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Long term trends in stratospheric temperature using NCEP/NCAR data

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Abstract

The stratospheric temperature trend plays an important role in distinguishing between the climate systems responses to natural and human induced changes. A linear trend of monthly mean temperature from the NCEP/NCAR reanalysis dataset for both Hemispheres with 2.5° step in latitude and longitude for the period 1979–2011, were calculated on this paper. Four different stratospheric heights: 10 hPa, 30 hPa, 50 hPa, and 70 hPa were analyzed. The observed trend pattern changes with height as expected. The area of negative trends increases when we go up in the stratosphere. Lower and middle stratosphere shows positive trends, in a section of the latitudinal band between 50° S and 60° S. As we go down the stratosphere these positive trends are smoother. At 10 hPa all trends are negative. In Southern Hemisphere at 30 hPa significant negative trends at low middle latitudes were observed. These results were compared with others, obtained by models and observations.

Keywords: Atmosphere; Temperature trends; Stratosphere; Reanalysis

1. Introduction

The stratospheric components trends analysis is fundamental for understanding the climate system, moreover the global stratospheric cooling since the early 70’s is well established (Steiner et al., 2007; Schwarzkpof and Ramaswamy, 2008; Randel et al., 2009; Arblaster et al., 2014; Huang et al., 2014), as well as ozone concentration variation (Thompson and Solomon, 2005; Lamarque and Solomon, 2010; Son et al., 2010; Arblaster et al., 2014; Huang et al., 2014). The long-term trends from radiosonde and satellite temperature data indicate a cooling of 0.2–0.4 K/decade since the late 1970’s (Ramaswamy et al., 2001). From 1979 to 2012, the global mean temperature in the lower stratosphere decreased by around 1 K (Arblaster et al., 2014). Zerefos et al. (2014) assessed that the lower stratosphere has cooled by about −0.5 K/decade since 1980. Stratospheric temperature variation was analyzed by Schwarzkpof and Ramaswamy (2008) during the last century using a model considering anthropogenic and natural forcing agents. They showed that the stratosphere cooling became significant since the early 1900. Several studies have detected a step in long term trends in the late 70’s (Randel et al., 2009; WMO, 2011).

From 1980 to 1995, the global-mean lower stratosphere cooled by 1–2 K, the upper stratosphere cooled by 4–6 K, and there have been no significant long-term trends in global-mean lower-stratospheric temperatures since about 1995. “The global-mean lower-stratospheric cooling did

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not occur linearly but was manifested as downward steps in temperature in the early 1980 s and the early 1990 s" (WMO, 2011).

Zossi and Fernandez (2011) showed an upward trend in the period previous to 1979, and then a decrease for temperature time series for two zonal regions at 10 hPa and at 70 hPa for the period 1948–2009. Zerefos et al. (2014) assessed a significant cooling trend in the lower stratosphere before 1980 (-0.58 ± 0.17 K/decade for NCEP) and post-1980 (-0.79 ± 0.18 K/decade for NCEP). Furthermore, Randel et al. (2009) suggested a poor knowledge of trends for the period 1958–1978, noting a large variability in trend results among the different data sets, result of the sparse observational database and the known instrumental uncertainties.

The knowledge of the stratosphere temperature trends is very important to improve our understanding of stratosphere dynamics and processes, such as coupled stratosphere-troposphere dynamics/climate (Baldwin et al., 2007).

In this paper, we analyze the temporal variation of stratospheric temperature trend for different latitudes and heights, between 10 hPa and 70 hPa, based on the monthly stratosphere temperature data from NCEP/NCAR reanalysis dataset.

2. Data characteristics and analysis

Monthly mean temperature from the NCEP/NCAR reanalysis dataset, available at http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.pressure.html, (Kalnay et al., 1996) was used at four different stratospheric heights: 10 hPa (~30 km), 30 hPa (~24 km), 50 hPa (~21 km) and 70 hPa (~18 km), for the period 1979–2011. The latitudinal range, 90° N–90° S, was covered with 2.5° steps. Linear trends were calculated in terms of latitude and longitude, at each height, during the whole period. Trends are significant at a 95% confidence level for absolute values greater than 0.025 K/decade. The confidence level was obtained using the Student's *t*-test. Only some negative trends observed are significant.

Analysis of Fig. 1 shows that the area of negative trends increases as we go up in the stratosphere. At 10 hPa all trends are negative, showing symmetry in almost all latitudes with a weaker cooling over high latitudes in a section of the southern hemisphere.

The other heights present positive trends in a section of the latitudinal band between 50° S and 60° S, the trend value is lower as we descend into the stratosphere. At 70 hPa the positive trends are observed from 150° E to 230° E, this result agrees with trends derived from the Remote Sensing System (RSS) data, which are based on satellite observations from the Microwave Sounding Unit (MSU) channel 4 during 1979–2014 (Mears and Wentz, 2009). For 30 hPa and 50 hPa the section with positive trends is between 110° E and 200° E, again these values agree with the trends obtained from RSS data, based on observations from the Advanced Microwave Sounding Unit (AMSU) channel 11. Zossi and Fernandez (2011), considering linear trends of zonal temperature values from the NCEP/NCAR reanalysis dataset for the period 1979–2004, obtained the positive trends in high latitudes corresponding mainly to the months from September to November.

Fig. 2 shows similar trend values considering the average of zonal temperature for the months September to November (SON) at 30 hPa, between −60° and −80°, for the period 1979–2011. These results are similar for 50 hPa and 70 hPa.

For all heights, the polar stratospheric temperature trends are negative, but each hemisphere shows different values for different heights. At 50 hPa and 30 hPa both polar trends values are similar.

In Southern Hemisphere at 30 hPa significant negative trends at middle latitudes are observed. The annual mean temperature anomalies for latitude band -30° to -40°, from the NCEP/NCAR reanalysis dataset (available at http://www.esrl.noaa.gov/psd//cgi-bin/data/timeseries/timeseries1.pl) during the period 1979 to 2011 are shown in Fig. 3. These anomalies are obtained using the average values of the period 1981–2000. The vertical dotted lines denote the volcanic eruptions of El Chichon (April 1982) and Mt. Pinatubo (June 1991). The figure shows clearly the negative trend since 1979, with transient stratospheric warming events after the volcanic eruptions; and temperatures are lower than they were before the eruption for each volcano. Lower temperatures occur following the transient warming associated with the Mt. Pinatubo eruption. These results are coincident with those observed by Randel et al. (2009) for time series of near-global (60N–S) temperature anomalies from SSU15x and MSU4 data. Zerefos et al. (2014) indicate that during the period following 1995, the global mean lower stratospheric temperatures are significantly lower than they were during the decades prior to 1980.

The temperature anomalies are roughly constant since the mid-90 s (Fig. 3). The trend value changes from −1.0 K/decade, for the period 1979–1995, to −0.07 K/decade, for the period 1996–2011.

"Stratospheric temperatures are controlled by a combination of radiative and dynamical processes. Since regional heating and cooling by dynamical processes tend to cancel out in the global mean, the global mean temperature is in radiative equilibrium to a good approximation and the dynamical processes lead to latitudinal variations in heating and cooling" (WMO, 2011).

3. Discussion and conclusions

Temporal variation of stratospheric temperature trend for different latitudes and heights has been analyzed, monthly stratosphere temperature data from NCEP/NCAR reanalysis dataset at 10 hPa, 30 hPa, 50 hPa and 70 hPa, have been used. Trends obtained during the period

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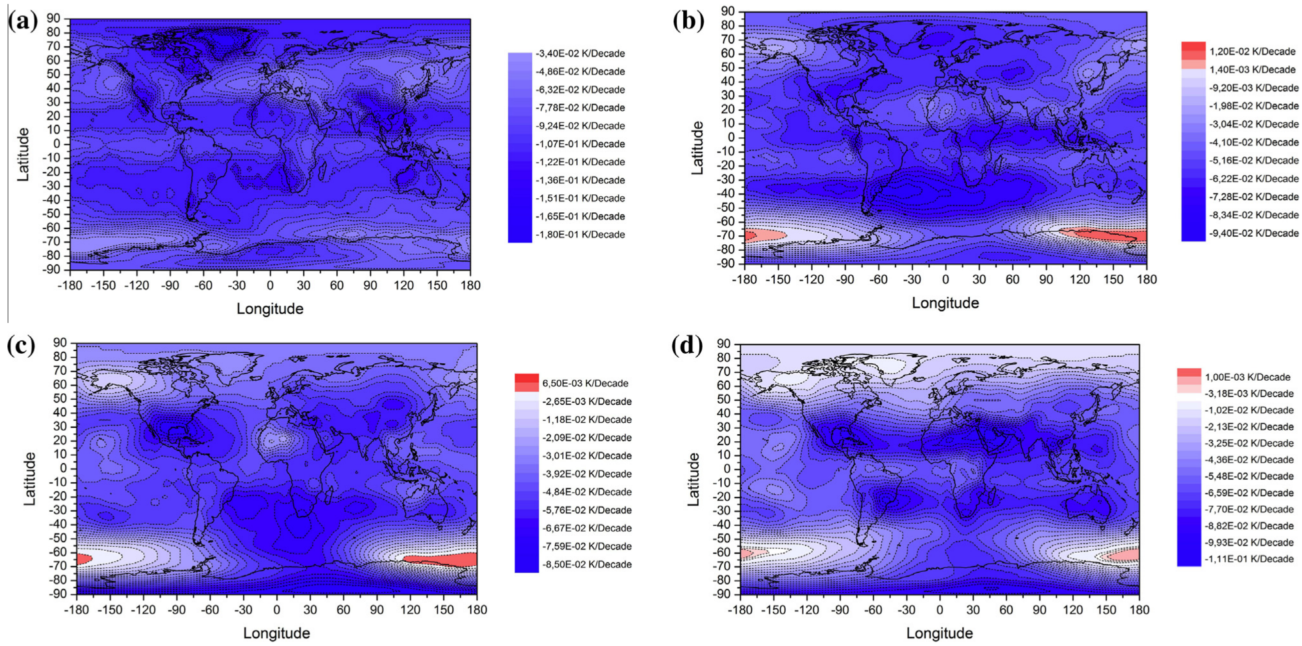

Fig. 1. Linear trend of monthly mean temperature from the NCEP/NCAR reanalysis dataset for the period 1979–2011, in terms of latitude and longitude, at four different stratospheric heights: (a) 10 hPa, (b) 30 hPa, (c) 50 hPa and (d) 70 hPa. The trend units are K/decade.

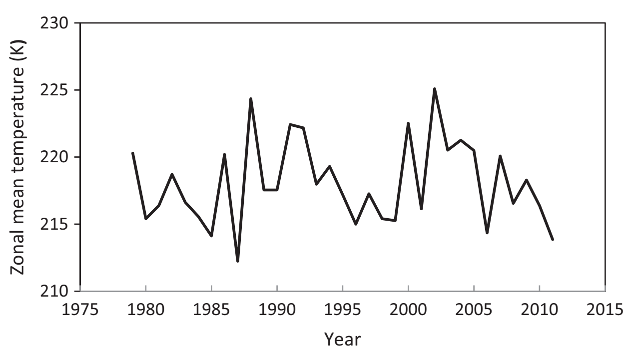

Fig. 2. Average of zonal mean temperature from the NCEP/NCAR reanalysis dataset at 30 hPa for the months September to November (SON), between −60° and −80°, for the period 1979–2011.

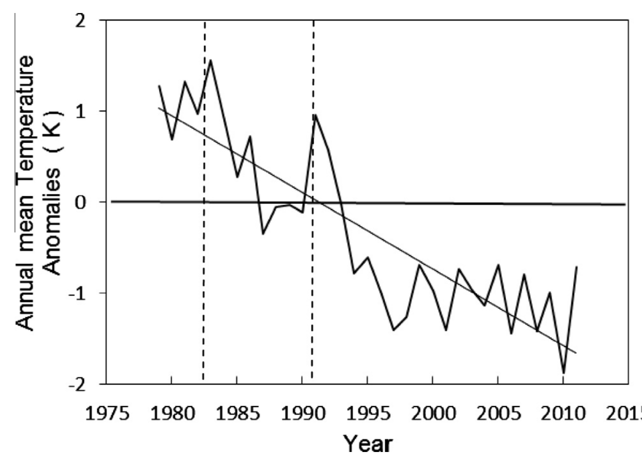

Fig. 3. Annual mean temperature anomalies at 30 hPa, for latitude band −30° to −40° from the NCEP/NCAR reanalysis dataset for the period 1979–2011. The vertical dotted lines denote the volcanic eruptions of El Chichon (1982) and Mt. Pinatubo (1991).

1979–2011 are mostly negative in agreement with the cooling expected in the stratosphere due to the higher CO_2 concentration. At high latitudes we assessed positive trends in some sectors, in agree with RRS results.

The cooling observed at tropical latitudes; at 30 hPa; could be by decreasing air temperature as result from either anomalous rising motion or in situ ozone depletion (Thompson et al., 2012)

Randel et al. (2009) showed a mean cooling of 0.5–1.5 K/decade during 1979–2005, with the greatest cooling in the upper stratosphere; and temperature anomalies throughout the stratosphere were relatively constant during the decade 1995–2005. Our results indicate that this behavior continues until 2011, even when CO_2 concentrations continue to increase.

The stratospheric ozone plays a significant role in the tropospheric circulation of the SH in austral summer. The stratospheric ozone depletion decreased the lower stratospheric temperature, increased the tropopause height, intensified the westerly jet and displaced it poleward, and expanded the Hadley cell poleward. The opposite is expected when stratospheric ozone increases (Thompson and Solomon, 2002; Son et al., 2010).

Furthermore, the temperature trends in middle and upper stratosphere are useful for understanding stratospheric circulation changes (Arblaster et al., 2014).

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