Stratospheric Influences on MSU-Derived Tropospheric Temperature Trends: A Direct Error Analysis

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Abstract

Retrievals of tropospheric temperature trends from data of the Microwave Sounding Unit (MSU) are subject to biases related to the strong cooling of the stratosphere during the past few decades. The magnitude of this stratospheric contamination in various retrievals is estimated using a vertical profile of stratospheric temperature trends based on observations. It is found that from 1979 to 2001 the stratospheric contribution to the trend of MSU channel 2 brightness temperature is about –0.08 K/decade, which is consistent with the findings of Fu et al. (2004). In the retrieval method developed by Fu et al. based on a linear combination of MSU channels 2 and 4, the stratospheric influence is largely removed, leaving a residual influence of about –0.01 K/decade. In contrast, the trend-error in the angular-scanning retrieval of lower tropospheric temperature from Christy et al. (2003) is about -0.03 to -0.04 K/decade.

Introduction

The Microwave Sounding Unit (MSU), since 1979, and its successor, the Advanced MSU (AMSU), from 1998, provide global coverage of temperature for several atmospheric layers from NOAA polar-orbiting satellites. The microwave radiation measured by MSU channels 2 and 4 are particularly useful for monitoring the temperature changes in the troposphere and stratosphere, respectively (Spencer and Christy 1990; Christy et al. 2003; Mears et al. 2003; Vinnikov and Grody 2003; Seidel et al. 2004). The widely used brightness temperatures of MSU channel 2 (T_2) and channel 4 (T_4) are averaged observations from five view angles near the nadir direction in order to minimize random measurement errors (Christy et al. 1998).

About 85% of the signal for the T_2 comes from the troposphere and surface, and the remaining 15% is from the stratosphere. To correct for the stratospheric influence, the University of Alabama at Huntsville (UAH) team created a synthetic channel called T_{2LT}, where LT means "lower-middle troposphere", by subtracting signals at different view-angles of MSU Channel 2 (Spencer and Christy 1992; Christy et al. 1998; Christy et al. 2003). However, this approach amplifies noise and increases satellite inter-calibration biases, and may introduce other complications involving the effects of changes in surface emissivity and mountainous terrain (e.g., Hurrell and Trenberth 1997; Hurrell and Trenberth 1998; Wentz and Schabel 1998; Swanson 2003). For this reason, the better-calibrated T_2 record is often directly used to represent mid-tropospheric temperatures (e.g., Prabhakara et al. 2000; Christy et al. 2003; Mears et al. 2003; Vinnikov and Grody 2003).

Because of the depletion of stratospheric ozone and the increase of greenhouse gases, the stratosphere has been cooling about five times faster than the troposphere has been warming during the last 20 years (Houghton et al. 2001). Therefore T_2 by itself is not a good indicator for the temperature trend in the lower atmosphere, because it reflects the combined influences of stratospheric and tropospheric changes, which largely cancel each other. Fu et al. (2004) recently developed a simple technique for deriving the tropospheric temperature. This method uses data from MSU channel 4 to remove the stratospheric contamination in T_2, which is free of the complications afflicting T_{2LT}. Herein we use the observed vertical profile of stratospheric temperature trend to evaluate the errors in different techniques used to remove stratospheric contamination from estimates of tropospheric temperature trends.

Data

We use MSU data compiled by the UAH team (Version 5; Christy et al. 2003) for the 23-year period from 1979 to 2001. Only the UAH team produces the T_{2LT} product; therefore, we do not consider herein MSU analyses by other groups. We obtain global temperature trends of -0.52 K/decade for T_4, 0.01 K/decade for T_2, 0.055 K/decade for T_{2LT}, and 0.09 K/decade for the temperature of the 850-300 hPa layer ($T_{850\text{-}300}$) as inferred from the simple linear regression scheme developed by Fu et al. (2004). Note that the T_4 trend is almost entirely determined by stratospheric temperature changes.

The mean vertical profile of temperature trend for 1979-1994 in the stratosphere at 45°N was provided in Ramaswamy et al. (2001) from 15 to 50 km, compiled from radiosonde, satellite, and analyzed data sets (their Table 6 and Fig. 30). Linearly

extrapolating their trends of –0.84 K/decade at 20 km and –0.49 K/decade at 15 km with respect to height, we obtain a trend of –0.27 K/decade at 11.8 km (200 hPa).

In order to make Ramaswamy's vertical profile of stratospheric temperature trends at 45°N more representative of global mean conditions, we multiplied it by the ratio

$$\frac{\dot{T}_4(global)}{\dot{T}_4(45^o N)} = \frac{-0.52K/decade}{-0.71K/decade}, \qquad (1)$$

where the numerator is the 1979-2001 trend in the global mean T_4 from Christy et al. (2003), and the denominator is the corresponding trend at 45°N, estimated applying the weighting function for T_4 from Christy et al. (1998) to the trend profile of Ramaswamy et al. This rescaled profile is shown in Fig.1 from 0 to 200 hPa.

Also shown in Fig.1 are the global temperature trends in the 300-100-hPa layer for 1979-2001 based on four different radiosonde datasets (Seidel et al. 2004), which range from –0.13 to –0.41 K/decade. The trend at the 200 hPa level based on a linear extrapolation with respect to height after rescaling is within this range (–0.20 K/decade), so these radiosonde datasets provide validation of the extrapolation.

Effective Weighting Functions

The retrieval method of Fu et al. (2004) for estimating tropospheric temperature anomaly is given by

$$T_{850\text{-}300} = -0.003 + 1.156T_2 - 0.153T_4, \qquad (2)$$

where the coefficients were derived by least-squares regression to relate monthly mean, global-average temperature anomalies for the layer 850-300 hPa to the corresponding simulated T_2 and T_4, using radiosonde observations (Lanzante et al. 2003). Hence, the effective weighting function for their retrieval method is

$$W_{fu} = 1.156W_2 - 0.153W_4, \qquad (3)$$

where W_2 and W_4 are the weighting functions for the MSU channels 2 and 4, respectively. As depicted in Fig.2, the sign of this effective weighting function changes from positive to negative above the 90-hPa level. It is not uncommon for effective weighting functions to exhibit layers with negative weights (e.g., see Fig. 6.23 of Grody 1993) by noticing that statistical retrievals are used operationally to produce soundings from NOAA and GOES satellites (e.g., Kidder and Vonder Haar 1995).

Christy (personal communication 2004) suggested an alternative effective weighting function, also by combining MSU channels 2 and 4 but with different weights, using the criterion that the effective weighting function should be positive throughout the atmosphere:

$$W_{pos} = 1.08W_2 - 0.08W_4. \qquad (4)$$

Using the effective weighting function defined in Eq.(4), we obtain a temperature trend of 0.053 K/decade, which is about the same as the trend of T_{2LT}. Also shown in Fig.2 are W_2 and W_{pos}, which obviously include significant contributions from the stratosphere.

Noted that the coefficients in Eq. (2) are latitudinally-dependent. For the tropical region (30°N-30°S), the effective weighting function becomes $1.12W_2 - 0.11W_4$, as derived from Fu et al. (2004). This effective weighting function can also be examined using the stratospheric temperature trend profile in the tropics. In this paper we will focus on testing the global mean effective weighting function.

Discussion

The stratospheric temperature trend profile based on observations is used to estimate the errors associated with stratospheric contamination in different techniques for deriving tropospheric temperature trends. These errors can be expressed as

$$\Delta\dot{T} = \int_0^{200} \dot{T}(p)W(p)dp, \qquad (5)$$

where p is the pressure, $\dot{T}$ the temperature trend profile in the stratosphere as represented in Fig.1, and W the effective weighting functions associated with different techniques used to derive the tropospheric temperatures, as represented in Fig.2. The global mean tropopause is set at 200 hPa.

Shown in Fig. 3 are the errors in temperature trends related to these different methods. The stratospheric contamination in T_2 is –0.076K/decade, which is consistent with the finding (-0.08K/decade) of Fu et al. (2004). The error associated with the method of Fu et al. (2004) (Eq. 3) is only –0.008 K/decade. This error is small because the positive and negative portions of the integral in Eq. (5) largely cancel each other. Figure 3 also shows that the error based on Eq. (4) is –0.040 K/decade.

For a sensitivity test, we also derive the temperature trend below 15 km using a linear extrapolation with respect to pressure instead of height. This temperature trend is shown in Fig.1 as the dashed line. There are slight differences between these two trend profiles above 15 km (120 hPa) because both are rescaled to the observed global T_4 trend of –0.52 K/decade. Using the dashed profile, the errors associated with W_2, W_{pos}, and W_{fu} are –0.069 K/decade, -0.033 K/decade, and 0.000 K/decade, respectively, each of which differs from the results based on a linear height extrapolation by ~0.007 K/decade. Note

that the trend profile based on the linear extrapolation with respect to height is more consistent with radiosonde data (Fig.1).

Given that the stratospheric contribution is –0.08K/decade in T_2, we may derive a tropospheric temperature trend of 0.09 K/decade based on a UAH trend of 0.01 K/decade for T_2. By comparing this tropospheric temperature trend with a trend of 0.055 K/decade for T_{2LT}, we can conclude that the error in T_{2LT} is –0.035 K/decade, which is close to that based on W_{pos}. However, since the weighting function for T_{2LT} is near zero at all heights above 200 hPa (Christy et al. 1998), the error in T_{2LT} is not caused by stratospheric contamination but must be due instead to other problems involving the T_{2LT} retrievals. One indication of problems is the fact that within the tropical region (30N-30S), T_{2LT} is cooling at a rate of 0.04 K/decade relative to T_2. In view of the cooling trend in the stratosphere at all latitude (Houghton et al. 2001), one would expect that T_{2LT} should be warming relative to T_2. The validity of the T_{2LT} product as a measure of climate change is also in question at high latitudes. Swanson (2003) compared data for high latitudes in the Southern Hemisphere, demonstrating that the T_{2LT} product does not represent the seasonal cycle of temperature in the lower atmosphere, as seen in radiosonde data from Antarctica. The difference is a result of the yearly sea-ice cycle, thus trends in the sea-ice cycle may impact the T_{2LT} product. Arctic data are subject to similar influences.

In summary, we have tested the MSU channel 2 and the Fu et al. (2004) retrieval scheme for deriving tropospheric temperature trends using an independent, observation-based estimate of the stratospheric temperature trend profile. According to this test, the Fu et al. (2004) scheme yields a product that is largely free of stratospheric contamination.

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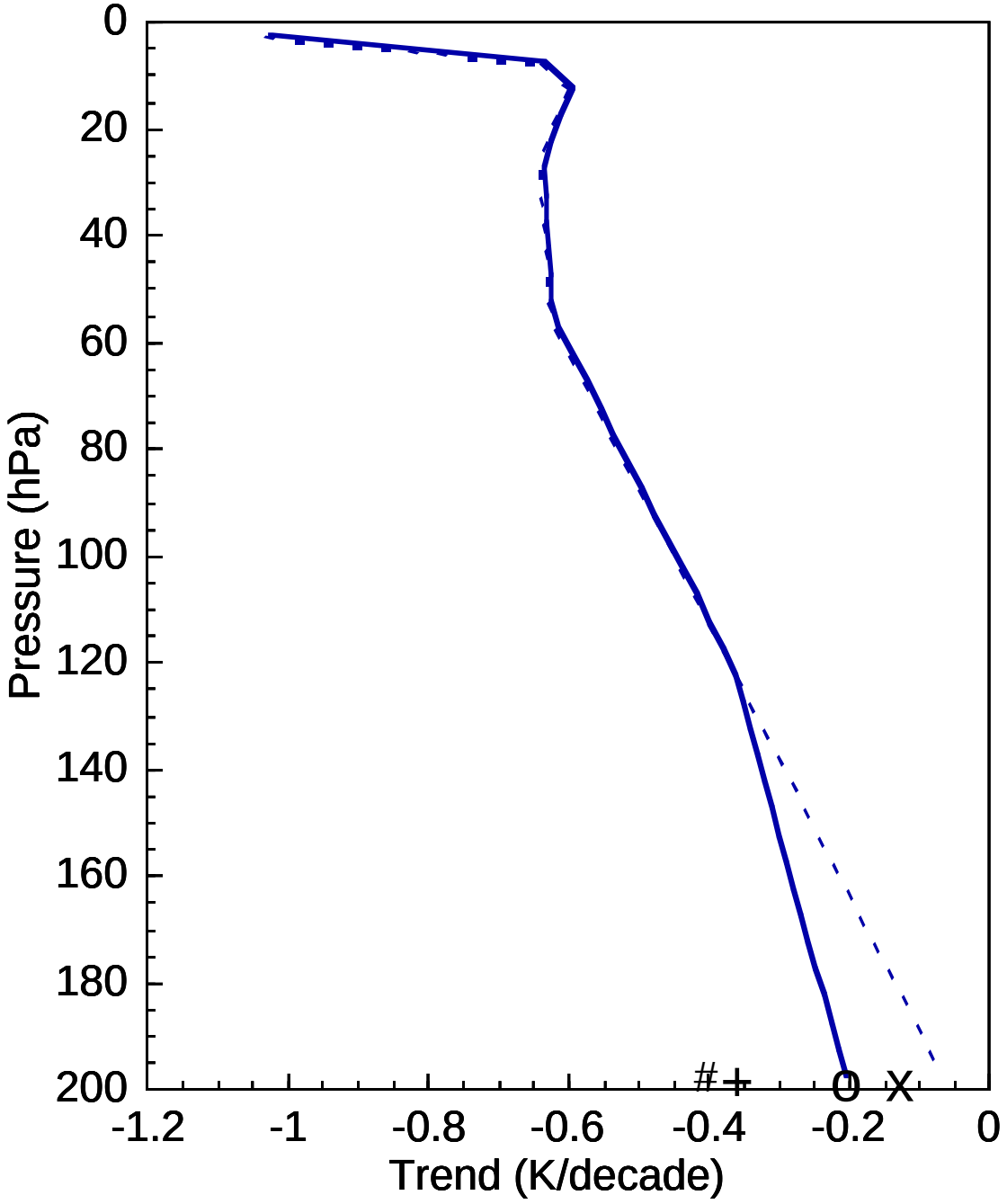
Figure Legends

Fig.1. Mean vertical profile of temperature trend in the stratosphere as compiled by Ramaswamy et al. (2001) using radiosonde, satellite, and analyzed data sets, rescaled to the global trend of UAH MSU T_4 over the 1979-2001 period. The solid and dashed lines represent trend profiles using linear extrapolation with respect to height and pressure, respectively, below 15 km (~120 hPa). Also shown are the global temperature trends for the layer between 100 and 300 hPa for the same time span, as derived from four radiosonde datasets: Angell-63 (#), Angell-54 (+), HadRT (o), and RIHMI (x) (See Seidel et al. 2004 for detailed descriptions of these datasets).

Fig.2. Microwave Sounding Unit weighting function for channel 2 (W_2), along with the effective weighting function (W_{fu}) following Fu et al. (2004), and an effective weighting function (W_{pos}) defined by $1.08W_2 - 0.08W_4$ where W_4 is the weighting function for MSU channel 4.

Fig.3. Stratospheric contributions to the MSU-derived tropospheric temperature trends using the three different weighting functions shown in Fig.2.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60
80
100
120
140
160
180
200
Pressure (hPa)
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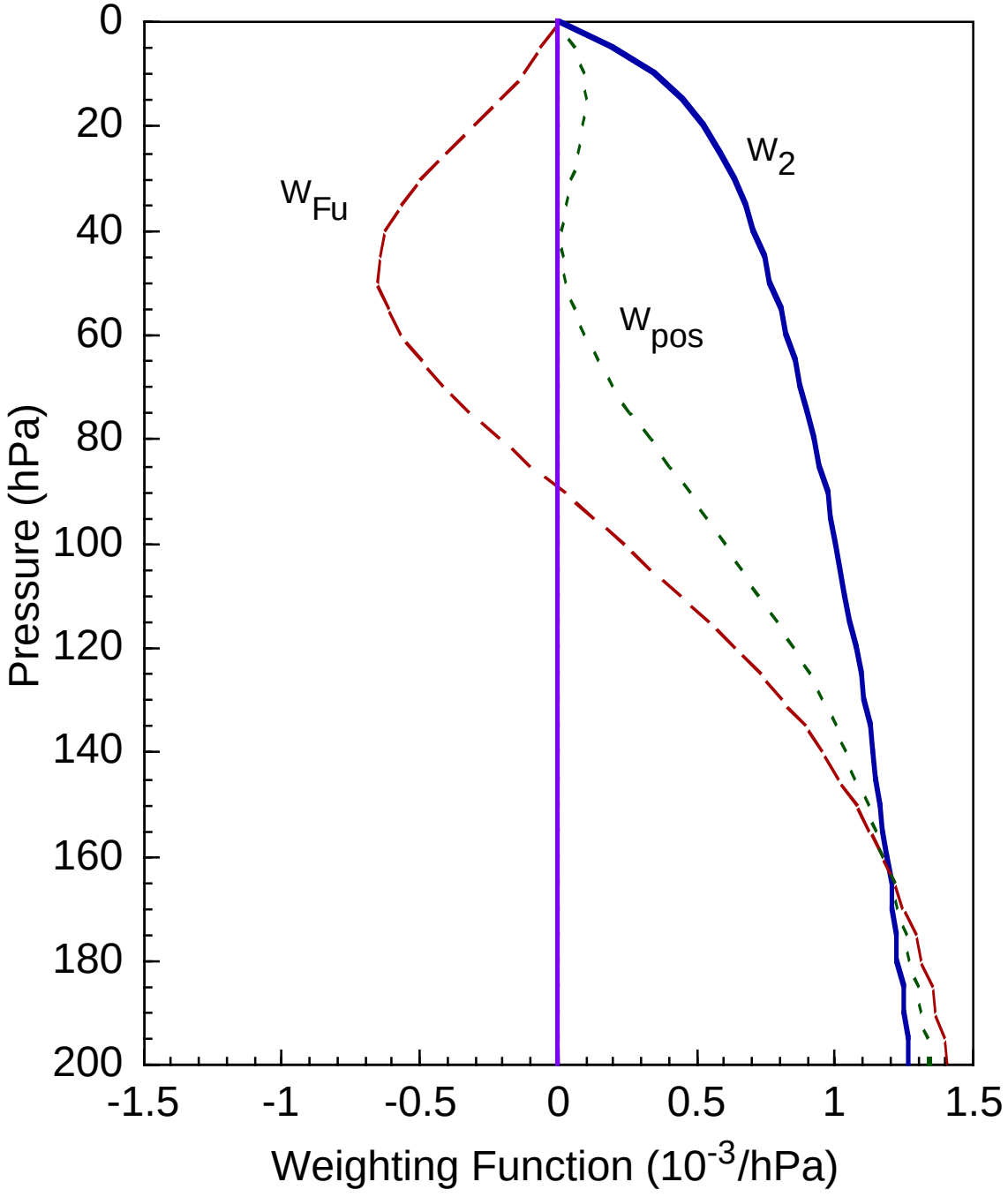
-0.4
-0.2
0
Trend (K/decade)
#
+
O
X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40
60
80
100
120
140
160
180
200
Pressure (hPa)
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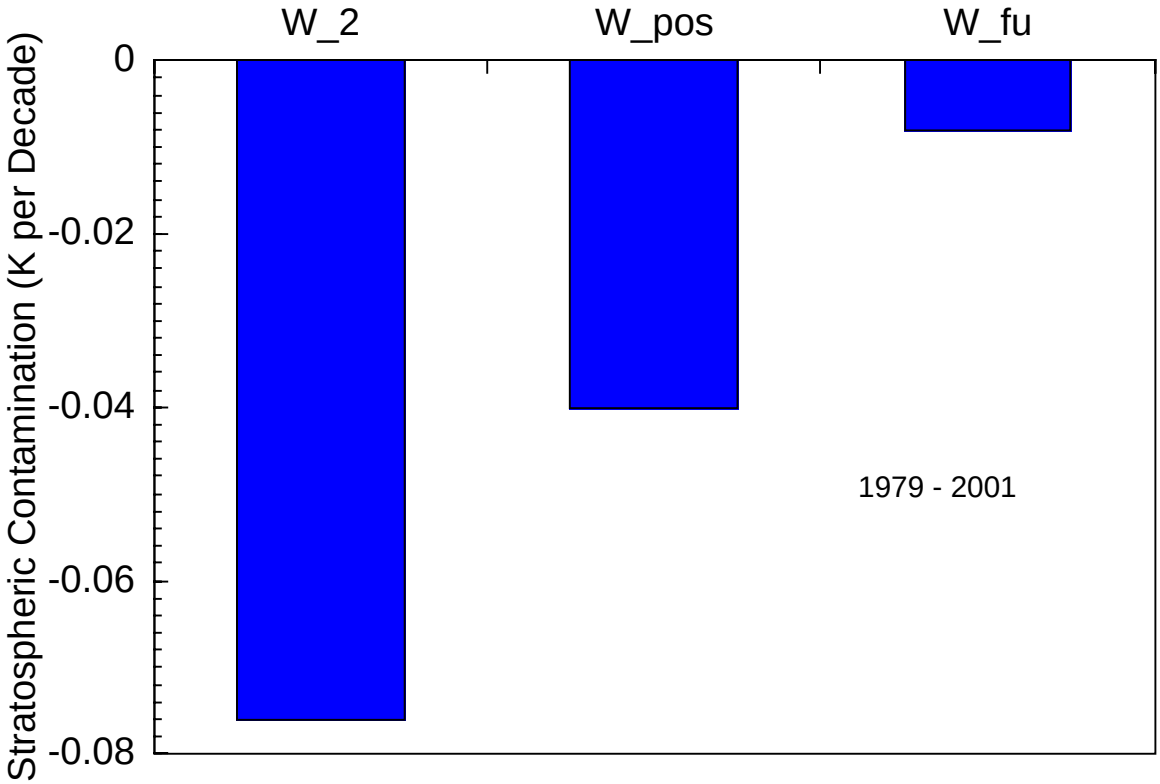
0
0.5
1
1.5
Weighting Function (10^{-3}/hPa)
W_{Fu}
W_2
W_{pos}


W_2
W_pos
W_fu
0
-0.02
-0.04
-0.06
-0.08
Stratospheric Contamination (K per Decade)
1979 - 2001