Global forecasts of atmospheric gravity waves for observational campaigns

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ECMWF Workshop:
Observational campaigns for better weather forecasts
10-13 June 2019, Reading

Gravity Waves Projects @ DLR

Objectives

- study **dynamical coupling processes** of gravity waves from the **troposphere to the stratosphere and mesosphere** by characterizing the complete life cycle of gravity waves:
  - **excitation,**
  - **propagation,**
  - **dissipation**

  employing observational and modelling tools

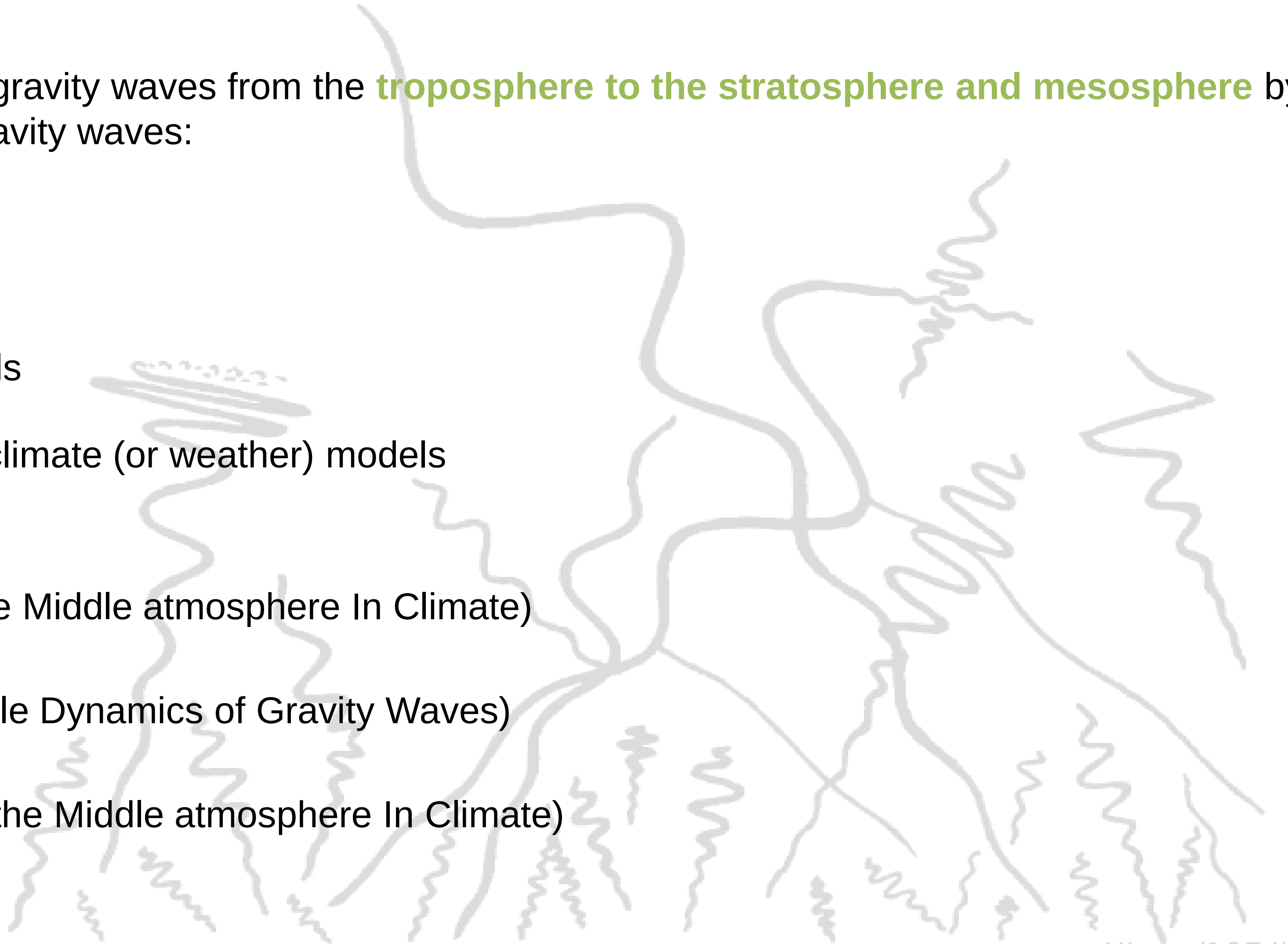
- improve GW parameterizations for use in climate (or weather) models

Projects

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

DFG Research Group: **MS-GWaves** (Multiscale Dynamics of Gravity Waves)
2014-2020

BMBF Research Initiative: **ROMIC II** (Role of the Middle atmosphere In Climate)
2019-2022



Hines (1974)

Gravity Wave Field Campaigns

(1) GW-LCYCLE 1

- 2 – 14 December 2013, Kiruna, Sweden
- DLR Falcon
- simultaneous 3 hourly radiosonde launches from Andøya (N), Esrange, Arena Arctica (S), Sodankylä (FIN)
- ground-based observations at ALOMAR (radars, lidars) and at Esrange (lidar)

(2) DEEPWAVE (DLR contribution)

- total period: 6 June – 22 July 2014, New Zealand
- DLR Falcon participation: 29 June – 21 July 2014
- ground-based observations (lidar, radiosondes) at Lauder

Photo: Petr Horalek

(3) POLSTRACC/GW-LCYCLE 2/SALSA

- winter 2015/2016, Kiruna, Sweden
- coordinated flight of HALO and Falcon
- radiosonde launches from Andøya (N), Esrange, Arena Arctica (S), and Sodankylä (FIN)
- ground-based observations at ALOMAR (radars, lidars), Esrange (lidar, radar), and Sodankylä (lidars)

(4) SouthTRAC

- ongoing (lidar), upcoming (HALO) Sept-Nov 2019, Rio Grande, Argentina

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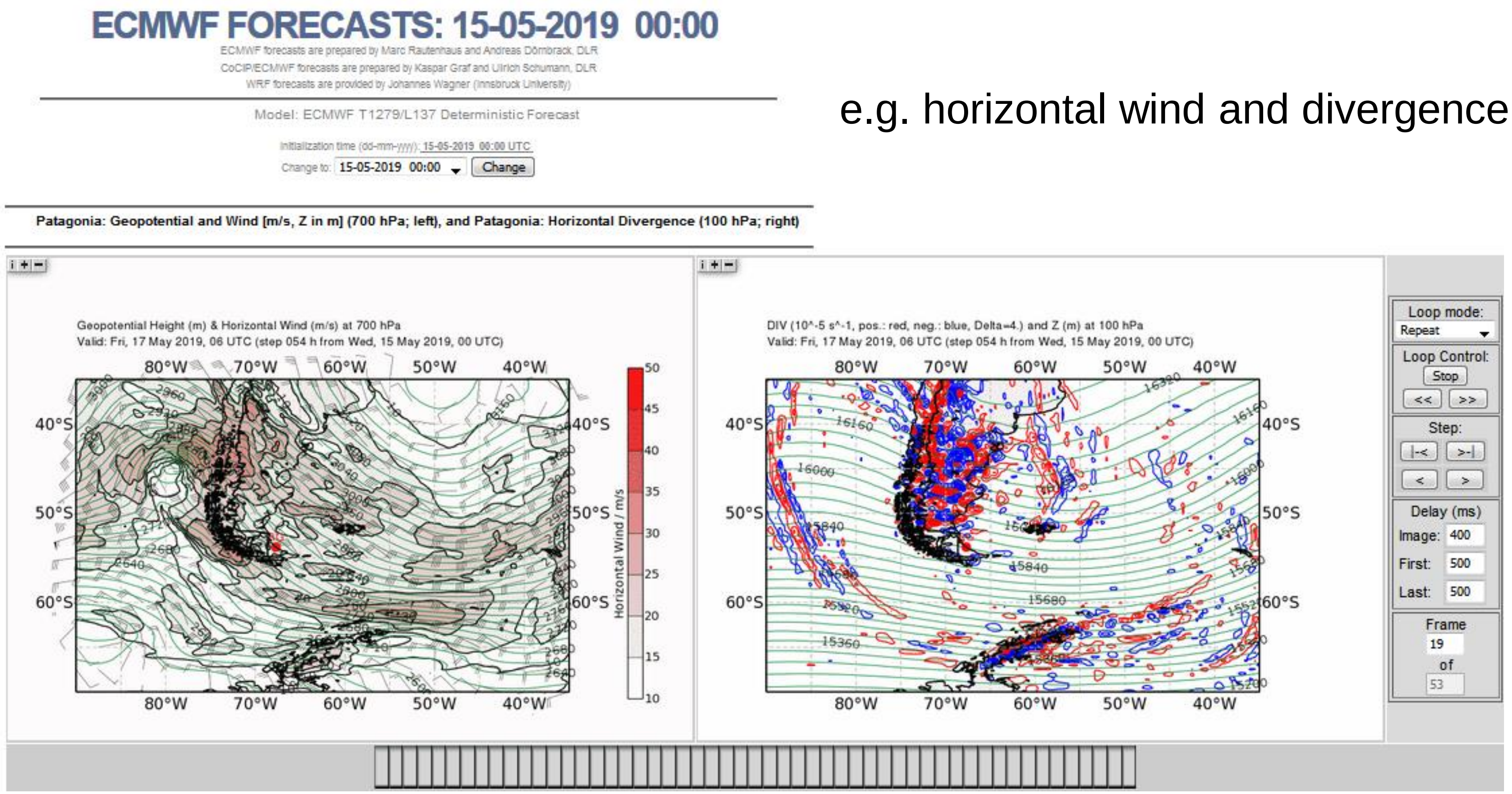
Forecasting and Flightplanning: Role of ECMWF IFS

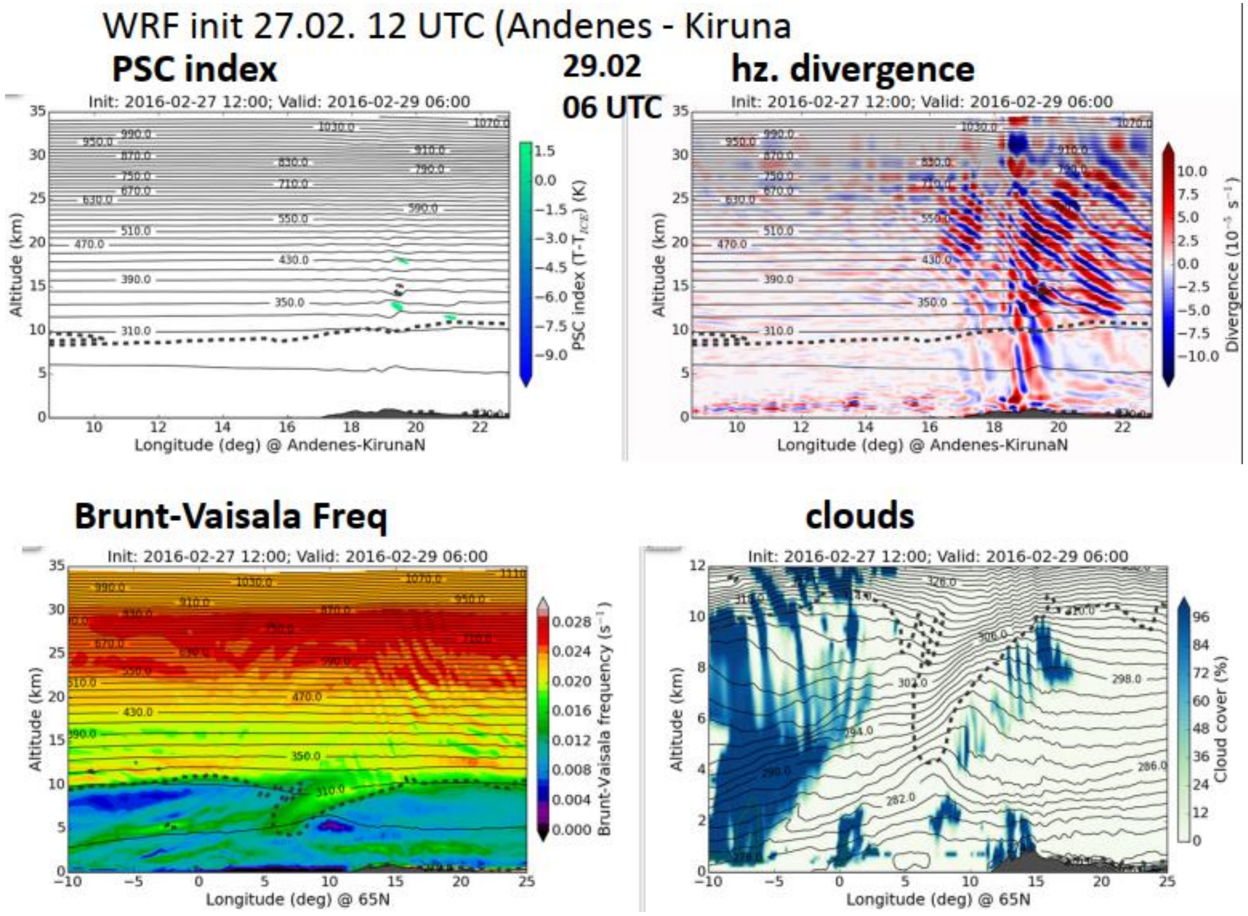
- **Website with forecast maps adjusted for GW forecasting (parameters, levels, cross-sections)**



e.g. horizontal wind and divergence

Forecasting and Flightplanning: Role of ECMWF IFS

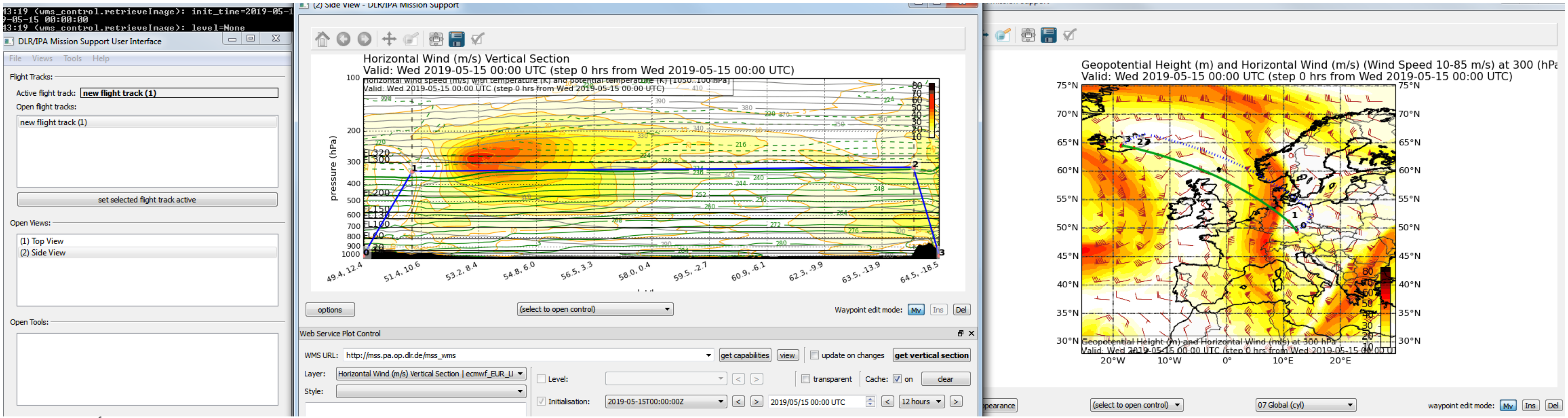
- Website with forecast maps adjusted for GW forecasting (parameters, levels, cross-sections)
- **Initial and boundary conditions for nested WRF simulations**



Forecasting and Flightplanning: Role of ECMWF IFS

- Website with forecast maps adjusted for GW forecasting (parameters, levels, cross-sections)
- Initial and boundary conditions for nested WRF simulations
- **Horizontal and vertical meteorological information in the Mission Support System (MSS) → interactive flight planning tool (*Rautenhaus et al. 2012,* https://mss.readthedocs.io/en/stable/index.html)**

control *side view along flight track* *top view*



Forecasting and Flightplanning: Role of ECMWF IFS

- Website with forecast maps adjusted for GW forecasting (parameters, levels, cross-sections)
- Initial and boundary conditions for nested WRF simulations
- Horizontal and vertical meteorological information in the Mission Support System (MSS) → interactive flight planning tool (*Rautenhaus et al. 2012)*
- **Input for automated lidar measurements (currently Rio Grande)**

CORAL at the EARG Station in Tierra del Fuego, Argentina

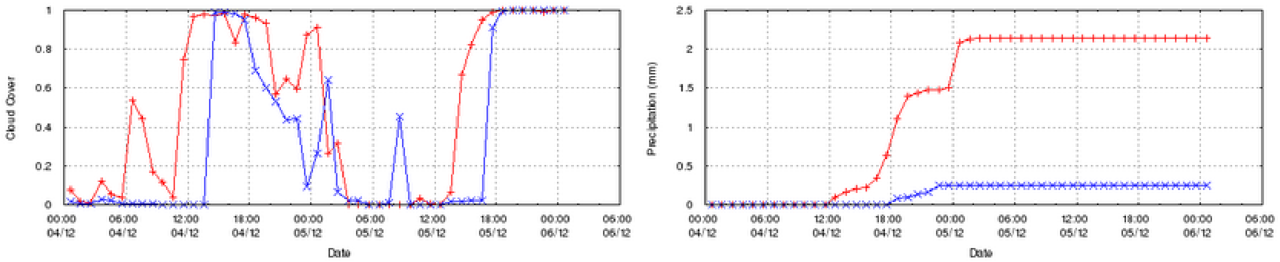
Laser replacement on Nov 2nd, 2018. We will operate manually until aligned, and then switch back to automatic control.

Cloud Cameras

live at http://kaifler.net/coral/

ECMWF Forecast

Rio Grande (red) and Rio Gallegos (blue)



Airborne measurements
GW-LCYCLE 2

trace gases

HALO

Gloria

in-situ (u,v,w,p)

upward looking H2O-Lidar

Falcon

trace gases

airglow imager GRIPS

in-situ (u,v,w,p)

downward looking wind-lidar

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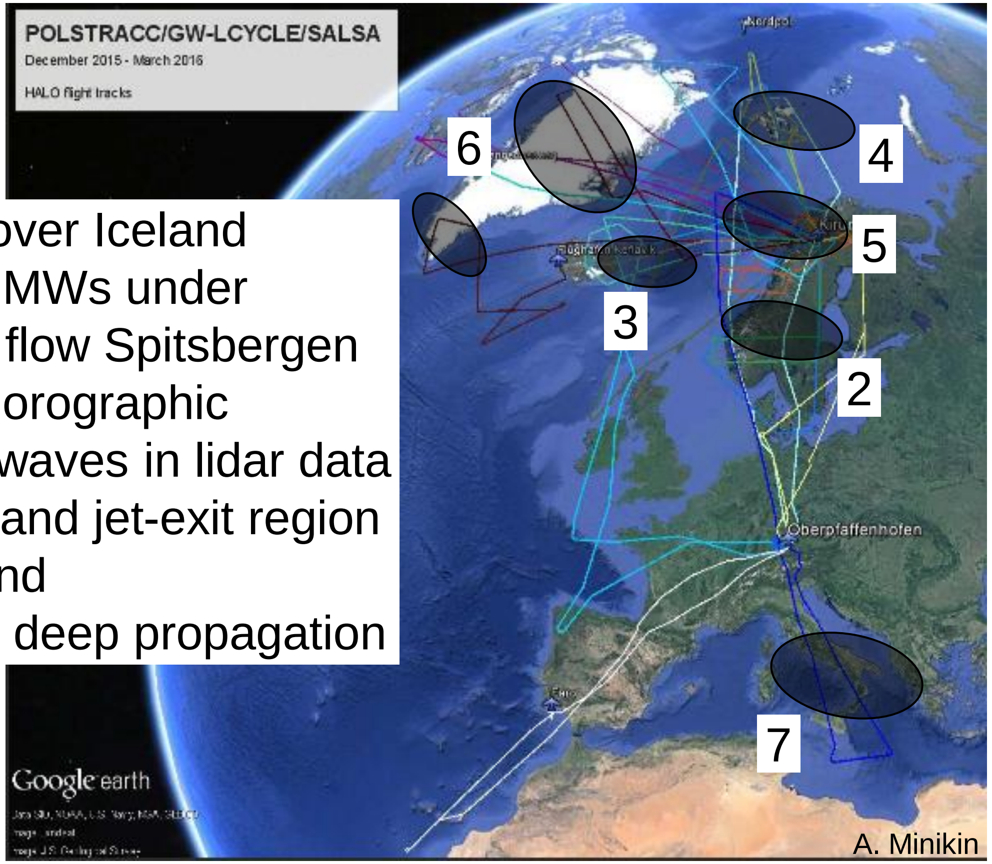
Airborne measurements – GW-LCYCLE 2

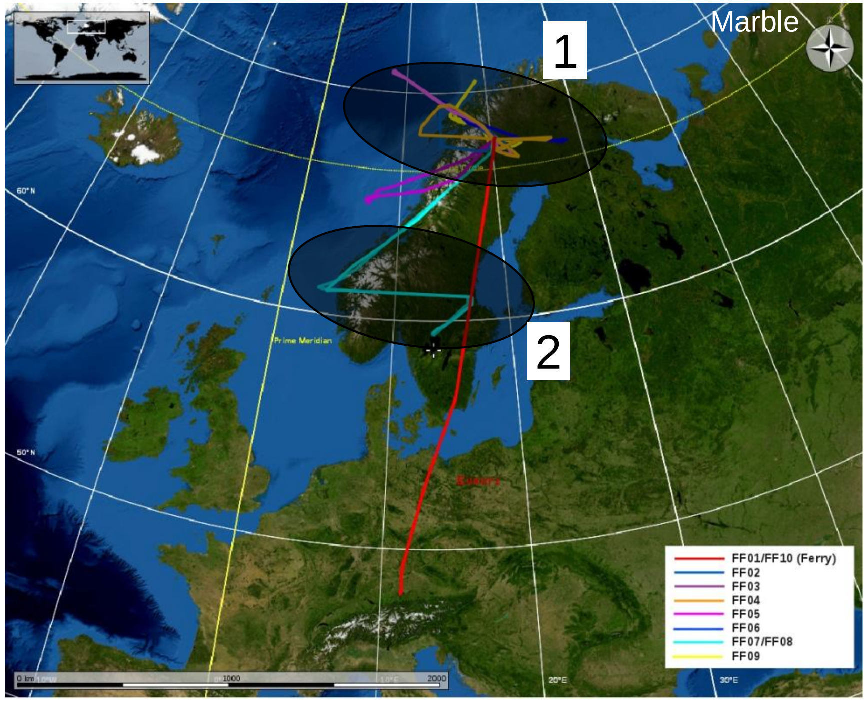
Gravity Wave Events

HALO



3 MWs over Iceland
4 weak MWs under easterly flow Spitsbergen
5 weak orographic forcing, waves in lidar data
6 MWs and jet-exit region Greenland
7 MWs, deep propagation

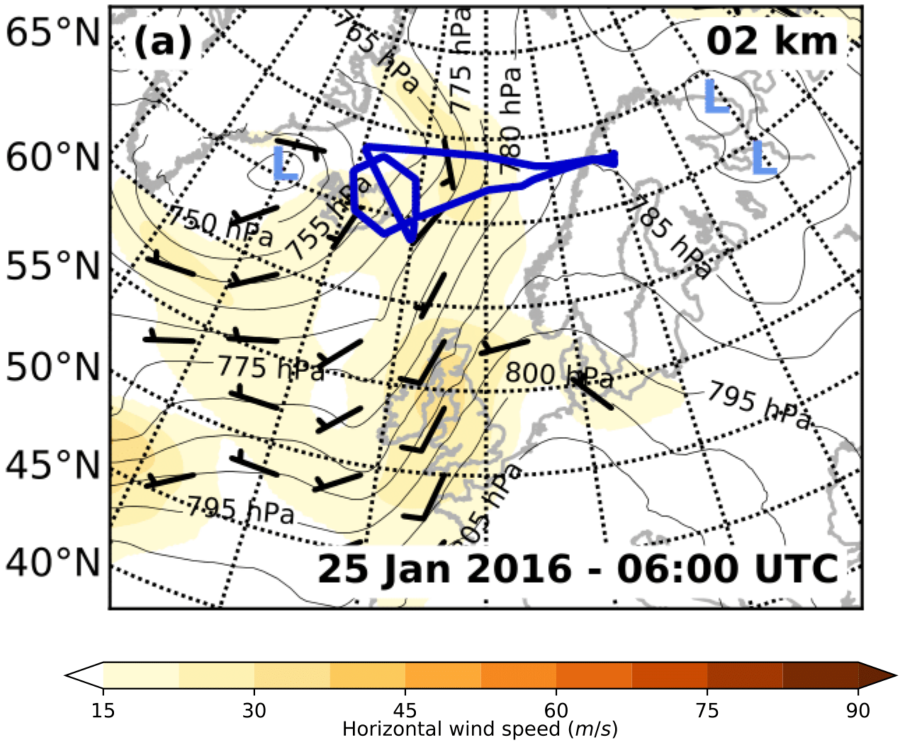
Falcon



1 GWs with weak and no orographic forcing, with and without polar night jet (PNJ)
+ comparison ground and airborne obs
+ other events captured by ground based instruments

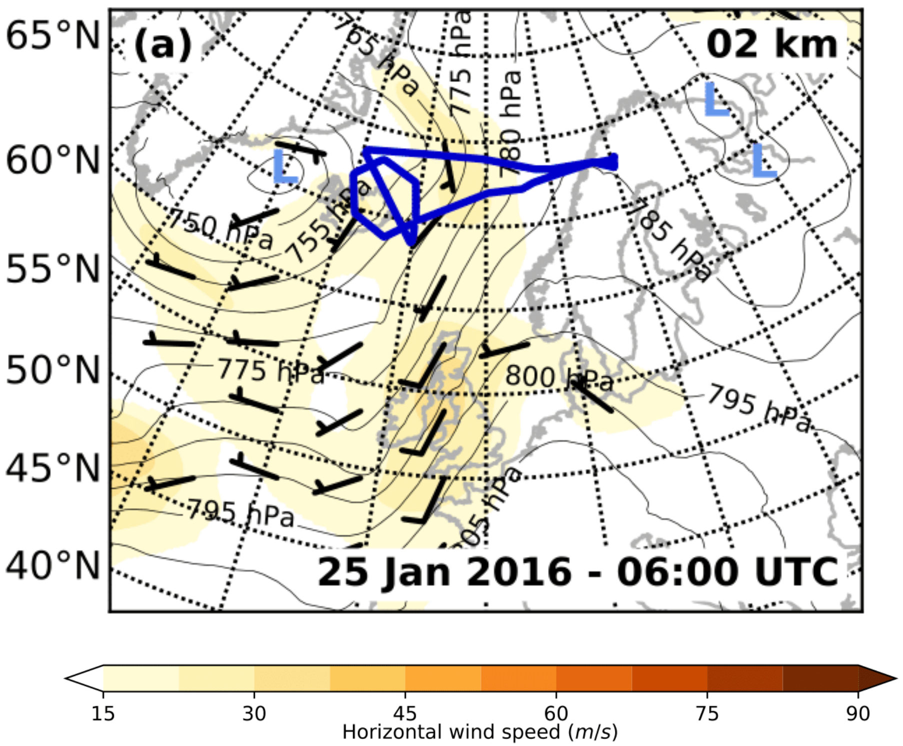
2 moderate and transient MW event

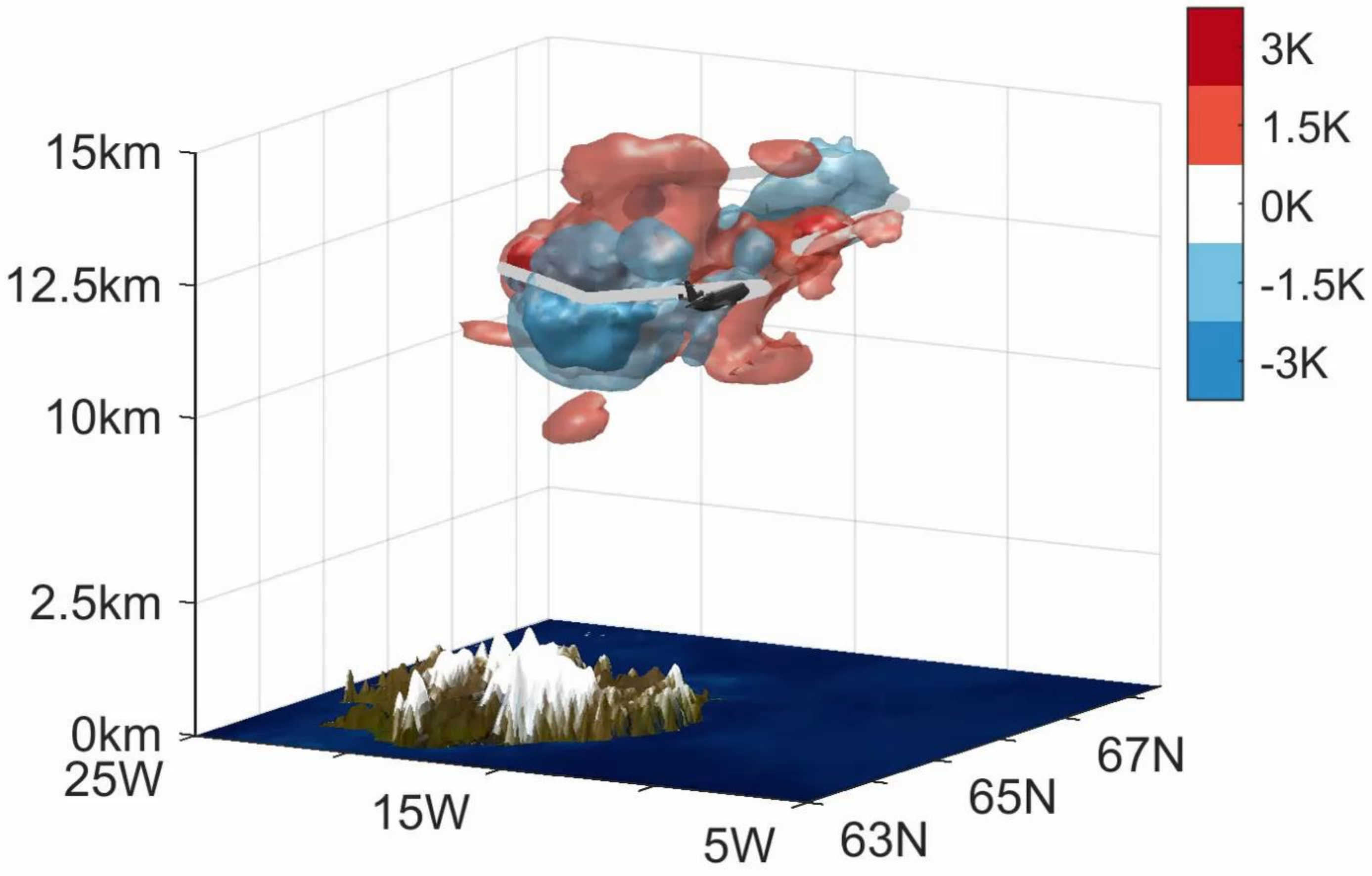
GW event over Iceland



GW event over Iceland

Tomographic measurements with GLORIA





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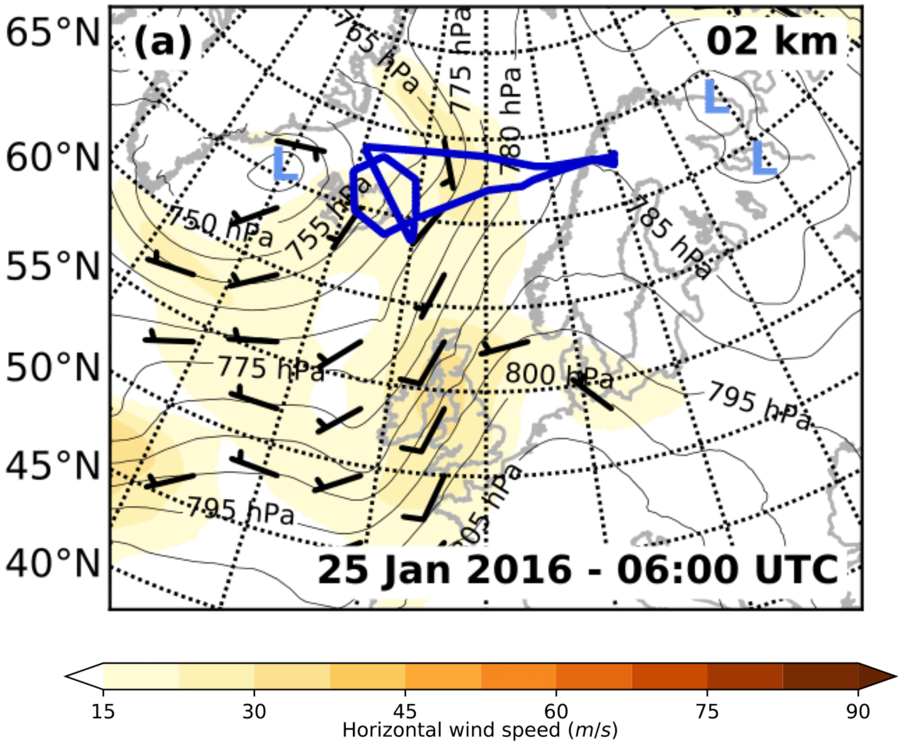

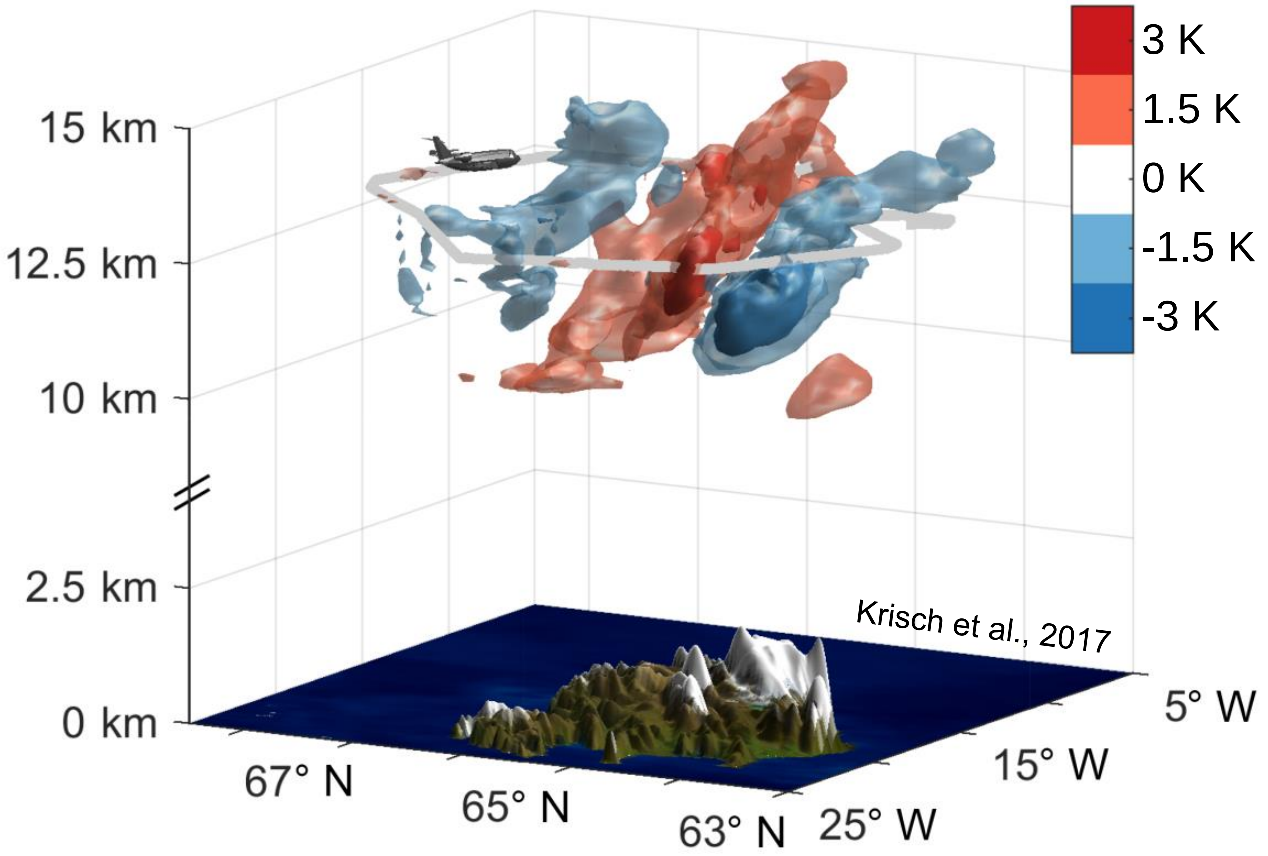

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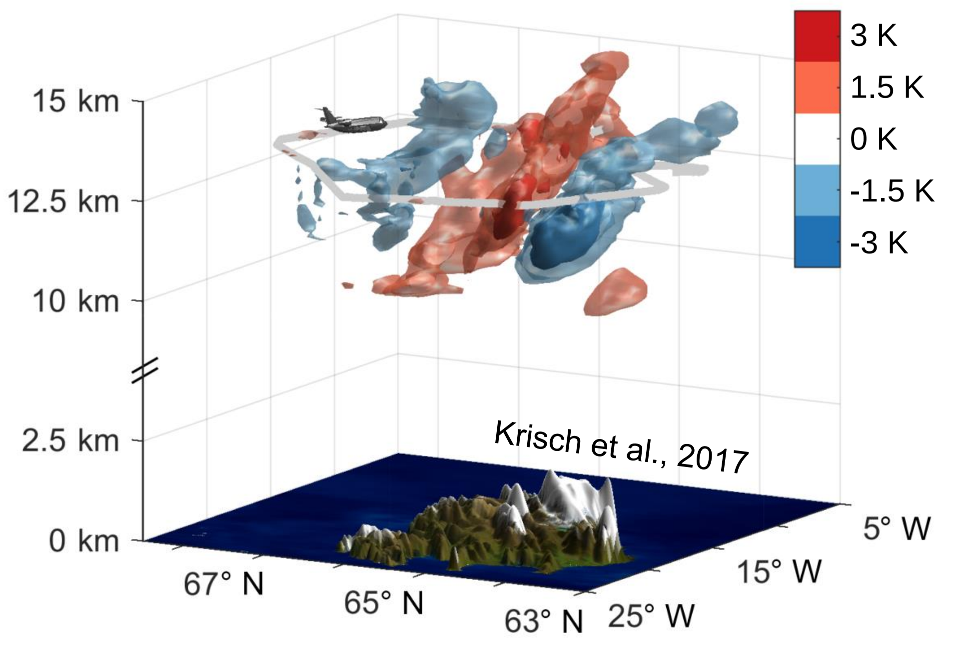
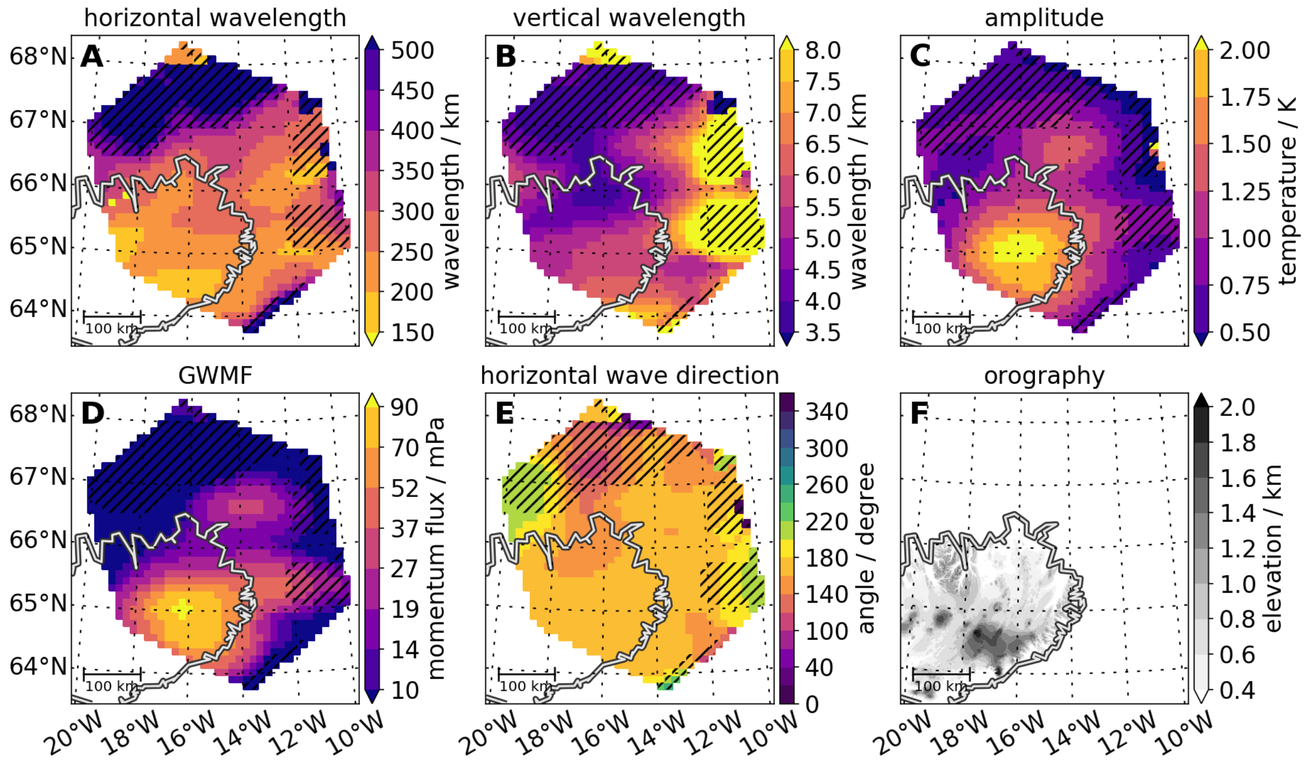


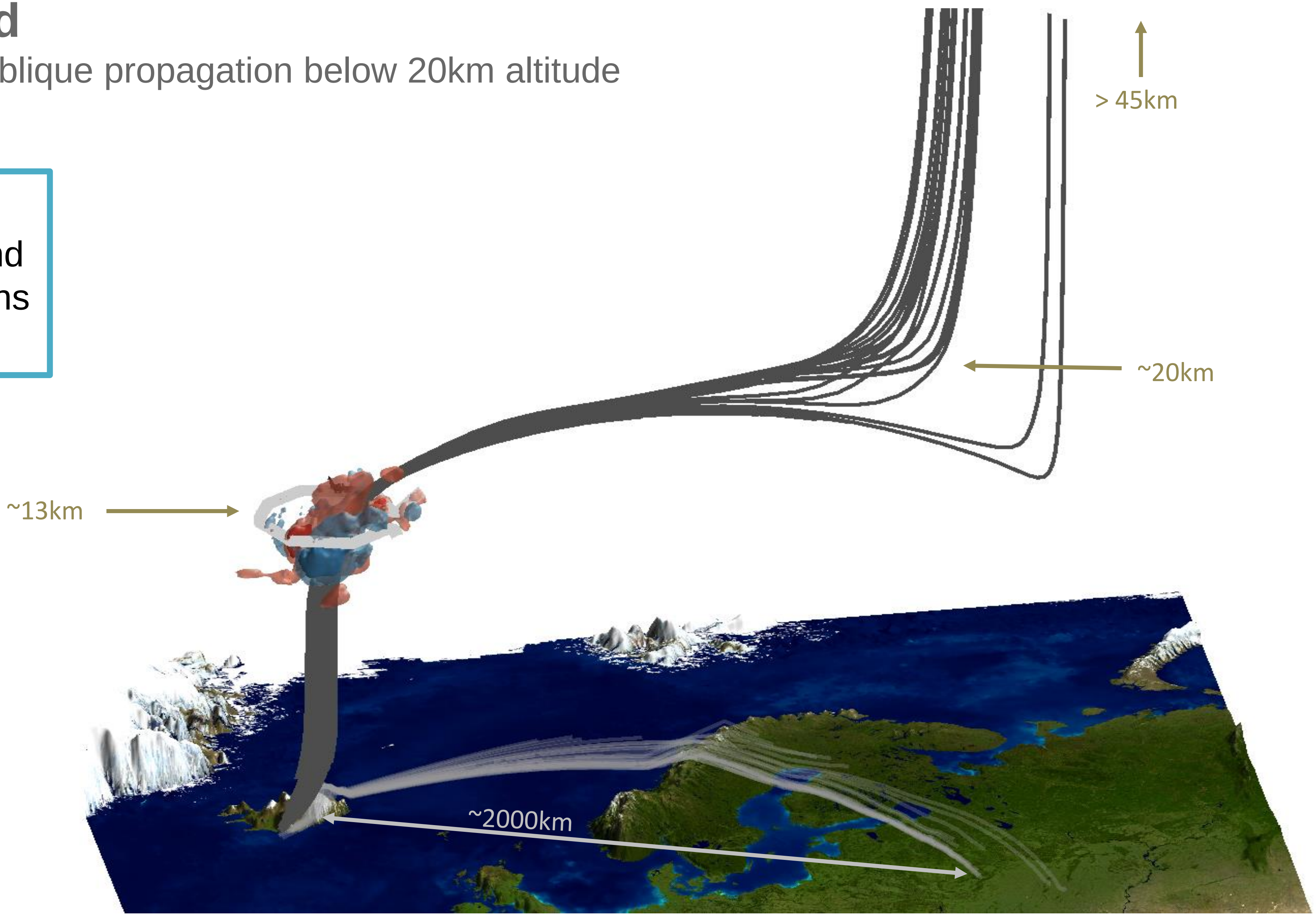


Krisch et al. 2017

GW event over Iceland

Ray-tracing shows extremely oblique propagation below 20km altitude

ECMWF IFS temperature and wind fields used as background state for ray-tracing calculations with GROGRAT



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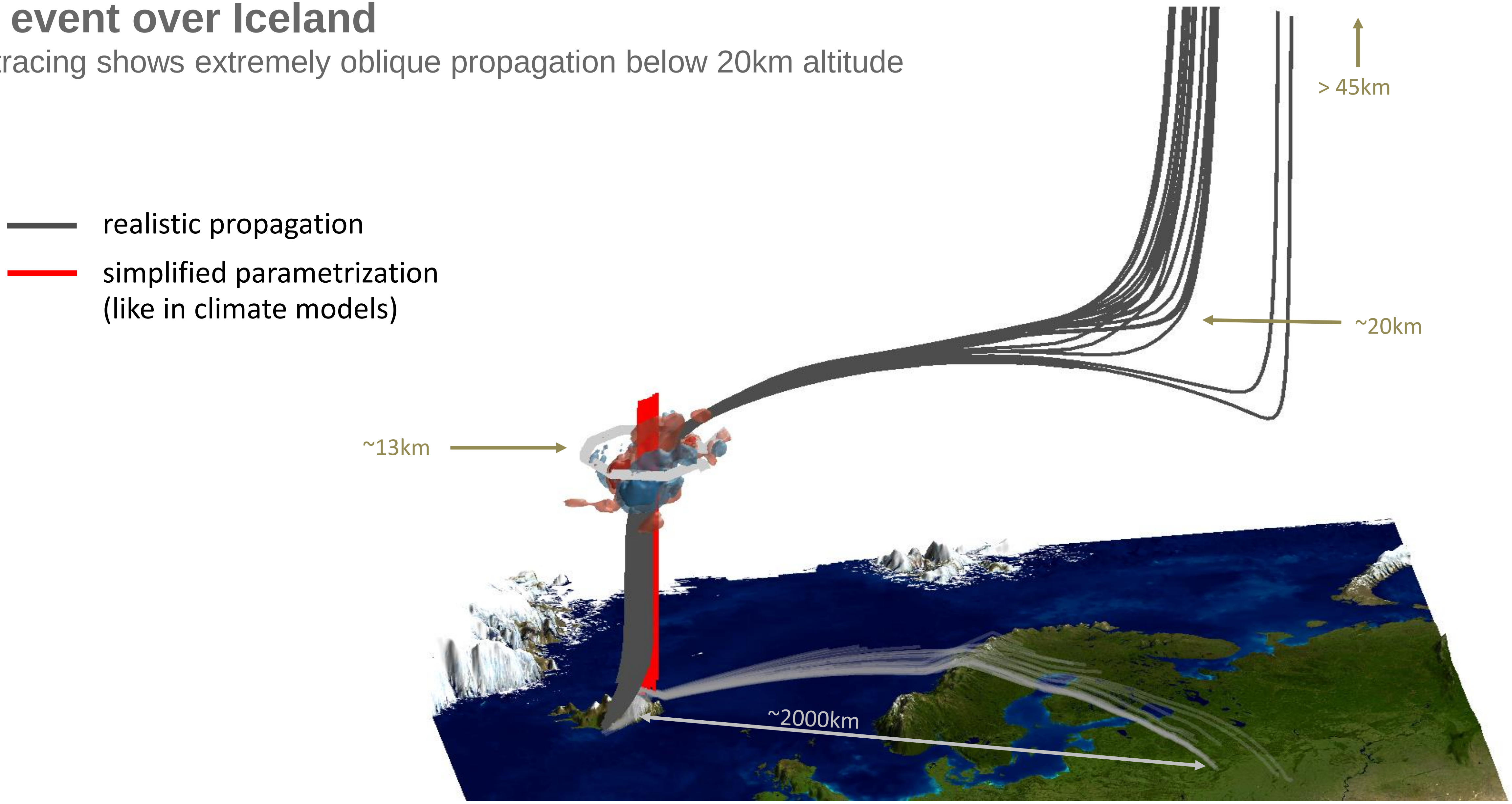
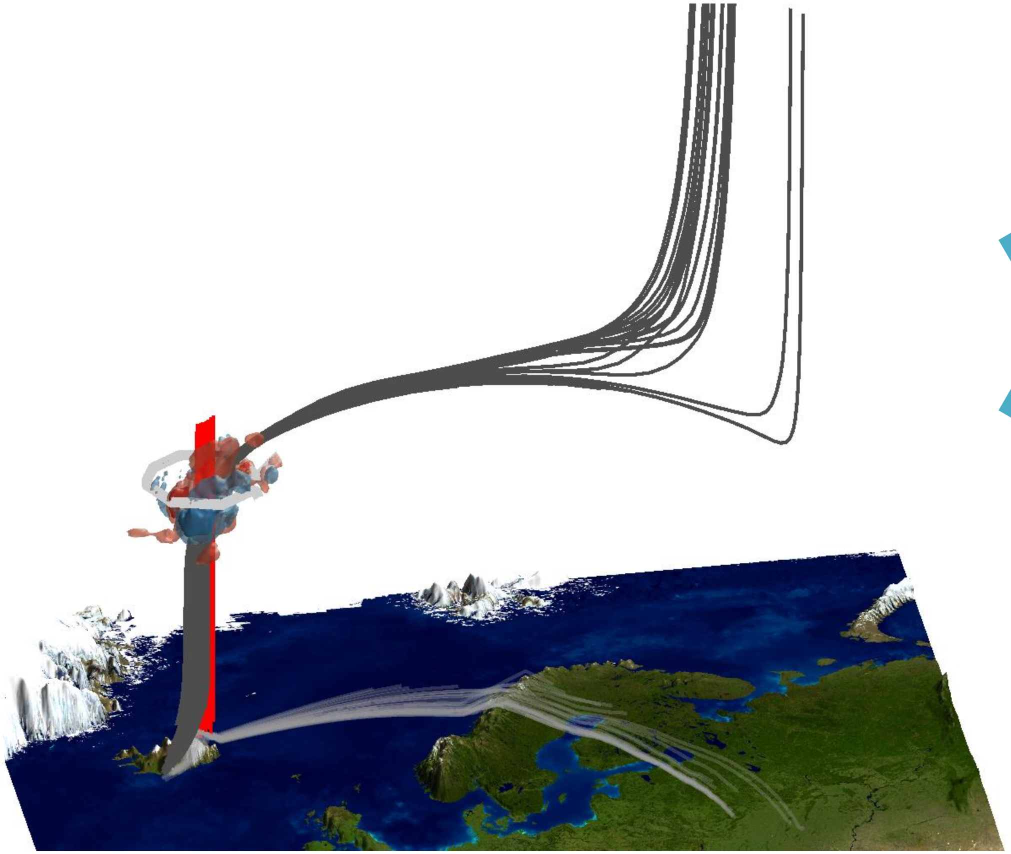
GW event over Iceland

Ray-tracing shows extremely oblique propagation below 20km altitude



GW event over Iceland

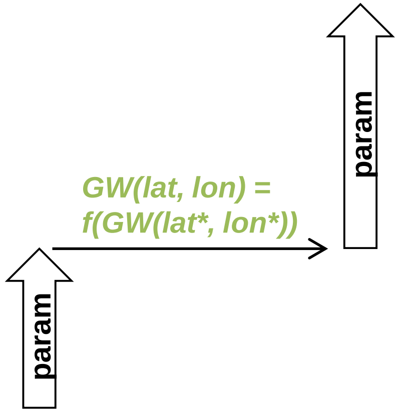
Impact on models



New GW parameterisation scheme for ICON including oblique propagation (MS-GWaves, GU Frankfurt)

MS-GWaM

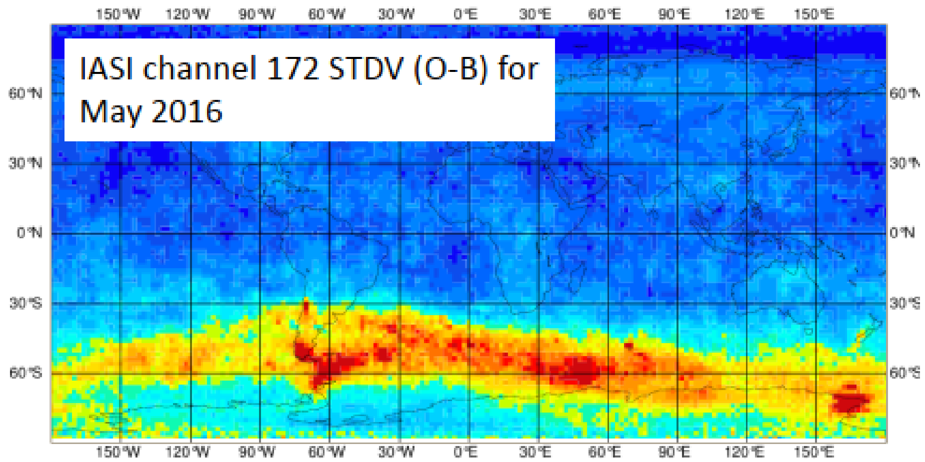
Transfer function for traditional parameterisation schemes based on GW resolving models (ROMIC II, FZ Jülich & DLR)

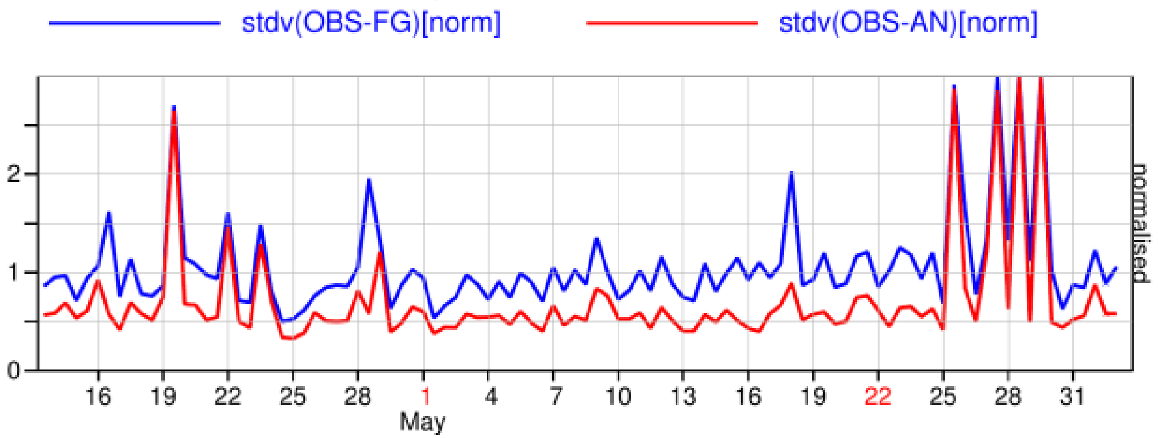


Lack of gravity wave drag in global circulation models

Mismatch between model and observations

Radiance monitoring in IR and MW stratospheric sounding channels showed elevated departures around the Antarctic Peninsula and the southern tip of South America



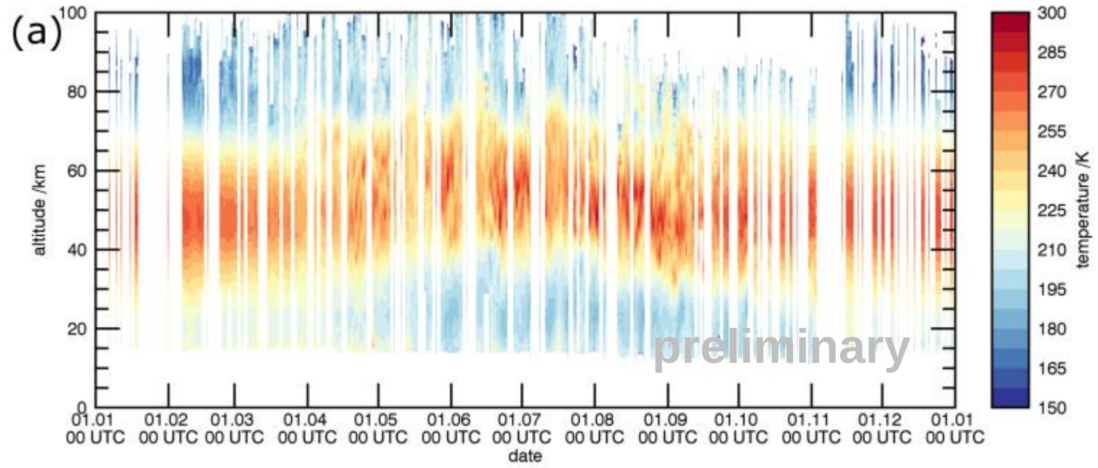


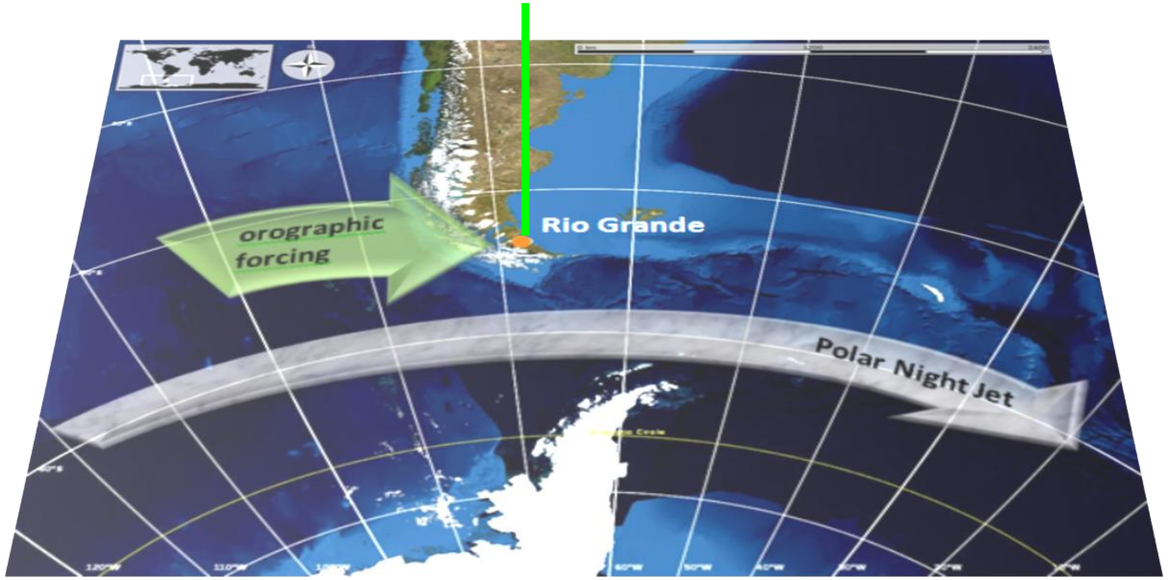
Similar elevated departures were seen in GPS-RO

ECMWF QED Meeting
MAM 2016
(Tony McNally)

Lidar Temperature Measurements in Rio Grande

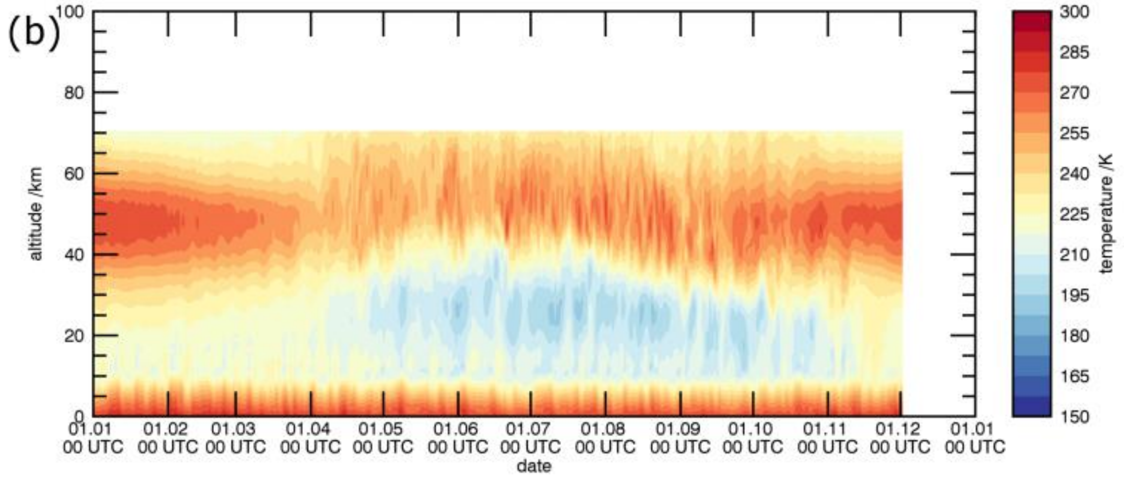
SOUTHTRAC





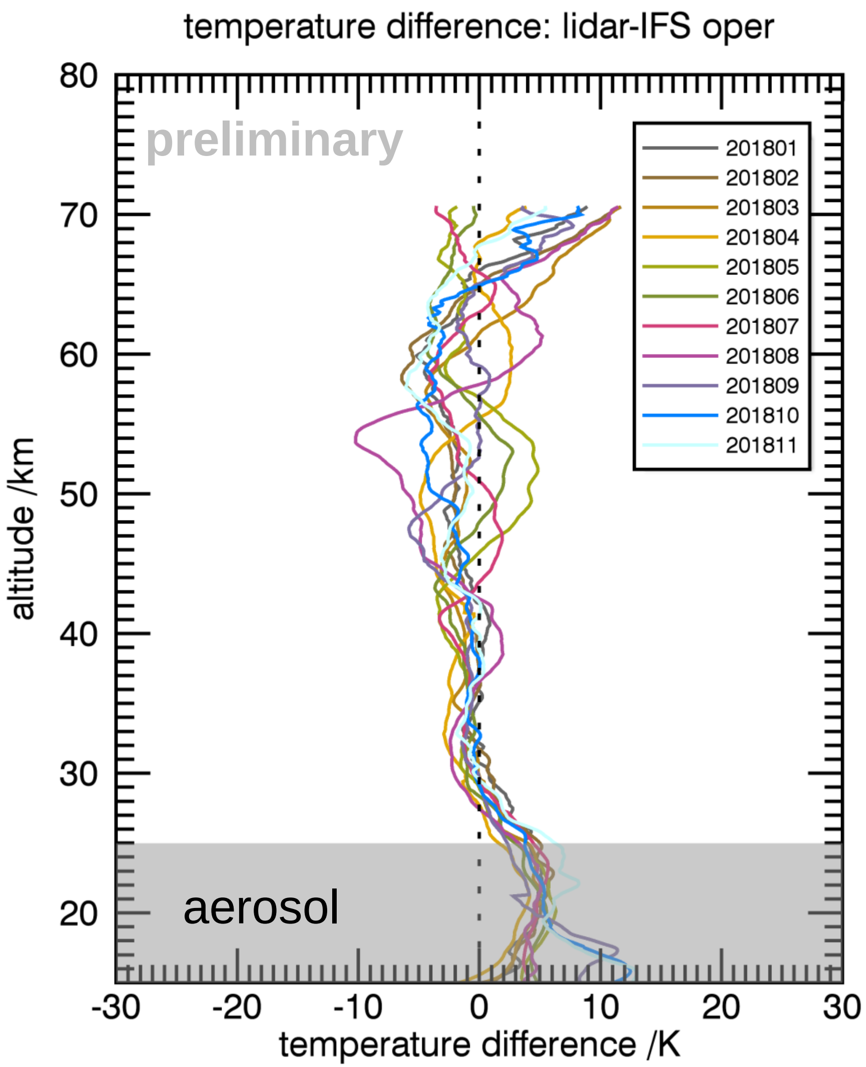
nightly mean

year 2018



ECMWF IFS operational analysis and forecasts
Cycle 45r1
(in cooperation with Inna Polichtchouk & Irina Sandu)

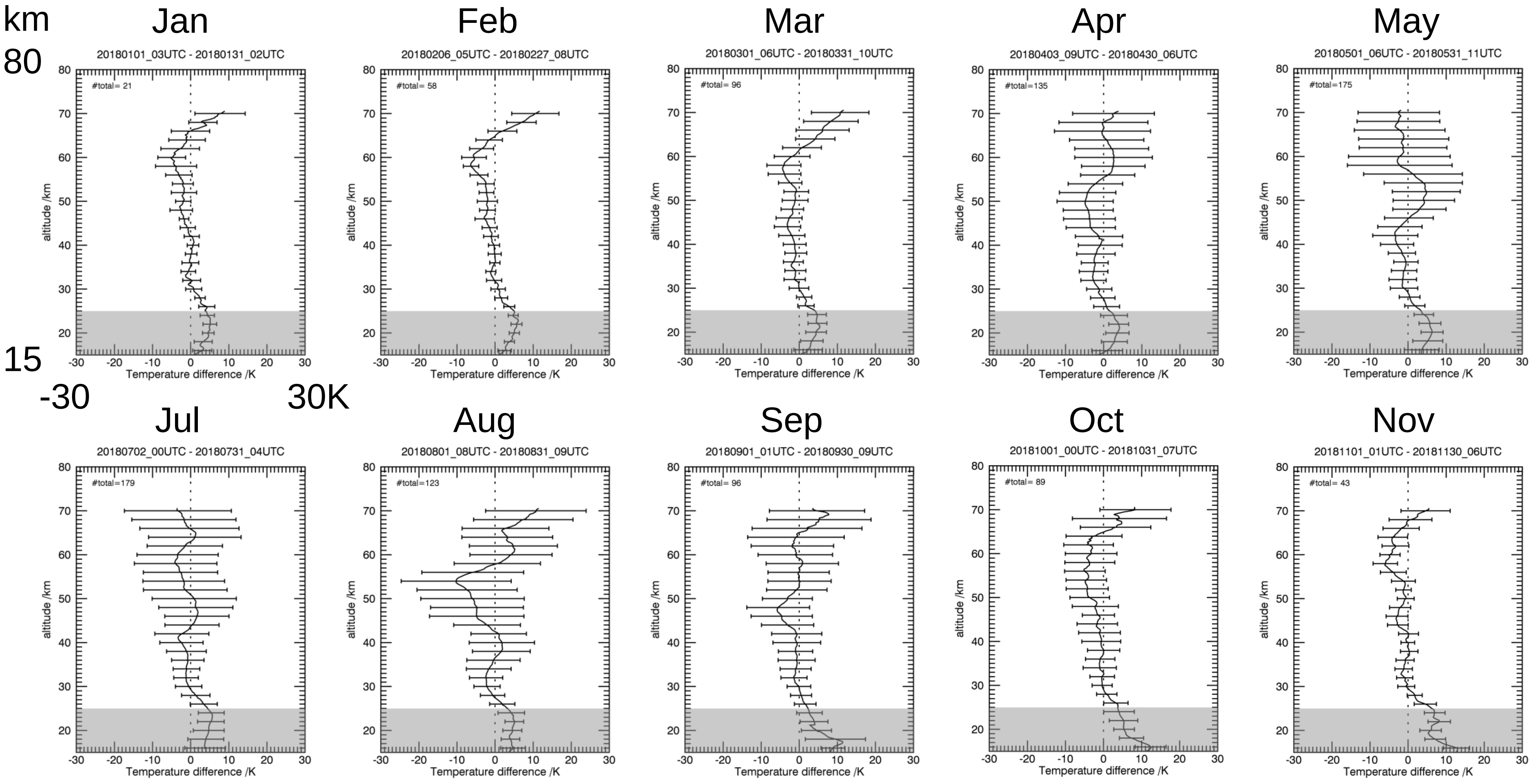
T-differences between lidar and ECMWF IFS (45r1)



mean difference is below 5K between 25 and 43 km altitude for all months

analysis and forecasts (+1,2,3,4,5,7,8,9,10,11h) preliminary

T-differences between lidar and ECMWF IFS (45r1)



the standard deviation of the temperature differences is larger from April to September (GW active period) compared to January to March, October, November

often a phase shift between lidar and IFS GWs is observed in T profiles

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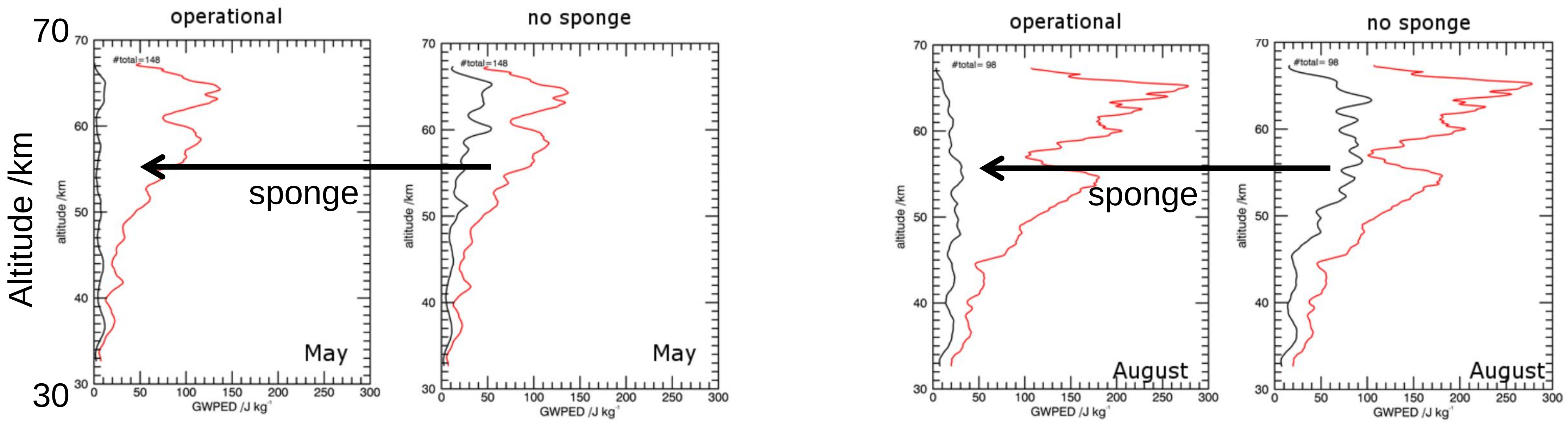
preliminary

Gravity Wave Potential Energy Density (GWPED ~T')
lidar and ECMWF IFS (45r1) analysis and forecasts 2018



$$\mathrm{GWPED} = \frac{1}{2}\frac{g^2}{N^2}\overline{\left(\frac{T'}{T_0}\right)^2}$$

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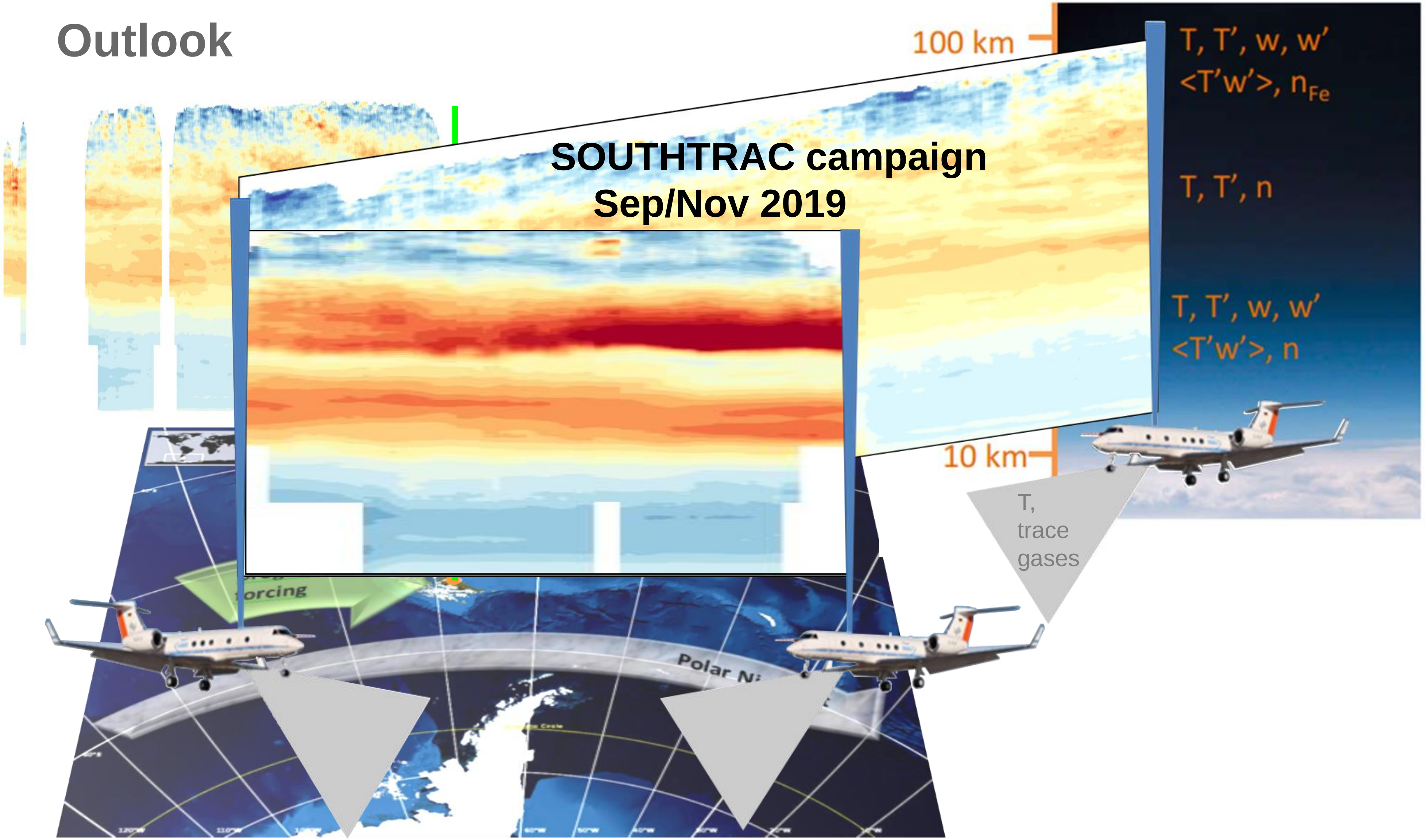
Summary

- **ECMWF used for multiple gravity wave field campaigns both for flight/operation planning as well as for the analysis**
- **GLORIA measurements**
  - ➢ extremely oblique propagation
  - ➢ new parameterisation schemes for GW being developed
- **Lidar measurements**
  - – Comparison to operational analysis and forecast:
    - ➢ mean difference is below 5K between 25 and 43 km altitude for all month
    - ➢ the standard deviation of the temperature differences is larger in April to September (gravity wave active period) compared to January to March, October, November
  - – Experimental forecasts
    - ➢ amplitudes increase to more realistic values when sponge is removed
    - ➢ effect of removal of sponge on GWPED for whole May and Aug 2018: GWPED above 45 km increases significantly (normalized differences are reduced to 65 and 75 % for May and Aug, respectively)

Outlook



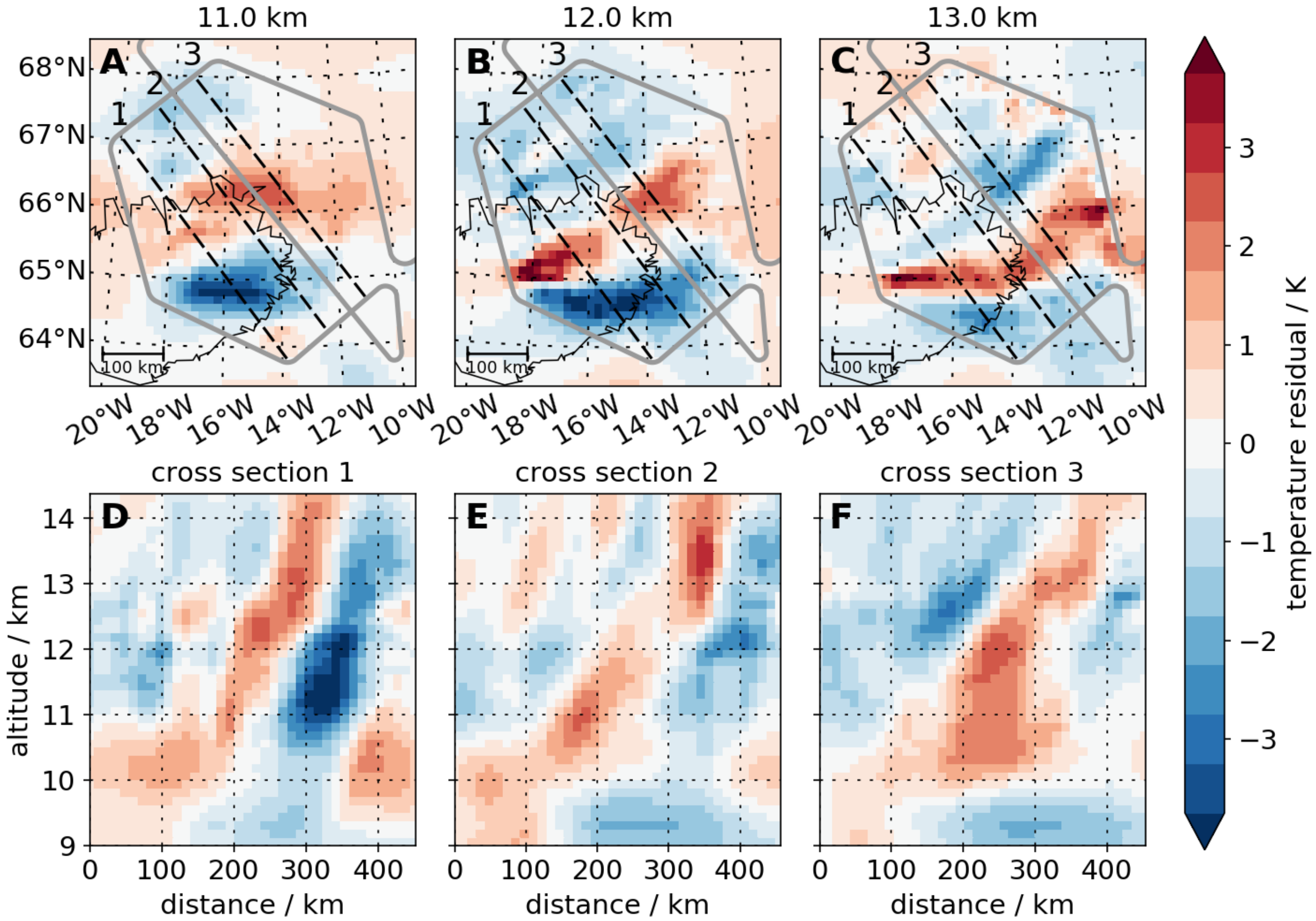
Airborne Lidar for Studying the Middle Atmosphere (ALIMA)

in-situ measurements

Gimballed Limb Observer for Radiance Imaging of the Atmosphere (GLORIA)

GW event over Iceland

Tomographic measurements with GLORIA



Krisch et al. 2017

IFS Sponge

diffusion coefficients

wavenumber 21

TCo1279

wavenumber 1279

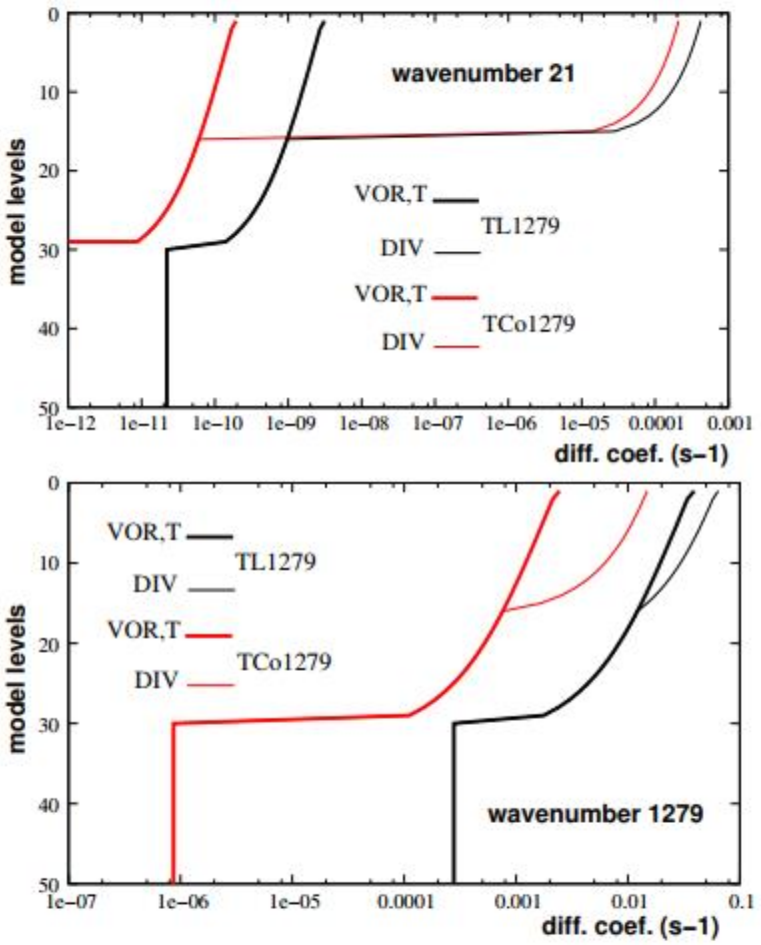


Figure 2: Vertical profils of the horizontal diffusion coefficients for wavenumbers 21 and 1279 at TL1279 and TCo1279.

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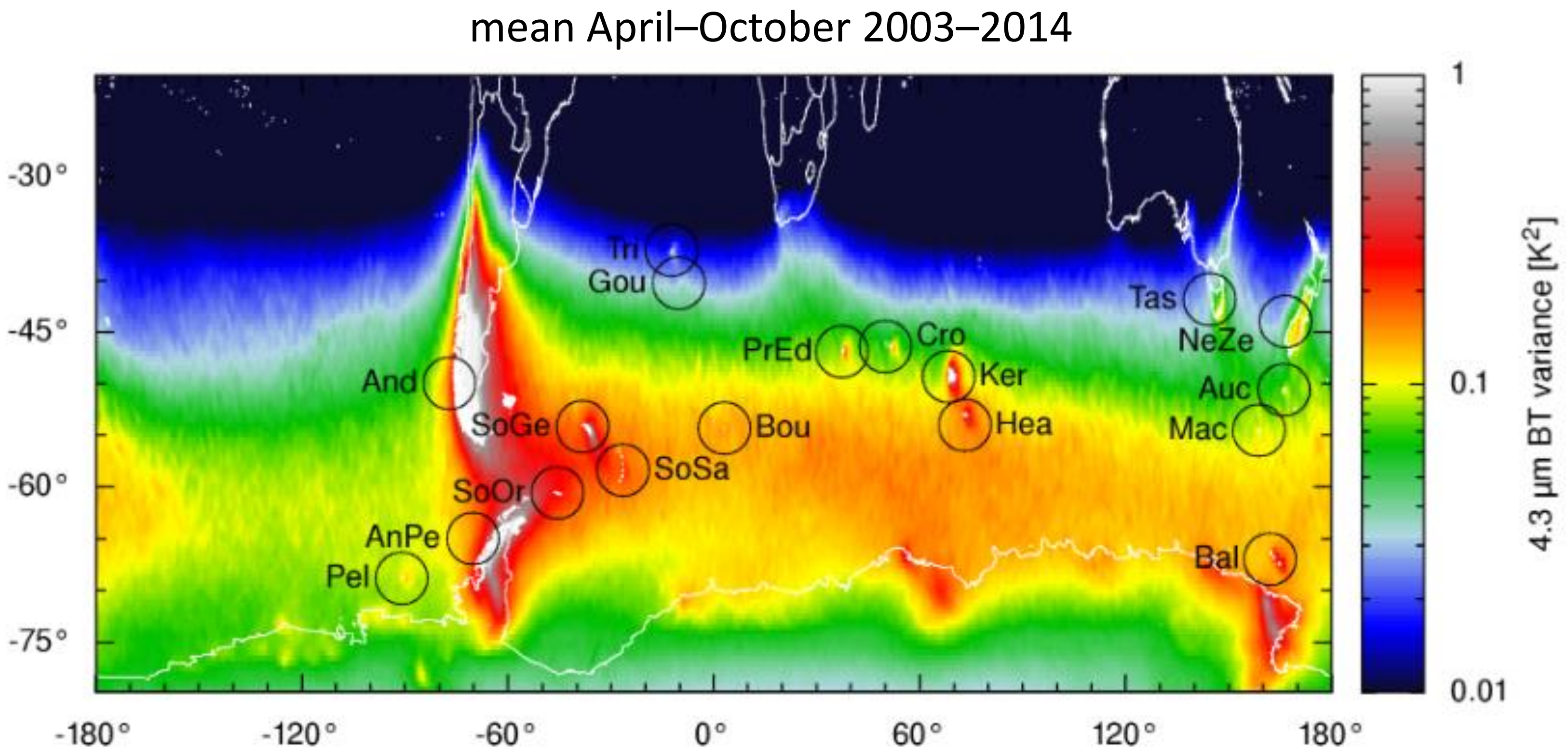
SH stratospheric gravity wave activity revealed by AIRS temperature variances

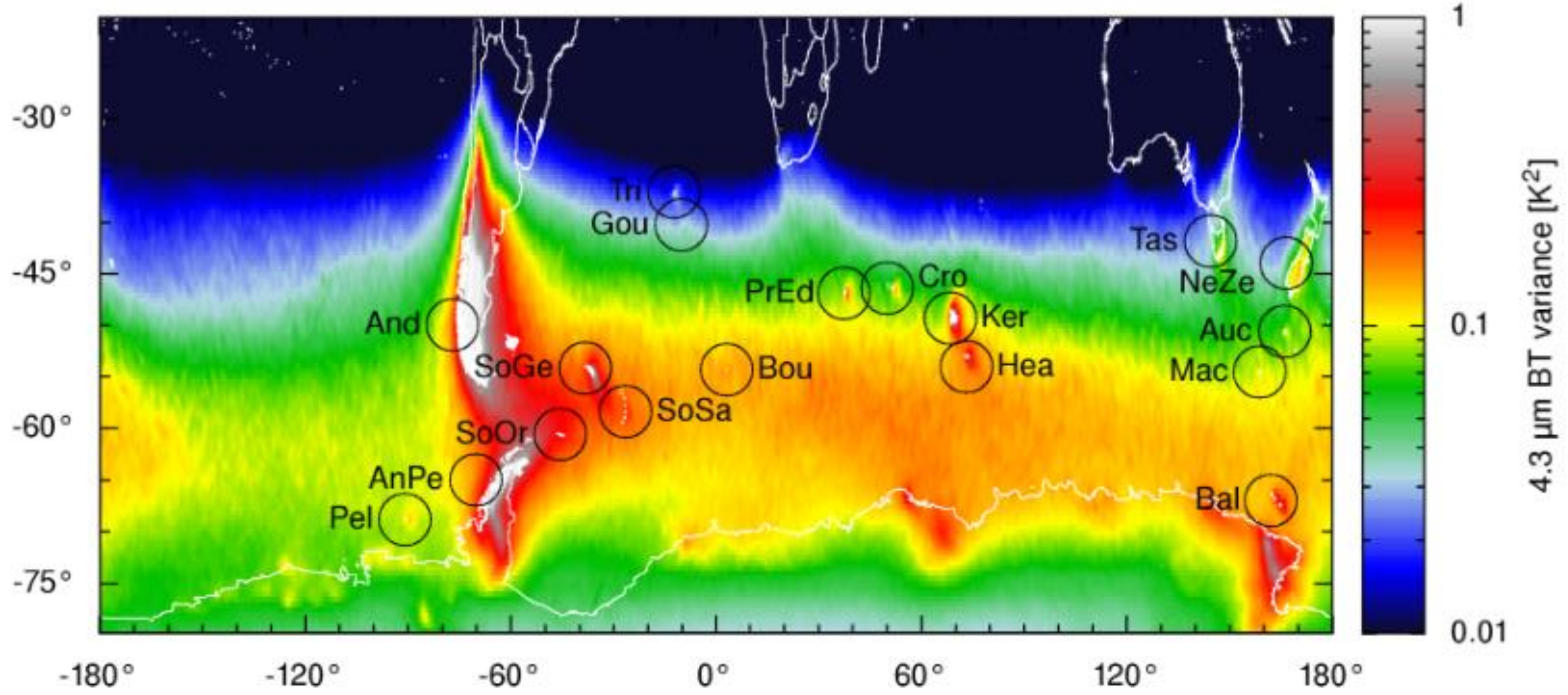


Hoffmann et al. 2016, ACP

the pattern of stratospheric GW activity is characterized by large values near orographic sources and a belt of enhanced values around 60S in winter

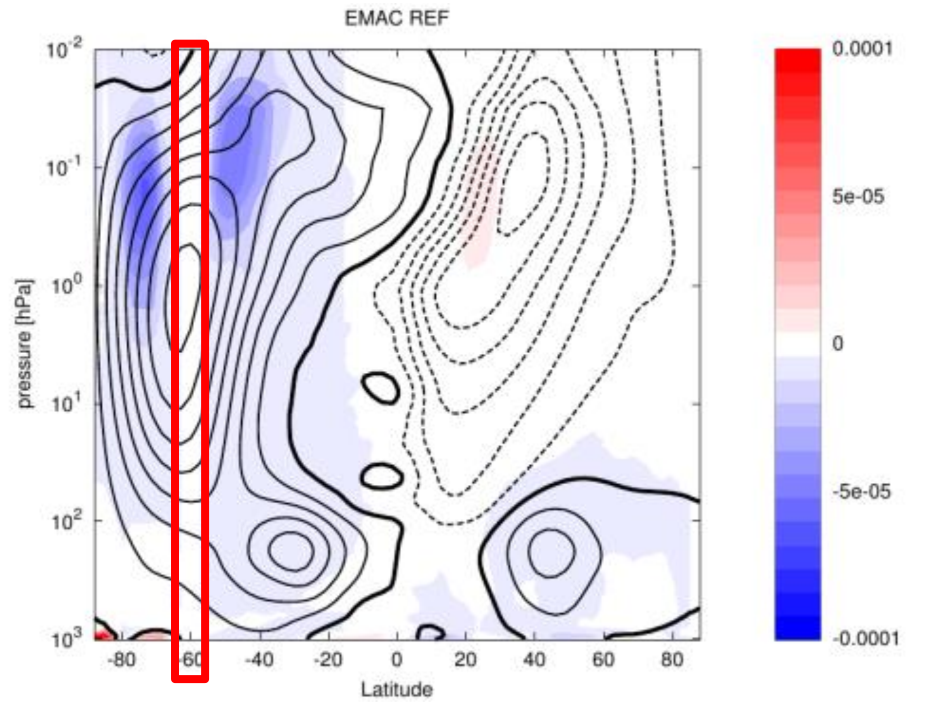
Lack of gravity wave drag in global circulation models

mean April–October 2003–2014



Hoffmann et al. 2016, ACP

EMAC orographic GWD



60S

Figure by H. Garny

see also McLandress and Shepard, 2012, JAS

→ affects polar vortex dynamics, polar stratospheric temperatures (cold pole bias), and ozone concentration

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