EO Africa // ARIES

D08 – Documentation of Processor/Toolbox/Software

Version 1.1, 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

<table>
<tr><td>ESA Contract No
4000139191/22/I-DT</td><td colspan="2">SUBJECT
EO Africa // ARIES</td><td>CONTRACTOR
VISTA Remote Sensing in Geosciences GmbH (VISTA)</td></tr>
<tr><td>* ESA CR( )No</td><td>* STAR CODE</td><td>Vol. 1</td><td>* ESA CR( )No</td></tr>
<tr><td colspan="4">ABSTRACT:

This report describes the processors, toolboxes and software developed and used within ARIES.

Version 1.1
Status: 28. August 2024</td></tr>
<tr><td colspan="4">The work described in this report was done under ESA Contract. Responsibility for the contents resides in the author or organisation that prepared it.</td></tr>
<tr><td colspan="4">Names of authors: Veronika Otto (Vista), Jeroen Degerickx (Vito), Louis Snyders (Vito), Silke Migdall (Vista), Nicolas Corti (Vista), Kanishka Mallick (List)</td></tr>
<tr><td colspan="2">** NAME OF ESA STUDY MANAGER
Mr. Z. Szantoi
DIV: EOP-SDR
DIRECTORATE: Earth Observation Programmes</td><td colspan="2">** ESA BUDGET HEADING</td></tr>
</table>

Authors of report

The present report was prepared by:

Veronika Otto, Silke Migdall, Nicolas Corti

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)

Content

Figures

Tables

List of Acronyms

ASI	Agenzia Spaziale Italiana
DAMA	Data Analytics and Management
ECOSTRESS	ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
EnMAP	Environmental Mapping and Analysis Program
EO	Earth Observation
ERA	European Centre for Medium-Range Weather Forecasts atmospheric reanalysis
ESI	Evaporative Stress Index
GUI	Graphical User Interface
KBDI	Keetch-Byram Drought Index
LST	Land Surface Temperature
LUT	Look-up Table
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
RMSE	Root Mean Square Error
PRISMA	PRecursore IperSpettrale della Missione Applicativa
PWR	Plant Water Retrieval
SDCI	hybrid Scaled Drought Condition Index
SIR	Service Runner
STR	Shortwave Infrared Transformed Reflectance
TEP	Thematic Exploitation Platform
UI	User Interface

1 Introduction

One important outcome of ARIES is the prototype implementation of the developed algorithms on a publicly available platform and as publicly available processors and services, so that Early Adopters can use their own data and test-sites to produce the products for their own needs. The Food Security Explorer (formerly Food Security TEP) was chosen as platform solution for the integration of the newly developed algorithms, as it is a platform that is focused both on agricultural applications from Earth Observation as well as on African users and user needs. This, as well as the fact that two of the consortium partners were part of the original consortium that built the platform (VISTA as lead and VITO as subcontractor) made it the logical choice for ARIES. Additionally, the Food Security Explorer hosts the ECOSTRESS data as processed by the consortium partner LIST in the first phase of the ECOSTRESS Hub, which means that the thermal input data is already available on the platform.

In the following chapters, the platform as well as the processors and toolboxes to analyse the thermal and hyperspectral data are described in more detail.

2 Platform Solution – Food Security Explorer (formerly Food Security TEP)

All developed services and products will be made available to the Early Adopters and potential other future users via the Food Security Explorer. The Food Security Explorer hosts almost all relevant data necessary to deliver the proposed products.

The Consortium follows agile development methods and engineering best practices in order to develop the proposed products and implementation of first prototypes on the Food Security TEP.

Generation of new products after the project time will be enabled by making available toolboxes and services for product generation on the Food Security TEP that will allow users to generate products developed within the project after the end of the project. The calculated products will be stored in collections on the Food Security TEP and will thereby be made easily deployable to third parties. The data can either be further utilized within the TEP or be downloaded from the Food Security TEP for offline analysis.

To better serve the needs of the EOAfrica Explorers, an update of the original Food Security TEP is being implemented. It has been rebranded to Food Security Explorer and will be available in the Network of Resources (tender to RHEA has been submitted).

EOAfrica users can request access to explore satellite datasets, especially ECOSTRESS data, and process these directly by using a range of available and generic applications as well as bringing their own new and experimental algorithms to the platform. The Food Security Explorer provides a service to efficiently generate spatial information in a cloud environment, visualization, and download of desired resulting products.

The upgraded platform is built using the current standards and technologies in cloud computing. After the update, it provides a more stable, scalable and flexible infrastructure, allowing sustainable and consistent usage. Additionally, the new architecture provides improved and tailor-made user profiling to handle a wider variety of user needs. Below is a list of the different possible user profiles, where EOAfrica Explorer Users are expected to become USERS or EXPERT_USERS depending on whether they only want to use already established processors or develop their own. The roles of CONTENT_AUTHORITY and ADMIN are filled by VISTA.

Table 1: Food Security Explorer User Profiles

ROLE	Can do	Cannot do
GUEST	• Temporary role assigned to user upon registration with the platform (first EO-SSO Login). Has same rights as USER but no coins assigned yet.	
USER	• Search data • Run publicly available services • Use collections and groups	• Access developer tab
EXPERT_USER	• All functionalities available to USER. • Develop services using developer tab	• Publish services
CONTENT_AUTHORITY	• All functionalities available to	• Edit user roles

	EXPERT USER • Publish services	• Assign TEP coins
ADMIN	• All functionalities available to CONTENT AUTHORITY • Edit user roles • Assign coins	

The User Interface (UI) is tailored to allow easy usability, good user experience and display data analytics on the fly. For data discovery and analytics, a DAMA (Data Analytics and Management) component is integrated. Also, a SIR (Service Runner) component will be 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). Below are screenshots of the system that showcase the different functionalities (exemplary data).

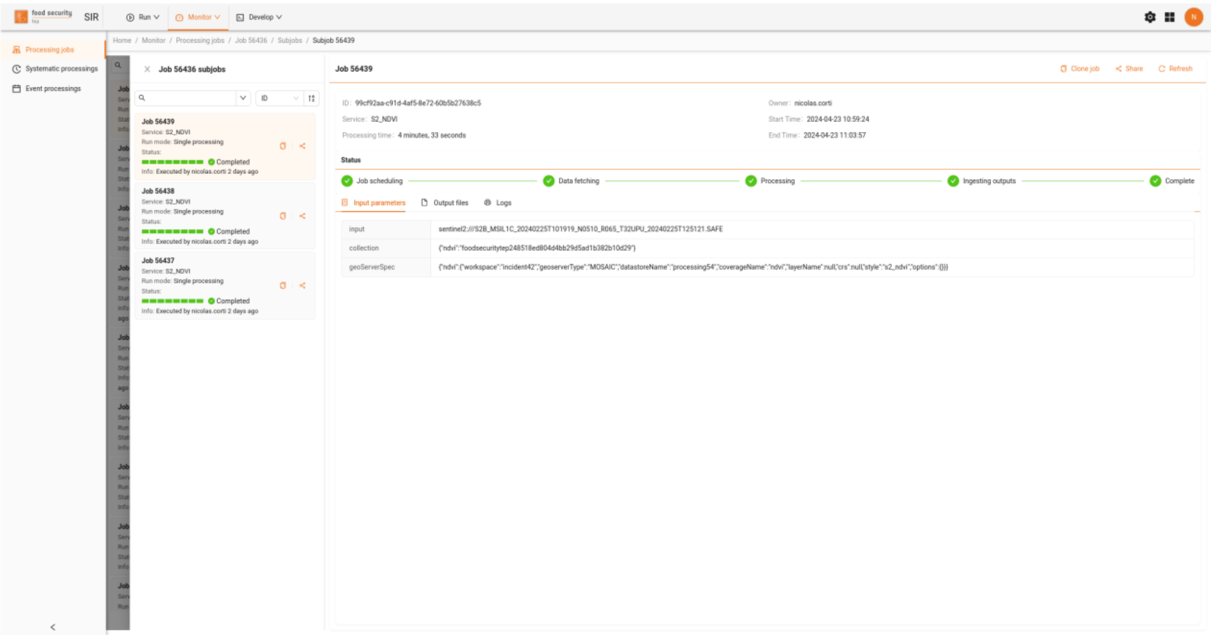

Figure 2: – Detail of a NDVI job monitoring from scheduling until complete

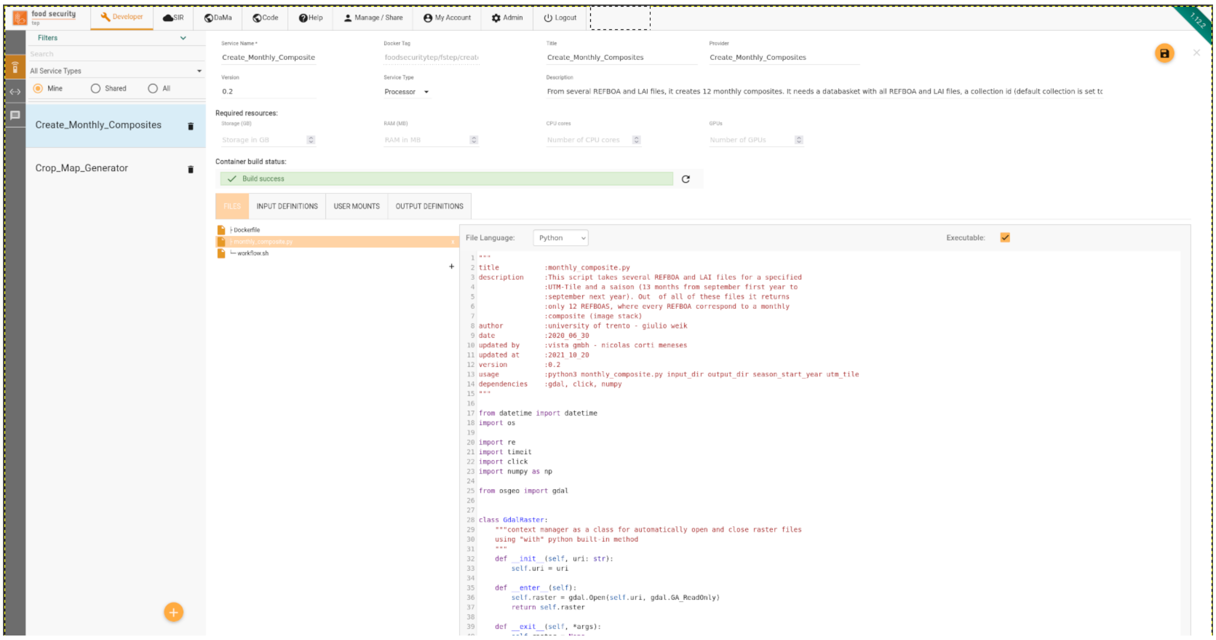

Figure 3: Example of service specification in the developer UI

Automated deployment, scaling, and management of containerized applications is possible on the Food Security Explorer via Kubernetes container orchestration.

In order to ensure platform interoperability, openEO functionalities will be added to the platform by Q3 2024. Via openEO graphs, science workflows can be expressed in a way that is independent from changing ICT. This ensures the longevity of the developed EOAfrica algorithms.

A user manual for the Food Security Explorer is available here: https://foodsecurity-explorer.com/user-manual/index.html

The platform also offers API functionality, which is specified here: https:// foodsecurity-tep.ope.insula.earth/secure/api/v2.0/browser/index.html#/secure/api/v2.0

3 Description of Processors/Toolboxes/Software

3.1 Thermal Processors

3.1.1 Drought Index Processors

Drought Index Processors will encompass programs for computing various thermal and optical remote sensing-based drought indicators, such as the Keetch-Byram

Drought Index (KBDI), Normalized Difference Water Index (NDWI), Shortwave Infrared Transformed Reflectance (STR), hybrid Scaled Drought Condition Index (SDCI), and Evaporative Stress Index (ESI). End users are required to extract the data and subsequently upload the input time series data according to the program's specifications. The software processes the data and generates the results in the form of .txt files.

3.1.2 High-Resolution Crop Water Stress Processor

This processor generates a crop water stress indicator at 20 m resolution, based on a data fusion workflow using Sentinel-2 optical data, Sentinel-3 thermal data, ERA5 air temperature data and the Copernicus Digital Elevation Model (the workflow itself is described in detail in D07_ATBD_PS_II). The workflow also includes two corrections of the generated high-resolution Land Surface Temperature (LST) product based on comparisons between Sentinel-3 LST and ECOSTRESS LST data for the same region and period. This correction can either be done based on previously estimated parameters or can be recalibrated manually using a set of Python scripts provided to the user. The processor is entirely built using open-source Python packages and has been conceived as a series of Python source code files, publicly available on GitHub.

Link to the repository: https://github.com/jdegerickx/sen-et-openeo

Main point of entry to run the workflow developed within ARIES for a specific area and time period of interest is the Python script “run_lst_ta_tile.py”, located in the “scripts” folder within the aforementioned GitHub repository.

The script downloads the required input data from the Copernicus Data Space Ecosystem and the Copernicus Climate Data Store and then generates the indicator locally. After product generation, the data is prepared to be uploaded to the Food Security TEP Explorer (FSTEP), where it can be easily visualized. Actual upload to the FSTEP platform is done in “upload_fstep.py”, also located within the same “scripts” folder.

The required workflows to estimate LST correction parameters (based on intercomparison with ECOSTRESS LST) are all located within the “corrections_ecostress” folder, in turn located in the “scripts” folder.

A complete list of required Python packages can be found in the “requirements.txt” file, located in the sen-et-openeo repository.

3.2 Hyperspectral Processors

For the hyperspectral analysis, the EnMAP Box is utilized to process PRISMA (and EnMAP) data. The EnMAP Box is available as a QGIS plug-in, so that it can be used via the GIS graphical user interface (GUI).

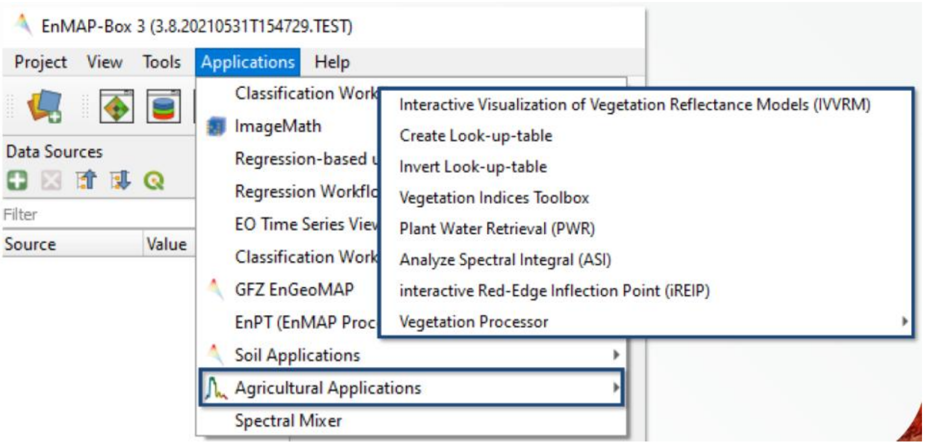

Figure 4: The agricultural toolbox of the EnMAP box (Hank et al. 2021)

The EnMAP Box has a variety of agricultural applications implemented that can be used to analyze hyperspectral data. The toolbox can read in PRISMA data since Version 3.7. For the derivation of leaf area, leaf water content and canopy water content, the functionalities “create look-up-table”, “invert look-up-table” and “Plant Water Retrieval (PWR)” are utilized.

Both the creation and inversion of look-up tables is done using the PROSAIL radiative transfer model described in more detail within D07_ATBD_PS_I.

Creating Look-up Tables

In a first step the user needs to choose the recording sensor (PRISMA, EnMap etc.) of the image to be analysed. If the sensor is not yet available or pre-processing steps have been taken to diminish the number of bands a new sensor can be created based on the image to be analysed. Other choices to be made here include: model versions, soil characterization, the size of statistical drawings for distributed parameters, no-data value. Most importantly this is where the user defines the parameter set used to create the LUT. Once all parameters and options have been set, the tool is able to give an estimate regarding the time needed to create the LUT.

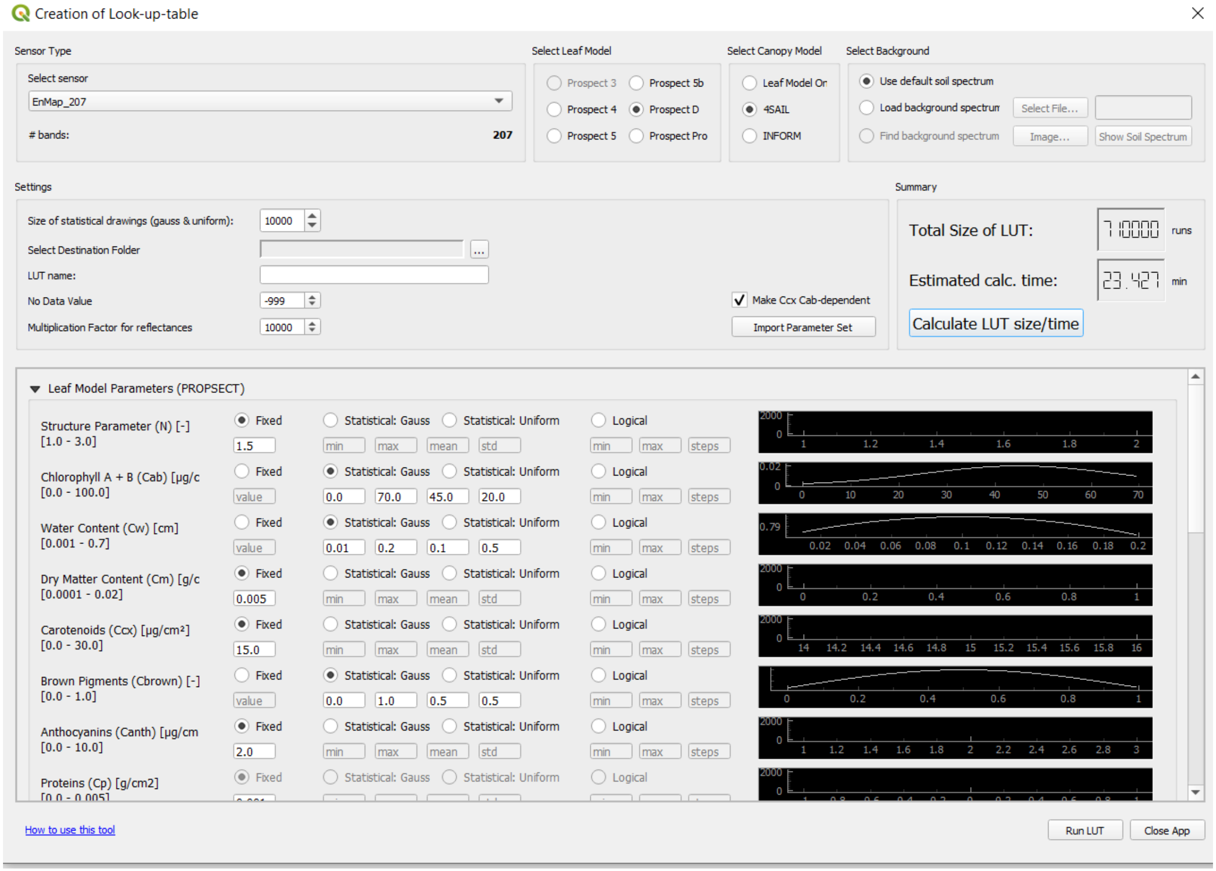

Figure 5: LUT Creation with in EnMAP Toolbox Agricultural Applications

A parametrization of the model inversion for the African use case has been done and the processing parameters detailed in Table 2 have been adopted. A separate LUT was created for each hyperspectral image acquired over the test site, accounting for highly diverse sun-sensor geometries.

Table 2: Model parametrization for use at AKTC Test Site, Zambia

Description	**Unit**	**Inversion status ARIES**	**Value (fixed) / Range (distributed)**	**Mean (Gaussian)/ Number of Steps (Logical)**	**Standard Deviation (Gaussian)**
Leaf structure parameter	-	fixed	1.5	-	-
Leaf	µg	Inversion	0.0 – 70.0	45.0	20.0

Chlorophyll a+b content	cm^{-2}	(distributed)			
Leaf Equivalent Water content	cm	Inversion (distributed)	0.01 – 0.2	0.1	0.5
Leaf Mass per Area	g cm^{-2}	Fixed	0.005	-	-
Leaf Carotenoids content	µg cm^{-2}	Fixed	15.0	-	-
Fraction of brown leaves	-	Inversion (distributed)	0.0 – 1.0	0.5	0.5
Leaf Anthocyanins content	µg cm^{-2}	Fixed	2.0	-	-
Leaf Area Index	m^2 m^{-2}	Inversion (logical)	0.01 – 7.0	71	-
Average Leaf Inclination Angle	deg	Inversion (distributed)	40.0 – 70.0	60.0	10.0
Hot Spot size parameter	-	Fixed	0.01	-	-
Soil Reflectance (optional)	-	Fixed	-	-	-
Soil Brightness Parameter	-	Fixed	0.6	-	-
Sun Zenith Angle	deg	Fixed	Taken from image metadata	-	-
Observer Zenith Angle	deg	Fixed	Taken from image	-	-

			metadata		
Relative Azimuth Angle	deg	Fixed	Taken from image metadata	-	-

Inversion of Look-up Tables

Once the LUT has been created it can be used to inversely determine the above parameters within the hyperspectral imagery (Figure 6). Options for fine tuning the results like adding artificial noise, choosing between cost functions and basing the results on different numbers of best fits are available. Additionally, a mask can be applied to drastically reduce processing time. For the Zambian test site, we ran our inversion without artificial noise. RMSE was chosen as cost function and 10% of best fitting spectra are taken into account for the calculation.

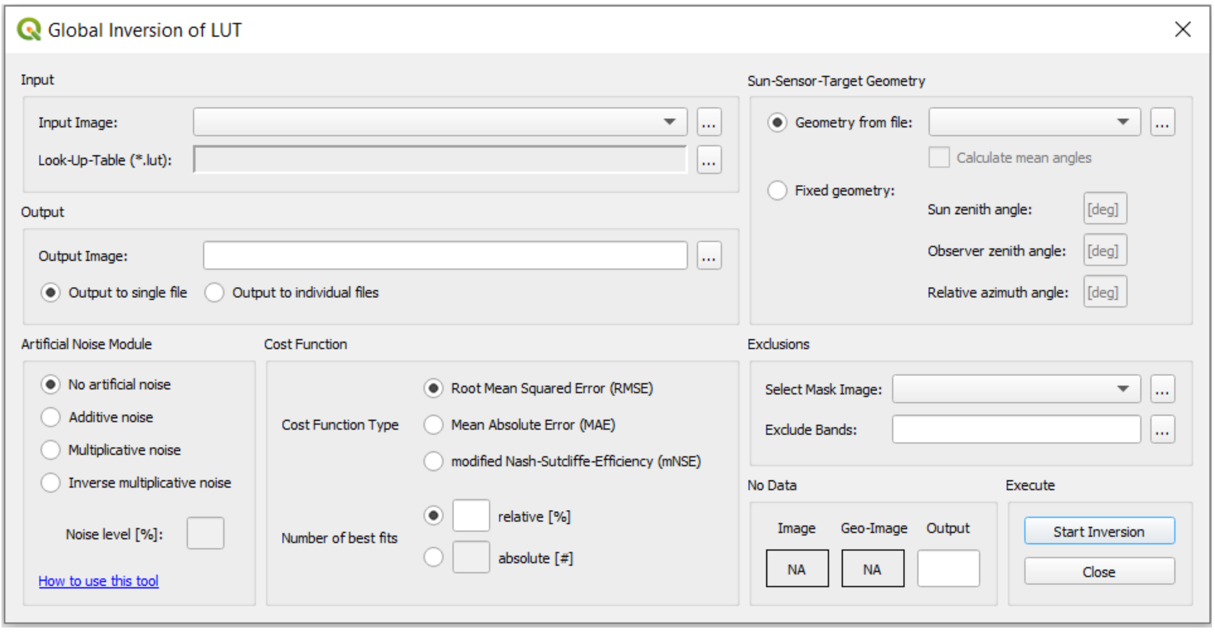

Figure 6: Inversion of LUT within the EnMap Toolbox

At this point, the validation of the results has not been completely finished yet, so the above input parameter set (Table 2) might change slightly still. The inversion has however already produced a stable timeseries of LAIs from PRISMA and EnMAP data for the Zambian pilot area.

The PWR Tool needs considerably less input and is thus comparatively easy to apply even for inexperienced users (Figure 7).

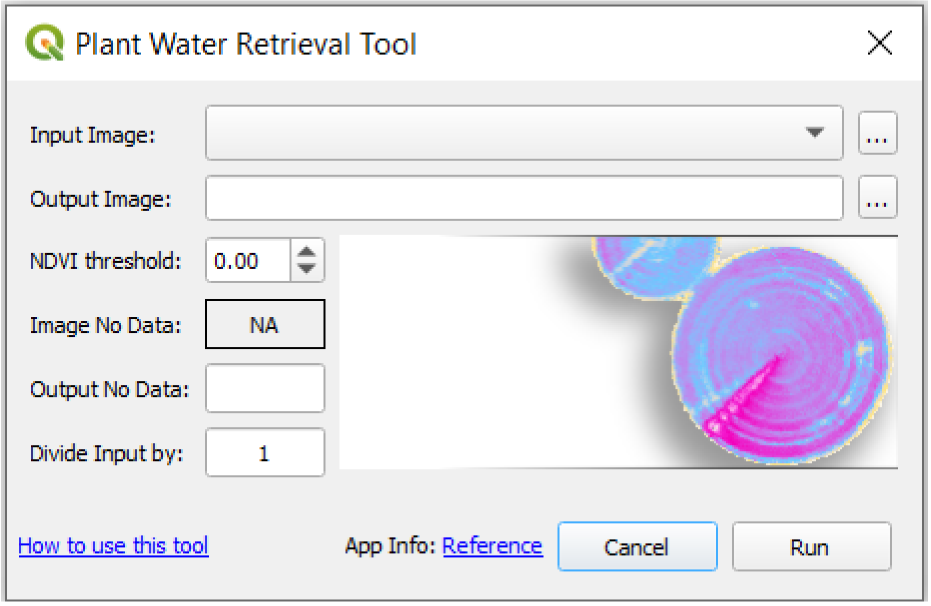

Figure 7: Plant Water Retrieval within the EnMap Toolbox

A detailed documentation of all the agricultural applications available within the EnMAP toolbox is available at https://enmap-box-lmu-vegetation-apps.readthedocs.io/en/latest/index.html.

4 Data and Processor - Availability and Access

ECOSTRESS data as well as data from Sentinel-2 and Sentinel-3 are readily available on the Food Security Explorer. ECOSTRESS data are available at various processing levels (see Table 3). Sentinel-2 data are available as Level-1c and Level-2 data.

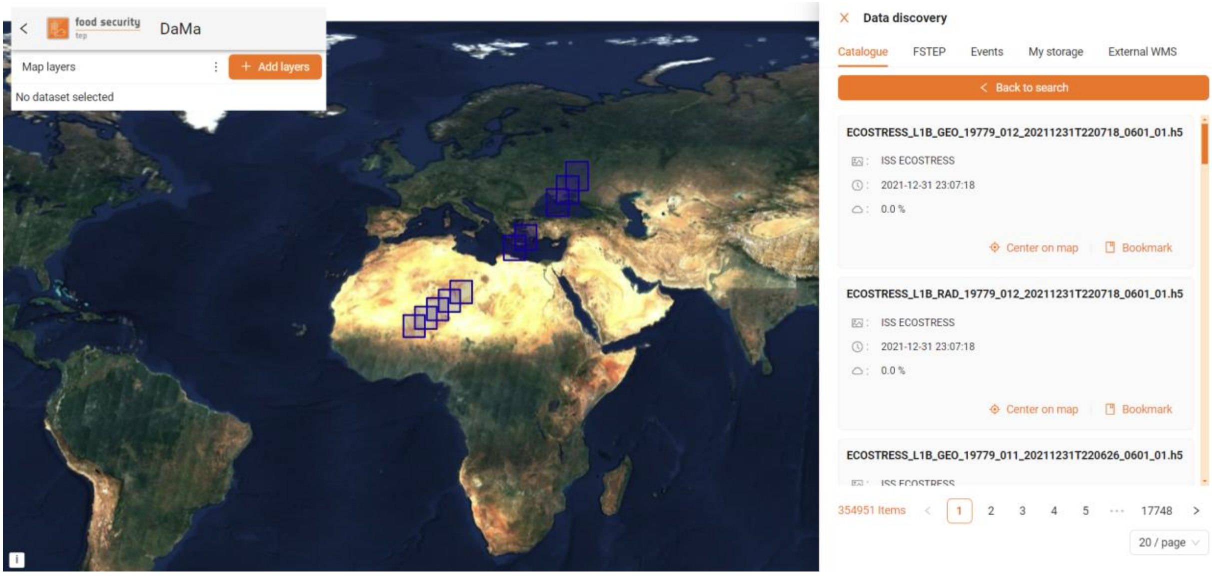

Figure 8: The ECOSTRESS data catalogue as viewed in the DAMA UI, >350 000 data sets are available

Table 3: Food Security Explorer Data Availability

Source	Sensor	Type	Format
Sentinel-1	IW	L1 SLC	SAFE
Sentinel-1	IW	L1 GRD	SAFE | COG
Sentinel-2	MSI	L1C	SAFE
Sentinel-2	MSI	L2A	SAFE
Sentinel-3	SLSTR	L1	SAFE
Sentinel-3	OLCI	L1	SAFE
Sentinel-3	SRAL	L1	SAFE
Sentinel-3	SLSTR	L2	SAFE
Sentinel-3	OLCI	L2	SAFE
Sentinel-3	SRAL	L2	SAFE
Landsat-8	OLI-TIRS	L1T	GeoTIFF
Landsat-8	OLI-TIRS	L1GT	GeoTIFF
Landsat-7	ETM	L1P	GeoTIFF
Landsat-5	TM	L1T	GeoTIFF
Envisat	MERIS	L1B	N1 ASCII
SMOS	MIRAS	L1B Science	EEF ASCII
SMOS	MIRAS	L1C Full Resolution	EEF ASCII

SMOS	Aggregated Information Product	L2 Soil Moisture	NetCDF
SMOS	Aggregated Information Product	L2 Ocean Salinity	NetCDF
CLMS	Aggregated Information Product	FAPAR (10daily)	NetCDF
CLMS	Aggregated Information Product	LAI (10daily)	NetCDF
CLMS	Aggregated Information Product	FCOVER (10daily)	NetCDF
CLMS	Aggregated Information Product	NDVI (10daily)	NetCDF
CLMS	Aggregated Information Product	Dry Matter Prod. (10daily)	NetCDF
CLMS	Aggregated Information Product	Gross DMP (10daily)	NetCDF
CLMS	Aggregated Information Product	Soil Water Index (monthly)	NetCDF
CLMS	Aggregated Information Product	Water Bodies (10daily)	NetCDF
CLMS	Aggregated Information Product	Surface Albedo (10daily)	NetCDF
CLMS	Aggregated Information Product	Burnt Area (10daily)	NetCDF
Ecostress	PHyTIR	L1B RAD	NetCDF
Ecostress	PHyTIR	L1B GEO	NetCDF
Ecostress	PHyTIR	L2 Cloud	NetCDF
Ecostress	PHyTIR	L2 LSTE	NetCDF
Ecostress	PHyTIR	L3 ET	NetCDF
Ecostress	PHyTIR	L4 ESI	NetCDF
Ecostress	PHyTIR	L4 WUE	NetCDF

Due to license restrictions by ASI, PRISMA data can unfortunately not be made public on the Food Security Explorer. It is however possible for users to upload the data to their private data space and utilize the tools available on the Food Security Explorer to analyze the data.

The developed processors and necessary toolboxes for the analysis of ECOSTRESS and PRISMA data to derive the drought indices as well as LAI and plant leaf and canopy water content will become public services on the Food Security Explorer. Thus, all users who have a user or expert_user account on the platform can utilize them. As exemplary screenshot, the current list of public services is shown below. Since the update of the Food Security Explorer is not finished yet and the processor integration for ARIES is not finished, either, the ARIES services do not show up yet.

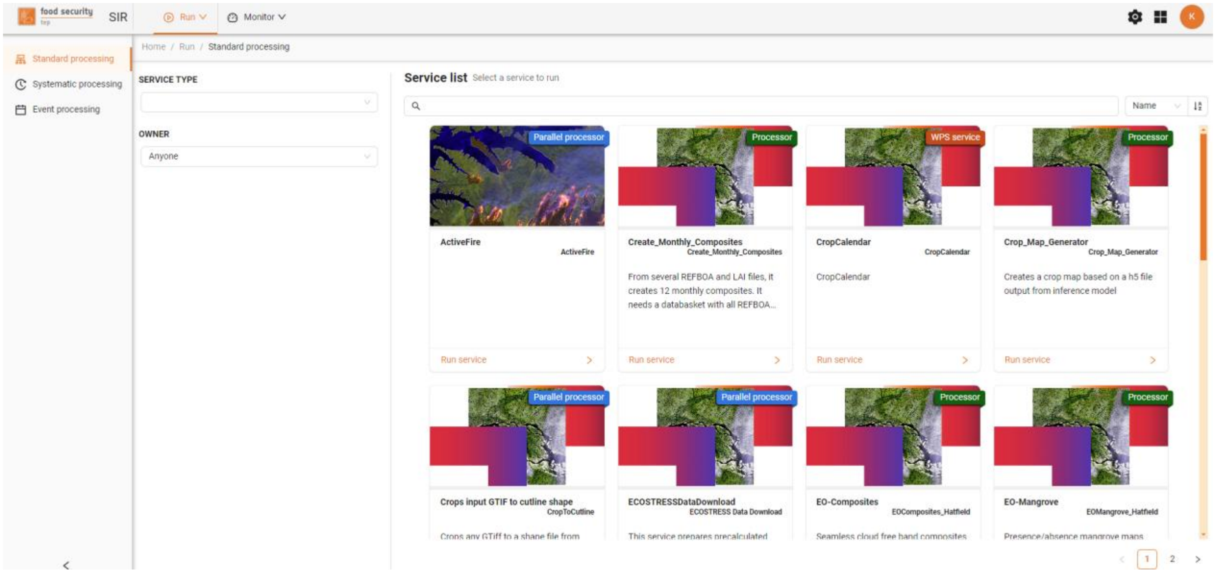

Figure 9: Food Security TEP / Food Security Explorer service list

5 Conclusion

At the current point, the protype implementation of the newly developed algorithms is not finished yet. Hence, the processors and their publication are also not finished yet. However, the necessary technological basis is provided with the update of the Food Security Explorer, which has been online in its new iteration since March 2024. It provides direct access to ECOSTRESS data and the possibility to upload PRISMA data as well as a QGIS version with the EnMAP box plugin that is needed to process the hyperspectral data. For the thermal data, dockerization and integration of the algorithms for the prototype implementation on the platform is currently in progress.