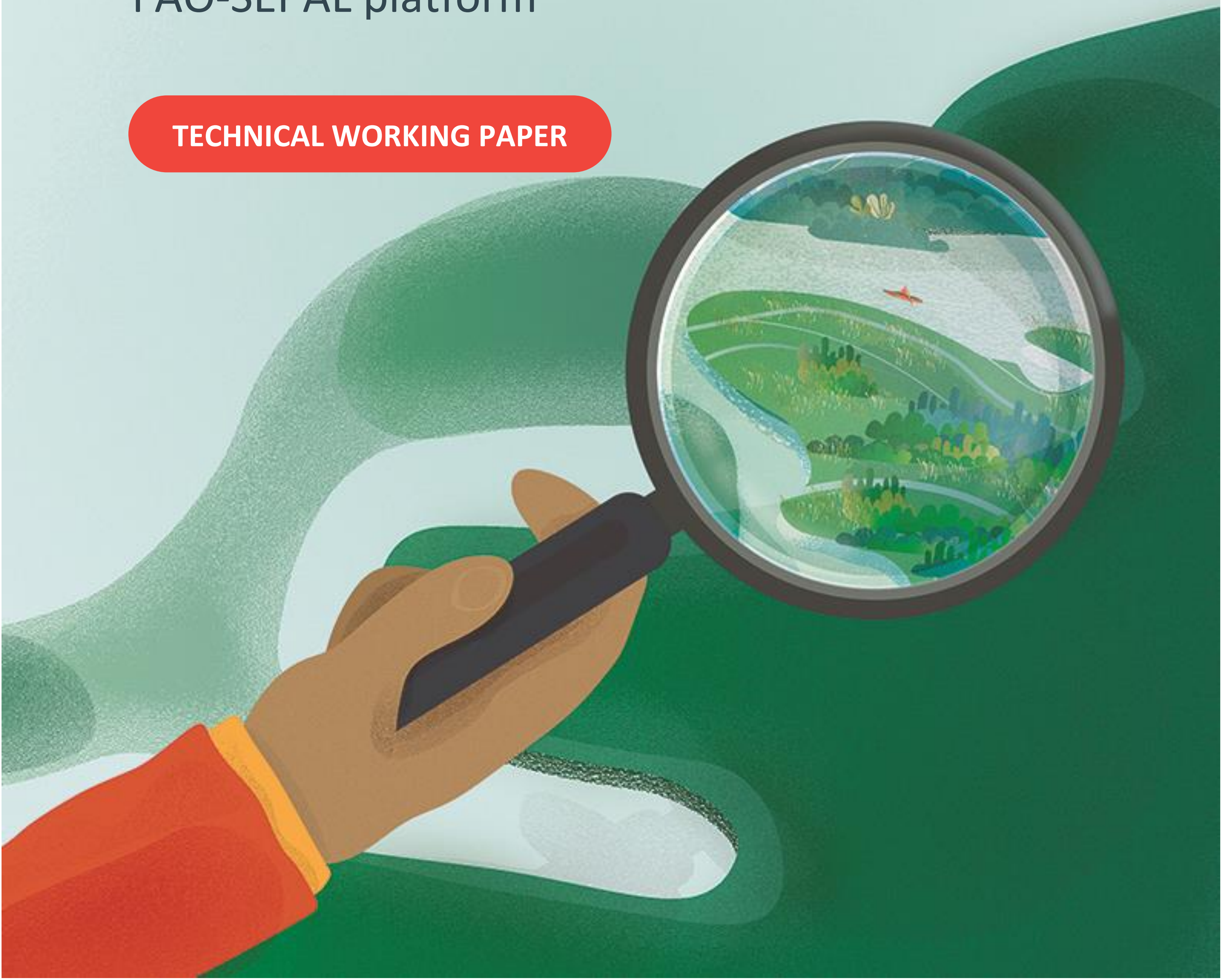
Food and Agriculture Organization of the United Nations

Practical guidance for peatland restoration monitoring in Indonesia

A remote sensing approach using FAO-SEPAL platform

TECHNICAL WORKING PAPER



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Executive summary

Indonesia committed in 2015 to rewet over two million hectares of drained, degrading and often burning peatlands. The key focus was to reduce fire risk and threats to lives and livelihoods, and to mitigate climate change. While large-scale peatland restoration effort started in 2016 in Indonesia with efforts of several partners and coordinated through two key agencies, peatland restoration monitoring approaches' development was started a bit later. A particular challenge was to monitor cost-effectively the ground-water level as a key variable of the restored peatland areas, which only had a limited number (less than 50 in 2016) of scattered ground-water level field measurement points. Therefore, remote sensing was proposed as a means of collecting data over large areas of peatlands at low-cost.

FAO was requested to support the task through its Earth monitoring tools in SEPAL. This document guides practitioners in the use of the monitoring tools by describing and demonstrating the use of FAO SEPAL for peatland monitoring by evaluating changes in soil moisture. The document uses examples from Indonesia, providing the supporting information and some examples to analyse and interpret results and make informed decisions when planning restoration measures.   Finally, it discusses knowledge gaps while offering recommendations to practitioners and developers to improve methodologies for peatland monitoring in relation to the tools presented. The guidance has a special focus on soil moisture due to its strong relationship with Ground Water Level (GWL), which in turn is related to GHG emissions.

FAO provides free and open access spatial data and processing tools support the capacity of countries to monitor peatlands. Information on the status and changes over time in the status of peatlands is critical for the national monitoring and reporting systems. The System for Earth Observation Data Access, Processing and Analysis for Land Monitoring (SEPAL) is an online, open-source platform that allows users to easily access, query and process satellite data and undertake a range of geospatial analyses tailored for different needs. Guidance on how to perform analysis in SEPAL for peatland monitoring can greatly contribute to countries capacity to improve the monitoring and management of their natural resources.

Keywords: *greenhouse gas; peatland; organic soil; forest; monitoring; reporting; climate change; wetland; IPCC; satellite data; remote sensing; Earth observation; data; groundwater level; peat; UNFCCC; emission reduction; capacity development.*

Contributors

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Abbreviations and acronyms

ALOS	Advanced Land Observing Satellite
AOI	Area of interest
BFAST	Breaks for Additive Seasonal and Trend
BRG	Badan Restorasi Gambut (Peatland Restoration Agency of Indonesia) – name used until end of year 2020. Mangroves were included
CPU	Central Processing Unit
FAO	Food and Agriculture Organization of the United Nations
GEE	Google Earth Engine
GHG	Greenhouse gas emissions
GLDAS	Global Land Data Assimilation System
GWL	Groundwater level in the peatlands
ISMN	International Soil Moisture Network
ISRO	Indian Space Research Organisation
IPCC	Intergovernmental Panel on Climate Change[1]
NASA	National Aeronautics and Space Administration
NISAR	NASA-ISRO Synthetic Aperture Radar
OCSVM	One-Class Support Vector Machine
PHU/KHG	Peatland Hydrological Unit
RAM	Random Access Memory
RMSE	Root-Mean-Square Deviation
SAR	Synthetic aperture radar
SEPAL	System for Earth Observation, Data Access, Processing and Analysis for Land Monitoring build and maintained by FAO
SIPALAGA	*Sistem Pemantauan Air Lahan Gambut*
SMM	Soil Moisture Mapping
SRTM	Shuttle Radar Topography Mission
WRI	World Resources Institute

[1] https://www.ipcc.ch/

Useful resources to support the use of these guidelines

Peatland ecology and practical webinars:

- FAO Mitigation of Climate Change in Agriculture Programme webinars
- FAO Peatland and climate change video playlist

FAO. 2020. Peatland mapping and monitoring: Recommendations and technical overview. Peatland mapping and monitoring: Recommendations and technical overview. http://www.fao.org/3/CA8200EN/CA8200EN.pdf

FAO. 2014. Towards climate responsible peatland management. R. Biancalani & A. Avagyan, eds. Mitigation of Climate Change in Agriculture Series No. 9. Rome. 100 pp. http://www.fao.org/3/a-i4029e.pdf

FAO. 2012. Peatlands - guidance for climate change mitigation through conservation, rehabilitation, and sustainable use. http://www.fao.org/3/a-an762e.pdf

Joosten, H. & Clarke, D. 2002. Wise Use of Mires and Peatlands. Background and principles including a framework for decision-making. International Mire Conservation Group and International Peat Society. http://www.imcg.net/media/download_gallery/books/wump_wise_use_of_mires_and_peatlands_book.pdf

Wösten, H., Rieley, J. & Page, S. 2008. Restoration of Tropical Peatlands. Alterra - Wageningen University and Research Centre, and the EU INCO - RESTOPEAT Partnership. https://www.wur.nl/upload_mm/e/5/a/4d874adb-f5e6-4da4-9f8a-79114e7b2291_RestorationBook5.pdf

Part 1: Introduction

Peatlands have a critical role in the global carbon cycle, are important for water regulation, disaster risk reduction, provide food, non-timber products and other livelihood opportunities, and are refuge to biodiversity and many endangered species. Peatlands are, however, highly vulnerable ecosystems. Historically, they have been degraded, drained, and burned, mainly for agricultural and forestry purposes, contributing to at least 5 percent of the total global anthropogenic carbon emissions (see e.g., IPCC, 2014).

To be successful in the restoration of peatlands, monitoring the water table levels and soil moisture is critical to assess the status of the peatland and its carbon balance. Draining peatlands through lowering the water table levels causes peat oxidation and consequent carbon emissions, subsidence, and increased fire risk.

This technical document gives an overview and guides the use of the remote sensing tools produced by the Food and Agriculture Organization of the United Nations (FAO) for peatland restoration monitoring in Indonesia. At the core of these tools is the Soil Moisture Mapping (SMM) module in the FAO System for Earth Observation Data Access, Processing and Analysis for Land Monitoring (SEPAL).

First, a brief overview of how to use the terminal in SEPAL is presented. Then it explains step by step how to create a soil moisture map for a given area of interest and run analytic tools to assess trends in soil moisture over time. The document also guides the reader on how to interpret the products generated with real examples as the validation exercises that have been carried out with field data. It aims at supporting and advising practitioners to analyse and interpret results combined with other techniques, sensors and auxiliary data and make informed decisions when planning restoration measures.

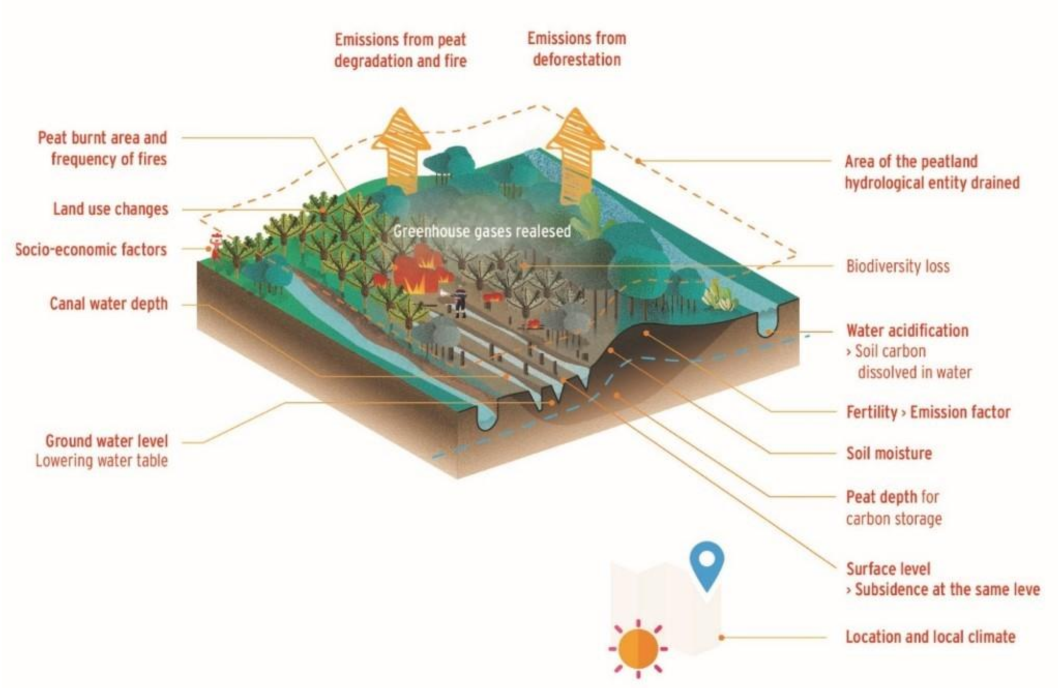
This guide is prepared under the framework of the project "Development of an Innovative Peatland Monitoring System in Indonesia" funded by the Government of Norway and implemented by FAO in close collaboration with the Indonesian Peatland Restoration Agency and the World Resources Institute (WRI). The project has supported the Peatland Restoration Agency (BRG); called BRGM since 2021, in setting up a system to monitor the impact of peatland restoration activities and facilitate data transparency.

WHY MONITOR SOIL MOISTURE IN PEATLANDS?

While first peatland restoration trials date back to 1970s (see e.g., Similä et al. (eds), 2014) the related monitoring efforts have been mostly small-scale, local efforts. There has been a lot of progress made on peatland assessment, mapping and monitoring in the past few years with the increasing recognition of how important peatlands are for issues of major global concern, including climate change and disaster risk reduction (see e.g., FAO, 2020).

When the water table in a peatland is drawn down, for example, to allow agriculture or forestry, oxygen enters the upper peat layers. This facilitates microbial degradation (oxidation) of the peat and a rapid loss of stored carbon to the atmosphere – in the form of the various greenhouse gases (GHGs) – and into the water as dissolved organic carbon (FAO, 2020). Restoring peatlands is a complex multi-dimensional task that should include biophysical and socio-economic variables (Figure 1.1).

Figure 1.1. *Data needed for peatland monitoring, the case for drained peatland with canals.*



Source: FAO, 2020.

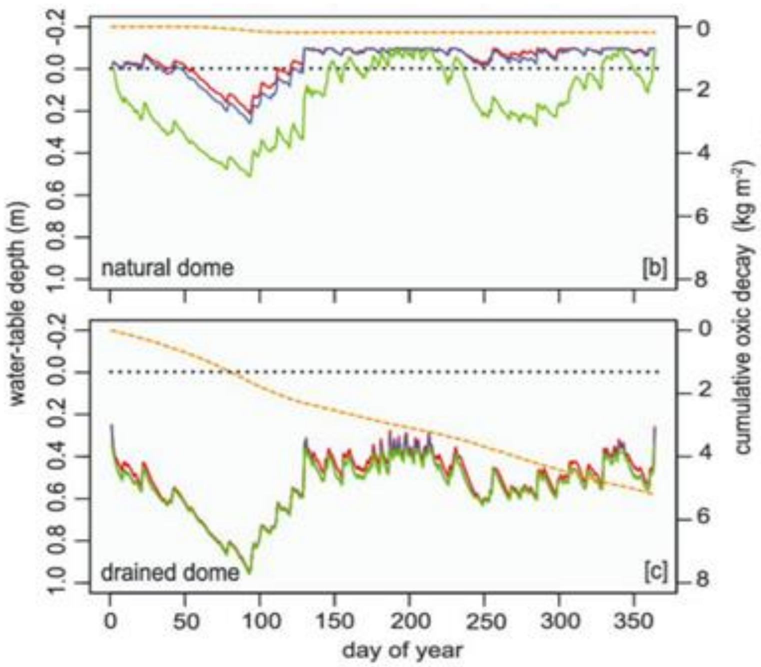
Peatlands cover only three percent of global land area but store nearly 30 percent of the world's soil carbon and are estimated to contain twice as much carbon as the world's forests. Peatlands are found in many countries and have come under increased threats including overexploitation and degradation in the past few decades. Degraded peatlands contribute five percent of the global anthropogenic emissions.

Indonesia has estimated that 99 percent of its peatlands are degraded out of 24 million hectares (MoEF, 2020). In its first Nationally Determined Contributions (NDC), Indonesia has set some ambitious targets that should provide significant result in the Agriculture, Forestry, and Other Land Use (AFOLU) sector – for example, "peat restoration achieves 90 percent survival rate, and the area of peat restoration reaches two million hectares by 2030". In 2016, Indonesia created the Peatland Restoration Agency to plan and coordinate the restoration work, and then established the International Tropical Peatlands Centre (ITPC) in 2018 to support peatland research and capacity development.

There is a scientific consensus that drained peatlands have very high emissions and that the depth of the groundwater level (GWL) has a good correlation with GHG emissions, therefore it can act as a proxy estimation. Figure 1.2, below, shows the dynamics of GWL depth and cumulative peat mass loss in a pristine peatland (Figure 1.2b) and a drained one (Figure 1.2c). The different coloured lines represent different locations on the peatland, the black dotted line indicates peatland surface, and the dashed orange line indicates cumulative peat mass lost. Water table depth suffers less variation when the peat and the vegetation act as a buffer to prevent it from dropping under the surface of the peat for prolonged periods. In this case, peat loss and associated GHG emissions are prevented. When the peatland is drained (Figure 1.2c), the water table drops under the surface for longer periods. In this case, all year, allowing peat oxidation and loss. In the latter case, we can see larger variations in the water table depth between dry and wet season in a drained peatland, because the regulation capacity of the peatland is altered by peat and vegetation degradation.

The Intergovernmental Panel on Climate Change (IPCC) 2013 Wetlands Supplement is the most agreed methodology to assess peatland restoration process and, its impact on GHG emissions. IPCC outlines two main means for assessing if peatland degradation has been halted through rewetting: the high GWL and the subsidence rate (IPCC, 2014; summarized also in FAO, 2020). In the development of the project, FAO has been able to demonstrate that in the case of scarce data, the soil moisture values estimated from satellite data are a practical proxy for GWL estimations, and therefore, demonstrate the progress of the restoration measures.

Figure 1.2. *Modelled water tables and cumulative peat mass lost in (b) conserved peat bog, and (c) drained peatland*



Source: Baird et al., 2017

Monitoring the impact of restoration measures is crucial for assessing peatland's climate impact. However, direct estimations of peatland's GHG emissions are challenging, expensive and cover limited areas. Therefore, monitoring variables such as GWL levels and soil moisture can aid to understand climate impacts and disaster risks associated with peatlands, and hence promote better management in the future. Peatland monitoring is, therefore, essential to support corrective action, avoid continued degradation and loss of ecosystem services; and to contribute information to report for various international commitments, including Sustainable Development Goals and contributing Conventions[2].

Further resources

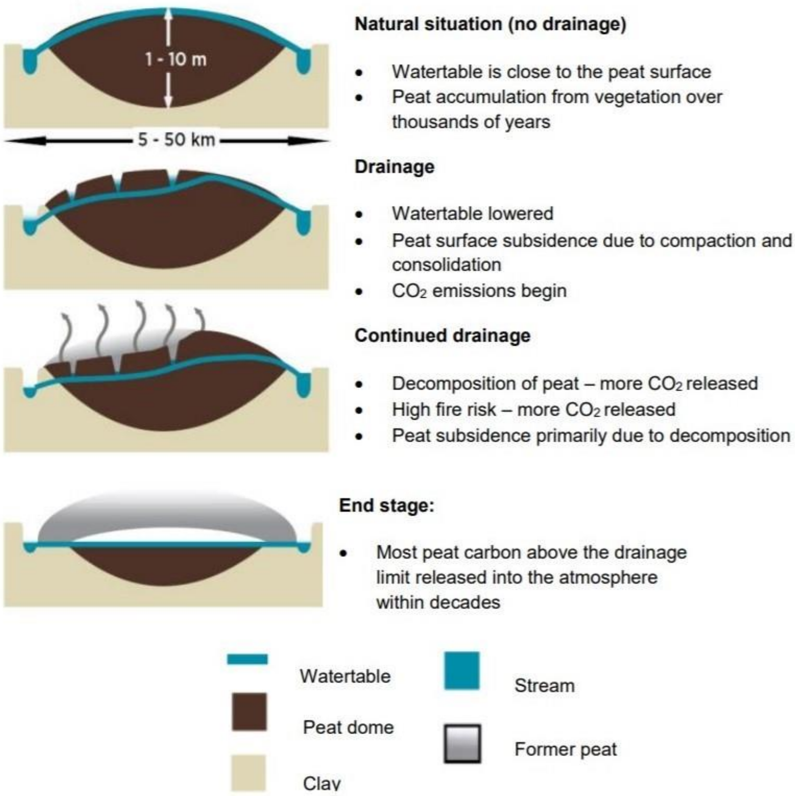
The importance & utility of peatland mapping & monitoring for climate action, presentation by Prof. Hans Joosten

[2] For example: the United Nations Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD), the Ramsar Convention on Wetlands and the United Nations Convention to Combat Desertification (UNCCD).

PEATLAND SOIL MOISTURE ESTIMATES WITH RADAR SENSORS

Measuring groundwater level in peatlands and canals is a priority for assessing the changing conditions in the peat (Figure 1.3), the impact of drainage in various parts of the system (e.g., in a peat dome), fire risk, and thus likely carbon emissions, restoration requirements and results (FAO, 2020). Whereas GWL is critical to halt peatland degradation, optimal depths are not the same for all peatlands, but depend on peat physical properties (i.e., water retention, unsaturated conductivity), which are related to the degree of peat rewetting (fibric, hemic, and sapric) (Taufik et al., 2019).

Figure 1.3. *Representation of the process of drainage and land subsidence in a peatland*



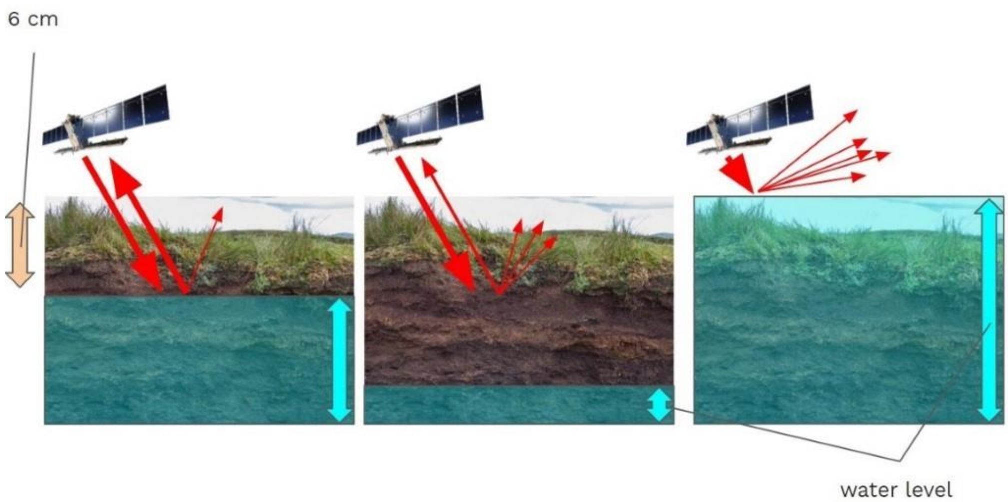
Source: Susan Page, University of Leicester[3].

GWL data in Indonesia is only available from sparse and scattered field measurement sites, does not have a long time series available and often faces quality issues and high costs. Measurement stations, often located in sites that are relatively easy to access, to protect and maintain the equipment, may not be in the optimal scientific location for representing GWL in different land cover and land use types. These factors create challenges and gaps when using the field data for the wider estimation of GWL across the landscape and assessing the status of the peatland.

[3] https://www2.le.ac.uk/departments/geography/research/projects/tropical-peatland/susidence-a-progressive-problem

Water table depth and soil moisture are closely linked (Hirano et al., 2014). Estimation of soil moisture using microwave-based radar sensors in remote sensing is a good indirect method that addresses the challenges posed by field measurements of GWL. When microwaves interact with physical objects on the Earth´s surface, the information obtained can indicate moisture content (Figure 1.4), salinity and physical characteristics (shape, size, and orientation). Concerning soils, the scattering properties are dependent on the surface roughness and the vertical distribution of soil moisture content (Woodhouse, 2005). Increase in soil moisture has been detected using radar imagery after the construction of dams in a degraded peatland area in Indonesia, demonstrating that the comparison of multitemporal images can be used to monitor soil moisture. Moreover, a strong correlation was found between groundwater level and the backscatter received by the radar sensor in these areas (Jaenicke et al., 2011), over degraded peatlands in Sarawak, Malaysia (Hashim et al., 2002) but also found in boreal peatlands in Alaska (Kasischke et al., 2009). For all these studies, increases in groundwater level (i.e., increase in soil moisture) were positively correlated with an increase in backscatter.

***Figure 1.4**. Synthetic aperture radar interaction with soil moisture*



Source: Pablo Martin, FAO. Created for the report

PEATLAND MONITORING IN INDONESIA

Indonesia has established an institutional framework for peatland monitoring (FAO, 2020). Peatland monitoring in the country has focused on providing up to date information on peatlands, restoration activities' implementation stage, and information to detect peatland fires. However, to be able to reduce peatland fires and degradation, and to report on peatland related GHGs, peatland degradation monitoring would need to be the focus. (BRG, 2020).

Peatland information provided by the monitoring system includes distribution, administrative status, land uses and allocation, and peatland condition – peatland status of protection, degradation, canal network, and other activities' implementation is assessed to determine the progress, adjust the measures, and enhance the effectiveness of peatland restoration efforts. Also, monitoring activities aim at detecting peatland degradation to support the fire early warning system and facilitate law enforcement.

An important condition for monitoring is the mapping of peatland areas. In Indonesia, several methods have been applied for this purpose, such as remote sensing and hydrological analysis methodologies, Light Detection and Ranging (LiDAR) and field surveys. The Indonesian "One Map" policy's aim is to harmonize different maps into a set of officially acknowledged national maps, including a peatland layer (FAO, 2020).

Peatland data are the input for the design of landscape-based restoration planning – based on peatland hydrological units (PHU) – and the Peat Ecosystem Restoration Plan with a scope of 25 years. Restoration measures that are currently implemented include rewetting, revegetation, and revitalization.

The Peatland Restoration Information and Monitoring System (PRIMS)[4] was created by BRG as an open online web-mapping platform to provide recent restoration progress in seven priority provinces. PRIMS enables users to monitor restoration activities, such as canal blockings and revegetation sites, peat degradation indicators, such as tree cover loss, and restoration impacts, such as fire hotspots and soil moisture trends.

The PRIMS platform is a very ambitious effort, and a rare one, at its scale, to track progress in peatland restoration. Key information that can inform BRG, the public and other agencies now include:

- PHU delineations;
- canals (actively draining);
- canal blockings and back-filling (that aim to raise water table to or near the surface);
- groundwater level alerts;
- trends in soil moisture;
- changes in vegetation moisture levels;
- information on the year when specific canals of a PHU have been blocked with the aim to have water raised at or near the surface; and
- soil moisture changes from field data stations and FAO SEPAL satellite estimates.

It is important to assess the extent and condition of peatlands, not only for climate purposes but for land use and management planning at a national level. Peatland monitoring can support the national forest monitoring systems by providing information on forest resources on peatlands. In Indonesia, a country with

[4] https://prims.brg.go.id/

around 24 million ha of peatland areas, peatland monitoring is fundamental to build a robust and comprehensive National Forest Monitoring System (NFMS) and overall Earth monitoring, including aquatic ecosystems.

Responding to Indonesia's urgent need to monitor peatland areas, FAO developed free, cloud-based modules for remotely monitoring soil moisture to analyse the effect of peatland restoration measures in Indonesia. These tools are integrated into the online platforms SEPAL, which allow free and open access to geo-spatial data and processing power. Using supercomputing and the latest satellite imagery, updated maps of peatland soil moisture, an important indicator of the health of the peatland, can be assessed on massive scales. Indonesian national institutions are already taking advantage of the tools to process, assess and demonstrate the results, and refine the restoration action.

Further resources

- FAO, 2020. Peatland mapping and monitoring: Recommendations and technical overview Chapter 6: Country case studies.
- Training: SEPAL tools for peatland monitoring in Indonesia
- Innovative tools to address peatland monitoring challenges in Indonesia, presentation by Budi Wardhana.
- Page, S. & Rieley, J. 2016. Tropical peat swamp forests of South East Asia.

Part 2: Modelling soil moisture in peatlands using remote sensing

FAO's work in PRIMS is focused on offering technical support on estimating soil moisture using remotely sensed data in the peatland areas in the process of restoration. To achieve this, the FAO is using a cloud-based processing platform. The System for Earth Observation Data Access, Processing, and Analysis for Land Monitoring (SEPAL) is an online, open-source platform that allows users to query and process satellite data and undertake a range of geospatial analyses tailored for different needs. Field monitoring data can be processed through SEPAL's integrated tools by combining optical satellite-based time series analysis with radar-based soil moisture estimates and trends. Specific state-of-the-art peatland restoration monitoring modules are being developed by FAO and partners and are accessible in SEPAL.

SEPAL is a powerful cloud-computing platform for autonomous land monitoring, which uses remotely sensed data to readily process satellite data efficiently to generate advanced geospatial and statistical analyses (e.g., uncertainty). Notable innovations of the platform include:

- Improved, easier data access
- system for rapid and standardized image processing
- cloud-based processing capacity with high-speed processing and huge storage capacity
- powerful and useful open-source tools that can be customised by users; and
- effective user interface that operates smoothly without the latest computers or high-speed internet connection.

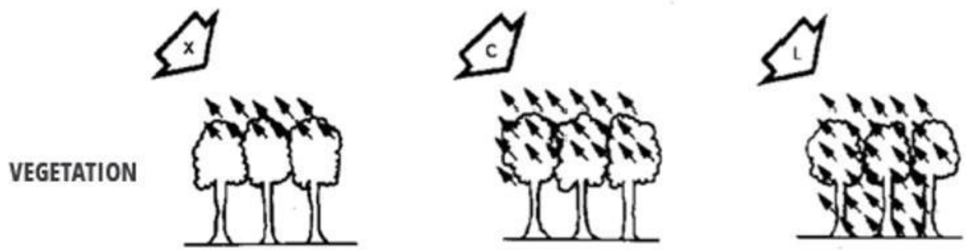
Because SEPAL is based on open-source code, it can easily be tailored for different users and countries, with their own working methods suited to their areas. This manual covers the generation of soil moisture maps (SMM) and analytic tools to visualize trends in soil moisture. Initially, the soil moisture is being validated and calibrated for Indonesia peatlands, but potentially applicable in other countries. The SEPAL soil moisture map (SMM) product has shown encouraging results during a preliminary validation.

SOIL MOISTURE MONITORING MODULE

The SEPAL Soil Moisture Monitoring Module makes heavy use of radar-based remote sensing. Synthetic aperture radar (SAR) sensors, such as Sentinel-1 (C-band) or Advanced Land Observing Satellite (ALOS) Phased Array type L-band Synthetic Aperture Radar (PALSAR) L-band are increasingly being used for peatland monitoring due to their advantages in comparison with optical sensors (Landsat). Besides the sensitivity of SAR sensors to soil moisture, they are not affected by cloud cover which is a great advantage to overcome the frequent cloudiness in tropical regions. As active sensors, they can also work during the day and night, because and external source of illumination, like the sun, is not needed. Additionally, the frequency of observations, for example, every 12 days for Sentinel-1 over Indonesia, provides an excellent temporal resolution for monitoring changes (FAO, 2020). These features make Sentinel-1 a very interesting SAR sensor for peatland monitoring. FAO SEPAL has explored its capabilities to develop accurate soil moisture estimation tools.

Sentinel-1 still presents some physical limits due to the nature of its wavelength (C-band), but its free availability in comparison with costly imagery of ALOS PALSAR L-band, offsets this disadvantage. Ideally, the interpretation would be improved if the two sensors were used. The radar pulses interact with vegetation of about the same size as the radar wavelength, and larger, illustrated in Figure 2.1. Because of the penetration limits of C-band radar, the signal will be backscattered by the leaves or small branches (~ 6 cm) in dense tree canopies, therefore it will be more accurately showing soil moisture in relatively clear areas, with low and sparse vegetation, such as pastures, cropland, or peatland areas with sparse and low trees. With the L-band, if the tree trunks or other objects are smaller than ~23 cm, part of the incoming electromagnetic wave will reach the ground and the backscattered signal will contain a component that is related to soil moisture. After a correct interpretation and calibration, soil moisture could be inferred as well (Flores-Anderson et al., 2019).

Figure 2.1. Interaction of radar pulse with a vegetated surface at different wavelengths



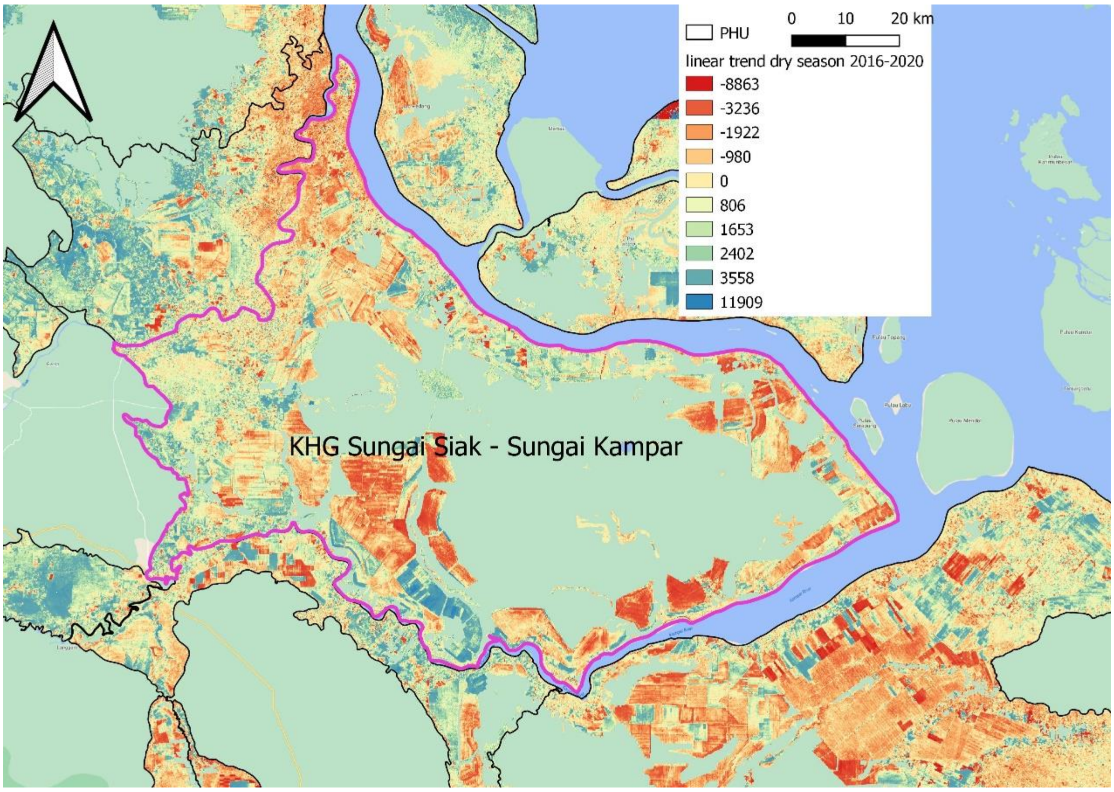
Source: CEOS, 2018

Based on the correlation between soil moisture and backscatter intensity, Greifeneder et al. (2019) developed a model with the ability to compute wall-to-wall soil moisture maps using Sentinel-1 and ancillary data (pySMM). Even though the basic condition for the retrieval of soil moisture is its correlation with radar backscatter, additional factors such as surface roughness, vegetation structure and density influence the model. Additionally, the model also feeds on the Global Land Data Assimilation System (GLDAS) which provides modelled soil moisture at the top layer (0-10 cm) (Rodell et al., 2004) serving as a source of additional data. This results in a non-linear relationship, which makes necessary to use complex retrieval models (Greifeneder et al., 2019; Pasolli et al., 2015).

Therefore, the choice to model soil moisture is based on a Support-Vector-Regression (SVR) machine learning approach. SVR was selected for i. the ability to handle complex and non-linear problems, ii. the ability to manage different types of inputs, and iii. it can reach high-level performance even when data are scarce (Pasolli et al., 2015).

The model training was performed based on in-situ data from the International Soil Moisture Network (ISMN). All processing steps for spatial and temporal mapping of surface soil moisture are fully executed online using the Soil Moisture Mapping (SMM) tool built into SEPAL, which utilizes the computing power of GEE to calculate a time series of soil moisture information over a selected area of interest (Figure 8) and other geospatial libraries for statistical operations and further analyses.

Figure 2.2. *Soil moisture linear trend during dry seasons for 2016–2020. The legend specifies the slope of the trend*



Source: Pablo Martin, FAO

Further resources.

- Training on the SEPAL soil moisture module and Hands on SMM
- Launch of the SEPAL module for tropical peatland monitoring: https://fao.adobeconnect.com/_a1026619000/p93sggg5e3cw /
- Jupyter notebooks interfaces have been created to process the soil moisture maps for an area of interest. The area needs to be uploaded as a Google Earth Engine asset. To upload an asset, follow the instructions here.
- If you would like to learn more information about soil moisture mapping, this site is informative.
- For more information about SAR in general, this very comprehensive handbook on how to use SAR data for forest monitoring and biomass estimation, use this book.

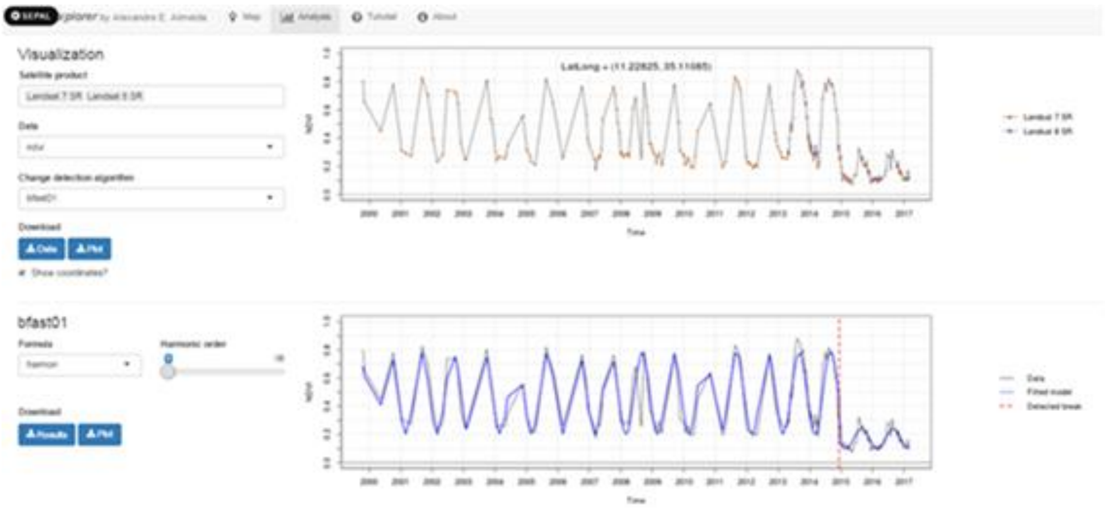
ANCILLARY TOOLS TO MONITOR PEATLANDS RESTORATION

BFAST analysis to model vegetation cover changes

In recent years, dense time series have been increasingly used, largely attributed to open data policies (e.g., opening of the Landsat data archive in 2008) and access to cloud computing systems (such as SEPAL). The BFAST approach can be used for near-real-time disturbance detection and continuous change monitoring trend analysis (Verbesselt et al. 2010). BFAST methods can be applied to any series of satellite images (i.e., MODIS4, Landsat, Rapid Eye, RADAR5 data and Sentinel data). The tool is based on the concept that deviations from average seasonal vegetation dynamics trend (derived from vegetation indices, e.g., NDMI, NDVI6) over multiple years can indicate disturbances (abrupt and gradual). The BFAST approach iteratively estimates the time and number of abrupt changes within time series and characterizes changes by its magnitude and direction.

SEPAL hosts a user interface called BFAST explorer, which shows the trend and breaks in the trend for a point location selected by the user (Figure 2.3). Different parameters for the algorithm can be tested and modified by using this application with the objective to explore and identify what are the most relevant custom settings required for running the BFAST algorithm at a spatial scale (i.e., running the dense time series analysis for an area of interest rather than for one coordinate).

Figure 2.3. *BFAST explorer in SEPAL can be used to view the trends and identify breaks (red dotted line) in a trend for a point location*

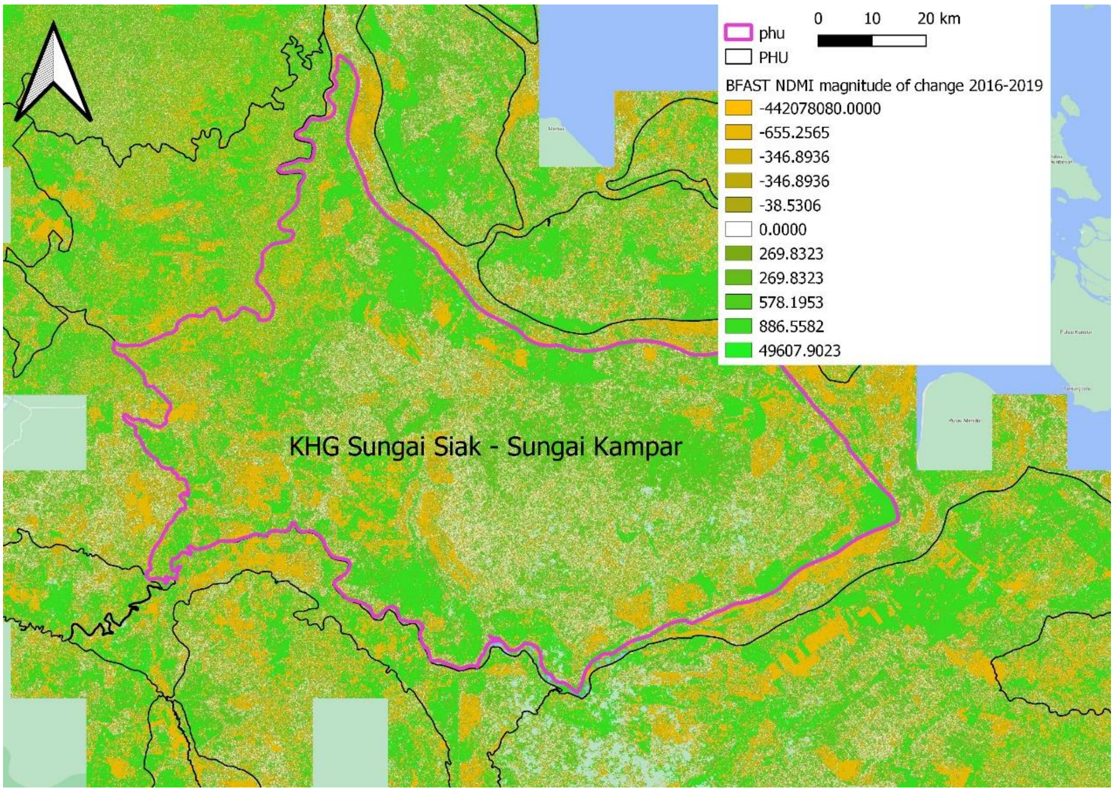


Source: BFAST Explorer caption from SEPAL.

To perform a time series analysis, SEPAL uses the BFAST Spatial Algorithm7 that applies the pixel-based approach of BFAST Monitor in a spatial context. Running BFAST spatial requires high-quality time series data and a benchmark vegetation mask that is used to limit the algorithm to the pixels, which are known to have been vegetated at the beginning of the first monitoring period.

SEPAL provides an additional module to produce time-series analysis of Landsat imagery and compute BFAST over an area of interest (Figure 2.4). With this module BFAST will be calculated at every location (pixel) detecting deviations from seasonal or interannual trends. Abrupt changes will be detected for the monitoring period selected getting an image as the final output instead of analysing a single location (pixel) as BFAST Explorer showed in Figure 2.4.

***Figure 2.4**. Positive and negative changes in vegetation moisture (NDMI) 2016–2019 in comparison to the historical period 2013–2016, using the BFAST algorithm*



Source: Pablo Martin, FAO.

Further resources.

- Training on BFAST in SEPAL & hands on BFAST modules
- Detecting changes in land cover – BFAST monitor and SEPAL: https://www.youtube.com/watch?v=iIixatm-tfg
- Breaks for Additive Season and Trend (BFAST) manual for peatland restoration monitoring with FAO tools.

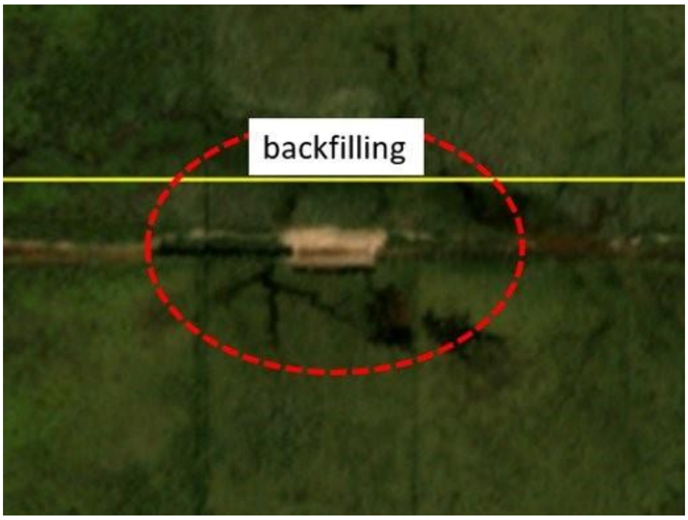
Planet imagery to monitor land cover change and restoration activities in peatlands

Through Norway's International Climate & Forests Initiative[5], high spatial and temporal resolution imagery from Planet Labs is now available to anyone and will help in accurately identifying and classifying land

[5] https://www.planet.com/nicfi/#:~:text=Through%20Norway's%20International%20Climate%20%26%20Forests,biodiversity%2C%20and%20facilitate%20sustainable%20development.

cover, vegetation structure and other biophysical properties (such as the canal blockings that are not covered by trees, as seen in Figure 2.5) in Indonesian peatlands. Additionally, Planet provides a consistent time series of imagery, which is important to analyse land cover changes that affect soil moisture (such as fire, logging or settlements).

***Figure 2.5**. Example of the use of high-resolution satellite data for monitoring canal blocking and canal backfilling*



Source: Yelena Finegold, FAO.

Further resources

Training on Planet imagery for peatland monitoring & Hands on PLANET imagery

Part 3: Practical guidance for the use of the soil moisture mapping module

The objective of this section is to show with an exercise how to process Sentinel 1 imagery to produce wall-to-wall information on soil moisture.

The prerequisites are:

- **SEPAL account**
- **Google Earth Engine access**
- **FileZilla**
- **GIS programme (e.g., ArcGIS, QGIS)**

STEP 1: OPEN SEPAL

1. Open SEPAL and login

If SEPAL is not already open, click the following link to open SEPAL in your browser: https://sepal.io/ . For specific login or sign-up instructions please see Annex 1, 'Logging into SEPAL'.

2. Connect SEPAL to Google account

Make sure SEPAL is connected to your google account as described in Annex 1, 'Connecting to Google Earth Engine'

3. Upload your area of interest (AOI) shapefile as a GEE asset

Instructions for uploading a shapefile as an asset can be found here: https://developers.google.com/earth-engine/importing

4. Start a t1 instance in the terminal

Instructions can be found in Annex 1 'Using the terminal to start an instance'

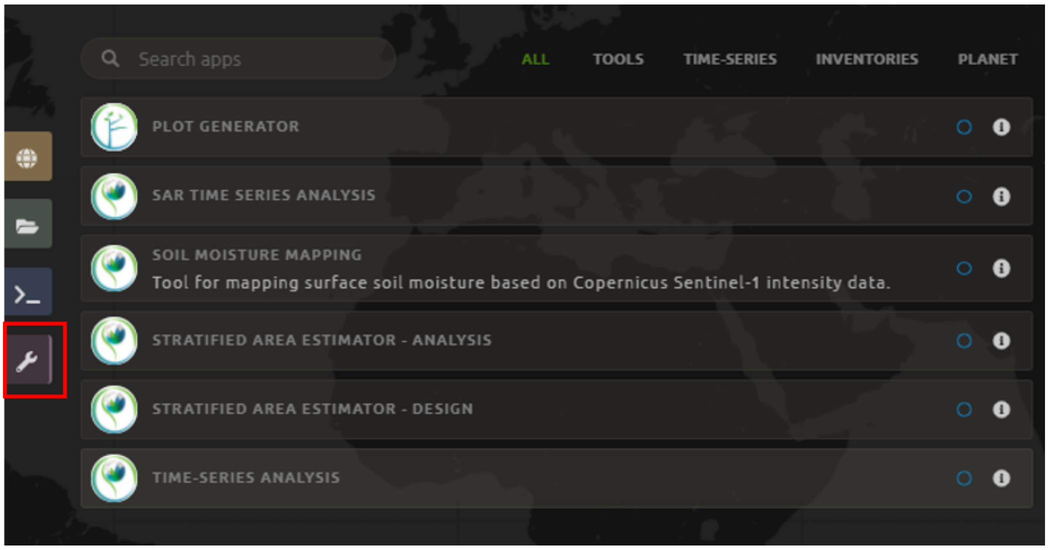
STEP 2: PROCESS SENTINEL-1 TIME SERIES DATA TO GENERATE MAPS OF SOIL MOISTURE

1. Open and launch the Soil Moisture Mapping module

- To access the module, click on the Apps tab in SEPAL. Then use the search box and write "Soil Moisture Mapping" or use bottom pagination and find it manually (Figure 3.1).

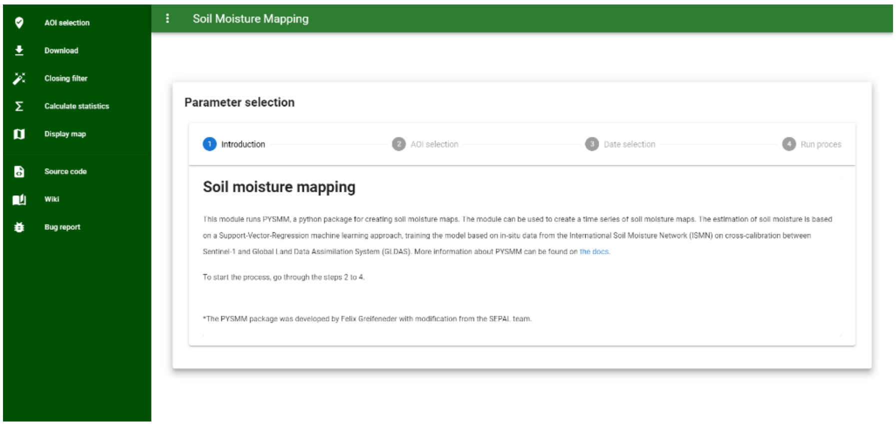
- The application will be launched and displayed over a new tab in the SEPAL panel (Figure 3.2).

Figure 3.1. *Location of the 'Apps' tab in the SEPAL interface*



Source: https://sepal.io/, accessed 2020

Figure 3.2. *Soil Moisture Mapping application in SEPAL*



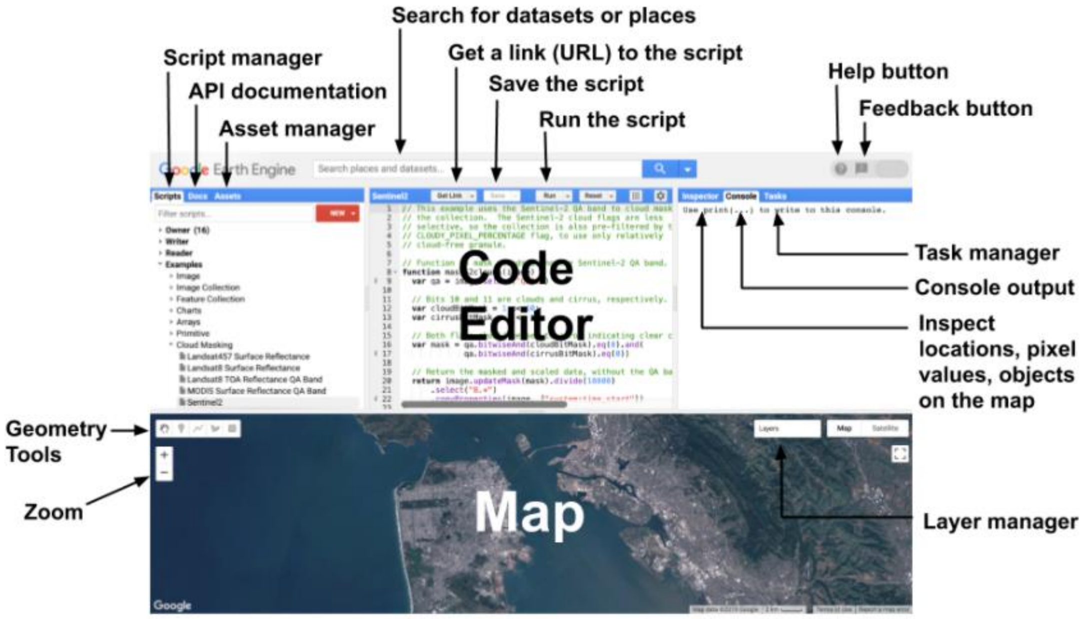
Source: https://sepal.io/, accessed 2020

- The module has 5 main steps that can be selected in the left panel: AOI selection, download, closing filter, calculate statistics, and display map.

- Click over the AOI selection step and follow the next 4 sub-steps.

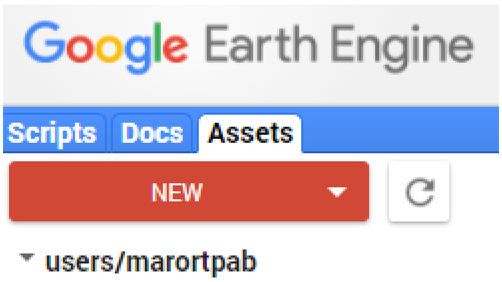
- In the AOI selection step, choose 'Use GEE asset', paste your GEE Asset ID into the box and click on the "Use asset" button to select that as your AOI. To check the asset ID, go to the GEE playground and click on the third tab on the left "Asset manager".

Figure 3.3. Google Earth Engine interface's elements



Source: Google Earth Engine[6], accessed 2020

Figure 3.4. Google Earth Engine assets

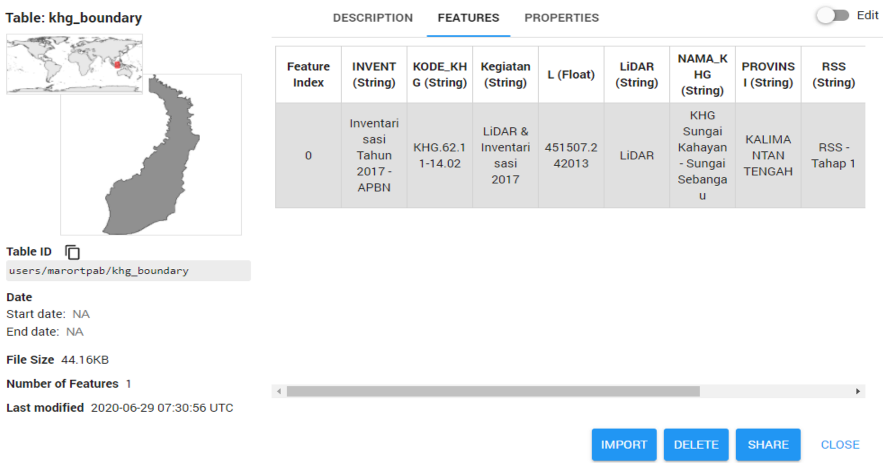


Source: Google Earth Engine, accessed 2020

- When you click on the asset i.e., a shapefile, a new window appears showing the asset properties.

[6] *https://developers.google.com/earth-engine/guides/playground*

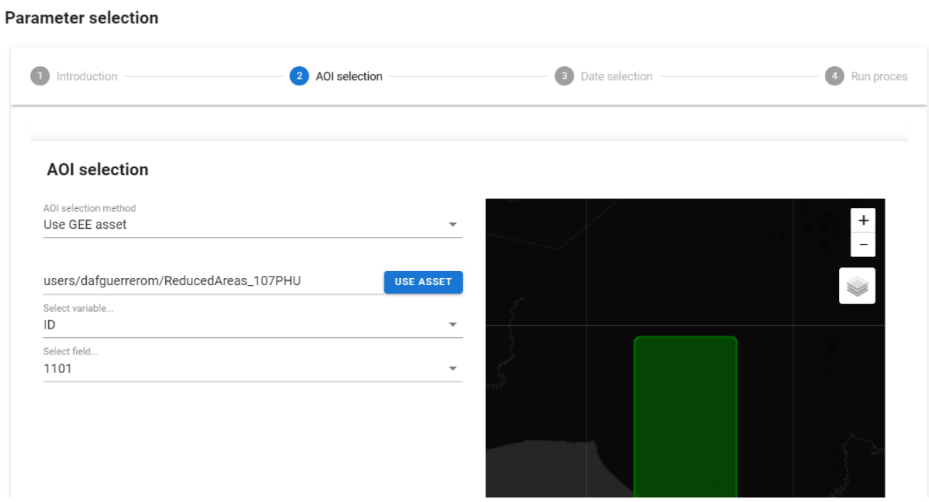
***Figure 3.5.** Uploaded asset properties on Google Earth Engine*



Source: Google Earth Engine, accessed 2020

- Copy the "Table ID" manually or make double-click on the button, the ID will be automatically copied on the clipboard.
- Two new select dropdowns will appear, choose your variable, field, and wait until the polygon is loaded into the map.

***Figure 3.6.** Area of interest selection*



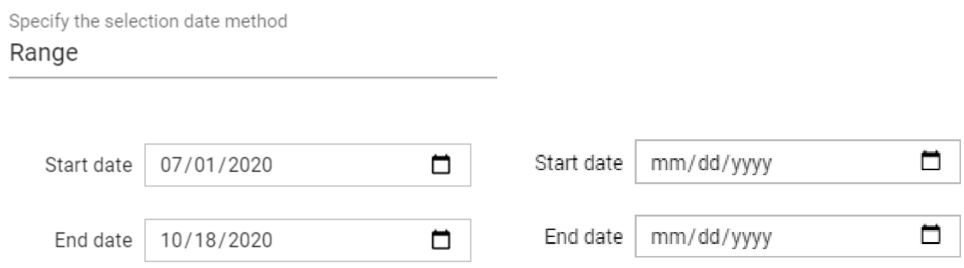
Source: SEPAL

2. Feature and date range selection

The next step in this process is to select the date range of the data that you want to process through GEE, there are three options:

- **Single date**: will process one soil moisture closest to the date selected;
- **Range**: will process all Sentinel-1 data to create a time series of soil moisture maps for the date range selected; and
- **All-time series:** will process all available Sentinel-1 data, since the launch of the satellite in 2015, to create a time series of soil moisture maps.

***Figure 3.7**. Feature and date range selection, and format of the data to process in Google Earth Engine*



Source: SEPAL

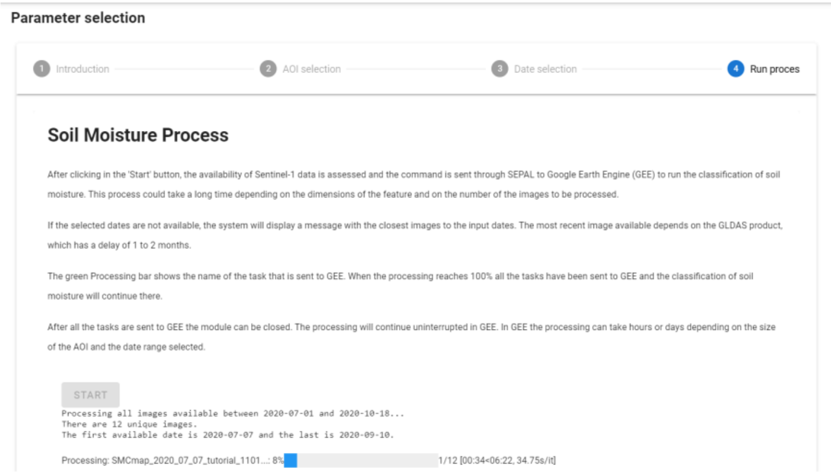
Please pay attention to the date format, it is labelled as month/day/year, for example, 20 June 2020, would be 06/20/2020.

3. Initiating the soil moisture processing

- After the filters are selected, go to the *"Run Process"* tab.
- Once the "*Start*" button is clicked, the availability of Sentinel-1 data is assessed, and the command is sent to Earth Engine to run the classification of soil moisture.
- This process could take a long time (hours or up to days) depending on the dimensions of the feature and on the number of images to be processed.
- If the selected dates are not available, the system will display a message with the closest images to the input dates.
- The most recent image available depends on the GLDAS product, which has a delay of one to two months.
- The green processing bar shows the name of the task that is sent to GEE.
- When the processing reaches 100 percent all the tasks have been sent to GEE and the classification of soil moisture will continue there.

- After all the tasks are sent to GEE the module can be closed. The processing will continue uninterrupted in GEE. In GEE the processing can take hours or days depending on the size of the AOI and the date range selected.

Figure 3.8. *Soil Moisture processing*

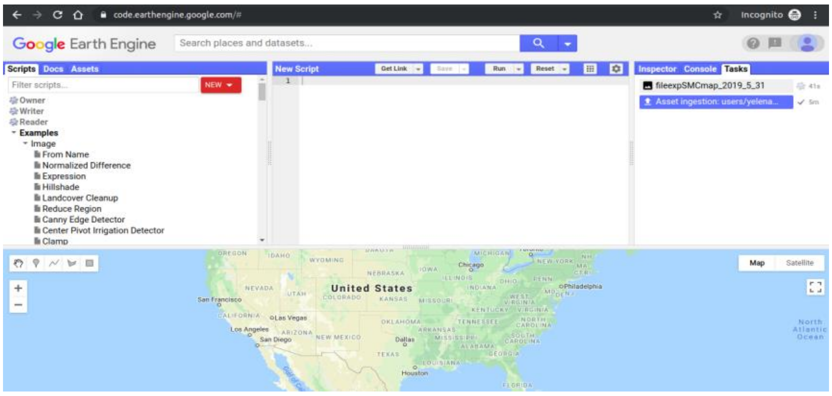


Source: SEPAL

4. Checking the progress of the soil moisture processing GEE

- A way to check on the status of each task is to go to the GEE code editor.

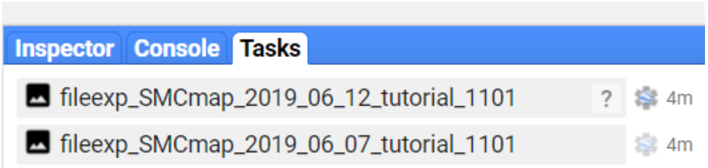
Figure 3.9. *Status of the task in Google Earth Engine code editor*



Source: Google Earth Engine

- Click on the ‘Tasks’ tab in the section on the right. You should see the process running with the spinning gear.

Figure 3.10. *Location of 'Tasks' bar on Google Erath Engine*



Source: Google Earth Engine

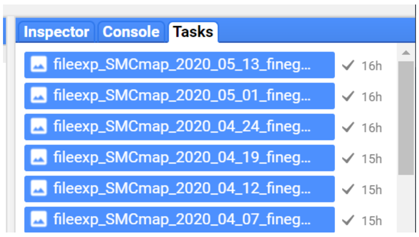
- When the download completes you will see a blue checkmark. Check periodically on your download to make sure all the dates specified are being downloaded.

STEP 3: DOWNLOAD THE SOIL MOISTURE MAPS FROM GEE TO SEPAL

1. Check if the processing is complete in GEE

- Check on the status of each task in the GEE code editor. Click on the '*Tasks'* tab in the section on the right. You should see blue checkmarks next to all the tasks.
- The soil moisture maps for each date have been downloaded to your Google Drive. The next step will automatically move those images from your Google account to your SEPAL account.

Figure 3.11. *Completed tasks in Google Erath Engine code editor*



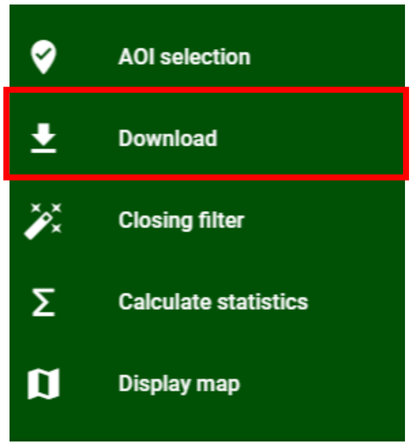
Source: *Google Earth Engine*

- You can start downloading the images while they are being processed in GEE, but we recommend waiting until all or part of the images has been processed in GEE.

2. Use the download step

- Log-in to SEPAL and start the SMM App as before.
- In the left panel, click over the 'Download' button.

Figure 3.12: *Use the download step in SEPAL*



Source: SEPAL

3. **Select the download task file**

- The file structure for downloading and managing the soil moisture data follows this structure:

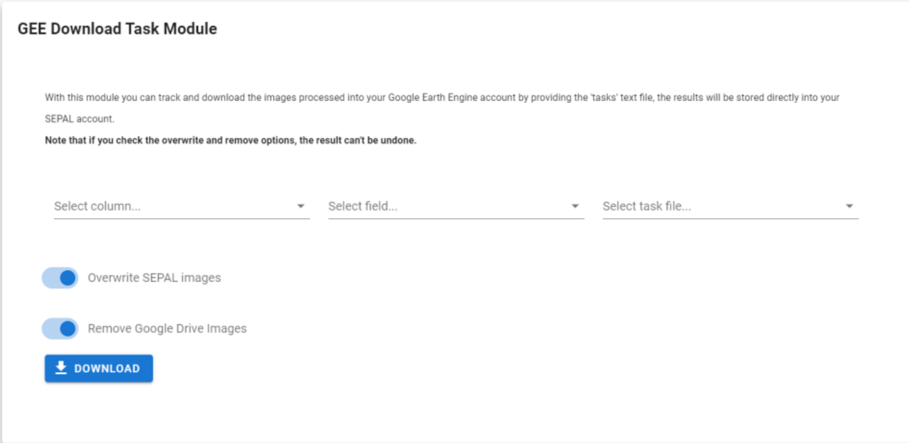
  home/username/pysmm_downloads/0_raw/asset_name/row_name

  i. All downloads can always be found in the pysmm_downloads folder. The pysmm_downloads folder can be found by clicking in the folder icon in the main SEPAL screen. Then as in any explorer window you can navigate to the desired folder.

  ii. Each time a different asset is used to derive soil moisture, a new folder for the asset will be created.

  iii. For each polygon that is used from the asset, selected by specifying the column and row field names, a unique folder with the row field name will contain the task download file.

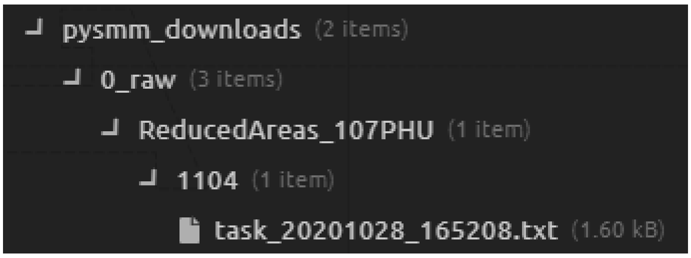
Figure 3.13: *Google Earth Engine download task module*



Source: Google Earth Engine

- The task download file can be found in the folder home/user/pysmm_downloads/0_raw/assetname/rowname/
- The task download file naming convention is: task_datedownloadinitiated_code.txt

Figure 3.14: *Task download file name convention*



Source: SEPAL

- Use the three dropdown lists to select the desired task text file by clicking on the folder names.
- There are options to overwrite duplicates already downloaded into SEPAL and to remove the downloaded images from Google Drive. Once the images are removed from Google Drive the task download file will no longer function because those images will not be stored in Google Drive.

    i. **Overwrite SEPAL images**: In case you previously have downloaded an image in the same path folder, the module will overwrite the images with the same name.

    ii. **Remove Google Drive images:** Mark this option if you want to download the images to your SEPAL account and delete the files from your Google Drive account.

- Click on the Download button to download the soil moisture maps from your Google Drive account to SEPAL.
- The images will download one by one, leave the application open while the download is running.
- After the data download completes you can use tools available in SEPAL to process and analyse these soil moisture maps.

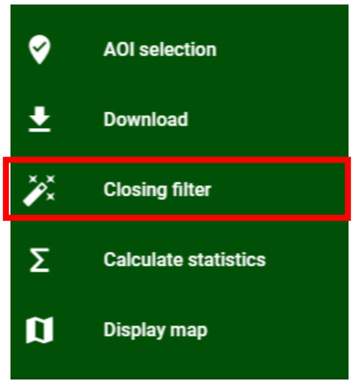
STEP 4: POST-PROCESS AND ANALYSE SOIL MOISTURE TIME-SERIES DATA

After the download is complete, we can apply a robust methodology for image filtering to fill no-data gaps and assess trends in the time series of soil moisture maps. This will require more powerful SEPAL resources. You must start a powerful cloud computer from the SEPAL interface.

1. **Select the Closing filter step**

- Shut down any running SEPAL cloud computers. For instructions, see Appendix 1 section 'Shut down and existing instance'.
- Next start up a new SEPAL cloud computer capable of running the intensive post-processing. See Appendix 1 section 'Using the terminal to start and instance' and 'What kind of instance do I need'. Also see Appendix 1 section 'Keeping an instance alive'.
- Once a new, powerful instance has initiated, start the SMM App as before. The SMM App will now be running on the more powerful cloud computer.
- In the left panel select the "*Closing filter*" tab.

Figure 3.15. *Closing filter tab in SEPAL*

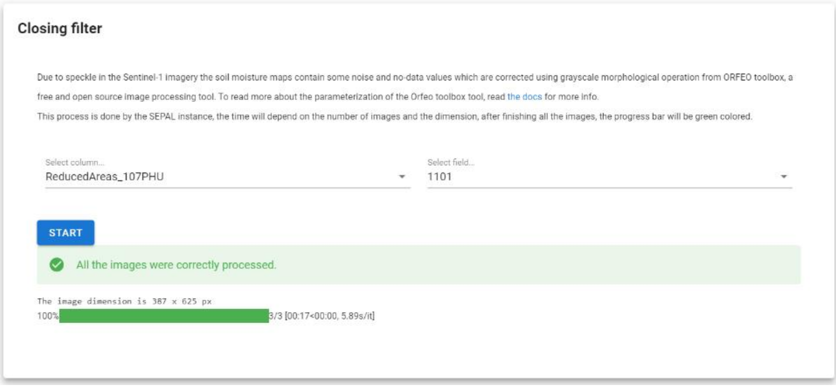


Source: SEPAL

2. **Run the post-processing section of the module**

- Navigate to the folder where the images are stored. This module will process a folder with many images, going through each of the images. Therefore, the input should be the folder in which the raw images are stored. The module will automatically display two select menus, select the desired options.

Figure 3.16. *Closing filter processing*



Source: SEPAL

The raw imagery is stored in the same folder that the task download file is located.

- Click on the *'Start'* button to run a data-filling algorithm on each of the soil moisture maps.

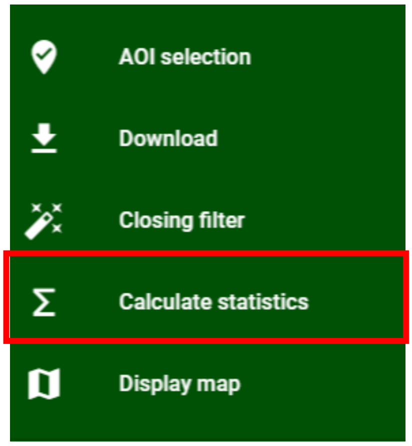
  Due to speckle in the Sentinel-1 imagery the soil moisture maps contain some noise and no-data values are corrected – to some extent – using grayscale morphological operation from Orfeo toolbox, a free and open-source image processing tool. To read more about the parameterization of the Orfeo toolbox tool, visit: https://www.orfeo-toolbox.org/CookBook/Applications/app_GrayScaleMorphologicalOperation.html.

  This process is done by the SEPAL instance, the time will depend on the number of images and the dimension, after finishing all the images, the progress bar will be green coloured.

3. Run the Statistics postprocess

- In the left panel select the *"Calculate statistics"* tab.

Figure 3.17. *Statistics postprocess tab in SEPAL*



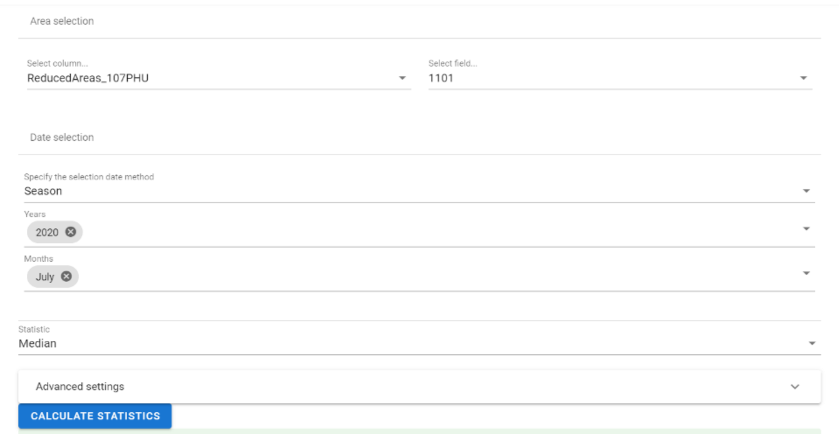
Source: SEPAL

- After the data is filtered, a time series analysis of the soil moisture maps can be performed. Several statistics can be applied whether to the entire time series or a specified range, statistics as median, mean, standard deviation, or linear trend (slope of the line) are available to process the selected data.

- This module uses the [Stack Composed python module](), which is a module that computes a specific statistic for all valid pixel values across the time series using a parallel process.

- Select column and field to process all images inside that folder.

Figure 3.18*. time series analysis of the soil moisture maps*



Source: SEPAL

- There are three options for analysing the data for different time frames.

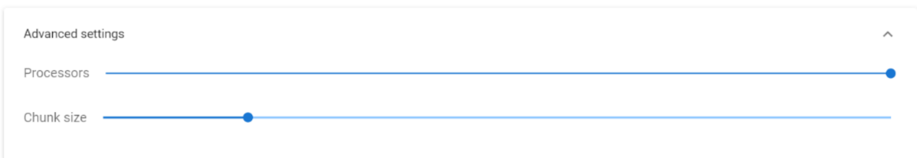
  i. **All-time series:** runs the analysis for all the images in the folder

  ii. **Range:** runs the analysis for all the images within the time frame selected

iii. **Season:** the user can define a season by selecting months. The analysis is run for only the months selected within the years selected. For example, if January, February, and 2016, 2017, 2018 are selected, then the analysis would run for January 2016, January 2017, January 2018, February 2016, February 2017, and February 2018.
You can also select only one year or month, hence it will process all the years/months in the selection.

- There are different options for the statistics that can be calculated. The options are:
  - Median
  - Mean
  - Gmean, geometric mean
  - Max
  - Min
  - Std, standard deviation
  - Valid pixels
  - Linear trend
- The '*Valid pixels'* option will create a new image representing only the count of the valid pixels from the stack.
- The Median, Mean, Geometric Mean, Max, Min, Standard Deviation and Valid pixels, are statistics that do not require much computing requirements, so the time to perform those tasks it is relatively quick, depending on the extent of the image.
- The advanced settings are intended to be used to improve the time and manage the system resources. Normally this is optimized automatically but can be modified by the user. This setting controls the number of processors you use for parallel processing, allowing you to optimize the time by processing a huge image by using several processors at the same time. Automatically all available processors will be used. Note that the more CPUs available in the instance you selected in the terminal, the faster the processing will be.

Figure 3.19. *Advances setting of the process can be modified by the user*

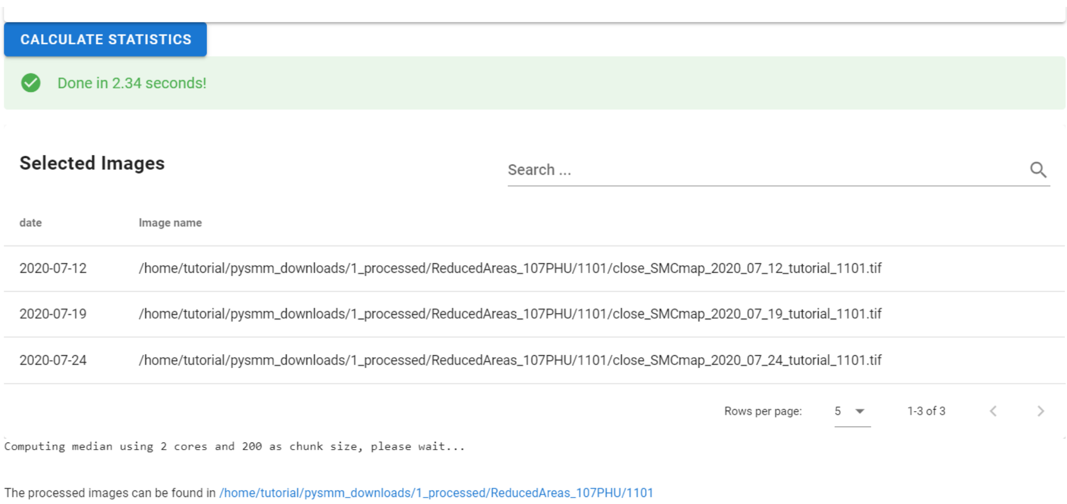


Source: SEPAL

- **Processors**: by default, the module will display the number of processors that are active in the current instance session and will perform the stack-composed with all of them, however, to test the best benchmark to the specific stack, this number could be changed within the advanced settings tab.
- **Chunks**: the number in the chunk specifies the shape of the array that will be processed in parallel over the different processors. i.e., if 200 is the specified number of chunks, then the stack-composed module will divide the input image into several small square pieces of 200 pixels with its shape, for more information about how to select the best chunk shape, follow the dask documentation.

- Once the settings are specified, click on the '*Calculate statistics*' button.
- After selecting the temporal range to run the analysis and parameter to calculate, the images that are processed are listed, along with the date of the imagery.

Figure 3.20. *List of images that were processed with date*



Source: SEPAL

- The processed images can be found in the folder: *home/user/pysmm_downloads/1_processed/assetname/rowname/stats*

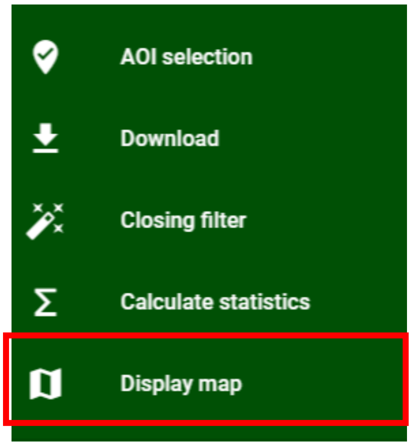
Figure 3.21. *Folder were processed images are stored*

Source: SEPAL

STEP 5: VISUALIZING IMAGERY

1. In the left panel select the "*Display map*" tab.

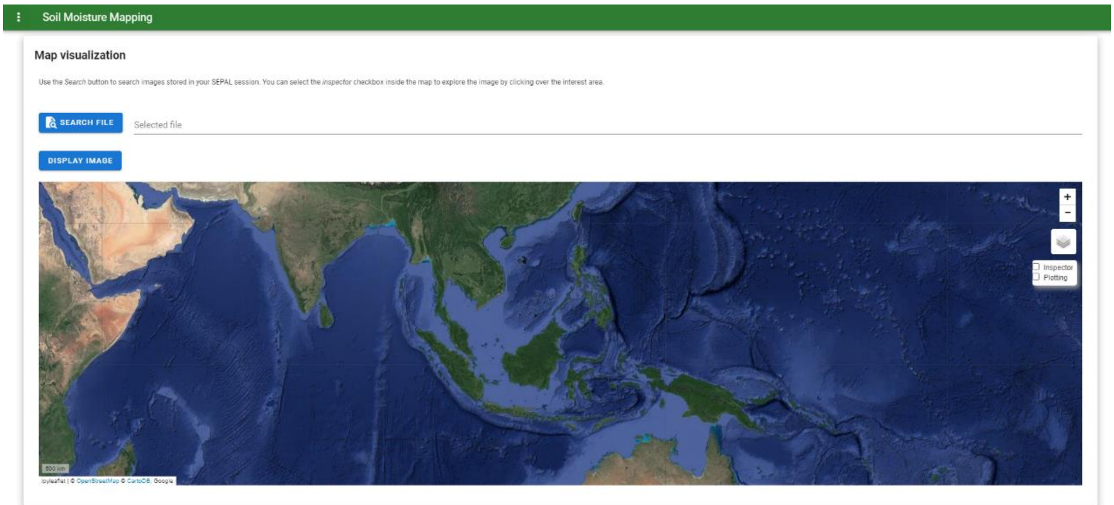
Figure 3.22. *'Display map' tab in SEPAL*



Source: SEPAL

2. The map visualization tab will allow you to display any monoband image in your SEPAL account, not only the downloaded data.

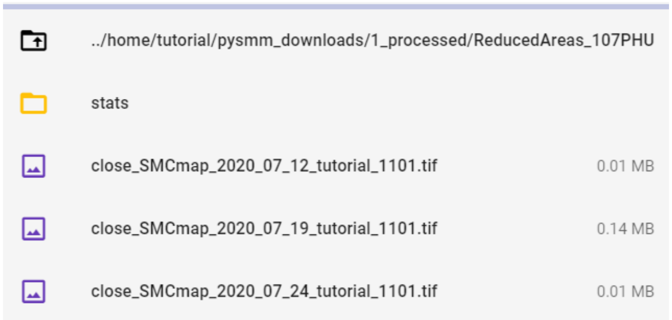
Figure 3.23. *'Map visualization' tab in SEPAL*



Source: SEPAL

3. Click over the *"Search file"* button and navigate over the dropdown list, search the desired image, and click on the *"Display image*" button.

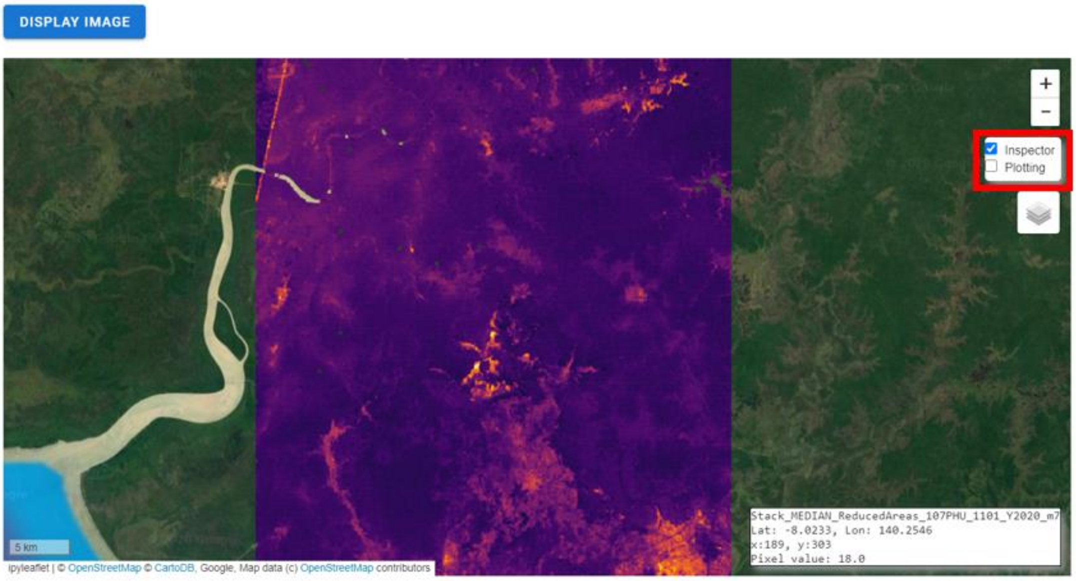
Figure 3.24. *'Search image' functionality in SEPAL*



Source: SEPAL

4. Wait until the image is rendered in the map and explore the general output.

Figure 3.25. *Output visualization in SEPAL*



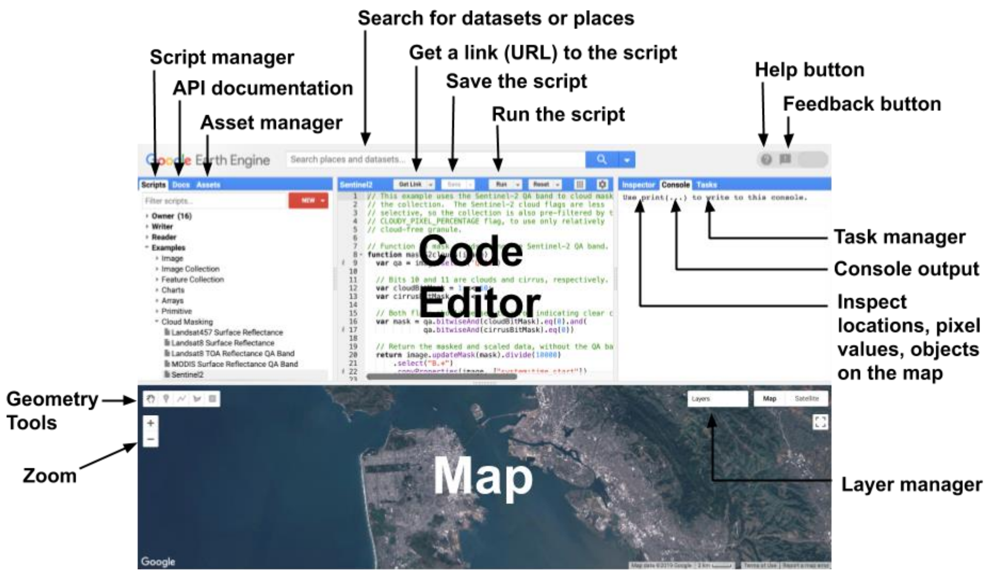
Source: SEPAL

5. Mark the "*Inspector*" checkbox and click over any coordinate inside the image to explore the pixel values, you will see an output box in the bottom right corner with the data.

While waiting for the soil moisture maps to download let us explore the availability of Sentinel 1 imagery over Indonesia. Click on this link to see the number of acquisitions of Sentinel 1 globally:

https://code.earthengine.google.com/6c919eaa51cb77507e373af8eca3fbc7

***Figure 3.26**. components of Google Earth Engine*



Source: Google Earth Engine

6. For more information about using Google Earth Engine, go to: https://developers.google.com/earth-engine/playground

Guiding questions

1. *Choose an area that you work in. How many Sentinel-1 images are available over your area of interest?*
2. *How many Sentinel-1 images are available over a location in Germany?*

STEP 6: DOWNLOAD AND UPLOAD DATA FROM OR TO SEPAL TO OR FROM YOUR COMPUTER

1. **Connect FileZilla to your SEPAL account**

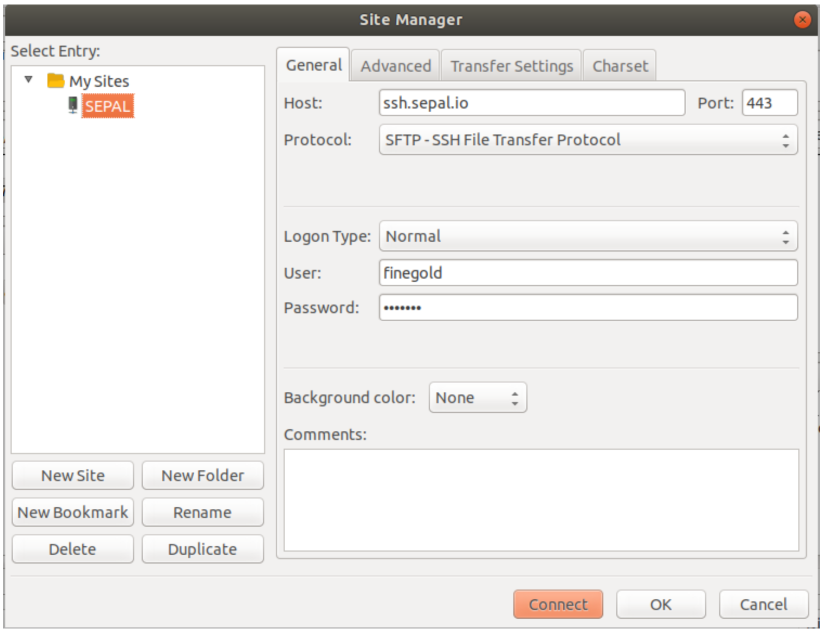
- Download FileZilla from this link.
- Accessing files in SEPAL is easy using FileZilla. To use FileZilla, open the application and connect to the SEPAL server by selecting Menu File --> Site Manager in the menu tab.

2. **In the site manager pop-up click on the 'New Site' button. Use the screenshot below as a guide for filling in the form:**

- Host: ssh.sepal.io
- Port: 443
- Protocol: SFTP – SSH File Transfer Protocol
- Logon Type: Normal
- User: your SEPAL username

- Password: your SEPAL password

***Figure 3.27**. Site manager pop-up in FileZilla*



Source: FileZilla

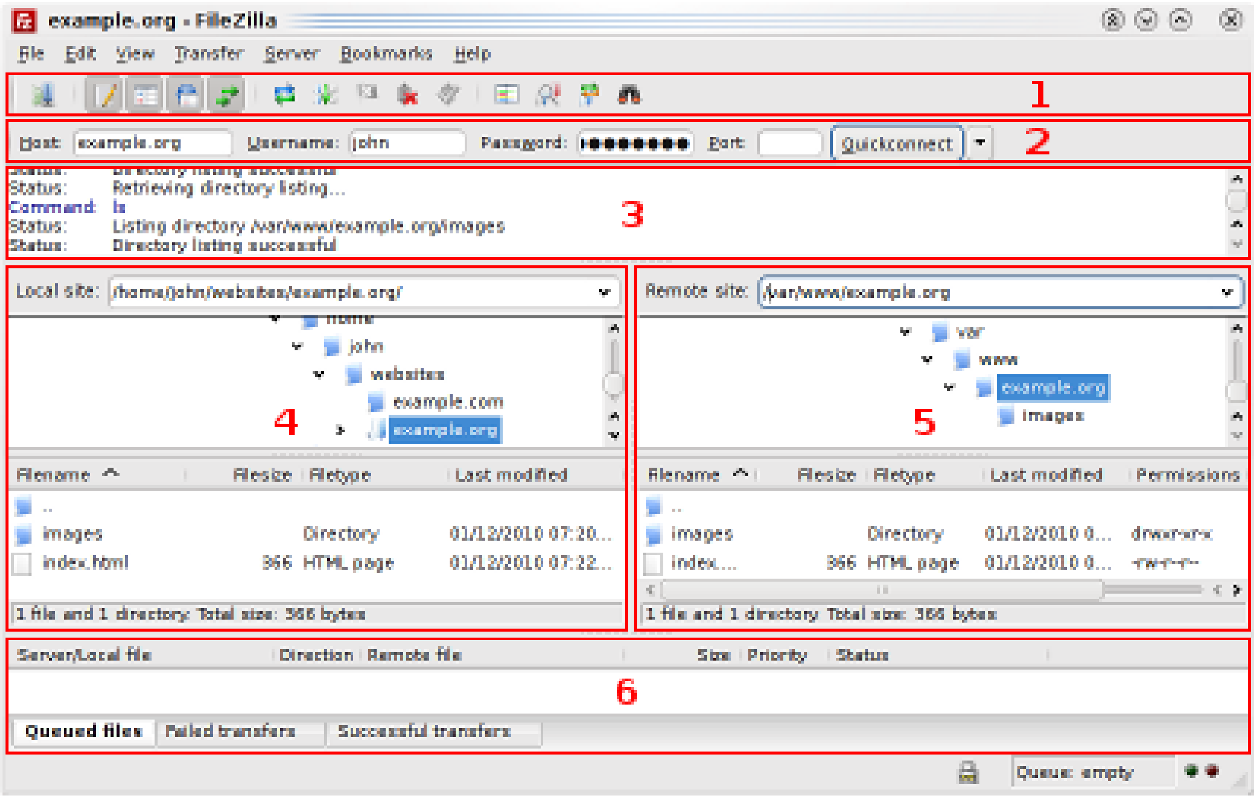
3. **Click Connect and your SEPAL drive will appear in the right panel, parallel to the panel on the left with the files on your computer.**

4. **Using FileZilla**

Here is a quick introduction from the FileZilla online tutorial corresponding to the image below:

- the toolbar (1)
- quick connect bar (2),
- The message log (3) displays transfer and connection related messages. Below, you can find the file listings.
- The left column (local pane, 4) displays the local files and directories, i.e., the folders on your PC. Make sure you are located in the right folder. Ideally, you should have a folder on your computer that will store all data related to this process, click on that folder.
- The right column (server pane, 5) displays the files and directories on the server you are connected to. Both columns have a directory tree at the top and a detailed listing of the currently selected directory's contents at the bottom. You can easily navigate either of the trees and lists by clicking around like in any other file manager.
- At the bottom of the window, the transfer queue (6) lists the to-be-transferred and already transferred files. It is important to check in here whether the files have been successfully transferred.

***Figure 3.28**. FileZilla main components*

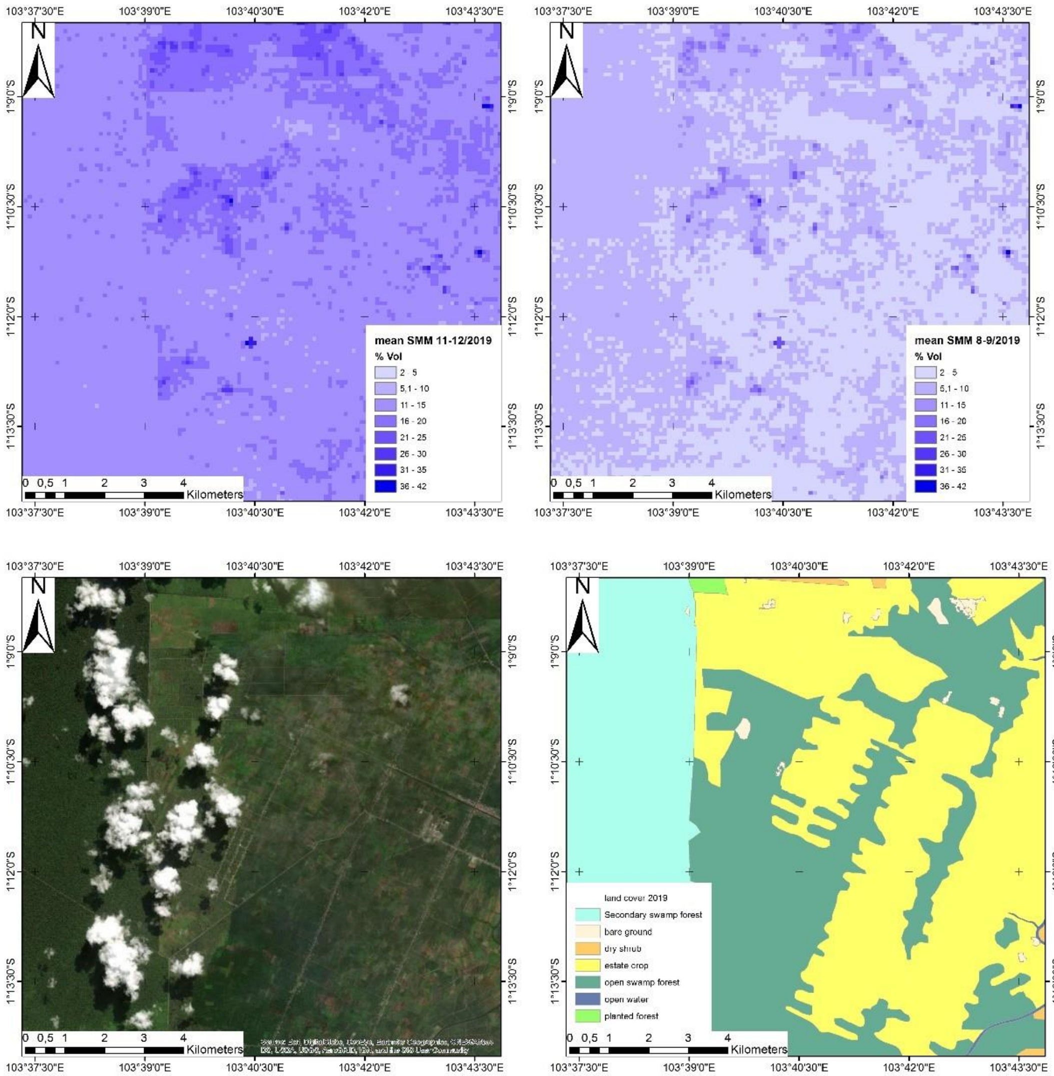


Source: FileZilla

Part 4: Interpretation of results

The individual maps contain soil moisture values that are expressed in percentage of volume, in m^3 of water per m^3 of soil, using the algorithms and calibration of Greifeneder et al. (2019). Values can range from 0 to 100 percent, being very dry and very wet, respectively. Values above 100 could be interpreted as flooded areas, but further analysis is needed (Figure 4.1).

Figure 4.1. *Example of mean soil moisture mapping (SMM) product in 2019 of an area with diverse land uses. Dry and wet seasons in that location are in November–December (Upper left) and August–September (Upper right)*



Source: Pablo Martin, FAO.

SMM products are subject to further development and undergoing calibration and validation exercises. At the time of writing in December 2020, the underlying model is calibrated by global field data from the International Soil Moisture Network (ISMN), which only contains a few measurement stations for the whole SEA region. Throughout the elaboration of the project, it has been found that the model estimates follow the general trend of soil moisture over time when compared to local field data. Thus, the retrieval of trends and anomalies is feasible based on the SMM product. However, as the SMM product is subject to systematic errors, its absolute values might considerably differ from the field measurements. Local calibration is therefore needed to correct for that bias.

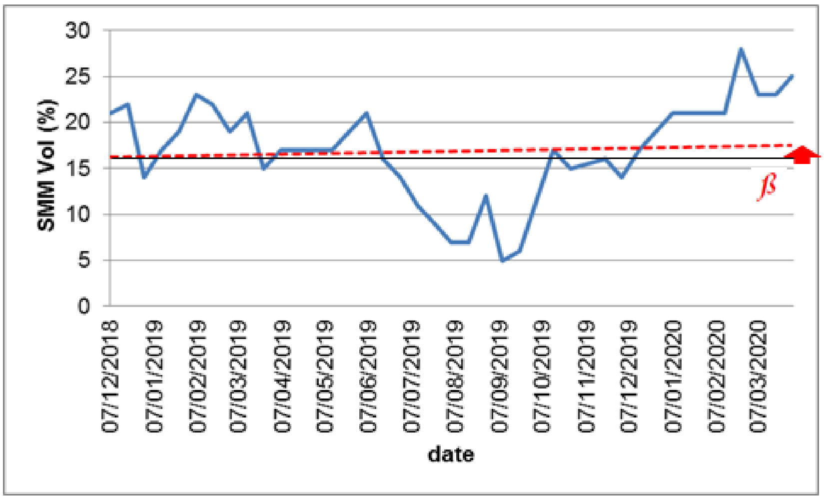
A. PIXEL LEVEL INTERPRETATION

SMM products should not be interpreted at a pixel level. Drained and degraded peatlands contain highly porous peat with high hydraulic conductivity, i.e., water moves easily within the peat and penetrates layers where the remotely sensed information can be detected. A pixel showing high SMM values may be adjacent to others that have slightly higher topography, and therefore appear drier on the surface, even though still the same amount of water is moving underneath. Other similar variables might also influence the SMM results, e.g., differences in land cover such as differences between forested and non-forested land. Further field data would help in verifying the peatland ecosystem characteristics where the SMM works best, and where it is not recommended to be used. However, FAO has established the areas where the model, in its current state, has proven to correspond with the conditions on the ground. There are other, alternative ways to monitor GWL, including using LiDAR for detecting canal water depth, however their cost and complexity currently exceeds that of the FAO tools explained in this manual.

B. STATISTICAL ANALYSES

The soil moisture mapping module in SEPAL produces several statistical analyses, the slope of a linear trend, median, mean, maximum value, minimum values, and standard deviation within a user-defined period. A direct quantitative interpretation alone of the SMM product is not considered appropriate use of the data. For example, monitoring peatland restoration using the linear trend product, which measures the slope of a positive or negative linear regression between SMM and time, requires some knowledge of the seasonality in the area analysed to be able to interpret the variation of such product. This is because the linear trend depends strongly on the start and end dates selected in the analysis. The linear trend product describes the positive or negative change of soil moisture throughout time at the pixel level. In general, a positive change means that the latest SMM selected has higher values than the past SMM, and a negative change if the latest SMM have lower values than the previous ones. Therefore, the value of a single pixel represents the trend after the selection of images from different dates. Calculating a linear regression between date and soil moisture will result in the plot in Figure 4.2.

***Figure 4.2**. Linear trend calculated throughout a period, using all available SMM data over a location*



Source: Pablo Martin, FAO

The simplest linear regression between time and soil moisture can be written as:

$$y = \alpha + ßx$$

Where:

y = soil moisture

α= intercept value of the equation

ß= Slope of the line

x= date of the image[7]

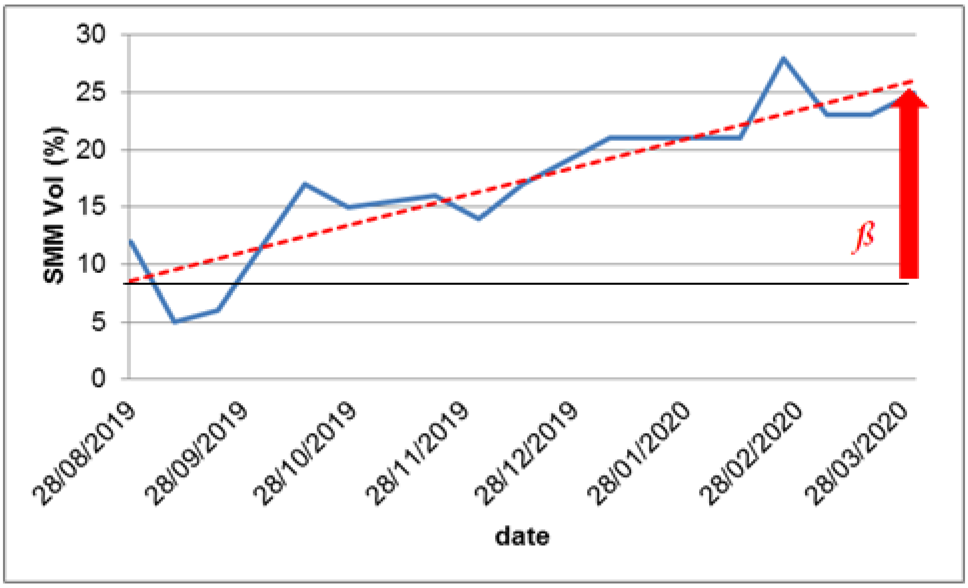
In Figure 4.2, ß represents the slope of the linear trend which approximates the trend (positive or negative) in soil moisture in the range of dates selected. ß is the angle between the horizontal line (black) and the linear trend (red dashed line). In this case it is positive because the angle is above 0, but very low. The last value in the time series is higher than the first one, but there is a lot of variation in between due to wet and dry periods, peat decomposition state, and origin of the water, which may increase the variability of the soil moisture values.

However, in Figure 4.3, a stronger trend can be seen, ß is also positive, but with a higher value than before. Soil moisture at the start of the selected date range is much lower (this is the dry period in this location)

[7] This unit is expressed by default in milliseconds since 1970-01-01 T00:00:00Z. This is a conventional way to label date and time in satellite imagery. Because this unit has large values i.e., 2020/10/30 (YYYY/MM/DD), 12:00:00 (HH:MM:SS) equals to 1604055600000 milliseconds, the output values of the linear trend product are usually large as well (https://currentmillis.com/)

than at the end (start of the wet period). The analysis is for the same location, showing a clear example of how important it is to select the appropriate dates to generate this product, and have a basic knowledge of the seasonality of the area that is being explored.

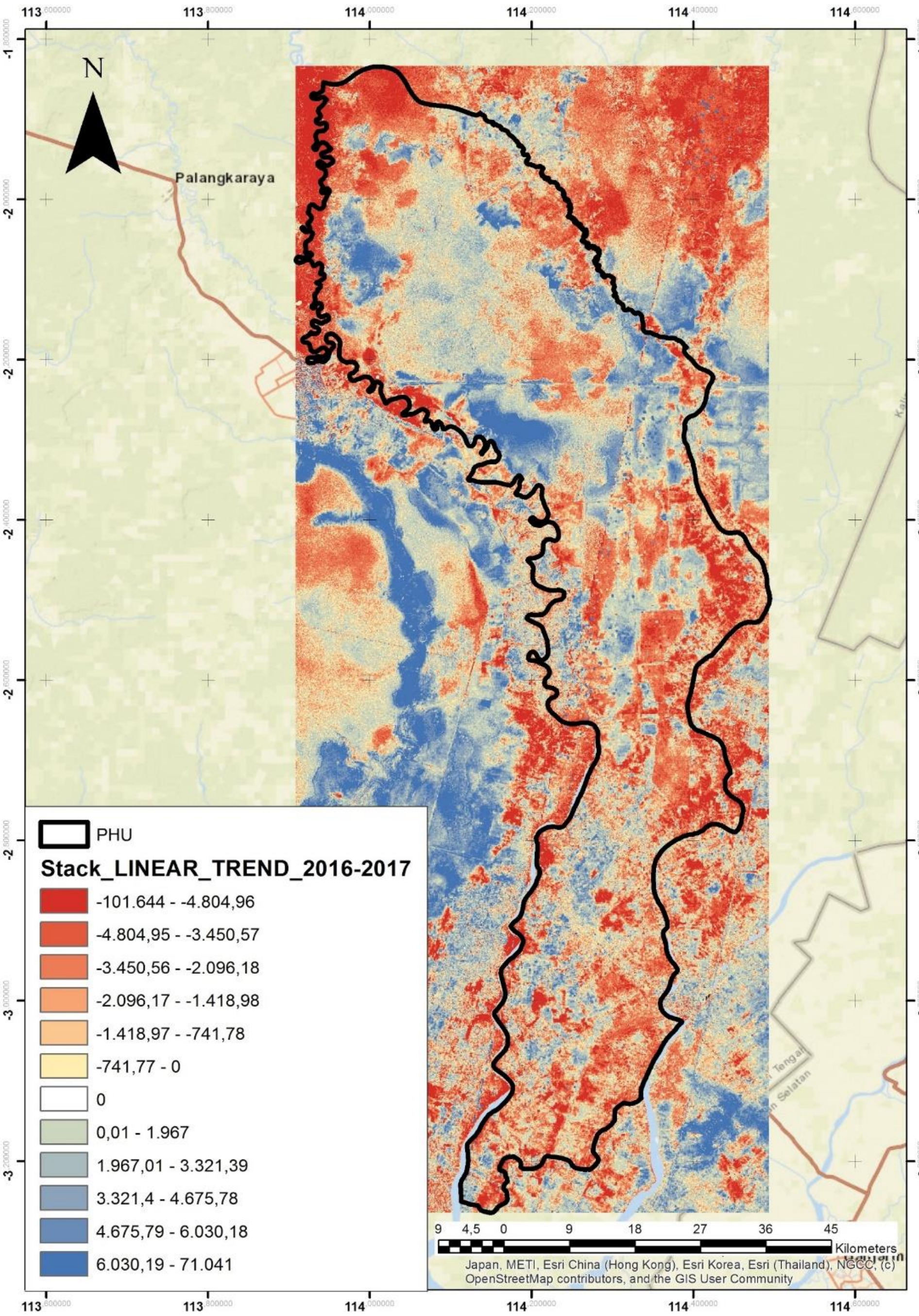
***Figure 4.3**. Linear trend calculated over a shorter period than the one selected in Figure using less available SMM data over the same location*



Source: Pablo Martin, FAO

The pixel values shown in a linear trend image correspond to the slope (ß) value of the equation (Figure 4.4). The linear trend product can be directly used to interpret the trends with some limitations (see the following section: 'D. Limitations to interpret soil moisture in the peatland landscape'), however, because of the large values displayed, the product can be rescaled using ArcGIS, QGIS or any other geospatial software. The recommendation is to rescale the product within the interval (-1,1).

Figure 4.4. *Linear trend image as a result of using all available SMM images in the years 2016–2017 over the Peatland hydrological unit "KHG Sungai Kahayan – Sungai Kapuas"*



Source: Pablo Martin.

C. VALIDATION OF THE SOIL MOISTURE MAPPING PRODUCTS

The validation of the SMM product has been done using field data provided by BRG. These data were collected in the field between the years 2018, 2019 and 2020 by the system called Sistem Pemantauan Air Lahan Gambut (SIPALAGA[9]). The variables available are GWL (m) and soil moisture (SM) (Kg/m^2). For each variable, minimum, mean, and maximum values were provided for each date of measurement. Linear Pearson correlations were calculated using values of GWL and soil moisture against available SMM values for the same location and date. Using the coordinates of the SIPALAGA measurement points, the closest overlapping one-hectare pixel for the SMM product was selected and all available values for that pixel were compared with available measurements matching the same dates.

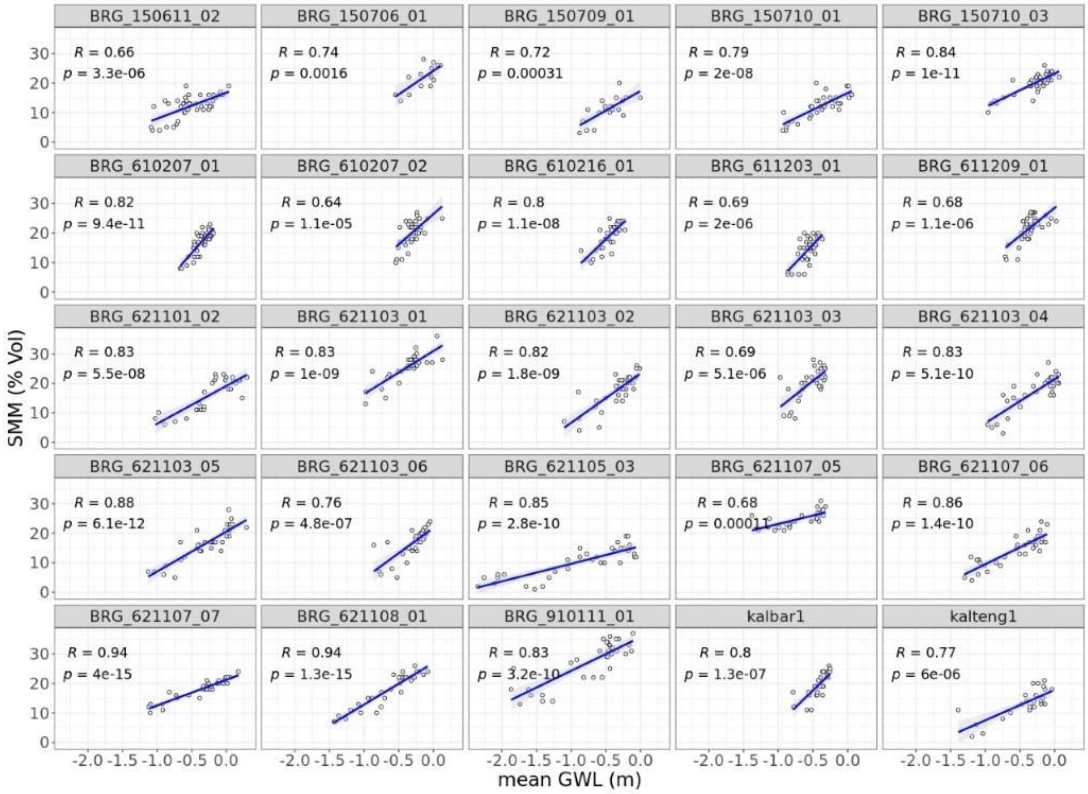
High and significant correlations were found between SMM values and GWL for some measurements, with correlations ranging from 0.63 to 0.93. Some correlations were also significant between soil moisture and SMM but to a less extent. However, there are areas where the SMM model is not recommended due to low correlations. These low correlations could be due to the type of land cover or other factors: dense vegetation might be interfering with the radar signal, the land surface might be degraded, and the peat properties might have changed its dynamics or errors in field data collection might have occurred.

For locations that showed correlation coefficients equal to or higher than 0.5 a filtering was made based in the following criteria:

- Only correlations between GWL–SMM, as soil moisture seems to have more errors in the collection of field data;
- Locations were selected with a timespan covering as many dates as possible or well distributed throughout the year and including low and high values for higher variability (dry and wet seasons respectively);
- Locations were avoided where field data seem to be faulty or not reliable due to strong variations in the measurements, long periods without collecting any data (flat lines), or the same value for a long period (indicating possible machine error); and
- Trends between field data and simulated are visually reasonable matching peaks and valleys in the same dates between datasets (as shown in Figure 4.5).

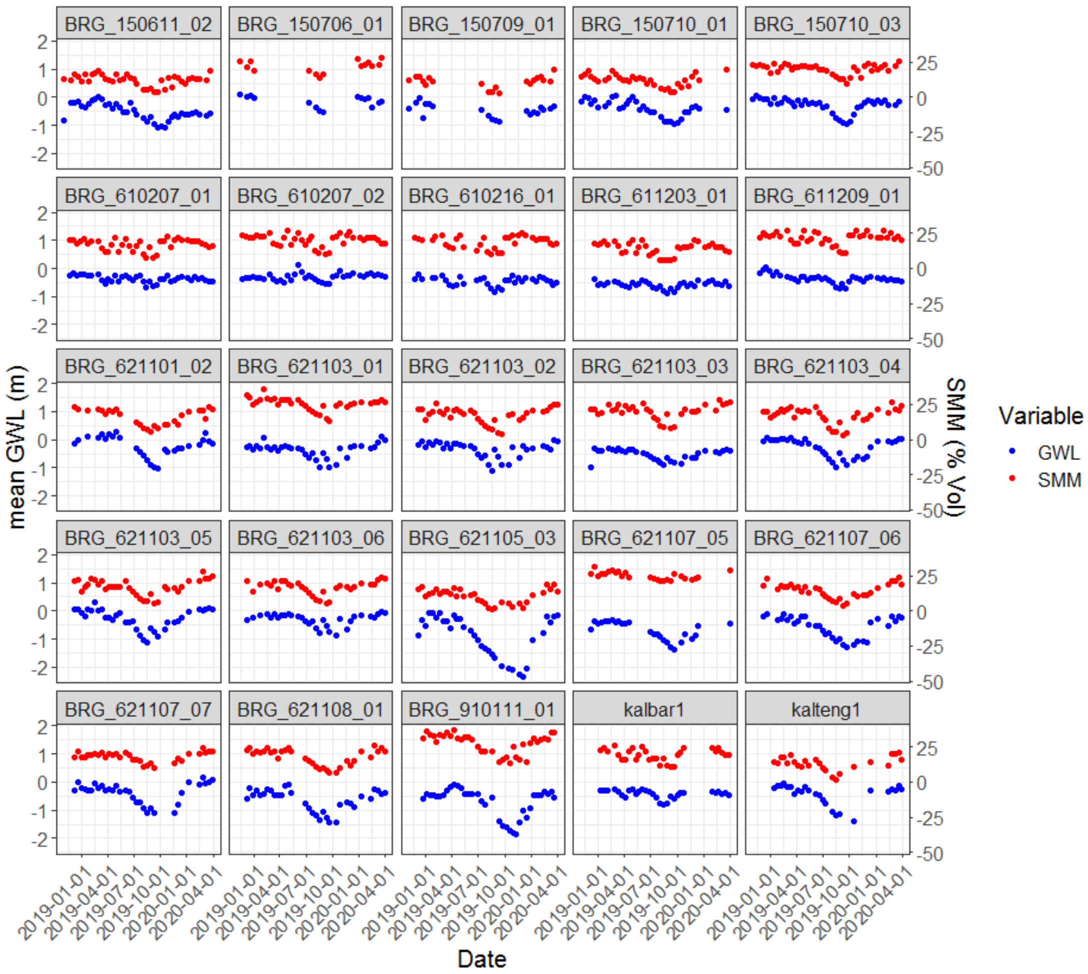
The result of this filtering process was the selection of 25 locations across the country (Figure 4.5 and Figure 4.6). Because of the high correlations found in these locations, it is suggested that land cover and physical features like vegetation structure, topography and soil structure are appropriate for a good retrieval of the soil moisture product.

Figure 4.5. *Pearson correlation and level of significance between mean groundwater level (m) and the soil moisture mapping product for the selected locations*



Source: Pablo Martin, FAO

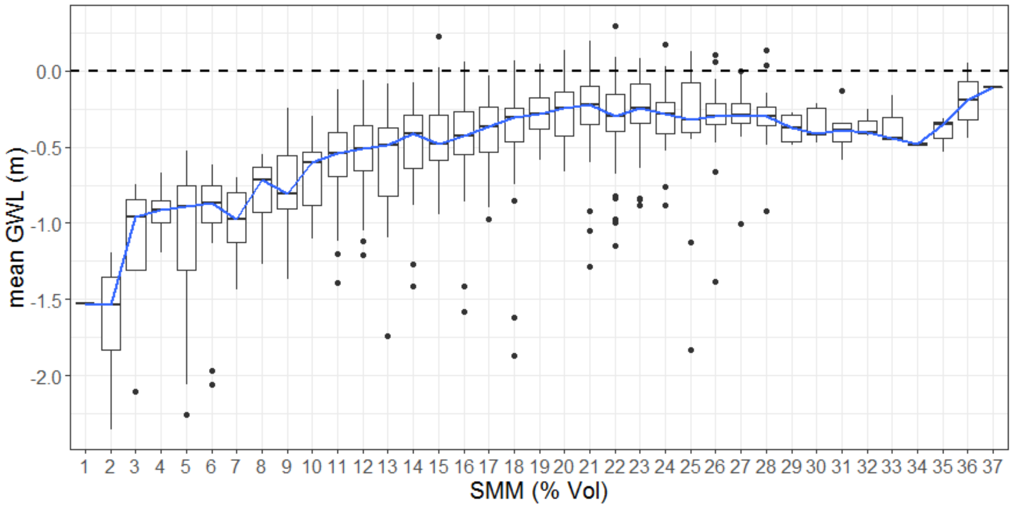
__Figure 4.6.__ Groundwater level and soil moisture mapping values for the selected locations



Source: Pablo Martin, FAO

When the distribution of GWL data is displayed against SMM, an increase in GWL is observed as SMM increases (Figure 4.7). However, the data employed in this analysis is limited in sample size (n=826) and period. The SMM product has been only evaluated with field data collected during the end of the year 2018, all 2019, and the beginning of 2020 (Figure 4.8). Field data from a more extended period would be needed to compare the model with data from dry and wet seasons that considers interannual variations from different years. Recent data agreements between FAO and BRG have provided a larger dataset for longer time series to continue with this validation. Future agreements between the FAO and the World Resources Institute and FAO-NASA are on the process to collect more diverse data into this analysis.

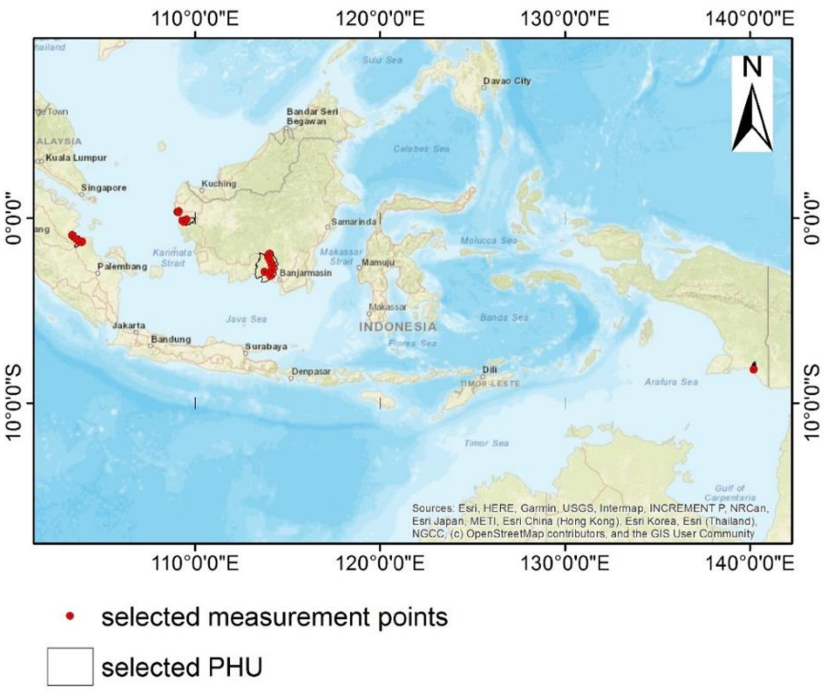
Figure 4.7. *Distribution of mean groundwater level compared to soil moisture modelled values*



Source: Pablo Martin, FAO

Despite the results presented here, the evaluation of linear correlations is a quick and straightforward approach to validate the data. Comparisons with rainfall data and testing different time delays when comparing GWL and SMM can also improve the analysis, as it is known that the movement of water inside the peatland layer is driven by complex factors (Jaenicke *et al*., 2011).

Figure 4.8*. Selected measurement points and peatland hydrological units to validate the soil moisture mapping model in Indonesia*



Source: Pablo Martin, FAO

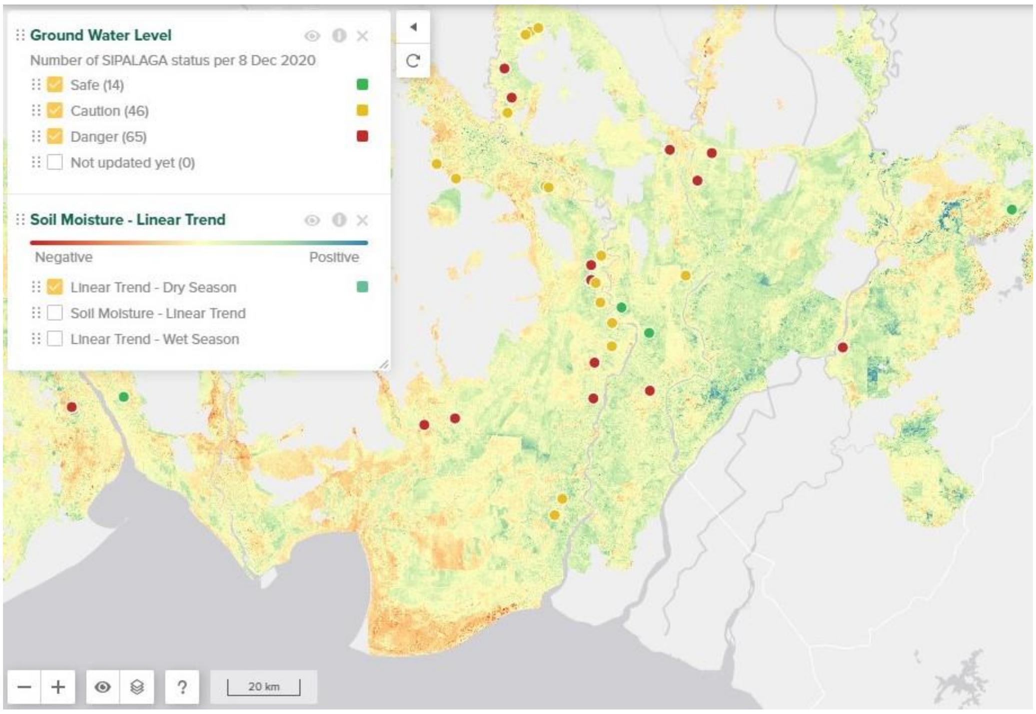
To date, most of the measurement points used to validate the SMM product are frequently placed as standalone locations in easily accessible areas next to roads, degraded agricultural areas, or open woodlands. More information about the sampling design of SIPALAGA would be needed to assess the representativeness of field data. The distribution of measurement points along transects or with a regular distribution in the landscape is needed to represent the different gradients (distance from canals, peat depth, vegetation density or burnt areas) affecting the water dynamics in peatlands. Measurement points placed in more remote areas or under dense vegetation are scarce. A transect of measurement points under different vegetation densities, i.e., from open peatlands to densely forested peatlands, will help to detect the threshold under which GWL-SMM datasets are no longer correlated, limiting the canopy density were to utilize the SMM product.

Despite the limited validation points used to date, this has proven to be a powerful method for spatially estimating SMM and GWL and suggesting a correlation with GHG emissions. The work is still in progress and in the meantime, SMM data is being exchanged with other partners (WRI Indonesia, NASA peat fire project) on improving access to a wider range of reliable datasets for groundwater level and surface soil moisture to help improve the analysis of all teams working on peatland monitoring in Indonesia.

A shown in Figure 4.9, SMM is available on the PRIMS platform[8]. Derived products (linear trend and yearly average) represent a preliminarily selected extent of data masking out primary and secondary swamp forest, due to canopy penetration limitations in the Sentinel-1 C- band sensor. The masked soil moisture trend data excludes about 25 percent of the area from the 107 PHU. The mask of land cover was made using the 2015 land cover maps from the Ministry of Forestry and Environment. To note that the latest land cover maps are not considered in this mask and changes in land cover might have occurred.

[8] https://prims.brg.go.id/

Figure 4.9. *Soil moisture linear trend for dry seasons from 2015-2020 and the associated GWL measurement stations as shown in PRIMS platform*



D. LIMITATIONS TO INTERPRET SOIL MOISTURE IN THE PEATLAND LANDSCAPES

The 25 selected measurement points are not fully covering the complexity of the peatland landscape in Indonesia, but these locations are representative of a set of physical features, that seem to be optimal for the functioning of the SMM due to the strong correlations we found between SMM and GWL. Therefore, the interpretation of the SMM product with the data available now must be limited to areas with similar physical features to those observed in the selected locations.

To limit the extent and validity of our SMM product one possible approach is to look for locations with similar physical features across the country. With this aim we selected a set of physical variables (Figure 4.10), using spatial raster datasets that are important for the configuration of peatland landscape and have an influence on the behaviour of the main component of the SMM model, radar backscatter (Table 1).

Table 1 – List of available spatial datasets and their sensitivity to physical variables on a peatland landscape

Dataset	Units	Spatial resolution	Description/relation with peatland landscape
Landsat 2019 Red band[9]	Reflectance (0-255)	30 meters	Reflectance in the different wavelengths is related to changes in vegetation density, biomass, health status and water content, helping to differentiate between types of land cover
Landsat 2019 Near-infrared band[9]	Reflectance (0-255)	30 meters	
Landsat 2019 Short-wave infrared band 1[9]	Reflectance (0-255)	30 meters	
Landsat 2019 Short-wave infrared band 2[9]	Reflectance (0-255)	30 meters	
Global Ecosystem Dynamics Investigation (GEDI)[10]	Canopy height (meters)	30 meters	Canopy height is directly related to tree biomass and vegetation density
Shuttle Radar Topography Mission (SRTM)-elevation[11]	Elevation (meters)	30 meters	The topography is related to the presence of peatlands, frequently located in the lowlands with gentle slopes
SRTM-slope[11]	Slope (degrees)	30 meters	
SRTM-aspect[11]	Aspect (degrees)	30 meters	
Distance to canals[12]	meters	1 meter	Proximity to canals is related to drained and degraded peatlands in comparison to

[9] http://earthenginepartners.appspot.com/science-2013-global-forest

[10] https://glad.umd.edu/dataset/gedi

[11] https://cmr.earthdata.nasa.gov/search/concepts/C1000000240-LPDAAC_ECS.html

[12] Generated using the 2016 canal network provided by WRI.

			peatland areas located at further distances
Sentinel-1-StdDev (Standard Deviation) VV band (2019)	decibels	30 meters	Temporal variation of backscatter is an indicator of variation in soil moisture. Permanent forest canopy shows very low variation, whereas bare soil or grassland shows higher variation.
Sentinel-1-StdDev (Standard Deviation) VH band (2019)	decibels	30 meters	

Source: FAO, 2020.

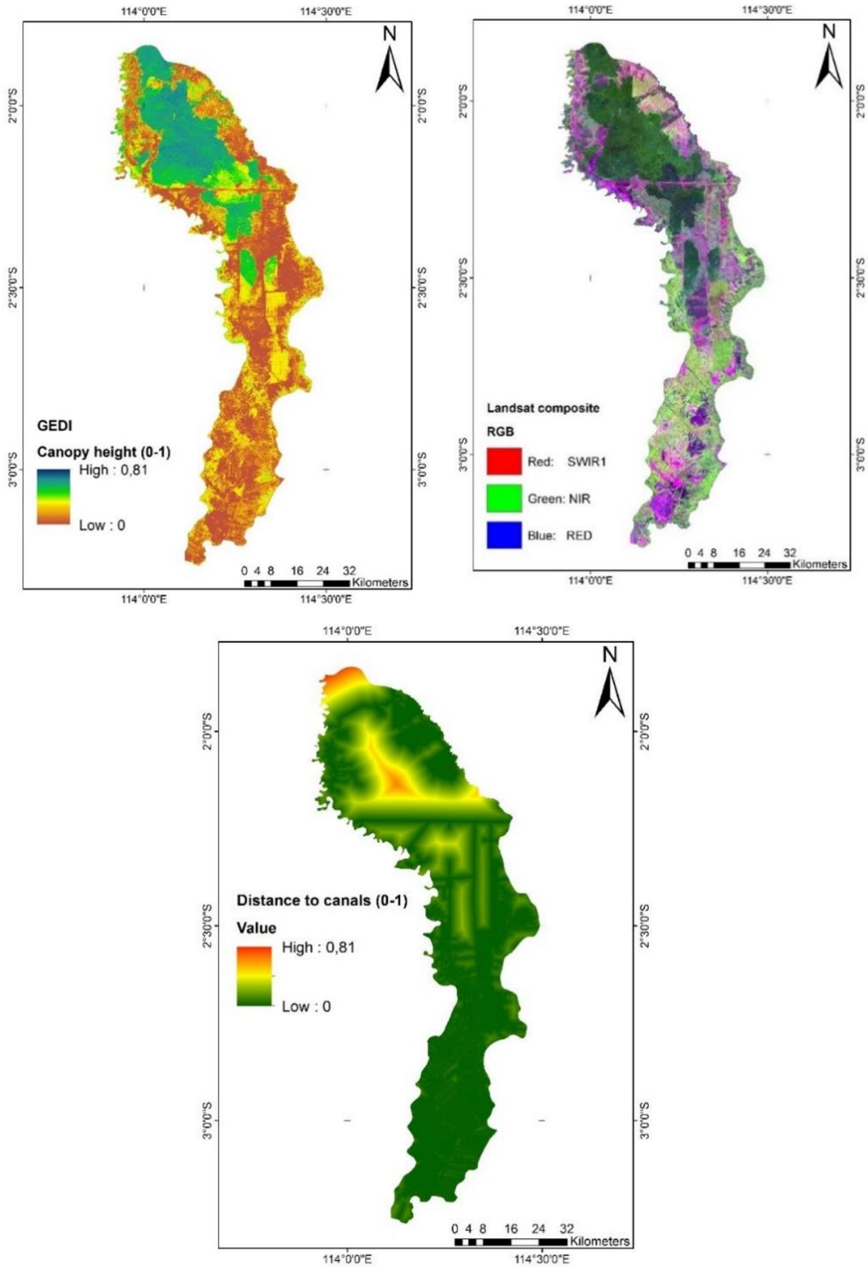
The features of the measurement points, although they can be similar in terms of canopy height, topography, or distance to canals are not identical. Different combinations of these features can offer similar conditions to the radar signal to allow it to penetrate the objects and retrieve similar soil moisture values. A machine learning approach was used to capture these complex and non-linear relations between the different types of variables selected and determine areas with similar characteristics. Aiming to include a higher variation and representativity of data across all PHUs, an additional number of 14 measurement points were added into the computation. These new measurement points although having less amount of data in terms of dates, also showed highly significant correlations.

When a specific class of interest must be classified and separated from all other classes a One-Class Support Vector Machine (OCSVM) algorithm can be implemented (Moya et al., 1993). OCSVM has been used in the fields of remote sensing and ecological modelling to construct maps based on binary classifications, i.e., the “target class” and the “outlier class”. Using the OCSVM classification, training data and allocation can be focused on the specific target class only, in our case the features of the measurement points.

The OCSVM algorithm analyses the inputs given and defines the target class. In a second step, it searches throughout the rest of the data and defines the outlier class with the outlier values of the target class. Some examples of the use of OCSVM have been the mapping of species distribution (Song et al., 2016), paddy rice mapping (Xu et al., 2018) or specific land cover classifications (Sanchez-Hernandez et al., 2007).

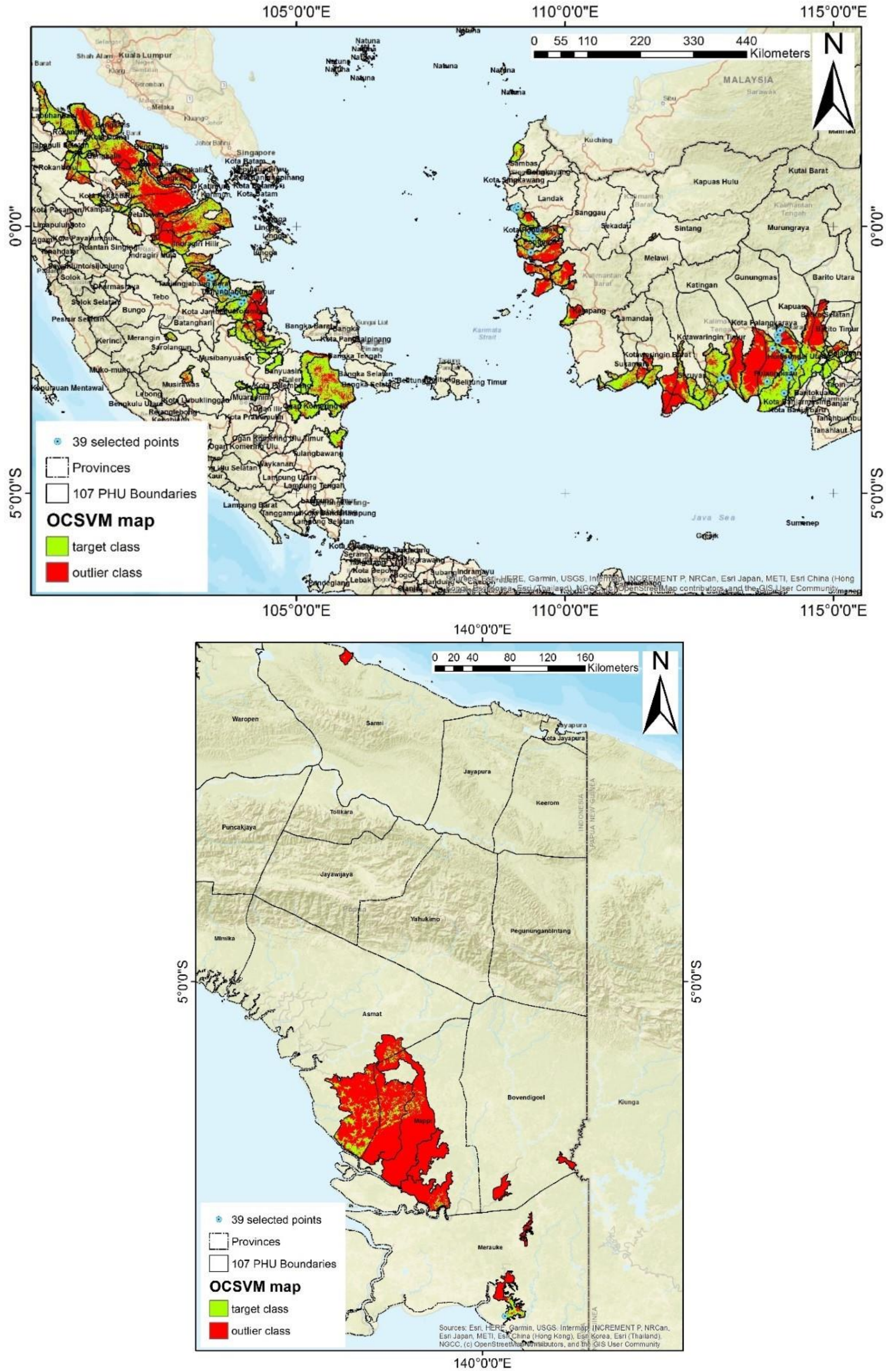
To validate the classification of target and outlier classes, 65 percent of the measurement points were used for training the algorithm and 35 percent were left for testing. Finally, when the classification was tested over the testing samples the overall accuracy of the classification was 97 percent. The output of this classification map is a raster image at 30 m spatial resolution that can be used to limit the interpretation of the SMM product. This product has a binary classification, the target class, where one can be confident of interpreting the SMM product and the outlier class, where the interpretation should be avoided. Target and outlier classes are coloured in green and red colours respectively in the example of Figure 4.11).

***Figure 4.10**. Example of three datasets selected as inputs for the One class Support Vector Machine model. Tree canopy height using GEDI data (upper left), Landsat composite (SWIR1, NIR, RED) using Hansen datasets (upper right), and distance to canals calculated using the canal 2016 map provided by WRI. All values have been transformed into the range 0-1 to be used in the modelling*



Source: All datasets are available in Google Earth Engine, except the canal dataset transformed from data provided by WRI

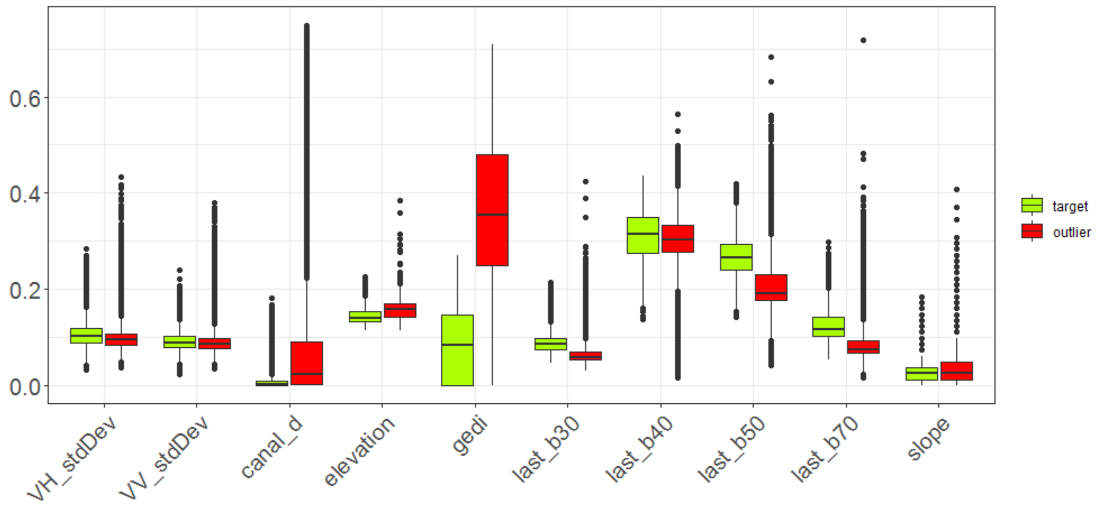
Figure 4.11. *One-Class Support Vector Machine classified map showing the spatial limit to interpret SMM product across the target 107 PHUs defined by BRG, target class is shown in green and outlier class in red. The map is divided into two parts to account for the whole extent in Indonesia*



Source: elaborated by Pablo Martin.

To interpret the difference between classes from a numeric perspective 10 000 spatially random points were scattered over each class (20 000 points in total), the target class and the outlier class. While both classes show similar distribution of their values regarding topography, like altitude or slope, they show extreme differences especially in canopy height (GEDI) or distance to canals (canal_d). Locations similar to the measurement points of the target class show a lower distance to canals and lower canopy height values as compared to the outlier class. Reflectance in the Short-Wave Infrared bands (SWIR1 and SWIR2; respectively last_b50 and last_b70 in Figure 4.12), is also higher in the target class compared with the outlier class, which indicates differences in vegetation moisture conditions (less vegetation compared with more dense vegetation, or a stronger presence of soil component). Additionally, it can also be seen how the variation in backscatter (measured as the standard deviation of VH and VV) is slightly higher in the target class, which would indicate that these areas are more sensitive to soil moisture variation. In Figure 4.12, all variables were rescaled between the interval (0,1).

Figure 4.12. *Distribution of the normalised values for the different variables used as inputs in the OCSVM classified map.VH_stdDev and VV_stdDev: Standard deviation in time for all available Sentinel-1 images in 2019 for the VH and VV band, respectively; canal_d: canal distance in meters (2016); elevation: elevation in meters (2000); gedi: tree canopy height in meters (2019); last_b30,40,50 and 70: landsat 8 red, nir , swir1 and swir2 bands, respectively (2019); slope: slope in degrees (2000)*



In summary, with the data available so far, we can be confident that the SMM product can be interpreted for accessible areas, close to canals, with low canopy height and relatively open vegetated areas with lower soil moisture conditions. The SMM product is not recommended to be used or relied on for very dense vegetated areas where it is very likely that the Sentinel C-band is not able to penetrate.

For future improvements of this methodology, additional data can be ingested into the algorithm, such as peat depth or multitemporal SAR mosaics, which are also expected to influence the radar interaction with soil moisture. Moreover, a larger number of measurement points under a more diverse range of physical conditions will be useful to increase the accuracy of this map. Finally, this methodology was developed using data from 2019, because most of the field data available were also from that year. However, due to frequent land cover change in Indonesia and harsh field conditions with extreme temperatures, risk of fire and other changes, the measurement points can be affected, and their features modified from time to time, also modifying the response in radar backscatter. We recommend updating these maps always with the latest available data.

Further resources.

- Training on interpretation of soil moisture maps
- Training on combining tools in SEPAL for peatland monitoring

Part 5: For further study and development

The following sections are overall reflections suggestions for national decision-makers, the Ministry of Environment and Forestry and the Peatland and Mangrove Restoration Agency, and research institutions, civil society and private sector actors working in peatland restoration. They aim to share ideas for further study and development of the tools and approaches. A general recommendation for the standardization of methodologies for peatland monitoring would be to develop these aligned with overall UNCCC transparency efforts, including REDD+ activities, measurement, reporting and verification (MRV) processes, and forest reference levels (FRLs).

A. A COMBINED SENSOR APPROACH FOR PEATLAND MONITORING

Actors in charge of peatland monitoring is encouraged to carry out the SMM analysis supported by available field data from peatland hydrological units (PHUs). FAO also recommends for national decision-makers to harmonize the different satellite sensors that can be utilized for peatland monitoring, and to establish a clear methodology to employ a combination of them.

Sentinel-1 as the main component of the SMM product, is the best candidate to incorporate in this methodology. Other optical sensors as Landsat or Sentinel-2 offer similar characteristics in terms of spatial and temporal resolution. In this sense, the combination of radar and optical data is crucial, and BFAST can be a powerful tool to understand the changes in land cover that could have affected the interpreted soil moisture trends. Recent acquired PLANET imagery provides dense time-series imagery that can also be employed to monitor both canal blockings, certain fire events, as well as land cover changes.

Researchers from organizations or academia are also particularly prompted to use these tools and products to advance in the understanding of the relation of soil moisture and GHG emissions. Knowing the characteristics of peat degradation status, bulk density, the vegetation, historical data (including fire and management history), and peat depth in the area and other aspects of peatland ecology of the PHU, will help to interpret the SMM products and its trends.

B. SPATIAL DISTRIBUTION OF THE FIELD MEASUREMENT POINTS

The SEPAL SMM tool is sensitive to soil moisture using a globally calibrated model and has been validated using field data. The SMM trends show a strong correlation with field data and steps have been taken to further test and calibrate a model using field data from Indonesia. Tests using local field data have shown that the accuracy of the model can potentially improve with field data from a wider time span and more training samples.

To create a locally calibrated SMM model, the workflow behind pySMM (Greifeneder et al., 2019) will need to be reproduced and rerun with correctly formatted training data. Additionally, it is pending to formulate a relationship (equation) between GWL and SMM based on field data.

To improve the validation process of SMM products, more validation points (field measurement points) are needed, and the data should be "cleaned" to remove low quality data to enable bulk processing. A solid field measurement network would be the responsibility of government institutions in this case, which is vital to build a robust peatland monitoring system across the country.

Harmonization and more open exchange of field data would be important to optimize the analysis and the validation of the SMM data, as well as better understand the short- and long-term impacts of peatland restoration. Given the frequency of the availability of satellite and field data, this would help to detect problems during the collection of the data and be able to provide timely solutions. National academia, international technical agencies or private companies which are establishing field measurement points for commercial and non-commercial purposes, are also encouraged to use the SMM tools and products to evaluate their performance.

Ideally, it would be good if the monitoring data (both field and remote sensing products) are more easily accessible for researchers and if possible, freely available. If data-sharing agreements are needed, then we suggest that simple, standard approaches be used with recognition of the original data providers could be useful to encourage wider sharing of data. This could help improve the quality of results and speed up improvements to getting improved data and monitoring products.

C. CAPACITY DEVELOPMENT SUGGESTIONS

Although this manual provides clear, step-by-step instructions to generate soil moisture mapping products, it is highly advised that the technical staff using the tools takes part in trainings or have otherwise experience with the use of both radar and optical sensors applied to forest monitoring. FAO provides several resources and trainings for the use of free available tools related with peatland monitoring in Indonesia.

Previous knowledge of the suite of Open Foris tools available at (http://www.openforis.org/), and knowledge of Javascript and Python languages which are used in Google Earth Engine and SEPAL respectively would be an advantage. Cloud computer processing is at the foundation of the tools presented here and will be crucial to develop robust monitoring tools at large scales and national levels. FAO has provided several face-to-face and online trainings during the years 2019–2020 developing the capacity of over 100 Indonesian stakeholders, and stands ready to continue supporting as soon as further resources become available.

D. TOOL INTEGRATION IN WIDER MONITORING EFFORTS

The combination of remotely sensed and field-collected data is already at the core of the Indonesian National Forest Monitoring System (NFMS). Adding variables relevant to peatlands on already established National Forest Inventory plots could provide an already well-established regular methodology for the collection of field data. The machine-learning approaches used for the SMM tool highlight the potential of these techniques to offer faster and more accurate analyses, and such approaches could also be utilized for the Indonesian Satellite Land Monitoring System. As the NFMS is progressively being improved and re-designed, it is a good opportunity for the system to be further developed to capture well peatland monitoring.

E. MONITORING LANDSCAPE-LEVEL REWETTING

As underlined by all technical partners with peatland expertise, the peatland rewetting needs to happen at the landscape level, meaning across whole PHUs for best results. It is recommended to perform the SMM analysis in PHUs where all canals have been blocked, to be able to achieve a better understanding of peatland restoration indicators. BRG has proposed to focus on creating cases in Riau and Central Kalimantan to demonstrate what full rewetting can achieve in terms of peatland restoration. Success cases of rewetting in restoration sites will be crucial to demonstrate the effectiveness of the SMM products and its power as a potential national peatland monitoring tool. It is recommended that the Peatland Restoration Agency and MoEF evaluates the tool in known sites to have a deeper knowledge about its strengths, weaknesses, and limits. FAO welcomes feedback on these tools and is willing to continue their development when funding and resources are available.

Until there are fully rewetted PHUs, the SMM results of partial rewetting – by blocking only certain canals – will mainly demonstrate how sensitive the SMM tool is to changes in moisture. This should most likely be available for field observations through the vegetation that can develop in partially rewetted peat areas, in comparison to fully rewetted areas. The results and methods shown in this report have proven the enormous potential of remote sensing and open-source supercomputing power to continue the development of analysis in Indonesia, and potentially in other countries.

Part 6: Exercise

Introduction

The aim of this exercise is to compute and download the SMM product over a study area and interpret the results. Auxiliary data will be provided to help you justify your decisions.

Study area

Figure 6.1. *Location of the AOI (red) within the "PHU KHG Sungai Mendahara - Sungai Batanghari" in Jambi province*

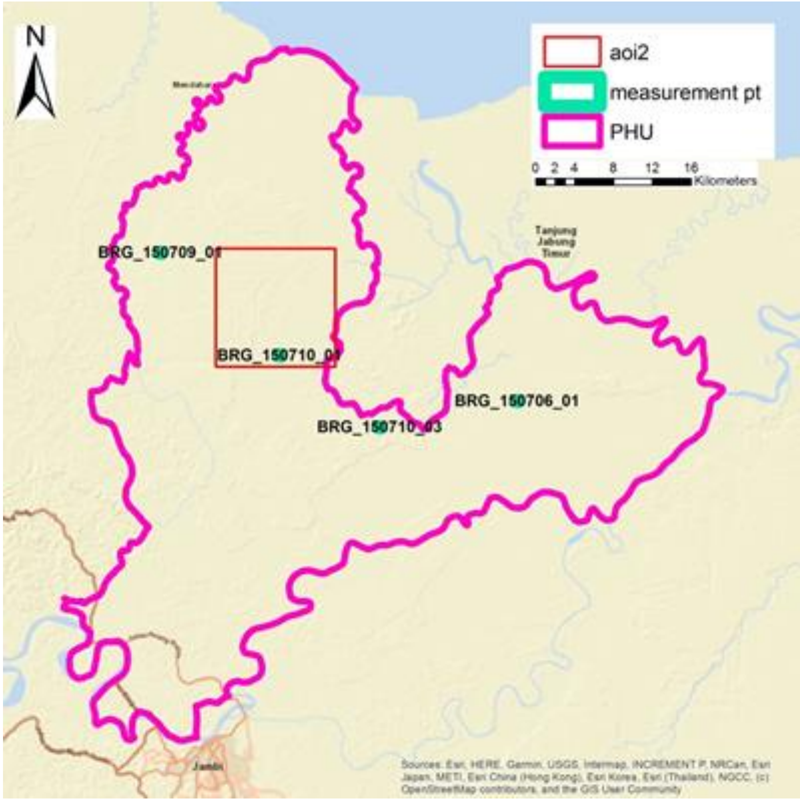


Figure 6.2. *Land cover map for 2019 and elements (dams) within the AOI*

Figure 6.3. *Mean GWL (left) and mean soil moisture (right) measured in the field between the years 2018-2020 for the stations available in the PHU KHG Sungai Mendahara - Sungai Batanghari*

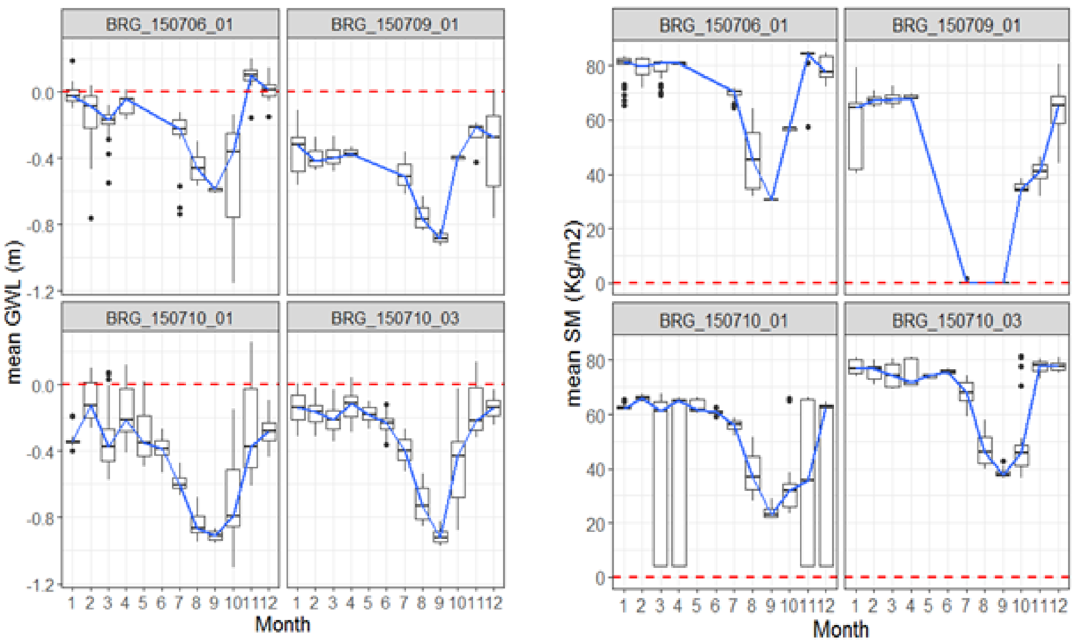
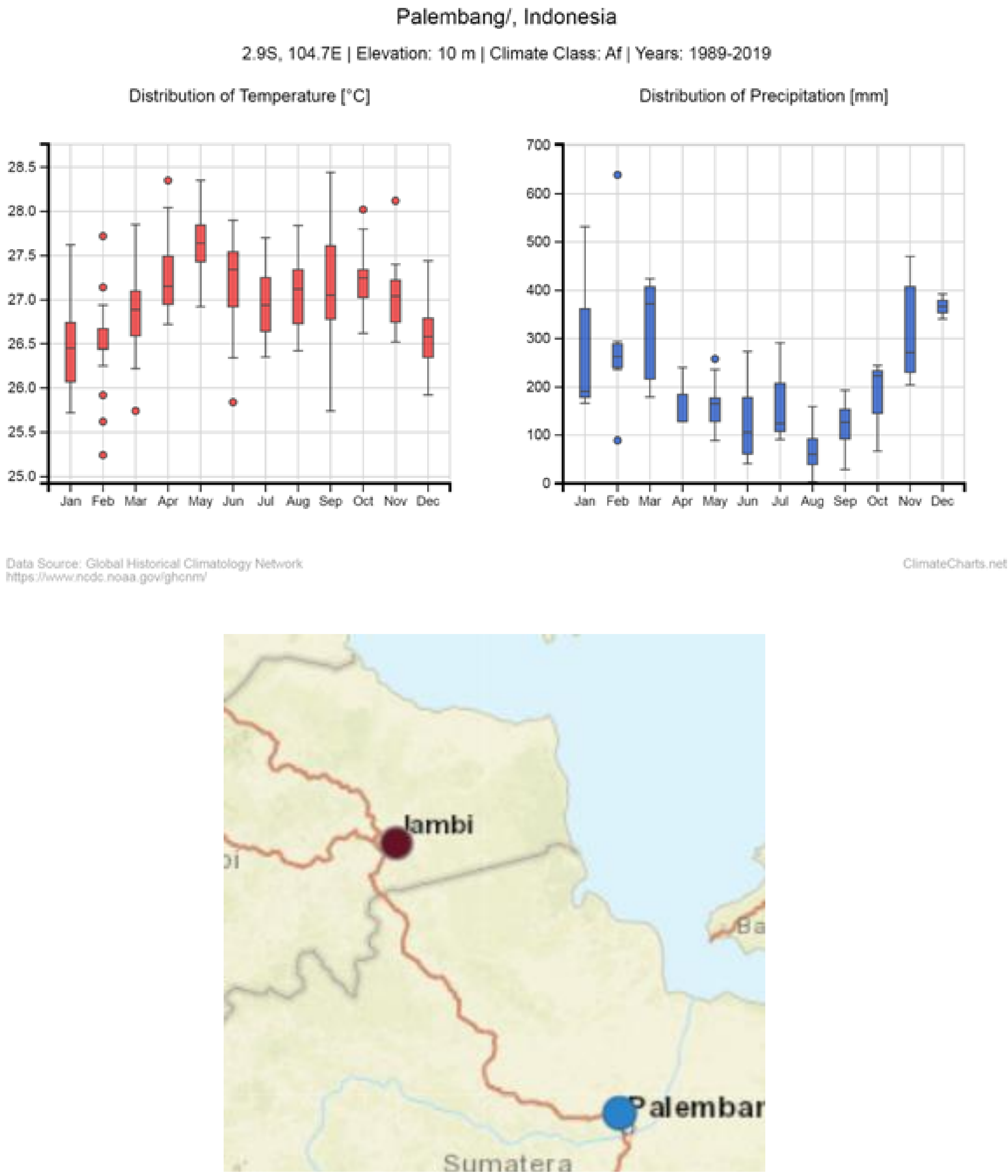


Figure 6.4. *Temperature and precipitation data over a nearby location to the study site. Closest available meteorological data are in Palembang*[13]



13 https://climatecharts.net/

Take action: Compute the SMM product over the AOI

1. Use the "**aoi2.shp"** file (link) and import it as an asset into your GEE account **OR** use this e-table: ***users/marortpab/FAO/indonesia/BFAST/aoi2***
2. Select a range of dates to produce your images (compute all images available to date for that AOI takes 5-6 hours approximately)
3. Compute the statistics of your preference (mean, standard deviation, linear trend)
4. Use the auxiliary information provided or spatial data owned by you to interpret changes of soil moisture in the AOI
5. Follow these steps: STEPS

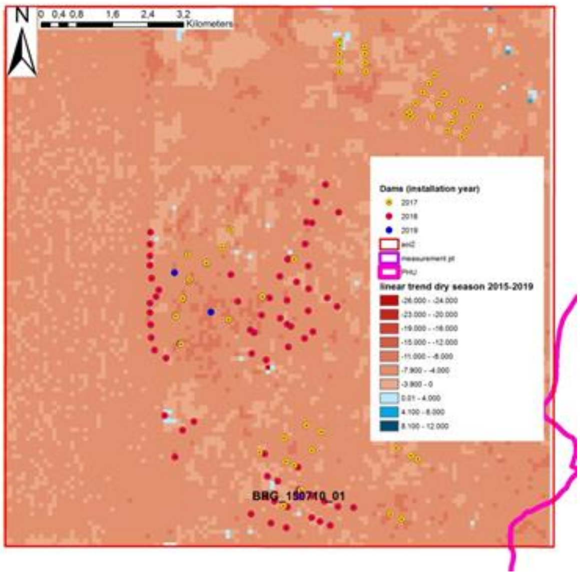
Possible analysis

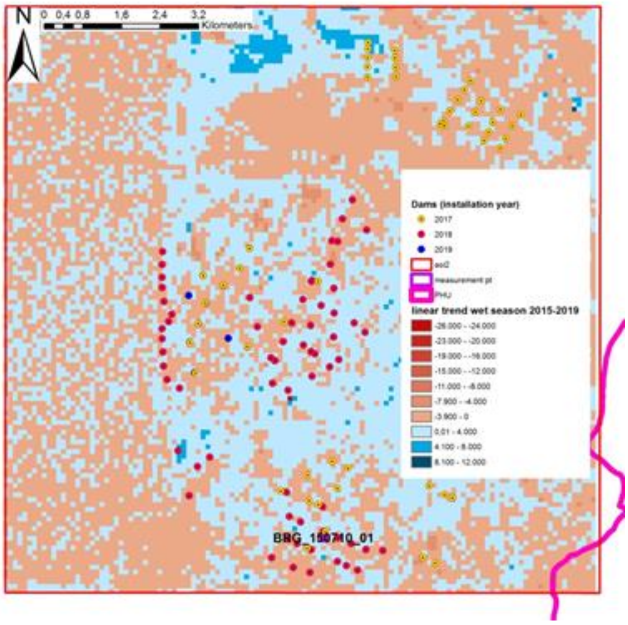
1. The GWL and soil moisture plots show that minimum values are found in August-September (dry season) and maximum values around in November-December (wet season). Choose these months to run your statistics and compare them between years.

2. To see temporal trends, use the linear trend statistic between same seasons across different years.

- How do you interpret what you see?
- Is soil moisture increasing or decreasing?
- Does the canal blocking have an effect? Why?
- Does the land cover have an effect? Why?

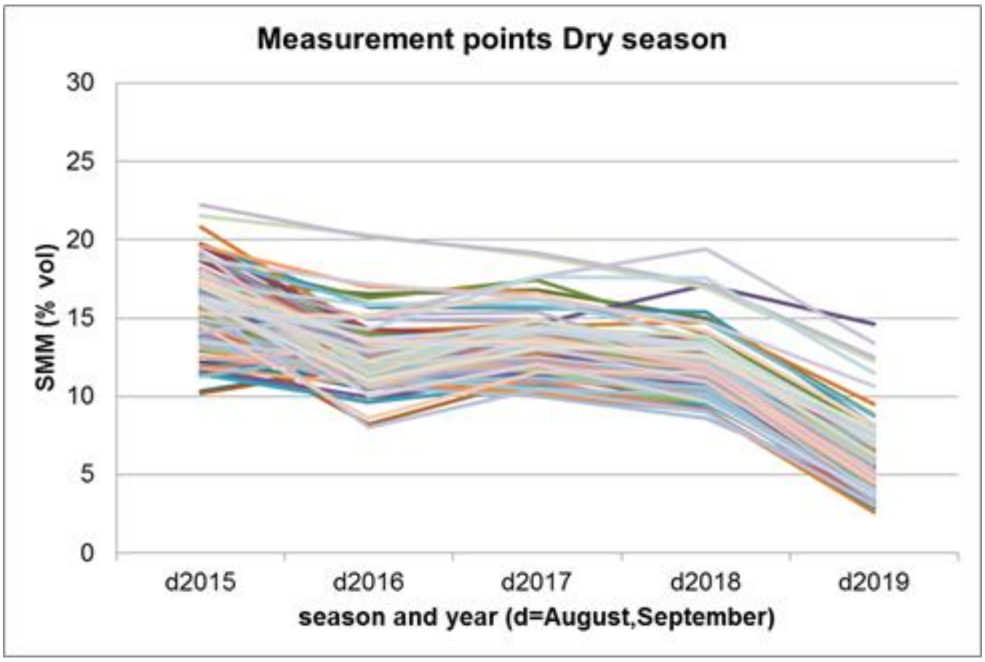
Figure 6.5. *Linear trend in the dry season (above) and the wet season (below).*





Use spatial data that you own to describe possible changes, restoration activities, recently planted area, burned area, etc. Extract the values of your statistics to those features and try to explain what is happening.

***Figure 6.6**. Mean SMM values calculated for the dry season (above) and wet season (below) and compared across the years 2015–2019. Each line represents a dam present in the AOI*



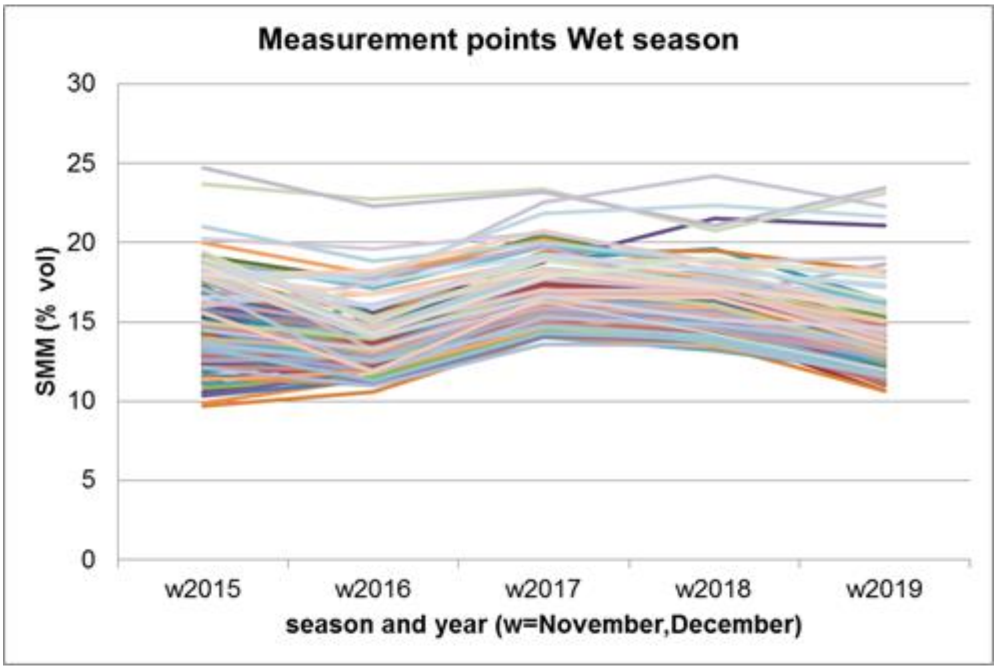
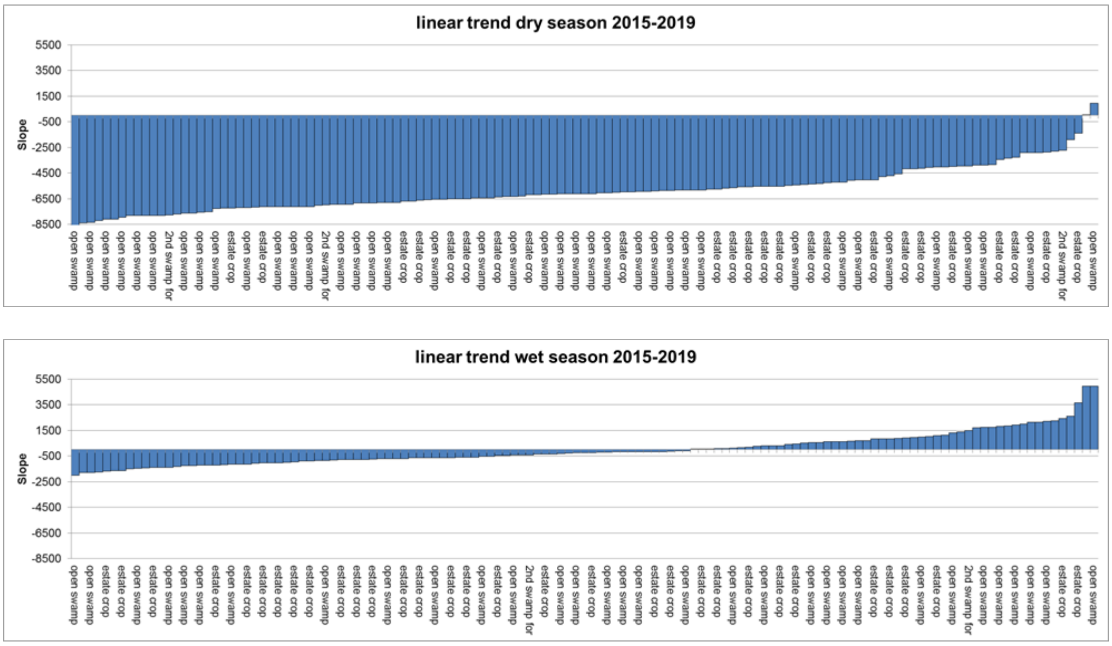


Figure 6.7. *Linear trends calculated for the dry season (above) and wet season (below). The values represent the slope of the linear trend. Each bar represents one dam in the AOI and the horizontal axis shows the land cover around the dam for the year 2019.*



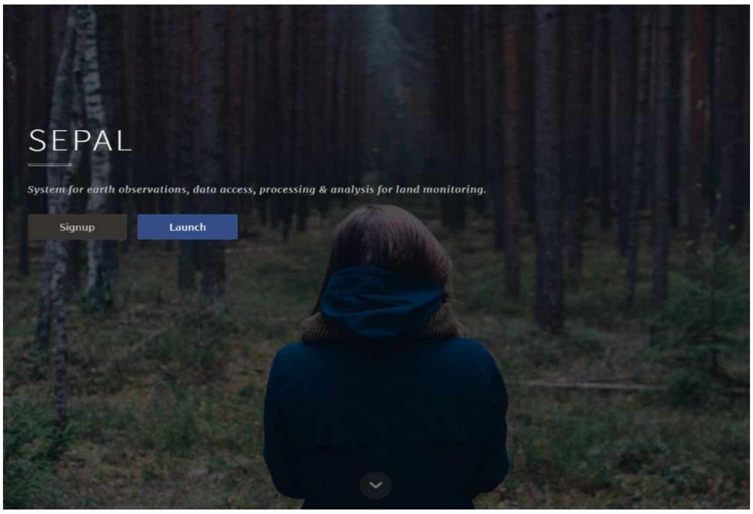
Annex 1. Using the SEPAL Platform

FAO PLATFORM FOR EARTH OBSERVATION

Step 1: Logging into SEPAL

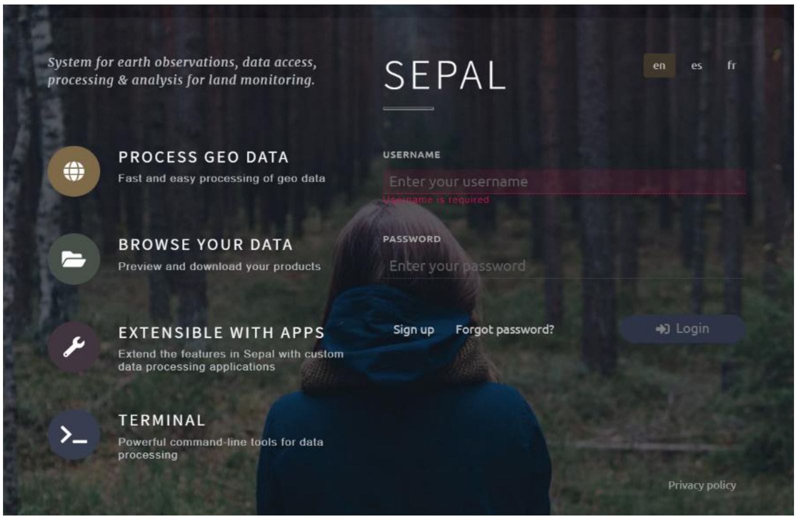
The first step in processing is to start a SEPAL session. To do this go to the start page of SEPAL (sepal.io) (**Error! Reference source not found.**), click launch and insert your username and password (**Error! Reference source not found.**). If you do not have a SEPAL account yet, please register here.

Figure 7.1. *Start page of the SEPAL platform I, click "launch"*



Source: https://sepal.io/

Figure 7.2. *Start page of the SEPAL platform II, insert username and password*



Source: https://sepal.io/

If you do not have a username and password, you can sign up to receive one by clicking on 'sign up'. You will be directed to a simple form to fill out your name, e-mail address, institution, country, and reason for wanting to use SEPAL. Fill in this information and you will receive an e-mail with your username and access to SEPAL. You will be prompted to fill in a password. This process can take a day or 2 to complete as all user requests are reviewed manually.

USING THE TERMINAL TO START AN INSTANCE

First, click on the terminal button in the list of icons on the left side of the screen. This will take you to a prompt and allow you to start a computer in the SEPAL cloud, called an 'instance'.

If you do not have any instance running, you should see the option to start a new session and the list of instances (Figure 7.3). Type the name of the instance you wish to start at the prompt. To stop a previously started session, enter '1s' at the prompt.

WHAT TYPE OF INSTANCE DO I NEED?

It is good practice to adapt the type of instance to your needs for resource efficiency and good connectivity performance while doing the analysis.

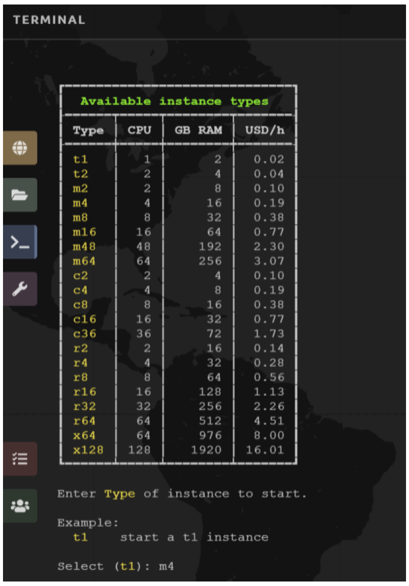
For example, if you are running the soil moisture download in Jupyter notebook, you do not need much processing power because the bulk of the processing is sent to Google Earth Engine (GEE) (see more on GEE in the next section 'Connecting your Google account to SEPAL'). You can use a t2 or m4 instance. In the post-processing part of the soil moisture mapping app requires more CPU and RAM, and an m4 or m8 instance is recommended. A smaller instance will cause the process to run slower and potentially crash if there is not enough memory to process the imagery.

If an app is selected in SEPAL without previously selecting an instance in the terminal, instance t1 will automatically start which has one CPU and two GB of RAM.

If you want to run more complex calculations with big objects (national scale raster), you may want to select a bigger instance with more RAM requirements.

To select the instance, you need to type the instance "Type" in the first row of the available instance type, corresponding to the instance you would like to start. For example, to start the instance t1 in the terminal, type t1, and then hit the ENTER key on the keyboard. The command line only works by typing text in the terminal.

Figure 7.3. *The list of available instances on the SEPAL platform. To start an instance, enter the type of instance you want to start at the prompt*


TERMINAL

Available instance types

Type	CPU	GB RAM	USD/h
t1	1	2	0.02
t2	2	4	0.04
m2	2	8	0.10
m4	4	16	0.19
m8	8	32	0.38
m16	16	64	0.77
m48	48	192	2.30
m64	64	256	3.07
c2	2	4	0.10
c4	4	8	0.19
c8	8	16	0.38
c16	16	32	0.77
c36	36	72	1.73
r2	2	16	0.14
r4	4	32	0.28
r8	8	64	0.56
r16	16	128	1.13
r32	32	256	2.26
r64	64	512	4.51
x64	64	976	8.00
x128	128	1920	16.01

Enter Type of instance to start.

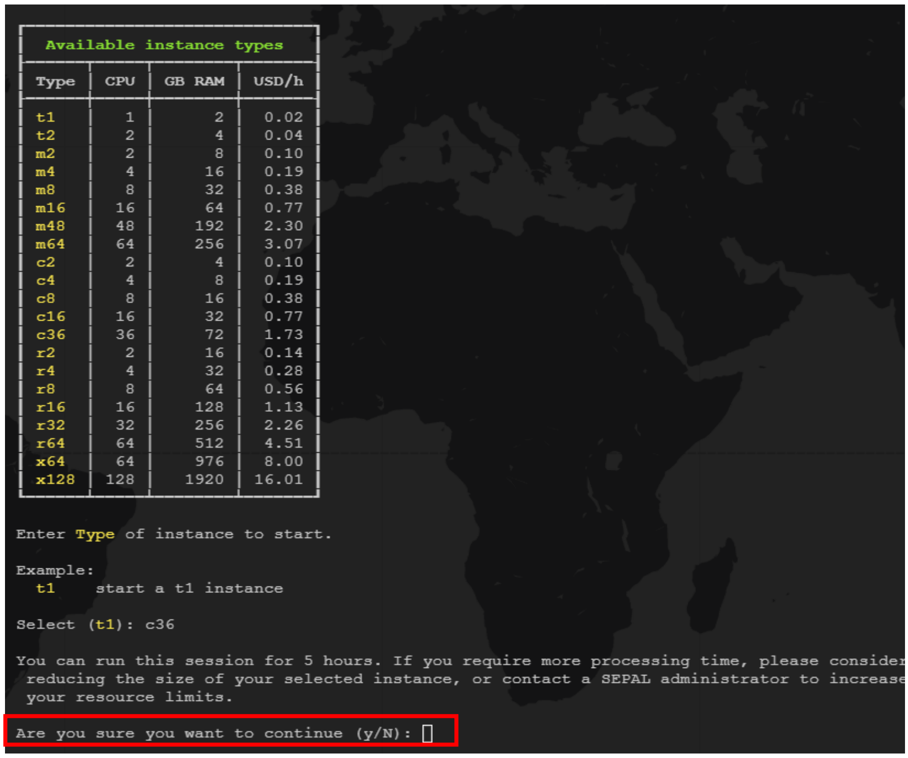
Example:
t1 start a t1 instance

Select (t1): m4

You will then see text about the amount of time you can leave your session running according to your user resources.

1. If your user resources are limited, you will be asked if you would like to proceed with starting this instance.

Figure 7.4. *Approval request when resources are limited*


Available instance types

Type	CPU	GB RAM	USD/h
t1	1	2	0.02
t2	2	4	0.04
m2	2	8	0.10
m4	4	16	0.19
m8	8	32	0.38
m16	16	64	0.77
m48	48	192	2.30
m64	64	256	3.07
c2	2	4	0.10
c4	4	8	0.19
c8	8	16	0.38
c16	16	32	0.77
c36	36	72	1.73
r2	2	16	0.14
r4	4	32	0.28
r8	8	64	0.56
r16	16	128	1.13
r32	32	256	2.26
r64	64	512	4.51
x64	64	976	8.00
x128	128	1920	16.01

Enter Type of instance to start.

Example:
t1 start a t1 instance

Select (t1): c36

You can run this session for 5 hours. If you require more processing time, please consider reducing the size of your selected instance, or contact a SEPAL administrator to increase your resource limits.

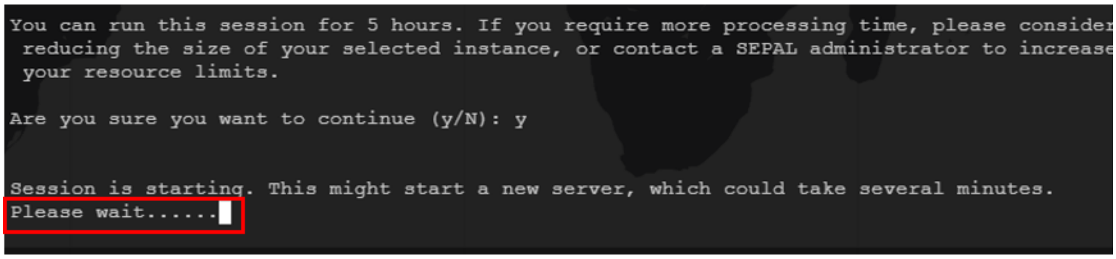
Are you sure you want to continue (y/N):

2. If you would like to proceed, type **y** (which stands for yes) in the terminal. Otherwise, if you would like to select another instance type **N** (which stands for no).

3. If you have plenty of resources, you will not see this text.

It can take a minute to start an instance. You will see a text that says, 'Please wait….'

***Figure 7.5.** Waiting to start an instance*



When the session has completed loading you will see your username@numbersandletters:~$

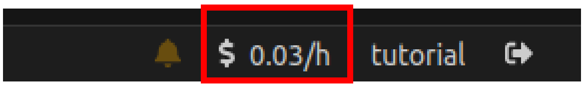
***Figure 7.6.** Session has completed loading*

KEEPING AN INSTANCE ACTIVE

You can manually keep an instance active in your user resources, which you can access by clicking on the instance budget.

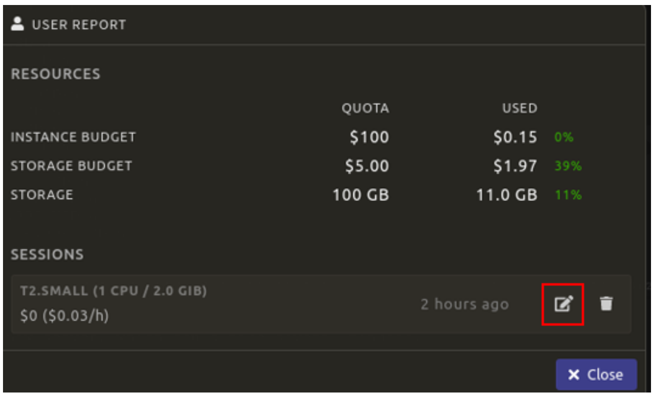
1. Click over the budget:

***Figure 7.7.** Budget available*



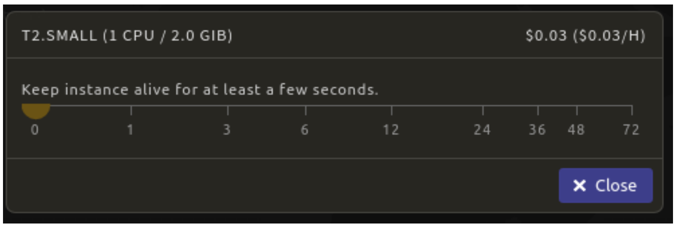
2. Click on the edit icon:

Figure 7.8. Edit icon on the user report



Use the slider to choose the amount of time to keep the instance alive. You can keep the instance alive for up to 72 hours. Only use this feature if you are using a process that you know needs an active instance, such as the time series analysis. Make sure to check on the process  to ensure something is running on the instance.

Figure 7.9. Slider to choose the amount of time to keep the instance alive

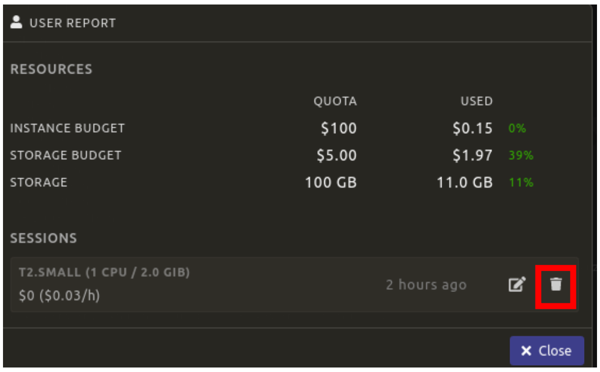


SHUT DOWN AN EXISTING INSTANCE

You can manually shut down an instance in your user resources, which you can access by clicking on the instance budget (Figure 7.7).

Click the  next to the running instance to shut down the existing instance.

Figure 7.10. Shut down an existing instance



WHAT CAN I DO IN THE TERMINAL?

SEPAL is running under a Linux server with the latest long-term release Ubuntu operating system and the corresponding Bash Shell. You can run all the basic Linux commands in the terminal. Also, several geospatial processing libraries are available such as GDAL/OGR [14] or the Orfeo Toolbox[15] and you can run processing

14 GDAL/OGR Geospatial Data Abstraction Library (www.gdal.org)

15 www.orfeo-toolbox.org

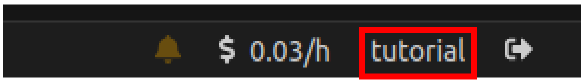
commands from the terminal. You can also clone, update, and push GIT[16] repositories directly in the terminal.

CONNECTING YOUR GOOGLE ACCOUNT TO SEPAL

Some of the core functionality of SEPAL utilizes Google Earth Engine (GEE). To take full advantage of SEPAL you need to connect your Google account to your SEPAL account.

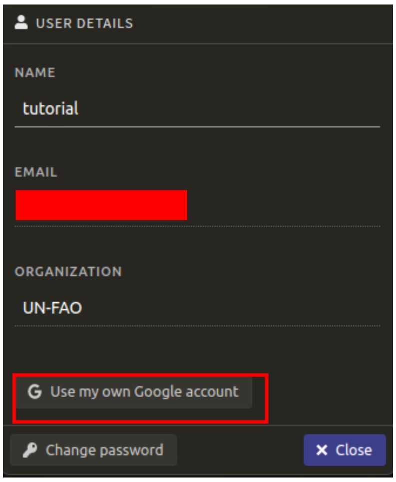
- First, make sure you have a Google account, and it is whitelisted in GEE.
- If you do not have a GEE enabled account, sign up here.
- After you get an email confirming your access to Google Earth Engine you can connect your SEPAL account to Google.
- Click on your username in the bottom right corner.

Figure7.11. *Username in the bottom right corner*



- If you see *'Use my own Google account'*, your Google account is not yet connected to SEPAL. In the following steps, you will connect your account.
- First, click on *'Use my own Google account'*. This will redirect you to a Google sign-in page.

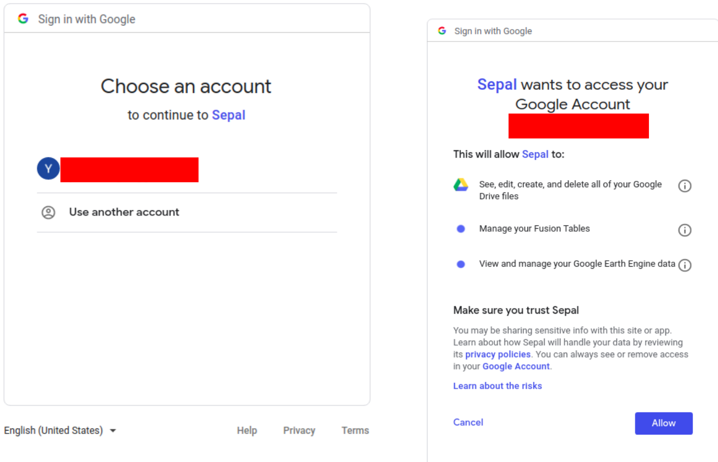
Figure 7.12. *User details, click on 'Use my own Google account'*



16 Distributed version-control system for tracking changes in source code during software development (https://github.com/)

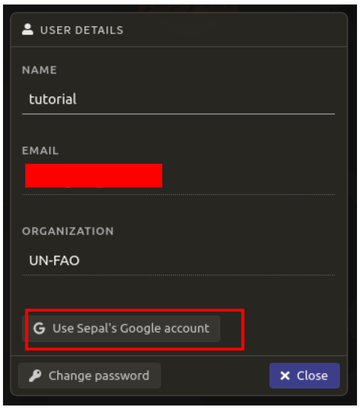
- Select the Google account that is already approved for the use of GEE. Sign into your account with your Google password. Then click on '*Allow'* to grant SEPAL access to your Google account.

Figure 7.13. *Select your google account and grant SEPAL access*



- After clicking '*Allow*', you will be automatically redirected to the SEPAL page. You can check your Google account connection by clicking on your username again. It should now say '*Use SEPAL's Google account*'. Do not click on this button, as it would disconnect the connection between your personal SEPAL account and your personal Google account.

Figure 7.14. *Check your Google account connection*



Further resources

- What is SEPAL? http://www.openforis.org/tools/sepal.html
- SEPAL links in GitHub: https://github.com/openforis/sepal/wiki

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GLOSSARY

Peatland: are a type of wetlands that occur in almost every country, currently covering 3% of the global land surface. The term 'peatland' refers to the peat soil and the wetland habitat growing on its surface.

Peatland restoration: is mainly used to refer to hydrological restoration, such as canal blocking and associated measures, which would help create conditions for the peatland species to return, peat degradation to stop, and ideally, it would allow peat accumulation to take place again. Peat restoration is can be done in different classes to define areas where and what hydrological or revegetation restoration is required. Re-vegetation is also an additional activity that would be good to be done as well to help restore the hydrological functioning and help restore some biological diversity to peatland areas.

Peatland rewetting: the action of raising the mean water table level as close to the peat surface as possible in the entire peatland unit, e.g., peatland hydrological unit, that has been drained to allow activities such as dryland crop cultivation, plantation forestry and livestock grazing, among others. Drained peat can be too dry and chemically unsuitable for peatland plants (Lamers et al. 2002). Raising the water table will rewet the surface peat, creating more suitable conditions for recolonization by peatland plants and potentially allow peat accumulation.

Rewetting techniques include e.g., blocking drainage ditches or gullies (using peat, rocks, plastic dams, or wooden dams), planting flood-resistant vegetation in ditches to slow water flow, blocking underground channels or peat pipes, building raised embankments or berms (elongated mounds of peat or rows of straw bales) to retain water, inserting dams (e.g., straw bales) below the peat surface to slow subsurface drainage, switching off drainage pumps, or restoring inflows.

Peatland monitoring: is referred to here as the regular and systematic observation of specific variables and their changes over time, within a known peatland area. Monitoring is often used to inform and understand how peatland function and condition is evolving and to assess the effectiveness of water management strategies, restoration interventions, and the risk of fires. To achieve results, a true landscape approach is important.

Subsidence: Peatland subsidence is a lowering of the peatland surface that happens after drains are dug. In the first few years after drainage, physical peat compression processes (consolidation and compaction) are dominant factors causing subsidence. Subsequently, the loss of peat volume occurs mainly through biological oxidation (but also fire, in some locations) (FAO, 2014).

The landscape approach: The landscape approach in the case of peatlands means, among other things, considering the water level changes in the whole peatland hydrological unit as one unit. It should also consider people's livelihoods, vegetation interactions, and different sectors' impact and activities, sometimes located far from the peatlands but having an impact on them. Some features in particular landscapes: 1) sectors (e.g., cropping; oil palm plantations; conservation; ecotourism); 2) stakeholders (e.g., those clearing land with fire; policymakers; law enforcement; restoration implementers; large plantation owners; smallholder farmers); 3) scales (e.g., impact of global palm oil trade down to the local level social and power relations); as well as 4) governance matters. For ecosystem monitoring, the analysis of these features, allows to focus on certain key aspects impacting the peatland landscapes.

Terminal: A menu in SEPAL to select the type of web-based computer or instance where all the data processing is executed.

Practical guidance for peatland restoration monitoring in Indonesia

A remote sensing approach using FAO-SEPAL platform

Food and Agriculture Organization of the United Nations

Viale delle Terme di Caracalla, Rome