966162	0.834895776	1.46335	-2.29343	-0.18542	5
25	3.028472	0.687731	0.091744	-0.59915	2.340741	2.065509	0.2787	0.39945	0.39945	0.158441	0.991195	0.832753801	1.705687	1.886081	8.65	6
26	-1.76806	0.358333	-0.15401	-0.24576	-2.12639	-1.66435	0.2729	-0.38184	-0.38184	0.179645	1.019684	0.840039113	1.974697	-0.78718	6.00625	7
27	-0.18542	2.232176	-0.43441	-0.2804	-2.41759	-1.11435	0.2668	-0.37352	-0.37352	0.203454	1.055481	0.852026742	2.287508	1.111606	3.520833	8
28	8.65	4.823611	-1.37863	-0.94421	3.826389	7.962269	0.2502	1.898655	1.898655	0.263358	1.205954	0.942595597	3.158254	10.51958	5.804167	9
29	6.00625	6.059028	-1.90023	-0.5216	-0.05278	5.647917	0.2609	1.886121	1.886121	0.262158	1.196912	0.934753474	3.0148	11.71739	6.061806	10
30	3.520833	5.110417	-0.95941	0.940818	-1.58958	1.288657	0.2632	0.735939	0.735939	0.251768	1.259245	1.007476479	2.869508	7.318233	3.582639	11
31	5.804167	5.128935	-0.10177	0.857639	0.675231	0.980556	0.2655	0.410048	0.410048	0.256093	1.246663	0.99056971	2.893237	6.359079	2.740278	12
32	6.061806	5.149537	0.303164	0.404938	0.912269	0.002778	0.2657	0.083979	0.083979	0.253077	0.840954	0.587877002	2.857846	5.401475	2.743056	13
33	3.582639	4.128241	0.327392	0.024228	-0.5456	-1.52778	0.2416	-0.34607	-0.34607	0.231334	0.775975	0.544640274	2.872074	3.090037	4.56875	14
34	2.740278	3.021991	0.702315	0.374923	-0.28171	-2.38866	0.2377	-0.66713	-0.66713	0.222523	0.79517	0.572646384	2.80793	1.020598	12.90208	15
35	2.743056	3.350694	0.599614	-0.1027	-0.60764	-2.40648	0.2392	-0.76403	-0.76403	0.224551	0.584273	0.359721487	2.816259	1.058608	18.17986	16
36	4.56875	6.737963	-0.86991	-1.46952	-2.16921	0.440509	0.2104	-0.18913	-0.18913	0.215504	0.746945	0.53144136	3.072974	6.170579	8.723611	17
37	12.90208	11.88356	-2.95386	-2.08395	1.018519	9.880093	0.2387	2.305187	2.305187	0.21195	1.108779	0.896828925	2.663267	18.79913	6.655556	18
38	18.17986	13.26852	-3.30594	-0.35208	4.911343	14.82917	0.2385	4.192619	4.192619	0.315432	1.213099	0.897666926	3.967623	25.84637	4.170139	19
39	8.723611	11.18634	-1.48279	1.823148	-2.46273	1.985648	0.2393	1.657789	1.657789	0.342176	1.557938	1.215762041	4.289516	16.15971	15.07708	20
40	6.655556	6.516435	1.789043	3.271836	0.13912	-5.22801	0.2561	-0.95477	-0.95477	0.360979	2.49639	2.135410798	4.228587	3.652116	14.18889	21
41	4.170139	8.634259	1.544753	-0.24429	-4.46412	-9.09838	0.2695	-2.63496	-2.63496	0.477927	2.597518	2.119591069	5.319811	0.729374	5.531944	22
42	15.07708	11.14537	0.013657	-1.5311	3.931713	3.890741	0.2630	0.46701	0.46701	0.54826	2.885608	2.337348621	6.254473	12.5464	2.865972	23
43	14.18889	11.59931	-1.69429	-1.70795	2.589583	7.672454	0.2681	2.148083	2.148083	0.565122	3.141632	2.576509628	6.324751	18.04355	-0.45347	24
44	5.531944	7.528935	0.368441	2.062731	-1.99699	-3.10231	0.2727	-0.45485	-0.45485	0.571872	3.610065	3.038192827	6.292223	6.164383	-2.14029	25
45	2.865972	2.648148	2.832407	2.463966	0.217824	-8.2794	0.2821	-2.40536	-2.40536	0.555135	4.145151	3.590016169	5.904113	-4.56793	-0.4029	26
46	-0.45347	0.090737	3.836189	1.003782	-0.54421	-12.0528	0.2932	-3.82324	-3.82324	0.499685	4.135422	3.635736303	5.113598	-11.379	3.746154	27
47	-2.14029	-0.99889	2.842607	-0.99358	-1.1414	-9.66922	0.2926	-3.29645	-3.29645	0.505574	3.994015	3.488440725	5.183927	-10.8882	8.214388	28
48	-0.4029	0.400989	0.749053	-2.09355	-0.80389	-3.05105	0.2921	-1.29919	-1.29919	0.494427	3.987527	3.493099998	5.078518	-3.49658	9.748252	29
49	3.746154	3.852548	-1.25394	-2.00299	-0.10639	3.655416	0.2922	0.90805	0.90805	0.491654	4.459925	3.968271716	5.04719	6.576697	9.194444	30
50	8.214388	7.236265	-2.74505	-1.49111	0.978124	9.213275	0.2960	2.82915	2.82915	0.498853	4.380875	3.882021546	5.055103	15.72372	9.379167	31
51	9.748252	9.052362	-2.88379	-0.13874	0.69589	9.347263	0.2953	3.083088	3.083088	0.499314	3.12875	2.629436131	5.071896	18.30163	11.70972	32
52	9.194444	9.440621	-1.86269	1.0211	-0.24618	5.341897	0.2825	1.979386	1.979386	0.477445	3.29813	2.820684682	5.070811	15.37878	6.160417	33
53	9.379167	10.09444	-0.95273	0.909964	-0.71528	2.142902	0.2846	0.899142	0.899142	0.481889	3.248013	2.766124421	5.079106	12.79187	1.386111	34
54	11.70972	9.083102	-0.01025	0.94248	2.62662	2.657361	0.2835	0.887783	0.887783	0.485567	3.031518	2.54595091	5.138256	11.74645	-0.24317	35
55	6.160417	6.41875	1.00729	1.017537	-0.25833	-3.2802	0.2807	-0.78065	-0.78065	0.478563	2.724638	2.246074547	5.11445	4.076811	-2.15315	36
56	1.386111	2.434454	2.55333	1.54604	-1.04834	-8.70833	0.2889	-2.61969	-2.61969	0.363458	2.244446	1.8809878	3.774645	-5.42462		37
57	-0.24317	-0.33673	3.139945	0.586615	0.093568	-9.32627	0.2848	-3.03758	-3.03758	0.326654	2.137597	1.810942866	3.440628	-9.44947		38
58	-2.15315													0		39

Annex 5: Calculation result of GWL prediction using SESAME system data in KHDTK Tumbang Nusa with N=1, L=3, and p=8

N=1	L=3	w(k)	v(k)	l(k)-z(k-L)								p=8		
z[k]	x[k]	x(k)-x(k-1)	l(k)-z(k)	y[k]	K(k)	x(k/k)	x(k+1/k)	C(k/k)	C(k+1/k)	W(k)	V(k)	z(k+p/k)	GWT[cm]	
2.208383			-4.62172											
3.240694			4.239167											
5.20463			-0.54907											
3.539815	0.443811		-0.06134	1.270089										
1.491898	-0.58293	-1.02674	0.993519	-0.75528										
-0.27431	-1.82631	-1.24338	-1.21389	-6.69282										
-1.56898	-1.70293	0.12338	-0.25116	-5.35995										
-0.91204	-0.80131	0.90162	-0.48657	-2.89051										
0.275	0.183102	0.984414	0.207639	0.756944										
0.150694	0.573225	0.390123	1.590278	3.309954										
0.46412	0.458719	-0.11451	-2.23565	-0.85949										
1.288657	0.337886	-0.12083	0.134259	1.147917										
3.007639	0.952315	0.614429	1.206944	4.063889										
3.647454	1.061111	0.108796	-0.26204	2.921296										
4.397665	1.036336	-0.02478	-1.0553	2.053704										
5.929378	0.973913	-0.06242	0.535839	3.457579										
8.35785	1.570132	0.596219	-0.37729	4.333102										
7.893287	1.165207	-0.40492	2.734491	6.230113			1.165207		1000	0.419496407	3.559717			
6.567361	0.212661	-0.95255	-1.49583	-0.85785	0.3332	-0.28556	-0.28556	0.265721	0.673303	0.407581336	2.392129	4.282845	8.65	1
3.00162	-1.78541	-1.99807	1.001157	-4.35507	0.2694	-1.22816	-1.22816	0.129066	0.728292	0.599226513	1.437065	-6.82362	6.00625	2
0.962963	-2.31011	-0.5247	-1.03241	-7.96273	0.2718	-2.39118	-2.39118	0.134344	0.751561	0.617216666	1.48258	-18.1665	3.520833	3
-0.1037	-2.22369	0.08642	-0.94074	-7.61181	0.2718	-2.5103	-2.5103	0.138751	0.684919	0.546168285	1.531502	-20.1861	5.804167	4
0.928935	-0.6909	1.532793	-0.12616	-2.19884	0.2694	-1.07393	-1.07393	0.131401	0.790672	0.659270886	1.46335	-7.6625	6.061806	5
0.687731	-0.09174	0.599151	2.340741	2.065509	0.2689	0.347736	0.347736	0.152877	0.829822	0.676945003	1.705687	3.469617	3.582639	6
0.358333	0.154012	0.245756	-2.12639	-1.66435	0.2636	-0.36605	-0.36605	0.173529	0.85603	0.682501705	1.974697	-2.57009	2.740278	7
2.232176	0.434414	0.280401	-2.41759	-1.11435	0.2570	-0.37021	-0.37021	0.195979	0.883864	0.687885588	2.287508	-0.72954	2.743056	8
4.823611	1.378627	0.944213	3.826389	7.962269	0.2386	1.794601	1.794601	0.251189	0.977666	0.726477827	3.158254	19.18042	4.56875	9
6.059028	1.900231	0.521605	-0.05278	5.647917	0.2483	1.860172	1.860172	0.249494	0.993119	0.743625683	3.0148	20.94041	12.90208	10
5.110417	0.959414	-0.94082	-1.58958	1.288657	0.2523	0.777225	0.777225	0.24135	1.056853	0.815502326	2.869508	11.32822	18.17986	11
5.128935	0.101775	-0.85764	0.675231	0.980556	0.2556	0.431894	0.431894	0.246493	1.114129	0.867636182	2.893237	8.584086	8.723611	12
5.149537	-0.30316	-0.40494	0.912269	0.002778	0.2594	0.096513	0.096513	0.24711	1.084913	0.837802977	2.857846	5.921641	6.655556	13
4.128241	-0.32739	-0.02423	-0.5456	-1.52778	0.2576	-0.37157	-0.37157	0.246587	1.078863	0.832276079	2.872074	1.155644	4.170139	14
3.021991	-0.70231	-0.37492	-0.28171	-2.38866	0.2586	-0.70096	-0.70096	0.242007	1.022941	0.780934264	2.80793	-2.58572	15.07708	15
3.350694	-0.59961	0.102701	-0.60764	-2.40648	0.2553	-0.77846	-0.77846	0.239618	0.711139	0.471520558	2.816259	-2.87695	14.18889	16
6.737963	0.869907	1.469522	-2.16921	0.440509	0.2252	-0.15331	-0.15331	0.230683	0.799304	0.56862063	3.072974	5.511445	5.531944	17
11.88356	2.953858	2.083951	1.018519	9.880093	0.2433	2.362105	2.362105	0.215964	1.026348	0.810383584	2.663267	30.7804	2.865972	18
13.26852	3.305941	0.352083	4.911343	14.82917	0.2332	4.167559	4.167559	0.308386	1.007096	0.698709911	3.967623	46.60899	-0.45347	19
11.18634	1.482793	-1.82315	-2.46273	1.985648	0.2263	1.788014	1.788014	0.32351	1.32444	1.000929427	4.289516	25.49045	-2.14029	20
6.516435	-1.78904	-3.27184	0.13912	-5.22801	0.2460	-0.81814	-0.81814	0.346812	2.159428	1.812615946	4.228587	-0.02869	-0.4029	21
8.634259	-1.54475	0.24429	-4.46412	-9.09838	0.2617	-2.55686	-2.55686	0.464064	2.274444	1.810380252	5.319811	-11.8206	3.746154	22
11.14537	-0.01366	1.531096	3.931713	3.890741	0.2553	0.394994	0.394994	0.532301	2.4653	1.932999307	6.254473	14.30532	8.214388	23
11.59931	1.69429	1.707948	2.589583	7.672454	0.2594	2.077792	2.077792	0.546863	2.693743	2.146879667	6.324751	28.22164	9.748252	24
7.528935	-0.36844	-2.06273	-1.99699	-3.10231	0.2646	-0.39287	-0.39287	0.555072	2.951706	2.396634244	6.292223	4.38599	9.194444	25
2.648148	-2.83241	-2.46397	0.217824	-8.2794	0.2727	-2.32941	-2.32941	0.536726	3.306173	2.769447174	5.904113	-15.9871	9.379167	26
0.090737	-3.83619	-1.00378	-0.54421	-12.0528	0.2844	-3.77002	-3.77002	0.484854	3.297914	2.813060354	5.113598	-30.0694	11.70972	27
-0.99889	-2.84261	0.993582	-1.1414	-9.66922	0.2838	-3.3044	-3.3044	0.49035	3.413129	2.922778078	5.183927	-27.4341	6.160417	28
0.400989	-0.74905	2.093554	-0.80389	-3.05105	0.2860	-1.34153	-1.34153	0.484225	3.768089	3.283864603	5.078518	-10.3312	1.386111	29
3.852548	1.253937	2.00299	-0.10639	3.655416	0.2902	0.886829	0.886829	0.488149	4.06095	3.572801003	5.04719	10.94718	-0.24317	30
7.236265	2.74505	1.491113	0.978124	9.213275	0.2928	2.80569	2.80569	0.493431	4.070707	3.577275996	5.055103	29.68178	-2.15315	31
9.052362	2.883791	0.138741	0.69589	9.347263	0.2928	3.078049	3.078049	0.495015	3.758999	3.263983875	5.071896	33.67675		32
9.440621	1.862691	-1.0211	-0.24618	5.341897	0.2899	1.949749	1.949749	0.489982	3.813216	3.323233805	5.070811	25.03861		33
10.09444	0.952727	-0.90996	-0.71528	2.142902	0.2904	0.873572	0.873572	0.491591	3.632739	3.141147685	5.079106	17.08302		34
9.083102	0.010247	-0.94248	2.62662	2.657361	0.2881	0.884128	0.884128	0.493379	2.863155	2.369776758	5.138256	16.15613		35
6.41875	-1.00729	-1.01754	-0.25833	-3.2802	0.2781	-0.76591	-0.76591	0.474162	2.935194	2.461031894	5.11445	0.291498		36
2.434454	-2.55333	-1.54604	-1.04834	-8.70833	0.2917	-2.63562	-2.63562	0.366969	2.797687	2.430717168	3.774645	-18.6505		37
-0.33673	-3.13995	-0.58662	0.093568	-9.32627	0.2933	-3.05188	-3.05188	0.336333	2.476164	2.139830141	3.440628	-24.7517		38