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# Assessment of the relationship between the combined solar cycle/ENSO forcings and the tropopause temperature

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## Abstract

The tropopause region of the atmosphere shows large variability over time and by region. The complex changes near the tropopause are not fully understood, especially in terms of interdecadal and interannual forcings. The purpose of this paper is to investigate forcings in the tropopause region by using microwave sounder observations and comparing the results to previous analyses.

On the basis of the satellite retrieved temperatures from the Microwave Sounding Unit (MSU) Channel 3 (CH3) measurements which began in 1981 and continue to the current time, this analysis will assess the solar forcing and the El Nino Southern Oscillation (ENSO) forcing within the tropopause layer (300–100 hPa). The temperature variability from the combined "downward" solar forcing and the "upward" ENSO forcing have been investigated using wavelet, multiple linear regression and lag correlation analyses.

The results show that the temperature variability within the tropopause layer was dominated by 3.5–7 and 14–28 year oscillations. The temperature responses to the two forcings apparently depend on the location, season and time scale of the measurements.

The temperature response to solar forcing can be found over the Arctic and Antarctic zones in winter. On the interdecadal time scale, the temperature response to solar forcing was markedly amplified with a lag of 1–2 years or 5–7 years and was out of phase between the Arctic, and all other latitudes. Interestingly, the statistically significant response to solar forcing was only identified over the tropical central and western Pacific in summer.

The temperature response to the ENSO forcing is much stronger than the solar forcing based on the magnitude of the regression coefficients. A significant positive response occurs over most of the tropical ocean areas in winter and a negative temperature response is confined to the tropical western Pacific in summer. On the interannual time scale, the temperature response is observed within the tropical areas and reaches a positive maximum 4–5 months later, and can be identified up to 10 months later with statistically significant values. After 10 months, the response is negative.

## Highlights

► Combined “downward” solar forcing and the “upward” ENSO forcing. ► Interdecadal temperature response to solar forcing was amplified lag of 1–2 years. ► Interannual temperature response reaches a maximum lag of 4–5 months to ENSO events.

## Introduction

The tropopause is defined as the boundary between two very different atmospheric layers, namely, the turbulently mixed troposphere and the stably stratified stratosphere. Accurate knowledge of tropopause change is very important to understand the interaction between the stratosphere and troposphere. Currently two datasets including radiosonde and re-analysis data have been used to determine the trends in the tropopause layer in many previous studies. Based on the radiosondes, Seidel et al. (2001) found a multi-decadal decrease in temperature of −0.5 K per decade in the tropopause layer. Randel et al. (2000) found a downward trend in tropopause temperature of −0.5 K per decade but could not find it in the re-analysis of the National Centers for Environmental Prediction (NCEP) during 1979–1997. These previous studies lead us to expect that similar trends will be found in the analysis of a new observational dataset. In addition, we will also investigate forcing mechanisms responsible for interannual and interdecadal variability in the tropopause temperature.

The satellite retrieved temperatures from the Microwave Sounding Unit (MSU) Channel 3 (Ch3) were first created by the Center for Satellite Applications and Research (STAR) (Zou et al., 2009) from the TIROS-N, NOAA-10, 11, 12, and 14 satellites operated by the National Environmental Satellite, Data, and Information Service (NESDIS). The Ch3 satellite observations provided a useful dataset for the study of the tropopause layer (300–100 hPa) temperature (Zou and Wang, 2010).

The causal mechanism responsible for the interannual and interdecadal temperature variability in the tropopause layer is very complicated. Santer et al. (2003) pointed out that natural variability alone cannot explain the observed decreases in tropopause temperature, and mainly attributed the changes to anthropogenic activity. Gage and Reid (1981) suggested that the tropopause temperature was initially interpreted as being caused by changes in total solar irradiance associated with the solar cycle. Another study (Hatsushika and Yamazaki, 2001) indicated the tropopause temperature is lower over the equatorial eastern Pacific during El Nino compared with La Nina.

Although the total solar irradiance variations from the minimum to the maximum of a solar sunspot cycle are only approximately 0.1%, evidence has been presented in the literature that variations in solar radiation can play a significant role in earth's climate variability. Two possible mechanisms may explain the response of the magnitude seen in the observations. The first involves a “top–down” response of the earth's atmosphere due to the absorption of ultraviolet (UV) radiation by ozone (Haigh, 1996, Shindell et al., 1999, Ziemke et al., 2000, Hood and Soukharev, 2010, Powell and Xu, 2011). The variability in the UV and shorter wavelengths is significantly higher (a few percent) than the integrated or net change across the spectrum which is only about 0.1% of the total solar variation. However, if the variability is amplified by constituent absorption, then perhaps a solar signal can be ascertained as a result of both absorption and the resulting dynamic changes.

Why is this a possibility? First, Haigh (1996) demonstrated a top–down mechanism in a modeling study showing a broadening of the Hadley cells in response to enhanced UV that increased as the solar-induced ozone change was included. Second, a "bottom–up" mechanism that can enlarge the response to an initially small solar forcing involves air–sea interaction. In a recent review article, Gray and her collaborators (Gray et al., 2010) pointed out that the solar influence on tropical circulations through direct Total Solar Irradiance (TSI) effects at the surface involves solar absorption over relatively cloud-free subtropical oceans. In addition, this effect increases during solar maximum (Meehl et al., 2008). This mechanism increases evaporation, and the increased moisture converges into the precipitation zones, which then intensifies the climatological precipitation maxima and associated upward vertical motions. This results in stronger trade winds, greater equatorial Pacific ocean upwelling and colder SSTs, which are consistent with stronger Hadley and Walker circulations. This strengthened circulation also enhances the subtropical subsidence, resulting in a positive feedback that reduces clouds and thus further increases solar forcing at the surface.

A recent study (Meehl et al., 2009) claimed that these two mechanisms are not mutually exclusive and suggest that both could be acting together to enhance the response. However, the bottom–up coupled air–sea forcing from El Nino/Southern Oscillation (ENSO) events can operate independently from the bottom–up coupled air–sea mechanism associated with the 11 year solar cycle since there are some differences in the climate responses to ENSO and solar (van Loon and Meehl, 2008).

For the purpose of understanding the impacts of the combined solar cycle "downward" and coupled air–sea "upward" forcings on the temperature variability in the tropopause layer, in this study, we seek answers in two areas: (i) what is the interannual and interdecadal temperature variability within the tropopause layer and the lag in the atmospheric response; (ii) in addition, we will also address the possible multiple mechanism approach of combining the solar cycle "downward" and the ENSO "upward" forcing by using multiple linear regression and lag correlation analysis. Note, this is different from the combined "top–down" and "bottom–up" mechanism proposed by Meehl et al. (2009) where these two mechanisms may work together to produce an amplified SST, precipitation and cloud response in the tropical Pacific from a relatively small solar forcing. The data and analysis techniques are described in Section 2. Section 3 shows the temperature variability based on the monthly satellite observations. The combined mechanism discussion in terms of the regression analysis is presented in Section 4. The final summary and discussion will be given in Section 5.

## Section snippets

### Data

To understand the temperature variability within the tropopause layer (300–100 hPa) and the mechanisms responsible for the variability, three datasets will be used to assess the impacts. The Microwave Sounding Unit (MSU) Channel 3 (CH3) provides calibrated direct brightness temperature measurements of the tropopause layer and was created by STAR (Zou et al., 2009). The other two datasets include the solar F10.7-cm radio flux obtained from http://www.ngdc.noaa.gov/stp/SOLAR and ENSO index defined …

### Temperature variability within the tropopause layer

The time series of the global mean temperature retrieved from MSU CH3 measurements (Fig. 1a), which represents the temperature of the tropopause layer from 300 hPa to 100 hPa, displayed strong interannual and interdecadal temperature variations. The warm anomalies appeared in 1983, 1988, 1992, 1998, and 2002–2006, and cool anomalies occurred in 1984–1986, 1989–1991, 1993–1997 and 2000–2001.

To identify the multiple time scale variation of the temperature anomalies, the wavelet transform method is…

## Solar forcing

For the tropopause layer, the multiple linear regression analysis of temperature with the normalized 10.7-cm solar flux in winter (December–February) shows (Fig. 2a) a large positive regression coefficient (warming) in the Arctic zone north of the European–Asian continent with negative values (cooling) in the middle latitudes of the North American continent and a portion of the southern middle-high latitudes. However, few regression coefficients exceeded the statistical significance test at the …

## Summary

Using the satellite retrieved temperatures within the tropopause layer (300–100 hPa) from the Microwave Sounding Unit (MSU) Channel 3 (CH3), the temperature variability associated with solar ultraviolet (UV) forcing and ENSO events have been investigated based on wavelet methodology, multiple linear regression analysis and lag correlation analysis. The results can be summarized as follows:

1) The temperature response to solar forcing shows a strong seasonal variation. A negative response can be…

…

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