GLOBAL GRAVITY WAVE DISTRIBUTIONS

Inferred from satellite observations and NWP models

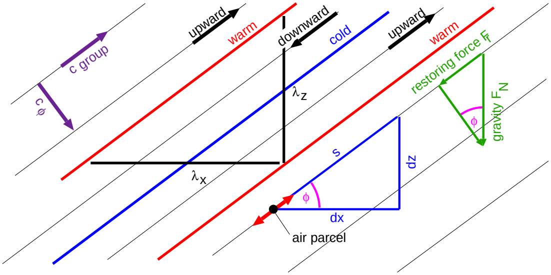
21 Nov 2019 | Peter Preusse, Manfred Ern, Cornelia Strube | ECMWF

Gravity waves are waves visible in:

- Temperatures $\rightarrow$ Clouds
- Horizontal and vertical winds
- Density

PROPERTIES OF GWS

- Pure GWs:
  winds along phase lines
- Intrinsic phase velocity
  perpendicular phase lines
- Intrinsic group velocity
  parallel phase lines



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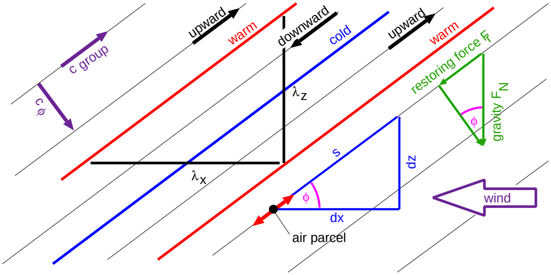
- Slow waves (relative to ground)
  are tilted versus the wind
- Vertical wavelength of a
  mountain wave:

$$\lambda_z \simeq 2\pi \frac{u}{N} \tag{1}$$



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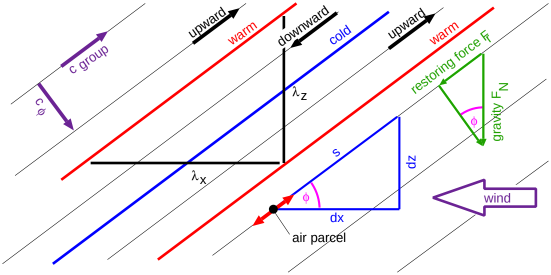


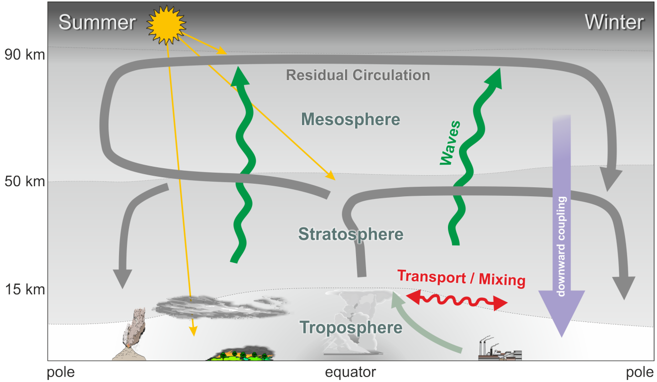
$$F_{px} = \bar{\rho}(1 - \frac{f^2}{\hat{\omega}^2})\overline{u'w'} = \frac{1}{2}\rho\frac{k}{m}\left(\frac{g}{N}\right)^2\left(\frac{\hat{T}}{\bar{T}}\right) \qquad (2)$$

- Carry energy flux and momentum flux
- Deposit this flux when dissipating

$$\bar{X} = -\frac{1}{\rho}\frac{\partial}{\partial z}F_{px} \qquad (3)$$

RELEVANCE OF STRATOSPHERIC GRAVITY WAVES

- Atmospheric waves convey momentum
- Depositing this momentum, they drive the residual circulation
- By downward coupling this induces synoptic temperature changes up to 2° C



JÜLICH Forschungszentrum

RELEVANCE OF STRATOSPHERIC GRAVITY WAVES

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- Gravity waves are a primary source of uncertainty

nature geoscience

PERSPECTIVE

PUBLISHED ONLINE: 21 SEPTEMBER 2014 | DOI: 10.1038/NGEO2253

Atmospheric circulation as a source of uncertainty in climate change projections

Theodore G. Shepherd

„The most uncertain aspect of climate modelling lies in the representation of unresolved (sub-gridscale) processes such as clouds, convection, and boundary-layer and gravity-wave drag, and its sensitive interaction with large-scale dynamics.“

RELEVANCE OF STRATOSPHERIC GRAVITY WAVES

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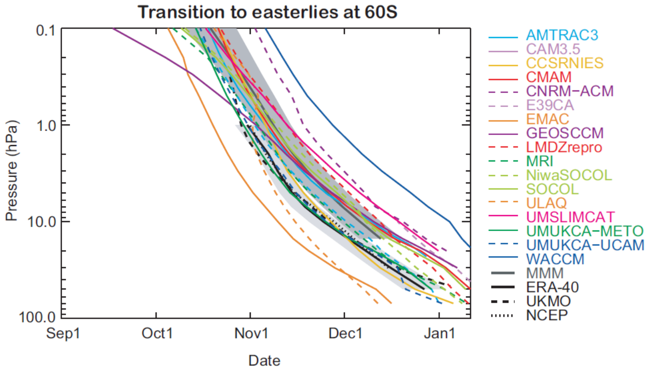
- Gravity waves are a primary source of uncertainty
- Can satellite observations give guidance?

Satellite observations used to tune Non-Oro Scheme in IFS

Ern et al., ACP, 2006; Orr et al., J. Clim., 2010

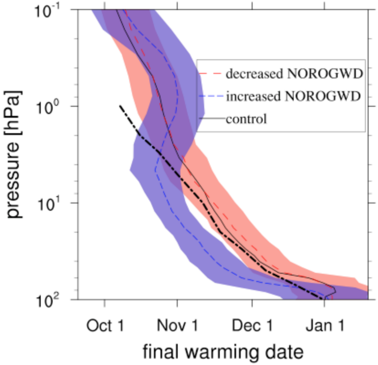
SH POLAR VORTEX LASTS TOO LONG

This is a multi-model finding



Butchart et al., SPARC report, 2011

And depends on GW drag



Polichtchouk et al., JAS, 2018

But what are these GWs and their sources? ← Global observations and modeling

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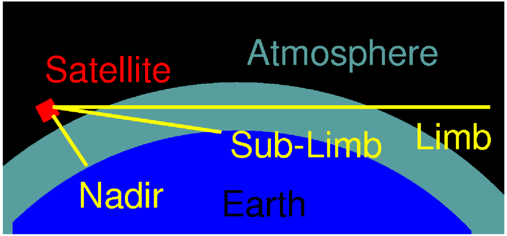
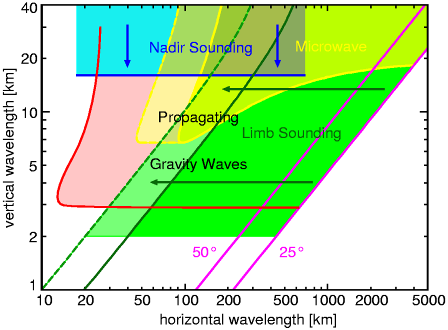
SATELLITE GEOMETRIES AND OBSERVATIONAL FILTER





Limb Sounding: resolution limited by geometry,
good vertical and moderate horizontal resolution
Only absolute values of GWMF

Nadir Sounding: resolution limited by radiative transfer,
moderate vertical and good horizontal resolution
Only very long vertical wavelengths

Preusse et al, JGR, 2008
Alexander et al, QJRMS, 2010

ACTIVITIES WORLDWIDE

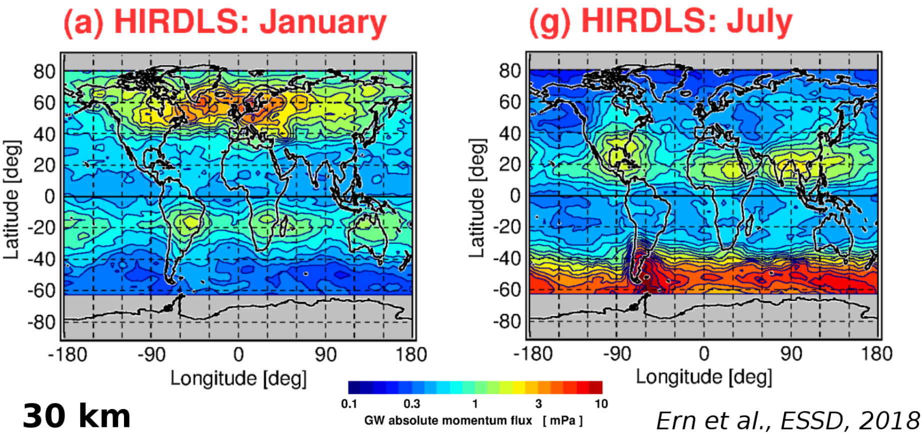
Review papers:

- Fritts and Alexander, RG, 2003
- Kim, Eckermann, Chun, Atmos. Ocean, 2003
- Alexander et al, QJRMS, 2010
- Geller et al., J. Clim., 2013

Groups all around the world are evaluating satellite data and global models

$\rightarrow$ From here on, a Juelich perspective

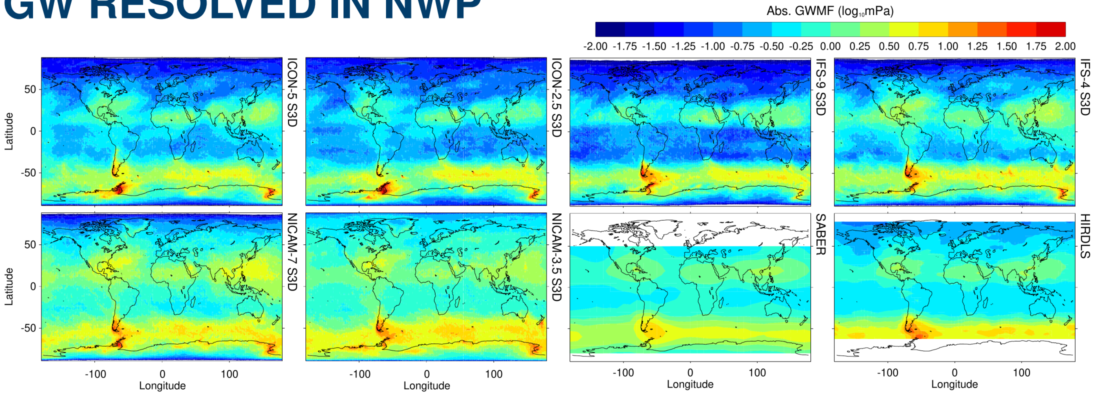
GLOBAL DISTRIBUTION: LOWER STRATOSPHERE



Salient patterns (climat.):

- Polar vortex: mountain waves + general enhancement (sources ?)
- Subtropical convection

GW RESOLVED IN NWP

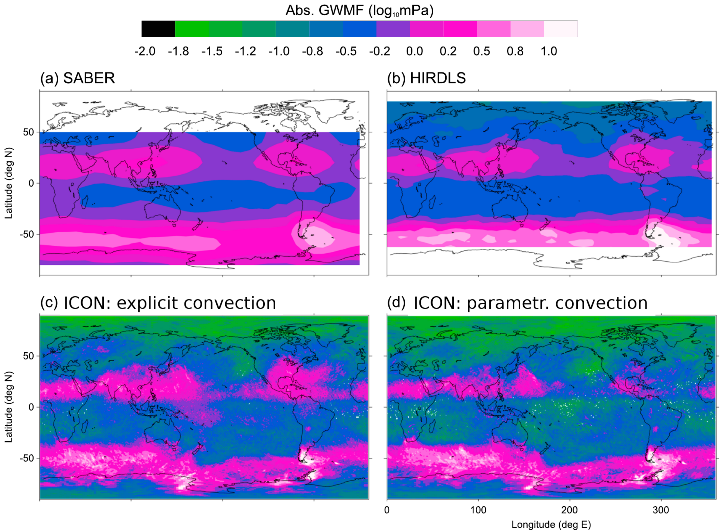


Stephan et al., JAS, 2019 (MPI & FZJ, MS-GWaves)

- No observational filter applied!
- Calculating GW momentum flux from real(istic) data is non-trivial
- Large range of different scales: **Caution!**
- Satellite methods applicable; new satellites needed

JÜLICH Forschungszentrum

PROCESSES IMPORTANT



Stephan et al., JGR, 2019
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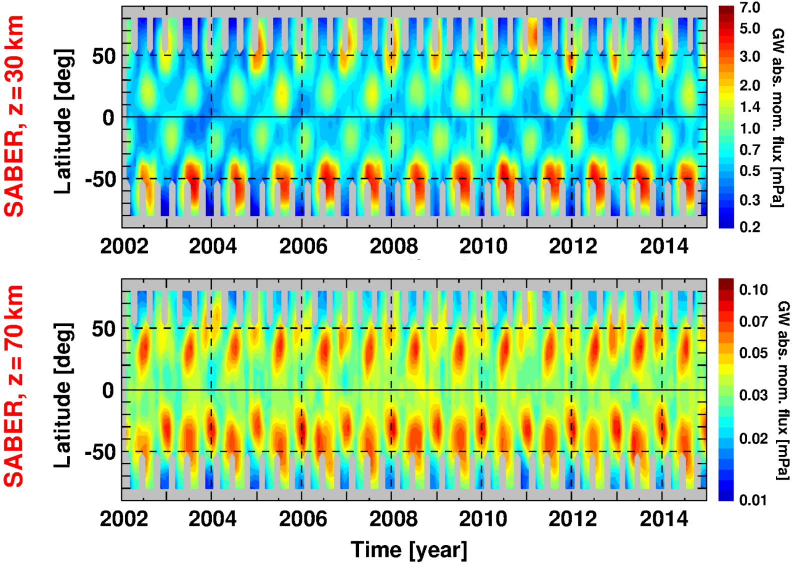
SABER: WHOLE MIDDLE ATMOSPHERE



Convective maxima

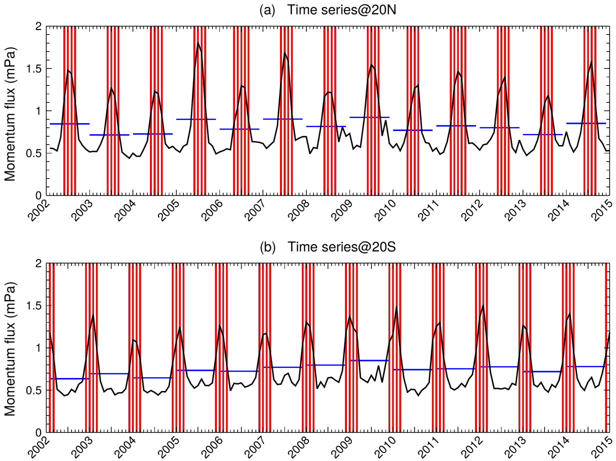
- propagate polewards
- relatively gain in strength

Polar vortex

- stronger on SH
- overlap in latitude with summer maxima

Ern et al., ESSD, 2018

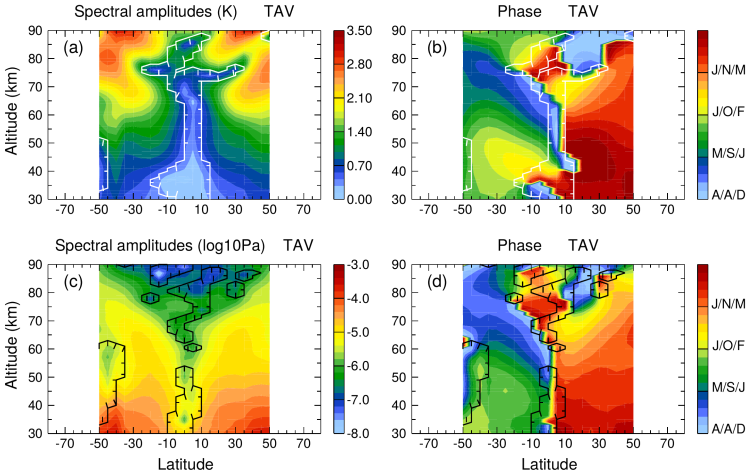
4 MONTH OF CONVECTION → TAV



Dan Chen et al., Annales Geophys., 2019

- Pulse-like occurence of subtropical convective GW cause a Terrannual Variation
- TAV is a higher harmonic of the annual cycle

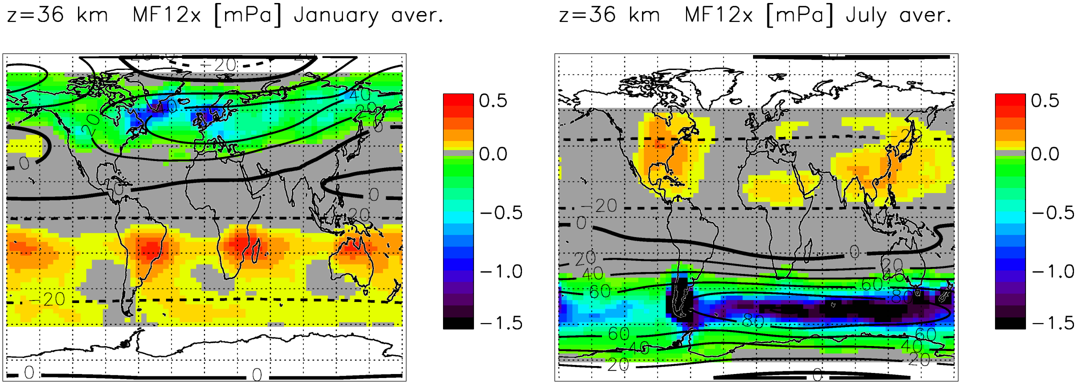
TAV → POLEWARD PROPAGATION



Dan Chen et al., Annales Geophys., 2019

- TAV emphasizes poleward propagation from convective centers

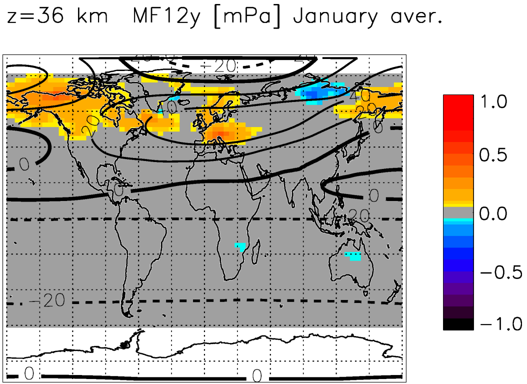
AIRS: NET MOMENTUM FLUX (ZONAL)

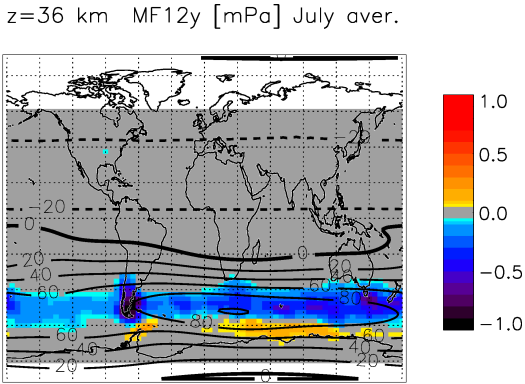


Ern et al., GRL, 2016 and work in progress

- Momentum flux is directed opposite to background wind:
  - westward in polar vortex
  - eastward in subtropics
- behavior enhanced by long vertical wavelength (observational filter!)

AIRS: NET MOMENTUM FLUX (MERIDIONAL)

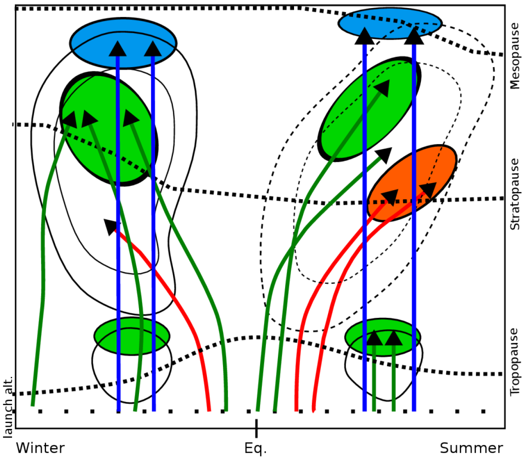




Ern et al., GRL, 2016; work in progress

- Confluence at 60°S
- Nortward tendency in NH winter

3D, OBLIQUE PROPAGATION



Kalisch et al., JGR, 2014

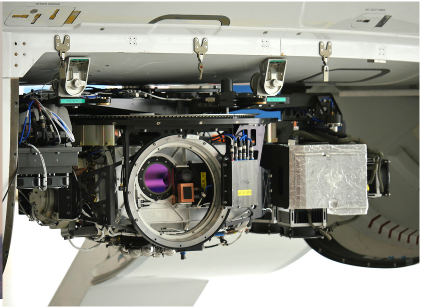
There is need to replace GW parametrization in the grid column

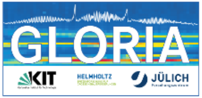
- Oblique propagation avoids critical level filtering
- Relevant for:
  - Summer mesopause
  - Stratwarmings (Ern et al., 2016)

cf. also Sato et al., 2009; Preusse et al., 2009

Vortex-GW already at 20 km ⇒ Local sources?

GLORIA LIMB SOUNDER

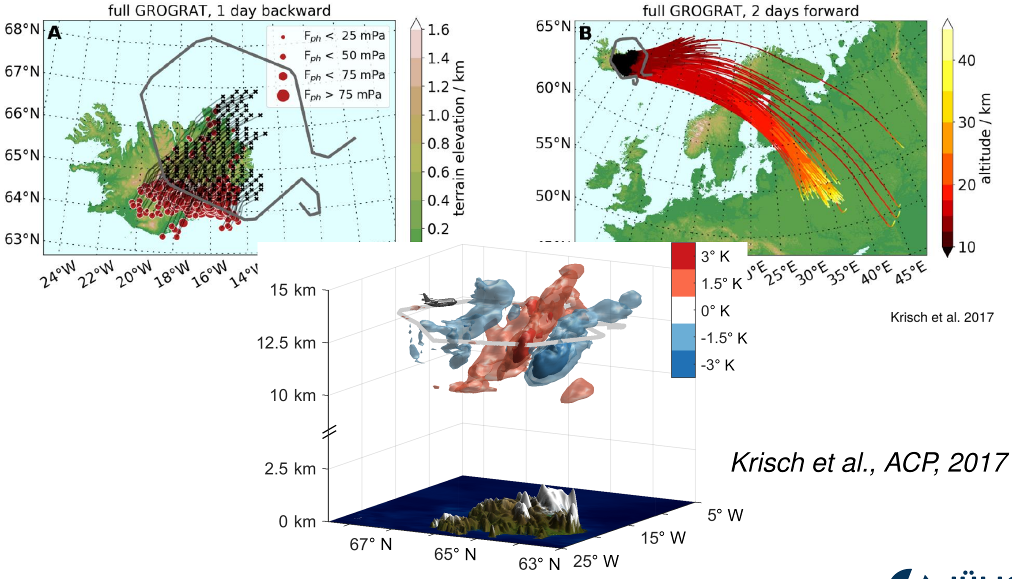




In 2016 the HALO aircraft was deployed from Kiruna.

The flight towards Iceland on 25 January targeted a mountain wave event

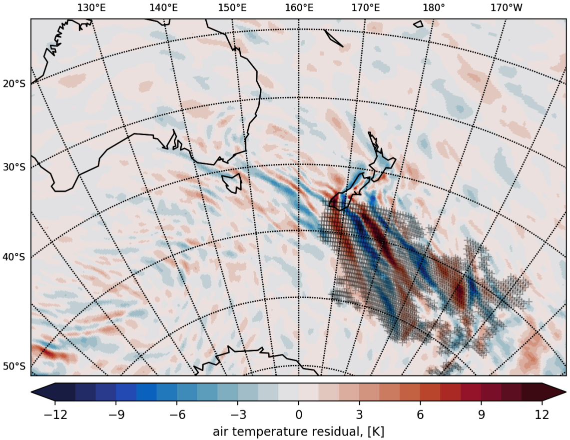
FORWARD AND BACKWARD RAY-TRACING



Krisch et al., ACP, 2017

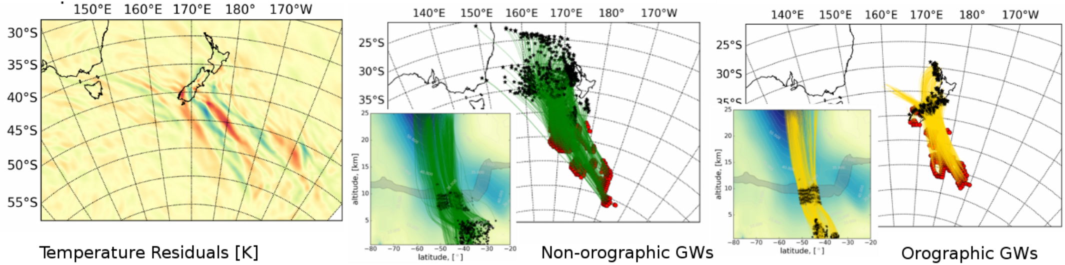
ECMWF ANALYSIS DATA ON SH

Case study for DeepWave: 01-Jul-2014



Strube et al., work in progress

OBLIQUE PROPAGATION



- gravity waves propagate up to 25° poleward
- major part from New Zealand
- additional sources: fronts, jet-exit regions
- oblique propagation in particular in the UTLS (10-15km)

CONCLUSIONS

- GWs are important for middle atmosphere circulation
- Prominent example: SH polar vortex
- Satellite observations show global picture
- NWP models resolve already large part of GW spectrum $\rightarrow$
  Danger of double counting
- Extremely-oblique propagation can redistribute drag $\rightarrow$
  Not in GW parametrization

Global limb imaging needed!

Global data need to be complemented with case studies!

Campaign at world-hot-spot of GWs:
Tierra del Fuego


Tierra del Fuego, Rio Grande