Evapotranspiration and Soil Water Index derived using the GEONETCast and ISOD toolboxes

A contribution to the Partners voor Water project entitled

"Demonstration of the HydroNet Water Control Room for South-African Water Institutions"

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Acronyms

ECMWF	European Centre for Medium-Range Weather Forecasts
FEWS-NET	Famine Early Warning System Network
GDAS	Global Data Assimilation System
ISOD toolbox	In-Situ and Online Data toolbox
LSA-SAF	Land Surface Analysis-Satellite Applications Facility
MSG	Meteosat Second Generation
NOAA	National Oceanic and Atmospheric Administration
TESSEL	Tiles ECMWF Scheme for Surface Exchange over Land
USGS	United States Geological Survey

1. Introduction

Following a meeting with Hydrologic and ITC-WRS in Amersfoort on 15 May 2014, it was agreed that ITC would develop an application capable of delivering three data products. The selected data products are:

1) 250 m spatial resolution daily actual evapotranspiration (ET_a)
2) 250 m spatial resolution daily Potential evapotranspiration (ET_p)
3) Soil Wetness Index (SWI) as an indicator for soil moisture availability and storage.

The general approach adopted utilizes operational coarse resolution products available via GEONETCast or the associated low volume data from the ISOD toolbox (http://52north.org/communities/earth-observation/isod-toolbox) that is also part of the ILWIS software package. The finer resolution information would be achieved through downscaling for which the monthly climatology of high spatial resolution data would be used. Similar methods are typically adopted for regional climate and land surface models, such as WRF (http://www.wrf-model.org/index.php).

It should, however, be noted that the operational coarse resolution products include uncertainties and contain inconsistencies among each other. Also, the downscaling procedure holds imperfections and does not propagate also sources of variability into the final downscaled product. The evapotranspiration and soil moisture application comes, therefore, with no warranty nor will the author be responsible for any damage done coming forth from the use of the product.

2. Technical description

Three operational native products available at coarse resolution are utilized as the daily input for deriving the ET_a, ET_p and *SWI* at the targeted resolution via downscaling using readily available high resolution MODerate Resolution Imaging Spectrometer (MODIS) data products. The selected daily native products are:

- The EUMETSAT LSA-SAF ET_a (available via ILWIS' GEONETCast toolbox);
- The FEWS-NET ET_p (available via ILWIS' ISOD toolbox);
- The Copernicus Global Land *SWI* (available via ILWIS' GEONETCast toolbox).

The MODIS products from which a monthly climatology's are developed to downscale the native coarse resolution data are:

- MOD11A2 – Emissivity (Land surface temperature & emissivity 8-day 1 km);
- MCD43A3 – Albedo (Albedo 16-day 500 m);
- MYD13Q1 – Fraction vegetation cover (Vegetation Indices 16-day 250m).

It should be noted that in the case of the surface albedo and fraction vegetation cover the monthly climatology is only utilized to add spatial information. Time dependency is supplied via the operational surface albedo and fraction vegetation cover products provided by the LSA-SAF available via GEONETCast (http://landsaf.meteo.pt/). As such, two additional daily inputs are needed for operating the downscaling application, namely:

- LSA-SAF fraction vegetation cover (available via ILWIS' GEONETCast toolbox);
- LSA-SAF surface albedo (available via ILWIS' GEONETCast toolbox).

The following sections of this chapter provide a brief description of the i) native ET_a, ET_p and *SWI* products, ii) development of the monthly climatology's for emissivity, FVC and albedo, and iii) downscaling procedure.

2.1 Native coarse resolution products

The scientific basis for the *EUMETSAT LSA-SAF* ET_a data products and a preliminary validation is documented in Ghilain et al. (2011). The TESSEL Soil-Vegetation-Atmosphere-Transfer (SVAT) scheme (Balsamo et al. 2009) developed for the ECMWF weather and climate forecasting models serves as the baseline model. Vegetation and soil parameters needed to operate the TESSEL SVAT are obtained from the 1km resolution ECOCLIMAP database. Daily inputs needed for driving TESSEL are adopted from the ECMWF 4DVAR analysis and forecast fields available at a 0.5^o x 0.5^o resolution supplemented with EUMETSAT LSA-SAF daily albedo, and half hourly down-welling shortwave and longwave radiation.

The ET_p made available via the Famine Early Warning System Network (*FEWS-NET ET_p*) is computed using the Penman-Monteith formulation (Shuttleworth 1993). Analysis fields, generated every 6-hours, (e.g. air temperature, atmospheric pressure, wind speed, relative humidity and net radiation) produced by the Global Data Assimilation System (GDAS) of NOAA are employed for the Penman-Monteith calculations. The 6-hourly GDAS forcing data is utilized to produce a daily ET_p product with a 1.0^o spatial resolution that is available as part the USGS early warning services.

The *Copernicus Global Land SWI* is one of the climate services that has been selected for the initial operational phase as part of the European Commission's Earth monitoring programme formerly known as Global Monitoring for Environment and Security (GMES). The algorithm utilized for developing SWI product is described by Kidd et al. (last verified 8 May 2015) available at http://land.copernicus.eu/global/sites/default/files/products/GIOGL1_ATBD_SWIV2-I1.01.pdf. The adopted approach essentially applies a low pass filter to the so-called Surface Soil Moisture data is derived from the view-angle normalized scatterometer data (e.g Metop Advanced Scatterometer) subjected to scaling between the minimum and maximum value, also known as change detection.

2.2 Monthly climatology

For the production of monthly surface albedo, emissivity and faction vegetation cover climatology's MODIS products (e.g. MOD11A2, MCD43A3 and MYD13Q1) have been processed for a twelve-year period from July 2001 up to July 2014 for the area demarcated by 23^o - 29^o S and 28^o E– 34^o E (latitude/longitude, datum WGS'84), which covers the Inkomati basin as well. The processing consists of two steps: i) reprojection the sinusoidal to the latitude/longitude (datum: WGS'84) projection, and ii) derivation of the biophysical variable of interest. The first step is performed using the MODIS reprojection tool (MRT) and the second step depends on the respective biophysical variable.

For *surface albedo*, the shortwave white-sky albedo data is taken from the MCD43A3 product. The usage of the white-sky albedo implicates that the angular effect coming from the directional solar illumination is removed.

The *emissivity* is calculated following the approach by Ogawa and Schmugge (2004) that allows the calculation of the broadband emissivity as follows,

$$e_{8-13.5\mu m} = 0.986 - 0.226 \cdot \mathrm{d}e_{\max-\min} - 0.0757\, \rho_{2.13\mu m} \quad (1)$$

where $e_{8\text{-}13.5\mu m}$ represent the broadband emissivity (-), $de_{max\text{-}min}$ is the difference between the emissivity in channels 31 and 32 (-), $\rho_{2.13\mu m}$ stands for the mid-infrared, 2.13 µm, reflectance (channel 7) (-). MODIS channels 31 and 32 are available with the MOD11A2 and MODIS channel 7 is included in the MYD13Q1 product.

The *fraction vegetation cover* is derived from the readily available MODIS NDVI products using the method reported in Carlson and Ripley (1997), according to,

$$\mathrm{FVC} = (NDVI - 0.0156)^2/0.712 \qquad (2)$$

where NDVI stands for the Normalized Difference Vegetation Index (-) that is available as part of the MODIS vegetation indices (MYD13Q1) product.

The text above describes the approach followed for the calculation of the surface albedo, emissivity and fraction vegetation cover from individual MODIS products. The monthly climatology's are subsequently computed by taking the average of all individual biophysical product for each specific month. Figure 1 shows a sample of the January surface albedo and the February fraction vegetation cover climatology.

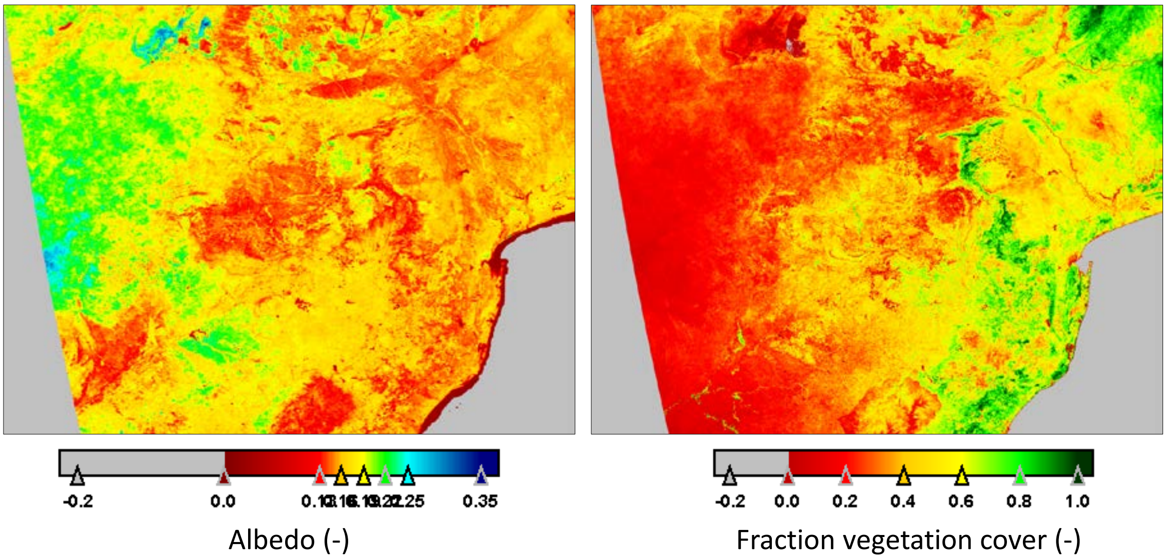


Figure 1: Surface albedo (left panel) and fraction vegetation cover (right panel) climatology for the months January and February respectively.

2.3 Downscaling procedure

2.3.1. ET_a, ET_p and *SWI*

The downscaling procedure makes use of the fact that evapotranspiration is typically larger for dense vegetation covers, and is smaller for more reflective and emissive surfaces, viz higher surface albedo and emissivity. As such, a so-called downscaling factor, *F*, is defined as,

$$F_{250\mathrm{m}} = \frac{FVC_{250\mathrm{m}}}{FVC_{\mathrm{msg}}} \,\mathrm{x}\, \frac{\alpha_{\mathrm{msg}}}{\alpha_{500\mathrm{m}}} \,\mathrm{x}\, \frac{\varepsilon_{\mathrm{msg}}}{\varepsilon_{250\mathrm{m}}} \qquad (3)$$

where *FVC* is the fraction vegetation cover (-), α is the surface albedo (-), ε is the surface emissivity (-), and subscripts $_{250m}$ and $_{500m}$ stand for the latitude & longitude WGS'84 projection at approximate 250m and 500m resolutions, and subscript $_{MSG}$ stands for the MSG projection.

The downscaling factor, *F*, is adopted to compute 250m spatial resolution ET_a and ET_p fields from the native MSG ET_a and FEWS-NET ET_p according to,

$$ET_a^{250m} = F_{250m} \text{ x } ET_a^{msg} \quad (4)$$

$$ET_p^{250m} = F_{250m} \text{ x } ET_p^{FNET} \quad (5)$$

where superscript FNET stands for the FEWS-NET as ET_p data source.

The *SWI* at the targeted 250m resolution (SWI_{250m}) is achieved by defining the evaporative fraction at 250m resolution (Λ_{250m}) as,

$$\Lambda_{250m} = \frac{ET_a^{250m}}{ET_p^{250m}} \quad (6)$$

The Λ_{250m} is utilized as follows for the calculation of SWI_{250m},

$$SWI_{250m} = \Lambda_{250m} \text{ x } SWI \quad (7)$$

2.3.2. Surface albedo, emissivity and fraction vegetation cover

The procedure for arriving at the high resolution surface albedo and fraction vegetation cover maps can be expressed as,

$$v_{modis}^t = v_{msg}^t + \left(v_{modis} - \langle v_{modis} \rangle_{msg}\right) \frac{v_{msg}^t}{\langle v_{modis} \rangle_{msg}} \quad (4)$$

where *v* stands for an arbitrary variable being surface albedo or fraction vegetation cover, subscripts *MODIS* and *MSG* stand for the origin of the data source, superscript *t* highlights that a daily time dependency of the variable, and $\langle \quad \rangle_{MSG}$ indicates that the MODIS variable is aggregated to the MSG grid.

The essence of this approach is that the MODIS climatology is utilized to add spatial detail at the MSG pixel level. Systematic differences (e.g. bias) between the average MODIS and MSG fields are taken into consideration via $v_{msg}^t / \langle v_{modis} \rangle_{msg}$ in the second term on the right-hand side of eq. (3). Hence, the downscaling procedure assumes that the spatial variability within a MSG pixel remains constant during a month and does not change over the years. This allows using the monthly MODIS climatology for representing the spatial variability, whereas the time varying component is supplied by the MSG surface albedo and fraction vegetation cover products.

Unfortunately, the downscaling of the surface emissivity cannot be performed as describe above because LSA-SAF does not supply an operational emissivity product and the monthly emissivity climatology is utilized directly in eq. (3). This has only a marginal impact on the results since the spatial variability in the emissivity is rather limited.

2.3.3. Further considerations

Concluding vegetation (fraction vegetation cover) and radiative (albedo and emissivity) properties are employed for supplying the spatial information to downscale MSG ET_a and FEWS-NET ET_p. This leaves out soil moisture as variable contributing to the spatial variability ET_a as the scale of the MSG pixel. Unfortunately, this cannot be avoided since no high spatial resolution soil moisture data source is operationally available at the moment.

Another aspect that requires further attention is the merger of MSG ET_a and FEWS-NET ET_p. Originally, the idea was to use only data from GEONETCast for the calculation of the potential evapotranspiration using a Priestley & Taylor (1972) approach. However, the 2-m air temperature needed for the calculation of the slope of saturated vapour pressure curve is not available via GEONETCast. Therefore, the low volume FEWS-NET ET_p product is selected, which is supplied via the ISOD toolbox through an internet connection. This has, however, two main disadvantages. First, the spatial resolution of the native FEWS NET ET_p is rather low (1.0^o) and not all spatial details can be reconstructed through downscaling alone. Second, the approaches utilized for the MSG ET_a and FEWS-NET ET_p are inherently different, which will cause discrepancies even under non-limiting evaporative conditions. A bias correction is, therefore, needed to match the MSG ET_a and FEWS-NET ET_p. The bias correction is here established by correlating the maximum MSG *ET* and FEWS-NET *ET* available for the entire study domain. The rationale for selecting the maximum MSG as well as FEWS-NET *ET* is to supress the differences due to water limiting conditions, known as soil moisture stress.

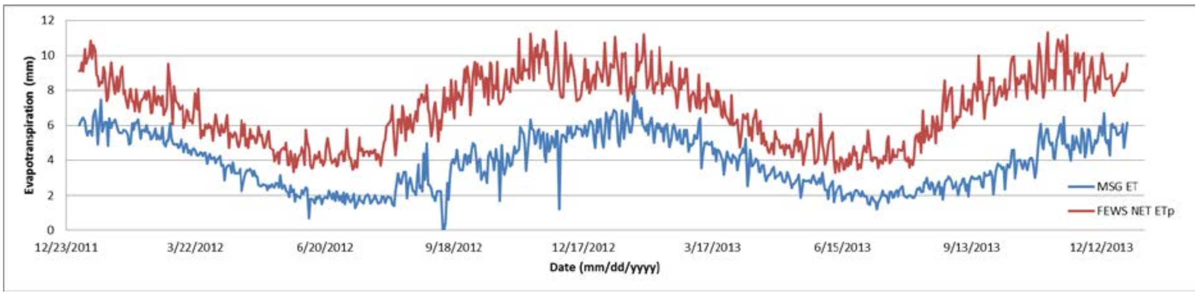


Figure 2: Maximum ET observed across the study domain with the LSA-SAF MSG and FEWS-NET data products for the period from 1 January 2012 to 31 December 2013.

Figure 2 presents the time series of the maximum LSA-SAF MSG and the FEWS-NET *ET* across the study area for the period from 1 January to 31 December 2013. The plot illustrates the bias between the two data products, and also demonstrates that LSA-SAF MSG and FEWS-

NET *ET* are almost linearly proportion to each other in the period from 1 March to 1 July. This can be argued for because at the end of the rainy season the soil is sufficiently filled with water to sustain evapotranspiration under non-limiting for a prolonged time period. Hence, this period is taken to fit a linear equation of the form $ET_{\mathrm{p}}^{\mathrm{FNET}} = \boldsymbol{a}\, ET_{\mathrm{a}}^{\mathrm{msg}} + \mathbf{b}$ for matching the two data products.

Figure 3 presents the relationship between the LSA-SAF MSG and FEWS-NET *ET* products found for the selected period as a scatter plot and provides the linear regression equation (***a*** = 1.076 & ***b*** = 1.943 with R^2 of 0.77) that can be utilized for the bias-correction. Although the regression coefficient can be used to convert either of the two products into the other, it is recommended to modify the LSA-SAF MSG towards FEWS-NET product because the former is found to be somewhat low in magnitude. This has been confirmed by Ghilain via personal communication. Figure 4 shows the result of applying the linear regression equation to the mean and maximum LSA-SAF MSG *ET*.

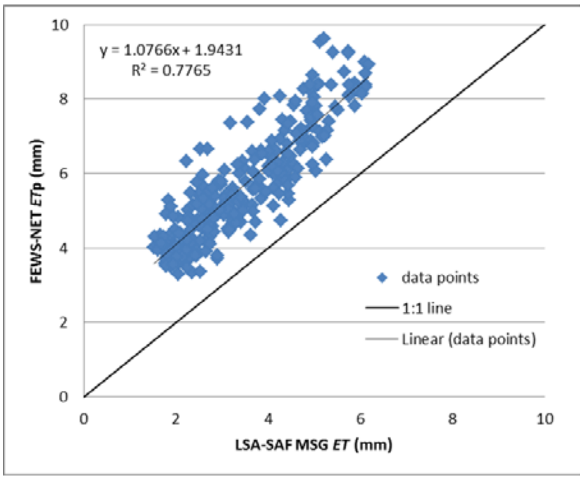


Figure 3: FEWS-NET ET_p plotted against the LSA-SAF MSG ET for the months March- June for the years 2012 and 2013, for which soil moisture conditions are assumed to be not limiting the evapotranspiration.

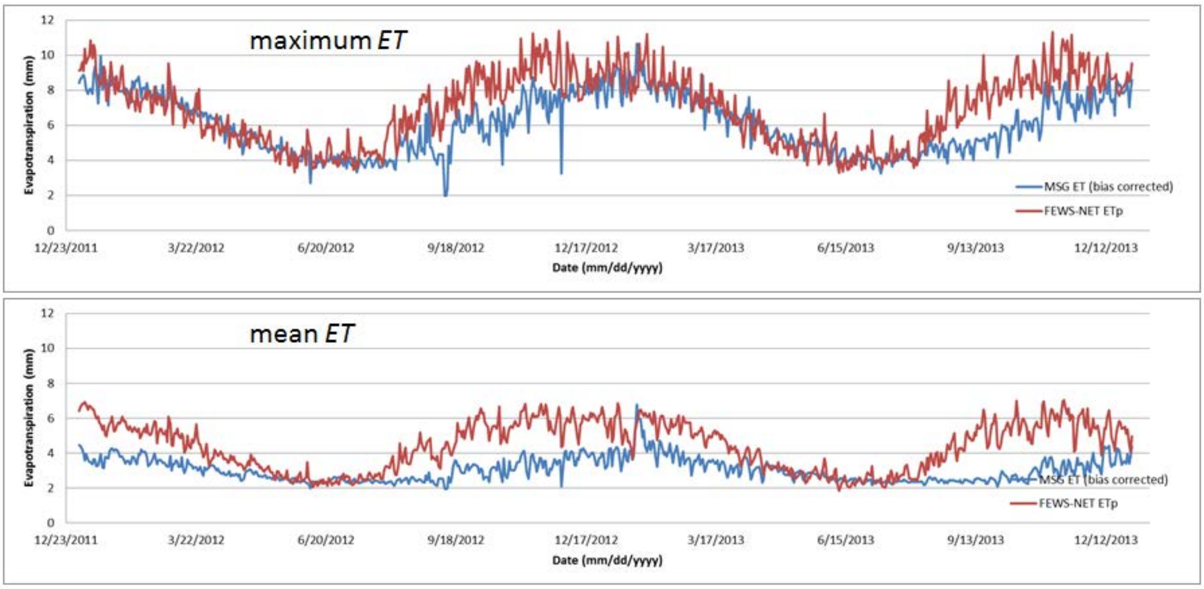


Figure 4: Bias-corrected LSA-SAF MSG and FEWS-NET ET products for the period from 1 January 2012 to 31 December 2013; upper panel maximum and lower panel minimum ET for the study area.

3. Data access

The data needed for running the downscaling application are supplied by three different organisations and are on a near-real-time available via the GEONETCast and ISOD toolboxes. Both toolboxes can be linked to ITC's ILWIS GIS & Earth Observation software package (available from http://52north.org/downloads, last verified 19 May 2015). Archives of the data broadcasted via GEONETCast are also available through internet portals, which could prove useful for retrospective analyses. The text below provides a brief description of the download procedures through the internet portals.

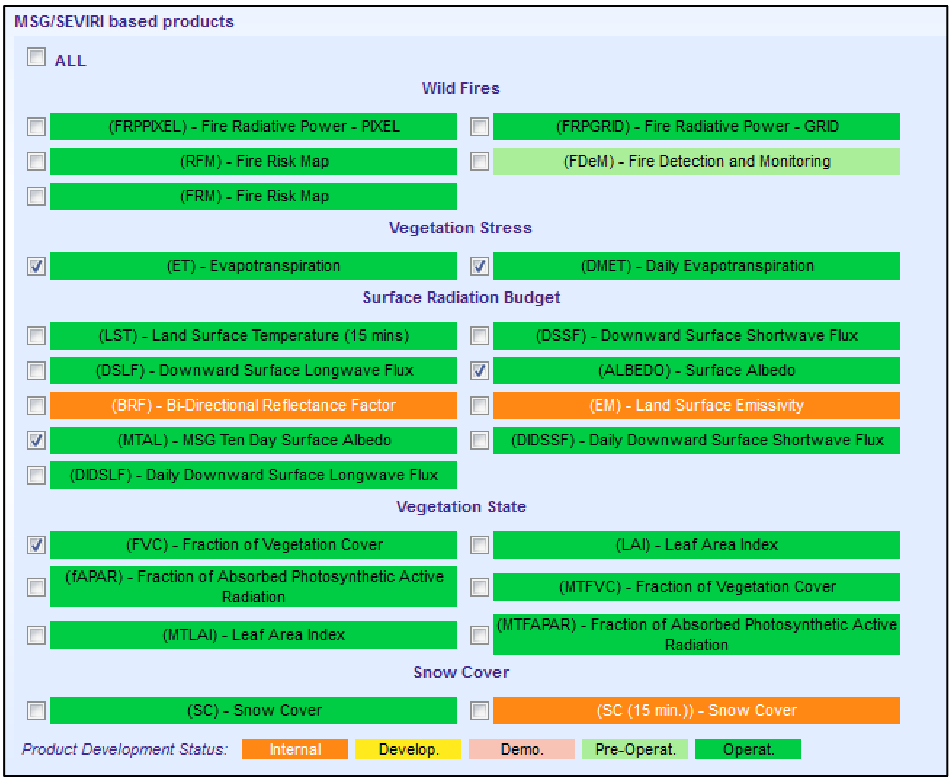


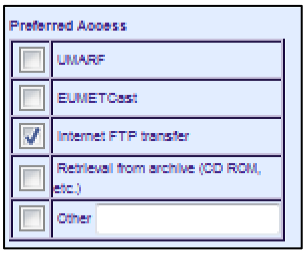
Figure 5: LSA-SAF MSG SEVIRI products (boxes are ticked) that can be used for the ET and SWI application.

3.1 LSA-SAF

The LSA-SAF MSG/SEVIRI products that can be used for the ET and SWI application are (see Figure 5):

- Evapotranspiration : (half-hourly) ET or (daily) DMET
- Surface albedo: (daily) ALBEDO or (10-day albedo) MTAL
- Fraction of Vegetation cover: FVC

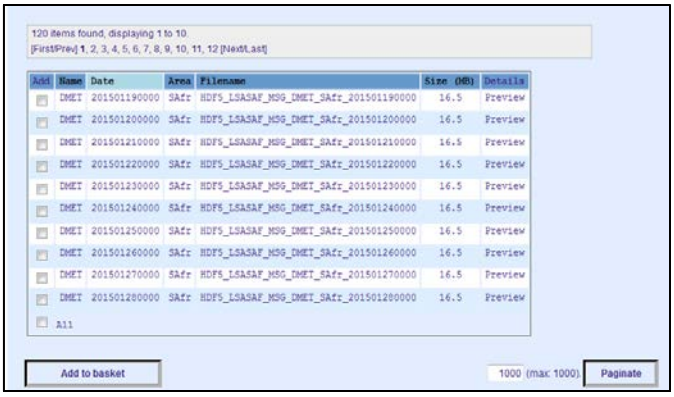
For retrospective analysis, it is recommended to use the DMET and MTAL products to reduce the time needed to perform calculations. In near-real-time mode the application will consider the half-hourly LSA-SAF ET file when the time interval of MSG ET product is set to 'hourly' instead of 'daily' in the configuration file. The usage of either the



daily or 10-daily albedo product does not require any modifications to configuration file.

For downloading the LSA-SAF products one should visit https://landsaf.ipma.pt/ (preferably with Firofox as internet browser). First, a registration is required and makes sure that for the 'Preferred Access' at least the box 'Internet FTP transfer' is ticked. Once registered,

- login with the supplied username and password;
- Click under the 'product menu' on 'download' and select 'random slot' ordering with as dissemination method 'LandSAF Server (user account)';
- Selected data product, geographic area and study period. This will give a list with products by default with 10 items per page;
- Enlarge this to 1000 items per page and click on 'Paginate';
- Select 'all' by ticking the box at the bottom of the page followed by 'Add to basket';
- Go to the 'Basket' at the top page, select 'all' by ticking the box and click on disseminate;



The selected data will now be disseminated via the anonymous landsaf ftp-server that can be access via any ftp-client. Note this procedure allows ordering of a maximum of 1000 items each time and the data will available on the server for a limited period of time (several days).

3.2 Copernicus Land

The SWI product is supplied via the Global Land Service of the Copernicus programme by the European Commission. Access to the Copernicus SWI products can be obtained by registering at http://land.copernicus.vgt.vito.be/. With the granted username and password all Copernicus land data products, including SWI, can be downloaded through the Copernicus internet portal hosted by VITO. In addition, the SWI products can be pooled from the Copernicus servers using command line that invoke the wget tool (available at http://www.gnu.org/software/wget/) as follows,

wget -r --http-user=*xxxxx* --http-passwd= *xxxxx* http://land.copernicus.vgt.vito.be/PDF////datapool/Water/Soil_Water/SWI_V2/2013/1/1/

whereby one fills on the *xxxxx* the username/password of the respective user and one has to change the date to retrieve the respective product. The command lines can be called sequentially in a batch file via command prompt.

3.3 FEWS-NET

The selected potential evapotranspiration product is supplied as part of the FEWS-NET programme. Unlike the LSA-SAF and Copernicus Land data is this product made available in ILWIS via the ISOD toolbox through an internet connection which allows also access to archived data. This archive is also available at http://earlywarning.usgs.gov/fews/datadownloads/Global/PET (last verified 19 May 2015) from which also monthly and yearly data can be downloaded in bulk.

4. Operation

4.1 Runtime contents

The content of the application consists of the:

- Runtime (folder):
    - IDL82 folder -> IDL runtime
    - *xxxxxx*.sav -> executable IDL programme
- MODIS (folder) :
    - Albedo (folder):
        - Monthly climatology at MODIS resolution (1 file per month)
        - Monthly climatology at MSG resolution (1 file per year)
        - Monthly climatology at FEWS-NET resolution (1 file per year)
    - Emissivity (folder):
        - Monthly climatology at MODIS resolution (1 file per month)
        - Monthly climatology at MSG resolution (1 file per year)
        - Monthly climatology at FEWS-NET resolution (1 file per year)
    - FC (or fraction vegetation cover, folder):
        - Monthly climatology at MODIS resolution (1 file per month)
        - Monthly climatology at MSG resolution (1 file per year)
        - Monthly climatology at FEWS-NET resolution (1 file per year)
- Static (folder):
    - Map definition to conversion MSG into Lat/Lon WGS'84 projection

The runtime reads a configuration file (further explained below), in which all input data and various options can be specified. It is recommended for running the application to create separate folders for the daily input data and the output.

4.3 Configuration file

Below is a copy of the configuration file, called *config_ET.txt*, that is needed for running the app. Comments are provided in the file.

```
;-----------------------------------------------------------
;/ 1) day, 2) month, 3) year
;-----------------------------------------------------------
13
12
2014
;-----------------------------------------------------------
;/ output directory
;-----------------------------------------------------------
D:\projects\App_PvW\output
;-----------------------------------------------------------
;/ 1) invalid data , 2) nodata
;-----------------------------------------------------------
-0.5
-1.0
;-----------------------------------------------------------
;/ interval MGS ET product: 'daily' or 'hourly'
;-----------------------------------------------------------
```

Comment: Achived data is only provided as daily ET values, while via GEONETCast there is only hourly data

```
daily
;------------------------------------------------------------
;/ factors to MSG ET pot -> FEWSNET PET
;/ 1) a  & 2) b
;/ form is ET = a + b * ETmsg
;------------------------------------------------------------
```

Comment: MSG and FEWSNET were biased to each other for the selected study period (2013)

```
1.9431
1.0766
;------------------------------------------------------------
;/ kernel size median filter (0 ~ no filter)
;------------------------------------------------------------
```

Comment: Sometime the data is noisy a median filter is implemented with kernel of (2#+1) x (2#+1) pixels as a possible mitigation measure

```
0
;------------------------------------------------------------
;/ weighed spatial interpolation
;/      1) power, 2) threshold (in degrees)
;------------------------------------------------------------
```

Comment: The programme perform a nearest neighbour interpolation between MSG pixels to add spatial variability, but is imperfect due to its awkward shaped pixels once projected as lat/log WGS84

```
0.5
0.015
;------------------------------------------------------------
;/ file name map definition
;------------------------------------------------------------
```

Comment: Filename with data needed to efficient project the data towards lat/lon WGS84

```
D:\projects\App_PvW\runtime\MSG_mapdef\MSG2xydef250m_weights.tif
;------------------------------------------------------------
;/ paths for data:
;/      1) albedo
;/      2) emisivity
;/      3) vegetation cover fraction
;/      4) main daily data
;------------------------------------------------------------
```

Comment: first three are paths are for the static data and fourth is for the daily data beyond this path is the description of the data

```
D:\projects\App_PvW\runtime\MODIS\Albedo
D:\projects\App_PvW\runtime\MODIS\Emissivity
D:\projects\App_PvW\runtime\MODIS\FC
D:\projects\App_PvW\hydro_data
;------------------------------------------------------------
;/ 1) filename MSG ET data (w/o hhmm specification):
;/ 2) scaling factor
;/ 3) data set name
;------------------------------------------------------------
HDF5_LSASAF_MSG_DMET_SAfr_20131213
1000.
ET
;------------------------------------------------------------
;/ 1) filename MSG fraction vegetation cover data (w/o hhmm specification):
;/ 2) scaling factor
;/ 3) data set name
;------------------------------------------------------------
S-LSA_-HDF5_LSASAF_MSG_FVC_SAfr_20141213
10000.
FVC
;------------------------------------------------------------
;/ 1) filename MSG albedo data (w/o hhmm specification):
;/ 2) scaling factor
;/ 3) data set name
;------------------------------------------------------------
S-LSA_-HDF5_LSASAF_MSG_ALBEDO_SAfr_20141213
10000.
AL-BB-BH
;------------------------------------------------------------
;/ 1) filename FEWSNET PET data (w/o extension)
;/ 2) scaling factor
```

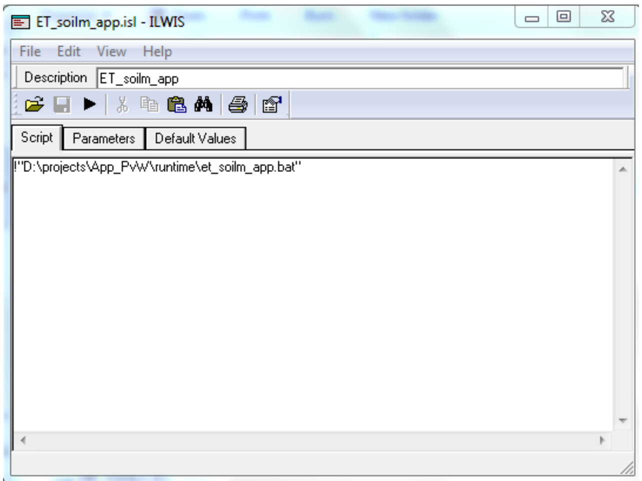
```
;/ 3) byte order (little or big
;----------------------------------------------------------
et141213
100.
little
;----------------------------------------------------------
;/ 1) filename ASCAT file name (is reading .tiff)
;/ 2) scaling factor to convert to fraction (-)
;----------------------------------------------------------
g2_BIOPAR_SWI_201412160000_GLOBE_ASCAT_V2.0.0
200.
```

4.2 Setup for ILWIS

To create a script for ILWIS do the following:

Step 1:

- Open ILWIS
- Go To *File->create->script*
- Fill *description*
- Type command:
  !" *yourpath**runtime**et_soilm_app.bat"*
- Save script
- Close ILWIS



Step 2:

- Go to the following path:
  *yourpath**runtime*\\
- Right click on *et_soilm_app.bat* and select *edit*
- Make the following changes if needed:
  `D:`
  change to >> *your drive letter*
  `cd D:\projects\App_PvW\Runtime`
  change to >> cd *yourpath*\Runtime
  ```
  copy config_file_ET.txt .\et_soilm_app\*
  cd et_soilm_app
  .\IDL82\bin\bin.x86_64\idlrt.exe -vm=et_soilm_app.sav
  Pause
  ```
- Save and close

4.4 Running the App within ILWIS

For running the App you needed modify the configuration file above by specifying the correct data and paths. Once this is done,

- Open ILWIS
- Go to *Operation -> Script -> YourScriptName* and the following will popup, click on this and the app starts running and a progress bar will appear.

5. Reference

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