The use of MSU in climate change studies

Peter Thorne, Simon Tett, and David Parker
Hadley Centre for climate prediction and research, Met Office, FitzRoy Road, Exeter, EX1 3PB, UK
Peter.Thorne@metoffice.gov.uk

Introduction
To fully comprehend the processes underlying recently observed climate change it is necessary that we understand the full 4-dimensional evolution of the system. Satellite data potentially provide the information in the troposphere and stratosphere, where until now sparse and homogeneous radiosonde data have been our only data source. We show how available MSU climate datasets have been used in two examples of recent work.

Tropical lapse rates
There has been much controversy over recently observed global mean surface warming whilst the upper-air has exhibited little to no warming (3). In combination with available radiosonde records the MSU series imply that this arises primarily within the tropics, and is possibly the reverse of an earlier trend (4).

We used the MSU series created by John Christy (1) which contains a Lower Troposphere retrieval (LTL) and compared this to near-surface temperature records (5). Figure 1 implies that the relative tropospheric cooling is concentrated within the tropics and follows the seasonal migration of the ITCZ.

Tropical convection regions are precisely where climate models predict a warming of the troposphere relative to the surface. The lower tropospheric trend is not entirely sensitive to whether the MSU series are substituted by radiosonde records, although due to sparse coverage of the radiosonde network this analysis can only be undertaken in a zonal mean sense (Figure 2).

In all observed tropospheric datasets there is a marked tropical minimum which is not replicated in HadAM3 predictions. We note that strong global stratospheric cooling has occurred over the satellite period, primarily as a result of ozone depletion. We hypothesise that the tropospheric bulk temperature is in fact a two boundary problem on climate timescales. The major heat loss vector is a radiative term away to deep space. If the stratosphere were cooling then the net effect at the tropopause would be an increased efficiency of radiative heat loss. This might be expected to change the convective structure and heating / cooling profiles within the troposphere. The questions, therefore, are:

1. Is there evidence that the tropospheric temperatures in the deep tropics are affected by both the surface and the stratosphere?
2. If so is this link replicated in climate models?
If not then why not?

For small changes in temperature the problem can be approximated by a linear regression model. In all observed datasets a robust stratospheric signal is found in tropospheric temperature (Table 1). The HadAM3 model replicates this, investigation as to the causes of this disagreement is ongoing.

<table>
<thead>
<tr>
<th>Dataset</th>
<th>HadGEM1</th>
<th>HadAM3</th>
<th>UAH MNS</th>
<th>RSS MNS</th>
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<tr>
<td>TMT (mid-troposphere)</td>
<td>0.61</td>
<td>0.72</td>
<td>0.64</td>
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<tr>
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<tr>
<td>RSS (full)</td>
<td>0.61</td>
<td>0.68</td>
<td>0.67</td>
<td>0.68</td>
</tr>
</tbody>
</table>

Table 1. Results from the regression analysis $T_{\text{surf}} = a T_{\text{trop}} + b$, where $T$ are temperatures and $x$ is years. Trop. MNS and LNS denote mid-troposphere and lower-troposphere respectively. $T_{\text{surf}}$ is a radiosonde surface temperature and tropospheric $T_{\text{trop}}$ is from the MSU. The figure tabulates the correlation coefficients for the tropical region for the period 1979-2001. For model and surface temperature analysis the troposphere is defined as the layer between 125 and 5 hPa.

Figure 1. Mean TLT minus surface temperature trends 1979-2001. Black crosses mark areas of significance according to a Student’s $t$-test, white crosses mark areas of significant upper level divergence from NCEP reanalysis (10) fields.

Figure 2. Zonal mean trends for the lower troposphere from MSU (UAH), two independently produced radiosonde datasets (HadGEM1 and HadAM3), and the latest version of our atmospheric model, HadAM3. HadAM3 field is an ensemble average from a group of six runs forced with all natural and anthropogenic forcings (8) and observed sea surface temperature fields (9). Also shown are available surface observations (10) in red.

Figure 3. Global mean annual anomaly time series for TLT (top panel), TMT (mid-troposphere) and TMM (bottom panel). Observed anomalies are UAH (black) and RSS (orange, top TLT products). Model scenarios consist of all forcings (full), anthropogenic forcings only (pink), tropospheric anthropogenic forcings only (green), and natural forcings (solar and volcanic, blue).

Figure 4. Difference between observed MSU deep layer temperature trends and ALL forcings ensemble mean estimates from HadAM3. Where the differences are significant at the two-tailed 95% (90%) level they are indicated by light (dark) grey.

Figure 5. Detection results for TMT products. Each plot shows amplitude estimates from the regression for different spherical harmonic truncation (x-axis) and temporal averaging (y-axis). For each $x$-value all pass a consistency test on the residuals and are therefore physically realistic.

Detection and attribution
We ascertain the most likely causes of recent climate change through a comparison of models with observations. The analysis is simple multi-linear regression with optimisation of the input fields with respect to the noise estimate from the climate model control (8). Previous analysis on our current climate model, HadAM3, has been limited to either the surface or radiosonde upper-air temperatures (8, 11). The use of MSU products permits a more globally complete analysis of the causes of observed upper-air temperatures.

The simplest analysis is a comparison of global means (Figure 3). On this basis the MSU observations are most similar to our ALL forcings run. However, discrepancies remain, at least in part because we are considering a coupled model which does not capture observed ocean variability (e.g. 1998, strong ENSO year, in an obvious observational outlier in the troposphere).

Finally, we undertake a formal detection analysis. We use a spherical harmonic representation to retain information only on large scales when considering the response in the model (12). We consider sensitivity to both spherical harmonic truncation and temporal averaging (from annual to 11 years). We consider 3 signals in our regression: GSO, Natural, and O3 (greenhouse gases + sulphate aerosols + tropospheric ozone; solar + volcanic forcing, and atmospheric ozone depletion). Figure 5 gives results for the TMT product from both MSU series. For UAH, Natural and O3 are robustly detected and GSO more marginally. For RSS O3 is relatively less robustly detected but GSO more so. These results all pass a consistency test on the residuals and are therefore physically realistic.

We compare the observed trends to those for a perfect model by replacing the observations with the model ALL forcings ensemble mean. This analysis implies that the Natural response is over-estimated in the MSU series and the GSO response underestimated, but in both cases this is significant only in a subset of the spatial and temporal filtering combinations considered. For RSS, O3 but not UAH is generally inconsistent with this perfect model result.

Summary
We have shown two examples of how data from TOVS AVHRRs can be used to improve our understanding of climate change. It is of paramount importance that we continue to monitor the system in a consistent manner and under climate monitoring principles to succumb this potential.

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References