Clear Sky Radiance (CSR) Product from MTSAT-1R

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Abstract

The Meteorological Satellite Center (MSC) has developed a Clear Sky Radiance (CSR) product from MTSAT-1R and has been disseminating the CSR product to operational numerical weather prediction (NWP) centers since August 2006. The CSR product provides area average radiances and brightness temperatures for cloud-free pixels. The cloud detection algorithm is based on a threshold technique and determines whether a pixel is clear or cloudy. The CSR is determined for each 16 x 16 pixel segment, which corresponds to approximately 60 x 60 km^2 resolution at the sub-satellite point. This product will be useful for the assimilation into NWP models and also for the assessment of the quality of modeled land surface temperature.

1. Introduction

The Clear Sky Radiance (CSR) product provides area average radiances and brightness temperatures (TBs) for cloud-free pixels. The product has been developed for use in numerical weather prediction (NWP). For operational NWP, data from geostationary satellites have primarily been used in the form of atmospheric motion vectors (AMVs) derived from tracking cloud features in successive images. In addition to AMVs, the direct assimilation of radiances from geostationary imagers has been established in recent years (e.g. Köpken et al. 2004; Munro et al. 2004). This follows the direct assimilation of radiances from sounding instruments on polar-orbiting satellites, which has a significant positive impact on NWP forecasts. The CSR products from geostationary observations with high temporal resolution are favorable for four-dimensional variational data assimilation (4D-Var) systems. Furthermore, the water vapor (WV) CSR data give valuable information about the upper tropospheric humidity field.

The Meteorological Satellite Center (MSC) of the Japan Meteorological Agency (JMA) has been providing AMVs from Japanese geostationary satellites for more than two decades. With the launch of the MTSAT (Multifunction Transport Satellite) -1R satellite in February 2005, MSC has developed the CSR product from the MTSAT-1R as well as the AMVs and started the dissemination of the CSR product to the Numerical Prediction Division (NPD) of JMA in August 2006.

This paper introduces the CSR product from MTSAT-1R. Section 2 describes the data used for the CSR product. Section 3 describes the algorithm with emphasis on the cloud detection. Section 4 presents some results obtained by using the MTSAT-1R CSR product. Conclusions are given in section 5.

2. Data

MTSAT is a Japanese geostationary multi-purpose satellite program with two objectives: an aeronautical mission and a meteorological mission. The meteorological mission of MTSAT takes over the observation of five GMS (Geostationary Meteorological Satellite) satellites, which were launched between 1977 and 1995. As of this writing, MTSAT-1R, which was launched on 26 February 2005, is the operational satellite at 140°E.

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Table 1: MTSAT-1R JAMI Characteristics

Spectral bands	VIS: 0.55 - 0.90 μm IR3.8: 3.5 - 4.0 μm WV6.8: 6.5 - 7.0 μm IR10.8: 10.3 - 11.3 μm IR12.0: 11.5 - 12.5 μm
Ground resolution at nadir	1 km in VIS, 4 km in infrared channels
Digitization	10 bits

The JAMI (Japanese Advanced Meteorological Imager) on board MTSAT-1R has five channels (see Table 1). The visible (VIS) channel has a spatial resolution of 1 km at the sub-satellite point while the four thermal infrared (IR) channels have a resolution of 4 km. A full disk image of the earth consists of 11,000 x 11,000 pixels for the visible channel and of 2,750 x 2,750 pixels for the four infrared channels. The spatial coregistration of visible and infrared channels is done in such a way that a 4 x 4 pixel array for the visible channel nominally corresponds to an infrared pixel. JAMI observes the earth's full disk with an hourly cycle. The hourly CSR product from MTSAT-1R is derived from geolocated and calibrated full-disk image data.

3. Algorithm

3.1. Overview

The processing of the algorithm is as follows. A flowchart of the processing is shown in Figure 1.

- Step 1 (Preparation of surface information): The surface type is identified for each pixel using fixed land mask data. The types are land, sea, and coast (mixture of land and sea). The data over coast areas are not used in the following steps. The surface type is used to define the threshold tests which can be applied. The thresholds also vary depending on the surface type. The latest daily Sea Surface Temperature (SST) analysis by JMA (Kurihara et al. 2006) is used as a parameter of the thresholds. The SST analysis is derived from satellite observations (AVHRR and AMSR-E) and in situ measurements. The predicted clear sky brightness temperature ($CSBT_{pred}$) of IR10.8 channel is used as a parameter of the thresholds. The maximum IR10.8 brightness temperature in the last 20 days, which usually contains the clear sky surface temperature information, is used as a proxy for the $CSBT_{pred}$. Hourly $CSBT_{pred}$ data are prepared to take account of the diurnal cycle of surface temperature.
- Step 2 (Solar zenith angle check): Day or night condition is determined for each pixel using the solar zenith angle. This defines the channels and the threshold tests which are used in the following step.
- Step 3 (Scene type identification): This step determines whether each IR pixel is clear or cloudy. The cloud detection algorithm is based on a threshold technique. Several image data are compared with the thresholds (see section 3.2).
- Step 4 (CSR calculation): IR image data are divided into segments of a 16 x 16 pixel array, which corresponds to approximately 60 x 60 km^2 resolution at the sub-satellite point. The CSR is calculated by taking the average of the radiances/brightness temperatures from the cloud-free pixels for each 16 x 16 pixel array. The location (latitude/longitude) of a segment is derived by converting from the arithmetic mean of the line and pixel position of the clear pixels within the segment. The spatial consistency is checked in order to avoid mixing pixels of different surface types in the same array.

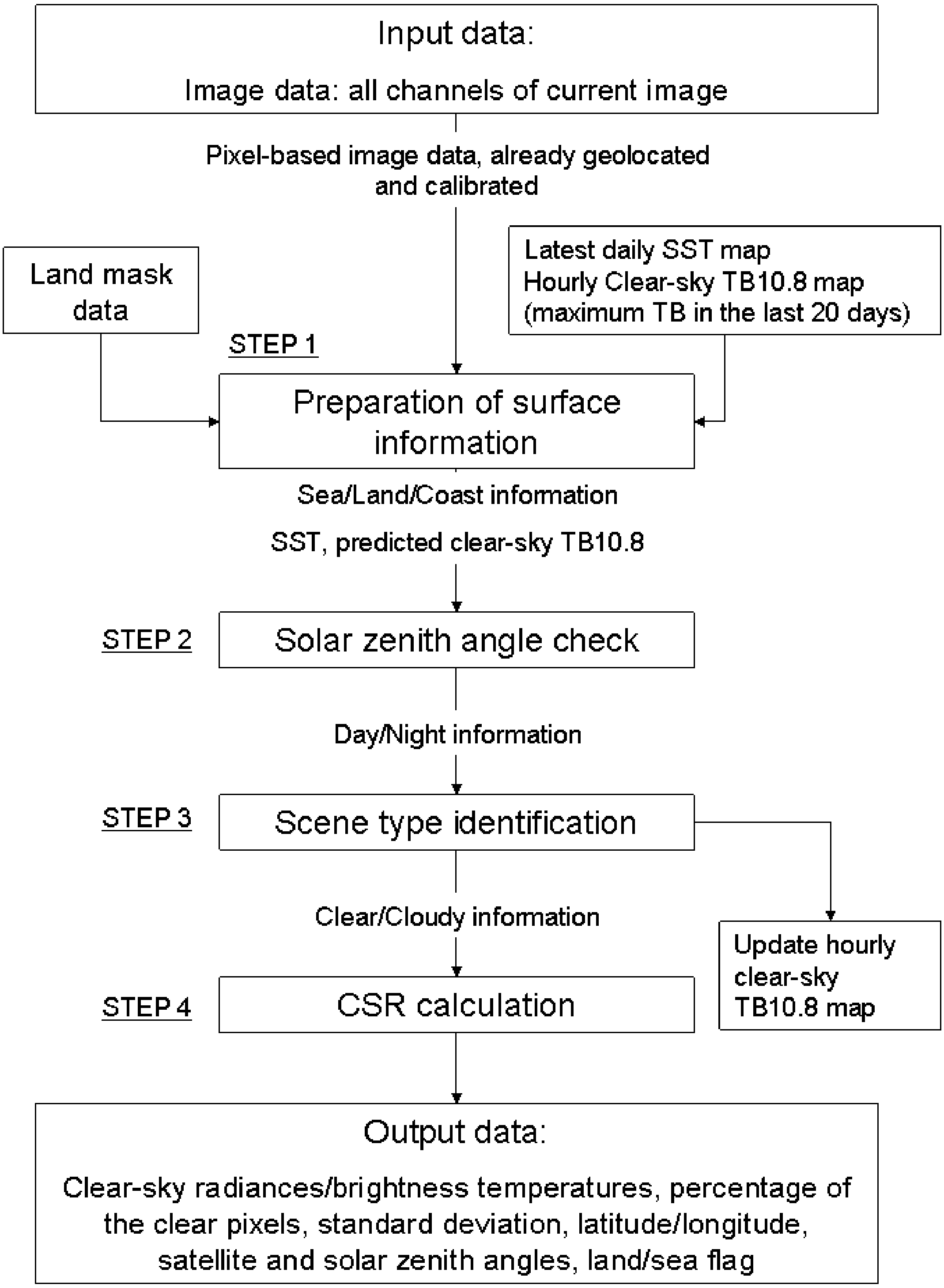

Figure 1. MTSAT-1R CSR processing

3.2. Cloud Detection Tests

The cloud detection algorithm is based on a threshold technique using several threshold tests. The threshold tests are comparisons of the image data with thresholds over which the data are likely to be cloud-contaminated. The threshold technique also makes use of the spectral difference in the emission properties of clouds between the two wavelengths in MTSAT-1R/JAMI channels. Spatial information such as range (i.e. the highest value minus the lowest value) and standard deviation is also used in the threshold tests.

The cloud detection algorithm is performed on an infrared pixel-basis. Six thresholds described below (THR_VIS_MAX, THR_IR1_MAX, THR_SP1_MAX, THR_SP1_MIN, THR_VIS_VAR_MAX and THR_IR1_VAR_MAX) are used in the algorithm. The steps in the algorithm are as follows:

- <u>Visible reflectance test</u>: If the brightest reflectance in VIS channel for a 4 x 4 VIS pixel array corresponding to an IR pixel is larger than THR_VIS_MAX, the IR pixel is considered cloud-contaminated. THR_VIS_MAX is defined as 10% over the ocean and 25% over land. If IR10.8 brightness temperature is less than 265K, THR_VIS_MAX over land is increased by a factor of 1.5 to account for the brightness of snow. In addition, the threshold over land is multiplied by the cosine of the solar zenith angle in order to account for low sun angles. This test is not used either in nighttime or in the area of sunglint (near the point where the sun's specular reflection is expected) over the ocean.
- <u>Thermal-IR cloud test</u>: If the brightness temperature in IR10.8 channel is lower than THR_IR1_MAX, the pixel is considered cloud-contaminated. THR_IR1_MAX is determined from SST (only over the ocean) and $CSBT_{pred}$.
- <u>Split window channels test</u>: If the difference between IR10.8 channel and IR12.0 channel brightness temperature is greater than THR_SP1_MAX or lower than THR_SP1_MIN, the pixel is considered cloud-contaminated. The purpose of this test is to eliminate thin cirrus and stratus, which is difficult for a single channel test. Inoue (1989) developed a simple way to classify clouds according to the difference in their emission properties at 11 and 12 μm. THR_SP1_MAX and THR_SP1_MIN are determined from SST (only over the ocean) and $CSBT_{pred}$.
- <u>Visible uniformity test</u>: If the range of VIS channel reflectance for a 4 x 4 contiguous VIS pixel array corresponding to an IR pixel is larger than THR_VIS_VAR_MAX, the IR pixel is considered cloud-contaminated. THR_VIS_VAR_MAX is defined as 1% over the ocean and 3% over land. This test is not used either in nighttime or in the area of sunglint over the ocean.
- <u>Thermal-IR uniformity test</u>: If the standard deviation of IR10.8 channel brightness temperature for a 3 x 3 array of contiguous pixels is larger than THR_IR1_VAR_MAX, its center pixel is considered cloud-contaminated. This test does not determine whether the surrounding pixels are clear or cloudy. THR_IR1_VAR_MAX is defined as 0.2 K over the ocean and 0.3 K over land. The spatial coherence technique used by VIS and IR uniformity tests rests on the idea that either completely clear or completely cloudy areas will exhibit little spatial variability, whereas partly cloudy areas will exhibit large spatial variability.

If a pixel passes all of the above tests, the pixel is set to ‘clear’. Otherwise it is set to ‘cloudy’.

Setting thresholds is the major difficulty in threshold techniques. The problem is that thresholds are functions of many variables: surface type, surface condition, atmospheric conditions, season, time of day, and satellite-earth-sun geometry (Kidder and Vonder Haar 1995). The thresholds used in the MTSAT-1R CSR algorithm are functions of the surface type, the SST, the $CSBT_{pred}$, and the current TB. These functions are empirically predetermined based on the statistical behavior of MTSAT-1R visible and infrared observations and comparisons of the infrared observations to simulated brightness temperatures using a radiative transfer model.

4. Results

Figure 2 shows a CSR data plotted on the visible image from MTSAT-1R. There is a reasonable correspondence between the clear areas on the imagery and the percentages of the cloud-free pixels.

It is known that the number of CSR data with high clear percentage from MTSAT-1R is fewer than similar products from other geostationary satellites (Meteosat and GOES). There seem to be several reasons: 1) clouds are climatologically more prevalent in the MTSAT viewing area (mainly western Pacific warm pool) as compared with Meteosat and GOES areas, 2) some thresholds for cloud detection are so strict that some clear pixels might be classified as cloudy, and 3) low clouds can be regarded as clear for WV channel, but the cloud detection algorithm now used classifies them cloudy. In order to include low-level cloud pixels in the CSR, another algorithm is needed to estimate cloud information (especially cloud-top height) for every cloud pixel.

WV CSR data from MTSAT-1R are compared to the expected TBs calculated from the JMA global model short-range forecast first-guess fields using the RTTOV fast radiative transfer model (Radiative Transfer for the Television and Infrared Observation Satellite (TIROS) Operational Vertical sounder; Eyre 1991; Saunders et al. 1999; Matricardi et al. 2004). The version used was RTTOV-9. Figure 3 shows an example of the comparison. In this case, MTSAT-1R observations are on average about -0.8 K colder than the TBs calculated from the model profiles. The standard deviation of the difference is about 2.3 K. It should be noted that neither bias correction nor quality controls are applied. The WV CSR data quality seems to be satisfying for assimilation into NWP models.

Figures 4 and 5 show comparisons of the MTSAT-1R window channel (IR10.8) CSR data with the expected TBs. In the Australian region (Figs. 4(b) and 5(b)), the TB differences of the IR10.8 CSR minus the expected TBs are larger over land (especially in the daytime), while the differences are smaller over the surrounding ocean. Since the atmosphere is fairly transparent for the window channel over dry and clear-sky regions, analysis of the discrepancies between observed and calculated window channel clear-sky radiances will serve not only to monitor the quality of the CSR data but also to assess the quality of the modeled land surface temperature and its diurnal cycle (Trigo and Viterbo 2003).

5 Conclusions

MSC has been routinely deriving the CSR product from full disk image data of all MTSAT-1R/JAMI channels since August 2006. The spatial coverage is up to satellite zenith angles of 65° from the sub-satellite point. The processing is performed hourly. The CSR is determined for each 16 x 16 infrared pixel array that corresponds to approximately 60 x 60 km^2 resolution at the sub-satellite point. For each 16 x 16 pixel array, the CSR is calculated by taking the average of the radiances/brightness temperatures of the clear pixels.

The CSR product also includes the percentage of the clear pixels, the standard deviation of the radiances and the brightness temperatures from the clear pixels, the center latitude and longitude of the clear pixels, satellite zenith and solar zenith angles of the center of the clear pixels, and land/sea flag (‘Output data’ in Fig. 1). The CSR data are encoded in BUFR (Binary Universal Form for the Representation of meteorological data). The CSR product is available approximately thirty minutes after the nominal start (hh:32:30) of the MTSAT-1R/JAMI full disk imaging.

As of this writing, MSC provides the MTSAT-1R CSR product to the European Centre for Medium-Range Weather Forecasts (ECMWF) and the Canadian Meteorological Centre (CMC) via FTP as well as NPD/JMA. Although the WV CSR data assimilation was operationally implemented in the JMA global 4D-Var system in June 2007, the use of the CSR data has been suspended since the new global forecast model (TL959L60) was introduced in November 2007. JMA plans to resume assimilating the WV CSR data within the new global 4D-Var system after pre-operational experiments (Ishibashi, NPD/JMA, personal communication).

MTSAT-2, which was launched on 18 February 2006, is the successor to MTSAT-1R. The specifications of MTSAT-2 Imager are the same as those of MTSAT-1R JAMI (Table 1). MSC will provide the CSR product from MTSAT-2 as soon as MTSAT-2 takes over as the primary operational satellite from MTSAT-1R, which is planned for 2010. MSC also plans to derive the CSR product from GMS-5 for the forthcoming reanalysis project by JMA. These CSR products will make a continued contribution to the meteorological community in the future.

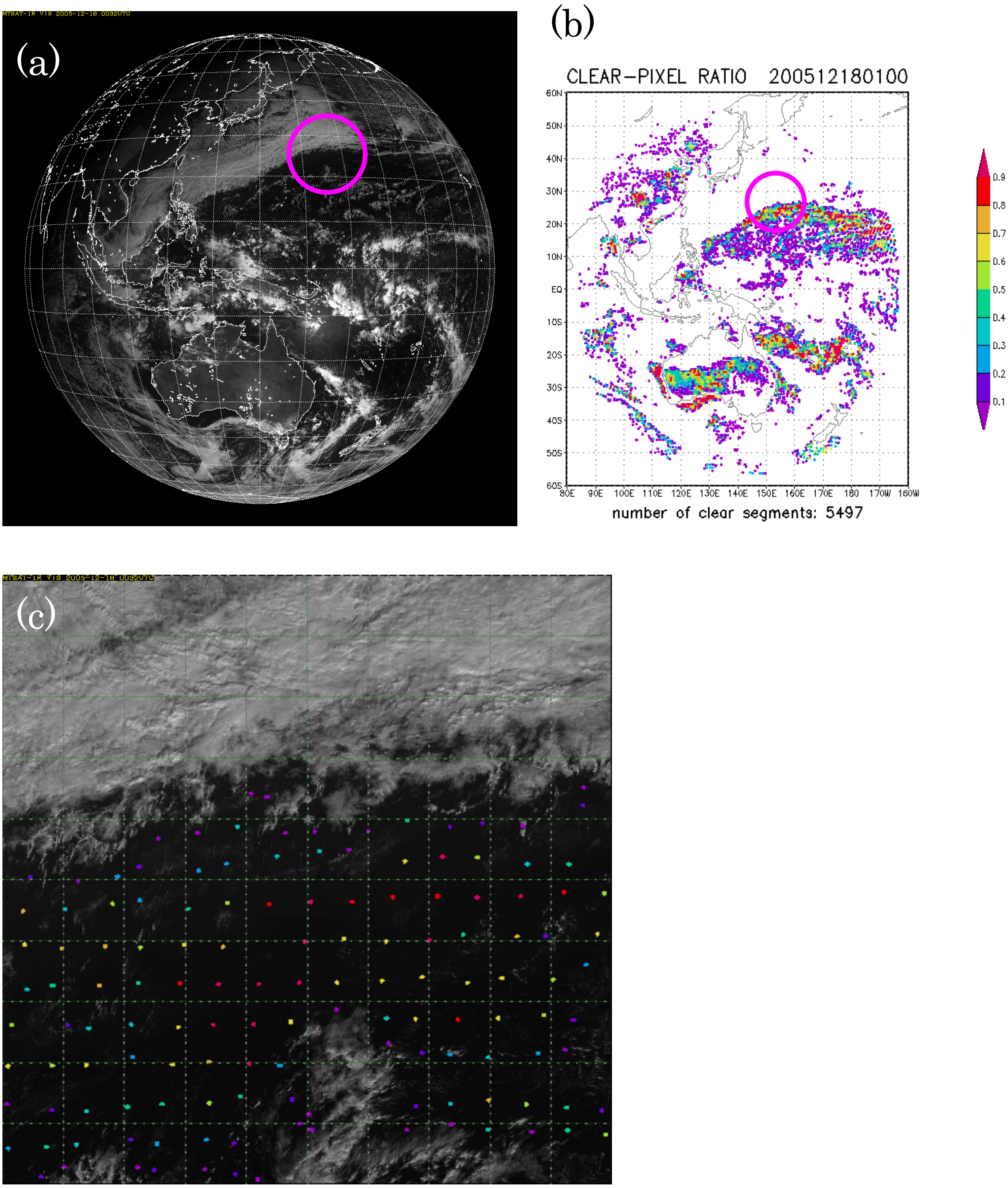

Figure 2. MTSAT-1R CSR data plotted on the visible image for 01 UTC December 18, 2005: (a) MTSAT-1R visible image; (b) Percentage of clear pixels from MTSAT-1R CSR data; (c) MTSAT-1R visible image with overlay of CSR data from 20N to 30N and 150E to 160E. The CSR data points are colored according to the percentage of clear pixels. The color scale is the same as (b).

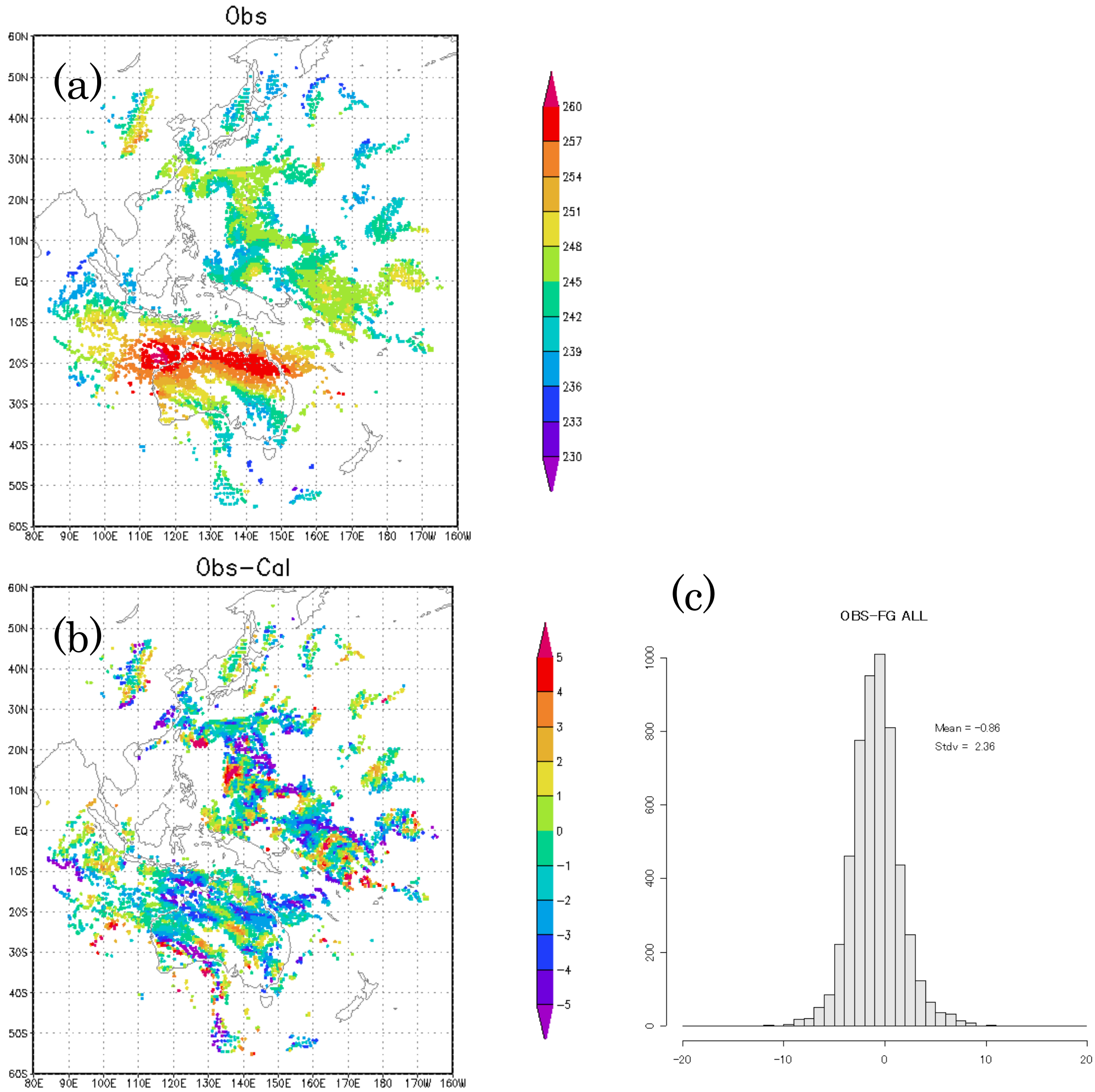

Figure 3. A comparison of the MTSAT-1R water vapor (WV) CSR [as TB (K)] with the expected TBs (K) calculated from the JMA global model 6-hour forecast first-guess fields using RTTOV-9 for 12 UTC July 5, 2008: (a) MTSAT-1R WV CSR data; (b) Difference of MTSAT-1R WV CSR minus first-guess values; (c) Histogram for departures of TB (K) between the CSR and model first guess. Neither bias correction nor quality controls are applied.

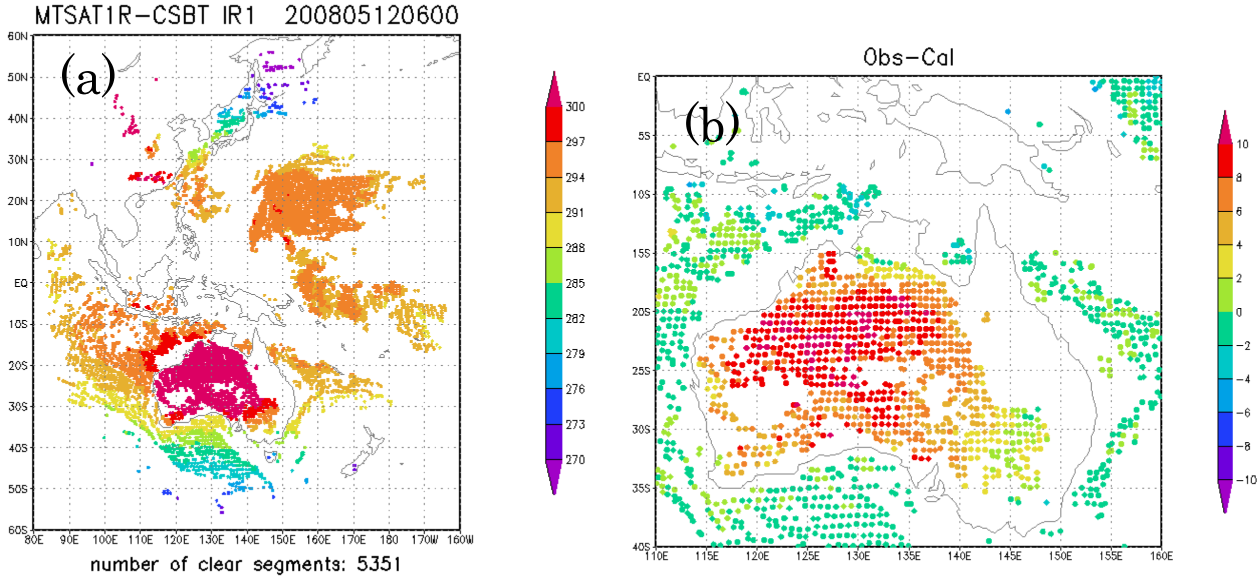

Figure 4. A comparison of the MTSAT-1R window channel (IR10.8) CSR [as TB (K)] with the expected TBs (K) calculated from the JMA global model 6-hour forecast first-guess fields using RTTOV-9 for 06 UTC May 12, 2008: (a) MTSAT-1R IR10.8 CSR data; (b) Difference of MTSAT-1R IR10.8 CSR minus first-guess values for the Australian region (110°E–160°E and 0°S–40°S). Neither bias correction nor quality controls are applied.

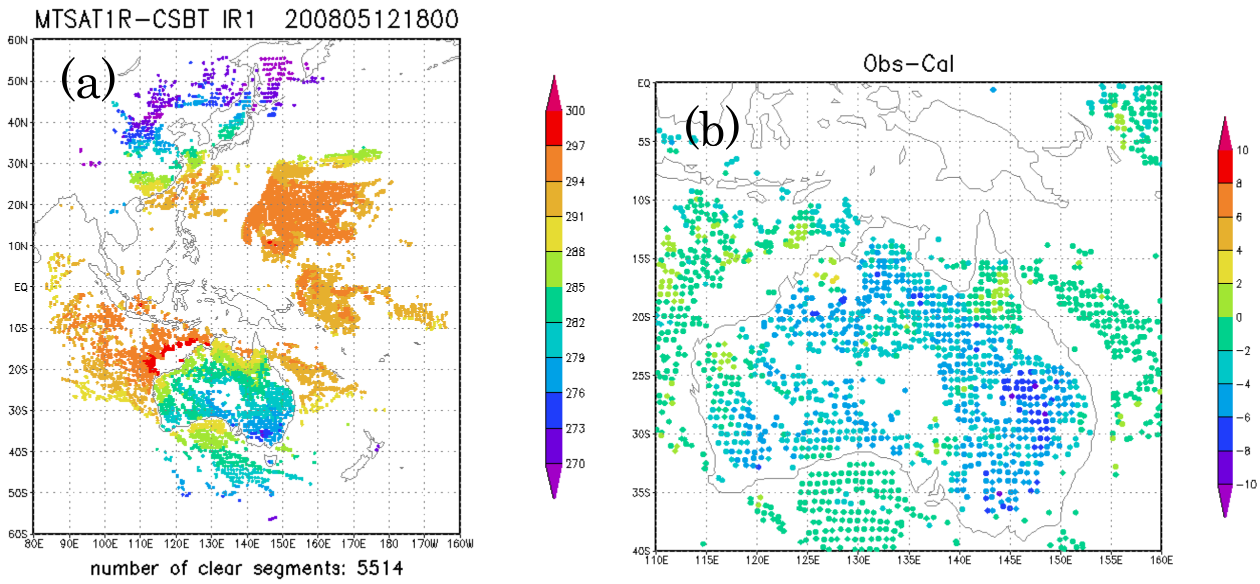

Figure 5. Same as Fig. 4, but for 18 UTC May 12, 2008.

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MTSAT-1Rデータによる晴天放射輝度温度プロダクト

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要　旨

気象衛星センターは晴天放射輝度温度プロダクト（CSR）を開発し、2006年8月より数値予報センターへの提供を行なっている。CSRは晴天ピクセルの放射輝度および輝度温度の領域平均値を与えるデータである。晴天判別アルゴリズムは閾値法に基づいており、ピクセル単位で晴天か否か判別するものである。CSRは16×16ピクセル単位（赤道直下点でおよそ60×60 kmの分解能に相当）に含まれる晴天ピクセルの放射輝度/輝度温度それぞれの平均をとって算出される。本プロダクトは数値予報モデルへの同化およびモデル地表面温度の精度評価に有効であろう。

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