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EO AFRICA R&D Facility

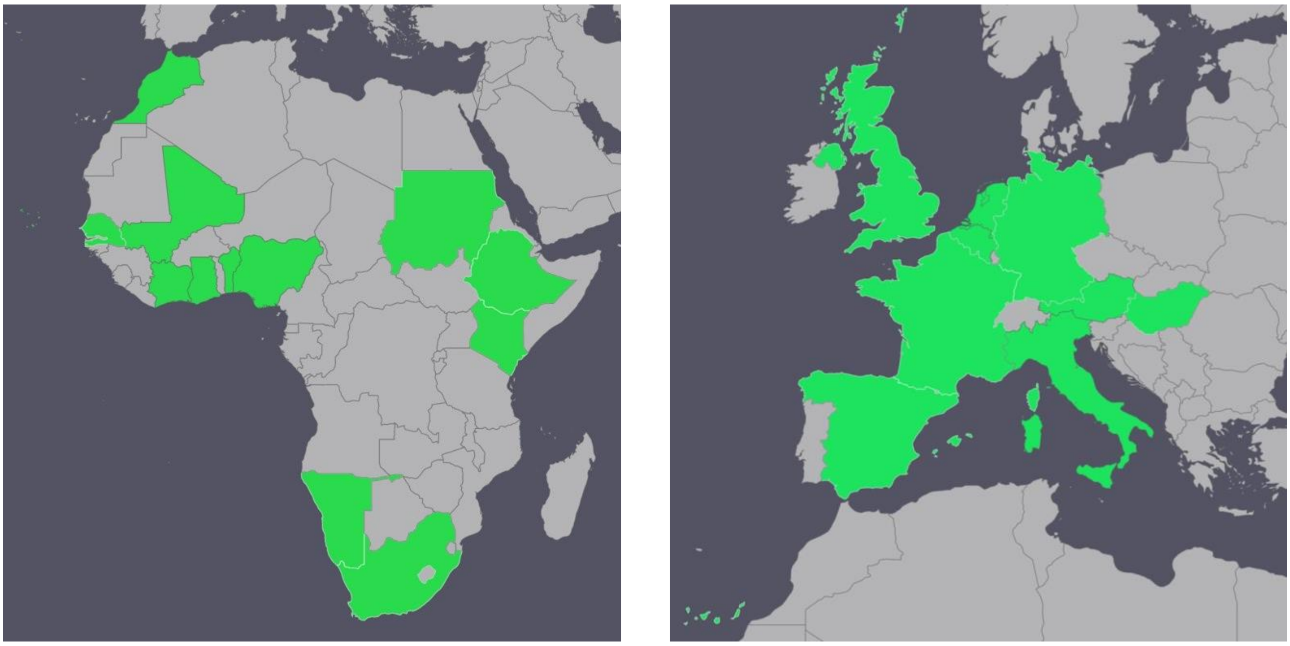
Research Projects 2022

Foreword

In the framework of the ESA EO AFRICA initiative, the EO AFRICA R&D Facility in collaboration with the **European Space Agency** (ESA) and the **African Union Commission** (AUC), launched at the end of 2021 a call for research proposals to support African-European collaborative efforts to develop innovative, open-source EO algorithms and applications adapted to African solutions for African challenges.

Proposals in the themes of water scarcity and food security were expected to create EO algorithms and workflows by leveraging cutting-edge cloud-based data access and computing infrastructure. A budget up to 25,000 EUR for research activities during a period of 12 months, free access to cloud-based Virtual Research Environments through the Innovation Lab of the Facility, dedicated user and technical support, access to the EO AFRICA Space Academy events, and integration into the EO AFRICA Network for international scientific collaboration, were the benefits offered to the research projects.

62 proposals were received from research teams lead by African-European tandems from **23 African and 16 European countries**. After a comprehensive evaluation process, which involved review of each proposal by at least two domain experts for 40 different criteria and scoring in 6 different categories, 26 proposals from 14 African and 9 European countries were qualified for the second round of evaluation by the Selection Committee. This included all proposals "highly recommended" by the reviewers with a minimum overall score of 75/100. Considering aspects such as scientific excellence, innovative use of digital tools, impact for fostering the use of EO data and services in Africa, and geographic representation of Africa, the Committee in collaboration with ESA and AUC awarded **15 research projects** for funding from **12 African and 9 European countries**.



African and European countries of the funded projects

This document aims to provide a short summary of the scientific background, objectives, study area, research plan, and team members of the funded research projects.

Research Projects

1. DroughT impACt on the vegeTation of South African semIarid mosaiC landscapes: Implications on grass-crop-lands primary production

Project Acronym

TACTIC

Scientific Background and Objectives

Semiarid rangelands are one of Africa's most complex and variable biomes. They are a mosaic of land uses, where extensive livestock is the main economic activity, and agriculture, soil for livelihood, or conservational uses are also crucial. They are highly controlled by the availability of water, e.g., pasture and rainfed crop production. Although the vegetation is adapted to variable climatic conditions and dry periods, the increase in drought intensity, duration, and frequency, changes in agricultural practices, and other socioeconomic and environmental factors precipitate their degradation.

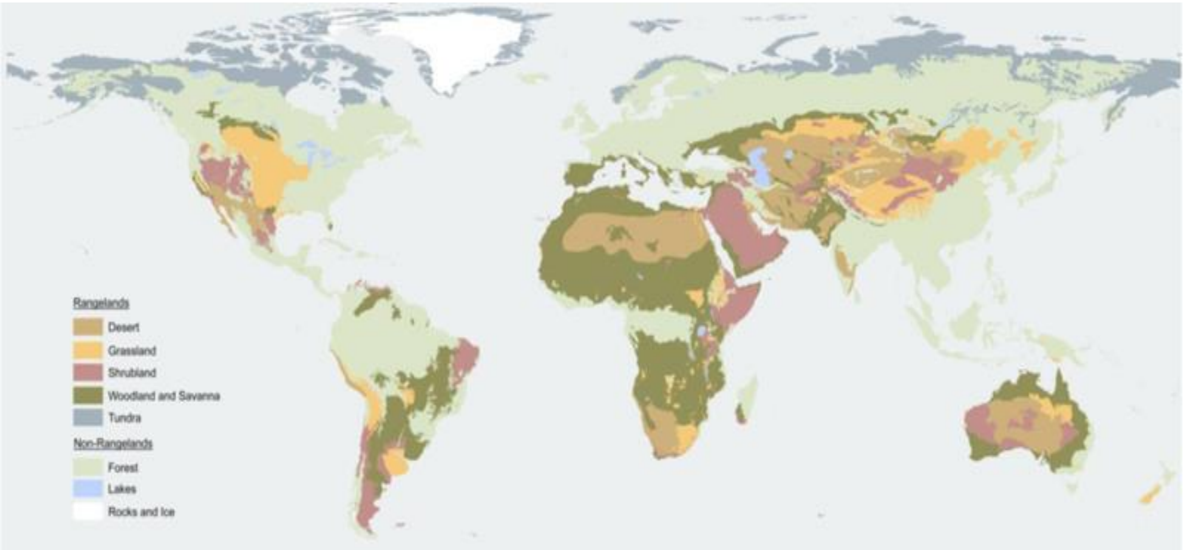


Figure 1: Rangelands of the World. From University of Idaho. Wikimedia Commons

Through the integration of Earth Observation data into models, we can evaluate, on the one hand, the water consumed by semiarid ecosystems and their vegetation water stress and, on the other, its primary production. Thus, allowing us to assess the interaction of both processes, improving our knowledge about the vegetation's behavior in the face of drought.

TACTIC will map water consumption and primary production of semiarid mosaic crop-rangelands at the optimal spatiotemporal scales, setting up an open-source cloud framework to monitor these processes' interaction in the long term and analyze system tipping points. This information can help reduce the uncertainty associated with the administration and farmers' decision-making processes.

Study Area

Our pilot area is located in the Limpopo region, with great agricultural importance but subject to periodic droughts, and Kruger National Park home. The timeframe will be from 2014 to 2021. The Skukuza Fluxnet site (Scholes et al., 2001) and cropland data from farmers and a field campaign will be used for validation. Meteorological data will be obtained from the South African Weather Service stations (spatial interpolation between stations) and/or the ECMWF ERA5 reanalysis (Hersbach, 2016).

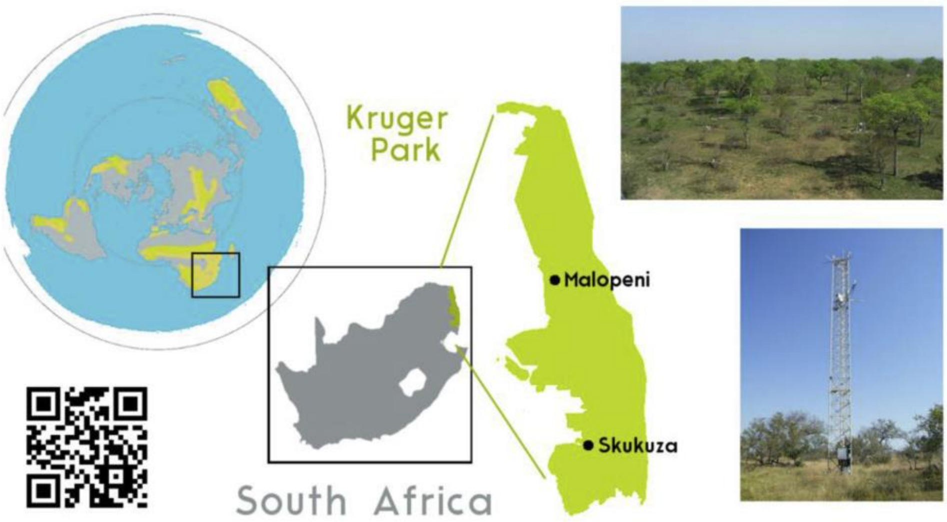


Figure 2: Map of the study area: Kruger National Park.

Research Outline

Overview of our methodology:

Our **methodology** has been validated over our pilot area or in another semiarid savannas. The **working plan** encompass:

1. Assessing water consumption and vegetation water stress
    1. Adaptation of the Kc-FAO56 crop-coefficient method (Allen et al., 1998, Carpintero et al., 2020)
    2. Two Source Energy Balance model (Kustas and Norman, 1999) & STARFM (Gao et al., 2006)
    3. Ratio ET/ETo anomalies

2. Assessing biomass production (Light Use Efficiency model). (Monteith et al., 1997, Gomez-Giraldez et al., 2019)

3. Assessment of the drought impact on grass/crop production (Gonzalez-Dugo et al., 2021)

Figure 3: Scheme of the methodology.

In more detail:

1. **WP1- Assessing water consumption and** vegetation **water stress**:
   a) Using an adaptation of Kc-FAO56 crop-coefficient method (Allen et al., 1998[6]) to assimilate EO data, the VI-ETo model (Carpintero et al., 2020[12]), integrating VIS/NIR Sentinel 2 (20m), and Landsat (30m).
   b) Using the Two-Source Energy Balance model (Kustas and Norman, 1999[7]) and the STARFM sharpening algorithm (Gao et al., 2006[1]), integrating TIR Sentinel 3/MODIS (1km), and S2/Landsat (20m/30m).
   c) Computing the relative evapotranspiration (ratio ET/ETo) anomalies, a proxy of savanna vegetation water stress (Gonzalez-Dugo et al., 2020[10]).

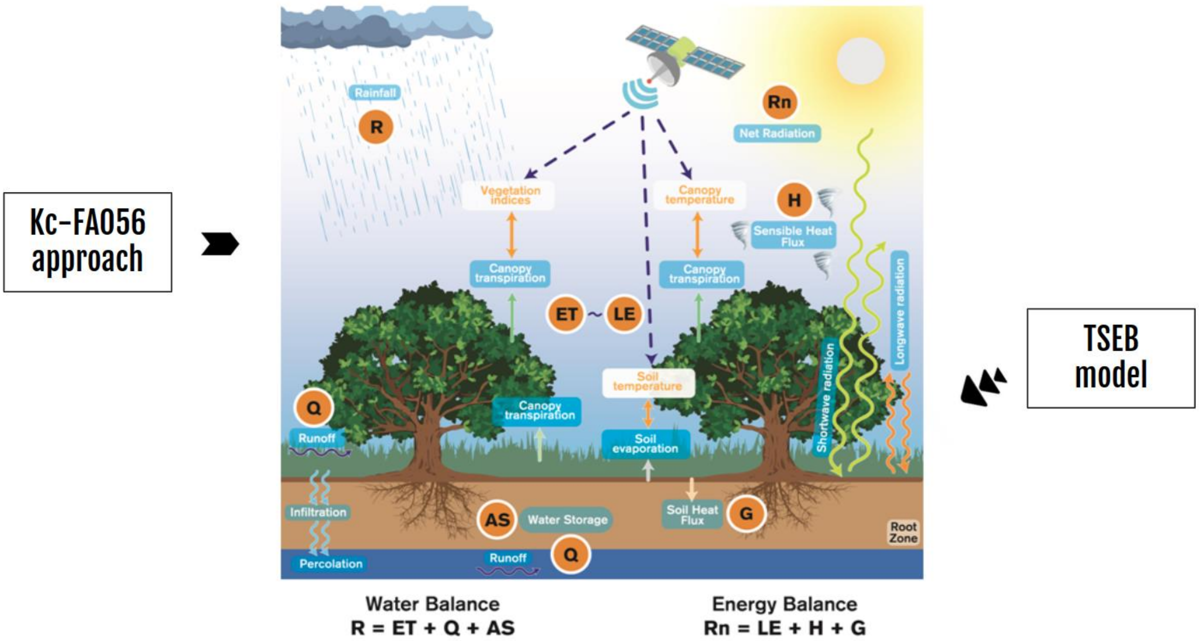


Figure 4: Kc-FAO56 and TSEB models approach (figure from Carpintero, 2021)

2. **WP2- Assessing biomass production** using a light use efficiency (LUE) model (Monteith et al., 1997[8]) assimilating remotely sensed data derived by Gómez-Giraldez et al. (2019)[14] for rangelands using S2.
3. **WP3- Validation** with data from Skukuza, from our field campaign, and farmers' annual water use and yield statistics for crops.
4. **WP4- Assessment of the drought impact on grass/crop production.** An analysis of the drought events and their effects on pasture/crop production (Wolf et al., 2016[2]; Ma et al., 2016[3]).
5. **WP5- Integrating the workflow into an open-source interactive tool** (e.g., Jupyter Notebook).

[1] Gao, F., Masek, J., Schwaller, M., Hall, F. On the blending of the Landsat and MODIS surface reflectance: predicting daily Landsat surface reflectance. IEEE Transactions on Geoscience and Remote Sensing, 44(8), 2207-2218. (2006). https://doi.org/10.1109/tgrs.2006.872081

[2] Wolf, S. et al. Warm spring reduced carbon cycle impact of the 2012 US summer drought. PNAS 113, 5880–5885 (2016). https://doi.org/10.1073/pnas.1519620113

[3] Ma, S., Baldocchi, D., Wolf, S. & Verfaillie, J. Slow ecosystem responses conditionally regulate annual carbon balance over 15 years in Californian oak-grass savanna. Agricultural and Forest Meteorology 228–229, 252–264 (2016). https://doi.org/10.1016/j.agrformet.2016.07.016

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2. Crop Stress Monitoring in the semi-arid context of Doukkala, Morocco

Project Acronym

CroSMoD

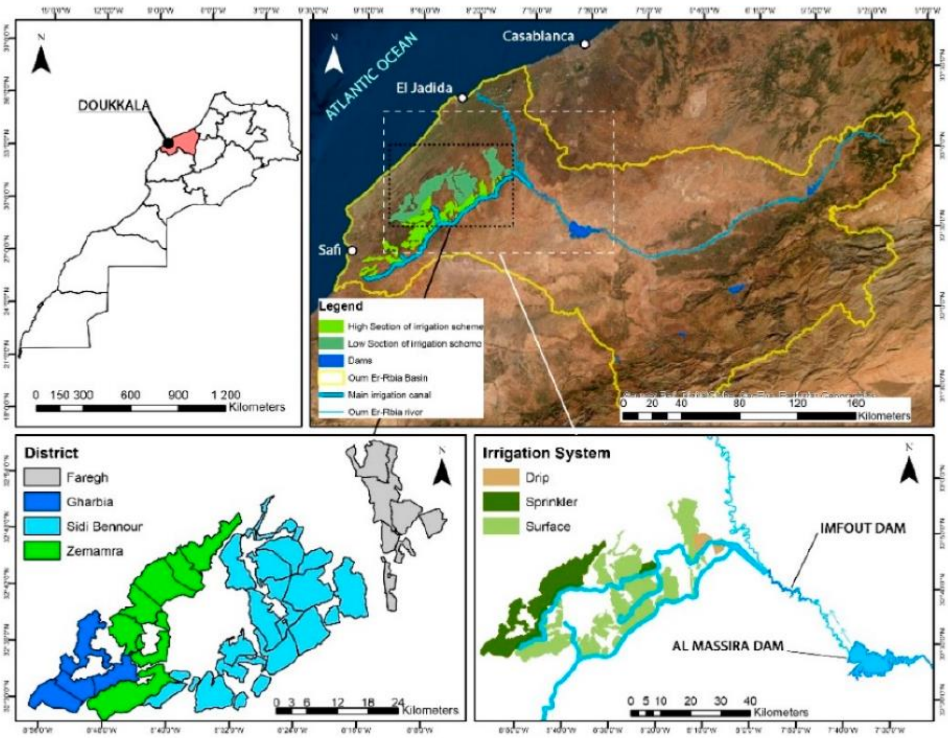
Scientific Background and Objectives

Agriculture is the largest and at the same time less modern consumer of water worldwide. Moreover, with world's population projected to increase and with climate change effects, water scarcity conflicts will be exacerbated. Thus, improving crop production and water use management is a fundamental step to achieve sustainable food and water security.

One of the crucial problems currently facing the Moroccan irrigated area of Doukkala is the scarcity of water for irrigation, with the irrigation management authorities which are not distributing irrigation water due to a shortage of water volume in the dam reservoirs. Such situations, according to climate projections, will become periodic and, during them, farmers draw from the groundwater, considered strategic for the country's water security. Hence there is the need to set up an adaptation strategy to help farmers to cope with this new situation.

The project aims at developing a procedure for crop yield estimates and extreme events crops shocks monitoring or pest and diseases by integrating multiple satellite data and water-energy-crop modelling, able to support farmers precision agriculture.

Study Area



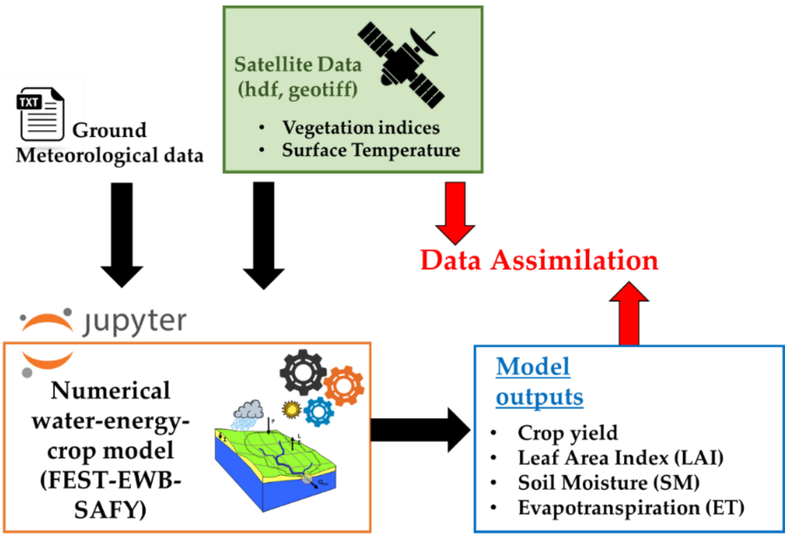
The Doukkala irrigation scheme in western Morocco

Research Outline

The project will develop an EO Service able to support precision agriculture practices for farmers and farms associations.

The modelling chain will rely on the assimilation of multiple-EO data (LST, LAI and SM) into the pixel wise crop-energy-water balance model FEST-EWB-SAFY, allowing to compute, continuously in time (with hourly to daily scale), high spatial resolution (30 m) evapotranspiration, soil moisture, crop yield and LAI. This will allow detecting crop shocks and failures due extreme events (droughts, floods or hailstorms), pests or diseases or unknown irrigation events, otherwise non-reproducible by the model alone. The pixel-wise architecture of the implemented tools determines an original and accurate methodology, allowing a mathematically consistent passage from field and to Irrigation Consortium scale maintaining the original pixel dimension as scale unit.

The expected outputs will be: a) a tool for estimating the crop damages caused by shock events, by mapping crop stress/drought/failure, b) maps and temporal series of evapotranspiration, soil moisture, crop yield and LAI. Project outputs will be validated against specific ground measurements of LAI, soil moisture and evapotranspiration, which are already available to partners and that will be further acquired during the project through dedicated field campaigns.



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3. Monitoring water level and volume of Buyo and Kossou dams in Côte d'Ivoire using optical and radar satellite imagery

Project Acronym

SISEB-CI

Scientific Background and Objectives

Cote d'Ivoire like many countries in west Africa is experiencing climate change impact such drought which affect water resources. Indeed, the decrease in rainfall and runoff has significantly impacted the filling of dams (figure 1), the production of hydroelectric power, the supply of water to urban areas, and agropastoral activities (Fratmat, 2021).

Figure 1 : An almost empty dam near Bouaké (central Côte d'Ivoire)

The Kossou and Buyo lakes and reservoirs, two large water reservoirs that are strategic for the Ivorian economy in terms of both agricultural and energy production, have experienced variations in water levels in recent years (figure 2). These variations are at the origin of load shedding, water shortages in Côte d'Ivoire and decreases in economic and fishing activities (Goli Bi et al. 2019). Indeed, in several regions of the country, access to drinking water and electricity are dependent on the level and volume of water present in these reservoirs (Jeune Afrique, 2018; Afrobarometer 2018 and 2020).

In response to these problems, Ivorian authorities have undertaken different strategies to ensure a sustainable management of water resources. These measures consist of monitoring water resources both quantitatively and in terms of its spatial distribution in order to have continuous long-term and readily available data on lakes of Côte d'Ivoire.

The water resources of lakes can be monitored in 3 ways: using in situ measurements, modeling process or based on remote sensing data. In recent years, water resources monitoring of Buyo and Kossou lakes has become increasingly difficult due to the decreasing number of measuring stations, the high cost of maintenance, the tedious collection and analysis of data, and the difficulty in modeling water resources.

Figure 2 : Decrease of the water level in the lake dam of Kossou

The use of satellite data remains the only way to go. Indeed, recent developments in remote sensing technology has spawned more and more access to high resolution images that allow regular monitoring of lake extent in time and space. In addition, the use of satellite radar altimetry can contribute to monitor changes in lake water level. This study aims to monitor water volume fluctuations by combining in situ data, satellite images and several satellite altimetry measurements.

Study Area

The study area (Figure 3) includes the Kossou and Buyo lakes and their surroundings. Lake Kossou is the largest lake in Côte d'Ivoire. It is located on the Bandama River in the center of the country. It is an artificial lake that covers an area of 1700 km^2 and created in 1973 by the dam of the Bandama River in Kossou. As for Lake Buyo, it owes its existence to the construction of a hydroelectric dam in 1981 on the main river Sassandra. It has an area of about 600 km^2. From an environmental and socio-economic point of view, these lakes are of great interest to the country as they contribute to electricity supply, drinking water supply, agriculture, fishing, forestry area, etc.

Figure 3 : geographic location of the two lakes (Buyo and Kossou)

Research Outline

The methodological approach is summarised in 4 steps (figure 4). First, the water level or surface height data are obtained by processing Jason, Envisat and Sentinel 3 satellite altimetry data (step 1); then, the water surface is extracted from the Sentinel 1 and 2 images (step 2). Then, the relationship between these variables and the water volume change is established by combining the water level data and the lake surface data (step 3). Finally, the relative water volume variation is obtained using the machine learning model (step 4).

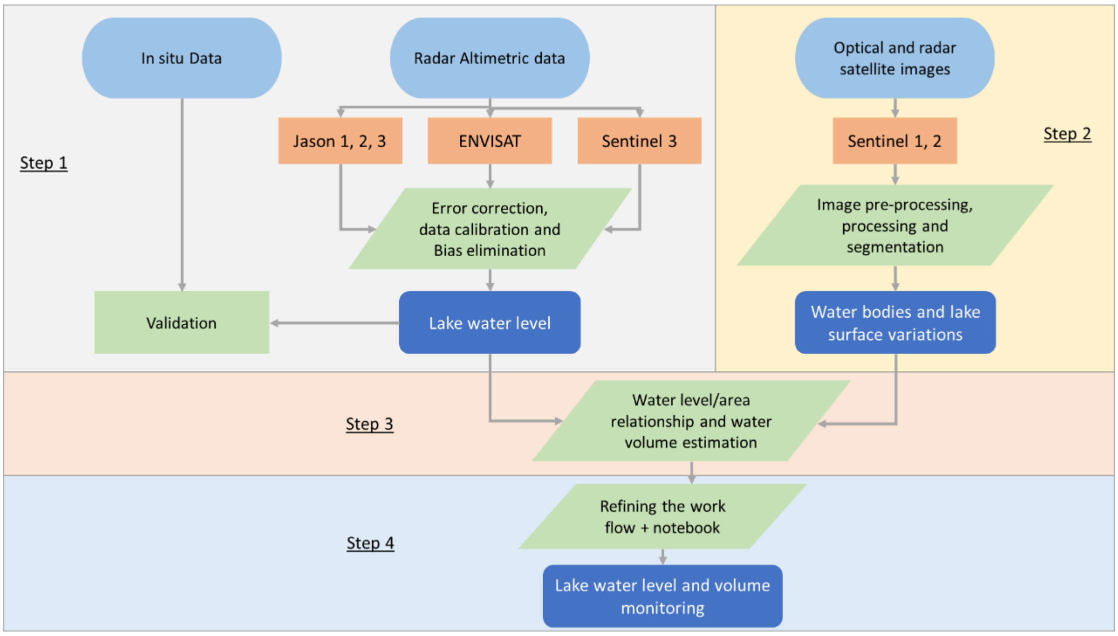

Figure 4 : Scientific approach of the project

This project will be carried out through five (5) major activities selected according to the expertise of the team members and the needs of the identified partners (figure 5).

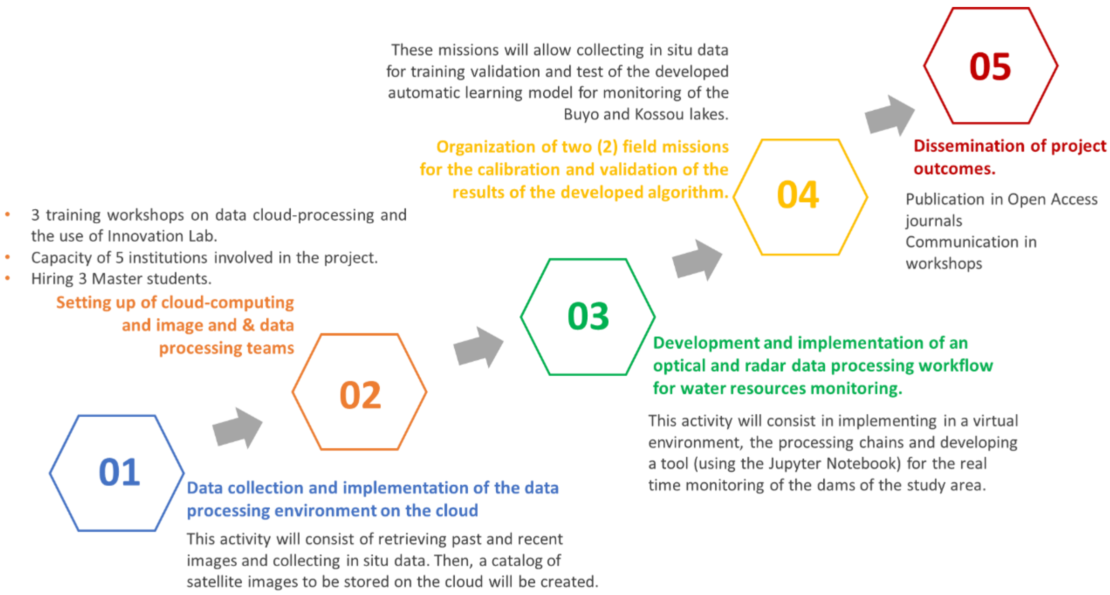

Figure 5 : Project implementation plan

The main expected impacts are:

At the methodological level

The project will develop methods and processing chains (Notebook) for operational applications to improve knowledge on shortages and impacts of climate change on water resources in Côte d'Ivoire; this method could be replicated on other African lakes and could be used to implement a monitoring system and integrated management of water resources for sustainable development.

At the decision-making level

This project will make available for each lake, useful information for hydrological monitoring by users and decision makers of the structures in charge of water resources management in Côte d'Ivoire. It will accompany the development of a tool for monitoring and early warning in situations of shortage and abundance.

At the academic level

This project will support the design of educational resources for training and research at the Virtual University of Côte d'Ivoire (UVCI) and the Centre for Research and Application in Remote Sensing (CURAT).

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4. Rising with temperature! Reconstructing the hydroclimatic record of Lake Naivasha with Earth Observation

Project Acronym

EO4-Naivasha

Scientific Background and Objectives

The water level of Naivasha Lake has been accelerating at unprecedented rates, damaging the Lake's ecosystem services and social-economic goods. Climate change is the leading hypothesis explaining the increase in water level. Precipitation analysis shows a drastic (>50%) increase in rainfall intensity over the Lake since 2018, thus, an upsurge in river discharge from the Gilgil and Maliwa rivers feeding the Lake. In addition, agricultural practices and land use increase sediment load in the rivers, which causes siltation.

Except for analysing the rainfall and river discharge data. There is no scientific evidence verifying and expanding on the climate change hypothesis. This project will research the climate change hypotheses by use Earth Observation (EO) data and models to map the distribution of precipitation, evaporation, water extent and level, and the sedimentation rate.

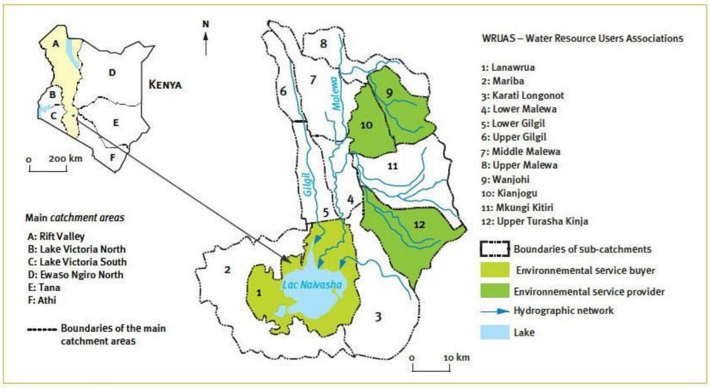
ITC and RCMRD will develop a framework integrating these EO-products to reconstruct the Lake's hydroclimatic record and attribute the Lake's water level fluctuations to the different hydro-meteorological drivers.

Objectives

We understand that studies have been conducted before, however, they have been offering a disjointed approach towards understanding water bodies. The proposed research offers a holistic approach to studying large water bodies. The endeavour is to provide a comprehensive and novel approach to understand rainfall, temperature, evapotranspiration, spatial water extent and siltation for continental large water bodies for emulation. Specifically, the project will:

- Capitalise on the existing data of CCI_Lake and combine them with other data sources in one framework that links water quantity to quality.
- Develop an EO-based approach to estimate the sedimentation rate in the Lake and verify the SWAT model – Long Term Objective.
- Integrate the effect of siltation on the water storage capacity in the water balance.
- Attribute fluctuations in the Lake level rise to the main hydro-meteorological drivers.
- Implement the immense amount of data from different sources as an open-source could-based framework that can be applied to other African lakes.

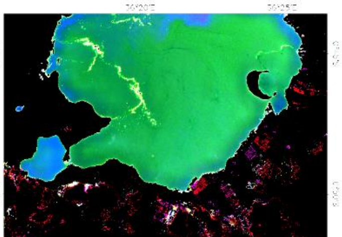
Study Area



- Lake Naivasha is RAMSAR site classified as wetland of international importance – High number of Hippos, Flamingos, Variety of Birds
- An important source of fresh water in the area
- Horticultural farms – Source of vegetable, flowers
- High population, pollution, High water abstraction
- Rapid increase in the spatial extent

Research Outline

Activity	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
A1. Mapping Precipitation–Evaporation distribution over the Lake;												
A2. Mapping lake water extent;												
A3. Mapping suspended sediments ;												
A4. Reconstruction of the Lake's water budget.												
A5. Final report												
A6. Fieldwork of Ongo												
A7. ITC staff visits to Kenya												
A8. Ongo's visit to ITC												
A9. Attending conferences												



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5. Sentinel-1 and -2 data fusion for mapping smallholder cropping areas in southern Africa to support crop monitoring and yield forecasting

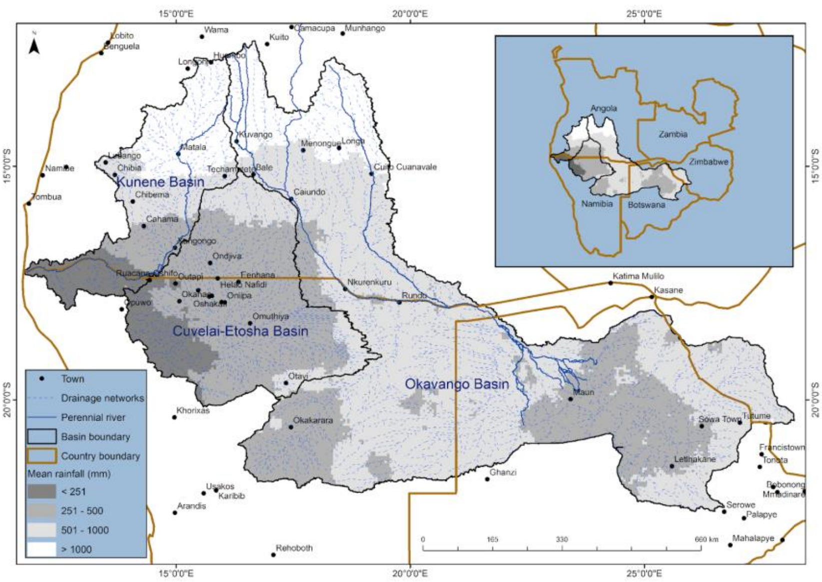
Project Acronym

SENT-CROP

Scientific Background and Objectives

Small-scale and rain-fed crop farming is the backbone of livelihood for millions of people in sub-Saharan Africa. However, climate change is increasingly affecting crop production in this region through frequent droughts and floods, often accompanied by pest outbreaks, leading to crop failure or low yields. In the events of crop failure, food supplies from government and the donor agencies are the only available livelihood safeguard for many rural resource-poor households which rely on smallholder subsistence farming. The efficiency and effectiveness of government and donor agencies interventions to provide food supplies, however, is often undermined by lack of reliable and timely information on areas which are most affected and where food insecurity is imminent. The recent advancements in satellite remote sensing whereby data with high resolution, for example from European Copernicus Sentinel satellites are freely available every 5 day, provides reliable alternative solution for monitoring crop development in a timely manner. In this way, early warning and food security information system powered by earth observation can be developed to identify, in a timely manner, the areas where crop failure is imminent. However, lack of accurate spatially explicit dataset for field boundary of smallholder crop farms hinders the use of freely available high resolution satellite data for targeted farm-level crop monitoring and yield estimation using earth observation. This project aims to fill this gap by (i) creating consistent reference dataset for crop field boundaries to train and validate EO algorithm for mapping cropping areas, (ii) developing an innovative EO algorithm and workflow for mapping cropping areas across a diversity of landscapes in southern Africa using imagery from European Copernicus Sentinel-1 and -2 satellites. The factors that affect accurate mapping of cropping areas across various landscapes in southern Africa will be identified.

Study Area



The study will be conducted in 3 water basins (Kunene, Cuvelai-Etosha and Okavango) in southern Africa.

Research Outline

Step 1: Elaborate and consistent polygon-based reference dataset for crop field boundaries to train and validate EO algorithm for mapping cropping areas will be created. The study area will first be sub-divided into 10 km x 10 km grids which will then be grouped into two groups (crop and non-crop areas) based on the existing cropland maps. A total sample of 5 000 grids will be selected from each sub-group through probability sampling. The boundary of crop field in the selected grid will be digitised manually from high resolution images from Google Earth and Planet analysis-ready mosaics of images freely available through Norway's International Climate & Forests Initiative. Reference data will then be split into training and test validation sets.

Step 2: The workflow/algorithm for mapping cropping areas using a combination of optical and radar imagery from European Copernicus Sentinel-1 and -2 satellites will be developed. The algorithm will exploit complementary information available in optical and radar imagery to enhance the mapping of cropping areas.

Step 3: The developed mapping algorithm/workflow will be applied over the entire study area to map cropping areas at 10 m resolution using the cloud-based computational resources provided under the ESA EO AFRICA R & D Facility.

The following outputs are expected:

- At least one peer-reviewed publication
- Polygon-based reference data digitised at 200 areas of 5km x 5km size each
- Point-based reference data (50 000 samples)
- A 10m resolution map of cropping areas for the study area

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6. Integration of open-source solutions with deep learning for estimating crop production in data-scarce smallholder farming areas

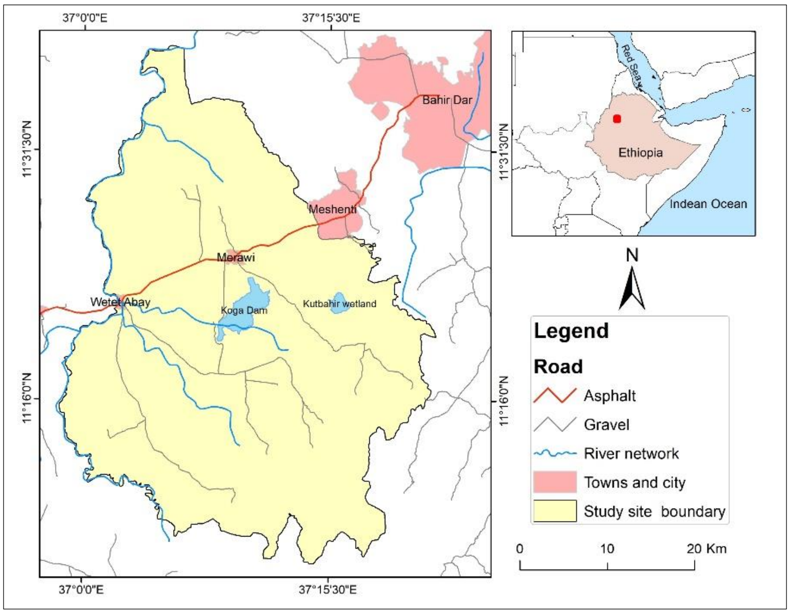
Project Acronym

DeepCrop

Scientific Background and Objectives

In smallholder farming areas where crop production is the mainstay of livelihood, early identification and monitoring of crop production status will be very useful for assessing the forthcoming food availability, food security and food market stability of the region at a pre-harvest season. In the presence of climate related shocks, this information would be even necessary for estimation of damage and further insurance pay-outs. Collection of this information through manual approaches is time consuming, influenced by human and technical bias and mostly impractical because of inaccessible terrain, availability of resources and time to run logistics of intensive field data collection. Presence of wide array of earth observing satellite has provided possibility of monitoring and mapping of objects and phenomena everywhere in the world. Though this is the general trend, mapping of crops and crop production using conventional approaches is challenging which is constrained by inherent characteristics of smallholder farming areas like seasonality of crops, fragmented small fields, and dominance in complex topography. Therefore, in our proposed project we have planned to integrate multi-temporal multi-source optical and radar satellite imagery with artificial intelligence (deep learning models) with powerful statistical tools to map crop types and estimate crop production in smallholder farming areas, in selected Ethiopian landscape using open-source innovative solutions. Under this broader objective we have planned to undertake crop land extraction, specific crop type mapping and further estimation of crop production.

Study Area



Research Outline

To achieve the overall objective stated in the background section, we will mainly utilize multi-temporal, multi-source and multi-modal satellite observations with medium to high spatial resolution and frequent observations. In tropical smallholder farming landscapes where growing seasons are accompanied by heavy and thick clouds, probability of getting cloud free optical scenes is less probable. Here is what justifies our intention to synergistic use of optical and radar imagery. From optical imagery we will use sentinel and planet scope while from radar imagery, TerraSAR-X and sentinel-1 will be utilized. In large scale farming areas and commercial plantations where farm plots are fairly large enough being detected in medium spatial resolution images, sentinel-2 could be sufficient to map and characterize crop types in the landscape. When it comes to smallholder farming areas where even small plots are fragmented and occupied with more that two crops, it calls for high resolution images like planet scope and TerraSAR-X images.

After proper pre-processing and generation of useful information (features) from both optical and satellite images, it would be fed to deep networks and statistical models to map crop types and further estimate crop production. This would be done in combination with field data which is proposed to be collected in the forthcoming growing season which is almost to onset. As a baseline we would implement some model which fully can capture seasonal evolution and phenology of crops from generated earth observation features. Here it should be noted that deep models equipped with artificial neural networks are data intensive by nature, we have a plan to investigate sample efficient transfer learning strategies where we can leverage field samples collected from completely different geographies and archived openly (USDA Crop Data Layer, PDOK and others). We will follow either joint training strategy or completely exclusive where trained model knowledge is transferred and applied with our data. The mapping strategy is undertaken hierarchically where we first map crop land extent. Within cropland extent, specific crop types will be mapped. To estimate crop production, first crop yield will be estimated using crop yield statistical record and vegetation indices through regression approach. In combination with generated crop type map, and crop yield output, crop production estimate for the test site will be generated.

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7. A workflow for forecasting primary productivity and its determining climatic factors using remote sensing in the eastern Sahel region

Project Acronym

Primary productivity in the Sahel region

Scientific Background and Objectives

Understanding the dynamics of primary productivity and determining climatic factors is essential to determine a given area's socio-economic and ecological vulnerability. The eastern Sahel region has been described as a hotspot of land degradation, resulting in significant natural and human crises. While the region's population is expected to grow faster than the rest of the world, the climate of the eastern Sahel is predicted to become arider. As such, increased demand for food will likely coincide with a decline in agricultural productivity in the region. An innovative approach is required for positive transformation and effective natural resources management. In this regard, the use of earth observation (EO) data and inexpensive cloud computing technologies in Africa has been under-represented and, therefore, needs a dramatic boost to inform the sustainable management of primary productivity. This project aims to forecast primary productivity and climatic factors (soil moisture, precipitation etc) using remote sensing techniques. The project seeks to develop an open-source interactive workflow to predict for 12 months ahead, considering the prevalence of subsistence livelihoods that largely rely on short-to-medium term preparations in the region. The project also offers hands-on training for African stakeholders to handle African challenges by leveraging cutting-edge open-source EO algorithms.

Study Area

Research Outline

The project aims to forecast primary productivity and determine its climatic factors using remote sensing. Three main climatic variables, including soil moisture, precipitation and temperature, will be used to forecast primary productivity. Specifically, the project seeks to predict for 12 months ahead, considering the prevalence of subsistence livelihoods that largely rely on short-to-medium term preparations in the region.

Soil moisture provides an immediate source of water for plant growth and is therefore key in primary productivity modelling efforts. Soil moisture data produced by the European Space Agency's Climate

Change Initiative (ESA CCI) will be used in the project. The data will be divided into training and validation sets. Commonly used time-series analysis methods will be explored to characterise the trend and develop models from the training set. The developed models will then be evaluated using the validation set. The model with the best estimation accuracy will be used to forecast soil moisture for 12 months ahead.

Soil moisture is largely replenished through precipitation, particularly in areas where groundwater availability is scarce. As a result, precipitation is a vital meteorological factor that influences primary productivity. Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) will be used as a source of precipitation data for the project. CHIRPS combines spaceborne microwave data, station records and environmental variables (e.g. topography) to produce a gridded precipitation map. Time-series analysis to forecast monthly rainfall for 12 months ahead will be accomplished by following similar procedures as those for soil moisture forecasting.

Temperature is an important climatic variable that directly influences primary productivity by driving (evapo)transpiration and photosynthesis. The project will use remotely sensed land surface temperature (LST) sensitive to vegetation and bare soil temperature variations. Specifically, Sentinel-3 Sea and Land Surface Temperature Radiometer (SLSTR) will be used in the project. Time-series analysis and forecasting procedures similar to those used for soil moisture and precipitation forecasting will be applied to the temperature data.

Primary productivity forms the main goal of the project. The people of the eastern Sahel region, as in other regions, extract ecosystem services such as agriculture, livestock rearing, energy generation, construction purposes and climate moderation from plants. It is, therefore, crucial to monitor and forecast primary productivity in the region to sustain and adapt to the dynamics. In the proposed project, vegetation indices derived from relevant bands of Sentinel-2 Multispectral Instrument will be used to represent primary productivity. Two approaches will be explored to forecast primary productivity for 12 months ahead. The first approach will solely use the historical trend of primary productivity similar to the approach and procedures used to forecast soil moisture, precipitation and temperature data. The second approach will build a model relating the environmental variables and primary productivity using historical data. The trained model will then be applied to the forecasted environmental models to predict the productivity of 12 months ahead.

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8. Fusion of EO data for crop yield forecast in Benin and Morocco

Project Acronym

FudCast

Scientific Background and Objectives

For Africa, a recent review by Chivasa et al. (2017) identified several research gaps related to remote sensing of crop yields in Africa:

- Only few studies derived yields for fragmented agricultural lands as widespread in African countries.
- The low availability of crop type maps in important agricultural areas.
- To date, no system is available which forecasts yields based on a sufficiently high spatio-temporal coverage to account for small field sizes. To our knowledge, the only study focusing on this important topic is based on AVHRR data with a spatial resolution of 16 km (Unganai & Kogan, 1998). This is by far too coarse for many parts of Africa.

Within **FudCast** project, we will address all above-mentioned research gaps by developing a novel set of methods to be applicable to Sentinel 1, 2, and 5. The code supplied as a Jupyter notebook will be developed for two core regions but can be easily applied to other areas. Therefore, interfaces will be included which allows future users to easily adopt the code and the training data to their research area.

The final aim of **FudCast** project is to provide finer forecast of crop yield with 6 weeks lead based on various satellite products and ground truth.

Study Area

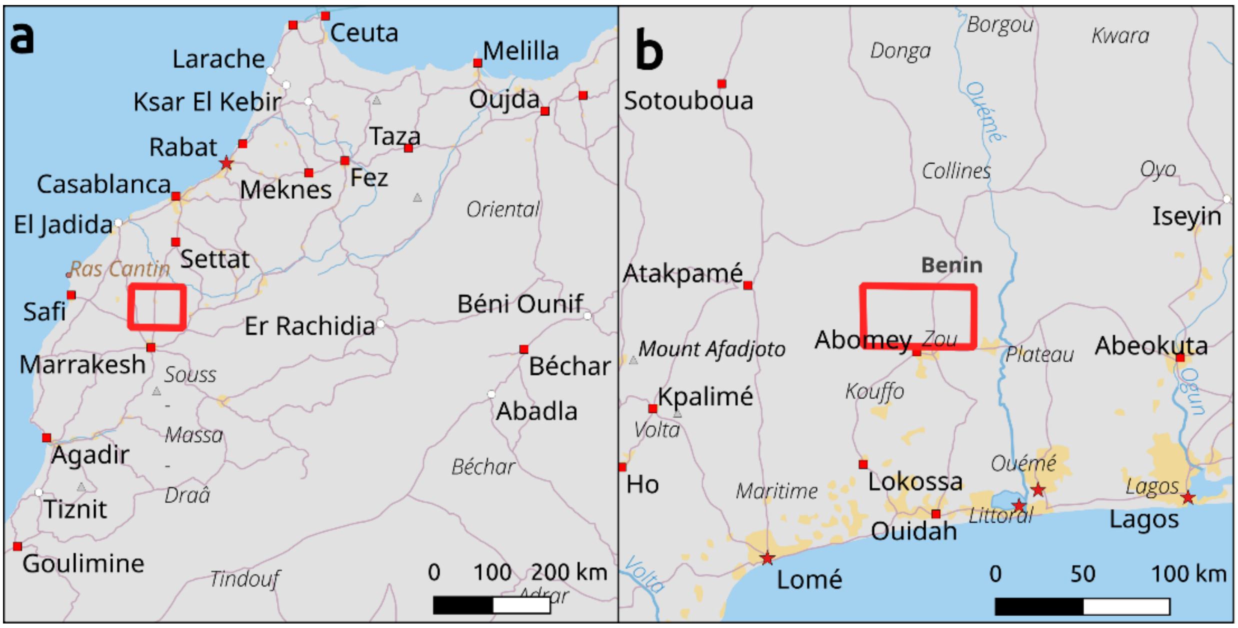

Fig. 1: Location of the two areas of investigation in Morocco (a) and Benin (b).

Research Outline

The project aims to develop a novel open-source approach to forecast yields of two important crops, maize and wheat. The approach will be developed and tested in two case study regions in Morocco and Benin (Fig. 1). The selected plants are the main local crops and, consequently, crucial for local food security and economy. To forecast yields, we will fuse several earth-observation datasets based on Sentinel 1, Sentinel 2 and Sentinel 5 data. The project is structured into four working packages (Fig. 2):

In the first working package, extensive historic data collection and indexation will be performed and will cover: land use, crop management, climate, and any infrastructure or other anthropic activity interfering with crops in the two regions of interest (with more focus on reference plots). A Geodatabase will be built for each region to be used in the subsequent work packages.

Within the second work package, a land-cover classification will be developed for both areas of investigation using Sentinel 2 data (Level 2). The classification aims to identify the most dominant crop types in both areas. For the classification, data collected in the field will be used as reference to train a machine learning model (Random Forest).

In the third working package, above-ground biomass will be estimated approximately 6 weeks before harvest. Therefore, Sentinel 1 data will be used in combination with field reference data sampled in both areas of investigation. At least 120 plots (each 1 x 1 m) for each crop will be harvested in the field and weighted to collect the reference samples.

The fourth working package focuses on the development of a statistical model which allows to forecast crop yields six weeks before harvest based on biomass, crop type, average chlorophyll fluorescence (Guanter et al. 2021) and actual precipitation data from ERA5 reanalysis (Hersbach et al. 2018). This will be achieved by training a machine learning model based on crop yields of the years 2018 to 2021 in both areas. Calibrated crop models, such as AquaCrop and DSSAT, might be used to generate more biophysical parameters and to simulate crop yields if needed. As predictors of the machine learning model, mean chlorophyll fluorescence derived from Sentinel 5 data (Guanter et al. 2021), averaged 10 to 6 weeks before harvest, crop type and aboveground biomass will be used. This model allows us to forecast crop yields on a spatially explicit basis for both areas.

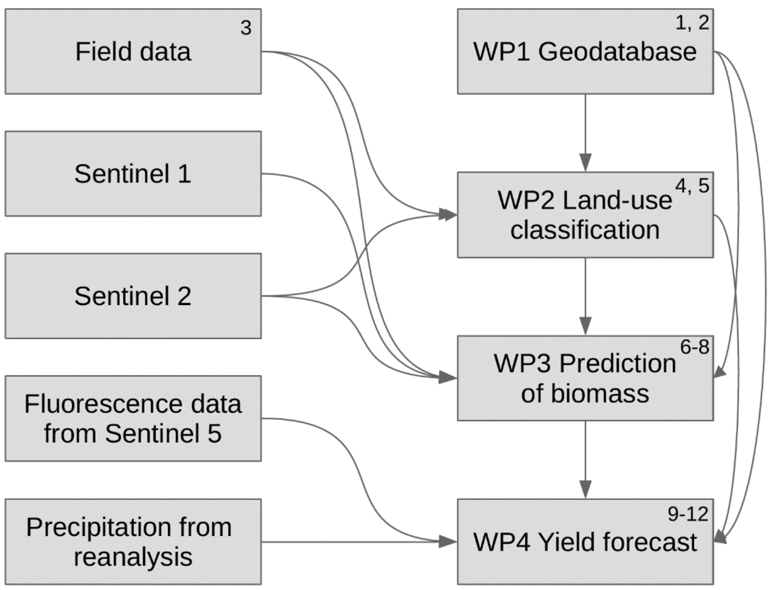

Fig. 2: Flow chart of the proposed methodology

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9. Improvement of Agricultural Statistics in the cotton zone of Mali thanks to the synergy of the Sentinel 1 and 2 time series

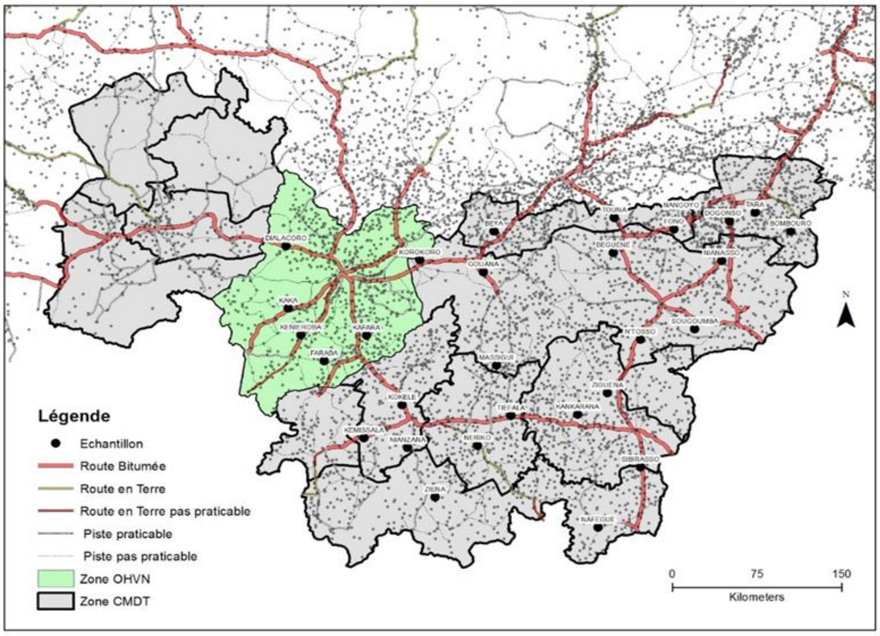
Project Acronym

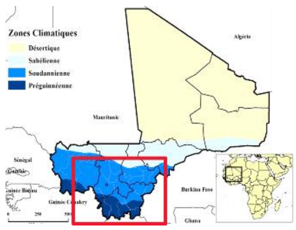
ASAS

Scientific Background and Objectives

The European Copernicus program produces massive amounts of valuable data for crop recognition and monitoring provided it can be processed efficiently using cloud-based computing infrastructure to provide crop mapping and early estimates of agricultural land within a sufficiently short period of time. The project will allow a Malian team to demonstrate this processing capacity for an area of approximately 150,000 km² (estimated population of 8 million habitants in 2017) while testing the contribution of cloud-insensitive Sentinel-1 data. This ambition is possible thanks to open-source tools such as Sen2Agri and Sen4Stat and experience in field data collection acquired within the framework of the Sen2Agri project. The objective is to improve the agricultural statistics available in Mali for the main crops in the cotton zone using a transparent, precise and reproducible method. The sustainability of the project's achievements is ensured by the financing of a doctoral scholarship for a member of the Malian team with the European partner.

Study Area





Pilot site: Malian cotton belt (CMDT+OHVN zone)

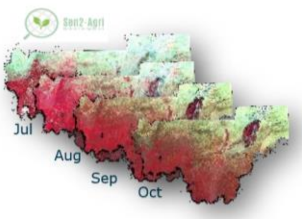
Size: ~ 150 000 sq.km

Population: 7.5 M. hbts (worldpop, 2021)

Major: contribute to ~50% National crop production (CMDT-OHVN, 2013)

Main crops: Cotton, Sorghum, Millet, Maize, Groundnut and Rice

Research Outline



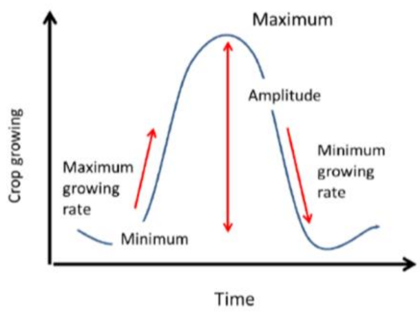
1. EO consistent time series preparation

- Collection and processing of L8/L9 and S1/S2 for 2022 cropping season
- The time series of backscatter coefficients (including the VV/VH ratio) acquired by Sentinel-1 (GRD) will be processed by a spatio-temporal filter
- All images will then be subjected to quality control to ensure good signal consistency for the different time series

2. Field data collection

- About 11 200 crop samples will be collected in 28 areas randomly distributed in the Cotton Zone (~ 400/area).
- Windshield survey method will be use to collect data along the road using JECAM protocol (jecam.org/)
- Mobile phone with ODK tool will be use for data collection
- Final field boundary will be delineated using high resolution images

3. Calculation of crop growth monitoring indices and temporal metrics



Different spectral indices and biophysical variables for monitoring growth (NDVI, LAI, fCover, fAPAR, Chlorophyll retrieval) will be calculated throughout the cycle of the cropping season

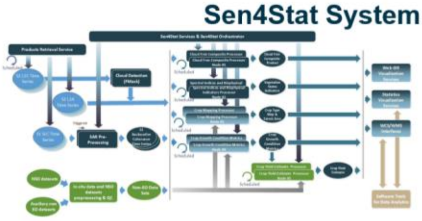
The contribution of biophysical variables such as the Leaf Area Index (LAI) and minRed will be evaluated as well as that of temporal metrics particularly suited to the S1 series (coefficient of variation, amplitude, max, etc.).

4. Production of cultivated area and crop maps and area estimation

Sen2Agri System

http://www.esa-sen2agri.org/

Sen4Stat System

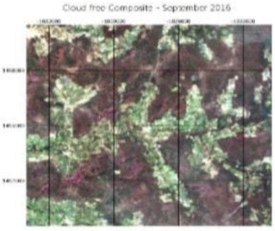


Production of crop type map for dominant crops in the area based on collected field data through Sen2Agri chain

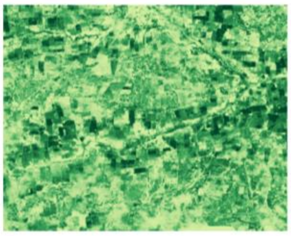
Validation of the results using confusion matrix

EOs crop type areas will be compared with the areas of static services (correlation and bias correction by regression estimator) at different levels of aggregation

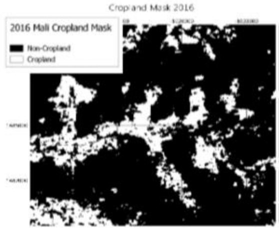
Expected outputs



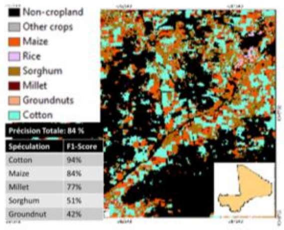
Monthly cloud free surface reflectance composite at 10-20m for the cropping period (may-October)



Vegetation status map (NDVI, LAI) at 20m delivered for each cloud free observation



Binary map identifying annually cultivated land at 10m. First produced at the mid-season, then updated every month



Crop type map at 10m for the 5 main crops first produced at the mid-season and, produced again at the end of the season

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10. Applying innovative cloud computing technology for the effective management of Groundwater resources to promote SUStainable food security within the Sokoto Basin, Nigeria

Project Acronym

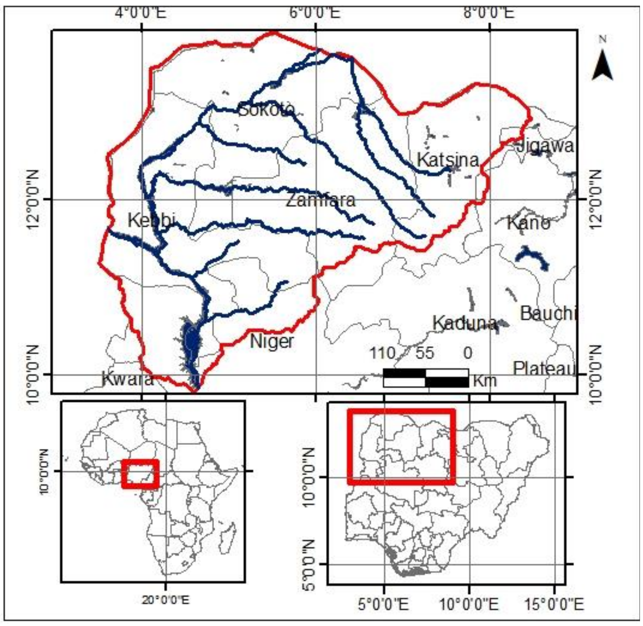
AGSUS

Scientific Background and Objectives

The livelihood of over 70% of the population within the study area relies on subsistence farming, and hugely dependent on groundwater resources, which unfortunately has been largely inhibited by characteristic irregular rainfall pattern, and hence further increased risks posed to agricultural production. Therefore, the aim of this project is to apply cloud computing technology for effective groundwater resources management to promote sustainable food security within the area of study. The specific objectives are to:

1. Develop an integrated hydrological model for groundwater resources management within the Innovation Lab environment;
2. Estimate groundwater resource availability using flow model developed in (1) above;
3. Carry out simplified water needs assessment for the local agricultural, domestic and industrial use;
4. Propose water usage allocation under prioritization to promote sustainability of food security.

Study Area



Age	Formation	Class	Group	Description
Quaternary	Sandy Drifts and Laterites		Continental	
Post Paleocene	Gwandu Fm	Aquifer	Continental	Laterites, Sst; Grits;
Paleocene	Oolitic Ironstone		Sokoto	
	Gamba Fm	Aquiclude		Clay; Clayite Fm
	Kalambaina Fm	Aquifer		Marine Lst;
	Dange Fm	Aquiclude		Marine Lst
Maastrichtian	Wurno Fm	Aquifer	Rima	Sand; Sst
	Dukamaje Fm	Aquiclude		Clay; Shale
	Taloka Fm	Aquifer		Clayite; Sst
Cretaceous / Late Jurassic	Gundumi Fm	Aquifer	Basal	Sst
	Illo Fm	Aquifer		
PreCambrian	Basement Complex	Aquiclude		Metamorphic Rks

- ✓ Latitude: 10°00’ - 14°00’ N
- ✓ Longitude: 3°30’and 8°30’ E
- ✓ Approx. 64,000 km^2 of land area; 4 States & with over 150 inhabitant/km^2

Research Outline

The flowchart for the project methodology showing the workflow and data sources is presented in the Figure 1 below.

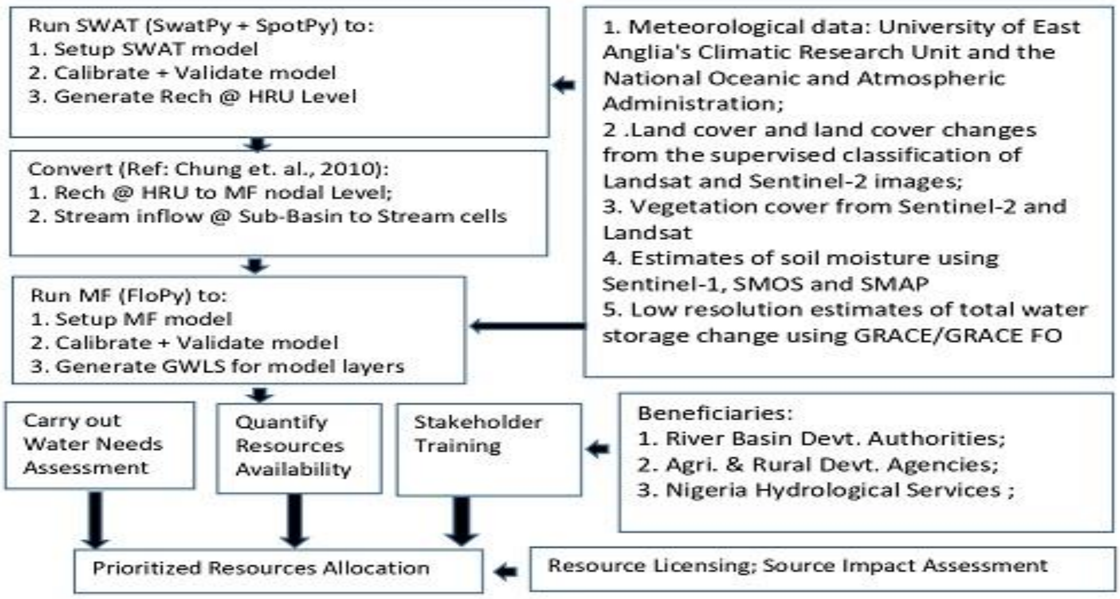


Figure 1: Project workflow

<u>Highlights of the Project methodology</u>

1. The method integrates a quasi-distributed hydrological model, SWAT (Figure 2), and a fully distributed groundwater flow model, MODFLOW (Figure 3), in order to quantify availability of groundwater resources.

2. The integrated models will utilize a module adaptor that will map hydrological parameters, namely recharge flux and stream inflow generated by the SWAT model at sub basin (HRU) scale, onto the MODFLOW nodal cells.

3. Subsequently, MODFLOW model will be employed to simulate groundwater heads under the prevailing study area scenarios. The spatial and temporal differences between the initial static water levels and the predicted groundwater heads, as a function of porosity, will constitute the transient available groundwater resource over the period of simulation.

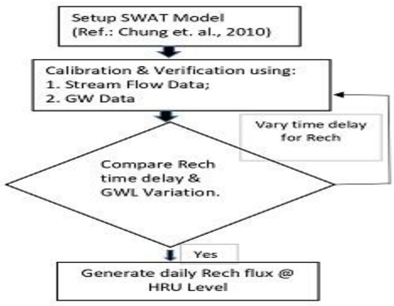


Figure 2: SWAT model workflow

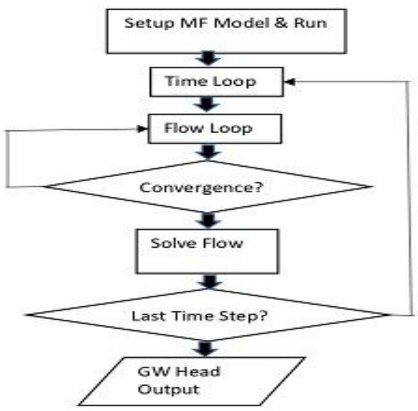


Figure 3: MODFLOW model workflow

4. The data requirements and sources for model setup include: Meteorological data (University of East Anglia's Climatic Research Unit and the National Oceanic and Atmospheric Administration); Land cover, land cover changes and vegetation cover (Supervised classification of Landsat and Sentinel-2 images); Soil moisture (Sentinel-1, SMOS and SMAP); and Low resolution estimates of total water storage change (GRACE/GRACE FO);
5. The integrated model will be implemented on the Innovation Lab Platform. Therefore, the model setup, generation of the required input files, model runs, reading of the model outputs, and post processing of the results for SWAT and MODFLOW models will be carried out using SwatPy and FloPy Python libraries, respectively.
6. Other major Python libraries that will be employed in this project are: Numpy for array manipulations; Matplotlib for graphics; Spotpy and Scipy for optimization; and Pandas for data exploration and analyses.
7. Subsequently, simplified water needs assessment for irrigation and domestic purposes will be carried out based on evapotranspiration consumptive use and per capital consumption factors, respectively. The industrial water needs will be assumed to be the difference between the total predicted water availability and the summation of the needs for both the irrigation and domestic purposes.
8. Finally, stakeholders meeting will be facilitated to create awareness regarding recharge rate, groundwater resources availability, principal water needs and prioritized allocation, in order to ensure effective resource management and consequently promote sustainable food security.

The Expected Project Outputs

1. Quantitative estimation of recharge flux and stream inflow at sub basin scale and subsequently at nodal cells of the flow model;
2. Transient groundwater resource availability for the area of study;
3. Water needs requirements for irrigation, domestic and industrial use, that will ensure reduced risks posed to agricultural activities, and hence promote sustainable food security;
4. Prioritized and transparent resource allocation and reduced rate of expanding desertification;
5. Reduced conflicts and threats between the pastoralists and the farmers, and hence increased national and food securities.

The Specific Deliverables

1. Progress Report (M6)
2. Final Report (M12)
3. Research Highlights Document (M12)
4. Jupyter Notebook document incorporating the Integrated Flow model (M12)
5. Report on Awareness Program administered to the representatives of the beneficiary communities (M12)
6. Peer-reviewed Journal Publication (M12)

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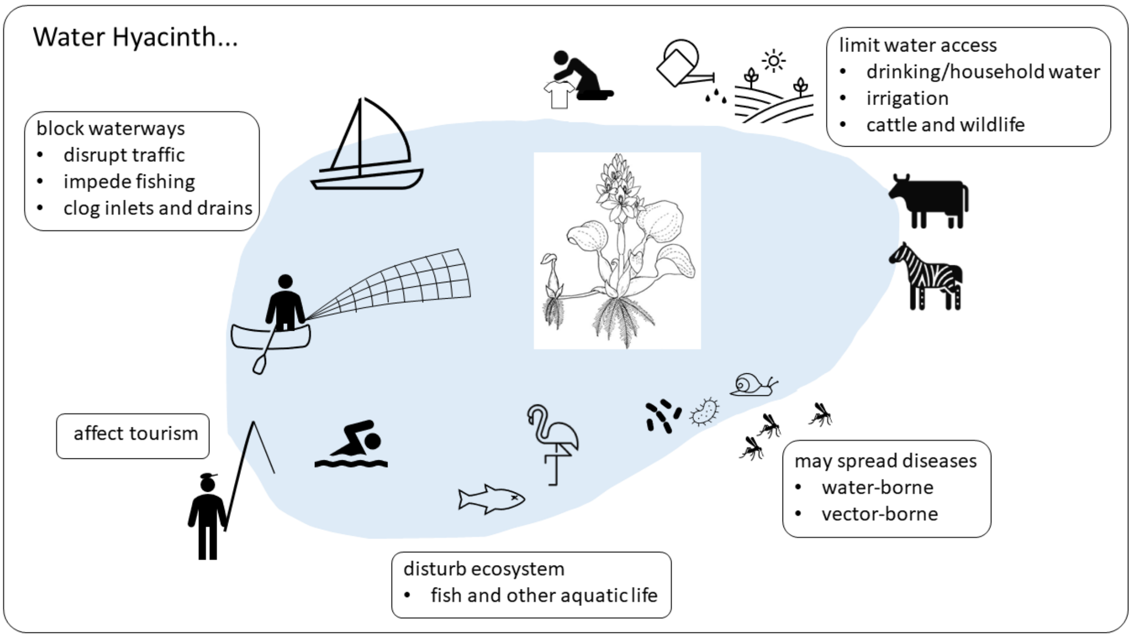
11. Towards daily maps of water hyacinth cover: exploiting synergies between Sentinel-2 and 3

Project Acronym

WHYmapping

Scientific Background and Objectives

Water HYacinth (WHY) is one of the world's most disturbing invasive plant species. The weed is a nuisance to boat traffic and fishery, clogs water treatment plants and hydroelectric dams, and renders lakes and reservoirs unattractive to tourists. Removal of WHY is an expensive undertaking due to the sheer scale of infestation.



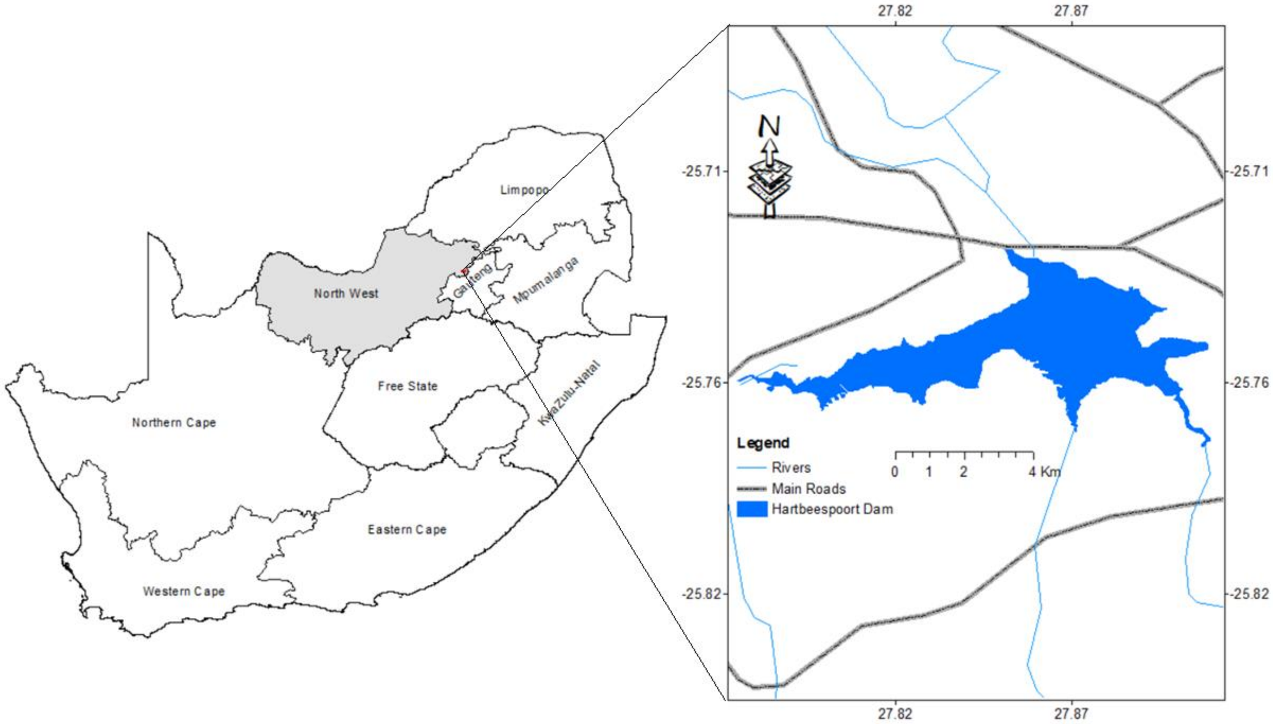
Numerous studies have shown that dense, floating mats of WHY can be detected using satellite instruments such as MSI[4] on Sentinel-2. The OLCI[5] instrument on Sentinel-3 has a coarser spatial resolution and is less suitable for WHY detection. However, it achieves global coverage in two days, compared to ten days for MSI, providing an opportunity to monitor WHY at near-daily resolution. This is crucial, considering that WHY cover patterns are highly variable due the plants' rapid reproduction and the influences of wind and currents.

We propose the development of an algorithm that exploits the complementarity of MSI's high spatial resolution and OLCI's high temporal resolution to create daily maps of WHY cover. These would improve the understanding of the driving forces of WHY spread and aid policy makers in combating WHY or curbing its effects on traffic and fishing.

[4] Multi-Spectral Imager for Sentinel-2
[5] Ocean and Land Colour Imager

Study Area

The study will be conducted at the Hartbeespoort Dam, in the Northwest Province of South Africa.



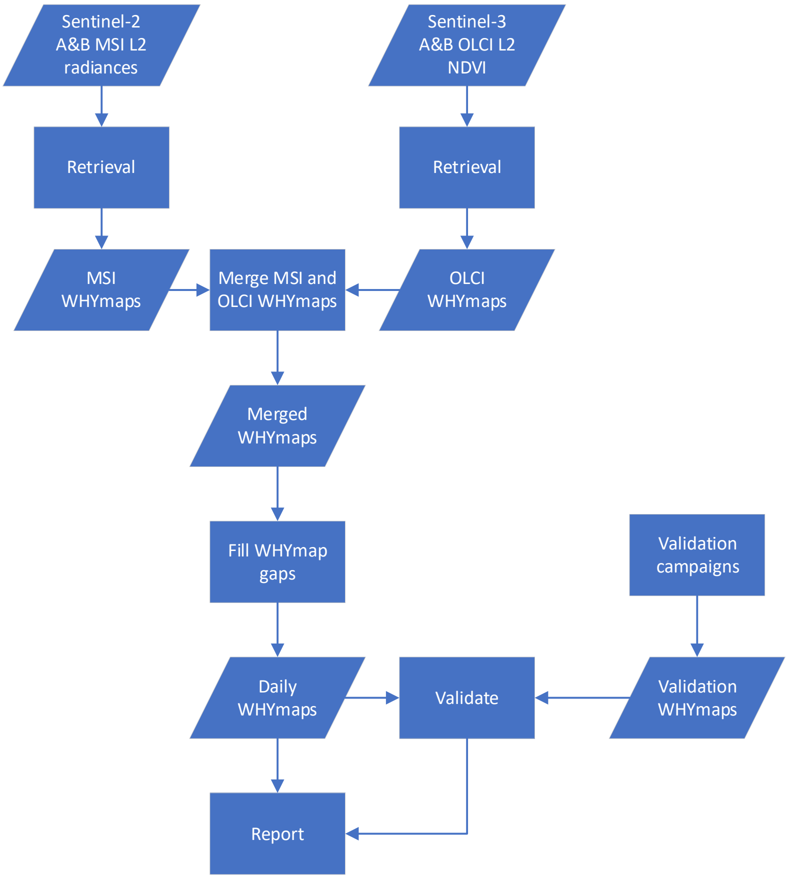
Research Outline

Main objective: Develop a tool which exploits the synergy of multiple satellite missions to map water hyacinth cover on a daily basis.

Sub-objectives:

- Develop and apply WHY detection algorithm for MSI Level-2 reflectances;
- Create WHY maps from OLCI Level-2 NDVI data;
- Design and apply algorithm for merging OLCI and MSI WHY maps;
- Develop and apply gap-filling algorithm to generate daily WHY maps;
- Execute validation campaigns and create validation maps of WHY cover;
- Validate WHYmapping algorithm;
- Present results and validation in an open access journal publication and at international conferences.

The individual steps of the WHYmapping algorithm are illustrated in the flowchart below.



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12. West Africa Lake Monitoring System

Project Acronym

WALMOST

Scientific Background and Objectives

In most West African countries, water authorities face real challenges in monitoring and managing lakes. The uncontrolled spread of brush park fisheries (a traditional fishing method, locally called acadja) is causing environmental pressures in coastal lagoons in many areas of the world. The most extensive forms of brush-park fisheries, also called acadja (Figure 1), occur in Benin - more precisely in the Ahémé (80 km^2) and Nokoué (150 km^2) lakes. Elsewhere, brush-park fisheries are found in Nigeria, Côte d'Ivoire, Ghana, Togo, Madagascar, but also in some lagoons in Sri Lanka and Mexico. The main environmental pressures linked to the practice of acadja are reduction of fish biodiversity, amplification of eutrophication, deterioration of water quality and rapid filling of the water body. In most cases, these pressures are combined with the strong proliferation of water hyacinth, thus causing serious problems of water quality (increase in eutrophication and in the production of chlorophyll-a) and food safety (decrease in biodiversity and fish productivity).

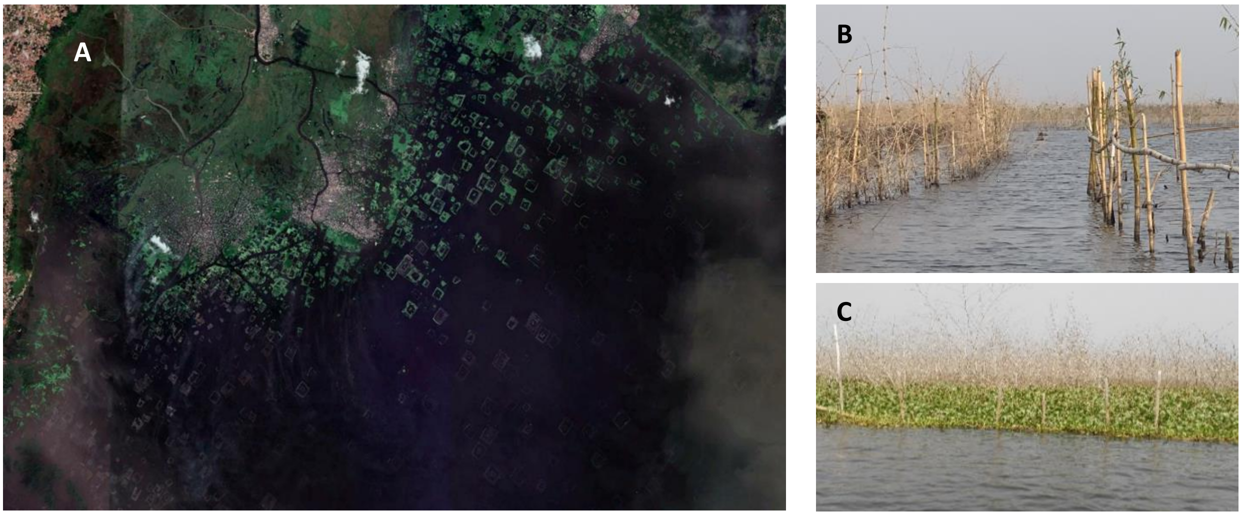

Figure 1: Satellite image of the North of Lake Nokoué in November 2020 (A). It is possible to distinguish on the image rectangular shapes inside the body of water, these are the acadjas (B). Inside these rectangles we can see green carpets, these are water hyacinth carpets (C).

Several studies in west Africa have linked the occurrence of both acadja and water hyacinth to the decline in fish productivity. As a result, the government of Benin adopted on August 7, 2014, the law n°2014-19 relating to fisheries and aquaculture which in its article 73 prohibits the use of acadja in water bodies. In addition, since 2016, Benin government actions for the ecological restoration of coastal lakes have been intensified with the objective of increasing natural fish productivity and the sustainable use of ecosystem services. Therefore, all the acadjas have been removed from Lake Ahémé in 2019, while at Lake Nokoué several actions to reduce pollution discharges into the lake have been implemented. However, the authorities and municipalities have challenges regulating acadja because of the densification of the practice and the lack of adequate control tools to follow the progress actions. It appears necessary to have rapid and low-cost monitoring tools to support decision-makers on the regulation of acadja and the fight against water hyacinth.

It is in this context that the National Water Institute (INE) and IHE Delft initiated in 2017, several studies on the effect of acadja and water hyacinth control on the water quality of coastal lakes in Benin. Part of the studies focused on the use of sentinel images for mapping acadja and water hyacinth dynamics in lake Nokoué.

The objective of the project is to use EO data to develop an open-source online monitoring system (dashboard) on water quality, water hyacinth, and acadja for West African lakes to improve water management for food security.

Study Area

The study sites are lake Ahémé and lake Nokoué, both located in the south of the Republic of Benin in West Africa.

The climate of the study area is of the subequatorial type, characterised by two dry seasons and two rainy seasons (bimodal), with an average annual rainfall of 1270 mm over 1971-2020. The hydrological cycle of the two lakes is characterized by complex and rhythmic exchanges between the continental waters coming from the tributary rivers and the marine waters coming from the Atlantic Ocean. These different hydrological exchanges determine the spatio-temporal variation of flows, as well as water quality. Thus, from December to July, the waters of the Aheme and Nokoué lakes present high concentrations of salinity that can inhibit the development of water hyacinth. At other times of the year, salinity values drop and allow the excessive development of water hyacinth with negative consequences on boat trips, water quality and fishing.

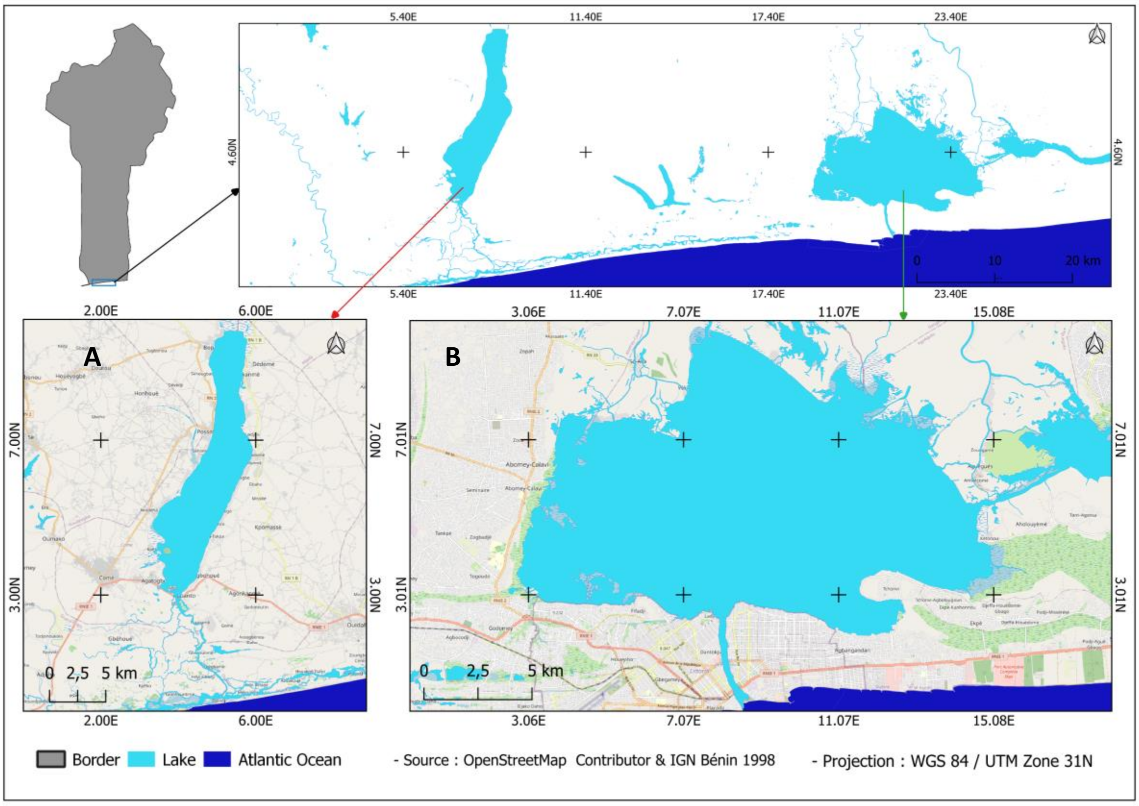

Figure 1: Maps of the study area: Lake Ahémé (A) and lac Nokoué (B).

Research Outline

The methodology to be implemented to develop the monitoring system (dashboard) includes 4 major points namely: detection of water hyacinth, detection of acadjas, detection of Chl-a and mapping of fish habitats. To do this, it is important to have enough field data to assess the accuracy of the results obtained and thus to iteratively adjust the detection methods used.

Data sources

Local research institutions in Benin will provide available data. This includes ground data on water hyacinth localisation and characteristics, data on the characterisation of acadjas, water quality data (temperature, Chl-a concentrations, and turbidity). In addition, this study will collect additional field data such as data on water hyacinth coverage in lake Ahémé and lake Nokoué. Water quality data on temperature, Chl-a, turbidity will be collected in both lakes from July to September 2022 on a weekly basis.

The study will also require data from the following ESA missions covering Lake Nokoué (150 km^2) and Lake Ahémé (80 km^2) in Benin for the period 2016-2022: (i) Sentinel 1, (ii) Sentinel 2a and (iii) Sentinel 2b.

Analysis workflow

The dashboard will cover three different components: spatial and temporal dynamics of (1) water hyacinth, (2) acadjas, and (3) algae blooms. In addition, it will also present a qualitative indicator for how these combined components affect fish habitats.

For the detection of spatio-temporal dynamics of water hyacinth, anomalies in NDVI and other vegetation indices will be calculated on time series of Sentinel 2 A/B images. For the monitoring of acadja we will build on the approach by Ovienmhada et al. (2020), which uses supervised classification of Sentinel 1 and 2 images. Sentinel 1 is used, because SAR backscatter is not hampered by clouds and has the potential to separate water from other objects in lakes. Different classifiers combining both SAR and optical data will be assessed for improvement of the method. For this component Lake Ahémé is a useful case, because acadja has recently been completely removed. For algae blooms detection several existing methods (Bramich et al., 2021) will be evaluated for deriving Chl-a for lakes with Sentinel 2 images. Finally, the study will develop a qualitative indicator for fish habitats, combining the 3 components.

The code will be implemented in Jupyter Notebooks and results will be presented in maps, graphs and infographics. There will be a synchronisation of the field data dates and the dates of taking the satellite images for the evaluation of the accuracy of the results.

Stakeholders will be involved in the development of the tool to ensure that it provides useful visualisations. In this regard, a mid-term stakeholder meeting will be organized. The purpose of this meeting is to present the research project as well as to demonstrate already implemented features. This meeting of stakeholders will identify their ideas on what they would like to see in the monitoring system to improve the dashboard.

Expected outputs

The expected output of the study are:

- A low-cost monitoring tools to support decision-makers on the regulation of acadja and the fight against water hyacinth
- Seasonal monitoring of anomalies in water hyacinth coverage in West African lakes
- Assess the impact of acadja fishing practices on the spread of invasive water hyacinth and frequent algae blooms using cloud-based EO services.
- Basis for the development of more indicators for lake monitoring in West Africa in the future

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13. SENTINELs for Cape Verde Water & Food Security Monitoring

Project Acronym

SENCAPE

Scientific Background and Objectives

Cape Verde Islands (country: Cabo Verde)

- Most Western part of the Sahel region, extremely vulnerable to weather and climate,
- Recurring droughts (historical famines) are an entire part of its climate and socio-economic history,
- Rural populations remain dependent on rain-fed & irrigated agriculture for sustaining their livelihood [1]

- Standard int'l seasonal (3-monthly) weather forecasts do not provide sufficient information for local water & agricultural management [2].
- Medium- to high resolution vegetation-index based agricultural monitoring coupled to near real-time satellite-based rainfall observations is needed, to provide more adequate information for water and agriculture.

SENCAPE will design and implement Sentinel and EU-Copernicus data derived cloud-computing workflows for vegetation & agricultural monitoring and rainfall, optimized for Cape Verde, as an EO use case for Small Island Development States [3].

Photo inset: Rural farmstead, local population, drip irrigation on slope land on Santiago- Photo credits: C. Mannaerts, Creative Commons CC-BY-NC-ND 2.0

Study area

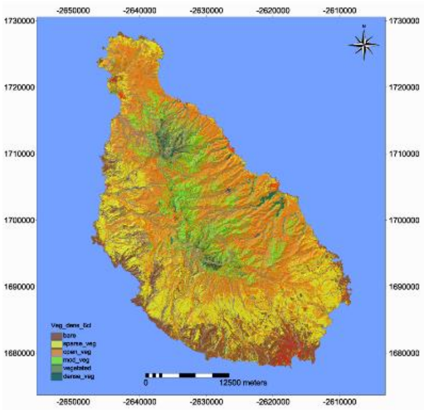
Cape Verde islands location, Sentinel-3 300-m Natural Colour Composite (2021) and pilot study area (Santiago island), shown with 10-m Lidar DEM, Sentinel-2 Natural Colour (2020-11-12) and classified vegetation density map (by Ilwis386 free software)

Research Outline

We will engage in building the three cornerstones (datasets) of the Water & Food Security Monitoring System under development by INIDA. Due to the steep mountainous topography of most islands, medium to high resolution (5 to sub 30-m) is required to generate meaningful LULC information of rain-fed and irrigated agriculture. We will build Jupyter Python/R-kernel based workflows (in the EO-Africa Innovation Lab), and also use stand-alone applications (SNAP, GDAL, ILWIS, QGIS..) for:

Views of rural areas on Santiago island - Photo credits: C. Mannaerts, Creative Commons CC-BY-NC-ND 2.0

10-m LULC classification (Santiago island)

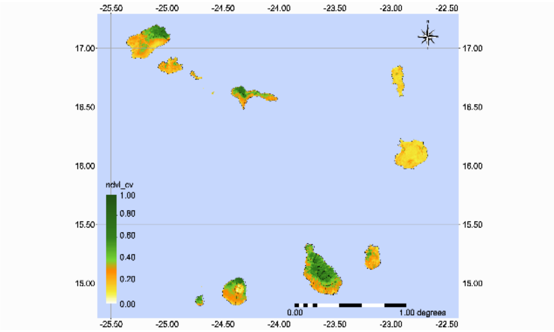


- Current e.g. Copernicus GLC100m (and other data) are not adequate for CV. Next to testing of conventional un- and supervised classification approaches [refs. 9,10,11,12], incl. multi-temporal Random Forest, an own developed classification method, based on multi-temporal NDVI thresholding and a decision / regression tree approach (incl. topographic, hydrographic and other land features) will be implemented in Jupyter NB (ilwispy package). Preliminary tests using Planet Scope Nicfi monthly NDVI composites were promising *(see inset Figure; NDVIs of 2021*). This novel approach will be tested on S2A/B 10-m.
- Data sources: S2A/B NDVI time series (from L1C or L2A) at 10-m and 10-day or bi-monthly time step; 10-m DEM and 0.5-m ortho-images airborne Lidar datasets (available); ancillary vector datasets; PlanetScope NICFI monthly composites. Digital ground control campaign data (SW Map App).
- **Expected output:** a LULC classification approach, applicable to semiarid, mountainous islands or similar continental regions with small-scale rain-fed and irrigated agricultural practices (incl. scientific pub.).

Long-term Vegetation climatology (Santiago) and linking to S2A/B time series

- An accurate vegetation climatology6 is required EO-based WFS7 monitoring. Resolution requirement is also 5-m to sub 30-m, due to small field sizes and patchy Land use and steep topographies. For the pre-Sentinel-2 period, the Landsat system will be mined in order to obtain long-term e.g. >20-yrs NDVI time series at 30-m; and extended by the Sentinel-2 series. We will verify sensor radiometry using near coinciding overpasses. We subject the raw data series to outlier detection, filtering (e.g Savitsky-Golay type, ref. [4] VICI Toolbox (ITC), phenology assessment, statistical analysis e.g. long-term median, etc. using TimeSat and R.
- Data sources: S2A/B L1C and L2A; Landsat series from e.g. EE, USGS archives; Atmospheric correction data sources e.g. from Aerosol Robotic Network (2 Cape Verde stations available), ERA, GSOD and more (refs. [7] [8]).

[6] The term "Climatology" here stands for a long-term reference time series of an ECV variable
[7] WFS or Water & Food Security (Monitoring System)



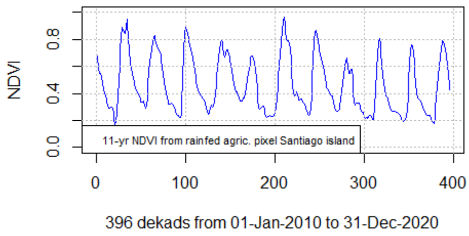


Figure insets: Jan, 2018 Probav 300-m NDVI example of CVI; 11 year (250-m) NDVI of rain-fed agriculture sample pixel, Santiago

Long-term Precipitation climatology

- We will investigate source data (screening, selection and validation) and build a long-term rainfall climatology for the archipelago. Current available (e.g. CHIRPSv2.0, ERA5, H-SAF and more) will be subject to validation with ground station data from the National Meteorological Service (INMG). Spatial interpolation and downscaling will be applied [6].
- **Expected outputs**: Long-term vegetation and rainfall climatology's and statistics (incl. phenology), for further use in the WFS Monitoring & Forecasting system (under development). Report a/o scientific publication on vegetation – rainfall responses and climate change dynamics (central East Atlantic).

Dissemination of research findings

- We will work towards the dissemination and publication of our findings:
  - LULC assessment methodology for steep mountainous semiarid regions with small-scale rain-fed subsistence and irrigated agriculture, reforestations and other land cover and/or use types
  - Long-term vegetation - rainfall interaction and climate change trends (Cape Verde as example of Central East Atlantic region)
- This will include an assessment of the opportunities and (eventual) pitfalls of the use of cloud-based and Jupyter-based workflows and technologies.

From research to operations

- The generated core datasets will be applied to further develop the WFS monitoring system of Cabo Verde, focusing on (near-real time) drought (crop failure) detection & monitoring and agricultural water and crop productivity using modelling approaches (next research to operations faze)

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[3] https://www.un.org/ohrlls/content/about-small-island-developing-states. UN Office of the High Representative for LDC and Small Island Development States - SIDS. (web portal visited Jan, 10 2022)
[4] https://www.itc.nl/about-itc/organization/scientific-departments/water-resources/software-tools-models/ilwis3-and-toolbox-plugins/vici-toolbox/ *Ilwis v386 & Toolboxes.* (visited, May, 10 2022)
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Figure inset: Sentinel-2 10-m Pseudo Color Composite (2020-Nov-12) of Santiago island (with Praia city in bottom-right corner) - quick 3D view by ILWIS 386 free software (see Ref. [4] ©ITC)

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14. Quantifying Soil Moisture from Space-based Synthetic Aperture Radar (SAR) and Ground-based Geophysical and Hydrological Measurements

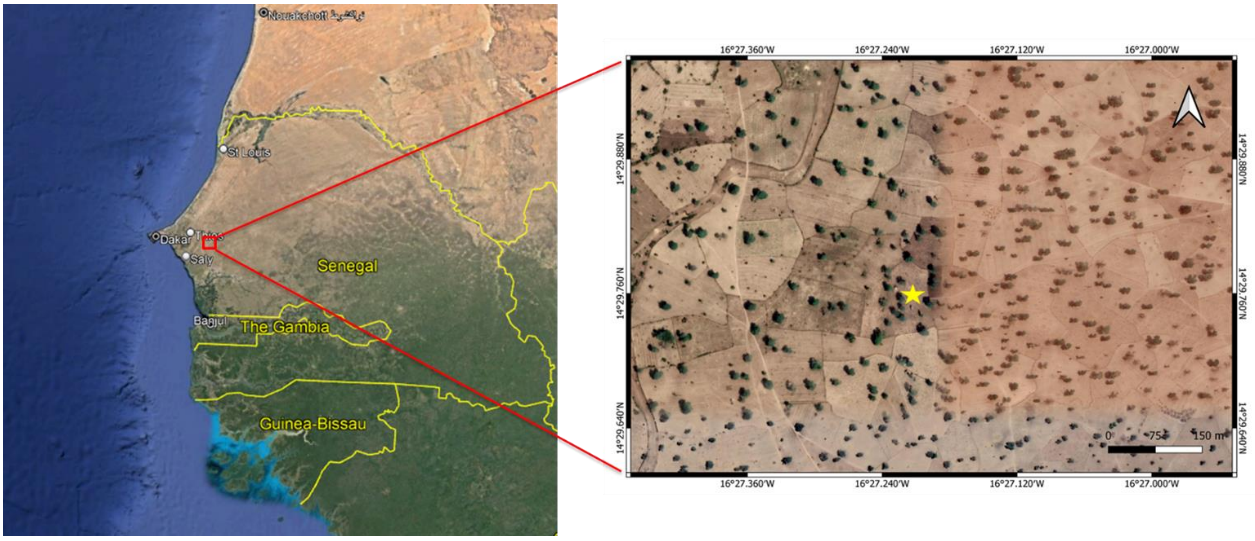
Project Acronym

SM-SAR-GM

Scientific Background and Objectives

Soil moisture (SM), which is the water content in the soil, plays an essential role in agriculture activities. With climate change and global warming, water scarcity is exacerbating in many parts of the world. Africa is facing the most significant challenges of water stress because food production and security depend on those water resources. Thus, monitoring SM at high resolution is of vital importance for irrigation activities, estimation of crop yields, and food security. Our proposal focuses on a 100-meter resolution soil moisture product, whose resolution is suitable for agriculture studies, as this is a characteristic size of an agricultural parcel. We investigate the feasibility of using Sentinel-1 C-band Synthetic Aperture Radar (SAR) data recorded in the VV (vertical-transmit, vertical-receive) polarisation to retrieve 100m SM every 12 days and combine it with ground high resolution (cm) measurements collected five times per day to both validate and improve the estimate. The innovation of our approach is the integration of large-scale SM from satellite data with a soil roughness infer from a multispectral camera embarked on a drone, field-scale ground geophysical measurements such as electrical resistivity tomography (ERT), and point observations such as time domain reflectometry (TDR) to improve the SM results.

Study Area



Our study area is located in Senegal, where tropical climate is dominated with well-defined dry (December to April) and humid (May to November) seasons that result from northeast winter winds and southwest summer wind. Our instruments are installed in the star-marked field to provide insitu geophysical and hydrological measurements

Research Outline

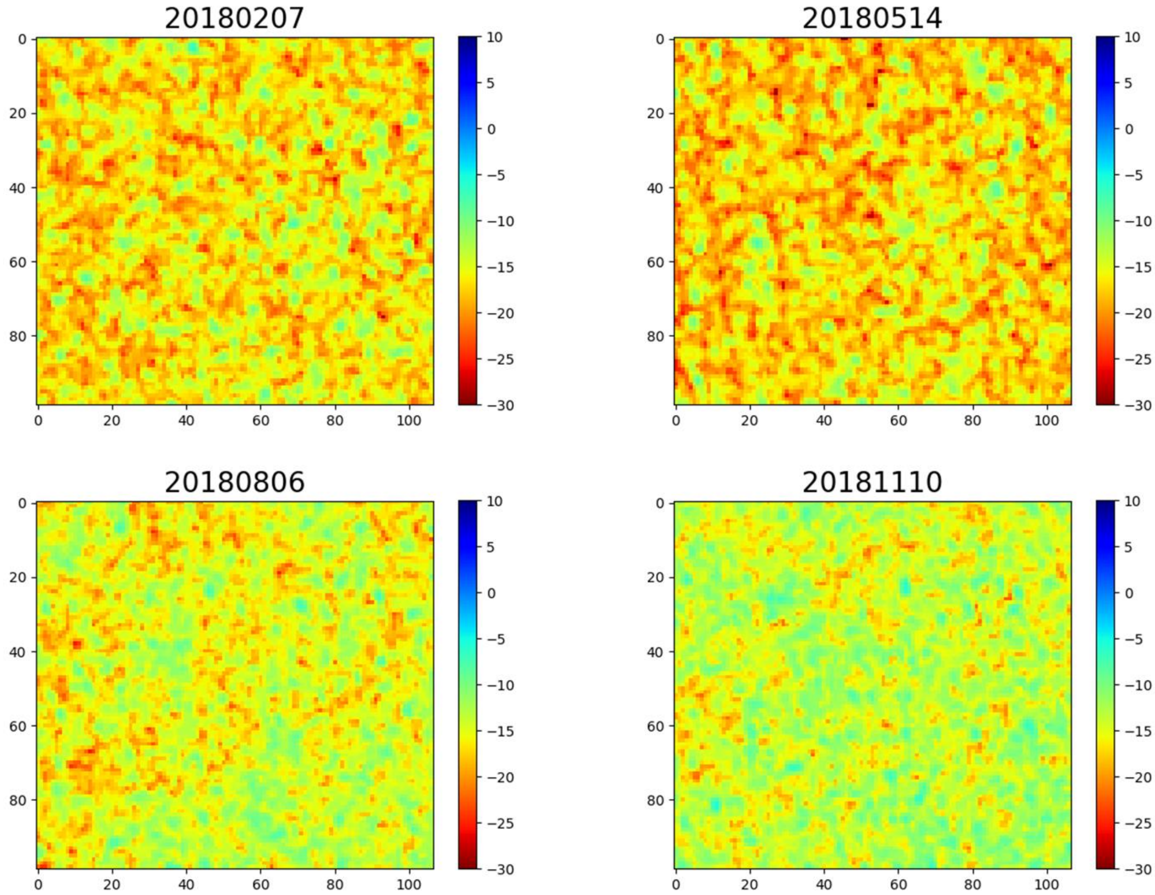
We will emphasize on two work packages in additional to management and innovative open-source codes:

WP: High-resolution soil moisture production from SAR data. Sentinel-1A data will be used to estimate soil moisture in Senegal, both in dry and wet seasons. The algorithm will be developed based on SAR backscatters and vegetation index using a change detection method considering consecutive acquisition dates and will be optimized by considering the soil roughness and the vegetation coverage and will be integrated with ground measurements.

WP: Ground-based data module. Field characterization of the study site will be performed to provide information necessary for the application of the new algorithm and to validate the results.

Given the possible heterogeneity of the study area, a permanent 3-D ERT monitoring system will be installed, consisting of 4 parallel lines of 32 electrodes, with 1 m electrode spacing and 10-m interline spacing. Also, point observations such as from field campaign and time domain reflectometry (TDR) will be included to improve the SM results.

A quick look of Sentinel-1 SAR backscatters over our study area in different dates:



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15. Mapping and Monitoring Artisanal Mining from Space

Project Acronym

3MSpace

Scientific Background and Objectives

Artisanal small-scale mining in Ghana dates back to the 15th century, regulated by a small-scale mining law. In the last decade, however, there has been a proliferation of illegal mining activities ("galamsey") that employ heavy machinery along river bodies, destroying vegetative cover and polluting water bodies (Figure 1). Identifying these activities using Earth Observation (EO) data is an important first step towards operationalizing monitoring and pursuing targeted interventions to save the environment. Compared to ground surveys, EO satellites have an advantage of covering large areas and repeating acquisitions at a lower cost. Unfortunately, data from the well-known and often-used satellites (i.e. optical sensors) have had limited use due to excessive could cover in illegal mining hotspots such as southern Ghana. Conversely, data from satellites that have limited or no susceptibility to cloud cover (i.e. Synthetic Aperture Radar (SAR)) have not been sufficiently explored. Based on an initial work by Forkuor et al. [1] in 2020, this project will further investigate and promote increased usage of Sentinel-1 data to monitor illegal mining by developing an automated detection and monitoring algorithm in a cloud-based environment. It will seek to extend preliminary analysis that were conducted to identify solutions that suit the data and environmental conditions in Ghana and similar African countries. This particularly relates to determining a suitable change detection method that yields optimal results in terms of identifying illegal mining activities.

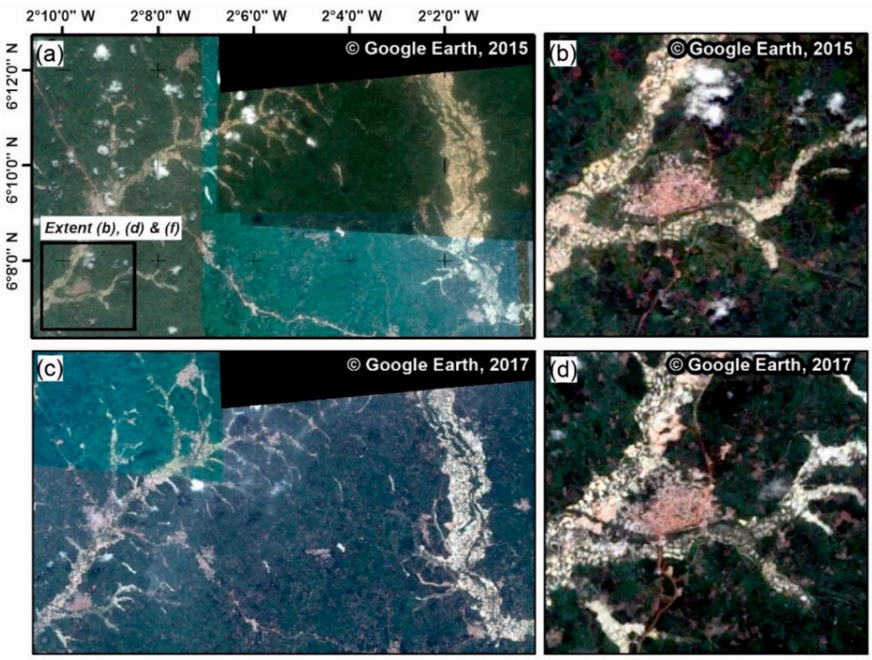

Figure 1: *Example imagery on artisanal small-scale mining in Ghana from Google Earth: (a, b) Google Earth Imagery 2015 (© Maxar Technologies), (c, d) Google Earth Imagery 2017 (Image ©CNES/Airbus & ©Maxar Technologies)*

[1] Forkuor, G., Ullmann, T. and Griesbeck, M., 2020. Mapping and monitoring small-scale mining activities in Ghana using sentinel-1 time series (2015–2019). *Remote Sensing*, *12*(6), p.911.

Study Area

The key study area is located in South-Western Ghana and encompasses an area of 9071 km² (Figure 2). It overlaps three administrative regions (Ashanti, Central and Western South) which are the main regions in which industrially operated gold mines in the country are located. Some of the worst affected municipalities and district assemblies such as Amansie West and Central, Wassa Amenfi East and Central, Wassa West, Upper Denkyira, Obuasi Municipal and Adansi North are located in, or overlap, the study area. Major rivers that drain the area, along which illegal mining takes place include Ankobra, On, Oda and Pra. During the project, it is planned to enlarge the study area to other affected parts in Ghana and to other West-African countries (Figure 2).

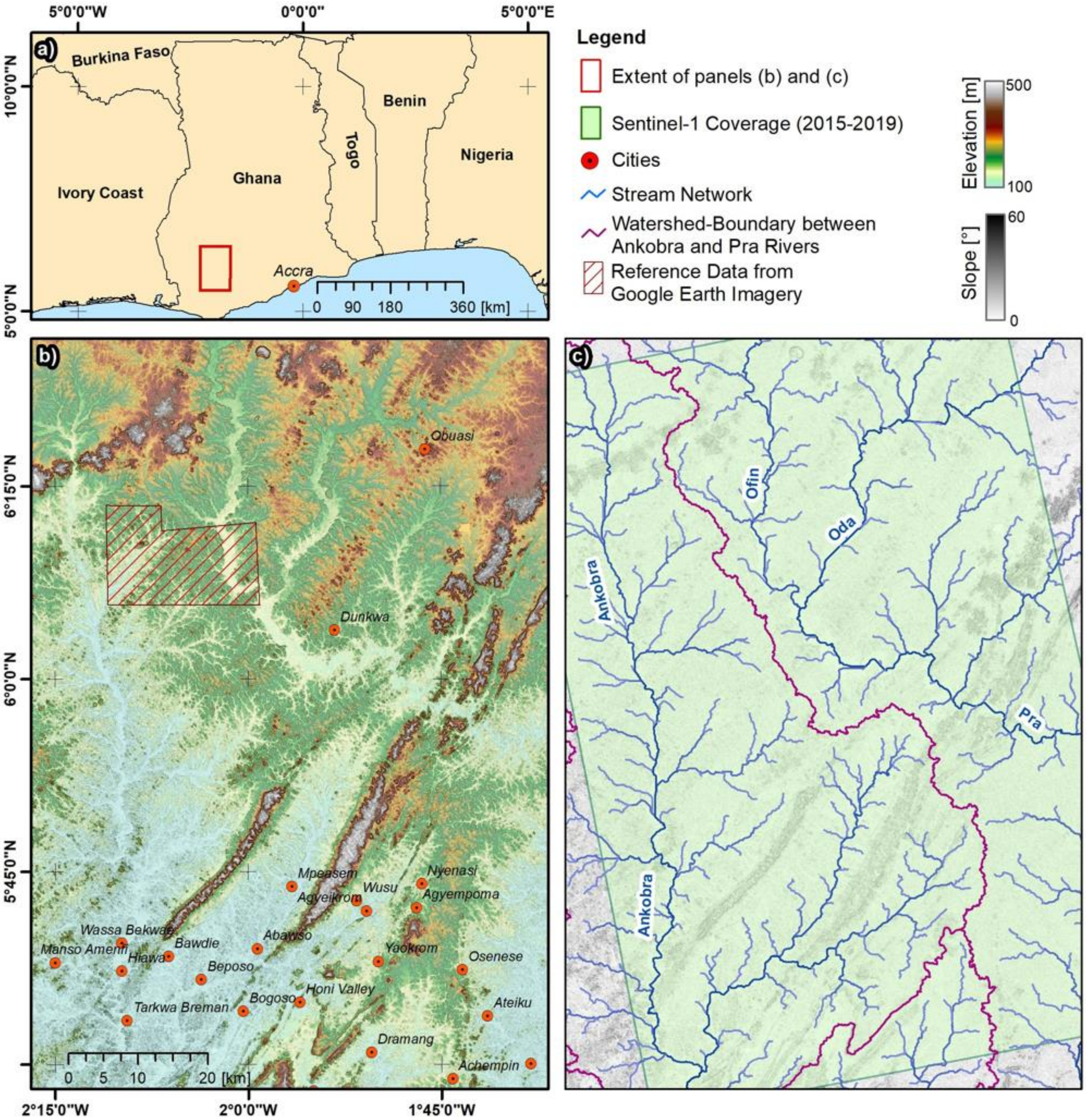

Figure 2: *Study area and data coverage: (a) regional overview; (b) topographic setting and major cities/towns; (c) hydrographic setting and coverage of Sentinel-1 imagery.*

Research Outline

SAR data are known to be sensitive to the geometrical and dielectric properties of the illuminated target, and thus react particularly strongly to changes related to structural distortion. This sensitivity makes SAR data suitable for identifying surface changes, such as those caused by illegal mining. These activities are typically characterized by the initial removal of vegetation, the ponding of water and the creation of artificial water bodies for washing. Based on the regular acquisitions of Sentinel-1, this change-pattern can be captured by analysing the temporal evolution of the SAR signal and by employing spatio-temporal metrics that allow storing temporal characteristics of the SAR time series in single layers, suited for further analysis (Figure 3). Using these metrics facilitate change detection as the speckle effect, noise and seasonal changes causing potential false detections, can be reduced significantly.

Following this strategy, the full spectrum of change detection approaches, from simple thresholding to semi-supervised classification, is applicable in a fast and efficient manner, which is a perquisite to implementing the algorithm in a cloud-based environment and to execute the approach for large regions and long time periods. Developing an automated algorithm in a cloud-based environment represents an advancement over existing efforts in using SAR data to map and monitor illegal mining. Considering the limited application of SAR data for monitoring environmental degradation in Africa, this project will make significant scientific contribution by investigating and recommending optimal change detection approach(es) with SAR data for environmental monitoring.

Low stakeholder capacity to process SAR data is a major reason for the limited application of SAR for environmental monitoring in Africa. Capacity enhancement has mostly focused on optical images, partly due to previous unavailability of open access SAR data. Therefore, the cloud-based algorithm will foster increased use of EO data among key stakeholders as it will not require expert knowledge in processing SAR data with a separate software. Further, it will be a starting point for state and non-state actors to initiate the development of EO services on environmental monitoring.

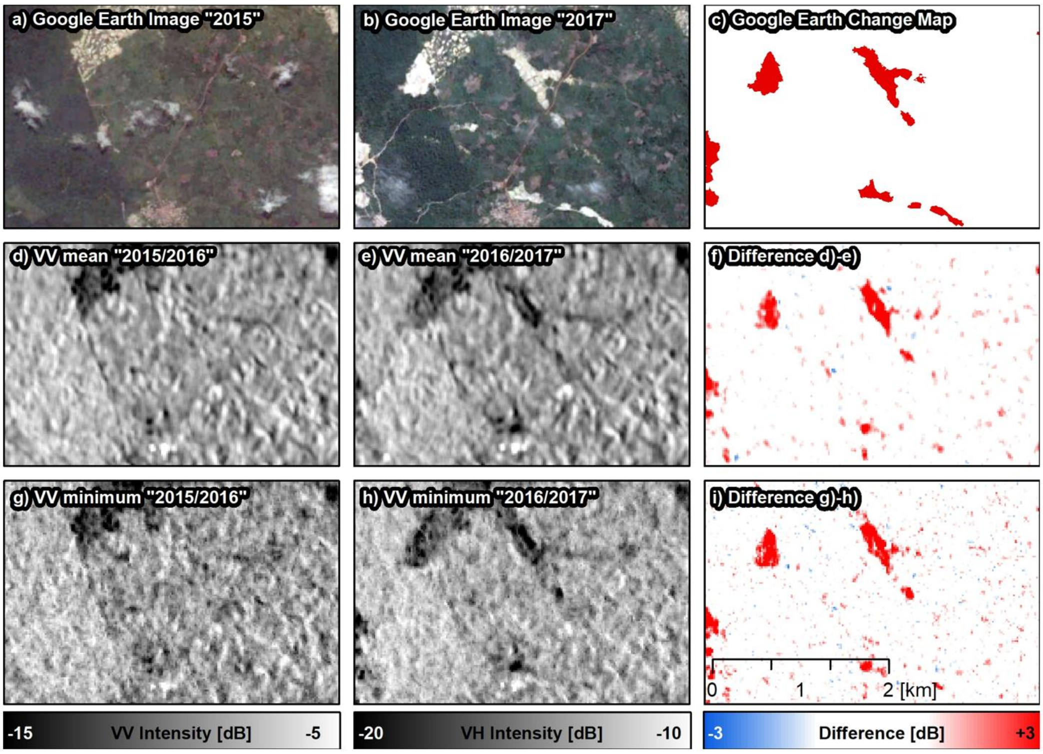

Figure 3: *Example of detected changes using the mean and minimum VV intensities of Sentinel-1 time series and the sets "2015/2016" and "2016/2017". Credits to (a) and (b) are as indicated in Figure 1.*

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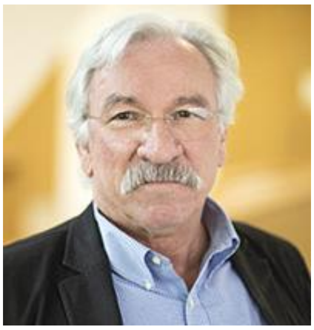

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