Earth Planets Space, **62**, 647–653, 2010

A comparison of optically measured daytime OH temperatures over the tropics during solar maximum and minimum periods

C. Vineeth[1], T. K. Pant[1], S. Gurubaran[2], M. M. Hossain[1], and R. Sridharan[1]

[1]*Space Physics Laboratory, Vikram Sarabhai Space Centre, Trivandrum, India*
[2]*Equatorial Geophysical Research Laboratory, Tirunelveli, India*

(Received August 4, 2009; Revised June 30, 2010; Accepted July 15, 2010; Online published October 28, 2010)

This paper deals with the variability of optically measured daytime OH temperatures during two different solar activity epochs, over Trivandrum (8.5°N, 76.5°E), a tropical station in India. The data used for the present study span the period of February–March, during the solar maximum year of 2001 and solar minimum year of 2005. The mean daytime temperature (180±5 K) during the 2001 study period was found to be lower than the mean temperature (195±9 K) of the 2005 study period by ∼15 K. However, apart from this noticeable shift in mean temperature level, the variabilities in the temperature of both years were strikingly similar. Moreover, the wave periodicities present during these periods were also quite similar. Possible reasons for these observations were investigated in the context of the various forcings that control the energetics of the equatorial mesopause region. The observations presented in this study are unique and reveal a number of newer aspects of the energetics of the tropical mesopause.

Key words: Waves and tides, mesopause temperature, hydroxyl airglow.

1. Introduction

Researchers are becoming increasingly aware of the importance of the mesopause region as they obtain more knowledge of the significance of the coupling processes between various atmospheric regions. The upper mesospheric region, especially the mesopause, is an area of considerable dynamical activity. The short-term variabilities in temperature, wind, and density of this region are dominated by gravity waves, tides, and planetary waves, which grow in amplitude as they propagate upward from the sources in the troposphere and stratosphere. In the mesopause region, the effect of tides on the temperature, wind, and density structures are especially significant because of its proximity to the turbopause. The wave activity and rapid drop in temperature make this region the most turbulent part of the atmosphere. In this context, the mesopause is of primary importance as it represents the coldest part of the atmosphere, which acts as a gateway between the lower atmosphere and the thermosphere.

The thermal structure of the mesopause region, where most of the energy deposition occurs, is mainly controlled by dynamical, chemical, and radiative processes. The mean background temperature in the mesosphere is largely determined by the radiative balance between the absorption and emission of solar radiation (Gavrilov and Roble, 1994). Below 95 km, the absorption of solar radiation is in the Hartley band (200–300 nm). Mesospheric ozone (O_3) is the main source of solar heating in this region. Above 95 km, the absorption of solar UV radiation by molecular oxygen (O_2) in the Schumann-Runge continuum (135–200 nm) and the Lyman-α line (121.5 nm) are the dominant heat sources. Solar heating is dominated by the absorption of solar UV radiation by O_2 and O_3 (Mlynczak and Solomon, 1993). An excellent description of the various factors affecting the mesopause energetics during the solar maximum and minimum periods and their individual role in controlling the energy budget of the mesopause region has been reported using the HAMMONIA chemistry climate model by Schmidt *et al.* (2006). Many other studies have also attempted to determine the contribution of solar heating on mesopause temperatures (Bittner *et al.*, 2002; Offermann *et al.*, 2004; Azeem *et al.*, 2007). A linear relation of mesopause temperature with $F_{10.7\text{-cm}}$ radio flux has been established using nighttime hydroxyl (OH) measurements (Offermann *et al.*, 2004). In a recent study by Beig and Fadnavis (2009), a positive correlation (∼3 K/100 sfu) was found between the temperature and solar flux at an altitude of 60–75 km. Similarly, the modeling studies of Marsh *et al.* (2007) and Schmidt *et al.* (2006) also show a positive solar response at the altitude of the mesopause. In contrast, Bittner *et al.* (2002) were unable to find a conclusive correlation between OH rotational temperatures and the $F_{10.7\text{-cm}}$ flux; rather, they found a reasonable agreement between planetary wave activity and the general solar bipolar magnetic field (22-year Hale cycle). These studies clearly indicate the necessity of extended studies to understand this problem comprehensively.

In addition to the solar forcings, a significant part of the mesospheric energetics is contributed by exothermic reactions involving odd-oxygen and odd-hydrogen species, including the quenching of excited photolysis products

---

doi:10.5047/eps.2010.07.009

(Mlynczak and Solomon, 1993) by radiative cooling associated with infrared emission of CO_2 at 15 μm (Andrews *et al.*, 1987; Rodgers *et al.*, 1992). Chemical heating is dominated by the reaction $O_3 + H = O_2 + OH^*$ and is greater at night when the O_3 concentrations are maximum. According to the calculations by Mlynczak and Solomon (1993), about 60% of the energy of this reaction is lost as heat while only 40% is released as airglow. The main source of O_3 in the mesopause region is the three-body recombination of O and O_2. The O is generated through the photolysis of O_2 in the lower thermosphere and brought to the mesopause through downward diffusion or mean advection. A temperature enhancement of 3–4 K is accounted for during nighttime due to this chemical heating (Smith, 2004).

The dynamical parameters which influence the mesopause temperature include tides, gravity waves, and planetary waves. There have been a number of studies dealing with the effect of waves and tides on the mesosphere/lower thermosphere (MLT) region (Fritts and Vincent, 1987; Forbes *et al.*, 1995; Hagan *et al.*, 1999; Beig *et al.*, 2003; French and Burns, 2004). The dynamical factors contribute almost ~30% of the total energy of this region (Beig *et al.*, 2003). Due to the dominant tidal structures, the local time of maximum temperature varies with altitude, latitude, and season. The temperature perturbations at upper mesospheric altitudes associated with the diurnal tides are observed to maximize over the tropics and to vary somewhat regularly with season (Hagan *et al.*, 1999). The diurnal tide is generally the largest amplitude wave in the tropical mesosphere region and has a major impact on not only the dynamics of the region, but also its composition (Akmaev and Shved, 1980). The gravity waves (GWs) propagating through this region would therefore be affected by these tidal wind and temperature fluctuations, resulting in an alteration of the gravity-wave drag in the middle atmosphere, which in turn affects the winds and temperatures. However, all these factors further depend indirectly on solar activity, and they also exhibit significant day-to-day variability. In this context, the study of mesopause energetics in terms of the various parameters those influence it, is very important.

The relative inaccessibility of the mesosphere region compared to other parts of the atmosphere, especially during daytime, has made it rather difficult for researchers to come to a conclusion on the direct solar influence on temperature. Most of the earlier measurements in this region originated from rocket-borne experiments and satellite-borne experiments, such as the wind imaging interferometer (WINDII) and the high-resolution Doppler imager (HRDI) onboard the upper atmosphere research satellite (UARS); this satellite has provided much needed global measurements in recent years (Shepherd *et al.*, 2001 and references therein). However, ground-based Lidars and spectrometers from different locations over the globe have also enabled measurements of upper atmospheric temperatures and its temporal variabilities (Taylor *et al.*, 2001; She *et al.*, 2003; French and Burns, 2004). In terms of equatorial mesospheric energetics, recent observations using meteor wind radar and the unique multi-wavelength dayglow photometer (MWDPM) has already produced some interesting results (Sridharan *et al.*, 1999; Pant *et al.*, 2004; Vineeth *et al.*, 2005).

The MWDPM has been operating at Trivandrum (8.5°N, 76.5°E), a near-equatorial station in India, since 2001. The study reported here is an attempt at comparing the daytime OH temperature during February–March of the solar maximum and minimum years. The solar, chemical, and dynamical factors that have a significant control over OH temperature, as discussed, were expected to be totally different in the solar maximum and minimum years. However, despite all these variabilities, the temperature exhibited a remarkable similarity during the study period (February–March) in both years. The authors feel that such repeatability in the temperatures is very important in terms of our knowledge of the mesopause region and that the scientific community should be aware of our results. An attempt was also made to characterize the important parameters (solar/dynamical) that influence the tropical mesopause temperature using the available limited set of data.

2. Experimental Details

The MWDPM is a unique instrument which can measure daytime intensities of three different wavelengths nearly simultaneously (Sridharan *et al.*, 1998; Vineeth *et al.*, 2005 and references therein). Daytime OH rotational temperatures were estimated by the selection of two wavelengths, 731.6 and 740.2 nm (Meinel 8-3 band). The daytime OH emission intensity measurements at the wavelengths mentioned above were then used to estimate the mesopause temperature adopting the method of Krassovsky (1972). It must be mentioned that the OH emission layer is co-located with the mesopause within the uncertainty of ±4 km on either side of the mesopause. Therefore, for most of the practical cases, the OH measured temperature could be considered as the mesopause temperature, although the height of the OH layer does exhibit some degree of seasonal variability (Liu and Shepherd, 2006). The time spans of the OH temperatures used for this study is 0900–1800 IST (Indian Standard Time) in 2001 and 0900–1700 IST for 2005. The temperatures obtained in each 10-s interval are averaged out for whole day and used to represent that day's mean temperature. Due to various constraints in making regular observations, continuous temperature measurements were available only during days 35–75 in 2001. However, in 2005, the temperature measurements were available from January to May; thereafter continuous measurements of the dayglow emissions could not be made because of the overcast weather conditions associated with the 'monsoon'.

3. Results and Discussion

The OH temperatures obtained using the aforementioned technique during February–March of 2001 (solar maximum) and 2005 (solar minimum) are depicted and compared in Fig. 1. The mean temperature during 2001 was 180±5 K and much lower than that (195±9 K) during 2005. The temperatures for both years showed fairly similar overall trends during these periods. For example, the temperatures showed a decreasing trend prior to day 46. Immediately thereafter, an increasing trend was observed until day 62, followed by a steady decrease. However, a marked dif-

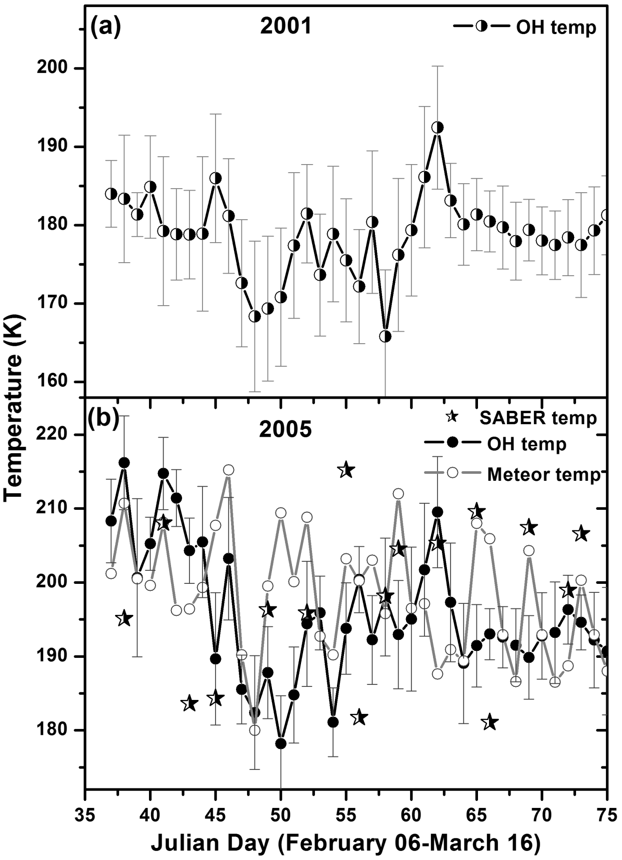

Fig. 1. Daily variation of daytime mesopause temperature for the year 2001 and 2005. The corresponding Meteor Radar and SABER temperatures are also shown for the year 2005.

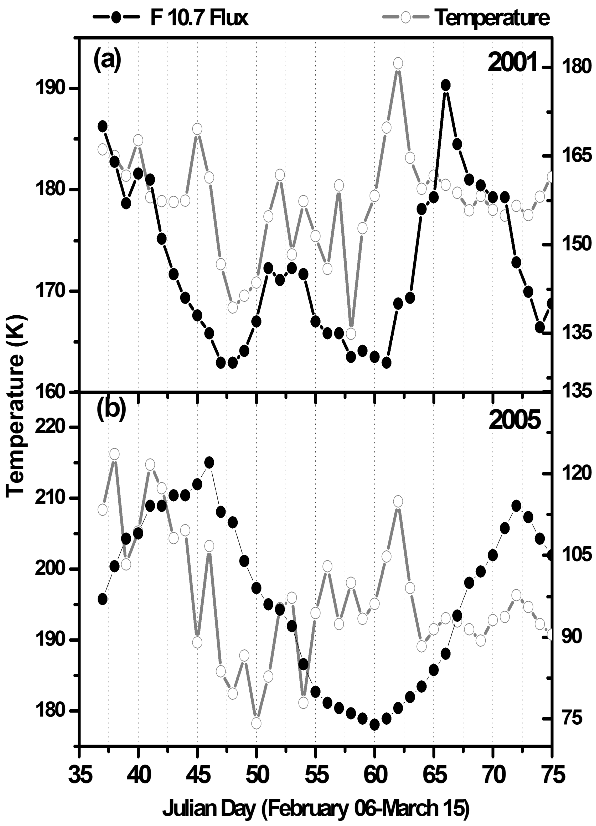

Fig. 2. Time variation of the $F_{10.7}$ radio flux (26–34 nm) along with the temperatures for the years (a) 2001 and (b) 2005.

ference was observed in the extent of the decrease in temperatures prior to day 46. During 2005 (solar minimum), this drop in temperature between days 40 and 48 was found to be larger (~35 K) than that observed in 2001 (solar maximum), which was only ~18 K. This temperature difference is believed to be due to the upwelling of the atmosphere and subsequent adiabatic cooling during the solar maximum year. This in turn would decrease the overall atomic oxygen concentration in the mesopause region, thereby altering the exothermic chemical reactions of the region. Mlynczack and Solomon (1993) estimated the mesopause energetics by considering the reaction involving H and O_3 that leads to the vibrationally excited OH, which is radiatively active in the Meinel band and is an important contributor to the chemical heating at the mesopause altitudes. The main source of O_3 in the mesopause region is the three-body recombination of [O] and O_2. The [O] is generated through the photolysis of O_2 in the lower thermosphere and brought to the mesopause through downward diffusion or mean advection (Smith, 2004). In other words, a larger downward diffusion of [O] leads to larger concentration of O_3, which in turn leads to a higher temperature in the mesopause through the exothermic OH chemistry. Therefore, the upwelling of the overall atmosphere during the solar maximum period opposes the downward diffusion of the [O]. This would cause a reduction in the O_3 concentration and OH emission rates in the mesopause region, which would in turn manifests as a lowered temperature. In this context, the dynamical variability would be indirectly affecting the chemical heating, thereby contributing to the observed temperature lowering during the solar maximum year, i.e., 2001. In fact, using a modeling study, Marsh *et al.* (2007) demonstrated that significant changes exist in terms of composition and dynamical variables between the solar maximum and minimum years. They also showed that large changes in NO and [O] can dramatically alter the energy budget of this region in the lower thermosphere. However, the proposed mechanism of atmospheric upwelling and the reduction in exothermic reaction rate is a conjecture at this moment, and further experimental evidence is necessary to prove this mechanism. It must be mentioned that it is remarkable and intriguing to observe very similar trends in the mesopause temperature, as seen here, despite all of the inherent background variability of the mesosphere being quite different during the two different solar epochs.

Temperatures measured at the mesopause altitudes have generally been found to be highly variable (both spatially and temporally) from location to location. The main explanatory factor for this variability is that the temperatures are affected by many strong and competing forcings that come from both the atmosphere below (general circulation, various kinds of waves, tides, etc.) and that above (solar cycle influences, geomagnetic activity, etc.). The temperatures appear to be dependent not only on the time but also on other parameters, such as latitude, longitude, and season (Espy and Stegman, 2002; Semenov *et al.*, 2002;

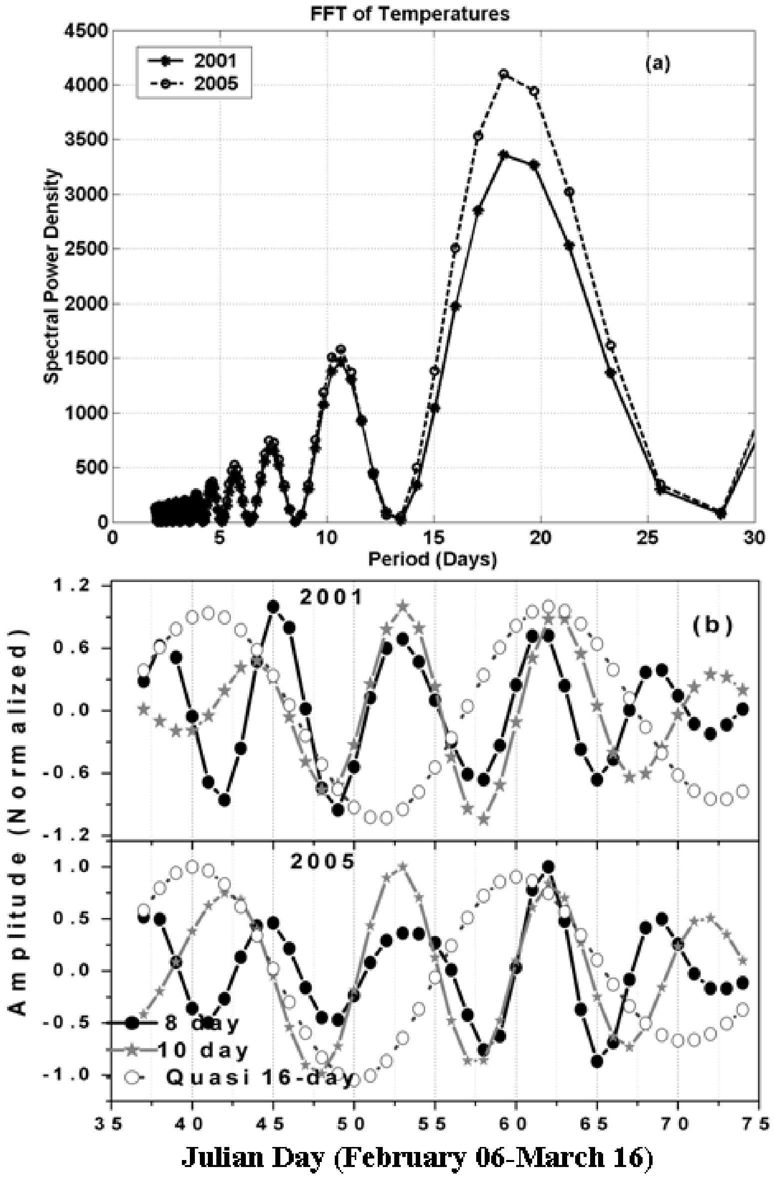

Fig. 3. (a) The FFT periodogram of temperatures for both 2001 and 2005. (b) The periods of dominant wave modes obtained from the wavelet analysis.

Beig *et al.*, 2003). In this context, the striking similarity in the mesopause temperatures during different solar activity epochs as presented here needs to be further investigated.

In order to determine the role of solar flux in causing the observed temperature variability, if any, we analyzed the $F_{10.7\text{-cm}}$ radio fluxes during the study periods. The temperatures for both years are plotted together with the $F_{10.7}$ flux in Fig. 2(a) and 2(b). In general, the fluxes during the solar minimum year were found to be almost half of those of the solar maximum year. During the solar maximum year, a fairly good correlation was found between the variability in temperature and $F_{10.7}$ flux up to day 57; thereafter no such correlation was observable. In comparison, in the solar minimum year, no simple direct relation was found between $F_{10.7}$ flux and temperature. This result is in contradiction with recent results of Beig and Fadnavis (2009) showing a positive response between the temperature at 65–75 km and the solar flux. However, our study has been extended further to determine the behavior of other governing factors, such as background dynamical condition and the role of GWs and planetary waves, among others, during this period.

The spectral analysis, i.e., fast Fourier transform (FFT) technique, was performed on the temperature data corresponding to both high and low solar activity periods in order to identify the dominant periodicities; the corresponding peridograms are depicted in Fig. 3(a). It is clear from the figure that the wave periodicities present during the study periods were exceptionally similar except for a small difference in amplitude. The periodicities range from ~3 to ~16 days. As is clear from the figure, the significant periods are those above 5 days. The dominant periodicities present were 8, 10, and quasi 16-day. These waves were separated out using the Morlet wavelet analysis (Torrence and Compo, 1998) for both years and plotted in Fig. 3(b). All three waves were found to be in same phase (positive) at around day 62 and negative phase at around day 45; at all other times, there was no correspondence in their phases. It must be mentioned that the temperature showed an increase,

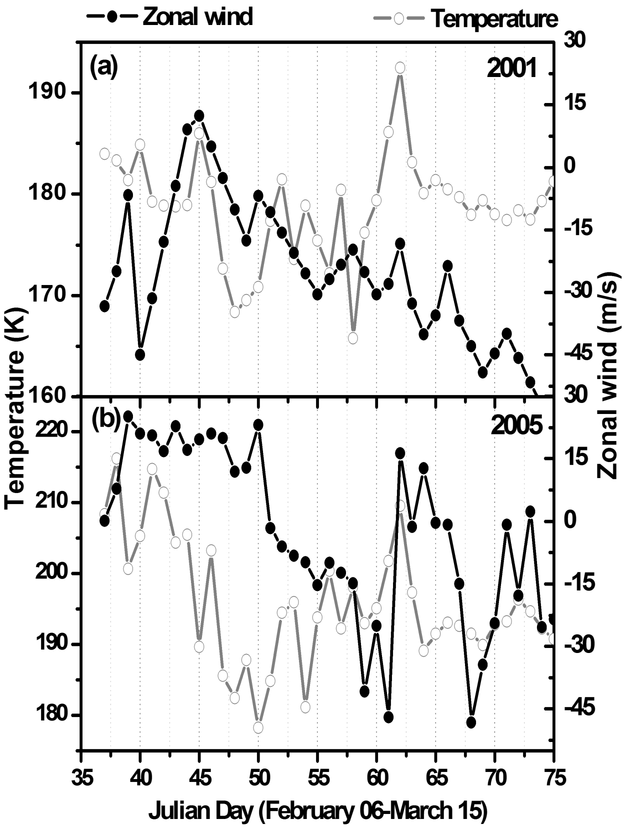

Fig. 4. Time variation of mean zonal wind along with the temperatures for the years (a) 2001 and (b) 2005.

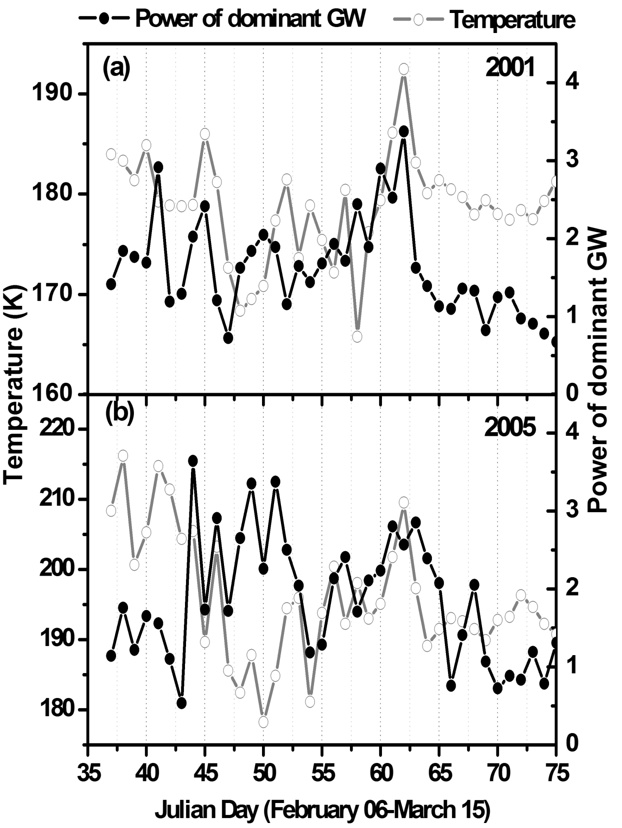

Fig. 5. Time variation of the mean power of the dominant GW period along with the temperatures for the years (a) 2001 and (b) 2005.

as evident from Fig. 1, when the waves were in the positive phase and decrease when the phase was negative.

Further, as is known, the background wind condition plays an important role in the upward propagation of these waves and, consequently, variations in the prevalent zonal wind have also been studied into. Figure 4(a) and 4(b) shows the time variation of mean zonal wind at an altitude of 88 km averaged for daytime (8–18 h), together with the variation in the daytime mesopause temperatures, for the years considered in this study. The wind measurements were made using partial reflection radar operating at a nearby equatorial station, Tirunelveli (8.7°N, 77.8°E). The short-term time variability in the wind was found to be totally different in these years. Overall, the winds during both years turned from eastward to westward at around days 45–50. In 2001, the winds remained westward during the other days, whereas large eastward excursions were seen during 2005 between days 60 and 75.

If the zonal wind, as conjectured earlier, plays a direct role in modulating the temperatures, then one would have expected the temperature trends to be very different during these two years. In contrast, the striking similarity in the temperature trends indicates the plausible role(s) of other dynamical factors, such as the gravity waves. However, it must be mentioned that the wave activity, in turn, can be modulated by the prevailing zonal wind conditions. Therefore, to investigate the possible contribution from factors such as GWs, we subjected the temperatures on each day to Morlet wavelet analysis and separated out the dominant periods. The powers of the wave periods between 0.5 and 2.5 h were averaged for each day to represent the strength of the wave activity.

Figure 5(a) and 5(b) shows the time variation of the power of the dominant gravity wave period obtained from the wavelet power spectra (averaged for daytime) along with the temperatures for both years. It is fairly evident from the figures that the GWs make a definite contribution to the variabilities in the mesopause temperature, especially for the short-term variability. The enhancements seen in temperatures between days 57 and 62, and the decrease afterwards, corroborate well with the powers of the dominant gravity waves. Hence, it can be inferred that GW activities along with other dynamical factors do have a strong influence on the tropical mesopause temperature, in comparison to direct solar control.

Further, if one attempts to view the present set of temperature measurements over Trivandrum with a global perspective, the increase in mesopause temperature over the mid-latitudes around day 85 can be seen as a ‘springtime transition’, which is very similar to that observed over Trivandrum around day 62. The temperatures during both years show a prominent increase of ~20 K around day 62 (March 3) during both 2001 and 2005, irrespective of the background conditions. Earlier studies from mid-latitudes show an increase in the mesopause temperature and OH airglow intensities during the spring equinox (around day 85), denoted the ‘springtime transition’ (Shepherd *et al.*, 1999, 2002). This phenomenon has been attributed to the mean

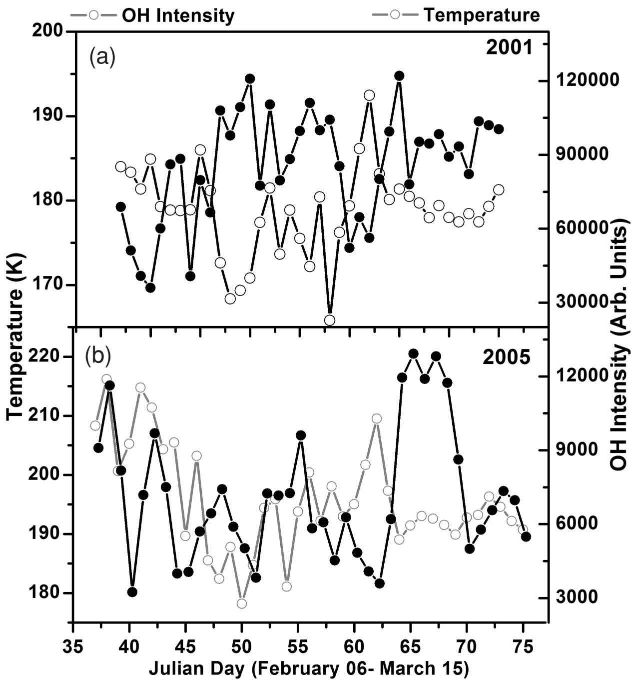

Fig. 6. Time variation OH airglow intensities along with the temperatures for the years (a) 2001 and (b) 2005.

wind reversal and subsequent dynamical perturbations during the spring (vernal) equinox. The 'springtime' transition in temperature is always associated with an increase in the airglow intensity. In this context, in order to determine whether the enhancement seen in temperature is having any dynamical influence similar to the so-called 'springtime transition', we examined the intensity of the OH (731.6 nm) emission; the results are plotted in Fig. 6(a) and 6(b). It is evident from these figures that the OH intensities also exhibit an enhancement by a factor of ~4 when the temperature shows the enhancement. However, the enhancement in the intensity is delayed by 2–3 days compared to the temperature. These enhancements in temperatures and OH intensities exhibit a characteristic similar to that of the mid-latitude 'springtime transition', but they occur ~20 days earlier. However, for these aspects to be characterized in more detail, more studies are required with extended data.

Although the exact causative mechanisms of the observed temperature variability over Trivandrum have not been established in our study, the question of whether the equatorial variability is the counterpart of the variability over mid/high latitudes needs to be comprehensively studied as a part of the global mesopause dynamics.

The remarkable resemblance in the temperatures, despite of the similarities and differences in the dynamics, chemistry, and solar conditions, is quite intriguing. Since most of the optical techniques operate at nighttime, the daytime mesopause temperatures obtained using optical technique presented in this paper are unique. The repeatability of the temperatures irrespective of the background conditions has significant implications in establishing mean temperature trends of tropical mesopause region. Knowledge of these trends is important for providing insight into the MLT coupling processes and also for quantifying the consequences of unique equatorial geophysical phenomena, such as the equatorial electrojet and counter-electrojet. The observed variabilities in the equatorial mesopause temperatures, as discussed here, correspond more with the dynamical forcings than with the solar activity. However, the data used in this study are inadequate for discussing the long-term trends in mesopause temperature. These factors should be further confirmed with extended data by means of different experiments in multiple platforms.

4. Conclusion

We report here the first comparison of 'daytime' mesopause temperatures observed during two different solar activity epochs from equatorial latitudes. The temperatures show a remarkable similarity in terms of trend and periodicity and are consistent in both study years during the months of February–March. The similarities between temperature, zonal wind, and GW power pattern and the dissimilarity between temperature and $F_{10.7}$ flux during these periods are indicative of the dominance of dynamical forcings on direct solar forcing. A systematic and significant enhancement in temperature and hydroxyl airglow intensities are observed around day 62 (approx. March 3), which is similar to the 'springtime' transition over the mid-latitude region. This enhancement deserves special attention and comprehensive investigation.

Acknowledgments. This work was supported by the Department of Space, Government of India. One of the authors, C. Vineeth, gratefully acknowledges the financial assistance provided by the Indian Space Research Organization through a research fellowship.

References

Akmaev, R. A. and G. M. Shved, Modelling of the composition of the lower thermosphere taking account of the dynamics with application to tidal variations of the (OI) 5577 Å airglow, *J. Atmos. Terr. Phys.*, **42**, 705–716, 1980.

Andrews, D. G., J. R. Holton, and C. B. Leovy, *Middle Atmosphere Dynamics*, Chapter 6, 259–294, Academic Press, Inc, 1987.

Azeem, S. M. I., G. G. Sivjee, Y.-I. Won, and C. Mutiso, Solar cycle signature and secular long-term trend in OH airglow temperature observations at South Pole, Antarctica, *J. Geophys. Res.*, **112**, A01305, doi:10.1029/2005JA011475, 2007.

Beig, G. and S. Fadnavis, Solar response in the temperature over the equatorial middle atmosphere, *J. Atmos. Sol. Terr. Phys.*, **71**, 1450–1455, 2009.

Beig, G., P. Keckhut, R. P. Lowe, R. G. Roble, M. G. Mlynczak *et al.*, Review of mesospheric temperature trends, *Rev. Geophys.*, **41**, 1015, doi:10.1029/2002RG000121, 2003.

Bittner, M., D. Offerman, H. H. Graef, M. Donner, and K. Hamilton, An 18-year time series of OH temperatures and middle atmosphere decadal variations, *J. Atmos. Sol. Terr. Phys.*, **64**, 1147–1166, 2002.

Espy, P. J. and J. Stegman, Trends and variability of mesospheric temperature at high latitudes, *Phys. Chem. Earth*, **27**, 543–553, 2002.

Forbes, J. M., M. E. Hagan *et al.*, Quasi 16-day oscillation in the mesosphere and lower thermosphere, *J. Geophys. Res.*, **100**, 9149–9163, 1995.

French, W. J. R. and G. B. Burns, The influence of large scale oscillations on long term trend assessment in hydroxyl temperatures over Davis, Antarctica, *J. Atmos. Sol. Terr. Phys.*, **66**, 493–506, 2004.

Fritts, D. C. and R. A. Vincent, Mesospheric momentum flux studies at Adelaide, Australia: Observations and a gravity wave-tidal interactions model, *J. Atmos. Sci.*, **44**, 605–619, 1987.

Gavrilov, N. M. and R. G. Roble, The effect of gravity waves on the global mean temperature and composition structure of the upper atmosphere, *J. Geophys. Res.*, **99**, 25773–25780, 1994.

Hagan, M. E., M. D. Burrage, J. M. Forbes, J. Hackney, W. J. Randel, and X. Zhang, QBO effects on the diurnal tide in the upper atmosphere, *Earth Planets Space*, **51**, 571–578, 1999.

Krassovsky, V. I., Infrasonic variations of OH emission in the upper atmosphere, *Ann. Geophys.*, **28**, 739, 1972.

Liu, G. and G. G. Shepherd, An empirical model for the altitude of the OH nightglow emission, *Geophys. Res. Lett.*, **33**, L09805, doi:10.1029/2005GL025297, 2006.

Marsh, D. R., R. R. Garcia, D. E. Kinnison, B. A. Boville, F. Sassi, S. C. Solomon, and K. Matthes, Modeling the whole atmosphere response to solar cycle changes in radiative and geomagnetic forcing, *J. Geophys. Res.*, **112**, D23306, doi:10.1029/2006JD008306, 2007.

Mlynczak, M. G. and S. Solomon, A detailed evaluation of the heating efficiency in the middle atmosphere, *J. Geophys. Res.*, **98**(D6), 10,517–10,541, 1993.

Offermann, D., M. Donner, P. Kneiling, and B. Naujokat, Middle atmospheric temperature changes and the duration of summer, *J. Atmos. Sol. Terr. Phys.*, **66**, 437–450, 2004.

Pant, T. K., D. Tiwari, S. Sridharan, R. Sridharan, S. Gurubaran, K. S. V. Subbarao, and R. Sekar, Evidence for direct solar control of the mesopause dynamics through dayglow and radar measurements, *Ann. Geophys.*, **22**, 3299–3303, 2004.

Rodgers, C. D., F. W. Taylor, A. H. Muggeridge, M. Lopez-Puertas, and M. A. Lpoez-Valverde, Local thermodynamic equilibrium of carbon dioxide in the upper atmosphere, *Geophys. Res. Lett.*, **19**, 589–592, 1992.

Schmidt, H., G. Brasseur, M. Charron, E. Manzini, M. A. Giorgetta, V. Fomichev, D. Kinnison, D. Marsh, and S. Walters, The HAMMONIA Chemistry Climate Model: Sensitivity of the mesopause region to the 11-year solar cycle and CO2 doubling, *J. Clim.*, **19**, 3903–3931, doi:10.1175/JCLI3829.1, 2006.

Semenov, A. I., N. N, Shefov, E. V. Lysenko, G. V. Givishvili, and A. V. Tikhonov, The season peculiarities of behavior of the long-term temperature trends in the middle atmosphere on the mid-latitudes, *Phys. Chem. Earth*, **27**, 529–534, 2002.

She, C. Y., J. Sherman, T. Yuan, B. P. Williams, K. Arnold, and T. D. Kawahara, The first 80-h continuous lidar campaign for simultaneous observation of mesopause region temperature and wind, *Geophys. Res. Lett.*, **30**(6), 1319, doi:10.1029/2002GL016412, 2003.

Shepherd, G. G., J. Segman, P. Epsy, C. McLanddress, G. Thullier, and R. H. Wiens, Springtime transition in lower thermospheric atomic oxygen, *J. Geophys. Res.*, **104**, 213–223, 1999.

Shepherd, M. G., B. Prawirosoehardjo, S. P. Zhang, and B. H. Solheim, Retrieval and validation of mesospheric temperatures from WINDII, *J. Geophys. Res.*, **106**, 24,813–24,829, 2001.

Shepherd, M. G., P. J. Espy, C. Y. She, W. Hocking, P. Keckhut, G. Gavrilyeva, G. G. Shepherd, and B. Naujokat, Springtime transition in upper mesospheric temperature in the northern hemisphere, *J. Atmos. Sol. Terr. Phys.*, **64**, 1183–1199, 2002.

Smith, A. K., Physics and chemistry of the mesopause region, *J. Atmos. Sol. Terr. Phys.*, **66**, 839–857, 2004.

Sridharan, R., N. K. Modi *et al.*, Multiwavelength daytime photometer-anew tool for the investigation of atmospheric processes, *Meas. Sci. Technol.*, **9**, 585–591, 1998.

Sridharan, R., A. Taori, S. Gurubaran, R. Rajaram, and M. G. Shepherd, First results on daytime mesopause temperatures using ground based photometry from equatorial latitudes, *J. Atmos. Sol. Terr. Phys.*, **61**, 1131–1142, 1999.

Taylor, M. J., W. R. Pendleton Jr., H. L. Liu, C. Y. She, L. Gardner, R. G. Roble, and V. Vasoli, Large amplitude perturbations in mesospheric OH Meinel and 87-km Na lidar temperatures around the autumnal equinox, *Geophys. Res. Lett.*, **28**, 1899–1902, 2001.

Torrence, C. and G. P. Compo, A practical guide to Wavelet analysis, *Bull. Am. Meteor. Soc.*, **79**, 61, 1998.

Vineeth, C., T. K. Pant, M. Antonita, G. Ramkumar, C. V. Devasia, and R. Sridharan, A comparative study of daytime mesopause temperatures obtained using unique ground-based optical and Meteor wind radar techniques over the magnetic equator, *Geophys. Res. Lett.*, doi:10.1029/2005 GL023728, 2005.

C. Vineeth (e-mail: cnvins@gmail.com), T. K. Pant, S. Gurubaran, M. M. Hossain, and R. Sridharan