NOTES AND CORRESPONDENCE

An Intercalibration of METEOSAT-1 and GOES-2 Visible and Infrared Measurements

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ABSTRACT

An intercomparison between radiative parameters determined from visible and infrared channels of the METEOSAT-1 and GOES-2 geosynchronous satellites has been carried out using data obtained over the central Atlantic Ocean for 5 November 1978. Hourly visible–infrared measurement pairs at a nominal resolution of 5 km (METEOSAT) or 8 km (GOES) have been stored in 1° × 1° longitude–latitude regions. For the infrared intercomparisons, the GOES 11.5 μm radiance has been compared to METEOSAT infrared counts. The scatter in partly cloudy regions is interpreted as being caused by meteorological differences arising from differences in measurement time between the two data sets. For the visible intercomparison, the GOES measurements for clear and cloudy scenes have first been converted with the aid of scene-dependent angular reflectance and albedo models to estimates of the filtered shortwave radiance that GOES would have measured had it been in the METEOSAT position. This value has then been compared to METEOSAT counts for the shortwave channel. The results indicate that earlier METEOSAT calibrations made from airplane overflights of a limited variety of surfaces are applicable to much larger areas of cloud and ocean.

1. Introduction

The increasing availability of satellite measurements that can be interpreted in terms of radiative parameters has made clear the desirability of comparing data sets from different sources in order to understand the earth's radiative behavior over more comprehensive geographic and temporal scales than can be observed by any single satellite. Toward this end, the intercalibration of radiometric quantities obtained from different satellites is essential. An obvious way to perform such intercalibrations is to compare measurements made by different satellites at the same time and place. Two geosynchronous satellites that provide hourly measurements over their field of view and that have substantial areas of overlap are GOES-2 (GOES) and METEOSAT-1 (MET). Both satellites have similar visible (VIS) and infrared (IR) channels and have been used extensively for radiation budget analysis (Minnis and Harrison, 1984; Saunders and Hunt, 1983). The MET VIS channel has a spectral bandpass from 0.4 to 1.1 μm with a resolution of 2.5 km at satellite nadir. The GOES VIS channel has a spectral bandpass from 0.55 to 0.75 μm with nadir resolution of 1 km. Both VIS channels are digitized at 6-bit resolution, but the MET channel is transmitted as an 8-bit value with the addition of random noise in the lower 2 bits.

Both the MET and GOES IR channels have a spectral bandpass from 10.5 to 12.5 μm. The MET channel has a nadir resolution of 2.5 km, and the GOES channel has a nadir resolution of 8 km. Both channels are digitized and transmitted as 8-bit values. The MET radiometer scans from south to north in about 25 min and the GOES radiometer scans from north to south in about 20 min.

2. Preparation of intercomparison data sets

The GOES satellite is located nominally over the equator at 75°W longitude and the MET at 0° longitude; consequently, each satellite views the surface with the same satellite zenith angle at approximately 37.5°W longitude. Accordingly, a comparison region was established, which consists of 900 1° × 1° boxes centered from 41.5 to 32.5°W longitude and from 44.5°N to 44.5°S latitude. This area is mostly open ocean; the small portion of Brazil included within its boundaries was ignored for this study. The comparisons were done for 5 November 1978, a date for which full VIS and IR images are available from each satellite.

For each satellite, VIS–IR pixel pairs within the calibration region were sampled from the available measurements. For GOES, every IR pixel was used, and for VIS data, every eighth pixel of every eighth scan line was retained. For MET, every IR pixel was used, with the VIS data averaged to the same resolution. Each sampled pixel pair was stored in the appropriate 1° × 1° region. The average solar zenith angle, satellite zenith angle and relative azimuth angle at the time of the measurement were stored for each region. The relative azimuth is defined as zero in the backscatter direction.

3. Calibration of the infrared channel

The GOES and MET IR channels are nearly identical; consequently, the 11.5 μm GOES radiance has been compared directly to MET IR counts. Because the viewing zenith angles from the two satellites are approximately equal, no limb-darkening correction has been applied. There is no specific scene dependence for longwave (LW) radiance, so the comparison is made for all pixels regardless of the scene being viewed. The GOES IR counts have been related to LW broadband radiance L_{LW} by Minnis and Harrison (1984) using Nimbus-7 data.

4. Calibration of the visible channel

There are several reasons why a direct count-to-count or radiance-to-count comparison is not possible for the MET and GOES VIS data, even if there was no misregistration of the pixel pairs within the 1° × 1° regions. For the VIS comparison, with its strong dependence of shortwave (SW) radiance on solar and viewing geometry, a direct comparison would require that each satellite view the same region with the same viewing zenith angle at a time when the sun was directly over the region being viewed. However, the time difference between the two data sets (about half an hour) is such that this situation can be only approximated. Accordingly, the comparison has been carried out by first assuming that the SW radiant exitance of a region and scene type (clear ocean or overcast) can be measured accurately by one satellite (GOES). Bidirectional reflectance models and solar-zenith-angle-dependent directional models for albedo [as developed for several scene types from GOES data by Minnis and Harrison (1984)] were then used to calculate the radiance this satellite would see if it were in the position of the MET satellite.

Conversion of GOES VIS counts to SW radiance L_{SW} is based on Nimbus-7 broadband SW radiance measurements (Minnis and Harrison, 1984). In terms of GOES VIS counts D,

$$L_{\mathrm{SW}} = 1.3615(D^2 - 6.25)^{1/2} + 0.07636(D^2 - 6.25) \qquad (1\mathrm{a})$$

for $D^2 < 1450$ and

$$L_{\mathrm{SW}} = 28.334 + 0.09226D^2 \qquad (1\mathrm{b})$$

for $D^2 2 \geqslant 1450$. The SW radiant exitance M_{SW} is given in terms of L_{SW} and the bidirectional function χ, which is a function of scene type, solar zenith and angle θ, satellite viewing zenith angle ϕ, and relative azimuth angle ψ. The radiant exitance measured by GOES is

$$M_{\mathrm{SW}}(\mathrm{GOES}) = \pi L_{\mathrm{SW}}(\mathrm{GOES})/\chi(\mathrm{scene};\, \theta,\, \phi,\, \psi\ @\ \mathrm{GOES}), \qquad (2)$$

and the albedo is

$$\alpha(\mathrm{GOES}) = M_{\mathrm{SW}}(\mathrm{GOES})/[E_0\mu(\mathrm{GOES})], \qquad (3)$$

where E_0 is the distance-corrected solar constant (1376 W m^{-2} sr^{-1} at 1 AU) and μ is the cosine of the solar zenith angle. The spectral radiant exitance at the MET location is

$$M_{\mathrm{SW}}(\mathrm{spectral}\ @\ \mathrm{MET}) = \alpha(\mathrm{MET})E_0\mu(\mathrm{MET})(900.9/1376), \qquad (4)$$

where the ratio 900.9/1376 corrects broadband radiance for the spectral bandpass of the MET instrument. The MET albedo may be written in terms of the GOES albedo:

$$\alpha(\mathrm{MET}) = \alpha(\mathrm{GOES})\delta[\mu(\mathrm{MET})]/\delta[\mu(\mathrm{GOES})], \qquad (5)$$

where $\delta(\mu)$ is the directional function evaluated for the appropriate scene type and solar zenith angle.

The spectral radiant exitance measured by MET is defined to be

$$M_{\mathrm{SW}}(\mathrm{spectral}\ @\ \mathrm{MET}) = \pi L_{\mathrm{SW}}(\mathrm{spectral}\ @\ \mathrm{MET})/\chi(\mathrm{scene};\, \theta,\, \phi,\, \psi\ @\ \mathrm{MET}). \qquad (6)$$

Substituting (2), (3), (5) and (6) into (4) yields the assumed relationship between the broadband SW radiance observed by GOES and the spectral SW radiance that would be measured by GOES if it were in the MET position:

$$L_{\mathrm{SW}}(\mathrm{spectral,\ GOES}\ @\ \mathrm{MET}) = \frac{L_{\mathrm{SW}}(\mathrm{GOES})\chi(\mathrm{MET})\mu(\mathrm{MET})\delta[\mu(\mathrm{MET})]900.9}{\chi(\mathrm{GOES})\mu(\mathrm{GOES})\delta[\mu(\mathrm{GOES})]1376}. \qquad (7)$$

The MET VIS channel is significantly wider than the GOES VIS channel, and its response is peaked strongly at about 0.7 μm. As a result, the radiance calibration of the MET VIS channel is a strong function of the surface being viewed. The GOES VIS channel response is also strongly peaked (at about 0.65 μm), but its total bandwidth is sufficiently narrow that the scene dependence is much less prominent. It is clear, in any case, that the MET–GOES SW intercomparisons must be done separately for different scene types. For this purpose, an albedo threshold has been used to identify clear ocean surfaces and regions of total overcast. The threshold has been applied to each pixel in each 1° × 1° region, and the contribution of each pure scene type to the total regional radiance has been calculated. Four Universal Time (UT) hours on 5 November 1978 have been examined for this study: 1300, 1400, 1600 and 1800. For hours 1300, 1400 and 1600, a maximum albedo of 0.10 has been used for clear ocean. Minnis and Harrison (1984) have shown that the GOES ocean albedos are higher in the afternoon than at midday, and a value of 0.15 has been chosen at 1800 on the basis of their results. For isolating overcast regions, only albedos greater than 0.75 have been used for all hours. It should be noted that within every region there typically were substantial differences between the fractions of total pixels that MET and GOES identified as being clear or overcast. However, there were numerous regions at each hour for which both MET and GOES identified clear or overcast pixels. This thresholding was assumed to eliminate partially cloudy regions, with the attendent problem of determining cloud amount.

5. Results

The 11.5 μm LW radiance from GOES is shown as a function of MET IR counts in Fig. 1. All pixels in the comparison region (except the land regions in Brazil) have been used for the selected hours. Each

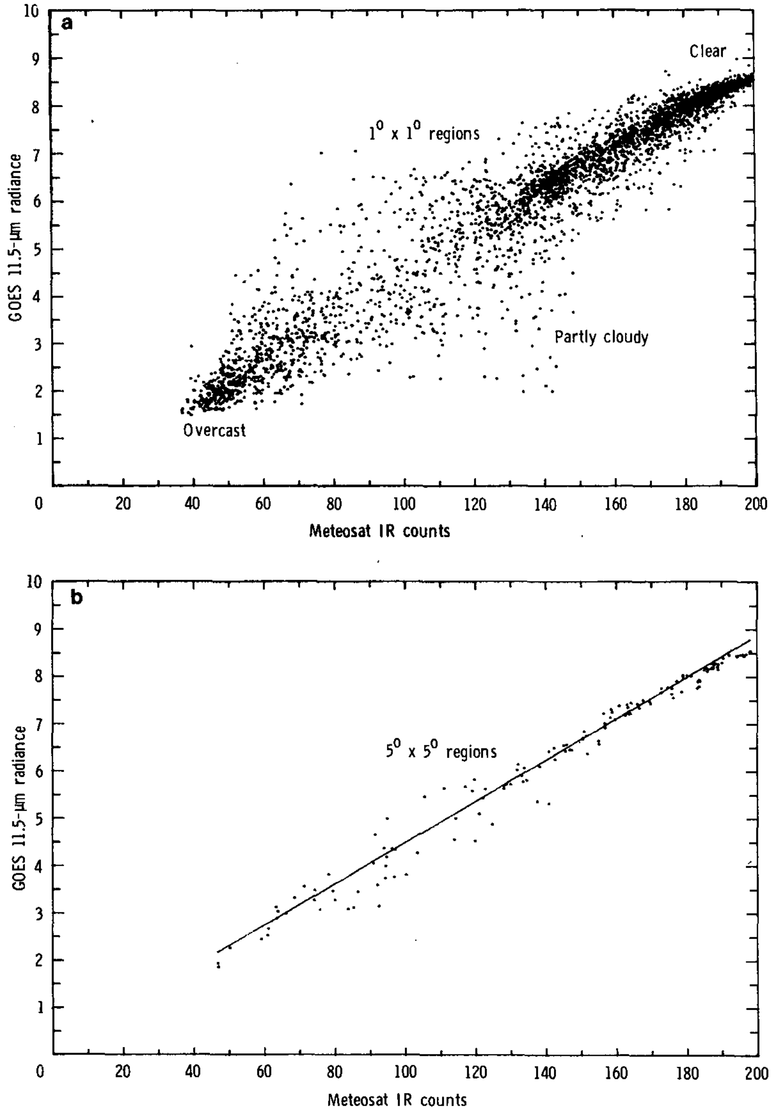

FIG. 1. Comparison between METEOSAT-1 IR counts and GOES-2 11.5 μm radiance for (a) 1° × 1° regions, (b) 5° × 5° regions.

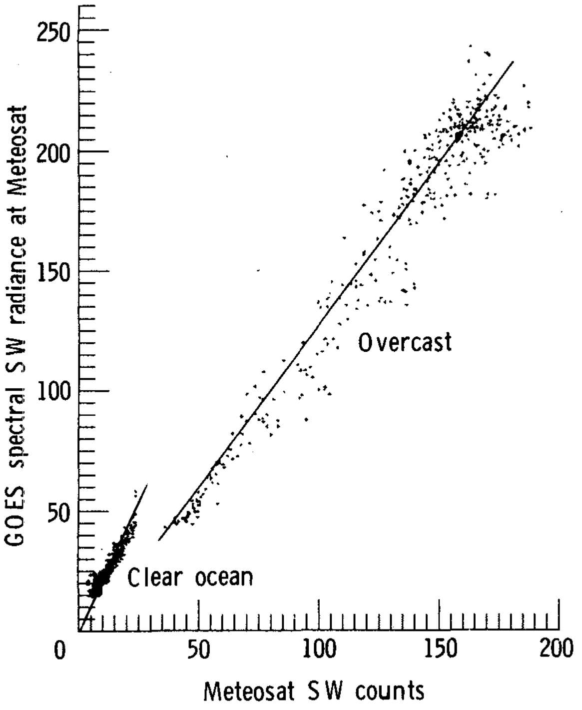

FIG. 2. Comparison between METEOSAT-1 SW counts and spectral SW radiance that GOES-2 would measure in the METEOSAT-1 position.

point in Fig. 1a represents the average 11.5 μm GOES radiance and MET IR count for all totally clear or completely overcast pixels within a 1° × 1° region. Small (cold) values can be interpreted as overcast regions, the largest (warmest) ones are identified as clear, and the ones in between represent partly cloudy regions. Because of the time difference between the MET and GOES data, the partly cloudy regions are not expected to be as well correlated as pure scene types. The scatter in the data can be attributed to changing meteorology within the partly cloudy regions as well as to possible small misregistrations of the regions. These effects could be expected to be much less significant for those pixels that are totally clear or completely overcast, as determined by both satellites. The effects of pixel misregistration and the advective processes can be minimized by averaging over larger areas. In Fig. 1b, the pixels have been averaged over 5° × 5° regions, with significant reduction in the scatter observed over partly cloudy pixels. A linear regression through zero and the data of Fig. 1b gives an 11.5 μm calibration of 1 MET IR count = 0.0436 W m^{-2} sr^{-1}. This value is in excellent agreement with accepted IR calibrations for MET.

The VIS comparisons are summarized in Fig. 2. The filtered (spectral) SW radiance that would be measured by GOES if it were in the MET position is given as a function of MET VIS counts. A linear regression through the overcast data is also shown in Fig. 2. The derived value of 1 MET VIS COUNT = 1.31 W m^{-2} sr^{-1} (filtered radiance) compares favorably with a value of 1.35 derived by Kriebel (1981) for stratocumulus clouds, based on airplane overflights of selected areas in the North Atlantic.

The linear regression through the clear scene data has been forced through zero. This fit yields a calibration of 1 MET VIS count = 2.24 W m^{-2} sr^{-1} (filtered radiance). There are several reasons why this calibration is considered less reliable than the one done for cloudy scenes and why it was considered necessary to force the regression through zero: a highly uneven distribution of data over a limited range of radiances, heavily weighting the lowest radiances in the present data; a digitization bias present in the MET data [which was also noted by Kriebel (1981) as a major source of error at low radiance levels]; nonlinearities and uncertainties in the GOES calibrations for low radiance levels; sunglint and possible cloud contamination; and the unknown effects of the assumption that MET spectral radiance is simply proportional to the SW broadband radiance [an assumption that is reflected specifically in (4)]. However, even with these uncertainties, the derived slope still lies in the middle of the range of values from 2.0 to 2.4 W m^{-2} sr^{-1} per MET VIS count found by Kriebel (1981) for ocean surface calibrations taken over the Atlantic and Mediterranean. Although it is not obvious that either the stratocumulus or clear-surface airplane-derived calibrations should be applicable to other areas, the present results indicate that Kriebel's calibrations and the Nimbus-based GOES calibrations are in substantial agreement over large areas of cloud and ocean in the Atlantic.

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