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A Comparative Study of Atmospheric Profiles over Central Himalayan Region by using Ground-Based Measurements and Radiosonde Observations

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ABSTRACT

In this study, we analyzed and compared the data of meteorological parameters such as pressure, temperature and relative humidity, obtained with the Microwave Radiometer Profiler (MWRP) and radiosonde. The MWRP was deployed at Aryabhatta Research Institute of Observational Sciences (ARIES) Nainital, during Ganges Valley Aerosol Experiment (GVAX) in order to carry out the vertical profiling of these meteorological parameters, for a period of 10 months (June 2011 to March 2012). Simultaneously, four radiosondes were launched in a day during the entire campaign. For MWRP, quality checked vertical profiles of the data archived for the months of February (winter) and March (spring) 2012, are analyzed on the basis of diurnal and monthly variations of height above mean sea level (AMSL) from 2 km to 12 km. The analysis showed that the same pressure variation for both the observations during February and March 2012. However, significant differences in the variation of temperature and relative humidity were observed. For the mentioned period, MWRP observations of pressure and temperature showed relatively lower values as compared to radiosonde on going above from 2 to 12 km. The correlation between MWRP and radiosonde observations have been calculated for the above-mentioned parameters. A strong and significant correlation (0.90 to 0.99) for temperature and pressure were observed between MWRP and radiosonde observations, however, the insignificant correlation has been found in the case of relative humidity.

***Keywords*:** MWRP, radiosonde and meteorological parameters, Radiosonde Observations

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1. INTRODUCTION

The meteorological parameters play a key role in enhancing the knowledge of atmospheric dynamics. The data of these parameters, such as, pressure, temperature, rainfall, relative humidity, water vapor, wind speed, and wind direction profiles are more useful to understand the atmospheric phenomena related to weather nowcasting, forecasting models, radiative transfer theory, building energy consumption, ground-based evolution and cloud-aerosols interaction, etc. (Turner et al., 2007a; Comisky et al., 2009; Bhandari et al., 2012; Dalong et al., 2017, Negi et al., 2018). The meteorological parameters affect the number density of aerosols and are also responsible for the growth of aerosols near the earth surface (Singh et al., 2000; Tiwari et al., 2015). A number of techniques such as radiosonde, MWRP, satellites, Automatic Weather Station (AWS), etc. are available for measuring these parameters from ground to upper atmosphere. Radiosondes are the standard technique for profiling of meteorological parameters with an intrinsic error of about 0.5 K in temperature and 10% in relative humidity measurements (Pratt, 1985; Miloshevich et al., 2006; Candlish et al., 2012). Different types of radiosondes (Vaisala RS80, Japanese RS80, RS12/15, and RS18/21, etc.) are being utilized to measure these parameters throughout the world since 1960, on the basis of their potentials (Luers and Eskridge, 1997). Assessment of humidity and temperature data, as measured by radiosonde are beneficial for the prediction of strong condensation trails phenomena, now casting of thunderstorm and rain (Radel and Shine 2007; Lee 2007; Chan 2009). Additionally, the radiosonde observations data are widely used in the estimation of various thermodynamic parameters and stability indices. The radiosonde measurements are also reported to characterize and compare with co-located instruments all over the world (Miloshevich et al., 2009; Rowe et al., 2008; Kottayil et al., 2011; Ratnam et al., 2012; and Wang et al., 2013). It has been observed that the combination of multiple instruments, give better results of atmospheric properties rather than a single instrument (Stonkov 1998; Bianco et al., 2005). Therefore, for the study of profiles of atmospheric parameters (pressure, temperature, and humidity), it is essentially required that the multiple instruments should provide better agreement with each other, at least with admissible or expected error.

Several studies have been made to compare the radiosonde and MWR measurements. Recently Xu et al. (2015) compared profiles of temperature, relative humidity, and water vapor density measured by radiosonde and MWR over Wuhan, China region. In the lower atmosphere and in cloudy conditions, better agreement in temperature profiles has been reported from both the instruments. A comprehensive study based on the importance of the MWR profiles in nowcasting of intense convective weather was discussed by Chan (2009) during a field experiment over Hong Kong in 2004. Ratnam et al. (2012) and Madhulatha et al. (2013) reported a comparative study between MWR and radiosonde observations over Gadanki, a tropical region of India during the year 2011. On the basis of their study, they concluded that both the measurements are comparable within the limit so that the thermodynamic parameters derived by each instrument can be utilized to model for now casting and forecasting at least two hours prior to the episode of thunderstorms. Precipitable water vapor was observed from radiosonde and MWR in northern Oklahoma from 1994 to 2000 and radiosonde observations showed 5 % dry bias as compared to MWR (Turner et al., 2003).

Based on recent year's studies, a number of statistical approaches have been used to improve the prediction models for thunderstorm and lightning (Lambert et al., 2005; Shafer and Fuelberg 2006). In a study by Liljegren et al. (2005) a statistical method was used to the estimation of liquid water path and precipitable water vapor by using MWRP brightness temperature observations. For the accuracy of ground-based observations and upper atmospheric observations, a number of field studies have been done successfully all over the world and experiments showed encouraging results of atmospheric characteristics (Neill and Hsu 1998; Guldner and Spankuch 2001; Ware et al., 2003; Westwater et al., 2003; Cimini et al., 2002; Cimini et al., 2003). All these reported field experiments have been conducted by the United States of America, Department of Energy's under Atmospheric Radiation Measurement (ARM) program (Cadeddu et al., 2013). In the continuation of above-mentioned experiments under ARM program, climatic observation station, for the study of aerosols and meteorological parameters, has been set up at ARIES Nainital, India from June 2011 to March 2012. It was the first ARM mobile facility observations in India and this experiment named as RAWEX GVAX field campaign, carried out for the measurements of aerosols, meteorological profiling and cloud properties (Dumka et al., 2015; Naja et al., 2016; Singh et al., 2016 (a,b)).

Due to complex topography and difficult terrain of the Himalayan region, it is quite difficult to conduct the regular ground-based measurements at very fine spatial and temporal resolutions. Hence, this campaign proved to be fruitful as far as the observations over this data void region are concerned. MWRP was one of the most valuable and sophisticated instruments, operated during the campaign, which could provide the information about atmospheric parameters up to a height about 10 km from ground level. In general, the atmospheric study has been done at diurnal, monthly and seasonal scales and having their own significance. In this paper, an attempt is made to study data obtained with MWRP and radiosonde observations during February and March 2012. Each month representing winter and spring, respectively. The months are chosen such that the influence of the transition of one season to others may also be studied. A detailed comparison for vertical profiles of parameters also discussed at different hours during a day between these two instruments for the same period of study.

2. INSTRUMENTS AND SITE DESCRIPTION

In the present investigation, we have collected the data of meteorological parameters by two instruments namely, MWRP & radiosonde, at ARIES Nainital, Uttarakhand, during GVAX. A sitemap is depicted below in Figure. 1. As clear from Figure 1, ARIES is situated at Manora peak and lies between the 29.4° N latitude and 79.5° E longitudes with an altitude of ~1.951 km AMSL (Sagar et al., 2014). ARIES is located at a high altitude in the Central Himalayas and 9 km away from urban city Nainital. According to tropospheric classification, 0-3 is considered as a boundary layer, 3-6 km as a lower troposphere and 6-12 km as a middle troposphere. (Naja et al., 2016). Therefore, 2-5 km, 5-8 km and 8-14 km are taken as the boundary layer, lower troposphere, and middle troposphere, respectively for ARIES, Nainital. The temperature ranges from 5 ℃ to 20 ℃ in winter whereas, in summer it varies from 15 ℃ to 35 ℃. Summer is quite mild and moderates followed by a good rainfall during monsoon. MWRP, a passive instrument, measures a number of parameters such as pressure, temperature, humidity, brightness temperature, water vapour density, and liquid water content during clear and cloudy conditions (Solheim et al., 1998). MWRP was installed at ARIES during GVAX for ten months (June 2011-March 2012). It records data continuously for 24 hours with a step size of 1 minute (Cimini et al., 2015). Moreover, it has the flexibility to record data vertically from ground level to 10 km, in all weather conditions.

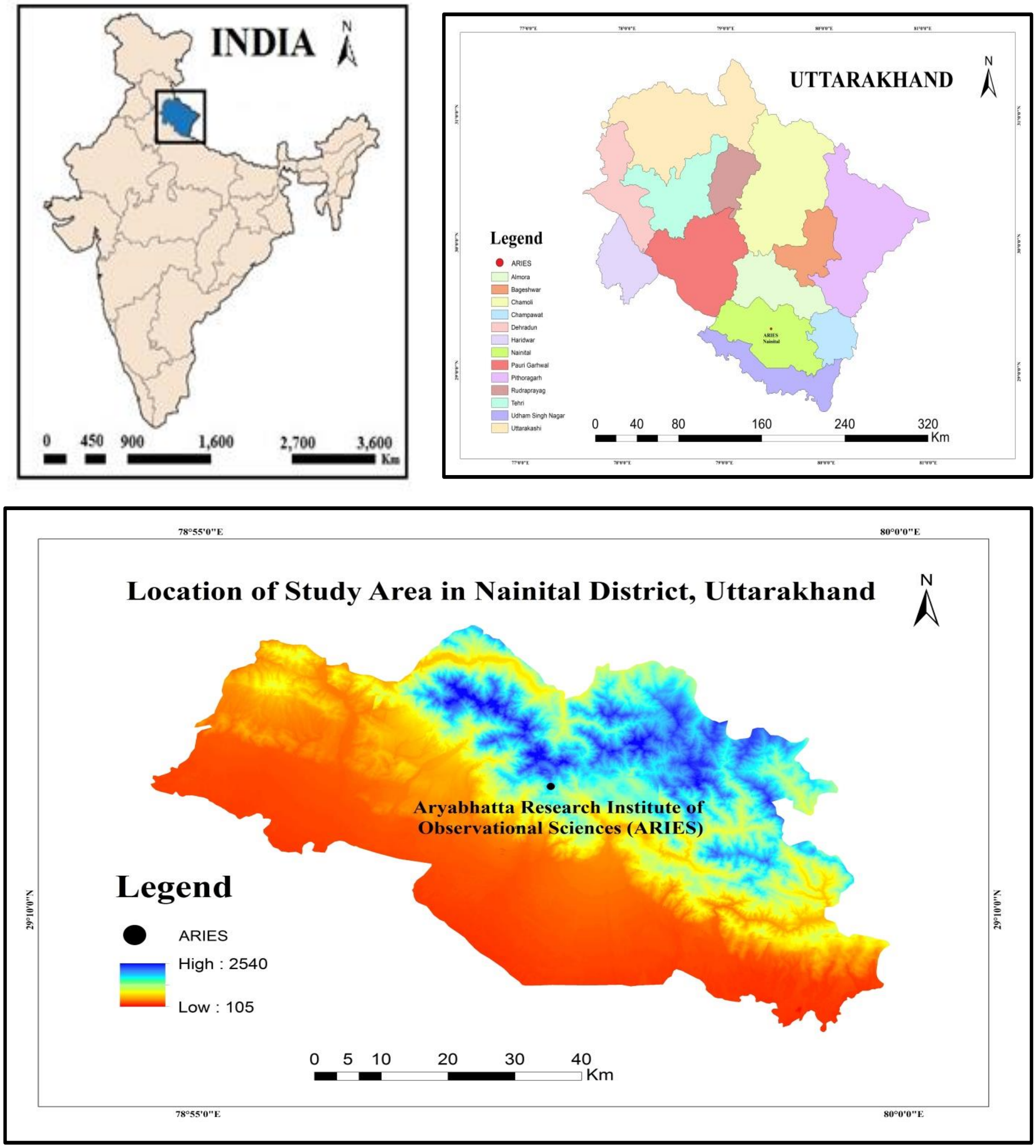

Figure 1. Study site map of ARIES Nainital, Uttarakhand, India.

In order to perform a comparative study of MWRP observations for February and March 2012, radiosonde data was also collected. In general, India meteorological department (IMD) observes meteorological parameters information by launching of radiosonde twice a day in morning and evening hours. India has a total of 39 stations of balloon-born observation located at different parts, however, no such station is present in Uttarakhand. Consequently, the radiosonde was also included as a part of this campaign and four balloons carrying radiosonde were launched each day to observe meteorological parameters as pressure, temperature, relative humidity, and wind during this study. These balloons were launched at 0000, 0600, 1200 and 1800 GMT every day corresponding to the local times of 0530 (early morning), 1130 (noon time), 1730 (evening) and 2330 (midnight) in IST. For scientific research, the data are checked regularly for storage and made available at the ARM site (www.arm.gov) freely. In this study, we have calculated the average of each day of every month and analyze the data using MATLAB and Origin to show the monthly variations of selected parameters. For this study, the radiosondes data were selected up to 12 km from 1.951 km which is the ground level for the study site. The MWRP observations data of meteorological parameters were averaged for about 30 minutes period with respect to launching times of radiosondes in each day of months. To evaluate the accuracy and performance of the observations, the most popular statistical parameters are Mean Bias Error (MBE), Root Mean Square Error (RMSE) and Mean Percentage Error (MPE) are calculated by using the following set of equations (Zeroual et al., 1996):

$$MBE = \sum\left(\frac{X_{Rs} - X_{Mw}}{n}\right) \tag{1}$$

$$RMSE = \sqrt{\sum\left(\frac{X_{Rs} - X_{Mw}}{n}\right)} \tag{2}$$

$$MPE = \frac{\sum\left(\frac{X_{Rs} - X_{Mw}}{X_{Mw}}\right)}{n} \times 100, \tag{3}$$

where $\boldsymbol{X_{Mw}}$ and $\boldsymbol{X_{Rs}}$ are the MWRP and Radiosonde mean values, respectively and n is the number of observations.

3. RESULTS AND DISCUSSION

Comparative studies of pressure, temperature, and relative humidity were carried out at ARIES, Nainital, (29.4º N, 79.5º E; 1.951 km AMSL) Kumaon region of central Himalaya during February and March 2012. A total data set of MWRP and radiosonde observations are subjected to diurnal, monthly mean analysis and correlation coefficient is calculated, as shown in the following segment.

3. 1. Diurnal variations

A comparison of diurnal variation of pressure, temperature, and relative humidity observed from MWRP and radiosonde over ARIES, Nainital during 28 February-01 March 2012 is depicted in Figure 2. The radiosonde observations data were selected only up to an altitude of 10 km from ground level. Additionally, for this comparative study, MWRP data were averaged for half an hour corresponding to data measured by radiosondes at the interval of six hours (launched at 0000, 0600, 1200 and 1800 GMT) during a day.

The maximum pressure and temperature are found near the ground level and both decrease with height, which generally happens, as shown in Figure 2 (a-d). In the case of relative humidity, both observations show high humidity near earth surface i.e. between 2 km to 3 km AMSL as mentioned as in Figure 2(e) for MWRP and Figure 2(f) for radiosonde.

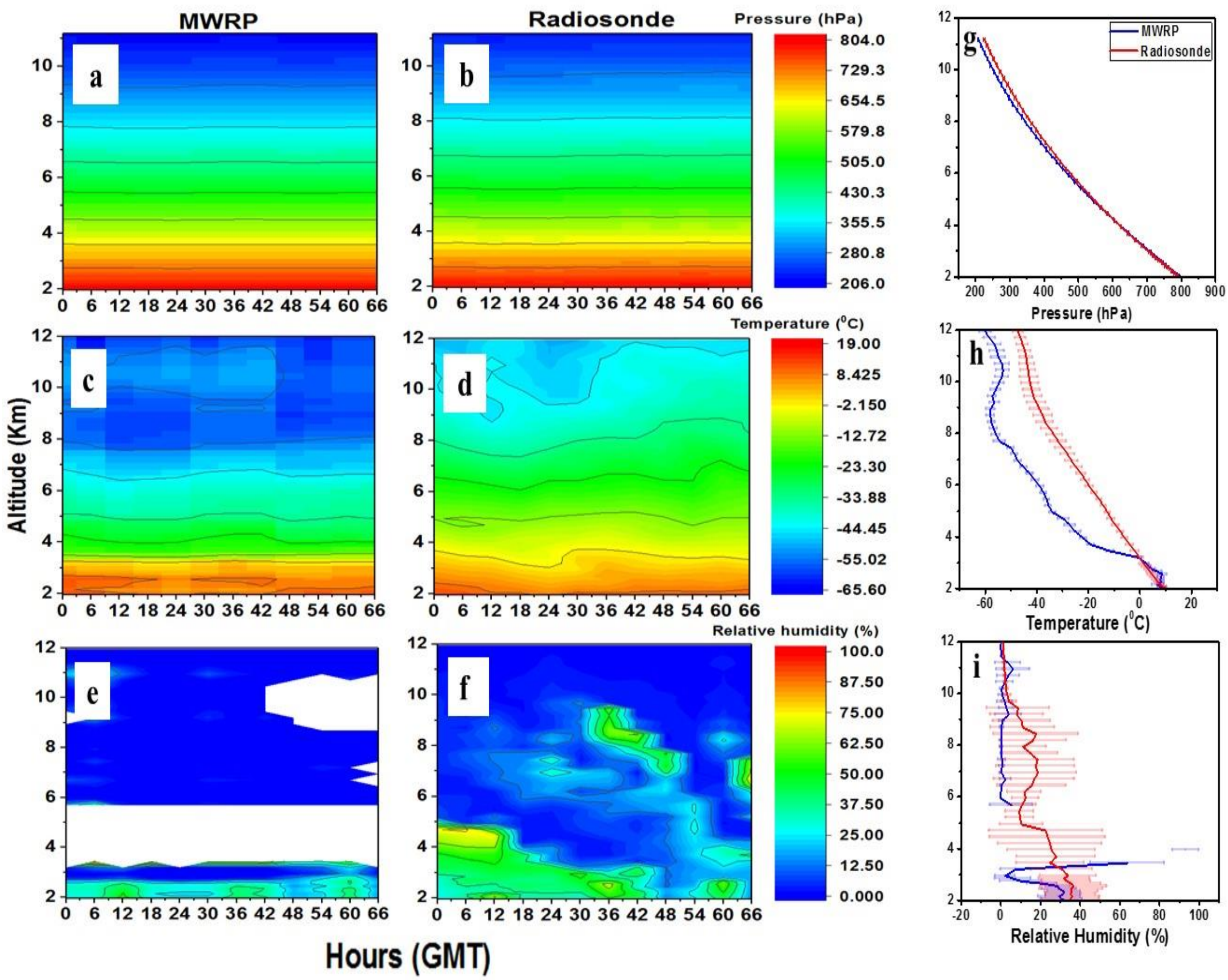

Figure 2. Contour maps showing a diurnal variation of pressure, temperature, and relative humidity, as observed by MWRP (a, c, e) and Radiosonde (b, d, f). Mean profiles of pressure (g), temperature (h) and relative humidity (i) along-with standard deviation, during 28 February (0000 GMT) to 01 March 2012 (1800 GMT).

Figure. 2 also shows the mean profiles with standard deviation for pressure (Figure 2g), temperature (Figure 2h) and relative humidity (Figure 2i), as observed from both the instruments during the above-mentioned period. It is clear from Figure 2g the pressure variation was the same for both the observations, however, the pressure observed from MWRP was slightly higher around 1 to 4 hPa than radiosonde pressure up to 4 km and MWRP shows lower pressure values above 4 km. Figure 2h shows that the average temperature from MWRP was lower about 1 to 2 ℃ near the earth surface and 10 to 20 ℃ above 3 km, as compared to radiosonde measurements. As clear from Figure 2 (h), the temperature shows warm bias in MWRP between 2 and 3 km whereas, shows cold bias above 3 km. In the case of relative humidity (Figure 2i), MWRP mostly shows dry bias from 2 km to 12 km except from 3 to 4 km and at around 11 km. MWRP shows slightly higher values or wet bias with respect to radiosonde around 11 km. The observed variations are in agreement with the previous reports, in which the best matching of meteorological parameters, measured by two different co-located instruments, are found near the earth surface, but reduces at higher altitude (Cimini et al., 2006; Xu et al., 2015).

3. 2. Vertical profiles comparison at different times

The vertical profiles at different times provide detailed information about temperature and relative humidity variations during study months. For this, the difference between MWRP and radiosonde data corresponding to each day was taken and averaged over both the months at a different time i.e. 0000, 0600, 1200 and 1800 GMT. The biases in temperature and relative humidity as a function of altitude are shown in Figure 3.

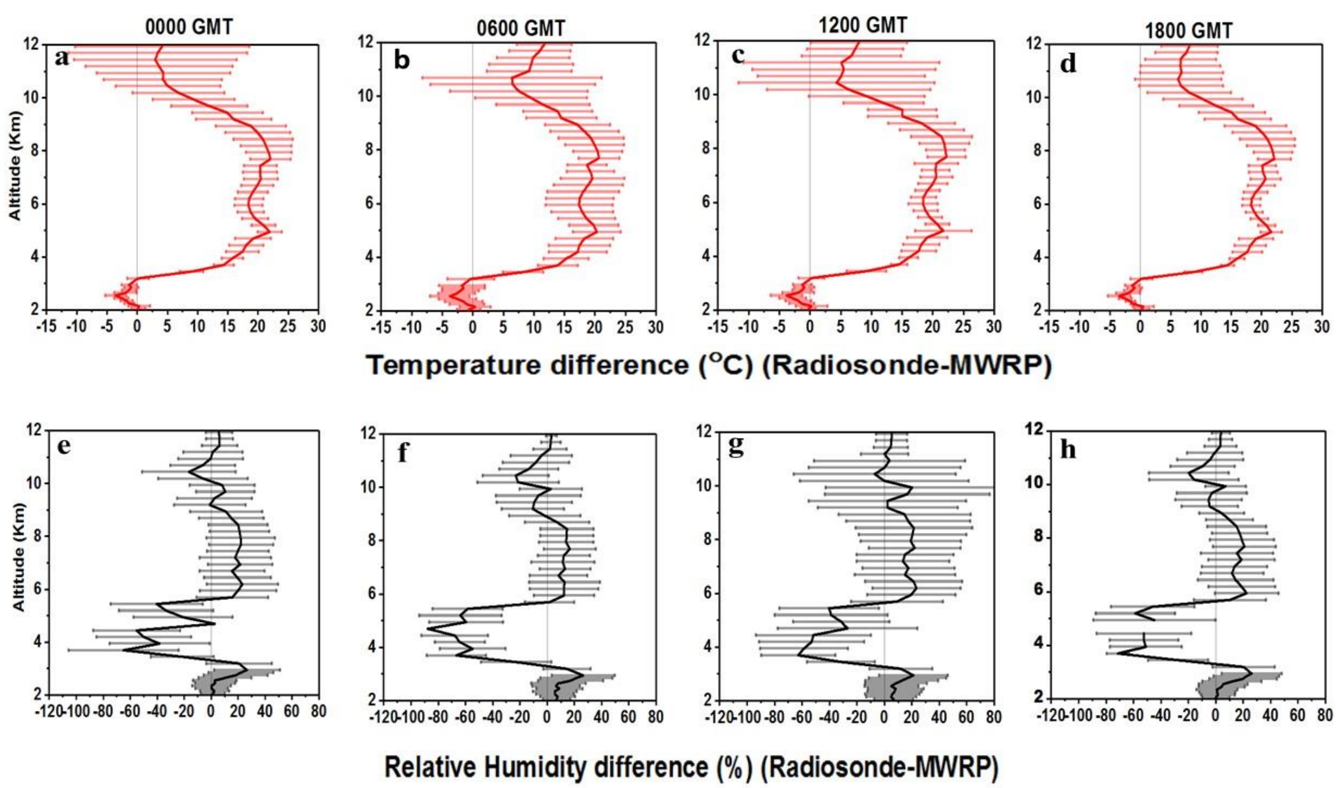

Figure 3. Vertical profiles observed from MWRP and radiosonde observations of temperature (a, b, c and d) and relative humidity (e, f, g, and h) for 0000, 0600, 1200 and 1800 GMT respectively.

A small warm bias of less than 1 °C was observed around 0000, 0600, 1800 GMT and ~ 4 °C was observed around 1200 GMT in MWRP temperature near the ground, as shown in Figure 3 (a-d). The warm bias changes to cold bias around 3 km height and above that, cold bias with a maximum value of ~20 °C was recorded in MWRP temperature in all the mentioned time durations. Noteworthy, the mean difference in temperature values between the used instruments also decreases at 10 km, however, the maximum standard deviation of 13-15 °C in the temperature differences was noticed. Interestingly, a minimum standard deviation was found around midnight.

Figure 3 (e-h) shows the relative humidity differences between MWRP and radiosonde at 0000, 0600, 1200 and 1800 GMT over ARIES, Nainital. The relative humidity observed from MWRP shows wet bias around 3-6 km and 11 km at all timings. Noticed that the biases values are minimum near the ground and upper atmosphere. It is also interesting and clear from the figure and table that, maximum biases with large standard deviations were observed around 1200 GMT. The MBE, RMSE, and MPE at different times between MWRP and radiosonde observations at 0000, 0600, 1200 and 1800 GMT, near earth surface, are presented in the tabular form (Table 1).

Table 1. Statistical parameters at different time between MWRP and Radiosonde observations near the earth surface.

Time (GMT)		Near earth surface (~2 km)	
		Temperature (°C)	**Relative Humidity (%)**
0000	MBE	0.23	0.79
	RMSE	0.48	0.89
	MPE (%)	2.19	2.39
0600	MBE	-0.59	7.93
	RMSE	0.77	2.82
	MPE (%)	-5.29	21.48
1200	MBE	4.66	5.92
	RMSE	2.16	2.43
	MPE (%)	43.11	12.13
1800	MBE	0.32	-0.23
	RMSE	0.56	0.47
	MPE (%)	2.94	-0.63

3. 3. Monthly variations

A comparative study between MWRP and radiosonde data for two months February and March has been carried out. As per IMD classification, February is considered as the last month of winter and March is referred to as the first month of spring, thereby, called as early spring (Naja et al. 2016).

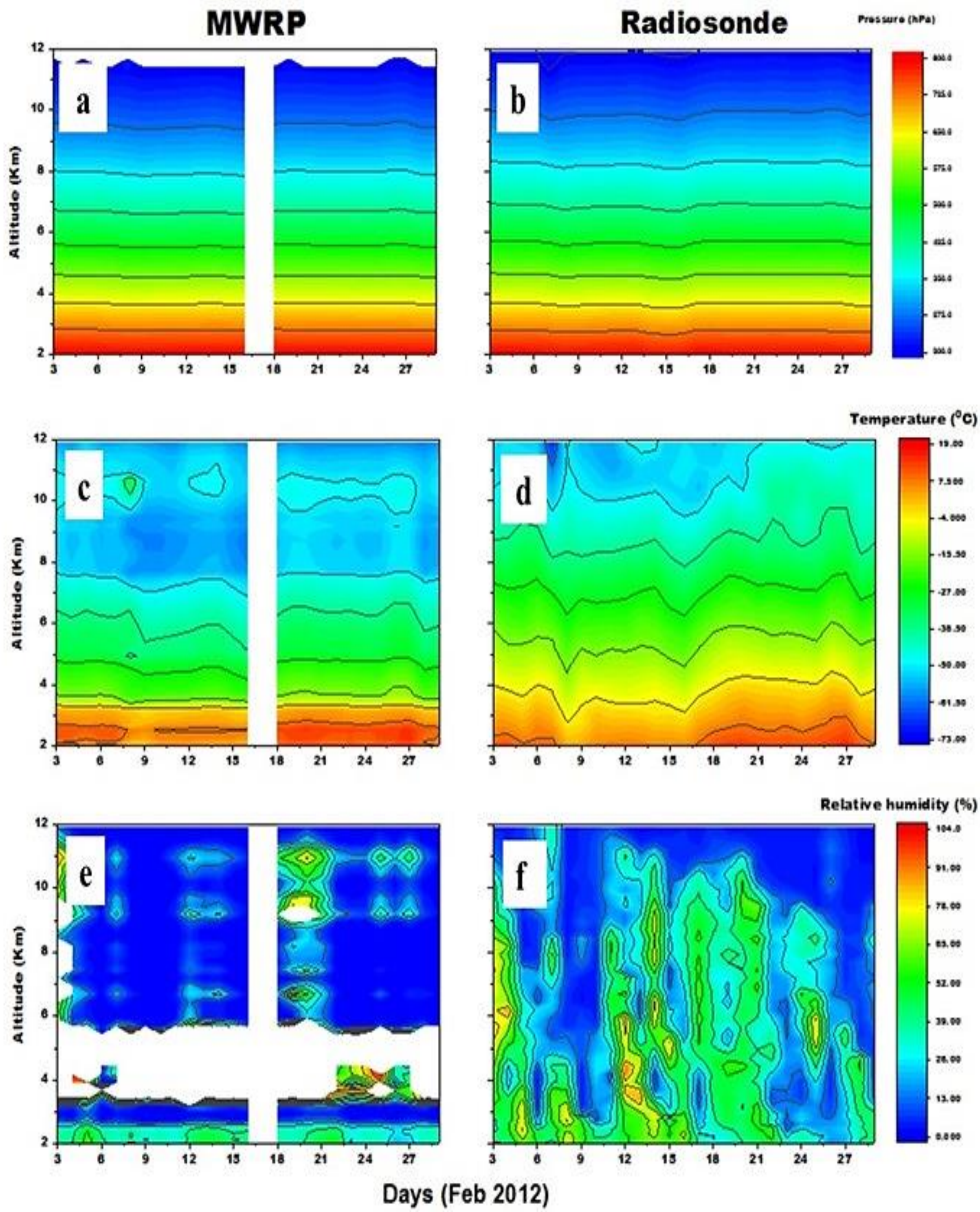

Figure 4. Contour maps of the pressure (a), temperature (c) and relative humidity (e) as observed by MWRP and contour maps of the pressure (b), temperature (d) and relative humidity (f) as observed by radiosonde during February 2012.

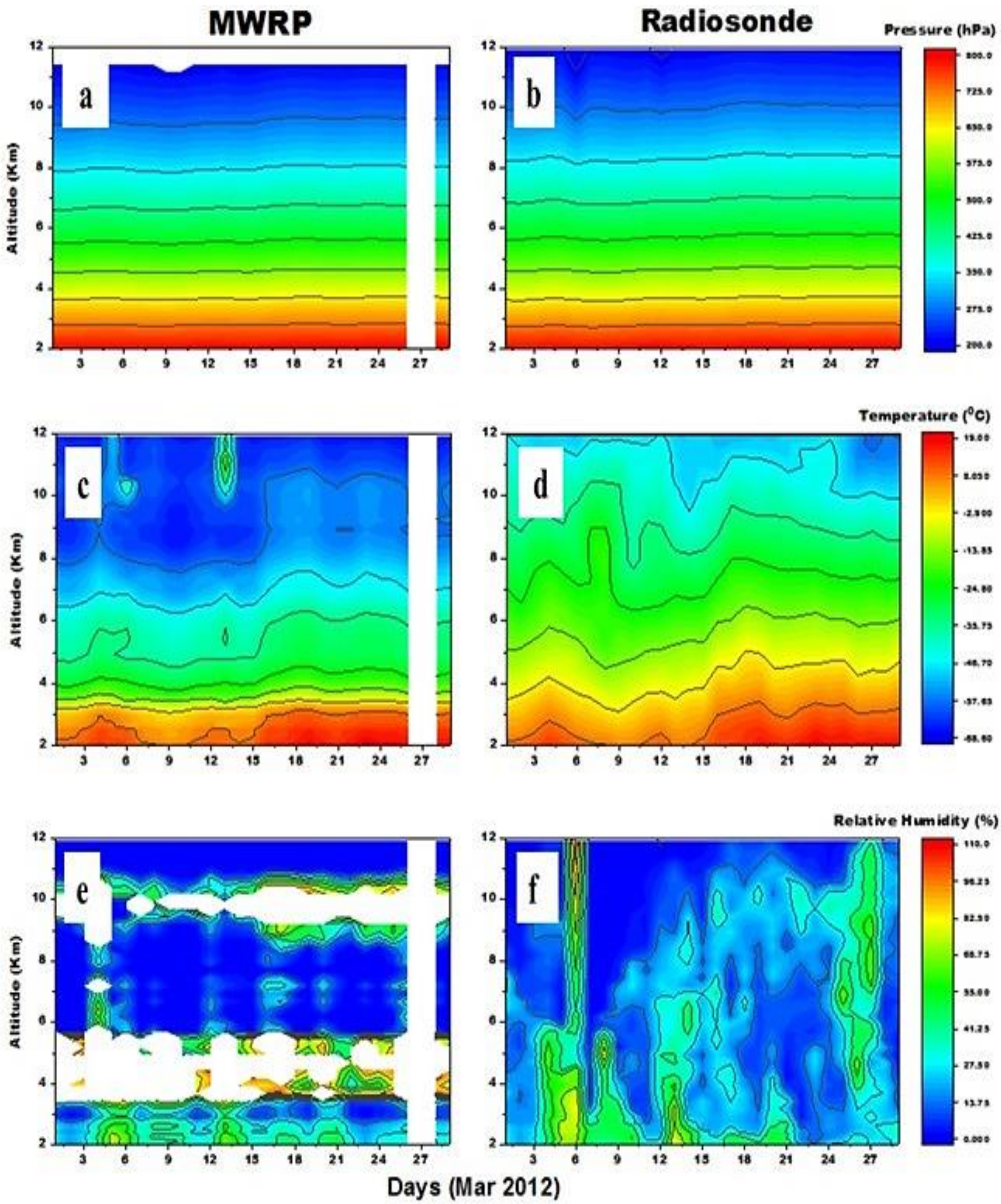

Figure 5. Contour maps of the pressure (a), temperature (c) and relative humidity (e), as observed by MWRP and contour maps of the pressure (b), temperature (d) and relative humidity (f), as observed by radiosonde for March 2012.

Figure 4 shows the daily variations of pressure (Figure 4a), temperature (Figure 4c) and relative humidity (Figure 4e) with altitude corresponding to each day of February, as observed from MWRP. For comparison, pressure, temperature and relative humidity, as observed from radiosonde for the same month, are also depicted in Figure 4(b), 4(d), and 4(e) respectively. Similar kind of contour maps, showing a daily variation of the meteorological parameter with height for each day of March, is also shown in Figure 5.

From the contour maps of MWRP and radiosonde, the mean profiles of pressure, temperature and relative humidity for corresponding to February and March, as a function of height, are shown in Figure 6 and 7, respectively.

The calculated difference along with standard deviation and RMSE in the corresponding meteorological parameter values, as measured by MWRP and radiosonde, is also shown in Figure 6 and 7 for February and March, respectively. It is obvious from the above plots that, in both months pressure decreases exponentially with height and follow barometric law (Jacob, 1999). The maximum pressure (~800 hPa) was found near the earth's surface and a minimum value of pressure (~200 hPa) was recorded at 12 km AMSL during all days of study months.

The average MWRP pressure was slightly higher (1 to 3 hPa) than radiosonde pressure up to 3 km altitude and above 3 km to 12 km MWRP pressure show lower values (5 to 20 hPa) than radiosonde. It is important to mention that the difference in pressure data measured by MWRP and radiosonde increases with altitude up to 12 km in both months. The similar trend of increase in the value of standard deviation is observed for above-mentioned months, on moving up to the height of 12 km. The temperature also decreases with height and the maximum temperature was recorded near the ground from both observations for selected months.

The rate at which temperature decreases with altitude in the troposphere is called the environmental lapse rate and the average value of the lapse rate is 6.5 ºC per km (Fredrick and Edward 2012). At the study site, snowfall occurs during winter. Near the surface, the minimum temperature recorded by MWRP and radiosonde were 1.12 ºC and 2.22 ºC, respectively, on February 8, 2012. The maximum temperatures of 13.92 ºC and 14.77 ºC was noticed on February 27, 2012, by MWRP and radiosonde, respectively, near earth surface.

In March, the minimum temperature of 7.33 ºC from MWRP and of 6.29 ºC from radiosonde were observed on 9^{th}. Whereas, the maximum temperature of 19.39 ºC and 18.93 ºC were noticed on 23^{rd} from MWRP and radiosonde, respectively. There is a significant difference in the minimum and maximum values of temperature during February and March due to the beginning of spring in the month of March. Therefore, the weather conditions are relatively found clear in March and atmosphere receive good radiation leading to significant absorption of solar radiation by earth's surface. Consequently, a substantial increase in temperatures was noticed in the transition from winter to spring. As clear from Figure 6 and 7 that the temperature difference between two observation is about 1 ºC near the earth surface and it increases with height.

The vertical mean profiles of temperature from both observations are shown in Figure 6(d) and 7(d) for February and March, respectively. The difference with a deviation and RMSE between temperature data, as measured by MWRP and radiosonde, are also shown in Figure 6(e) & 6 (f) and 7(e) & 7(f) for February and March, respectively. MWRP temperature shows warm bias near earth surface (~100 m above ground level), whereas, shows a cold bias above 3 km, with respect to the balloon sounding. The standard deviation between two instruments increase with altitude but smaller than 5 ºC and 7 ºC for February and March, respectively.

The vertical variation of relative humidity during February and March is shown in Figure 6(g) and 7(g). In general, temperature and relative humidity are inversely proportional to each other. In our study near earth surface, we found minimum relative humidity of 20.63 % and 14.48 % on 26-27th February from MWRP and radiosonde observations, respectively. Similarly, maximum relative humidity of 56.81 % (5th February) and 74.28 % (8th February) was recorded during the first week of February from MWRP and radiosonde observations, respectively.

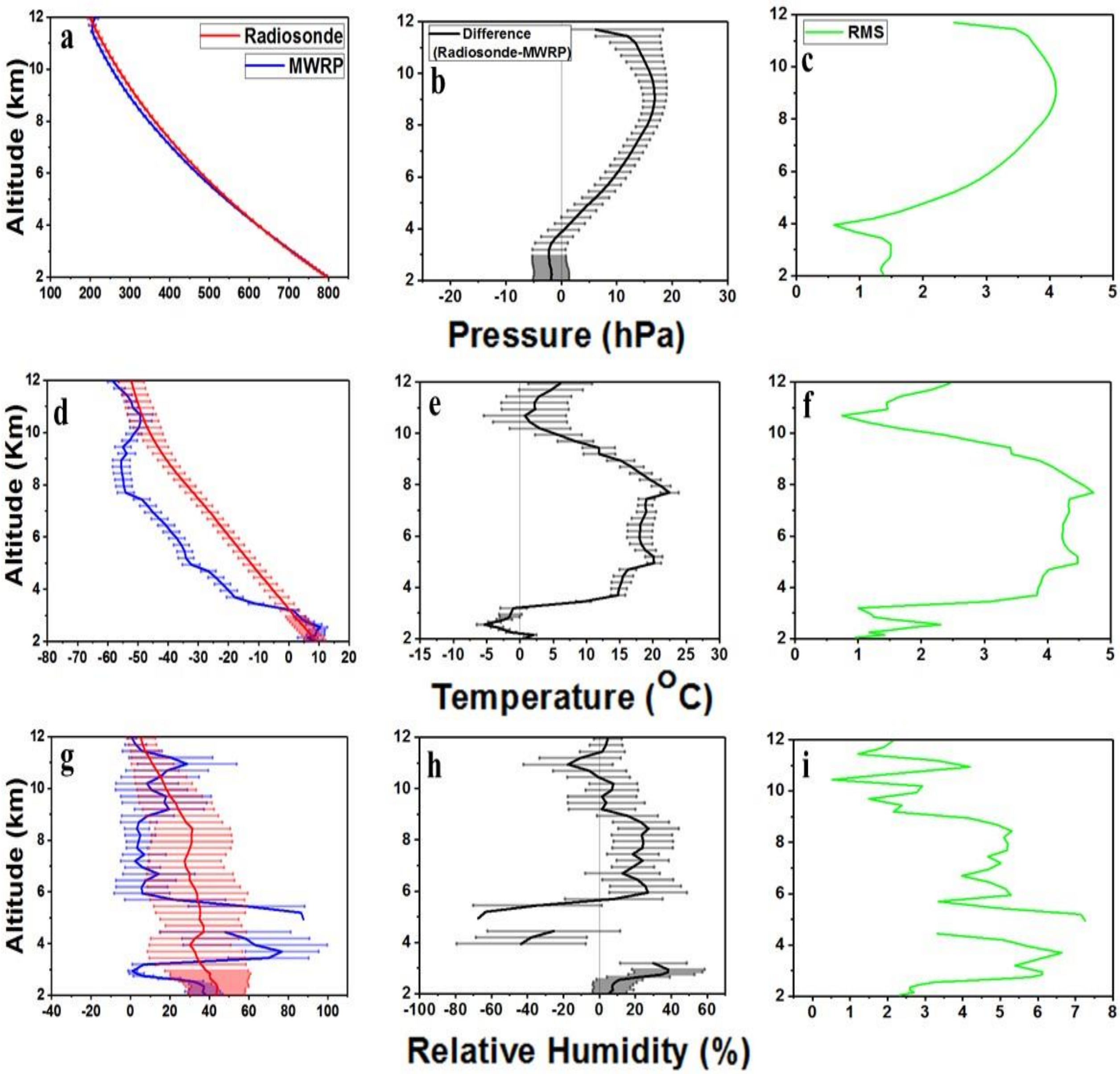

Figure 6. The mean profiles, biases with standard deviation and RMSE of the pressure (a-c), temperature (d-f) and relative humidity (g-h), as observed by MWRP and radiosonde for February.

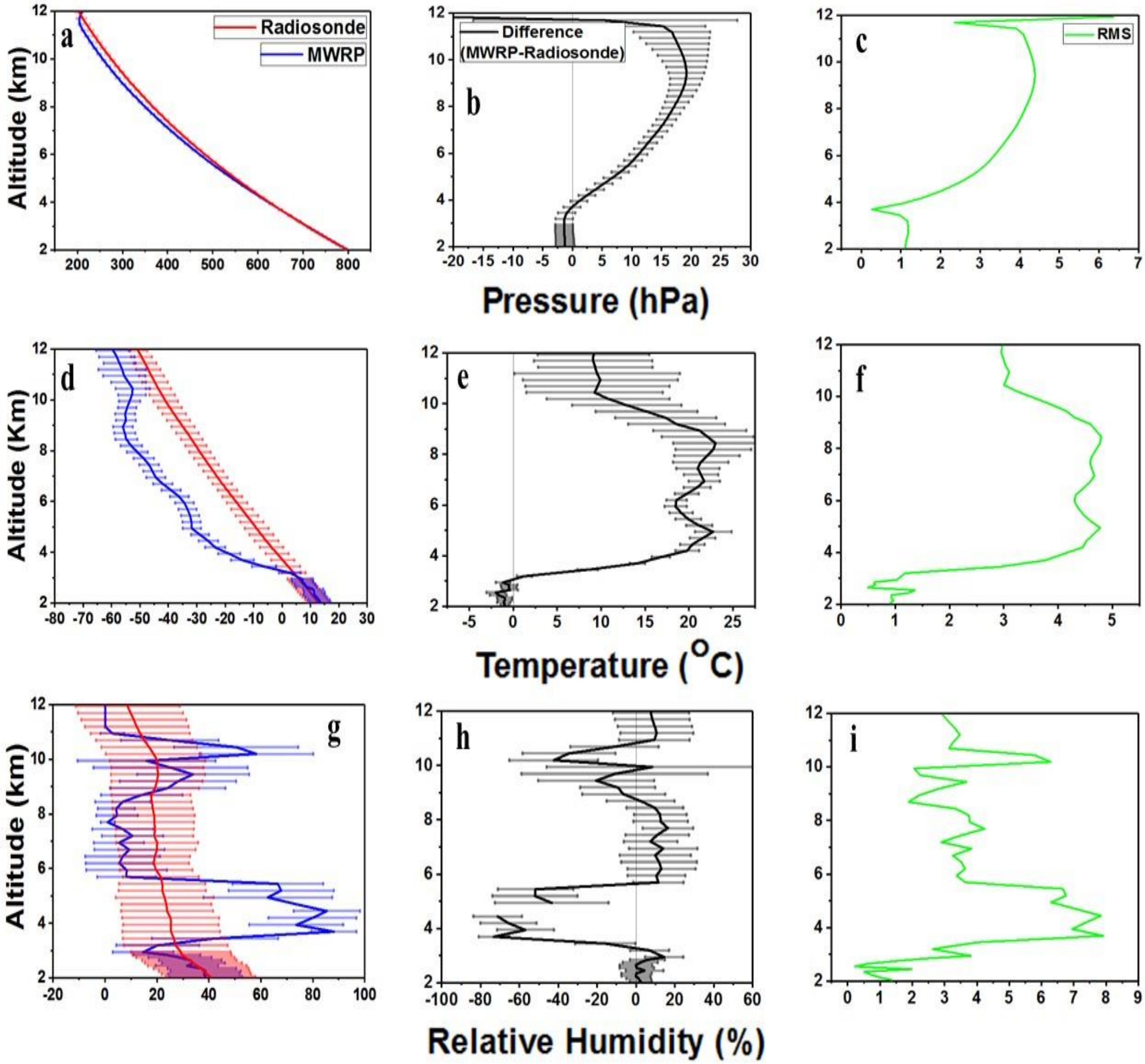

Figure 7. The mean profiles, biases with standard deviation and RMSE of the pressure (a-c), temperature (d-f) and relative humidity (g-h), as observed by MWRP and radiosonde for March.

Similarly, in March, the minimum relative humidity values of 18.17 % and 14.14 % were recorded from MWRP and radiosonde, respectively on 23rd. On the other hand, the maximum relative humidity was observed on 5th March by MWRP (75.53 %) and on 13th March from and radiosonde (80.98 %). The mentioned days are agreeing well when maximum and minimum temperatures were noticed in the months of February and March. The mean biases with standard deviation and RMSE in the relative humidity data as a function of altitude, as observed by two instruments, is also shown in Figure 6(h) & 6(i) for February and Figure 7(h) & 7(i) for March. MWRP, Relative humidity shows lower values in the altitude range of 2-3 km and again in 6-9 km. Thus, we observed that the MWRP shows dry bias with respect to radiosonde particularly in the lower and middle troposphere for both the months of study. As clear from the Figures, the humidity shows wet bias around 4 km and 11 km altitude. The minimum standard deviation in the values of relative humidity was found near the earth surface while the maximum was calculated in the middle troposphere between two observations during the study.

3. 4. The Statistical parameters (MBE, RMSE, and MPE) calculations

Table 2 shows the calculated (using Equation 1-4) statistical parameters such as MBE, RMSE, and MPE for temperature and relative humidity at altitudes 2, 5 and 10 km, representing different troposphere regime during February and March 2012, as observed from MWRP and radiosonde.

Highest mean bias temperatures 20.10 ºC and 22.83 for February and March, respectively, was observed at 5 km altitude. At the height of 10 km, the differences between both observations were positive (5.55 ºC) for February and negative (-12.75 ºC) for March.

Table 2. Statistical parameters at a different height between MWRP and Radiosonde observations.

		February 2012		March 2012	
		Temperature (ºC)	Relative Humidity (%)	Temperature (ºC)	Relative Humidity (%)
2 km	MBE	0.91	5.41	-0.82	1.86
	RMSE	0.96	2.33	0.90	1.36
	MPE (%)	11.32	14.27	-6.10	4.80
5 km	MBE	20.09	-52.77	22.83	-39.70
	RMSE	4.48	7.26	4.78	6.30
	MPE (%)	62.06	-60.18	71.91	-63.36
10 km	MBE	5.55	7.68	-12.75	-4.23
	RMSE	2.35	2.77	3.57	2.05
	MPE (%)	10.80	72.70	-23.74	-26.47

The minimum value of mean bias temperature 0.91 ºC and -0.82 ºC was noticed at 2 km. Therefore, from the table, we can say that MWRP temperature was positively (cold) biased except at 2 km and 10 km for March. In case of relative humidity, MWRP observations were positively biased at 2 km and 10 km while, negatively biased at 5 km. It is interesting to note that mean percentage errors were minimum near ground (~ 2 km) and around 12 km.

3. 5. Correlation between MWRP and radiosonde observations

The correlation analysis between the values observed by these two instruments is important for testing the reliability of data. Pearson statistical method was utilized to find out the correlation between MWRP and radiosonde observations, as shown in Figure 8 during the study period. We observed that pressure and temperature values from MWRP and radiosonde observations show good agreement with a correlation coefficient of 0.99 (Figure 8a) and 0.92 (Figure 8b), respectively. However, in the case of relative humidity, the value of correlation coefficient is 0.25 (Figure 8c), which indicates a weak relationship between observations taken by MWRP and radiosonde.

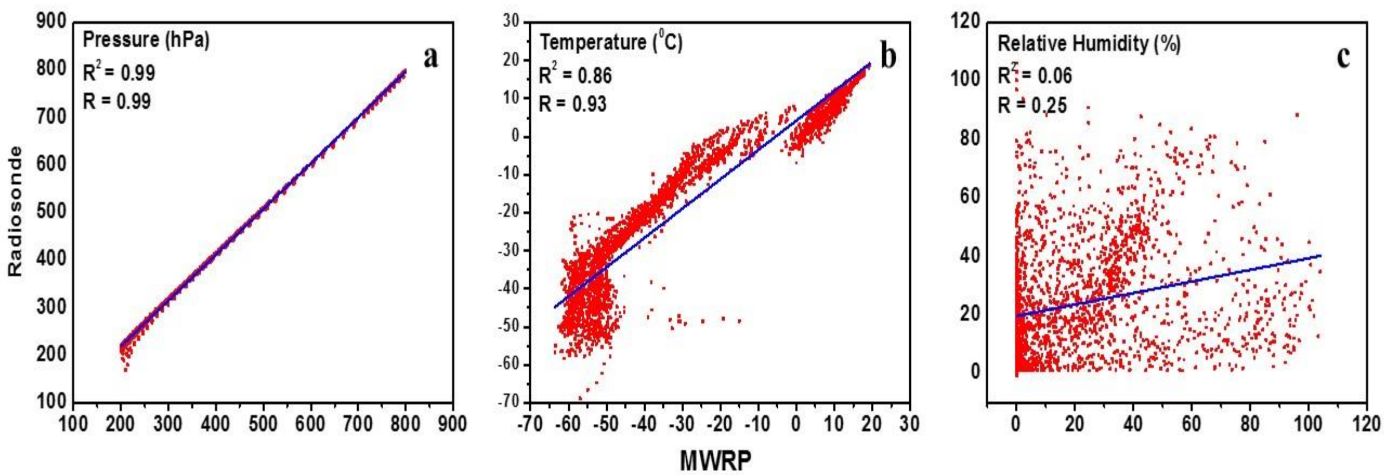

Figure 8. Correlation between MWRP and radiosonde observations of pressure, temperature, and relative humidity during the study period.

4. CONCLUSIONS

A comparative study of atmospheric parameters such as pressure, temperature and relative humidity observed from MWRP and radiosonde, over ARIES, Nainital was carried out for the period of February and March 2012. From the present comparative study following conclusions are drawn;

- Diurnal observations showed that the pressure variation was almost the same for both measurements however, MWRP shows slightly lower values than radiosonde. In case of temperature, a cold bias in MWRP observations was noticed except between 2-3 km at all timing.
- A strong diurnal variation was observed in relative humidity observation from both the measurements. The maximum relative humidity was found around 1200 GMT, during all selected days from MWRP as well as radiosonde measurements.
- The vertical profiles of these independent observations were compared during different times in a day. These profiles showed good agreement in pressure and temperature values with increasing deviation on going up from the surface to 12 km AMSL, except a large difference in temperature and relative humidity around 1200 GMT.

- The monthly observations also demonstrate that MWRP temperature profiles are positively biased (warm) below 4 km height over ARIES, Nainital. But above 4 km height, it is negatively biased (cold). However, relative humidity positively biased (dry) below 3 km and between 6 and 9 km. It is negatively biased (wet) between 3 and 5 km (amsl) with a maximum at 4 km during the study months.
- The average pressure and temperature observed from MWRP and radiosonde show strong and a good agreement with a correlation coefficient of 0.99 and 0.92 respectively. While the insignificant correlation (0.25) has been observed in the case of relative humidity between the values measured by MWRP and radiosonde.

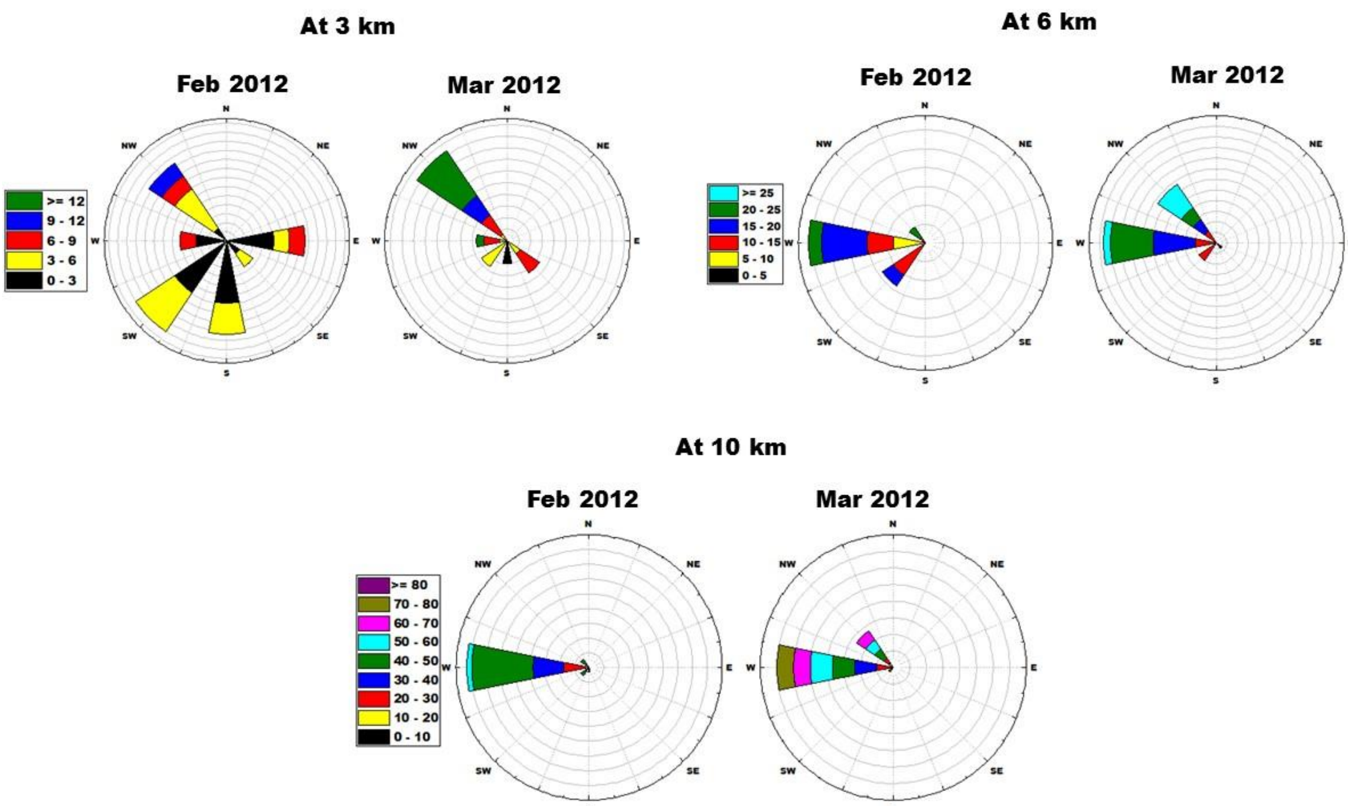

Figure 9. Variations in average wind speed and directions around 3, 6, and 10 km over ARIES, Nainital.

As mentioned before, that MWRP is ground-based observation whereas, the radiosonde is the balloon-based, therefore, in the radiosonde measurements, the effect of wind-speed as a function of height and season should be taken into account. Figure 9 shows the monthly and seasonal variability of wind speed and wind direction at a different altitude (3 km, 6 km, and 10 km) over ARIES Nainital. Around 3 km, winter and early spring are dominated by south westerlies and north-westerlies winds respectively with speed lying between 3 to 12 ms^{-1}. Around 6 km, both seasons are dominated by westerlies wind with the magnitude of wind speed between 3 to 25 ms^{-1}. Around 10 km height wind was westerlies with the magnitude of 3-80 ms^{-1} which was quite higher than that observed at the height of 3 and 6 km for both months of study. Thus, it is very clear from Figure 9 that, wind speed increases with altitude. In both the months, therefore, more deviations in the measurements have been recorded on going to higher altitude.

The response of radiosonde as wind speed is changing on moving up at higher altitudes is not well studied. Therefore, in order to improve comparison between these two instruments the effect of wind on the movement of radiosonde should be taken in to account. As the present report is the first attempt to compare these two measurements in this region, therefore more rigorous study by including the effect of wind and other disturbances is required to be done in further studies. However, at the ground-level both the observations are found to be comparable hence, MWRP observations are reliable for the study of meteorological parameters.

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