Gravity wave observations by Rayleigh lidar: extreme events, downward propagation, AMTM comparisons and coupling to tides

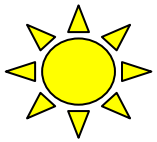
Activities of the DLR lidar group during DEEPWAVE and beyond

Natalie Kaifler, Bernd Kaifler, Benedikt Ehard,
Robert Reichert , Andreas Dörnbrack
and Markus Rapp

Steve Eckermann,
Dominique Pautet,
Mike Taylor

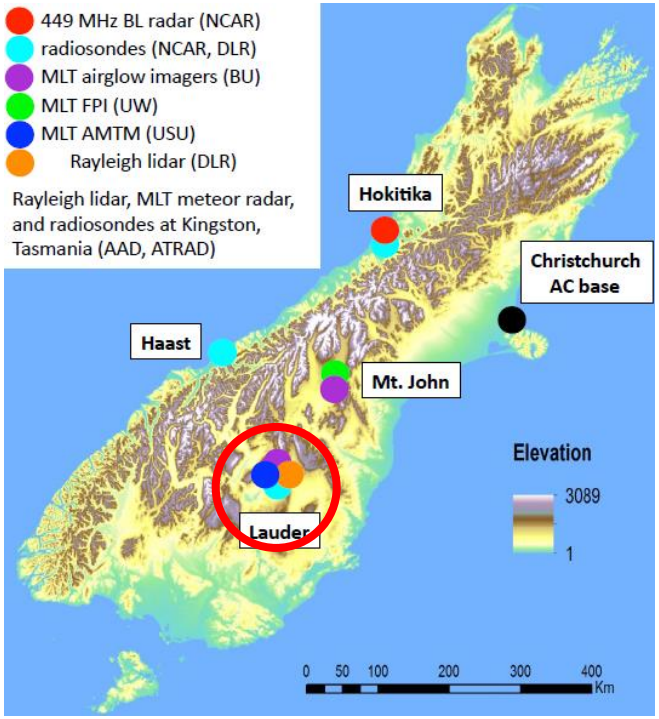
DLR

Quick outline



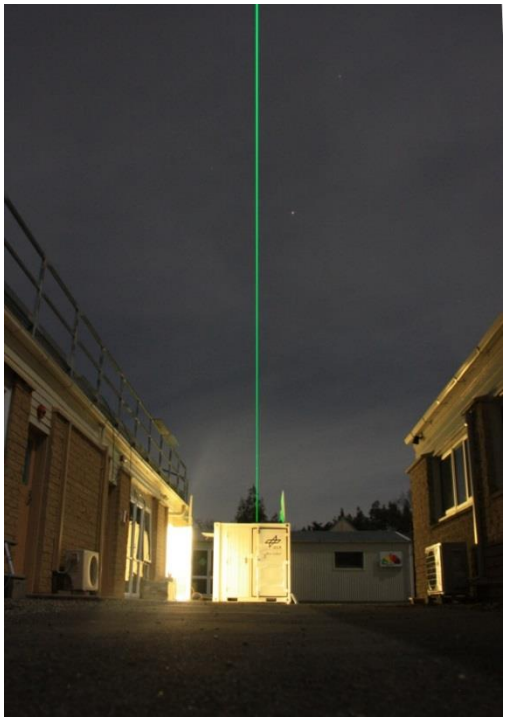
0. About us
1. Extreme events
2. Downward propagating GW waves
3. GW in lidar and AMTM
4. Tides in lidar and NAVGEM

Who we are

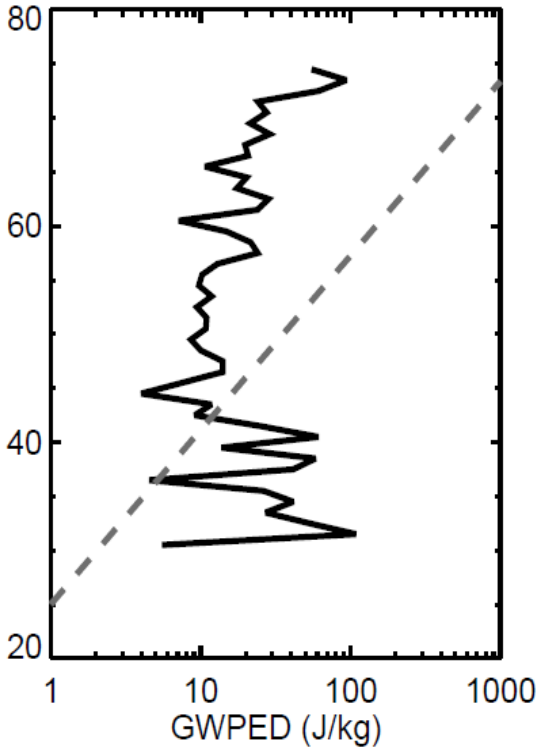


Fritts et al., BAMS

- Rayleigh lidar
- 532 nm



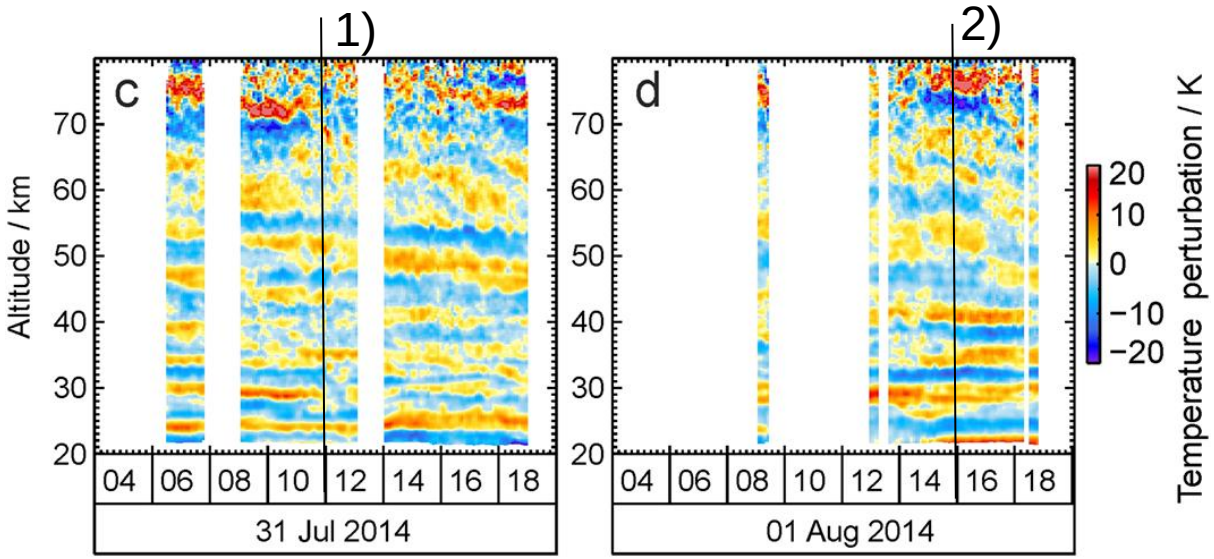
- ρ, T, T‘, E_p
- 30-96 km, darkness
- 10 min, 990 m



Available Rayleigh lidar data sets

1. Extreme events

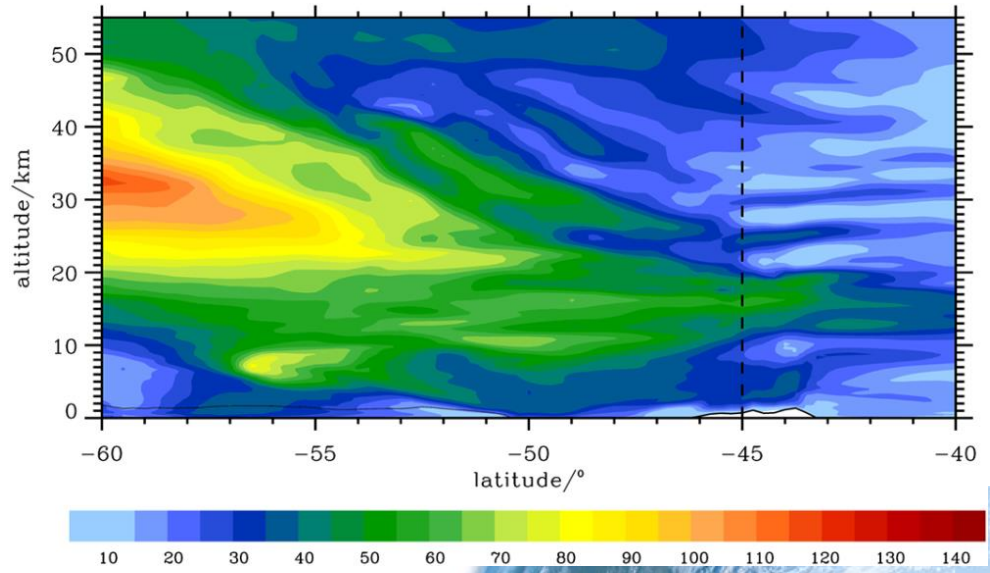
High-amplitude mountain wave

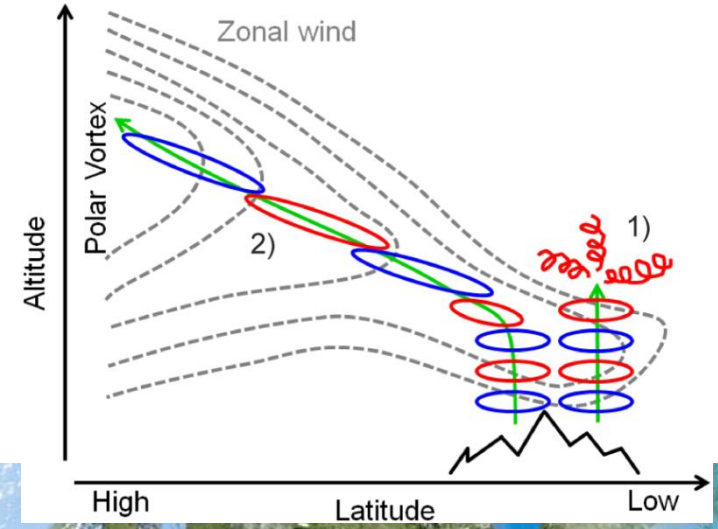


1) Wave breaking due to instabilities

2) Refraction of GW into the PNJ

→ Need for observations upstream of hot spots

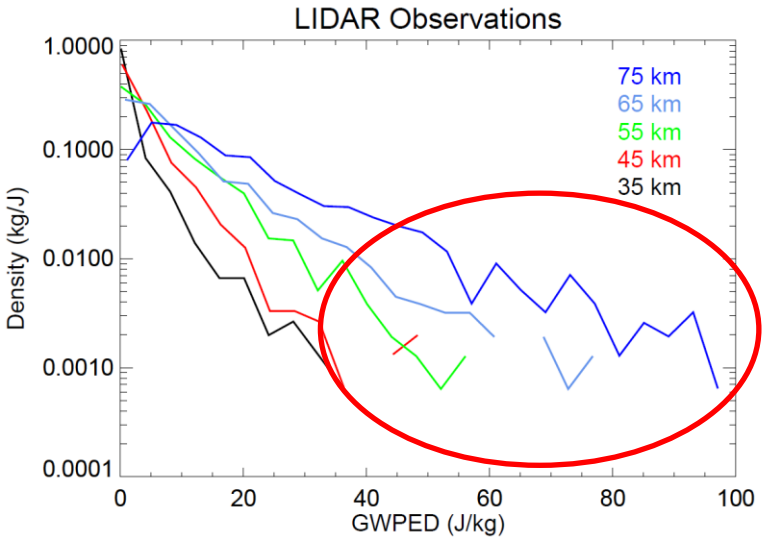




Jul – Oct 2014, Lauder

Kaifler et al., 2017, in preparation

E_p Probability Density Functions



Long tail with high energy densities

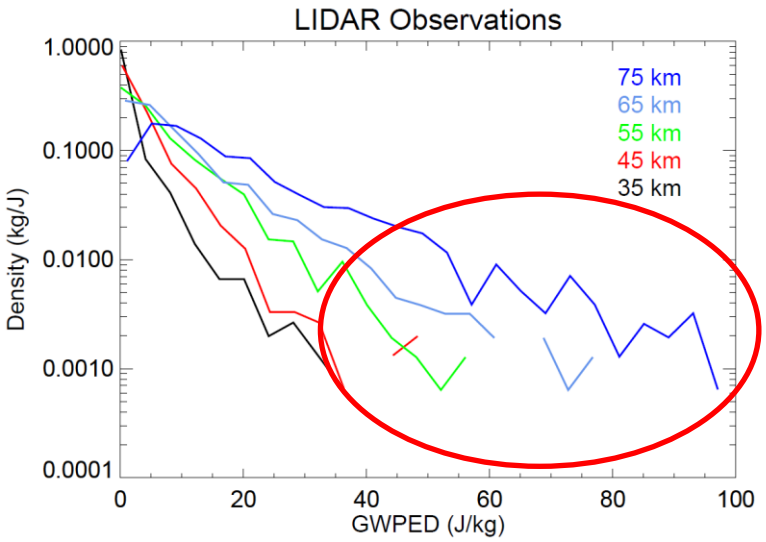
Extreme events

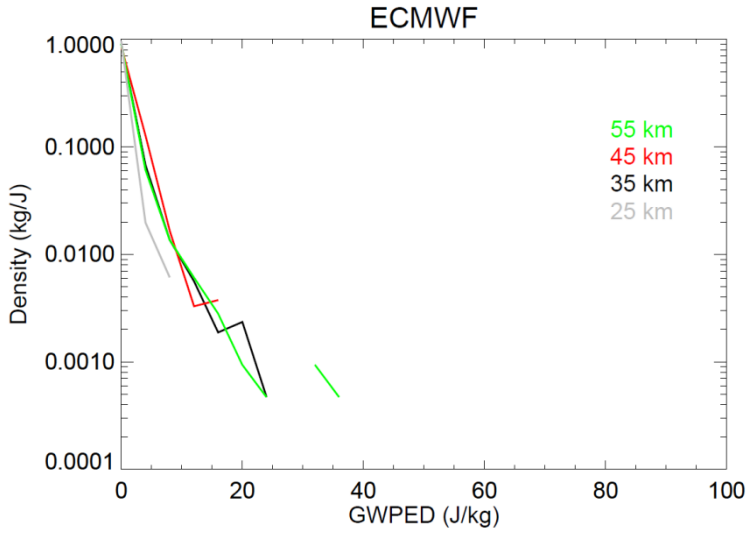
- Hourly profiles

Jul – Oct 2014, Lauder

Kaifler et al., 2017, in preparation

E_p Probability Density Functions





Long tail with high energy densities

Extreme events

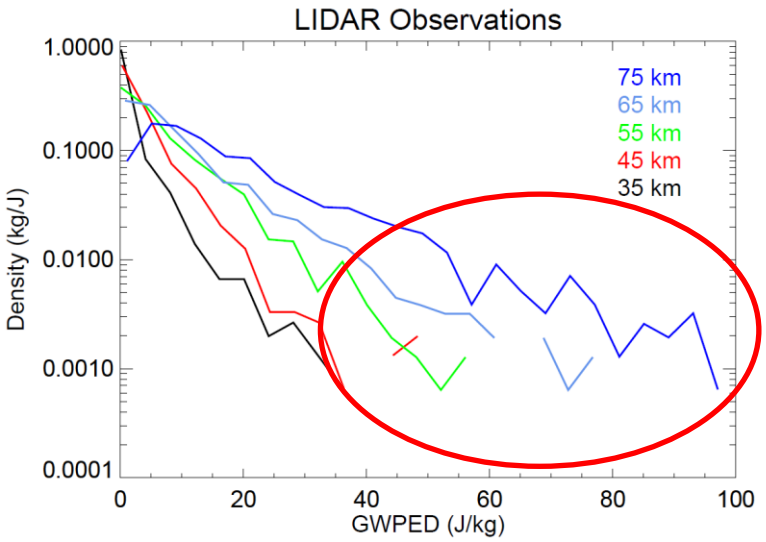
- Energy densities are generally smaller
- No/little growth with altitude
- No „tails“: extreme events missing?

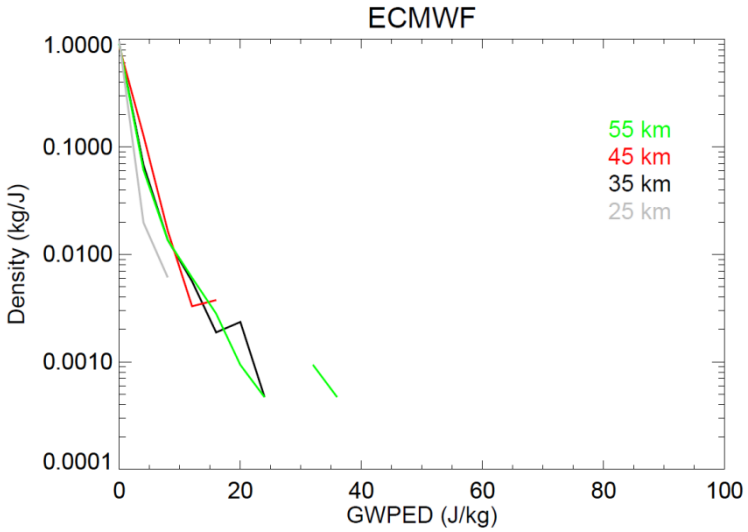
- Hourly profiles

Jul – Oct 2014, Lauder

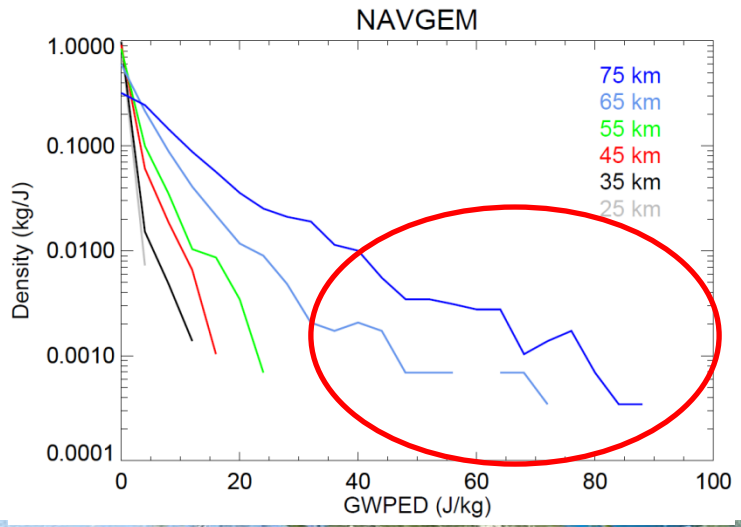
Kaifler et al., 2017, in preparation

E_p Probability Density Functions





Long tail with high energy densities



Some extreme events in NAVGEM, but smaller occurrence rate

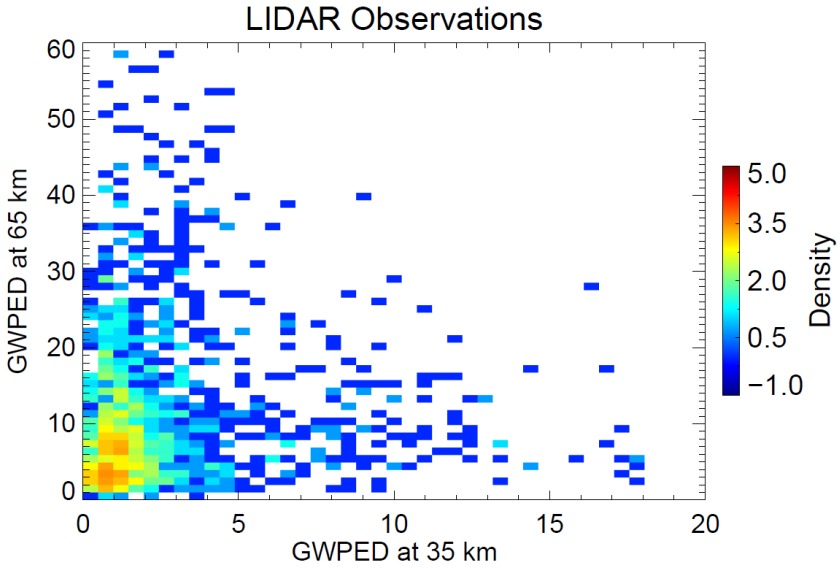
NAVGEM T119L74 hybrid-4DVAR reanalysis

DLR

Jul – Oct 2014, Lauder

Kaifler et al., 2017, in preparation

Extreme Events – Where in the Atmosphere?

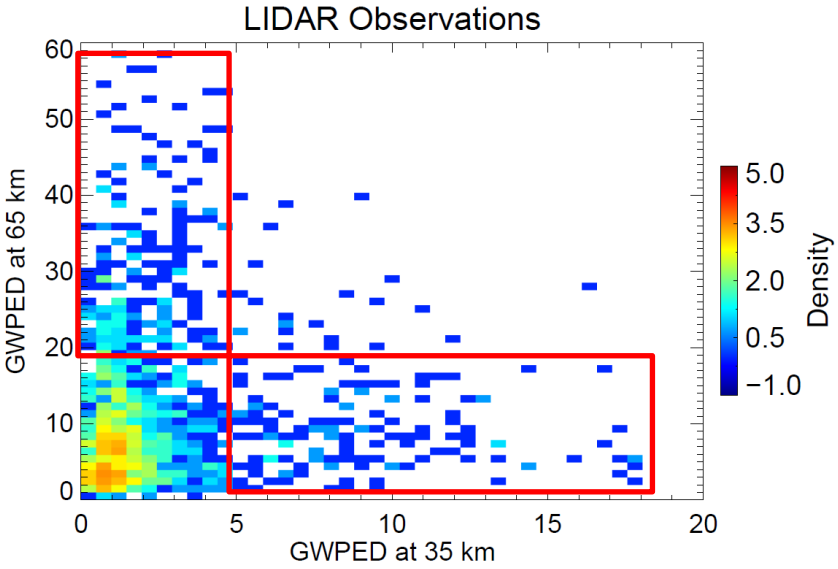


Extreme events (large E_p) in the **stratosphere or mesosphere**

Jul – Oct 2014, Lauder

Kaifler et al., 2017, in preparation

Extreme Events – Where in the Atmosphere?

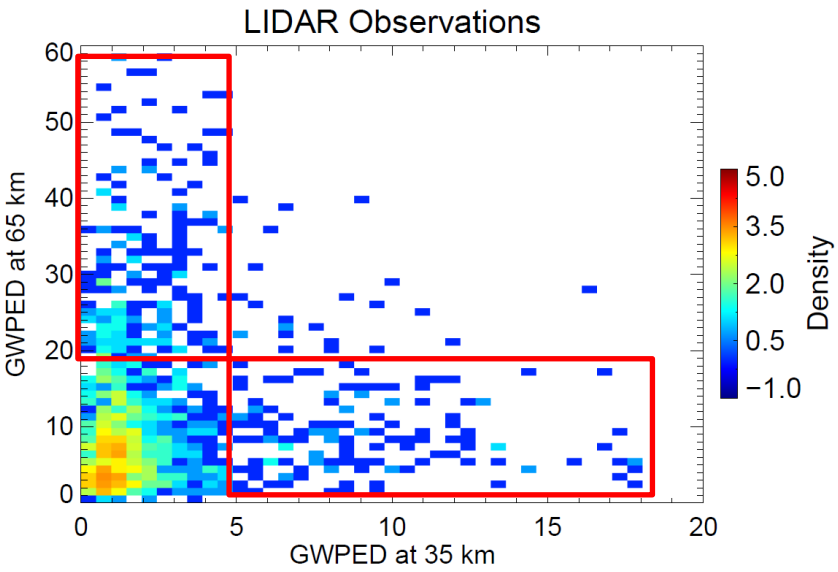


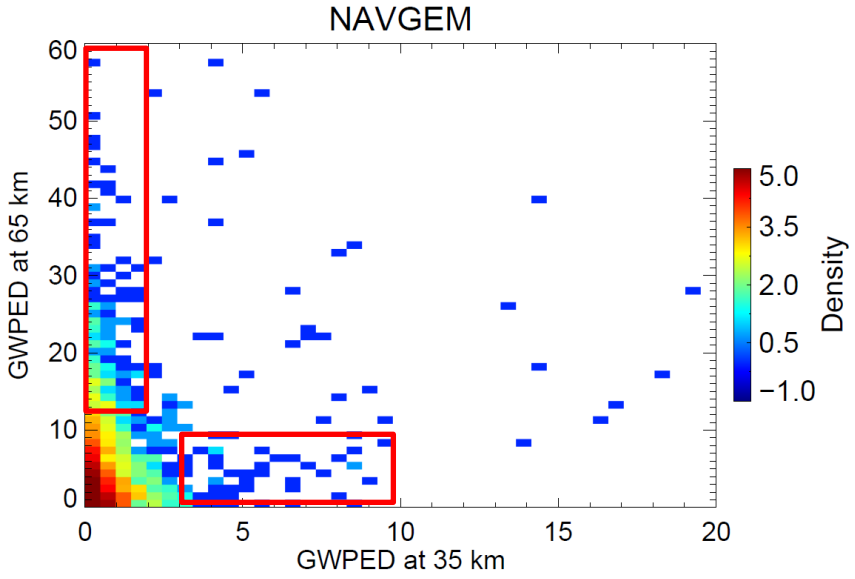
Extreme events (large E_p) in the **stratosphere or mesosphere**

Jul – Oct 2014, Lauder

Kaifler et al., 2017, in preparation

Extreme Events – Where in the Atmosphere?

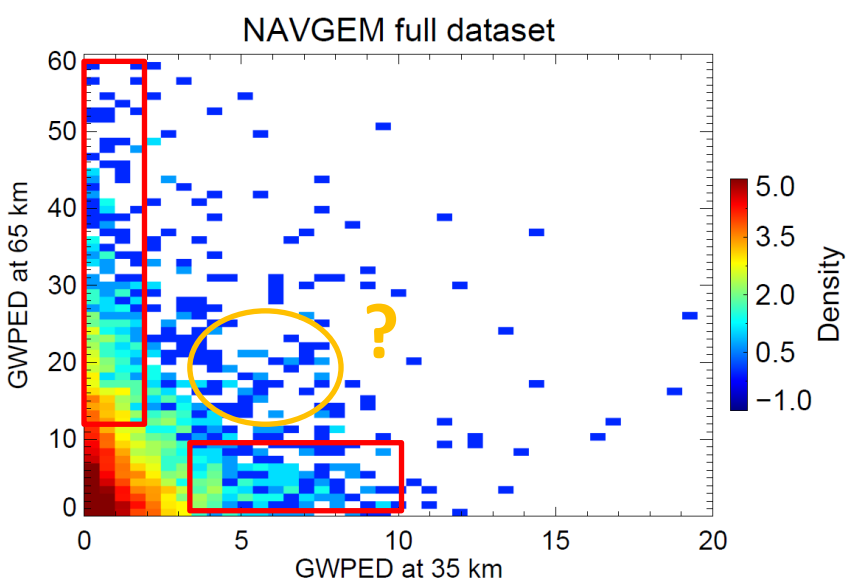


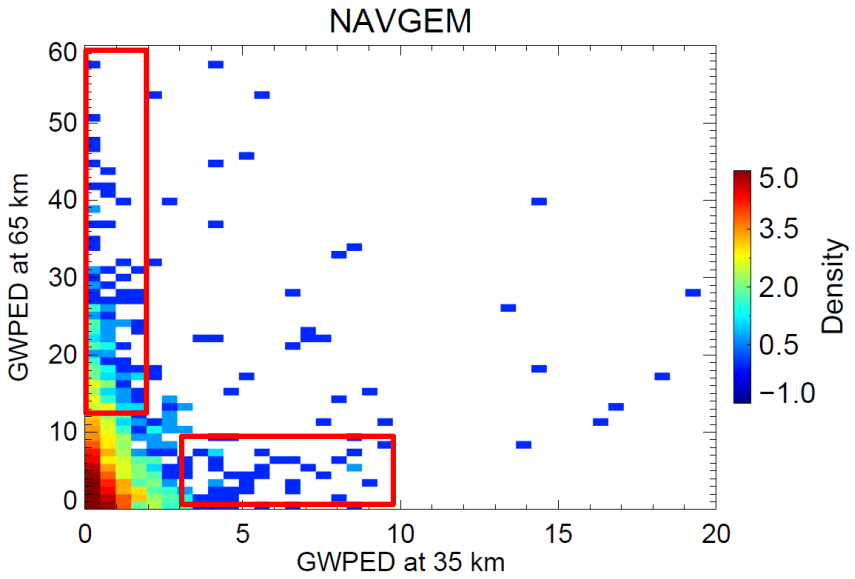


Extreme events (large E_p) in the **stratosphere or mesosphere**

Stratospheric extreme events underrepresented

Extreme Events – Where in the Atmosphere?

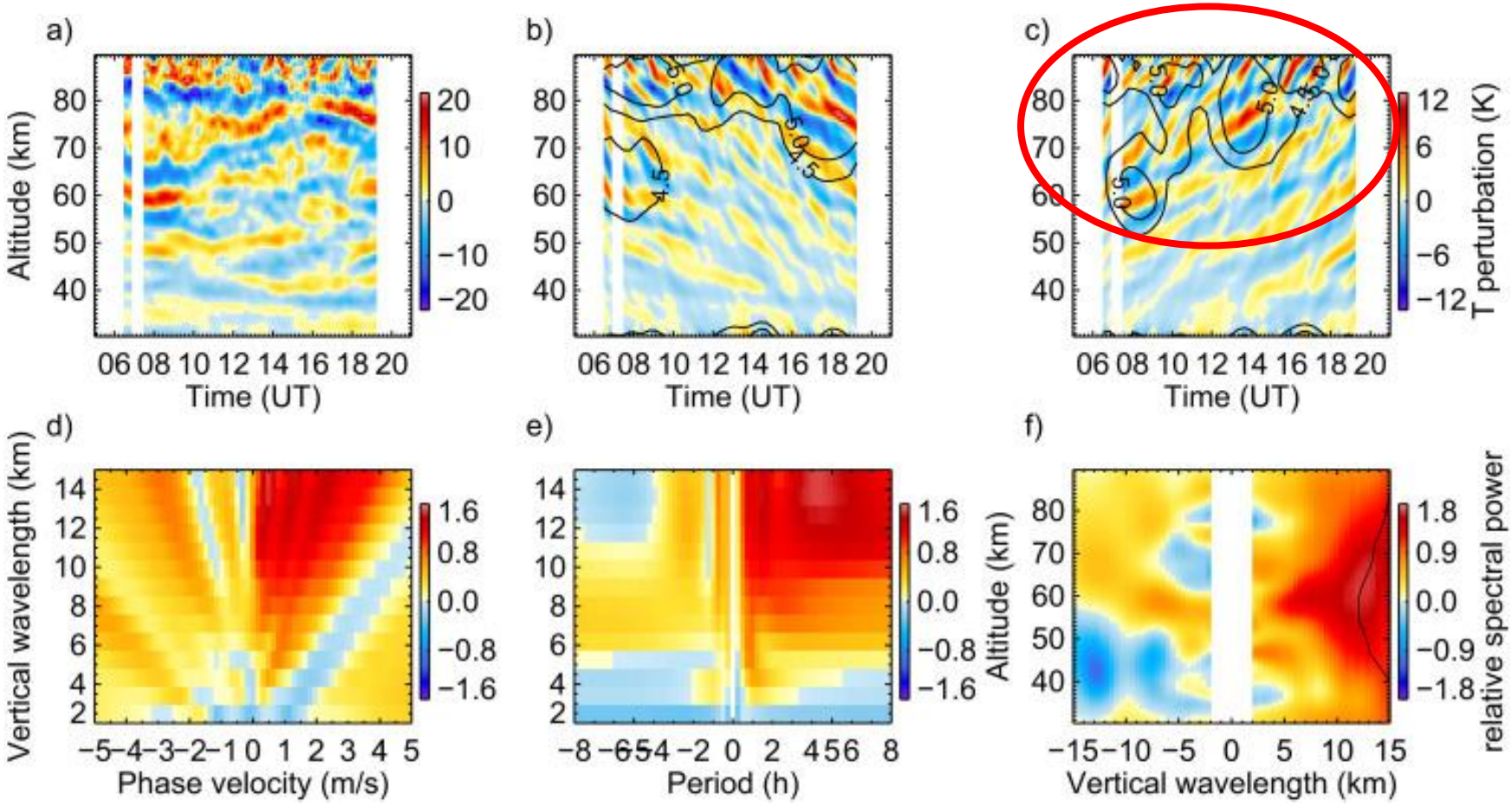




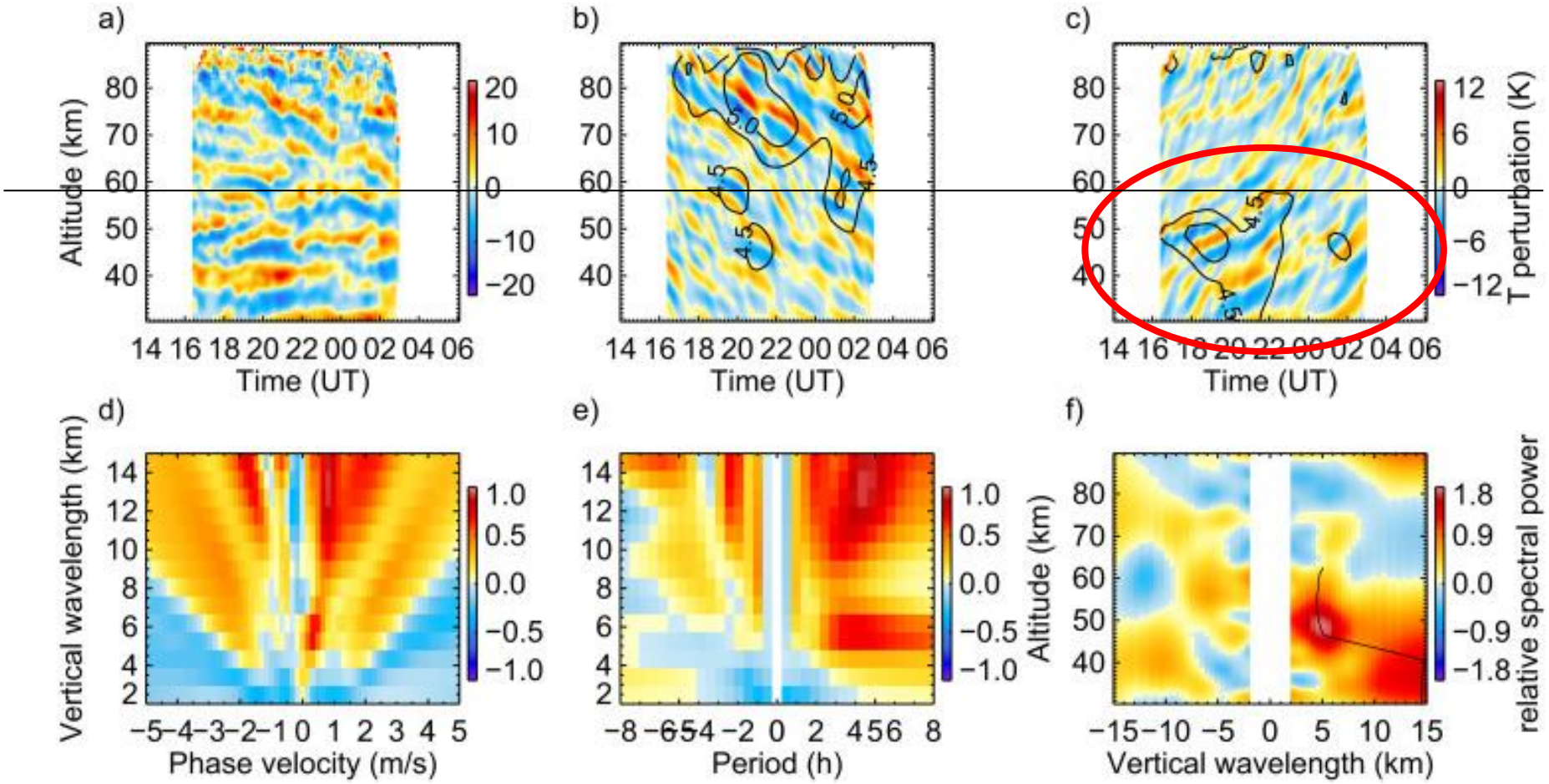
- A few cases with large energy densities in the **stratosphere and mesosphere**
- We do not have lidar observations for these events

2. Downward propagating waves

Case 1: High-amplitude downward propagating waves during deep propagation condition

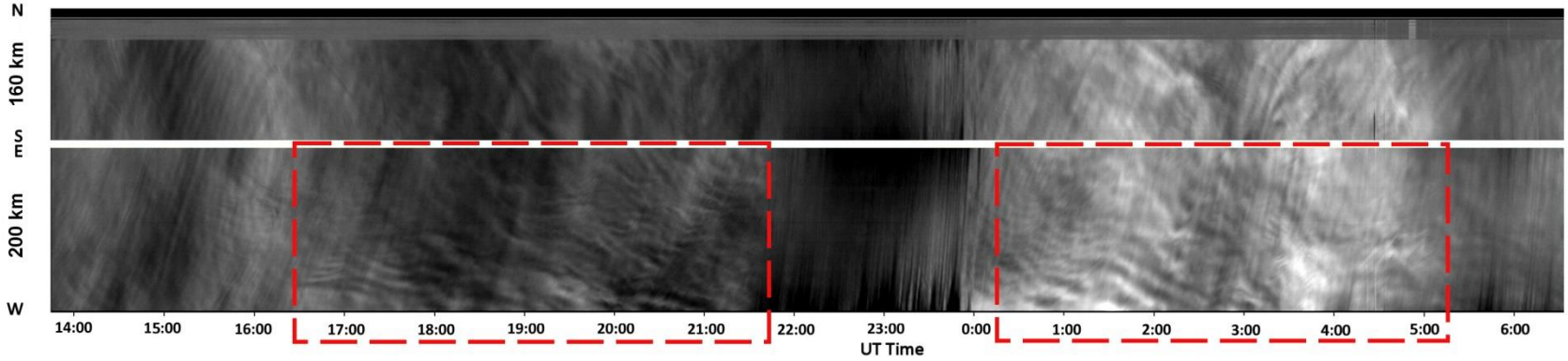


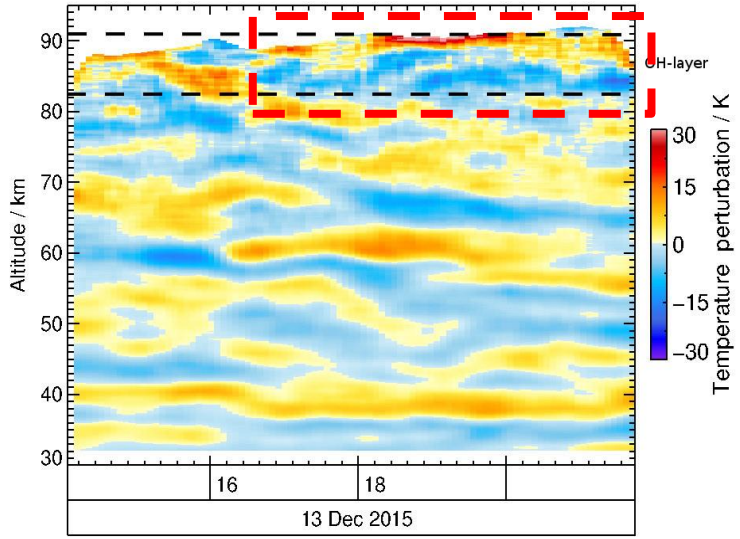
Case 2: GW generated by PNJ at 50-65 km



3. AMTM comparisons

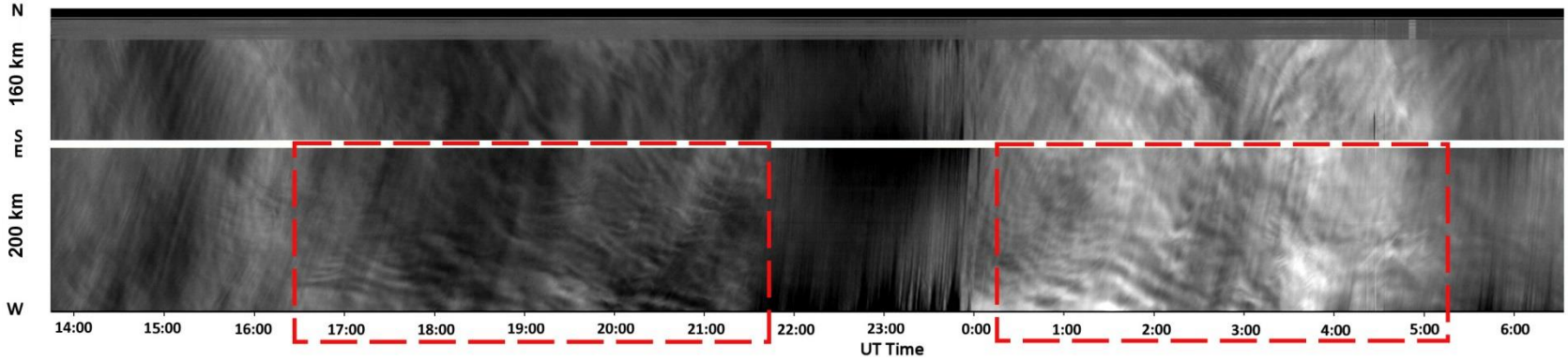
Case 1: Mesospheric mountain wave

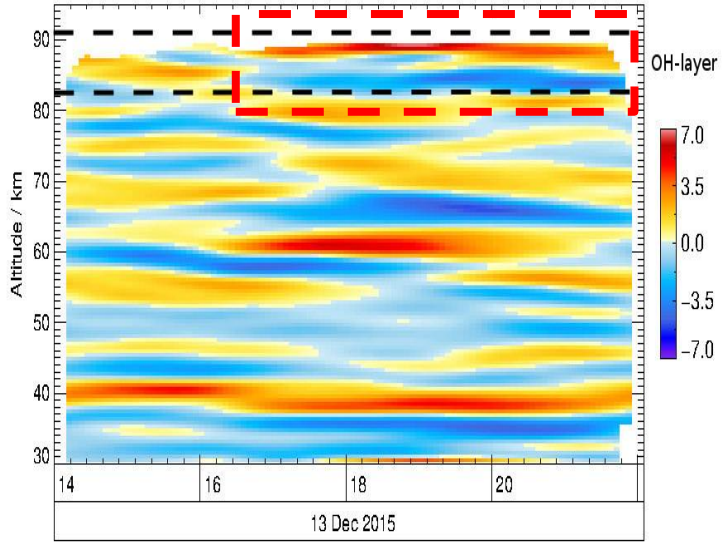




- Horizontal structures in keogram indicate mountain waves
- Derive GW parameters from lidar and AMTM by spectral analysis
- 16 km vertical wavelength
- 20 km horizontal wavelength

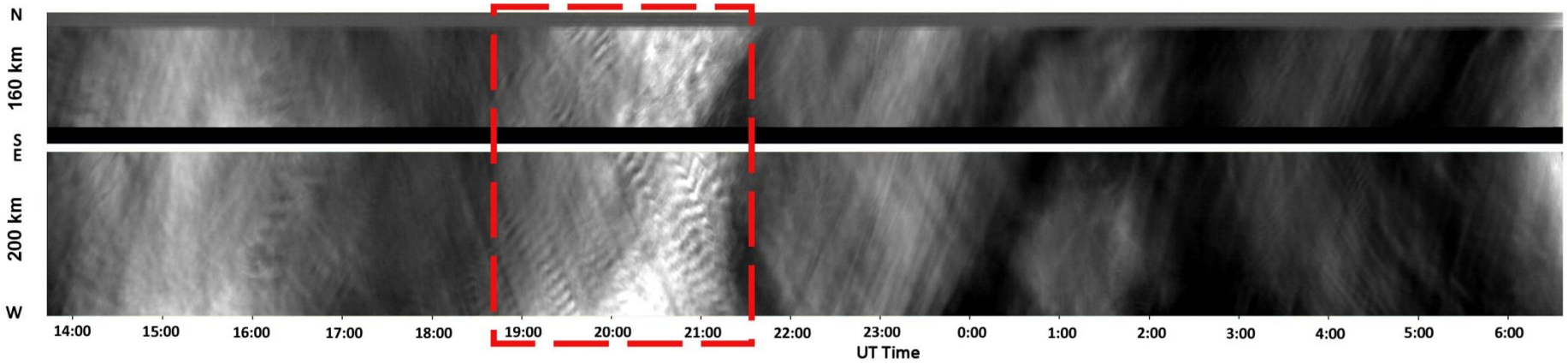
Case 1: Mesospheric mountain wave

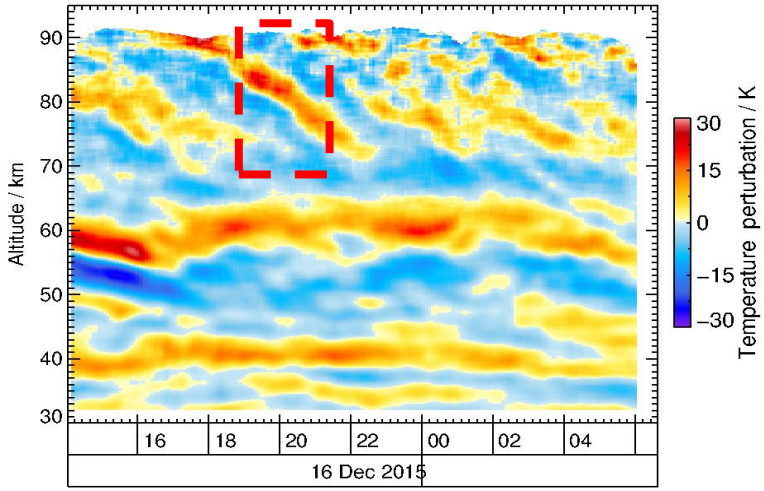




- Horizontal structures in keogram indicate mountain waves
- Derive GW parameters from lidar and AMTM by spectral analysis
- 16 km vertical wavelength
- 20 km horizontal wavelength

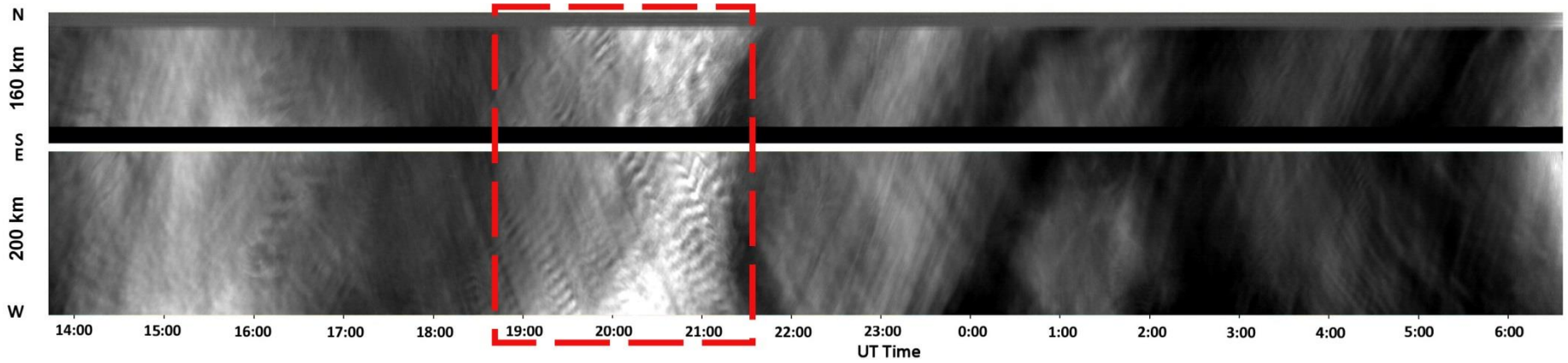
Case 2: Wave breaking event





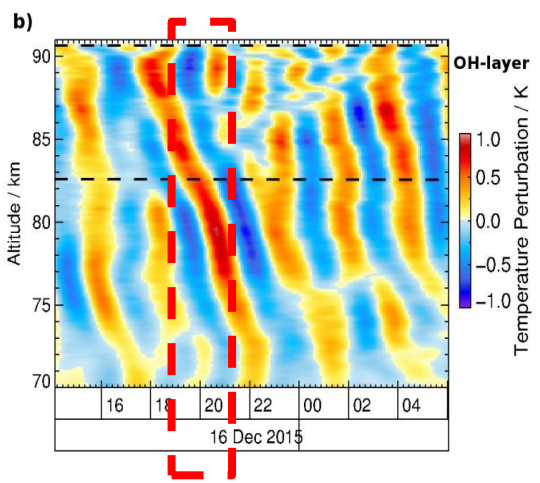
- Very high T amplitudes
- 835 km horizontal wavelength
- 92 m/s horizontal phase speed
- Dominant 2.7 h and 4.1 h period from keograms
- 9.3 km vertical wavelength
- 2.7 h wave likely breaks

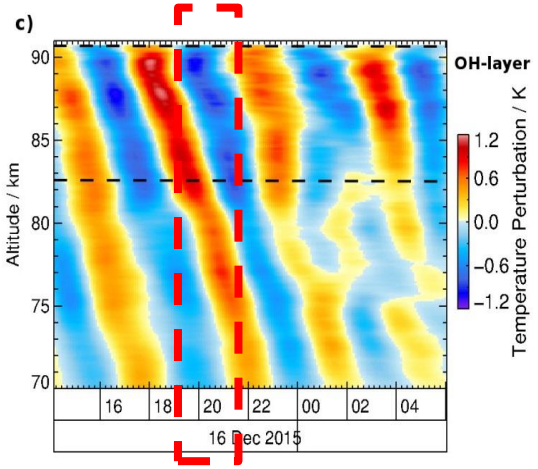
Case 2: Wave breaking event

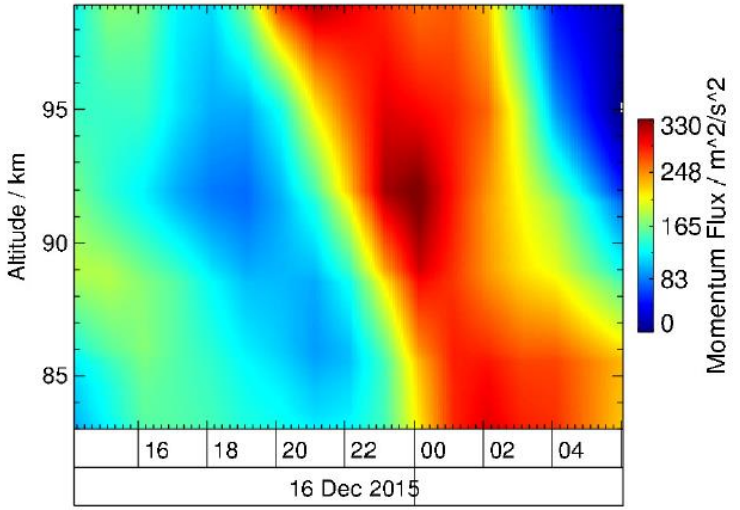


τ = 2.7 h

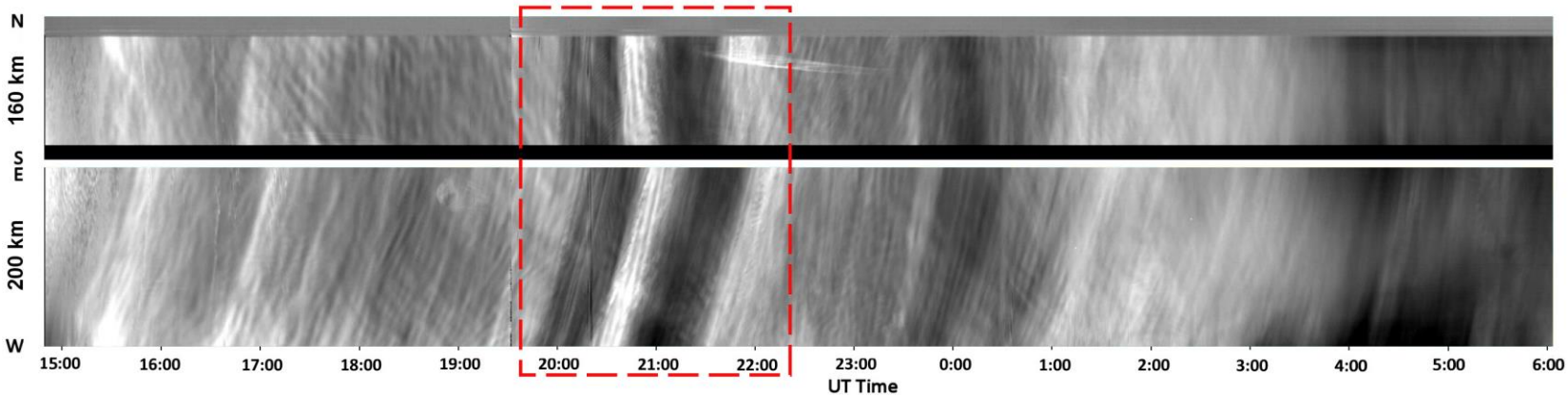
τ = 4.1 h

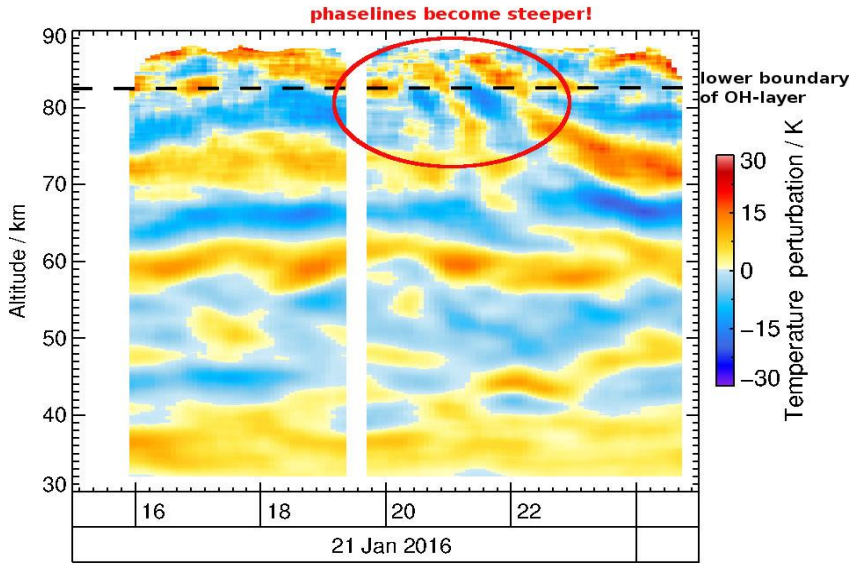






Case 3: Large phase tilts



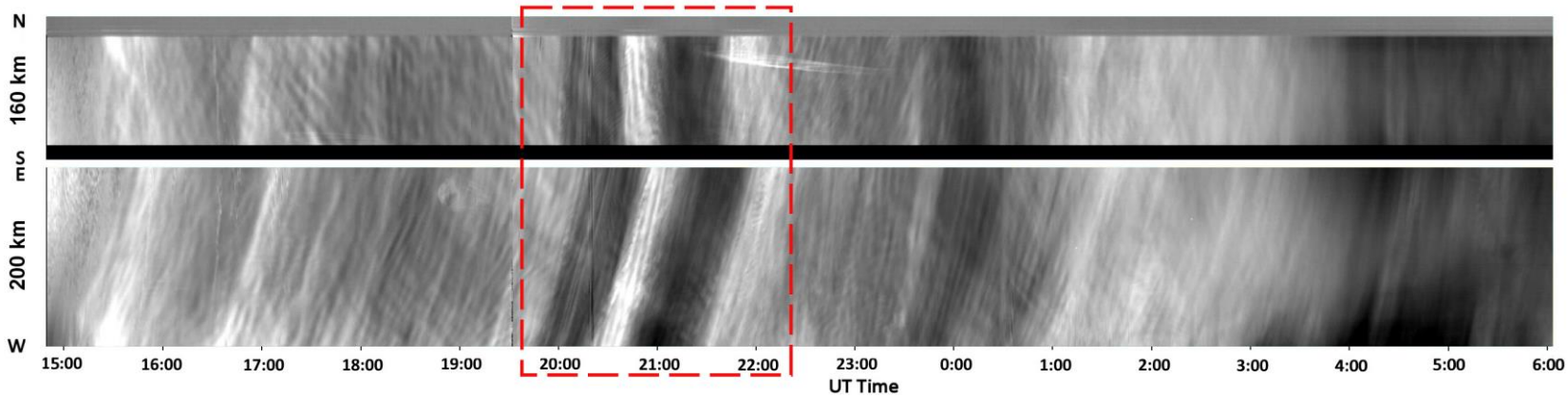


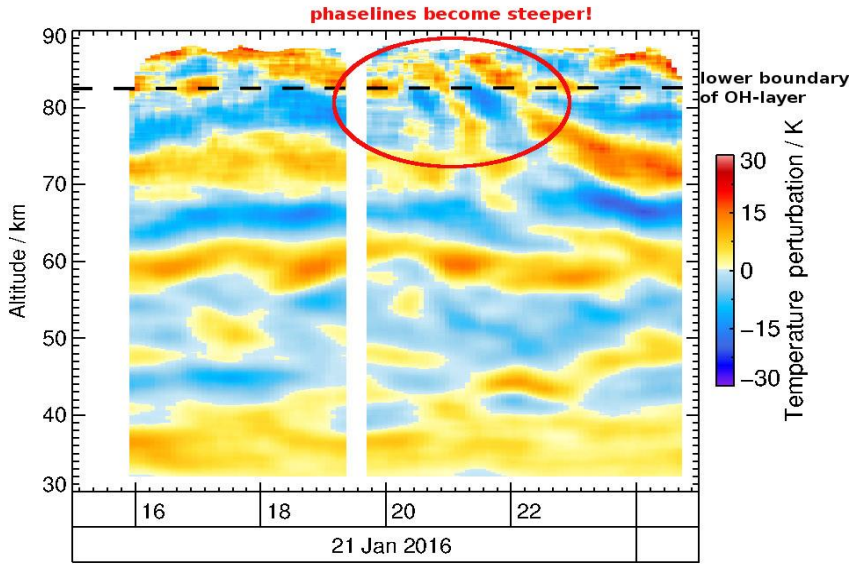
- 67 min period
- Band-pass filter
- Overplot wind structure

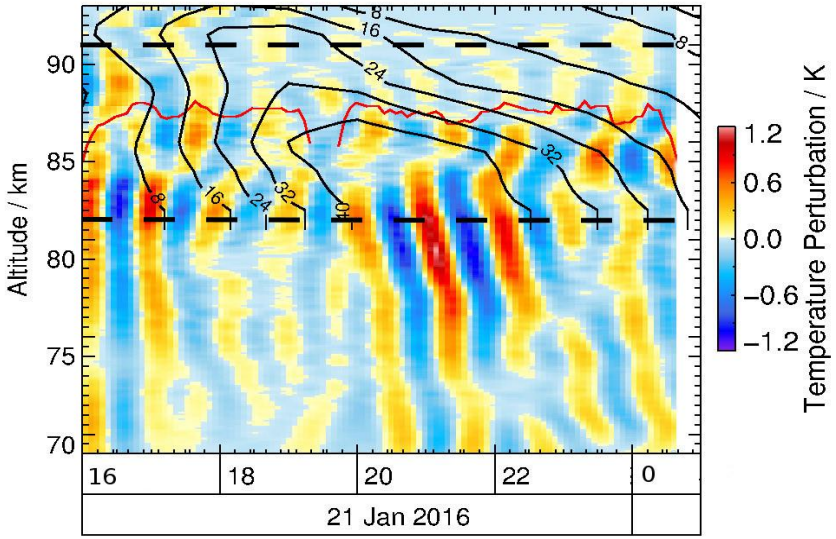
→ Warning!

→ interaction Doppler shift and bandpassfilter

Case 3: Large phase tilts

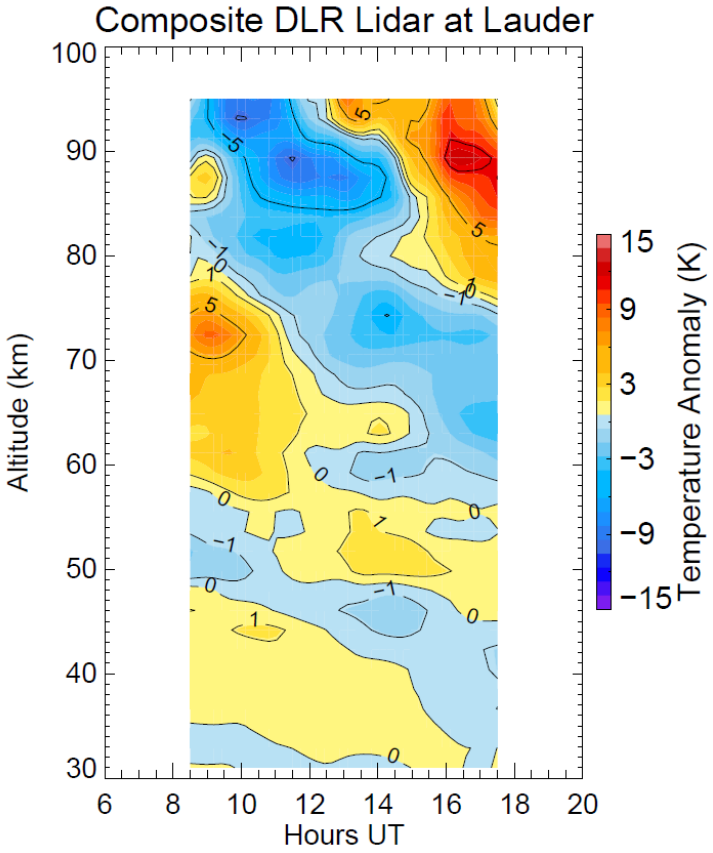






4. Coupling to tides

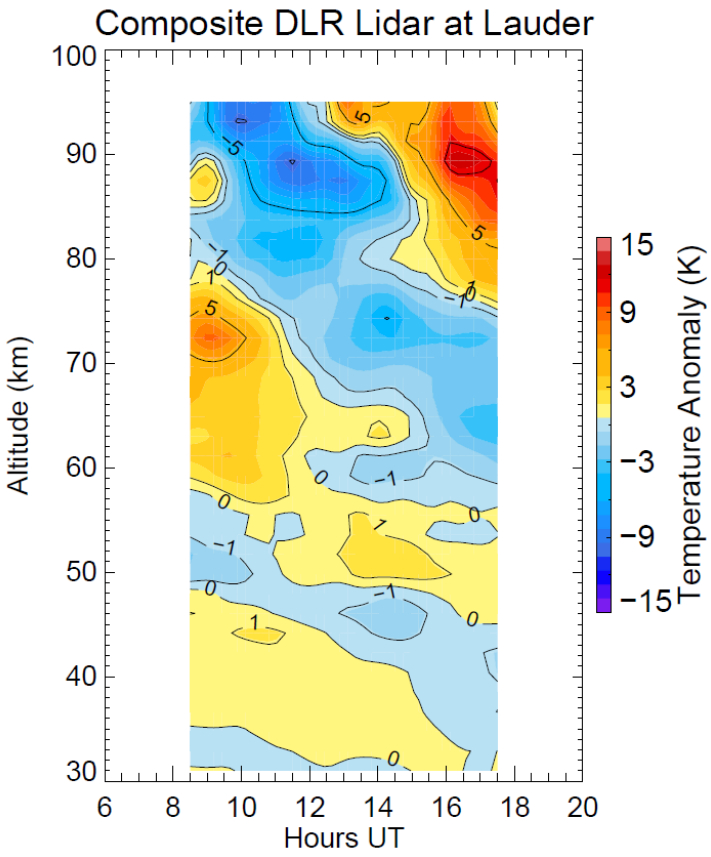
Epoch analysis revealing tides



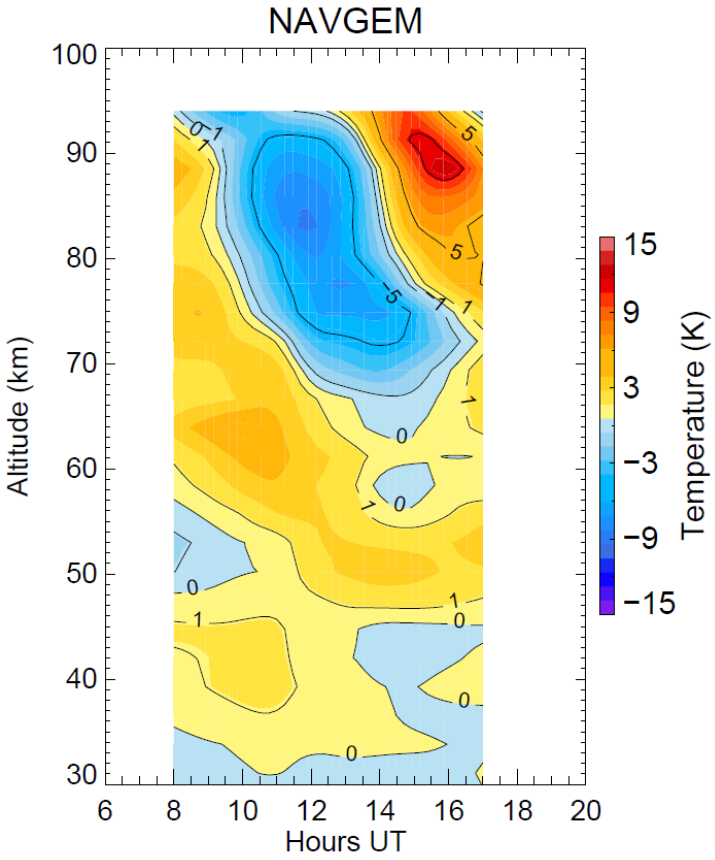
16 days, 14 July – 28 August

July: 14, 16, 17, 23, 24, 25, 27, 31
Aug: 3, 4, 16, 17, 19, 26, 27, 28

Epoch analysis revealing tides



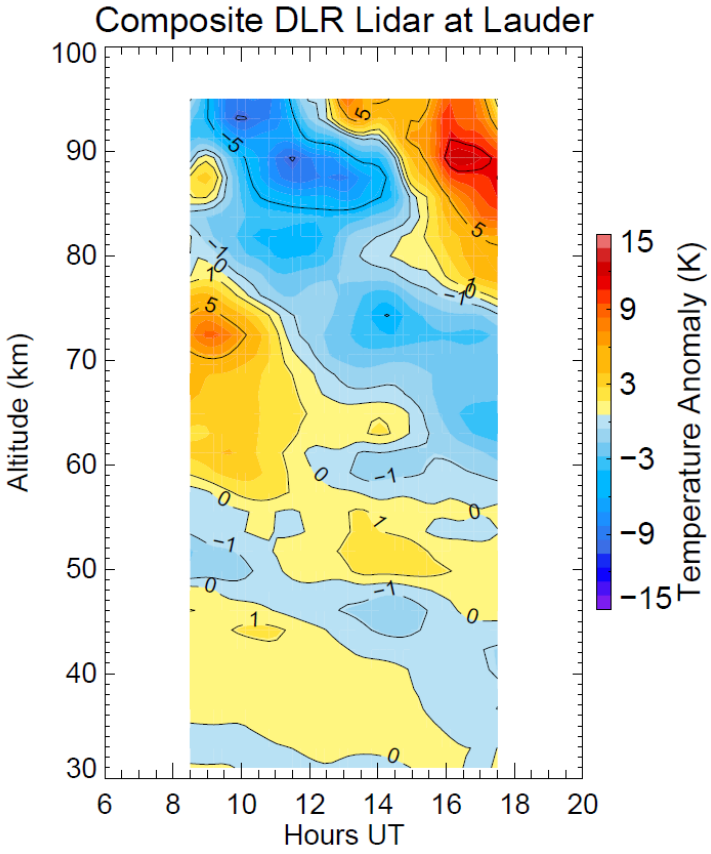
16 days, 14 July – 28 August

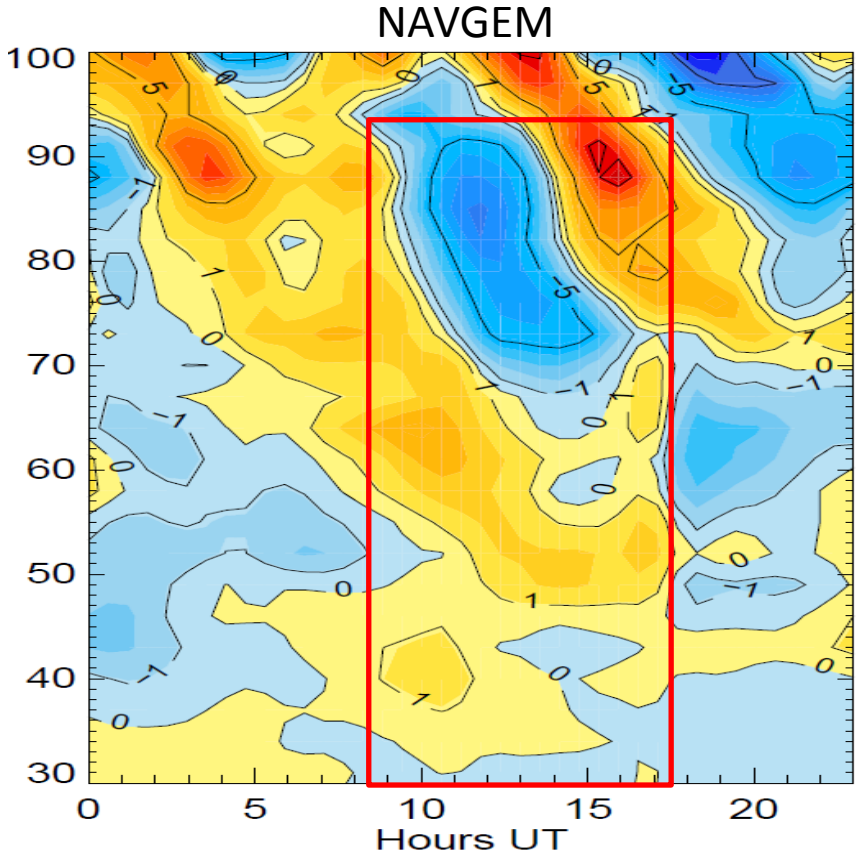


16 days, 14 July – 28 August

July: 14, 16, 17, 23, 24, 25, 27, 31
Aug: 3, 4, 16, 17, 19, 26, 27, 28

Comparison to NAVGEM: diurnal and semidiurnal tide



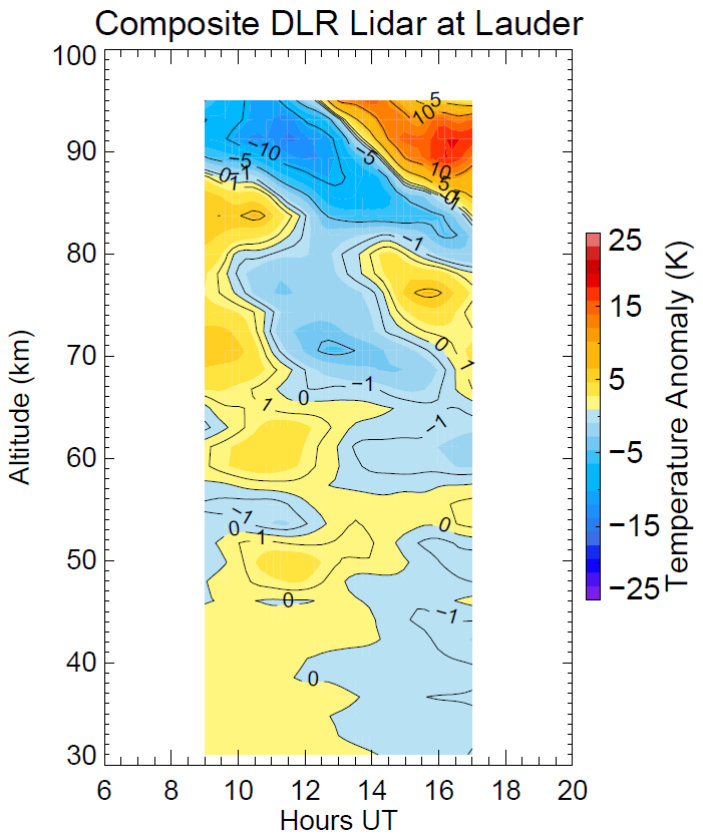


16 days, 14 July – 28 August

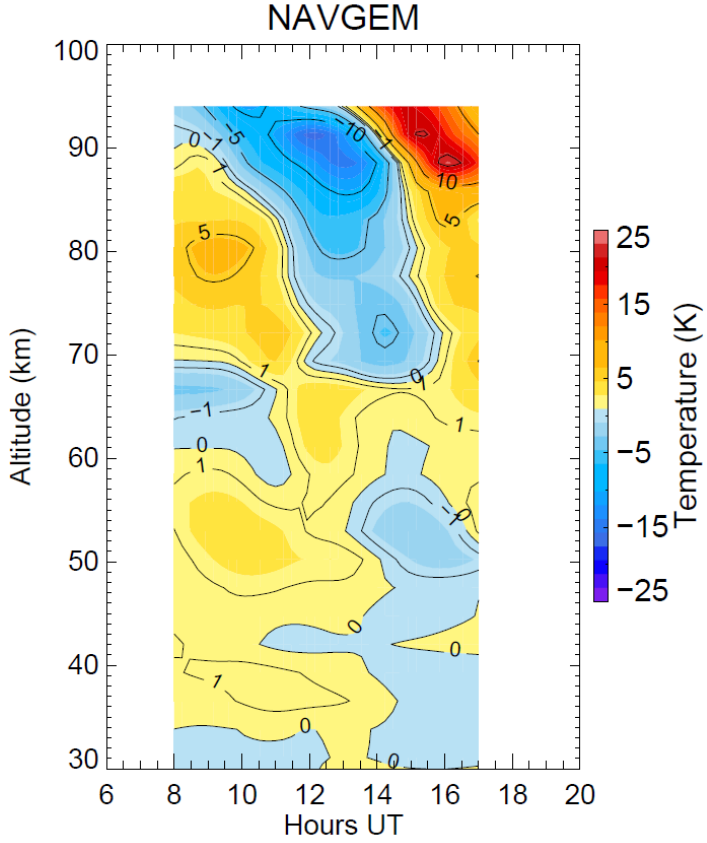
16 days, 14 July – 28 August

July: 14, 16, 17, 23, 24, 25, 27, 31
Aug: 3, 4, 16, 17, 19, 26, 27, 28

Large amplitudes on short time scales

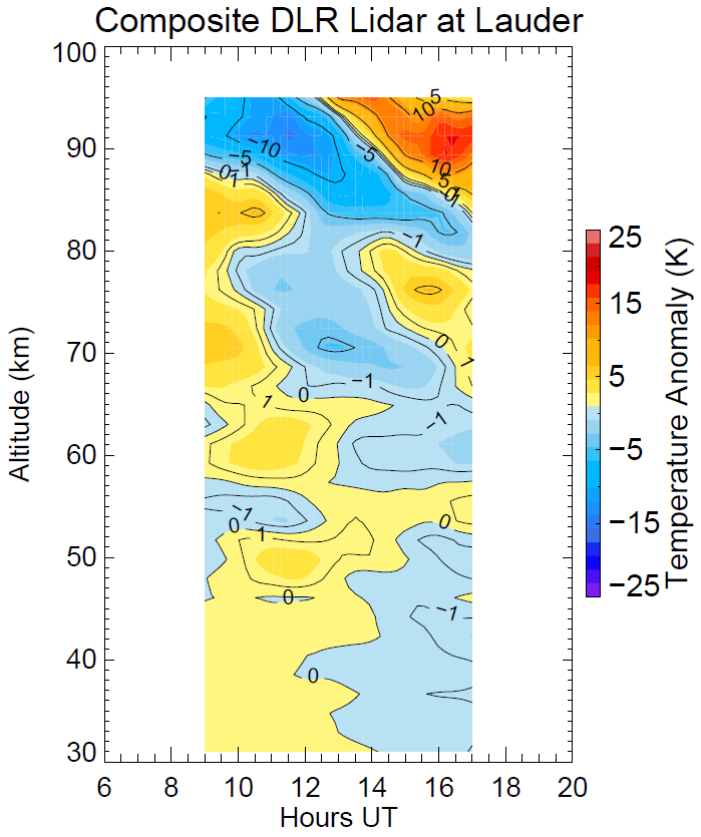


3 days, 26-28 August

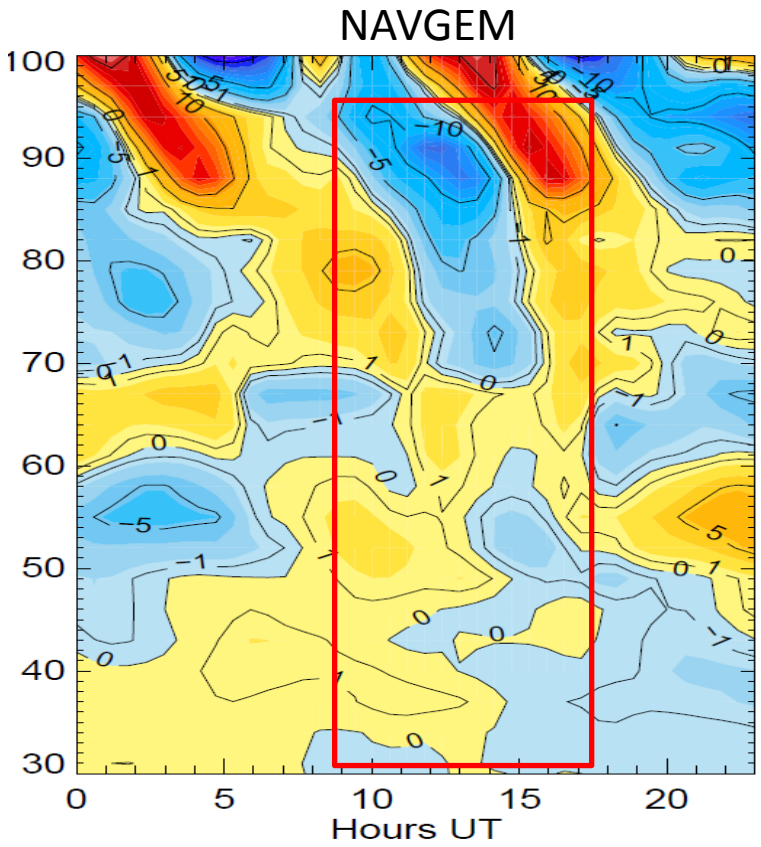


3 days, 26-28 August

Large amplitudes on short time scales

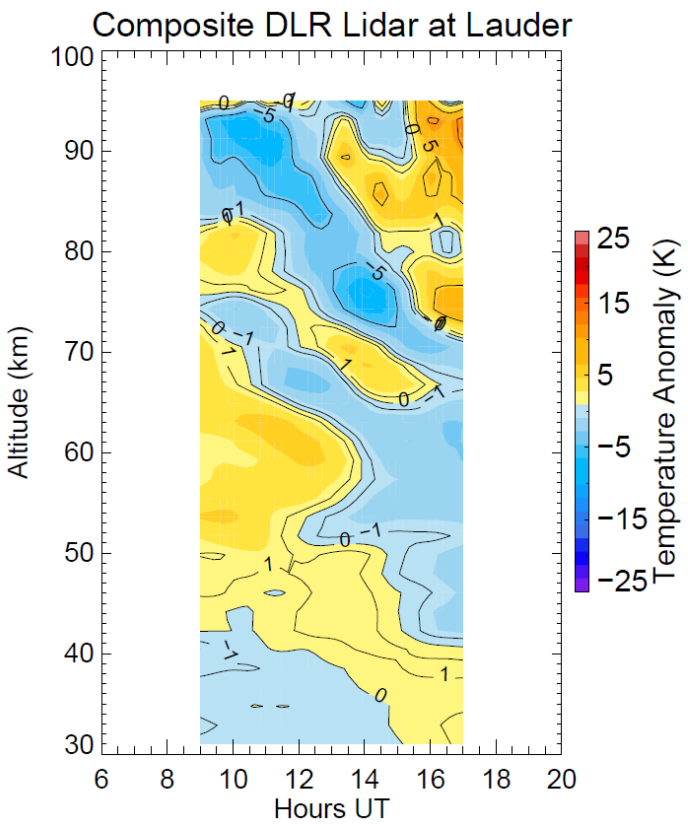


3 days, 26-28 August

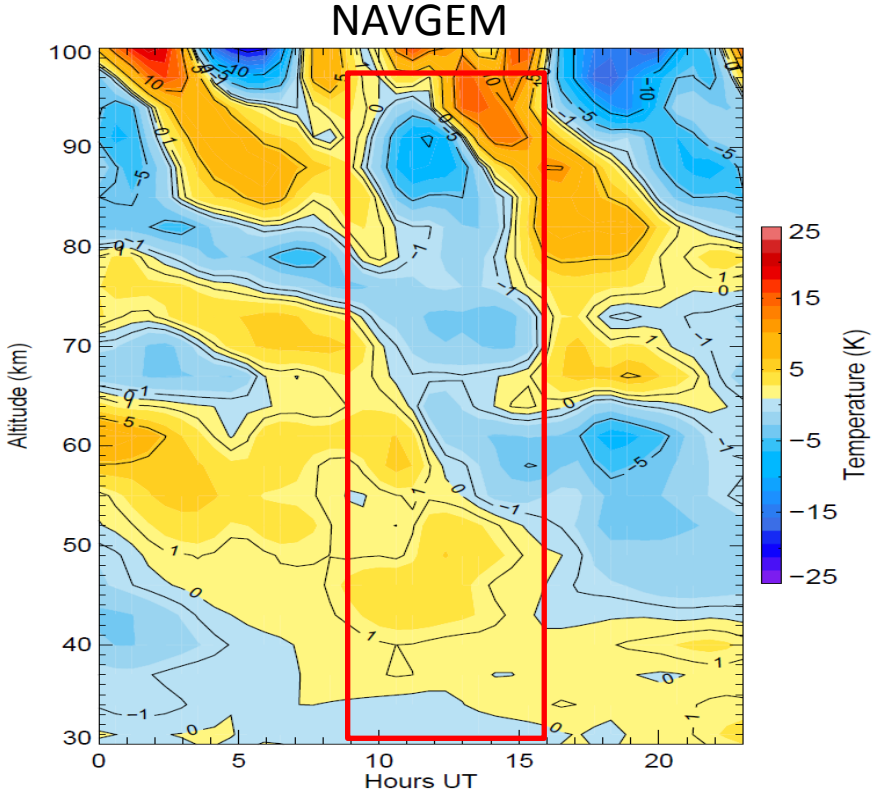


3 days, 26-28 August

Afterwards: lower amplitudes

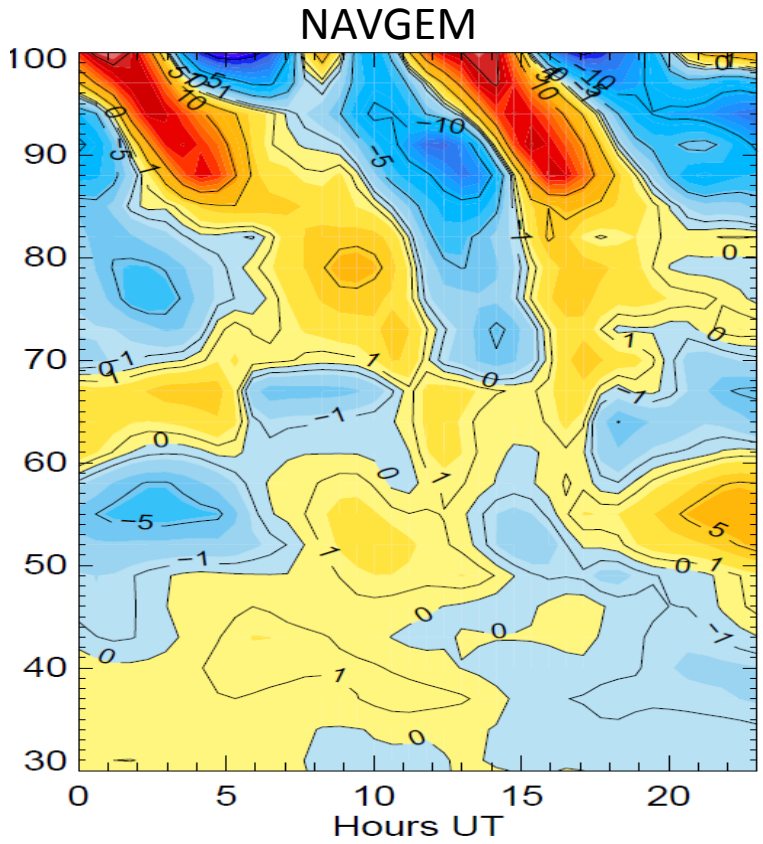


4 days, 29 Aug – 2 Sep

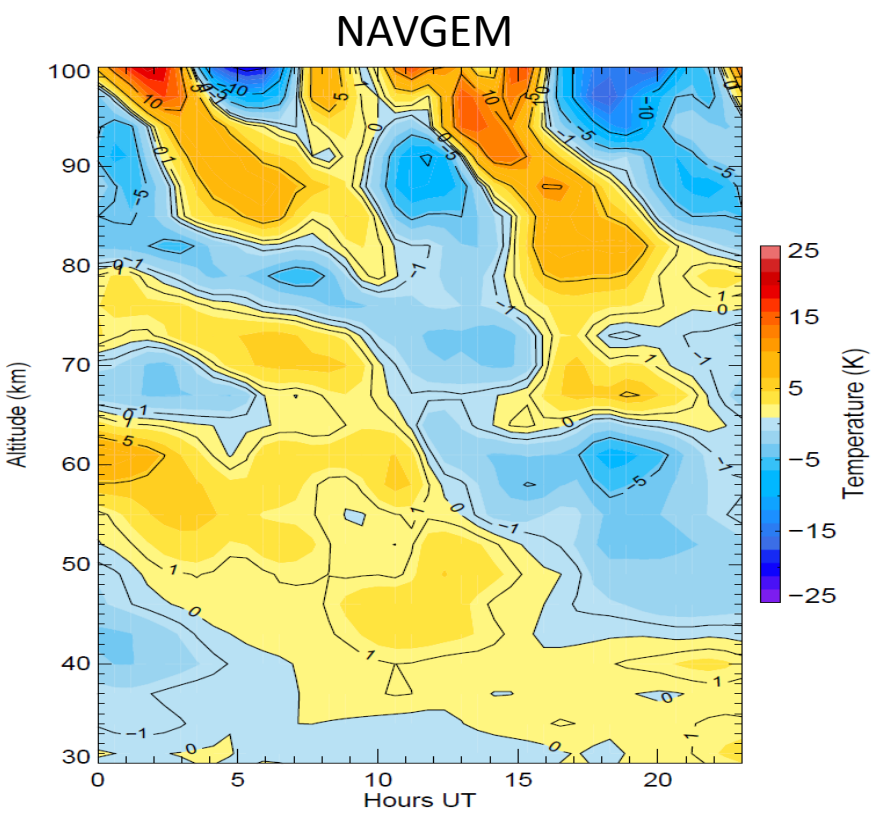


4 days, 29 Aug – 2 Sep

Variability



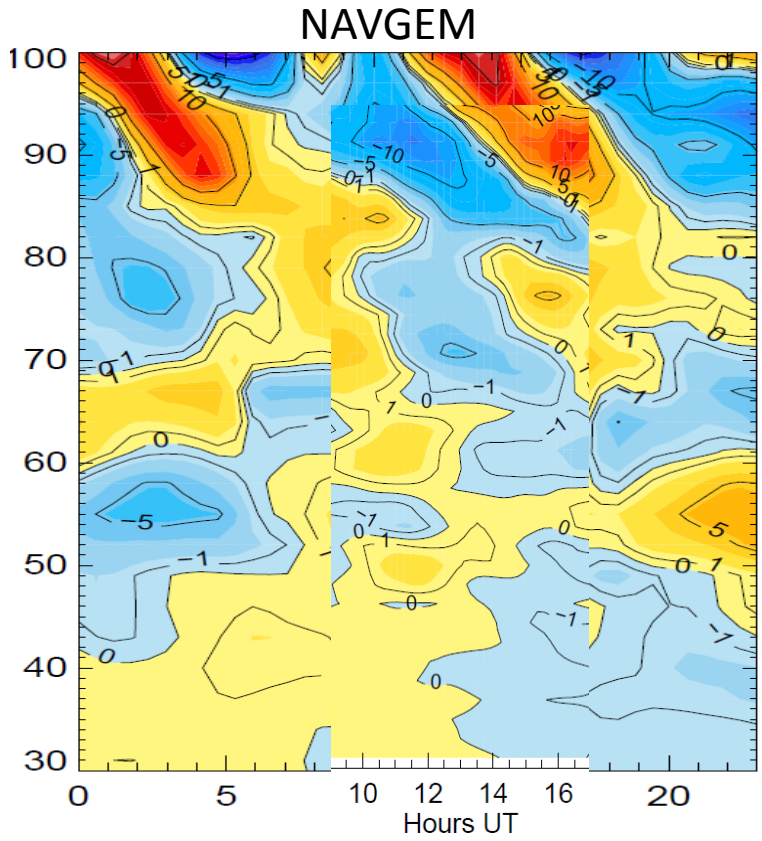
3 days, 26-28 August



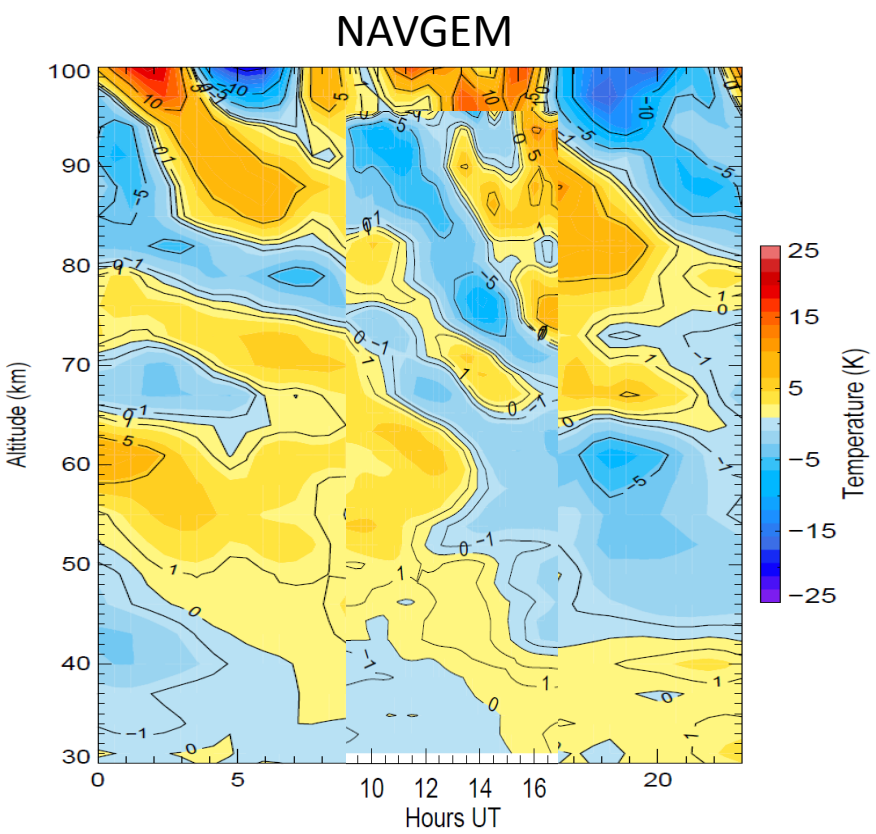
4 days, 29 Aug – 2 Sep

DLR

Variability



3 days, 26-28 August

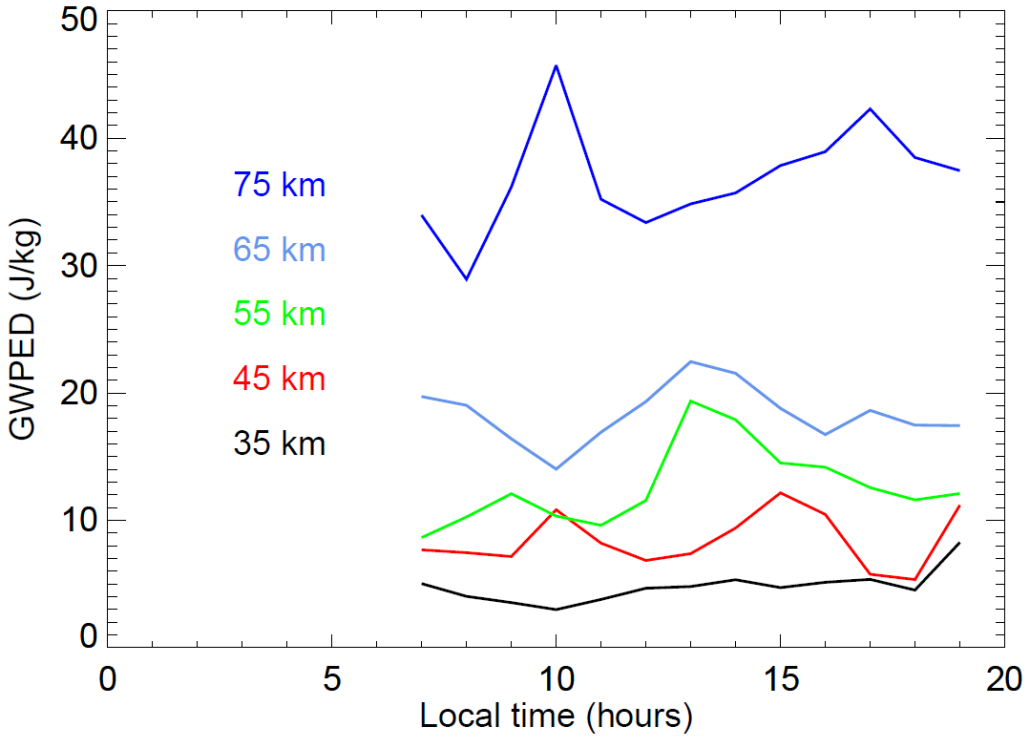


4 days, 29 Aug – 2 Sep

DLR

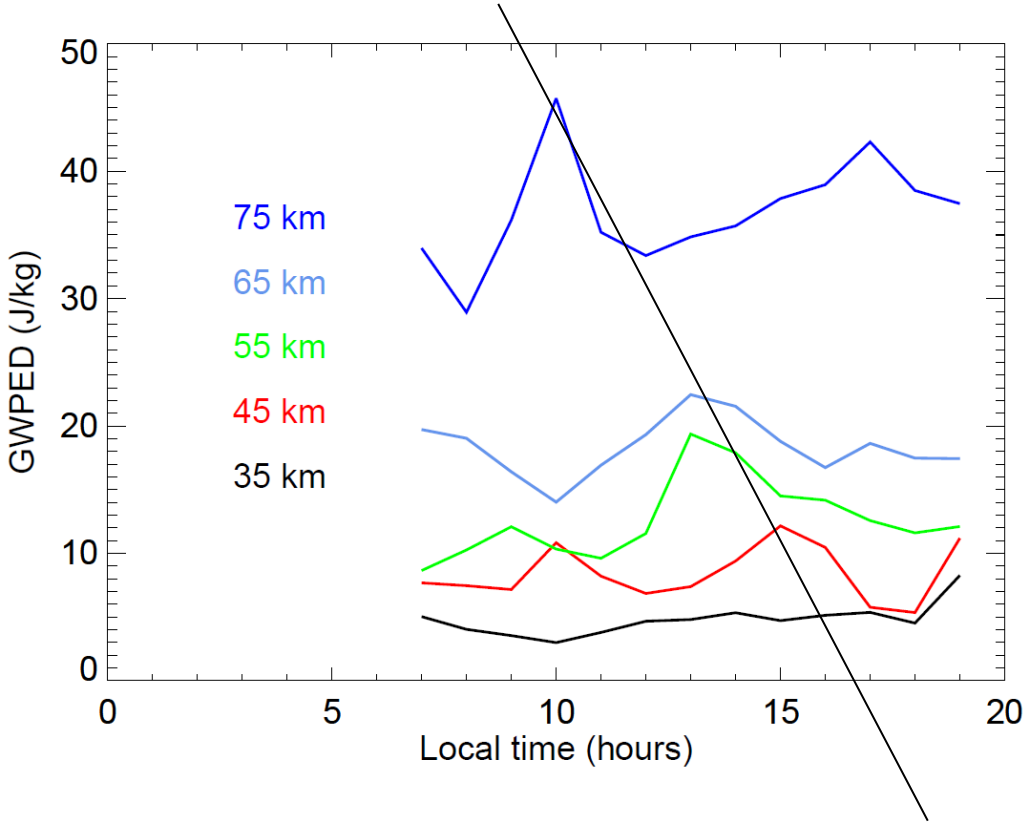
Local time effects of gravity waves

- Gravity waves with vertical wavelengths <12 km
- Tides should be suppressed
- Evidence for GW-tide interactions?



Local time effects of gravity waves?

- Gravity waves with vertical wavelengths <12 km
- Tides should be suppressed
- Evidence for GW-tide interactions?



Summary

- Horizontal propagation of a high-amplitude mountain wave
- Probability density functions of gravity wave potential energy density
- Extreme events either in stratosphere or mesosphere
- Detection of downward propagating waves
- Hints for generation in stratosphere and thermosphere
- Same waves visible in lidar and AMTM
- Very good agreement of tide analysis for lidar and NAVGEM