Regional Bias in the OLR Estimated from the Geostationary Orbit

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Abstract

The analysis of one year of CERES–Terra data provides further evidence that the longwave radiation escaping from the atmosphere exhibits significant variability according to the azimuthal angle of observation. A regional analysis of this variability shows that the anisotropy in azimuth is maximum over mountain and desert areas and under cloud–free conditions. A relative difference between North and South views of about 5% in annual average is observed over the Himalayan region in the $8-14$ μm infrared window. We think that the remote sensing community should be aware of this variability, in particular when analyzing infrared data provided by instruments on geostationary orbits. Indeed, in this case, the azimuthal anisotropy may lead to systematic overestimation of the outgoing longwave radiation and to biases on retrieved quantities such as the surface temperature.

1 Introduction

The observation of the Earth in an atmospheric infrared window (such as $8-14$ μm) is widely used to quantify surface properties (e.g. temperature) and processes (e.g. evapotranspiration). Broadband measurement of the longwave radiance (such as from 4 to 50 μm) is used to estimate the Outgoing Longwave Radiation (OLR, in fact irradiance) which is one of the components of the Earth's radiation budget.

The measured narrowband and broadband radiance at the Top Of Atmosphere (TOA) is usually supposed to be dependent on the Viewing Zenith Angle (*VZA*) and not on the Viewing Azimuth Angle (*VAA*). The dependency in *VZA* is explained [e.g. *Otterman*, 1997] as a result of the absorption/emission by the atmospheric constituents along an optical path that increases with the *VZA* as well as by the surface emission according to this angle. Azimuthal variability of the thermal emission just above vegetated surfaces has been described in various studies and explained as a result of differential solar warming of the vegetation structure [e.g. *Kimes*, 1981]. Logically, the anisotropy at the surface level should propagate up to the TOA albeit reduced due to the atmospheric constituents and clouds.

Lipton and Ward [1997] have simulated the anisotropy for mountain areas in North America using digital elevation data and an atmospheric model. They have shown that the variation of the incoming solar flux with the surface slope can lead to large biases in satellite retrieval of surface temperature.

Using simultaneous IR radiances from GOES-8, -9 and -10 satellites, *Minnis and Khaiyer* [2000] were able to observe the anisotropy in the azimuth direction. They have shown that the phenomenon is closely correlated with surface slopes, as suggested by *Lipton and Ward.* Nevertheless, using only observations from geostationary satellites (i.e. located over the Equator) the *Minnis and Khaiyer* [2000] analysis may underestimate the magnitude of the azimuthal anisotropy. On the other hand, this approach allows an interesting analysis of the diurnal cycle of it.

In this paper, evidence of azimuthal anisotropy is highlighted using a simple statistical analysis of CERES data. The data and methodology used allow to estimate the annual average of the azimuthal variability at regional scale. In addition, the study provides a quantitative relationship between the anisotropy in the atmospheric infrared window and the one observed for broadband longwave radiance.

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2 CERES–Terra data

Our study is based on 12 months of the Cloud and the Earth's Radiant Energy System (CERES) [*Wielicki et al.*, 1996] data from the Terra spacecraft. The satellite is operating in a sun–synchronous orbit with the descending node crossing time of 10:30. This implies that the satellite observations are done at Local Time (LT) close to 10.30 and 22:30. The CERES instrument is a 3–channels broadband radiometer providing accurate measurement of shortwave ($0.3 - 5$ μm), longwave ($5 - 50$ μm) and infrared window ($8 - 12$ μm) radiances. There are two identical CERES instruments aboard Terra. One instrument is operating in a cross–track scan mode and the other in a biaxial scan mode. The first mode is used to obtain the complete spatial coverage of the Earth while the biaxial scan mode is mainly used to characterize the angular distribution of the radiation (*Angular Distribution Model*). In the second mode there is a complete sampling in zenith VZA and azimuth VAA angles. For the analysis, 314 days of CERES–Terra data in biaxial scan mode are used, ranging from November 2000 to November 2001. This amounts to about $1.6 \cdot 10^9$ observations, half during the morning pass and half during the evening pass.

3 Methodology

According to the VAA, each CERES observation of the Earth is classified as observation *from the South* or *from the North*. An observation *from the South* corresponds to a viewing azimuth VAA in the range $90° - 270°$. The averaged CERES longwave and infrared window radiances measured *from the South* L_S and *from the North* L_N are evaluated on a $1° \times 1°$ box grid. For the data used, there are about 13 000 *South* and *North* observations for each box and instrument channel. The difference $(L_S - L_N)$ between these two radiances is a simple indicator of the anisotropy in azimuth. In the following, the relative difference Δ, expressed in percent, will be used as the measurement of the anisotropy:

$$\Delta = \frac{L_S - L_N}{(L_S + L_N)/2}. \tag{1}$$

4 Results

Figure 2a shows the regional variation of Δ for the CERES infrared window channel for the morning orbit (10:30 LT). This figure provides evidence that, on average, the anisotropy in azimuth Δ is positive in the Northern hemisphere and negative in the Southern. The largest anisotropy is observed over mountain and desert areas like the Himalayan region, the Alps, the Atlas, the North and South American Cordilleras, the South African and Australian deserts. For land surface, the typical annual average anisotropy at 10:30 LT ranges between 1% and 5%.

Applying the same analysis on data from the evening orbit at 22:30 does not produce these areas of large azimuthal anisotropy over mountains or deserts. The anisotropy appears then to be caused by a difference in the daytime solar warming of North and South faces of the surface.

Regional anisotropy for the CERES longwave channel is given in Figure 2b. Compared to the infrared window case, the anisotropy is here reduced due to the atmosphere absorption/emission in spectral regions outside of the atmospheric windows. The scatter plot on Figure 1 shows the correlation between broadband and window anisotropy. On this graph, the anisotropy for broadband longwave radiance appears to be roughly 57% of the one in the infrared window.

To study the influence of the cloud cover on the anisotropy, the ERBE scene identification is used. This scene identification is done using the Maximum Likelihood Estimation (MLE) algorithm of *Wielicki and Green* [1989] which classifies the cloudiness according to the cloud fraction as clear ($< 5\%$), partly cloudy ($5 - 50\%$), mostly cloudy ($50 - 95\%$) or overcast ($> 95\%$). Figure 2c shows the regional variation of Δ when only the CERES clear or partly cloudy measurements are used to evaluate the *South* and *North* radiances in Equation 1. The

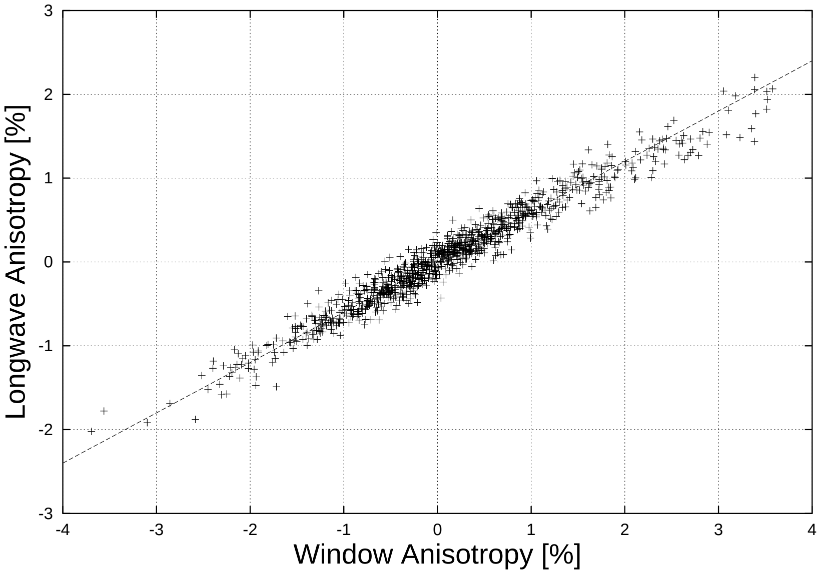

Figure 1: Scatter plot of the longwave versus the window anisotropies. Each dot corresponds to a 1 by 1 degree box. The correlation coefficient is 0.978 and the RMS error is 0.14%.

main result here is that, for cloud free conditions, the infrared radiance does not exhibit azimuthal anisotropy over the ocean. This is a valuable result for the remote sensing of the sea surface temperature. In Figure 2c, too high values of the azimuthal anisotropy appear to be measured over the ice packs near Antarctica and over Canadian tundra and Siberia. This is probably due to the fact that over reflective surfaces, such as ice and snow, the ERBE scene identification relies mainly on the CERES longwave measurement and is then correlated to the (small) signal we want to retrieve.

5 Conclusions

Our simple statistical analysis of CERES–Terra data demonstrates a significant dependency in azimuth for the thermal radiance field at the TOA, mainly over arid and mountain regions.

The regional analysis has only been done for the 10:30 and 22:30 local time. The data from the CERES instruments on the Aqua satellite will allow the same kind of analysis for 4:30 and 16:30 local time.

Since in the near future, new Earth observation capabilities will be available from geostationary orbits, one should be aware of this anisotropy in azimuth when using thermal infrared measurements. Indeed, from a geostationary orbit, the Northern hemisphere is always observed *from the South* and the opposite is true for the Southern hemisphere. As an example, Meteosat Second Generation which is planned to be launched in summer 2002 will carry the Geostationary Earth Radiation Budget (GERB) instrument, a broadband radiometer similar to CERES but designed for the geostationary orbit. The data processing for the GERB instrument (mainly estimation of the fluxes from the directional measurements) should take into account this azimuthal anisotropy to avoid overestimation of the Outgoing Longwave Radiation over the arid and mountainous areas.

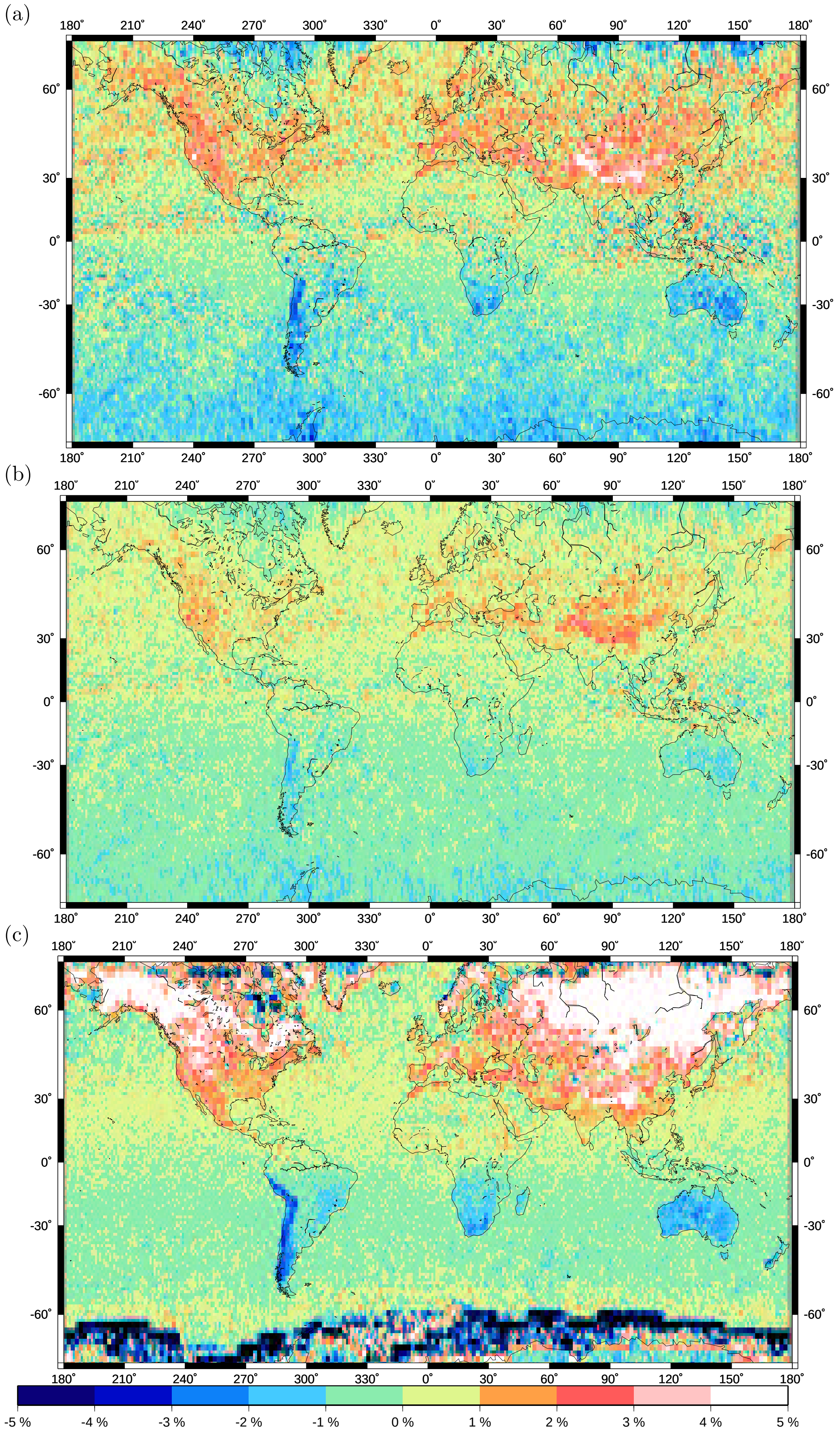

Figure 2: Annual average of the azimuth anisotropy Δ_4[%] for the CERES: (a) infrared window channel, (b) broadband longwave channel and (c) infrared window channel under clear and partly cloudy conditions only.

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