The use of MSU in climate change studies

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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 this information in the troposphere and stratosphere, where until now sparse and inhomogeneous radiosondes have been our only data source. We show how available MSU climate datasets (1,2) have been used in two examples of our 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 net warming (3). In combination with available radiosonde records the MSU series imply that this arises primarily within the tropics, and is possibly the reversal of an earlier trend (4).

We used the MSU series created by John Christy (1) which contains a Lower Tropospheric retrieval (TLT) 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 overly 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).

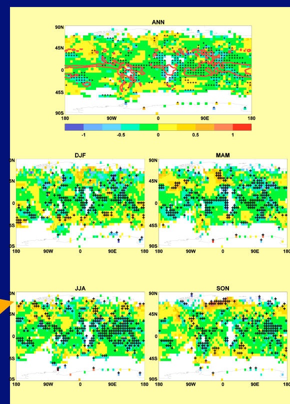

Figure 1. MSU TLT minus surface temperature trends 1979-2001. Black crosses mark areas of significance according to a student's t-test. Overplotted on annual fields are areas of significant upper-level divergence from NCEP reanalysis (6) fields.

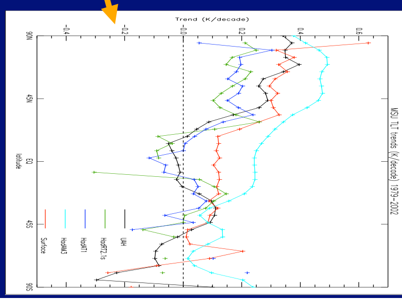

Figure 2. Zonal mean trends for the lower troposphere from MSU (UAH), two independently produced radiosonde datasets (HadRT2.1s (7) and HadAT1 (developmental product)), and the latest version of our atmospheric model, HadAM3. HadAM3 field is an ensemble average from a group of six runs forced with all natural and anthropogenic forcings (8) and observed sea surface temperature fields (9). Also shown are available surface observations(5) in red.

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 fails to replicate this; investigation as to the causes of this disagreement is ongoing.

Dataset	HadRT2.1s		HadAT1		UAH MSU		RSS MSU		HadAM3 (1979-1999)		HadRT2.1s (1965-2001)		HadAT1 (1965-2001)	
	□$_{Sfc}$	□$_{LS}$	□$_{Sfc}$	□$_{LS}$	□$_{Sfc}$	□$_{LS}$	□$_{Sfc}$	□$_{LS}$	□$_{Sfc}$	□$_{LS}$	□$_{Sfc}$	□$_{LS}$	□$_{Sfc}$	□$_{LS}$
TMT (mid-troposphere)	1.43 0.50	0.42 0.12	1.11 0.37	0.49 0.13	1.64 0.44	0.34 0.14	1.69 0.42	0.30 0.14	1.30 0.73	0.03 0.17	1.50 0.37	0.35 0.14	1.24 0.22	0.41 0.10
TMT full field					1.41 0.29	0.18 0.10	1.53 0.25	0.12 0.10	1.47 0.27	0.04 0.08				
TLT (lower-troposphere)	1.38 0.35	0.28 0.09	1.39 0.22	0.23 0.08	1.65 0.33	0.34 0.14			1.33 0.65	-0.05 0.10	1.50 0.34	0.21 0.12	1.58 0.19	0.13 0.09
TLT full field					1.32 0.34	0.19 0.12			1.61 0.28	-0.02 0.08				

Table 1. Results from the regression analysis T_{Trop}=_$_{Sfc}T_{Sfc}$+ _$_{LS}T_{LS}$ where T are temperatures and _'s scalings. Trop, Sfc and LS denote troposphere, surface and lower stratosphere respectively. We subsample surface and tropospheric temperatures to have the same coverage and consider only tropical values (defined as between 20°N and 20°S), but use global lower stratospheric temperatures. In each row the top number is the _ parameter with significance indicated by colour: red 99%, orange 95%, blue not significant. The bottom row is the 2□ on the scaling. For MSU and model products the analysis has been undertaken on both spatially complete tropospheric fields and those subsampled to HadRT2.1s. RSS and UAH differ in their chosen treatment of the effects of non-climatic noise (1,2) with RSS having a more positive TMT trend. RSS do not produce a TLT product. Unless otherwise stated results are for 1979-2001.

Detection and attribution

We ascertain the most likely causes of recent climate change through a comparison of models with observations. The analysis is simply multi-linear regression with optimisation of the input fields with respect to a noise estimate from the climate model control (8). Previous analyses on our current climate model, HadCM3 (10), have 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, a strong ENSO year, is an obvious observational outlier in the troposphere).

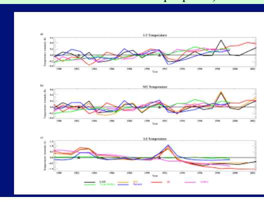

Figure 3. Global mean annual anomaly timeseries for TLT (top panel), TMT (middle panel) and TLS (bottom panel). Observed timeseries are UAH (black) and RSS (orange, no TLT product). Model scenarios considered are ALL forcings (red), anthropogenic forcings (pink), tropospheric anthropogenic forcings only (green), and natural forcings (solar and volcanic, blue).

We also consider the spatial patterns of change (Figure 4) by comparing available MSU observations to our ALL forcings run ensemble average. The significance of differences between the two is assessed with reference to an uncertainty estimate based upon a combination of internal climate variability from the HadCM3 control run and published uncertainty estimates for the observations. Significant differences exist, particularly within the stratosphere where the model may grossly underestimate internal climate variability. UAH data imply a major observations versus model discrepancy in TLT within the tropics in particular, in agreement with the observational analyses in Figures 1 and 2.

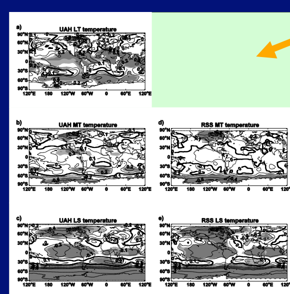

Figure 4. Difference between observed MSU deep layer temperature trends and ALL forcings ensemble mean estimates from HadCM3. Where the differences are significant at the two-tailed 90% (95%) level they are indicated by light (dark) grey.

Finally, we undertake a formal detection analysis. We use a spherical harmonic representation to retain information only at large scales where we have confidence 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_T, Natural, and O_3, (greenhouse gases + sulphate aerosols + tropospheric ozone; solar + volcanic forcing; and stratospheric ozone depletion). Figure 5 gives results for the TMT product from both MSU series. For UAH, Natural and O_3 are robustly detected and GSO_T more marginally. For RSS O_3 is relatively less robustly detected but GSO_T more so. These results all pass a consistency test on the residuals and are therefore physically realistic.

We compare the observed results 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_T response under-estimated, but in both cases this is significant only in a subset of the spatial and temporal filtering combinations considered. For O_3 RSS but not UAH is generally inconsistent with this perfect model result.

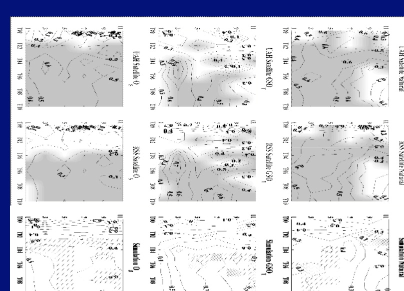

Figure 5. Detection results for TMT products. Each plot shows amplitude estimates from the regression for different spherical harmonic truncation (x-axis) and temporal averaging (y-axis). In observed plots grey shading shows where the signal is detected. Dense (light) hatching in the right hand plots shows where model and UAH (RSS) results are inconsistent.

Summary

We have shown two examples of how data from TOVS/ATOVS 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 maximise this potential.

Acknowledgements

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