Gravity wave activity and dissipation around tropospheric jet streams

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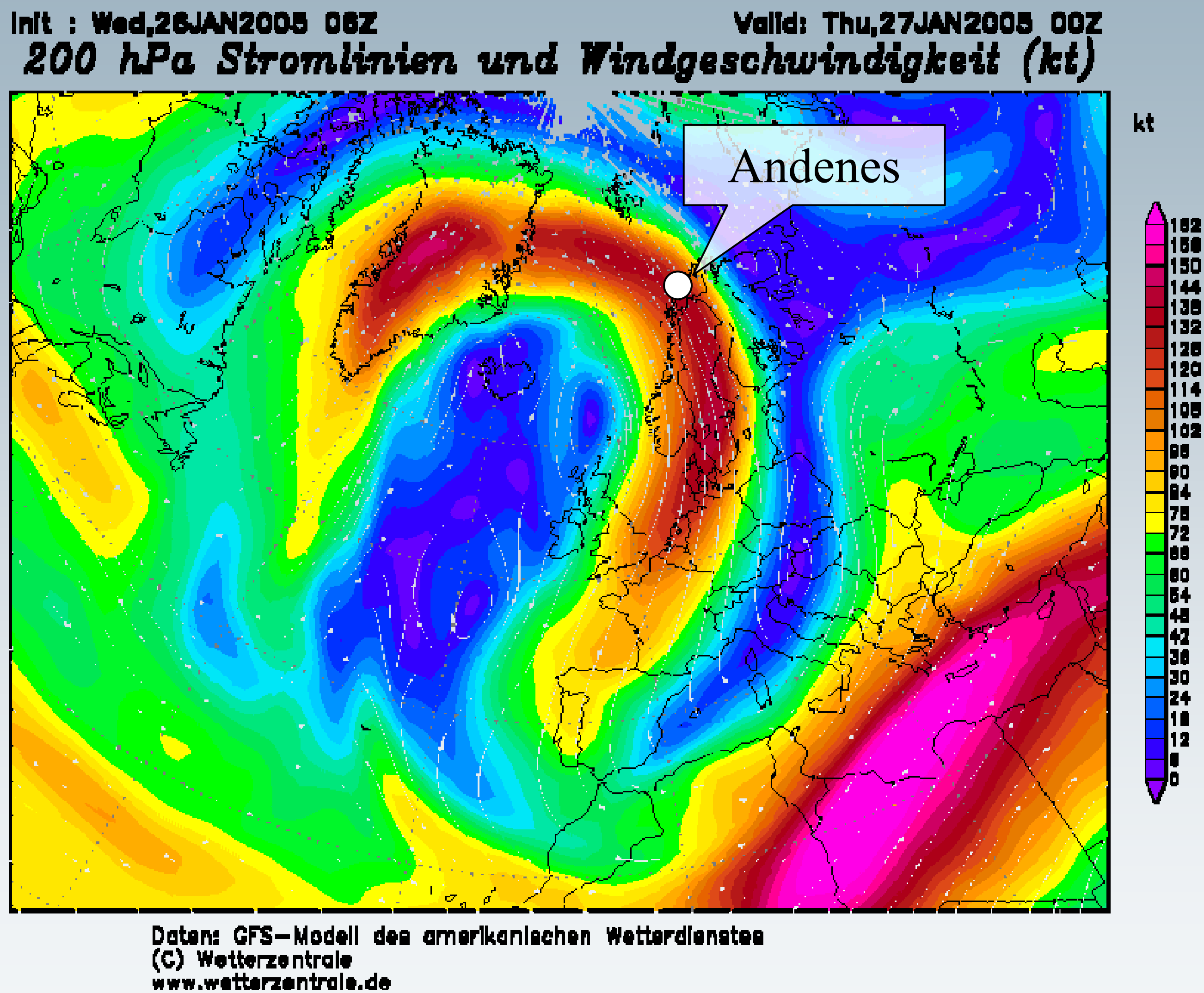
Outline

Study of gravity waves and their dissipation in the troposphere and lower stratosphere in connection with tropospheric jets at Andenes (69°N) in January 2005 using a VHF radar and radiosondes

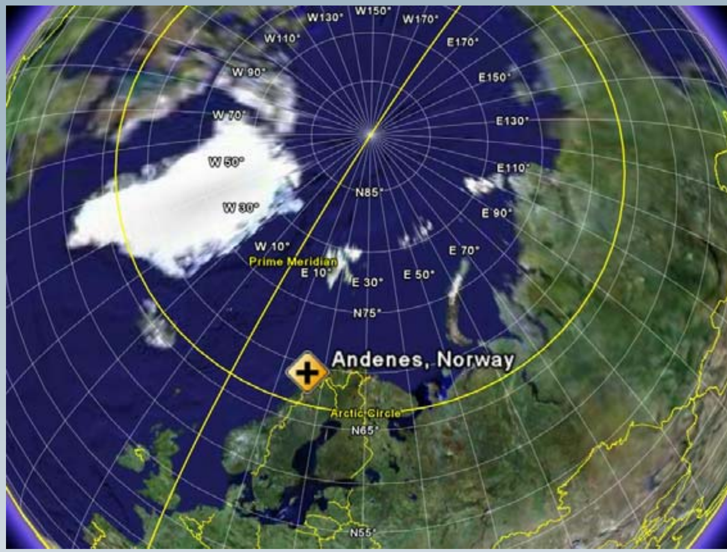
- Estimation of gravity wave parameters
  - wavelengths, periods, energy propagation
- Determination of energy dissipation rates from
  - spectral width of received radar signal
  - absolute echo power of received radar signal
- Discussion of gravity wave propagation and observed turbulent energy dissipation rates

23 – 29 January 2005

strong southeastward directed winds above Andenes



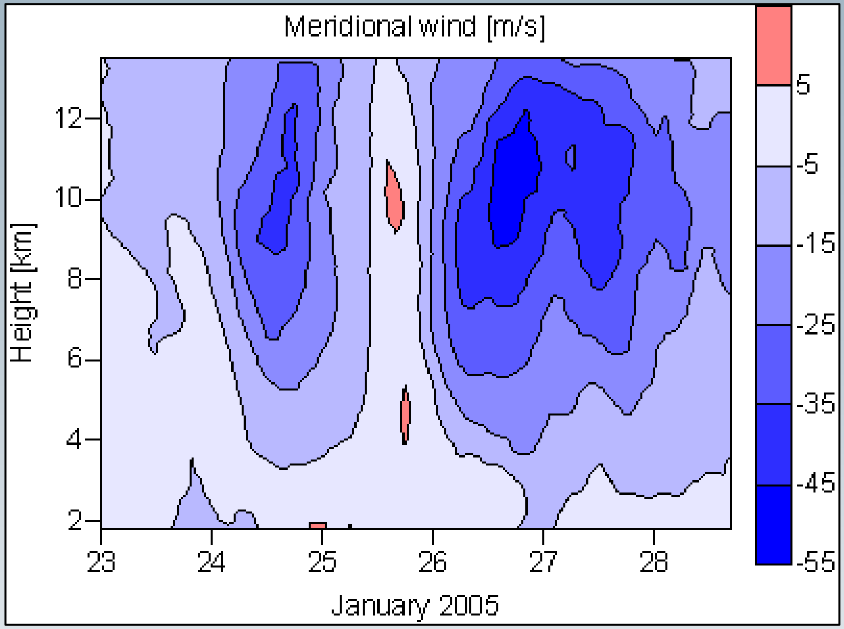
Observations in January 2005

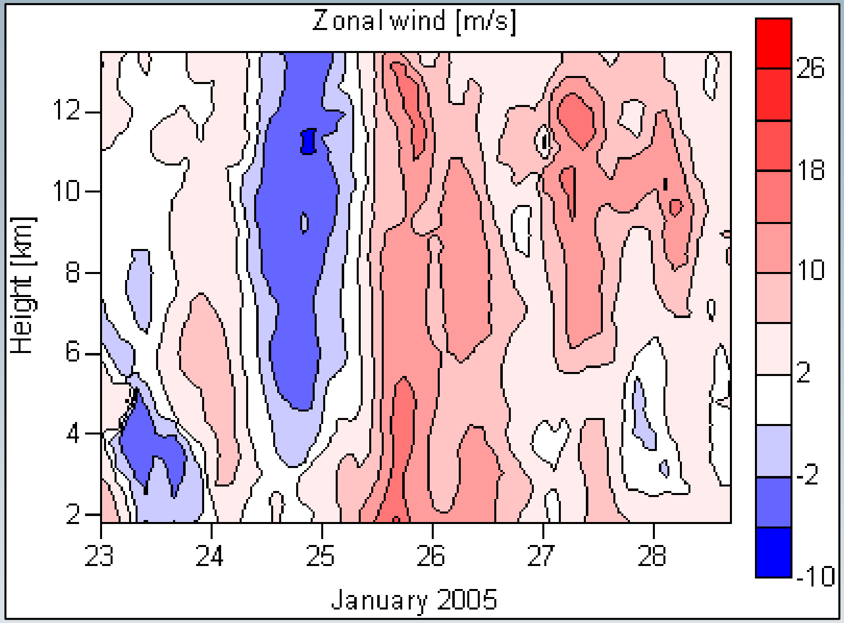


- Andenes (69.2°N; 16.0°E)
- MST radar **ALWIN**
  - backscattered echo power
  - 3D-winds
  - ➢ waves, dissipation rates
  - altitude range: 1 – 16 km
  - resolution: 300m, 2min
- Radiosonde launches
  - horizontal winds, temperature

ALWIN MST radar	
Radar frequency	53.5 MHz
Peak power	36 kW
Pulse width	600m
Range resolution	300m
Altitude range	1 – 16 km, 50 – 114 km
Operation modes	DBS, SA
Half power beam width	6.0°
Beam directions	Vertical, 4 off-zenith

23 – 29 January 2005
horizontal wind components from ALWIN VHF radar





- two southward directed jets at tropopause altitudes
- weak low level jet at around 3 km on 25 January 2005
  - mountain waves
- ➢ gravity wave analysis for selected periods

Gravity Wave Parameters

- observed frequency ω_{ob}
- vertical wavenumber m
- ratio of the polarization ellipse R
- Coriolis parameter f
- Brunt - Väisällä frequency N
- mean horizontal wind components || and ⊥ to the wave propagation $\overline{U}$ and $\overline{V}$

↓

$$R = \left| \frac{f}{\omega_{in}} - \frac{k}{m\omega_{in}} \frac{\partial \overline{V}}{\partial z} \right| \qquad \omega_{in}^2 = f^2 + \frac{N^2 k^2}{m^2} - \frac{2fk}{m} \frac{\partial \overline{V}}{\partial z} \qquad \omega_{ob} = \omega_{in} + \overline{U}k$$

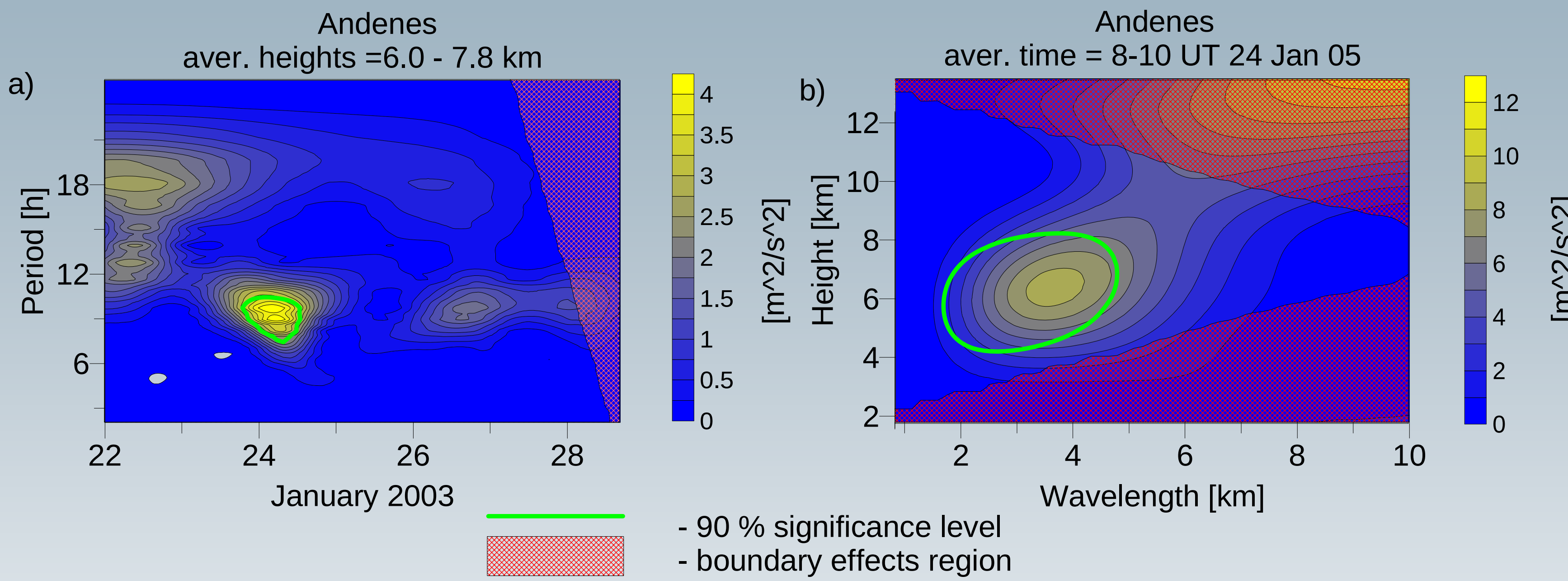
↓

- intrinsic frequency ω_{in}
- horizontal wavenumber k

- Phase velocity υ_{ph}, υ_{pz}
- Group velocity c_{gh}, c_{gz}

Case 1: **24 January 2005**

Wavelet transform



Wavelet spectra applied to the meridional winds for periods < 20 h

a) wavelet transform of the time series averaged over the altitude ranges 6 – 7.8 km

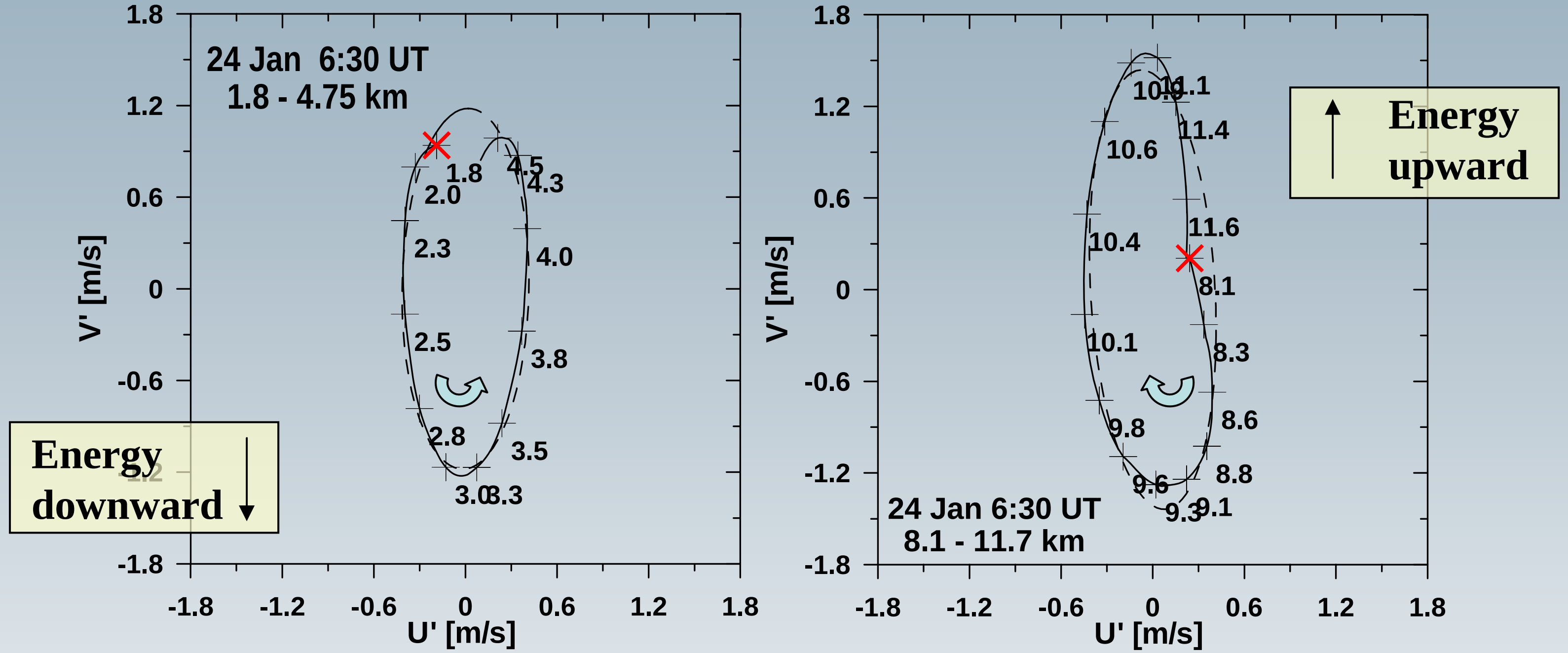
- ➢ **wave with observed periods of ~ 7 - 11 hours on 24 January**
- ➢ **typical for inertia gravity waves**

b) wavelet transforms of vertical profiles of meridional winds

- ➢ **waves with vertical wavelengths of 3 – 4 km**

Case 1: **24 January 2005**

Hodograph wave analysis



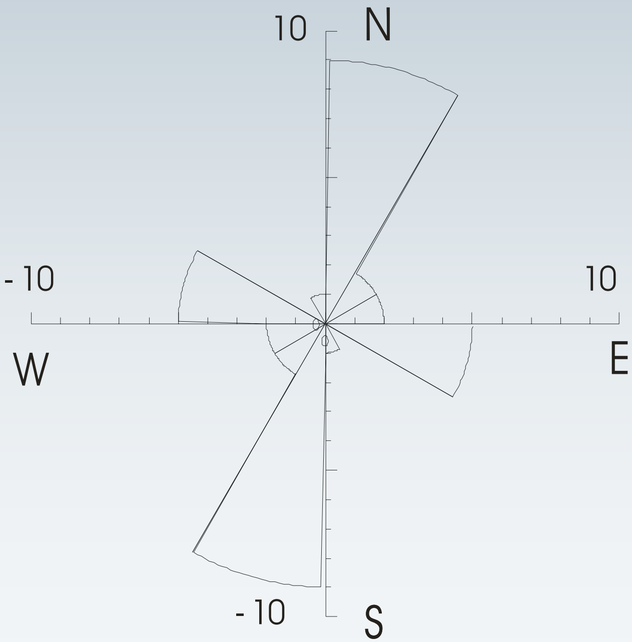
- applied to radar measurements on 24.01.05, 06:30 UT
  - solid line: measured profiles
  - dashed line: fitted ellipse,
  - X starting point of the hodograph)
- Results
  - ➢ wave propagate north ↔ south
  - ➢ change in the vertical propagation direction at about 5 km

Case 1: **24 January 2005**

Gravity wave parameters above 6 km

Observed period	T_{ob} [h]	**10**
Intrinsic period	T_{in} [h]	**2.4**
Horizontal wavelength	L_h [km]	**71**
Vertical wavelength	L_z [km]	**3.8**
Horizontal phase velocity	v_{ph} [m/s]	**8.2**

Vertical phase velocity	v_{pz} [m/s]	**0.4**
Horizontal group velocity	v_{gh} [m/s]	**7.9**
Vertical group velocity	v_{pz} [m/s]	**-0.4**

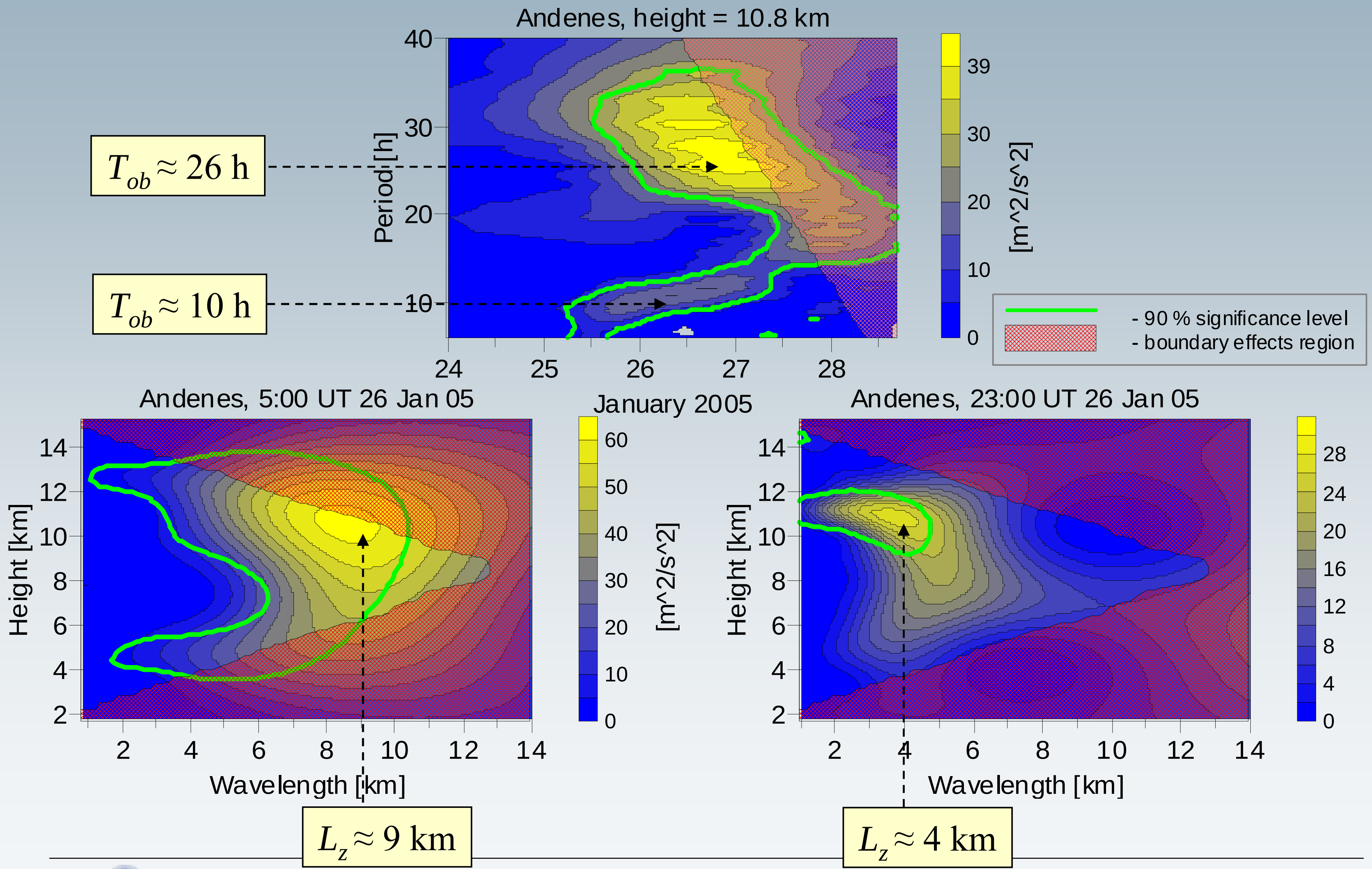


Mean propagation direction, derived from Stokes analysis

Compare hodograph !

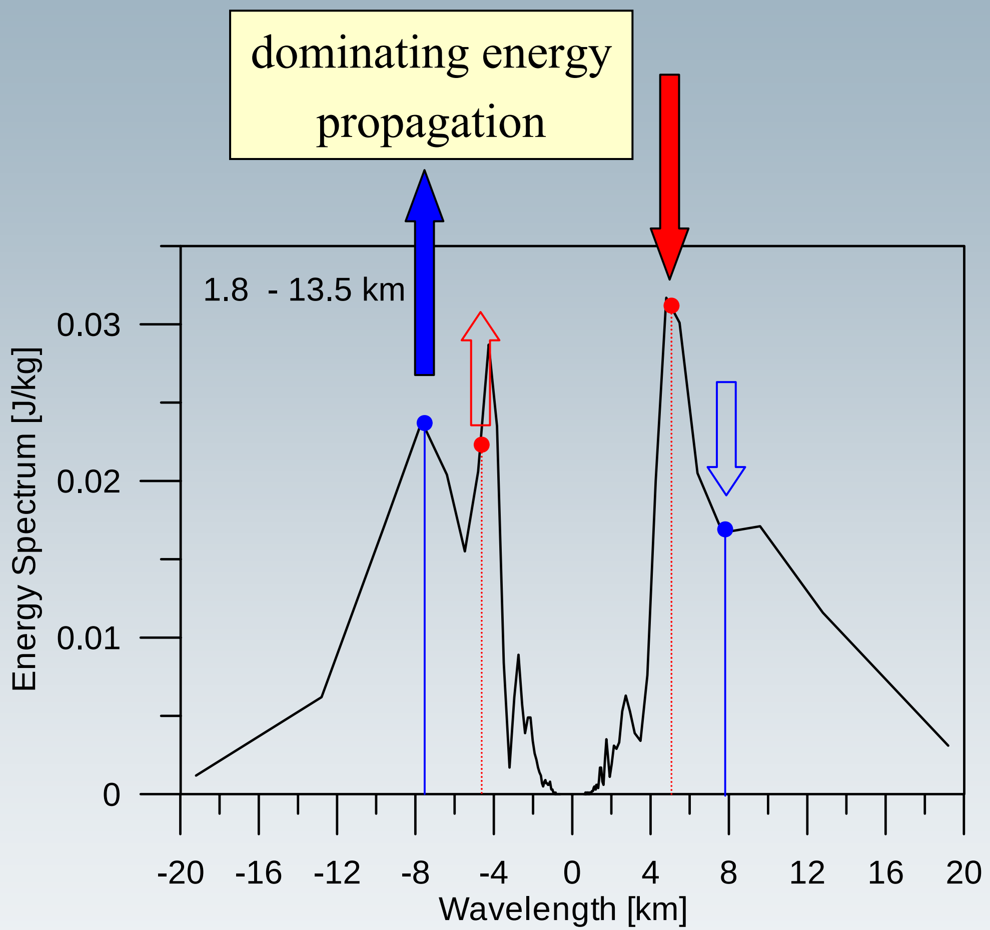
Case 2: **26 January 2005**

Wavelet transform



Case 2: **26 January 2005**

Wave analysis and gravity waves parameters

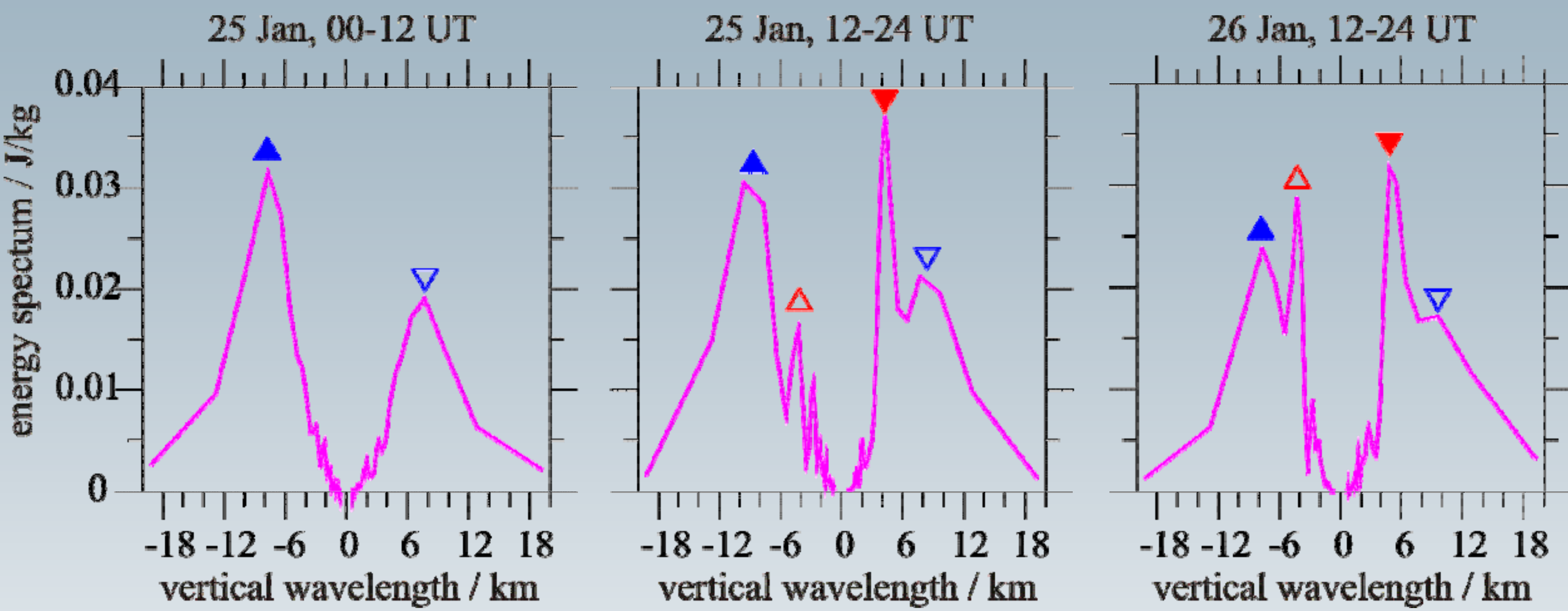


Gravity Waves Parameters		
Degree of wave polarization		0.80
Ellipse axial ratio		0.16
Direction of horizontal propagation	**Θ [°]**	-30°
Observed period	**T_{ob} [h]**	10.7
Intrinsic period	**T_{in} [h]**	3.0
Horizontal wavelength	**L_h [km]**	-92
Vertical wavelength	**L_z [km]**	4.0

- spectra averaged for 12 h starting on 26.01.03, 12:00 UT
- gravity waves with vertical wavelengths of 3–6 km and >7 km are present between 1.8 km and 13.5 km

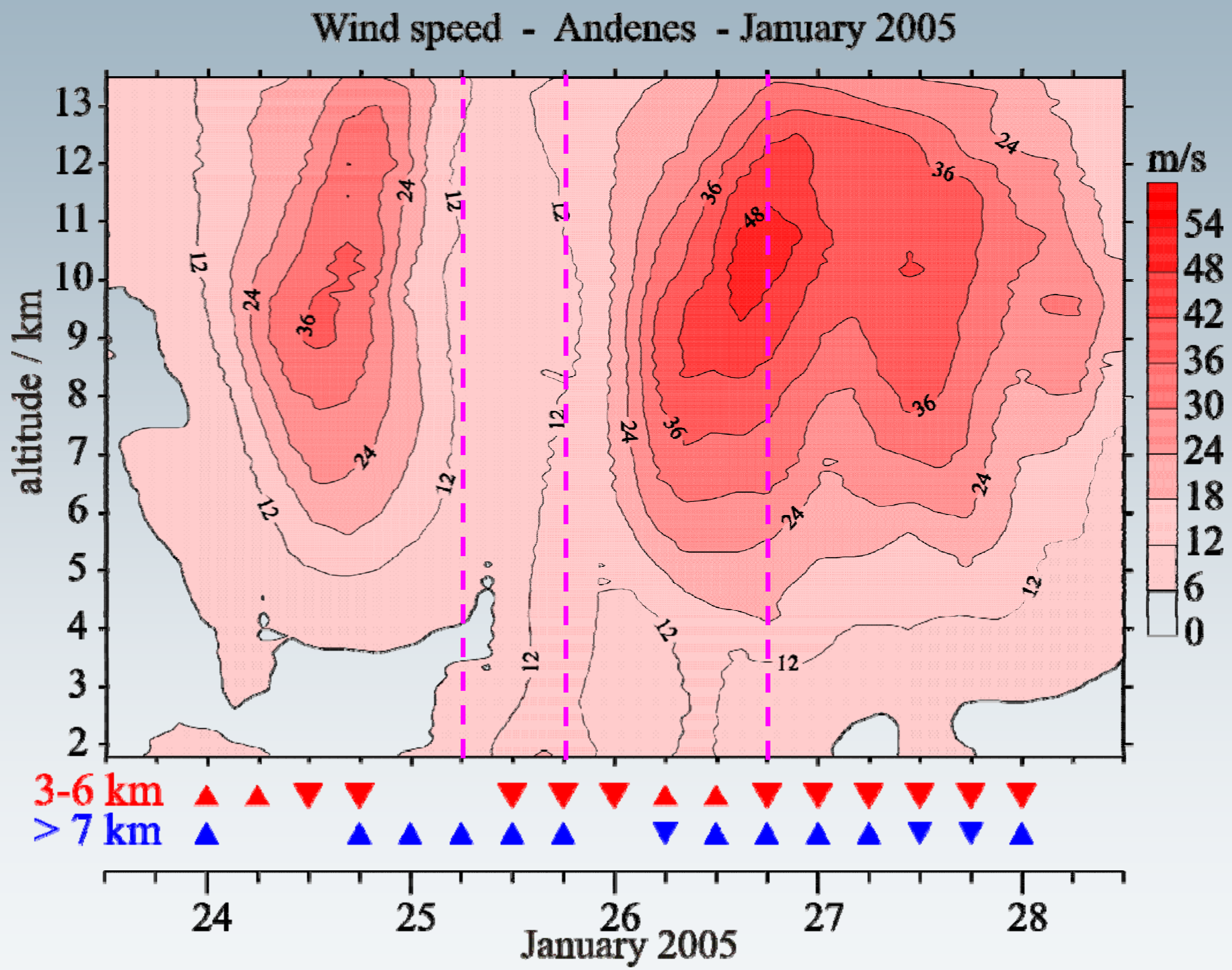
Mean rotary spectra

height range 1.8 – 13.5 km

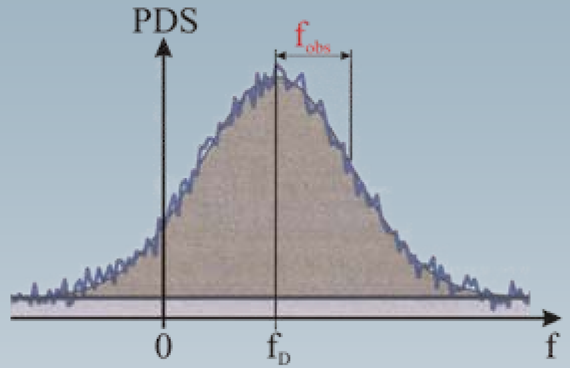


- mean rotary spectra (12hrs averaged) shifted by 6 hrs
- no gravity waves with a vertical wavelengths of 3–6 km were observed in absence of jets above Andenes
- gravity waves with vertical wavelengths > 7 km are characterised by a predominant upward directed energy propagation ▲
- gravity waves with vertical wavelengths of 3–6 km and downward directed energy propagation ▼ dominated in times of full developed jets above Andenes

Wind speed and dominating energy propagation of GW derived from 12 hrs averaged spectra



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



Observed spectral width

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

$$\sigma_{obs}^2 = \sigma_{turb}^2 + \sigma_{non-turb}^2$$

- accurate calculation of spectral beam broadening ($\sigma_{non\text{-}turb}$) by means of **background wind field** and **wind gradient**, **antenna radiation pattern**, **pulse form** and **aspect sensitivity**

Hocking, *JATP* 1983,
Hocking, MST10 proceedings

Mean fluctuating velocity

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

Turbulent kinetic energy dissipation rate

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

c = 0.4
ω_B = Brunt-Väisälä frequency from radiosondes

Determination of turbulent kinetic energy dissipation rate from absolute power P_r of a received radar signal

Hocking, *Radio Science*, 1985
Cohn, *JAOT*, 1995

$$\eta = \frac{P_r \cdot 128 \cdot \pi^2 \cdot 2 \cdot \ln(2) \cdot r^2}{P_t \cdot G_t \cdot G_r \cdot \lambda^2 \cdot e \cdot \Theta^2_{1/2} \cdot c \cdot \tau}$$

Volume reflectivity

$$\eta = P_r \cdot c_{sys} \cdot r^2$$

P_r [W] $\rightarrow$ absolute calibration !

Turbulent refractivity structure constant

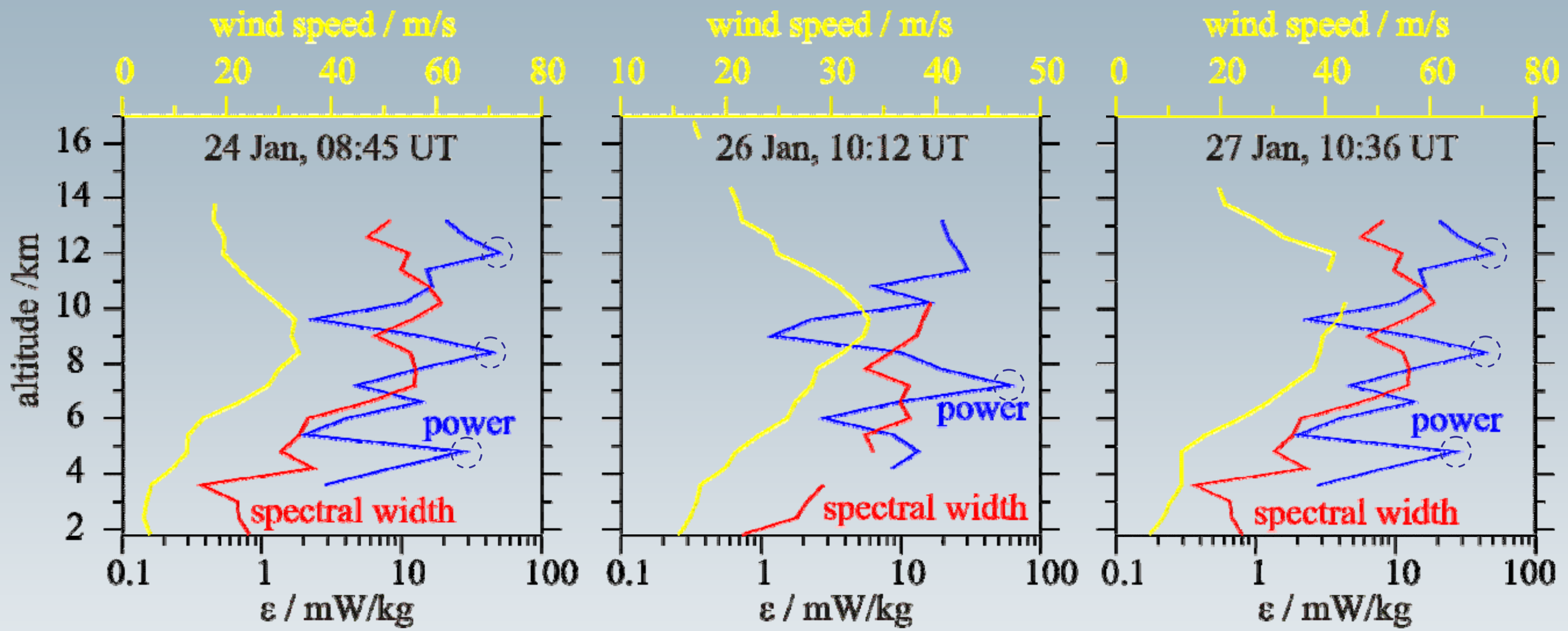
$$C_n^2 = \frac{1}{0.38} \cdot \eta \cdot \lambda^{1/3}$$

Turbulent kinetic energy dissipation rate

$$\overline{\varepsilon}_{turb} = \left(1.43 \cdot C_n^2 \cdot \omega_B^2 \cdot M^{-2} \cdot F^{-1}\right)^{\frac{2}{3}}$$

M = generalized potential refractive index gradient $= -77.6 \cdot 10^{-6} \cdot \frac{P}{T \cdot g} \cdot \omega_B^2$
ω_B = Brunt-Väisälä frequency
P = pressure
T = Temperature
g = acceleration due to gravity
F = volume fill factor = 1

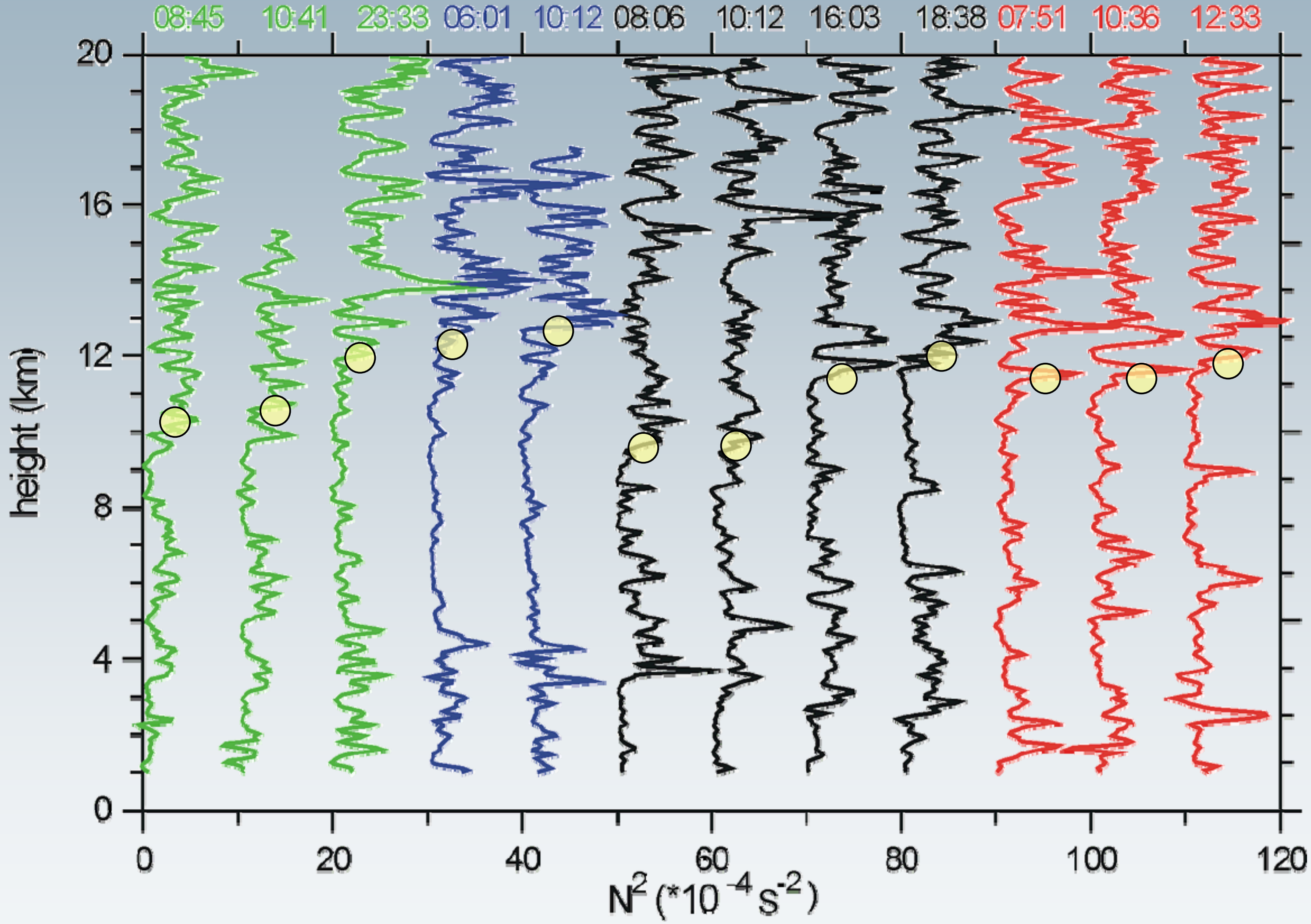
Turbulent kinetic energy dissipation rates derived with different methods



- radar volume filled with turbulent scatterers (F=1) is assumed
- Brunt-Väisälä frequency from simultaneous radiosonde sounding
- disturbed power profiles due to external interference ◌
- turbulent energy dissipation rate profiles from both methods are in good agreement
- turbulence generation at altitudes of wind gradient

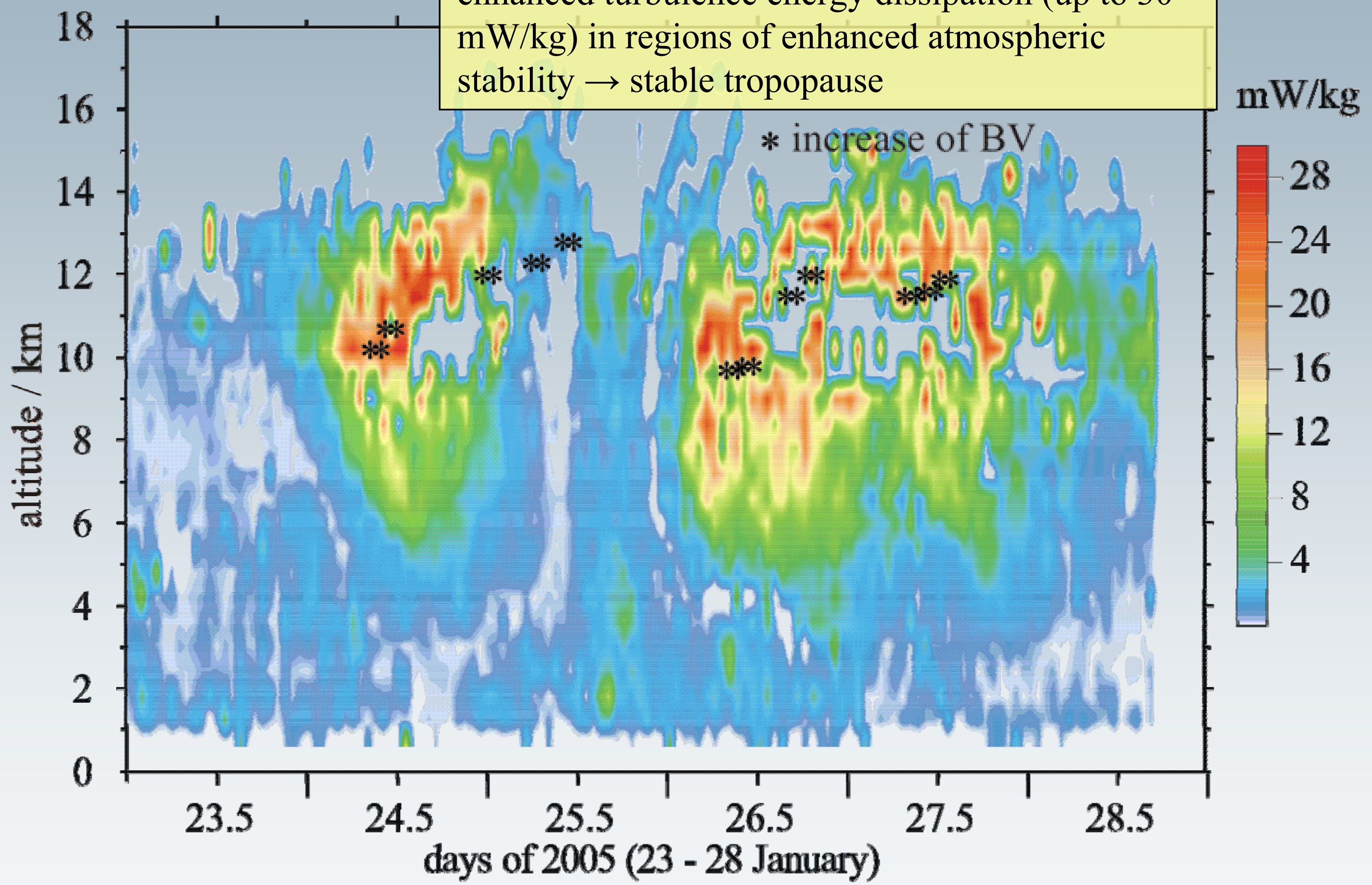
Brunt-Väisälä frequency from GPS radiosondes

24 – 25 – 26 – 27 January 2005



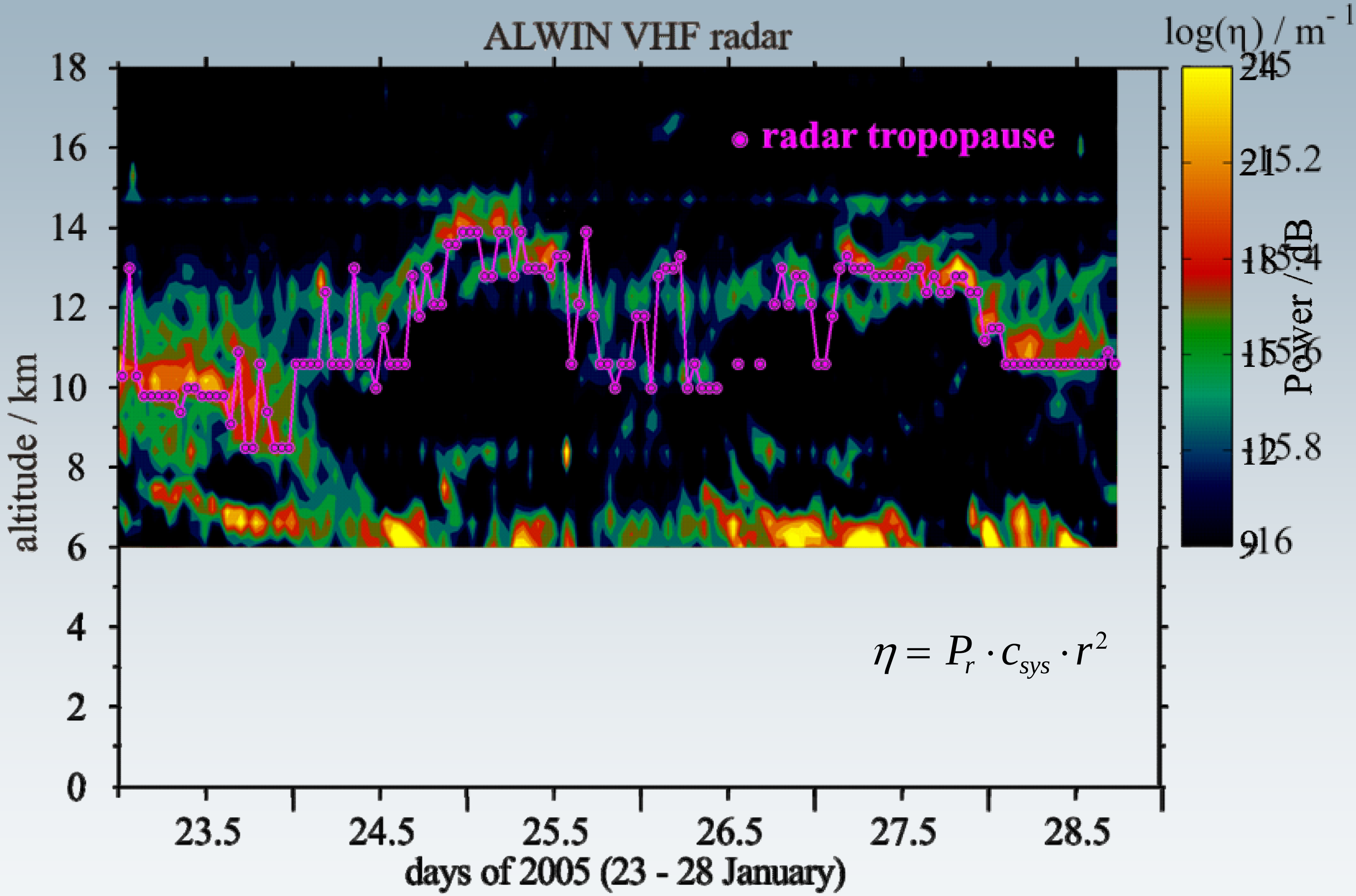
Turbulent energy dissipation rates from spectral widths

enhanced turbulence energy dissipation (up to 30 mW/kg) in regions of enhanced atmospheric stability → stable tropopause



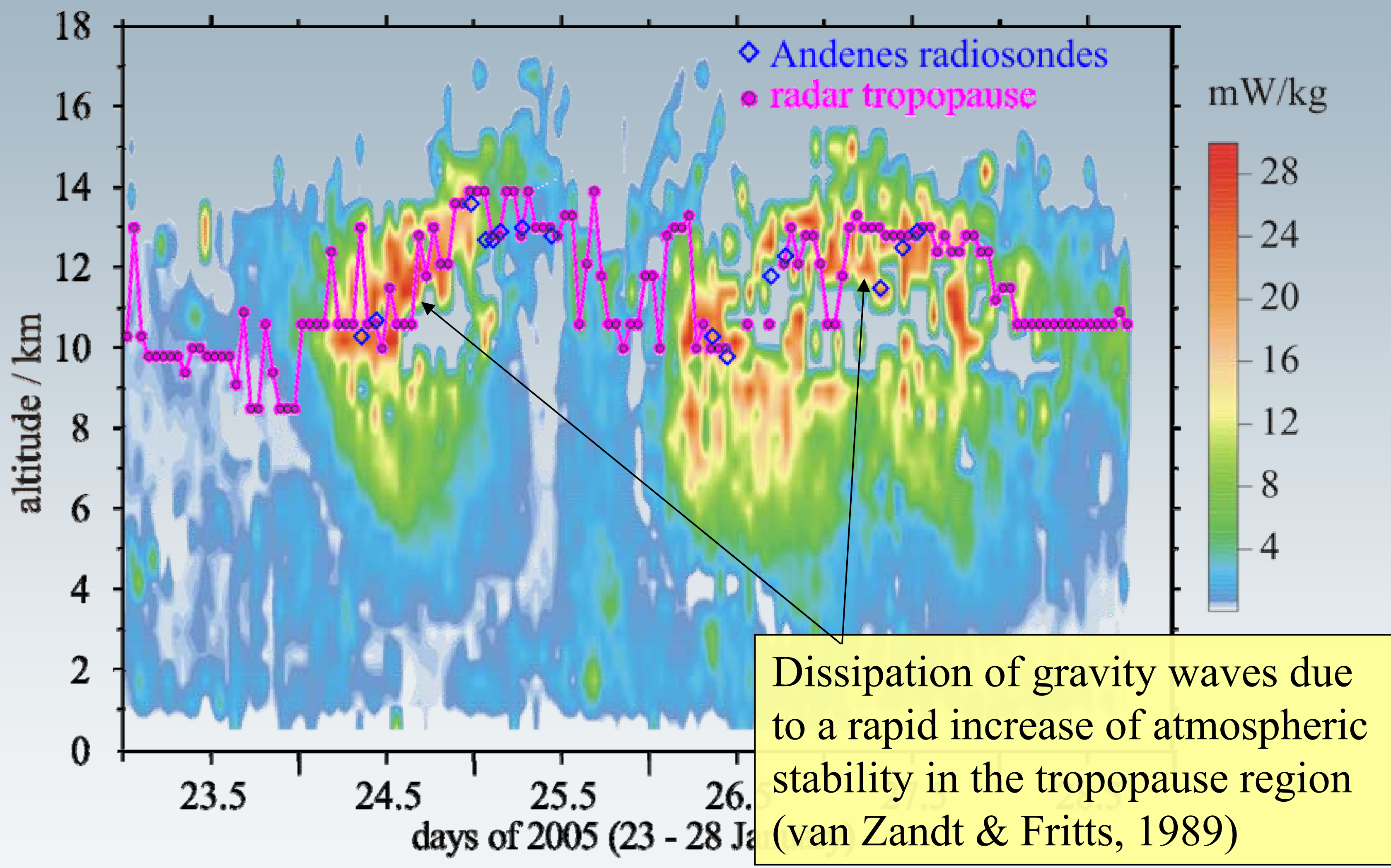
Estimation of the radar tropopause

based on Gage/Green 1985



$$\eta = P_r \cdot c_{sys} \cdot r^2$$

Tropopause altitude and energy dissipation



Dissipation of gravity waves due to a rapid increase of atmospheric stability in the tropopause region (van Zandt & Fritts, 1989)

Summary

- VHF radar measurements and radiosonde soundings performed during the passage of tropospheric jet streams with core wind speeds up to 110 m/s have been analysed
  - gravity waves with vertical wavelengths of 3-4 km and > 7 km have been identified
  - short period waves were generated during jet passages
  - a stable tropopause around 12 km has been detected

- turbulent energy dissipation rates derived from
  - the spectral width of the received radar signal and
  - the absolute echo power of received radar signal

  are in good agreement

- enhanced turbulence energy dissipation (up to 30 mW/kg) was observed in regions of enhanced atmospheric stability around a stable tropopause of about 12 km
  - dissipation of gravity waves due to a rapid increase of atmospheric stability in the tropopause region (van Zandt & Fritts, 1989)