EO Africa // ARIES

D16 – Platform Integration (Report)

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ESA STUDY CONTRACT REPORT

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ABSTRACT:

This document describes the platform integration 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.

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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
ASI	Agenzia Spaziale Italiana
CWC	Canopy Water Content
DaMa	Data Analytics and Management
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
FS-X	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
NoR	Network of Resources
OTC	Open Telekom Cloud
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
SiR	Service Runner
SM	Soil Moisture
SMAP	Soil Moisture Active Passive
STD	Standard Deviation
STR	Shortwave Infrared Transformed Reflectance
SWI	Soil Water Index
S3	Sentinel 3
TEP	Thematic Exploitation Platform
UI	User Interface

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) (formerly Food Security-TEP) and thus is publicly available. For the sponsoring of platform services for the data processing and prototype hosting needed by the project, a Network of Resources (NoR) sponsorship (https://portfolio.nor-discover.org/) was requested and granted by ESA.

The test prototype implementation followed Agile Development methods and engineering best practices. This allowed to rapidly move from the initial algorithm/s and processor assessment, towards the test prototype, while maintaining iterative interactions with the Early Adopters and frequent development cycles.

The prototype will be maintained long-term on the Food Security-Explorer (FS-X) as per FAIR principles. Since VISTA is the owner of the Food Security Explorer, no additional business agreements with other parties are necessary for this, though in the long-term, business models based on pay-per-use consumption of the prototype chain by third parties with minimum yearly consumption can be utilized to cover the costs of hosting the service.

2 Platform solution – Food Security Explorer

Figure 1: Food Security Explorer – Data Analytics and Management (DaMa) view

The Food Security Explorer was formerly named Food Security TEP and was upgraded in 2023 and 2024 to use the current standards and technologies in cloud computing, have more reliable resources assignment, and more efficient scaling up. It has been ported from Creodias to the Copernicus Data Space Environment and OTC. It provides stable, scalable and flexible infrastructure, allowing sustainable and consistent usage. The new architecture provides improved and tailor-made user profiling to handle a wider variety of user needs, including a User Interface (UI) that can display data analytics on the fly. The Food Security Explorer hosts many datasets relevant for this project, including the full range of the Copernicus acquisitions via connection to the CDSE as well as directly hosting the ECOSTRESS dataset (see

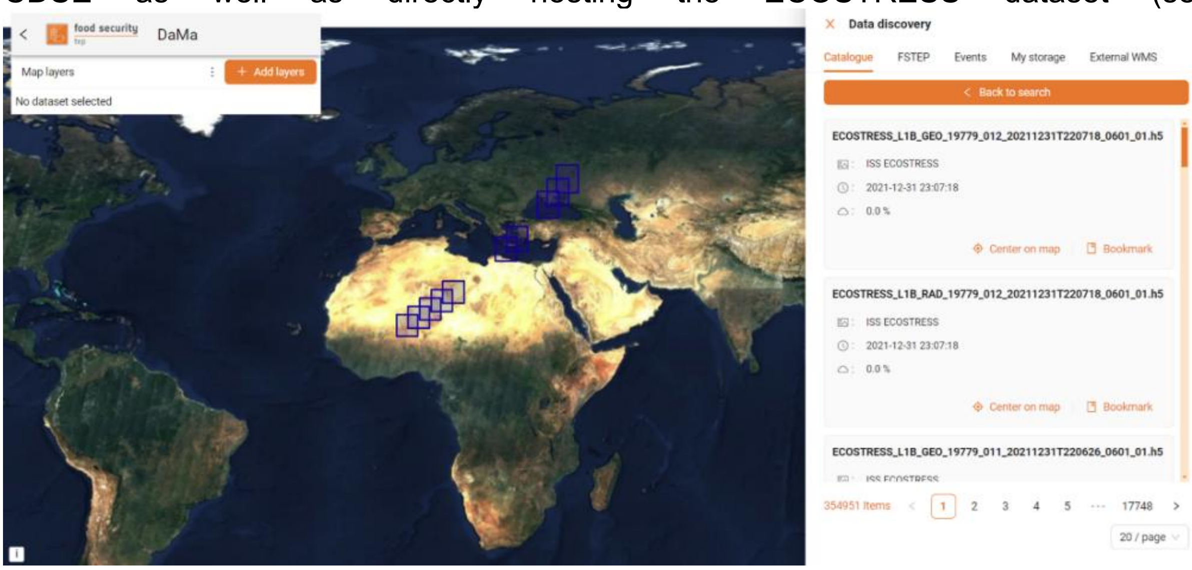

Figure 1, which is of course very relevant for this project. Automated deployment, scaling, and management of containerized applications is the principal focus of the platform. It employs Kubernetes, which has the following benefits:

- High availability: it rolls out changes, while monitoring the application health, avoids terminating all the instances at the same time.
- Storage orchestration: whether local, public, or object storage, Kubernetes mounts these systems automatically in different modes according on the application needs.
- Resources characterization: depending on the application needs, resources are allocated and appropriate computing nodes are scheduled.
- Platform robustness: in case of failure, Kubernetes restarts failed processes (containers).
- Load balancing and service discovery: thanks to its native mechanism for assigning IP addresses and DNS name for a set of pods, load balancing of the individual platform

For data discovery and analytics, a DAMA (Data Analytics and Management) component is integrated. Also, a SiR (Service Runner) component is available for processing in different modes. This means, inputs can either be chosen at run time (standard), bulk processing support (processing campaign) is available, or triggering services automatically upon occurrence of a specific event (event driven). In order to ensure platform interoperability, openEO functionalities is currently being added to the platform. Via openEO graphs, science workflows can be expressed in a way that is independent from changing ICT. This ensures the longevity of any deployed algorithms. Additionally, AI workflow processing has been added early in 2024 via Kubeflow.

Cloud computing capabilities together with availability of datasets makes FS-X suitable for algorithm integration. For algorithm development, prototyping, testing or integration the platform offers application services (e.g. QGIS, SNAP) as well as Jupyter Hub (

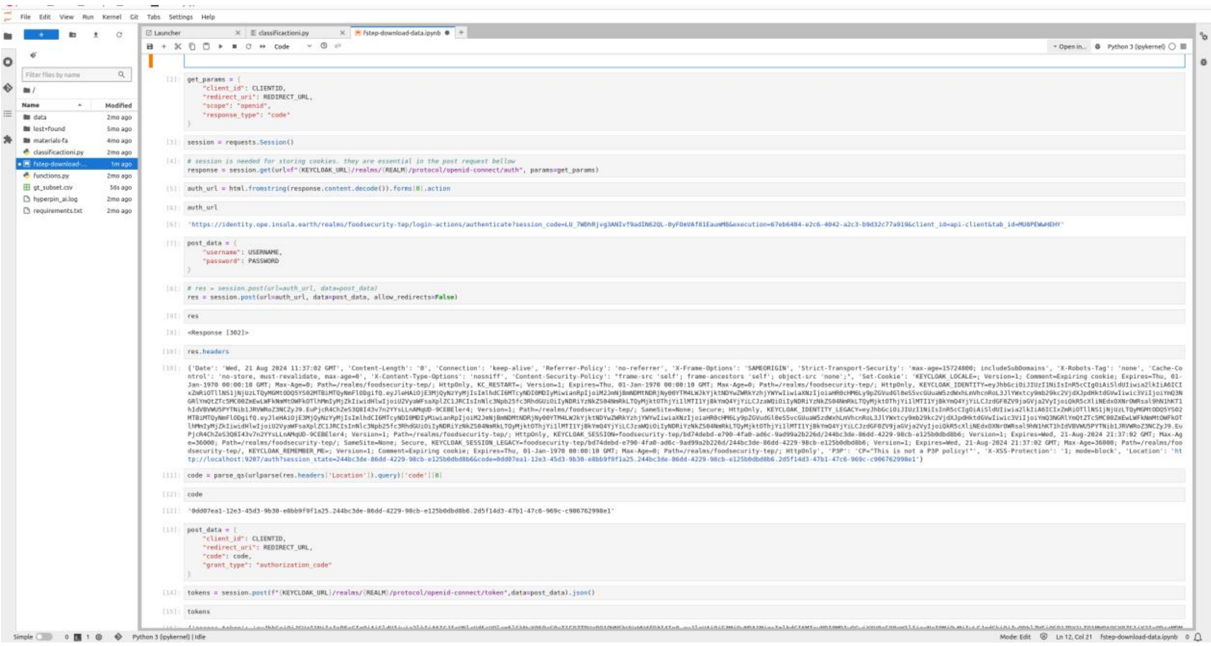

Figure 3) in a basic and data science environment. Algorithms can also be shared with users in the form of services (

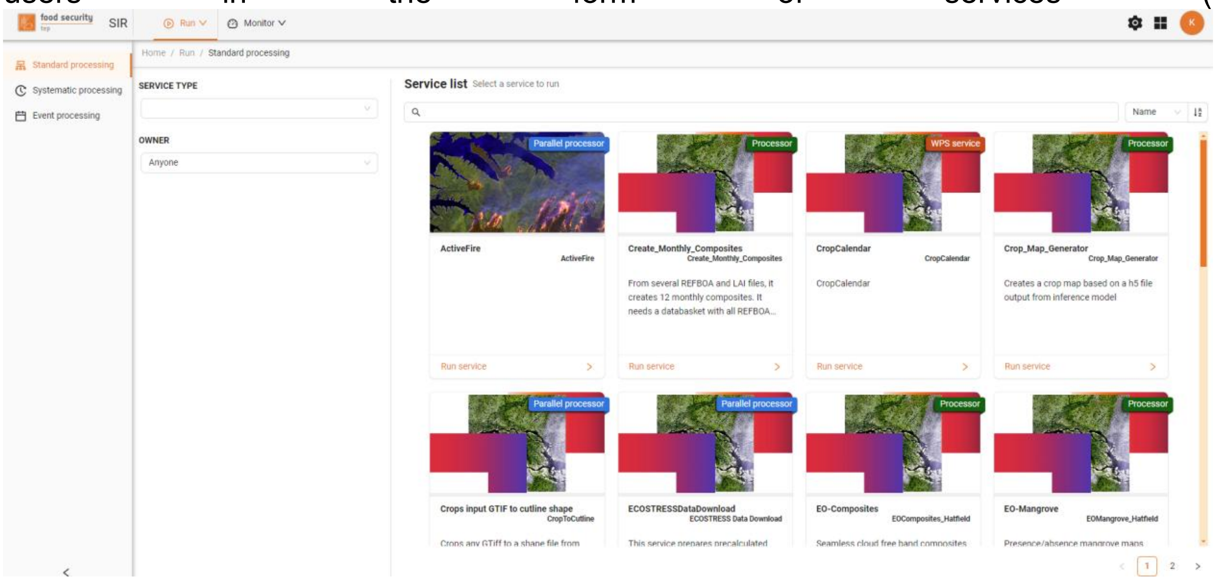

Figure 2)

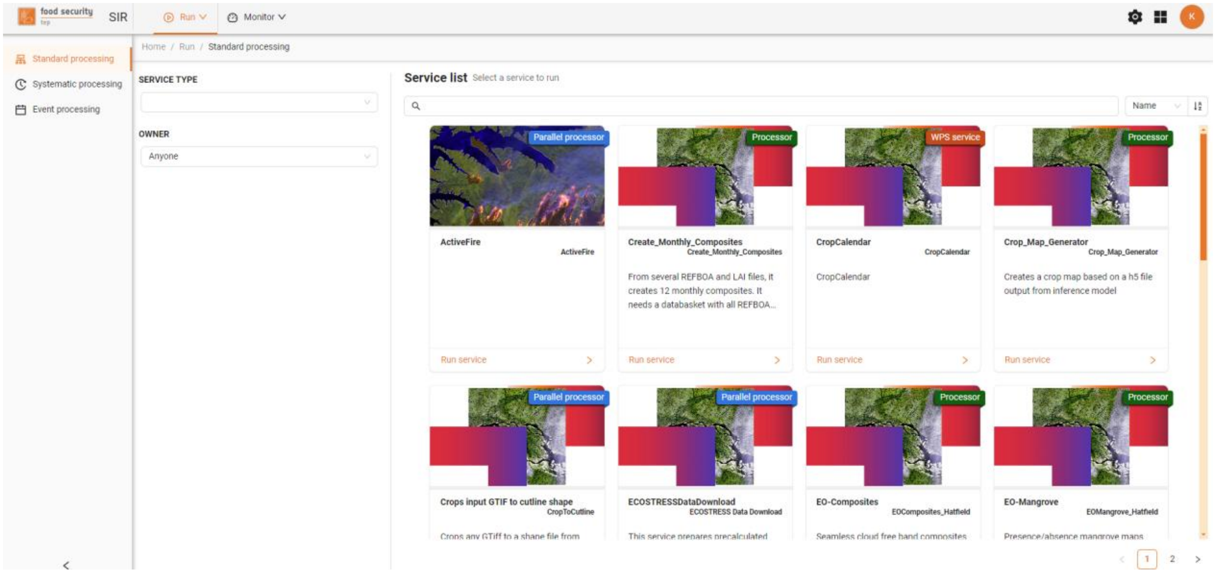

Figure 2: Exemplary service list on FS-X

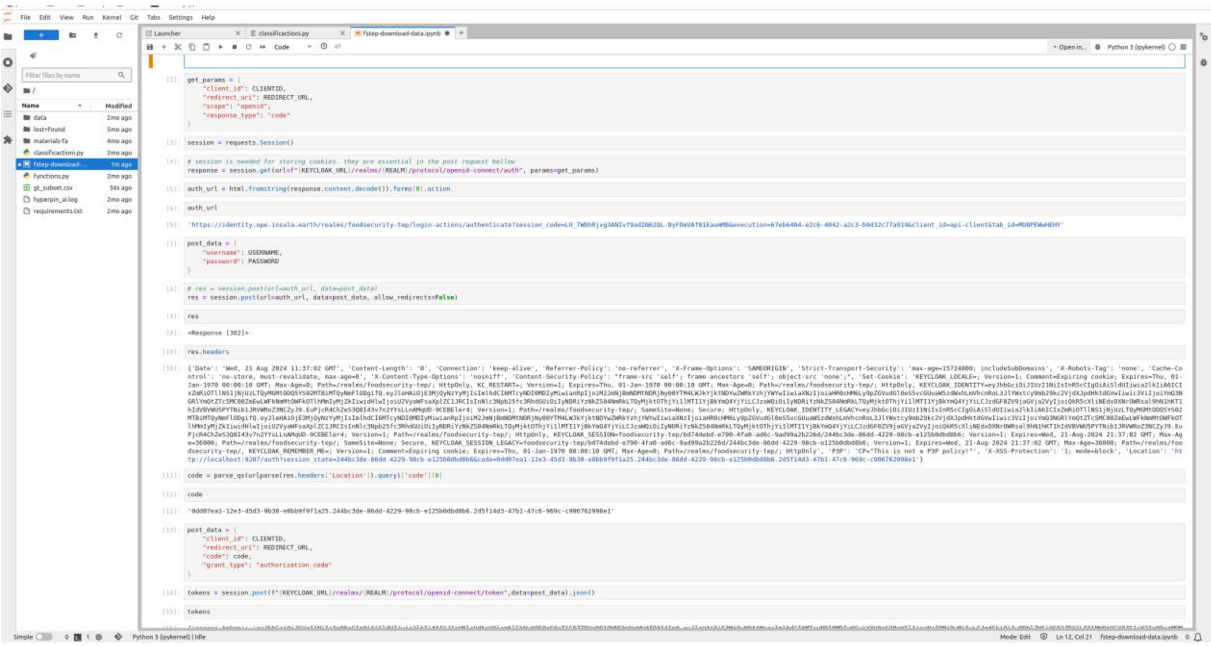

Figure 3: Jupyter Notebook on FS-X

3 Product and Algorithm Integration

3.1 Drought Indices

The codes of six Drought Indices have been integrated to the Food Security Explorer, and end-users can implement the functions by linking the required input data sampled at the regions of interest to the processors.

- Normalized Difference Water Index (NDWI): NDWI normalizes water-sensitive near-infrared band and aims to monitor changes in water content of leaves and soil. Surface reflectance information is required as input data, including reflectance from near infrared band (centred at ~0.86 μm) and shortwave near infrared band (centred at ~1.24 μm):

$$NDWI = \frac{\rho_{0.86} - \rho_{1.24}}{\rho_{0.86} + \rho_{1.24}}$$

- 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. [https://doi.org/10.1016/j.rse.2015.04.007]

$$STR = \frac{(1 - \rho_{2.13})^2}{2\rho_{2.13}}$$

- Keetch-Byram Drought Index (KBDI): The KBDI, initially designed for daily fire risk monitoring, is calculated using normal annual precipitation, daily maximum air temperature, and daily precipitation. Some studies considered it as an indicator of surface moisture deficient in their analysis. It is based on water balance theory, ranging from 0 to 800 (0.01 inches, using English units) or 0 to 203.2 (mm, using S.I. units), representing the spectrum from wet to dry conditions. The computation process to obtain KBDI (Q) is represented as:

$$dQ = \frac{[203.2 - Q][0.968exp(0.0875T + 1.5552) - 8.30]d\tau}{1 + 10.88exp\,(-0.001736R)}$$

$$Q = Q_0 + dQ - dP$$

where dQ represents drought incremental rate that is used for updating KBDI (Q0) of the previous day, T is daily maximum air temperature, R is mean annual precipitation, dP is daily precipitation, dτ denotes the time increment set to 1 day in this study. The daily KBDI is averaged to 8-day/monthly for sensitivity evaluation. Note that dQ = 0 when T < 10°C, and only the dP is considered when it exceeds the net accumulated precipitation of 5 mm.

- hybrid Scaled Drought Condition Index (SDCI): SDCI is scaled drought index, averaged using detrended precipitation anomalies (precipitation condition index, PCI), vegetation anomalies (vegetation condition index, VCI), and temperature anomalies (temperature condition index, TCI).

$$SDCI = 0.5PCI + 0.25VCI + 0.25TCI,$$

$$TCI = \frac{LST_{max} - LST_i}{LST_{max} - LST_{min}},$$

$$PCI = \frac{P_i - P_{min}}{P_{max} - P_{min}},$$

$$VCI = \frac{NDVI_i - NDVI_{min}}{NDVI_{max} - NDVI_{min}},$$

- 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.

- 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. [https://doi.org/10.1029/2019WR026058]

$$ESI = \frac{ET}{ET_0}$$

where ET represents the evapotranspiration, ET_0 is the reference evapotranspiration.

3.2 Crop water stress products

As specified in Deliverable D08 (Documentation of Processor/Toolbox/Software), the generation of the 20 m resolution crop water stress indicator based on a fusion between Sentinel-2, Sentinel-3 and ECOSTRESS data is done on the users' local machine through execution of a series of Python scripts. The scripts fetch the required EO input data automatically from both the Copernicus Data Space Ecosystem and the Copernicus Climate Data Store. These data are stored on the users' machine, after which further processing generates the final crop water stress indicator as a series of Cloud-Optimized GeoTiff files. Alongside this indicator, also a smoothed NDVI product is generated, which can assist the user during product interpretation. As a final step in the workflow, both indicators are uploaded to the Food Security Explorer platform, where they can be publicly consulted and visualized using the available visualization tools on the platform.

Figure 4 shows a screenshot of the Crop water stress indicator (LST-Ta) as uploaded to the platform.

Figure 4: Crop water stress indicator uploaded to the Food Security Explorer platform.

3.3 Hyperspectral Products

Providing flexibility in processes and data volumes, FS-X is ideal for working with hyperspectal data. Although these data sets do not have a large spatial coverage, they require larger and scalable computing power due to their spectral resolution (~ 200 channels). Due to licensing conditions by ASI, the hyperspectral EnMAP and PRISMA data itself can unfortunately not be integrated into the FS-X as publicly available datasets. However, every user can upload their own data – including hyperspecral data – to their private storage space on the platform and then use the available processing options to derive the hyperspectral products, e.g in agricultural applications. For those capabilities / questions free available software packages, like QGIS including extensions offer corresponding options.

For this, the user has to open the QGIS application, which includes the EnMAP Toolbox extension (https://www.enmap.org/data_tools/enmapbox/). The user can then utilize QGIS and the EnMAP Toolbox the for the derivation of the leaf area index LAI, leaf water content LWC and plant water content PWC. (suitable parameterisations are predefined, details and options can be found in the tutorial)

The resulting tiffs are stored in the user's private data space and can either be further processed or downloaded. Of course, the QGIS functionality also allows to save map layouts for presentation of the results. The installation of QGIS, including preinstalled EnMAP Toolbox, can be found under application area SIR in the FS-X.

In Figure 5 the logic of the integration of EnMap functionality is given. Data from the FS-X can be used in the QGIS / EnMap Service and stored and reused in the processing outputs.

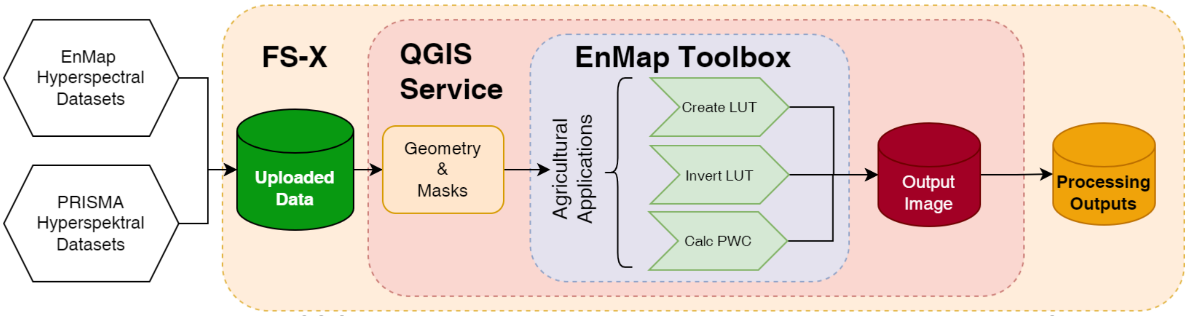

Figure 5: QGIS and EnMap Toolbox with hyperspectral processing capabilities on FS-X

User can provide their own hyperspectral datasets (in the range of 1.5 GB for 30 x 30 km) via Upload and store them in their Processing Outputs. The QGIS service is running on a time base, a timeout (default 60 minutes) needs to be given.

Within ARIES, hyperspectral datasets have been used for assessment and monitoring of LAI, Leaf Water Content and Canopy Water Content for the test sites. All necessary processing steps are now/soon available on the FS-X. A tutorial for the exemplary use of the QGIS embedded Enmap Toolbox on LAI and PWC retrieval, and the resulting Leaf Water Content, will be released. With the use of QGIS, user have the full options on data handling and product provision regarding geospatial raster and vector data.

Figure 6 illustrates QGIS application start, including input data selection, and EnMap toolbox activation, including selection of agricultural applications.

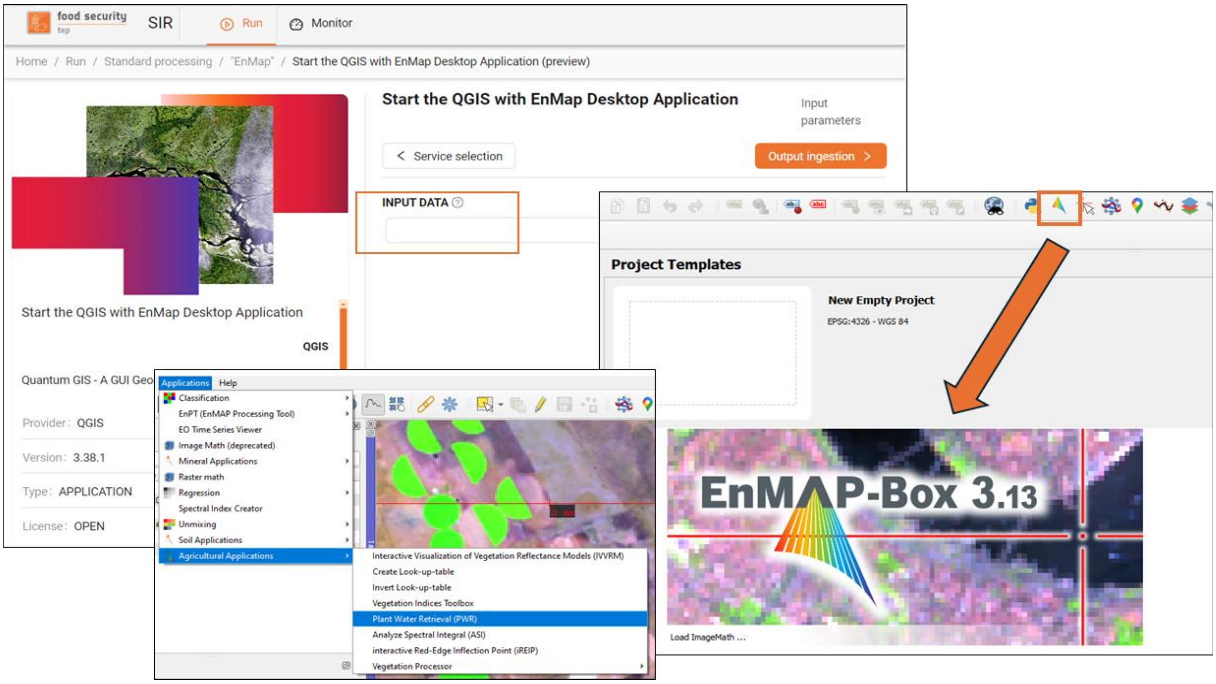

Figure 6: QGIS and EnMAP Toolbox on FS-X. Access to Plant Water Retrieval calculations as example.

Exemplary results of the Plant Water Retrieval, including map visualization and spectral analysis of irrigated fields (center pivot circles from Zambia as example) within the EnMap Toolbox are illustrated in Figure 7.

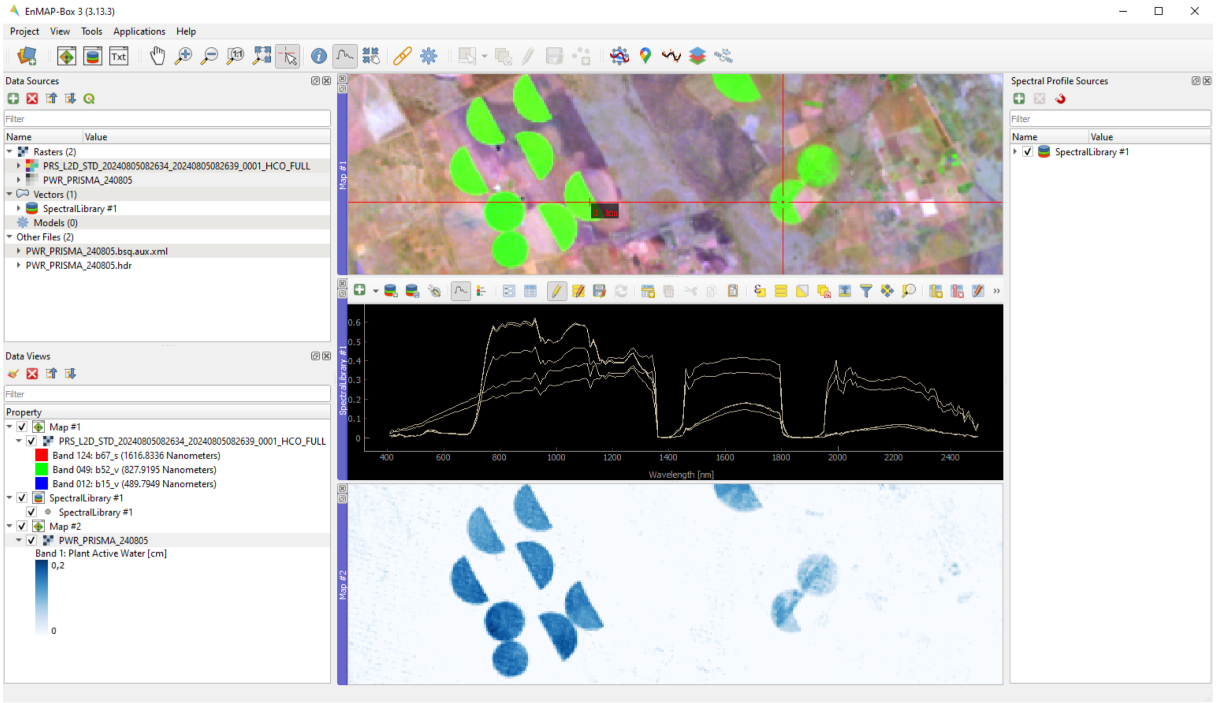

Figure 7: Retrieval of the Plant Water Content using the PWR Algorithm of the EnMAP Toolbox, visualisation as map and spectra of test pixel as illustrated

4 Conclusion

In conclusion, the prototype integration into the Food Security Explorer is progressing for both thermal and hyperspectral products, albeit slightly later than expected due to the updates of the Food Security Explorer, which were funded in a CCN to ARIES and are still on-going. The new FS-X infrastructure allows for much easier and smoother service handling and will support the uptake of activities by African stakeholders.