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SEVIRI PrePro: A Novel Software Tool for the Pre-processing of SEVIRI Geostationary Orbit EO Data Products

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ABSTRACT

The Spinning Enhanced Visible and Infrared Imager (SEVIRI) is a geostationary orbit multispectral sensor on-board the MSG Earth Observation (EO) platform, acquiring data over Earth's land surface from the optical to infrared parts of electromagnetic spectrum every 15 minutes. SEVIRI data include also a number of operational products that are all provided to the user's community at no cost via EUMETSAT or LSA SAF portals.

Herein an open access stand-alone software product developed in Java programming language is presented for automating key pre-processing to all the operationally distributed products distributed by the SEVIRI radiometer. The software tool, named Seviri PrePro, makes use of present day multi-core processors, and is being able to process very large datasets in a short time period, making it appropriate as well for use in a High Performance Computing (HPC) environment. The practical usefulness of this tooklit is demonstrated herein as well using as a case study the SEVIRI evapotranspiration (ET) product .

The development and distribution of SEVIRI PrePro is of significant importance to the SEVIRI users' community and is also very timely given that, to our knowledge, no similar software tool is openly available at present. Use of this tool aims at supporting the wider dissemination and implementation of SEVIRI all operational products in general. It is anticipated to make a significant contribution to a large number of practical applications requiring use of SEVIRI data, including, but not limited, weather forecasting and global climate monitoring at a range of geographical scales.

KEYWORDS: *Earth Observation, SEVIRI, pre-processing, geostationary, operational products, software tool*

1. INTRODUCTION

Monitoring the inter-related processes, feedbacks and exchanges between the biosphere, atmosphere and hydrosphere that inherently shape the physical environments within our planet is a topic of key research priority today to be addressed (Mason and Calow, 2012; North et al., 2015). These complex land-surface-atmosphere interactions are important drivers of weather and climate systems and govern the terrestrial hydrological, energy and biogeochemical cycles which are responsible for the existence of life in the planet (Wood et al., 2011; Destouni et al. 2013).

In the last decades, Earth Observation (EO) technology has played an increasingly important role in determining various parameters characterising the land surface from space. This is because of its advantages related to the speed at which data can be acquired (instantaneous updating of information) by EO over large areas (synoptic views in a spatially contiguous fashion). Also, EO overcomes many problems inherent to traditional data collection methods (e.g. access to otherwise inaccessible areas). Additionally, remote sensing provides an efficient and cost-effective approach for the systematic repeat-coverage of areas of interest without a disturbing influence on the area (Kalivas et al., 2013). The advent of satellite-based EO, particularly over the last few decades, has even reached a significant milestone in maturity that has allowed obtaining several land surface parameters from spaceborne EO systems at an operational level (Srivastava et al., 2015). Geostationary obit satellites are of particular interest to studying and monitoring Earth's physical environment and the changes which occur by either anthropogenic activities or natural hazards. The principal advantage of those satellites is that they are able to provide a width of spectral information over large areas and at a time step compatible with the dynamics of several physical processes of the Earth system.

The Spinning Enhanced Visible and Infrared Imager (SEVIRI) is a geostationary orbit imaging radiometer which serves as the main payload on-board the Meteosat Second Generation (MSG) satellite. This is a co-funded space mission between the European Space Agency (ESA) and EUMETSAT. SEVIRI has 12 spectral channels, consisting of three Visible and Near-InfraRed (VNIR) channels (centred at 0.6, 0.8 and 1.6 μm), eight InfraRed (IR) channels (centred at 3.9, 6.2, 7.3, 8.7, 9.7, 10.8, 12.0 and 13.4 μm) and one visible broadband channel (at 0.5–0.9 μm) called the High Resolution Visible channel (HRV). The satellite provides image data at 3 km spatial resolution at the sub-satellite point (nadir) for standard channels, and down to 1 km for the HRV channel, over 4 specific geographical regions (Europe, Africa - North_Africa and South_Africa- and South America), with a baseline repeat cycle of 15 minutes. A series of operational products from SEVIRI are provided by EUMETSAT and distributed by the Satellite Application Facility (SAF) on Land Surface Analysis (LSA) (http://landsaf.meteo.pt/). SEVIRI data are have been used in a range of applications for example, solar modeling (Boojanowsi et al., 2013) agriculture studies (Eerens et al., 2014) and wildfires (Carvalheiro et al., 2010), meteorological studies (Ginoux et al., 2004). Yet, despite the large geographical coverage of SEVIRI data acquisition globally, to our knowledge, at present there is no software platform available to assist with the pre-processing of those operational products, which would in turn allow their dissemination to a wider spectrum of prospective users.

In purview of the above, herein we present an open source and stand-alone software tool, developed in Java, which allows performing basic, yet of key importance, pre-processing steps to the SEVIRI operationally distributed products. Our software platform, named "SEVIRI PrePro", makes also use of present day multi-core processors, being able to process fast very large datasets, making it also suitable for use in a High Performance Computing (HPC) environment. Furthermore, we demonstrate the practical applicability of this tool using as an example an operationally distributed product from SEVIRI, although equally any other operational product could be used.

2. THE SEVIRI PRE-PRO TOOLKIT

2.1 Introduction to the toolkit

The SEVIRI PrePro tool is a Java 8 (Gosling et al., 2014) based cross-platform tool that enables the user to extract information (i.e. geophysical quantities of interest) from a SEVIRI product file. SEVIRI product files come in HDF5 hierarchical format and each granule contains an image but instead of typical RGB imaging which assigns a vector of R, G and B values per image site, a vector of values corresponding to geophysical parameters is contained in this image. These values are sampled per image site which is part of the image grid. There can be four grids, one per region. The sites on the grid correspond to pairs of latitude and longitude and are indexed as in a typical image by image coordinates constrained by the width and height of the image. The translation from the grid (image) co-ordinates to region specific WGS84 coordinates is implemented through a list of region specific files that one has to download from the LSA SAF site after registration. The user of the tool can select various geographical sites from which can export, in batch mode, from near image sites, the corresponding image vector irrespective of operational product. This is facilitated by a convenient GUI. For HPC (High Performance Computing) reasons, a headless option has also been developed and is also available which comes through a Command Line Interface (CLI). Moreover the user can export via a Region of Interest (ROI) parts of the image. In SEVIRI PrePro the exporting is done in the native format of BEAM/VISAT open source software platform (Brockman, 2003), namely BEAM DIMAP format, for compatibility reasons. The tool automates the batch exporting through a ROI defibed ny a shape file (.shp). The user workflow is also easy to implement. Thanks also to recent Java releases, SEVIRI PrePro is able to take advantage of all processors installed in a given computer system. This way, the pre-processing is multithreaded and efficient in performance.

2.2 Software Installation Requirements

To execute SEVIRI PrePro, first the static HDF5 (Folk et al., 2011) files for the region of interest need to be downloaded, which are provided by LSA-SAF (Cihlar et al., 1999), subject to registration to their site. Once this step is completed, the user will need to authorise their account before they can request the necessary static files. Using this authorisation the user can download the necessary files located in the "Auxiliary Data" tab. On the website is a list of .bz2 files in HDF5 format. The user is advised to download all available files and store them in a folder since it can be used for further reference. The structure of the folder is illustrated in Figure 1. After the HDF5 data have been acquired, Java 8 needs to be installed to take advantage of speed and Graphical User Interface (GUI) available through Java FX improvements. The installation has been tested with the corresponding JDK (at time of writing JDK 8u60 was the most up to date version and used in implementation).

2.3 Installation of the SEVIRI PrePro Toolkit

The SEVIRI PrePro has been developed as open source software, released under the terms of the GNU General Public Licence, distributed by Aberystwyth University, United Kingdom (www.aber.ac.uk/seviriPrePro). The software tool is under GPLv3 and the user can either download the source code or build it using Eclipse (for Java developers) or download a binary release from the same site. In order to build it from source, the user needs a BEAM/VISAT compiled in Java 8 by using the corresponding build. The preferred way is to use a pre-compiled binary, which is available as a 7z file download. The toolkit download contains three launchers, the main .jar file, a sample file in the Comma-Separated Values (CSV) (Shafranovich, 2005) format for pixel extraction, a folder with jar dependencies and a folder with shape files (Figure 2).

2.4 *SEVIRI PrePro Implementation*

2.4.1 The Graphical User Interface (GUI)

The user should first update (if necessary) the runGUI.bat file. Java location and assigned memory can be modified. The defaults are a user wide installation of Java and 2048 MB of assigned memory. If the environment is Linux, the user can copy and paste the instruction at the shell prompt and execute it. A GUI appears as shown in Figure 3. One can immediately see that the tabbed interface at the bottom offers two utilities. The first is the "Country Export" and the other one is "Pixel Extraction". The generic part of the application allows one to re-project the whole products in the Equirectangular, plate carrée projection (Snyder, 1993) which is a slow process. In the next sections each of the three interfaces of the main toolkit menu shown in Figure 3 will be explained.

2.4.2 Inputs Requirements

In the generic part of the toolkit application the user needs to fill some input parameters (Figure 4). The user must first specify the folder where the re-projected BEAM DIMAP files will be saved. The user has also to provide the folder of the LSA SAF static files in order to achieve the grid translation. Then the user must specify where the SEVIRI product files reside. The folder must have a flat structure as no recursive searching has been implemented. Finally, the region the files belong must be given. The assumption is that all the files in the folder have to do with the same region. One can start the re-projection process which is very slow. We re-use the procedure in the BEAM VISAT API which is similarly slow. If the user needs a specific country re-projection, he should consult the next sub-section. It does not matter if in the folder there is a mix of operational products. The BEAM output files preserve this information in their filename.

2.4.3 Country Export Option

In order to export country specific information, the generic section must be already configured as above. Country specific re-projection and export can be accomplished by loading the list of countries from the CountriesSHP folder in the distribution. One has to select the shape file as shown in Figure 5. The drop down list of countries is populated and the user can localize the re-projection to the specific selected country. These countries through the grid translation, act as ROIs. A list of BEAM DIMAP files will be the result containing only the part of the image that corresponds to the country as opposed to the full region re-projection of the generic section. A typical run of the toolkit is shown in Figure 5.

2.4.4 Pixel Extraction Option

In order to export country specific information, the generic section must be already configured as above. Pixel extraction is another functionality provided by the SEVIRI tool. Each operational product can be viewed as a vector sampled at grid sites. The aim is to find samples close to the samples and extract the vectors as extracted site values. Figure 6 shows the main parametrisation.

One has to load a CSV file containing sites for which to extract values. The format of this file is given in Table 1, where an example (included in the distribution) is displayed. These sites maybe far away from sites. In order to determine the "farness" rule we resorted to a simple heuristic. The Vincenty distance (Vincenty, 1975) is calculated between this site and all the samples. The closest sample is selected. If the distance is less than 1 km then the site is included in the output with the values of this closest sample. The input CSV format required to be followed is shown in the code listing of Figure 7. The output is stored in a series of CSV files, each for every type of operational product in the SEVIRI files folder. This is necessary because of the uniformity of CSV file format. In this respect an ET or LST (for example) CSV file is created. This tool is also offered as a CLI tool option. The CLI tool serves for pixel extraction without using a GUI. For this reason, it can run in HPC environments in parallel in order to accelerate the pixel extraction process. Pixel extraction workflows are offered for both SEVIRI and ASCAT products. Two batch files are provided as customization guides to the user. They share similar concepts. Table 2 shows the user provided customisations to the command line SEVIRI pixel extraction.

3. SEVIRI Pre-Pro DEMONSTRATION

In this part, the use of SEVIRI PrePro is demonstrated in a real case study. The case study demonstrates how the SEVIRI PrePro software tool can be used to perform basic pre-processing in this particular operational product. It further demonstrates how a robust validation of the product accuracy can be conducted using our tool (and HPC facilities if available), provided that reference observations are available from ground measurements. As an example is used the SEVIRI Evapotranspiration (ET) operationally distributed product (Ghilain et al., 2011), although equally any other SEVIRI operational product distributed from LSASAF can be used. Concurrent ground measurements of ET from a selected European site belonging to the CarboEurope ground observational network (Baldocchi et al., 2003) are also used to demonstrate how comparison against some reference data, if available, can easily be done.

3.1 Datasets Description

3.1.1 SEVIRI ET Product

For the purposes of the demonstration of SEVIRI PrePro capabilities the SEVIRI instantaneous ET product (MET) was acquired for the Euro region of the Meteosat disk for the years 2010 and 2011. This is one of the operational products from SEVIRI, which are all readily distributed at no cost, by the Satellite Application Facility (SAF) on Land Surface Analysis (LSA) (http://landsaf.meteo.pt/). In this product, ET is operationally estimated every 15 minutes from the SEVIRI radiometer, whereas a daily ET flux operational product is also generated with a lag time of one day at a spatial resolution of 1 km. These two products are provided for the full disk divided in four sub regions through the LSA-SAF or via EUMETCast. The technical details concerning the technique implemented for computing ET in this operational product can be found in Ghilain et al., (2011).

3.1.2 Study Site Characteristics & In-Situ

In-situ data for the complete years 2010 and 2011 were also acquired from the Spanish ES_Agu *open shrubland* CarboEurope site (36.9406N, -2.0329E). This site is located at an elevation of ~ 200 m asl and is situated in an area of arid steppe climate. Fr this particular site *in-situ* data was obtained from the CarboEurope website (http://gaia.agraria.unitus.it/). For the purpose of this demonstration, those included primarily the *in-situ* measurements of ET and air temperature (Tair) as well as a number of other micrometerological parameters acquired for the same period (i.e. full years 2010 and 2011 at 30' time step).

3.2 SEVIRI ET Dataset Pre-Processing

Using SEVIRI Pre-Pro tool, the ET product acquired for the Euro region of the Meteosat disk was first reprojected from Normalized Geostationary Projection (NGP) to a regular latitude/longitude grid and tailored from the full disk image to the study region (34º-45ºN, 11ºW-5ºE). Subsequently, using again SEVIRI PrePro each image granule was clipped into the European country on which our experimental site was located. Following this, periods for which more than 10 % of each of the half-hour SEVIRI estimated ET (granules) were missing from a "site-day" were omitted from the comparisons. The data was further refined by excluding granules with negative values from the dataset. These values corresponded to flags or no-data values which were inappropriate for use in assessing the agreement between both datasets. In addition, a scaling factor was applied to each MET 30' product to derive the actual ET value from it (MSG-2 ET Product ATBD, 2008). Subsequently, the *in-situ* ET values that corresponded to the date/time of the SEVIRI ET product overpass were extracted (using an Excel MacroVBA), and assigned to point shapefiles of the test sites, where there was one shapefile per country (tabular join in ArcMap 10.1). These shapefiles were overlaid to the pre-processed SEVIRI images in the SEVIRI PrePro tool. Subsequently, the *in-situ* ET was matched against the SEVIRI ET of the pixel containing the site point. These pixels were then extracted using SEVIRI PrePro to excel for further analysis and comparisons against the *in-situ* data. An example of finally pre-processed products using SEVIRI PrePro are shown in Figure 7.

3.1.3 SEVIRI ET vs in-situ Results

Agreement between the SEVIRI ET operational product estimates and the corresponding *in-situ* data was evaluated based on direct point by point comparisons. Several statistical performance assessment metrics were used to evaluate the agreement between the compared datasets (Table 3) These statistical metrics have been prominently used in analogous validation experiments of relevant operational products validation studies (e.g. LSA-SAF Validation Report Evapotranspiration Products, 2010). Table 4 shows the key statistics related to comparisons of predicted and observed rates of ET over the ES_Agu experimental site for all days of comparison for the years 2010 and 2011 individually, and also when the study days for both years were combined. Figure 8 illustrates the agreement between the two datasets for years 2010 and 2011 separately, displaying the annual trends in the data. In general, the error metrics (Table 4) returned a low RMSD and MAE of 0.035 mm h^{-1} and 0.021 mm h^{-1} respectively, suggesting the SEVIRI ET product was able to estimate the *in-situ* measurements to a high degree of accuracy. Evidently, the low bias (-0.01 mm h^{-1}) and scatter (0.035 mm h^{-1}) results indicate a stable estimation of the observed by SEVIRI and suggest that the RMSD is derived predominantly from the scatter and not the bias. Correlation coefficient results, although not as strong as the error metrics results, indicated a strong correlation between the compared datasets (R – 0.655). In the 2010 comparisons (Table 4 and Figure 8), the bias is low for the ES_Agu site (0.03 mm h^{-1}) with almost no divergence from the *in-situ*. In contrast, for the 2011 results (Table 4 and Figure 8) a much larger underestimation is evident (-0.024 mm h^{-1}). However, results from both individual years indicate a stable and precise product estimation of the observed ET. RMSDs for both years are 0.036 mm h^{-1} and 0.045 mm h^{-1} for 2010 and 2011 respectively, with the product again performing better during 2010. Adversely to all other statistical metrics, the correlation coefficient was indeed greater for the 2011 results. Previous examinations into the performance of the SEVIRI algorithm over a range of land cover types in Europe have also returned comparable results to those presented herein. For example, Ghilain et al. (2011) evaluated the performance of the operational products algorithm over six European sites. Their study showed comparable results sites of short vegetation cover (RMSD ranging between 0.07 to 0.1 mm h^{-1}). More recently, Petropoulos et al., (2015b) evaluated the SEVIRI ET estimates against *in-situ* data for 9 sites form the CarboEurope network.

The results reported here illustrate the successful implementation of the SEVIRI PrePro software tool in providing a simple, fast and efficient way to undertake the usually complex pre-processing of SEVIRI ET operational data. The fact that comparable, or even improved results have been reported within the case study illustrate that there is no-loss of accuracy when the tool is used in place of the more general methodologies usually implemented to pre-process the SEVIRI data, with the added benefit of ease of use and the fact it is more time-efficient and computationally less expensive.

4. CONCLUDING REMARKS

In this short communication paper a new software tool for the pre-processing EO data of geostationary orbit acquired from the SEVIRI sensor, named SEVIRI PrePro, was presented. Following the presentation of the software functionalities, a demonstration of its use in practice was furnished using actual data from the SEVIRI ET product acquired for 2 years worth of data as well as corresponding *in-situ* observations acquired at an experimental site in Spain.

The product, developed in Java, is able to perform simple, yet of key importance, pre-processing steps which make the use of SEVIRI products much easier to use than ever before in many practical applications and research alike. The tool, which is also offered open access, makes use of present day multicore processors, being able to process fast very large datasets even for personal computers, making it also suitable for use in a High Performance Computing (HPC) environment. From an algorithmic and software development perspective, a further advantage is the tools' ability for inclusion of key functionalities such as shapefile incorporation for points or areas extraction, which also results in highly robust and accurate results from the tool implementation. Its application also allows for the analysis of a large amount of data from a single or multiple operational products, developing a long time series analysis of those data yet requiring much less effort and user expertise in comparison to more general methodologies (e.g. by a Matlab routine). Finally, SEVIRI PrePro is robust and adaptable to be potentially integrated with other EO data, and, as it is realised under GPL v3, in theory anybody can contribute changes or suggest features, which consists a further advantage of the tool.

ACKNOWLEDGMENTS

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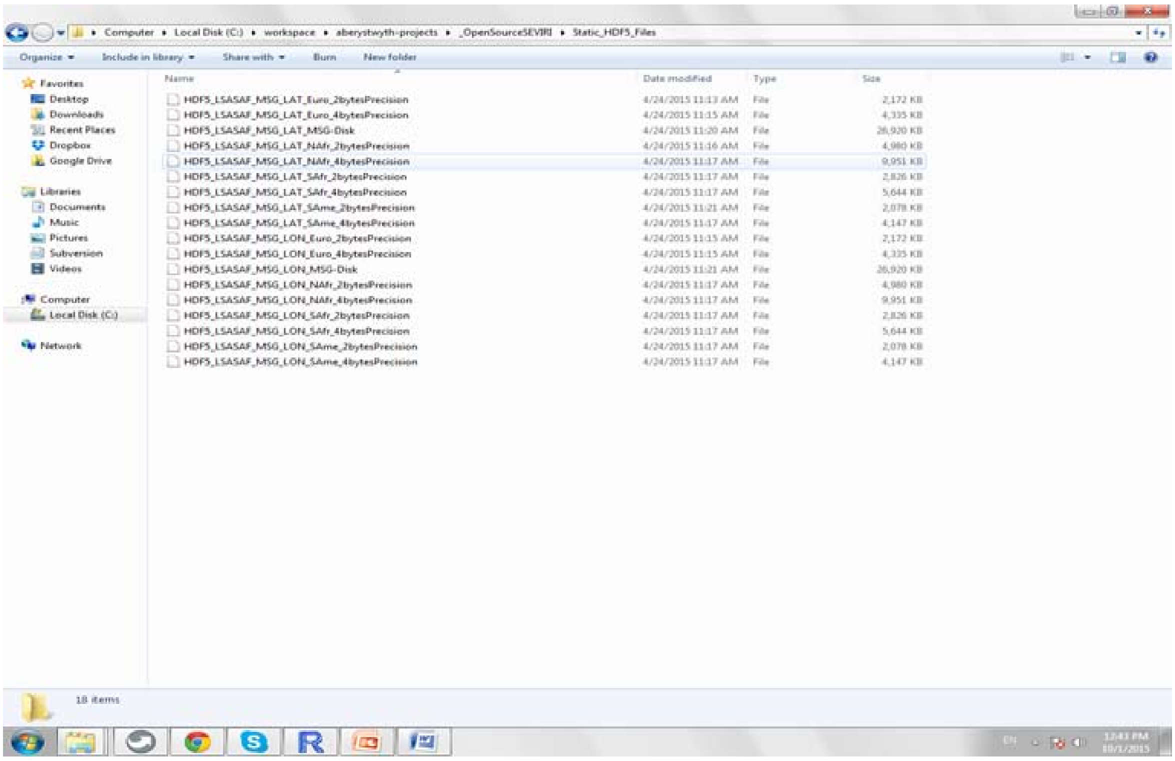

Figure 1: Folder structure of static HDF5 translation files in SEVIRI PrePro

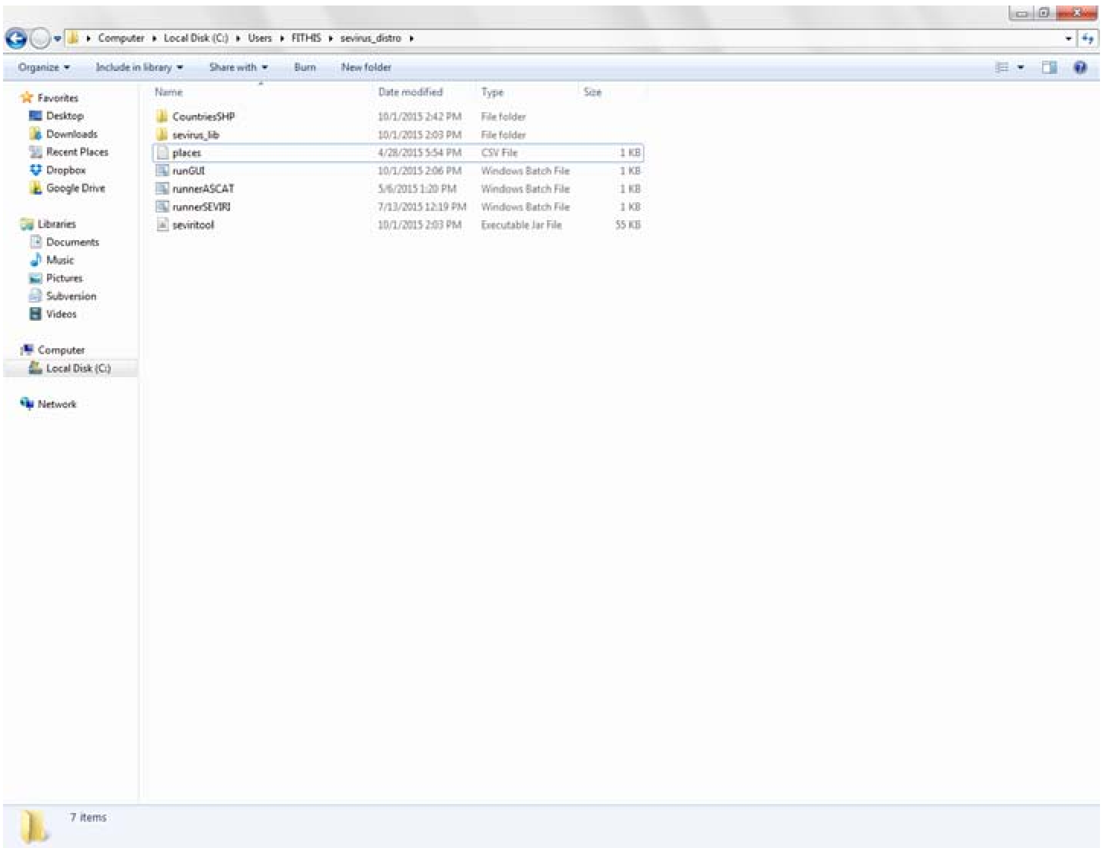

Figure 2: SEVIRI PrePro Toolkit Download Layout

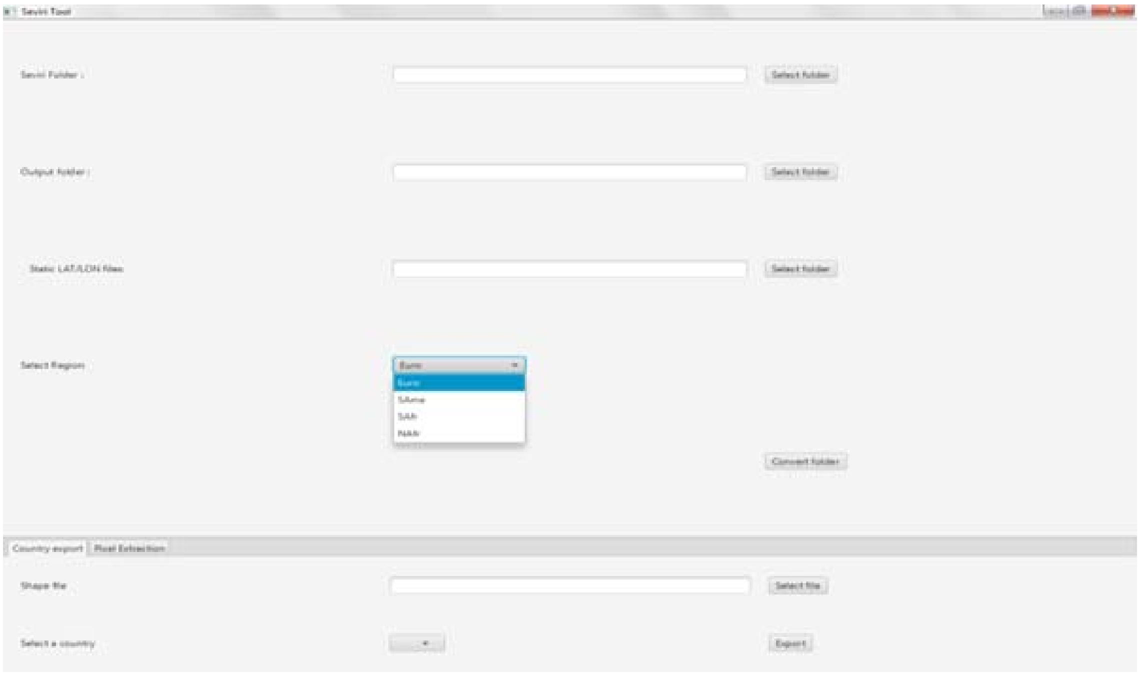

Figure 3: SEVIRI Pre-Pro toolkit initial screen menu

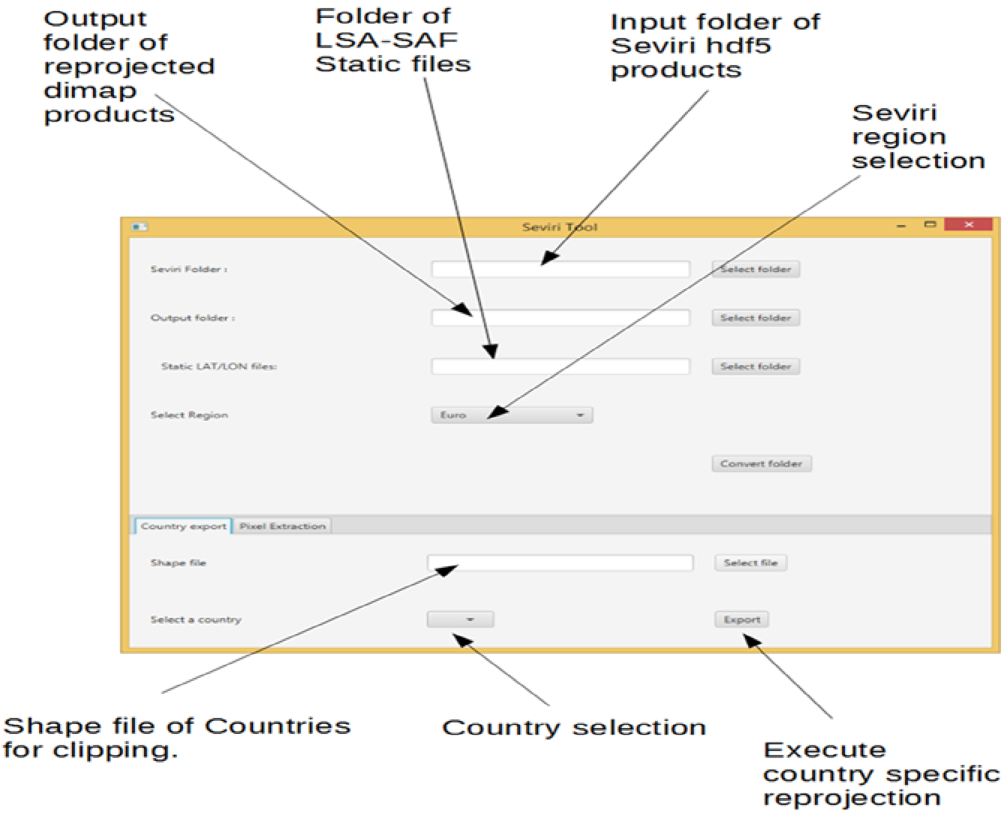

Figure 4: Parameters for reprojection under the SEVIRI PrePro toolkit

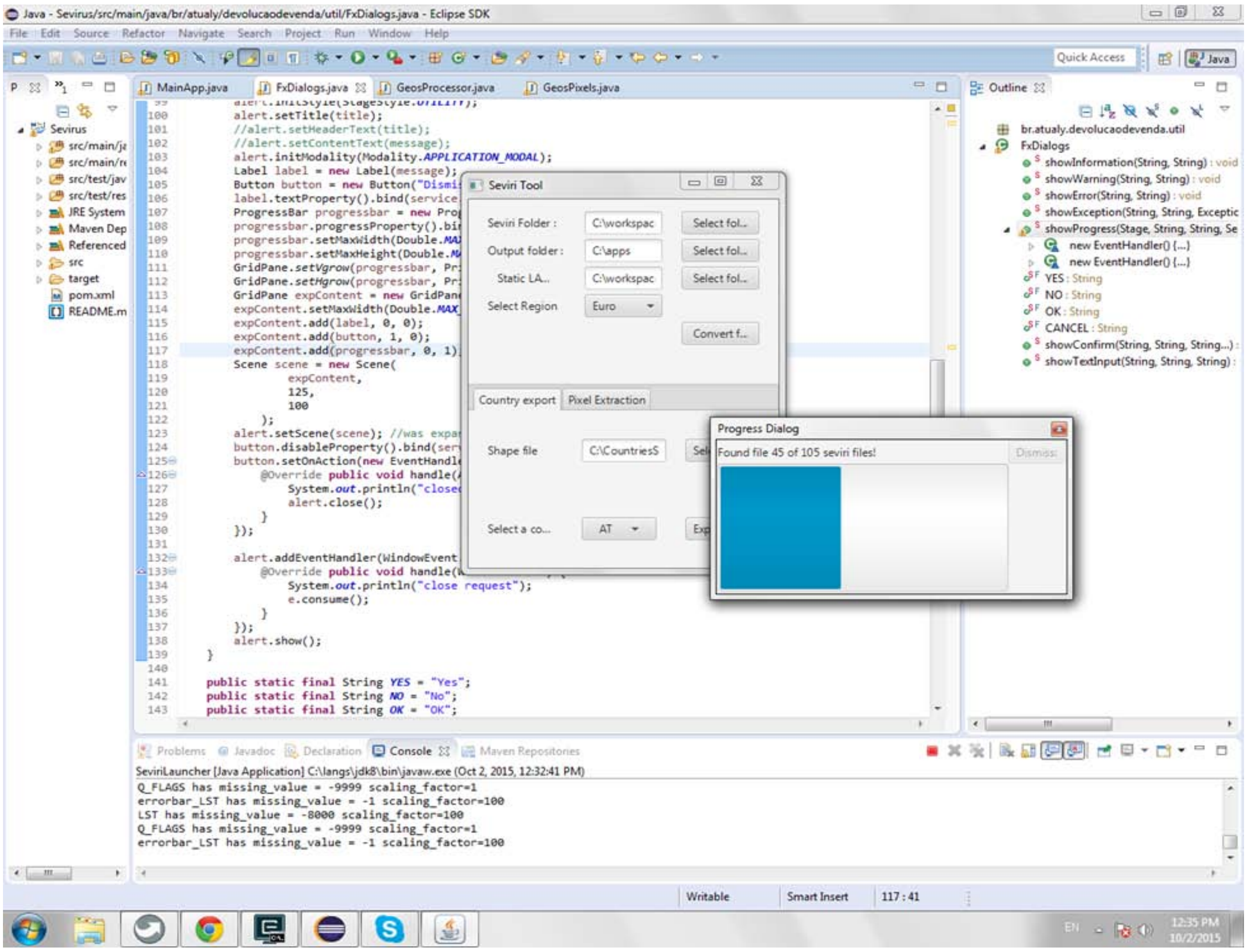

Figure 5: Country export using the SEVIRI PrePro toolkit

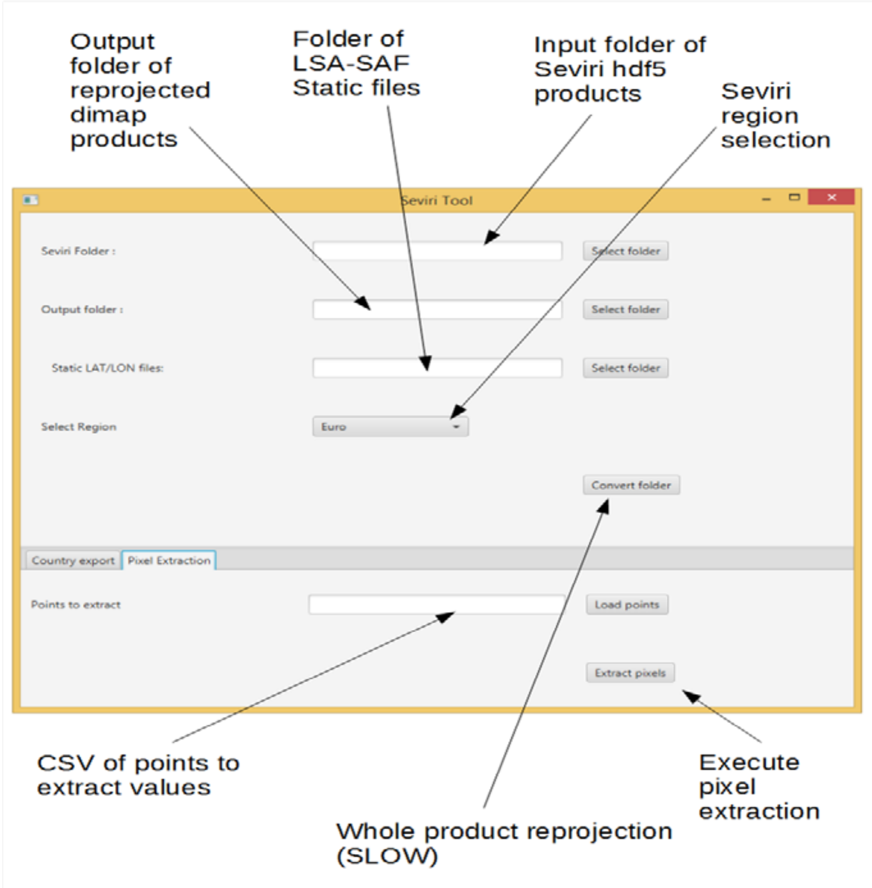

Figure 6: Pixel extraction with the GUI SEVIRI PrePro toolkit

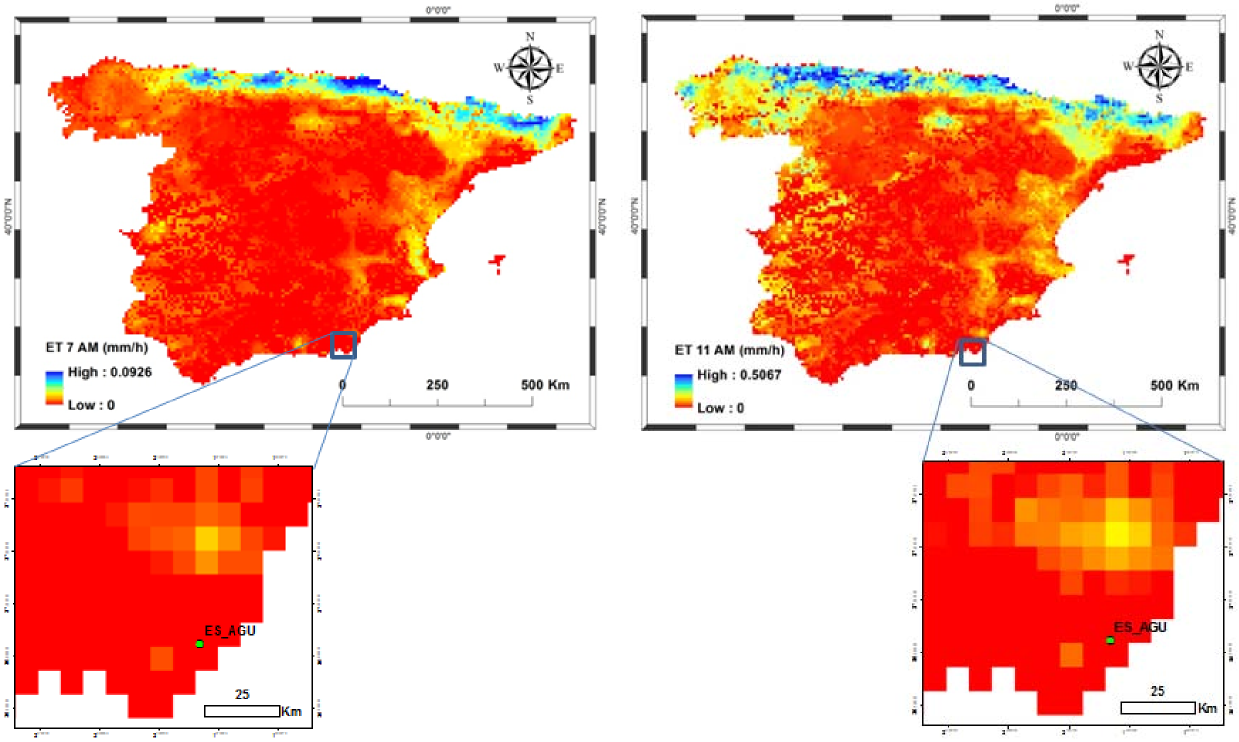

Figure 7: Maps of the SEVIRI ET final pre-processed product using our SEVIRI Pre-Pro software here for August 6th, 2011 acquired at 2 different times of the day (7 am pm left and 11am right) for the ES_AGU site in Spain in the zoomed area.

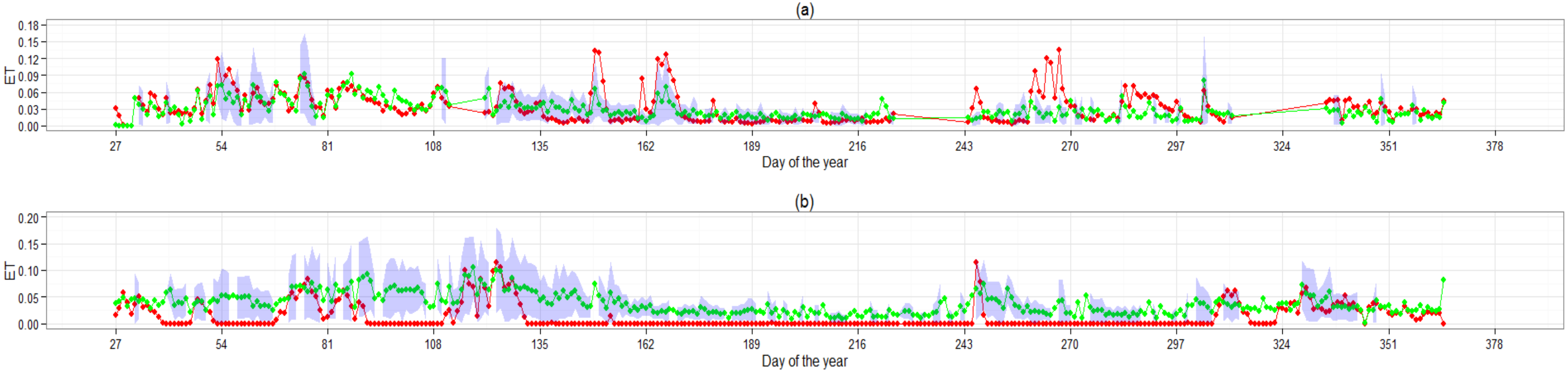

Figure 8: A comparison between in-situ and predicted ET from SEVIRI for the different seasons for ES_AGU site years 2010 (top) and 2011 (bottom). Green represents the in-situ ET daily mean, Red is the SEVIRI-predicted ET, Blue is daily standard deviation of the in-situ ET.

List of Tables

Table 1: Sample pixel extraction specification in CSV format

```
site,lat,lon
ES_AGU,36.9406,-2.0329
ES_LJU,36.9283,-2.7505
IT_CAS,45.0700,8.7175
FR_MAU,43.3853,1.2922
IT_REN,46.5878,11.4347
UK_EBU,55.8660,-3.2058
IT_MBO,46.0296,11.0029
US_ELM,25.5519,-80.782
US_ME2,44.4523,-121.5574
US_NE3,41.1797,-96.4396
US_WHS,31.7438,-110.0522
US_TON,38.4316,-120.9660
US_VAR,38.4067,-120.9507
Howard_Springs,-12.495,131.15
Daly_Pasture,-14.06333,131.318056
Sturt_Plains,-17.15076,133.350317
Wallaby,-37.426222,145.18725
Tumbarumba,-35.489144,148.151667
```

Table 2: Example specification of sites for pixel extraction

The SEVIRI pixel extraction follows the same concepts like the GUI pixel extraction. The next listing **Error! Reference source not found.** of the batch file shows the similarity./*

```
args[0] the data folder
args[1] the csv of places
args[2] the output folder
args[3] static files
*/

set args_0=c:/downloads/SEVIRI
set args_1=C:/downloads/places.csv
set args_2=C:/downloads/output
set args_3=C:/downloads/Static_HDF5_Files

java -Xmx2048m -jar SEVIRItool.jar %args_0% %args_1% %args_2% %args_3%
```

Table 3*:* An overview of the statistical measures implemented in this study to evaluate SEVIRI ET operational product predictions against the corresponding in-situ data for the ES_AGU experimental site used in this study

Name	Description	Mathematical Definition
Bias/MBE	Bias (accuracy) or Mean Bias Error	$bias = \frac{1}{N}\sum_{i=1}^{N}(P_i - O_i)$
R	Linear Correlation Coefficient of Determination of P_i to O_i	$R = \left[\sum_{i=1}^{N}(P_i - \overline{P})(O_i - \overline{O}) \Big/ \left[\sum_{i=1}^{N}(O_i - \overline{O})^2 \sum_{i=1}^{N} P_i - \overline{O})^2 \right]^{0.5} \right]$
Scatter/MSD	Scatter (precision) or Mean Standard Deviation	$scatter = \frac{1}{(N-1)}\sum_{i=1}^{N}(P_i - O_i - \overline{(P_i - O_i)})^2$
RMSD	Root Mean Square Difference	$RMSD = \sqrt{bias^2 + scatter^2}$
MAE	Mean Absolute Error	$MAD = N^{-1}\sum_{i=1}^{N}\lvert P_i - O_i \rvert$

Table 4: Results from comparison between SEVIRI-predicted and in-situ ET estimates for ES_Agu site in 2010, 2011.

Year	Bias	Scatter	RMSD	MAE	R
2010	0.003	0.035	0.036	0.022	0.684
2011	-0.024	0.038	0.045	0.030	0.546