Application of the dual-beamwidth method to a narrow beam MF radar for estimation of spectral width

R. Latteck, W. Singer, N. Engler

Leibniz-Institut für Atmosphärenphysik, Schloss-Str. 6, D-18225 Kühlungsborn, Germany

LEIBNIZ-INSTITUT FÜR ATMOSPHÄREN PHYSIK IAP

10th International Workshop on Technical and Scientific Aspects of MST Radar
Piura, Peru, May 13-20, 2003

Introduction

Spectral widths observed by narrow beam VHF/UHF Doppler radars are used to estimate turbulent energy dissipation rates. In case of broader beams, the observed spectral widths have to be corrected for the influence of beam and shear broadening using simultaneously measured horizontal winds. VanZandt et al. developed a new dual-beam width method to estimate the turbulent component of spectral width from MST radar observations without any additional assumptions and tested it successfully for the troposphere.

In summer 2002 the new Saura MF radar was put into operation on the Andoya island in Norway. The system has high flexibility in antenna beam forming allowing off-zenith beams with different beam widths. In addition, the beam steering capabilities of the Saura MF radar and the nearby located ALWIN VHF radar provide common volume observations at mesospheric altitudes in summer during the appearance of PMSE.

Experiments with different beam widths have been carried out with the MF radar to test the dual-beam width method at mesospheric altitudes. We compare spectral width estimates from both the single-beam width and the dual-beam width method on a case study basis.

The method

The variance of the observed radar Doppler spectral width σ^2_{obs} is related to velocity variance due to turbulence σ^2_{turb} and influenced by $\sigma^2_{beam+shear}$ and σ^2_{wave} what are variances due to the interaction of the background wind and shear and of waves with the radar beam:

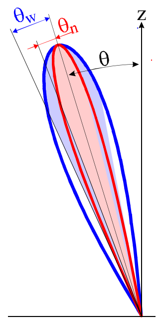
$$\sigma^2_{obs} = \sigma^2_{turb} + \sigma^2_{beam+shear} + \sigma^2_{wave} = \sigma^2_{turb} + \sigma^2_{corr} \quad (1)$$

The standard **single-beamwidth method** (1BW) consists of estimating σ^2_{wave} and evaluating $\sigma^2_{beam+shear}$ by

$$\sigma^2_{beam+shear} = \frac{\theta}{3}\left[\left(\cos^2\alpha U^2 + V^2\right) - 2\cos\alpha\sin^2\alpha U(u_z R) + \sin^4\alpha (u_z R)^2\right] \quad (2)$$

and substracting σ^2_{corr} from σ^2_{obs} to get σ^2_{turb}.

The **dual-beamwithmethod** (2BW) considers that the dominant terms in $\sigma^2_{beam+shear}$ are proportional to θ^2 what means that σ^2_{corr} is also approximately proportional to θ^2. If σ^2_{corr} is measured simultaneously in nested volumes with a narrow beamwidth θ_n and a broad beamwidth θ_w two simultaneous equations for $\sigma^2_{obs,n}$ and $\sigma^2_{obs,w}$ can be solved, what results in:



$$\sigma^2_{turb} = \frac{\theta^2_w \cdot \sigma^2_{obs,n} - \theta^2_n \cdot \sigma^2_{obs,w}}{\theta^2_w - \theta^2_n} \quad (3)$$

$$\sigma^2_{corr,n} = \theta^2_n \left[\frac{\sigma^2_{obs,w} - \sigma^2_{obs,n}}{\theta^2_w - \theta^2_n}\right] \quad (4)$$

$$\sigma^2_{corr,w} = \left(\frac{\theta^2_w}{\theta^2_n}\right) \cdot \sigma^2_{corr,n} \quad (5)$$

Advantage:
neither the coefficients in equation (2) nor the wind speeds and shears appear in equations (3) and (4)

References

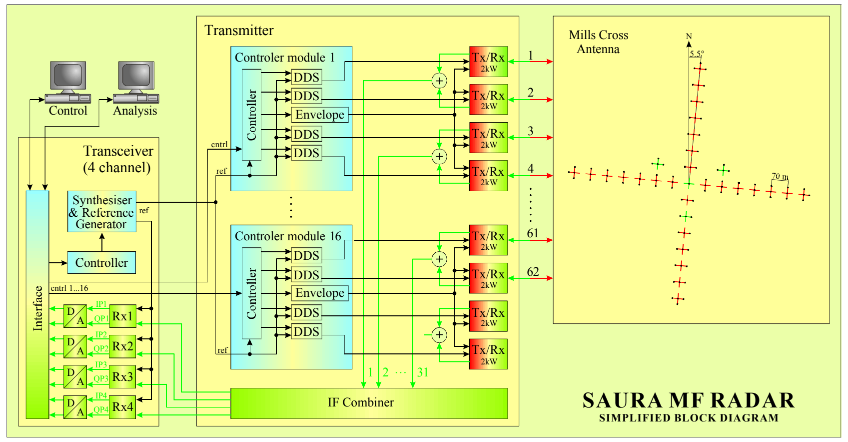
VanZandt, T.E., G.D. Nastrom, J. Furumoto, T. Tsuda, and W.L. Clark, A dual-beamwidth radar method for measuring atmospheric turbulent kinetic energy, *Geophys. Res. Lett.,* Vol. 29, No. 12, 13-1-13-3, 2002

Lübken, F.-J., The thermal structure of the Arctic summer mesosphere, *J. Geophys. Res.*, 104, 9135-9149, 1999.

Müllemann, A., M. Rapp, F.-J. Lübken, and Peter Hoffmann, In situ measurements of mesospheric turbulence during spring transition of the Arctic mesosphere, *Geophys. Res. Lett.,* Vol. 29, No. 10, 115-1 - 115-4, 2002.

The Saura MF radar

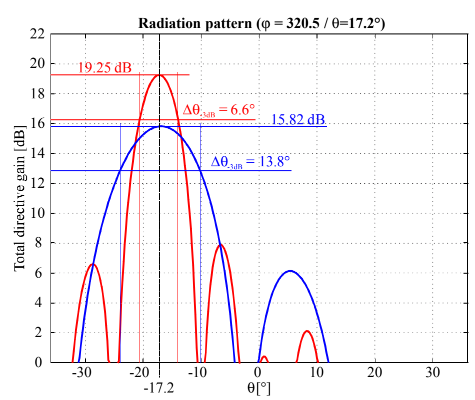
Radar frequency:	3.17 MHz
Peak power:	116 kW
Mean power: (0.2% dc):	230 W
Pulse form:	Gauss
Pulse width:	> 7 µs
Range resolution:	1000 m
Antenna:	29 crossed half wave dipols
Half power beam width:	6,4°
Beam directions:	vertical, off-zenith

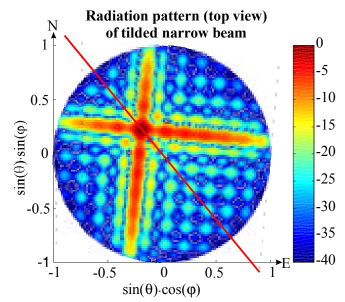


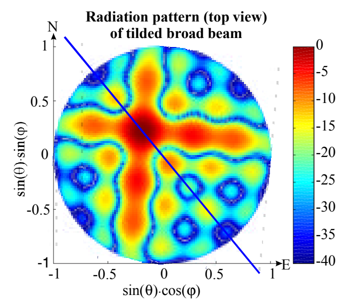
The experiment

The 29 crossed dipols of the new Saura MF radar are connected to individual transceiver modules each. If less than 29 modules are used a broad antenna beam is formed. A sequence of narrow beam (θ_{HPFW}=6.6°) and broad beam (θ_{HPFW}=13.8°) experiments, each pointing interleaved with 17.2° off-zenith towards NW and SE, were run in April 2003 to test the dual beam method. Additionally 4 DBS narrow beam experiments at 7.3° off-zenith provided the horizontal wind information.

Experiment configurations	broad beam	narrow beam	DBS wind
PRF [Hz]	150	150	150
Coherent integrations	16	16	8
Data points per beam	512	512	800
Range start [km]	50	50	50
Range end [km]	98	98	98
Sampling interval [km]	2	2	2
Pulse width [µs]	26.67	26.67	26.67
Beam direction sequence (azimuth/zenith)	140.5/17.2 320.5/17.2	140.5/17,2 320.5/17.2	50.5/7.3 230.5/7.3 140.5/7.3 320.5/7.3
Time resolution Δt [ms]	213.33	213.33	213.33
Experiment run time [s]	109.23	109.23	170.67



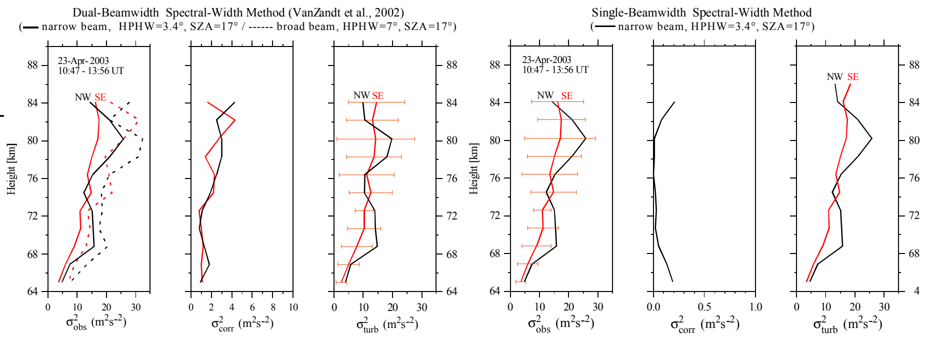


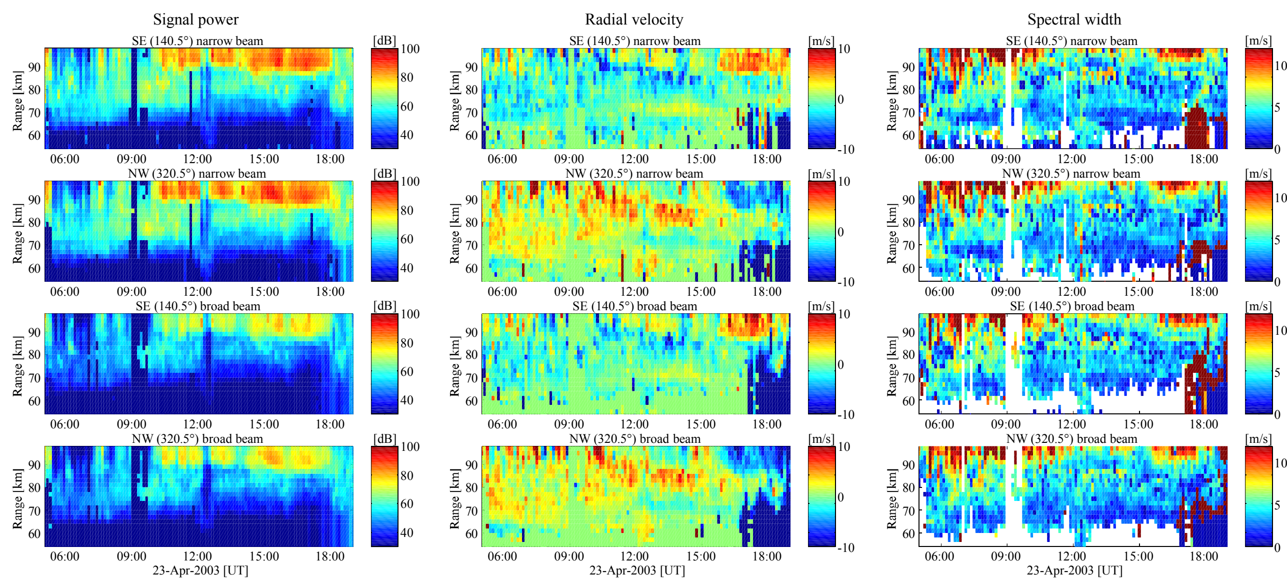


Radiation pattern plots of Saura MF radar antenna for a 17.2° tilded narrow (red) and broad (blue) beam to northwest direction. The red and blue lines in the contour plots mark the plane of the slices through the 3D radiation diagram shown above.

Results

The dual-beams were formed at 17.2° zenith angle with a minimum of the antenna radiation pattern in vertical direction to reduce the contamination by specular reflections. Individual estimates of turbulent spectral width are obtained from consecutive narrow and broad beam observations every 8 minutes with interleaved NW/SE observations for the narrow and broad beam. The 3-hour mean profile of σ^2_{turb} shows velocity variances between 5 and about 15 m²/s² below 78 km where contributions from specular reflections should be small or negligible. These turbulent velocity variances correspond to energy dissipation rates between 10 and 60 mW/kg based on a mean temperature profile for April after falling sphere measurements at Andenes (Lübken, 1999). The estimated dissipation rates are in agreement with rocket observations during spring transition (Müllemann et al., 2002). During the first dual-beamwidth observations the wind speeds were small (less than 10 m/s) and the correction for beam and shear broadening used in the single-beamwidth method is negligible. (Note: different abscissa scales in the middle panels!)

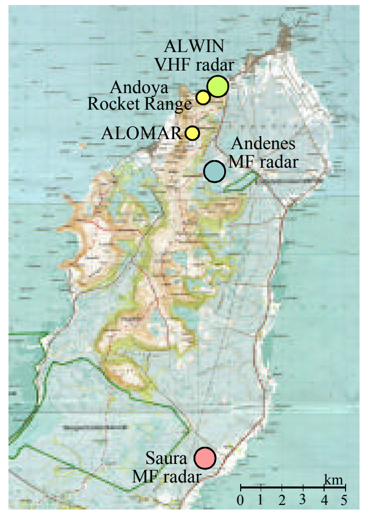




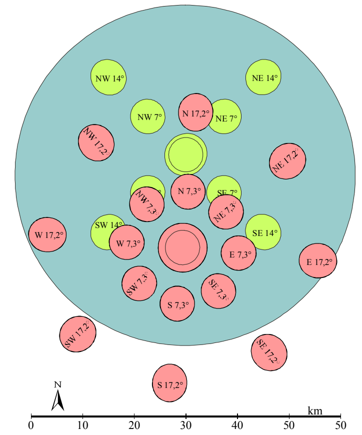
Contour plots of signal power, radial velocity, and spectral width obtained with narrow and broad beam experiments at 17.2° solar zenith angle. The differences in signal power between narrow and broad beams are due to less numbers of antennas forming the broad beam. The effective radiated power is reduced by about 50 per cent. The radial velocities in the middle panel show reversed signs for the opposite directed narrow and broad beams. For the broad beams lager spectral widths are observed all the time (right panel).

Future common MF/VHF experiments

The high flexible beam steering of the Saura MF radar allows common volume observations at mesospheric altitudes with the Southeast and Southwest beams of the nearby located ALWIN VHF radar and with the lidar experiments at ALOMAR. All possible beams of the ALWIN VHF radar and most of the possible Saura MF radar beams point also into the volume that is illuminated by the Andenes MF radar as well. This makes it possible to compare results obtained from the same volume but with radars operating on different frequencies and using similar or different analysis techniques. Furthermore comparisons with in-situ measurements from sounding rockets launched from the Andoya Rocketrange are possible. If the Saura MF radar beam is steered to the volume where the ALWIN NW 7° or NW14° beam point to, the rocket trajectories have intersections with both radar beams at altitudes between 75 and 90 km.



Northern part of Andoya island.



Areas at 85km altitude illuminated by oblique and vertical beams of ALWIN VHF radar (green), Andenes MF radar (blue) and Saura MF radar (red).