CM–SAF high resolution radiation budget products

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ABSTRACT

In this paper the system employed at the Royal Meteorological Institute of Belgium (RMIB) within the Climate Monitoring Satellite Application Facility (CM–SAF) for the production of Top Of the Atmosphere (TOA) radiation budget components is described. One of the goals of the CM–SAF is to provide consistent TOA and surface radiation budget components and cloud properties at high spatial resolution and on an approximate equal area grid for a region that covers at least Europe and part of the North Atlantic Ocean. The TOA radiation products will be based on data from polar orbiting satellites for northern latitudes, and on data from MSG (METEOSAT Second Generation) for mid latitudes. The instruments used for the reflected solar and emitted thermal flux estimates will be GERB (Geostationary Earth Radiation Budget) and SEVIRI as the geostationary instruments and CERES (Clouds and the Earth's Radiant Energy System) for the non geostationary instruments. Daily means, monthly means and monthly mean diurnal cycles are to be provided. Until MSG fluxes will become available, fluxes from METEOSAT and CERES are used for development. At the TOA the three radiative flux components of incoming solar radiation, reflected solar radiation and emitted thermal radiation will be given. The daily mean GERB and CERES fluxes will be merged to produce a homogenised TOA flux product. The method used for the merging of the TOA fluxes and together with results using currently available input data are shown. The merging consists in the collocation of the two instruments, detection and the removal of the systematic dependencies of the flux estimates on scene type and viewing angles and regridding on a common grid.

Keywords: merging, homogenisation, radiation budget at TOA

1. INTRODUCTION

The general purpose of the EUMETSAT (EUropean METeorological SATellite organisation) SAF (Satellite Application Facility) program is to prepare the exploitation of the new capabilities of the future MSG (METEOSAT Second Generation) and EPS (European Polar System) satellite systems. The specific purpose of the SAF on Climate Monitoring (CM–SAF) is to generate and archive high quality data sets on a continuous basis for applications like monitoring of the climate state and its variability, analysis and diagnosis of climate parameters to identify and understand changes in the climate system, studies of the processes in the climate system on an European and/or global scale. The CM–SAF activity should be seen complementary to the operational meteorological use of satellite data, which is driven mainly by near real time constraints.

At the Royal Meteorological Institute of Belgium (RMIB), member of the CM–SAF consortium, the radiation budget at the TOA (Top Of the Atmosphere) will be determined in its three components: TIS (TOA Incoming Solar flux), TRS (TOA Reflected Solar flux) and TET (TOA Emitted Thermal flux). Within the CM–SAF context, the aim is to produce satellite data that covers the largest possible area with good consistency in space and time. For this purpose, a combination of the best available data sources will be used. For the TIS, this is data from TSI (Total Solar Irradiance) instruments – the existing VIRGO/SOHO and ACRIM III, and the future SOVIM/ISS, PICARD and TIM/SORCE. For the TRS and TET, the best available input data comes from well calibrated broad band instruments – the existing and future CERES (Clouds and the Earth’s Radiant Energy System) [1] instruments on low earth orbit satellites and the GERB (Geostationary Earth Radiation Budget) instrument on MSG.

The radiometers that measure the TSI have a limited absolute accuracy. Therefore TSI data sets from different instruments should be adjusted relative to a common reference before they are merged. The TSI measurements of an individual instrument are adjusted by a specific adjustment coefficient. The TSI values used in CM–SAF are the mean Space Absolute Radiometric Reference (SARR) [2] adjusted TSI measurements from several available sources with known SARR adjustment factor.

The estimation of reflected solar and emitted thermal fluxes from single satellite broad band radiance measurements requires:

- The calibration of the broad band radiances. Usually a 'total' radiance is measured in the spectral range 0 – 50 μm and a 'shortwave' radiance is measured in the spectral range 0 – 4 μm.
- Separation of the reflected solar and the emitted thermal radiances. A synthetic 'longwave' radiance is usually computed by subtraction of the shortwave channel from the total radiance. After some small corrections, the shortwave and the longwave radiances are associated with the reflected solar radiance, respectively the emitted thermal radiance.
- The unfiltering of the non flat spectral responses of the shortwave and the synthetic longwave channel. This involves a modeling of the spectral distribution of the observed radiation and, since the spectral behaviour is scene type dependent, it can be expected that some residual scene type dependent errors are made in the radiance estimation.
- The radiance to flux conversion. This involves the modeling of the angular distribution of the observed radiation and, since the angular behaviour is scene type dependent, it can be expected that some residual scene type and viewing geometry dependent systematic errors remain.

Errors made in each of these steps contribute to those made in the instantaneous flux estimation. Usually, errors made in the last step, which result in angular and scene type dependent errors, dominate.

Geostationary flux estimates have a perfect time sampling, but a limited sampling of viewing geometry. Thus systematic errors in daily mean flux estimates can occur due to random errors in the angular modeling. Polar flux estimates have a different angular sampling, but a limited temporal sampling. Daily mean flux estimates from polar measurements require the modeling of the diurnal variation of the observed radiation. This can result in a different kind of systematic errors.

Co-angular geostationary and polar unfiltered broadband radiance estimates can be compared with each other on an instantaneous basis. This can validate the calibration and spectral unfiltering. Non co-angular geostationary and polar flux estimates can be compared with each other on an instantaneous basis. This can validate the used angular modeling. Time series of geostationary flux estimates can be compared with model interpolated polar flux estimates. This can validate the diurnal variation model used for the interpolation of the polar flux estimates.

Geostationary and polar flux estimates can be merged with each other. In the regions with good viewing conditions for the geostationary satellite its flux estimates can be used. For regions close to the poles, the geostationary viewing conditions become bad and the temporal sampling by the polar satellites becomes good, so polar flux estimates can be used. In between, a combination of the two sources of flux estimates can be used if the systematic differences are accounted and corrected for in a homogenisation process.

In this paper we describe the system developed at RMIB for the production of TOA radiation budget components. The methods used for the computation of the TIS and merging of TRS and TET fluxes are shown, together with the main features of the output products.

2. METHODOLOGY

2.1 TIS product generation

On an instantaneous basis, the TOA Incoming Solar flux (TIS) is determined by the Total Solar Irradiance (TSI) at 1 A.U., the distance to the sun *d*, and the solar zenith angle θ_{sz}. The mean TIS is calculated for every box of the CM–SAF common grid (see definition in section 2.3) as the product of the daily mean SARR adjusted TSI (at 1 A.U.) and a geometrical factor. The SARR TSI series is the mean of the available daily mean SARR adjusted measurements of individual instruments.

The geometrical factor is the one hour mean cosine of the solar zenith angle divided by the square of the distance of the grid box to the sun. The position of the sun relative to the centre of the earth is calculated by a state of the art model using NASA Jet Propulsion Laboratory ephemerides. The earth is modeled as the reference ellipsoid.

On an instantaneous basis, one has:

$$\mathrm{TIS} = (\ \mathrm{TSI} / d^2\ ) * \cos(\theta_{sz}). \tag{1}$$

The only factor which requires satellite measurement is the TSI, whereas d and θ_{sz} can be calculated geometrically. The geometrical calculations can be decomposed in a calculation of the sun's position relative to the earth, and a subsequent calculation of d and θ_{sz} for every observed point on earth.

Over a period of one hour the distance to the sun d can be considered constant, while the daily TSI is constant. Thus on a one hour mean basis one has:

$$\langle\ \mathrm{TIS}\ \rangle_{1\mathrm{h}} = (\ \mathrm{TSI} / d^2\ ) * c_{1\mathrm{h}}, \tag{2}$$

where $c_{1\mathrm{h}}$ is the mean of $\cos(\theta_{sz})$ over one hour. $c_{1\mathrm{h}}$ depends only on the position of the considered point on earth and on time.

Since the sun moves at an angular speed of 360º / 24h from east to west, $\cos(\theta_{sz})$ at longitude l and time $t + \Delta t$ is equal to $\cos(\theta_{sz})$ at longitude $l + \Delta l$ and time t, with $\Delta l / \Delta t = 15º / 1\mathrm{h}$. To evaluate $c_{1\mathrm{h}}$ for the time interval [t, t + 1h], we first evaluate the instantaneous values of $\cos(\theta_{sz})$ as function of latitude and longitude at time t. $c_{1\mathrm{h}}$ at longitude l is then calculated as the mean of $\cos(\theta_{sz})$ values for longitudes between l and l + 15º.

Figure 1 depicts the system employed for the generation of TIS products, while Figure 2 shows a sample plot of an hourly mean of TIS regridded on the CM–SAF common grid.

2.2 TET and TRS generation

For the TOA Emitted Thermal (TET) and TOA Reflected Solar (TRS) products generation, the outputs of existing single instrument processing chains will be used as input. It can be expected that the best available input data come from well calibrated broad band instruments – the existing and future CERES instruments on low earth orbit satellites and the GERB instrument on MSG. The work done at RMIB within the CM–SAF is the fusion of these input sources into consistent output products.

Figure 3 depicts the system used for the generation of TET and TRS products. The process consists in the homogenisation of the inputs, which aims at removing the detectable systematic errors in the estimation of radiative fluxes from the CERES and GERB instruments, merging of the homogenised fluxes and then averaging for the final output products.

The homogenisation for the CM–SAF of the TOA radiative fluxes is done in three steps, of which the first two have to be executed off-line on a large quantity of data. The three processing steps are:

- Collocation: A large number of collocated CERES and GERB (GERB–like for the development) pairs of fluxes and radiances are collected. These pairs are divided in two databases: a database of collocated and co-angular radiances and a database of non co-angular collocated fluxes.
- Statistical analysis: The statistical analysis of the database of collocated co-angular radiances allows the detection of systematic errors with scene type. The statistical analysis of the database of collocated non-coangular flux estimates allows the detection of systematic errors with scene type and viewing angles.
- Correction: Once the systematic errors are known, GERB and CERES measurements can be corrected. Since the errors are detected from a comparison of GERB and CERES, the corrections make GERB and CERES homogeneous.

The core of the homogenisation is the statistical analysis process. In the next two paragraphs we give a brief description of this process.

In the TET case, for a certain scene type and GERB viewing zenith angle (GERB reference TET), all CERES footprints that fall in a certain viewing zenith angle bin are selected. An averaging over all these footprints of the CERES TET values ratios to GERB reference TET is performed. This is the factor which is then used to scale the CERES TET to obtain the homogenised CERES TET. The operation is repeated on all CERES viewing zenith angle bins. The homogenised GERB TET is obtained in a similar manner using as reference the homogenised CERES TET. More details are given in [3].

The database for the homogenisation of TRS has three additional dimensions which arrive from the binning of the solar zenith and relative azimuth angles and cloudiness (two cloudiness classes are defined based on the albedo). The operations which are then performed are similar to the case of TET, except that the scaling factor is replaced by a homogenisation offset. The mean CERES TRS is used as the initial reference for a certain bin. The offsets of the GERB TRS values located in that bin to the reference value are then averaged. The homogenised GERB TRS is obtained by subtracting this mean offset. The homogenised CERES TRS is obtained in a similar manner using as reference the homogenised GERB TRS. More details are given in [4].

Instantaneous CERES [5] and high resolution GERB measurements [6] are collocated and compared on a CERES footprint basis. From the statistical analysis of the database of pairs of CERES and GERB flux estimates over CERES footprints, an objective characterisation of the systematic flux errors in terms of viewing geometry and scene identification is obtained.

The GERB and CERES fluxes are then corrected for their observed differences. Two options exist for this correction: a priori and a posteriori correction. For the a priori correction option, the characterisation of the systematic errors is used as a feedback to correct the errors that arise in the GERB or CERES processing systems (which is outside the scope of the CM–SAF). The a posteriori correction option is used on the output products. On the CERES side the synoptic output product [7] will be used, so that the diurnal variation modeling that is done in the CERES processing system is not duplicated in the CM–SAF. After the correction the GERB and CERES fluxes are merged and then averaged on a daily mean, monthly mean and monthly diurnal mean cycle basis.

The merging procedure of the fluxes is described next. At higher latitudes, where CERES provides the best coverage, CERES fluxes are used. For lower latitudes, where GERB provides the best coverage, GERB fluxes are used. In between, the flux $\mathbf{F}$ is a weighted mean of the homogenised GERB flux $\mathbf{F}_{\mathrm{GERB}}$ and homogenised CERES flux $\mathbf{F}_{\mathrm{CERES}}$, as follows:

$$\mathbf{F} = w * \mathbf{F}_{\mathrm{GERB}} + (1 - w) * \mathbf{F}_{\mathrm{CERES}} \tag{3}$$

The weight changes linearly with the MSG viewing zenith angle θ_{vz}, so that spatial discontinuities in the merged flux product are avoided:

$$\begin{aligned} w &= 1 && \text{for } \theta_{vz} < 70° \\ w &= 1 - (\theta_{vz} - 70°) / 10° && \text{for } 70° < \theta_{vz} < 80° \\ w &= 0 && \text{for } \theta_{vz} > 80° \end{aligned} \tag{4}$$

Figure 4 gives a sample plot of merged TRS regridded on the CM–SAF common grid.

2.3 CM–SAF common grid

The products (TIS, TRS, TET) will be derived as daily, monthly and monthly diurnal mean fluxes over the full MSG disk, gridded on a nested 0.5° equal angle grid, described in Table 1. In higher latitudes regions the TET and TRS are derived from synoptic CERES data which is gridded on a similar nested 1° equal angle grid [8]. The CERES data resolution is doubled by interpolation for the purpose of merging.

Latitude	Grid Size
0° – 45°	$0.5° \times 0.5°$
45° – 70°	$1° \times 0.5°$
70° – 80°	$2° \times 0.5°$
80° – 89°	$4° \times 0.5°$
89° – 90°	$180° \times 0.5°$

Table 1: CM–SAF nested 0.5° equal angle grid description

3. DATA AND RESULTS

For the development of the CM–SAF software, since the MSG data is not yet available, GERB–like data and existing CERES data was used. The GERB–like data is derived at RMIB from METEOSAT 7 data. This data is produced with the ground segment software [9] which will be used for the processing of real GERB data once it will become available. CERES data used [10] comes from the instrument flying on TRMM. Future validation will be performed using data products of the CERES instrument flying on Terra.

The accuracy of daily mean TIS is anticipated to be better than 1 Wm^{-2}.
The accuracy of daily mean TRS is anticipated to be better than 10 Wm^{-2}.
The accuracy of daily mean TET is anticipated to be better than 5 Wm^{-2}.

An outline of the method that will be used within the CM–SAF for the merging of TOA radiation budget components has been given. The implementation is in the system integration phase. We expect that the products derived at RMIB will fulfill the consistency requirements of the Climate Monitoring SAF.

4. ACKNOWLEDGMENTS

All METEOSAT images used for this study were obtained from the METEOSAT Archive and Retrieval Facility at EUMETSAT. All CERES products used for this study were obtained from the NASA Langley Distributed Active Archive Center.

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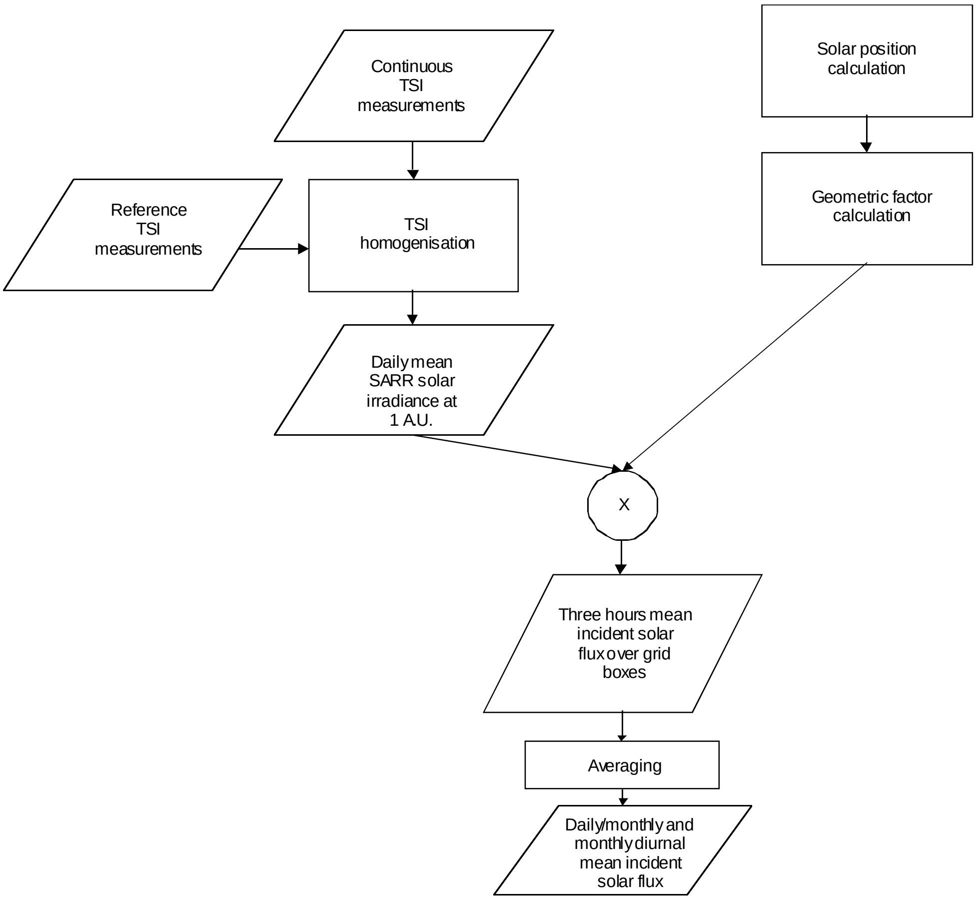

Figure 1: Flowchart of the system for the generation of the mean TIS.

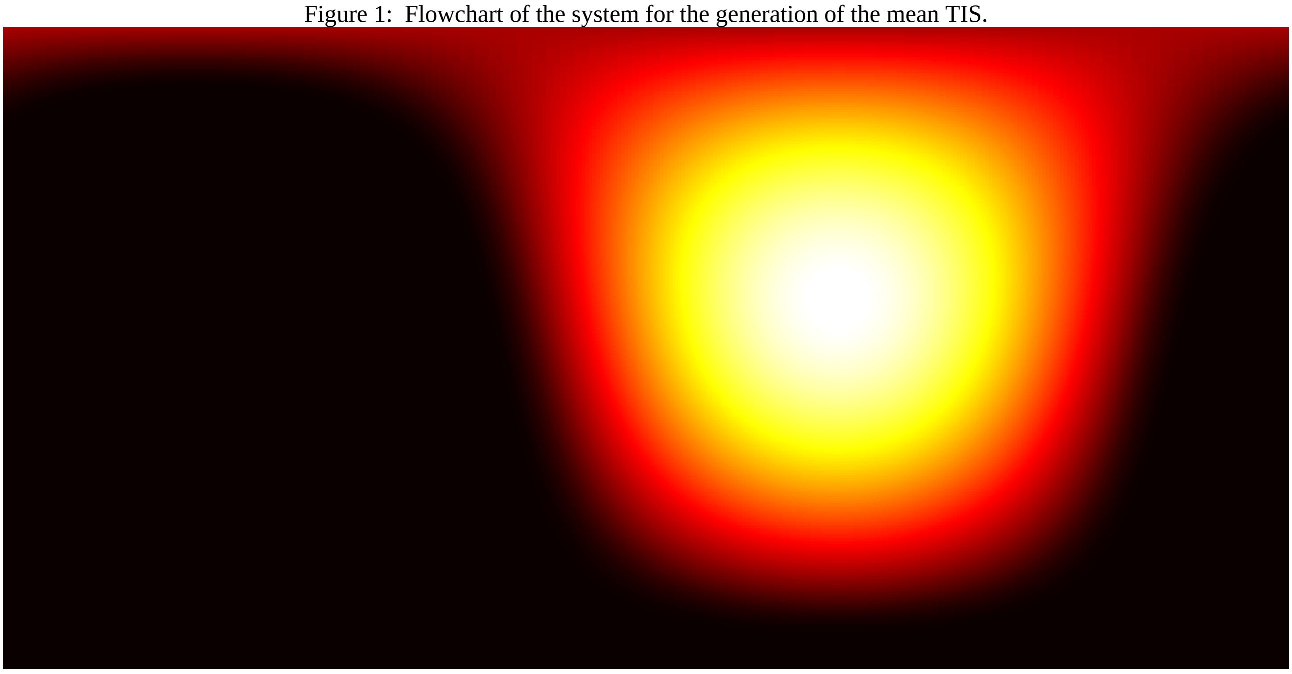

Figure 2: Mean TIS for the month of August 2001 08:00–09:00 UTC

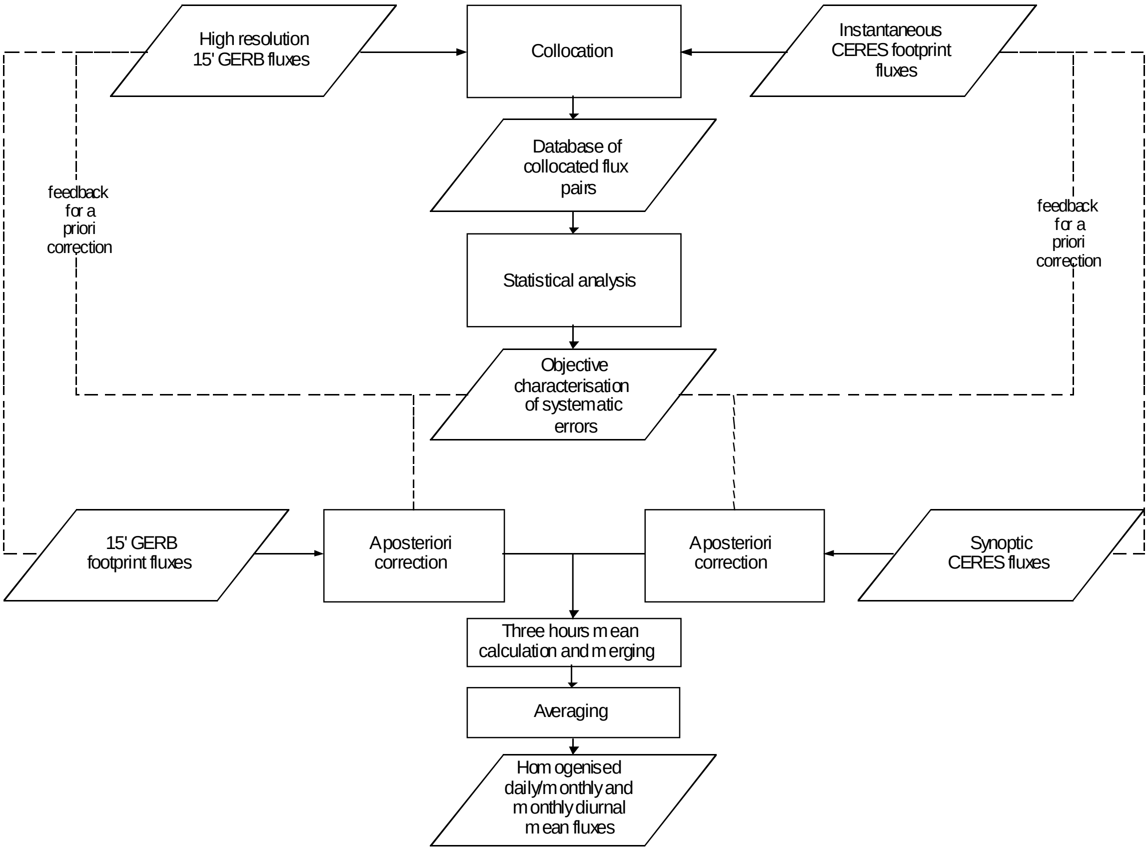

Figure 3: Flowchart of the system for the generation of the mean merged TRS and TET.

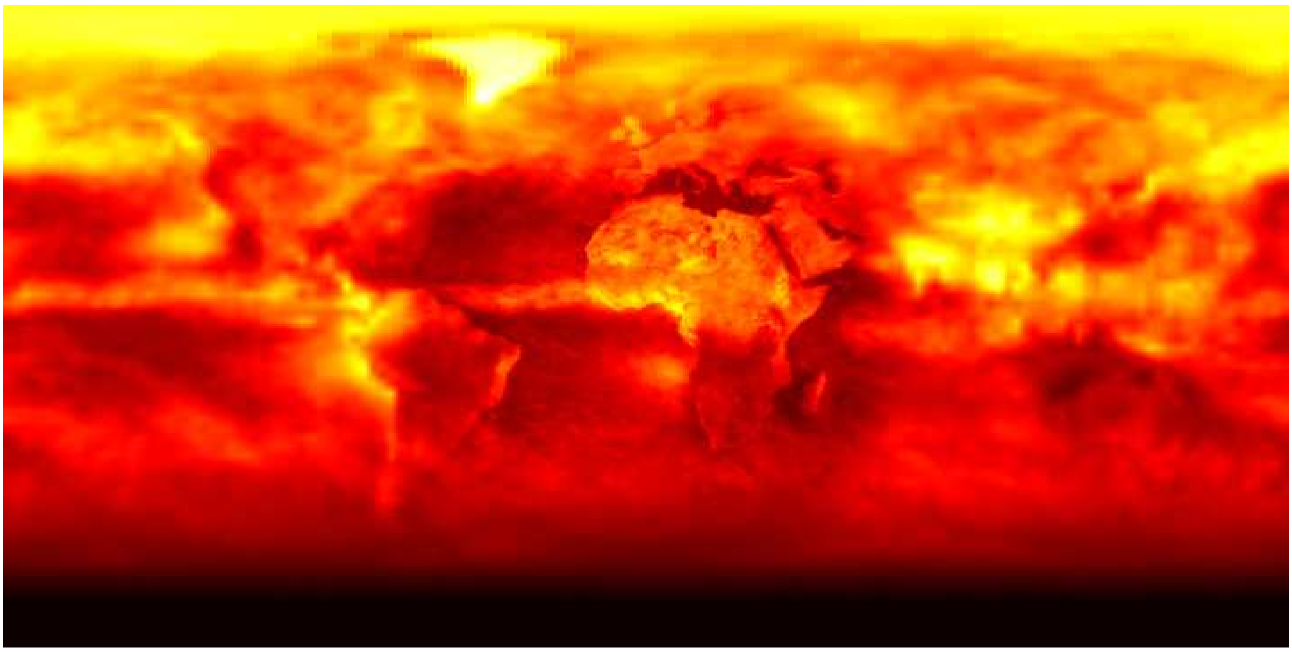

Figure 4: Merged TRS for the month of August 2001