Remote Sensing of Vertical Wind for the characterization of Atmospheric Convection

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Abstract

Vertical wind (*w*) profile is an important parameter that affects various meteorological processes throughout all scales, ranging from micro to synoptic and planetary scales. Vertical wind affects the growth and development of most of the weather event viz., cyclone, mesoscale convective systems, thunderstorms, deep convective clouds, and cloud electrification. Advanced clear-air Wind profiler technology is the only tool that enables the direct *w* measurement in all weather conditions at high time-height resolution throughout the troposphere and lower stratosphere. Due to dynamic and thermodynamic factors, the turbulent eddies create refractive index variations which is the primary source of scattering for these clear-air radars. The wind profiler is an efficient means to study convection whose intensity can be determined by vertical wind measurements. The convective activity over India changes according to local and large scale features, showing a clear annual cycle. The Indian Summer Monsoon (ISM) is a large scale phenomenon bringing forth significant convection and cloud across the Indian latitudes. The annual cycle of vertical structure of basic atmospheric conditions created for versatile convective regimes provides the evolution of atmosphere features. This study analyzes and builds a hypothesis of the existing vertical velocity field and its variability from the available wind profiler observations over different convective regimes in the Indian region. An attempt will be made to understand the factors determining the vertical wind characteristics during different convective scenarios like shallow, moderate and deep convection.

1. Introduction

Atmospheric convection plays a significant role in energy circulation by transporting heat, momentum, and moisture from the planetary boundary layer to the free atmosphere/troposphere. The genesis of convective cloud systems has a profound effect on the structure and dynamics of the troposphere. One crucial element determining the convective dynamics is vertical wind velocity (*w*), which is difficult to measure. Vertical wind (*w*) profile is an important parameter that affects various meteorological processes throughout all scales, ranging from micro to synoptic and planetary scales[1]. Vertical wind affects the growth and development of most of the weather event viz., cyclone, mesoscale convective systems, thunderstorms, deep convective clouds, and cloud electrification. Vertical wind various in the order of centimeters per second to maximum up to two orders high from fair to foul weather conditions[2]. Advanced clear-air Wind profiler technology is the only tool that enables the direct *w* measurement in weather conditions at high time-height resolution throughout the troposphere and lower stratosphere. The wind profiler is a remote sensing Doppler radar that works in frequency ranges of VHF (30 to 300 MHz) and UHF (300 to 3000 MHz). These radars are also known as clear-air radars, and the primary source of echoes is due to Bragg scattering in the atmosphere arising from irregularities in the refractive index of length scale equal to one-half of the radar wavelength. In the troposphere and stratosphere, the irregularities in the refractive index mainly depend on the gradients of temperature, pressure, and humidity. Wind profiler provides an effective way to characterise convection by vertical velocity structure. Over India, during summer, the radiative heating and moisture availability results in the northward movement of Inter Tropical Convergence Zone, changing the convective activities[3]. This progresses the onset of the Indian Summer Monsoon (ISM) over the Indian landmass. The heterogeneity of convection, turbulence, and cloud over the Indian region with meridional cross-sections of the country is mainly due to the variability of vertical wind components and related moist processes.

2. Observation sites, data and methodology

2.1 Observation sites and data

Locations selected (Fig 1) include different latitudes across India based on the convective regimes, geography, and availability of reliable observations. Wind profiler locations at different geographical locations across India, west coast, east coast, and North India are selected to study different convective regimes. The main wind profilers in India selected for this study are 53 MHz MST radar at National Atmospheric Research Laboratory (NARL) Gadanki (13.5°N;79.2°E), 205 MHz wind profiler radar located at Cochin (10.04°N;76.44°E), 206.5 MHz Stratosphere and Troposphere Radar ARIES, Nainital (29.4°N;79.2°E). The radar can provide information of u, v, and *w* wind. The radar specifications are provided in Table 1.

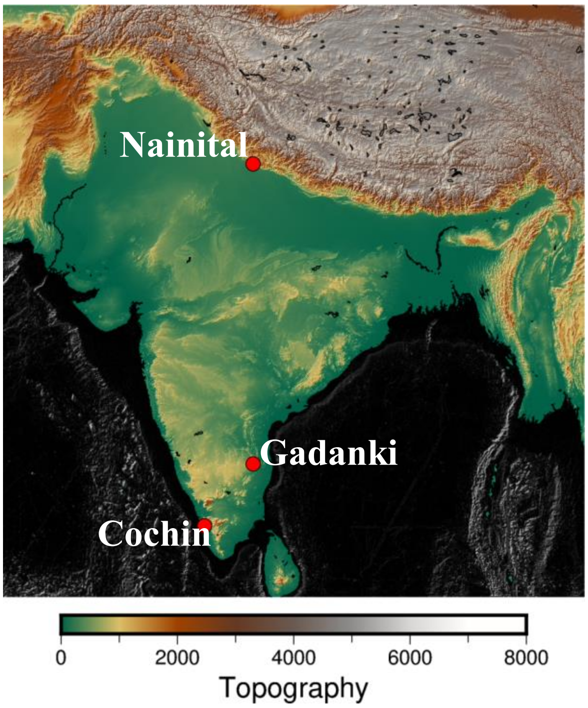

Figure 1. Topographic map of India with observational sites shown in red dots.

Table 1. Radar specifications

Parameter	**CUSAT Cochin 10.0°N;76.4°E**	**NARL Gadanki 13.5°N;79.2°E**	**ARIES Nainital 29.4°N;79.2°E**
Operating Frequency (MHz)	205	53.3	206.5
Pulse width (μs)	0.3-76.8	0.5-64	0.5-64
Peak power aperture product (W m^2)	1.6 X 10^8	7 X 10^8	1 X 10^8
Beam width	3.2°	3°	3.3°
Total number of Yagis	619	1024	588

Construction of the annual cycles of dynamical and thermodynamical vertical structure is carried out using IMDAA reanalysis and radiosonde to infer conditions conducive for sustained convection and evolution of atmospheric state. Four years (2017-2020) of 12 km spatial resolution IMDAA (Indian Monsoon Data Assimilation and Analysis reanalysis) is used to study vertical evolution of atmosphere. The three hourly data of temperature, relative humidity (RH) and wind information in a 1ºX1º grid provide location specific features at Nainital and Cochin. Due to availability, twelve years of radiosonde data is utilized for characterising the vertical structure of atmosphere at Gadanki.

2.2 Methodology

Woodman (1985) explains about finding the spectral moments from radar Doppler spectra from radar. The returns from any one height form a random time series which, for the purpose of work, we will consider quasi-stationary (stationary within an integration time) and Gaussian. A Gaussian power spectra has the form

$$S = \frac{P}{\sqrt{2\pi m w^2}} \exp\left(-\frac{(\omega-\Omega)^2}{2w^2}\right) \quad (1)$$

P, Ω and w corresponds to total power, frequency shift and spectral width. They are the measure of three important physical properties, turbulence intensity, mean radial velocity and velocity dispersion. The moments of this equation give the quantities and wind is computed from the Doppler frequency shift as $\frac{\lambda}{2} f_d$. λ denotes radar wavelength and f_d Doppler frequency shift. Continuous vertical wind measurements used in this study.

3. Results and discussions

The annual cycle of vertical structure of atmosphere for temperature, RH and wind is created by taking daily mean of four years of IMDAA reanalysis for Nainital and Cochin. Gadanki vertical structure is plotted using radiosonde data.

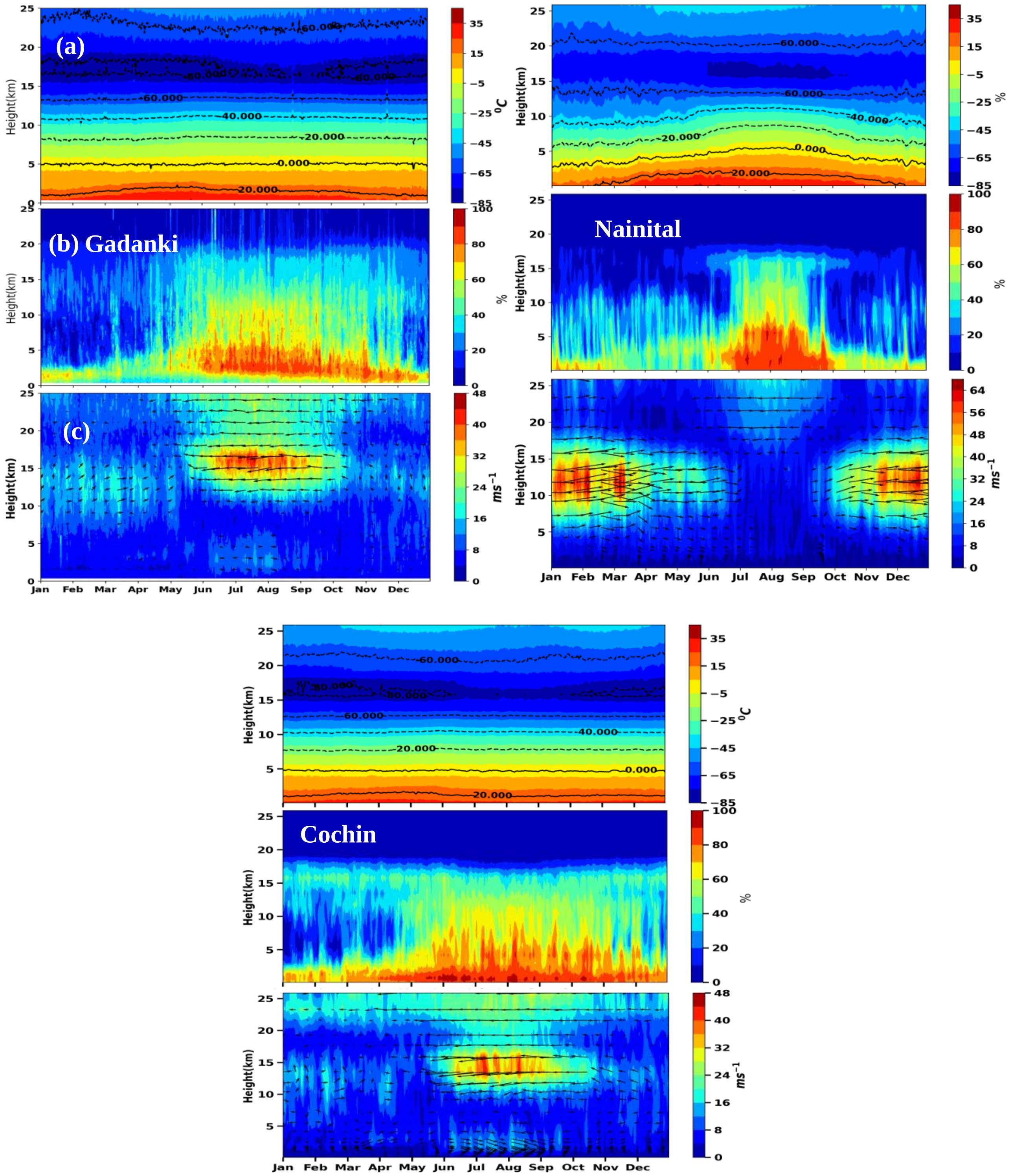

Figure 3. (a) Temperature (b) RH and (c) wind speed and direction for Gadanki, Cochin and Nainital

The most prominent climatological feature visible throughout all the sites includes the reversal of wind feature which is associated with the large scale circulation of ISM. ISM season is defined as occurring during June, July, August and September, with its onset starting near June 1 in Kerala. The ISM brings copious amount of moisture content to the land region and favours cloud formation. A study done on a site in monsoon core zone found an increase in convective available potential energy and the interaction of three level cloud system (low, mid and high) during ISM[4]. This cloud vertical structure and background represents the active monsoon convection. Using this site as a reference of monsoon, Nainital atmospheric features resembles mostly as that of monsoon core. The steady increase of RH throughout the atmospheric vertical structure is conspicuously seen during ISM compared to other locations. The elevation of temperature isotherms during ISM results in warmer atmospheric column holding more moisture. The southern peninsular locations have similar wind features with strong tropical easterly jet around 15 km and no elevation of temperature isotherms at higher altitudes. The RH increases during ISM for Gadanki and persists at lower heights till December. Cochin remains humid throughout the year at surface. The presence of moisture and favourable conditions of surface heating can lead to convective activity any time of the year. More consistent conditions occur during monsoon all over India, where large scale circulation supports the growth of convective activity. During other seasons, local agreeable features can result in convection.

Vertical wind indicates the strength of convection. A case from each site using continuous w measurements from wind profiler is given in Fig 3. Fig. 3**a** shows a two-hour observation of vertical wind at Nainital on 17 June 2021, a day in monsoon season with a temporal resolution of 1 min and height resolution of 75 m. The data was obtained as part of data collection. The variation of w is confined below 7 km during the observation time. An updraft activity starts developing at 10:00 LT persists for almost 45 min. During the rest of the time, downdraft activity can be observed. Fig. 4**b** shows a composite of w measured for continuous afternoon three hours at Cochin on 13 February 2020 with temporal resolution 1 min and height resolution 180 m collected as part of the site visit. The figure showcases the updraft and downdrafts features throughout the vertical structure in the atmosphere. Fig. 4**c** displays w at Gadanki obtained from archived data at 75 m height and 1 min temporal resolution. A sudden increase in vertical wind is witnessed from 16:58 hrs LT throughout the height range with adjacent updrafts and downdrafts. It may be due to some convective activity over the area. Three sites show different features specific to the site in distinct environmental conditions

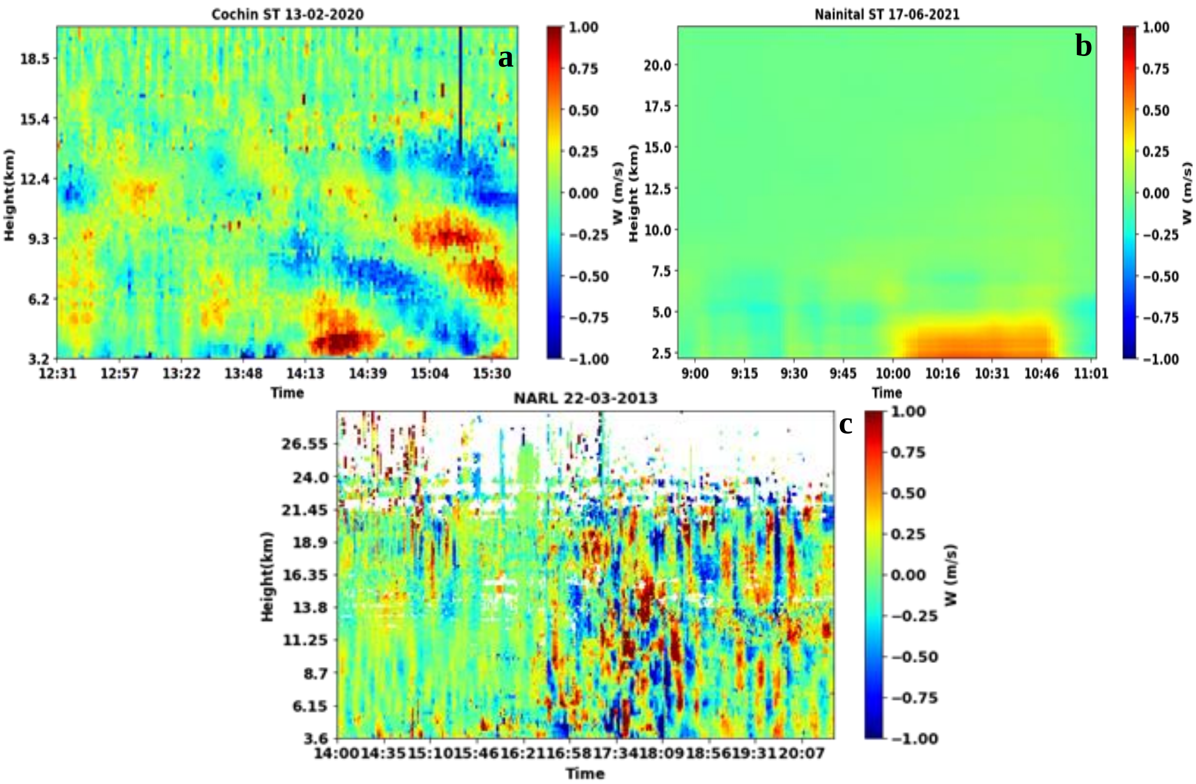

Figure 4. Vertical wind measurements from (a) Cochin on 13 February, 2020 (b) Nainital on 17 July, 2021,9 (c) Gadanki on 22 May,2013

4. Summary

Different convective regimes selected across India shows distinct kinematic and dynamic vertical structure of atmosphere. Basic atmospheric parameters show considerable difference across varying latitudinal regions. The sub tropic site show significant humidity and elevation of temperature isotherms at higher height during ISM, which is not present in southern India. Wind reversal associated with monsoon is visible in the vertical structure across all sites. Indian Summer Monsoon provides the most favourable conditions for convection over India. Convection studies are more informative with vertical velocity measurements to study its growth and evolution. Case study displays different vertical velocity characteristics over wind profiler locations.

A more robust study on characterization of different convection like shallow, mid and deep convection will be done in future and presented in the conference proceedings. Further investigation is needed to understand the vertical wind features specific to locations.

5. References

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6. Acknowledgements

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