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Characterization Of Dual-Beam MST Radar For The Analysis Of Atmospheric Turbulence And Instrumental Noise

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Abstract:

In this paper, a brief experiment is conducted for a certain period of time to test the dual-beam width method of estimating the turbulence kinetic energy (TKE) of the MST Atmospheric Radar. An elliptical beam was used with a modified dual beam-width analysis. The dual-beam width method employs the spectral widths measured simultaneously with two different beam-widths and the ratio of the magnitudes of the beam-widths is used under the assumption that the TKE is the same in the sample volumes viewed by both beam widths. The dual-beam width method can be used only at a small number of radar sites that have dual-beam width capability. The wet atmospheric delay of radio signals of earth satellite links can be inferred from ground-based microwave radiometry. Hence it is possible to use microwave radiometers to test models. We present results using data from two co-located radiometers. This gives us a variety of different combinations of data from the radiometers in order to derive parameters for atmospheric turbulence and instrumental noise. A scaling factor for the atmospheric turbulence is estimated using data from one single or both radiometers. We have also experimented with the impact of reduction in noise by increasing the Integration time of the Radiometer.

Keywords: Turbulence, Radiometer, Dual-beam, TKE, Spectral width, MST Radar, Instrumental Noise, Integration time.

1. Introduction

The dual-beamwidth method for measuring TKE using spectral widths from Doppler radar was recently introduced. It employs the spectral widths measured simultaneously with two different beamwidths and the ratio of the magnitudes of the beamwidths is used under the assumption that the TKE is the same in the sample volumes viewed by both beamwidths.

The uncertainty of the TKE estimates from the dual-beamwidth method is governed only by the uncertainty of the observed spectral widths. The dual-beamwidth method can be used only at a small number of radar sites that have dual-beamwidth capability.

In this work we present results using data from two co-located radiometers. This gives us a variety of different combinations of data from the radiometers in order to derive parameters for atmospheric turbulence and instrumental noise.

The wet atmospheric delay of radio signals of earth satellite links can be inferred from ground-based microwave radiometry. Hence it is possible to use microwave radiometers to test models. We tested this model describing the correlations between slant wet delays in different directions using the Astrid radiometer. In that work we had to assume that the atmosphere did not change significantly during a short time period since we only used one radiometer and could hence only measure in one direction at the time.

2. Theory

Atmospheric turbulence, small-scale, irregular air motions characterized by winds that vary in speed and direction. Turbulence is important because it mixes and churns the atmosphere and causes water vapor, smoke, and other substances, as well as energy, to become distributed both vertically and horizontally. Atmospheric turbulence near the Earth’s surface differs from that at higher levels. At low levels (within a few hundred meters of the surface), turbulence has a marked diurnal variation under partly cloudy and sunny skies, reaching a maximum about midday. This occurs because, when solar radiation heats the surface, the air above it becomes warmer and more buoyant, and cooler, denser air descends to displace it. The resulting vertical movement of air, together with flow disturbances around surface obstacles, makes low-level winds extremely irregular.

Instrumental noise may dominate at lower frequencies (e.g. below 0.02 Hz) or at higher frequencies at sites with very low ambient Earth noise levels. Digital seismic recordings in this frequency band always contain noise, which essentially can be attributed to ambient Earth noise and instrumental noise, or self-noise, of the recording system. Instrumental noise of today's seismic sensors and high resolution digitizers is usually not considered during the interpretation of seismic data.

Fig1: MST RADAR

RADAR (Radio Detection and Ranging) is a device that sends out electromagnetic waves. MST Radar provides estimates of atmospheric winds on a continuous basis with high temporal and spatial resolutions. MST Radar uses the echoes obtained over the height range of 1-100 Km to study winds, turbulence. The Indian MST Radar has been operational for scientific studies of the atmosphere in the height range of 2-20 km (troposphere and lower stratosphere), 60-90 km (mesosphere), 100-150 km (E region) and 150- 800 km (F region). The echoes from the atmosphere are due to neutral turbulence in the lower height regions and due to the irregularities in electron density in the higher altitudes. Weak echoes between 30-60 kms were due to less availability of 3 m scale refractive index fluctuations. The radar consists of a phased antenna array that has two orthogonal sets (one for east-west polarization and another one for north-south polarization) of 1024 three element Yagi-Uda antennas arranged in a 32X32 matrix over an area of 130mX130m. It generates a radiation pattern with a main lobe of 30 and a gain of 36 dB. India has been operating 53 MHz atmospheric radar (Mesosphere, Stratosphere and Troposphere radar) for studying structure and dynamics of lower, middle and upper atmosphere.

3. Method of analysis

The spectral width $\boldsymbol{\alpha^2_{obs}}$ of an observed radar Doppler signal is related to the velocity variance due to turbulence $\boldsymbol{\alpha^2_{turb}}$ what can be used to estimate turbulent energy dissipation rates. If a relative wide radar beam is used is $\boldsymbol{\alpha^2_{obs}}$ also influenced by variances due to the interaction with the background wind and shear $\boldsymbol{\alpha^2_{beam + shear}}$ and of waves $\boldsymbol{\alpha^2_{wave}}$ with the radar beam.

$$\alpha^2_{obs} = \alpha^2_{turb} + \alpha^2_{beam + shear} + \alpha^2_{wave} \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$\alpha^2_{obs} = \alpha^2_{turb} + \alpha^2_{corr} \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

which have to be removed from the observed spectral width to get $\alpha^2_{turb.}$ The standard or traditional single-beamwidth method (1BW) consists of estimating $\alpha^2_{wave,}$ evaluating $\alpha^2_{beam + shear}$ and subtracting α^2_{corr} from $\alpha^2_{obs.}$ The dual-beam-width method (2BW) considers that the dominant terms in $\alpha^2_{beam + shear}$ are proportional to the beam width β^2 (**H**alf-**P**ower-**H**alf-**W**idth) what means that α^2_{corr} is also approximately proportional to β^2. If α^2_{obs} is measured simultaneously in nested volumes with radar beams characterized by a narrow beam width β_n and a wide beam width β_w two simultaneous equations for $\alpha^2_{obs,n}$ and $\alpha^2_{obs,w}$ can be solved.

$$\alpha^2_{turb} = \frac{\beta^2_w \,.\, \alpha^2_{obs,n} - \beta^2_n .\, \alpha^2_{obs,w}}{\beta^2_w - \beta^2_n} \ldots\ldots\ldots(3)$$

The advantage lies in the fact that neither the wind the shear, nor the pointing angle of the radar beam is required for correction. The dual-beam width method assumes that for both beam widths the same fraction of the pulse volume is filled with turbulence and requires the beam widths only.

The estimates of TKE from the traditional method and from a modified dual-beamwidth method are compared in this study.

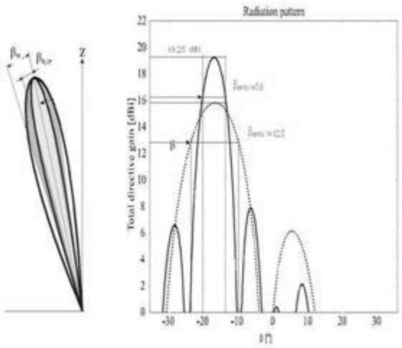

Fig2.:Left: Principle of nested volume measurements with two radar beams characterized by different beam widths. Right: Slice along the NW-SE axis through the 3D radiation pattern of the MF radar antenna for a narrow (solid line) and wide (dashed line) beam.

The equivalent zenith wet delay (slant wet delays mapped to zenith) of a radio signal observed in the direction i, l_i is defined as

$$l_i = 1/m(€_i) \int_S 10^{-6} N_w(r_i(z))\, ds$$

$$= 10^{-6} \int N_w(r_i(z))\, dz \ldots\ldots\ldots\ldots\ldots\ldots..(4)$$

Where m($€_i$) is the mapping function for elevation angle $€_i$, N_w is defined as **wet refractivity**, S is being considered as the slant path and $r_i(z)$ is the position of the signal at the height z. The correlation between two equivalent zenith wet delays of two different directions (i and j) is given by-

$$K^2 = \frac{C^2_n \cdot h^{8/3}}{C^2_{n0} \cdot h_0^{8/3}} \quad \ldots..(5)$$

Where $\mathbf{C_n}$ is the refractivity structure constant. Assuming that C_n is constant up to an effective tropospheric height **h** .

In order to avoid possible problems due to temporal variations in the atmospheric refractivity more than one radiometer need to be used. Using two radiometers their noise variances will in general be different.

$$\langle (l_i - l_j)^2\rangle = [K^2 \langle (l_i - l_j)^2\rangle]_0 + 1/m(€_i)^2 V\,ar[B1] + 1/m(€_j)^2 V\,ar[B2] \quad \ldots.(6)$$

Where V ar[B1] and V ar[B2] are the variances of the noise in the two radiometers. This model will hold if there are no biases between the two radiometers in the equivalent zenith wet delay. For both models we estimate one k2 value and one value for the noise variances for one day period.

4. Data observation

The Indian MST Radar is installed at National Atmospheric Research Laboratory (NARL) at Gadanki, near Tirupati, Andhra Pradesh. (13.47^0 N, 79.18^0 E). It operates at 53 MHz with average power aperture product of 7×108Wm2. The antenna array consists of 1024 crossed 3-element Yagi antennas covering 130×130m. Peak transmitted power is 2.5MW obtained from 32 transmitters, each feeding a sub-array of 32 Yagis. The one-way half-power full beamwidth of the full antenna is about 5.6^0.

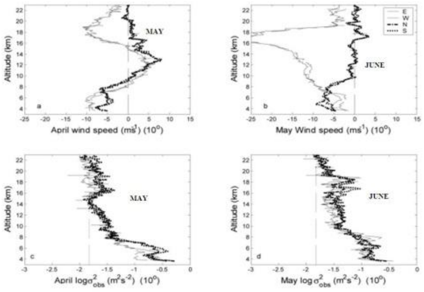

Fig. 3. Median (upper) winds and (lower) observed spectral widths over all observations taken at zenith angle during (left) May and (right) June

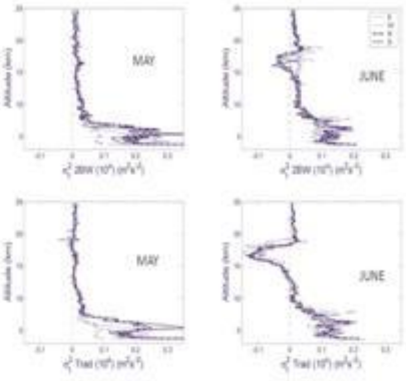

Fig. 4. Median (upper) α^2t -2BW and (lower) α^2t-Trad over all observations taken at zenith angle during (left) May and (right) June

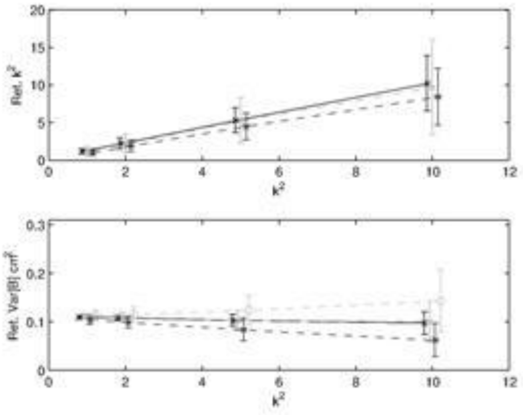

Fig. 5. Ratio of the median α^2t -Trad to the median α^2t -2BW during (left) May and (right) June

The narrow beamwidth (5.6^0) was obtained using the full antenna. By disconnecting 16 sub arrays from one polarization of the antenna a rectangular antenna was formed, with 5.6^0 beamwidth in one polarization and a second beamwidth, about 12.5^0, in the other polarization. The ratio of the broad and narrow beams is about 2.

5. Simulated results

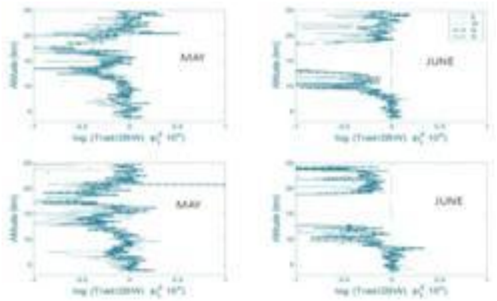

Fig. 6. Average retrieved values of k^2 and Var [B] as function of the value of k^2 used in the simulations. The error bar shows the standard deviation. The result from using one radiometer is shown with a blue solid line (sky-mapping radiometer) and the green dashed-dotted line (elevation angle scanning radiometer).The combined results are shown with the dashed lines.

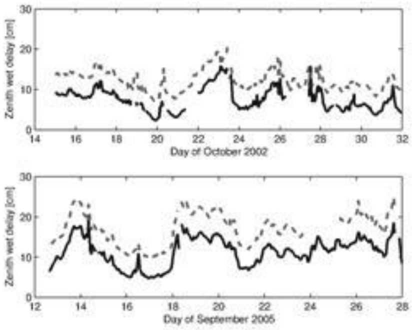

Fig. 7. Time-series of the zenith wet delay

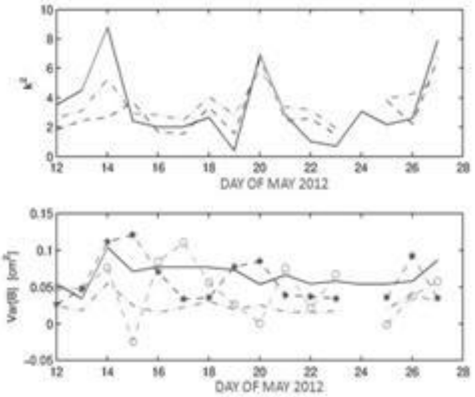

Fig. 8. Estimated zenith wet delay bias between the two radiometers

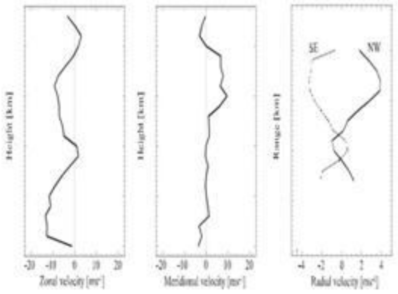

Figure 9: Mean zonal and meridional winds

6. Conclusion

A brief experiment was conducted with the MST radar at Gadanki, India, to test the dual beam width method for estimating TKE. Theoretical analysis showed that in the dual-beam width method for an elliptical beam there is a term that depends on the wind speed perpendicular to the beam. The results from the two experiments agree rather well in general, the observed difference between the retrieved values of k^2 is at the level which can be expected from the simulation results. The agreement between the k^2 values retrieved using one radiometer as in and using two radiometers. As seen the noise variances retrieved were rather constant during certain period. The investigation regarding the integration time shows that the value of k^2 estimated is relatively independent of the integration time.

Our estimates of TKE during May by the dual-beamwidth method for the zonal beam are positive while those from the meridional beam and from the traditional method are negative, giving a good illustration of the ability of this method to extract TKE during strong winds (at least in the beam parallel to the wind) when the traditional method fails.

7. References

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