General Circulation of the atmosphere over Bangalore (12° 58'N; 77° 34'E) using Radiosonde data.

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Abstract **:** In this study we have made an attempt to explain mean temperature, relative humidity, zonal and meridional winds for the years 2009 to 2017 from surface to a height of 25 km over Bangalore station, in India. It is observed that the zonal wind changes its direction from easterly to westerly when the season changes. During summer monsoon (June, July, August and September) zonal winds are westerly near the surface and above 5km it is easterly where as the remaining months the zonal wind is easterly near the surface and above 5km it is westerly. Meridional winds are weak northerly in the months of November, December, January, February, March, April and May but from 10 km to 20 km Meridional winds tends towards southerly. During winter season (November, December, January and February) temperature is below 20 deg Celsius and in summer and monsoon seasons (March to October) the surface temperature is above 20 deg Celsius. The temperature at the tropopause reaches -78 to -79 deg Celsius except for the month of May where the tropopause temperature is -80 deg Celsius. The relative humidity decreases steeply from 80 to 20 g/kg during winter with the increase in altitude but in remaining months it decreases almost linearly and reaches 10 g/kg at an altitude 15 km above the surface.

IndexTerms - Zonal wind, easterly, Meridional winds, northerly.

I. INTRODUCTION

In general circulation the Indian Summer Monsoon is one of the main tropical circulation systems over Indian subcontinent. During the monsoon season, the troposphere in tropical region has profound impacts on temperature, relative humidity, zonal and meridional winds. Hence it is necessary to consider these parameters for better perceptive of monsoon dynamics and its variability. Many investigations have made an attempt to explain seasonal changes in tropical areas using MST Radar at various locations [Basley et al. 1988; Rao et al. 1991; Gage et al 1991; Jagannadha Rao et al. 2002; Jagannadha Rao et al. 2003]. The stronger zonal wind extending towards westerlies during winter are not constructive for south west monsoon (Joseph 1978 and parthasarathy et al1990) but favourable to northeast monsoon in April and weak winds support meagre north east monsoon (Raj, 1998). In the months of August and September weak easterly jets in tropics over southern tip of India support north east monsoon but strong TEJ support northeast monsoon (Raj 1998 & 89). The purpose of the present study is to explore how the features of troposphere that progress over Bangalore are related to mean temperature, relative humidity, zonal and meridional winds from surface to a height of 25 km for the years 2009 to 2017.

During scarce and surplus rainfall years of Indian summer monsoon, the deviations the zonal winds in the tropical Upper Troposphere and Lower Stratosphere (UT/LS) region have been studied by Vazhathottathil Madhu (2014) and related to Indian Summer Monsoon Rainfall (ISMR). He observed zonal winds have westerly anomalies during poor rainfall but changes to easterlies during excess rainfall. From June to September zonal winds have a long-term trends and also observed weak tropical easterlies and the tropical jet stream. Quasi-Biennial Oscillation (QBO) described as periodic changes in zonal wind from easterly to westerly in the equatorial lower stratosphere [Vazhathottathil Madhu (2014)]. At 50 hPa level this QBO alters the global circulation (Holton and Tan). The phases of the QBO in zonal wind are connected with leaving of the summer monsoon rainfall over India studied by Mukherjee et al., and found strong easterlies in QBO was coupled with weak Indian monsoon but easterly phase with strong monsoon. The zonal winds at 30 km lead by 6 months with zonal wind at 24 km which endowed with a longer lead-time for predicting the Indian monsoon rainfall. The stratospheric zonal wind and Indian summer monsoon have been related in many studies (Rao, R.K.S. and Lakhole, N.T. 1978, Mukherjee, B.K., Reddy, R.S. and Ramana Murty, Bh.V. 1979) and Thapliyal, V. (1979).

II. DATA AND METHODOLOGY

High altitude radiosondes were launched systematically by ISRO from a few Indian stations during middle atmospheric program. Wind and temperature data between Jan 2009 to Dec 2017 over Bangalore have been used for the present study. Temperature, wind speed, wind direction and relative humidity data is collected from the website (www.weather.uwyo.html) There were two flights every day for the complete period. The atmospheric variables used in this study are temperature, relative humidity, wind direction and wind speed from surface to a height of 25 km. Using the wind direction and wind speed, zonal and Meridional components have been calculated for a paricular height and up to 25 km. For the variables temperature, relative humidity, zonal and Meridional components, monthly mean is calculated. Both wind, relative humidity and temperature data sets have been interpolated to yield wind values at every kilometre. Using available data the missing data is calculated using interpolation method. Both the zonal and the meridional components are presented together by solid and dashed lines respectively. A positive value of the wind means westerly for zonal wind and southerly for meridional wind case. Model wind profiles for each month are obtained by averaging all profiles in a particular month of all the years. These are called

multi-annual values of wind for each month. The model zonal wind profiles have been compared with CIRA ± 1986 model for a latitude of 20 deg N which is the closest available to Bangalore latitude.

The earlier report given by H Aleem Bash (1996) in his article "Zonal and Meridional winds over Hyderabad" behave similarly in zonal wind circulation in the troposphere (below 20 km) over Bangalore and has an annual cycle. Westerlies prevail for seven months from June to October. In the lower troposphere between altitude of 1km and 7km, easterlies are observed more frequently. Circulation in the months (June-September) are mostly easterlies. In the stratosphere region, the wind circulation over Hyderabad is predominantly easterly for all months of the year. This has already been reported by Gokhale et.al, (1967), Kumar and Nagpal (1984) and Aleem Basha (1999). The magnitude of wind velocity is found to increase by a factor of two during monsoon months as compared to winter months.

III. RESULTS AND DISCUSSION

3.1) Mean Zonal and Meridional winds over Bangalore from the years 2009 to 2017

Mean zonal and Meridional components of wind from the surface to an altitude of 25 km from the year 2009 to 2017 have been plotted over Bangalore station as shown below. The direction of the wind i.e. westerly or easterly, depends on positive and negative values of zonal wind and northerly or southerly for meridional winds. It is observed the winds are both westerly and easterly for different months and for different altitude. The profiles for zonal (solid line) and meridional (dashed line) winds have been plotted in figure 1 (January, February, March, April, May, and June) and figure 2 (July, August, September, October, November and December).

Zonal wind: In the month of January zonal wind is westerly above 3 km from the surface but easterly up to 3km from the surface. In February zonal wind is westerly above 7km and easterly up to 7km. In the months of March, April zonal winds are westerly above 5 km and easterly up to 5 km. In the months of June, July, August and September zonal winds are easterly above 6km and westerly up to 6km. In the month of May, October, November and December zonal winds are easterly from the surface of the earth to 25 km. The positive zonal winds are westerly and Meridional winds are southerly as described in the article "Zonal and Meridional winds over Hyderabad" by Gopa dutta, M N Joshi, J V Subba Rao and H Aleem Basha (1996). They have reported that westerlies prevail from November to May over Hyderabad and the similar pattern were observed over Bangalore for the duration 2009 to 2017. During monsoon period these winds are easterly but at the surface these winds are westerly. It is observed that these winds change direction from season to season above and below the surface reciprocally over Bangalore. The variation in zonal and meridional wind velocities over Bangalore have been compared with Thumba, Balasore, Hyderabad and noted in table 1.

Table1: Comparision of Circulation patterns of four stations in India

Stations	Latitude/Longitude	Circulation Pattern			
		Nov-May		Jun-Oct	
		Zonal	Meridional	Zonal	Meridional
Hyderabad	17.2° N; 78.3°E	Westerly (+23m/s)	Southerly	Easterly	Northerly
Thumba	8.5N°; 77°E	Weak Easterly	Southerly	Easterly	Northerly
Balasore	21.5N°; 87°E	Westerly (+35m/s)	Southerly	Easterly	Southerly
Bangalore	12° 58'N; 77° 34'	Westerly	Southerly	Easterly	Northerly

Meridional winds: From the surface of the earth to 10 km Meridional winds are weak towards Southerly during the months of November, December, January, February, March, April and May but from 10 km to 20 km Meridional winds tends towards Northerly. From June to October these winds are negligible as shown in fig 1 and 2. With the increase of altitude these winds change directions from north to south and vice versa.

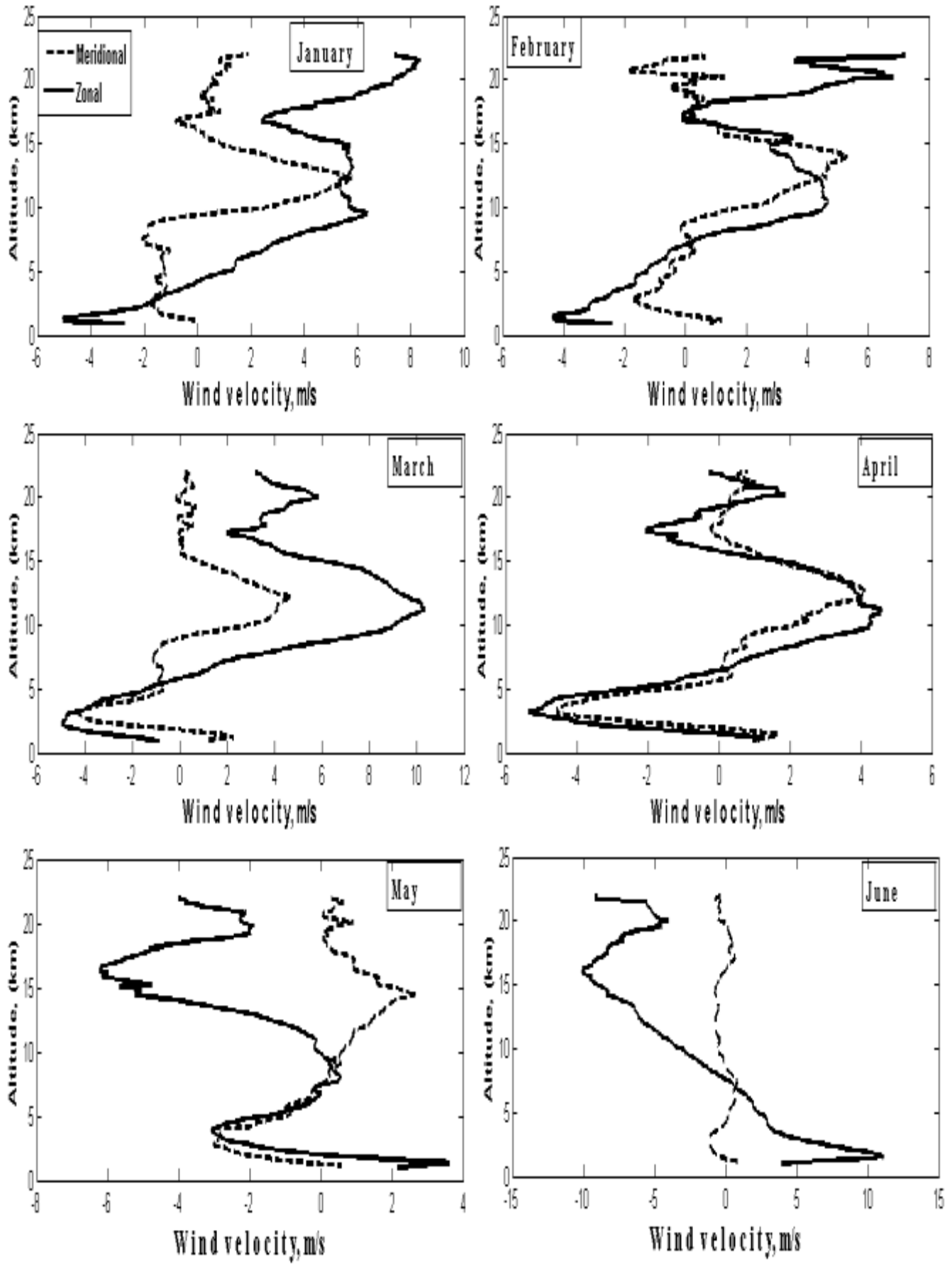

Fig 1: Mean Zonal wind (solid line) and Meridional wind (dashed line) at Bangalore from 2009 to 2017 for the months January, February, March April, May and June.

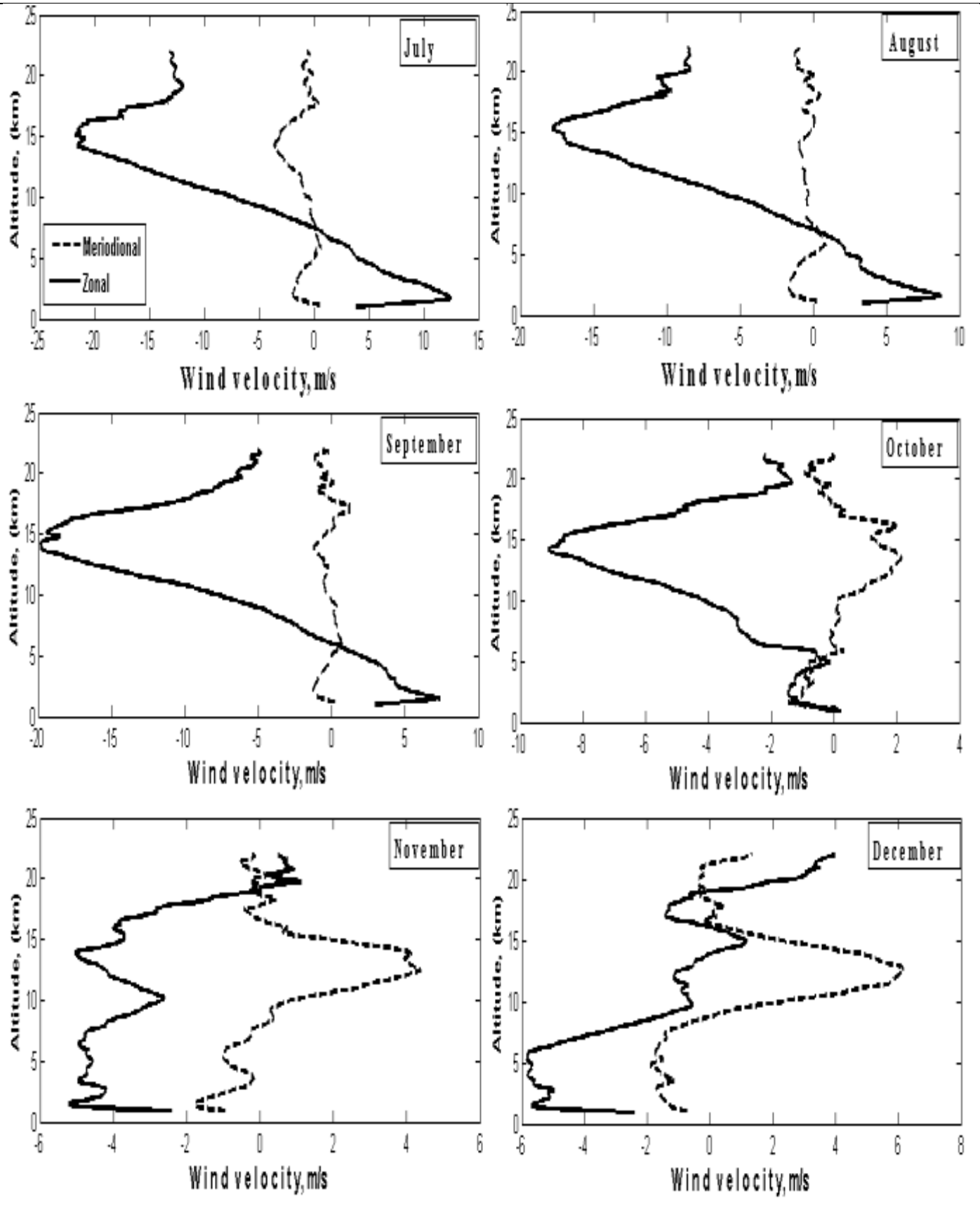

Fig 2: Mean Zonal wind (solid line) and Meridional wind (dashed line) at Bangalore from 2009 to 2017 for the months July, August, September, October, November and December..

3.2) Mean Temperatures over Bangalore for the years 2009 to 2017

Mean Temperature: It is observed that for the months November, December, January and February the surface temperature is below 20 deg Celsius. But from March to October the surface temperature above 20 deg Celsius. The tropopause height reaches to 17km approximately for the months. The temperature at the tropopause reaches -78 to -79 deg Celsius except for the month of May where the tropopause temperature is -80 deg Celsius. Mean temperature profiles of Bangalore from 2009 to 2017 were plotted and shown in figure 3 and 4.

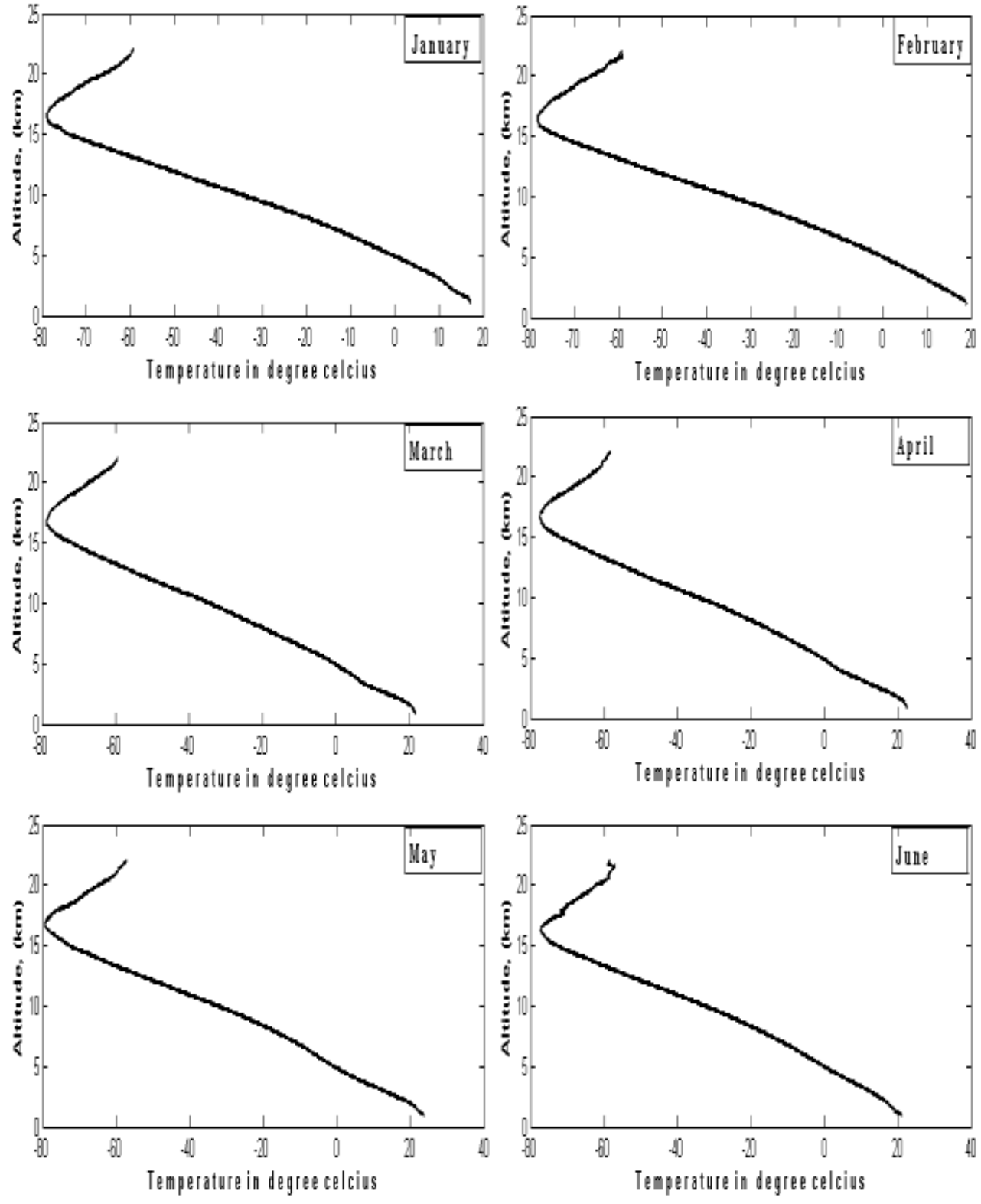

Fig3: Mean temperature over Bangalore for the months January, February, March, April, May, and June.

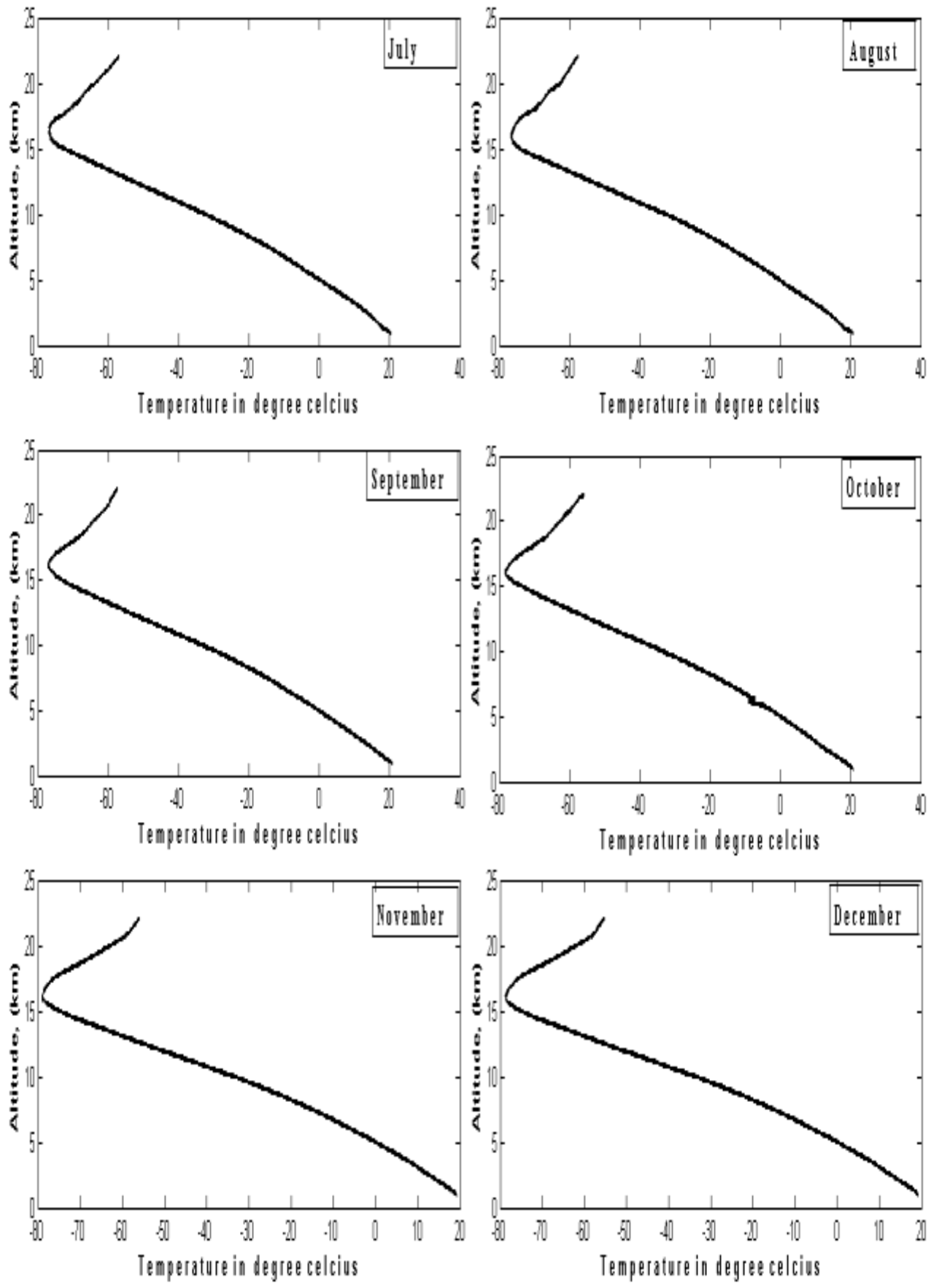

Fig4: Mean temperature over Bangalore for the months July, August September, October, November and December.

3.3) Mean Relative Humidity over Bangalore for the years 2009 to 2017

Relative Humidity: With the increase in altitude the relative humidity decreases steeply from 80 to 20 g/kg for the months November, December, January and February and remains 20 g/kg up to 15 km above the surface. For the months March, April, May, June, July, August, September and October, the relative humidity decreases approximately linearly and reaches 10 g/kg at an altitude 15 km above the surface.

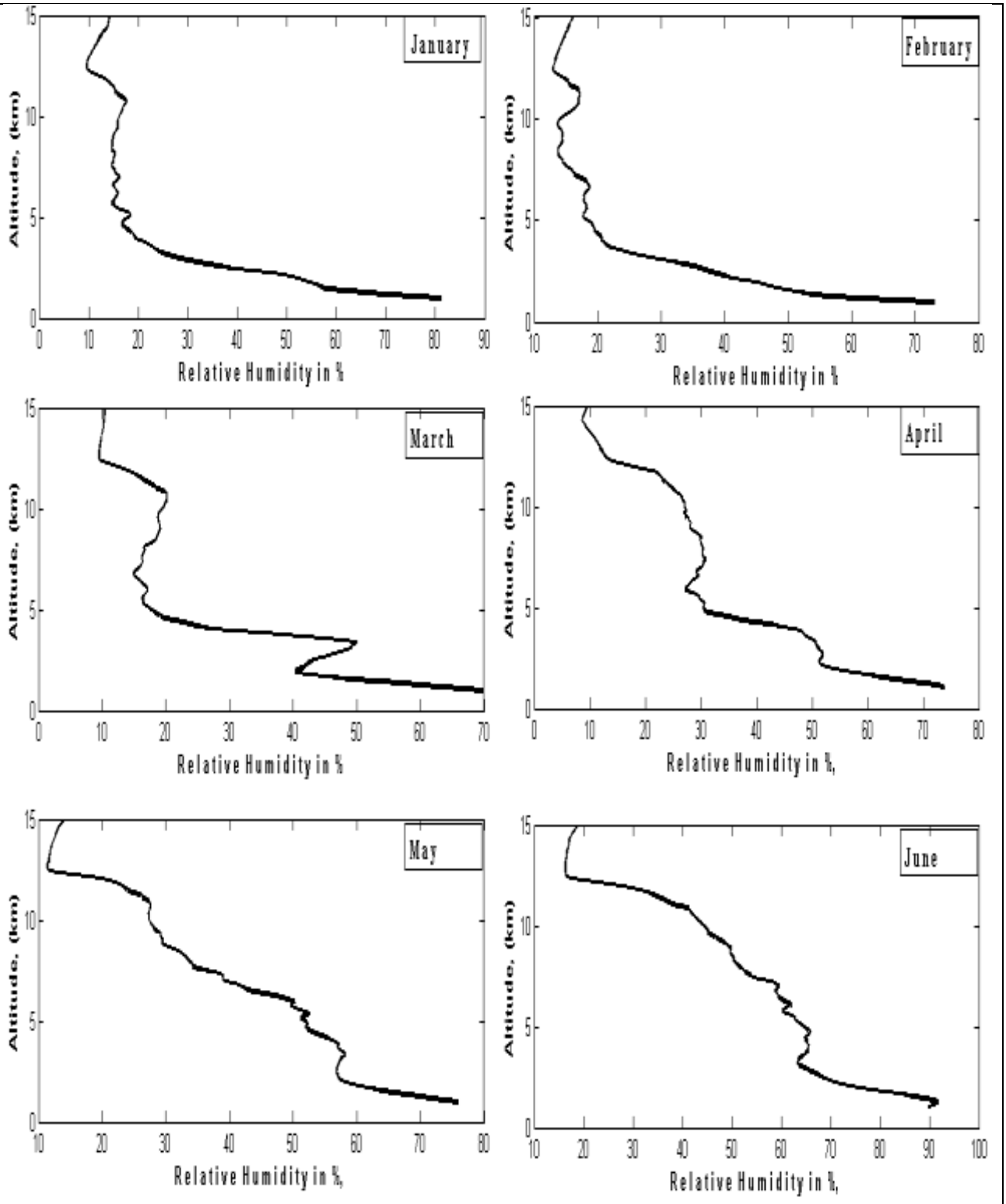

Fig5: Mean Relative Humidity over Bangalore for the months January, February, March, April, May and June.

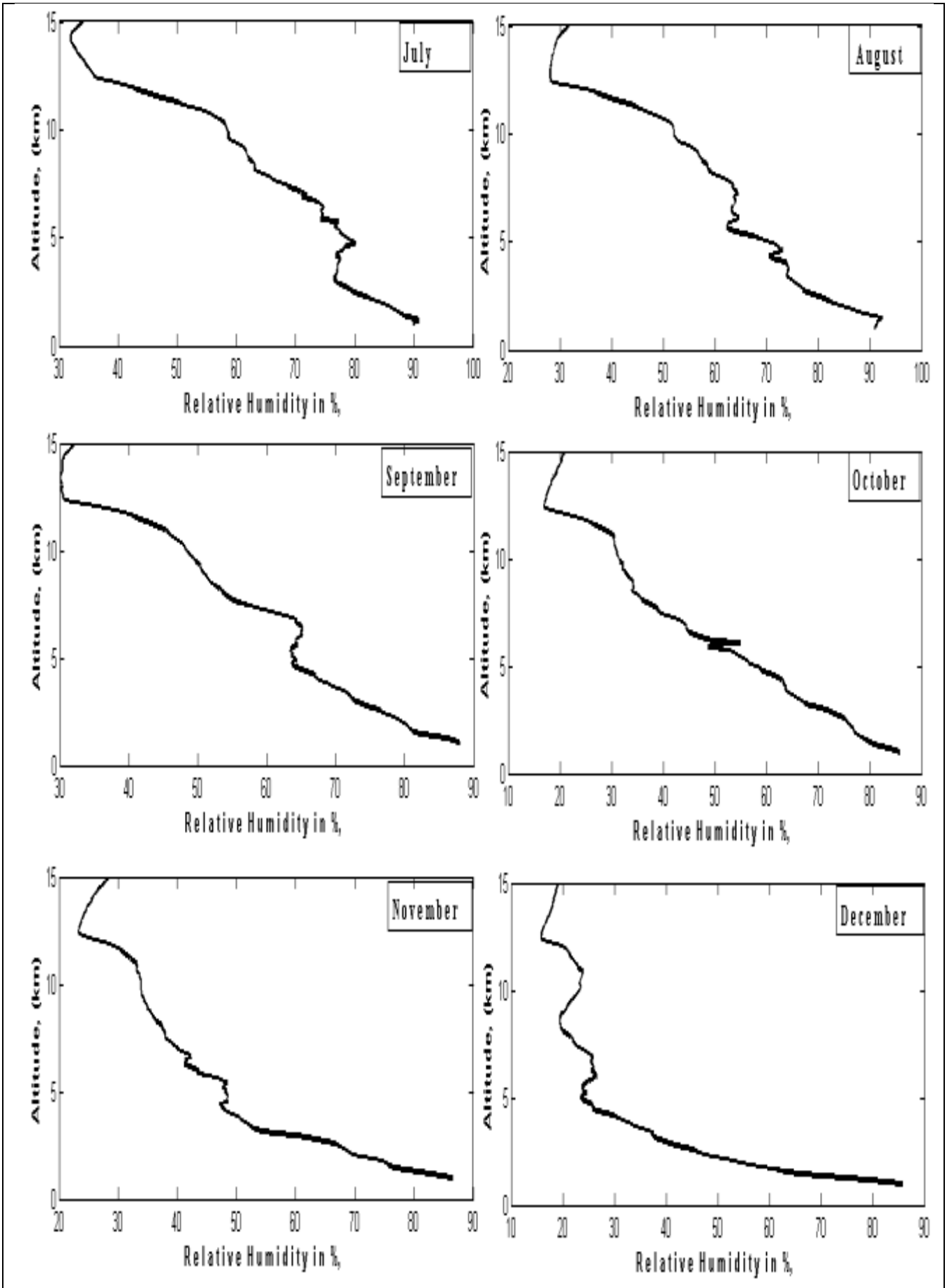

Fig6: Mean Relative Humidity over Bangalore for the months July, August., September, October, November and December.

Season wise Zonal Wind Profiles: The wind profiles have then been grouped season wise May to Aug (summer); Nov to Feb (winter); and Mar, Apr, Sep, Oct (Equinox) as shown in figure 7.

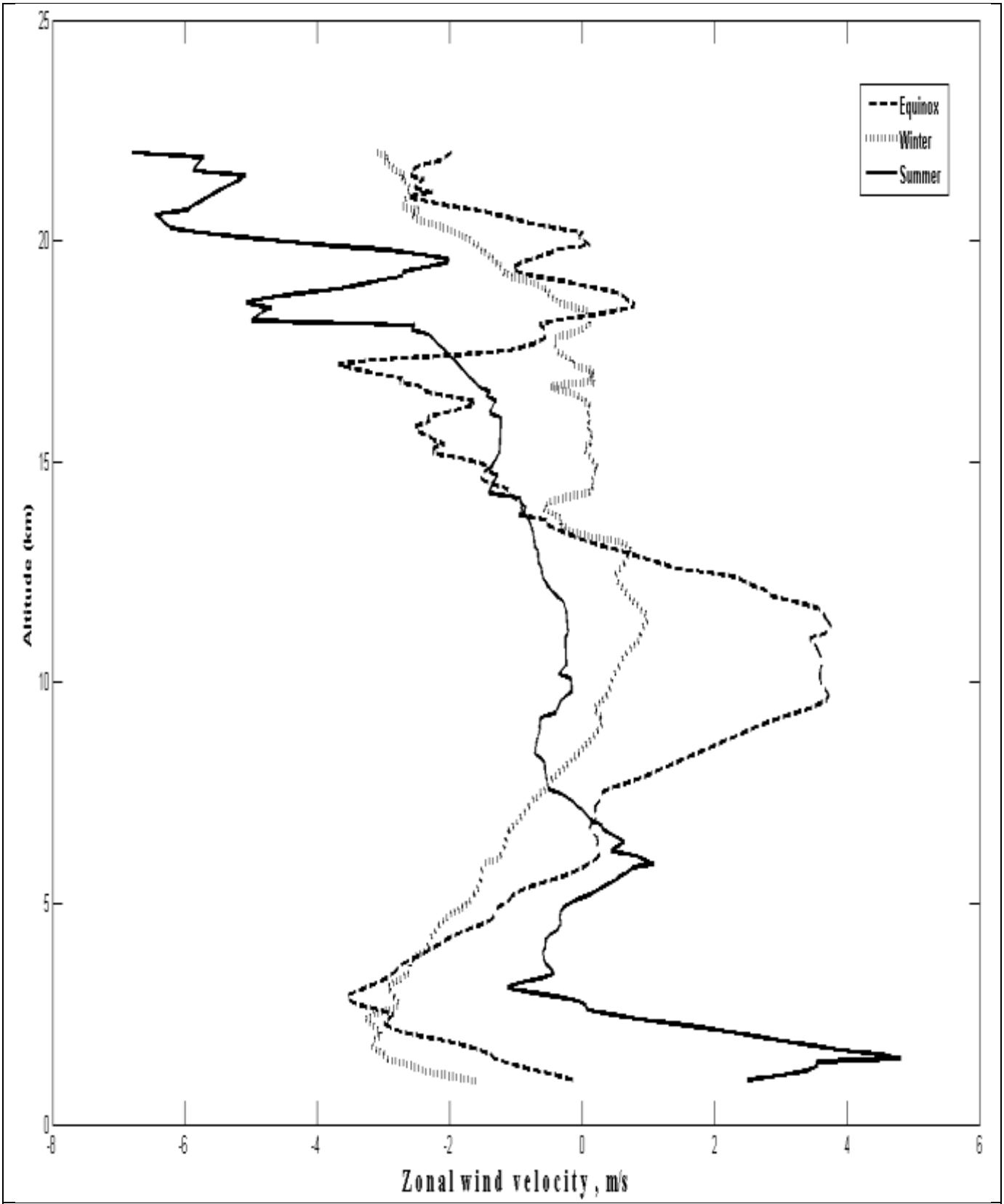

Fig7: Mean Zonal wind velocity season wise for the years 2009 to 2017 over Bangalore, India , Summer solid line, winter dotted and equinox dashed lines.

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