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A 205 MHz VHF radar at CUSAT for diverse atmospheric applications

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Abstract

Atmospheric radars, otherwise known as clear air radars, are advanced remote sensing system to investigate the atmospheric features through observation of the winds. They primarily depend on the back-scattered signals due to radio refractive index gradients associated with turbulent eddies to determine the velocity and range. Detecting the weak clear-air signal dictates the use of long coherent dwell times, low-noise system, low antenna side lobes, and careful attention to siting and potential interference [1]. In recent years, atmospheric radars have emerged as powerful tools for atmospheric research around the globe due to its capability of accurately measuring both the horizontal and vertical components of the wind in the vertical. The state-of-the-art VHF radar operating at 205 MHz at the Advanced Centre for Atmospheric Radar Research, Cochin University of Science and Technology (CUSAT) has played a pivotal role in exploring the physical processes occurring not only in the troposphere and lower stratosphere, but also in the earth's ionosphere reaching up to the F-region. In addition to estimating the 3-dimensional wind components ranging from 315 m to beyond 20 km above the earth's surface, it has the potential of detecting sub-metre scale field-aligned irregularities (FAI) in the E- and F- regions. The unexploited 200 MHz frequency band has the advantage of high signal to noise ratio, less cosmic noise, and good vertical coverage and in addition to high resolution especially in the lower troposphere. This paper unravels the potential of this particular Radar in exploring diverse atmospheric/ionospheric processes in the southern peninsular region.

1. Introduction

The 205 MHz wind profiling radar at CUSAT was commissioned and made operational in 2017 with the funding from the Science and Engineering Research Board (SERB), Govt. of India. Currently it is being maintained with the financial support of the Ministry of Earth Sciences, Govt. of India. The primary goal of the Radar is to monitor the Indian summer monsoon wind at its entry in to the Indian subcontinent. Brief technical details together with validation of winds with a concurrent and co-located radiosonde is provided. The diverse application of this stratosphere-troposphere (ST) Radar involves the research related to monitoring the monsoon winds and its diurnal evolution, land-sea breeze and development of thunderstorms, estimation of atmospheric boundary layer height, detecting the presence of internal gravity waves, besides the characterization of earth's ionospheric irregularities. Some preliminary discussions on the above topics are provided in this paper.

2. Technical merits of the Radar

(a) The wind profiling radar (WPR) working around the 50 MHz range suffers from no coverage below about 2 km. On the other hand, WPRs working in the UHF have a disadvantage of no data coverage at upper troposphere and lower stratosphere. However, WPRs around 200 MHz have good data coverage especially in the lower troposphere.

The bandwidth of CUSAT radar is 5 MHz, while the allotted bandwidth for the 50/400 MHz is at or below 2 MHz. Hence, the vertical resolution of wind data is higher for the 200 MHz range (45 m in the lower levels). Since the galactic noise is less for the 200 MHz, the signal-to-noise ratio is improved for wind measurements.

The lower VHF (~50 MHz) antennae require larger physical size and space (square area of about 100 m × 100 m) for installation, while the compact hardware of 200 MHz requires only lesser area (circular area of 30 m diameter) and hence cheaper costs. This cost-effectiveness makes it an attractive option over other frequency bands.

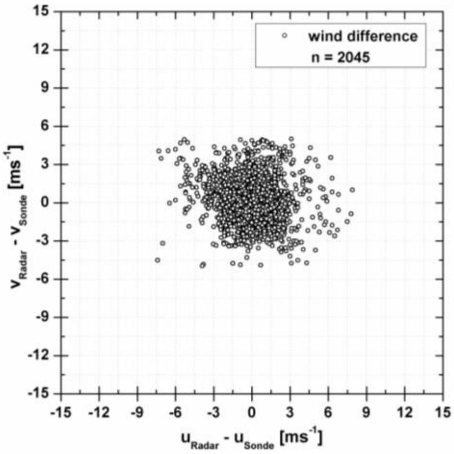

Figure 1. Scatter plot of differences between radar- and radiosonde-derived zonal and meridional wind components deduced in 2016

Fig. 1 show the comparison of winds obtained from radar and concurrent radiosonde observation. A high statistically significant correlation is obtained between the zonal (r=0.96) and meridional (r=0.92) components of radar and radiosonde.

3. Results and discussion

The following sub-sections portray the potential of the ST Radar in various research applications for unravelling the dynamical processes in the ST region and Ionosphere.

3a. Diurnal variation of monsoon winds

The monsoon low level jet (LLJ) and tropical easterly jet (TEJ) are among the prominent factors dictating the fate of the Indian summer monsoon (ISM). Here we investigate the diurnal cycle of LLJ and TEJ with reference to the core speed and core height variations during its onset phase over Kerala and subsequent northward progression in the year 2021. It is mainly facilitated by the 205 MHz wind profiling Radar. It is observed that the core speed and heights of both the LLJ and TEJ undergo significant diurnal variation, and the TEJ core height is observed to decrease with the monsoon northward progression as observed at Cochin station. The variability of the moisture flux is found to be positively related with the monsoon jet core which can have profound influence on the quantum of rainfall. Fig. 2 represents the diurnal variation of monsoon LLJ on 03rd June 2021, which witnessed a diurnal amplitude of about 5 ms^{-1} in speed and about 800 m in core height variation.

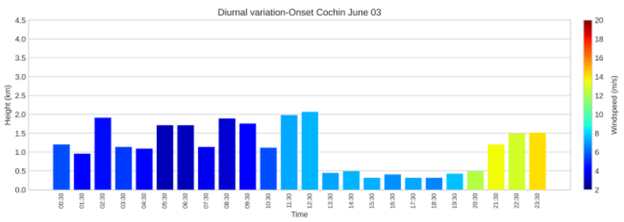

Figure 2. The diurnal variation of monsoon LLJ core speed as observed with the CUSAT Radar 03rd June 2021.

3b. Observing the development of thunderstorms

Being a mesoscale weather phenomenon, thunderstorm events are associated with high-speed winds, lightning, thunder, rainfall, and even hail. The prediction of thunderstorms with accurate and reliable space-time-intensity is a challenging task for various climatic regions. This paper presents the case study of a pre-monsoon thunderstorm event that occurred over Cochin, Kerala on 10th May 2018.

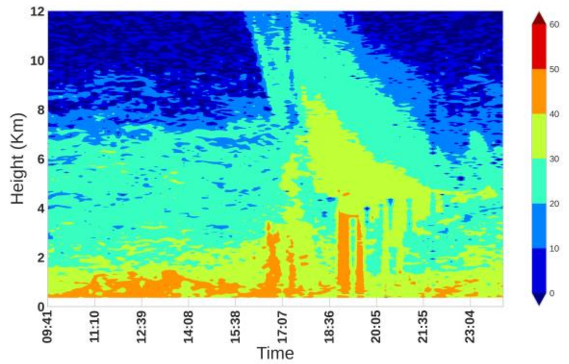

Figure 3. The HTI plot of SNR of the vertical beam during the thunderstorm on 10th May 2018.

3c. Estimation of atmospheric boundary layer height

Knowledge of the ABL height and its temporal fluctuations is essential for understanding the exchange of heat, moisture, momentum and transport of atmospheric constituents between the Earth's surface and the free atmosphere. This paper illustrates the estimation of ABLH over a Cochin using the VHF radar at CUSAT. Clear sky days of the year 2021 have been used for this study, provided for which both the radar and radiosonde datasets are available. The reference ABL Height is obtained from the mixing ratio profile and its gradient from the radiosonde data. A novel method has been devised to estimate the ABLH from the radar by combining the profiles of three parameters, viz. signal to noise ratio (SNR), wind speed (WS) and wind direction (WD; Equation 1). The ABLH is identified as that height at which the sum of the normalized standard deviations (NSD) of the three profiles peaks and subsequently drops immediately above it.

$$NSD = NSD_{SNR} + NSD_{WS} + NSD_{WD} \qquad (1).$$

This method has been verified against the ABLHs estimated from four other variables from the radiosonde, and a strong correlation (r=0.901 at 99.9% confidence level, N=36) between the ABLH derived from Radar and Radiosonde has been obtained. This study extends ample opportunity in exploring the high temporal variability such as the diurnal cycle of ABLH from the Radar unlike radiosonde measurement which are sparsely available. Fig. 3 depicts the agreement among various methods employed using radiosonde and radar.

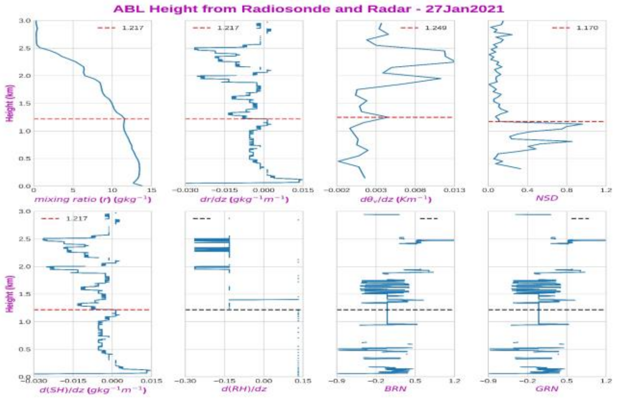

Figure 4. The ABLH over Cochin estimated from various methods.

3d. Detecting the presence of internal gravity waves

Figure 4 shows the time series of zonal and meridional wind profiles observed during 26th October 2016. Reversals in the zonal wind direction from easterly to westerly are clearly seen. This kind of feature is an indication of the modulation of background wind by atmospheric waves. Both zonal and meridional winds show the same kind of oscillation pattern, and both show a similar progression with time. A downward progression of phases of the zonal and meridional winds with time is also apparent from the figure. In this paper, we report on the characteristics of inertia-gravity waves observed at 10.04 N derived from dedicated measurements of the 205-MHz wind profiler radar. The waves were detected between the altitude ranges of 15–24 km. The predominant time period of the wave is found to be 1 hour. The short period gravity waves were found to have a vertical wavelength of 2.8 km, and were propagating upward at a rate of 0.076m/s. The waves occurred at a time when a deep depression prevailed over the Bay of Bengal.

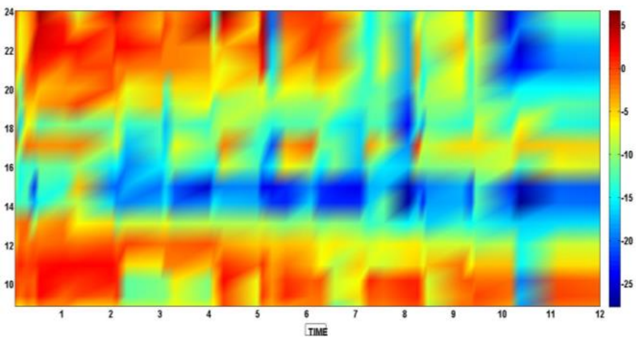

Figure 5. Contour plot of zonal wind as a function of time and altitude, observed on 26th October 2016.

3e. Ionospheric Applications

The following figures show the E- and F- region ionospheric irregularities observed on 01st March 2018 and 07th April 2021 by the CUSAT Radar. The instability leading to such mechanism will be discussed in detail.

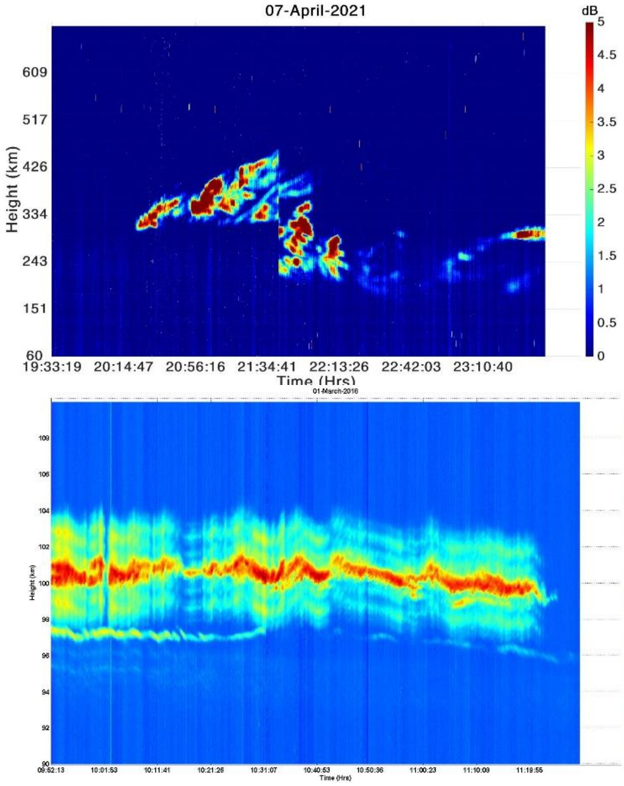

Figure 6. E- and F- region ionospheric irregularities observed on 01st March 2018 and 07th April 2021 by the CUSAT Radar.

5. Summary and conclusion

The state-of-the-art ST radar at CUSAT is expected to foster interdisciplinary and multidisciplinary research activities through exchange of experimental data. In addition, it provides a good opportunity to comprehend a wide spectrum of atmospheric processes such as turbulence, wave activities, stratosphere-troposphere exchange processes, severe weather events etc. This national facility is viewed as a major science producing Centre of the country.

6. Acknowledgements

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7. References

1. International Telecommunication Union – Radio Communication Sector (ITU-R) Report, Wind Profiler Radars, General subject matter. ITU-R Report **M.2013**, 1997, pp. 1–16.