Measurement of turbulent energy dissipation rates in the arctic middle atmosphere by a 3-MHz-Doppler radar

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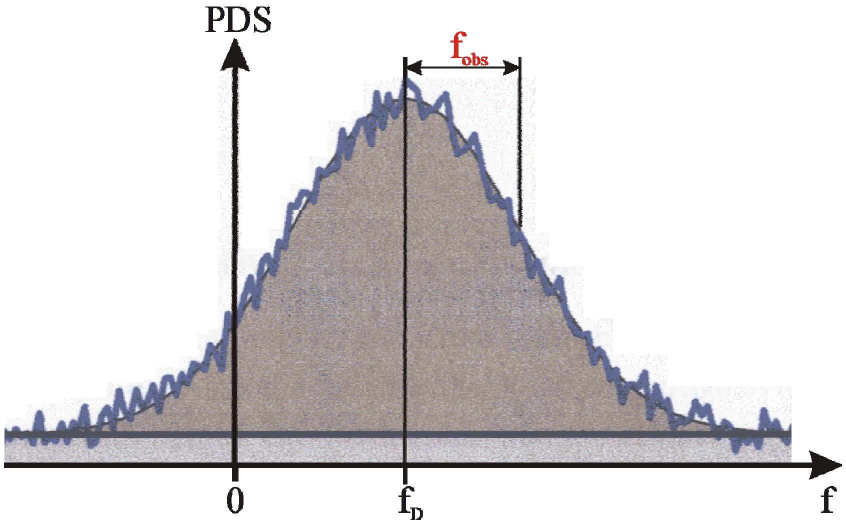
Objectives

- Turbulence is a heat source in the mesosphere and lower thermosphere because it transfers potential and kinetic energy from medium scales (for example generated by the breaking of gravity waves) to very small spatial scales where the energy is converted to heat by viscous dissipation.
- Typical turbulent energy dissipation rates for mesospheric altitudes are 0.01 to 0.2 W/kg which correspond to heating rates of about 1 to 20 K/d.
- The turbulent heating is comparable to other heating mechanisms, such as absorption of solar UV and EUV radiation.
- In addition, turbulence also indirectly affects the thermal structure of the atmosphere by the frictional forces on the momentum budget. The breaking of gravity waves induces drag via turbulent friction which changes the global circulation system and finally results in strong cooling (cold summer mesopause!) or heating, depending on season, due to vertical motion.
- Radar observations of the spectral width allow an estimation of turbulent energy dissipation rates, and these can be compared with rocket measurements.

Outline

- Energy dissipation rates from spectral width
- Spectral width and beam broadening effects
- Features of the new Saura MF radar
- Experiment configuration and algorithm for ε determination using Saura MF radar
- Results and comparisons
- Outlook

Determination of turbulent kinetic energy dissipation rate from spectral width of a received radar signal



Observed spectral width

$$\sigma_{obs}^2 = \left(\frac{\lambda}{2}\right)^2 f_{obs}^2$$

$$\sigma_{obs}^2 = \sigma_{turb}^2 + \sigma_{beam+shear}^2 + \sigma_{wave}^2$$

Mean turbulent velocity

$$v_{RMS}^2 = \frac{\sigma_{turb}^2}{2 \cdot \ln(2)}$$

Turbulent kinetic energy dissipation rate $\varepsilon_{turb} \approx c \cdot v_{RMS}^2 \cdot \omega_B \qquad (c \approx 0.4)$

Problem: non-turbulent part of observed spectral width may outweigh turbulent part !

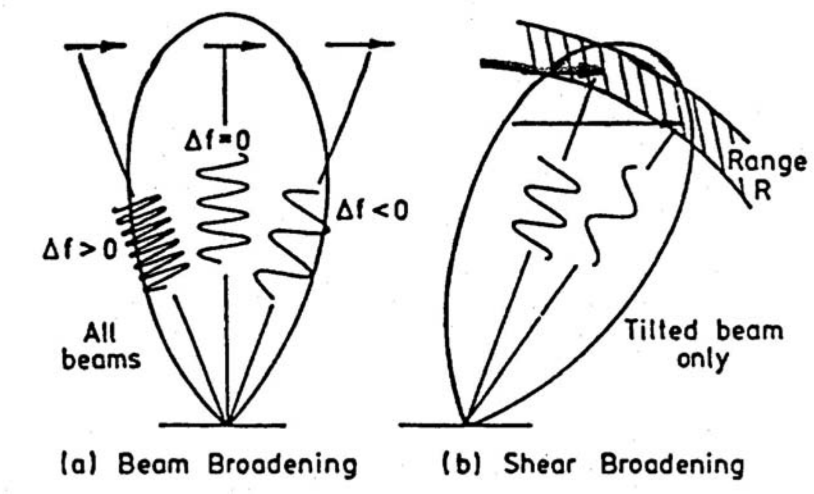
Spectral broadening effects on the reception signal

Beam broadening

$$\sigma^2_{obs} = \sigma^2_{turb} + \sigma^2_{beam+shear} + \sigma^2_{wave}$$

$$\sigma^2_{obs} = \sigma^2_{turb} + \sigma^2_{corr}$$

- narrow radar beam
- good range resolution



(Hocking, *JATP*, 1983)

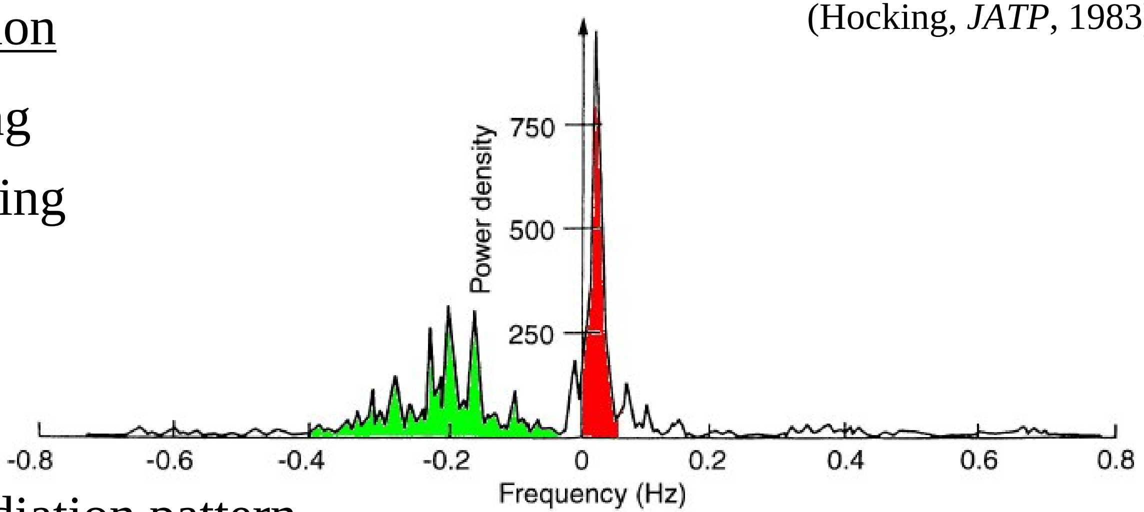
Fresnel scattering/reflection

< 80km Fresnel scattering

> 80km turbulent scattering

- tilting radar beam

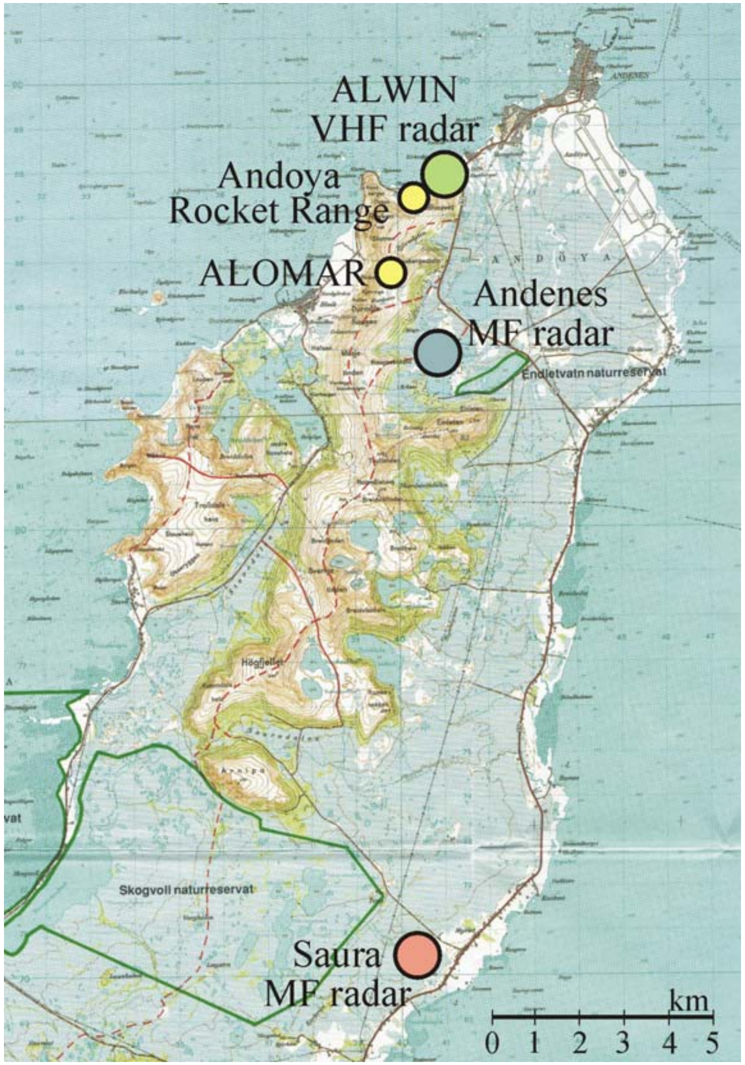
Multi peak spectra



Side lobes of antenna radiation pattern

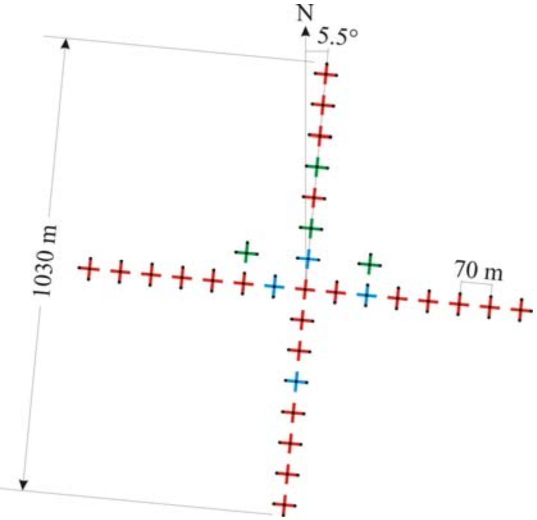
(Hocking, *Adv. Space Res.*, 1987)

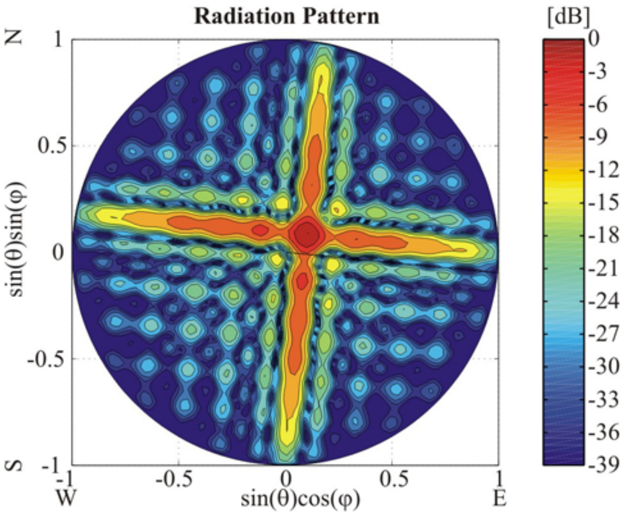
Saura MF radar (1)



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	1000m
Antenna	29 crossed dipoles
Half power beam width	6.4°
Beam directions	Vertical, 8 off-zenith

Saura MF radar (2)



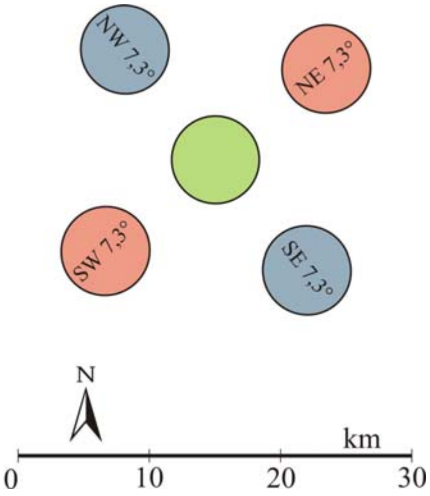


Beam steering features

- selectable beam widths e.g. 6.6°, 13.8° (1HPFW)
- preferred tilting angles: 7.3°, 17.2°
- preferred azimuth directions: NW, SE, NE, SW
- point-to-point coplanar beam steering

Operation mode	**Parameter**
Doppler beam steering	• Wind • Electron density • Energy dissipation rate • Momentum flux
Spaced Antenna	• Wind
Meteor	• Wind (90-110 km)

Doppler experiment configuration for ε determination

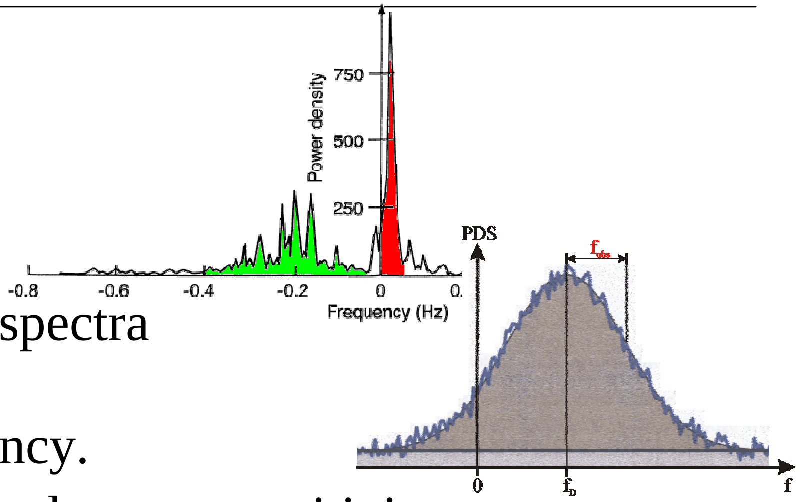


Illuminated areas in 85km

Beams	**SE-NW**	**SW-NE**	**vertical**
PRF [Hz]	80	80	80
Polarisation	O	O	O/X
Pulse width [μs]	10	10	10
Coherent integrations	2	2	2
Range [km]	40 – 103	40 – 103	40 – 103
Sampling res. [m]	1000	1000	1000
Data points / beam + polarisation	3500	3500	3500
Time series / beam [s]	175	175	175
Δt [ms]	50	50	50
Δf [Hz]	0.057	0.057	0.057
Nyquist frequency	10	10	10
Δv_{rad} [m/s]	0.27	0.27	0.27

Algorithm for determination of turbulent energy dissipation rates

(Hocking, *JATP*, 1983)



1. Determination of spectra from observed time series.
2. Selection of useful spectra
   - Effect of Fresnel reflections (spikes)
   - Peak selection in case of multi peak spectra
3. Gauss-fit and determination of spectral width (σ_{obs}) and Doppler frequency.
4. Determination of Doppler wind profile and aspect sensitivity.
5. Accurate determination of „non-turbulent“ spectra (σ_{corr}) by means of **background wind field** and **wind gradient**, **antenna radiation pattern**, **pulse form** and **aspect sensitivity**.
6. Correction of observed spectral width.
7. Determination of mean turbulent velocity.
8. Determination of turbulent energy dissipation rate. (ω_B from temperature climatology [Lübken,1999]).

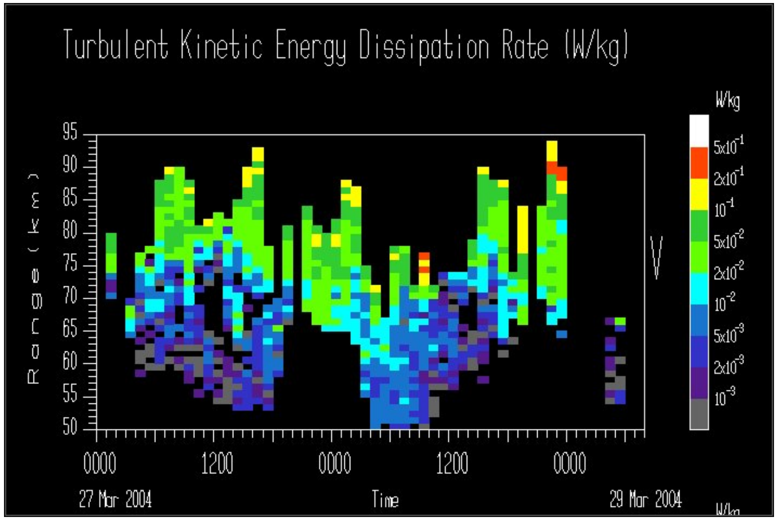
$$\sigma_{turb}^2 = \sigma_{obs}^2 - \sigma_{corr}^2$$

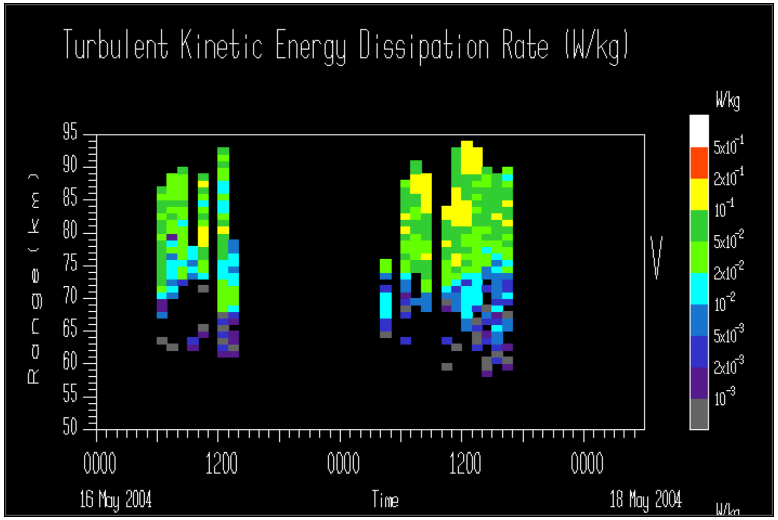
$$v_{RMS}^2 = \frac{\sigma_{turb}^2}{2 \cdot \ln(2)}$$

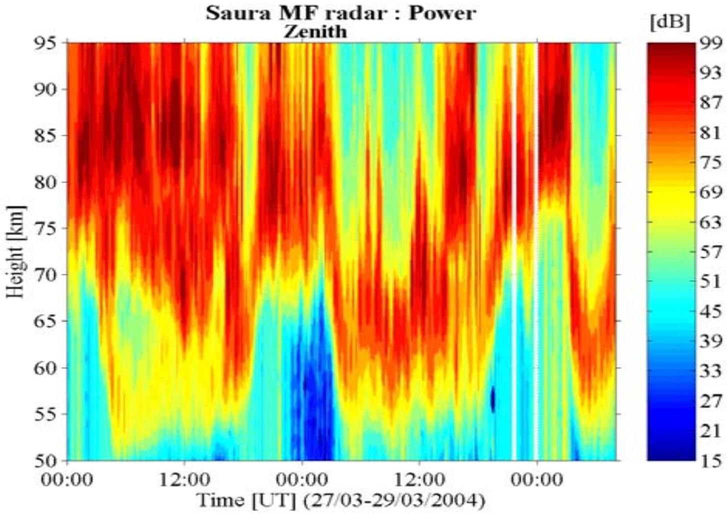
$$\varepsilon_{turb} \approx c \cdot v_{RMS}^2 \cdot \omega_B$$

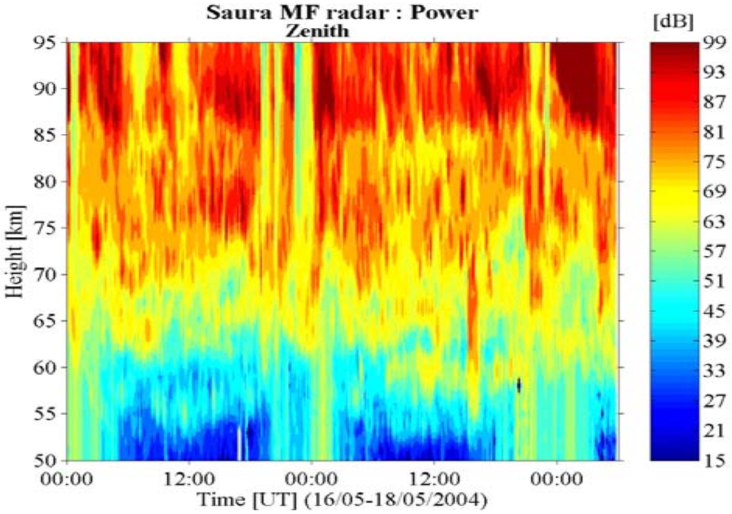
Continuous determination of energy dissipation rates

http://alwinda.rocketrange.no/SauraMF/MARDOC/edr.html

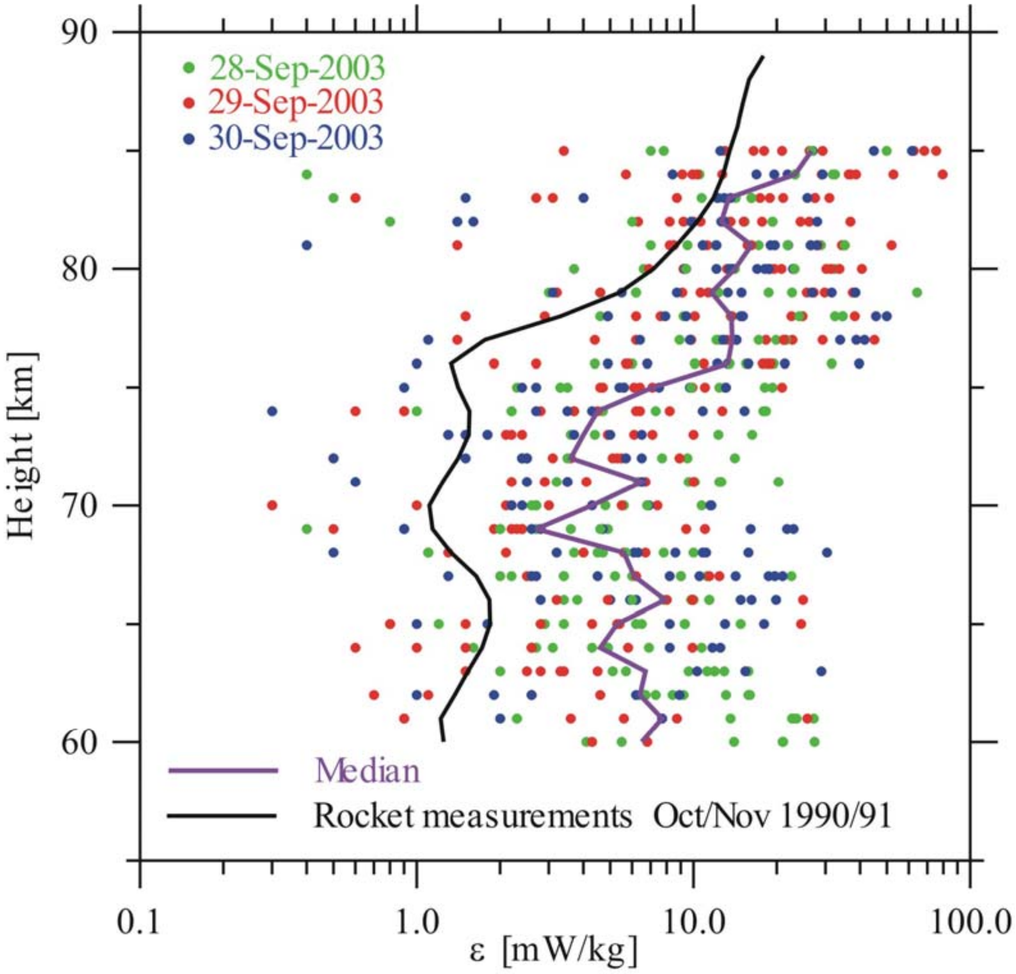






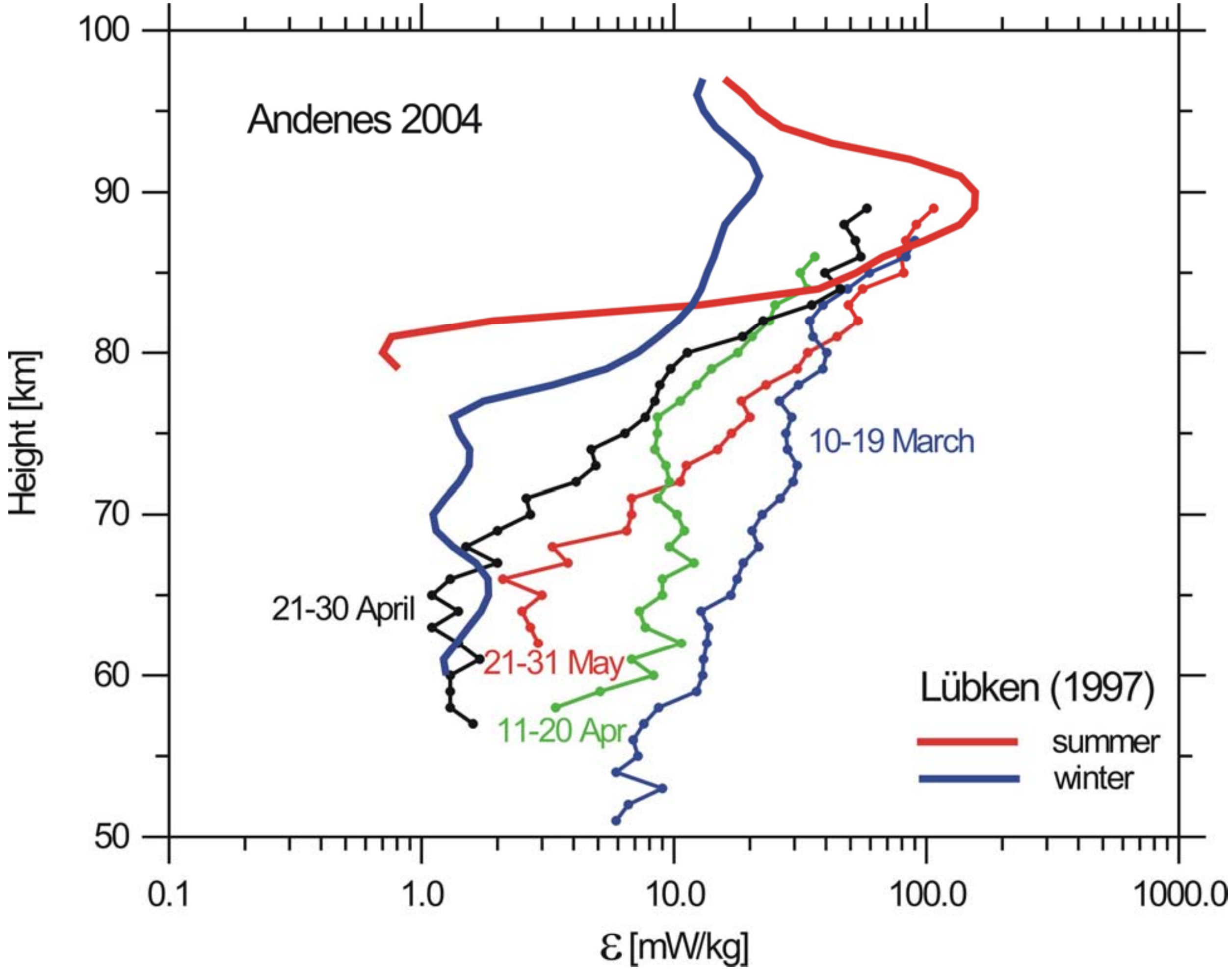


Comparison with climatological mean based on in-situ measurements from rocket soundings



- Hourly mean values (mainly daytime due to external interference at night)
- Brunt-Väisälä frequency from falling sphere temperature climatology at Andenes [Lübken,1999]
- In agreement with in-situ measurements

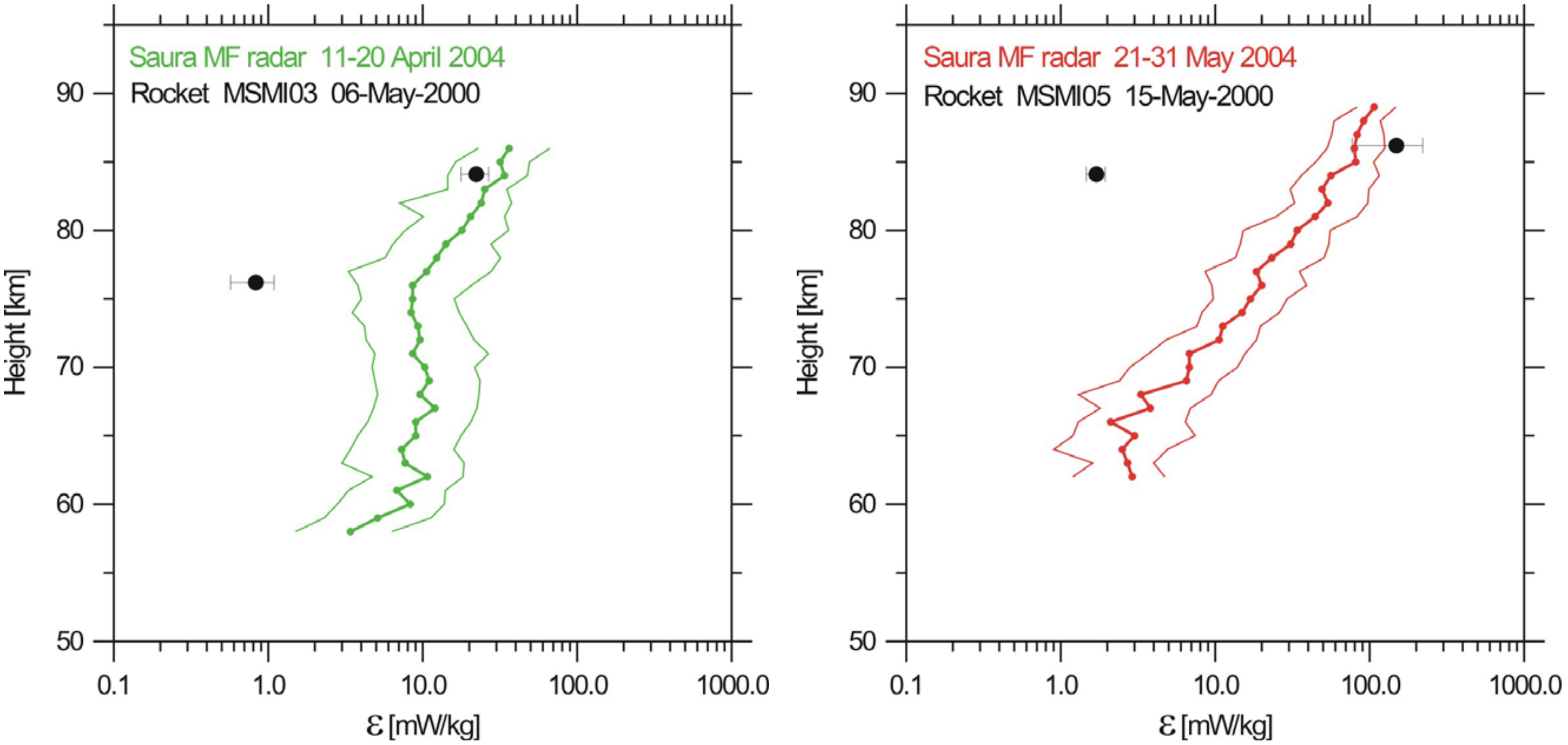
Spring time transition (1)



- 10 days medians of hourly mean values
- min. 20 values per height channel
- larger values below 75 km in March/April
- larger values above 80 km in summer

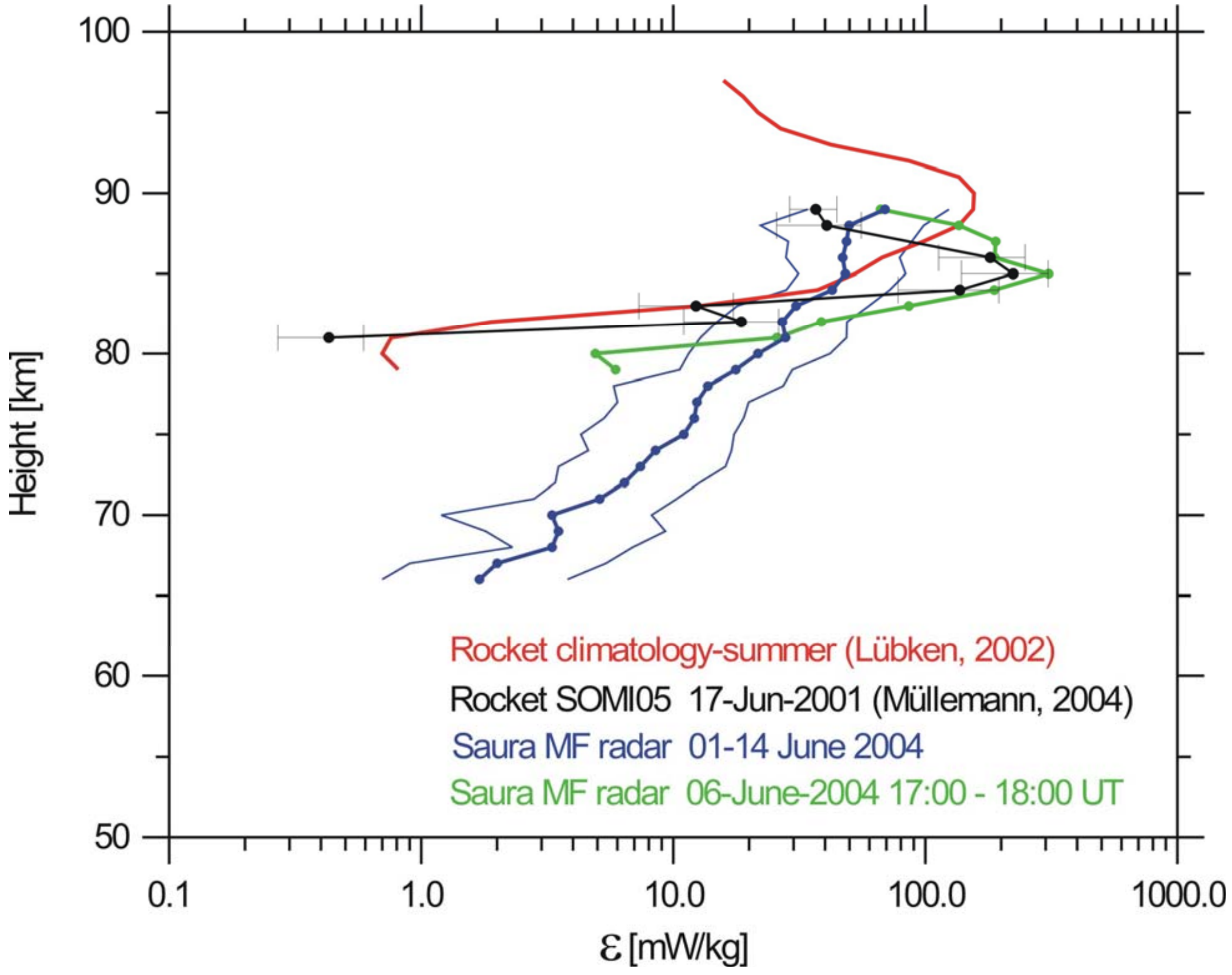
➢ qualitative agreement to rocket climatology

Spring time transition (2)



- Mean ε profiles (medians & quartiles) before and after spring time wind reversal in 2004 compared with rocket soundings at comparable conditions in 2000.

Summer observations



Note:

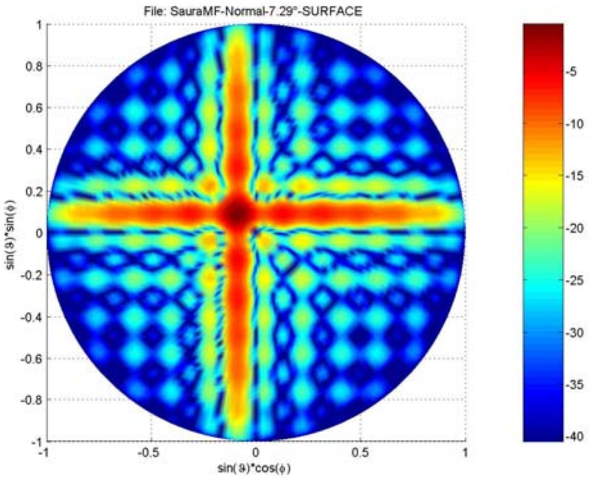
- green - 1 hour mean profile of max. ε derived from radar measurements in June 2004
- black – ε derived from SOMI05 on 17.06.2001

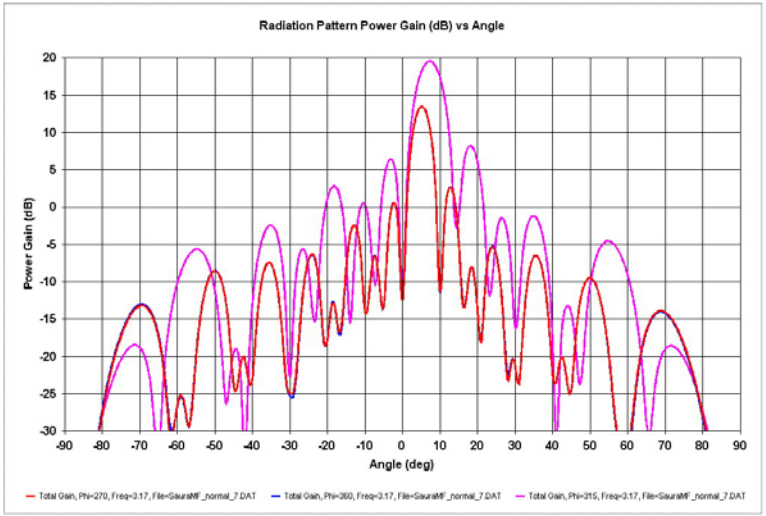
Summary

- The new Saura MF radar allows flexible beam steering and beam forming.
- An exact method for the determination of the non-turbulent contribution to the spectral width was implemented and allows a continuous real-time determination of turbulent energy dissipation rates under undisturbed measurement conditions.
- The energy dissipation rates vary in the order of 2 to 10 mW/kg at 70 km and between about 30 and 200 mW/kg at 85 km.
- Radar estimates are in agreement with results from rocket measurements.

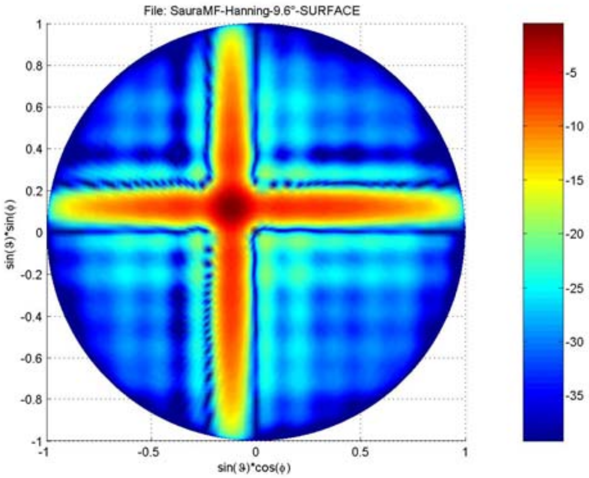
Outlook

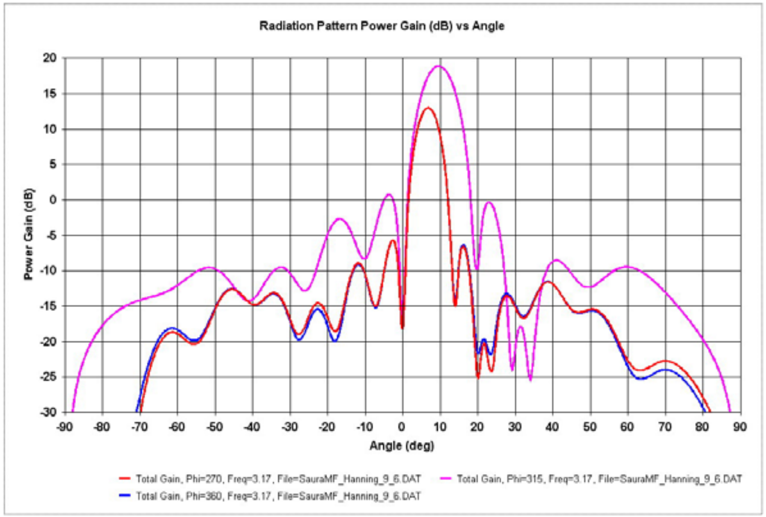
Tapering of polar diagram for side lobe reduction





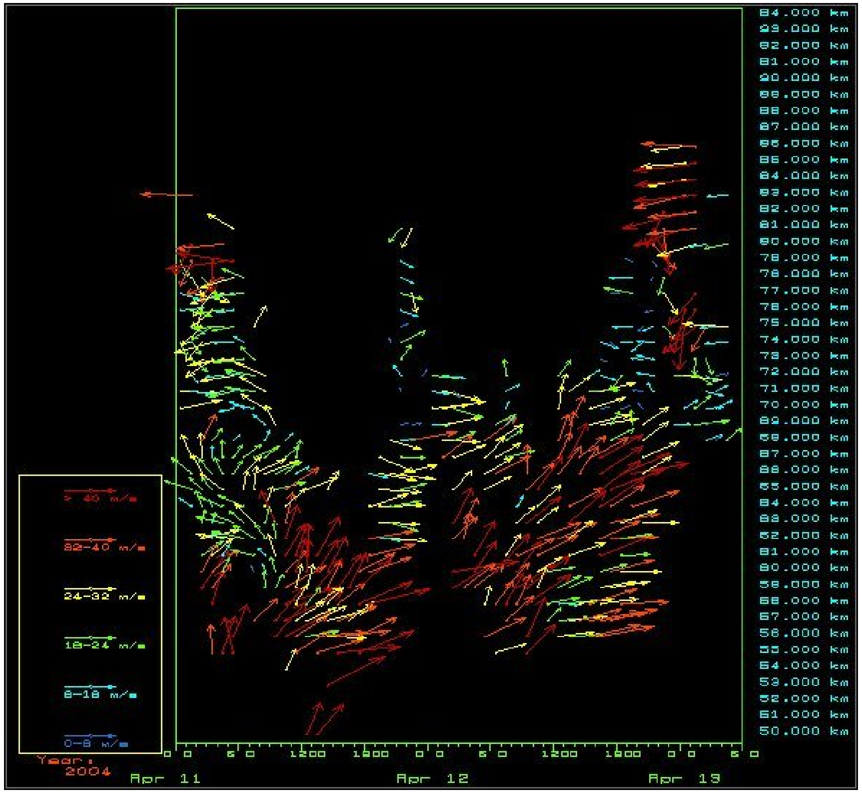
- non tapered
- 7.3° off-zenith





- $\cos^2$ tapered
- 9.6° off-zenith

Wind velocities before and after spring time wind reversal 2004



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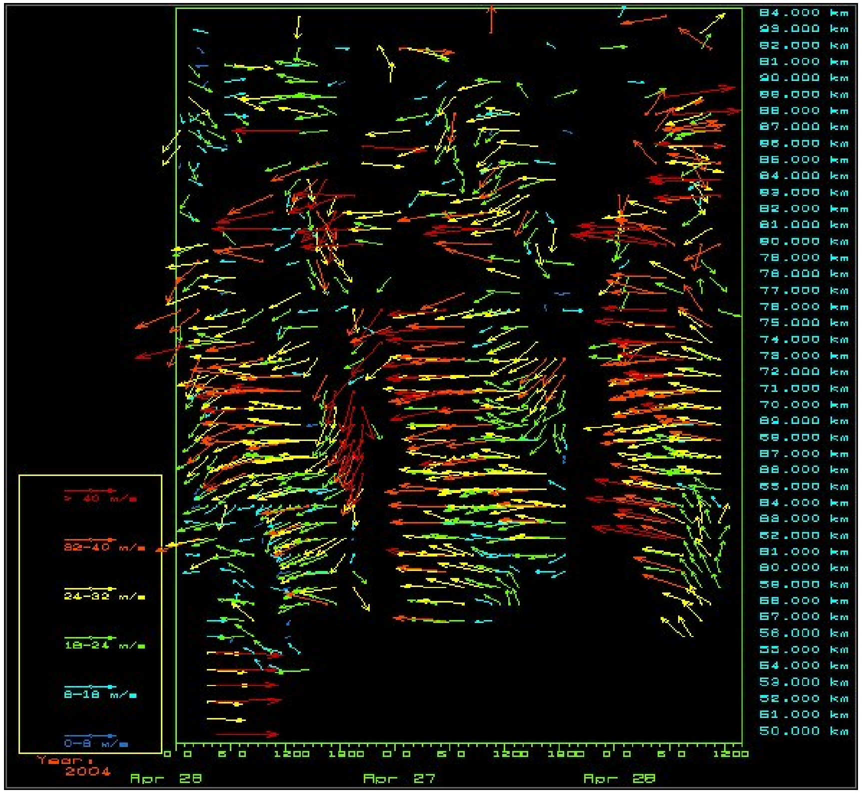

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