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Diurnal variation of atmospheric stability and turbulence during different seasons in the troposphere and lower stratosphere derived from simultaneous radiosonde observations at two tropical stations, in the Indian Peninsula

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ABSTRACT

Diurnal variability of atmospheric stability as well as the occurrence and strength of turbulence in the troposphere and lower stratosphere at two tropical stations, Trivandrum (8.5°N, 76.9°E) and Gadanki (13.5°N, 79.2°E), situated in the Indian Peninsula is studied. For the analysis three years of GPS-radiosonde data, collected as a part of the Tropical Tropopause Dynamics (TTD) Experiment under the CAWSES-India program, has been used. Thorpe method is adopted to estimate the turbulent parameters from radiosonde observations. This study shows that in the atmospheric boundary layer, both stability and turbulence parameters depict a pronounced diurnal variation. Over Trivandrum, the occurrence of turbulence as well as its strength peaks during night and falls off during the day, while at Gadanki it shows an opposite pattern. At both the stations, in the 3–10 km altitude layer, the occurrence and strength of turbulence are relatively high during night compared to day. Although the turbulence strength in the 10–15 km altitude layer is rather weak at both the stations, the occurrence of turbulence shows a clear diurnal pattern (high during the day), especially over Trivandrum. In the 3–15 km altitude layer, while the occurrence of convective instability is fairly the same at both the stations, the wind shear is significantly large at Trivandrum compared to Gadanki, with high values during night compared to the day. This shows that in this altitude region, while convective instability is mainly responsible for the generation of turbulence at Gadanki, wind shear induced dynamic instability is also responsible for the generation of turbulence at Trivandrum especially during night. Above 15 km, where wind shear driven instability leads the convective instability, turbulence at both the stations does not show any significant diurnal variability.

1. Introduction

Turbulence is one of the important dynamical characteristics of the atmosphere which plays a pivotal role in the exchange of mass (including atmospheric minor constituents and aerosols), momentum and energy between different atmospheric layers (Holton et al., 1995). Understanding atmospheric turbulence and its variability in different spatial and temporal scales has immense scientific interest in the dynamics of Atmospheric Boundary Layer (ABL) as well as in the free-troposphere and stratosphere. Quantitative assessment of spatio-temporal variations of turbulence structure in the troposphere is also important in improving the skill of numerical weather prediction and climate models (Yao and Cheng, 2012), as well as for understanding clear air turbulence, which would aid in obviating air-traffic disasters. Turbulence parameters such as eddy diffusivity and dissipation rate of turbulent kinetic energy are key elements used for modeling the vertical distribution of trace constituents in the atmosphere as well as for assessing the exchange between troposphere and stratosphere over the tropics. Understanding on the features of turbulence in the free-troposphere is rather poor because of the difficulty of making measurements and the consequent scarcity of observational data. Turbulence in free-troposphere and stratosphere is highly intermittent in time and space. *In situ* measurements from aircrafts with the help of turbulence probes (Strunin and Shmeter, 1996; Cho et al., 2003) are very costly and hence a very few in number. Remote sensing by atmospheric radars (*e.g.*, Kurosaki et al., 1996; Naström and Eaton, 1997; Satheesan and

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Krishna Murthy, 2002; Wilson, 2004) and lidars (Parameswaran et al., 1993) is convenient; but is often subjected to various uncertainties.

Luce et al. (2002); Gavrilov et al. (2005) and Clayson and Kantha (2008) described the application of Thorpe method, developed for oceanic mixing (Thorpe, 1977), to retrieve atmospheric turbulence parameters using from high resolution radiosonde data. This pioneering technique enables the use of high-resolution radiosondes, which have become quite standard in the recent years, for monitoring atmospheric turbulence in near real time and is being used for studying its spatio-temporal characteristics from the abundant archives of data from high-resolution soundings around the world. Wilson et al. (2010, 2013)) improved this method by accounting the effect of measurement noise and atmospheric moisture, which can influence dramatically the calculation of turbulent parameters.

Over the Indian region, a few studies on the variability of turbulent parameters have been carried out using radar as well as radiosonde observations. MST radar observations at Gadanki (13.5°N, 79.2°E), have been used to figure out the structure of turbulence in the troposphere, stratosphere and mesosphere during various seasons and in different atmospheric conditions (Rao et al., 2001a, 2001b, 2010; Satheesan and Krishna Murthy, 2002; Ghosh et al., 2003). Nath et al. (2010) studied the seasonal variation of turbulence over Gadanki using three years of radiosonde observations confined to 17:30 IST ascents. Using radiosonde data, Alappattu and Kunhikrishnan (2010) examined the structure of turbulence over the Bay of Bengal and the Arabian Sea during pre-monsoon season. In a recent study (Sunilkumar et al., 2015), though we have reported the annual, seasonal and monthly variations of turbulence parameters in the troposphere and lower stratosphere using data from simultaneous radiosonde observations for 3 years over Trivandrum and Gadanki, the diurnal cycle of turbulence and their altitude variation are not well explored. Only a very few studies on the diurnal variability of turbulence in the troposphere and lower stratosphere exists over the globe. Over Gadanki, Rao et al. (2001a) examined the diurnal variability of turbulence in upper troposphere (UT) using three years of MST radar data and showed that strength of the turbulence in the upper troposphere is strongest during the summer monsoon season. Liu et al. (2014) attempted to delineate the diurnal variation of UT turbulence using limited radiosonde observations over the western Pacific during May and June months of 1998. Most of these studies used relatively low resolution data during a limited period. The information on atmospheric turbulence in real time as well as its diurnal and seasonal variability are very valuable for the aviation sector.

In the present study, the diurnal characteristics of turbulence are examined from high resolution radiosonde observations carried out at Trivandrum (8.5°N, 76.9°E) and Gadanki (13.5°N, 79.2°E). Both these stations are located over the Indian Peninsula. Gadanki is an inland station situated ~120 km west of the east coast (adjoining the Bay-of-Bengal) at an altitude of 370 m Above Mean Sea Level (AMSL) and Trivandrum (6 m AMSL) is a coastal station located very near to the Arabian Sea (in the west coast). The locations of both these stations are marked in Fig. 1a. The onset of summer monsoon over the Indian subcontinent occurs first at Trivandrum and subsequently advances towards north and northeast. While Gadanki is influenced by deep convection from Bay-of-Bengal, the convection encountered at Trivandrum is rather shallow. Since Trivandrum is closer to equator, the convective outflows from Indonesian region and associated processes could influence this region, particularly during winter. Tropical Easterly Jet (TEJ) during summer monsoon also influences the dynamics of UTLS at the both stations (Ratnam et al., 2014). The turbulence parameters such as Thorpe scale, eddy diffusivity and turbulent kinetic energy dissipation rate are estimated from high resolution radiosonde data using Thorpe method. Stability parameters such as square of the Brunt Väisälä (BV) frequency (N^2), vertical shear of horizontal wind ($|\partial U/\partial h|$) and traditional Richardson number (Ri) are evaluated from radiosonde data. Using these parameters the relative role of static and dynamic (wind-shear) instabilities in generating turbulence in the troposphere and lower stratosphere are studied. A statistics of radiosonde observations and methodology used for the detection of turbulence are detailed in Section 2. Important results describing the altitude structure of atmospheric stability and turbulence (strength/intensity and frequency of occurrence) and their diurnal variations in the troposphere and lower stratosphere during different seasons are presented in Section 3. Discussion and conclusions are presented in Section 4.

2. Data and methodology

2.1. Radiosonde data

Simultaneous radiosonde ascents were carried out from Trivandrum and Gadanki at three hour interval for three consecutive days in each month regularly for a period of 40 months from December 2010 to March 2014 as part of Tropical Tropopause Dynamics (TTD) experiment under CAWSES-India Phase-II program (Ratnam et al., 2014; Sunilkumar et al., 2015). During the campaign, radiosonde soundings are carried out at 02:30, 05:30, 08:30, 11:30, 14:30, 17:30, 20:30 and 23:30 IST. However, there were a few gaps at the scheduled time due to unforeseen reasons. Statistics of radiosonde profiles in each campaign/month (Fig. 1b) indicates statistically significant number of profiles for delineating the mean diurnal pattern of turbulence and stability parameters during different seasons. At Gadanki, Meisei radiosondes are used for the entire observation period, while at Trivandrum both Pisharoty as well as iMet radiosondes are used. Pisharoty radiosondes are used only during night. All these radiosondes provide basic meteorological parameters like temperature, relative humidity, and wind components (zonal and meridional component) with a vertical resolution of ~4 to 6 m (1 s interval). Measurement accuracy of wind speed is $\pm 0.15 \text{ms}^{-1}$ and that of temperature is ± 0.5 K; the precision of temperature measurement is 0.01K (Sunilkumar et al., 2015). Mutual consistency of the data from the three types of radiosondes has been tested by launching them together. It is found that the data from these sondes agree well within the respective accuracy limits. Strict quality checks have been imposed on the data before the data is used for further analysis. Those profiles having abnormal (spurious) values on manual inspection and those having missing data for more than a kilometer are eliminated from analysis.

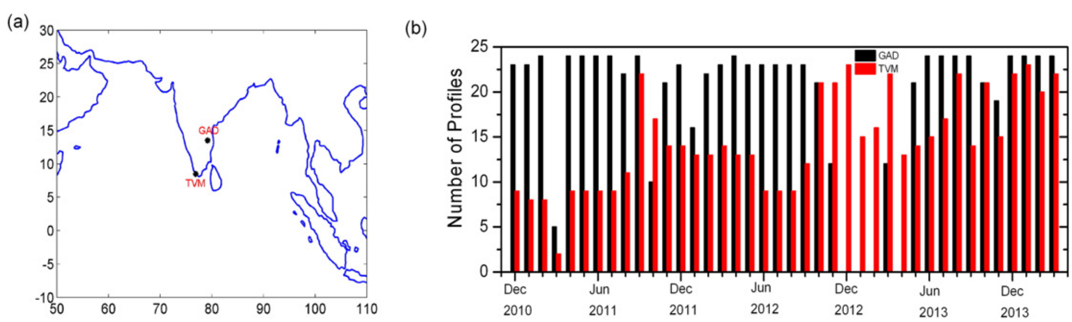

Fig. 1. (a) Map of the Indian region depicting the locations of Trivandrum (TVM) and Gadanki (GAD). (b) Number of radiosonde profiles in each month from December 2010 to March 2014 (used in the present study) at Trivandrum and Gadanki. Radiosonde launches were carried out at 3 h interval for three consecutive days in each month.