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# Solar biases in the TRMM microwave imager (TMI)

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# Solar biases in the TRMM microwave imager (TMI)

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ECMWF assimilates observations sensitive to atmospheric moisture, cloud and rain from a number of microwave instruments including TMI (TRMM Microwave Imager), which was launched in 1997. Data from TMI has been assimilated at ECMWF since 2007. While the majority of these instruments have a steady calibration, monitoring over the past year has shown a 42-day cycle in the bias of TMI. This is not corrected by variational bias correction, and the bias turns out to be due to changes in the solar heating of the instrument through the satellite's orbit. Here we discuss the measures that have been taken at ECMWF to deal with this problem.

### Analysing the problem

Figure 1a shows that the bias in the brightness temperature from TMI has a peak-to-peak variation of about 3 K, which is significantly greater than the changes seen in other microwave imagers that we assimilate, such as Special Sensor Microwave Imager (SSM/I, Figure 1b). While the TMI bias does not appear to have affected the quality of the ECMWF forecasts, it will be significant for users of TMI's long observational record.

TMI flies on the Tropical Rainfall Measuring Mission (TRMM), a satellite with a 35° inclined orbit designed to restrict sampling to the tropics and subtropics. It samples the entire daily cycle over the course of 42 days. The cycle in the ECMWF departures was obviously linked to this, and when plotted against local solar time, the bias had a clear diurnal cycle (Figure 2). Could this indicate a diurnal bias in the ECMWF model? The other microwave imagers we assimilate, SSM/I and Advanced Microwave Sounder for EOS (AMSR-E), are in polar orbits and have roughly fixed local solar times, which allow us to check parts of the diurnal cycle. There are in fact no large diurnal variations in the SSM/I and AMSR-E observations (Figure 2), which suggests the ECMWF model has no diurnally varying errors that would be significant here.

Early on in the TMI mission, it was found that the instrument's main reflector was not perfectly reflective. This means that the instrument measures a combination of earth emission and the temperature of the reflector. This problem was discovered during a number of 'deep space' manoeuvres, which rotate the whole satellite so that the instrument observes space rather than the earth.

The cosmic microwave background radiation can be used as a calibration source, since it has been accurately determined to 2.7 K by astronomical missions like COBE (Cosmic Background Explorer). The temperature of the TMI reflector is not measured on the spacecraft itself, and though the reflector was intended to be perfect, it is thought that its coating flaked off once in space, leaving a graphite under-surface. Based on the deep space manoeuvre and on intercalibration with SSM/I, a team led by Frank Wentz estimated the TMI reflector's properties. Their results suggested that about 4% of the measured signal came from the reflector, rather than the earth, and that the reflector's temperature was about 295 K. The data providers at NASA Goddard then made a correction based on these measurements and so the observations that ECMWF assimilates should in theory be free from this problem. However, the diurnal variations in ECMWF departures (Figure 2) suggested otherwise.

Satellites in low earth orbit experience large temperature variations, passing into and out of the earth's shadow during the course of 90 minutes. It seemed unlikely that the reflector's temperature would be constant, despite that assumption having been made in the NASA correction. With the ECMWF first guess as a calibration reference, it was possible to estimate the reflector's true temperature variation. It is necessary to assume that all differences between ECMWF simulated observations and the actual observations come from changes in the reflector's temperature. Of course, for any one observation, the main difference comes from forecast error, but averaged over an entire year these random errors should disappear. However, the estimate is also affected, like all observations, by systematic bias between ECMWF first guess and observation. Hence, it is possible to estimate the changes in the reflector's temperature with solar illumination, but not the absolute magnitude of that temperature.

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Figure 3 shows the yearly-mean reflector temperature for TMI, estimated from the data in Figure 2. The satellite emerges from the earth's shadow at a local solar time of around 4.30 am, earlier than would be experienced on the earth's surface since it flies 400 km higher up. Here, at the satellite's dawn, the reflector temperature is approaching its coldest for the day at around 245 K. Through the day, it appears that the sun warms the reflector, which peaks at a temperature of 285 K at around the satellite's dusk, at around 7.30 pm. The reflector's temperature then drops off through the night. This is a yearly mean, but the satellite's illumination conditions vary quite considerably through the 42-day orbital precession cycle. To resolve this better, the temperature can also be estimated as a function of solar zenith and azimuth. The plots are not shown here, but they reveal an even larger temperature variation, of up to 75 K. Figure 3 is based just on the 21 GHz channel, but reflector temperature can be estimated from all the different channels on TMI. Though the absolute temperature cannot be determined, the amplitude of the temperature variation is very similar.

There still remain unknowns in this analysis, such as the dip in reflector temperature at around 5 pm. Many causes can be speculated, such as shadowing from other parts of the satellite such as its solar panels. However, a full diagnosis would require a simulation of the illumination conditions and the thermal properties of the instrument in space. Nevertheless, it is clear that the current NASA correction is erroneous in assuming a fixed reflector temperature, and should instead account for the variation through the satellite's orbit. The TMI calibration team has independently noticed the problem and they hope to have a fix in place when version 7 of the TMI data is released in 2010. Comparison to ECMWF analyses will be able to show if it works correctly.

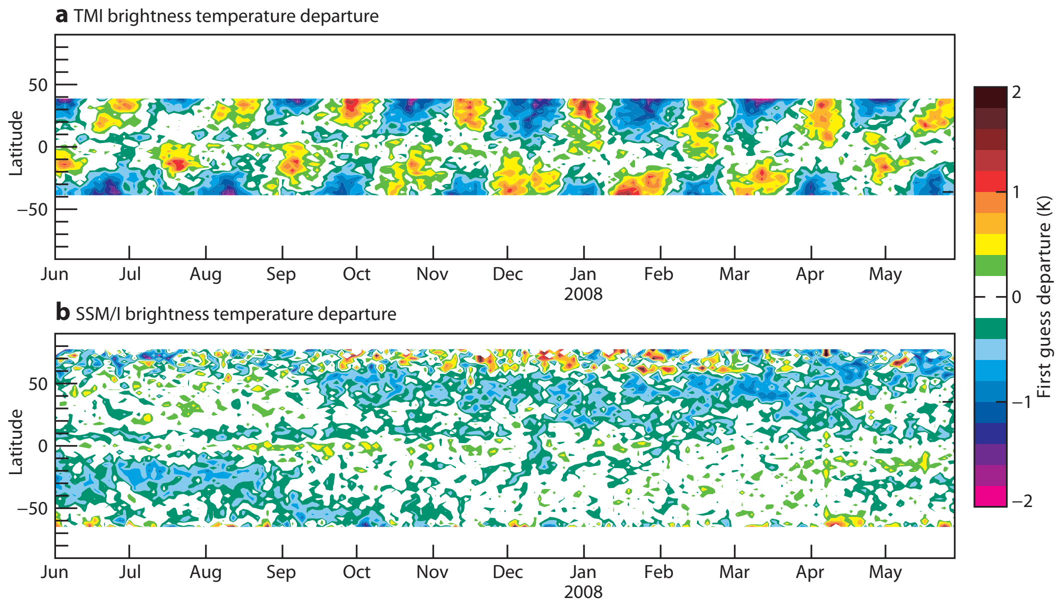


**Figure 1** Zonal mean first guess departures (observation minus ECMWF first guess) of brightness temperature in two-day bins from June 2007 to May 2008 for (a) TMI and (b) SSM/I. TMI has a clear periodic variation that is not seen in the SSM/I observations.

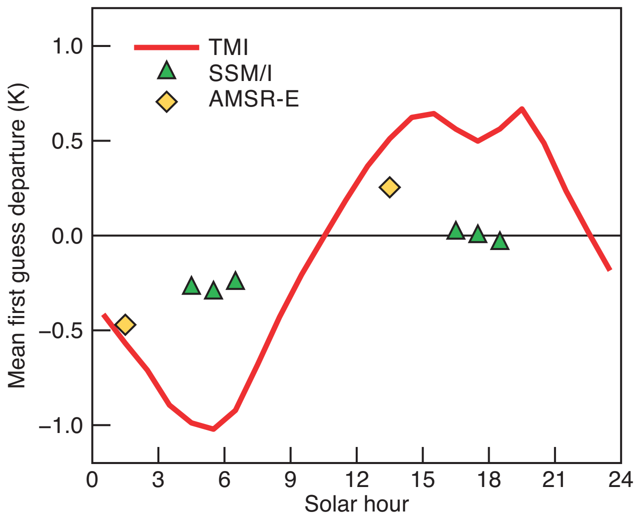


**Figure 2** Mean first guess departures (observation minus ECMWF first guess) of brightness temperature over the period 1 June 2007 to 31 May 2008 and the latitudes 40°S to 40°N. Observations have been binned by solar hour for TMI channel 21v (solid line), SSM/I channel 22v on DMSP-F13 and F-14 (triangles) and AMSR-E channel 24v (diamonds). Diurnal variations in TMI are much larger than in the other imagers, suggesting a problem with the observations rather than the first guess.

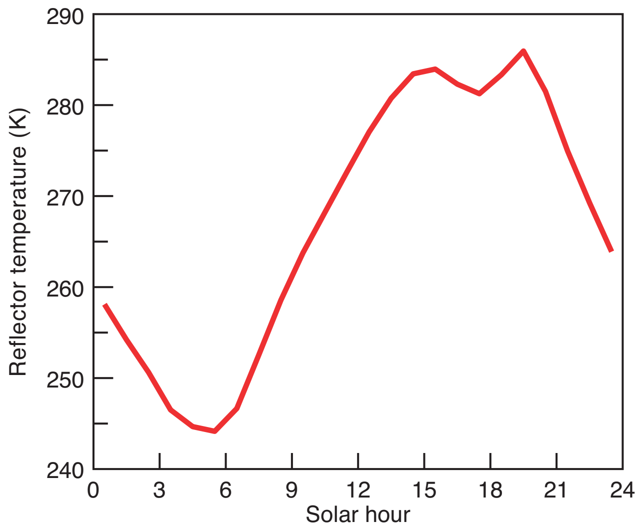


**Figure 3** TMI reflector temperature estimated from the first guess departures for TMI channel 21v.

## Current situation

TMI is not the only microwave imager that has experienced this problem. Similar issues affected the reflector on SSMIS (Special Sensor Microwave Imager/Sounder) and a bias correction was developed by Bill Bell at the Met Office in collaboration with the Naval Research Laboratory (NRL) which processes the data. For the longer term, it is clear that instrument builders need to take great care when designing these kinds of instruments. Reflectors need to be better designed and their temperature variations carefully monitored.

A number of measures have been taken to mitigate the problem at ECMWF, since the corrected TMI product will only be released in 2010. Figure 1 is based on bias corrected departures and shows that the 42-day cycle of bias is not currently corrected by the Variational Bias correction scheme (VarBC). As a precautionary measure, TMI has been removed from assimilation with cycle 35r2 (Cy35r2) of the ECMWF IFS (Integrated Forecast System) that was implemented in March 2009. However, recent problems with some of the SSM/I instruments and the continuing issues with its successor SSMIS mean that we are quite short of microwave imagers to assimilate. The only operational instrument available is the SSM/I on the DMSP F-13 satellite, which is now 14 years old. VarBC has been extended with a new predictor based on solar hour and taking a functional form similar to Figure 2. This reduces the diurnal amplitude of bias from 1.4 K to 0.6 K, which is comparable with the typical variations of AMSR-E and SSM/I. This will allow TMI to be reintroduced in Cy35r3 if one of the other imagers fails.


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## Microwave imagers

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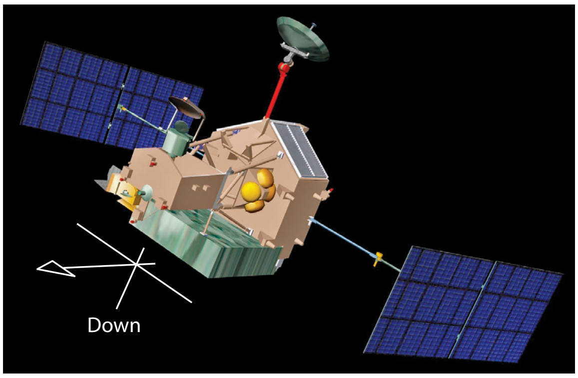
Microwave instruments are an important part of the global observing system because they use much longer wavelengths than infrared or visible radiation, where the radiative effect of clouds and rain is in general smaller and easier to simulate. When the wavelength becomes much longer than the size of particles such as cloud droplets, these particles no longer act as scatterers, but as absorbers. This means that cloud liquid water absorption and emission can be accounted for quite simply in some circumstances.

Microwave instruments come in two main designs: those that scan across the satellite track and those that use conical scanning. The cross-track design is usually used for sounding instruments such as AMSU-A, AMSU-B and MHS, where the main observable is temperature or moisture. However, instruments of this design have a field of view which is much larger at the ends of the scan than in the middle.

Conical scanning is used for imaging instruments, such as SSM/I, TMI, AMSR-E and SSMIS, because the zenith angle and the size of the field of view are kept constant. A fixed zenith angle makes it easier to deal with the polarisation of light by the sea surface. Also a fixed field of view has proved useful for observing cloud and rain, whose radiative influence is highly dependent on the scale of the observations.

Conical scanning uses a spinning reflector to rotate the observing beam. To collect sufficient radiation, these reflectors need to be large and are typically 0.5 m to 2 m in size. The size of the reflector leads to one problem in the design of the instrument: the reflector itself cannot be included in the instrument's calibration path. Hence, these instruments can only be properly calibrated by cross-calibration to other satellites or to analyses such as those from ECMWF, or by rotating the whole satellite in a deep space manoeuvre.




**The TRMM spacecraft.** The arrow indicates its direction of travel and 'down' shows the direction in which the earth would be found. TMI is the instrument at the front of the spacecraft at the top. Its main reflector is the obvious downward pointing dish, which rotates at 32 rpm about a parallel to the 'down' axis. To protect instruments from direct sunlight, TRMM flies about half the time in this configuration with the TMI instrument forward, and half the time yawed by 180° with TMI behind. Image courtesy NASA.

## Outlook

Microwave imager observations have an important influence on tropical forecasts of humidity and wind. Beyond this, they are also the first instruments to have been assimilated in cloudy and rainy conditions, giving better coverage in areas that were previously difficult to observe. A big development is the all-sky assimilation approach which is being introduced in Cy35r2. Here, clear-sky, cloudy and rainy observations are all assimilated together, which increases our ability to constrain and improve the cloud and precipitation parts of the water cycle. For these reasons it is important to maintain our capability to assimilate microwave imagers. Unfortunately a number of instruments have been affected by technical problems in recent years, but as we have seen, expertise is being developed to overcome these problems, both at ECMWF and elsewhere.

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## Further Reading

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