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The satellite derived surface radiation budget for BALTEX

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The Satellite Application Facility for Climate Monitoring (CM-SAF) will derive operationally consistent cloud and radiation parameters in high spatial resolution for an area that covers Europe and part of the north Atlantic Ocean in an off-line mode. The availability of the 12-channel instrument SEVIRI and the GERB onboard the MSG satellite, together with the five-channel AVHRR instrument onboard the NOAA and METOP satellites provides a unique opportunity to derive consistent cloud and radiation parameters. The cloud and surface radiation products will be based on data from the polar orbiting satellites NOAA and METOP for the northern latitudes, and on data from the MSG satellite for the mid-latitudes. To reduce inhomogeneities in the transition from the mid-latitudes to the northern latitudes as much as possible, the same algorithms will be used for both areas. Here a brief description of the planned surface radiation budget products and the selected algorithms is given.

Introduction

With the upcoming new satellite METEOSAT SECOND GENERATION (MSG), with its new and improved instruments GERB (Geostationary Earth Radiation Budget) and SEVIRI (Spinning enhanced visible and infrared imager), it is possible to monitor the environment and the atmosphere in high temporal and spatial resolution. The GERB instrument is specifically designed to derive broadband radiation fluxes at the top of the atmosphere. The 12-channel SEVIRI instrument allows for an improved determination of cloud parameters from a geostationary satellite. It not only includes the AVHRR channels, but also additional channels which can be useful for cloud parameter determination (e.g. use of 13.4 μm channel for cloud-top height determination). Cloud parameters influence strongly radiation fluxes. An improved cloud detection and cloud parameter generation should improve the determination of surface radiation fluxes. As a new element of the distributed EUMETSAT ground segment, the Deutscher Wetterdienst (DWD) is a host for the Satellite Application Facility for Climate Monitoring (CM-SAF) dedicated to produce consistent climate data sets for a region covering Europe and surrounding areas up to the Arctic. The project has started in 1999, and is at the moment in the algorithm development and implementation phase. After a five year development phase, it turns over into an operational phase of processing products in a routine manner. An overview of the planned products of the CM-SAF is available via the EUMETSAT homepage http://www.eumetsat.de (Programmes under development, satellite application facilities). The surface radiation budget products will have a horizontal resolution of 15 km by 15 km and a time resolution covering daily and monthly means. It is planned to make instantaneous products available on request.

In this paper, the surface radiation budget products will be discussed in more detail. Preliminary results and comparisons with surface measurements of the longwave radiation are presented.

The shortwave surface radiation budget

For the calculation of the surface incoming shortwave flux (SIS), an algorithm similar to the one developed by Pinker (e.g. Pinker and Laszlo 1992) will be used. The basic idea for the algorithm is that a relationship between the broadband (0.2–4.0 µm) atmospheric transmittance and the reflectance at the top of the atmosphere (TOA) does exist. Once the transmittance is determined from the TOA albedo, the surface irradiance can be computed from the incoming solar flux at the top of the atmosphere and the atmospheric transmittance. With a radiative transfer model, the broadband atmospheric transmittance is calculated once in relationship to the broadband TOA albedo for a variety of atmospheric and surface states. The actual computation of the surface irradiance involves two steps. First the broadband TOA albedo is determined from the satellite measurement. Then the atmospheric transmittance is determined from the precomputed tables using the TOA albedo together with information on the atmospheric and surface states.

Input parameters into the algorithm are the broadband TOA albedo, solar zenith angle, surface albedo, cloud properties such as e.g. the cloud optical depth, aerosol and ozone data, and the total water vapour content of the atmosphere. The broadband TOA albedo for the area covered by the MSG satellite, the surface albedo and the cloud properties are derived by other groups within the CM-SAF. All other input data are either from climatological data sets (aerosol, ozone) or NWP-data (water vapour). Depending on the availability of appropriate data sets, satellite-derived values could be used. To calculate the TOA albedo for the CM-SAF region not covered by the MSG satellite (north of 60°N), a narrow-to-broadband conversion of the satellite data and the application of an angular directional model (Suttles *et al.* 1988) is necessary.

Using broadband fluxes at the top of the atmosphere has the advantage that the algorithm is independent of the satellite instrument and allows for the application to multiple sensors (here MSG/SEVIRI and AVHRR).

The surface net shortwave radiation (SNS) will be calculated from the surface irradiance and the surface albedo. Alternatively, the net shortwave radiation can be derived directly from the TOA reflected flux. From radiative transfer modelling Li *et al.* (1993) established a relationship between the TOA reflected flux and the flux absorbed at the surface which is linear for a fixed solar zenith angle. Sensitivity studies (e.g. Masuda *et al.* 1995) showed that the relationship is independent of the cloud optical thickness and the surface albedo, and weakly dependent on the sun zenith angle, the amount of water vapour in the atmosphere and the cloud type. The algorithm is intended to be used for automatic quality control. As a preparatory study, the algorithm was applied to data from the Scanner for Radiation Budget (Hollmann and Bodas 2001).

The longwave surface radiation budget

The determination of the surface downward longwave flux (SDL) from satellite radiances is difficult as the atmosphere is only transparent to thermal radiation in the IR window spectral region (8–13 µm). Thus, in the other spectral regions, the TOA outgoing longwave radiation is de-coupled from the surface longwave radiation. More than 80% of the clear-sky longwave radiation reaching the surface is emitted within the lowest 500 m of the atmosphere. The downward longwave radiation at the surface depends mainly on the air temperature and water vapour profile of the lower layers of the atmosphere in clear-sky conditions. In cloudy cases the fluxes at the TOA and surface are entirely de-coupled. Clouds contribute at the surface through the 8–13 μm window. The cloud-base temperature, which is difficult to measure with passive satellite instruments, is an important parameter determining the radiation reaching the surface.

For the calculation of the surface downward longwave flux the algorithm described by Gupta (1989) and Gupta *et al.* (1992) is used. The algorithm is based on the assumption that there is a linear relationship between the clear-sky flux F_{clear} and the flux in cloudy conditions F_{cloudy} multiplied with the fractional cloud cover A_c. Based on extensive radiative transfer calculations, the clear-sky downward longwelling flux is parameterised as a function of the total water vapour content of the atmosphere and an effective emitting temperature (calculated as a weighted sum from different levels). The downward flux for the cloudy case is calculated as a function of the total water content below the cloud and the temperature at the cloud base. The cloud-base temperature is estimated from the cloud-top height with assumptions on cloud thickness (Telegades and London 1954). The required input cloud information such as cloud cover, cloud type, cloud-top temperature and height are derived from the satellite data. Profiles of temperature and humidity are from ECMWF-analyses.

The surface outgoing longwave radiation (SOL) is calculated from the Stefan-Boltzmann law. It requires maps on surface temperature and emissivity (e.g. from the CERES project http://www-surf.larc.nasa.gov/surf/emiss.html). For consistency it is intended to use the surface temperature from the same data set that is used to calculate the SDL, which is NWP model output.

Within the implementation phase of the CM-SAF project, the algorithm was coded and validation with surface measurements has started. August 1995 was chosen as a target month for comparisons with surface measurements. In this first testing phase the Gupta-algorithm was driven by cloud properties (cloud-top temperature and cloud flag), derived from ISCCP-DX (Brest *et al.* 1997) data. The necessary atmospheric profiles of temperature and specific humidity are from ECMWF data.

Input data

In order to have consistency between the cloud and radiation products of the CM-SAF, CM-SAF cloud products will be used as input to the surface fluxes. As the CM-SAF cloud software is still in the evaluation and tuning stage, alternative cloud products have been selected for the present prototyping activities. They are the ISCCP-DX data sets from August 1995 and ECMWF analysis data from the same time period. These data sets have been used to test the prototype software.

ISCCP data

The International Satellite Cloud Climatology Project (ISCCP, e.g. Rossow and Schiffer 1991) uses data from geostationary and polar orbiting weather satellites to derive a global cloud climatology. The ISCCP-DX data are sampled every three hours and 30 km. The surface downwelling longwave algorithm uses the cloud flag and the cloud-top temperature from the ISCCP-DX data. For the validation of the calculated results with surface measurements, so far the validation has been restricted to the METEOSAT field of view. For the monthly mean gridded image, all available (in space and time) METEOSAT and NOAA data have been used.

ECMWF data

European Centre for Medium Range Forecast (ECMWF) analysis data were used for the atmospheric variables temperature and humidity. ECMWF analysis data are available in a 0.5625° × 0.5625° rectangular latitude/longitude grid in 31 levels, which can be related to pressure levels. From the atmospheric profiles, total precipitable water and water content below the cloud was calculated. Additionally, the surface temperature and interpolated layer temperatures were used.

Verification of clear-sky parameterisation

The original parameterisation by Gupta used temperature values derived from TOVS soundings. Here an adaptation was made to apply it to ECMWF atmospheric profiles. To validate the adaptation, radiative transfer calculations (RTM) were made for four German measurement sites. The RTM calculations were made using the Fu *et al.* (1997) infrared radiative transfer model. ECMWF temperature profiles were selected for the nine pixels closest to the site and when surface and satellite observations reported clear-sky conditions. The clear-sky RTM calculations were compared with the parameterisation. The results can be seen in Table 1. The parameterisation is in good agreement with the RTM calculations for lower elevation stations, with a root mean square deviation (RMSD) of 4–5 W m^{-2} and a correlation coefficient better than 0.98.

Validation with surface measurements

Measured hourly values of the SDL are compared with instantaneous SDL values derived from the ISCCP-DX data. The nine closest pixels to the station and measured within the one-hour time interval of the surface station were averaged. In total for each of the four stations 248 measurements are available. The results can be summarised as follows:

— The mean bias error (MBE) reaches values up to 17 W m^{-2} (up to 5%, Table 2).
— The root mean square difference (RMSD) for instantaneous values is within 36 W m^{-2} (10%) and 24 W m^{-2} (7%) for daily averages.
— The results at present do not reveal a significant difference in the results at the main synoptic hours (0, 6, 12, 18 UTC) where ECMWF fields were available, and the intermediate synoptic hours (3, 9, 15, 21 UTC) where ECMWF fields were linearly interpolated .
— The results for clear sky show a negative bias (up to –21 W m^{-2} or 6%). The clear-sky comparison was performed when the surface observation and the nine pixel average indicated no clouds. Analysis of the occurrence of the clear-sky cases showed, that they almost exclusively appear during night-time hours.
— ISCCP cloud cover shows a good agreement with surface observations. Monthly averages for daytime and night-time cloud cover shows comparable agreement, the RMS is

Table 1. Comparison of clear-sky radiative transfer calculations with the Gupta-parameterisation for four stations in Germany.

	Geisenheim	Lindenberg	Schleswig	Stuttgart
Mean value RTM (W m^{-2})	329.3	332.7	331.7	328.7
Mean value param. (W m^{-2})	330.3	331.3	329.2	329.2
RMSD (W m^{-2})	3.8	3.9	5.0	3.7
RMSD (%)	1.2	1.7	1.5	1.3
MBE (W m^{-2})	–1.0	1.4	2.5	–0.5
MBE (%)	0.3	0.5	0.8	0.2
R	0.99	0.99	0.98	0.99

Table 2. Comparison of satellite derived surface downward longwave flux values with surface measurements.

	Lindenberg	Geisenheim	Schleswig	Stuttgart
Monthly mean in situ (W m^{-2})	343.1	357.4	339.6	342.1
Monthly mean satellite (W m^{-2})	356.9	358.9	356.7	358.1
RMSD (W m^{-2})	30.5	24.2	36.4	34.1
RMSD (%)	8.6	6.7	10.2	9.5
MBE (W m^{-2})	13.8	1.5	17.1	16.0
MBE (%)	3.8	0.4	4.8	4.5
R	0.6	0.67	0.45	0.46

slighter higher during night-time than during daytime.

Benefit for BALTEX

The CM-SAF surface radiation products cover the BALTEX region. They, therefore, support monitoring of the BALTEX region even beyond the major BALTEX research phase. The CM-SAF development contributes right now to the BALTEX experiment, as August 1995 has been chosen as a target month for comparison with surface observations. The derived surface radiative fluxes for this month will be available on request to the BALTEX community. The SAF on Climate Monitoring, as a registered BALTEX Data User, is using surface radiation measurements collected at the BALTEX meteorological data centre.

Summary and outlook

The development work so far has concentrated on the coding and validation of the net shortwave radiation using the Li-Leighton algorithm and the coding and validation of the longwave fluxes. In this paper the methods to derive the surface radiation budget are described. First comparisons with German and Swedish longwave radiation measurements show a mean bias error up to 17 W m^{-2} (up to 5%) and a root mean square difference for instantaneous values of up to 36 W m^{-2} (10%) and 24 W m^{-2} (7%) for daily averages. The comparison of the parameterised model with radiative transfer calculations for clear-sky cases and low altitudes shows a good agreement which indicates that the selection of ECMWF model layers for the parameterisation was appropriate. The validation activities for the longwave fluxes are being continued. The development activities presently focus on the surface incoming shortwave flux.

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