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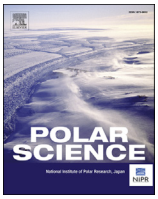

Operational high latitude surface irradiance products from polar orbiting satellites

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A R T I C L E I N F O

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It remains a challenge to find an adequate approach for operational estimation of surface incoming short- and longwave irradiance at high latitudes using polar orbiting meteorological satellite data. In this presentation validation results at a number of North Atlantic and Arctic Ocean high latitude stations are presented and discussed. The validation results have revealed that although the method works well and normally fulfil the operational requirements, there is room for improvement. A number of issues that can improve the estimates at high latitudes have been identified. These improvements are partly related to improved cloud classification using satellite data and partly related to improved handling of multiple reflections over bright surfaces (snow and sea ice), especially in broken cloud conditions. Furthermore, the availability of validation sites over open ocean and sea ice is a challenge.

1. Introduction

The surface radiation budget is an essential parameter for understanding our biological and physical environments. Over land, surface observations are quite frequent, while such observations are sparse over ocean areas. World Climate Research Programme (WCRP) initiated the Baseline Surface Radiation Network (BSRN, Ohmura et al., 1998), providing high quality in situ measurements for validation of satellite and climate model estimates of the surface radiation budget. In addition to these high quality measurements, a number of measurements of lesser quality also exist. However, these do by no mean cover all areas and are usually most dense over populated areas. Satellite remote sensing provides a mechanism to fill in the spatial gaps between the in situ measurements in order to provide spatially consistent products. These products can be useful for comparison with numerical simulations (especially since the cloud information is more accurate than cloud information from numerical simulations), for usage in biology etc.

The Norwegian Meteorological Institute (METNO) is part of the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) Satellite Application Facility (SAF) for Ocean and Sea Ice (OSISAF, see http://www.osi-saf.org/). Within this framework METNO is part of the High Latitude (HL) Processing Centre and has developed a system for estimation of the Surface Solar Irradiance (SSI) and Downward Longwave Irradiance (DLI) at the surface using polar orbiting satellites (NOAA and EUMETSAT). Similarly, for low and mid latitudes, Météo-France has developed and implemented algorithms doing the same, but using geostationary satellite information as input. Algorithms and processing is tuned for ocean areas although validation data in such conditions are sparse.

SSI is estimated from single passage AVHRR data. Single passage products are combined into a daily product at 5 km horizontal resolution and on a polar stereographic map projection. Data are presented north of 50°N at present.

This presentation provides details on how the OSISAF SSI and DLI products are generated using AVHRR data as input and how these products can be validated. These products were not included in the validation performed by Ineichen et al. (2009) and are validated using stations that are located further north than that study. The time period being examined is January 2013 through September 2015.

First the method is outlined, then the results are presented and discussed with final comments in the conclusion.

2. Methods and data

2.1. Surface solar irradiance

The solar irradiance at the surface (E) is a function (Eq. (1)) of the solar irradiance at the top of the atmosphere, the clear sky

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atmospheric transmittance (T_a), and the combined effects of clouds through a cloud factor (T_{cl}) (e.g. Brisson et al., 1994, 1999):

$$\begin{aligned} E &= S'\mu_0 T_a T_{cl} \\ S' &= \frac{S_0}{\rho^2} \\ \mu_0 &= \cos\sigma \end{aligned} \tag{1}$$

where σ is the solar zenith angle, S_0 is the solar constant (approximately 1367 W/m^2). ρ^2 (Eq. (2)) is a correction factor for the varying distance between the Earth and the Sun. The annual cycle in the extraterrestrial solar irradiance is approximately ±3% about the mean due to a variation in the distance between the Earth and the Sun. This variation can be defined in different ways, but here the specification of Paltridge and Platt (1976) will be used.

$$\rho^2 = \frac{1}{1.00011 + 0.034221\ \cos\theta + 0.001280\ \sin\theta + 0.000719\ \cos 2\theta + 0.000077\ \sin 2\theta} \tag{2}$$

where

$$\rho = \frac{D^{SE}}{\overline{D^{SE}}} \quad \text{and} \quad \theta = \frac{2\pi d_n}{365}$$

D^{SE} is the actual distance between the Sun and the Earth and $\overline{D^{SE}}$ is the mean distance (referring to $1AU$). d_n is the day of the year starting at 0 on January 1 and ending at 364 on December 31.

The parametrisation used for clear sky atmospheric transmittance (T_a) in this study (Eq. (3)) is described in Darnell et al. (1988, 1992). It was evaluated in Godøy (2000). This parametrisation is independent of the satellite observation. It includes the effect of absorption in water vapour, ozone, oxygen, and carbon dioxide, as well as scattering by aerosols and Rayleigh scattering. The atmospheric back-scatter of surface reflected rays is parametrized by the surface pressure (p_s) and albedo (A_s):

$$\begin{aligned} T_a &= e^{-\tau}(1 + 0.065 p_s A_s) \\ \tau &= \tau_0 \left(\frac{1}{\mu_0}\right)^N, \quad \textit{where } N = 1.1 - 2\tau_0 \\ \tau_0 &= \tau_{O3} + \tau_{H2O} + \tau_{O2} + \tau_{CO2} + \tau_R + \tau_a \\ \tau_{O3} &= 0.038 U_{O3}^{0.44} \\ \tau_{H2O} &= 0.104 U_{H2O}^{0.3} \\ \tau_{O2} &= 0.0075 p_s^{.87} \\ \tau_{CO2} &= 0.0076 p_s^{0.29} \\ \tau_R &= 0.038 p_s \\ \tau_a &= 0.007 + 0.009 U_{H2O} \end{aligned} \tag{3}$$

In the equations above, τ represents the optical depth due to various absorbers, μ_0 is as before the cosine of the solar zenith angle, p_s is the nominal surface atmospheric pressure in atmospheres and U is the atmospheric load (in cm) of various constituents. The cloud factor (T_{cl}) is a function of the cloud albedo and requires several processing steps to be determined.

1. AVHRR counts are converted to scaled radiance by the approach described by NOAA. This is a reflectance measure for overhead Sun.
2. The scaled radiance is converted to a pseudo bi-directional reflectance by division with the cosine of the solar zenith angle and correction for the distance between the Earth and the Sun (Eq. (2)).
3. Narrowband to broadband correction (Hucek and Jacobowitz, 1995).
4. Anisotropy correction (Manalo-Smith et al., 1998).

The result is a directional independent measure of the cloud albedo. However, it is well known that the visible channels of the AVHRR instrument is subject to degradation with time (e.g. Rao and Chen, 1996, 1999) after satellite launch. The corrections for AVHRR released regularly by NOAA through http://noaasis.noaa.gov/NOAASIS/ml/calibration.html are implemented in the processing when available.

Generally the cloud transmittance is related to the cloud albedo through the relationship (Eq. (4)).

$$a_c + T_c + A_c = 1 \tag{4}$$

where a_c represents cloud absorption, T_c represents cloud transmittance and A_c represents cloud reflection which is interpreted as albedo in this context following the narrowband to broadband and anisotropy corrections. This basically means that what is not transferred through a layer is either reflected by or absorbed in the layer. The main problem for estimation of satellite derived SSI is to determine the effects of clouds on radiation (multiple reflection, transmission, absorption). These processes have to be related to the observed cloud albedo and knowledge of the atmospheric conditions. This method is described in Frouin and Chertock (1992). The first equation (Eq. (5)) below relates the satellite observed albedo (A) to the combined cloud and surface albedo (A'). The second equation (Eq. (6)) describes the cloud absorption as a function of the combined albedo of the cloud and the surface and the surface albedo. By subtracting the surface albedo from the combined albedo, the cloud albedo remains. This is related to the cloud absorption through a cloud absorption factor (m). Originally (Frouin and Chertock, 1992) the relationship depended on a factor α which varied from 0.03 to 0.4, according to cloud liquid water content and the solar zenith angle (increasing zenith and liquid water gives decreasing α). In this implementation, α is replaced by $m\mu_0$. This implies that the dependency of cloud liquid water content is constant while the solar zenith angle dependency is dynamic. However, the combined effect of $m\mu_0$ is confined within the limits specified for α. The third equation (Eq. (7)) represents the cloud factor (T_{cl}), that is the effect of clouds on the irradiance that reach the surface.

$$A = A_{ray} + \frac{T_{dt} A'}{1 - S_a A'} \tag{5}$$

$$a_c = m\mu_0 (A' - A_s) \tag{6}$$