# Rayleigh Lidar unusual Stratospheric Temperature Inversion following the Stratospheric Warming

**G. Kiran Kumar, M. Krupa Swaroopa Rani, K. Kameswara Rao, M. Krishnaiah**

***Abstract: Rayleigh Lidar system established at National Atmospheric Research Laboratory (NARL) over a tropical site, Gadanki (13.8$^o$ N, 79.2$^o$ E), is operational since March 1998. Using photon count profiles and a model atmosphere (CIRA-86) temperature profiles are derived for the height range of 30-80 km. 628 Rayleigh Lidar observations covering the altitude range of stratosphere and mesosphere collected during the period March 1998 – August 2006. The long-term knowledge of this temperature profile has allowed us to know its average climatology as well as the nighttime evolution. During the period of Mar 2003 we observed profiles which differ considerably from the average for the same period in other years. Specially, profile obtained on the night 27 Mar 2003 called our attention by presenting an unusual stratospheric inversion layer with a decrease of 10-12 K between 38-41 km and there was a minor warming on stratopause. Analysis of additional SABER temperature data showed that inversion layer at the same altitude.***

***Keywords: (NARL), (13.8$^o$ N, 79.2$^o$ E), (CIRA-86), SABER 10-12 K between, Rayleigh Lidar systems***

## I. INTRODUCTION

The Rayleigh Lidar technique has been used to study the atmospheric temperature profiles from 30 to 80 km for more than two decades [1,2]. The possibility of measurements of temperature and density with a high time and height resolution has led to a variety of studies involving the temperature climatology at middle latitude [3-5], low and tropical latitudes [6-8] and high latitude [9]. Also, studies involving planetary waves [10,11], comparison with satellite measurements [6,12,13] and several studies of the mesospheric temperature inversion layers [14-18] have been carried out in the last few years. Middle atmosphere dynamics is governed by short and long-term wave propagation, such as gravity waves, planetary waves, Rossby waves, equatorial waves, Kelvin waves and [19] The strength of these wave amplitudes and its breaking has also been proved to be responsible for many of the peculiar middle atmosphere phenomenon (for eg., mesosphere temperature inversion, sudden stratosphere warming (SSW), double stratopause structure and etc.). One such interesting event used to occur in the middle atmosphere temperature profile, is SSW. The SSW is used to occur during winter and mostly in polar region. The strength of the warming and the direction of meridional circulations lead the effect of SSW even over mid- and low-latitudes [20].

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Basically the warming is observed below the stratopause height region and descends the warm stratopause by few kilometers. Generally, the cause for SSW occurrence is mainly attributed to propagation of planetary waves (PW). The planetary wave have source region in the troposphere and propagates upward into the stratosphere, where it interact with the mean flow and wave breaks [21]. Though, there are many instruments to provide middle atmosphere temperature profiles (satellite, radiometers, rockets and LiDARs), LiDAR measurements are found to be superior than the other instruments in terms of accuracy and efficiency. Using LiDAR, there are many evidences of occurrence of SSW over high- (e.g [22-26]), mid- (e.g.[27,28]) and low-latitudes [29]. More recent SSW observations by [29] is first of its kind and reported for low latitude station, Gadanki (13.5 N; 79.2 E). It evidenced the extension of SSW to low latitude depending on the strength of the warming and concluded that the warming event was mainly driven by the PW propagation from high- and mid- to low-latitudes consecutive to the major warming episodes over polar region. It is a single evident and there are no more any statistical results from low-latitude stations. The purpose of this study is to investigate the statistical characteristics of SSW phenomenon using LiDAR observations over a low-latitude station.

In this paper concerns the detection of a very unusual temperature profile obtained on the night of 27 march 2003 followed by warm stratopause ,compare with the SABER satellite temperature data and statistical charecteristics of SSW events observed over a low latitude station, Gadanki (13.5N, 79.2E), using 7 years of Rayleigh Lidar data from March 1998 to December 2004. In order to support and compare the Lidar observed SSW events, based on availability we also present data from the Halogen Occultation Experiment (HALOE) on board the UARS satellite.

## II. SYSTEM DESCRIPTION

### *A. Lidar System Description*

[6] The lidar system installed jointly by the Communication Research Laboratory (CRL-Japan) and the National MST Radar Facility (NMRF-India) employs an Nd:YAG Laser with a maximum energy of 550 mJ per pulse at the second harmonic of 532 nm. The laser operates at a pulse repetition frequency of 20 Hz and a pulse width of 7 nsec. A beam expander that expands the beam by 10 times is used to reduce the beam divergence from 0.45 mrad to 0.1 mrad. For receiving the Mie and Rayleigh components of the backscattered signal, two independent receivers are employed.

The Mie receiver uses a 35 cm telescope of Schmidt-Cassegrain configuration, primarily for aerosol and cloud studies. The Rayleigh receiver employs a 75 cm Newtonian telescope for molecular density and temperature measurements over the height range of _30–80 km. The Rayleigh receiver provides a field of view of _1 mrad, about 10 times larger than that of the transmitted beam. To extend the dynamic range of the detector, two channels with identical photo multiplier tubes (PMTs) set at different gains (9:1) are used. The low-sensitivity channel (U) is intended to collect the backscattered signal from lower altitudes (<50 km) where the signal intensity is fairly high and the highsensitivity channel (R) is for higher altitudes (>50 km) where the backscattered signal intensity is fairly low. The outputs from the PMTs are fed to pulse discriminators, which, inturn, feed to a PC based photon-counting system. It operates with a real-time multichannel scalar (MCS) software that provides a photon count profile with a range resolution of 300 m. The signal returns are integrated over 5000 laser shots, generating photon count profiles with a time resolution of 250 sec. The major specifications of the system are summarized in Table 1

**Table 1: .Lidar specifications [31]**

| Parameters | Specifications |
|---|---|
| Transmitter | |
| Laser Source | Nd:YAG |
| Model | PL 8020 (Continum, United States) |
| Operating wavelength | 532 nm |
| Average energy per pulse | 550 mJ |
| Pulse width | 7 nsec |
| Pulse repetition rate | 20 Hz |
| Beam width | 9 mm (Expanded to 90 mm) |
| Beam divergence | 0.1 mrad |
| Receiver[a] | |
| Telescope type | Newtonian; Schmidt-Cassegrain |
| Diameter | 750 mm; 350 mm |
| Field of view | 1 mrad; 1 mrad |
| Interference filter bandwidth | 1.07 nm; 1.13 nm |
| Maximum transmission | 48%; 48% |
| Photomultiplier tube | |
| Model | Hamamatsu, R3234-01; Head-on 2′ dia. |
| Cathode sensitivity | 64.2 μA/lumen |
| Anode sensitivity | 2170 A/lumen |
| Gain | 34 × $10^7$ |
| Dark current | 50 pA |
| Data acquisition | |
| Software | Four-channel PC-based data acquisition system operating with EG & G ORTEC MCS software |
| Bin width | 2 μ sec |
| Scan length | 1024 channel |
| Integration time | 250 sec (corresponding to 5000 laser shots) |

[a]Receiver specifications are given for the Rayleigh receiver and the Mie receiver, respectively.

## III. DATA

### A. LiDAR data

The data set presented in this paper are night time measured temperature profiles by ground based Rayleigh LiDAR system located in a Indian tropical station, Gadanki (13.5°N, 79.2°E) during the period from March 1998 to August 2006. The total number of LiDAR observations corresponds to 628 and the monthly distribution of observations is presented in terms of histogram in the Figure-1. It illustrates an average number of observations of about 26 profiles per month. Temperature profiles have been deduced using photon count profiles from the LiDAR data and a reference atmospheric model (MSISE-90) for the height range from 30 to 90 km following the retrieval method and analysis developed by [30]. Further details on the Gadanki LiDAR system and temperature derivation from the photon count profile is suitably modified and explained [31,32].

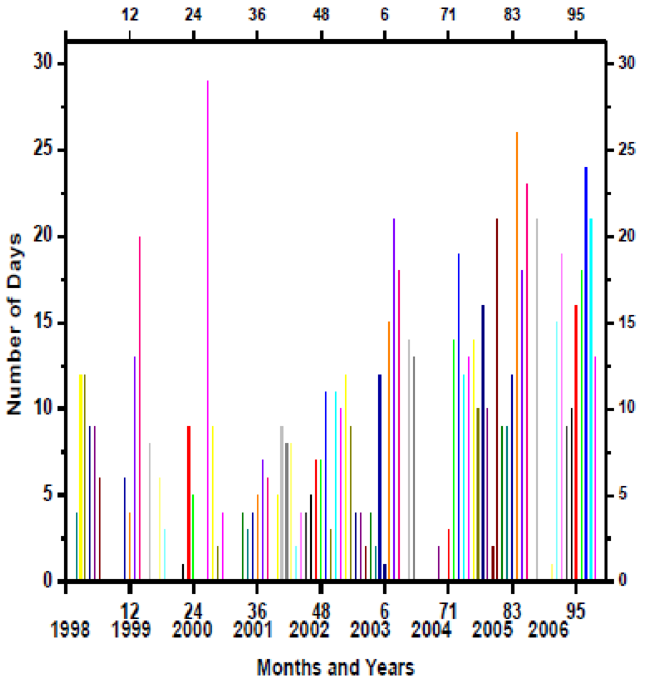


**Fig 1: Lidar data**

### B. SABER and TIMED

SABER and TIMED are acronyms for Sounding of the Atmosphere using Broadband Emission Radiometry and Thermosphere Ionosphere Mesosphere Energetic and Dynamics, respectively. Satellite, instrument and data description can be found in the TIMED web site [33].

### C. NCEP and other data

NCEP (National Center for Environmental Prediction) data has been used to classify the SSW events into major or minor. We use NCEP zonal mean temperature at 80°N and zonal mean wind at 60°N and for 10 hpa pressure levels. Quasi Bi-annual Oscillation (QBO) phase during the occurrence of SSW event has been examined using the zonal wind data from rawinsonde observations at Singapore (1°N, 103°E).

## IV. SSW DETECTION AND CLASSIFICATION CRITERIA

The SSW detection method used in the present study is same as described [28]. The warming event is subjected to qualitative analysis in terms of the temperature profile which show increase more than 8.2 K is found to be genuine. The magnitude 8.2 K is two times as that of calculated standard deviations. Using the above criteria, daily temperature profiles are compared to the extended winter (NDJFM) mean profile which is calculated using 193 temperature profiles and thereby the major and minor events are identified.

The following steps are adopted to classify the events;

**Major warming:** if there is zonal mean wind reversal in the NCEP data at 10 hpa and increase in LiDAR measured temperature.

**Minor warming:** if there is no zonal mean wind reversal in the NCEP data at 10 hpa but there is an increase in LiDAR measured temperature.

## V. OBSERVATION

During the night of March 27-28,2003 we made observations with the lidar from 20:38:44 to 01:36:23 accumulating a total of 25000 laser shots. The integrated profile during this 5 hr interval is shown in Figure 2. The figure shows outstanding in this profile is the very prominent stratospheric temperature inversion of nearly 12K between ~38 to ~41 km. Although stratospheric inversion layers are present in many lidar profiles obtained in other stations, this particular profile calls attention because of the magnitude of the temperature inversion in a small altitude range. A search in our entire data base, from 1998 to 2006 summing a total of 628 average nightly profiles, show in figure 1. In order to see whether this profile is characteristic of the entire measurement period or not, we have divided the data into three 1/2-hour bins which still gives enough precision. This is shown in Fig. 3, where we can see that this inversion layer is a persistent characteristic throughout the night. We have also compared our data with satellite data obtained by the SABER instrument on board of TIMED satellite. Profiles were found around our station in nocturnal on March 27. Figure 2 shows the lidar profile and SABER profiles obtained at the coordinates indicated in the legend at 18:27:13. We can see that despite of the differences between the profiles, mainly above 55 km, the inversion layer is present in the SABER profile, also compared with CIRA model data and month mean.

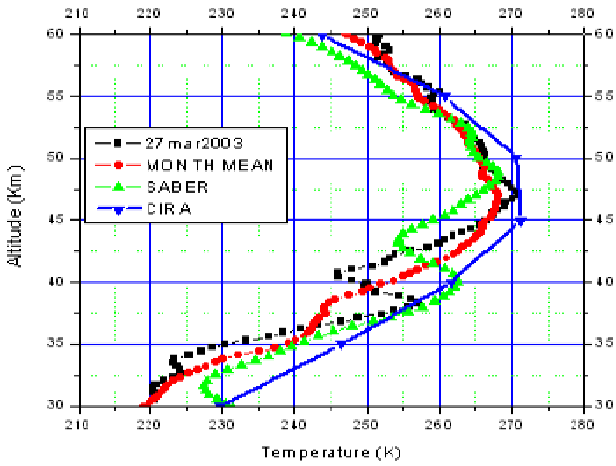


**Fig 2: Unusual Lidar temperature profile comparison with mean month, SABER temperature and CIRA model data.**

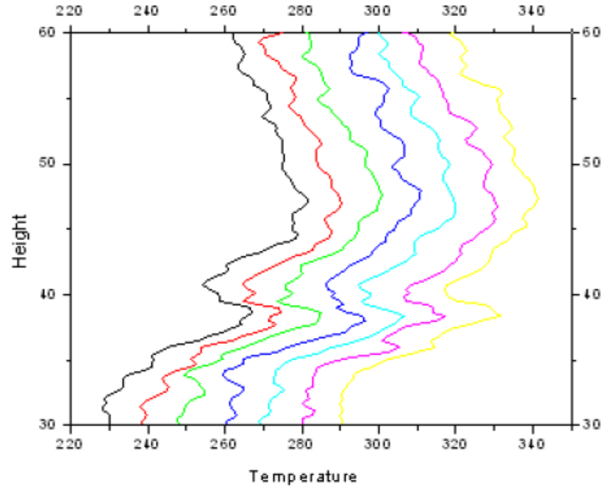


**Fig 3: 30 min averaged temperature profiles**

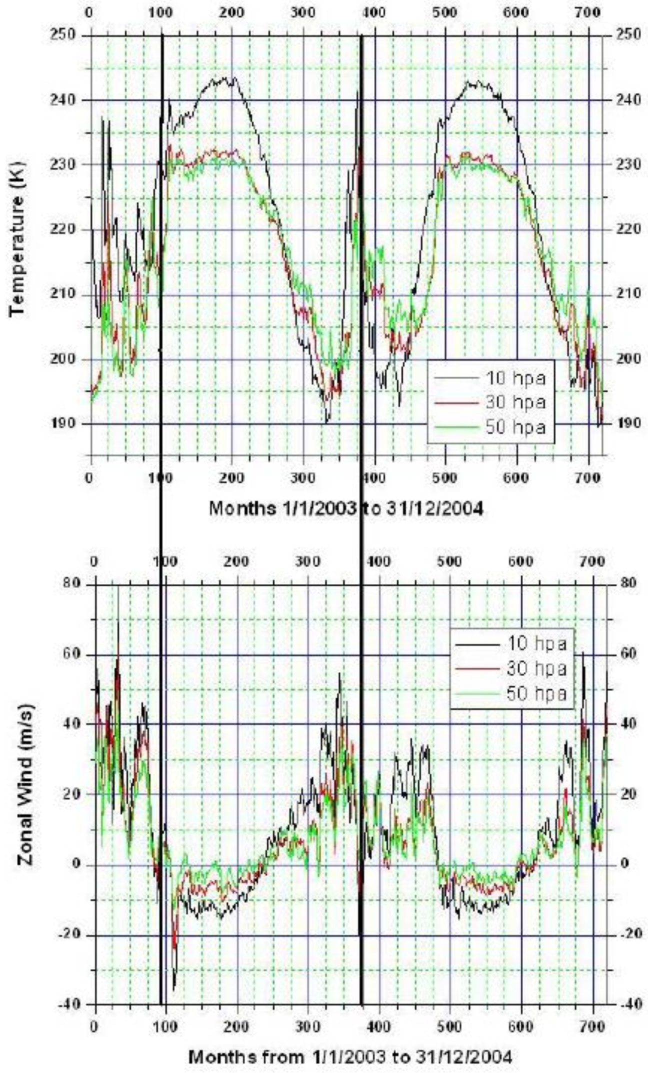


**Fig: 4: NCEP temperature and wind plots for sudden stratospheric warming**

**Table 2: Statistics of sudden stratospheric warming events observed over gadanki[34]**

| Date of SSW observed | | $\Delta T$ | Height ( km ) | | | Reference |
|---|---|---|---|---|---|---|
| NCEP | NARL | (K) | SSW | $S_w$ | $S_d$ | |
| 15 to 21-12-1998 | 23-01-1999$^{+m}$ | 09.81 | 51.8 | 47.8 | -4.0 | |
| | 31-01-1999$^{+m}$ | 10.49 | 52.9 | 47.8 | -5.1 | |
| | 06-02-1999$^{+m}$ | 09.53 | 52.3 | 47.8 | -5.0 | |
| | 14-02-1999$^{+m}$ | 10.28 | 47.8 | 47.8 | 0.0 | |
| | 22-01-2001$^{+m}$ | 09.96 | 48.4 | 47.2 | -1.2 | |
| 12 to 23-02-2001 | 22-02-2001$^{+/-M}$ | 18.16 | 45.4 | 47.2 | 1.8 | *Sivakumar et al .,2004* |
| 18-01-2003 | 29-01-2003$^{-m}$ | 08.41 | 52.3 | 48.1 | -4.2 | |
| | 26-02-2003$^{-m}$ | 12.61 | 44.2 | 48.1 | 3.9 | |
| | 26-03-2003$^{-m}$ | 10.73 | 46.6 | 48.1 | 1.5 | |
| 05 to 13-01-2004 | 20-01-2004$^{+M}$ | 11.86 | 51.4 | 49.9 | -1.5 | |
| | 03-02-2004$^{+m}$ | 12.66 | 48.1 | 49.9 | 1.8 | |
| | 18-02-2004$^{+m}$ | 14.06 | 43.6 | 49.9 | 6.3 | |
| | 27-02-2004$^{+m}$ | 08.16 | 49.0 | 49.9 | 0.9 | |
| | 01-11-2004$^{-m}$ | 08.90 | 44.2 | 47.2 | 3.0 | |

classify the SSW events as described in section-IV, among these two events (presented in figure-4), the event observed on 20 January 2004 show evidence of warm temperature (difference between daily temperature profile and extended-winter mean temperature) of about 11.8 K, which also coincident with a zonal wind reversal in the NCEP data (see. Figure-4). Hence, this event observed on 20 January 2004 is classified as major warming [34]. The descent of stratopause (height difference between yearly-mean winter stratopause and the observed SSW profile stratopause) associated with the occurrence of this major SSW event is noticed to be ~1.5 km. Further, the events observed on 26 March 2003 (Figure-4) shows the warm temperature of magnitude ~12.6 K (at stratopause height 48.1 km) but no coincidence of wind reversal (Figure-4) is observed. Hence, the event observed on 26 March 2003 is classified as minor warming (see table-2).

## VI. DISCUSSION

At the time of the observations we did not have any satisfactory explanation for such an "unusual" profile. A search in the literature showed that similar temperature profiles occur at low southern latitude station following a midwinter stratospheric warming. During March 2003 the tropics also experienced a minor stratospheric warming which was shown in figure 4, and it shows that difference between the Major and minor warming events. Although being mainly a high latitude stratospheric phenomenon, there is evidence that this is a hemispheric disturbance which extends to higher latitudes and altitudes. A stratopause and a warming with temperature above 270K are shown. The profile is compared with SABER satellite temperature that one obtained on March 27. Also for reference the CIRA model temperature data is shown. One can see that the mean march 2003 profile is abnormal with a temperature increase from 10-12 K between 38-41 km.

## VII. CONCLUSIONS

The lidar facility at Gadanki (13.5N 79.2E), India which provides data since 1998, mainly dedicated to study the middle atmospheric temperature profiles from 30 to 80 km. During all the period from 1998 to 2006 when Rayleigh temperature profiles were obtained on a regular basis only on one occasion a profile with an outstanding temperature inversion in the upper stratosphere has been obtained. The validity of this profile has been demonstrated by comparing it with satellite data. It is concluded that this kind of profile similar only to low southern latitude station profiles obtained during the period which follows midwinter stratospheric warming is a consequence of the very disturbed upper stratosphere which followed the minor Stratospheric Warming. How this low latitude region has been affected by a high latitude phenomenon is still a motive of research.

## REFERENCES


1. Hauchecorne, M. L. Chanin, "Density and temperature profiles obtained by lidar between 35 and 70 km",Geophys. Res. Lett. 7, 565-568 (1980).
2. A. Hauchecorne, M. L. Chanin, P. Keckhut, D. Nedeljkovic, "Lidar monitoring of the temperature in the middle and lower atmosphere", Appl. Phys. B 55, 29-34 (1992).
3. A. Hauchecorne, M. L. Chanin, P. Keckhut, "Climatology and trends of the middle atmospheric-temperature (33-87 km) as seen by Rayleigh lidar over the so7uth of France", J. Geophys. Res. 96, 15297-15309 (1991).
4. Adriani, G. P. Gobbi, F. Congeduti, G. di Donfrancesco, "Lidar observations of stratospheric and mesospheric temperature - November 1988-November 1989", Ann. Geophys. 9, 252-258, (1991).
5. G. P. Gobbi, C. Souprayen, F. Congeduti, G. Didonfrancesco, A. Adriani, M. Viterbini, S. Centurioni, "Lidar observations of middle atmosphere temperature variability", Ann. Geophys.-Atmos. Hydros. Space Sci. 13, 648-655 (1995).
6. V. Siva Kumar, P. B. Rao, M. Krishnaiah, "Lidar measurements of stratosphere-mesosphere thermal structure at a low latitude: Comparison with satellite data and models", J. Geophys. Res, 108, 4342 (2003).
7. J. B. Nee, S. Thulasiraman, W. N. Chen, M. Venkat Ratnam, D. Narayana Rao, "Middle atmospheric temperature structure over two tropical locations, Chung Li (25°N,121°E) and Gadanki (13.5°N,79.2°E)", J. Atmos. Sol.-Terr. Phy. 64, 1311-1319 (2002).
8. Q. H. Chang, G. T. Yang, S. S. Gong, "Lidar observations of the middle atmospheric temperature characteristics over Wuhan in China", J. Atmos. Sol.-Terr. Phy. 67, 605-610 (2005).
9. T. D. Kawahara, C. S. Gardner, A. Nomura, "Observed temperature structure of the atmosphere above Syowa Station, Antarctica (69°S, 39°E)", J. Geophys. Res., 109, D12103 1-9 (2004).
10. A. Hauchecorne, M. L. Chanin, "A mid-latitude ground based lidar study of stratospheric warmings and planetary wave propagation", J. Atmos. Sol.-Terr. Phy. 44, 577-583 (1982).
11. P. Kishore, S. P. Namboothiri, K. Igarashi, V. Sivakumar, S. Thulasiraman, I. V. Subba Reddy, K. Mizutani, D. Narayana Rao, S. V. B. Rao, Y. Bhavani Kumar, Rayleigh lidar observations of planetary waves in the middle atmosphere over Gadanki (13.5° N, 79.2 ° E)", J. Atmos. Sol.-Terr. Phy. 68, 901-910 (2006).
12. J. D. Wild, M. E. Gelman, A. J. Miller, M. L. Chanin, A. Hauchecorne, P. Keckhut, R. Farley, P. D. Dao, J. W. Meriwether, G. P. Gobbi, F. Congeduti, A. Adriani, I. S. McDermid, T. J. McGee, E. F. Fishbein, "Comparison of stratospheric temperatures from several lidars, using national-meteorological-center and microwave limb sounder data as transfer references", J. Geophys. Res. 100, 11105-11111 (1995).
13. E. E. Remsberg, P. P. Bhatt, L. E. Deaver, "Seasonal and longer-term variations in middle atmosphere temperature from HALOE on UARS", J. Geophys. Res. 107, 18.1-18.13(2002).
14. Hauchecorne, M. L. Chanin, R. Wilson, "Mesospheric temperature inversion and gravity wave breaking", Geophys. Res. Lett. 14, 933-936 (1987).
15. T Leblanc, A. Hauchecorne, "Recent observations of mesospheric temperature inversions", J. Geophys. Res. 102, 19471-19482 (1997).

16. V. Siva Kumar, Y. B. Kumar, K. Raghunath, P. Rao, B. Krishnaiah, K. Mizutani, A. Taori, M. Yasui, T. Itabi, "Lidar measurements of mesospheric temperature inversion at low latitude", Ann. Geophys. 19, 1039- 1044 (2001).
17. H.-L. Liu, J. W. Meriwether, "Analysis of a temperature inversion event in the lower mesosphere", J. Geophys. Res. 109, D02S07 (2004).
18. S. Fadnavis, G. Beig, "Mesospheric temperature inversions over the Indian tropical region", Ann. Geophys. 22, 3375-3382 (2004).
19. Andrews, D.G., J.R. Holton, and C.B. Leovy, Middle Atmosphere Dynamics. Academic Press, 1985.
20. Sivakumar,V., B. Morel, H. Bencherif, J. L. Baray, S. Baldy, A. Hauchecorne, and P.B. Rao, Rayleigh LiDAR observation of a warm stratopause over a tropical site, Gadanki (13.5°N; 79.2°E), Atmos. Chem. Phys., 4, 1989-1996,2004.
21. Matsuno, T.: A dynamical model of the stratospheric sudden warming. J. Atmos. Sci., 28, 1479-1494, 1971.
22. Whiteway, J.A., and A.I. Carswell, Rayleigh LiDAR Observations of Thermal Structure and Gravity Wave Activity in the High Arctic during a Stratospheric Warming. J. Atmos. Sci. 51, 3122-3136, 1994.
23. Donfrancesco G., A. Adriani, G.P. Gobbi., and F. Congeduti, LiDAR observations of stratospheric temperatures above McMurdo Station (78S, 167E), Antarctica . J. Atmos. Terr. Phys., 58, 1391-1399, 1996.
24. Whiteway, J.A., T.J. Duck, D.P. Donovan, J.C. Bird, S.R. Pal., and Carswell, Measurements of gravity wave activity within and around the Arctic stratospheric vortex, Geophys. Res. Lett., 24, 1387-1390. 1997.
25. Duck, T. J., J. A. Whiteway, and A.I. Carswell, LiDAR observations of gravity wave activity and Arctic stratospheric vortex core warming, Geophys. Res. Lett., 25, 2813-2816, 1998.
26. Walterscheid, R. L., G. Sivjee, and R.G. Roble, Mesospheric and lower thermospheric manifestations of a stratospheric warming event over Eureka, Canada (80°N), Geophys. Res. Lett., 27, 2897-2900, 2000.
27. Hauchecorne, A., and M.L. Chanin, Mid latitude observations of planetary waves in the middle atmosphere during the winter over 1981–1982, J. Geophys. Res., 88, 3843-3849, 1983.
28. Charyulu, D. V., V. Sivakumar, H. Bencherif, G. Kirgis, A. Hauchecorne and D. Narayana Rao, 20-year LiDAR observations of stratospheric sudden warming over a mid-latitude site, Observatoire de Haute Provence (44°N, 6°E): Case study and statistical characteristics. Atmos. Chem. Phys. Discuss., 2007.
29. Sivakumar,V., B. Morel, H. Bencherif, J. L. Baray, S. Baldy, A. Hauchecorne, and P.B. Rao, Rayleigh LiDAR observation of a warm stratopause over a tropical site, Gadanki (13.5°N; 79.2°E), Atmos. Chem. Phys., 4, 1989-1996, 2004.
30. Sivakumar.V., Y. Bhavanikumar, K. Raghunath, P.B. Rao, M. Krishnaiah, K. Mizutani, T. Aoki, M. Yasui, and T. Itabe, LiDAR measurements of mesospheric temperature inversion at a low latitude, Ann. Geophys., 19, 1039-1044, 2001.
31. Sivakumar, V., P.B. Rao, and M. Krishnaiah, LiDAR studies of Stratosphere-Mesosphere Thermal Structure over Low Latitude: Comparison with satellite and models, J. Geophys. Res., 108 (D11), 4342, doi: 10.1029/2002JD003029, 2003.
32. Timed Web Site. http://www.timed.jhuapl.edu.
33. Sivakumar, V., H. Bencherif, A. Hauchecorne, P. Keckhut, D.N. Rao, S. Sharma, H. Chandra, A. Jayaraman and P.B. Rao, Rayleigh LiDAR observations of double stratopause structure over three different northern hemisphere stations, Atmos. Chem. Phys. and Discuss., 6, 6933-6956, 2006.
34. http://researchspace.csir.co.za/dspace/bitstream/10204/3279/1/Charyulu1_2007.pdf