Seasonal variation of turbulent energy dissipation rates in the northern polar mesosphere using spectral width measurements at 3MHz

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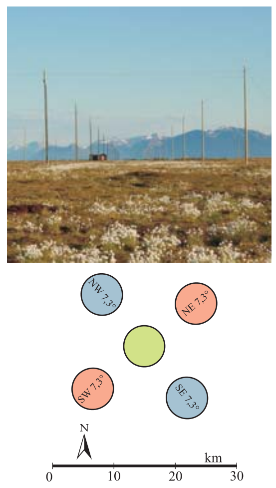
Introduction

Turbulence is a heat source in the mesosphere and lower thermosphere and is also important for diffusive processes. It transfers potential and kinetic energy from medium scales (e.g., 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 10–200 mW/kg which correspond to heating rates of about 1–20 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 and dynamical structure of the atmosphere by 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 or heating (depending on season) due to vertical motion.

The Saura MF radar

Radar system parameter			
Radar frequency / wave length	3.17 MHz / 94,6m		
Peak power	116 kW		
Antenna	29 cross dipoles		
Beam width (HPFW)	6.4°		
Beam directions	vertical, oblique		
Experiment parameters			
Experiment sequence	SE-NW	SW-NE	vertical
Pulse repetition frequency	80 Hz		
Pulse width	10 µs		
Altitude range	40 – 103 km		
Range resolution	1000 m		
Time series per beam	175 s		
Δt	50 ms		
Δv_{rad}	0.27 m/s		



The Saura MF radar operating at 3.17 MHz has been installed close to the Andøya Rocket Range in Andenes, Norway in summer 2002. The main feature of the radar is a Mills Cross transmitting/receiving antenna consisting of 29 crossed half-wave dipoles. The system provides a high flexibility in beam forming and pointing. In general, vertical and oblique beams with a minimum one way half-power full-beam width (HPFW) of 6.6° are used. The observations are usually performed with a height resolution of 1 km and with off-zenith beams at 7.3° directed towards NW, NE, SE, and SW.

The method

Turbulence produces changes in the spectral width of a backscattered radar signal which can be used to deduce turbulent energy dissipation rates at the region of the scatter. The observed spectral width f_{obs} of a received radar signal is defined as the half power half width of its power density spectrum. The radar signal spectrum is also influenced by non-turbulent processes. These contributions $f_{nonturb}$ have to be determined first in order to estimate the turbulent part:

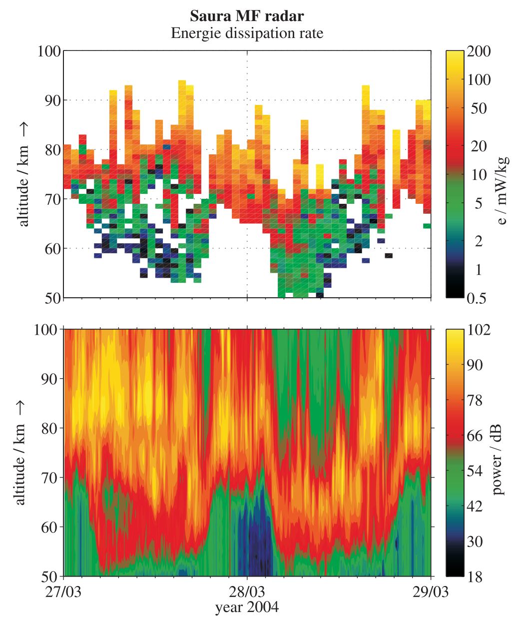
- determination of spectra from observed time series.
- selection of useful spectra
  - removal of specular reflections
  - peak selection in case of multi peak spectra
- Gauss-fit and determination of spectral width (f_{obs}) and Doppler frequency.
- determination of Doppler wind profile and aspect sensitivity.
- determination of non-turbulent contribution $f_{non\text{-}turb}$ to the observed spectral width f_{obs} by means of **background wind field** and **wind gradient, antenna radiation pattern, pulse form** and **aspect sensitivity.** (Hocking, 1983, 2003)
- correction of observed spectral width.

Once the turbulent contribution f_{turb} to the spectral width has been separated it can be converted into the mean square fluctuating velocity v^2_{RMS} and turbulent kinetic energy dissipation rate ε can be derived, where c is a numerical constant of about 0.49 and ω_B is the Brunt-Väisälä frequency.

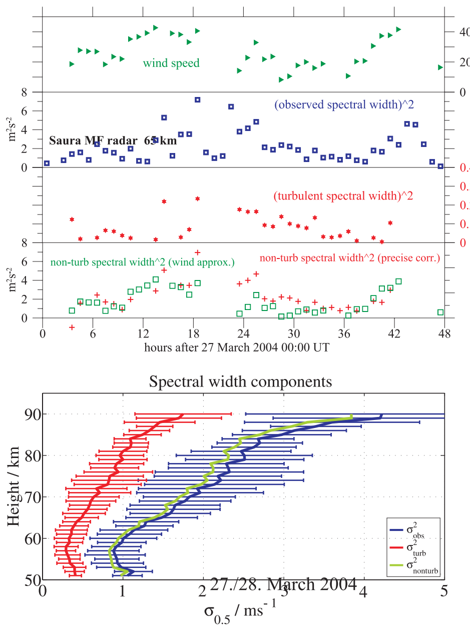
$$f^2_{turb} = f^2_{obs} - f^2_{nonturb}$$

$$v^2_{RMS} = \left(\frac{\lambda}{2}\right)^2 \frac{f^2_{turb}}{2 \cdot \ln(2)}$$

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



Energy dissipationrate and echo power during a period of geomagnetic disturbance with particle precipitation on 27./28. March 2004.

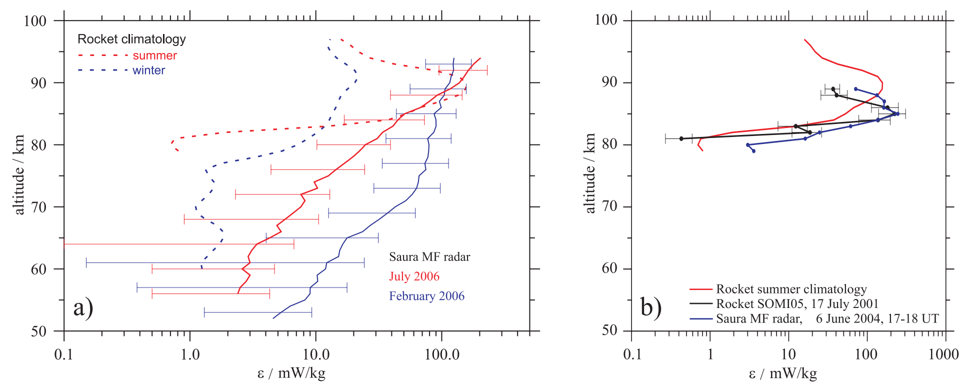


Mean values of the spectral width components expressed in velocity units.

Compassion of radar observations and in-situ measurements

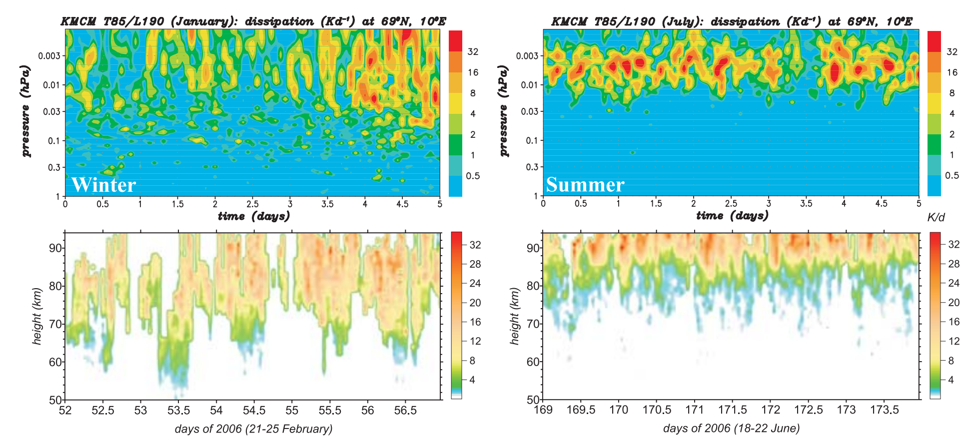
Radar observations have been compared with climatological data of energy dissipation rates from in situ measurements for summer and winter conditions (Lübken, 1999). The mean radar profile of energy dissipation (Figure a, solid lines) are in general agreement with the rocket climatology (dashed lines) whereas the radar data are general larger below 80 km.

Hourly mean profile of ε based on radar data with the largest dissipation rates observed during the first 10 days of June (blue) and a rocket sounding (black, Müllemann et al., 2003) are comparable regarding profile shape and absolute values (Figure b). Note, however, the radar and rocket measurements have been carried out in different years.



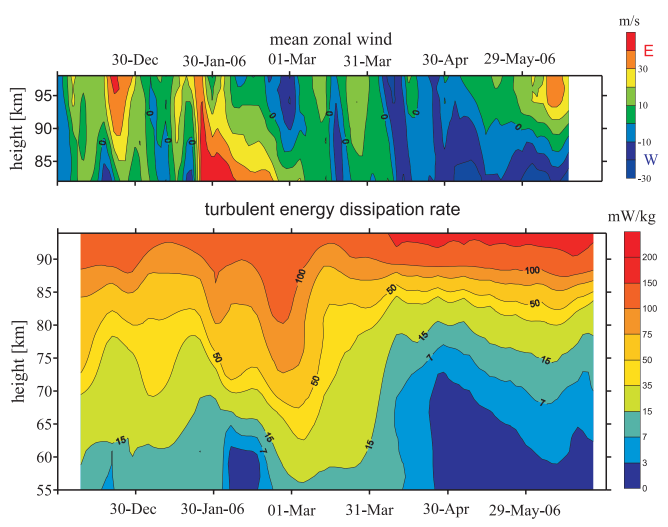
Comparsion of radar observations and model results

The Kühlungsborn Mechanistic circulation model (KMCM) is a simplified general circulation model with high vertical and horizontal resolution in order to describe gravity wave effects explicitly (Becker and Fritts, 2006). KMCM-model runs for winter and summer conditions show a pronounced short time variability of turbulent energy dissipation rates (top panels) comparable to the radar observations. Both data sets are comparable in height/time resolution (Δt~1h, Δh~1 km), the larger dissipation rates are observed above 80 km in summer and below 80 km in winter.



Seasonal variation of turbulent energy dissipation rates

Energy dissipation rates between about 3 mW/kg and up to 50 mW/kg are found at altitudes below 80 km in winter 2005/2006. The dissipation rates decrease to values lower than 7 mW/kg in early summer starting in the middle of April. This reduction is accompanied with the reversal of the mesospheric wind system from eastward directed winds in winter to westward directed winds in summer. The wind reversal changes the propagation conditions for gravity waves which dissipate at higher altitudes in summer resulting in a decrease of turbulence at lower heights.



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