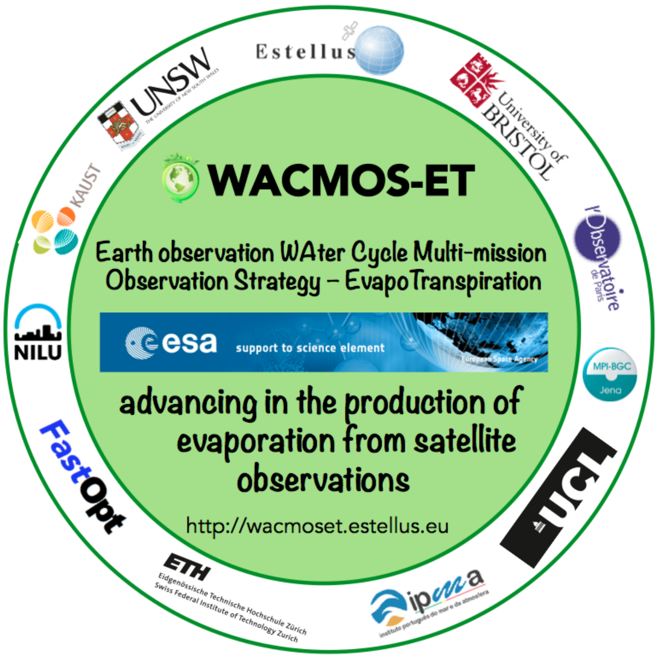

WP2300

Reference Input Data Set

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Contents

1 Introduction

The products of the WACMOS-ET Reference Input Data Set (RIDS) are described here. The main drivers for the product selection and development were to fulfill the input requirements for existing ET parameterizations, exploiting European Earth Observation Assets as much as possible, while assuring a relatively large internal consistency between the different products. The RIDS targeted spatial and temporal coverage and resolution are first presented. This is followed by a presentation of the products internally generated by the project and the third-party products included to complete the RIDS. Finally, the gridding and formatting of the data is discussed.

2 Spatial coverage and resolution

The project imposed two large continental sites (Europe and Australia). This was initially intended to be complemented by two other large regions, the African continent, and North America. At the end the project consortium decided to extend the project to cover all continental surfaces. This was done in order to provide a RIDS that could be used to facilitate global analyses of the generated ET estimates, that could be better compared and assessed together with the ET estimates from other initiatives and projects.

Regarding spatial resolution, ET at the continental sites is produced at a resolution of ∼25 km. This resolution satisfies a large number of users according to the WP1100 users survey, and it is is judged as a good intermediate resolution to merge at the continental scale the fine resolution of the RIDS products generated during the project (1-2 km) with the resolution of some of the other critical inputs for ET estimation (e.g., the surface meteorology at ∼75 km). All input datasets are spatially upscaled/downscaled to match the 25 km resolution and reprojected into a common low resolution sinusoidal grid (see Section 5).

Specific regional sites were identified for production and evaluation of ET estimates at a finer resolution during the project WP1300. The rationale for the pre-selection was based on (1) covering different climate/land-use conditions, (2) existence of relevant data for evaluation, (3) existence of relevant data at the required fine spatial resolution to drive the models, and (4) local knowledge of the area by the consortium members to facilitate data acquisition and interpretation of results. Finally only the site in Europe was retained as a demonstration of ET production at fine spatial resolution, though the original intended area has been largely extended in order to cover a larger spread in surface conditions. This site originally corresponded to a pre-alpine region with pasture and coniferous forest, and included the well studied sub-catchment of Rietholzbach, managed by one of the consortium members. The area around the catchment has been extended to cover a region of ∼500 x 600 km^2 and is displayed in Figure 1 together with its IGBP land cover classification. Regarding the input data, runs from the mesoscale model COSMO at ∼7 km resolution were the finest resolution meteorological inputs that could be located for the project, and will be used together with some of the other project inputs at resolutions of $\sim$1 and 5 km. Concerning evaluation data, one of the consortium members manages a lysimeter that provides ET measurements representative of the Rietholzbach catchment, and that will be used in the analyses as in situ data.

It should be noted that even if only one regional site is available as part of the RIDS with all required inputs at fine resolution, the RIDS also includes key satellite products at fine resolution, such as the land surface temperature, albedo, LAI and FAPAR. So if an external meteorological dataset at comparable resolutions could be found by potential users, some key products of the RIDS can still be applied for fine spatial resolution ET estimation. It should also be stressed here that the definition of fine spatial resolution depends on application, and that even a 1 km spatial resolution may not be adequate for specific applications such as irrigation management, where sub-km resolution and nearly real-time acquisition may be required [Prasanna et al., 2008]. These was reflected in the survey carried out during WP1100, where some users asked for resolutions of 30 meters and real or near-real time availability. This type of user requirements cannot be met by the developments of this project, but there will be a discussion in the roadmap at the end of the project, where EO developments that could start addressing them will be suggested.

3 Temporal coverage and resolution

The period 2005-2007 is selected for the RIDS. Three years are judged enough and compatible with the resources allocated to the project. A continuous time period common to all sites is judged more comprehensive than scattered and/or different years for each site, as a well defined observation period can facilitate the use of the RIDS by third parties. The selection of these specific years is based on a compromise between data availability for driving the ET algorithms and for validating the produced estimates. The 2007 year is determined by (1) the temporal coverage of the in situ data set for ET evaluation (the FLUXNET La Thuille Synthesis Dataset, www.fluxdata.org), and (2) the temporal coverage of the product used for radiation data (NASA/GEWEX SRB, [Stackhouse et al., 2004]). This means missing the SMOS measuring period but the WACMOS soil moisture is available and will be integrated in the RIDS.

Regarding the temporal resolution, WP1100 showed that 80% of the users who answered the questionnaire wished a daily temporal resolution. Providing sub-daily values was initially considered low priority in this project due to the responses from the questionnaire and the fact that daily is the scale where most methodologies operate. Nevertheless given the links of this project with the GEWEX Data and Assessments Panel (GDAP) LandFlux initiative and their efforts to produce sub-daily ET estimates, it has been decided to also produce and evaluate 3-hourly ET to contribute to these GEWEX efforts. Consequently the RIDS is prepared to be used for 3-hourly ET estimation. This concerns mainly the meteorological inputs, as a large fraction of the other required inputs

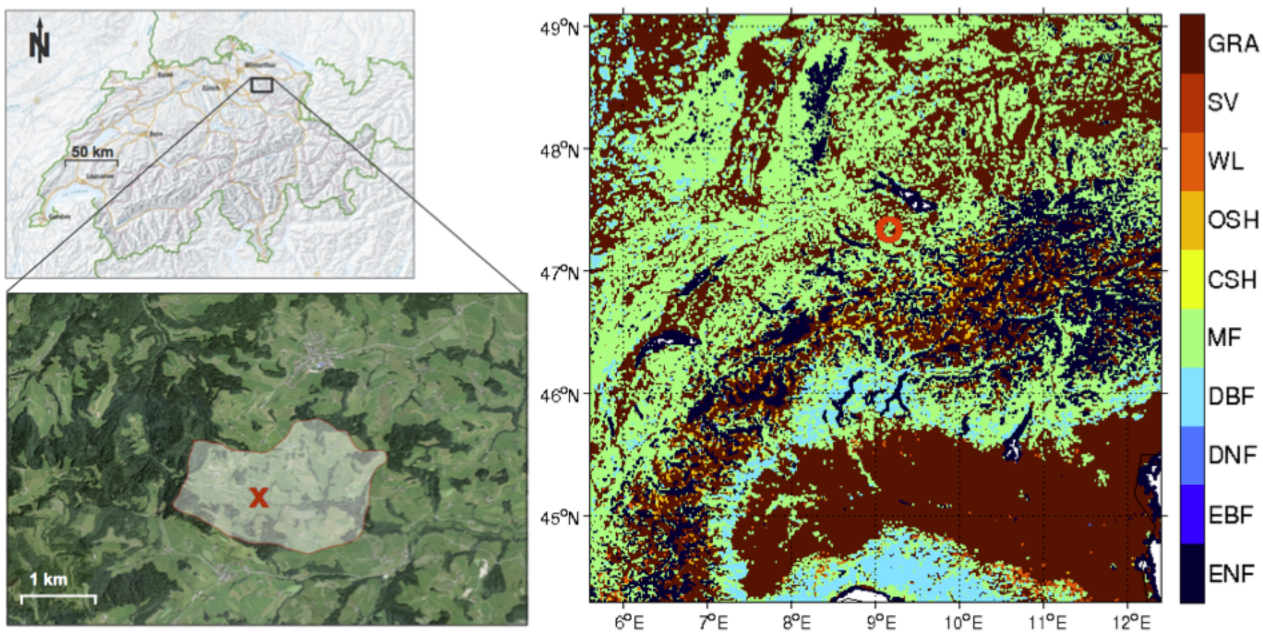

Figure 1: Maps of the regional area selected to provide fine resolution inputs for ET estimation. The left panel shows the location of the sub-catchment of Rietholzbach, with the red cross denoting the position of a lysimeter providing ET measurements. The right panels shows the IGBP classes of the selected area (ENF: evergreen needleleaf forest; EBF: evergreen broadleaf forest; DNF: deciduous needleleaf forest; DBF: deciduous broadleaf forest; MF: mixed forest; WL: woody savannas; SV: savannas; CSH: closed shrubland; OSH: open shrubland; Grass: grassland, urban and built-up, barren or sparsely vegetated; Crop: cropland).

do not exist at such fine spatial resolution. The importance of this depends on the nature of the inputs. For instance, while 3-hourly air temperature is critical to capture the diurnal cycle in the ET estimates, vegetation phenology at sub-daily scales is not required due to the usually slow plant growth.

4 Products

As discussed during the WP1300, there is a relatively large number of products for some of the ET drivers, and a strategy to select the products was needed. A logical approach is to try to select the "best" product for each category. The problems were that (1) lack of consistency between these products related to different sensors, different auxiliary information, etc, could have an impact on the produced ET estimates, and that (2) the perceived quality of the products are very difficult to judge at the global scale and over climatological records spanning many years. For this project internal consistency and exploiting European Earth Observation (EO) assets were identified as a very important criteria for product selection. This has resulted in some critical products being developed internally during the project. The developed products form a relatively consistent dataset of albedo, vegetation FPAR, LAI, and land surface temperature built to a large extent by using European EO assets. The remaining products to run the ET algorithms have been selected from already developed products.

The following Sections describe the individual RIDS products. The RIDS is summarized in Table 1

4.1 Land cover

The project adopts GlobCover as the source of land information. GlobCover produces a global land cover map at 300m resolution by a classification process that transforms cloud-free reflectance mosaics derived from the MERIS measurements of solar radiation reflected by the Earth (15 spectral bands from about 412.5nm to 900nm) into a land cover map with 22 land cover classes defined with the UN Land Cover Classification System (LCCS). More detailed regional maps are also derived by similar regionally-tuned classifications with a land cover typology extended to 51 possible land cover classes. A more detailed description of the product can be found at the GlobCover website (*http://ionia1.esrin.esa.int*).

The International Global Biosphere Programme (IGBP) global land cover classification is also used in the project. NOAA AVHRR data for every part of the globe land surfaces were collected between April 1992 and September 1996, followed by a classification and mapping methodology that transformed the radiances into a land cover map at 1km resolution with 17 land cover classes. More information can be found in Loveland and Belward [1997].

Table 1: Table summarizing the RIDS. Listed the main inputs, product selected, and original time and space resolutions, and the satellite sensors used to derive the product. The inputs that require developments or modifications by the project are listed in bold. For the remaining inputs already existing products are used. For the surface meteorology (air temperature, humidity, and wind) and the regional site, a at finer resolution alternative (COSMO, hourly at $\sim$7 km) is used.

Type	**Product**	**Time Resolution**	**Space Resolution**	**Sensors**
Land cover	ESA GlobCover IGBP		300 m 1 km	MERIS AVHRR
Surface Albedo	ESA GlobAlbedo	8 days	1 km	VEGETATION, MERIS, MODIS
FPAR	derived from GlobAlbedo	8 days	1 km	“
LAI	derived from GlobAlbedo	8days	1 km	“
Surface Temperature	Institute of Meteorology	twice per day (polar) hourly (geo)	1-2 km (polar) 3-5 km (geo)	AATSR MSG-2, MTSAT, GOES-12
Surface Radiation	SRB	3-hourly	100 km	Constellation of VIS-IR sensors
Near-surface Air Temperature	ECMWF ERA-Int	3-hourly	75 km	Assimilation of satellite and other meteo obs
Near-surface Humidity	ECMWF ERA-Int	3-hourly	75 km	“
Near-surface Wind Speed	ECMWF ERA-Int	3-hourly	75 km	“
Soil Moisture	ESA WACMOS	daily	25 km	SSM/I, TMI, AMSR-E, SCAT, ASCAT
Precipitation	CMORPH CFSR-Land	30 min hourly	15 km 40 km	SSM/I, AMSU-B, AMSR-E TMI Assimilation of satellite and other meteo obs
Snow Extent, Water Equ.	ESA GlobSnow	daily	1 km	ATSR-2, AATSR, AMSR-E

4.2 Albedo, vegetation FAPAR and LAI

The generation of ET estimates and related inputs such as the surface radiation requires land surface albedo for snow and snow-free surfaces as well as vegetation parameters such as FAPAR and LAI, where vegetated land cover is present. The project has adopted the GlobAlbedo estimates and derive LAI and FAPAR by applying the two JRC two-stream inversion package (hereafter, TIP, [Pinty et al., 2007, 2011a,b]) on the GlobAlbedo bihemispherical reflectance in visible and near infrared broad wavebands. Here, LAI is defined as the one-sided leaf area per unit ground area; fAPAR is the fraction of absorbed photosynthetically active radiation in the 400-700 nm region. The reader is referred to the product ATBD and Validation Report for all the details about these products.

It should be noted that care must be taken in comparing and interpreting LAI values derived from different sources: different assumptions will lead to different values of LAI. Here, LAI derived from the TIP is a 1D-equivalent LAI, for solving RT in a 3D medium and IS consistent with the fluxes from which it is derived. It is NOT consistent with LAI derived using a 3D RT scheme that allows some form of horizontal clumping (e.g. MODIS LAI). In practical terms this means that if a ET model was constructed to use MODIS-like LAI/FAPAR, a straight use of the project LAI/FAPAR will result in the ET model seeing lower values than expected. The ET dynamics will not be in principle affected (there is a high degree of correlation between different LAI/FAPAR estimates), but the ET absolute values will be. The best would be to rethink the model assumptions or calibrations to incorporate a different LAI/FAPAR, but we also recommend to produce site or biome (depending on application) calibrations between our TIP-derived LAI and fAPAR products against those derived from the radiative transfer approach and assumptions of the ET model. The reader is referred to the Validation Report again for more information and a detailed comparison of the TIP and MODIS LAI/FAPAR.

4.3 Land Surface Temperature

Land Surface Temperature (LST) is a critical variable for the estimation of ET based on surface energy balance models [e.g. Anderson et al., 2007, Mu et al., 2011]. These two variables are closely linked, since over land surfaces LST is mostly driven by the total radiation reaching the surface and by the partitioning between sensible and latent heat fluxes. For the project, LST estimates have been generated from L1 radiances from AATSR, onboard ESAs EnviSAT polar-orbiting satellite, from MTSAT-2 (over Australia), MSG-2 and GOES-12 (full disks). The data sets are reported over the project sinusoidal grid with 1 km resolution for AATSR at the two daily satellite overpasses ($\sim$10 am descending node) and 5 km for the remaining sensors (1-hourly estimates for MSG and MT-SAT, 3-hourly for GOES). Ancillary atmospheric information for the inversion of the L1 radiances comes from ERA-Interim, so there is a degree of consistency between the near surface meteorology used for the ET estimation and the characterization of the overlying atmosphere used by the LST inversion algorithm.

For more details about the project LST products and their validation the user is referred to the LST ATBD and Validation Report.

4.4 Surface Radiation

The surface net radiation is a critical input to most of the ET formulations. In practice, most of the ET formulations are used to parameterize the partition of the net radiation into their sensible and latent heat flux components. The radiative energy balance at the surface can be expressed as:

$$R_{net} = (1 - \alpha)\, R_{SW} + R_{LW} - (\epsilon\, \sigma\, LST^4) \tag{1}$$

where R_{net} is the surface net radiation, R_{SW} and R_{LW} are, respectively, the incoming shortwave radiation and the downwelling longwave radiation, σ is the Stefan-Boltzman constant, and α, ϵ, and LST are here the surface albedo, emissivity, and land surface temperature, respectively. This equation clearly shows the dependence of the net radiation on the albedo and LST, so having a radiation product relatively consistent with the other project generated products would have required to also develop an internal radiation product. Such a product needs the parameterisation of the downward fluxes using top-of-the-atmosphere radiances and a modelisation of the underlying atmosphere, but these developments have not been possible within the lifetime of the project. Therefore, the project adopts as a second best solution the GEWEX/NASA Surface Radiation Budget (SRB) satellite product [Stackhouse et al., 2004], which is used by a large number of ET products to characterize the radiation at the surface. The data sets include global 3-hourly averages of surface and top-of atmosphere (TOA) longwave and shortwave radiative parameters on a ∼100 km grid. The user is referred to the product website (*http://gewex-srb.larc.nasa.gov/*) for more details.

4.5 Near Surface Meteorology

Surface meteorology (air temperature, air humidity, and wind) are critical inputs for some of the ET algorithms. The synoptic network of weather stations is too sparse in some regions of the world, although products based on extrapolating the station data to regular spatial grids exist (e.g. the Climate Research Unit (CRU) monthly time series dataset [Mitchell and Jones, 2005]). Satellite observations of these near-surface variables over land are presently difficult (temperature and humidity) if not impossible (winds). Products from some satellite sounders exist (e.g., from AIRS, see an evaluation in [Ferguson and Wood, 2010]). An alternative is the atmospheric reanalyses, where the existing observational data (ground, radiosondes, satellite, etc) is assimilated into a physical model reproducing the state of the atmosphere (e.g. the ERA-Interim [Dee, 2011]). Although with a larger "modelling" component compared with ground-based or satellite retrieval-based products, they have the advantage of providing estimates at regular spatial grids at fixed time intervals and under all weather conditions.

The ERA-Interim reanalysis is selected here to provide the surface meteorology. Estimates are provided each 3 hours using the forecast fields at a spatial resolutions of ∼75 km. As ERA-Interim is also used in the derivation of LST, this seems the natural choice to assure inter-product consistency. In terms of accuracy, their products have been evaluated by comparison with other reanalyses and weather stations over specific areas [e.g. Mooney et al., 2011, Szczypta et al., 2011]. Based on these comparisons, the ability of ERA-Interim to reproduce observed surface meteorology seems comparable to the ability of other reanalyses, and although not strictly a "satellite" product, we consider it as the best alternative to provide near-surface meteorology for the RIDS.

Finer spatial resolution alternatives to ERA-Interim at the regional site is advisable, and as presented in Section 2 the analysis fields of the weather forecasting model COSMO is used in the region around the Rietholzbach Catchment site. Their fields are available in ∼7 km resolution, hourly, and has been obtained through a collaboration between ETHZ and MeteoSwiss. Given the large miss-match between the 100 km spatial resolution of SRB and the 1 km resolution at the regional site, the surface net radiation from COSMO will also be used at the regional site.

4.6 Soil Moisture

Soil moisture is a key variable for ET. However, most formulations for ET estimation at regional or continental scales do not use soil moisture as an input. Instead, other variables are used trying to capture the influence of soil moisture; for instance, by using indexes of soil water deficit assuming that for large enough temporal and spatial scales the soil moisture status is linked to the evaporative demand of the atmosphere [Fisher et al., 2008].

The first mission to specifically measure soil moisture from space was launched in 2009 (the Soil Moisture and Ocean Salinity mission, SMOS [Kerr et al., 2010]), so their estimates fall outside the proposed RIDS time period. A product combining observations from active and passive microwave sensors has been developed during the previous WACMOS project (*http://www.esa-soilmoisture-cci.org*) , and is adopted here to add soil moisture to the RIDS. Details on the exact WACMOS product algorithm can be found in Liu et al. [2011]. The data is provided on a regular grid with a resolution of 0.25°x0.25°. It should be noted that dense vegetation can mask microwave signals from the ground, making soil moisture retrievals impossible. Additionally, microwave observations are highly uncertain in regions of high surface roughness, such as mountainous areas. As a consequence, the product performs well in moderately vegetated regions, but shows a strong uncertainty in highly vegetated and mountainous regions.

The retrieval of soil moisture from passive sensors is also accompanied by an estimation of the vegetation optical depth using the Land Parameter Retrieval Model (LPRM) [Owe et al., 2001]. This parameter can also be used to account for the development of vegetation over the year. Although most ET models use parameters such as NDVI or LAI to characterize the vegetation state, vegetation optical depth is also used at least in one of the models proposed in WP1200 for

ET estimation. Therefore we will add this variable to the RIDS. Resolutions and coverage are similar to the soil moisture product.

4.7 Precipitation

Precipitation is not a direct input for most existing ET models at continental scales, but it is an important variable to analyse consistency between ET and other related hydrological variables. We use here the NOAA CPC Morphing Technique (CMORPH, [Joyce et al., 2004]). CMORPH uses precipitation estimates that have been derived from low orbiter satellite microwave observations exclusively, and whose features are transported via spatial propagation information that is obtained entirely from geostationary satellite IR data. The precipitation estimates are available every 30 minutes on a grid with a spacing of 8 km at the equator (though the resolution of the individual satellite-derived estimates is coarser at ∼12 x 15 km), with a coverage of 60S-60N.

The limited CMORPH coverage means that a second product is needed for the global runs. We use the CFSR-Land precipitation estimates [Coccia and Wood, 2015]. These precipitation estimates are taken from the hourly NECP Climate Forecast System Reanalysis (CFSR) output [Saha and et al., 2010], but are corrected with satellite data, in terms of number of rainy days and monthly total precipitation bias, using the NCEP Climate Prediction Center (CPC, [Xie and Arkin, 1997]) and GEWEX Global Precipitation Climatology Project (GPCP) [Adler et al., 2003] daily data sets. It would have been more adequate to use directly the GPCP estimates (in the sense of being a more ”satellite” product), but that was not possible as it does not provide sub-daily estimates.

4.8 Snow

Snow extent is needed in order to determine the spatial domain where adapted ET formulations to estimate sublimation can be run in the northern latitude winter months. For this project we will use the ESA funded GlobSnow snow extent and snow water equivalent products (*http://www.globsnow.info*). The snow extent data set is based on optical data from Envisat AATSR and ERS-2 ATSR-2 sensors covering the Northern Hemisphere. The snow area equivalent product combines satellite-based passive microwave measurements with ground based weather station data in a data assimilation scheme. The products exist at daily resolution at a spatial resolution of ∼1 km for snow extent and 25 km for the snow water equivalent.

Another source of snow extent exists also for the project, as the GlobAlbedo product also reports the presence of snow when estimating surface albedo. Therefore estimates of snow presence at 1, 5, and 25 km are also available for the project as part of the albedo/LAI/FAPAR product.

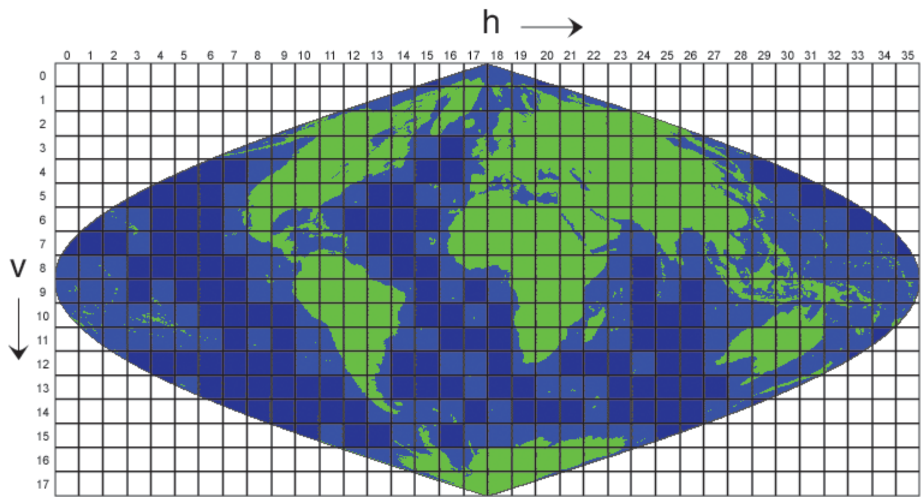

Figure 2: Map showing MODIS tile locations (courtesy of the MODIS team) Each tile contains 1200 km x 1200 km data arrays, which corresponds to 1200 x 1200 pixels, 240 x 240 pixels, and 48 x 48 pixels, at the resolutions of 1, 5, and 25 km, respectively.

5 Data grids and formatting

Equal-area grids with a sinusoidal projection adapted to different spatial resolutions are adopted to output the different products of the RIDS. An equal-area map is well suited to report ET as it facilitates any spatial integration of the ET fluxes. Sinusoidal projections are well used in the hydrological community and have been adopted by some satellite missions to report their L3 products. To facilitate the integration/analysis of our ET estimates with other relevant products, instead of deriving our own data grid system the project has adopted the MODIS tile system (tiles cover an area of 10^ox 10^oat the equator). Figure 2 shows the MODIS tile locations. In practical terms this means that the data storage "unit" is a tile containing ET model inputs or ET estimates at a given resolution (1, 5, or 25 km) and at a given time (1-hourly, 3-hourly, daily, monthly, or yearly).

Time and spatial resolutions depend on the data set. The project internally generated albedo, FPAR, and LAI products will be output at their finest resolution of 1 km, but also properly integrated (see the products ATBD for more details) at the resolutions of 5 and 25 km. The also internally generated LST will be ouput in the 1 km grid for the AATSR estimates, and in the 5 km grid for the MSG, MTSAT, and GOES estimates. The remaining products will be output at the spatial resolution selected for the ET products (at 1 and 5 km for the regional site, at 25 km for the global estimates).

NetCDF-4 Classic is adopted as the data format for the RIDS. Other data formats were considered (e.g. HDF5) but netCDF seemed adequate to handle the level of complexity and data volume of the RIDS. Also, as netCDF is self-describing (it contains information about the data), portable (it can be read by computer platforms with different ways of storing numbers), and allows direct access to small subsets (without the need to read all the preceding data), it is an excellent format to facilitate the public dissemination of the data.

The RIDS can be made available to interested parties upon demand, using the project website (http://wacmoset.estellus.eu) as gateway. Please visit the website to find out about the procedure to have access to the RIDS.

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