Rayleigh LiDAR investigation of stratospheric sudden warming over a low latitude station, Gadanki (13.5ºN; 79.2ºE) – a statistical study

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ABSTRACT

In this paper, we report the statistical characteristics of Stratospheric Sudden Warming (SSW) events observed over a low latitude station, Gadanki; 13.5°N, 79.2°E. The study uses 7 years (1998 to 2004) of quasi-continuous nighttime LiDAR temperature measurements, which corresponds to 312 observations. The statistical characteristics are presented in terms of major or minor, magnitude of warming, height of occurrence and stratopause descent with reference to the mean climatological profile. The warming events are classified into major or minor warming with respect to the observed warm temperature magnitude and reversal in the zonal wind direction in the polar region using National Centre for Environmental Prediction (NCEP) reanalysis data. In total, 14 SSW events observed and have been classified into 2 (14.3 %) major and 12 (85.7 %) minor warming events. The magnitudes of warm temperatures with respect to the mean winter temperature is in the range from 8.2 K to 18.1 K. Occurrence of SSWs are observed to accompany with the descent of stratopause layer from 0 km to 6.3 km with respect to the calculated mean winter stratopause height.

Keywords: LiDAR, Middle atmosphere, planetary waves, sudden stratosphere warming, low latitude

1. INTRODUCTION

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 etc. (Andrews, 1985). 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 e-g., 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 (*Sivakumar et al.,* 2004). 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 (*Matsuno,* 1971).

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 *Whiteway and Carswell* 1994; *Donfrancesco et al.,* 1996; *Whiteway et al.,* 1997; *Duck et al.,* 1998; *Walterscheid et al.,* 2000), mid- (e.g. *Hauchecorne and Chanin*, 1983, *Charyulu et al.,* 2007) and low-latitudes (*Sivakumar et al.*, 2004). More recent SSW observations by *Sivakumar et al.* (2004) 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.

Here, we shall describe the statistical characteristics of SSW events observed over a low latitude station, Gadanki (13.5°N, 79.2°E), 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. Since there have not been any extensive statistical studies on the SSW for low latitude using long database, we believe that our results is the first of its kind.

2. 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 16th March 1998 to 26th December 2004. The total number of LiDAR observations corresponds to 312 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 Hauchecorne and Chanin (1980). Further details on the Gadanki LiDAR system and temperature derivation from the photon count profile is suitably modified and explained in *Sivakumar et al* (2001, 2003).

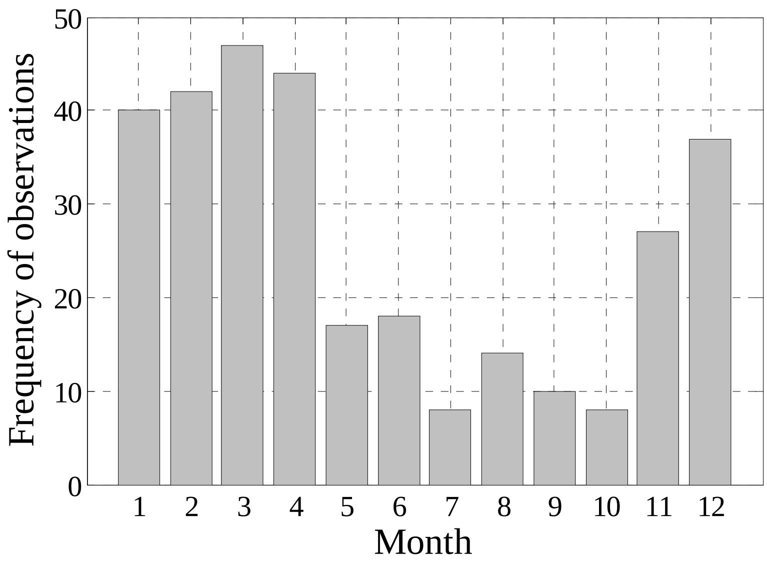

Fig. 1: Frequency distribution of LiDAR observations used for the present study.

b. HALOE data

SSW observation by LiDAR measurement is compared with HALOE (Halogen Occultation Experiment)/UARS satellite data. The UARS cyclic time is about 2 months to complete the entire hemisphere which limits the frequency of overpass over LiDAR site. In order to compare with the LiDAR derived temperature profile, we have used the quasi-simultaneous measurements (same date as LiDAR measurements or within 24 hours of time separation) of UARS/HALOE (sunrise and sunset) overpasses over Gadanki (13.5°N, 79.2°E) site, within ± 5° in latitude and ± 10° in longitude ranges. Further, retrieval of temperature profile from HALOE measurements and its validation are illustrated in various literatures (*Russell III et al.,* 1993; *Hervig et al.,* 1996).

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).

3. SSW DETECTION AND CLASSIFICATION CRITERIA

The SSW detection method used in the present study is same as described in *Charyulu et al.*, (2007-submitted for publication). 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.

Figure-2 demonstrates the evidence of occurrence of sudden stratosphere warming event on 14 February 1999 over LiDAR Site (Gadanki). The figure is superimposed by the overall mean temperature profile and the winter mean profile. It is evident from the temperature profile, the warming observed at ~47.5 km and high temperature observed to be about 276 K which is more than the standard deviations. The observed magnitude is about 10.3 K and it seems to occur almost at the warm stratopause height. Based on NCEP data, there were no zonal wind reversal observed during this event and thereby it is said to be minor warming. Further more details on the major and minor warming are explained in the following sections.

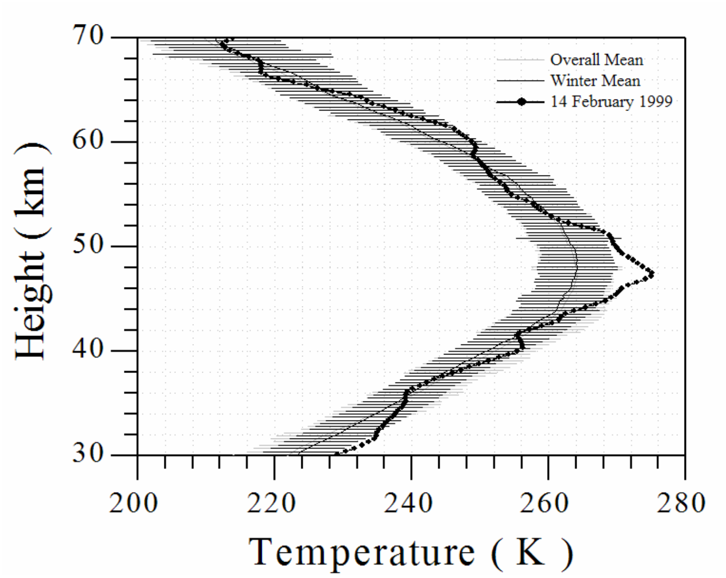

Fig-2: Height profile of temperature illustrating the sudden stratosphere warming observed by LiDAR on 14 February 1999.

4. OBSERVATIONS AND RESULTS

a. Case study

As a case study, we have investigated the temperature evolution for 2003/2004 winter profiles and we found four different warming occasions. The warm temperature is noted for 20 January, 03 February, 18 February and 27 February of the year 2004. In order to illustrate and study in detail, the first two events, 20 January 2004 and 03 Feburary 2004 are selected. These two dates are chosen which illustrate a significant difference in terms of major and minor warming occasions. The temperature profile of those days along with the mean profile is shown in figure-3. The HALOE overpass to the LiDAR-site is almost closer (10.53°N; 85.37°E) and during sunset events. The observed HALOE profile corresponds to the 03 February 2004 event. The HALOE measurement profile is closely mapping with the LiDAR measurement. A small difference in the temperature magnitude is noted between the LiDAR and HALOE measurement, which might be due to the temporal and special separation by the difference in measurements. The HALOE measurements are ~3 K cooler than the LiDAR measurements. Also, the LiDAR measurements stand for its accuracy and also pointing the atmosphere wave propagation.

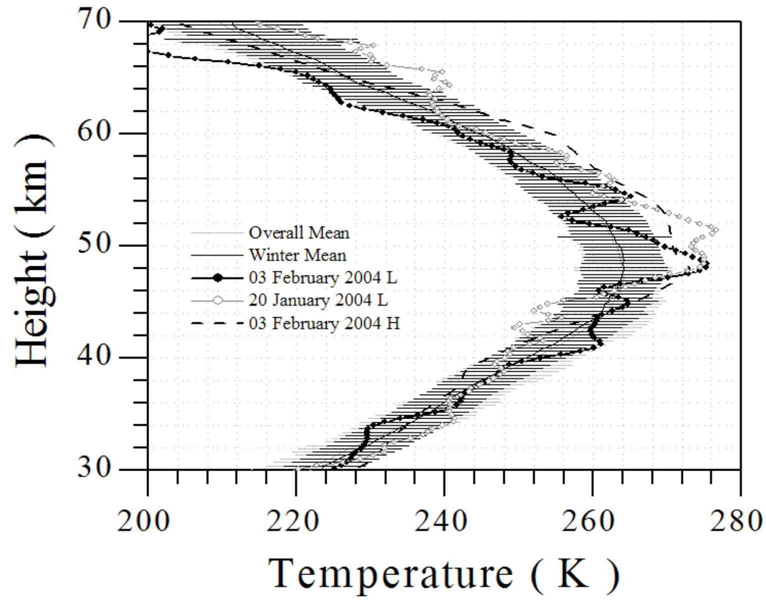

Fig.3. Height profile of temperature illustrating two of the warming events observed by LiDAR on 20 January 2004 and 03 February 2004. The over-all mean, mean winter and HALOE temperature (03 February 2004) profiles are superimposed in the same figure. The suffix 'L' and 'H' denotes the LiDAR and HALOE measurements, respectively.

Using the above criteria to detect and classify the SSW events as described in section-3, among these two events (presented in figure-3), 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. 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 03 February 2004 (Figure-3) 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 03 February 2004 is classified as minor warming and its occurrence found to be associated with descent of stratopause layer about 1.8 km. The other two remaining events in winter 2003/2004, observed on 17, 26 February 2004 show evidence of warm temperatures of the order of ~14 K, 8.2 K and its occurrence associated with positive difference of stratopause layer at about 6.3 km, 0.9 km respectively (see table-1). The high value of stratopause is might due to the occurrence of double stratopause where the case the upper level stratopause considered being warm stratopause. The double stratopause structure over mid- and low-latitudes has already been reported by *Sivakumar et al.,* (2006).

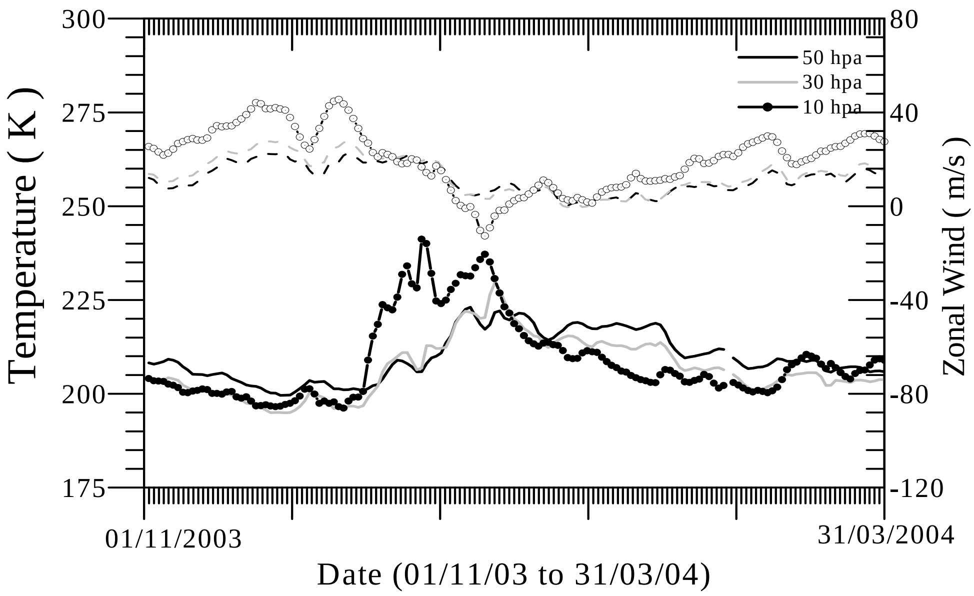

Fig.4: Time evolution of NCEP zonal-mean temperature at 80°N (Solid lines) and zonal mean wind at 60°N (Dotted lines) for 50, 30 and 10 hPa pressure levels for the period from 01 November 2003 to 31 March 2004.

b. Statistics

Applying the above criteria to the LiDAR observed SSW events (section-3), the classification and statistics are made in terms of major and minor warming, in consequences to the NCEP reanalysis data. Further, the magnitudes of warming, difference in the stratopause are obtained by comparing with mean extended winter (November to March) climatological profiles. The obtained values are tabulated in table-1 for all the SSW events. In total, there are 14 SSW events observed during eight sequent winters begin from March 1998 to December 2004.

Table -1: Statistics of SSW events observed over NARL

Date of SSW observed		ΔT	**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	

Where, +/- stands for QBO phase west/east; M – major warming, m – minor warming, S_w and S_d indicates the yearly mean winter stratopause and difference in the stratopause height.

During 1998, there are no warming event reported from LiDAR, the LiDAR has began to operational since March 1998. There are also no warming events noticed by LiDAR during winter 1999/2000 and 2001/2002. The basic reason is that LiDAR is not operated on daily basis and it is operated by requirement. There are no systematic observations planned for SSW. Our aim is to use the existing available data bases and to notice the SSW observations in case if it is detected during the LiDAR operational days. In the winter 1998/1999, four warming events are noticed respectively on 23, 31 January 1999 and 06, 14 February 1999. Based on the coincidence of no zonal-mean wind reversal (NCEP data) all the above four events are classified as minor warmings. Magnitude of warm temperatures is in the order of 9 K to 10 K and found to occur also associated with the ascent of stratopause by 0 to 5.1 km. SSW occurrence and associated with ascent of stratopause rather than descent of stratopause need further investigation to understand the dynamical causative mechanism. One reason could be the occurrence of double stratopause structure (see. *Sivakumar et al.,* 2006). In winter 2000/2001, two events (on 22 January 2001 and 22 February 2001) are found to occur which have magnitude of warm temperature 9.9 K and 18.1 K respectively. Among the two, the event observed on 22 January 2001 is classified as minor warming and the event observed on 22 February 2001 is classified as major. The major warming event observed on 22 February 2001 has already reported by *Sivakumar et al.* 2004. Both the events are found to be associated with stratopause descent of about 1.2 km and 1.8 km, respectively. In winter 2002/2003, there are three events observed each one per month from January to March. All these three events are classified as minor warmings. Magnitude of warm temperatures and descent/ascend of stratopause are noticed as 8.4 K, 12.6 K, 10.7 K and -4.2 km, 3.9 km, 1.5 km respectively. Using the data set up to 26 December 2004, one event noticed in the winter 2004/2005 and is classified as minor warming. Magnitude of warm temperature and descent of stratopause is noticed to be 8.9 K and 3 km respectively.

There are few evidences of occurrence of SSW events in connection to the QBO phase. Generally, the zonal wind data at the equator reflects the QBO phase. Based on it, we have used the zonal wind data corresponds to Singapore (1°N, 103°E). We have chosen the highest available pressure level 10 hpa assuming that it is the one nearer to stratopause height region. The number of occurrence of SSW events with respect to the QBO phase easterly or westerly (figure not shown) is examined and the results are as follows. Among the observed total 14 SSW events, 3 events are observed when QBO is in east phase, 8 events observed when QBO is in west phase and 1 event during transition phase (hard to define either east or west). Out of 2 major SSW events, one event observed when the QBO is in the transitional phase, and the rest of the event observed when the QBO phase is in the west phase. Among 12 minor SSW events, 8 events observed when the QBO is in west phase, 4 events observed when the QBO phase is east.

5. CONCLUDING REMARKS

This paper reports about statistical characteristics of SSWs observed over a tropical station, Gadanki (13.5°N, 79.2°E) for the first time using 7-years of quasi-continuous LiDAR data for the period from March 1998 to December 2004. The following salient points are noted from the results.

- LiDAR measurements of SSWs are compared with NCEP and HALOE observations and are in good agreement with each other. The HALOE observations show slight difference in magnitude of warm temperatures. It is understandable in terms of the HALOE observations are not in the same time as that of LiDAR.
- During 7-Years, 14 SSW events are found to occur. Among 14 SSW events, 12 events (about 86%) are minor warmings and 2 events (about 14%) are major warmings.
- Out of 8 sequent winters starting from March 1998 to December 2004: winter 1998, 1999/2000 and 2001/2002 are noticed to experience no warming. The maximum-minimum magnitude of the warm temperatures observed for the major and minor warmings are in the range of 11.8-18.2 K and 8.2 - 14.0 K respectively.
- The difference in the stratopause layer associated during major and minor warmings by -1.5 to 1.8 km and -5.1 to 6.3 km respectively. Maximum magnitude of warm temperatures noticed among all warming occasions are less than 18.2 K, which is significantly less than that of the earlier reported result from mid- and high latitude stations (30 K to 40 K) (*Hauchecorne and Chanin,* 1983; *Whiteway and Carswell,* 1994; *Donfrancesco et al.,* 1996; *Whiteway et al.,* 1997; *Duck et al.,* 1998; *Walterscheid et al.,* 2000). The reason might be attributed to 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 in support of the conclusion made by *Sivakumar et al* (2004).

- Out of 14 SSW event occasions, 6 events are associated with ascent of stratopause rather than usual descents of stratopause, which need further investigation in order conclude the dynamical causative mechanism including the double stratopause structure. Out of total 14 SSW events, number of events occurred when QBO phase was east are 4 and 9 events occurred when QBO phase was west, remaining 1 events occurred when QBO in the transitional phase (east/west).

Since the main objective of the present paper is to report the observed SSW statistical characteristics over a low-latitude, Gadanki (13.5 N; 79.2 E), the dynamical processes involved during the occurrence of SSW is not presented and which are of our future perspectives.

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