ICAM 2015, Innsbruck
P2.22

Institute of Meteorology and Geophysics · University of Innsbruck

DLR

Mountain Wave Propagation under Transient Tropospheric Forcing

A DEEPWAVE Case Study

Tanja Portele[1,2], Martina Bramberger[1,2], Andreas Dörnbrack[1], Benedikt Ehard[1], Sonja Gisinger[1], Alexander Gohm[2], Bernd Kaifler[1], Markus Rapp[1,3], Johannes Wagner[1]

[1] Institut für Physik der Atmosphäre, Deutsches Zentrum für Luft- und Raumfahrt, Weßling, Germany [2] Institut für Meteorologie und Geophysik, Universität Innsbruck, Innsbruck, Austria [3] Meteorologisches Institut, Ludwig-Maximilians-Universität, Munich, Germany

Motivation and Research Questions

- Large-scale models: steady-state assumption for gravity wave (GW) drag parameterization
- DEEPWAVE campaign in New Zealand 2014 shows: **Gravity wave events** are highly **sporadic** and **episodic**, **not permanent** and appear with their own **transience**
- Chen et al (2005, 2007): dramatic differences between the momentum fluxes in the slowly varying synoptic-scale flow and those determined by steady-state theory
- In particular, asymmetric distribution of vertical momentum flux profile with respect to the time of maximum forcing (Fig 1)

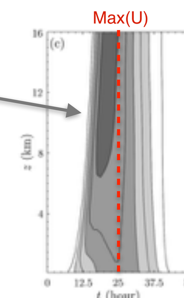


Fig 1: Momentum flux profile in Chen et al (2005)

Such a transient forcing case was observed during the DEEPWAVE IOP 9 from 28 June till 01 July 2014.

Goals:

1. Explore the wave response to a transient tropospheric forcing
2. Characterize the different phases of the transient forcing with WRF-simulations, in-situ Falcon and GV Flight Data, radio-soundings and lidar data
3. Compare to results of Chen et al (2005, 2007)

Methods for in-situ Data Analysis

- Corrected Pressure: $p_{corr} = p_{static} + \overline{\rho} g(z - z_{ref})$
- Perturbations: $\Psi \in \{\Theta, u, v, w, p_{corr}\}$
  $\Psi' = \Psi - \Psi_{lin} - \overline{\Psi}$ (detrend and zero-mean)
- Energy Flux: $EF = \int p'w' \, \mathrm{d}x$
- Momentum Flux: $MF_u = \overline{\rho} \int u'w' \, \mathrm{d}x$
- Non-Dimensional Mountain Height: $\epsilon = \frac{h_m N}{\overline{U}_{norm}}$ (Reinecke and Durran 2008)

Wavelet Analysis

- Energy flux spectrum for Queney mountain wave solution (Fig 3a,b)
- Wavelet of topography along Mt.-Aspiring-2b-transect (Fig 2, Fig 6)

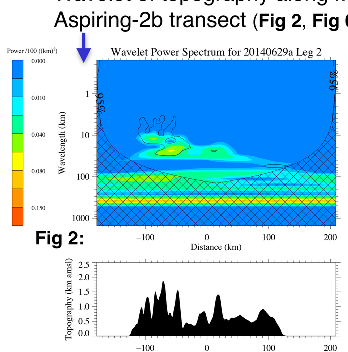


Fig 2:

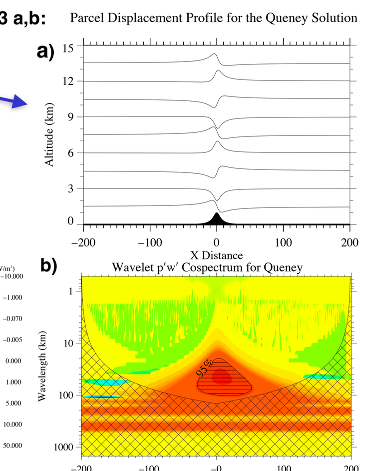


Fig 3 a,b: Parcel Displacement Profile for the Queney Solution; Wavelet p'w' Cospectrum for Queney

Characterization of IOP 9

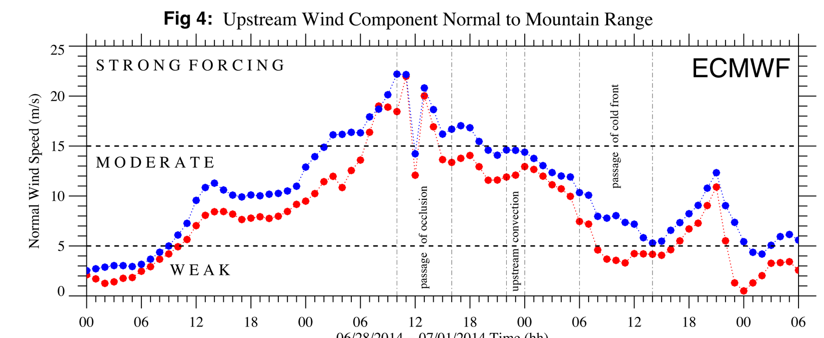


Fig 4: Upstream Wind Component Normal to Mountain Range

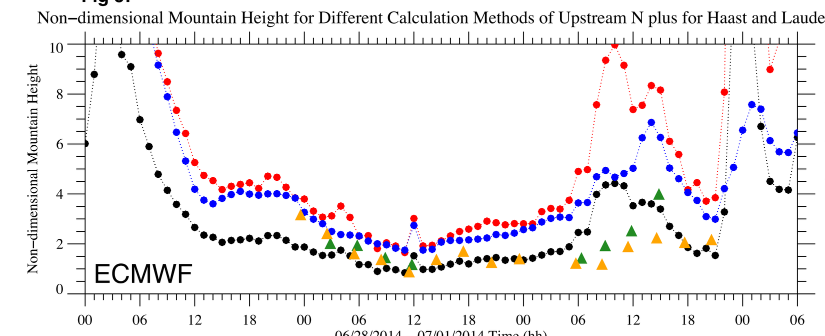


Fig 5: Non-dimensional Mountain Height for Different Calculation Methods of Upstream N plus for Haast and Lauder Soundings

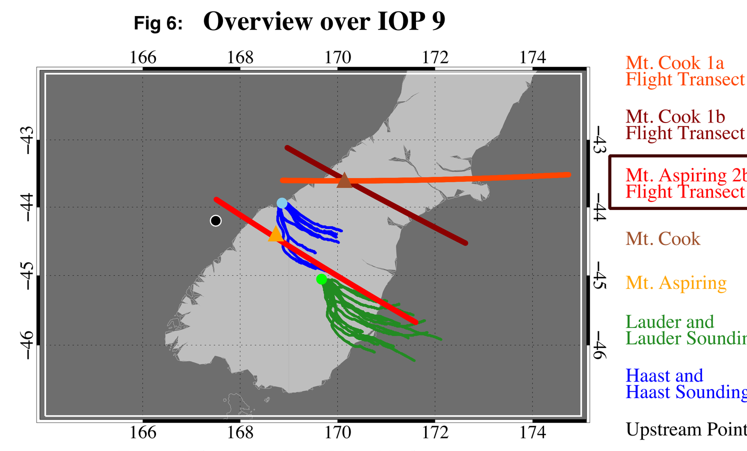


Fig 6: Overview over IOP 9

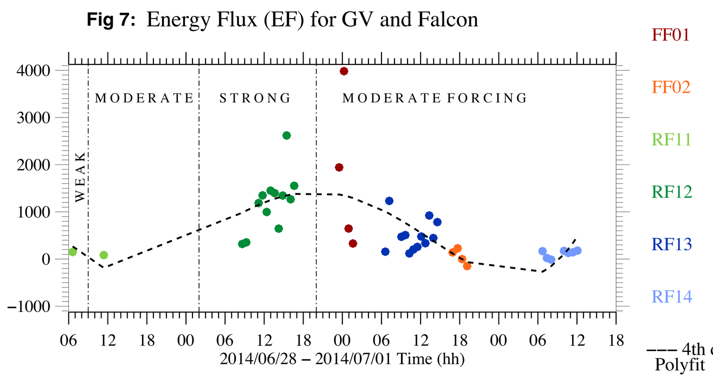
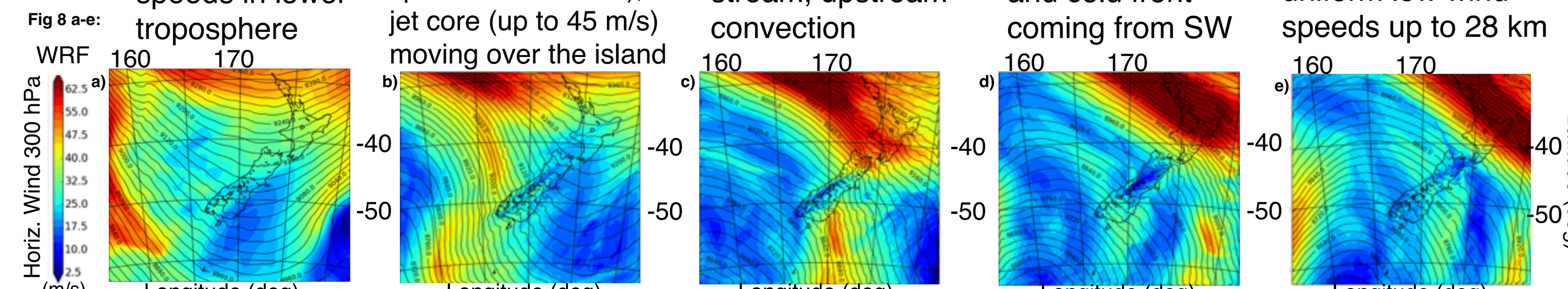


Fig 7: Energy Flux (EF) for GV and Falcon

3 Phases during the Transient Tropospheric Forcing:

06/28 18 UTC	06/29 08 UTC	06/29 23 UTC	06/30 11 UTC	06/30 18 UTC
Accelerating forcing: increasing wind speeds in lower troposphere	**Maximum forcing:** passage of occlusion (reduction of wind speeds below 3 km), jet core (up to 45 m/s) moving over the island	**Decelerating forcing:** jet moving downstream, upstream convection	second weaker jet and cold front coming from SW	second weaker jet has passed, nearly uniform low wind speeds up to 28 km

Fig 8 a-e:



Accelerating Phase

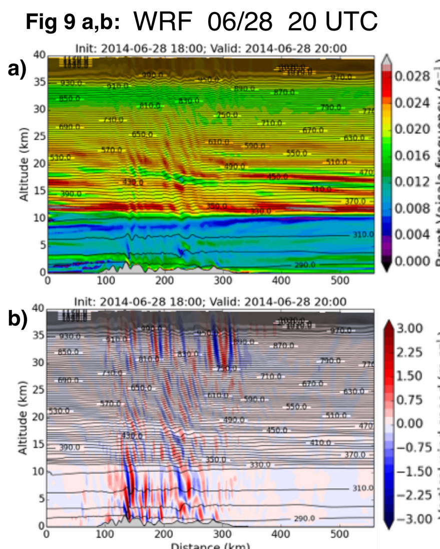


Fig 9 a,b: WRF 06/28 20 UTC

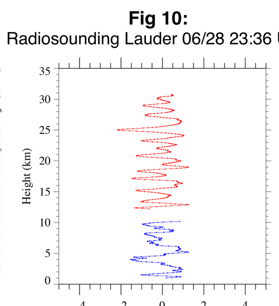


Fig 10: Radiosounding Lauder 06/28 23:36 UTC

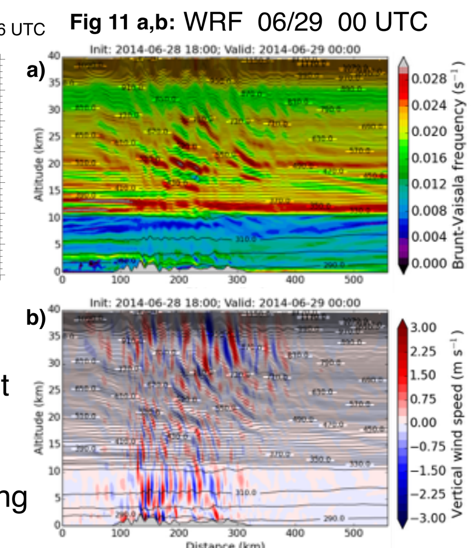


Fig 11 a,b: WRF 06/29 00 UTC

No research flight along Mt.-Aspiring-2b-transect during accelerating phase

- Local small-amplitude wave excitation, especially over main mountain ridge (Fig 9a,b, 10)
- Increasing wave amplitudes
- Local wave breaking (Fig 11a,b)

Phase of Maximum Forcing

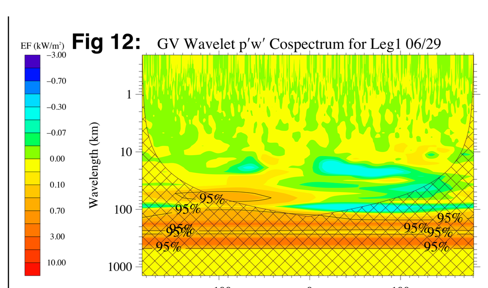


Fig 12: GV Wavelet p'w' Cospectrum for Leg1 06/29

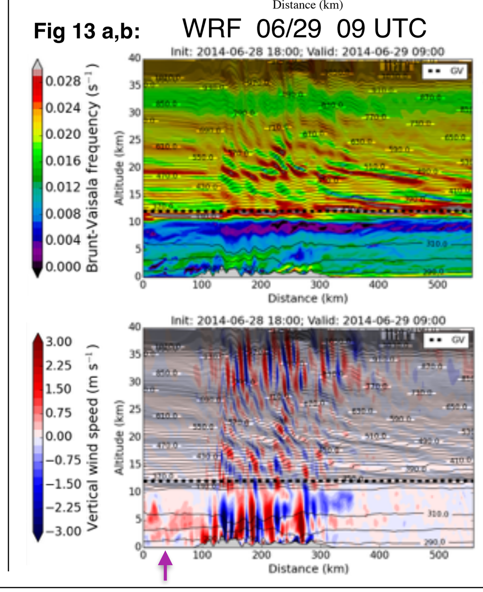


Fig 13 a,b: WRF 06/29 09 UTC

RF12

- GW breaking layer in troposphere —> self-induced critical layer, partial wave reflection
- Long wave propagation ($\lambda_x > 60$ km, Fig 12, 13a)
- Decreasing amplitudes in lower stratosphere (Fig 13b, 14)

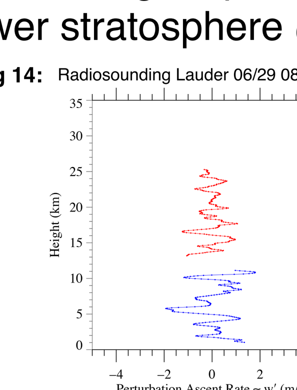


Fig 14: Radiosounding Lauder 06/29 08:52 UTC

- Behind occlusion: smaller evanescent signatures of individual peaks, ceasing wave breaking in troposphere (Fig 16a,b)

—> Decreasing wave response of main ridge (Fig 15, 16b)

- Local GW breaking in lower stratosphere
- Strong long wave response establishes (Fig 16a)

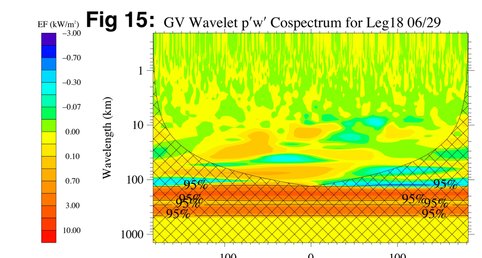


Fig 15: GV Wavelet p'w' Cospectrum for Leg18 06/29

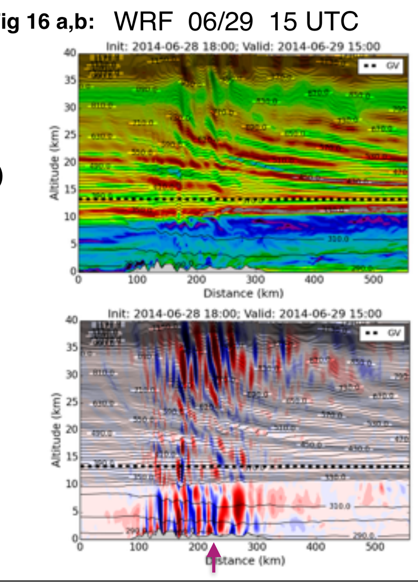


Fig 16 a,b: WRF 06/29 15 UTC

Decelerating Phase

FF01

- No GW breaking in troposphere (Fig 17)
- Elongated GW breaking layers in lower stratosphere (Fig 19) —> wave reflection (Fig 20b, 21b)

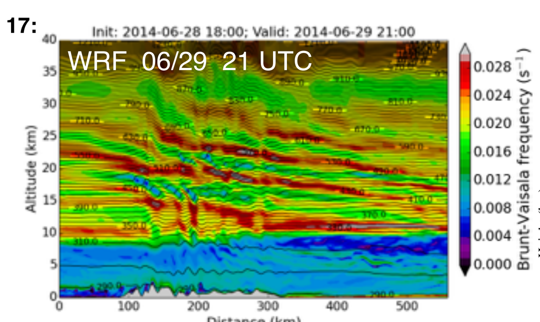


Fig 17: WRF 06/29 21 UTC

- Maximum of long wave response (Fig 17)

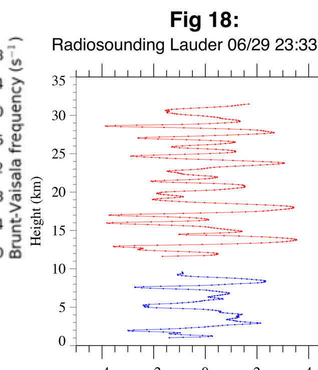


Fig 18: Radiosounding Lauder 06/29 23:33 UTC

- GW breaking layer only local —> propagation in sounding (Fig 18)

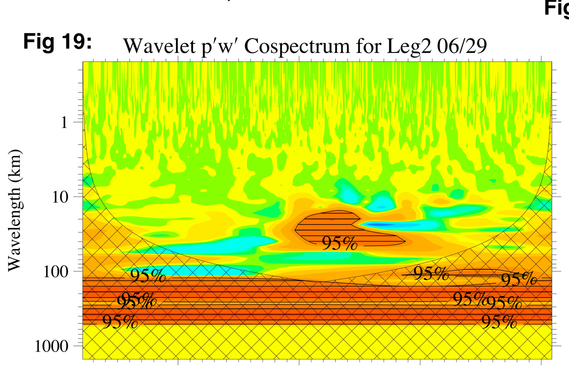


Fig 19: Wavelet p'w' Cospectrum for Leg2 06/29

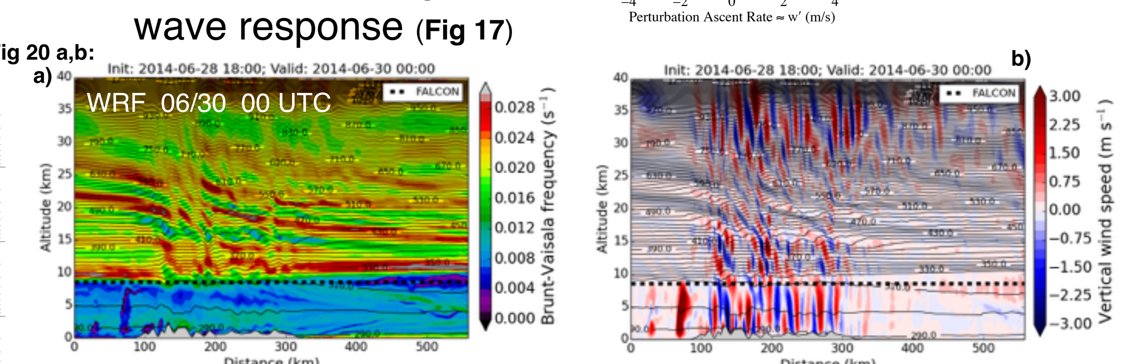


Fig 20 a,b: WRF 06/30 00 UTC

- Falcon below tropopause observes propagating mountain waves (Fig 19) <—
- Evanescent waves in troposphere, propagating above (Fig 20b)

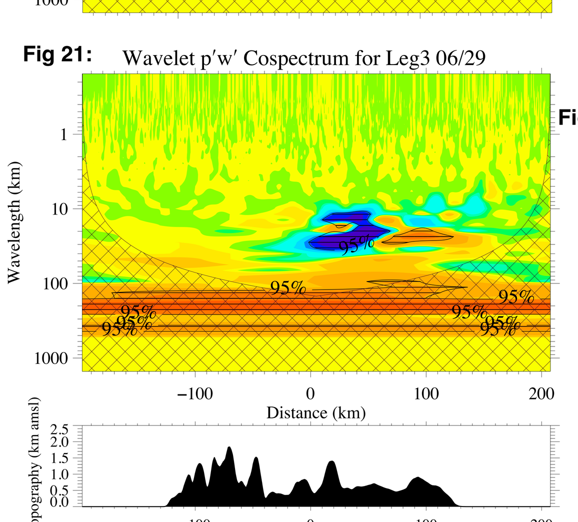


Fig 21: Wavelet p'w' Cospectrum for Leg3 06/29

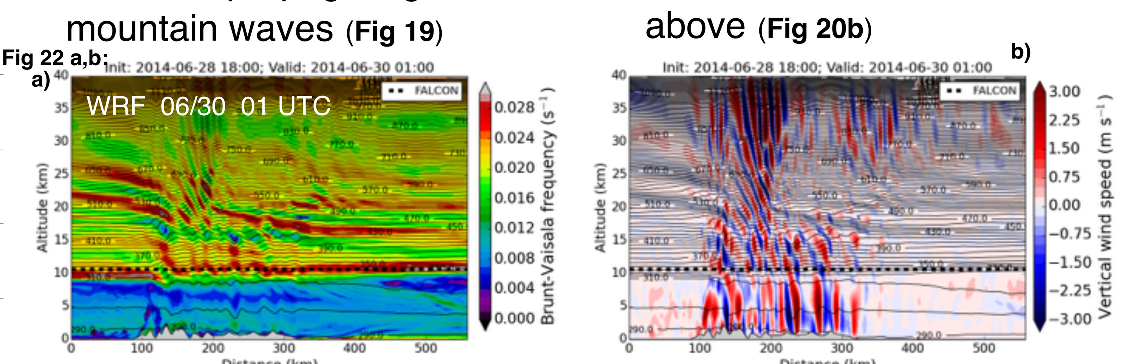


Fig 22 a,b: WRF 06/30 01 UTC

- Falcon observes partial wave reflection in tropopause region (Fig 21, 22b)
- GW breaking layer starts to decay (Fig 22a,b)

FF02

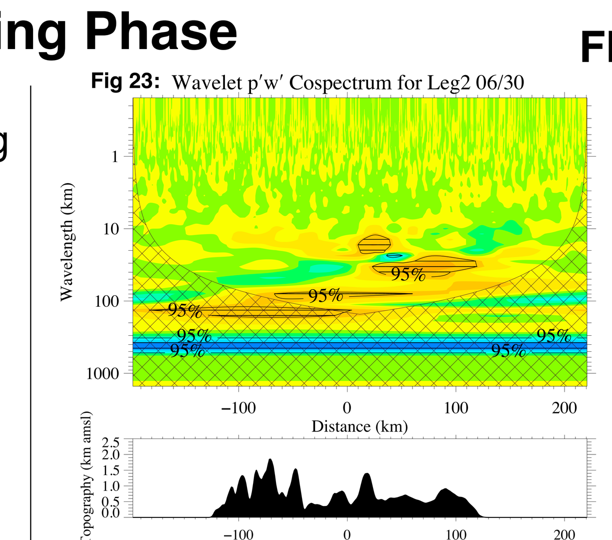


Fig 23: Wavelet p'w' Cospectrum for Leg2 06/30

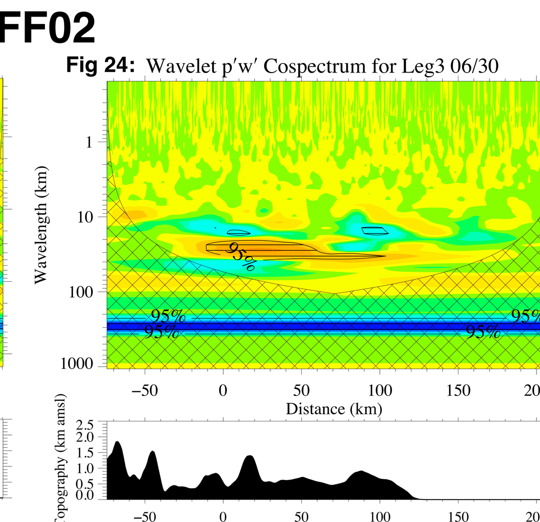


Fig 24: Wavelet p'w' Cospectrum for Leg3 06/30

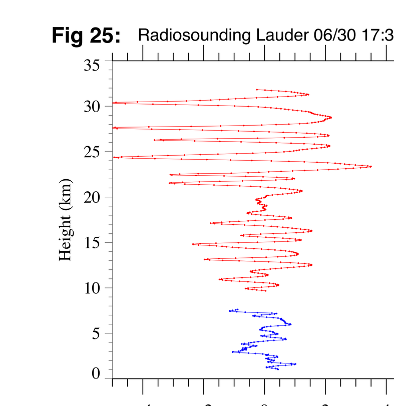


Fig 25: Radiosounding Lauder 06/30 17:39 UTC

- Waves still arrive in upper layer from previous excitation (Fig 25, 26a, 27)

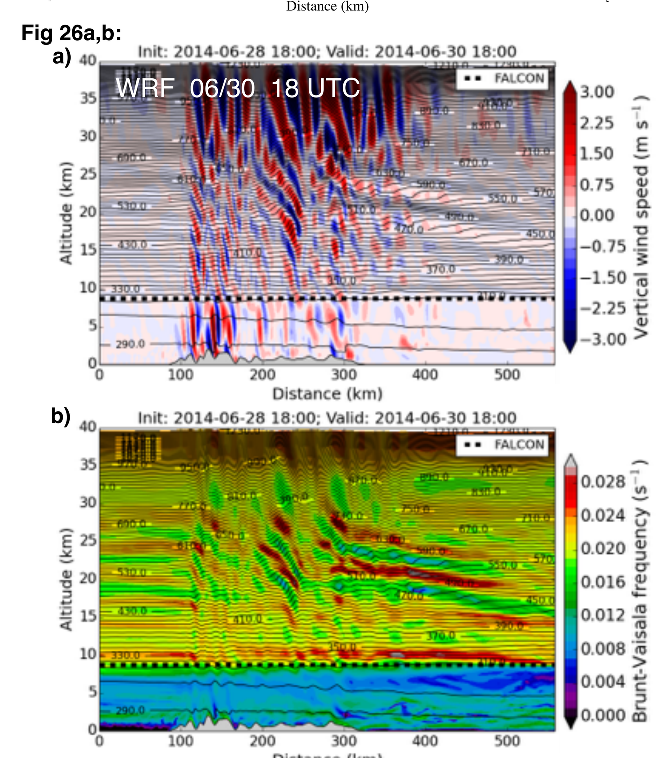


Fig 26a,b: WRF 06/30 18 UTC

- Long wave response vanishes (Fig 23, 24, 26b)
- Only main mountain peaks excite upward and in parts more upstream propagating waves (Fig 23, 24, 26a)
- Lauder Rayleigh Lidar: Peak in mesospheric wave activity from maximum long wave response? (Fig 27, 17)

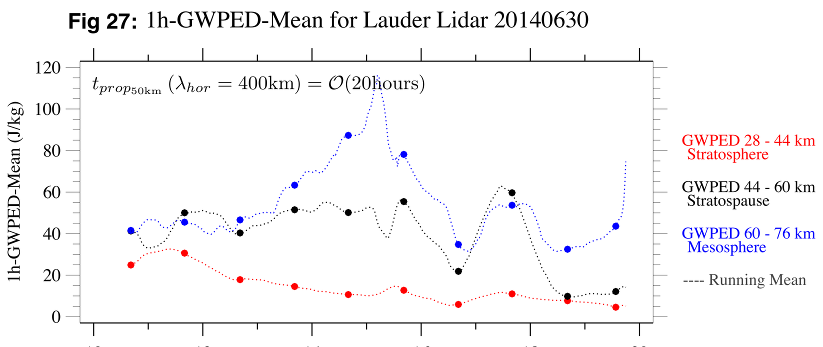


Fig 27: 1h-GWPED-Mean for Lauder Lidar 20140630

Summary and Conclusions

- Similar transience like in Chen et al (2005, 2007), non-stationary event, likewise accelerating and decelerating cross-mountain wind speeds
- However, waves stay quasi-linear in Chen et al (2005)
- Here: Wave breaking, wave reflection, non-linear processes occur in all 3 phases —> Propagation properties are altered
- However, waves are able to deeply propagate
- Maximum wave response at tropopause region not with maximum forcing, but decreasing forcing
- Due to lack of flight measurements can´t prove asymmetry in momentum flux like in Chen et al (2005)
- Wave response and the strength of non-linear processes clearly transient

Contact

tanja.portele@dlr.de tanja.portele@student.uibk.ac.at

Acknowledgements

This work was supported by the Austrian Ministry of Science BMWF as part of the UniInfrastrukturprogramm of the Research Platform Scientific Computing at the University of Innsbruck. GV data was provided by NCAR/EOL under sponsorship of the National Science Foundation. http://data.eol.ucar.edu/

References

Chen, C.-C., D. R. Durran, and G. J. Hakim, 2005: Mountain-wave momentum flux in an evolving synoptic-scale flow. *J. Atmos. Sci.*, **62**, 3213–3231.

Chen, C.-C., G. J. Hakim, and D. R. Durran, 2007: Transient mountain waves and their interaction with large scales. *J. Atmos. Sci.*, **64**, 2378–2400.

Reinecke, P. A., and D. R. Durran, 2008: Estimating topographic blocking using a Froude number when the static stability is nonuniform. *J. Atmos. Sci.*, **65**, 1035–1048.

8/21/15