Derivation of the Top Of The Atmosphere Radiative Fluxes from SEVIRI: Methodology, Accuracy and Perspectives.

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Abstract

A method to estimate the top of the atmosphere broadband unfiltered radiative fluxes from the Spinning Enhanced Visible and Infra Red Imager (SEVIRI) has been implemented at the RMIB in the frame of the Geostationary Earth Radiation Budget (GERB) data processing system. These estimations will be done operationally when the data from the first SEVIRI instrument will be available.

Estimation of TOA radiative fluxes from a narrow-band imaging device involves 3 stages: (i) the narrow-band measurements themselves, (ii) the estimation of the broadband unfiltered radiances from the NB measurements (spectral modeling) and (iii) the estimation of the fluxes from the unfiltered radiances (angular modeling). This paper presents the state-of-the-art methods for these modelings for both the reflected solar radiation and emitted thermal radiation. Expected accuracies, limitations and some perspectives are outlined.

1 Introduction

The top of the atmosphere (TOA) radiative fluxes are defined as the quantities of radiant energy leaving the Earth-atmosphere system. The radiant energy is usually separated into the *solar flux,* which corresponds to the reflection of the incoming solar radiation by the Earth-atmosphere system, and the *thermal flux* which is emitted by this system. The last one is sometimes refered to as *Outgoing Longwave Radiation (OLR)*. In conjunction with the incoming solar flux, these fluxes form the components of the Earth Radiation Budget (ERB).

The estimation of these fluxes is of great importance in the fields of meteorological, climatological and more generally environmental studies. For instance, they serve to validate the radiation scheme in numerical weather prediction systems [3] or general circulation models. They are also used to estimate radiative fluxes at the surface and hence to assess surface processes like evapotranspiration [7] or albedo [2]. An excellent synthesis of these uses can be found in [9], pages 19–38.

Satellite measurement of the Earth Radiation Budget (ERB) started more than 30 years ago using data provided by various weather satellite. These early studies serve to design the *Earth Radiation Budget Expriment* (ERBE) system [1] which has been launched in the mid-1980 and can be considered as the first valuable source of ERB measurements. This experience has been followed by the *Scanner for the earth Radiation Budget* (ScaRaB) [12] and since 1998 by the *Cloud and Earth's Radiant Energy System* (CERES) [21] on the TRMM and on the EOS-AM (*Terra*) satellites. In parallel, estimation of the TOA fluxes have been done from geostationary weather satellites like the ones of the GOES or Meteosat series [17]. In the future, improvements in the characterization of the ERB will be obtained through the launch of new satellites like the *Meteosat Second Generation* and its SEVIRI and GERB [10] instruments and the EOS-PM (*Aqua*) satellite with its CERES instrument.

All these experiences have outlined the 3 needed stages to estimate the TOA fluxes:

- The first steps are the *measurements* of the radiant energy using a radiometer. These provide the filtered radiances for different instrument channels L_{ch}:

$$L_{ch} = \int (L_{sol}(\lambda) + L_{th}(\lambda))\, \phi_{ch}(\lambda)\, d\lambda \tag{1}$$

  where $\phi(\lambda)$ is the spectral sensitivity of the channel *ch*.

- The *spectral modeling* is needed to convert those filtered radiances into the broadband unfiltered solar and thermal radiances:

$$\begin{aligned} L_{sol} &= \textstyle\int L_{sol}(\lambda)\, d\lambda \\ L_{th} &= \textstyle\int L_{th}(\lambda)\, d\lambda \end{aligned} \tag{2}$$

- The *angular modeling* is needed to convert the radiances (2) into the corresponding fluxes, which are defined as the integrals of the radiance fields on the upper-hemisphere:

$$\begin{aligned} F_{sol} &= \textstyle\int_{2\pi} L_{sol}(\Omega)\, cos(\theta)\, d\Omega \\ F_{th} &= \textstyle\int_{2\pi} L_{th}(\Omega)\, cos(\theta)\, d\Omega \end{aligned} \tag{3}$$

The structure of this paper follows these steps. Section §2 presents the measurement of the radiant energy using the SEVIRI radiometer. Sections §3 and §4 deal respectively with spectral and angular modelings in the case of SEVIRI. In section §5 are presented the improvements foreseen and possible validations using data from the GERB and CERES instruments. Some bottlenecks and possible bias due to observation from a geostationary platform are also discussed in this section.

2 The SEVIRI Instruments

The SEVIRI instruments will fly on the MSG series of EUMETSAT geostationary satellites. The geostationary orbit allows an excellent temporal sampling of the observations, 15 minutes in the case of SEVIRI. Furthermore, the dissemination of the measurements on a rectified grid simplifies greatly the data processing and allows an easy and accurate estimation of *clear sky* quantities. On the other hand, geostationary observation can only cover a small fraction of the Earth surface (about 40%) and this fraction is reduced when discarding the most oblique observation angles. For instance, if the viewing angle is limited to 60ř, the useful field of view reduces to 20% of the Earth surface.

For the estimation of TOA fluxes, 2 characteristics of the instrument are of prime importance:

- The *noise level* affecting the instrument's measurement. For SEVIRI, the specification for the noise level is very low (see [6], page 7) and one can prove that this will not contaminate the TOA fluxes significantly. Furthermore, ground characterization on the proto-flight model has shown noise levels well under these specifications [18].
- The *radiometric calibration* of the instrument channels. The calibration method is described in [15]. From this source, the expected calibration accuracies are better than: 0.5% for the thermal channels using the on board blackbody and 5% for the solar channels after vicarious calibration over bright deserts, ocean and cloudy scenes. The methodology for this vicarious calibration is explained in [8]. The solar channels accuracy of 5% should be available after about 1 year of instrument operation.

In the first approximation, the noise and the calibration errors will propagate through the spectral and angular modelings up to the final products.

3 Spectral Modeling

The spectral modeling aims to estimate the broadband unfiltered solar reflected and thermally emitted radiances (2) from the filtered radiances (1) in the different instrument's channels $\{L_i\}$. The spectral modeling for each kind of radiation (solar or thermal) is only dependent on the SEVIRI channels which are sensitive to that kind of radiation:

$$\begin{aligned} L_{sol} &= L_{sol}(L_{0.6\mu}, L_{0.8\mu}, L_{1.6\mu}) \\ L_{th} &= L_{th}(L_{6.2\mu}, L_{7.3\mu}, L_{8.7\mu}, L_{9.7\mu}, L_{10.8\mu}, L_{12\mu}, L_{13.4\mu}) \end{aligned} \tag{4}$$

The HRV channel, which is poorly calibrated and does not have full-disk coverage, and the $IR3.9\mu$, which is contaminated by solar reflected radiation, are not used in equations (4). The inference of the unfiltered radiances from NB measurements is usually done using polynomial regressions:

$$L_{sol} \ or \ L_{th} \ = \ c_0 \ + \Sigma_i \, c_i \, L_i \ + \Sigma_i \Sigma_j \, c_{ij} L_i L_j \ + \ ... \tag{5}$$

The parametrization of the solar and thermal regressions is obtained as a best-fit on a large number of Earth-atmosphere conditions. This is done by building a data base of spectral radiance curves $L_{sol}(\lambda)$ and $L_{th}(\lambda)$ using the SBDART radiative transfer model [16]. The parameters $\{c_i\}$ of the regressions are dependent on the solar zenith angle for the solar radiation and on the viewing zenith angle for the thermal radiation.

For both kinds of radiation, second order regression has proved to be the best choice. The error (standard deviation) introduced by the spectral modeling is estimated at $\epsilon = 3.2\%$ for the solar radiation and $\epsilon = 0.7\%$ for the thermal radiation. The better result for thermal radiation is explained by the greater number of channels and lesser dispersion of the spectral signature $L(\lambda)$ in the thermal part of the spectrum.

In the first approximation, the error on the unfiltered radiances L_{sol} and L_{th} is the sum of the instrument calibration error and the error ϵ introduced by the spectral modeling. An interesting fact when using regression on N narrowband measurements is that the noise and calibration errors may be attenuated during the spectral modeling by $\sqrt{N}$, but this is only true if the calibration errors for the different channels are not correlated. Due to the calibration method for SEVIRI, we expect a high correlation between the channel calibration errors and thus we do not expect this attenuation. On the other hand, the instrument noise is uncorrelated and will be attenuated during the spectral modeling.

4 Angular Modeling

The angular modeling aims to estimate the broadband unfiltered fluxes F from the directional solar and thermal radiances L. This is usually done using a model $R(\theta, \phi)$ of the radiance field:

$$L(\theta, \phi) \ = \ R(\theta, \phi) \, \frac{F}{\pi} \tag{6}$$

When $R(\theta, \phi)$ is known, the flux can be inferred from the radiance as:

$$F \ = \ \frac{1}{R(\theta, \phi)} \, \pi \, L(\theta, \phi) \tag{7}$$

Obviously, the directional repartition of the energy is dependent on the kind of observed scene. The scenes having close angular behavior can be merged together to create a set of angular dependency models (ADMs).

For the solar radiation, a set of 12 ADMs has been derived from the ERBE experiment [20]. The accuracy of the angular conversion using the ERBE ADMs is estimated to be within 12% for the standard deviation of the instantaneous conversion. In a close future, an improved set of about 200 ADMs will be available from the Langley Atmospheric Research Center (LARC/NASA).

This set is named CERES-TRMM ADMs because it is derived from measurements of the CERES instrument on the TRMM satellite. Various studies have been dedicated to the estimation of the angular conversion accuracy using this new set of ADMs. A study done at RMIB in the frame of an ESA contract has demonstrated an improvement of a factor 2 according to the ERBE models [11]. This improvement is also expected by the CERES team [13].

To convert one pixel radiance into the flux, one needs to select the best suited ADM for this pixel. For the ERBE ADMs this needs the characterization of the surface type and the cloud fraction value within the pixel. To use the CERES-TRMM ADMs an additional characterization of the cloud cover in term of optical depth and phase is needed. It has been shown that this scene identification is possible using the NB SEVIRI measurements [4].

For the thermal angular conversion, the radiance field is, in average, not dependent on the azimuth angle of observation. The equation (6) then reduces to:

$$L(\theta, \phi) \; = \; R(\theta) \, \frac{F}{\pi} \tag{8}$$

where the angular model $R(\theta)$ now represents the limb-darkening and is mainly dependent on the atmospheric profiles of temperature and humidity and on the cloud coverage. Various studies have outlined the angular behavior of the conversion accuracy [14]. Even with a poor characterization of the Earth-atmosphere system, an accurate conversion is obtained for an observation angle close to $\theta_v = 50^o$. For θ_v values far from this, the conversion error is dependent on the information we have about the Earth-atmosphere system. Without any information, the nadir observation error is about 2%, except in case of optically thin and high clouds (cirrus), where the conversion error can reach up to 10%. This problem and the improvement that can be obtained using the spectral information from the imager is analyzed in [19]. In all the cases, the improvement that can be obtained using spectral information from SEVIRI is limited.

5 Validations, Improvements and Perspectives

The spectral modeling described in section §3 can be validated in-flight using broadband measurements provided by the GERB instrument. This validation will be done at RMIB in the frame of the GERB project. It is also possible to by-pass the error introduced by this spectral modeling using the GERB instrument [5]. The combined use of the 2 instruments allows also to take advantage of the state-of-the-art calibration of GERB.

The TOA fluxes derived from SEVIRI can be compared and validated to the ones produced by the CERES instruments on the EOS Terra and Aqua satellites. Here also an interesting synergy between instruments is foreseen: the homogenization of the TOA fluxes derived from geostationary and low orbit satellites seems of great interest. This homogenization will be done operationally within the EUMETSAT Climate Monitoring Satellite Application Facility [22].

Some interesting points remain of great interest to improve the estimation of TOA fluxes from SEVIRI or other Earth observation systems from a geostationary orbit:

- How to characterize the angular distribution of the thermal radiation in case of cirrus clouds. Standard algorithms can be used to characterize the cloud properties, but with accuracy not sufficient to improve significantly the angular conversion. Indeed, cloud characterization is very difficult for semi-transparent clouds.

- How to derive accurate solar reflected flux in sun glint area. In case of sun glint, the application of solar ADMs using equation (7) produces important conversion errors because the flux is obtained as the ratio of 2 high values: the radiance $L(\theta_v, \phi)$ and the model $R(\theta_v, \phi)$.

- Also, the thermal flux observation may present bias for hilly or mountainous areas. From a geostationary satellite, one observes always the warmest side of the mountain: South faces in the Northern hemisphere and North faces in the Southern hemisphere. A quantitative study should be done on this subject.

6 Conclusions

In this paper we have seen that the methodology for TOA fluxes retrieval is well-defined and has been widely applied in the past on data provided by various instruments. The application of this methodology for the SEVIRI instruments does not present any particular problems. The table hereafter summarizes the magnitude of the errors that affect the TOA fluxes estimated from SEVIRI:

steps	**solar**	**thermal**
NB measurement	5%	0.5%
spectral modeling	3.2%	0.7%
angular modeling	6%	2%
total	**14.2%**	**3.2%**

These values must be understood as *typical accuracies* as the accuracy is known to show regional patterns due to the viewing geometry.

According to the current Meteosat series, improvements are obtained at each stage of the processing: better calibration of the instrument channels, better spectral modeling exploiting a larger number of channels and better angular modeling using the new CERES-TRMM ADMs.

At RMIB, TOA fluxes will be derived from the SEVIRI instrument(s) using the method and models presented in this paper. To this date, it is not yet decided if these products will be disseminated or not to the user community.

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