Gravity wave coupling from the troposphere to the mesosphere: insights from a series of combined airborne and ground based field campaigns in both hemispheres

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& GW-LCYCLE-team

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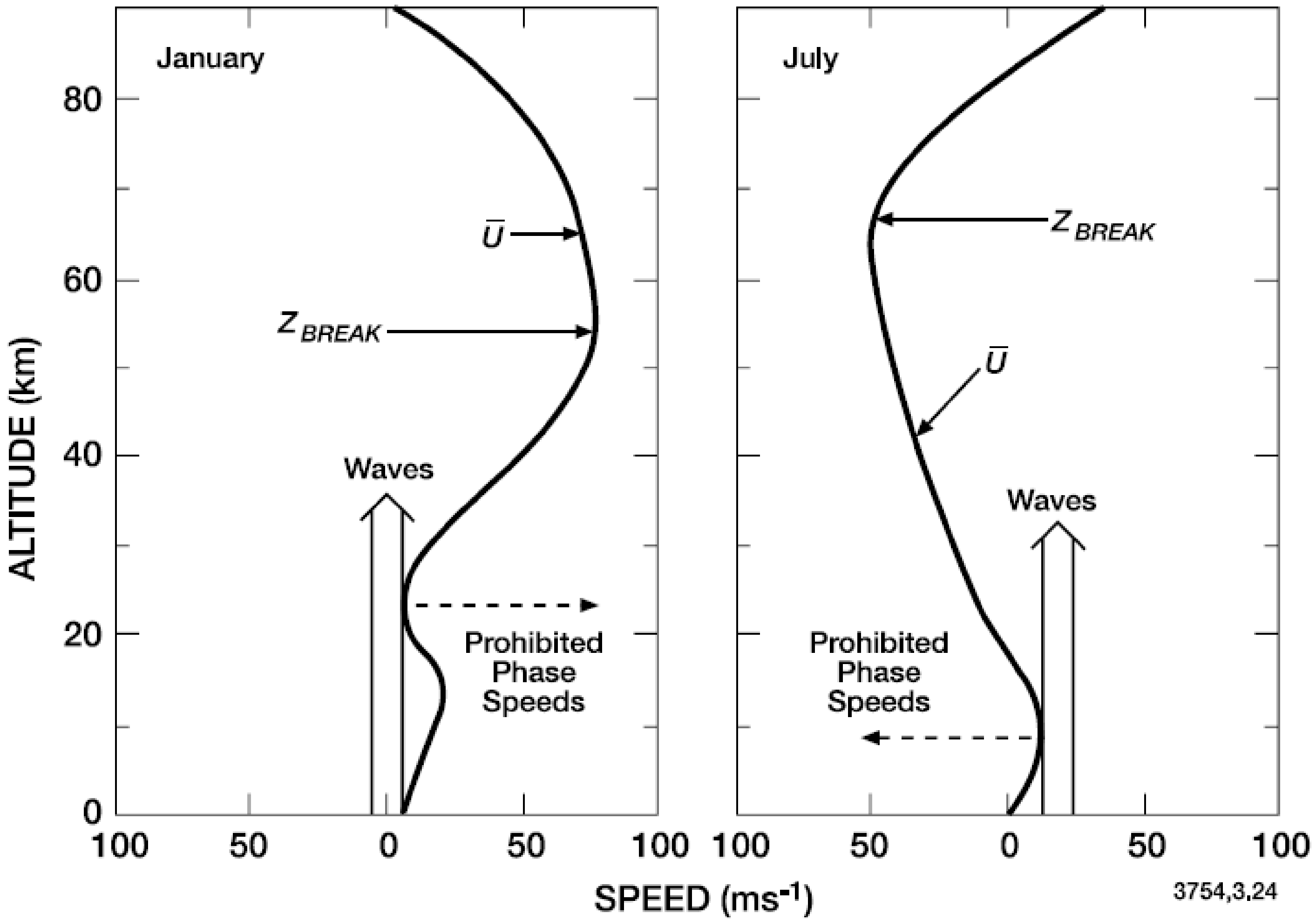
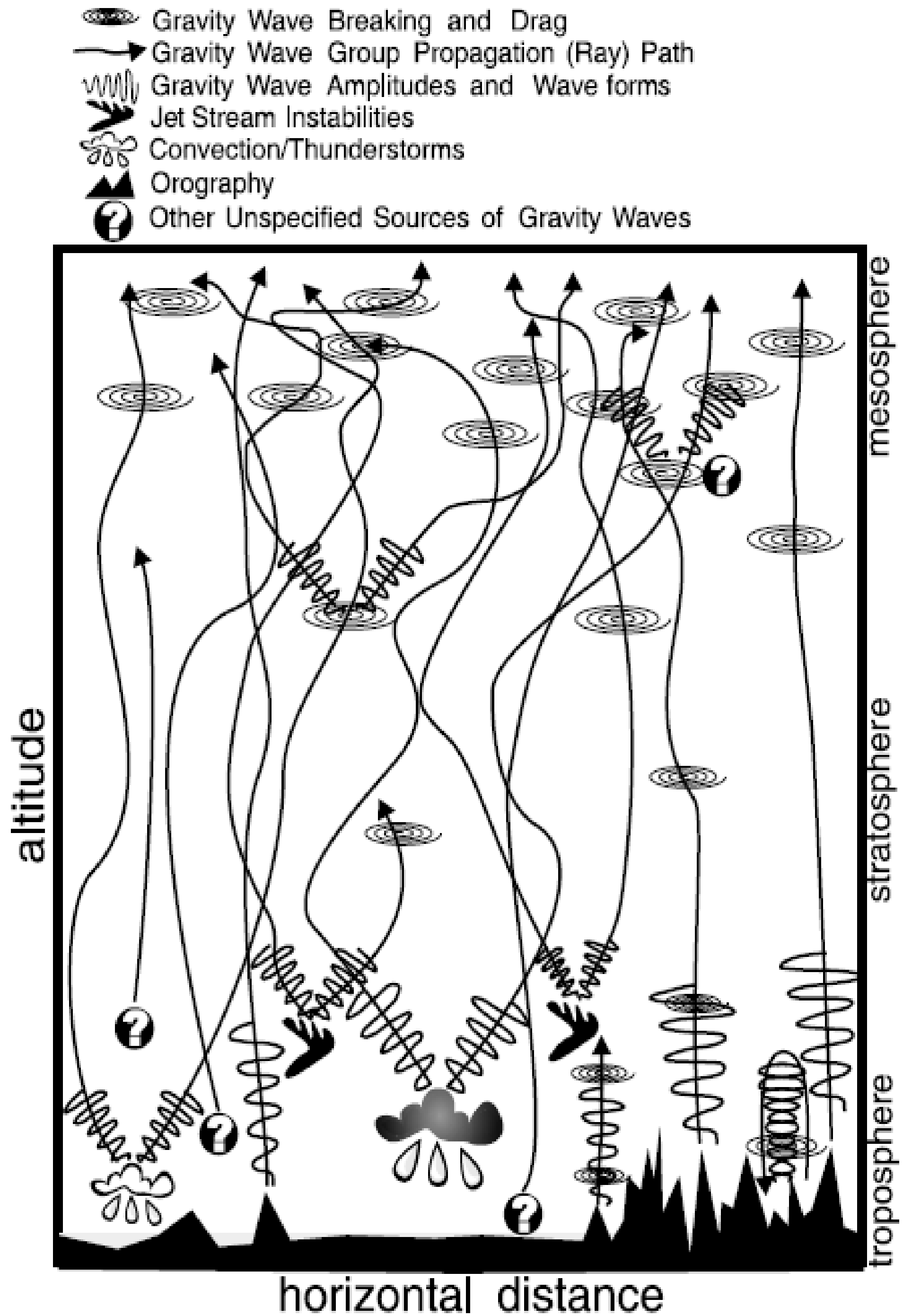
GW-driving of the mesophere: the „simple picture“



Lindzen, JGR 1981



Challenges and Scientific objectives

Physics-based parametrization requires solid understanding of:

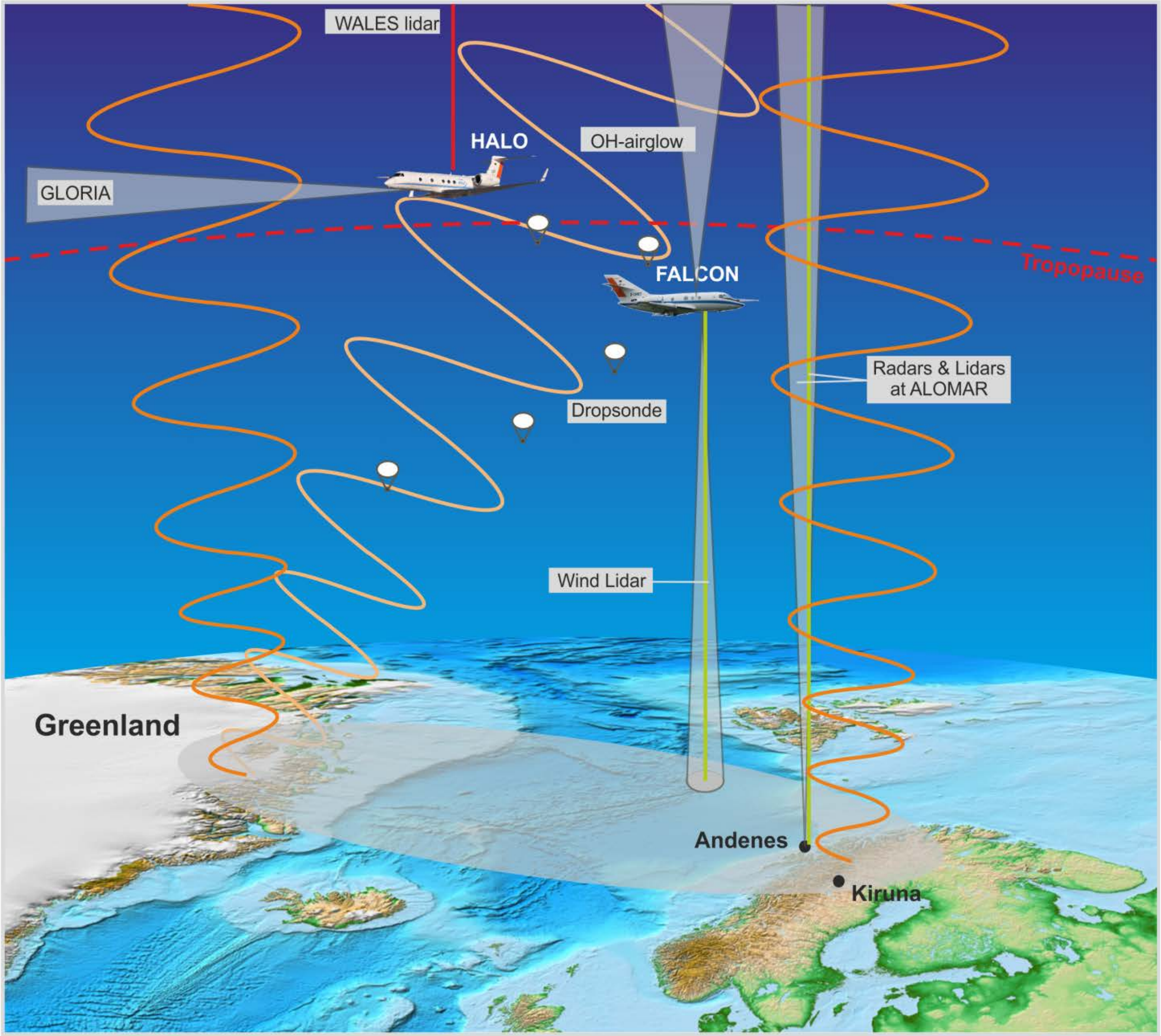
- GW-Sources
- GW-Propagation
- GW-Dissipation
- Wave-Mean Flow Interaction

Input for improved parametrization

Kim et al., 2003

GW-LCYCLE: concept

Partners: DLR, KIT, FZJ, IAP, U. Mainz



International partners:

MISU, FMI, ALOMAR
Utah State University

GEFÖRDERT VOM

Bundesministerium für Bildung und Forschung

ROMIC - Field Campaigns

(1) GW- LCYCLE 1

- 2 – 14 December 2013, Kiruna, Sweden
- DLR Falcon
- radiosonde launches at various stations
- ground-based observations at various stations

(2) DEEPWAVE (NSF- led with DLR contribution)

- 6 June – 22 July 2014, New Zealand
- DLR Falcon
- ground-based observations (Lidar, radiosondes) at Lauder

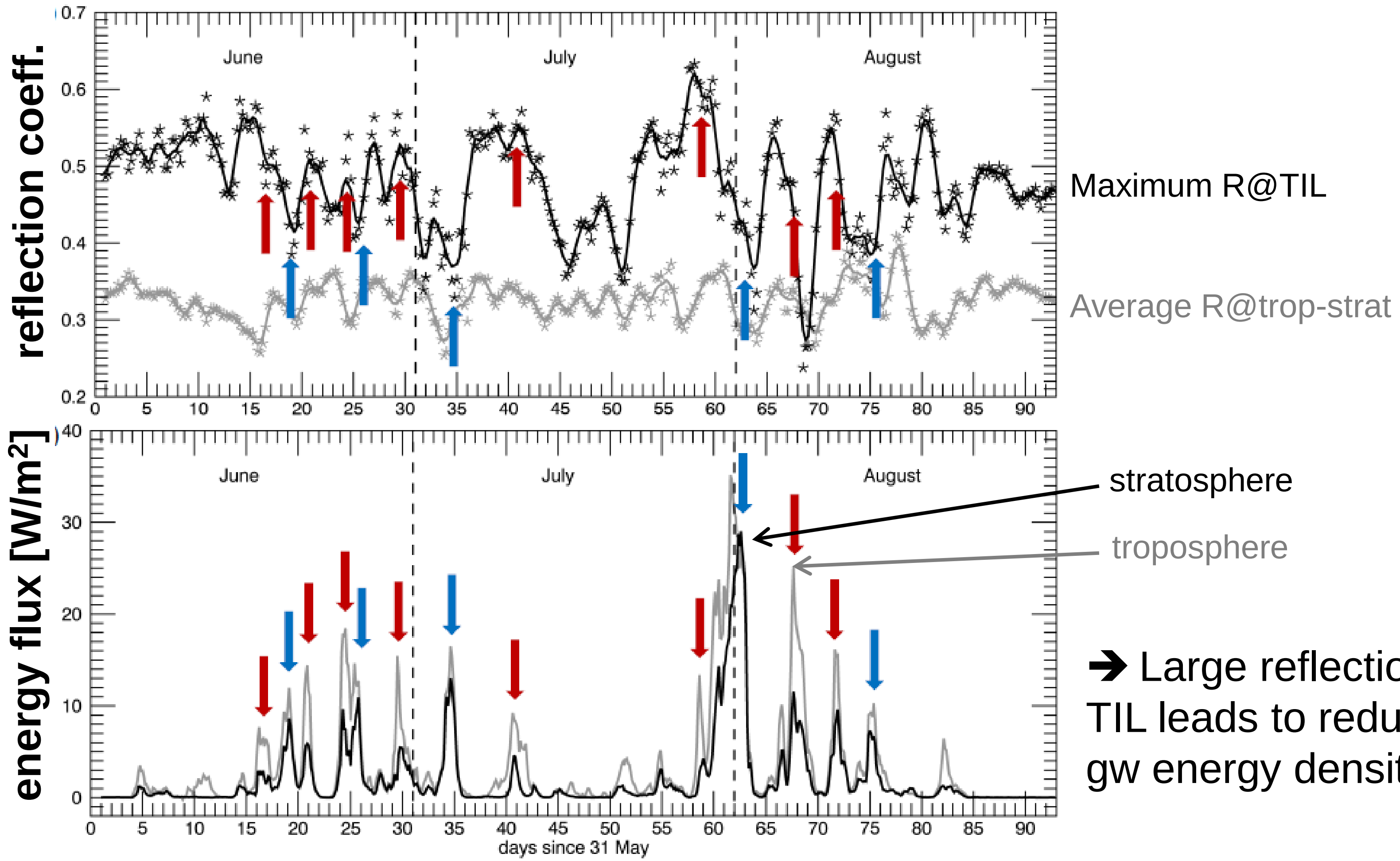
(3) GW- LCYCLE 2

- winter 2015/2016, Kiruna, Sweden
- coordinated flights of HALO and Falcon
- radiosonde launches at var. stations
- ground-based observations at var. stations

Results

GW reflection at the TIL = important GW filter

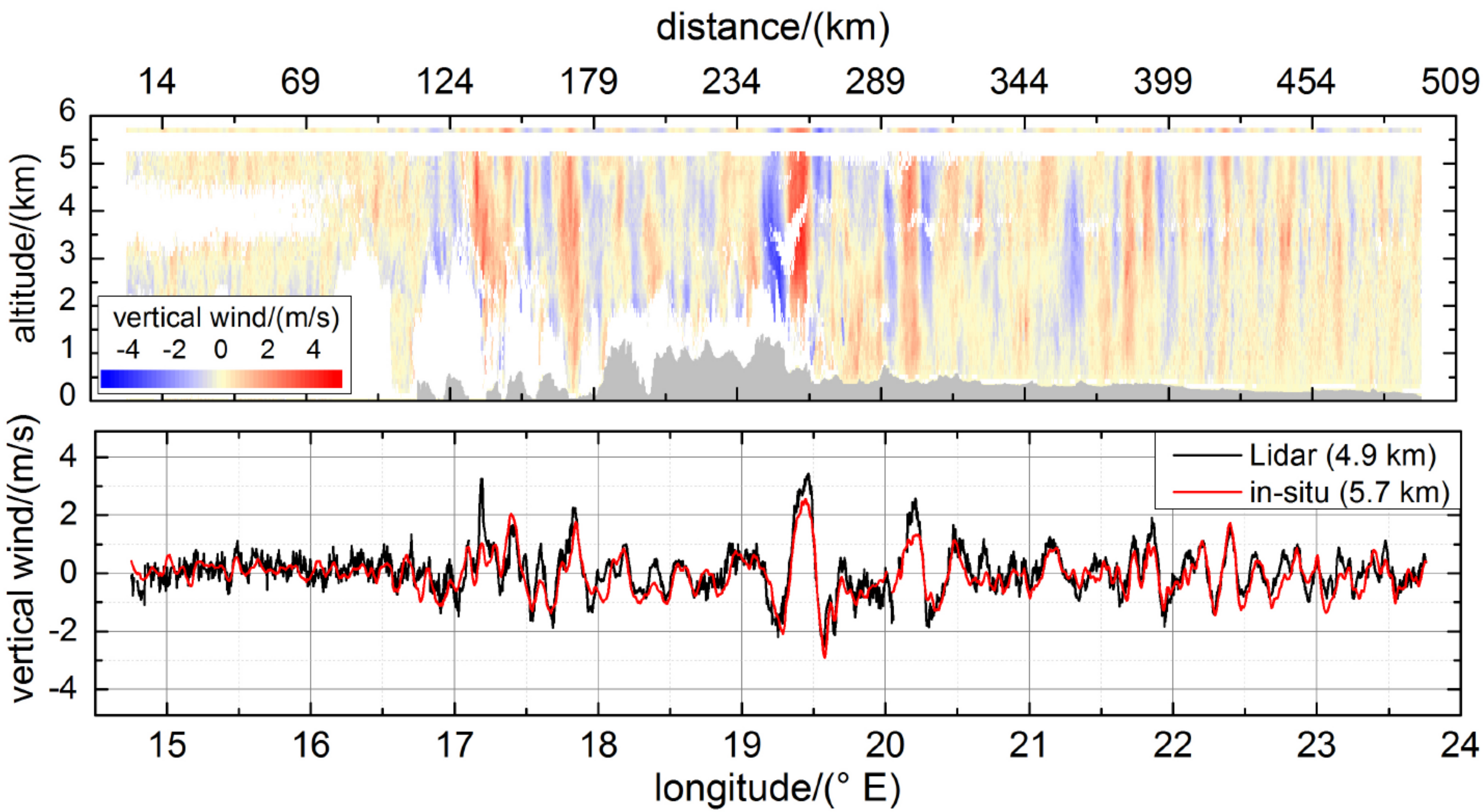
TIL = tropopause inversion layer



➔ Large reflection in TIL leads to reduced gw energy density

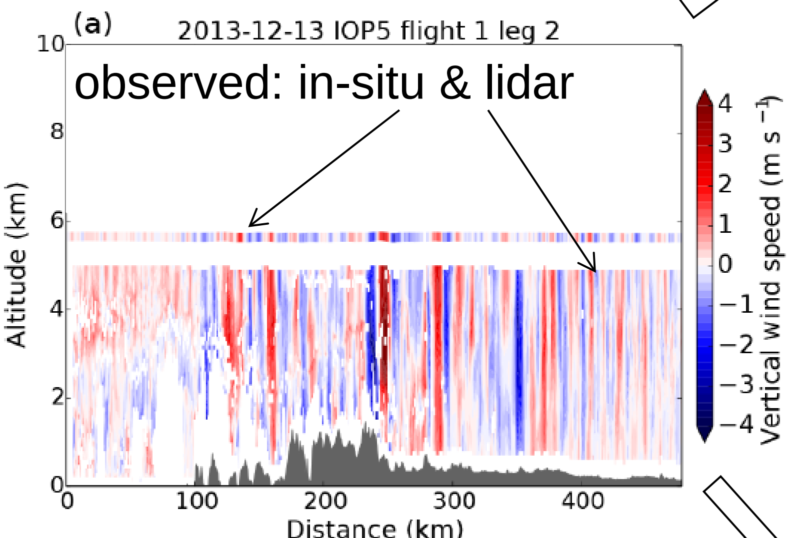
Gisinger et al., Monthly Weath. Rev., in press, 2017

Vertical wind measurements with airborne lidar reveal trapped waves below the tropopause TP ➔ TP = propagation barrier

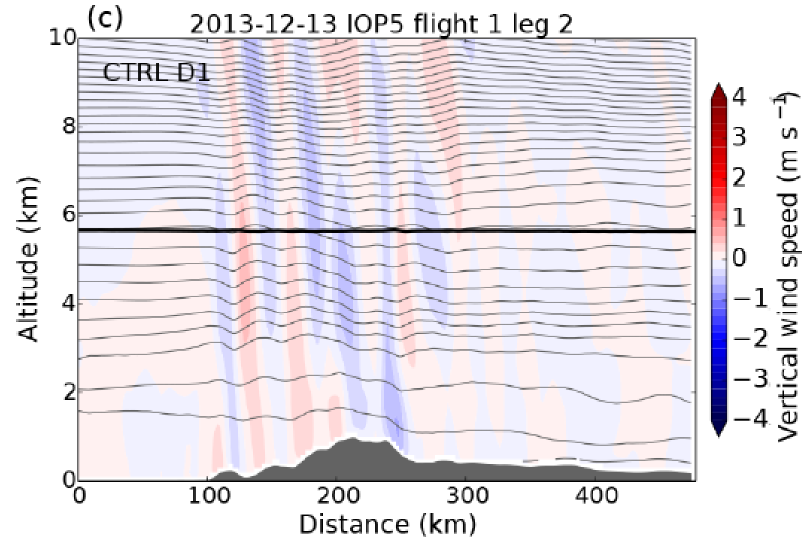


Witschas et al., JAOTech, 2017

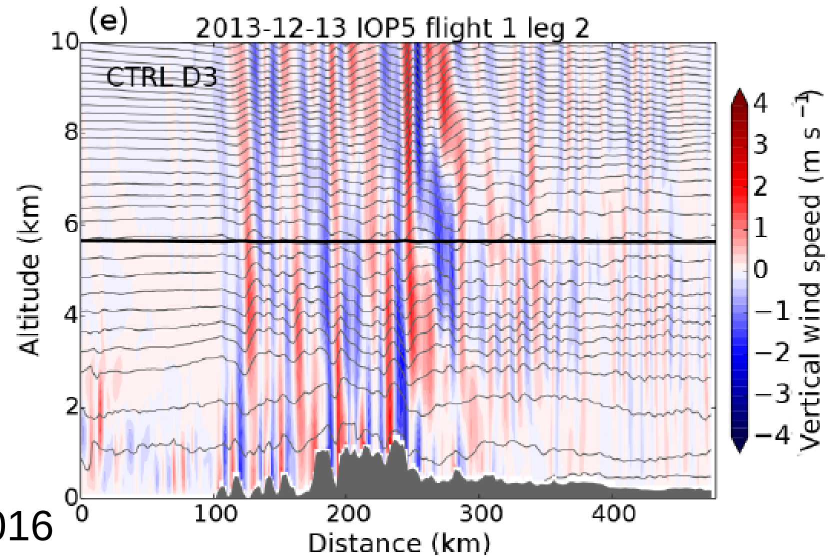
Mesoscale (WRF) modelling of observed gravity waves



WRF-simulation
with Δx=7,2km

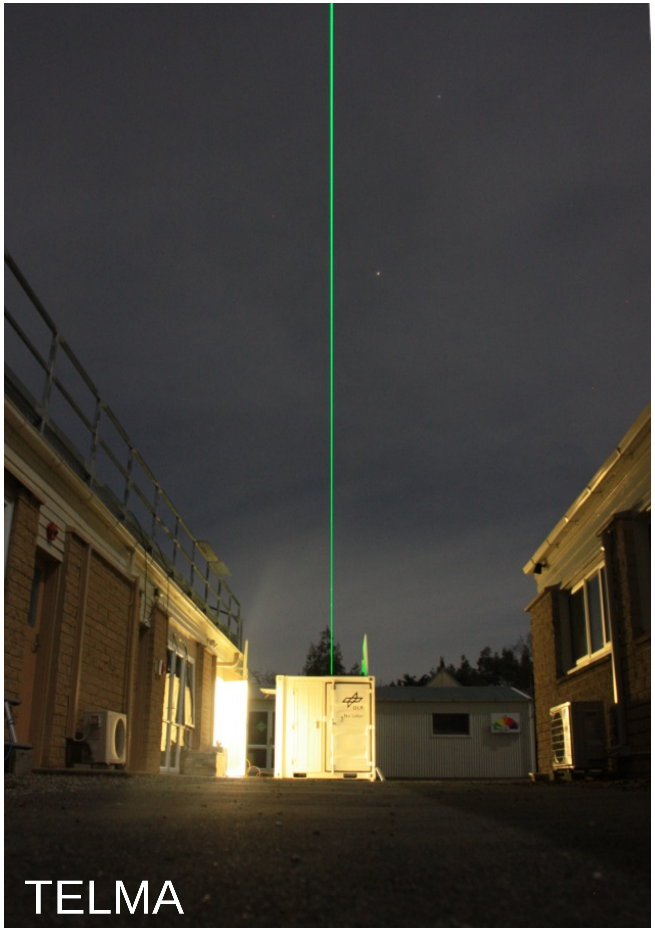


WRF-simulation
with Δx=0,8km



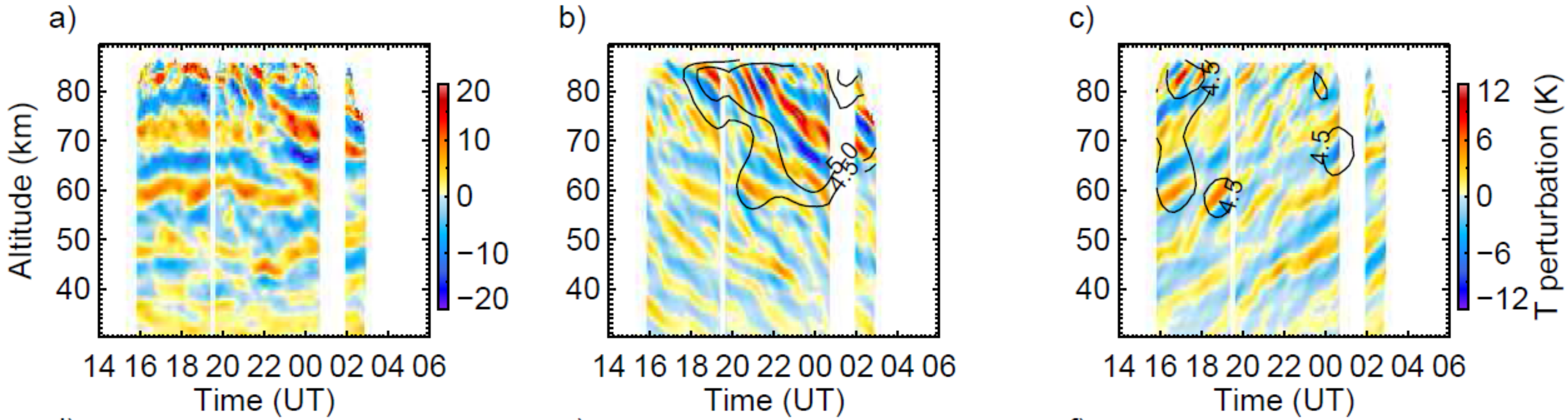
Wagner et al., ACP, 2017, Ehard et al., MWR 2016

Rayleigh-Lidar T-soundings (B. and N. Kaifler) at Lauder, NZ and Sodankylä, FI



Lidar observations reveal downward propagating GW in mesosphere: source processes in the mesopause?

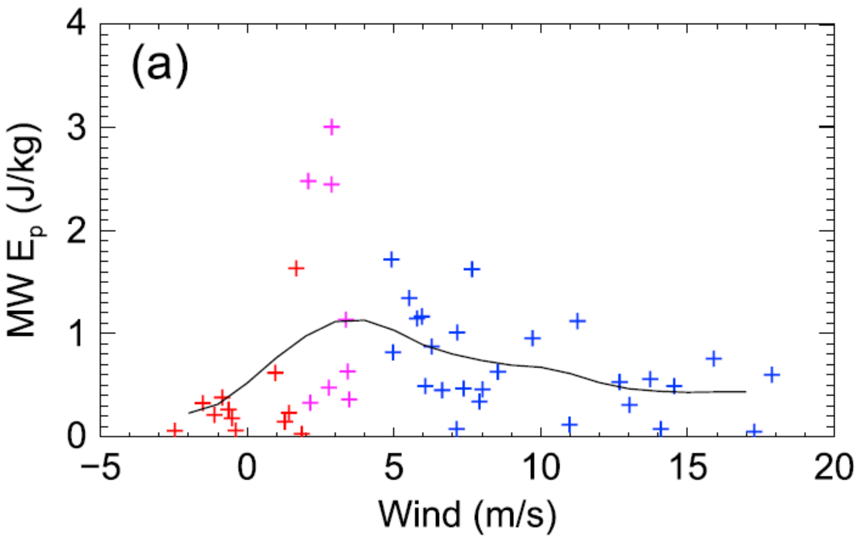
Lidar observations 21 January 2016 | Reconstructed upward propagating waves | Reconstructed downward propagating waves

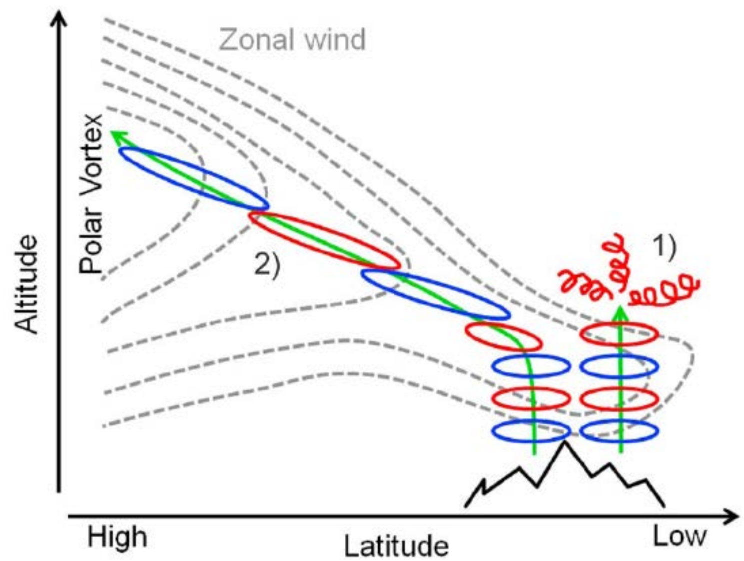


➔ Downward propagating waves generated by wave breaking or reflection in the mesopause region?

N. Kaifler et al., JASTP, in print, 2017

Deep wave propagation: dissipation in stratosphere and refraction by the horizontal wind are crucial!





➔ Correlation between surface wind and GW potential energy only for moderate forcing conditions

➔ Explained by either wave breaking in lower stratosphere or wave refraction out of observational volume

B. Kaifler et al., GRL 2015
D. Fritts et al., BAMS 2015

B. Ehard et al., JGR 2017

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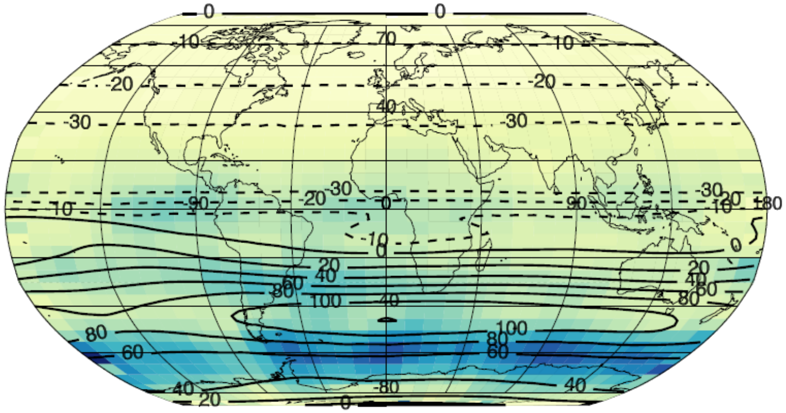
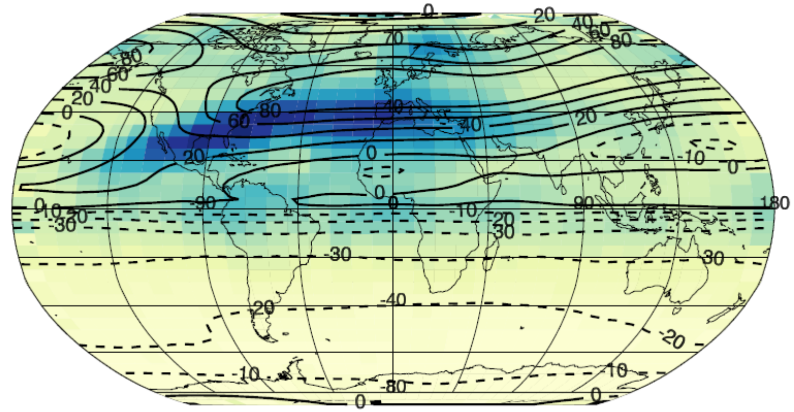
Horizontal refraction appears to be crucial @ global scale

Jul 2015, z=40km, λ_c=15km



Dec 2015, z=40km, λ_c=15km



- Gravity wave activity (blue shading) in the upper stratosphere seen in global METOP A/B radio occultation data is clearly aligned with large gradient in horizontal wind

➔ Polar night jet as focussing lense/waveguide (Dunkerton, 984; K. Sato et al., 2009; 2012) and potentially also as source of gravity waves (?)

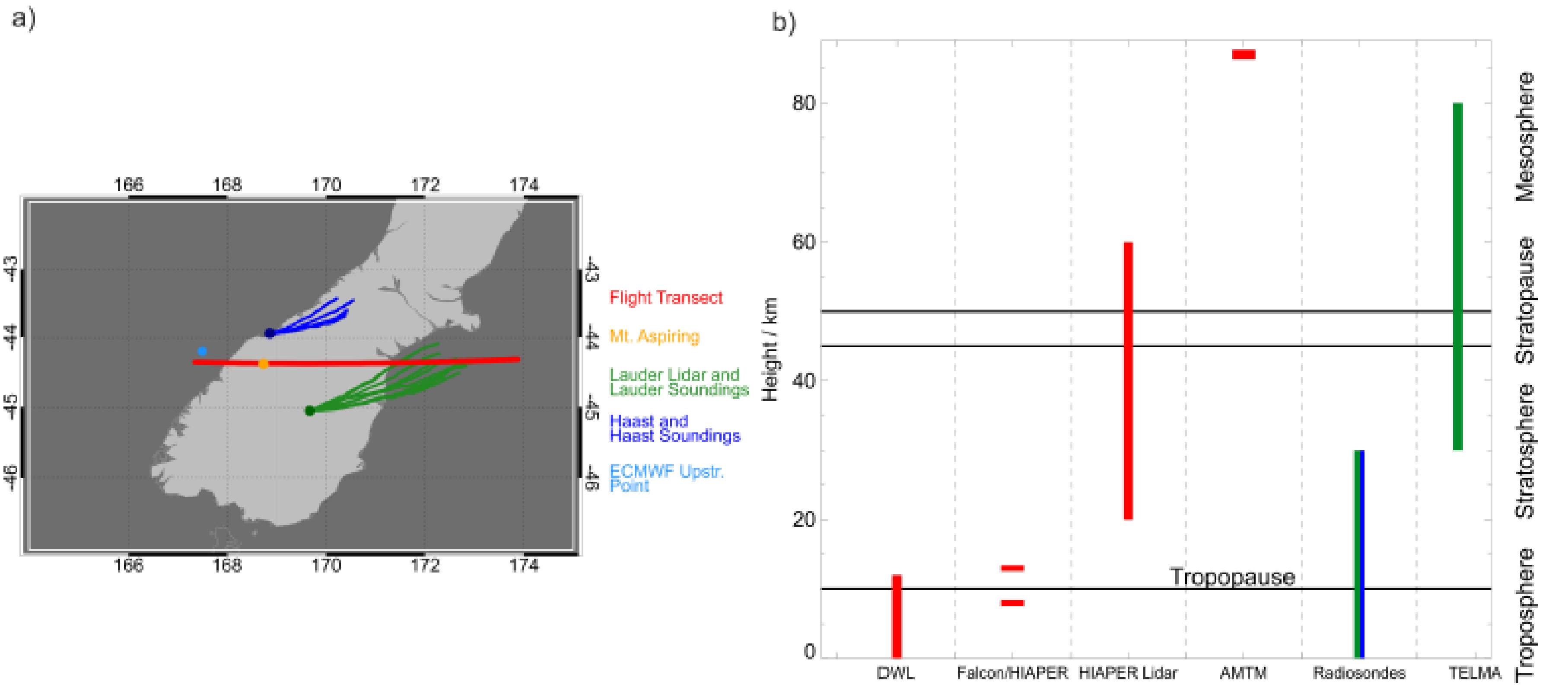
Rapp et al., subm. to AMT 2017

Are there cases where we can trace gravity waves from their excitation in the troposphere to the mesopause region?

→ detailed analysis of DEEPWAVE IOP-10 (04 July 2014)

(Bramberger et al., subm. to JGR 2017)

Tracing GW propagation from the troposphere to the mesopause region



Bramberger et al., JGR 2017, under rev.

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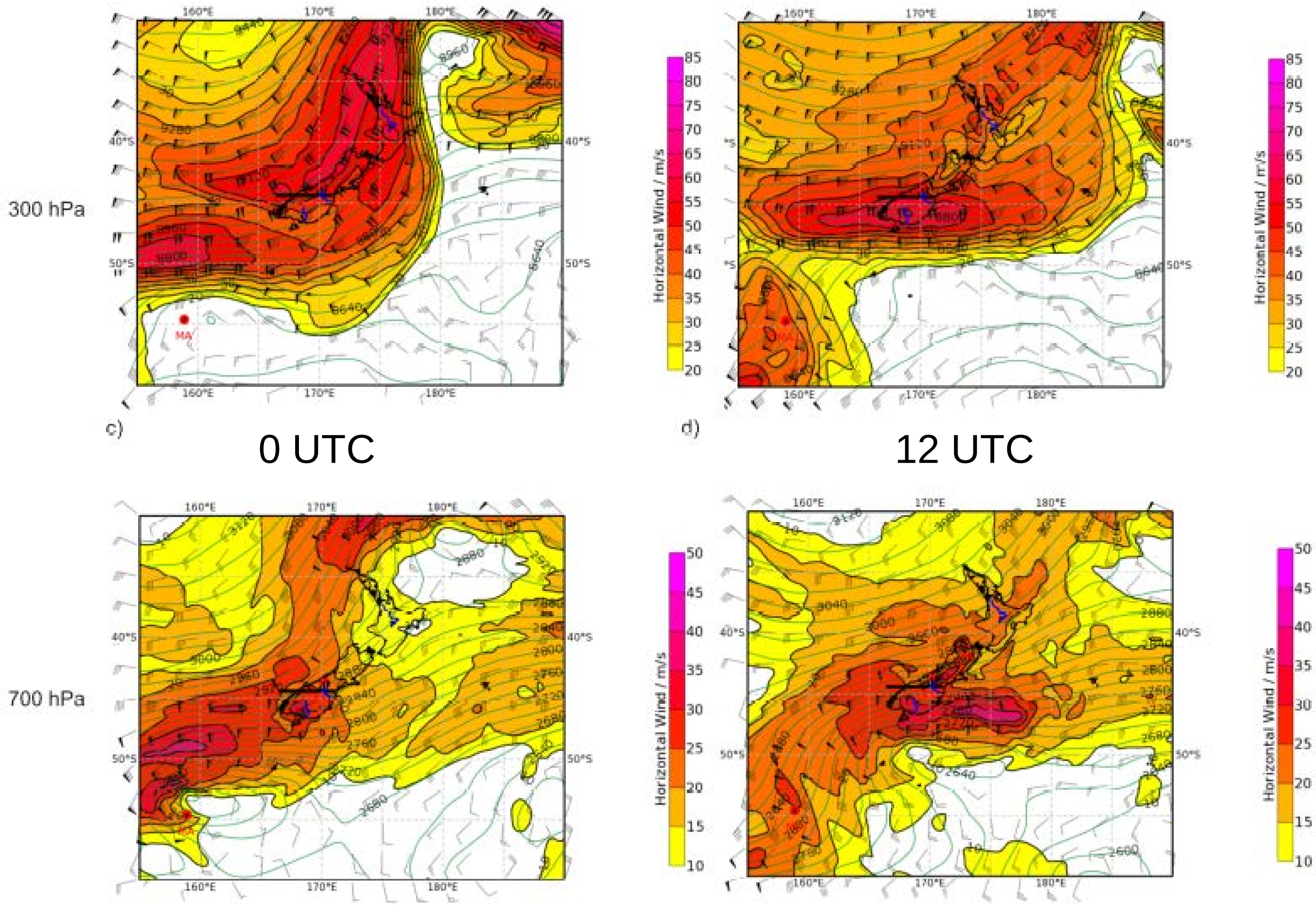

Bramberger et al., JGR 2017, under rev.

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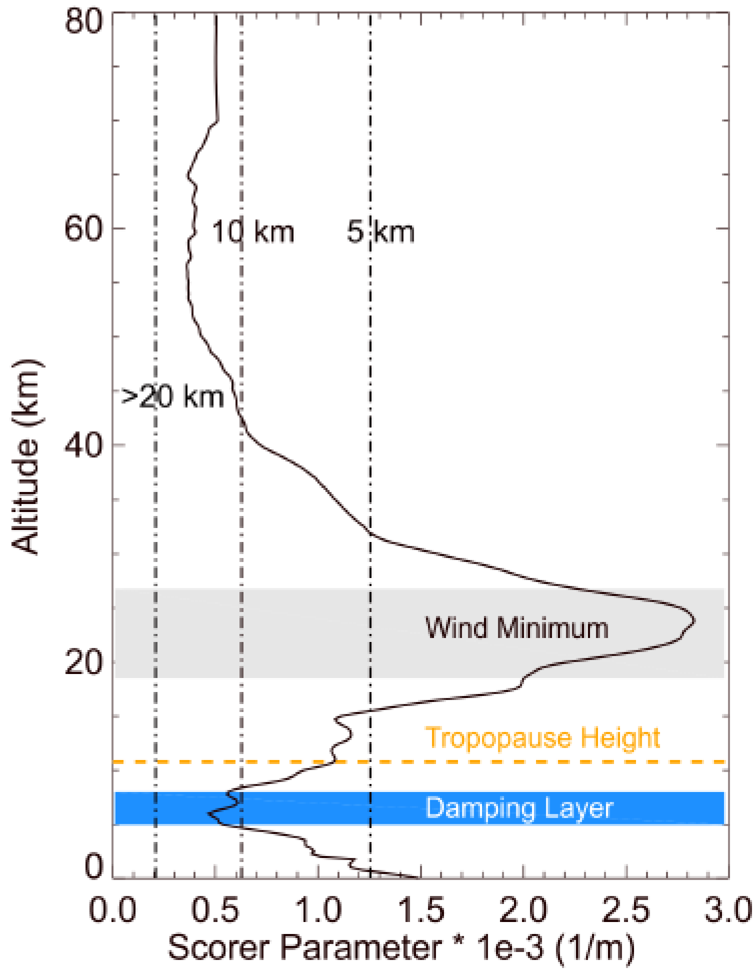


$$l^2 = \frac{N^2}{U^2}$$

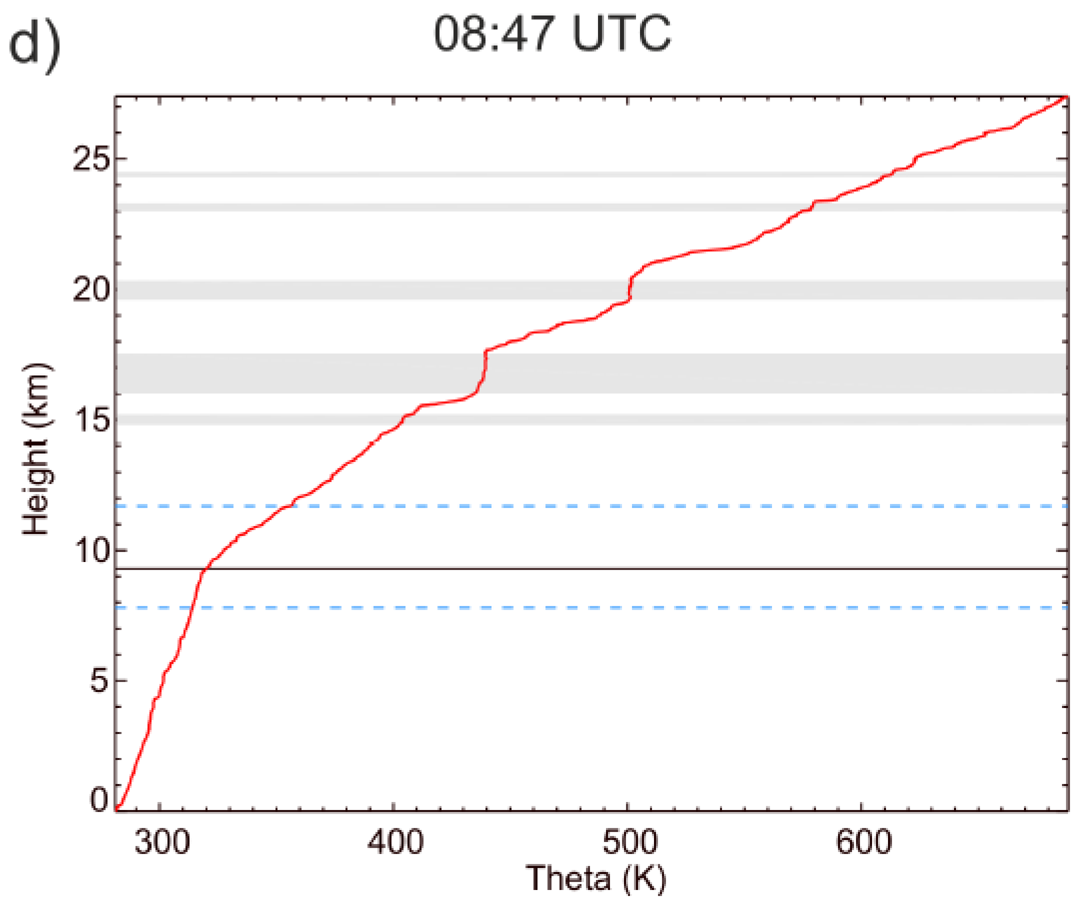
$k > l$ MW is evanscent

$k < l$ MW may propagate

$$m = \frac{N}{U}$$ Wind minimum => MW breaking

Bramberger et al., JGR 2017, under rev.

Tracing GW propagation from the troposphere to the mesopause region



Bramberger et al., JGR 2017, under rev.

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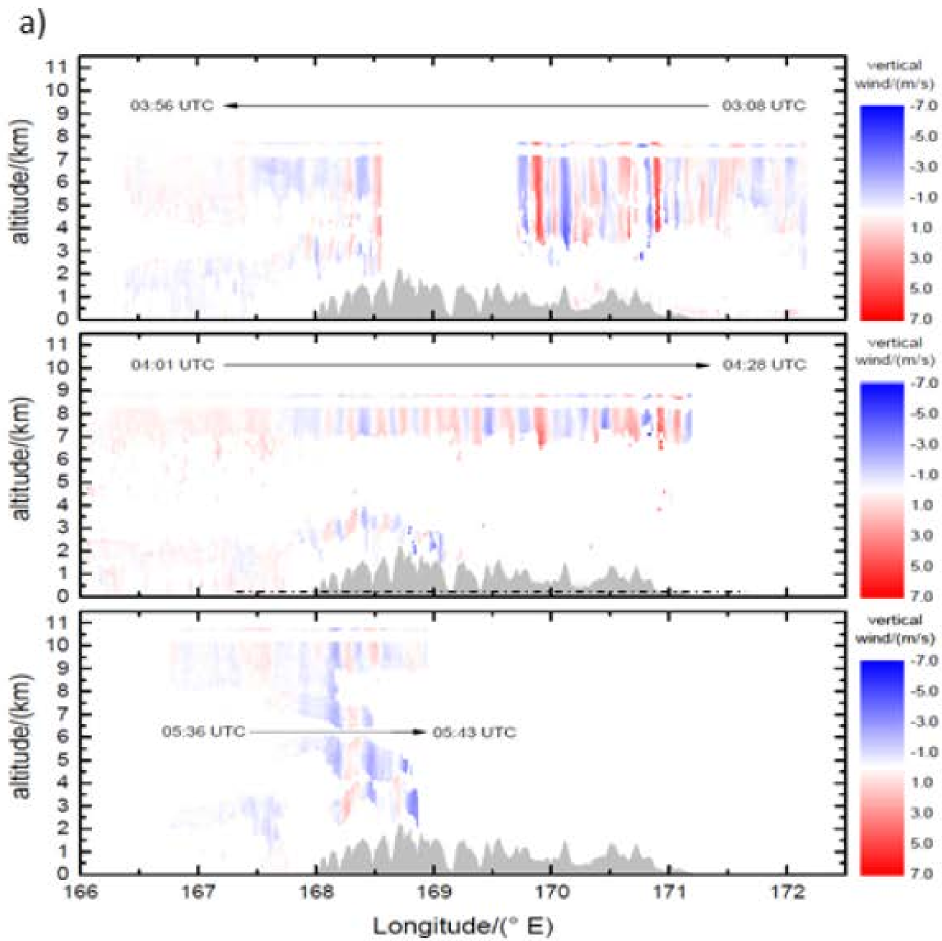

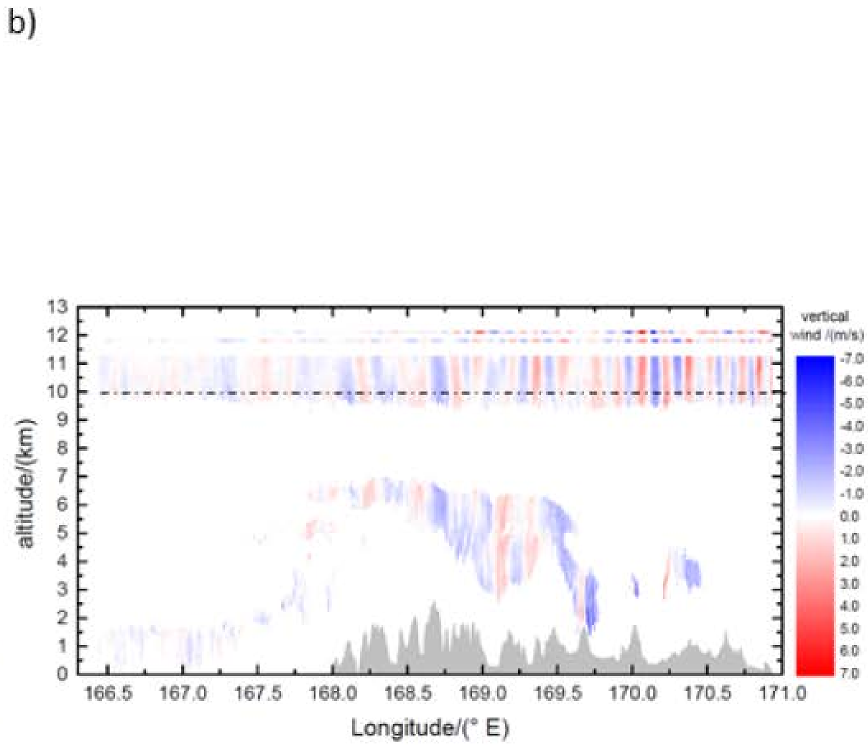

Bramberger et al., JGR 2017, under rev.

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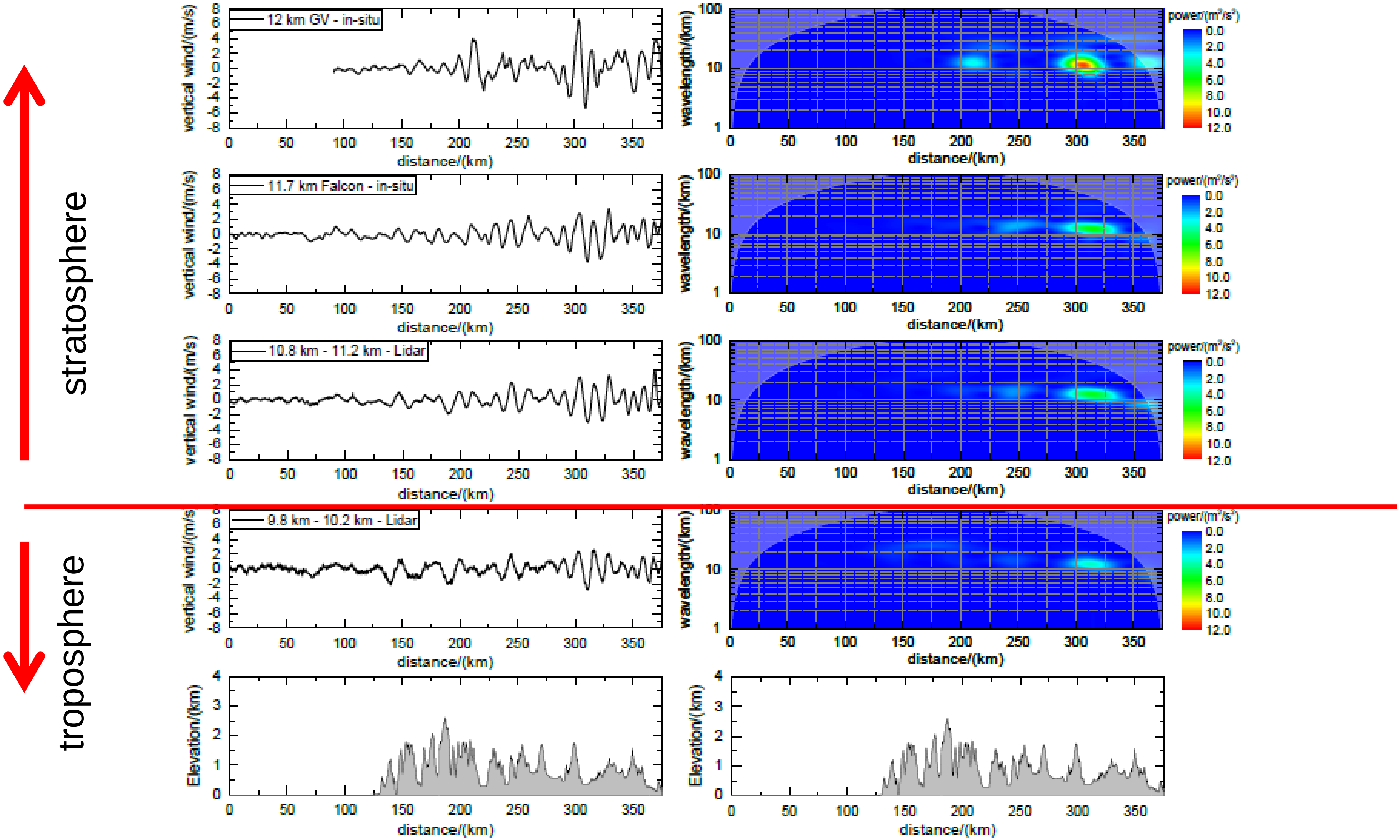

Bramberger et al., JGR 2017, under rev.

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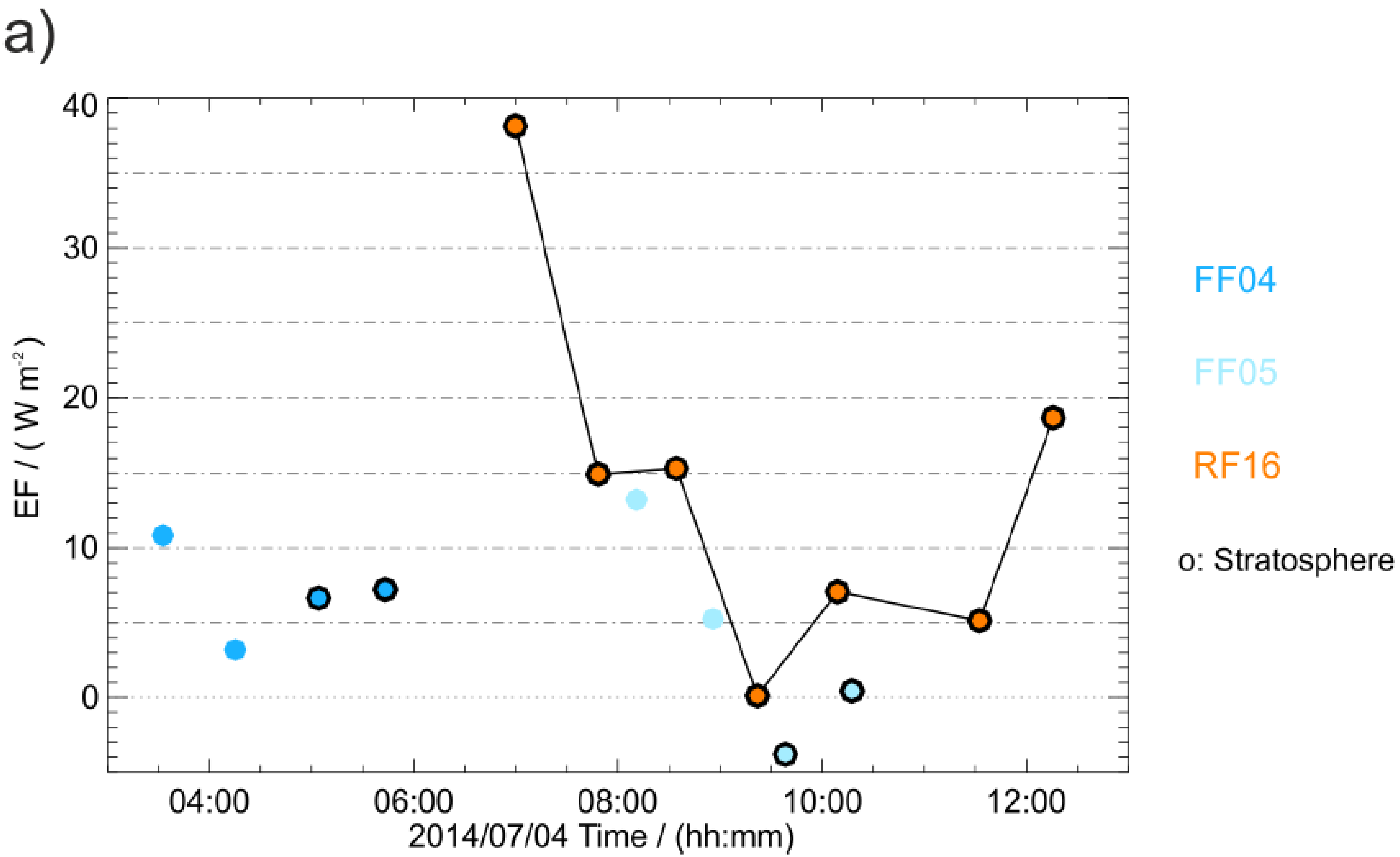
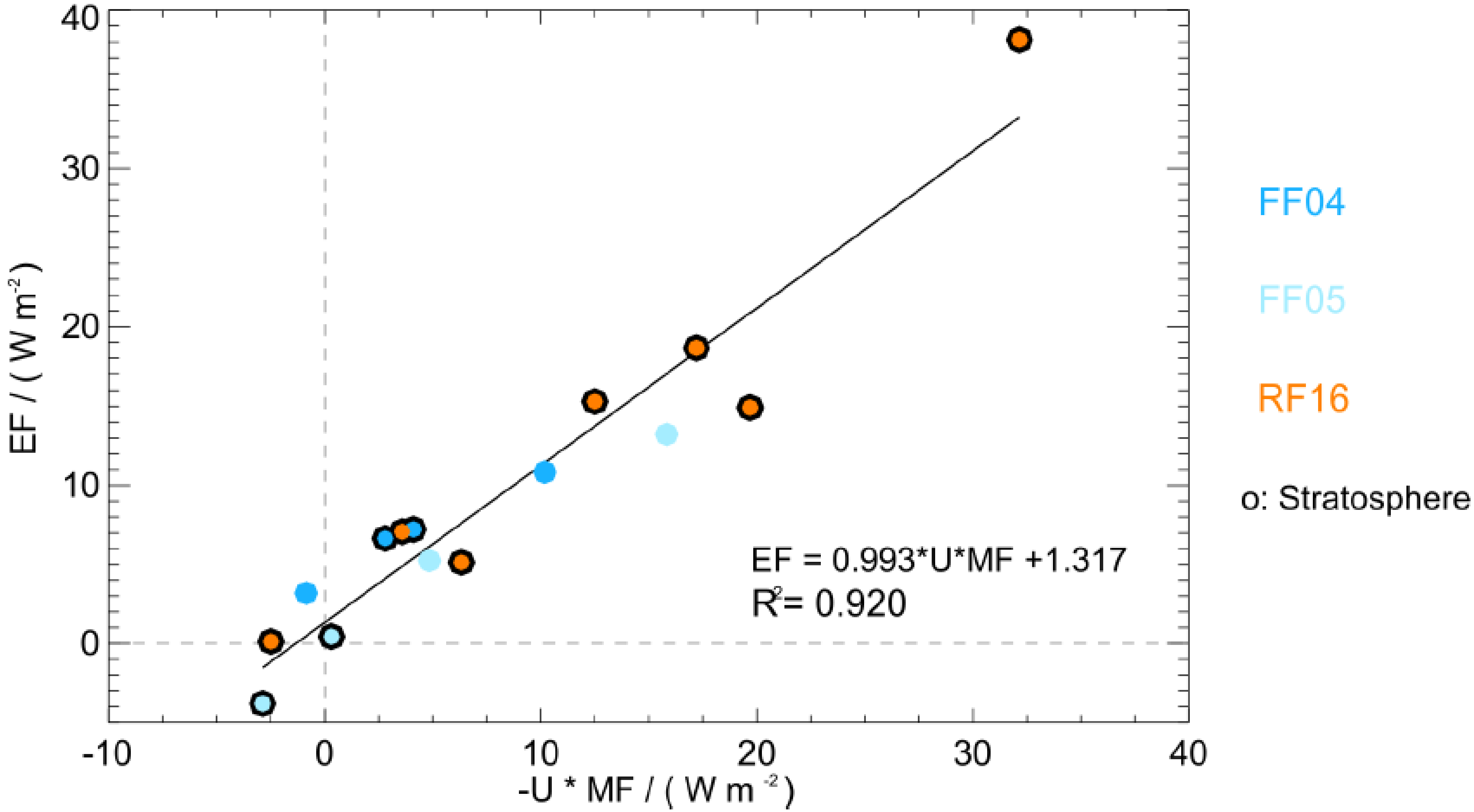


Bramberger et al., JGR 2017, under rev.

Tracing GW propagation from the troposphere to the mesopause region

b) Eliassen-Palm-relation satisfied ➔ linearly propagating MW



Bramberger et al., JGR 2017, under rev.

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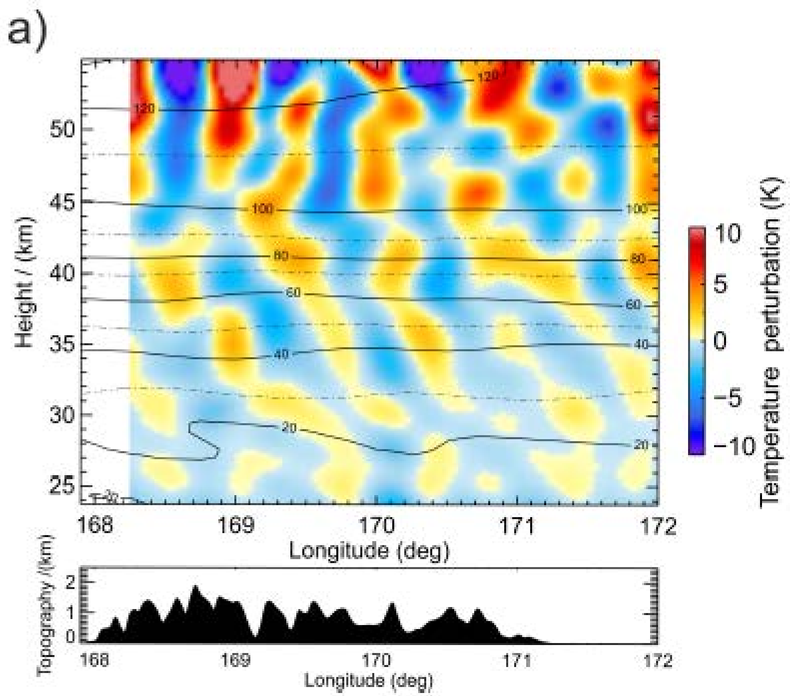
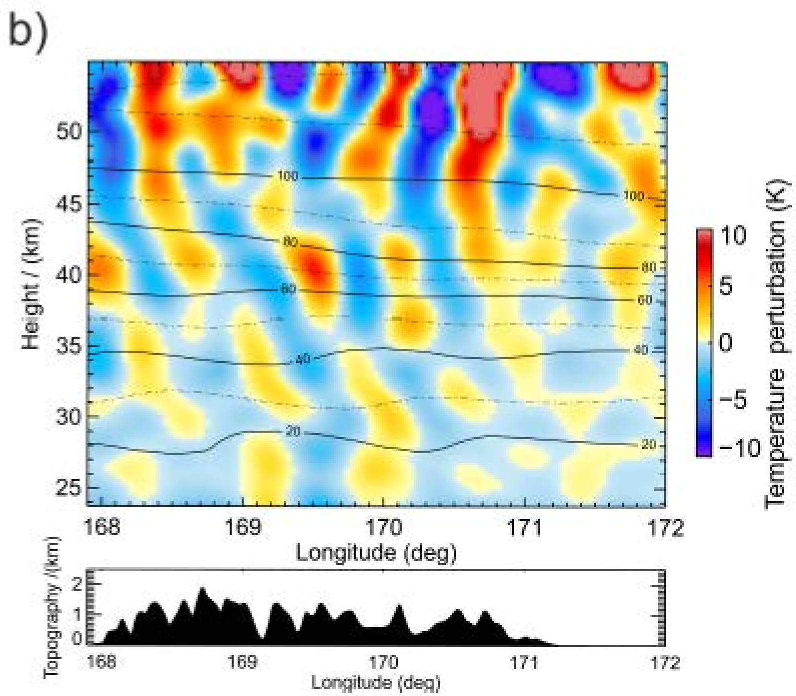
Tracing GW propagation from the troposphere to the mesopause region

GV-Rayleigh-lidar, courtesy Biff Williams, GATS





Bramberger et al., JGR 2017, under rev.

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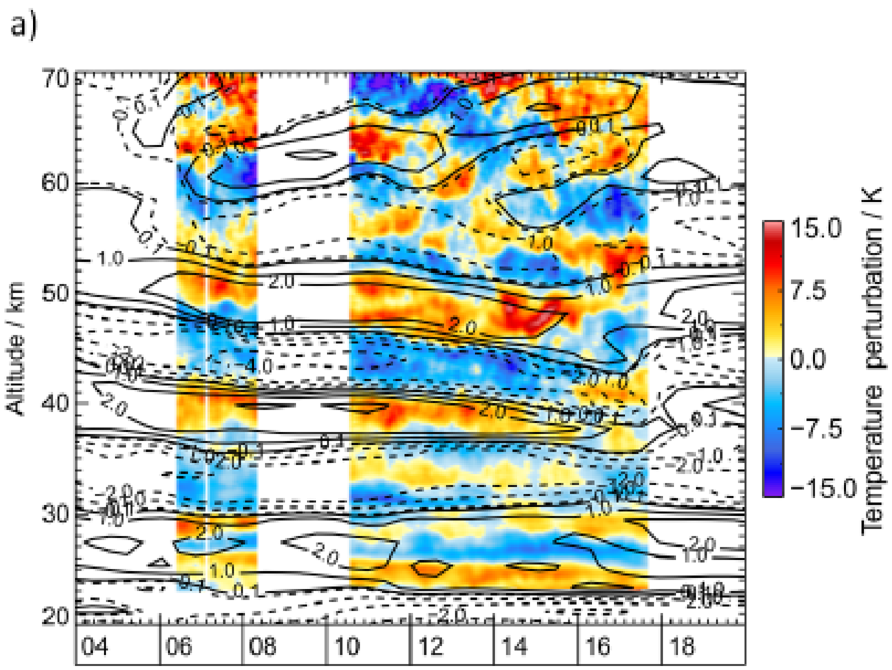
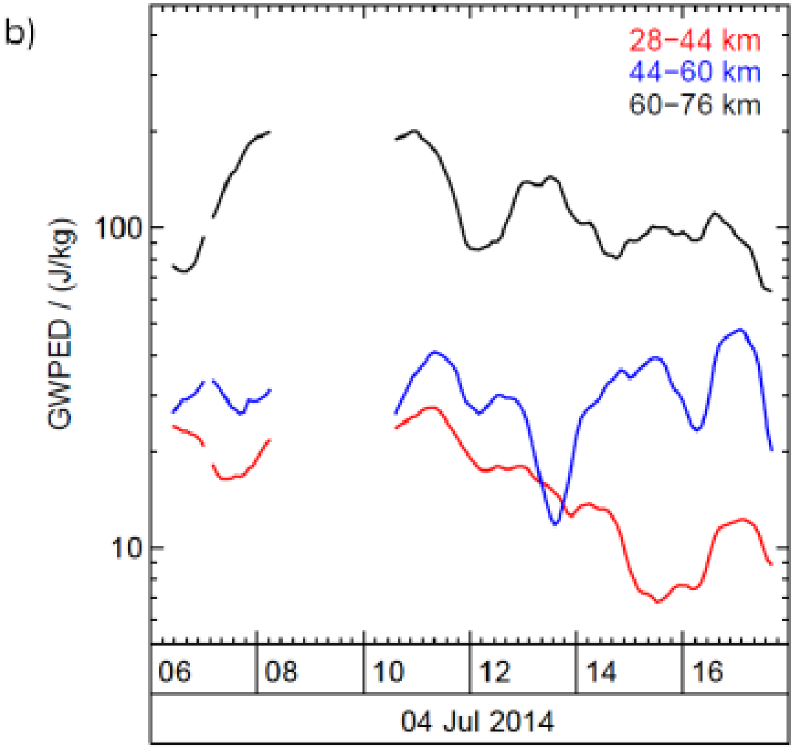
Tracing GW propagation from the troposphere to the mesopause region

Lauder, DLR-Rayleigh-lidar





Bramberger et al., JGR 2017, under rev.

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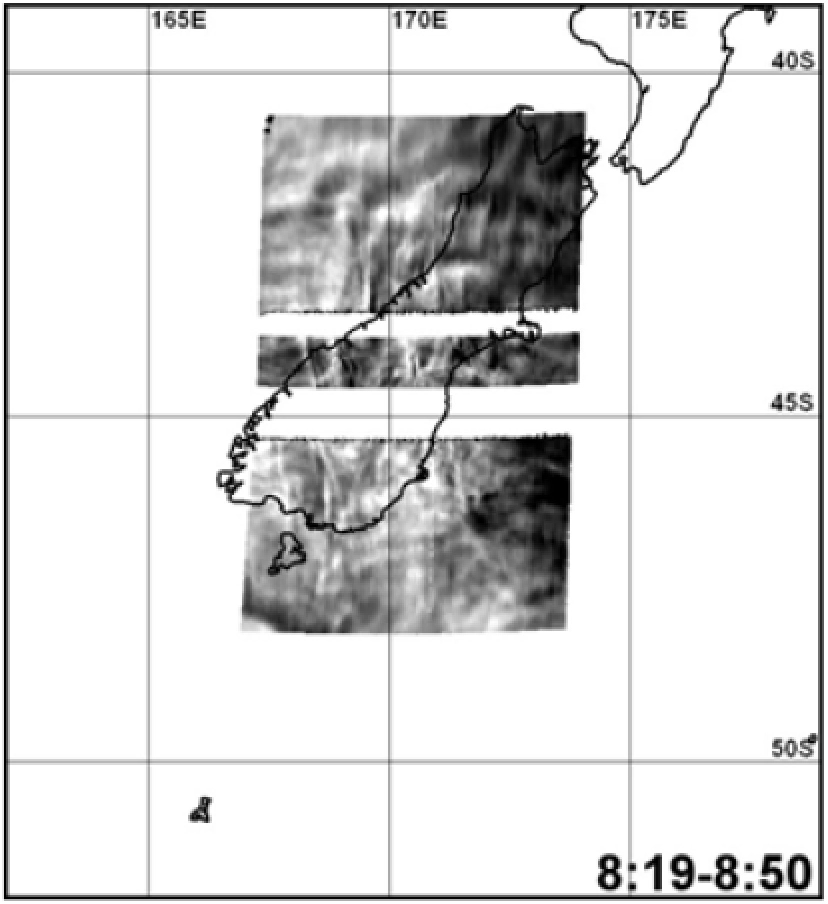
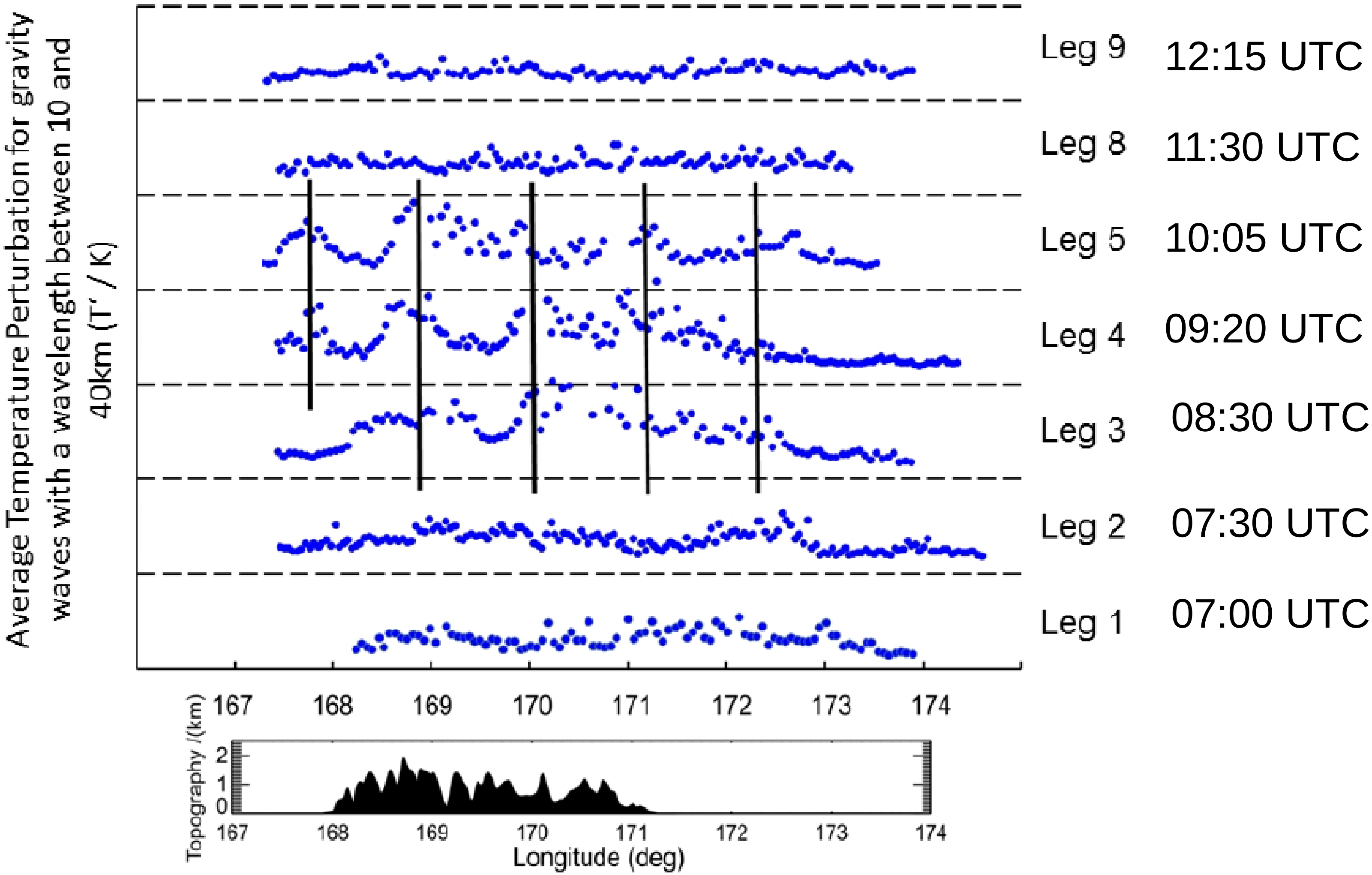
Tracing GW propagation from the troposphere to the mesopause region

b)



Bramberger et al., JGR 2017, under rev.

Tracing GW propagation from the troposphere to the mesopause region



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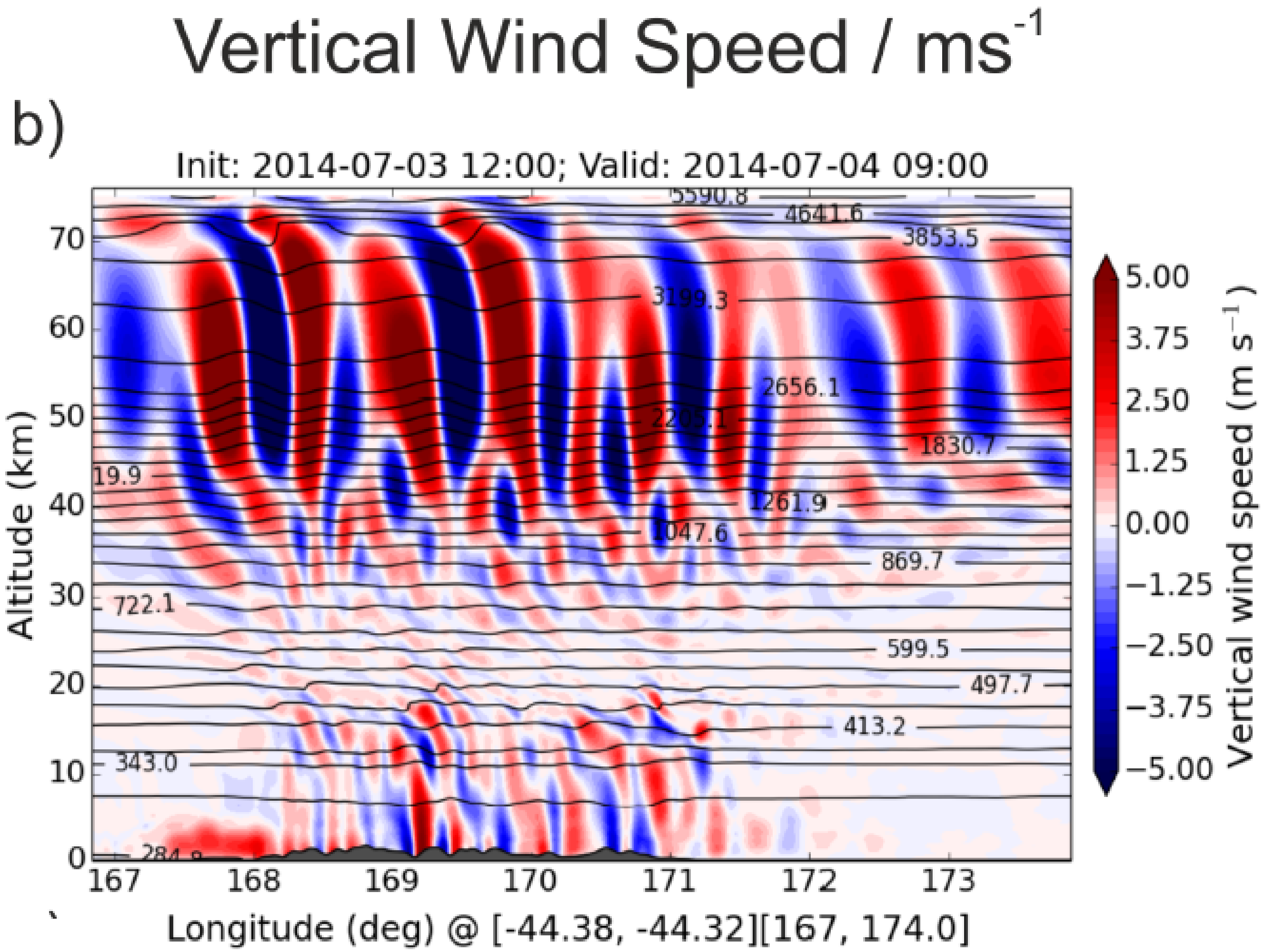
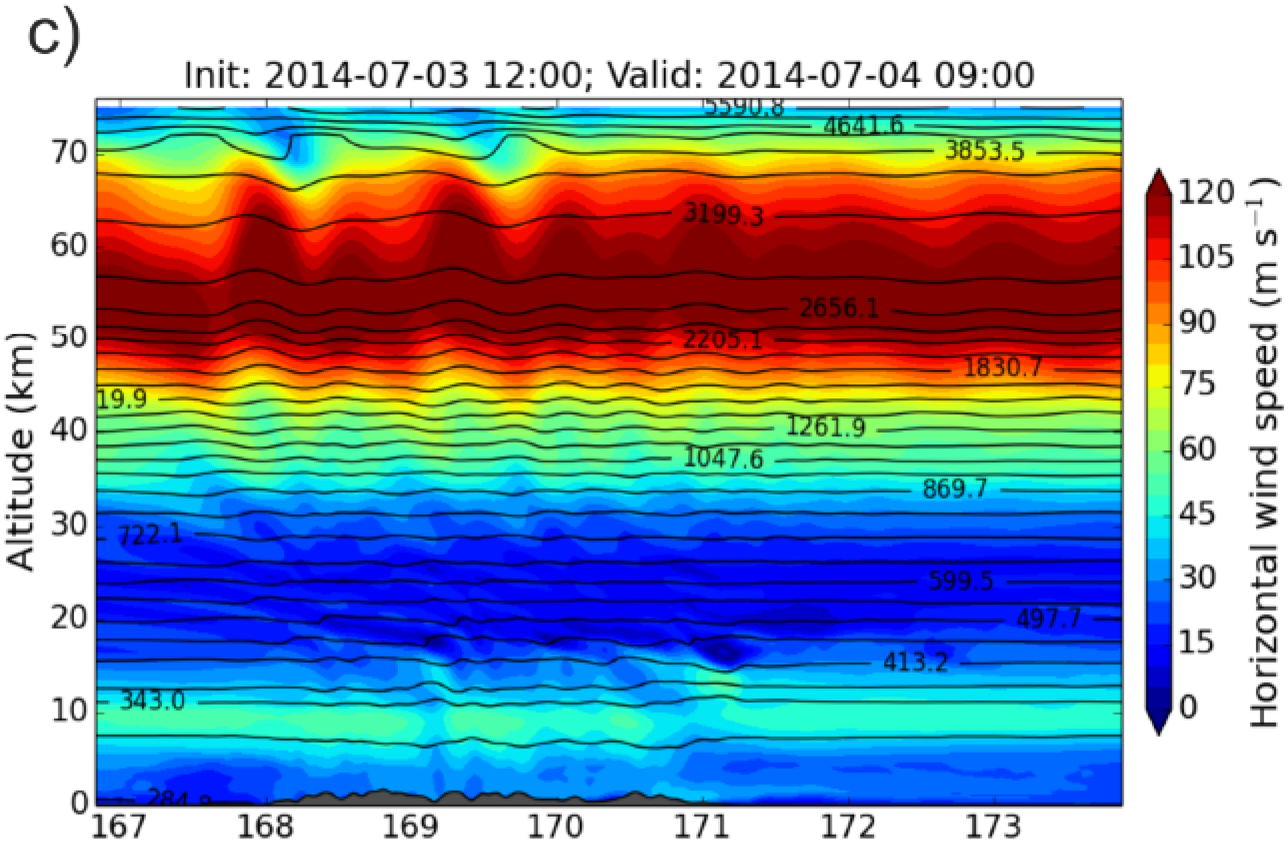
Tracing GW propagation from the troposphere to the mesopause region



Bramberger et al., JGR 2017, under rev.

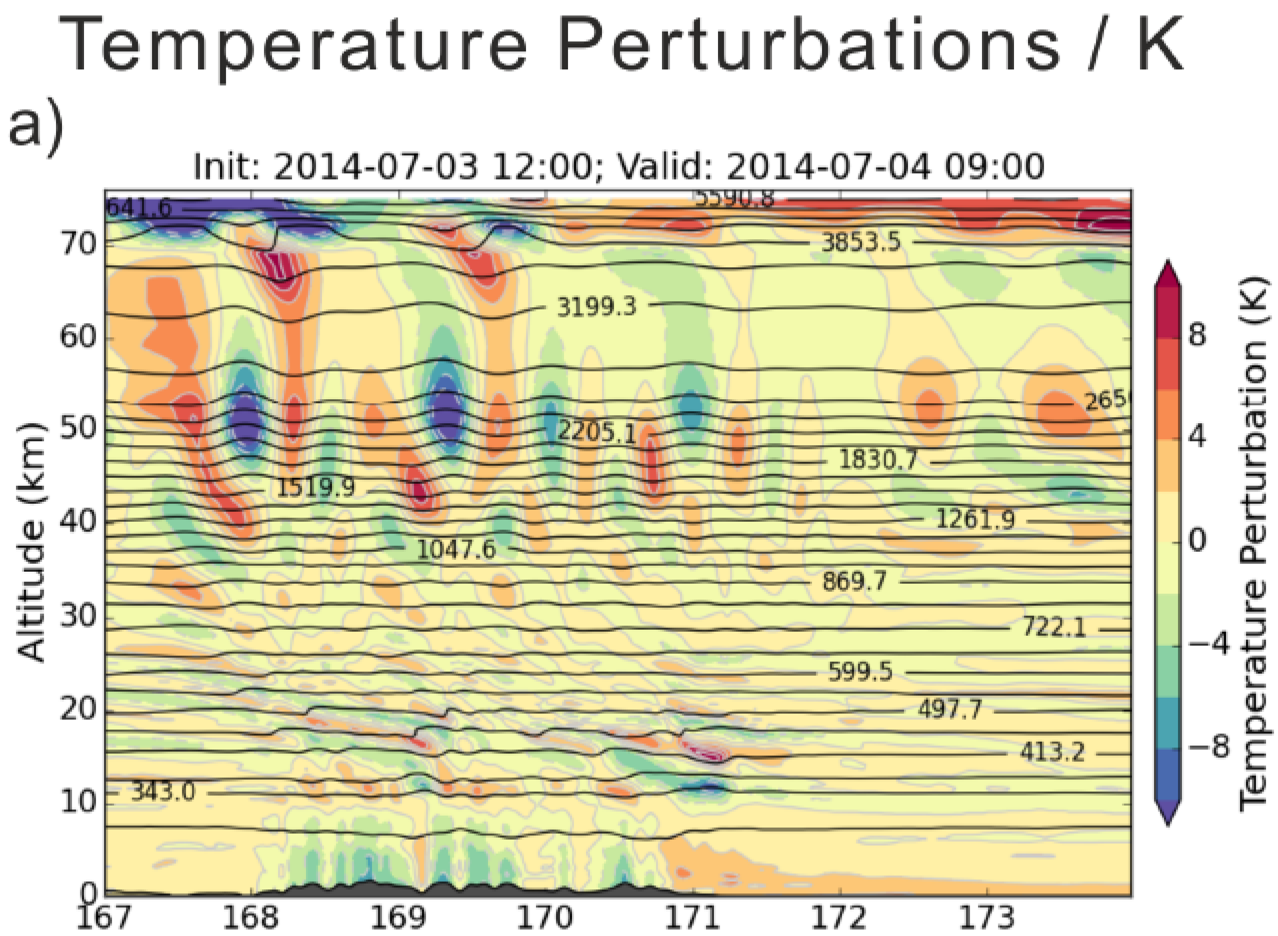
Tracing GW propagation from the troposphere to the mesopause region

Horizontal Wind Speed / ms^{-1}



Bramberger et al., JGR 2017, under rev.

Tracing GW propagation from the troposphere to the mesopause region



Bramberger et al., JGR 2017, under rev.

More details (hopefully) soon available in:

Does strong tropospheric forcing cause large-amplitude mesospheric gravity waves? - A DEEPWAVE Case Study

Martina Bramberger[1], Andreas Dörnbrack[1], Katrina Bossert[2], Benedikt Ehard[1], David C. Fritts[2], Bernd Kaifler[1], Christian Mallaun[3], Andrew Orr[4], P.-Dominique Pautet[5], Markus Rapp[1,6], Michael J. Taylor[5], Simon Vosper[7], Bifford Williams[2], Benjamin Witschas[1]

[1]Deutsches Zentrum für Luft- und Raumfahrt, Institut für Physik der Atmosphäre, Oberpfaffenhofen, Germany
[2]GATS, Boulder, USA
[3]Deutsches Zentrum für Luft- und Raumfahrt, Flugexperimente, Oberpfaffenhofen, Germany
[4]British Antarctic Survey, Cambridge, Great Britain
[5]Utah State University, Logan, USA
[6]Meteorological Institute Munich, Ludwig-Maximilians-Universität München, Munich, Germany
[7]UK MetOffice, Exeter, Great Britain

currently in revision for JGR-Atmospheres

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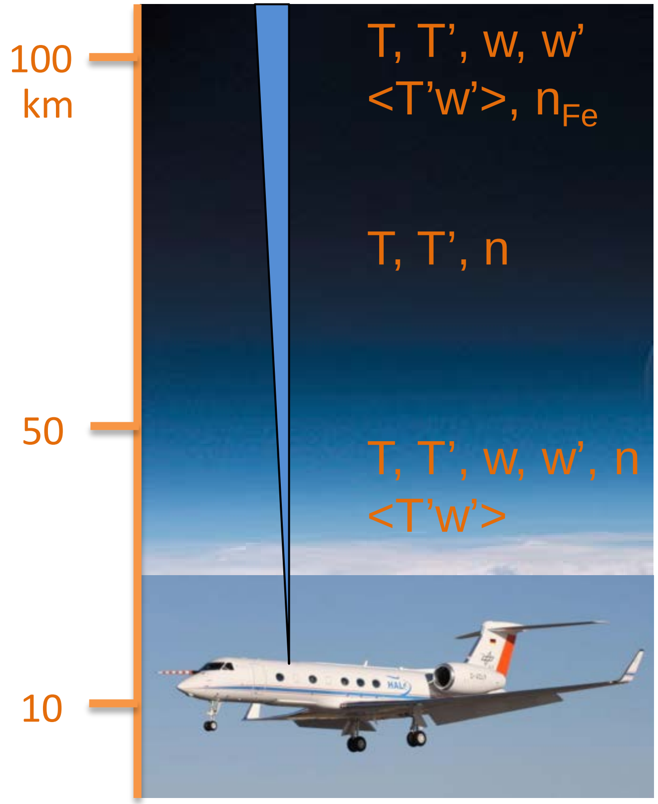
Conclusions

- GW often do not propagate simply vertically but show strong horizontal propagation; refraction by the horizontal wind
- Strong tropospheric forcing does not necessarily imply a strong mesospheric response; but it can
- Analysis of DEEPWAVE IOP10 shows exactly such a case where waves can be directly traced from their excitation to the mesopause region
- Lidar temperature observations are a versatile tool to study GW over a large vertical range (GWPED; secondary waves)
- Next step: ALIMA – airborne Rayleigh/resonance lidar covering 10-100km altitude range; 1st campaign planned for 2019 (South America)

Outlook

Future: Use airborne lidar for horizontal mapping of gw propagation



ALIMA: The airborne lidar for middle atmosphere research

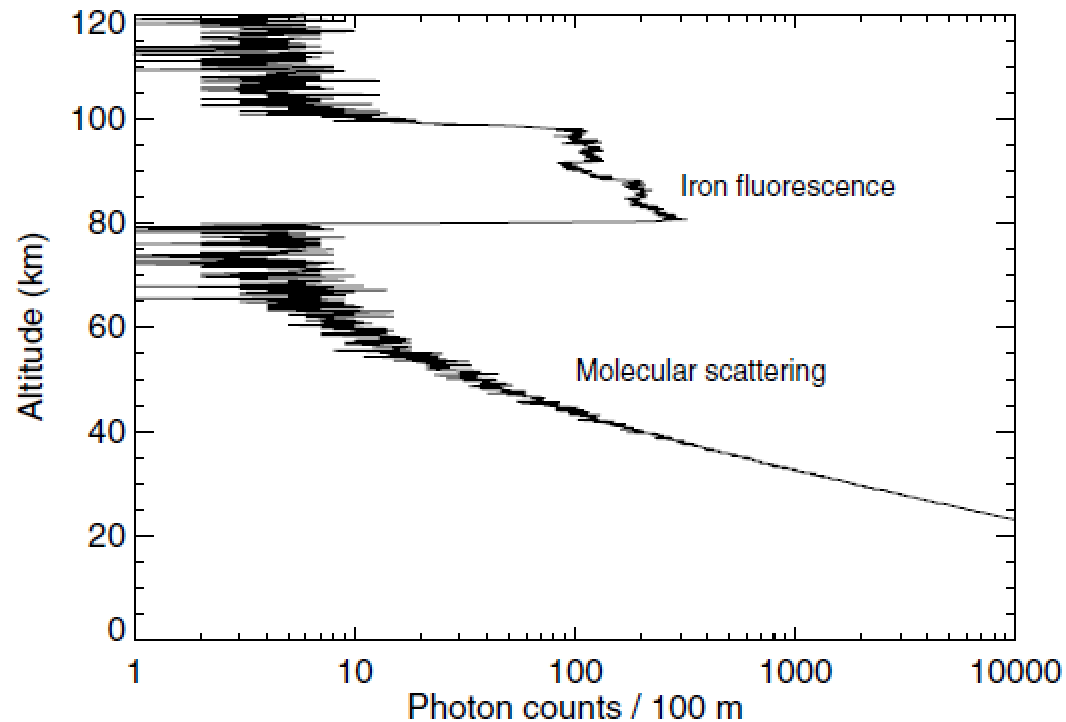
Currently under development at DLR: temperature and vertical wind in 15-100km height range, 30s time resolution

Available for initial airborne campaign in 2019 (on either DLR Falcon or HALO)

Optics Letters

Demonstration of an iron fluorescence lidar operating at 372 nm wavelength using a newly-developed Nd:YAG laser

BERND KAIFLER,[1,*] CHRISTIAN BÜDENBENDER,[1] PETER MAHNKE,[2] MATTHIAS DAMM,[2] DANIEL SAUDER,[2]
NATALIE KAIFLER,[1] AND MARKUS RAPP[1]



B. Kaifler et al., OL 2017

THANKS!