Mesospheric Small-Scale GWs Characteristics
+ DEEPWAVE vs GW_LCYCLE 2

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GV Upper Atmosphere Imagers

1 zenith imager (temperature + OH intensity) + 2 side cameras (just OH intensity)
Projection on a Geographical Map

Left camera

OH brightness

Zenith camera

OH brightness or temperature

Gravity waves activity at mesospheric altitude?

Right camera

OH brightness

11:50
Quantifying the GWs Observed With the Zenith Imager

Irregular shape for the field-of-view of the zenith camera
Quantifying the GWs Observed With the Zenith Imager

128x128-pixel box = 80x80 km

FFT
Small-Scale GW Power Spectrum

Integration of the power between the 2 circles
This power corresponds to the average temperature perturbation generated by the GWs

GWs with horizontal wavelength between 10 and 40 km
Small-Scale GW Power Spectrum

Short range of wavelengths, but:
- $<10\text{km}$, probably instabilities
- $>40\text{km}$, difficult to measure because of the small field-of-view (only 80km)
- Still representative of small scale GWs:

Typical horizontal wavelength distributions obtained using all-sky imagers at high (Rothera, Halley) and low (Cachoeira Paulista) latitudes (Nielsen et al., 2009)
Power vs Time - Example: RF16

Each dot corresponds to one zenith image.

Average Temperature Perturbation for GWs with a wavelength between 10 and 40 km (K)

UT Time
Between 06 and 12 UTC mesospheric gravity wave activity seems to be uncoupled from Stratosphere.
Comparison AMTM Power vs Lidar GWPED

- **Graph 1:** Average Temperature Perturbation for GWs, with a wavelength between 10 and 40 km (K).
  - X-axis: UT Time
  - Y-axis: Temperature Perturbation

- **Graph 2:** GW PED layer 1, GW PED layer 2, GW PED layer 3
  - X-axis: Time (06-20)
  - Y-axis: Pedo Levels

The graphs illustrate the comparison of AMTM power and Lidar GWPED, with specific data points highlighting temperature perturbations and pedo levels across different time periods.
Small-Scale GW Power Regional Distribution

Average power

Each square is 2.5° (longitude) x 2° (latitude)

25 nighttime flights
Each square is 2.5° (longitude) x 2° (latitude)
Small-Scale GW Power Regional Distribution

Average power

Each square is 2.5° (longitude) x 2° (latitude)

Trailing waves + Auckland Island effect
Small-Scale GW Power Regional Distribution

Lots of small scale GWs over the Tasman Sea, east of Tasmania

Each square is 2.5° (longitude) x 2° (latitude)
Small-Scale GW Power Regional Distribution

Average power

Each square is 2.5° (longitude) x 2° (latitude)

Only due to one flight (RF01)
Small-Scale GW Power Regional Distribution

Average power

Each square is 2.5° (longitude) x 2° (latitude)

Not much over the North of Tasman Sea, Pacific Ocean and Southern Ocean
Comparison with Stratospheric Measurements

Average power

<table>
<thead>
<tr>
<th></th>
<th>150°E</th>
<th>160°E</th>
<th>170°E</th>
<th>180°E</th>
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<tr>
<td>30°S</td>
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<td>40°S</td>
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<td>50°S</td>
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<td>60°S</td>
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AIRS GW RMS brightness temperature during July 2003-2011 at 2 hPa (~41 km, courtesy Steve Eckermann)

Each square is 2.5° (longitude) x 2° (latitude)
Small-Scale GW Power Over NZ (1°x1°)
Small-Scale GW Power Over NZ (1°x1°)

Lee side of the Southern Alps
Small-Scale GW Power Over NZ (1°x1°)

Trailing waves
What’s new (1)?
Quantifying the GWs Observed With the Side Imagers
Quantifying the GWs Observed With the Side Imagers

Five 128x128-pixel boxes (80x80 km)
Quantifying the GWs Observed With the Side Imagers

Five 128x128-pixel boxes (80x80 km)
Quantifying the GWs Observed With the Side Imagers

Five 128x128-pixel boxes (80x80 km)

FFT

Power for GWs with $10 < \lambda_x < 40$ km
Small-Scale GW Power Regional Distribution with 3 Cameras
Small-Scale GW Power Regional Distribution with 3 Cameras

- Using only OH brightness, not temperature
- Similar distribution over a larger region
- Regions with larger power better defined
It’s also possible to use the spectrum to look at the main direction of propagation by integrating over the 10-40km range and looking at the distribution vs angle. For RF16, the highest power (red) was just above the mountains and most of the GWs propagated in the East-West direction (since we use only single images, there is a 180° ambiguity and we cannot tell if they were going towards the East or the West with this method).
Small-Scale GWs (10<λ_x<40km) Power and Direction for all 25 Flights
Mountains vs Oceans

- Strong difference land vs ocean during the same flight
Mountain Flights – Small Power

- Weak GW power
- Direction ~NE
Mountain Flights – Large Power

- Larger GW power
- Direction ~E or ~SE
Evolution Power/Direction RF12

8:13-9:26 Avg 693
10:54-12:06 Avg 719
12:09-13:19 Avg 857

13:22-14:34 Avg 783
14:37-15:47 Avg 734
15:50-16:48 Avg 607
Evolution Power/Direction RF13

6:01-7:22 Avg 660
8:49-10:00 Avg 928
10:03-11:14 Avg 818
11:17-12:27 Avg 853
12:30-13:41 Avg 787
13:44-14:46 Avg 759
Small-Scale GWs Power

- Small-scale GWs ($10<\lambda_x<40\text{km}$) power and direction (180° ambiguity)
- Nightly evolution
- MW flights vs forcing
- Comparison lands vs oceans: average power and direction different if over land or over ocean
- Comparison with lower altitude measurements? Does it make sense?
The GW-LCYCLE2 Project Within ROMIC

Partners: DLR, KIT, FZJ, IAP and international partners

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

DFG Research Group: MSGwaves (Multiscale Dynamics of Gravity Waves) 2014-2020
AMTM Locations and Approximate FOVs
Mesospheric Mountain Waves Over Kiruna and Sodankylä – Dec 13-14, 2015
Mountain Waves Kiruna

Nov 28-29
Mountain Waves Kiruna

Dec 04-05
Mountain Waves Kiruna

Dec 15-16
Mountain Waves Sodankylä

Dec 13-14
Many MWs in Rayleigh Lidar Data
Differences NZ-Scandinavia

- Same distance to the mountains (100-150km) for Lauder and Kiruna
Differences NZ-Scandinavia

- Same distance to the mountains (100-150km) for Lauder and Kiruna
- W-E size: ~150km for S, ~100 km for NZ
Differences NZ-Scandinavia

• Same distance to the mountains (100-150km) for Lauder and Kiruna
• W-E size: ~150km for S, ~100 km for NZ
• Mountain top: ~2000m for S, ~3000m for NZ
Effect of Horizontal Wind

Lauder

- Larger winds (max ~90m/s @ ~50km)
- Goes to ~0m/s @ ~95km
- MWs should reach OH layer most of the time (if their amplitude is not too large)

Scandinavia

- Smaller winds (max ~40m/s @ ~40km)
- Second maximum at MLT altitude
- Goes to ~0m/s @ ~60km
- MWs might reach OH layer under the right circumstances
DEEPWAVE vs GW_LCYCLE 2

• Similar geographical situations for Lauder and Kiruna in 2 different hemispheres
• MWs rarely observed over Kiruna, 70% occurrence over Lauder
• Smaller horizontal wind at higher latitude may create critical levels at lower altitude, stopping MWs from reaching the MLT
• Other possibility: the MWs over Kiruna/Sodankylä have a shorter vertical wavelength (≤ 8km), thus cannot be observed with an AMTM (but can be detected by a Rayleigh lidar)
RF02

Geopotential Height (m) & Horizontal Wind (m/s) at 850hPa
Valid: Wed, 11 Jun 2014, 00 UTC (step 006 h from Wed, 11 Jun 2014, 00 UTC)

DIV (10^-5 s^-1, pos.: red, neg.: blue, Delta=4) and Z (m) at 1hPa
Valid: Wed, 11 Jun 2014, 00 UTC (step 006 h from Wed, 11 Jun 2014, 00 UTC)

2014.06.11 Descending 2 hPa
Max = 2.92 K, Min = -2.66 K
RF05

Geopotential Height (m) & Horizontal Wind (m/s) at 850 hPa
Valid: Mon, 16 Jun 2014, 06 UTC (step 006 h from Mon, 16 Jun 2014, 00 UTC)

2014.06.16 Descending 2 hPa
Max = 1.87 K
Min = -1.75 K
RF06

Geopotential Height (m) & Horizontal Wind (m/s) at 850 hPa
Valid: Wed, 18 Jun 2014, 06 UTC (step 006 h from Wed, 18 Jun 2014, 00 UTC)

DIV (10^-5 s^-1) pos.: red, neg.: blue, Delta=4.) and Z (m) at 1 hPa
Valid: Wed, 18 Jun 2014, 06 UTC (step 006 h from Wed, 18 Jun 2014, 00 UTC)

2014.06.18 Descending 2 hPa
Max = 2.61 K
Min = -4.16 K
RF07

Geopotential Height (m) & Horizontal Wind (m/s) at 850 hPa
Valid: Thu, 19 Jun 2014, 06 UTC (step 006 h from Thu, 19 Jun 2014, 00 UTC)

Horizontal Wind (m/s)
0 10 20 30 40 50

DIV (10^-5 s^-1): pos. red, neg. blue, Delta=4.1 and Z (m) at 1 hPa
Valid: Thu, 19 Jun 2014, 06 UTC (step 006 h from Thu, 19 Jun 2014, 00 UTC)

2014.06.19 Descending 2 hPa
Max = 3.13 K
Min = -4.50 K
RF09

Geopotential Height (m) & Horizontal Wind (m/s) at 850 hPa
Valid: Tue, 24 Jun 2014, 06 UTC (step 006 h from Tue, 24 Jun 2014, 00 UTC)

DIVERGENCE (10^-5 s^-1, pos.: red, neg.: blue, Delta=4.) and Z (m) at 1 hPa
Valid: Tue, 24 Jun 2014, 06 UTC (step 006 h from Tue, 24 Jun 2014, 00 UTC)

2014.06.24 Descending 2 hPa
Max = 2.78 K
Min = -2.35 K
RF11

Geopotential Height (m) & Horizontal Wind (m/s) at 850 hPa
Valid: Sat, 28 Jun 2014, 06 UTC (step 006 h from Sat, 28 Jun 2014, 00 UTC)

DIV (10^-5 s^-1, pos.: red, neg.: blue, Delta=4) and Z (m) at 1 hPa
Valid: Sat, 28 Jun 2014, 06 UTC (step 006 h from Sat, 28 Jun 2014, 00 UTC)

2014.06.28 Descending 2 hPa
Max = 2.13 K
Min = -1.92 K
RF12

Geopotential Height (m) & Horizontal Wind (m/s) at 850 hPa
Valid: Sun, 29 Jun 2014, 06 UTC (step 006 h from Sun, 29 Jun 2014, 00 UTC)

DIV \left(10^{-5} \text{s}^{-1}\right): pos. red., neg. blue. Delta=4.) and Z (m) at 1 hPa
Valid: Sun, 29 Jun 2014, 06 UTC (step 006 h from Sun, 29 Jun 2014, 00 UTC)

2014.06.29 Descending 2 hPa
Max = 1.53 K
Min = -2.18 K
RF14

Geopotential Height (m) & Horizontal Wind (m/s) at 850 hPa
Valid: Tue, 01 Jul 2014, 06 UTC (step 006 h from Tue, 01 Jul 2014, 00 UTC)

DIV (10^-5 s^-1, pos.: red, neg.: blue, Delta=4.) and Z (m) at 1 hPa
Valid: Tue, 01 Jul 2014, 06 UTC (step 006 h from Tue, 01 Jul 2014, 00 UTC)

2014.07.01 Descending 2 hPa
Max = 1.76 K
Min = -2.08 K
RF16

Geopotential Height (m) & Horizontal Wind (m/s) at 850 hPa
Valid: Fri, 04 Jul 2014, 06 UTC (step 006 h from Fri, 04 Jul 2014, 00 UTC)

DIV (10^-5 s^-1, pos.: red, neg.: blue, Delta=4) and Z (m) at 3 hPa
Valid: Fri, 04 Jul 2014, 06 UTC (step 006 h from Fri, 04 Jul 2014, 00 UTC)

2014.07.04 Descending 2 hPa
Max = 1.96 K
Min = -1.66 K
RF17

Geopotential Height (m) & Horizontal Wind (m/s) at 850 hPa
Valid: Sat, 05 Jul 2014, 06 UTC (step 006 h from Sat, 05 Jul 2014, 00 UTC)

DIV (10^-5 s^-1, pos.: red, neg.: blue, Delta=4.) and Z (m) at 1 hPa
Valid: Sat, 05 Jul 2014, 06 UTC (step 006 h from Sat, 05 Jul 2014, 00 UTC)

2014.07.05 Descending 2 hPa
Max = 2.81 K
Min = -1.90 K
RF18

Geopotential Height (m) & Horizontal Wind (m/s) at 850 hPa
Valid: Mon, 07 Jul 2014, 06 UTC (step 006 h from Mon, 07 Jul 2014, 00 UTC)

DIV (10^-5 s^-1, pos.: red, neg.: blue, Delta=4) and Z (m) at 1 hPa
Valid: Mon, 07 Jul 2014, 06 UTC (step 006 h from Mon, 07 Jul 2014, 00 UTC)

2014.07.07 Descending 2 hPa
Max = 2.66 K
Min = -3.22 K
RF19

Geopotential Height (m) & Horizontal Wind (m/s) at 850 hPa
Valid: Tue, 08 Jul 2014, 06 UTC (step 006 h from Tue, 08 Jul 2014, 00 UTC)

DIV (10^-5 s^-1, pos.: red, neg.: blue, Delta=4.) and Z (m) at 1 hPa
Valid: Tue, 08 Jul 2014, 06 UTC (step 006 h from Tue, 08 Jul 2014, 00 UTC)

2014.07.08 Descending 2 hPa
Max = 2.36 K
Min = -2.14 K
RF20

Geopotential Height (m) & Horizontal Wind (m/s) at 850 hPa
Valid: Thu, 10 Jul 2014, 06 UTC (step 006 h from Thu, 10 Jul 2014, 00 UTC)

DIV (10^-8 s^-1, pos.: red, neg.: blue, Delta=4) and Z (m) at 1 hPa
Valid: Thu, 10 Jul 2014, 06 UTC (step 006 h from Thu, 10 Jul 2014, 00 UTC)

2014.07.10 Descending 2 hPa
Max = 2.03 K
Min = -1.92 K

1.2
0.0
-1.2
Geopotential Height (m) & Horizontal Wind (m/s) at 850 hPa
Valid: Mon, 14 Jul 2014, 06 UTC (step 006 h from Mon, 14 Jul 2014, 00 UTC)

DIV (10^-5 s^-1, pos.: red, neg.: blue, Delta=4) and Z (m) at 1 hPa
Valid: Mon, 14 Jul 2014, 06 UTC (step 006 h from Mon, 14 Jul 2014, 00 UTC)

2014.07.14 Descending 2 hPa
Max = 1.96 K
Min = -1.93 K
RF25

Geopotential Height (m) & Horizontal Wind (m/s) at 850 hPa
Valid: Fri, 18 Jul 2014, 06 UTC (step 006 h from Fri, 18 Jul 2014, 00 UTC)

DIV (10^5 s^-1). pos.: red, neg.: blue, Delta=4.) and Z (m) at 1 hPa
Valid: Fri, 18 Jul 2014, 06 UTC (step 006 h from Fri, 18 Jul 2014, 00 UTC)

2014.07.18 Descending 2 hPa
Max = 2.95 K
Min = -2.27 K
RF26

Geopotential Height (m) & Horizontal Wind (m/s) at 850 hPa
Valid: Sun, 20 Jul 2014, 06 UTC (step 006 h from Sun, 20 Jul 2014, 00 UTC)

DIV (10^-5 s^-1, pos.: red, neg.: blue, Delta=4) and Z (m) at 1 hPa
Valid: Sun, 20 Jul 2014, 06 UTC (step 006 h from Sun, 20 Jul 2014, 00 UTC)

2014.07.20 Descending 2 hPa
Max = 2.61 K
Min = -2.83 K