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Temperature perturbations in the troposphere-stratosphere over Thumba (8.5° N, 76.9° E) during the solar eclipse 2009/2010

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Abstract. Measurements of atmospheric temperature profiles in the troposphere and lower stratosphere were made over Thumba Equatorial Rocket Launching Station (TERLS) (8.5° N, 76.9° E) during a partial solar eclipse (22 July 2009) and an annular solar eclipse (15 January 2010). It was observed that during the partial solar eclipse, the temperature decreased by 2–3 °C in the vicinity of the tropopause and in the lower stratosphere the temperature increased by ∼2.6 °C during the maximum phase of the partial solar eclipse. During the annular solar eclipse, a temperature reduction of ∼2 °C was observed around the tropopause. This study also revealed a feature of delayed effect in the form of a very intense warming of ∼8 °C at 18 km after about 4 h of the annular solar eclipse. The Cold-Point Tropopause (CPT) temperature increased slowly before the beginning of the eclipse (up to 10:00 IST) and during the maximum phase of the eclipse, the difference in CPT temperature and height was −3.5 °C and ∼110 m, respectively, as that of the control day. After the four hours of the eclipse, the CPT height had decreased by ∼1.7 km and the CPT temperature increased by ∼4.6 °C. This is for the first time that the diurnal variation of the tropopause has been reported during a solar eclipse day. The present study, thus, provided an opportunity to investigate the temperature perturbations in the troposphere and lower stratosphere during a partial and annular solar eclipse. The highlight of the present results are (1) cooling of the entire troposphere and lower stratosphere during the maximum phase of annular solar eclipse, (2) an intense heating of the lower stratosphere by 8 °C after nearly four hours from the maximum phase of the annular eclipse, and (3) drastic variations in the diurnal evolution of the tropical tropopause characteristics. The cooling effect is attributed to the radiative response of the atmosphere to the solar eclipse, where as heating is attributed to the dynamical response of the atmosphere to the solar eclipse. These results may have important implications in understanding the response of the atmosphere to the radiative, as well as dynamical, perturbations caused by any celestial or terrestrial disturbances.

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1 Introduction

A Solar eclipse is one of the most spectacular astronomical phenomena which occur when the Moon covers the Sun, casting its shadow on the Earth and it inspires meteorologists to conduct special investigations. Eclipses are connected with the rapid and short time, impulse-like decrease of solar energy flux reaching the area of its visibility, which can be exactly predicted before the occurrence of the phenomenon (Stoev et al., 2005; Krumov and Krezhova, 2008). It also provides a unique opportunity for meteorologists to study the response of the atmosphere or biosphere to the sudden turn off/turn on of the incidental solar radiation during and after the solar eclipse. There are a number of studies and observations made during the solar eclipses (Nymphas et al., 2009, and references therein) which include observations of meteorological parameters, such as wind speed and direction, air temperature, atmospheric pressure, humidity (Anderson et al., 1972; Szalowski, 2002; Dolas et al., 2002; Krishnan et al., 2004; Nymphas et al., 2009), gravity waves (Chimonas and Hines, 1971; Singh et al., 1989; Zerefos et al., 2007), ozone measurements (Chakrabarty et al., 1997; Zerefos et al., 2000; Tzanis et al., 2008) and heat and momentum fluxes within the boundary layer (Krishnan et al., 2004). The impact of a solar eclipse on atmospheric and surface temperature has been widely reported in the literatures (Kolarz et al., 2005; Founda et al., 2007; Nymphas et al., 2009). The solar eclipse event provides an excellent opportunity to study the temporal response of the atmosphere to an abrupt change in solar radiation. In India, many studies reported the observations of metrological parameter changes during the solar eclipse (Eliot, 1900; Agarwal, 1980; Appu et al., 1997; Singh et al., 1989; Dutta et al., 1999; Dolas et al., 2002; Krishnan et al., 2004). The observations at one hundred and fifty four meteorological stations in India recorded during the solar eclipse of 22 January 1898, have been discussed and published by Eliot (1900). The author discussed the latitudinal changes of temperature from 12° N to 20° N at the time of maximum obscuration and noted that the temperature of the air diminishes in proportion to the obscuration and amounted to 8 °C in the interior of India near the path of total eclipse. Observations made during the solar eclipse of 24 October 1995, at Thumba Equatorial Rocket Launching Station (TERLS) (8.5° N, 76.9° E), revealed a strong warming of the lower stratosphere towards the end of the solar eclipse (Appu et al., 1995). Dolas et al. (2002) reported changes in wind speed during the eclipse with minimum value during totality but without much change in wind direction. Niranjan et al. (1997) observed sharp increases in the UV flux after the last two hours of contact of the eclipse on 24 October, 1995. These authors attributed the observed increases in ground-based UV flux to the reduction of stratospheric ozone.

In the present study, we report the observations of two celestial events; the partial solar eclipse of July 2009 and the annular solar eclipse of January 2010 over TERLS. On 22 July 2009, a partial solar eclipse occurred during the early morning hours at 05:30 IST and another one, an annular solar eclipse on 15 January 2010 which had maximum obscuration at 13:00 IST hrs in the afternoon and was visible along the band of ∼300 km over TERLS. These events, especially the annular one which is unique due to its long duration and noontime occurrence, provided an excellent opportunity to measure the temperature and its variations in the atmosphere. The novelty of the present study lies in showing the response of the troposphere and lower stratosphere not only during the maximum phase of the eclipse, but also after a few hours of the eclipse, which shed light on the dynamical response of the atmosphere to the eclipse-induced temperature perturbations. Section 2 describes the experiments and data. Results are presented in Sect. 3 followed by discussion and the conclusions in Sect. 4.

2 Experiments and data

A campaign mode of multi-instrument observations was carried out at TERLS on 22 July 2009 during a partial solar eclipse and with a control day observations on 23 July 2009. Again, observations were carried out on 15 January 2010 during the annular solar eclipse with a control day observations on 14 January 2010. A total of five balloon flights

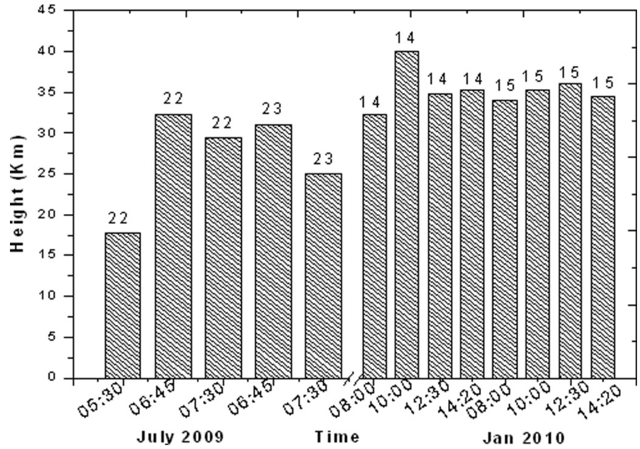

Fig. 1. Details of the balloon launch timings and its height coverage during partial solar eclipse of July 2009 and annular solar eclipse January 2010.

carrying Pisharoty GPS sondes were launched on the partial solar eclipse day of 22 July and on the control day of 23 July 2009. Since the balloon launched at 05:30 IST on 22 July 2009 burst at ∼18 km, a repeat launch was made at 06:04 IST and another flight at 07:30 IST to study the delayed effects of eclipse, if any. The millennium annular solar eclipse occurred on 15 January 2010 and maximum obscuration at TERLS was in the midday afternoon around 13:14 IST, while air temperature and turbulent activity were usually high. A total of eight meteorological balloon flights carrying Pisharoty sonde at 08:00, 10:00, 12:30 and 14:20 IST with four on the control day (14) and four on the eclipse day (15) of January 2010 were launched. Figure 1 provides the details of balloon flights launched in connection with two eclipse events. The important atmospheric parameters such as humidity, pressure, temperature and wind right from surface to ∼35 km altitude were measured from each flight. The annular eclipse at Thumba began at 11:04 IST and the annularity started at 13:10 IST. The maximum phase of the annularity was at 13:14 IST and the ending of annularity was at 13:17 IST. The end of the eclipse was at 15:05 IST. The total duration of annularity was 7 min and 16 s.

The above-mentioned observations were supplemented with the high resolution GPS sonde flights carried out by India Meteorological Department (IMD), Trivandrum daily at 05:30 and 17:30 IST. The present study focuses mainly on the temperature perturbations associated with the eclipse events in 2009 and 2010. The height profile of the mean-removed temperature fluctuations for each flight was derived for two separate eclipse events. The perturbations in the temperature profile during the eclipse compared to that on the control day were used to study the eclipse induced effects and the delayed effects of the eclipse. The temperature fluctuations were found to be more in the upper tropospheric-lower stratospheric region. The height profiles of temperature

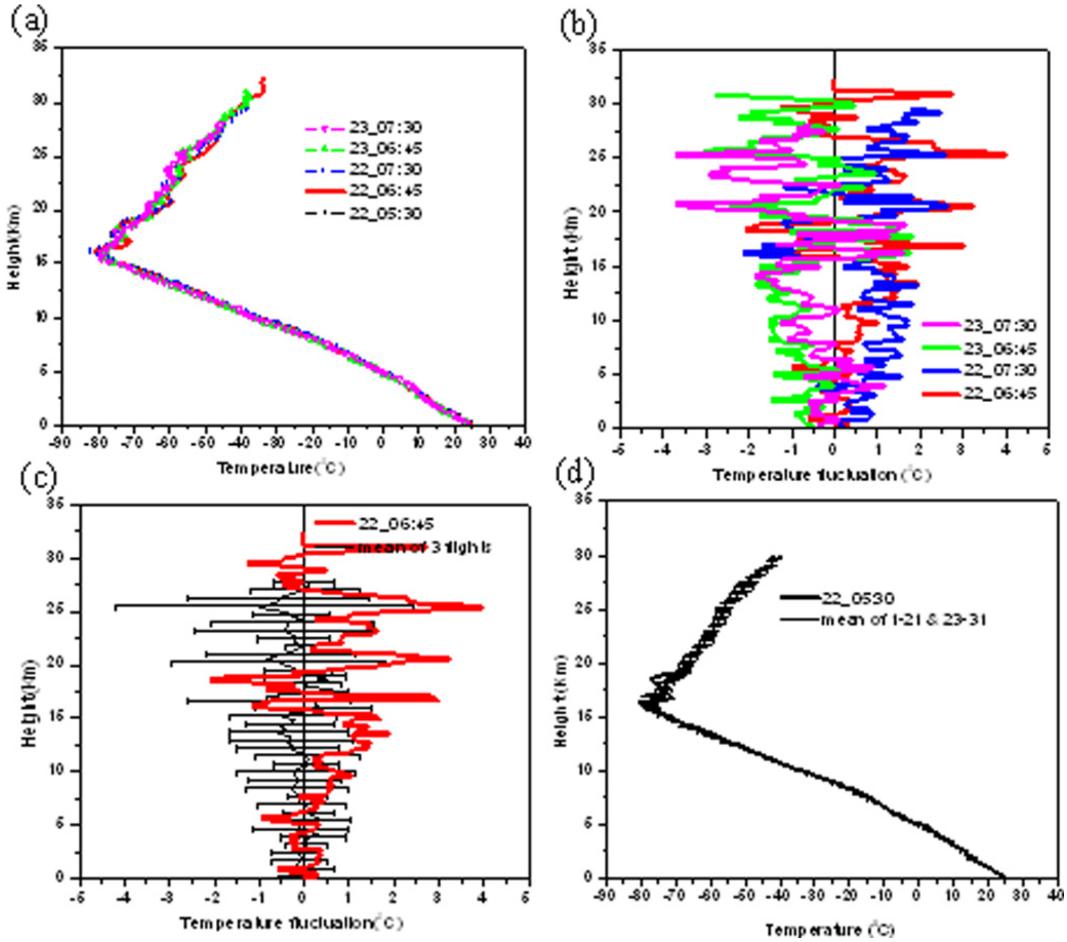

Fig. 2. (a) The height profile of the temperature in the 0–35 km region on 22 July 2009 at 05:30 (black), 06:45 (red) and 07:30 (blue) IST and on the control day of 23 July at 06:45 (green) and 07:30 (magenta) IST. **(b)** Temperature fluctuation profiles on eclipse (22) and control day (23) of July 2009. **(c)** Temperature fluctuation profiles at 06:45 (red) IST on eclipse day and mean fluctuation profile with standard deviations. **(d)** The height profile of the temperature at 05:30 IST on the eclipse day and mean temperature with standard deviation of non-eclipse days (1–21 and 23–31 July 2009) from IMD observations.

fluctuations in the mid-troposphere, tropopause and in the lower stratosphere regime were subjected to the wavelet analysis to find the vertical scale sizes of temperature fluctuations. The results from these analyses are presented in the next section.

3 Results and discussions

3.1 Partial solar eclipse during 22 July 2009

The temperature structure in the tropospheric-stratospheric region was measured during a partial solar eclipse event of July 2009 by making use of high altitude balloon flights along with measurements on control days. Figure 2a shows the height profile of temperature in the 0–35 km region on 22 July 2009 at 05:30 (black), 06:45 (red) and 07:30 (blue) IST and that on the control day of 23 July at 06:45 (green) and 07:30 (magenta) IST. Figure 2b shows the temperature fluctuation profiles on the eclipse (22) and control day (23) of July 2009. The temperature profile at 05:30 IST on July 2009 is available only up to 18 km since the balloon burst at that height. The temperature fluctuations profile on the eclipse day at 06:45 IST shows not much variation as compared to the control day at the same time. This can be clearly seen in Fig. 2c, which shows temperature fluctuation profiles at 06:45 (red) IST on eclipse day and mean of all three temperature fluctuations (at 07:30 IST on the eclipse day and at 06:45 and 07:30 IST on the control day) along with standard deviations. Right from surface to lower stratosphere, temperature fluctuations were within the standard deviation. During the partial solar eclipse of 2009, the temperature decreased by ∼2 °C at around the tropopause level and temperature inversion was observed just above the tropopause. This kind of temperature structure has been reported by Dalaudier et al. (1994) in the lower atmosphere (at least up to 25 km)

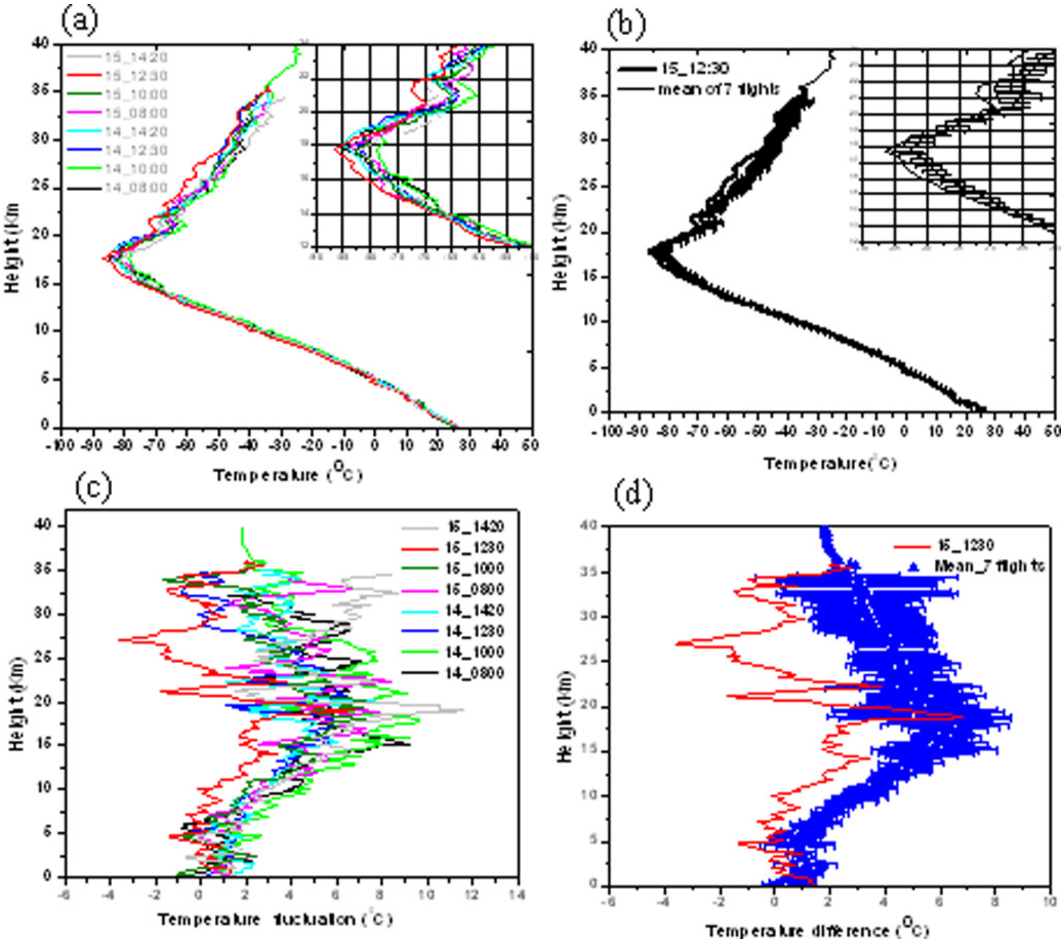

Fig. 3. (a) Height profiles of temperature at 08:00, 10:00, 12:30 and 14:20 IST on 14 and 15 January 2010 with different colours. **(b)** Height profile of temperature during the eclipse time (12:30 IST) compared with the mean of all other temperature profiles on non-eclipse timings along with standard deviations. **(c)** Mean-removed fluctuations on the control day (14) and eclipse day (15) of January 2010 at 08:00, 10:00, 12:30 and 14:20 IST. **(d)** Temperature fluctuation profile at 12:30 (red) IST on the eclipse day and mean for all other fluctuation profiles along with standard deviations.

along with the presence of very strong temperature sheets with in a very thin layer. It is further confirmed from Fig. 2d, which shows the height profiles of temperature at 05:30 IST on the eclipse day and mean temperature with standard deviation of non-eclipse days (1–21 and 23–31 July 2009) derived from IMD, balloon flights at Trivandrum. The temperature changes at the tropopause level was observed in this profile, also similar to that observed in Fig. 2a at 06:45 IST on the eclipse day. Unfortunately, on 22 July 2009, IMD flight only provided temperature information up to ∼20 km altitude as well.

3.2 Annular solar eclipse during 15 January 2010

The annular solar eclipse of 2010 started at 11:04 IST and ended at 15:05 IST over TERLS on 15 January. Figure 3a shows the height profile of temperature at 08:00, 10:00, 12:30 and 14:20 IST on 14 and 15 January 2010 with different colours. The temperature profile at 12:30 (red) IST on 15 January 2010 shows a cooling in the upper troposphere and in the lower stratosphere, as seen in enlarged graph in Fig. 3a. This feature is more clearly brought out in Fig. 3b, where the height profile of temperature during eclipse time (12:30 IST) compared with the mean of all other temperature profiles on non-eclipse timings along with standard deviation. It can be clearly seen from the figure that distinct cooling took place in the 12–18 km and above 20 km. The mean-removed fluctuations on control day (14) and eclipse day (15) of January 2010 at 08:00, 10:00, 12:30 and 14:20 IST are shown in Fig. 3c. It is clearly seen that a cooling of 2–8° occurred in the 7–28 km height region during the eclipse period compared with all other temperature fluctuations on 14 and 15 January 2010. Temperature fluctuation profiles on the control day shows diurnal/day-to-day variation of ∼3 °C, but the temperature fluctuation profile at 12:30 (red) IST on the

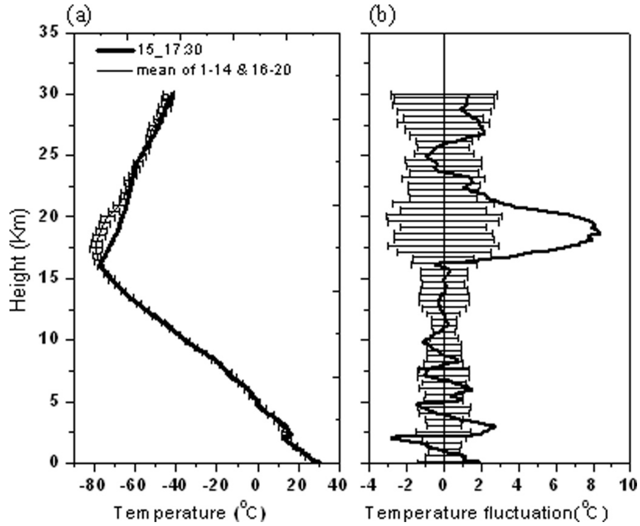

Fig. 4. **(a)** Temperature profile measured at 17:30 IST on eclipse day and mean of measurements at 17:30 IST on non-eclipse days (1–14 and 16–30 January 2010) along with standard deviations. **(b)** Temperature fluctuations on eclipse day (black) and on mean fluctuations in the month of January excluded on eclipse day along with standard deviation.

eclipse day shows a remarkable decrease of 2–8 °C in the 17–28 km region. The decrease in temperature was ∼2–4 °C in the lower and upper troposphere, whereas in the lower stratosphere the temperature was decreased by ∼6–8 °C during the maximum phase of the eclipse. The decrease in the temperature fluctuation can be attributed to the cooling in the atmosphere due to the sudden cut off of solar radiation. From the same figure, it is seen that towards the end of the eclipse at 14:20 IST on 15 January 2010, the temperature slowly came back to its normal position, except in the lower stratosphere, where the difference in temperature fluctuation was beyond the diurnal temperature fluctuations shown by the profile at 14:20 (grey) IST on the eclipse day. Figure 3d shows the temperature fluctuation profile at 12:30 IST on the eclipse day and mean of all other temperature fluctuation profiles along with standard deviation. Cooling of ∼2–8 °C is clearly observed in 7–28 km height region. Figure 4a shows the temperature profiles measured at 17:30 IST on the eclipse day and mean of measurements at 17:30 IST on non-eclipse days (1–14 and 16–30 January 2010) along with standard deviations. A remarkable increase in temperature is seen around 15–20 km. Figure 4b shows the temperature fluctuations on eclipse day, compared with the mean temperature fluctuation along with standard deviations on all non-eclipse days at 17:30 IST. There is an increase in temperature of ∼6 °C in the 18–19 km height region on 15 January compared to other days. It can be noted that unusual strong warming of ∼8 °C seen as a delayed effect due to the eclipse is significant in the lower stratosphere, whereas such warming is not seen in the tropospheric region. Appu et al. (1997) observed strong cooling in the tropospheric level after about three hours of the eclipse on 24 October 1995. Earlier observations at TERLS by balloon and rocket flights in connection with the partial solar eclipse of 16 February 1980, which occurred at local noon time, could reveal warming of 10 °C around 30 km and cooling of 9 °C in the upper troposphere after three to four hours of the eclipse (Appu et al., 1982). Each solar eclipse event is unique with its characteristics, like its occurrence of time, duration, percentage of maximum obscuration, etc., which can result in variations in thermal and dynamical response of the atmosphere.

Figure 5a and b shows the Cold-Point Tropopause temperature (CPT) and height variations on the eclipse (15 January) and control day (14 January), respectively. The diurnal variation in the CPT temperature on control day (14 January) can be clearly seen in Fig. 5a. In the case of the eclipse day (15 January) from 05:30 IST to 10:00 IST, CPT temperature varies as on the control day, but at the time of maximum obscuration, the CPT temperature suddenly drops by ∼4 °C compared to that on the control day. After that, the temperature increases pre-eclipse value and starts descending slowly following the diurnal pattern. The height of CPT is found to descend down by ∼110 m, and ∼400 m at 12:30 and 14:20 IST, respectively, due to the eclipse effect and after the eclipse the CPT height is found to decrease by ∼1.7 km from 17.8 to 16.1 km at 17:30 IST. The variation in the CPT temperature was about ∼4 °C around maximum obscuration with its pattern changed from the usual diurnal variations. Randhawa (1970) observed that the tropopause and lower stratospheric temperatures were also lower than those observed during eclipse compared to the control day. The present analysis also showed a delayed effect of eclipse on CPT height and temperature.

The maximum warming of 8 °C observed in the present study at ∼18 km could indicate the occurrence of maximum downward motion at that level as a delayed effect of eclipse. Wang and Liu (2010) recently reported warming of the 7 °C at 17 km altitude in the lower stratosphere and cooling of 2 °C in the troposphere. These authors attributed the warming to the eclipse-induced downward motion, which adiabatically heats the lower stratosphere, resulting in the warming of that region. These adiabatic compressions also can lead to lower the CPT height. The tropopause height can increase because of the cooling in the stratosphere and warming in the troposphere (Lorenz and DeWeaver, 2007). In addition to a rise in the tropopause height, climate models simulate the increase in upper level zonal wind and eddy kinetic energy, which appears to be associated with the rise in tropopause height (Kushner et al., 2001; Raisanan, 2003). Also the CPT height and temperature can vary with season and its location (e.g., Seidel and Randel, 2006; Fueglistaler et al., 2008; Gettelman et al., 2009). Study on variations of tropopause height using MST radar observations has shown that the day-to-day variation in CPT height is ∼1 km (Das et al., 2008). Gettelman et al. (2009) using theoretical and observational

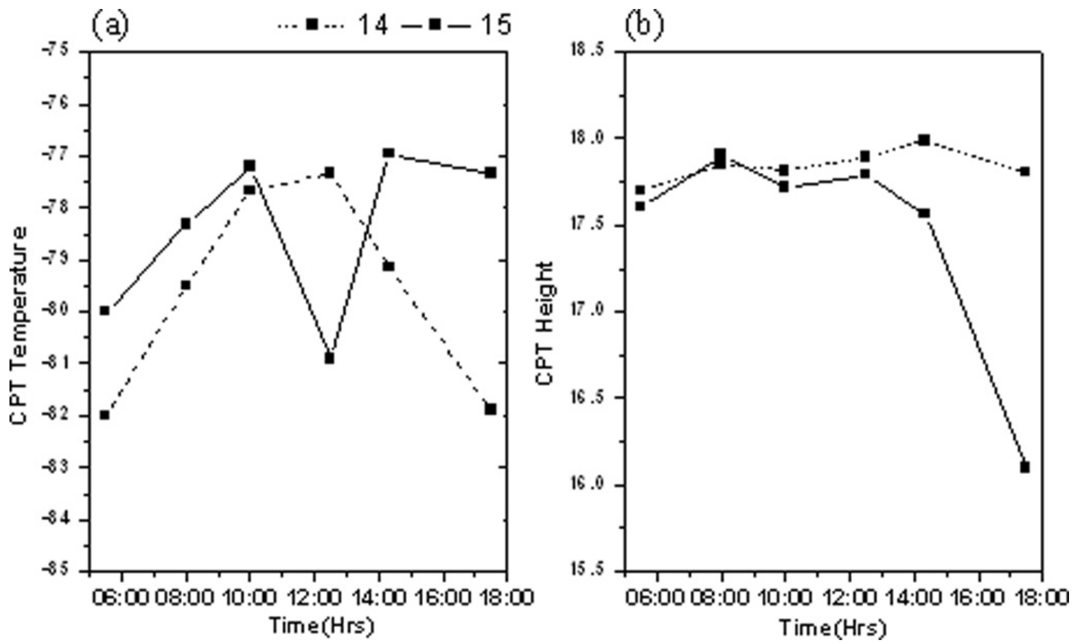

Fig. 5. CPT **(a)** temperature and **(b)** height variations on eclipse day (15 January) and on a control day (14 January).

studies have shown that the variation in CPT height might be due to the decrease in tropopause pressure resulting from stratospheric cooling or tropospheric warming and a change in greenhouse gas forcing. The observed decrease in the CPT height in the present study without much change in the troposphere can be attributed to the changes around the tropopause resulting from adiabatic compression of the atmosphere due to the solar eclipse. This is the first time that the diurnal variation of tropical tropopause is reported during the solar eclipse.

3.3 Wavelet power spectra of temperature fluctuations

The wavelet transform can be used to analyse time series that contain non-stationary power at many different frequencies (Daubechies, 1990). For this study the morlet (mother wavelet) was selected, since it has been proven to be suitable for the analysis of atmospheric fluctuations (Kumar, 2007). Figure 6a and b shows the Morlet wavelet spectra of the vertical profile of temperature fluctuation during eclipse time at 06:45 IST on the control day (23 July) and eclipse day (22 July) of the 2009 partial solar eclipse event. Short scale perturbations in the lower troposphere and lower stratosphere are seen on the eclipse day compared to the control day. Enhancement of 5–6 km vertical wavelength structure extending towards lower stratosphere on the eclipse day is clearly seen compared to the control day. In Fig. 6b, a pronounced shorter scale wavelength is seen in the 0–2 km height region, unlike that on the control day. An enhancement in amplitudes of 12–14 km vertical wavelength on the eclipse day is also observed. Figure 6c and d shows the wavelet spectra of height profiles of temperature fluctuations at 12:30 IST on the control day (14) and the eclipse day (15) for the annular solar eclipse event on January 2010. Distinct features like presence of short and large scale structures are seen during the eclipse event with increased amplitudes. Shorter scale fluctuation of 2 km vertical wavelength was at 21–23 km height region on the eclipse day, which was not seen on the control day. A vertical wavelength of 6 km is found to be present in the 15–32 km height region. The enhancement in amplitude of 12–14 km vertical wavelength on the eclipse day was also observed compared to the control day. These vertical structures in temperature fluctuations are believed to be due to the gravity waves excited by the thermodynamical imbalance in the atmosphere induced by the eclipse. However, one should have continuous observations of geophysical parameters for better characterisation of gravity waves.

4 Concluding remarks

Two field campaigns were carried out to study the response of the Earth's atmosphere to a partial solar eclipse and to an annular solar eclipse. The present study focused on the changes in the thermal structure of troposphere and lower stratosphere during these two celestial events. During the partial solar eclipse of 2009, the temperature observations showed a decrease of ∼2 °C at around tropopause level. During the annular solar eclipse of 15 January 2010, the cooling by ∼2–8 °C is observed in the troposphere and lower stratosphere with ∼4 °C cooling around the tropopause and ∼6–8 °C in the lower stratosphere at the maximum phase of

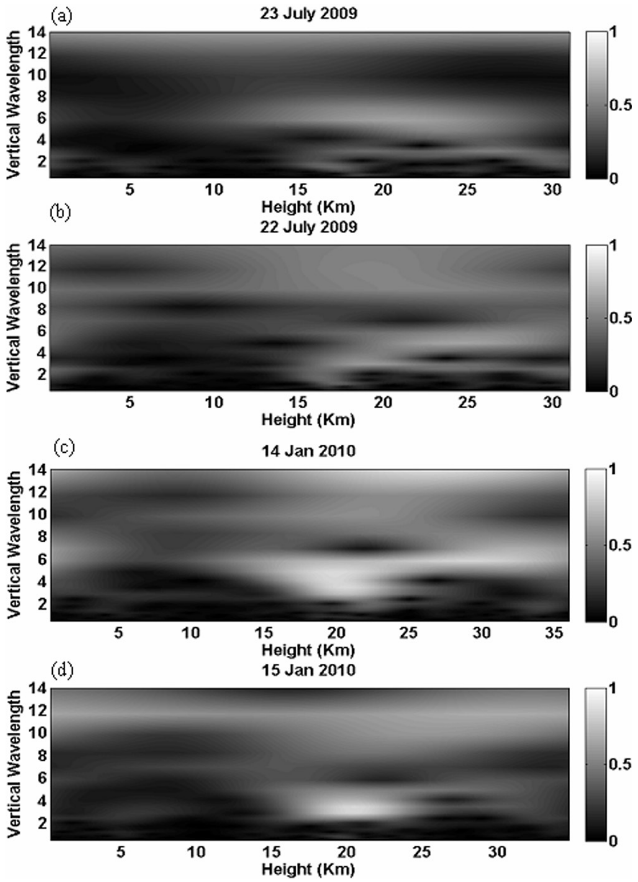

Fig. 6. Wavelet spectra of temperature fluctuations at 06:45 IST on **(a)** control day (23 July) and **(b)** eclipse day (22 July) of partial solar eclipse of 2009. **(c)** and **(d)** same as **(a)** and **(b)** but for the annular solar eclipse of January 2010 at the maximum phase of the eclipse time at 12:30 IST.

the eclipse. The present study also showed a strong warming of ~8 °C in the lower stratosphere after four hours of the eclipse, which is attributed to the compression of the atmosphere due to the eclipse induced thermal perturbations. Apart from these, the height of CPT was lowered by ~110 m and ~400 m at 12:30 and 14:20 IST, respectively, due to the eclipse and lowered by ~1.7 km from 17.8 to 16.1 km at 17:30 IST after the eclipse. The variation in the CPT temperature was about ~4 °C around maximum obscuration with its pattern changed from usual diurnal variations. The wavelet spectral analyses of the height profiles of the temperature fluctuations revealed the presence of gravity waves with vertical wavelengths in the range 2–6 km and 12–14 km, which could be attributed perturbations associated with the eclipse. The evidence for the gravity wave type of perturbations in the tropospheric-lower stratospheric region and their characteristics features are revealed from the wind observations during 2009 and 2010 eclipse events and will be reported subsequently. Thus, the present study brought out the changes observed in the thermal structure of troposphere and lower stratosphere during and after the eclipse. The changes observed during the eclipse are directly attributed to the radiative response of the atmosphere, whereas changes observed after the eclipse are attributed to dynamical response of the atmosphere.

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References

Agarwal, P. D., Janardhanan, K. V., Krishna Murthy, B. V., Kunhi Krishnan, P. K., Madhava anicker, P. R., Raghava Redyy, C., Reddy, C. A., Sen Gupta, K., Somayajulu, V. V., and Subbrao, K. S. V.: At,mopsheric Effects During Solar Eclipse Feb 16, 1980, SPD-SR-09-80, 1980.

Anderson, R. C., Keefer, D. R., and Myers, O. E.: Atmospheric pressure and temperature changes during the 7 March, 1970 solar eclipse, J. Atmos. Sci., 29, 583–587,1972.

Appu, K. S., Krishanmoorthy, B. V., Narayanan, V., Reddy, C. A., and Sen gupta, K.: Thermal Structure of the Atmosphere-Surface to Mesosphere-during the Solar Eclipse of 16 February 1980, Proc. Indian Natn., Sci. Acad, 48A, 506, 1982.

Appu, K. S., Santhikumar, K. S., Padmanabha Pillai, R., and Narayanan, V.: Results of October 24, 1995 Solar Eclipse Balloon Experiment from Thumba, Kodiakanal Obs. Bull., 13, 155–159, 1997.

Chakrabarty, D. K., Shah, N. C., and Pandya, K. V.: Fluctuations in ozone column over Ahmenabad during the solar eclipse of 24 October, 1995, Geophys. Res. Lett., 24, 3001–3003, 1997.

Chimonas, G. and Hines, C. O.: Atmospheric gravity waves induced by a solar eclipse 2, J. Geophys. Res., 76, 7003–7005, 1971.

Dalaudier, F., Sidi, C., Chrochet, M., and Vernin, J.: Direct Evidence of “Sheets” in the atmospheric Temperature Field, J. Atmos. Sci., 51, 237–248, 1994.

Das, S. S., Jain, A. R., Kumar, K. K., and Rao, D. N.: Diurnal variability of the tropical tropoause: significance of the VHF Radar measurements, Radio Sci., 43, RS6003, doi:10.1029/2008RS003824, 2008.

Daubechies, I.: The wavelet transforms time-frequency localization and signal analysis, IEEE Trans. Inf. Theory, 36, 961–1004, 1990.

Dolas, P. M., Ramchandra, R., Sen Gupta, K., Patil, S. M., and Jadhav, P. N.: Atmospheric surface-layer processes during the total solar eclipse of 11 August, 1999. Boundary-Layer Meteorol. 104, 445–461.from dry to wet season, J. Theor. Appl. Climatol., 89, 171–183, 2002.

Dutta, G., Joshi, M. N., Pandarinath, N., Bapiraju, B., Srinivasan, S., Subba Rao, J. V., and Aleem Basha, H.: Wind and temperature over Hyderabad during the eclipse of 24 Oct.1995, Indian J. Radio Space Physics, 28, 11–14, 1999.

Eliot, J.: Observations during the Solar Eclipse, Mon. Weather Rev., 10, 449–450, 1900.

Founda, D., Melas, D., Lykoudis, S., Lisaridis, I., Gerasopoulos, E., Kouvarakis, G., Petrakis, M., and Zerefos, C.: The effect of the total solar eclipse of 29 March 2006 on meteorological variables in Greece, Atmos. Chem. Phys., 7, 5543–5553, doi:10.5194/acp-7-5543-2007, 2007.

Fueglistaler, S., Dessler, A. E., Dunkerton, T., Folkins, I., Fu, Q., and Mote, P. W.: Tropical Tropopause Layer, Rev. Geophys., 47, RG1004, doi:10.1029/2008RG000267, 2009.

Gettelman, A., Birner, T., Eyring, V., Akiyoshi, H., Bekki, S., Brühl, C., Dameris, M., Kinnison, D. E., Lefevre, F., Lott, F., Mancini, E., Pitari, G., Plummer, D. A., Rozanov, E., Shibata, K., Stenke, A., Struthers, H., and Tian, W.: The Tropical Tropopause Layer 1960–2100, Atmos. Chem. Phys., 9, 1621–1637, doi:10.5194/acp-9-1621-2009, 2009.

Krishnan, P., Kunhikrishnan, P. K., Muraleedharan Nair, S., Ravindran, S., Ramachandran, R., Subrahamanyan, D. B., and Venkata Ramana, M.: Observations of the atmospheric surface layer parameters over a semi-arid region during the solar eclipse of 11 August, 1999. Proc. Indian Acad. Sci. (Earth Planet Sci.), 113, 353–363, 2004.

Kolarz, P., Sekaric, J., Marinković, B. P., and Filipović, D. M.: Correlation between some of the meteorological parameters measured during the partial solar eclipse, 11 August, 1999, J. Atmos. Sol. Terr. Phys., 67, 1357–1364, 2005.

Krumov, A. H. and Krezhova, D. D.: Imaging of the total solar eclipse on March 29, 2006, J. Atmos. Sol. Terr. Phys., 70, 407–413, 2008.

Kumar, K. K.: VHF radar investigations on the role of mechanical oscillator effect in exciting convectively generated gravity waves, Geophys. Res. Lett., 34, L01803, doi:10.1029/2006GL027404, 2007.

Kushner, P. J., Held, I. M., and Delworth, T. L.: Southern Hemisphere atmospheric circulation response to global warming, J. Climate, 14, 2238–2249, 2001.

Lorenz, D. J. and DeWeaver, E. T.: The Tropopause Height and the Zonal wind Response to Global Warming in the IPCC Scenario integrations, J. Geophys. Res., 112, D10119, doi:1029/2006JD008087, 2007.

Niranjan, K., Thulasiraman, S., and Sreenivasa Reddy, Y.: Indication of Atmopsheric Ozone Decrease in Solar UV-B flux changes during the Toatl Solar Eclipse of 24 October 1995, TAO, 8, 239–246, 1997.

Nymphas, E. F., Adeniyi, M. O., Ayoola, M. A., Oladiran, E. O.: Micrometeorological measurements in Nigeria during the total solar eclipse of 29 March, 2006, J. Atmos. Solar Terr. Phys., 71, 1245–1253, 2009.

Raisanen, J.: CO_2-induced changes in atmospheric angular momentum in CMIP2 experiments, J. Climate, 16, 132–143, 2003.

Randhawa, J. S., Williams, B. H., and Kays, M. D.: Meteorological Influence of a Solar Eclipse on the Stratosphere, Technical Report ECOM-5345, 1970.

Seidel, D. J. and Randel, W. J.: Variability and trends in the global tropopause estimated from radiosonde rata, J. Geophys. Res., 111, D21101, doi:10.1029/2006JD007363, 2006.

Singh, L., Tyagi, T. R., Somayajuh, Y. V., Vijayakumar, P. N., Dabas, R. S., Loganadham, B., Ramakirshna, S., Rama Rao, P. V. S., Dasgupta, A., Naneeth, G., Klobuchar, J. A., and Hartmann, G. K.: A multi-station satellite radio beacon study of ionospheric variations during solar eclipses, J. Atmos. Sol. Terr. Phys., 51, 271–278, 1989.

Stoev, A., Stoeva, P., Valev, D., Kishkinova, N., and Tasheva, T.: Dynamics of the microclimatic parameters of the ground atmospheric layer during the total solar eclipse on August 11, 1999, Geophys. Res. Abstr., 7, 10209, 2005.

Szalowski, K.: The effect of the solar eclipse on air temperature near the ground, J. Atmos. Sol. Terr. Phys., 64, 1589–1600, 2002.

Tzanis, C., Varotsos, C., and Viras, L.: Impacts of the solar eclipse of 29 March 2006 on the surface ozone concentration, the solar ultraviolet radiation and the meteorological parameters at Athens, Greece, Atmos. Chem. Phys., 8, 425–430, doi:10.5194/acp-8-425-2008, 2008.

Wang, K. Y. and Liu, C.-H.: Profiles of temperature response to the 22 July 2009 tottal solar eclipse from FORMASAT-3/COSMIC constellation, Geophys. Res. Lett., 37, L01804, doi:10.1029/2009GL040968, 2010.

Zerefos, C. S., Balis, D. S., Meleti, C., Bais, A. F., Tourpali, K., Vanicek, K., Cappenlanni, F., Kaminski, U., Tiziano, C., Stubi, R., Formenti, P., and Andreae, A.: Changes in environmental parameters during the solar eclipse of August 11, 1999 over Europe, effects on surface UV 20 solar irradiance and total ozone, J. Geophys. Res., 105(D21), 26463–26473, 2000.

Zerefos, C. S., Gerasopoulos, E., Tsagouri, I., Psiloglou, B. E., Belehaki, A., Herekakis, T., Bais, A., Kazadzis, S., Eleftheratos, C., Kalivitis, N., and Mihalopoulos, N.: Evidence of gravity waves into the atmosphere during the March 2006 total solar eclipse, Atmos. Chem. Phys., 7, 4943–4951, doi:10.5194/acp-7-4943-2007, 2007.