EO Africa // ARIES

D09 – Prototype Test (Report)

Version 1.0, August 2024

Contract No: 4000139191/22/I-DT

submitted by

	VISTA Remote Sensing in Geosciences GmbH (VISTA) Vlaamse Instelling voor Technologisch Onderzoek, Naamloze vennootschap (VITO) Luxemburg Institute of Science and Technology (LIST)

ESA STUDY CONTRACT REPORT

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ABSTRACT:

This document describes the prototype testing in ARIES and summarises the experiences made in the process.

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The work described in this report was done under ESA Contract. Responsibility for the contents resides in the author or organisation that prepared it.

Names of authors: Veronika Otto (Vista), Jeroen Degerickx (Vito), Louis Snyders (Vito), Silke Migdall (Vista), Kanishka Mallick (List), Aolin Jia (List)

** NAME OF ESA STUDY MANAGER Mr. Z. Szantoi DIV: EOP-SDR DIRECTORATE: Earth Observation Programmes	** ESA BUDGET HEADING

Authors of report

The present report was prepared by:

Veronika Otto, Silke Migdall

VISTA Geowissenschaftliche Fernerkundung GmbH

Gabelsbergerstr. 51, D-80333 Munich, Germany

Jeroen Degerickx, Louis Snyders

Vlaamse Instelling voor Technologisch Onderzoek, Naamloze vennootschap (VITO)

Kanishka Mallick, Aolin Jia

Luxemburg Institute of Science and Technology (LIST)

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List of Acronyms

ACF/AHH	Action contre la faim/Action Against Hunger
AGRHYMET	Centre régional de formation et d'application en agrométéorologie et hydrologie opérationnelle
AKTC	Zambian Agricultural Knowledge and Training Centre, LTD
CWC	Canopy Water Content
DMS	Data Mining Sharpener
ECOSTRESS	Ecosystem Spaceborne Thermal Radiometer Experiment on Space Station
EnMap	Environmental Mapping and Analysis Program
EO	Earth Observation
ESA	European Space Agency
ESI	Evaporative Stress Index
FAO	Food and Agriculture Organization of the United Nations
FSE	Food Security Explorer
HR	High Resolution
ISMN	International Soil Moisture Network
KBDI	Keetch-Byram Drought Index
LAI	Leaf Area Index
LST	Land Surface Temperature
LWC	Leaf Water Content
MAE	Mean Absolute Error
ME	Mean Error
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NDWI	Normalized Difference Water Index
PRISMA	PRecursore IperSpettrale della Missione Applicativa
PWR	Plant Water Retrieval
R&D	Research & Development
RCMRD	Regional Centre for Mapping of Resources for Development
SAlib	Sensitivity Analysis Library
SDCI	hybrid Scaled Drought Condition Index
SM	Soil Moisture
SMAP	Soil Moisture Active Passive
STD	Standard Deviation
STR	Shortwave Infrared Transformed Reflectance
S3	Sentinel 3

1 Introduction

After development of the algorithms, the next aim of ARIES is to deploy a prototype with the active involvement of African end-users, so that they can test the innovative EO solutions. Additionally, the prototype is used to trigger interest by a wider community of potential stakeholders, as it is integrated into the Food Security Explorer (https://foodsecurity-explorer.com) and thus is publicly available.

The engaged African Early Adopters and EO research groups (AKTC, ACF, Agrhymet, RCMRD) have contributed to the validation and quality assessment of the experimental EO analysis techniques and related products as well as the prototype implementations. This report summarizes the results of this prototype testing.

2 Prototype Test - Approach

2.1 Thermal Products

In this section, the prototype test report of different thermal drought indicators is provided. It includes the basic user guide for drought index calculation using the Food Security Explorer (FSE), an overview of the input and output data, and an illustration of the results. The drought indicators defined in this project are based on temporal series analysis. Additionally, external input data are typically required for the calculations. Therefore, data sampling based on the location of the regions of interest (ROI) is typically necessary before performing the calculations.

2.1.1 Product Provision

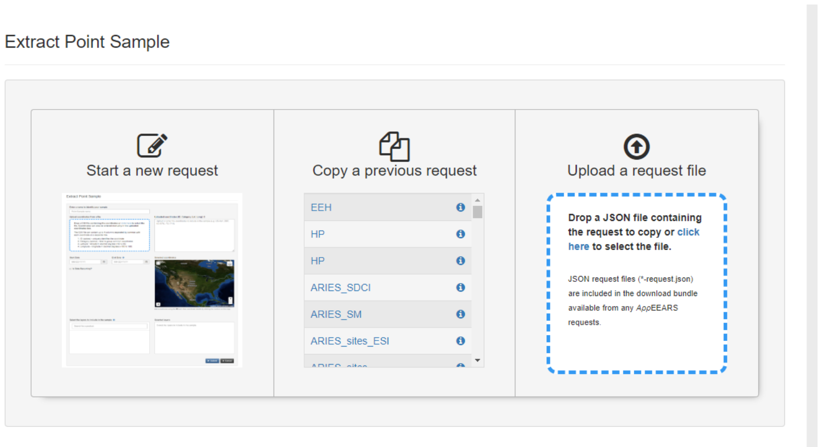
2.1.1.1 Normalized Difference Water Index (NDWI)

NDWI normalizes water-sensitive near-infrared band and aims to monitor changes in water content of leaves and soil. In the test, MODIS reflectance data was used. Other high-resolution remote sensing data of similar band wavelengths can also be utilized. The basic process for calculating NDWI using Food Security Explorer is as follows:

Step One: Input Data Sampling

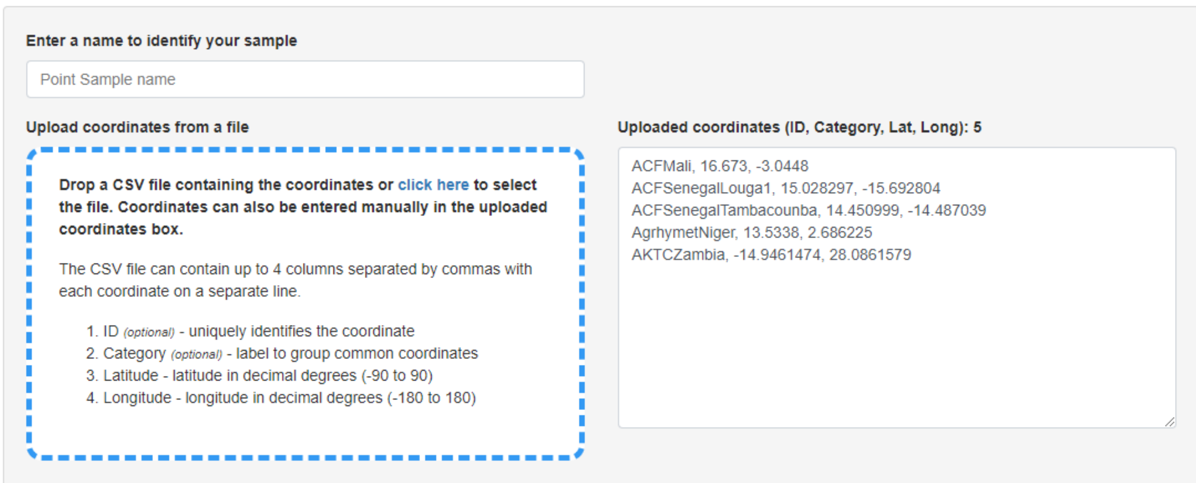
(1) Define your sampling locations including site name, latitude, and longitude.

(2) Navigate and login to the online sampling website NASA AppEEARS at https://appeears.earthdatacloud.nasa.gov/task/point.

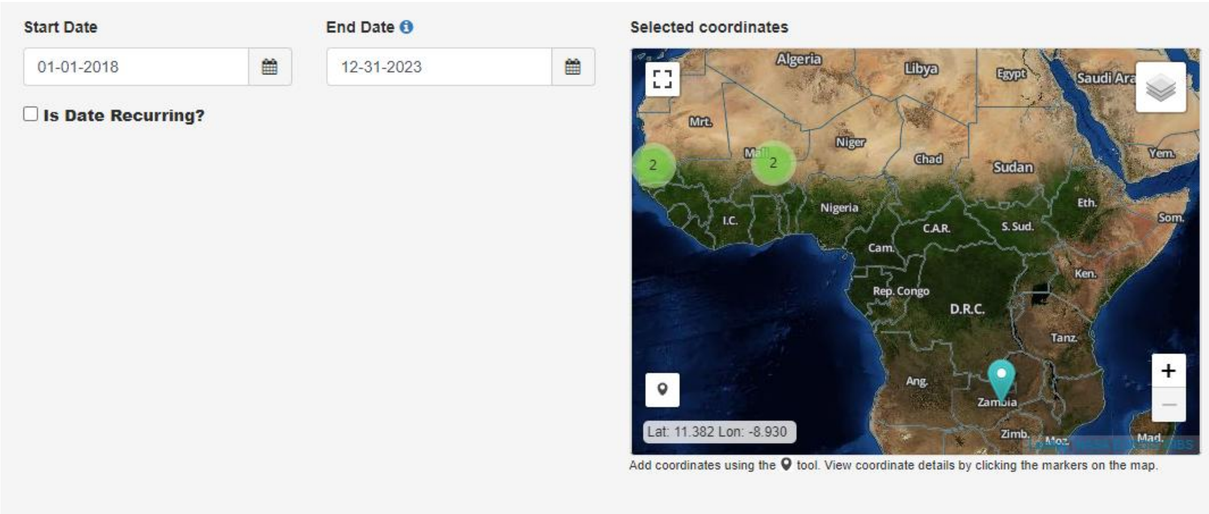


(3) Click "Start a new request"

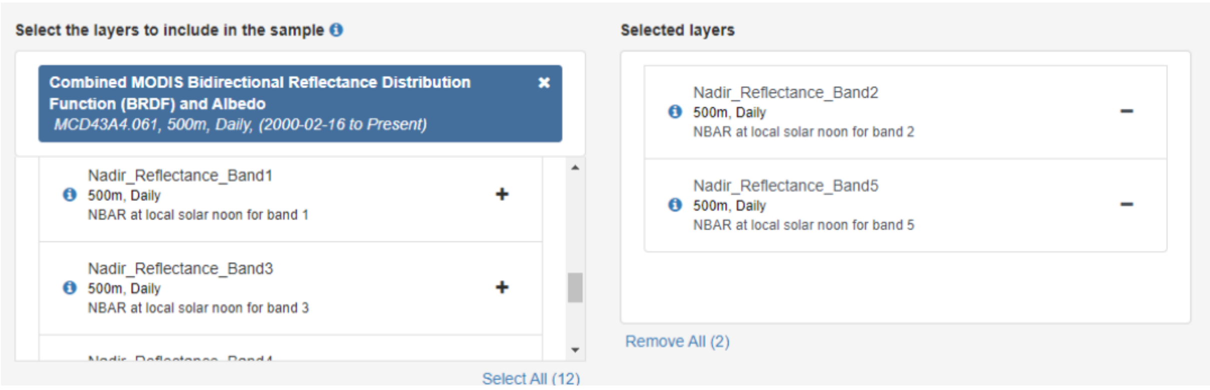
(4) Input the location information.



(5) Choose the data period.



(6) Choose the data source and variables of interest.



(7) Submit the order.

(8) Upon completion, receive the notification via email and download the data, which is csv format.

Step Two: data uploading

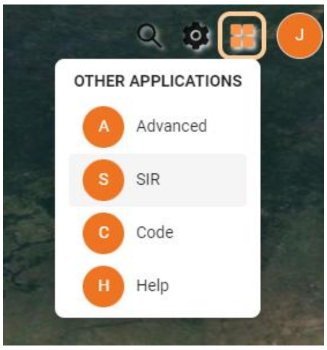
(9) collect the input data csv file and your site location csv file.

	A	B	C
1	Site	Lat	Long
2	ACFMali	16.673	-3.0448
3	ACFSenegalLou	15.028297	-15.692804
4	ACFSenegalTam	14.450999	-14.487039
5	AgrhymetNiger	13.5338	2.686225
6	AKTCZambia	-14.9461474	28.0861579

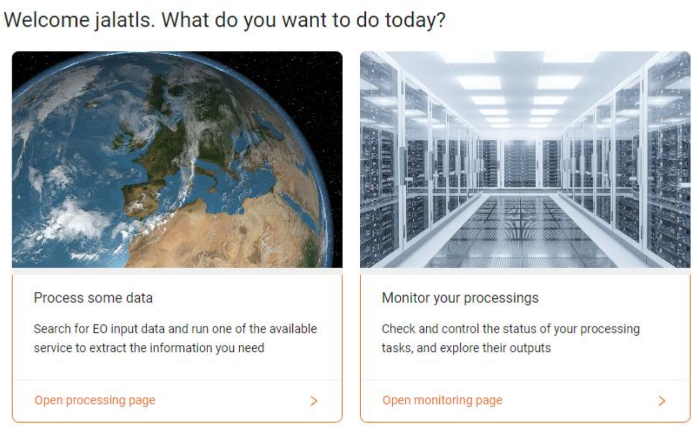
(10) upload them to the folder in the FSE system

Step Three: data online processing

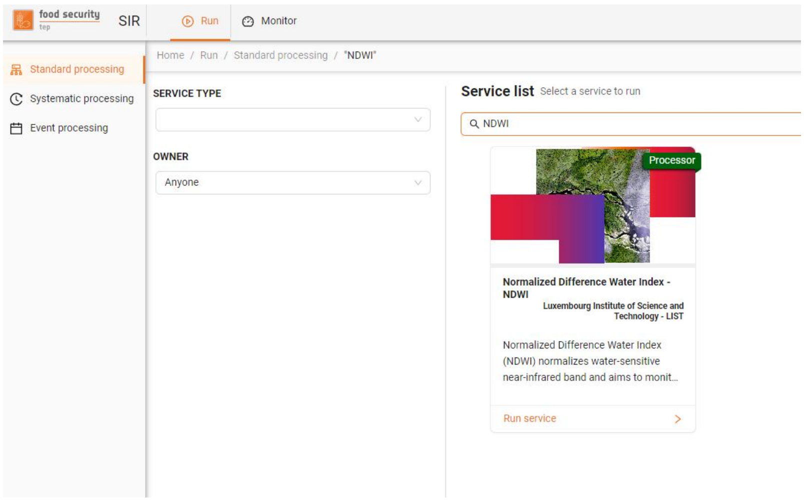
(11) Find the processors in SIR



(12) Click ‘Process some data’

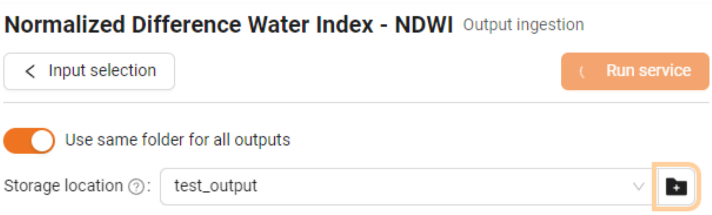


(13) Find NDWI in Standard Processing

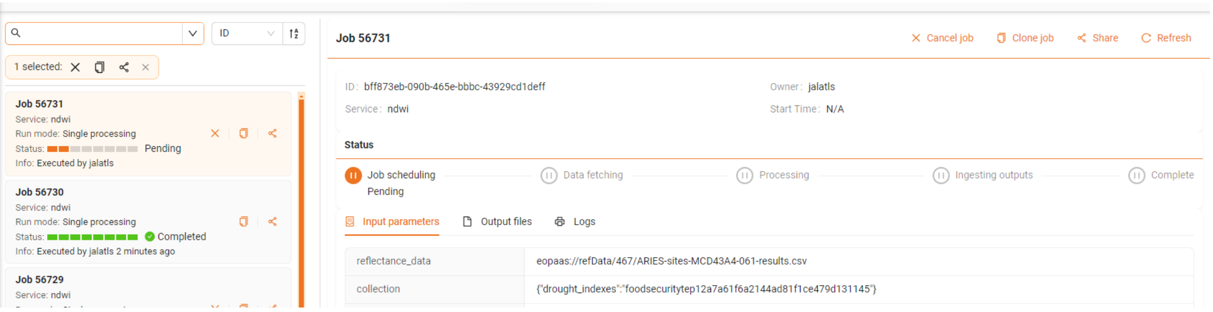


(14) Link the sample_site input to the site info csv file and link the reflectance input to the input csv file you uploaded.

(15) Select the output location



(16) Processing will be shown:



(17) Download the output files.

Step Four: Result Analysis

(18) click the result files and directly download to local computers

(19) pre-check the results at each region of interest:

	A	B	C
1	Date	NDWI	NDWI_Anomaly
2	2018-01-01	-0.13	-0.068
3	2018-01-02	-0.136	-0.07
4	2018-01-03	-0.137	-0.083
5	2018-01-04	-0.131	-0.075
6	2018-01-05	-0.122	-0.057
7	2018-01-06	-0.129	-0.064
8	2018-01-07	-0.127	-0.021
9	2018-01-08	-0.128	-0.02
10	2018-01-09	-0.135	-0.025
11	2018-01-10	-0.142	-0.028
12	2018-01-11	-0.148	-0.033
13	2018-01-12	-0.144	-0.047
14	2018-01-13	-0.145	-0.027
15	2018-01-14	-0.145	-0.026
16	2018-01-15	-0.145	-0.046
17	2018-01-16	-0.142	-0.07
18	2018-01-17	-0.141	-0.06

Three columns show the date, index value, and values that seasonal cycle has been removed.

(20) The plot can be drawn correspondingly.

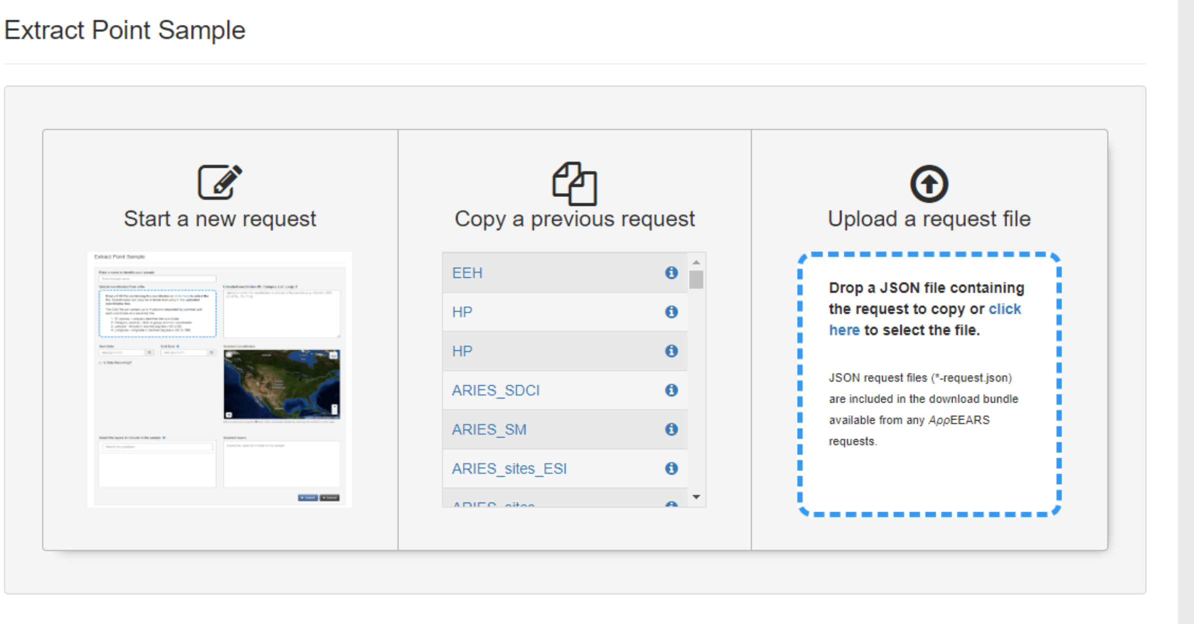
2.1.1.2 Shortwave Infrared Transformed Reflectance (STR)

STR is considered the transformed reflectance based on the shortwave infrared surface reflectance (centred at ~2.13 μm), and it is sensitive to soil water content. In the test, MODIS reflectance data was selected. Other high-resolution remote sensing data of similar band wavelengths can also be utilized. The basic process for calculating STR using Food Security Explorer is as follows:

Step One: Input Data Sampling

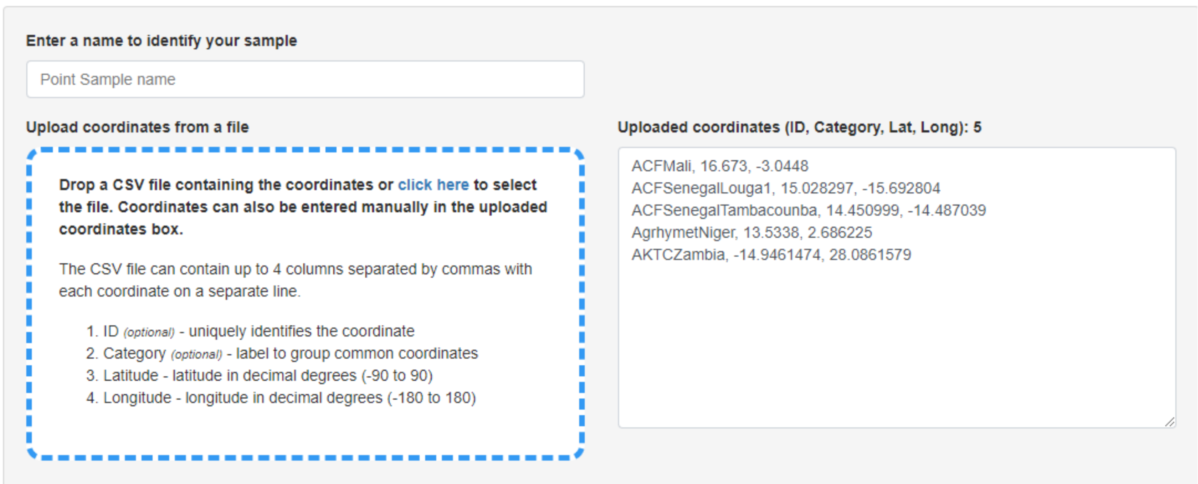
(1) Define your sampling locations including site name, latitude, and longitude.

(2) Navigate and login to the online sampling website NASA AppEEARS at https://appeears.earthdatacloud.nasa.gov/task/point

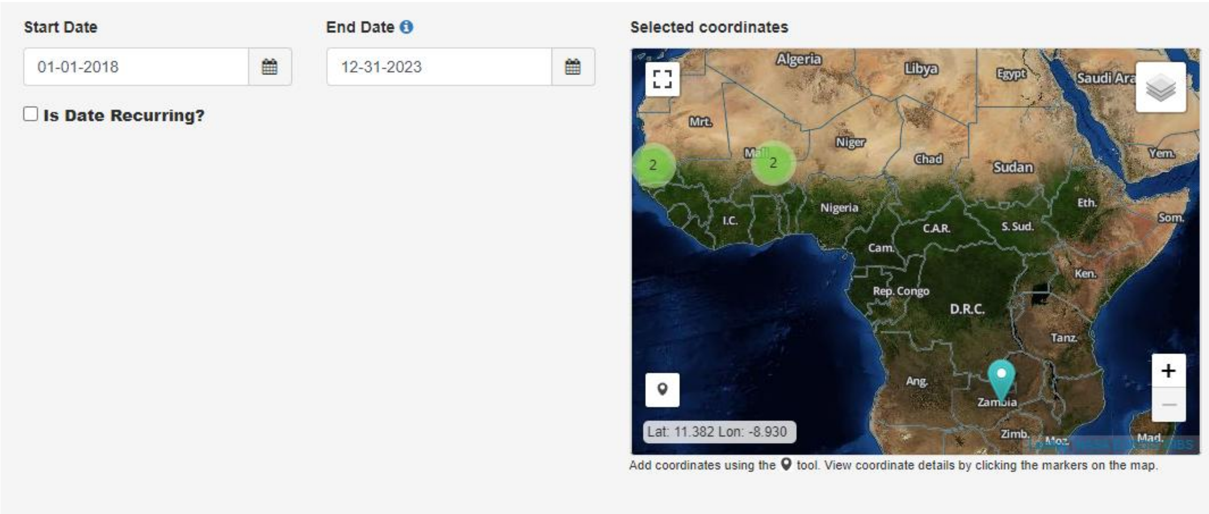


(3) Click “Start a new request”

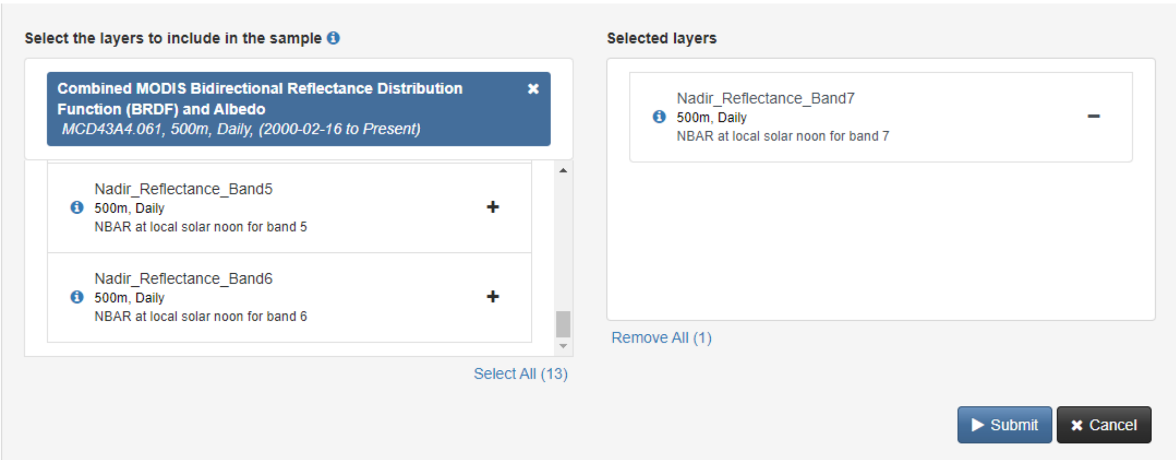
(4) Input the location information.



(5) Choose the data period.



(6) Choose the data source and variables of interest.



(7) Submit the order.

(8) Upon completion, receive the notification via email and download the data, which is csv format.

Step Two: data uploading

(9) collect the input data csv file and your site location csv file.

	A	B	C
1	Site	Lat	Long
2	ACFMali	16.673	-3.0448
3	ACFSenegalLou	15.028297	-15.692804
4	ACFSenegalTam	14.450999	-14.487039
5	AgrhymetNiger	13.5338	2.686225
6	AKTCZambia	-14.9461474	28.0861579

(10) upload them to the folder in the FSE system

Step Three: data online processing

(11) Same processing as NDWI.

Step Four: download results and Analysis

(12) click the result files and directly download to local computers

(13) pre-check the results at each region of interest:

	A	B	C
1	Date	STR	STR_Anomaly
2	2018-01-01	1.148	-3.491
3	2018-01-02	1.102	-3.489
4	2018-01-03	1.096	-3.261
5	2018-01-04	1.118	-3.221
6	2018-01-05	1.085	-3.146
7	2018-01-06	1.023	-3.221
8	2018-01-07	0.996	-3.903
9	2018-01-08	0.949	-3.809

Three columns show the date, index value, and values that seasonal cycle has been removed.

(14) The plot can be drawn correspondingly.

2.1.1.3 Keetch-Byram Drought Index (KBDI)

The Keetch-Byram Drought Index (KBDI), originally designed for daily fire risk monitoring, is calculated using normal annual precipitation, daily maximum air temperature, and daily precipitation. Some studies also considered it as an indicator of surface moisture deficiency. In this context, the Copernicus KBDI product is utilized.. The basic process for calculating KBDI using Food Security Explorer is as follows:

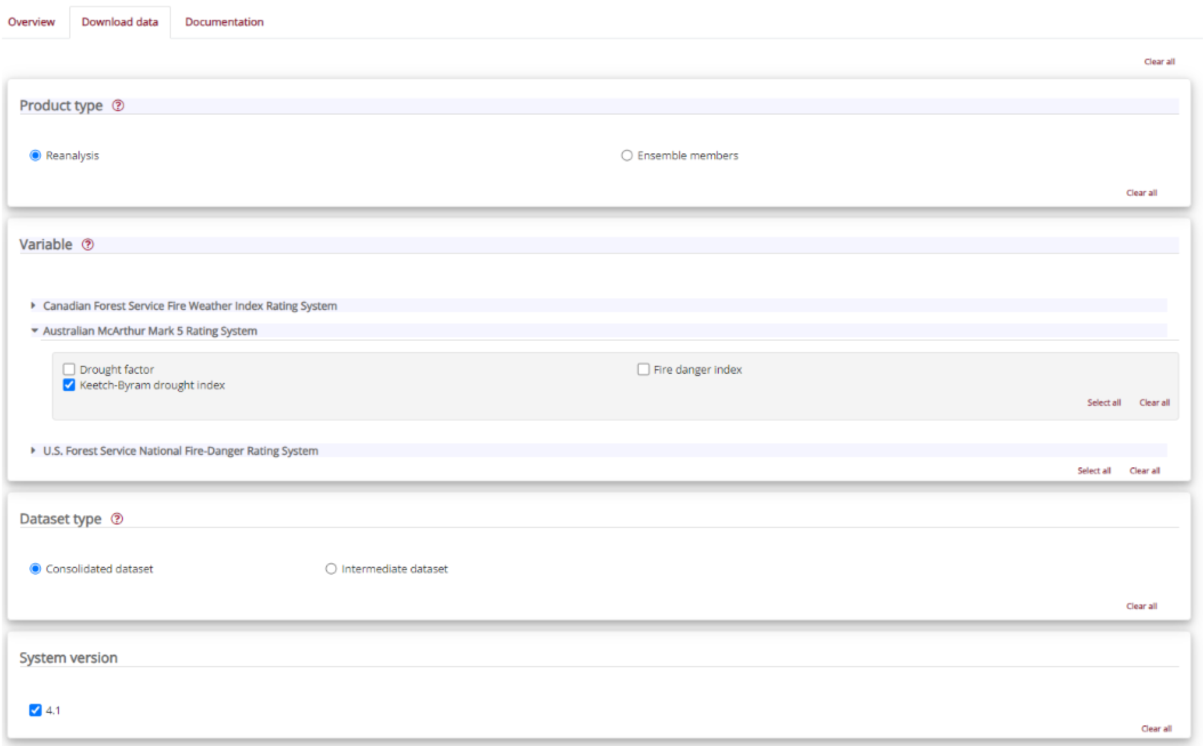
Step One: Input Data Sampling

(1) Define your sampling locations including sitename, latitude, and longitude.

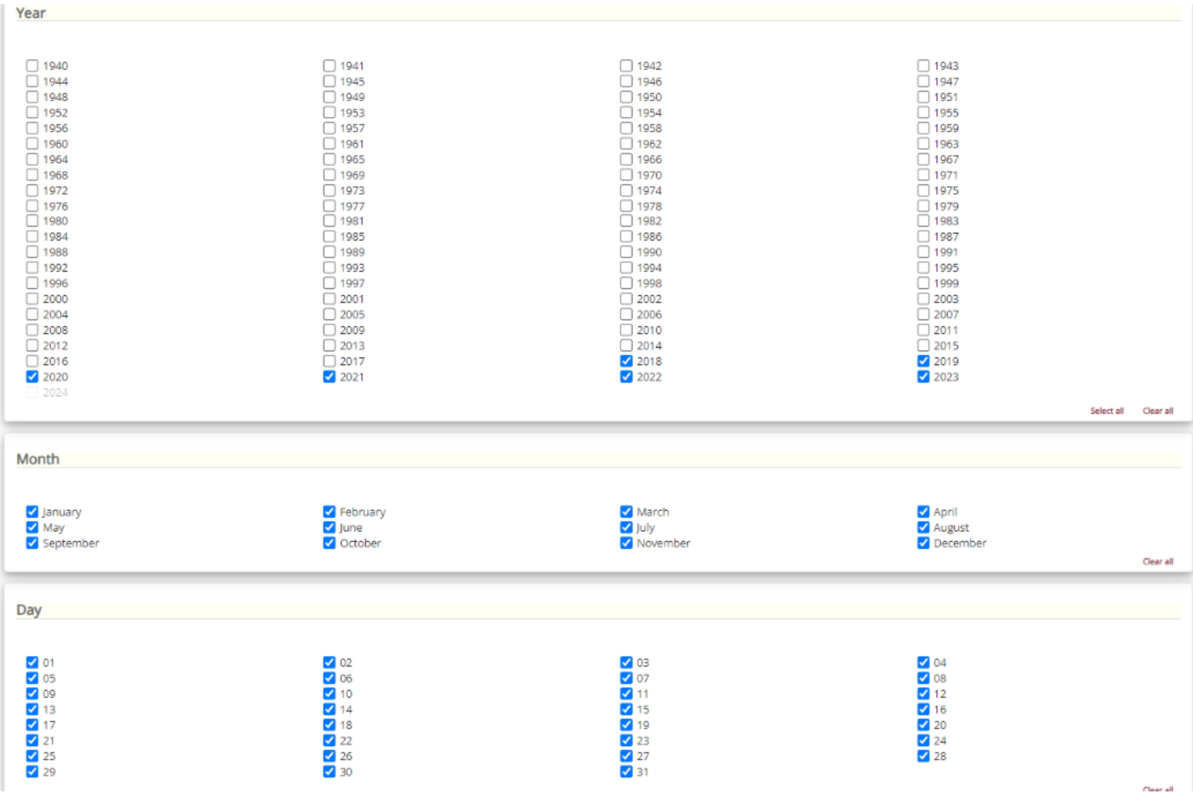
(2) Navigate to the Copernicus at https://cds.climate.copernicus.eu/cdsapp#!/dataset/10.24381/cds.0e89c522?tab=form

(3) Initiate a new request.

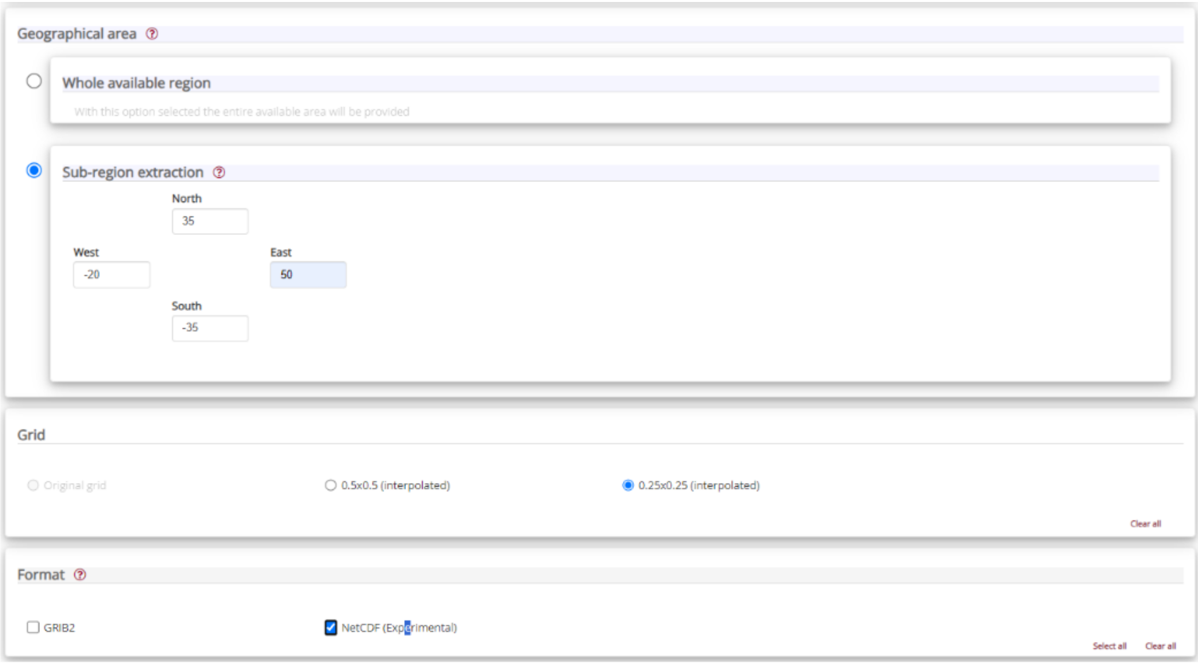
(4) Select data.



(5) Choose the data period.



(6) Choose the region of interest.



(7) Submit the order.

(8) Upon completion, download the file.

Step Two: data uploading

(9) collect the input data and your site location csv file.

	A	B	C
1	Site	Lat	Long
2	ACFMali	16.673	-3.0448
3	ACFSenegalLou	15.028297	-15.692804
4	ACFSenegalTam	14.450999	-14.487039
5	AgrhymetNiger	13.5338	2.686225
6	AKTCZambia	-14.9461474	28.0861579

(10) upload them to the folder in the FSE system

Step Three & Four: data online processing

(11) same processing as NDWI

2.1.1.4 hybrid Scaled Drought Condition Index (SDCI)

The Scaled Drought Condition Index (SDCI) is an averaged drought index, calculated using detrended precipitation anomalies (Precipitation Condition Index, PCI), vegetation anomalies (Vegetation Condition Index, VCI), and temperature anomalies (Temperature Condition Index, TCI). The test utilizes MODIS MCD43A4 reflectance bands 1 and 2, along with rainfall and temperature data from SMAP. The basic process for calculating SDCI using the Food Security Explorer (FSE) is as follows:

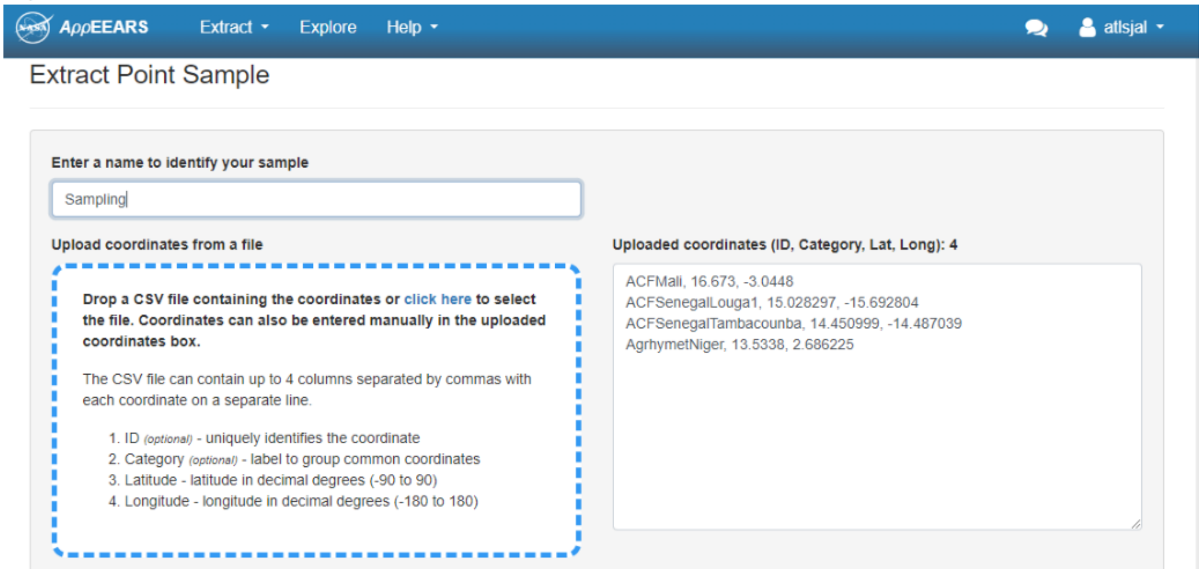
Step One: Input Data Sampling

(1) Define your sampling locations including site name, latitude, and longitude.

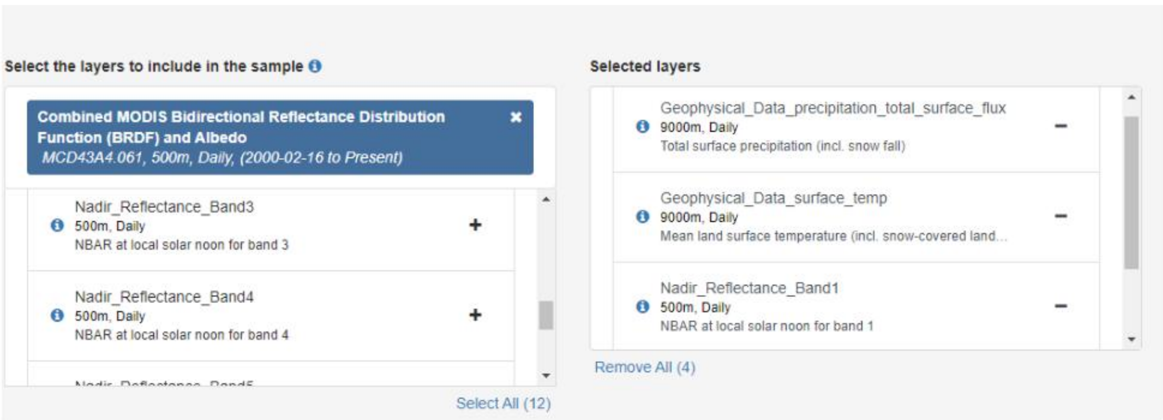
(2) Navigate to the online sampling website NASA AppEEARS at https://appeears.earthdatacloud.nasa.gov/task/point

(3) Initiate a new request.

(4) Input the location information.



(5) Choose the data period, data source, and variables of interest.



(6) Submit the order.

(7) Upon completion, receive a notification via email and download the data.

Step Two: data uploading

(8) collect the input csv file and your site location csv file.

	A	B	C
1	Site	Lat	Long
2	ACFMali	16.673	-3.0448
3	ACFSenegalLou	15.028297	-15.692804
4	ACFSenegalTam	14.450999	-14.487039
5	AgrhymetNiger	13.5338	2.686225
6	AKTCZambia	-14.9461474	28.0861579

(9) upload them to the folder in the FSE system

Step Three and Four: data online processing

(10) same processing step as NDWI.

2.1.1.5 Soil Moisture (SM)

The Soil Moisture Active Passive (SMAP) mission employs L-band radar and radiometer instruments to generate global gap-free maps of SM and freeze/thaw state. Furthermore, SMAP Level 4 dataset leveraged these observational data in conjunction with data assimilation techniques to offer insights into deeper root-zone soil moisture every three hours from advanced land surface modelling. The basic process for using SMAP SM to monitor drought from Food Security Explorer is as follows:

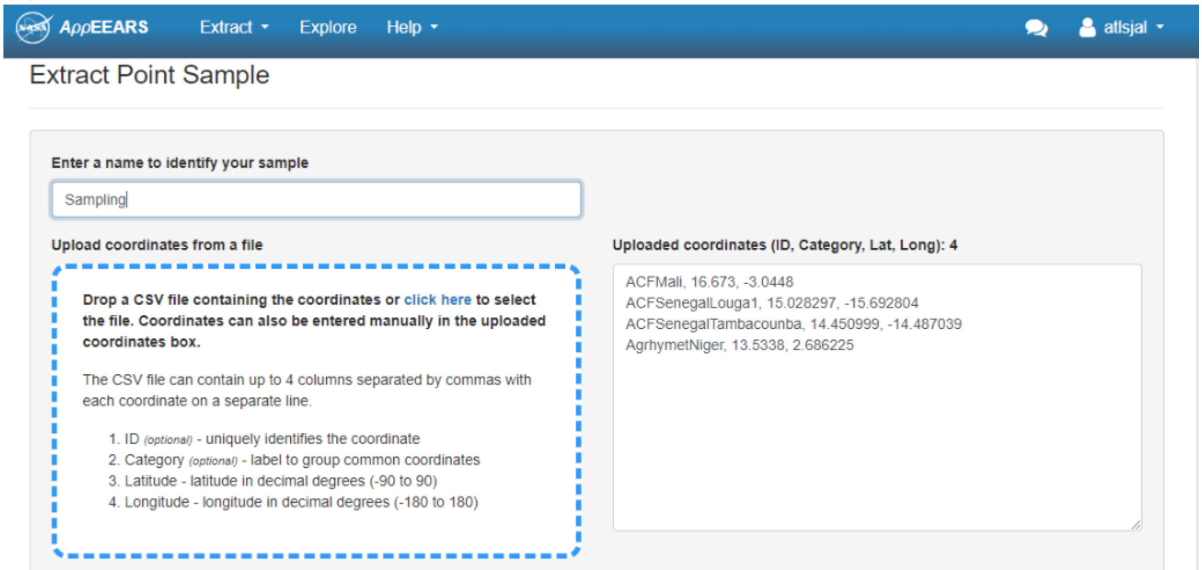
Step One: Input Data Sampling

(1) Define your sampling locations including sitename, latitude, and longitude.

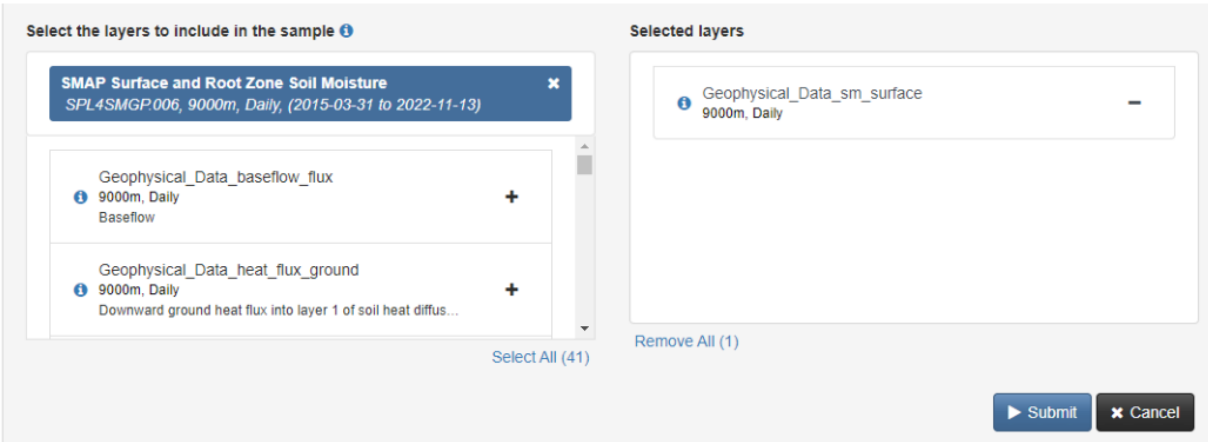
(2) Navigate to the online sampling website NASA AppEEARS at https://appeears.earthdatacloud.nasa.gov/task/point

(3) Initiate a new request.

(4) Input the location information.



(5) Choose the data period, data source, and variables of interest.



(6) Submit the order.

(7) Upon completion, receive a notification via email and download the data.

Step Two: data uploading

(8) collect the input csv file and your site location csv file.

	A	B	C
1	Site	Lat	Long
2	ACFMali	16.673	-3.0448
3	ACFSenegalLou	15.028297	-15.692804
4	ACFSenegalTam	14.450999	-14.487039
5	AgrhymetNiger	13.5338	2.686225
6	AKTCZambia	-14.9461474	28.0861579

(9) upload them to the folder in the FSE system

Step Three: data online processing

(10) same processing step as NDWI.

Step Four: download results and Analysis

(11) click the result files and directly download to local computers

(12) pre-check the results at each region of interest:

	A	B	C
1	Date	SM	SM_Anomaly
2	2018-01-01	0.023	-0.048
3	2018-01-02	0.017	-0.065
4	2018-01-03	0.03	-0.043
5	2018-01-04	0.031	-0.04
6	2018-01-05	0.02	-0.058
7	2018-01-06	0.027	-0.049
8	2018-01-07	0.025	-0.054

Three columns show the date, index value, and values that seasonal cycle has been removed.

(13) The plot can be drawn correspondingly.

2.1.1.6 Evaporative Stress Index (ESI)

ESI identifies temporal anomalies in evapotranspiration (ET) compared to potential ET, highlighting regions with unusually high or low water use rates across the land surface. The basic process for using ECOSTRESS ESI to monitor drought from Food Security Explorer is as follows:

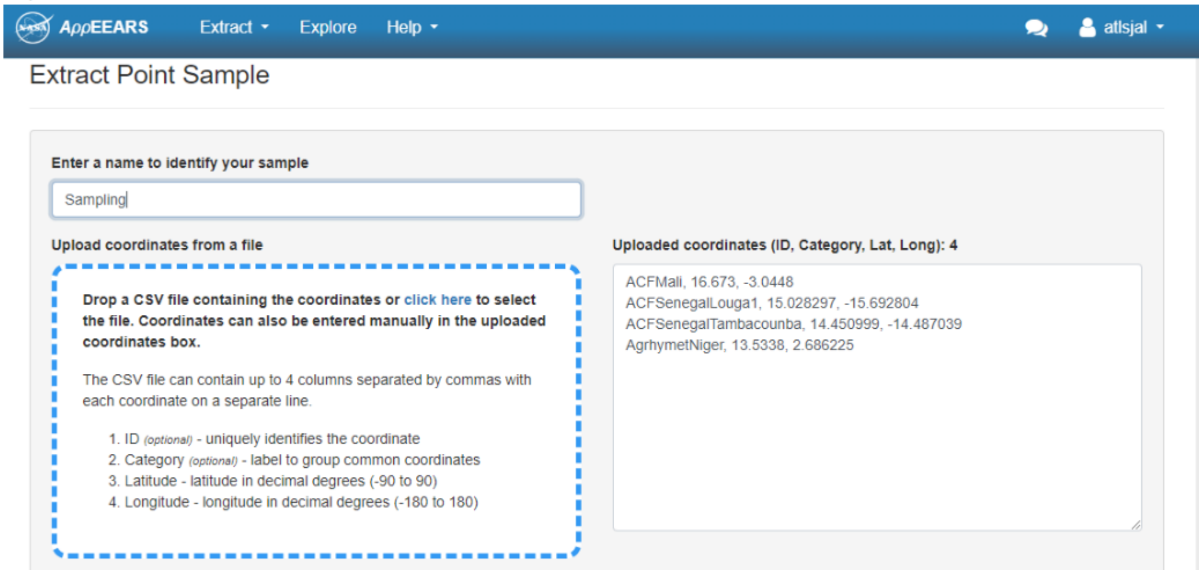
Step One: Input Data Sampling

(1) Define your sampling locations including site name, latitude, and longitude.

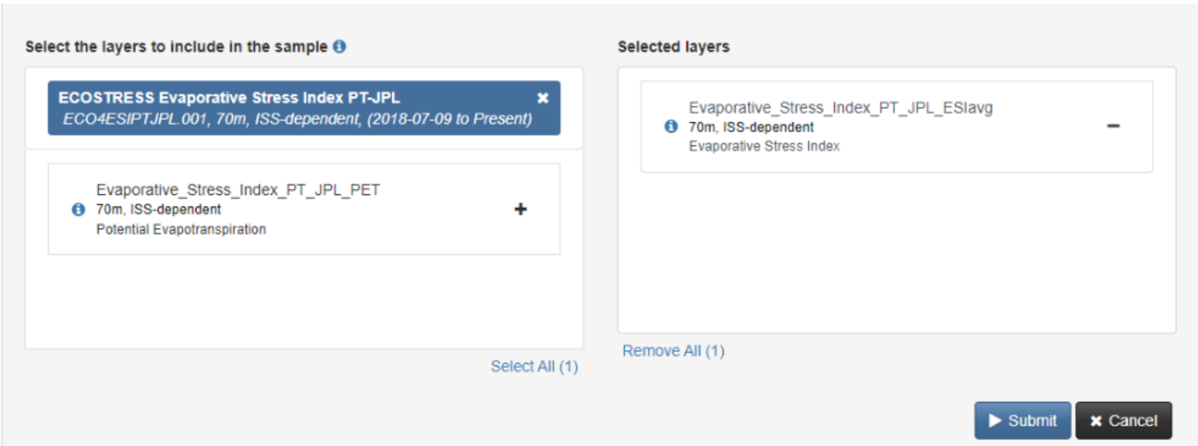
(2) Navigate to the online sampling website NASA AppEEARS at https://appeears.earthdatacloud.nasa.gov/task/point

(3) Initiate a new request.

(4) Input the location information.



(5) Choose the data period, data source, and variables of interest.



(6) Submit the order.

(7) Upon completion, receive a notification via email and download the data.

Step Two: data uploading

(8) collect the input csv file and your site location csv file.

	A	B	C
1	Site	Lat	Long
2	ACFMali	16.673	-3.0448
3	ACFSenegalLou	15.028297	-15.692804
4	ACFSenegalTam	14.450999	-14.487039
5	AgrhymetNiger	13.5338	2.686225
6	AKTCZambia	-14.9461474	28.0861579

(9) upload them to the folder in the FSE system

Step Three: data online processing

(10) same processing as NDWI

Step Four: download results and Analysis

(11) click the result files and directly download to local computers

(12) pre-check the results at each region of interest:

	A	B
1	Date	ESI
2	2018-08-24 15:4	0.665
3	2019-01-11 08:0	0.838
4	2019-01-21 17:3	0.549
5	2019-01-28 14:5	0.465
6	2019-01-31 13:5	0.455
7	2019-06-09 10:3	0.187
8	2019-07-19 18:3	0.279

Three columns show the date, index value, and values that seasonal cycle has been removed.

(13) The plot can be drawn correspondingly.

2.1.2 Feedback Collection

The system demonstrates a strong capability for processing data online, which is one of its significant strengths. However, there are several areas where improvements are needed based on user feedback. Currently, the system is still in its demo phase, which has led to some instability, particularly regarding user authority and account access. For instance, users occasionally experience difficulties logging in, and these issues can become more pronounced when switching browsers from Chrome to Firefox. Moreover, the functions sometimes cannot pop out normally. Additionally, the zoom functionality lacks smoothness, which can hinder the user experience when navigating through data. To enhance the system's usability and align it with industry standards, it is recommended to integrate an online coding interface similar to Google Earth Engine (GEE), which would provide users with more flexibility and advanced capabilities for data analysis.

2.2 Crop water stress products

2.2.1 Product Provision

The current implementation of the crop water stress indicator workflow allows users to generate this product for entire Sentinel-2 tiles on their local machine (see also Deliverable D08 – Documentation of processors/toolbox/software). Required input parameters include:

- Start and end date of desired processing period
- Sentinel-2 tile id (e.g. 30QVD)
- Local time zone (UTC)
- Path to directory where the output should be stored
- Path to directory where ERA5 data should be stored
- 3 LST correction parameters, resulting from the intercomparison of Sentinel-3 derived LST and ECOSTRESS LST: cross-calibration gain, cross-calibration offset and directionality parameter.

After product generation, the necessary routines are available to upload the results to the Food Security Explorer platform, where they can be easily visualized.

2.2.2 Feedback Collection

Feedback on the crop water stress product itself and its integration and visualization within the Food Security Explorer is collected during interactions with the project's Early Adopters. Aside from the first public webinar that was held on January 31st 2024, three important feedback events are still scheduled in the final stage of the project:

1) Milestone 3 meeting in Zambia between September 9th and September 13th 2024
2) EOAfrica Symposium at ESA between September 23rd and September 26th 2024
3) The second public project webinar, to be scheduled in October 2024

During all of the mentioned events, potential end users will be asked to provide feedback on the usefulness and user-friendliness of the current implementation of the crop water stress processor.

2.3 Hyperspectral Products

2.3.1 Product Provision

Prototype provision for the hyperspectral products was mainly focused on AKTC in Zambia, as they have irrigation pivots and are thus most interested in leaf and canopy water content for irrigation recommendations. Of course, the products were also calculated for the test-sites in Mali and Senegal, but since less management options are available on the ground there, these products are mainly for information purposes for the users there.

AKTC was introduced to the Food Security Explorer and given an introduction on how it is possible for them to calculate the results themselves, but between having to order the hyperspectral data from ASI and them not being very involved with geoscientific data handling usually, they decided that for them it would be much easier if the prototype provision was done in a more “low tech” way where they would have the results immediately available. Hence, VISTA calculated the results for leaf area, canopy water content and leaf water content for them and provided them as pdf maps. Both PRISMA and EnMAP data were used for this, as ideally the maps would be available weekly and as quickly after acquisition as possible.

2.3.2 Feedback Collection

Feedback collection happened both in direct talks with AKTC as well as over email. Since the user AKTC was very involved in the project, no multiple choice questionnaires or similar were utilized, but instead the route of expert interviews was taken.

3 Prototype Test - Results

3.1 Thermal Products

In this section, we analyze the results of thermal products generated using the FSE system. The seasonally detrended temporal variability of four drought indices (NDWI, STR, SM, and ECOSTRESS ESI) is summarized and compared across the test sites of the ARIES project. Additionally, we provide an interpretation of these results.

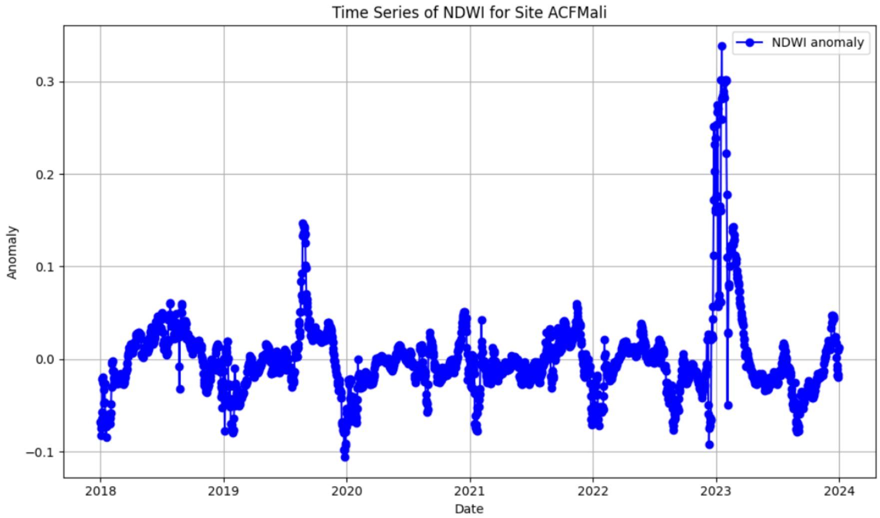


Figure 1: The temporal variation of detrended NDWI at site ACFMali.

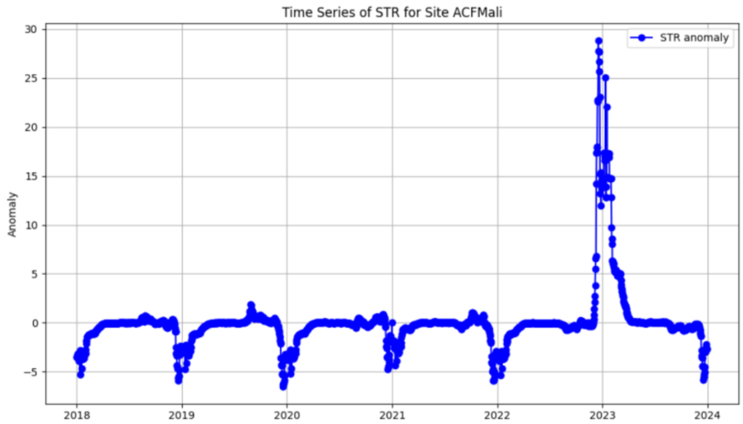


Figure 2: The temporal variation of detrended STR at site ACFMali.

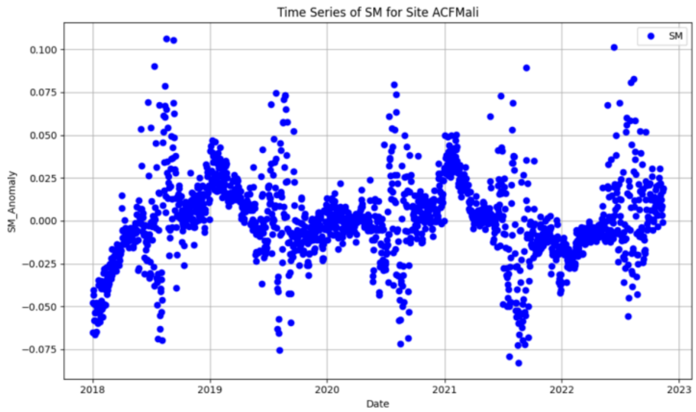


Figure 3: The temporal variation of detrended SDCI at site ACFMali.

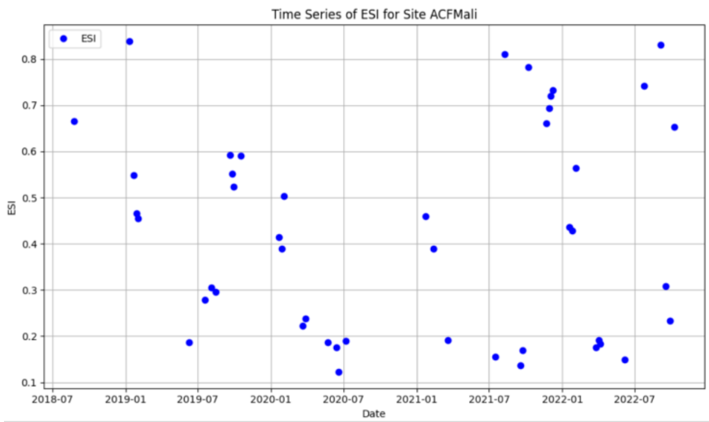


Figure 4: The temporal variation of detrended ESI at site ACFMali.

Each thermal product module releases both drought indices and their detrended results. The detrended results represent the index time series with the seasonal cycle removed, highlighting anomaly values. As drought is defined by soil moisture deficiencies below climatological norms, we propose that using anomalous values is more effective for detecting drought events.

Based on the anomaly time series of the four drought indices shown in the figures above, it is evident that a significant wet period occurred at the beginning of 2023, while dry periods were observed at the beginning of other adjacent years. Due to the limited temporal sampling frequency of ECOSTRESS ESI, it is suitable for local mapping but not for temporal anomaly detection at this time.

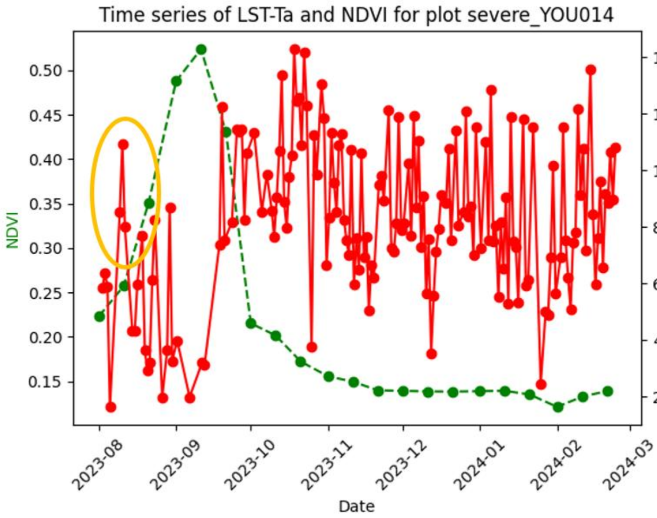
3.2 Crop water stress products

During the first public project webinar, the conceptual details with regard to the crop water stress indicator were shared with the represented Early Adopters and other interested parties. All involved Early Adopters confirmed the relevance of the indicator for their day-to-day operations.

During a first operational test, the high-resolution crop water stress product has been generated for a test site in South Africa. After careful visual inspection, no obvious product artefacts have been identified and the output matched expectations in terms of range of values observed.

The data upload procedure to the Food Security Explorer platform has been successfully tested: two test products for South Africa have been ingested and visualized in the platform (see also Deliverable D16 – Platform integration). Feedback was shared with the Food Security Explorer core team related to the incorrect handling of scale/offset information embedded within the GeoTiff files.

At the end of the project, the newly developed crop water stress products have been generated for the specific test sites in Mali (managed by Early Adopter ACF) and Zambia (managed by Early Adopter AKTC). The results were showcased to these Early Adopters during Milestone 3 meeting, as well as during the second public project webinar. For ease of interpretation, the crop water stress indicator is by default visualized alongside the NDVI time series, as land cover is an important factor to consider during product interpretation. An example of this visualization is provided in the next Figure:



3.3 Hyperspectral Products

The hyperspectral products were delivered as pdf maps and the prototype processing was integrated into the Food Security-Explorer.

Speedy provision was named as a prerequisite for usefulness by AKTC. Depending upon the date of acquisition the products can be provided within a day, but because the processing chain including data transfer to AKTC is not fully automated since these are scientific products, acquisitions taken on the weekend could not be processed as fast and delays of several days were the consequence.

AKTC was happy to give feedback and validate our results, especially the differences in LAI observed in both of the pivots (more details on that can be found in D06 Validation Report). AKTC conducts field demonstrations and research on 10, 27 and 62 hectares of land at the Golden Valley Agricultural Research Trust's (GART) Chaloshi farm in Zambia. Field trials and field demonstrations on the 10-ha field are run by a photovoltaic driven pivot whereas the 62 ha pivot operates under the main grid electricity supply. On the other hand, research done on the 27 ha are purely rain fed.

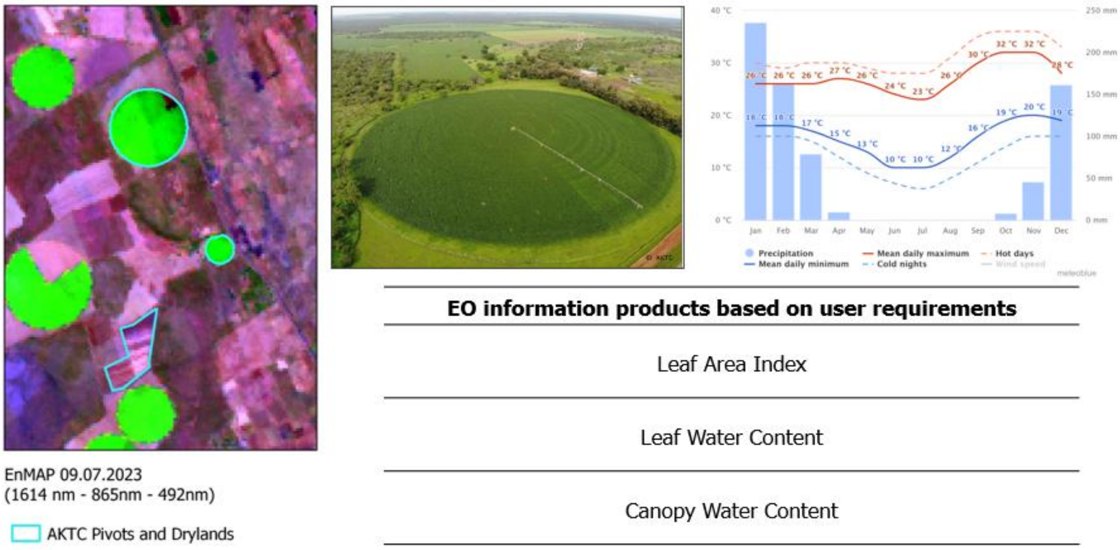


Figure 5: Prototyping area in Zambia

The prototype maps for AKTC were delivered in the format as follows:

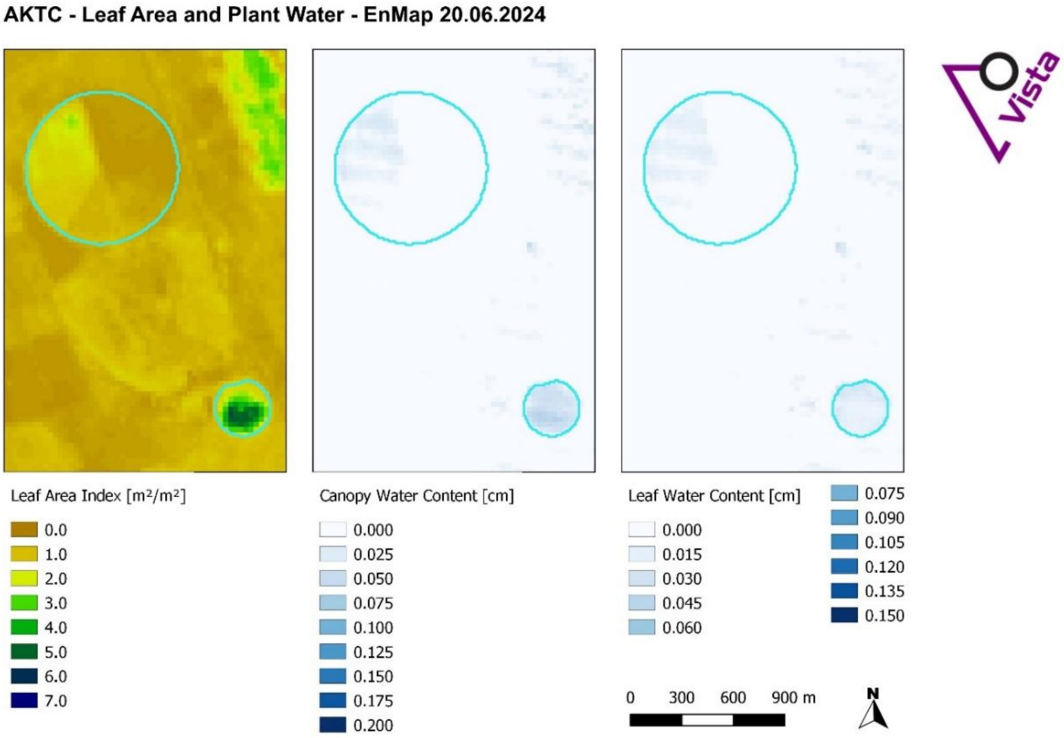


Figure 6: Prototype map for Zambian test-site, derived from EnMAP 20.06.2024

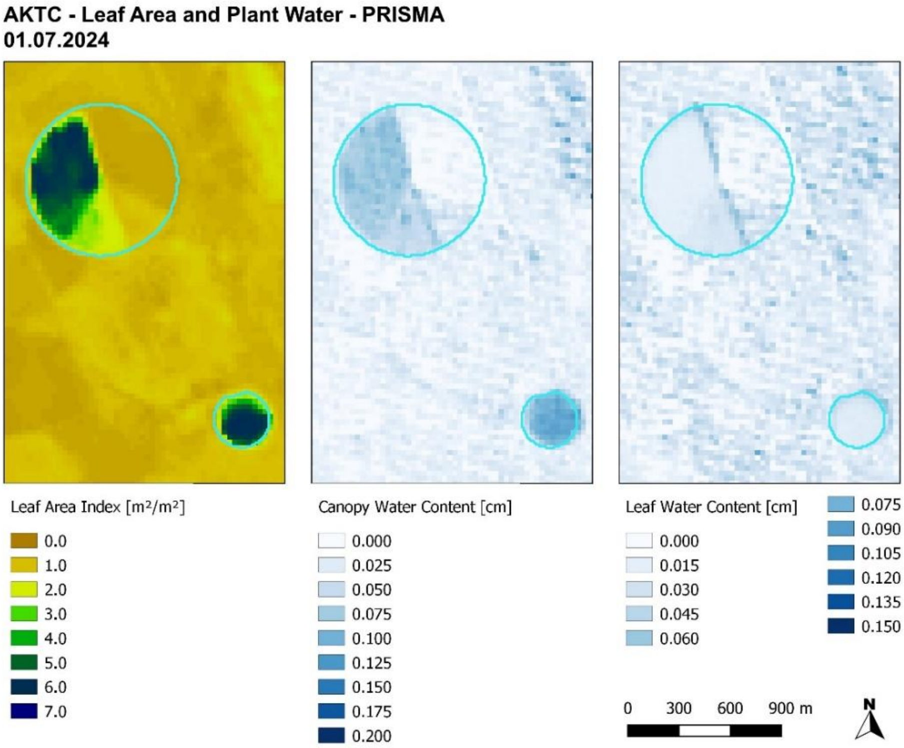


Figure 7: Prototype map for Zambian test-site, derived from PRISMA 01.07.2024

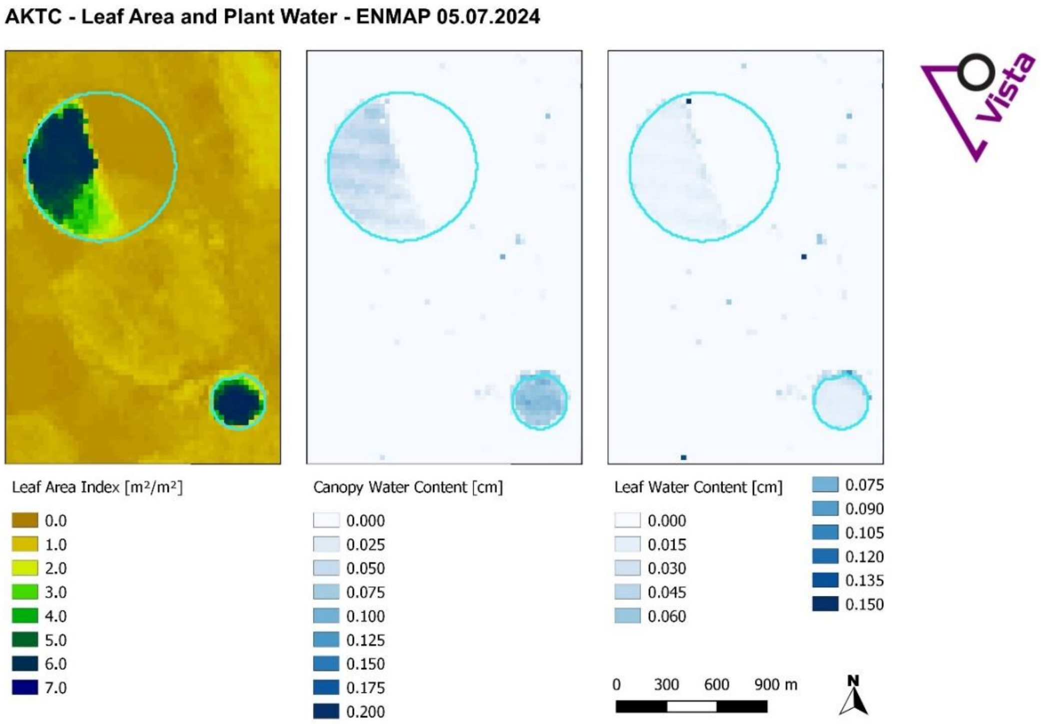


Figure 8: Prototype map for Zambian test-site, derived from EnMAP 05.07.2024

Overall, the impression was, that while the partner was happy to receive the data and give feedback for the prototype testing and validation, but that for operational farming it would be helpful for them to translate the products into more specific information, e.g. irrigation amount and timing. Specifically, we observed some difficulties in understanding the difference between leaf water content and plant water content, as these are not units that are immediately familiar to the user. Nevertheless, they could explain the differences in the pivots and draw conclusions concerning the status of the crops and the irrigation needs.

The user pointed out that due to the drought in Zambia they have challenges like low irrigation water availability or electricity cuts. These have effects on when and how much water can be irrigated. So for a direct irrigation recommendation, not only the plant status is a consideration, but also the conditions surrounding farm management.

Prototype maps were also calculated for the other test-sites in Mali and Senegal, where the focus was more on the drought indicators from thermal data. Hence, no direct feedback from the users has been collected for these prototype maps yet, though this can still change until the end of the project. In the following, exemplary maps for Mali are shown.

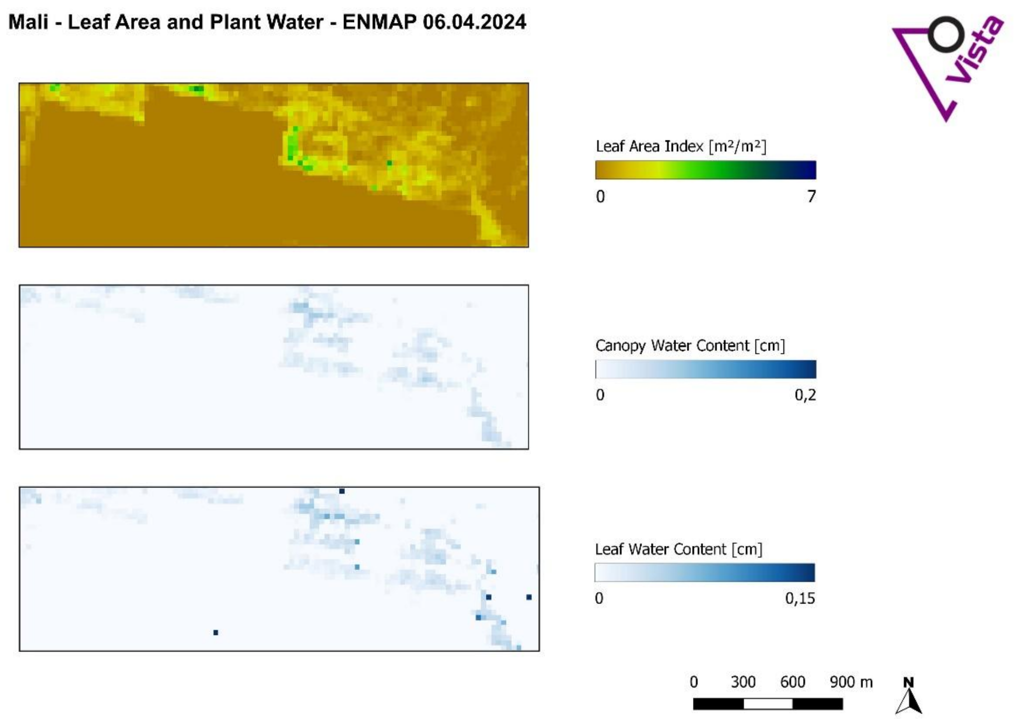


Figure 9: Prototype map for Malian test-site, derived from EnMAP 06.04.2024

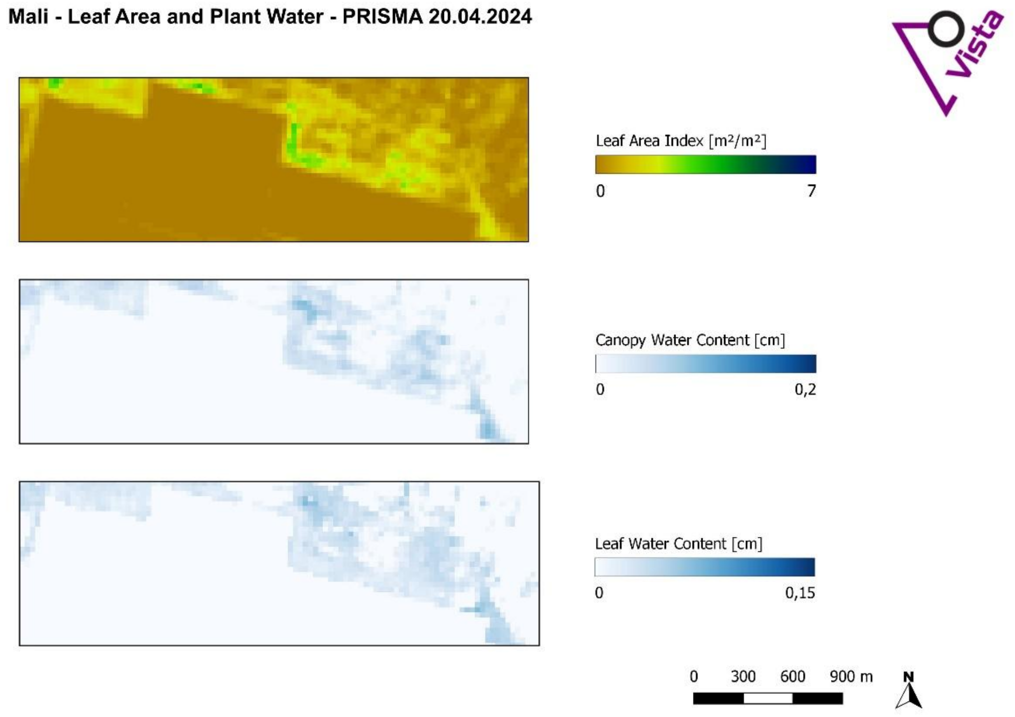


Figure 10: Prototype map for Malian test-site, derived from PRISMA 20.04.2024

4 Conclusion

In conclusion, prototype tests have been conducted for all test-sites for both thermal and hyperspectral data products. Since these products are scientific and not available operational in automated workflows and for regular acquisition times yet, there is a certain gap between user needs especially for the agricultural users and the currently available prototypes. This was to be expected and will in the future become an obsolete point, once CHIME and LSTM are launched. Nevertheless, the prototypes developed by ARIES have been deemed interesting by the users and several ideas for further enhancements and new products, which would also be useful, have been formulated by the users, which is a promising result.