Mountain wave trapping on the tropopause inversion layer revealed by idealized numerical simulations and evaluated by mid-latitude radiosonde measurements

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DFG Research Group: MSGwaves Multiscale Dynamics of Gravity Waves) 2014-2020

BMBF Research Initiative: ROMIC (Role of the Middle atmosphere In Climate) 2014 -2017

DLR

Reference:
PhD-Thesis S. Gisinger
LMU 2018

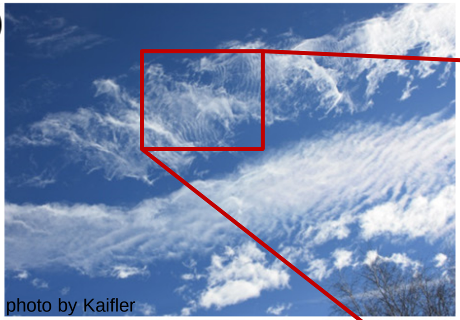
Gravity waves?

(a)


(b)


"While we cannot see atmospheric gravity waves, we can see the effects the waves have on the atmosphere." (Nappo, 2002)

(c)


(d)


(e)


(a) rotor clouds, (b) lenticularis clouds and (d) small scale wave structures in cirrus clouds, (c) polar stratospheric clouds, (d) noctilucent clouds

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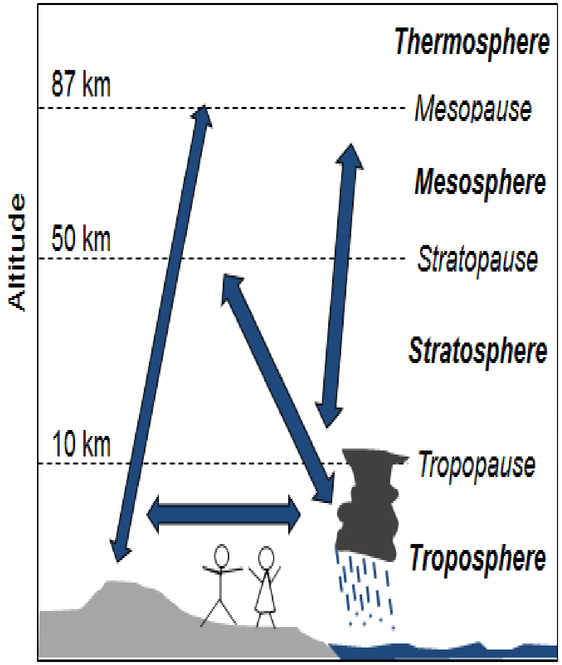
Reference: PhD-Thesis S. Gisinger LMU 2018

Why to care about gravity waves?

- hazard to aviation **(clear air turbulence)**
- horizontal and vertical distribution of momentum in the atmosphere **(coupling)**
- **global circulation** (without gravity waves atmospheric circulation models do not get the correct circulation patterns, mesospheric wind reversal)
- horizontal spatial scales from tens to hundreds of kilometers → **parameterizations** needed in weather and climate models
- models have deficits assigned to **missing gravity wave drag**, e.g., southern hemispheric cold pole bias



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Strategy to increase the knowledge about gravity waves and their behaviour in the real atmosphere

Strategy to increase the knowledge about gravity waves and their behaviour in the real atmosphere

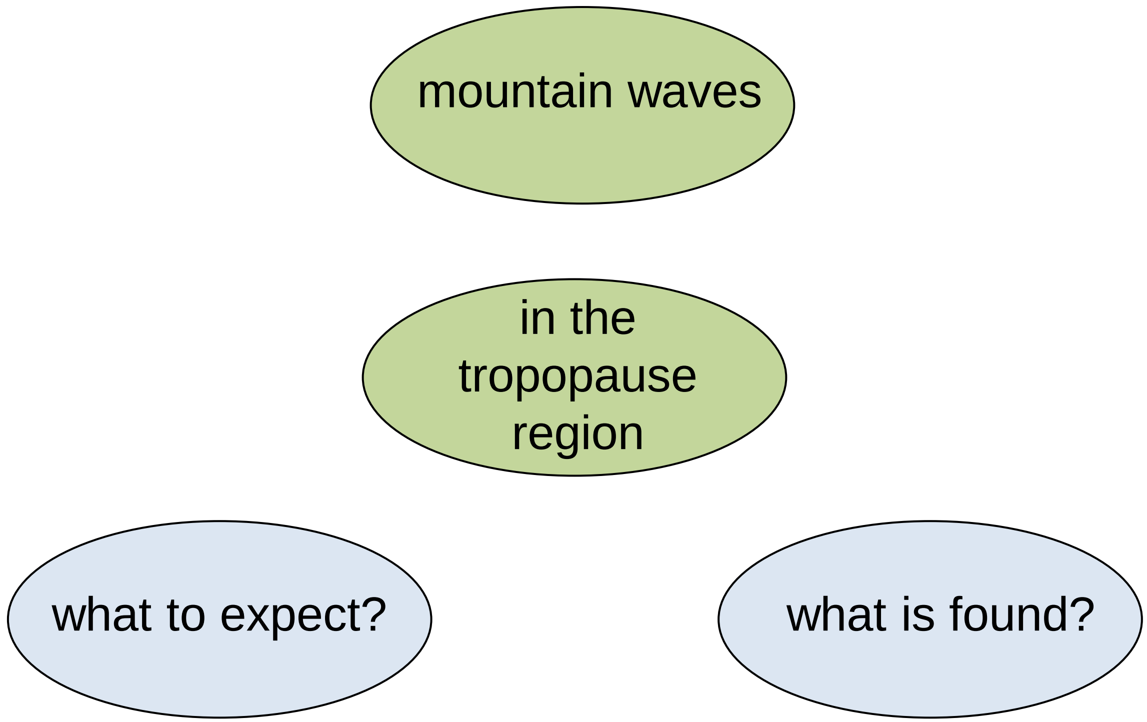
mountain waves

in an interesting region

what to expect?

what is found?

Strategy to increase the knowledge about gravity waves and their behaviour in the real atmosphere



Strategy to increase the knowledge about gravity waves and their behaviour in the real atmosphere

mountain waves

in the tropopause region

theory and simulations

what is found?

Strategy to increase the knowledge about gravity waves and their behaviour in the real atmosphere

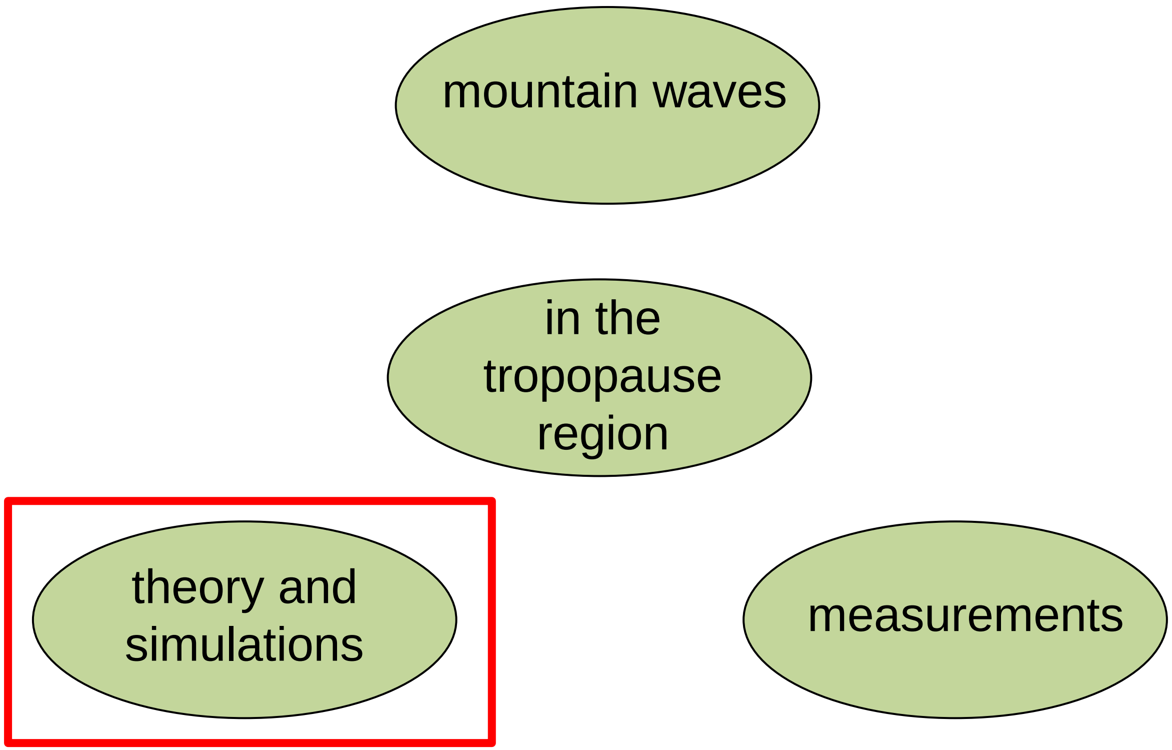
mountain waves

in the tropopause region

theory and simulations

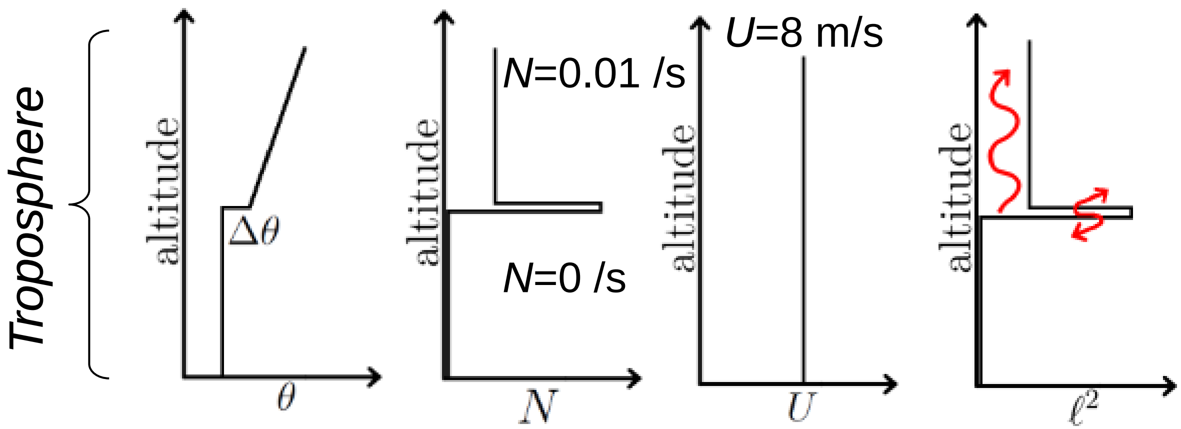
measurements

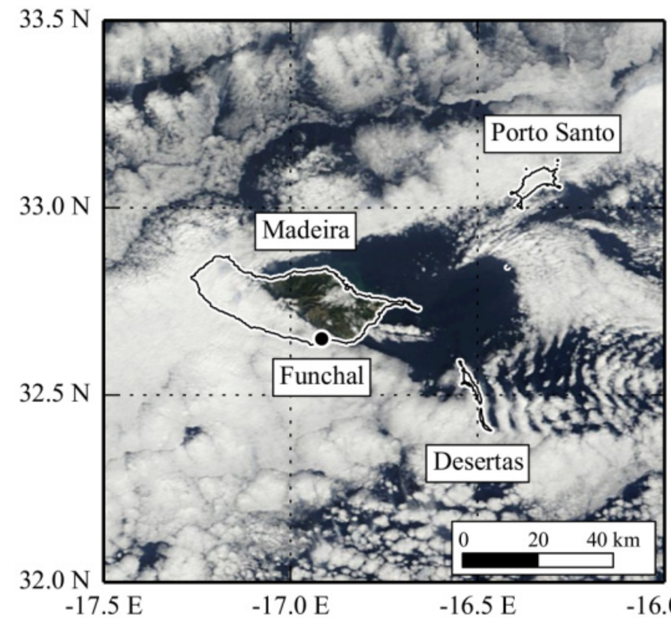
Strategy to increase the knowledge about gravity waves and their behaviour in the real atmosphere



Mountain wave propagation: trapping on an inversion

- an **inversion in the troposphere** (e.g., at the top of the boundary layer) can be a waveguide for trapped waves (**interfacial waves**) which propagate downwind of the mountain (Vosper 2004, Sachsperger et al. 2015)





Sachsperger et al. 2015

required condition:

$$F_i^2 \leq \tanh(Z)/Z$$

$$F_i = \frac{U}{\sqrt{g z_i \Delta\theta/\theta}}$$

$$Z = \frac{N z_i}{U}$$

occurrence of interfacial waves depends on **strength of inversion** $\Delta\theta$

Reference: PhD-Thesis S. Gisinger LMU 2018

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EULAG Setup

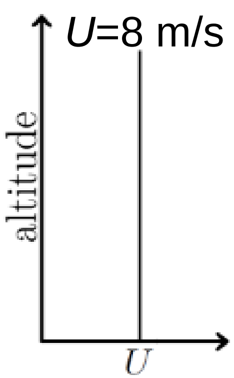
- 2D with 1032 x 2000 grid points
- $\Delta x = 100$ m and $\Delta z = 10$ m
- Δt is set to 1 s
- incompressible Boussinesq approximation
- inviscid
- TKE subgrid-scale model

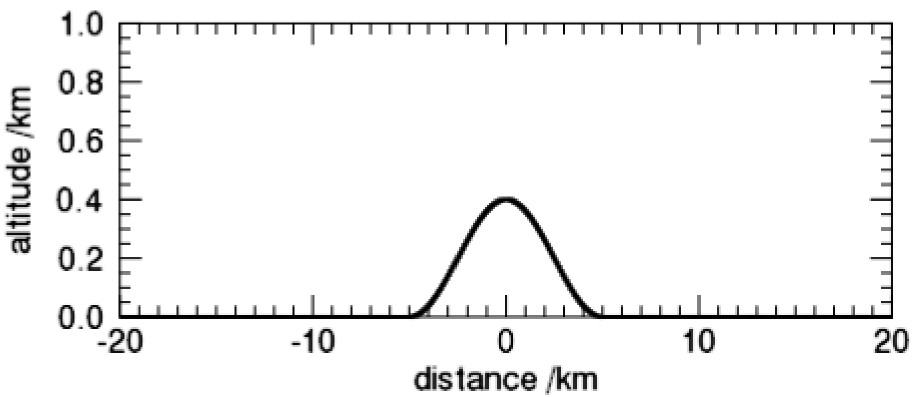
- idealized ridge:
- U(z)=const.=8 m/s

$$h(x) = \begin{cases} h_0[1+\cos(Kx)]/2 & \text{for } |x| \leq \pi/K \\ 0 & \text{for } |x| > \pi/K, \end{cases}$$

$$K = 2\pi/L$$

h_0 is set to 400 m and width L to 10 km or 5 km

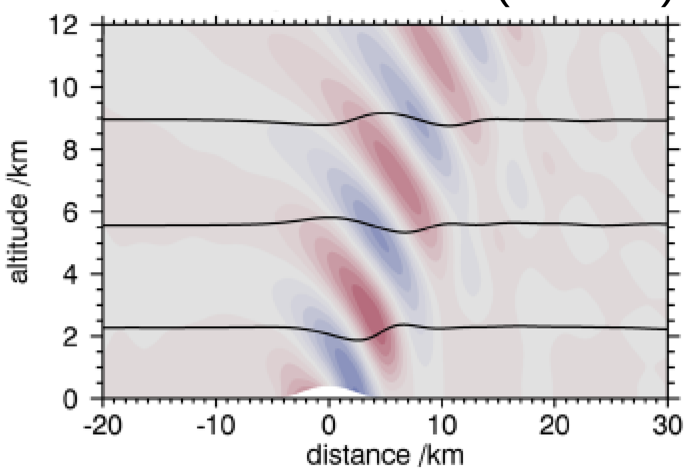




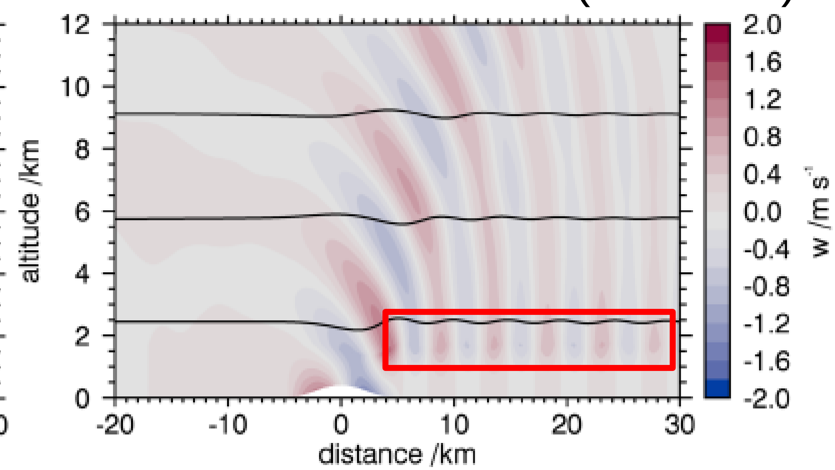
Mountain wave propagation: trapping on an inversion

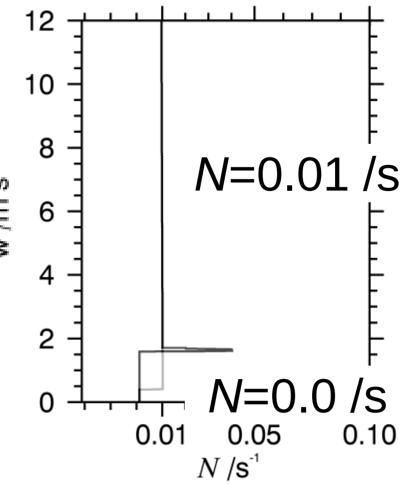
- an **inversion in the troposphere** (e.g., at the top of the boundary layer) can be a waveguide for trapped waves (**interfacial waves**) which propagate downwind of the mountain (Vosper 2004, Sachsperger et al. 2015)

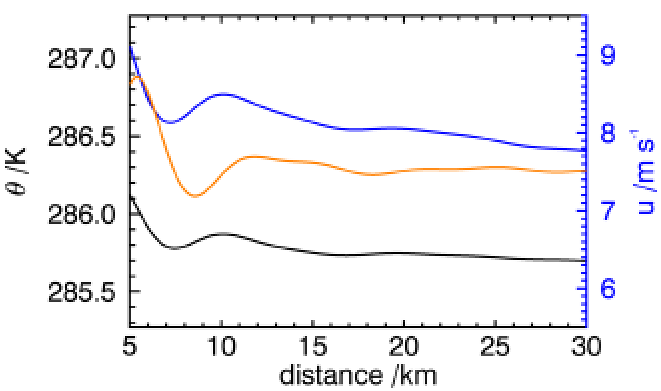
no inversion ($\Delta\theta$=0 K)

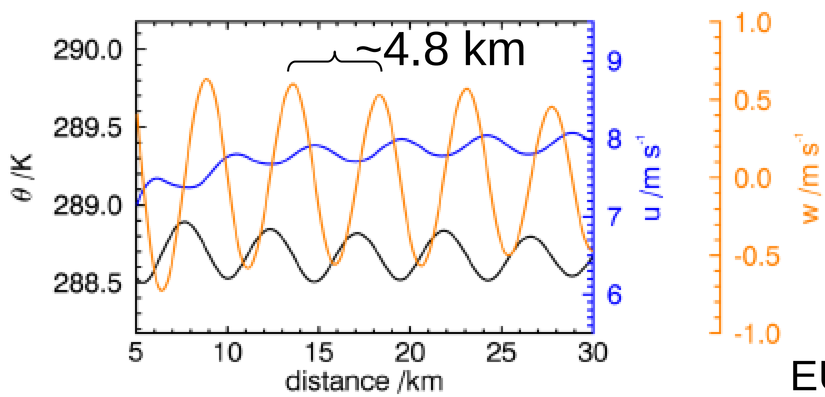


inversion at 1.6 km ($\Delta\theta$=3.3 K)







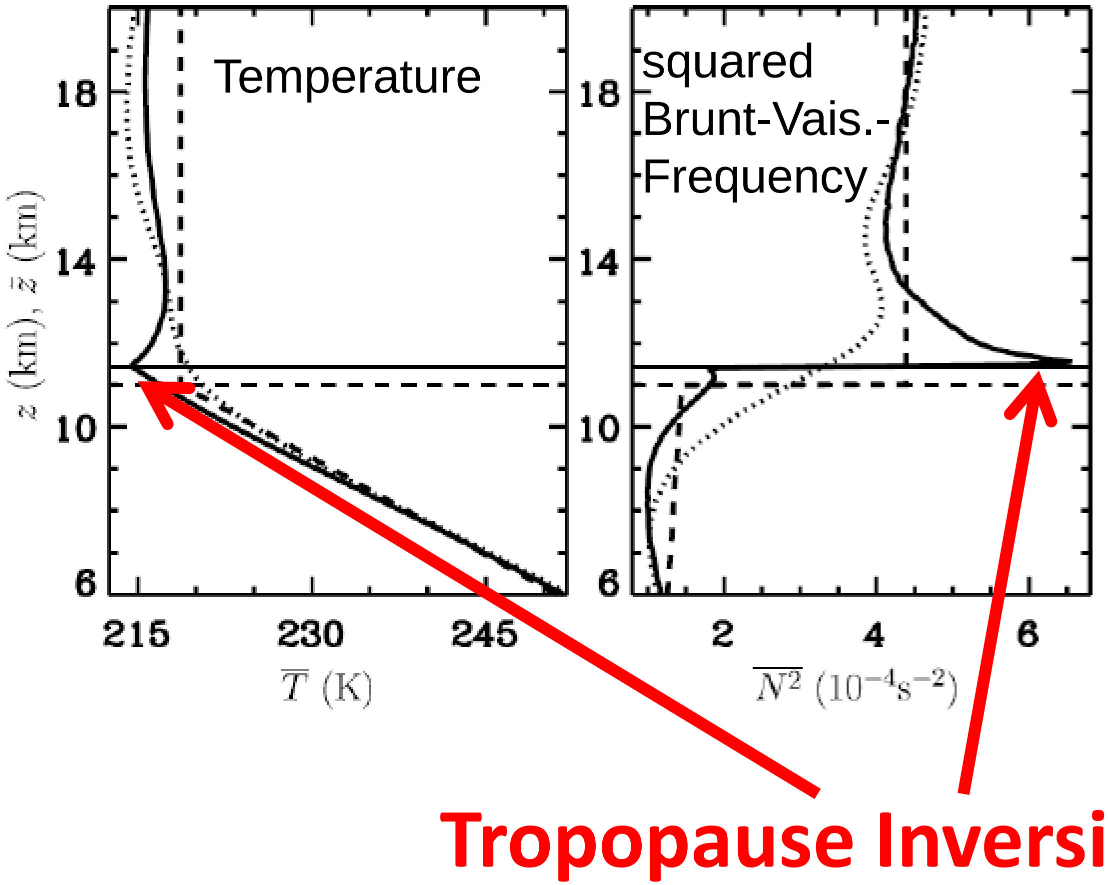


potential temperature, horizontal and vertical wind at 2 km

EULAG
Large Eddy Simulation

Reference:
PhD-Thesis S. Gisinger
LMU 2018

Mountain wave propagation: trapping on the TIL



Differences between tropospheric inversion and TIL:

- ***N* above inversion is 2 times larger**
- inversion is at **higher altitude**
- **stable stratification below TIL** in the troposphere

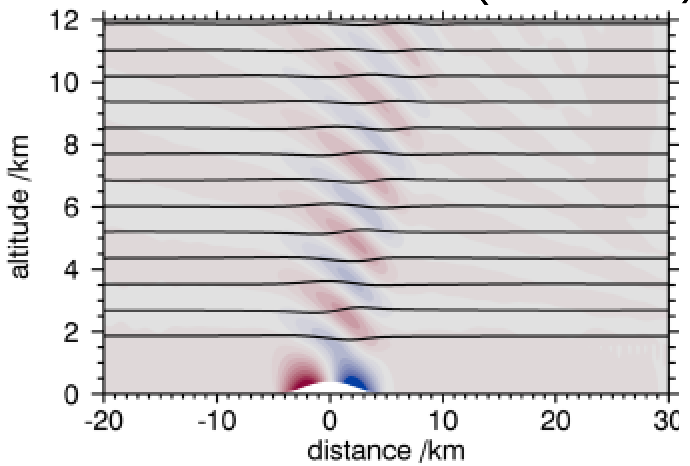
Figure taken from Birner (2006).

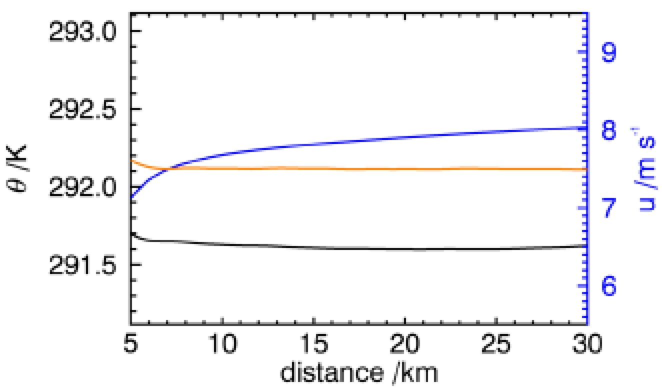
Reference: PhD-Thesis S. Gisinger LMU 2018

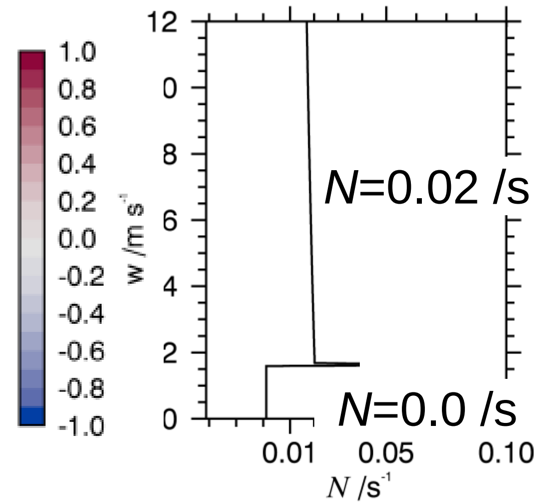
Mountain wave propagation: trapping on the TIL

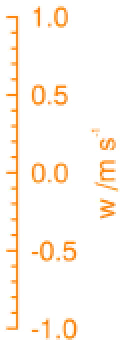
- Is concept of trapping on an inversion in the troposphere (Vosper 2004, Sachsperger et al. 2015) applicable for the **TIL**? **(*N*=0.02 /s)**

inversion at 1.6 km ($\Delta\theta$=3.3 K)









potential temperature, horizontal and vertical wind at 2 km

EULAG
Large Eddy Simulation

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LMU 2018

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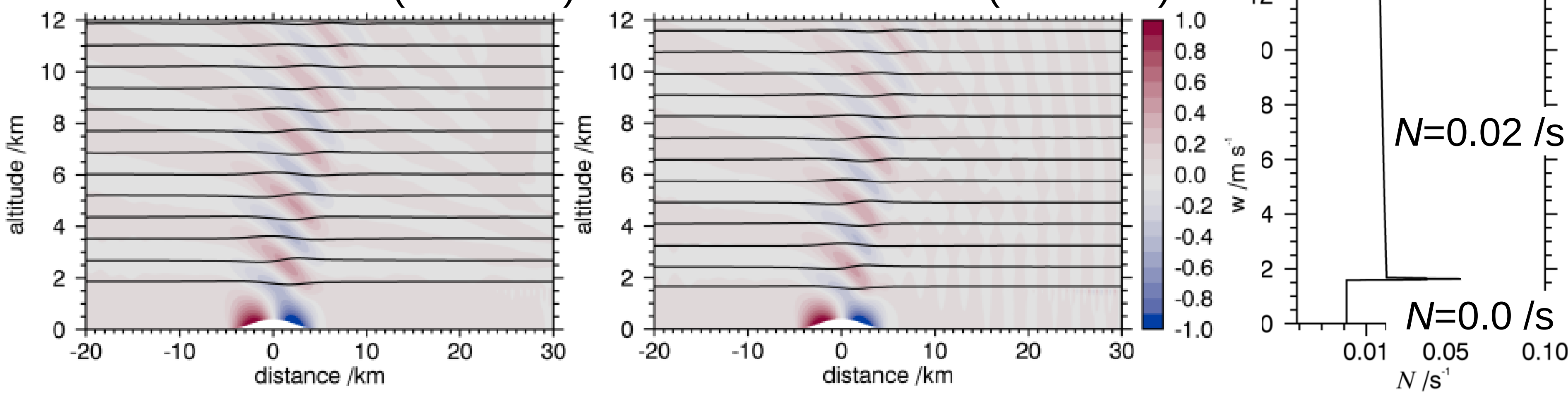
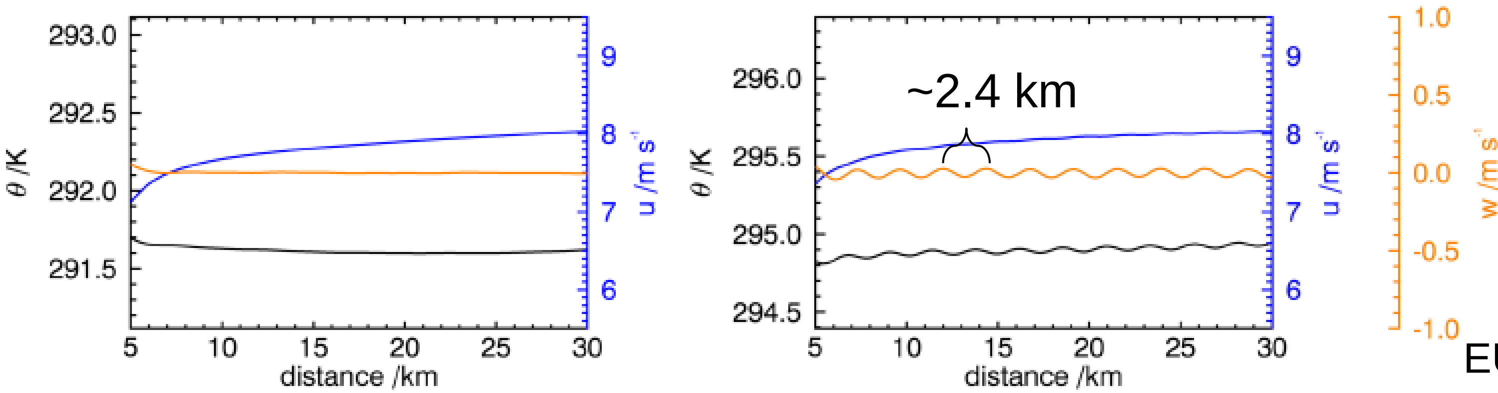
Mountain wave propagation: trapping on the TIL

- Is concept of trapping on an inversion in the troposphere (Vosper 2004, Sachsperger et al. 2015) applicable for the **TIL**? **(*N*=0.02 /s)**

→ inversion must be 2 times **stronger for trapping**

inversion at 1.6 km ($\Delta\theta$=3.3 K) | inversion at 1.6 km ($\Delta\theta$=6.6 K)





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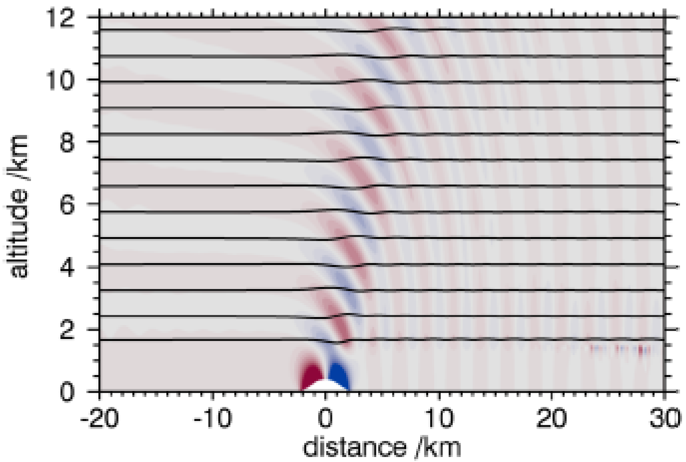
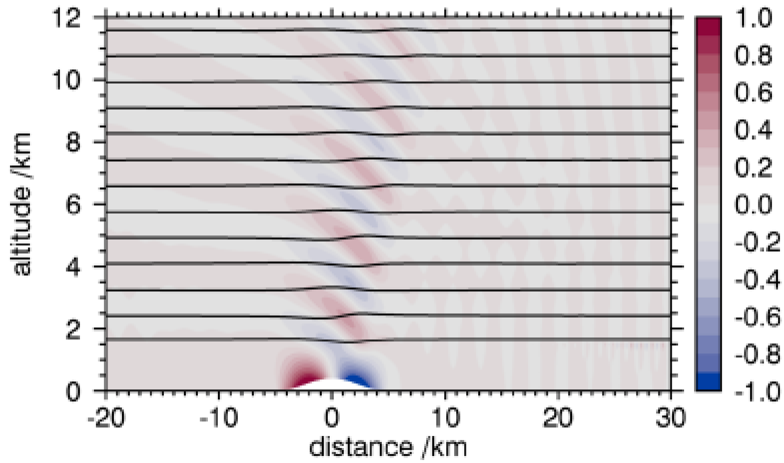
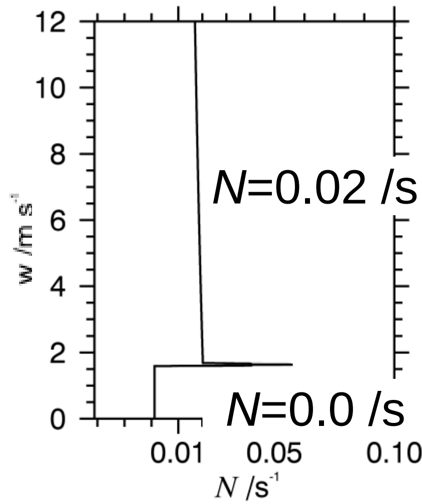
inversion at 1.6 km ($\Delta\theta$=6.6 K)

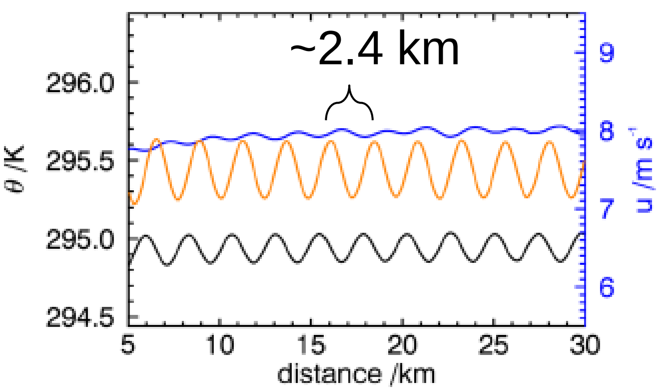
mountain width 5 km

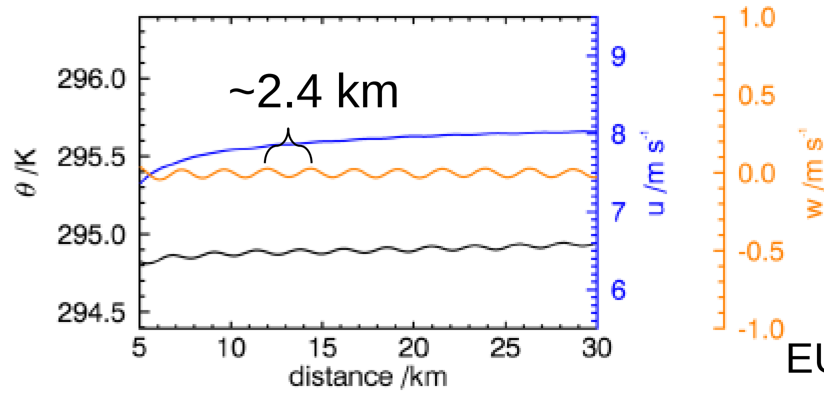


mountain width 10 km









potential temperature, horizontal and vertical wind at 2 km

EULAG
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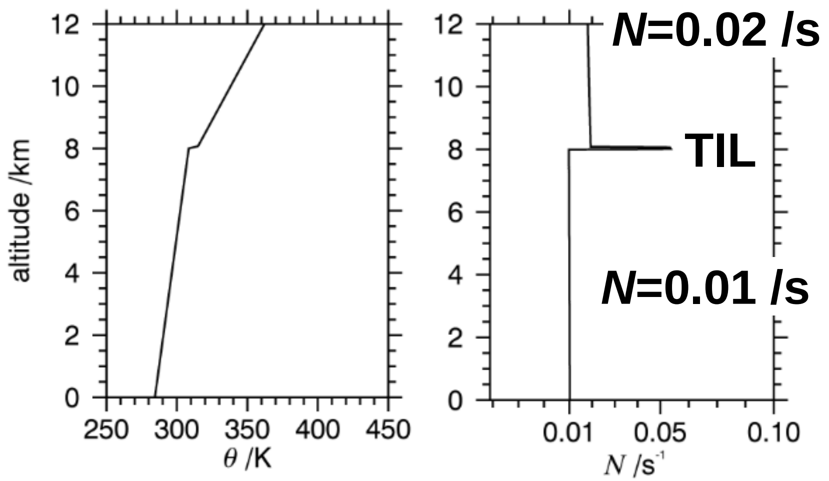
LMU 2018

Mountain wave propagation: trapping on the TIL

- Is concept of trapping on an inversion in the troposphere (Vosper 2004, Sachsperger et al. 2015) applicable for the **TIL**? **(N=0.02 /s, z_i= 8 km)**



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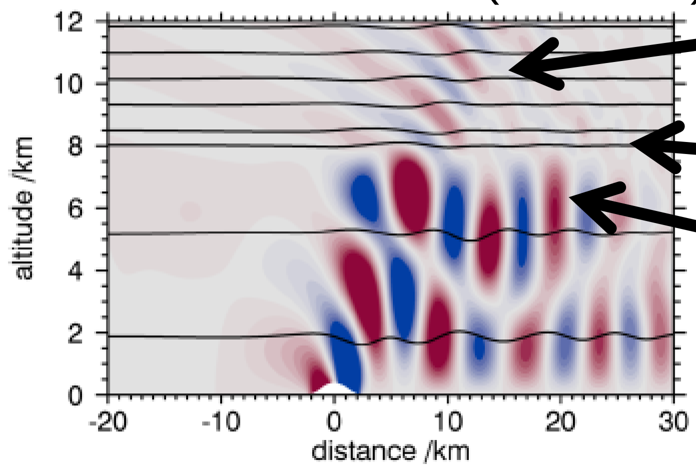
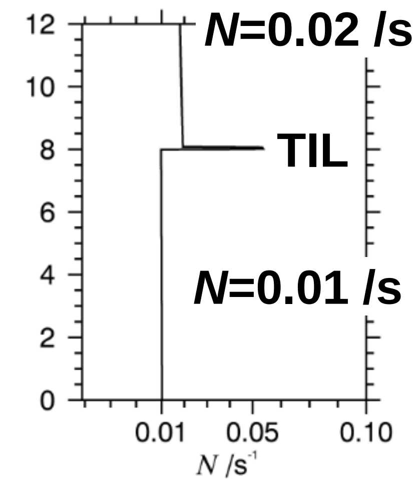
inversion at 8 km (Δθ=6.6 K)

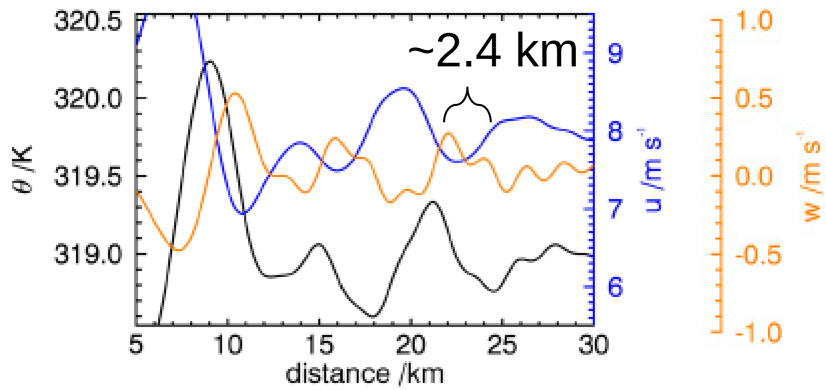


upward propagating waves

trapping on TIL

waves reflected at the tropopause →downstream wave propagation





potential temperature, horizontal and vertical wind at 8.4 km

EULAG
Large Eddy Simulation

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LMU 2018

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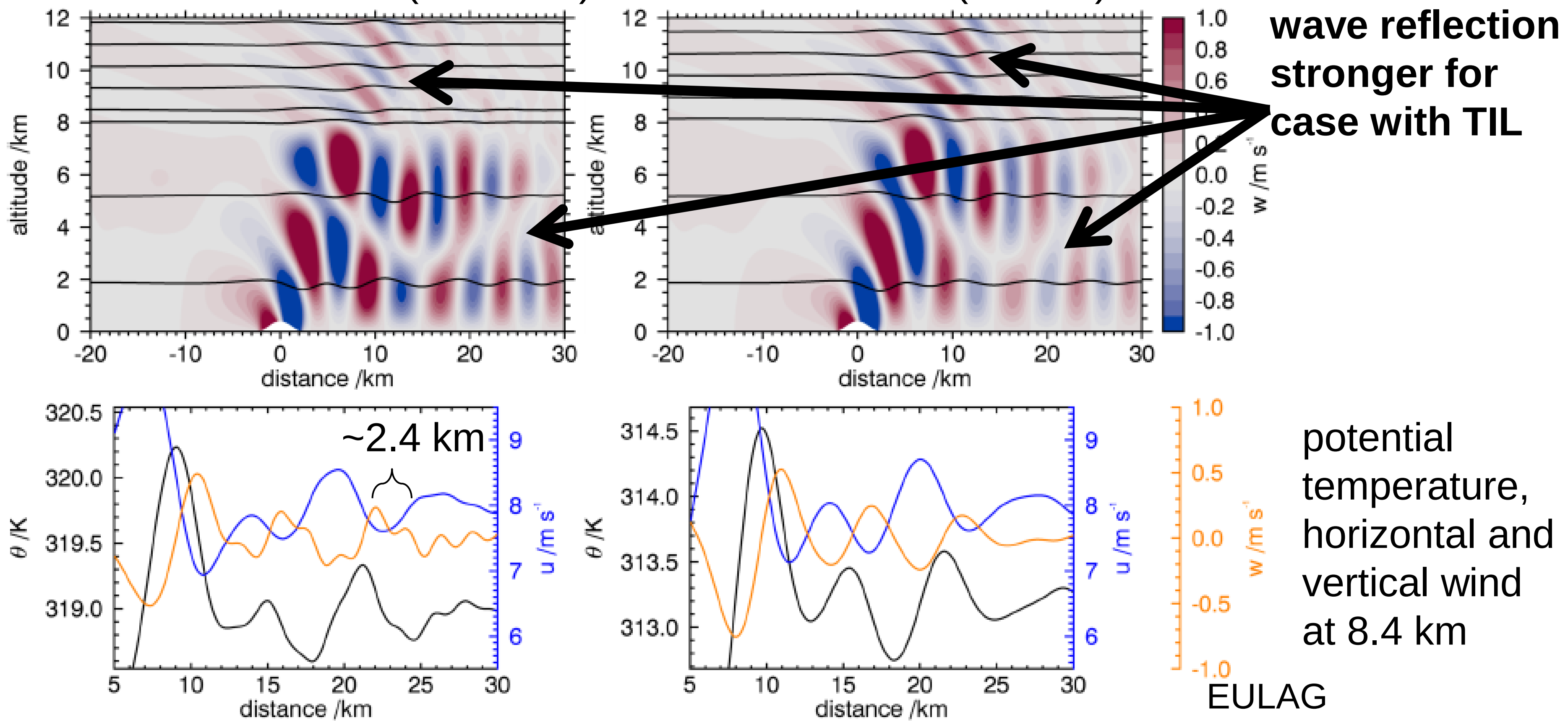
- Is concept of trapping on an inversion in the troposphere (Vosper 2004, Sachsperger et al. 2015) applicable for the **TIL**? **(*N*=0.02 /s, z_i= 8 km)**

inversion at 8 km (Δ*θ*=6.6 K) no inversion (Δ*θ*=0 K)



potential temperature, horizontal and vertical wind at 8.4 km

EULAG
Large Eddy Simulation

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LMU 2018

Mountain wave propagation: role of the tropopause

Concept of **trapping on an inversion** in the troposphere (Vosper 2004, Sachsperger et al. 2015) is applicable for the **TIL**

- **Inversion must be stronger than for the troposphere**
- Inversion must be even stronger when wind speed is larger
- **Horizontal wavelength decreases with increasing stability above the inversion (amplitudes depend on the generating terrain)**

- **tropopause causes wave reflection** and waves propagate downstream in the troposphere even though they are not evanescent in the stratosphere (**not classical Scorer trapping**)

- **TIL** causes stronger wave reflection than just the tropopause without inversion

→ the **amount of mountain wave energy** downstream in the troposphere and in the stratosphere **should vary** in dependence of **the trapping on the TIL and strength of reflection → strength of the TIL**

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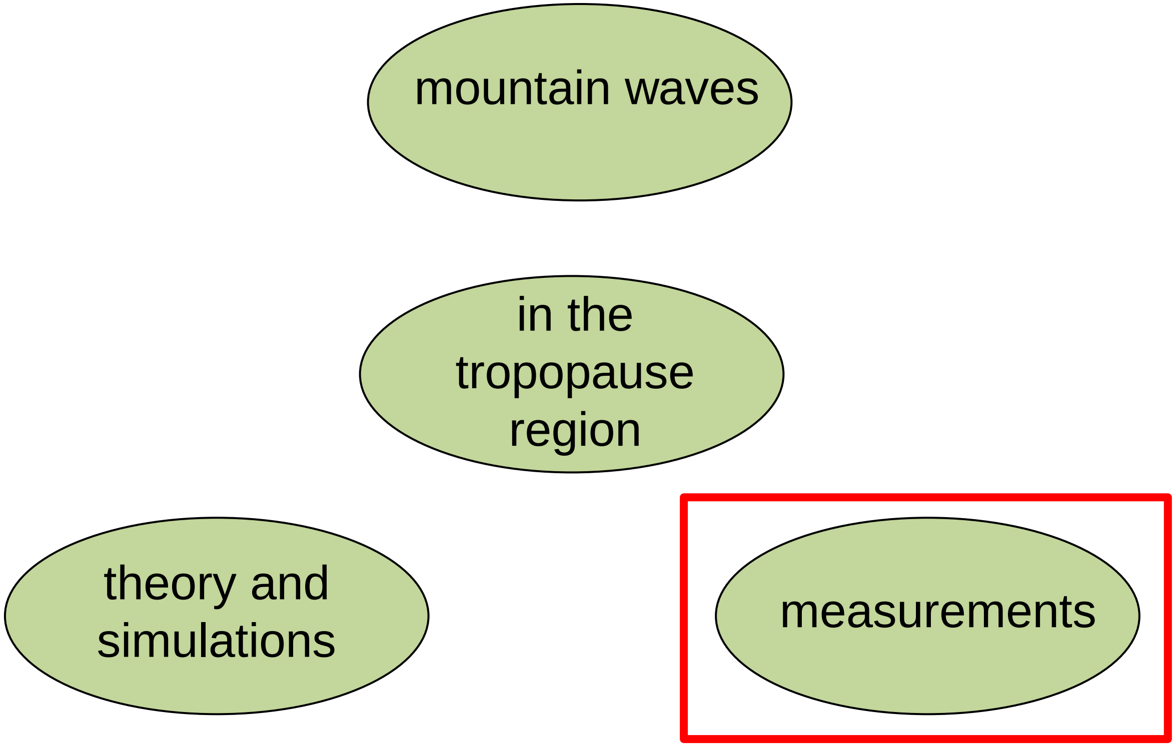
LMU 2018

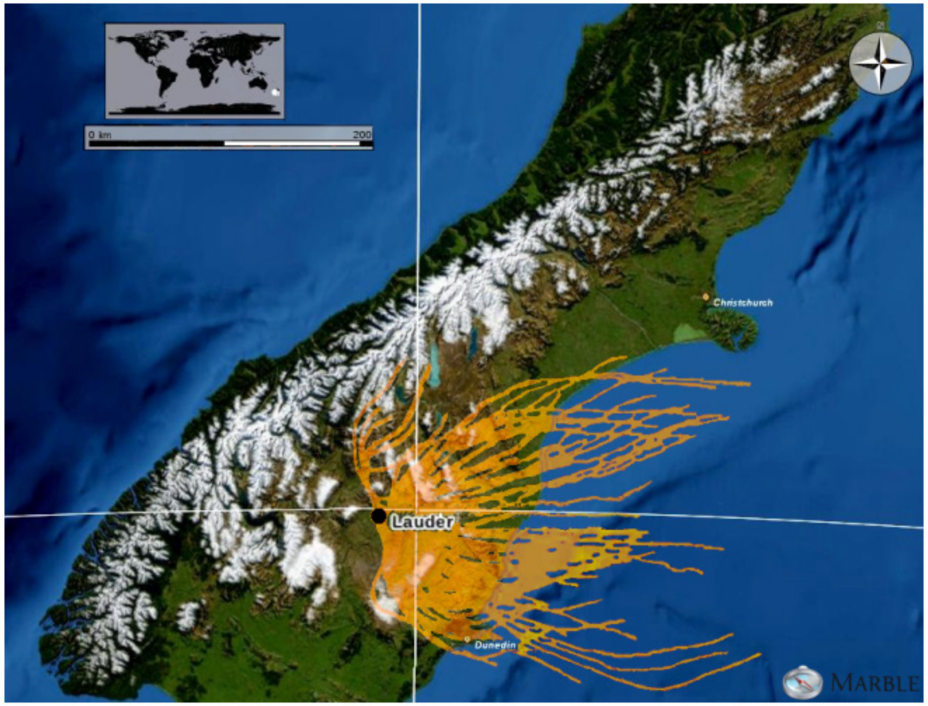
Strategy to increase the knowledge about gravity waves and their behaviour in the real atmosphere



Measurements: DEEPWAVE radiosondes (Lauder)

LAUDER soundings

98 soundings during
14 intensive observation
periods (**IOPs**)



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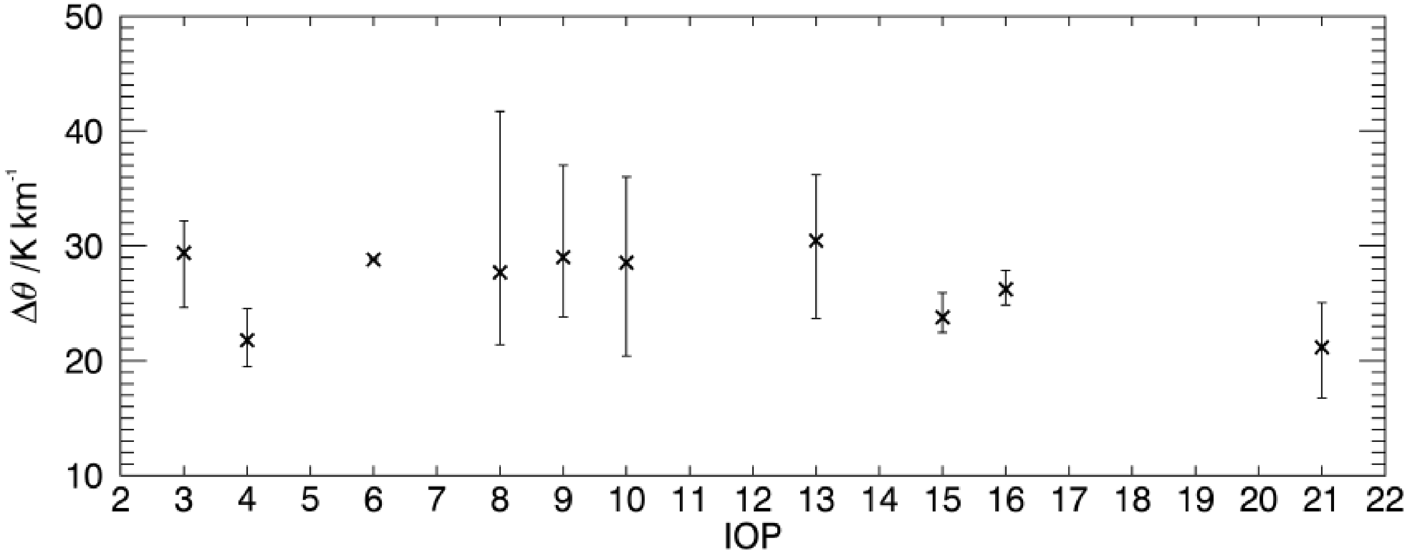
LMU 2018

Strength of the TIL from DEEPWAVE soundings



strength of the TIL of around 25-30 K
suggests trapping on the TIL and **enhanced mountain wave reflection** during DEEPWAVE

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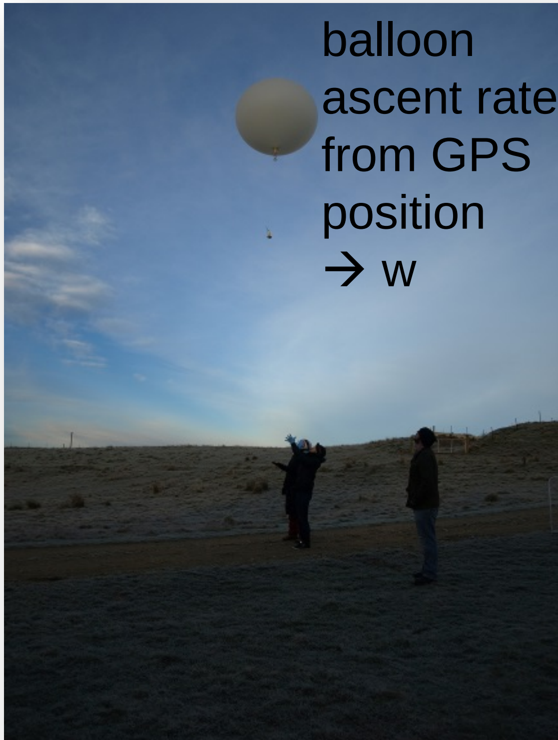
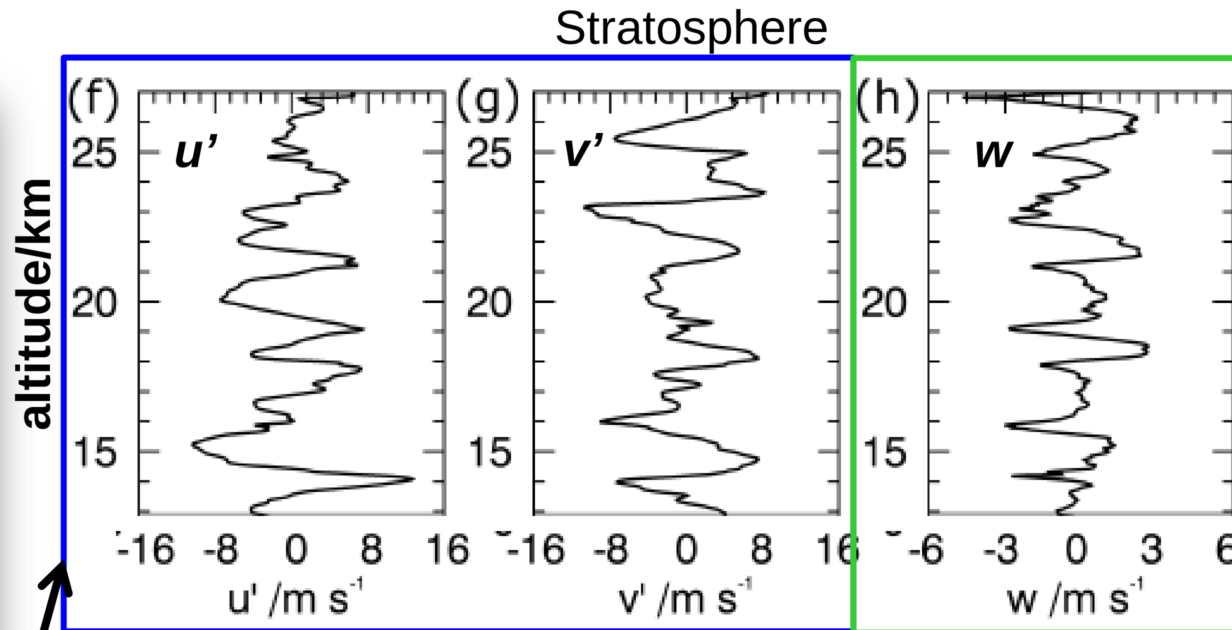
LMU 2018

Analysis of radiosonde data





perturbation profiles

measured profile minus background fit (2nd-polynomial-fit with additional 5-km running mean)

Assumption: perturbations are caused by GWs

→ measurements of **hz. wind** emphasize **low frequency waves** (inertia-GWs)

→ measurements of **vert. wind** emphasize **medium to high frequency waves**

(Lane et al 2000, Lane et al 2003, Geller and Gong 2010)

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Reference: PhD-Thesis S. Gisinger LMU 2018

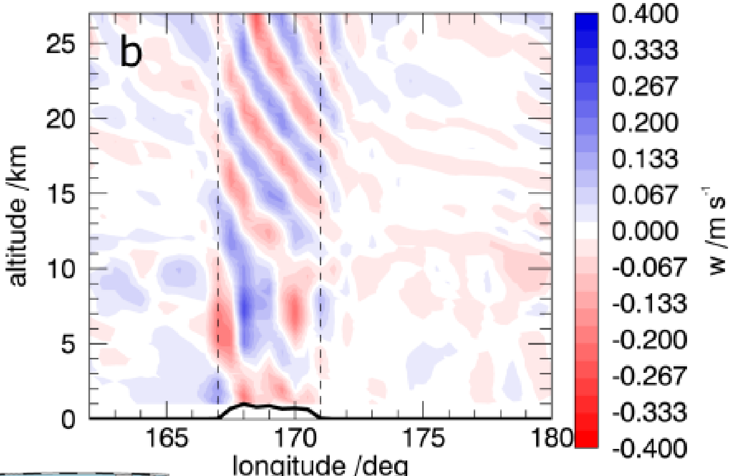
Medium to high frequency waves: mountain waves?

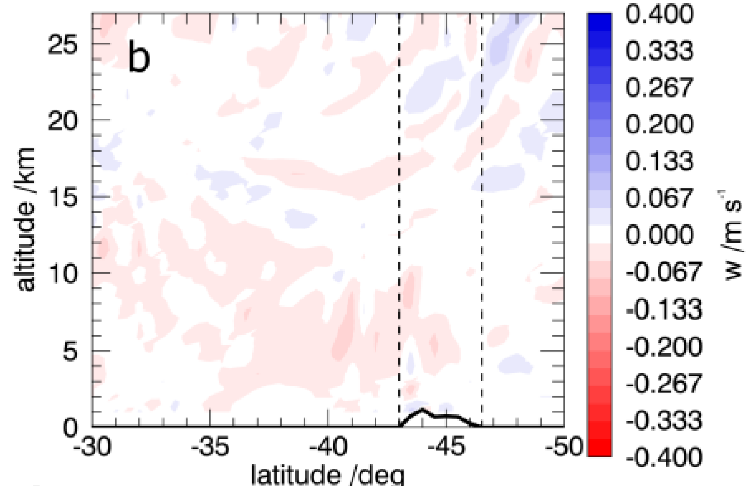
Approach: comparison of a mountain wave case to a non-mountain wave case

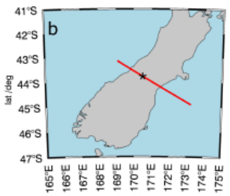
mountain wave case (IOP 4)

non-mountain wave case (IOP 15)

ECMWF vertical velocity



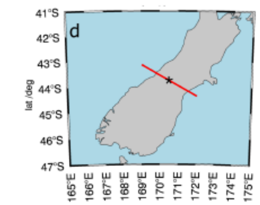


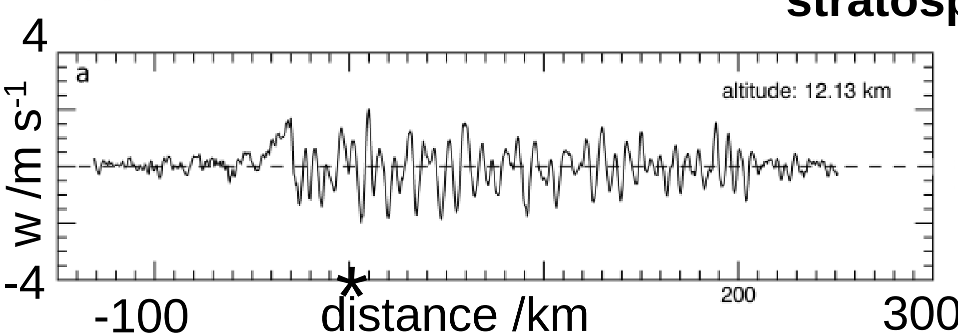


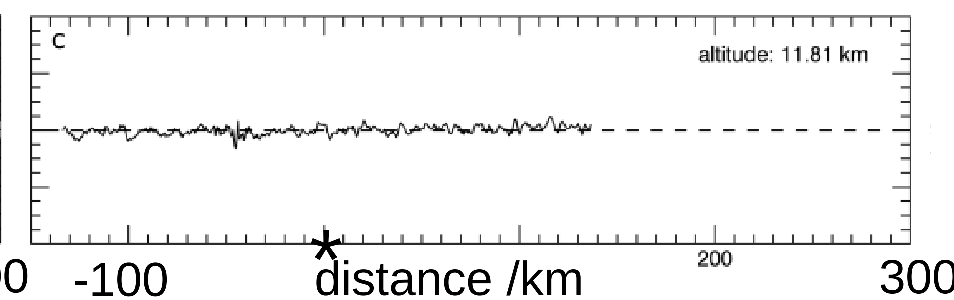
NCAR/NSF GV

Aircraft vertical velocity in lower stratosphere

DLR Falcon







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Medium to high frequency waves: mountain waves?

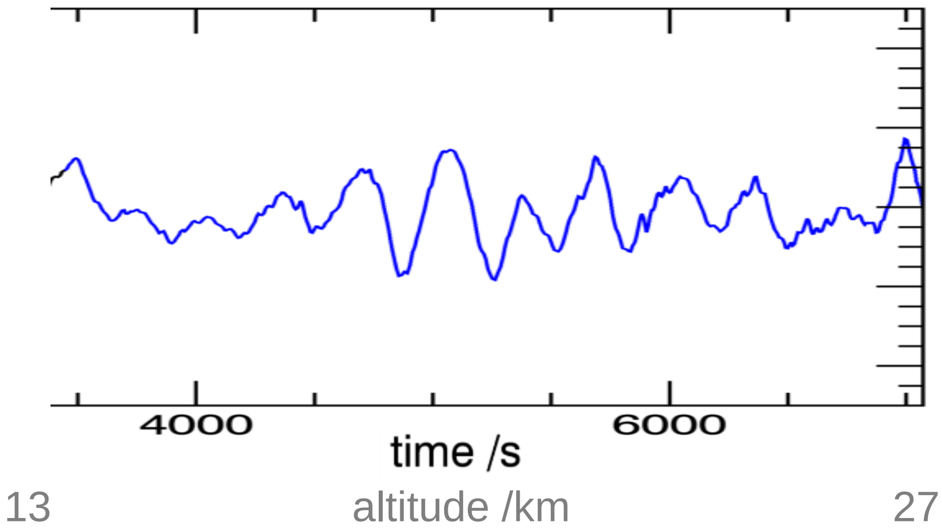
Approach: comparison of a mountain wave case to a non-mountain wave case

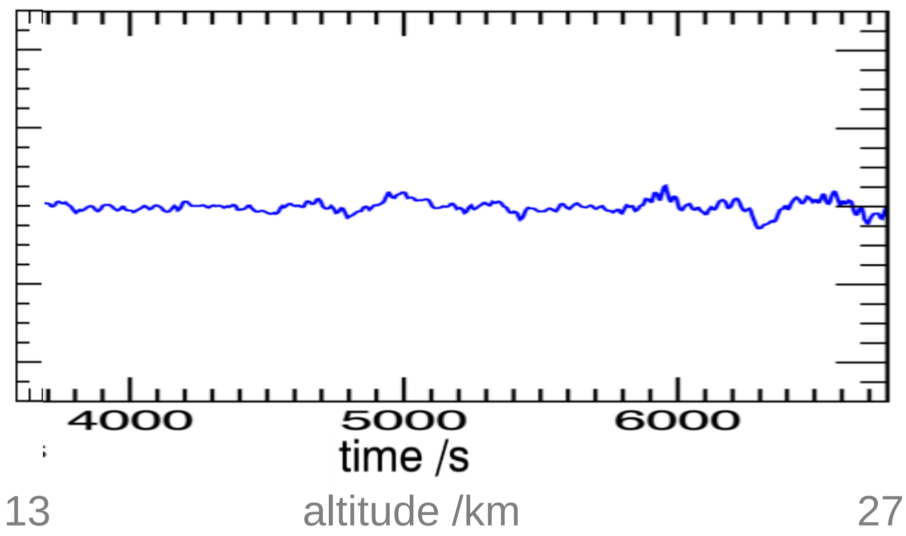
mountain wave case (IOP 4)

non-mountain wave case (IOP 15)

radiosondes

ascent rate perturbation (*w*) in the stratosphere

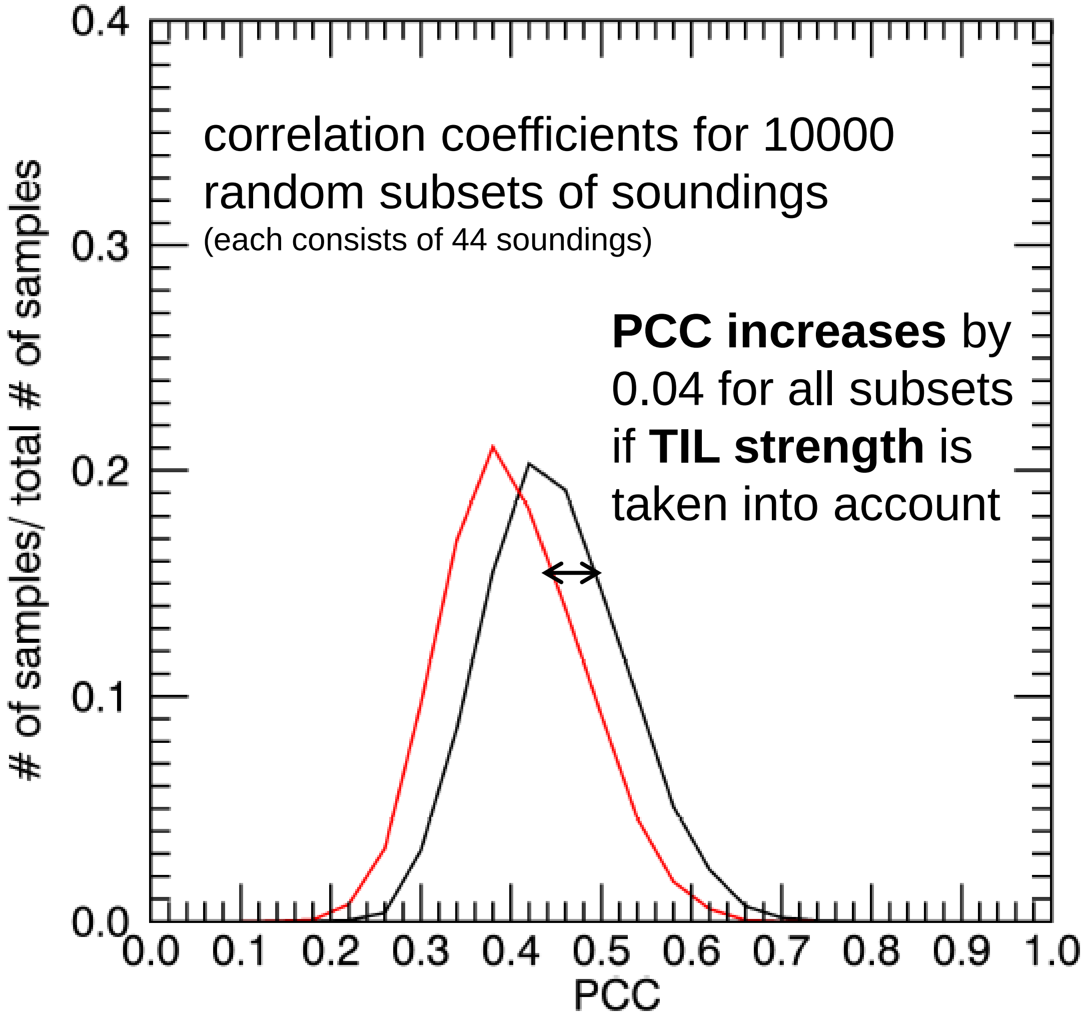




ascent rate perturbations (*w*) of soundings are caused by **mountain waves**

Reference:
PhD-Thesis S. Gisinger
LMU 2018

Correlation between MW forcing, strength of TIL and stratospheric MW activity (=1/2w^2) in DEEPWAVE soundings



Pearson Correlation Coefficient (linear correlation):

- low level MW forcing and MW activity
  → **0.396**

- low level MW and **TIL strength** and MW activity (multiple linear regression)
  → **0.434**

TIL strength and **associated processes** (trapping, reflection) influence the observed **stratospheric MW activity**

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LMU 2018

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Summary

mountain waves

in the tropopause region

theory and simulations

measurements

Concept of **trapping on an inversion** in the troposphere (Vosper 2004, Sachsperger et al. 2015) is applicable for the **TIL**

the **amount of mountain wave energy** downstream in the troposphere and in the stratosphere **should vary** in dependence of **the trapping on the TIL and strength of reflection** → **strength of the TIL**

strength of the TIL of around 25-30 K **suggests trapping on the TIL** and **enhanced mountain wave reflection** during DEEPWAVE

ascent rate perturbations (*w*) of soundings are caused by **mountain waves**

TIL strength and **associated processes** (trapping, reflection) influence the observed **stratospheric MW activity**

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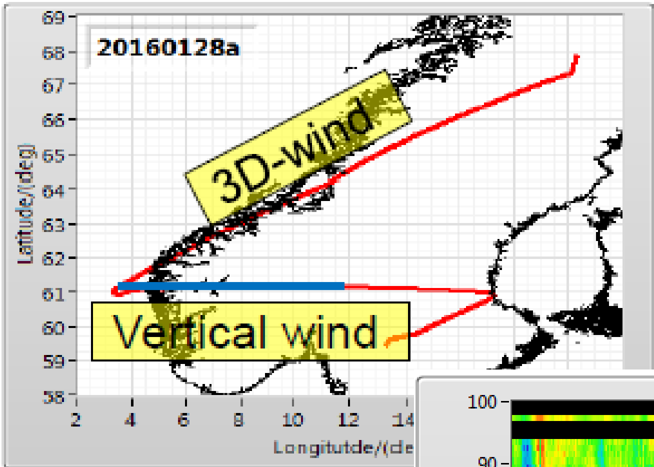
LMU 2018

Outlook

measurements

GW-LCYCLE 2 wind lidar (B. Witschas)



- horizontal wavelength from wavelet analysis
  below TP spectral max λ_h> 10 km, above TP spectral max λ_h < 10 km

vertical wind