Stratospheric Temperature Trends Between 10 and 70 hPa During the Period 1948-2009

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Abstract: Trends in zonal mean temperatures between 10 and 70 hPa have been assessed for the period 1948-2009 using zonal monthly mean temperature from the NCEP/NCAR reanalysis dataset. Monthly temperature linear trends were calculated for the Northern and Southern Hemisphere at a 5º step in latitude. The observed trend pattern agrees with a general cooling for every month. The area of negative trends, in the latitude-month grid, increases as we go down in the stratosphere. Positive trends are also observed, mainly at 10 hPa for equatorial zones and summer northern and southern latitudes, and also at southern high-latitudes during the months July-February for every height analyzed. The positive trends observed at 10 hPa at equatorial and mid-latitudes are due to a warming from the beginning of the record until the beginning of 1980s, coincident with the El Chichon eruption. In the case of high latitudes, also at 10 hPa, there seems to be a "step" in 1979. For lower altitudes the positive trends are smoother. In the case of 10 hPa we suggest as a hint, that the temperature behavior for the "warming" cases follows the 11-year running mean of the total solar irradiance.

Keywords: Long-term trends, stratosphere temperature, global change, reanalyses datasets.

INTRODUCTION

The decreasing trend of the middle and upper atmosphere temperature is part of the global change due to increasing greenhouse gases concentration [1, 2] which in the troposphere would be causing the well known increasing global temperature trend. Specially, the stratosphere trends are well documented regarding temperature as well as ozone concentration [3-5]. 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 [1], and estimates of ozone trends indicate a decrease of approximately 10% in observed ozone concentrations in certain regions of the stratosphere between 1979 and 2005 [5].

Great part of stratosphere temperature trend studies focus on the period after 1970s, since this is the earliest epoch of experimental data availability. Schwarzkopf and Ramaswamy [6] assessed stratospheric temperature variation over the entire 20th century using a coupled atmosphere-ocean climate model considering anthropogenic and natural forcing agents. According to their results for global temperature, the stratosphere cooling became significant since ~1905 at 10 hPa and at 30 hPa, by ~1920 at 50 hPa, and after ~1970 at 70 hPa. So, the temperature decreasing trend should be noticed since the mentioned years.

With the purpose of detecting the expected stratosphere cooling prior to the 1970s for different zonal regions, we used monthly zonal stratosphere temperature data from NCEP/NCAR reanalysis dataset, which is available since 1948, at four heights (10, 30, 50 and 70 hPa). The analysis of stratosphere trends in addition of being a main subject due to the increasing interest in global changes in the whole atmosphere, specially due to increasing greenhouse gases concentration, it is also important due to the great attention that is being paid to the coupling between different levels of the atmosphere which induce or amplify external signals in the coupling process.

DATA ANALYSIS

Zonal monthly mean temperature from the NCEP/NCAR reanalysis dataset (available at: http://www.cdc.noaa.gov/data/timeseries/) [7] was used at four different stratospheric heights: 10 hPa (~30 km), 30 hPa (~24 km), 50 hPa (~21 km) and 70 hPa (~18 km). The entire latitudinal range, 90ºN-90ºS, was covered at 5º steps for the period 1948-2009.

Linear trends were calculated for each month, at each height, and each zonal region, during the whole period. The confidence level was assessed using the Student's t-test. From Fig. (**1**), which shows the trend values in terms of month and latitude, it can be noticed a general cooling for every month. The area of negative trends, in the latitude-month grid, increases as we go down in the stratosphere. Positive trends are also observed. At 10 hPa these upward trends occur at equatorial latitudes for every month and for summer months at northern and southern latitudes. Positive trends are also seen at southern high-latitudes during the months July-February for every height here analyzed.

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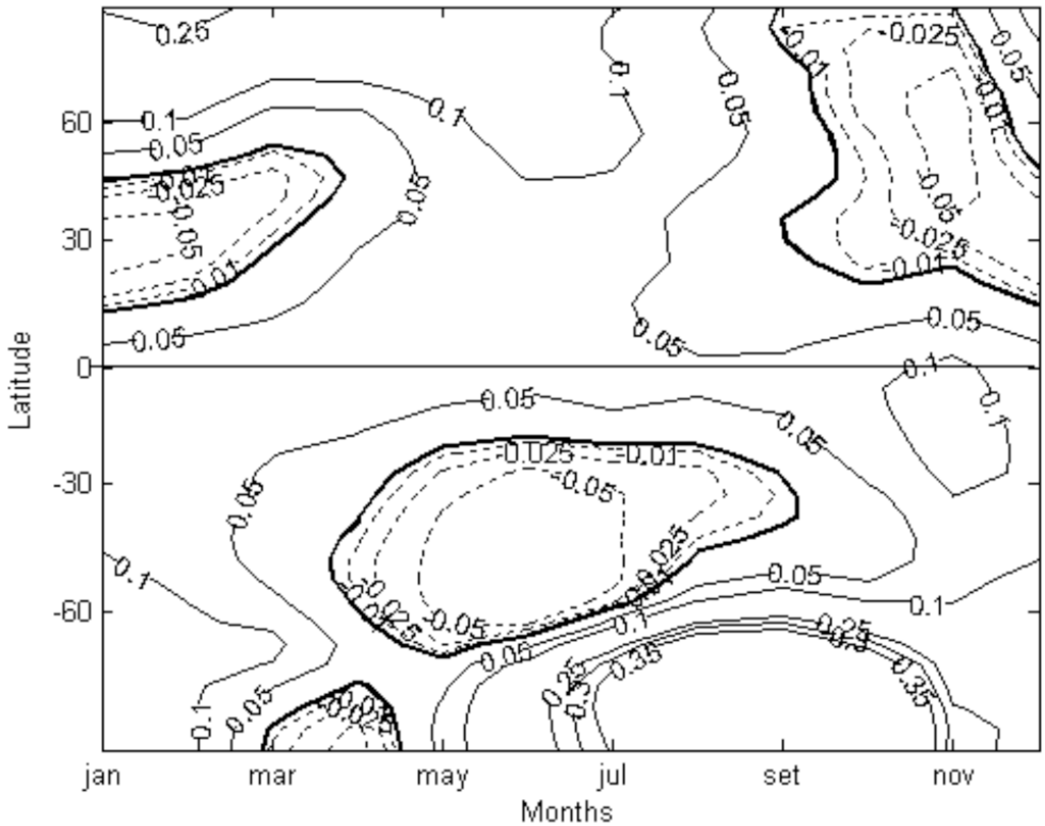
(**a**)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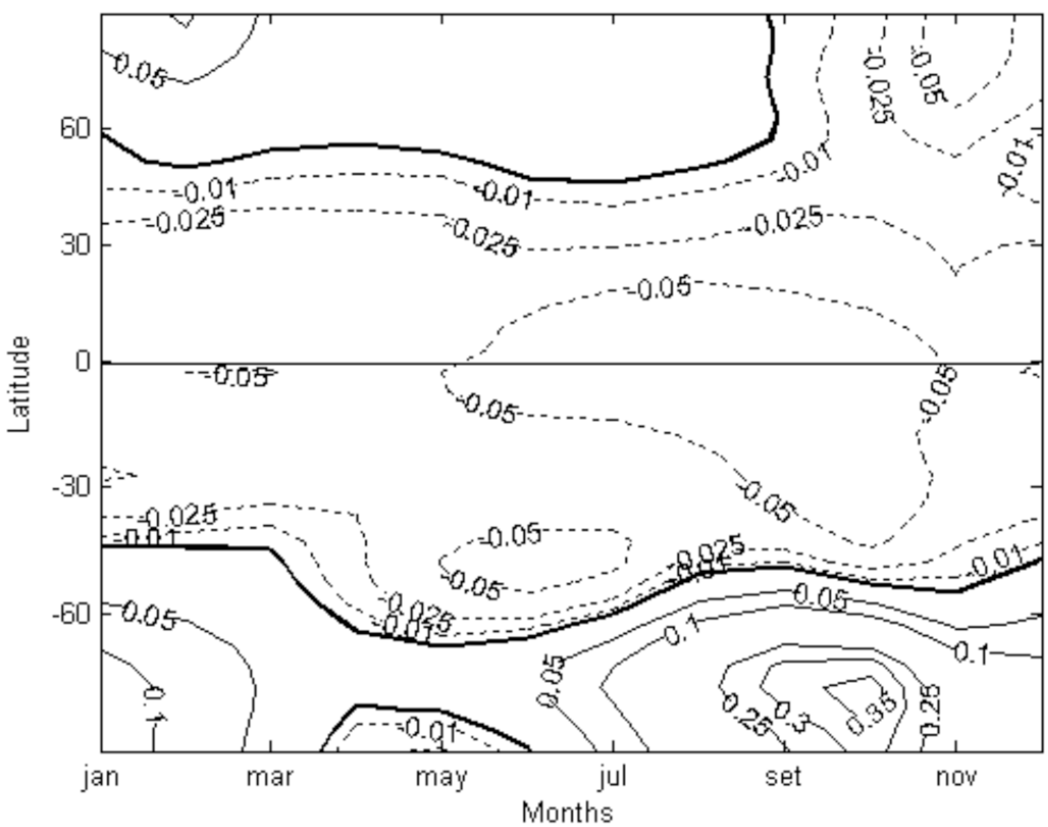
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(Fig. 1) contd…..

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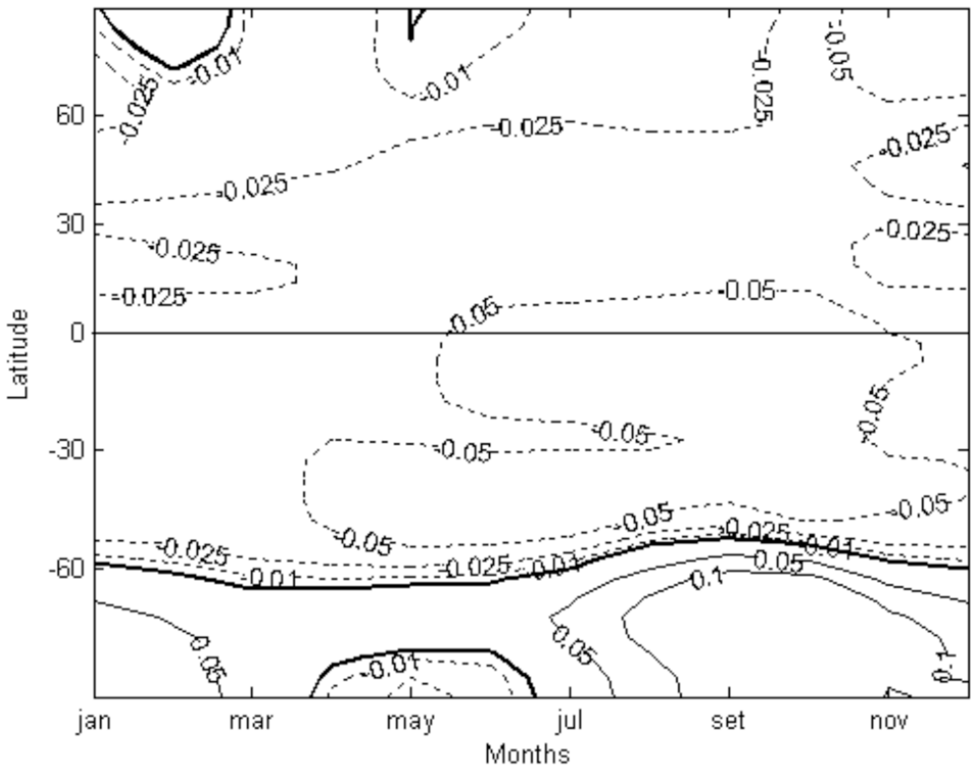

(**d**)

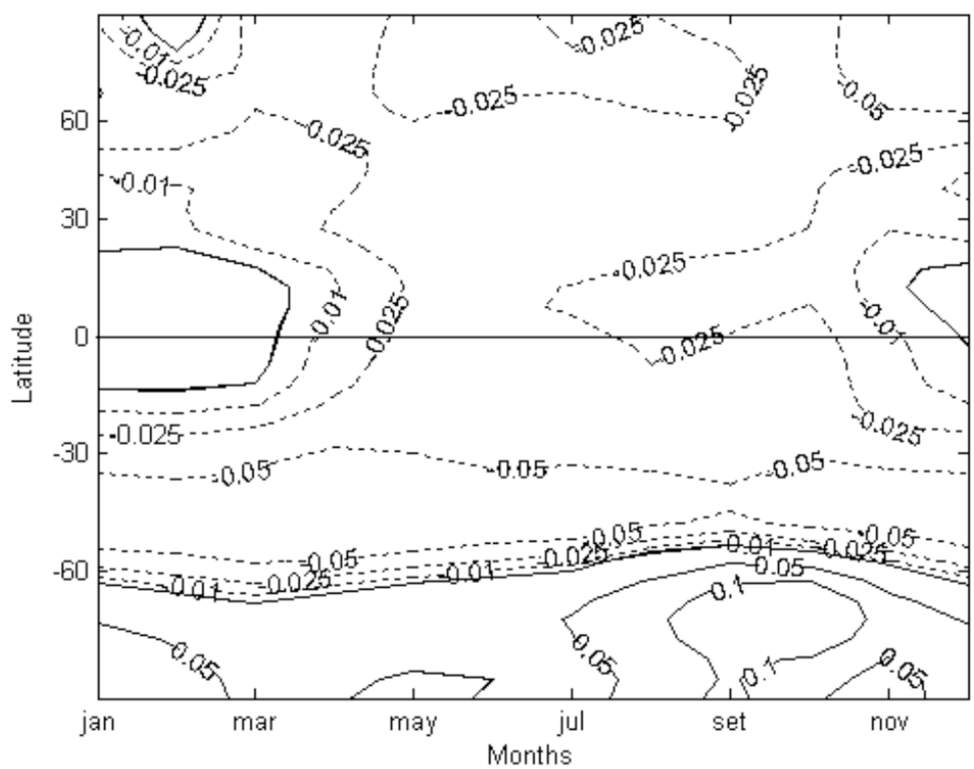

Fig. (1). Linear trend of zonal monthly mean temperature from the NCEP/NCAR reanalysis dataset for the period 1948-2009, in terms of month and latitude assessed for 5º steps, at four different stratospheric heights: (**a**) 10 hPa, (**b**) 30 hPa, (**c**) 50 hPa and (**d**) 70 hPa. Solid lines correspond to positive trends and dashed lines to negative trends. Trends are significant at a 95% condifence level for absolute values greater than 0.025 °/year.

Fig. (**2**) shows the temperature time series for two zonal regions at 10 hPa and at 70 hPa, which present positive trends when considering the whole available period (1948-2009). It can be clearly noticed that the upward trend obtained is due to the period previous to 1979, which presents a marked positive trend. Since 1979 the temperature decreases in almost all the cases. At 50 hPa instead (see Fig. **3**), temperature trend is monotonic decreasing for the 20ºN-10ºN zone. In the case of the 70ºS-80ºS zone the trend is still positive.

The "step" noticed in the case of 70ºS-80ºS at 10 hPa in 1979 is not coincident with any strong volcanic eruption. As can be seen in Fig. (**4**), which depicts the dust veil index (DVI) [8] for the period 1945-1995, the only strong eruption with a significant warming effect in the stratosphere

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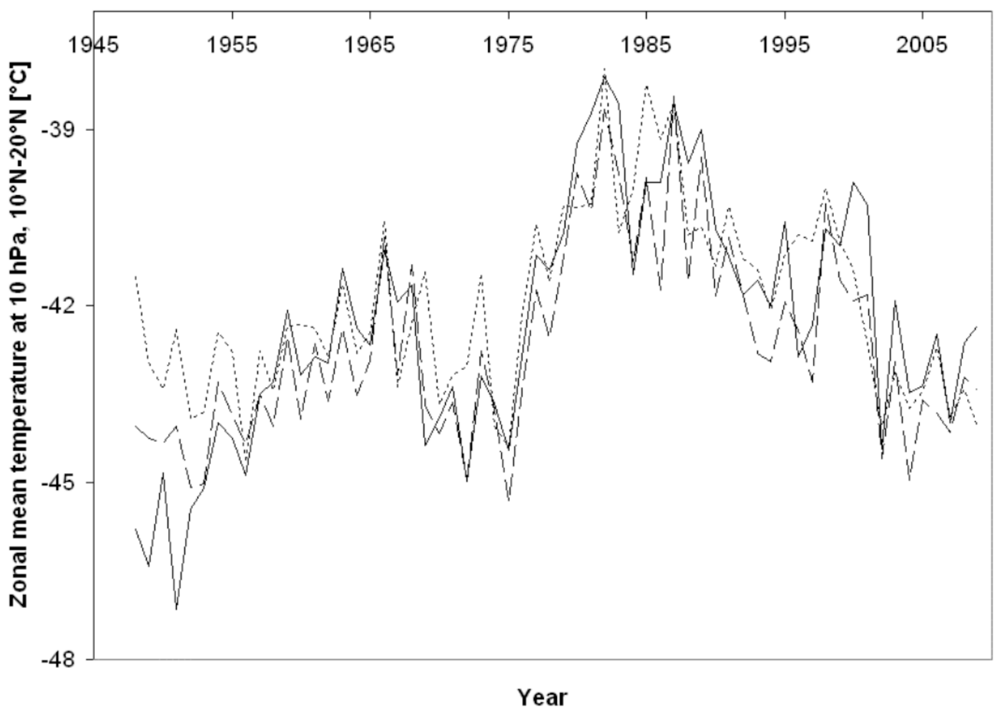

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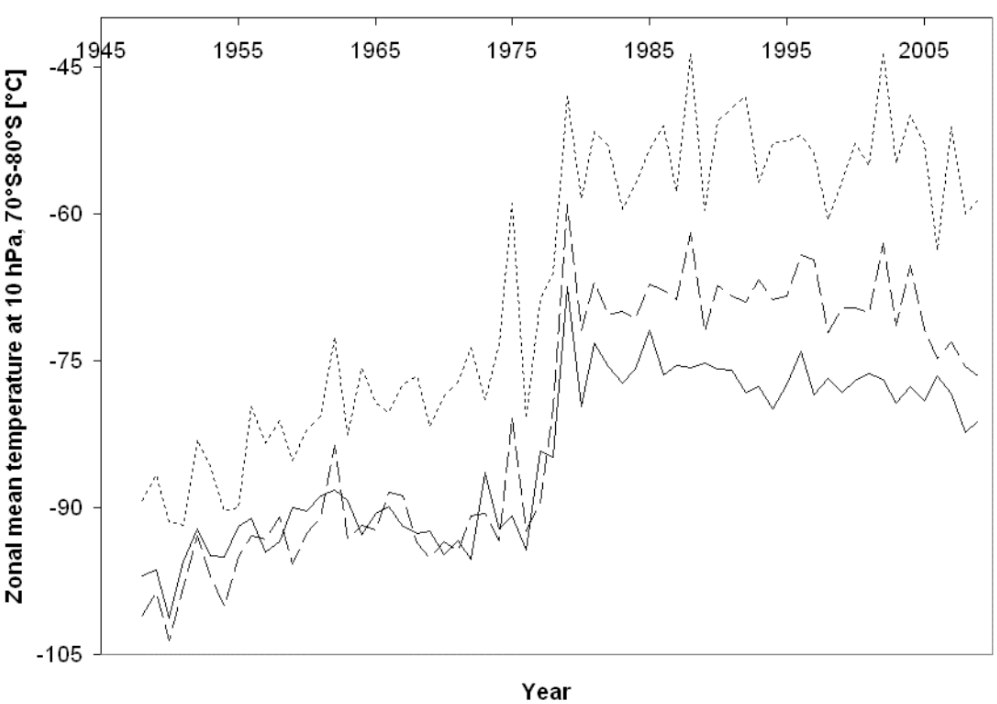
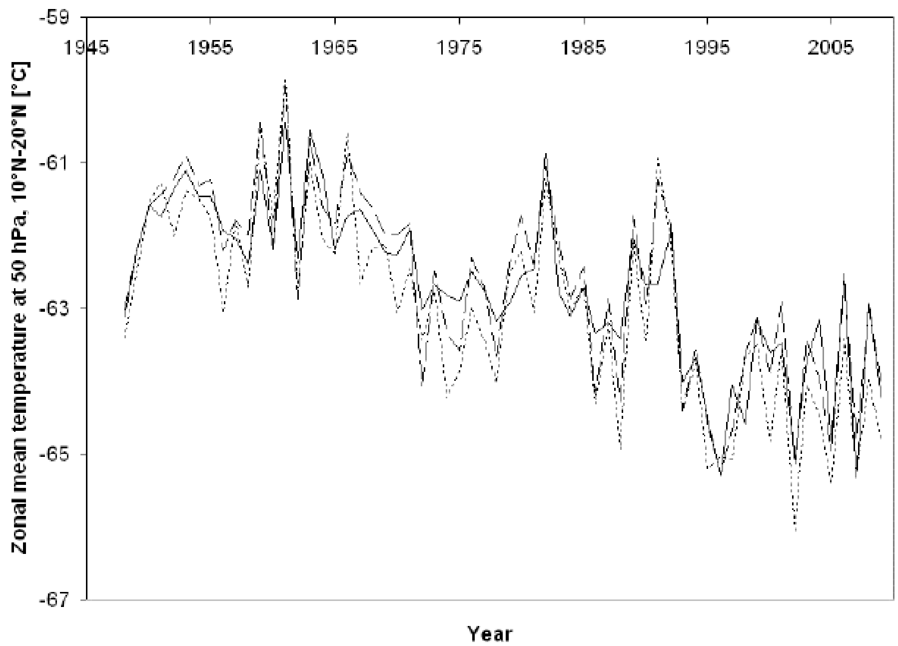


Fig. (2). Zonal monthly mean temperature from the NCEP/NCAR reanalysis dataset at 10hPa for July (solid line), August (dashed line) and September (dotted line) at (**a**) 20ºN-10ºN zone, and (**b**) 70ºS-80ºS zone.

(**a**)



(**b**)

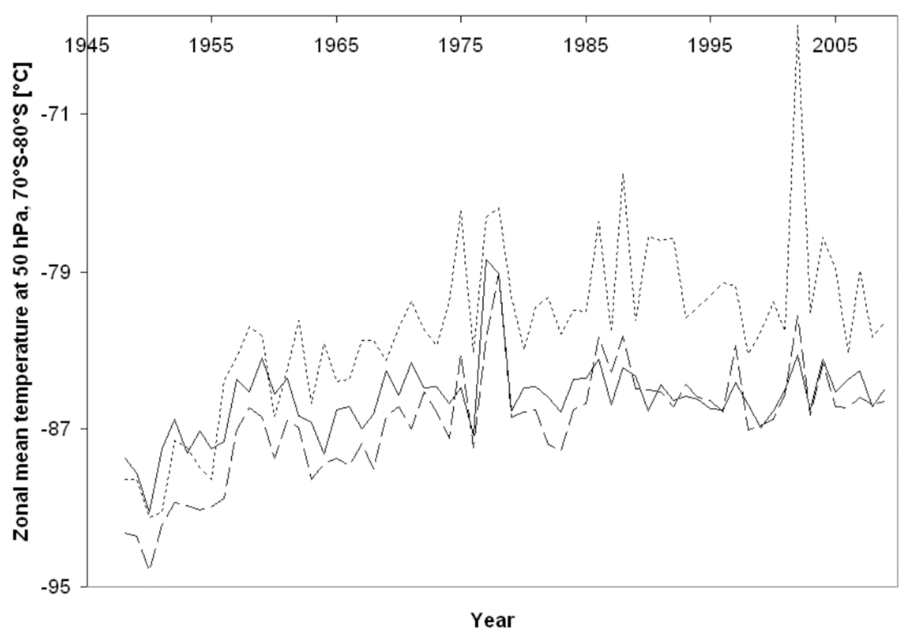


Fig. (3). Zonal monthly mean temperature from the NCEP/NCAR reanalysis dataset at 50 hPa for July (solid line), August (dashed line) and September (dotted line) at (**a**) 20ºN-10ºN zone, and (**b**) 70ºS-80ºS zone.

occurred in 1982 (El Chichon eruption) and in 1991 (Mount Pinatubo eruption). In the case of the "warming" noticed for the 20°N-10°N zone at 10 hPa (Fig. **2a**), El Chichon eruption marks the end of this upward trend. However, this is not an explanation for the almost sustained trend since 1948.

The two trend discontinuities mentioned may be due to changes in the observing systems within the reanalyses. Since, although these data were quality controlled and climate jumps associated with these kind of changes were eliminated, the reanalysis may be still affected by changes in the observing systems [9]. Among other several possible causes for this behavior, one may be solar UV radiation. In the case of the upper region temperature, that is at 10 hPa, stronger influences from the UV spectrum range of the solar irradiance should be expected than in lower regions. In fact, maximum temperature responses to TSI variations were obtained by Cahalan *et al*. [10] for the upper stratosphere, decreasing downward. Fig. (**5**) shows the 10hPa temperature in July for 20ºN-10ºN and 70ºS-80ºS zonal regions, together with the 11-year running mean of the total solar irradiance (TSI) [11, 12]. A similar behavior can be noticed between temperature and the smoothed TSI. However, this is only a hint and a deeper physical analysis should be made in order to corroborate this result.

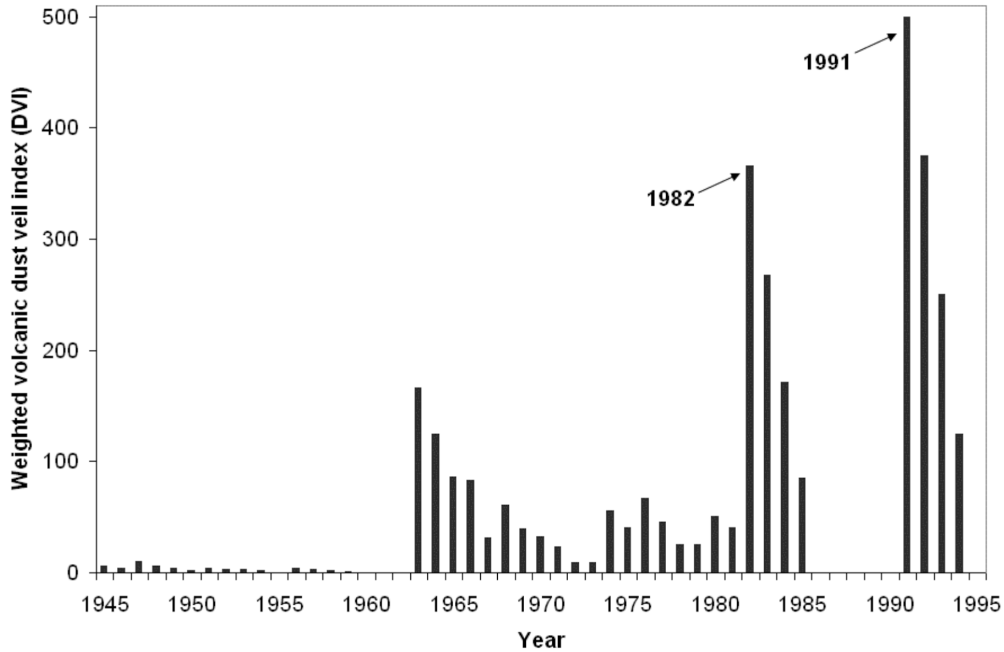


Fig. (4). Dust veil index (DVI) (Mann *et al*., 2000) for the period 1945-1995. The strongest eruptions occurred in 1982 (El Chichon) and in 1991 (Mount Pinatubo).

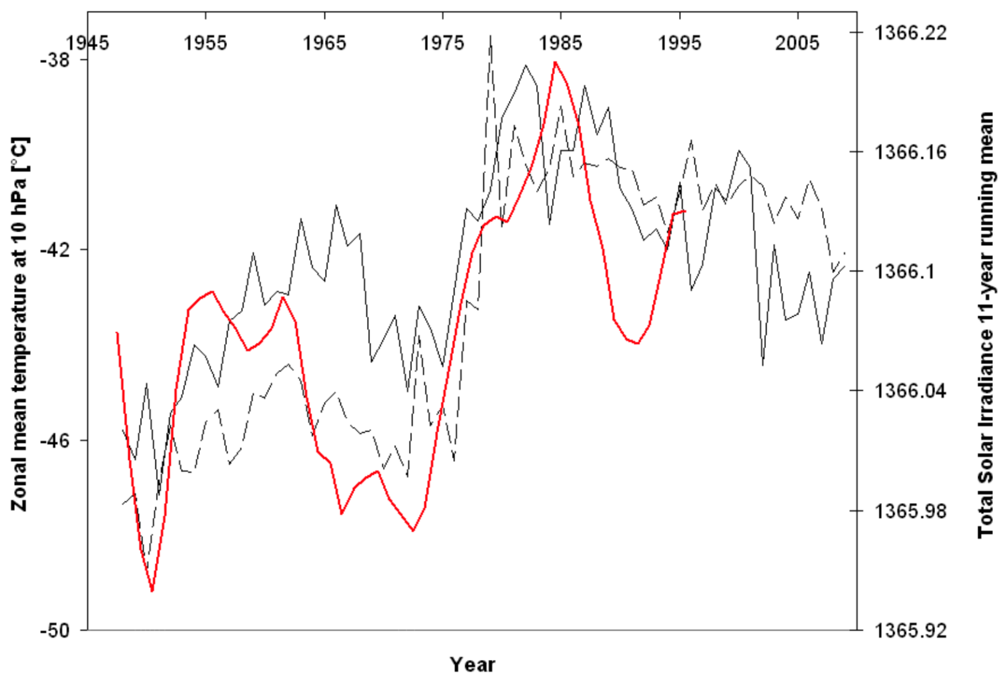


Fig. (5). Zonal monthly mean temperature from the NCEP/NCAR reanalysis dataset at 10 hPa for July at zones 20ºN-10ºN (solid line) and 70ºS-80ºS (dashed line) together with the 11-year running mean of the reconstructed total solar irradiance, TSI (enhanced red line) in W/m^2.

DISCUSSION AND CONCLUSIONS

Stratospheric temperature trends have been analyzed in a monthly zonal mean basis using data from NCEP/NCAR reanalysis dataset [7] at four different stratospheric heights: 10 hPa, 30 hPa, 50 hPa and 70 hPa. Linear trends assessed using the whole dataset, which covers the period 1948-2009, are mostly negative in agreement with the cooling expected in the stratosphere due to greater CO_2 concentrations that "should lead to increased longwave radiation from the middle atmosphere, and cooler temperatures" [13] and decreasing ozone concentrations. "Warmings" are also observed for certain heights and certain regions which may result from other sources, or a combination of them. We considered only one of them: the solar irradiance, TSI. A visual inspection of the behavior of temperature time series which present positive trends when considering the period 1948-2009 together with the TSI 11-year running mean, points out a kind of agreement (see Fig. **5**). A deeper analysis remains to be done considering also a comparison of trends prior and after 1979 using the NCEP/NCAR dataset.

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REFERENCES

[1] Ramaswamy V, Chanin ML, Angell J, *et al*. Stratospheric temperature trends: Observations and model simulations. Rev Geophys 2001; 39: 71–122.

[2] IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland 2007; p. 104.

[3] Thompson DWJ, Solomon S. Recent stratospheric climate trends as evidenced in radiosonde data: Global Structure and Tropospheric Linkages. J Climate 2005; 18: 4785-95.

[4] WMO (World Meteorological Organization). Scientific assessment of Ozone depletion: 2006, Global Ozone Research and Monitoring Project - Report No. 50, 572pp., Geneva, Switzerland, 2007.

[5] Lamarque JF, Solomon S. Impact of changes in climate and halocarbons on recent lower stratosphere Ozone and temperature trends. J Climate 2010; 23: 2599-611.

[6] Schwarzkpof MD, Ramaswamy V. Evolution of stratospheric temperature in the 20^{th} century. Geophys Res Lett 2008; 35: L03705.

[7] Kalnay E, Kanamitsu M, Kistler R, *et al*. The NCEP/NCAR Reanalysis 40-year Project. Bull Amer Meteor Soc 1996; 77: 437-71.

[8] Mann ME, Gille EP, Bradley RS, *et al*. Global temperature patterns in past centuries: An Interactive Presentation. Earth Interact 2000; Vol 4, Paper 4.

[9] Kistler R, Collins W, Saha S, *et al*. The NCEP–NCAR 50–Year Reanalysis: Monthly Means CD–ROM and Documentation. Bull Am Meteorol Soc 2001; 82: 247-67.

[10] Cahalan RF, Wen G, Harder JW, Pilewskie P. Temperature responses to spectral solar variability on decadal time scales. Geophys Res Lett 2010; 37: L07705.

[11] Lean J, Beer J, Bradley R. Reconstruction of solar irradiance since 1610: Implications for Climate Change. Geophys Res Lett 1995; 22: 3195-8.

[12] Lean J. Evolution of the Sun's spectral irradiance Since the maunder minimum. Geophys Rev Lett 2000; 27: 2425-8.

[13] Rind A, Suozzo A, Balachandran NK, Prather MJ. Climate change and the middle atmosphere. Part I: The doubled CO_2 climate. J Atmos Sci 1990; 47:475-94.

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