IMPROVEMENT OF THE TECHNIQUES FOR THE COMPUTATION OF EVAPOTRANSPIRATION MAPS

Lorenzo Stucchi[1,*], Martina Aiello[2], Alessia Gargiulo[2], Maria Antonia Brovelli[1]

[1]Politecnico di Milano, Department of Civil and Environmental Engineering, Piazza Leonardo da Vinci, 20133 Milano, Italy - (lorenzo.stucchi, maria.brovelli)@polimi.it
[2]Ricerca Sistema Energetico–RSE SpA, Milan, Italy - (martina.aiello, alessia.gargiulo)@rse-web.it

Commission III, WG III/10

KEY WORDS: Evapotranspiration, Remote Sensing, Copernicus, Sentinel Satellite, Sen-ET

ABSTRACT:

The definition of a methodology for estimating suitable areas for new renewable sources needs to identify possible indexes that describe the fields. One interesting index is the Evapotranspiration (ET). This is usually determined from hydrological models, which however do not provide a real-time estimation. So, new different procedures have been tested to compute it, for example, the use of Satellite images. The Sen-ET project allows using the Copernicus data to compute daily evapotranspiration. An improvement in the automatization of methodology is presented within this work. The model is tested in two different Italian regions with different climates and geographical conditions, considering also different months to study the results in different seasons over the same area. Results are then compared with those obtained in the same areas and period with two hydrological models (BIGBANG and GlobWat). The different outputs are analysed according to their spatial resolutions and respect to agricultural land cover classes. The comparison between Sen-ET evapotranspiration maps and hydrological model results has shown, in the analysed areas, relevant differences and suggests interesting future insights for continuous monitoring of land subject to water stress.

1. INTRODUCTION

In 2019, the European Commission with the European Green Deal supported the creation of "An Open, Democratic and Sustainable Society" and stated the necessity of reaching climate-neutrality by 2050. These aims have been confirmed also by the Next Generation EU programme in 2021. In this context, one of the most sensitive sectors is energy, in particular the renewable energy sector, which is thus characterised by a continuous research in new technologies exploitation. Among the emerging research themes related to energy, the water, energy and food nexus (meaning the interdependencies between water, energy and food) is commanding increasing attention. Due to climate change and the consequent reduction in water availability, more attention must be paid to the issue of the use of water in agriculture. As reported by The Food and Agriculture Organization (FAO, 2014) : "*in order to assess nexus interactions, reliable, pertinent and timely data is needed. Satellite observations, combined with in-situ data, provide a unique source of consistent information about the natural environment, on which we rely to produce water, energy and food*".

A fascinating recent technological solution that implies the co-existence of multiple landuses is represented by agrivoltaic. It's a hybrid agriculture-energy system in which agricultural crops are grown at the partial shade of the solar infrastructure. This combination fosters photovoltaic plants development with a low environmental impact without compromising agricultural land use. Besides, agrivoltaic systems could reduce water consumption in the agricultural field, limiting the losses due to evapotranspiration (ET) thanks to the shadowing provided by the solar panels (Barron-Gafford et al., 2019). Since agrivoltaic is an innovative solution, further investigations are desirable to test and estimate the actual benefits and their significance especially in relation to crop type and crop environmental conditions. Concerning data requirement, land use and in particular agricultural related data (e.g. crop type and evapotranspiration estimate) could be used to perform analysis on suitable sites for agrivoltaic plants (Stucchi et al., 2021). To this aim, evapotranspiration could be a proxy for identifying areas at risk of water and climate stress or agricultural land under high potential risk of abandonment, where the combined value of energy and agricultural production could make their recovery economically sustainable (Dinesh and Pearce, 2016). Evapotranspiration maps also support a variety of other studies on water management and agriculture, as the evaluation of effective evapotranspiration constitutes the central element of the hydrological balance.It constitutes both the highest rate among those into which the meteoric influx is divided, and because its estimate is affected by high uncertainty (Barron-Gafford et al., 2019). Moreover, accurately calculating the evapotranspiration in agricultural systems is crucial for the estimation of irrigation requirements since country statistics for agricultural water withdrawals are not always available and, when they exist, they are often unreliable (Dinesh and Pearce, 2016). The Copernicus programme through its services provides a variety of data that could be useful for studies related to the water-energy-food nexus (Stucchi et al., 2021).

The research presented within this work has the ambition to exploit the Sen-ET tool for continuous monitoring of evapotranspiration and land subject to water and climate stress. To facilitate the use of the Sen-ET plug-in, the process has been revised and automatised (Stucchi, 2022a). The procedure provides the possibility of computing monthly maps of different areas with less user effort, supporting in this way also the comparison of Sen-ET results with different literature evapotranspiration maps or hydrological model results.

* Corresponding author

The paper is structured in the following way. Section 2 presents the Sentinel for Evapotranspiration project and the improvements added for the automatic computation. Section 3 shows the used data and the results of two ET maps obtained by applying the Sen-ET tool to Sentinel data on two different Italian areas. In Section 4, the ET maps are compared with ET maps obtained by hydrological models. Finally, Section 5 describes the conclusion and the possible future development.

2. SENTINEL FOR EVAPOTRANSPIRATION

2.1 The Sen-ET procedure

The Sentinels for Evapotranspiration (Sen-ET) project (DHI GRAS, 2020b), founded by the European Space Agency (ESA), studies a new approach for evapotranspiration estimates from Copernicus data. The methodology uses data from the European Centre for Medium-Range Weather Forecast (ECMWF) called ECMWF Reanalysis v5 (ERA5), Sentinel-2 images and Sentinel-3 Land Surface Temperature (LST) images. The produced outputs are four modelled instantaneous land-surface fluxes at medium spatial resolutions (20 m) and high temporal resolution (daily): sensible heat flux, latent heat flux, ground heat flux and net radiation. The procedure also combines the latent heat flux with the meteorological data to produce the daily evapotranspiration output. Evapotranspiration maps have been also validated with some in-field measurements for agricultural usage (Guzinski et al., 2020).

The procedure is provided with a dedicated open-source plugin, called Sen-ET, available within the Sentinel Application Platform (SNAP) (European Space Agency, 2022) software developed by ESA. The process comprises multiple steps, which users can perform through the SNAP desktop application using graph builder and sentinel toolboxes, or through the command-line interface. In both cases, the process starts with the download in SNAP of the input data, Sentinel images and ERA5 data and ends with the computation of the ET map. However, the procedure is quite repetitive, requiring the user to set some parameters and manually select the requested input products for each step, which are mainly the outputs that have been generated by the procedure in the previous steps. This is explained in Figure 1, derived from the official documentation (DHI GRAS, 2020a) of the Sen-ET project and adapted to the aims of this work. Besides, the procedure should be repeated for each day on which the computation of the evapotranspiration maps is needed.

2.2 Improvement of the procedure

The Sen-ET procedure could be used to continuously monitor evapotranspiration and land subject to water and climate stress. However, to facilitate recurrent analysis, the process has been revised and automatised (Stucchi, 2022a). The procedure allows computing multi-day maps (also monthly maps) of different areas with less user effort. The automatic procedure has been created to connect all the different steps provided by the plug-in, thus reducing the number of steps required by Sen-ET to only one. The simplification is better explained in Figure 2, where the single step of the automatic procedure is shown.

At the beginning of the automatic procedure, the user is only required to indicate the input parameters in a dedicated file and to download the input data. The selection and the download of the Sentinel images from the Copernicus Hub are left to the

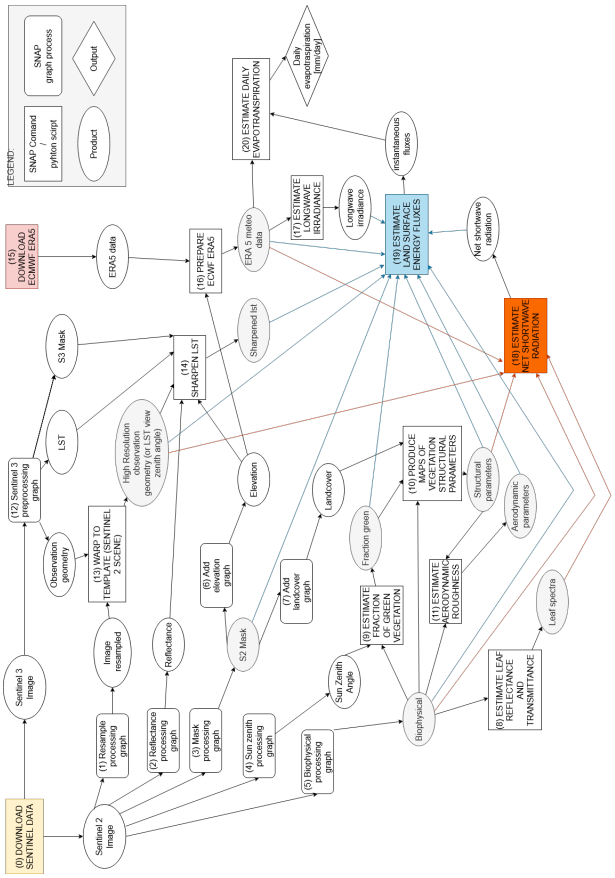

Figure 1. Sen-ET procedure schema.

users because their automatisation could lead to errors mainly related to the fact that the automatic procedure does not consider two important factors: the cloud coverage and the time lag due to offline images. Although a threshold for the maximum admissible cloud coverage percentage could be set in the download procedure inside the plugin, this value is referred to the full tile of the images and not a limited portion of the tile which could be of interest to the user. Thus, downloading data from the Copernicus Open Access Hub, where the user could check the validity of the image from its preview, is preferred. Moreover, while the Sentinel images of the last months are directly available, the older ones should be requested and will be available in a few hours. The first time the APIs ask for an offline image, the request proceeds with the order of the image. Some hours later, the user has to make the same call to download the images. However, there is not a notification system that reminds of the availability. . Rather, inside the Copernicus Hub, the user could select the images and then download them from the chart in a more simple way. The final outputs of the automation are daily maps for each daily input image saved as GeoTIFF, which can be further processed in standard GIS software. A complete guide of the automatization methodology is available online (Stucchi, 2022b).

2.3 Combination of the images to obtain monthly maps

Once the daily maps of evapotranspiration are created, they could be combined to create multi-day maps. Within this research, monthly maps are required in order to allow for consistent comparisons with other models, as will be explained in the next sections. The combination of the multiple maps could produce two different maps:

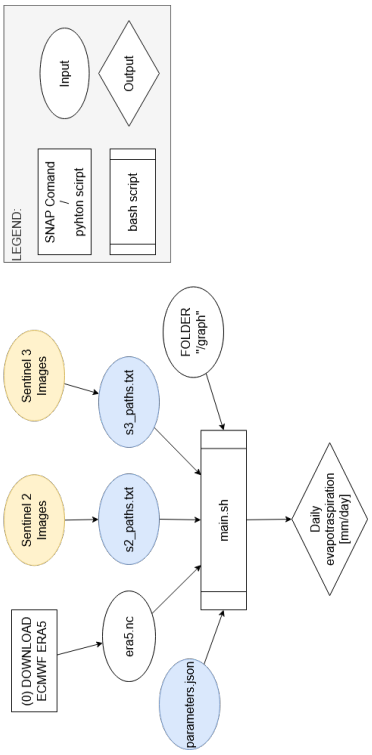

Figure 2. Sen-ET procedure automated.

- a map of the sum of the valid values for each pixel;
- a frequency map with the not null data for each pixel.

The two maps could be then combined to obtain the multi-day map. The map of the sum of the valid values could be divided by the frequency map and multiplied by a constant that represents the reference period, which could be 31 for a month or 7 for a week. The operation is done to fit all the values of the pixels on the same timespan. We are aware that this procedure could emphasise outliers. Anyway, the definition of a threshold to exclude pixels with a low frequency is left to future deeper analysis.

3. TEST AND FIRST RESULTS

The whole procedure has been tested on satellite data acquired in different regions of Italy in different months, in order to consider areas with different climate, land and geographical conditions. Besides, tests have regarded different seasons, considering also rainy months, when the contribution of irrigation is less significant.

In particular, tests have been performed on two Italian regions relevant for future research, Piedmont and Apulia for the month of March 2019. For Apulia tests have been performed also for the month of August 2019. These two regions have very different climate behaviour. While Piedmont in North Italy is a cold, wet and rainy region with irrigated and not irrigated land fields, depending on the different local areas, Apulia in southern Italy, is characterised by a warm and dry climate, with irrigated land fields.

The areas of analysis have been limited to one Sentinel-2 tiles for each region, considering the areas with a predominance of agricultural areas according to the 2018 CORINE Land Cover classification (Copernicus, 2020). Each tile covers an area of 100 km by 100 km. For Piedmont, the selected tile is the T32TLQ; the location of the tiles and the landcover present in the tiles are visible in Figure 3. For Apulia, the chosen Sentinel 2 tile is the T33TWF, its location and the landcover classes are visible in Figure 4.

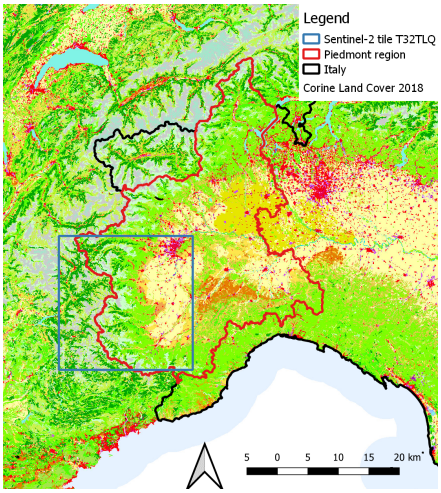

Figure 3. Sentinel 2 tile T32TLQ location and land cover.

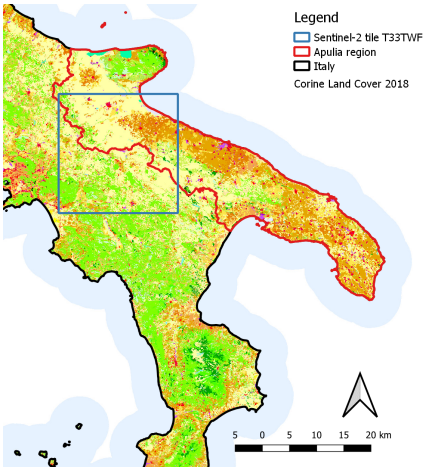

Figure 4. Sentinel 2 tile T33TWF location and landcover.

3.1 Input data

As said, the Sen-ET procedure requires as input ERA 5 data and Sentinel-2 and Sentinel-3 images. The ERA5 data used are the "ERA5 hourly data on single levels from 1979 to present" (Hersbach et al., 2018). Those data are available from the Climate Data Store (CDS) and should be downloaded for the whole period of interest. Sentinel images can be downloaded from the Copernicus Open Access Hub. As the Sentinel-3 mission is composed of two twin satellites (A and B), their combination guarantees a daily temporal revisit time, which is important for ET maps computation. Similarly, the Sentinel-2 mission is composed of two twin satellites (A and B), allowing to reduce the revisit time from 10 to 5 days. Since the crop status estimated from Sentinel-2 can be considered valid for a maximum of 10 days for ET maps computation, the max period between two images should be 20 days. Thus, for the computation of the monthly map at least three Sentinel-2 images have been used. The complete list of Sentinel 2 and 3 images used is in Table 1.

Study area	Period	Satellite image	Number of used images
Piedmont	March 2019	Sentinel-3	31
Piedmont	March 2019	Sentinel-2	4
Apulia	March 2019	Sentinel-3	31
Apulia	March 2019	Sentinel-2	3
Apulia	August 2019	Sentinel-3	31
Apulia	August 2019	Sentinel-2	3

Table 1. Input data

3.2 Results of the computation

The application of the Sen-ET methodology discussed in section 2 has been applied to produce daily ET maps on both the study areas for the considered periods, taking advantage from the previously described automatization. Daily maps have to be, then, combined into multi-days maps By way of example, Figure 5 shows frequency and Figure 6 sum maps for the Apulia region for March 2019.

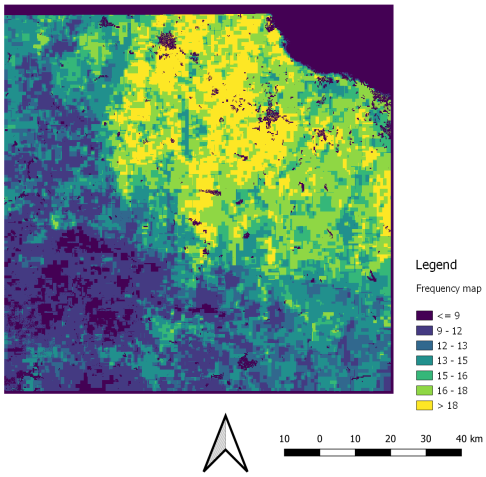

Figure 5. Frequency map of the daily evapotranspiration maps in the Apulia area in March 2019.

The frequency map shows that valid values follow a particular pattern, due to two different causes, individual conditions and constant conditions. The first are related to issues of the images (e.g. pixels masked due to clouds), and are more evident in case these issues are present in the Sentinel-2 image as they are retained for more days respect to the final computation (e.g. the darker area at the bottom right of the frequency map in Figure 10 is due to the presence of clouds in the Sentinel-2 data). Instead, the constant no values are due to some computation approximations, as those related to the missing computation of ET by the Sen-ET algorithm on residential and water area. Extreme cases where no valid pixels are retrieved from the map are excluded from the final computation.

To better understand the frequency of valid data, for each mask map, the cumulative sum has been computed and shown in Figure 7. For a given number of days, it is possible to estimate the percentage of valid pixels present on the map.

Finally, after understanding and managing the no value pixel, the last step is the combination of the sum map and the mask. As explained before the possibility of setting a threshold for the frequency has not been considered in this research. The

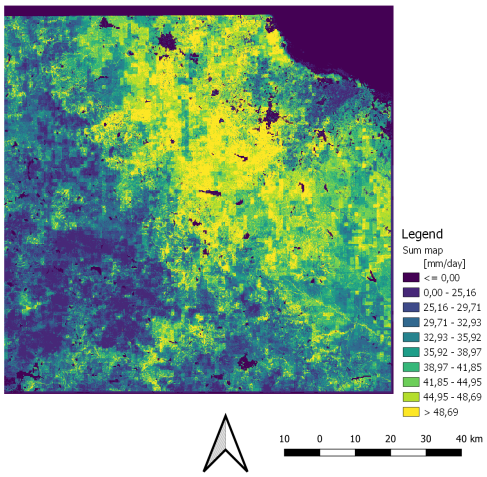

Figure 6. Sum map of the daily evapotranspiration maps in the Apulia area in March 2019.

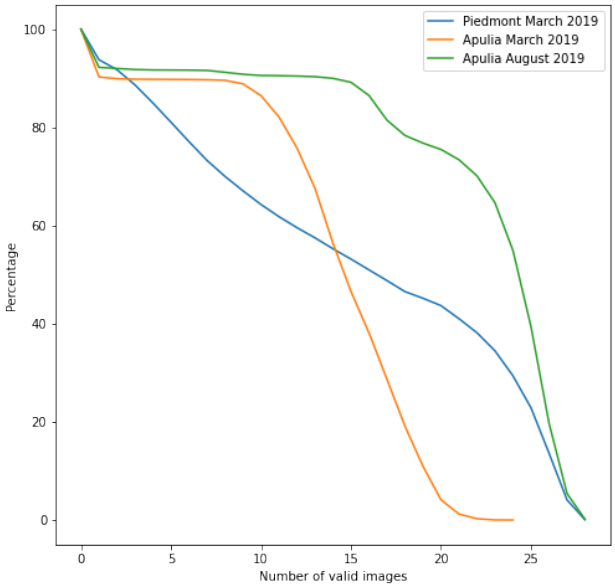

Figure 7. Percentage of valid pixels in the image for a given number of days.

monthly ET maps have been obtained, as explained before, dividing the sum maps for the frequency maps and multiplying each pixel for a constant value. Figure 8 shows the final Evapotranspiration for Apulia area in March 2019. Some ET maps report minimum (below zero) and maximum (above potential evapotranspiration) values which have no physical meaning and that could be caused by outliers. A deeper analysis of the outliers is described in the next section.

4. COMPARISON OF SEN-ET PRODUCTS WITH HYDROLOGICAL MODELS OUTPUTS

The results of the plugins provide a good estimation of the land-surface fluxes compared to the low-resolution images, particularly on agricultural fields (Guzinski and Nieto, 2019). Also, evapotranspiration computed from the Sentinel data produces similar results compared to what is produced with the Landsat LST (Guzinski et al., 2021). Nevertheless, the results of the use of Sentinel images for the estimation of the evapotranspiration should be validated in the different areas of interest and

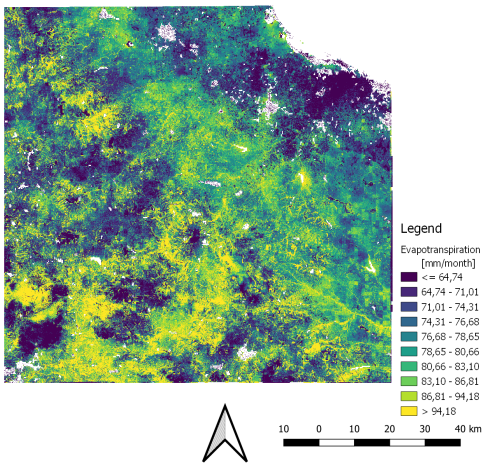

Figure 8. Evapotranspiration maps for Apulia area in March 2019.

according to the final usage. So, the produced ET maps are validated with consistent outputs of other models, such as hydrological models, which use a water balance to estimate the gain and losses of the water cycle. Thus, within this work the calculated evapotranspiration has been compared with that resulting from two reference hydrological models.

The BIGBANG (Bilancio Idrologico GIS BAsed a scala Nazionale su Griglia regolare) model developed by ISPRA (Italian institute for environmental protection and research) (Braca et al., 2021) is a GIS-based regular gridded water budget model. In the BIGBANG model the Actual Evapotranspiration is computed using the approach described by (Thornthwaite and Mather, 1957). The model is based on GIS methodology that combines spatial data of precipitation, temperature and DEM to provide 1 km resolution monthly maps of evapotranspiration and multiple other hydrological variables (e.g. snowfall, influx, runoff) from 1951 to 2019 over the whole national territory.

The GlobWat model is a freely distributed, global soil water balance model that is used by the Food and Agriculture Organization (FAO) to assess water use in irrigated agriculture. Unlike the BIGBANG model, GlobWat also provides the component of evaporation due to irrigation. Evaporation for crops under irrigation is calculated by multiplying reference evaporation by a crop and growing stage specific factor according to the FAO Penman–Monteith method (Allan et al., 1998). GlobWat model outputs are monthly average, to be considered valid for the year 2004 since the "*average of the years for which cropping calendar data are available is 2004*" (Hoogeveen et al., 2015). The produced maps cover the whole world with a resolution of 0.083 degrees, corresponding to 6 to 9 km at the Italian latitudes.

Within this work two different types of analysis of the three models have been done:

I) a spatial comparison to analyse discuss with respect to the different spatial resolutions of the model outputs

II) a land cover analysis, to discuss results with respect to different land cover classes.

4.1 Spatial comparison

An evaluation of the outputs of the three models according to their resolution is relevant considering that the models produce outputs with very different spatial resolutions (20 m for Sen-ET, 1 km for BIGBANG and 6-9 km for GlobWat). As confirmed by literature (Hong et al., 2011) and (Abiodun et al., 2018), the difference in the evapotranspiration is more evident at a finer spatial resolution; those impacts become thus less significant when the output is upscaled. For each comparison the Sen-ET maps have been resampled to the lower resolution of the reference model. In the downscaling process the pixel value obtained for Sen-ET is the mode of the values in the area of the low resolution model. Not all the products have been upscaled at the same resolution. Only Sen-ET has been upscaled to the resolution of the other two models to preserve the spatial information in the BIGBANG model. In fact, the maps at the BIGBANG resolution have two areas of interest, between 5.000 and 10.000 pixels, instead of GlobWat resolution, that have less than 100 pixels.

The box plot, in Figure 9, shows the distribution of the statistical properties. The Figure shows the comparison for March 2019 for the Piedmont area and the Apulia area in 2019 for the month of March and August.

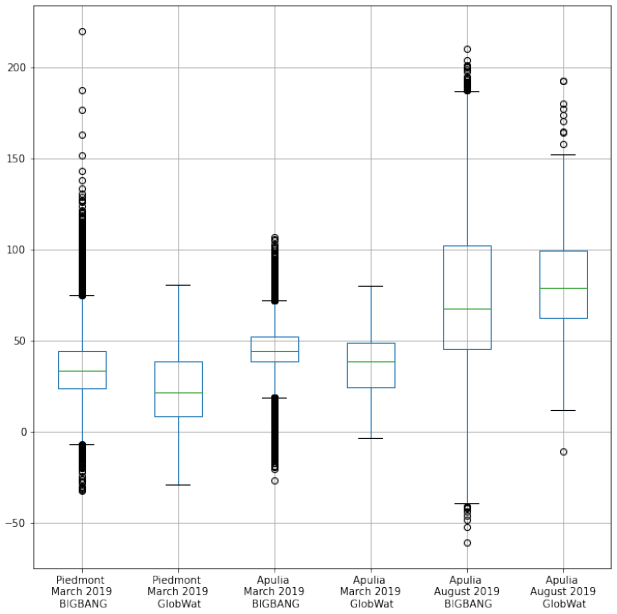

Figure 9. Boxplot of the ET values resulting from BIGBANG and GlobWat models for the area of interest in the different periods.

The boxplots presented some outliers, the values outside the whiskers and represented as points. Those values are due to probable errors in the computation of the Sen-ET maps. Those values are not considered in the following analysis since the high variability is present in the model. The plot represents the difference between the Sen-ET and the other models. Almost all the values are positive, meaning that the values of Sen-ET are greater than the other models. The ideal situation should be that the differences are around zero. The differences in the two areas in March present the same behaviour. Moreover, the values of the GlobWat model are closer to Sen-ET than BIGBANG. So, no particular trend is evident on the area in a rainy month. The comparison of the situation in Apulia provides different results in the two months. In August differences are bigger than in March. In particular, worst results are provided by GlobWat. Ideally, during summer the contribution of irrigation, which is considered only in the GlobWat model, should

provide values closer to reality. Thus, deeper analysis should be performed to better understand this behaviour.

4.2 Contribution of Land cover analysis

A second analysis has been done comparing results of the model on different land cover classes, considering only those related to agriculture for which evapotranspiration provides significant values. To this aim, the mean values of evapotranspiration from significant 2018 Corine Land Cover classes have been computed. The computation has been done for the three different models. Figures 10, 11 and 12 compare ET values generated by BIGBANG, GlobWat and Sen-ET models for the two study areas. In the figures, the labels of the different classes report the surface for that class in the study area. Some classes are represented by a few pixels by the different models. Each BIGBANG pixel has an area of 1 km^2, while for GlobWat, the pixel area is around 40 km^2. So, the value could be referred to few pixels for classes with small areas. The most significant classes to analyse are the ones with areas around 500 km^2, in which the comparison is based on more pixels and is less dependent on single possible outliers.

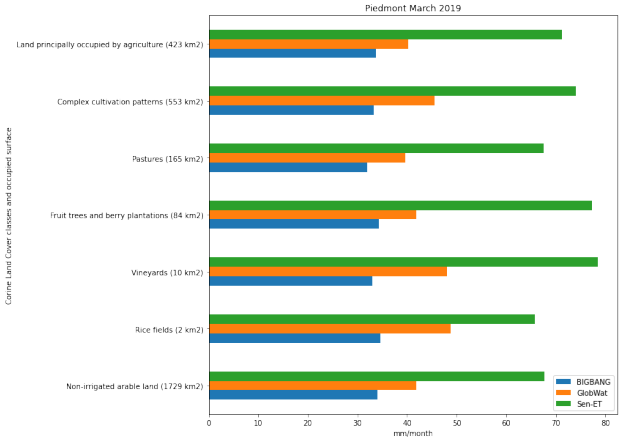

Figure 10. Comparison of ET values generated by BIGBANG, GlobWat and Sen-ET models for the Piedmont area in March 2019.

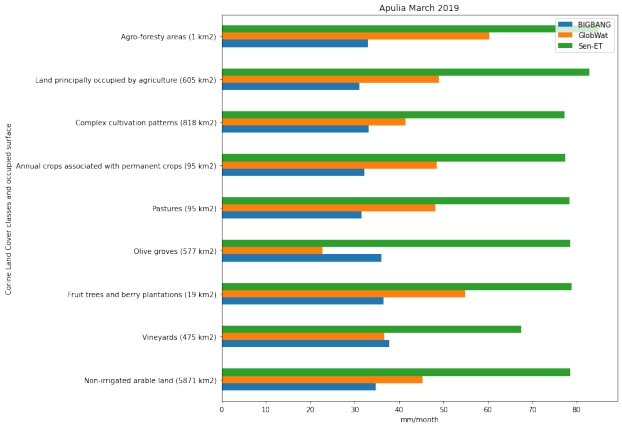

Figure 11. Comparison of ET values generated by BIGBANG, GlobWat and Sen-ET models for the Apulia area in March 2019.

In Piedmont in March 2019, Figure 10, the Sen-ET values are greater than the other models. As already shown in Figure 9, however, it is now possible to estimate that the differences are quite significant, and the Sen-ET values double BIGBANG and

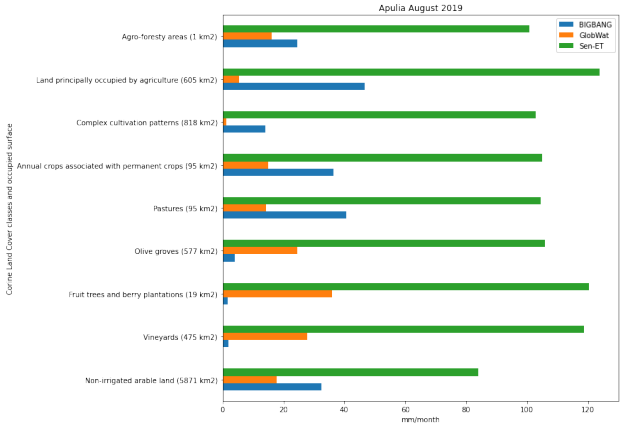

Figure 12. Comparison of ET values generated by BIGBANG, GlobWat and Sen-ET models for the Apulia area in August 2019.

the 1.6 times GlobWat values. The minor difference between GlobWat and BIGBANG could be due to the computed presence of irrigation. The same ratio is present also for March in Apulia, Figure 11. So, as before, the Sen-ET model's differences and results compared to the hydrological models in the two different areas shows how those differences are independent from the area.

Different results are shown in Figure 12 for the comparison in August 2019 in Apulia. The Sen-ET values computed are always 3 to 4 times bigger than the other models. However, GlobWat and BIGBANG present results that are not coherent in all the different classes. The biggest of the agricultural classes, the "Non-irrigated arable land" class, has values of Sen-ET and BIGBANG that are similar to the one in March. In this class, however, the value of GlobWat is reduced more than 1.5 times. This result could be related to the fact that GlobWat provides a multi-year mean value for August, while the other two models are specific for 2019.

The analysis of the evolution of the BIGBANG model in the area of interest could provide a global overview of the results. Figure 13 shows the comparison of the year 2019 with the mean of the previous years from 1951 to 2019. The value refers to the whole Apulia area and comprehends all the land cover classes.

The Figure shows that the historical mean values in March and August are similar. The same trend has been identified in the Sen-ET estimation. Besides, the ET values in March and August 2019 are no longer similar for the region. While the values are the same for some land cover classes. This different behaviour of the models detects that the values in 2019 are quite different from the historical mean. So, this could lead to the result that 2019 could be an anomalous year. Moreover, the behaviour of the BIGBANG and Sen-ET models could differentiate from the mean provided by GlobWat.

5. CONCLUSION AND FUTURE DEVELOPMENT

The comparison between Sen-ET evapotranspiration maps and hydrological model results has shown, in the analysed areas, relevant differences and suggests interesting future insights for continuous monitoring of land subject to water stress. Deeper comparisons should include many areas, periods and scales, evidencing the significance of a simplified, automated procedure availability. Moreover, a significant comparison could be

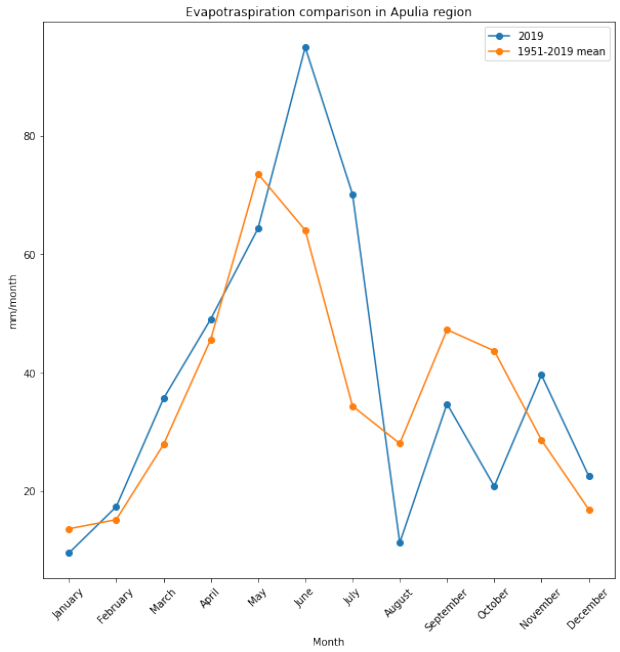

Figure 13. Comparison BIGBANG evapotranspiration of 2019 with the mean value from 1951 to 2019 for the Apulia region.

made using other models that estimate the ET from satellite images, like Modis. Other tests could be performed, including Sentinel-2 Level 1C products in the dataset, appropriately corrected for atmospheric effects. Using L1C images allows estimating the evapotranspiration since May 2016, when the first Sentinel 2 images are available.

It is important to remember that the main scope of the research is to evaluate the possibility of using ET maps to detect significant agricultural areas. This selection procedure uses the ET as one of the indexes combined with other vegetation indexes present in the literature that will be analysed and selected. Moreover, the considered value of ET should be used as a spatial index to compare the evolution of the ET in the areas.

ACKNOWLEDGEMENTS

This work has been partially financed by the Research Fund for the Italian Electrical System under the Contract Agreement between RSE S.p.A. and the Ministry of Economic Development - General Directorate for the Electricity Market, Renewable Energy and Energy Efficiency, Nuclear Energy in compliance with the Decree of April 16th, 2018.

REFERENCES

Abiodun, O., Guan, H., Post, V., Batelaan, O., 2018. Comparison of MODIS and SWAT evapotranspiration over a complex terrain at different spatial scales. *Hydrology and Earth System Sciences*, 22, 2775-2794.

Allan, R., Pereira, L., Smith, M., 1998. *Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56*. 56, FAO.

Barron-Gafford, G. A., Pavao-Zuckerman, M. A., Minor, R. L., Sutter, L. F., Barnett-Moreno, I., Blackett, D. T., Thompson, M., Dimond, K., Gerlak, A. K., Nabhan, G. P., Macknick, J. E., 2019. Agrivoltaics provide mutual benefits across the food–energy–water nexus in drylands. *Nature Sustainability*, 2(9).

Braca, G., Bussettini, M., Lastoria, B., Mariani, S., Piva, F., 2021. Elaborazioni modello bigbang versione 4.0. http://groupware.sinanet.isprambiente.it/bigbang-data/library/bigbang40. [Online; accessed 01-April-2022].

Copernicus, 2020. Corine land cover 2018. https://land.copernicus.eu/pan-european/corine-land-cover/clc2018. [Online; accessed 01-April-2022].

DHI GRAS, 2020a. Sentinel 5p mission. https://www.esa-sen4et.org/static/media/sen-et-user-manual-v1.1.0.5d1ac526.pdf. [Online; accessed 01-April-2022].

DHI GRAS, 2020b. Sentinels for evapotranspiration (sen-et) project. https://www.esa-sen4et.org/. [Online; accessed 01-April-2022].

Dinesh, H., Pearce, J. M., 2016. The potential of agrivoltaic systems. *Renewable and Sustainable Energy Reviews*, 54(C), 299-308. https://ideas.repec.org/a/eee/rensus/v54y2016icp299-308.html.

European Space Agency, 2022. Sentinel application platform (snap) website. https://step.esa.int/main/toolboxes/snap/. [Online; accessed 01-April-2022].

FAO, 2014. The water-energy-food nexus. http://www.fao.org/3/bl496e/bl496e.pdf. [Online; accessed 01-April-2022].

Guzinski, R., Nieto, H., 2019. Evaluating the feasibility of using Sentinel-2 and Sentinel-3 satellites for high-resolution evapotranspiration estimations. *Remote Sensing of Environment*, 221, 157-172. https://doi.org/10.1016/j.rse.2018.11.019.

Guzinski, R., Nieto, H., Sandholt, I., Karamitilios, G., 2020. Modelling High-Resolution Actual Evapotranspiration through Sentinel-2 and Sentinel-3 Data Fusion. *Remote Sensing*, 12(9). https://www.mdpi.com/2072-4292/12/9/1433.

Guzinski, R., Nieto, H., Sánchez-Tomás, J., López-Urrea, R., Boujnah, D., Boulet, G., 2021. Utility of Copernicus-Based Inputs for Actual Evapotranspiration Modeling in Support of Sustainable Water Use in Agriculture. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, PP, 1-1.

Hersbach, H., Bell, B., Berrisford, P., Biavati, G., Horányi, A., Muñoz Sabater, J., Nicolas, J., Peubey, C., Radu, R., Rozum, I., Schepers, D., Simmons, A., Soci, C., Dee, D., Thépaut, J.-N., 2018. Era5 hourly data on single levels from 1979 to present. http://doi.org/10.24381/cds.adbb2d47. [Online; accessed 01-April-2022].

Hong, S.-H., Hendrickx, J. M. H., Borchers, B., 2011. Down-scaling of SEBAL derived evapotranspiration maps from MODIS (250 m) to Landsat (30 m) scales. *International Journal of Remote Sensing*, 32(21), 6457-6477. https://doi.org/10.1080/01431161.2010.512929.

Hoogeveen, J., Faurès, J.-M., Peiser, L., Burke, J., van de Giesen, N., 2015. GlobWat – a global water balance model to assess water use in irrigated agriculture. *Hydrology and Earth System Sciences*, 19(9), 3829–3844. https://hess.copernicus.org/articles/19/3829/2015/.

Stucchi, L., 2022a. Automatization of the sen-et snap plugin for multi-temporal analysis. https://github.com/LorenzoStucchi/SEN-ET_automatization.

Stucchi, L., 2022b. Guide for the sen-et automation methodology. https://github.com/LorenzoStucchi/SEN-ET_automatization/blob/master/README.md.

Stucchi, L., Aiello, M., Gargiulo, A., Brovelli, M. A., 2021. COPERNICUS AND THE ENERGY CHALLENGE. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLVI-4/W2-2021, 189–196. https://www.int-arch-photogramm-remote-sens-spatial-inf-sci.net/XLVI-4-W2-2021/189/2021/.

Thornthwaite, C., Mather, J., 1957. *Instructions and tables for computing potential evapotranspiration and the water balance*. Publication in Climatology.