→ ADVANCED ATMOSPHERIC TRAINING COURSE 2014

Atmospheric Gravity Waves

Peter Preusse
Jülich

27–31 October 2014 | Forschungszentrum Jülich | Germany

gravity wave

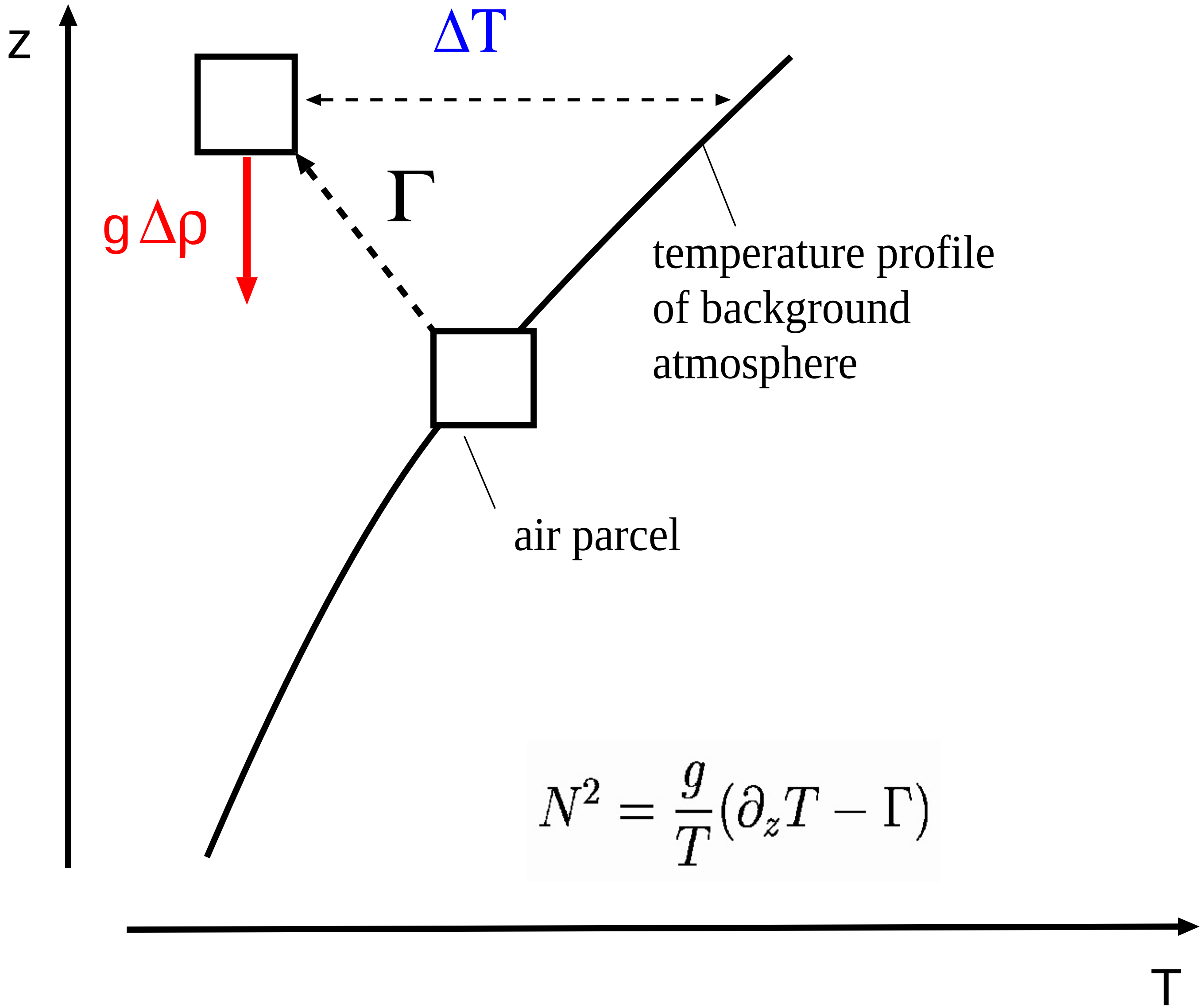
$$=$$

buoyancy wave

$$\neq$$

gravitational wave

Isolated Airparcel



$$N^2 = \frac{g}{T}(\partial_z T - \Gamma)$$

Gravity waves exist in

- Any stratified medium in the presence of gravity
- The sun $\rightarrow$ Helioseismology
- The ocean (e.g. Tsunami)
- Planetary atmospheres, e.g. Jupiter, Mars, Venus, Earth

The examples above propagate in 3D !

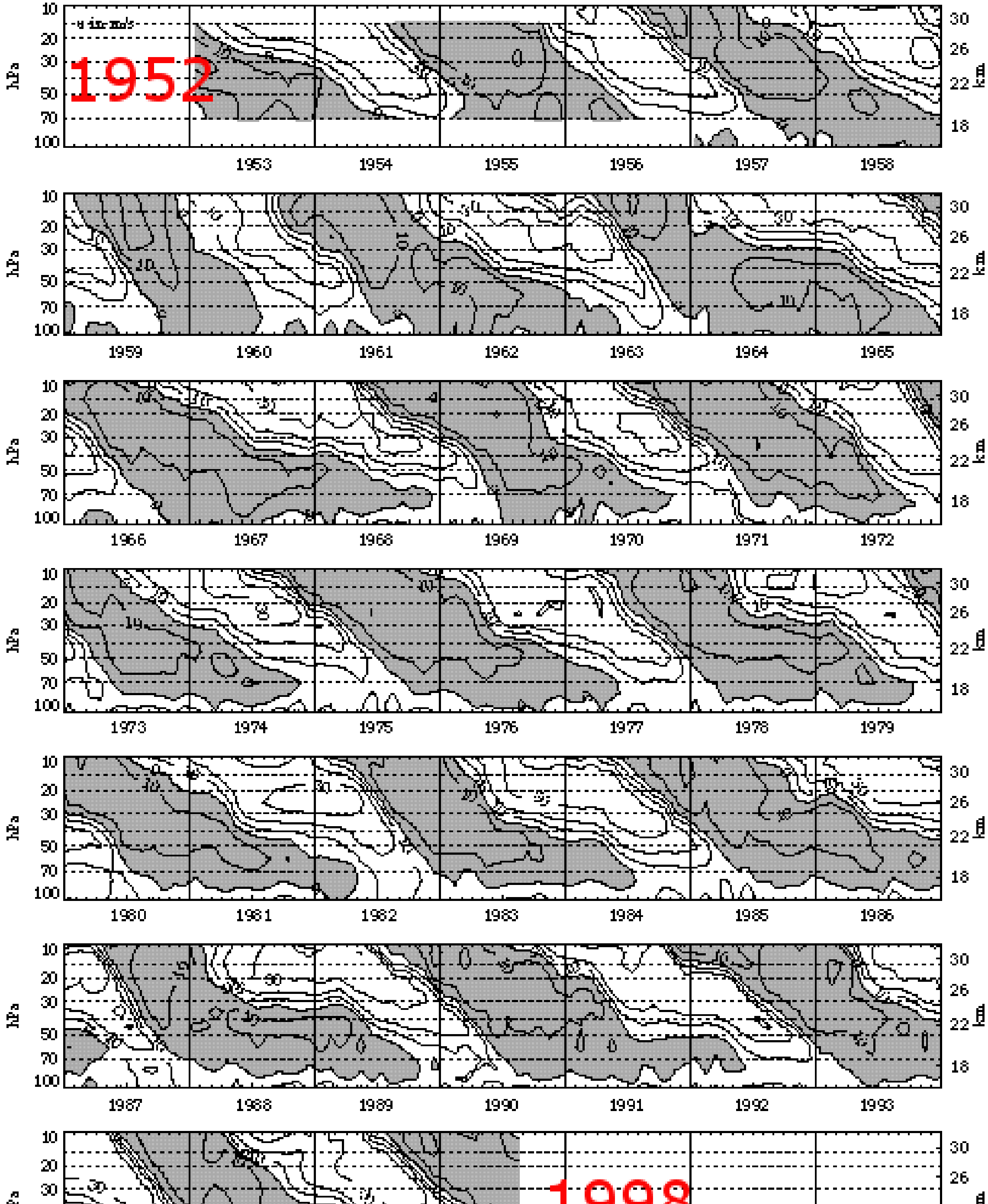
A special case of gravity waves are surface waves at the boundary of two media: e.g. water surface waves

Waves in wind and temperature

Clear Air Turbulence

Photo: Ken Meiris   DC8 über Evergreen, CO, 9.12.1992

Breaking waves accelerate wind

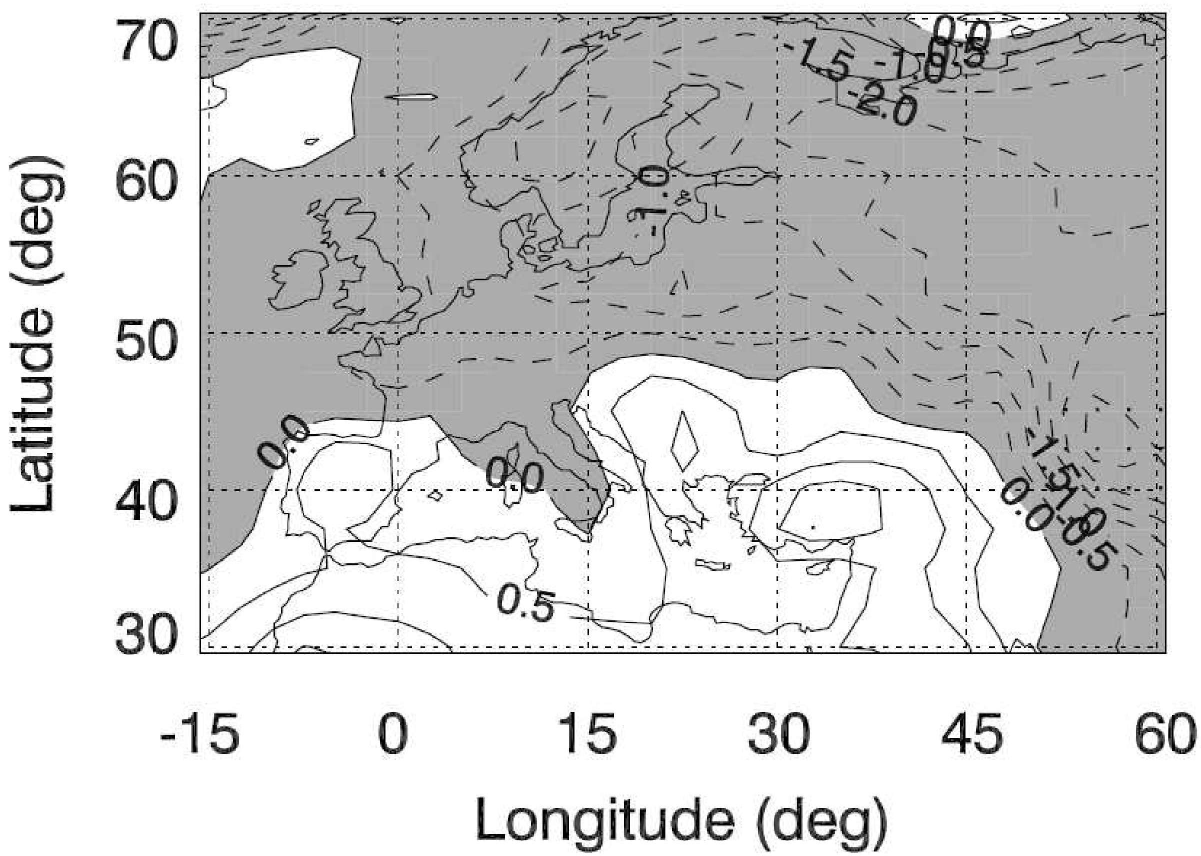


Quasi
Biennial
Oscillation
QBO

After:
B. Naujokat

driven to >50 %
by GWs, e.g.
Ern et al., 2014

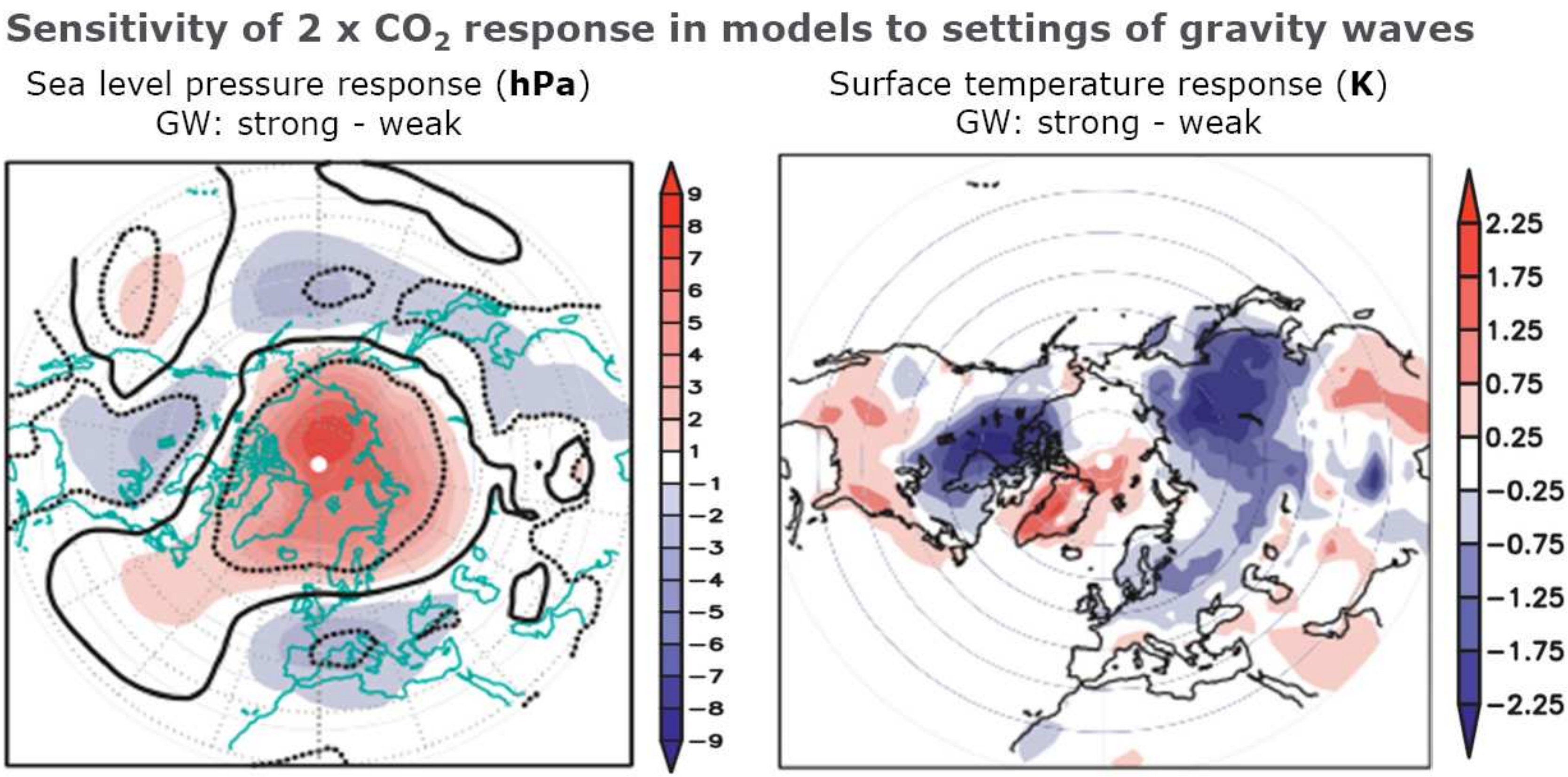
QBO → seasonal prediction?



from Marshall and Scaife, JGR, 2009

Difference of mean winter temperature between QBO phases in NCEP/NCAR reanalysis data.

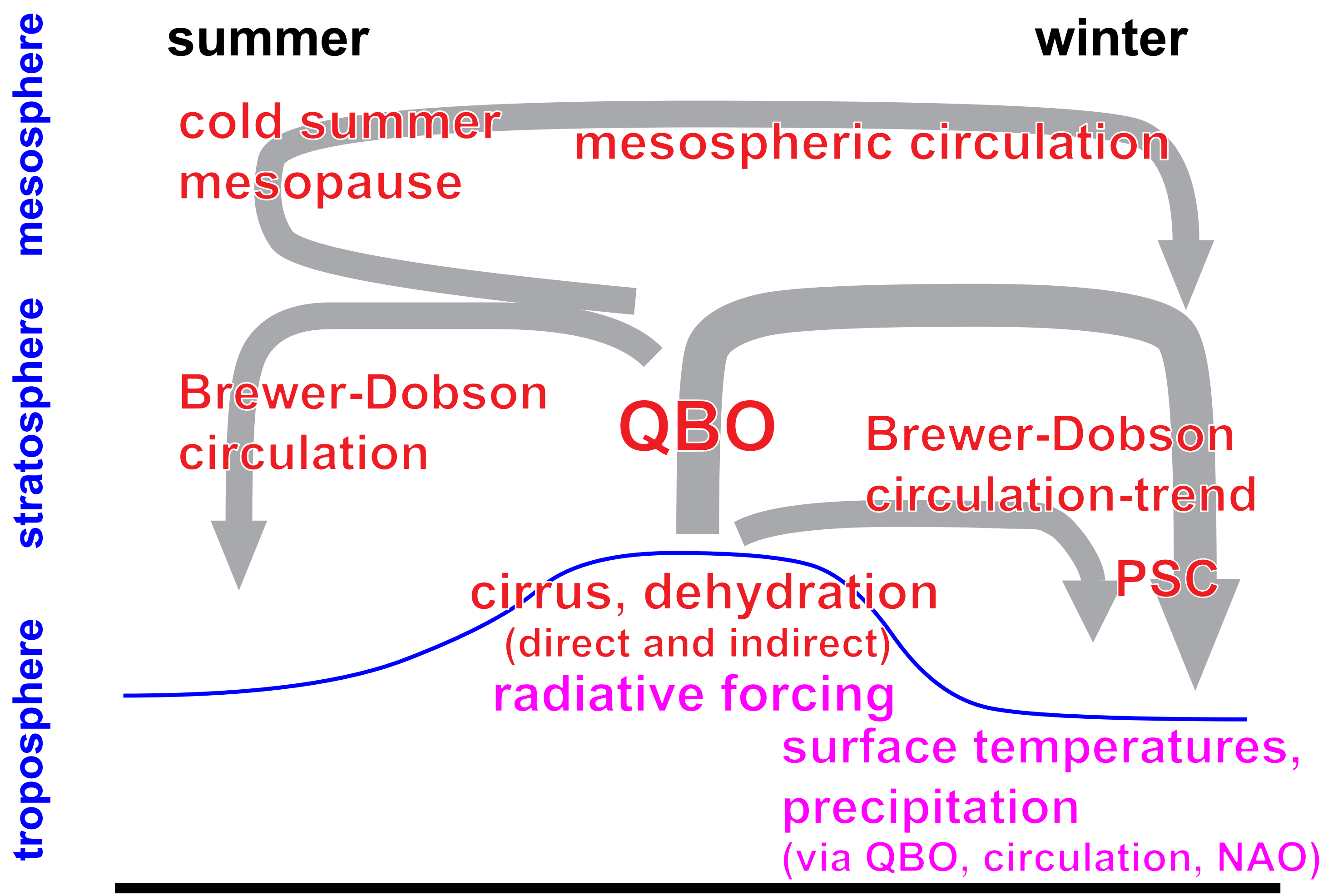
General circulation → polar troposphere



Sigmond and Scaife, J. Clim., 2010

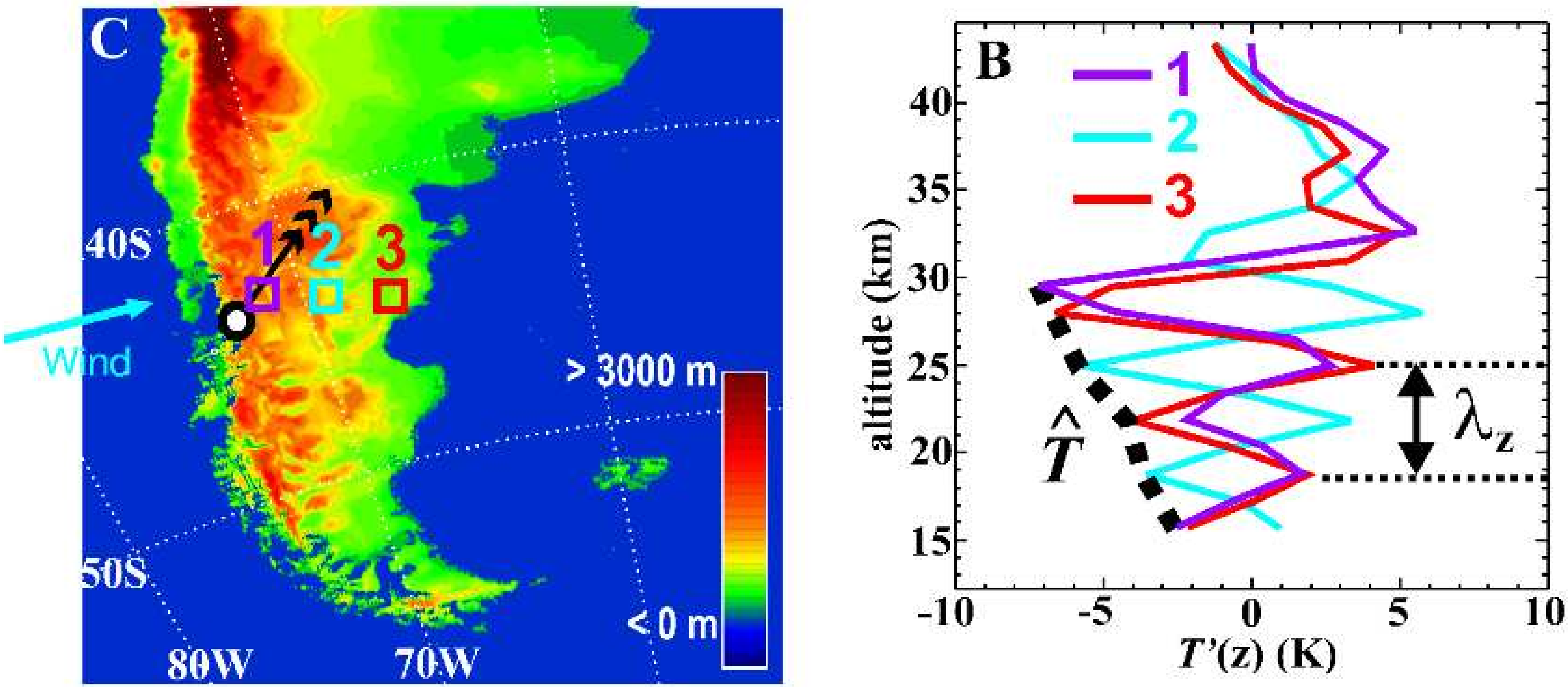
Sensitivity on the strength of GW momentum flux

GW impact on middle atmosphere



Red: Processes which are driven to >50 % by GWs
Purple: Indirect effects

CRISTA-1 (1994)



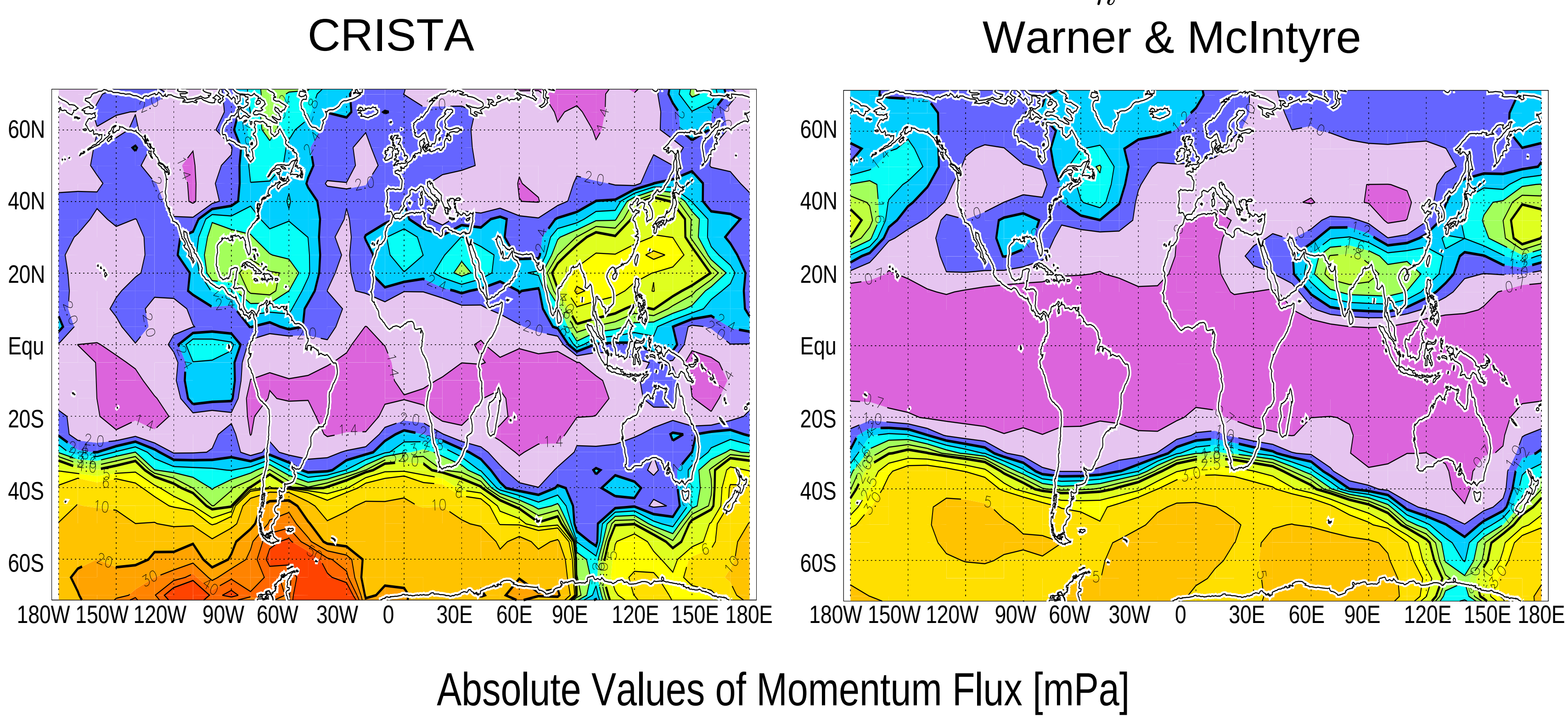
Eckermann and Preusse, Science, 1999

$$F \propto \frac{\lambda_z}{\lambda_h}(T')^2$$

Absolute values of momentum flux

CRISTA-2, August 1997

$$F \propto \frac{\lambda_z}{\lambda_h}(T')^2$$



Ern et al., JGR, 2004

Orr et al., J. Clim., 2010 :

CRISTA-tuned GW scheme in ECMWF

GW parameterization in GCM

Input from / validation by measurements:

1. Saturated part of GW spectrum obeys m^{-3} scaling law
2. Lower stratosphere m^{*} is of the order of 2 km
3. Separate parameterization for orographic waves
4. A favorable launch altitude for non-orographic parameterized GWs is the mid-troposphere

Additional information is urgently needed.

The key quantities

Very simplified:

- The momentum flux decides how much drag can be exerted
- The phase speed decides where it is exerted
- The direction decides whether it accelerates or decelerates

Current IR limb sounders: abs. value of GWMF, if along-track sampling is 250 km or less.

AIRS (IASI ?): direction

Superpressure balloons, radio sondes provide all three quantities, but not global coverage

Alternative for drag: missing drag in data assimilation

Comparison of GCM and measurements

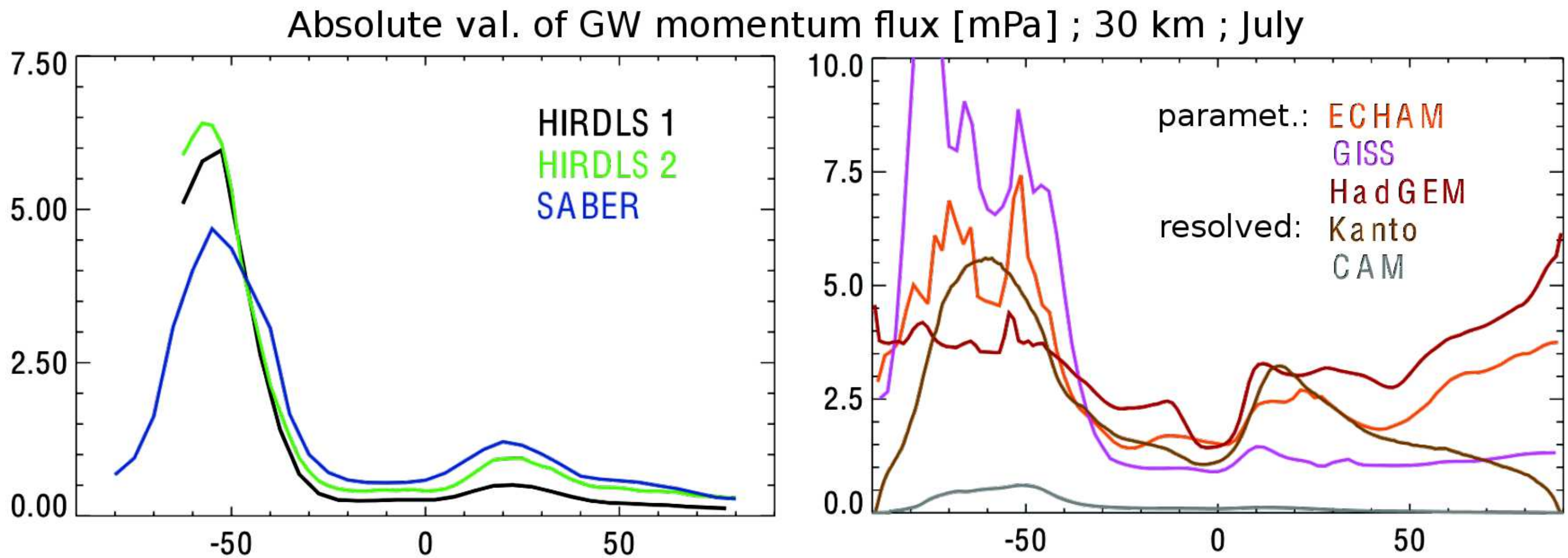
SPARC gravity wave initiative
(reinstated in 2008; lead Joan Alexander).

A Comparison Between Gravity Wave Momentum Fluxes in Observations and Climate Models

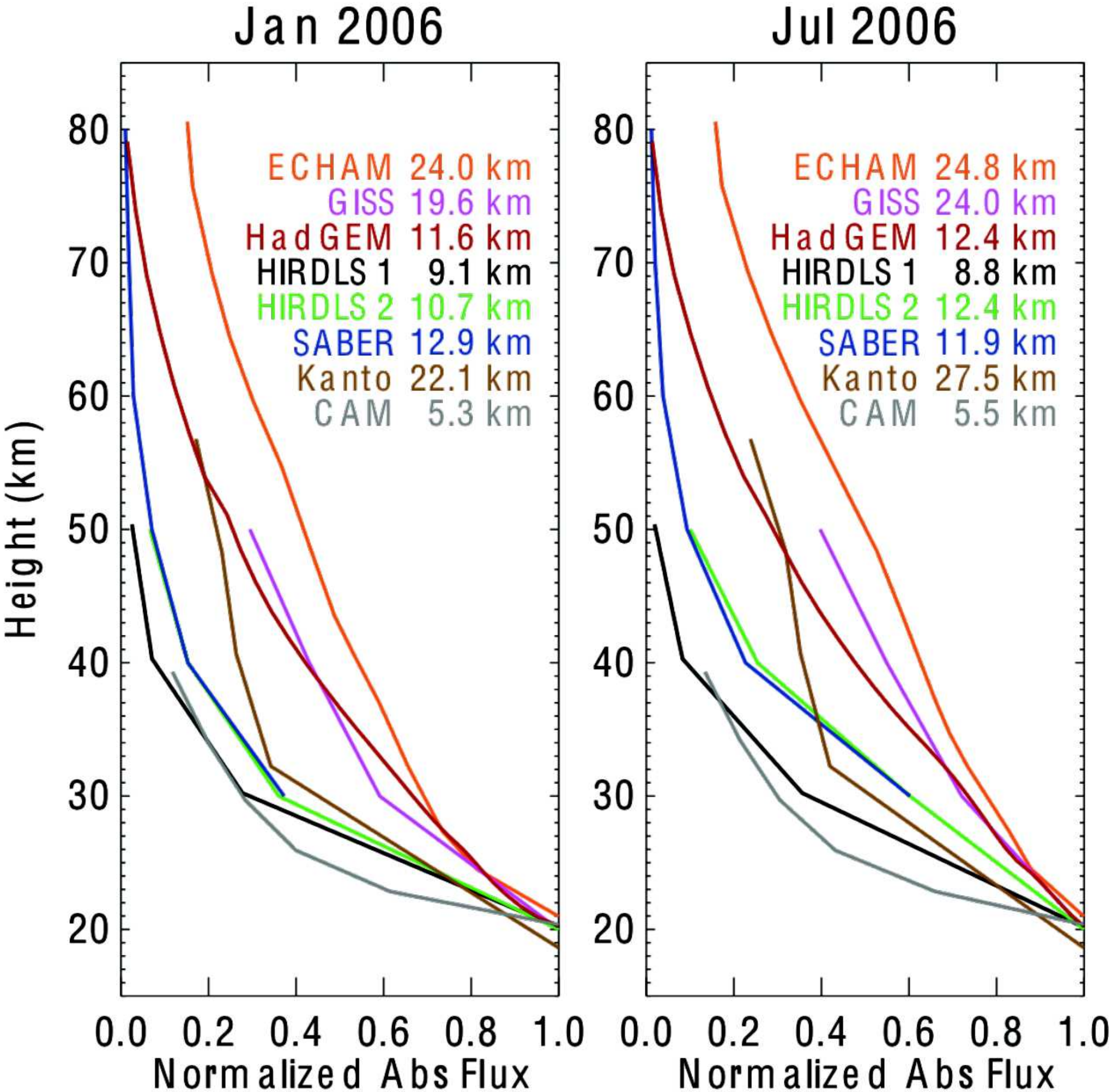
Marvin A. Geller, M. Joan Alexander, Peter T. Love,
Julio Bacmeister, Manfred Ern, Albert Hertzog, Elisa Manzini,
Peter Preusse, Kaoru Sato, Adam A. Scaife, and Tiehan Zhou

J. Clim., 2013

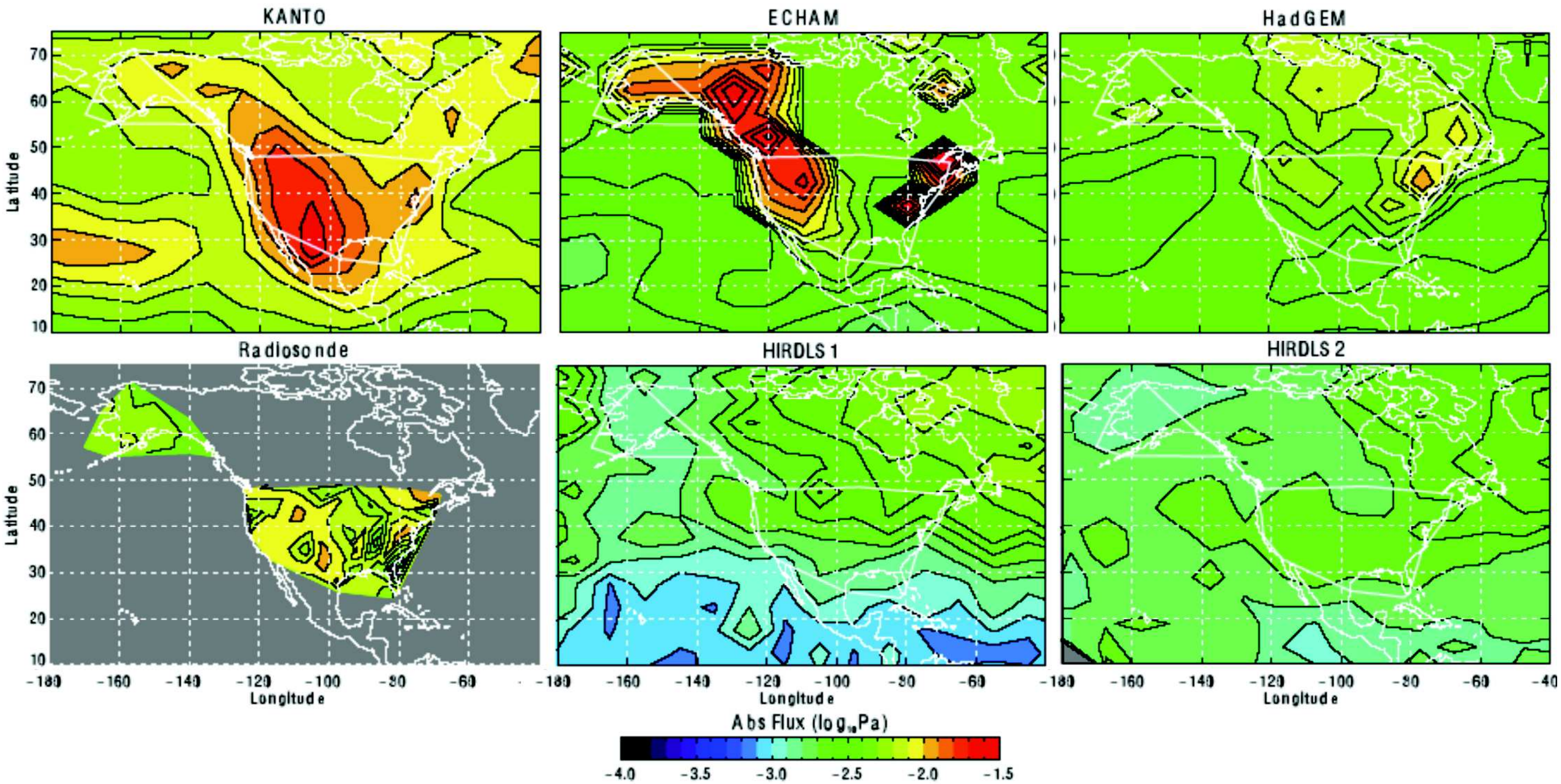
Zonal mean climatologies



- general agreement of shape
- quantitative agreement (better factor 2) in winter vortex
- indicates problem at summer high latitudes

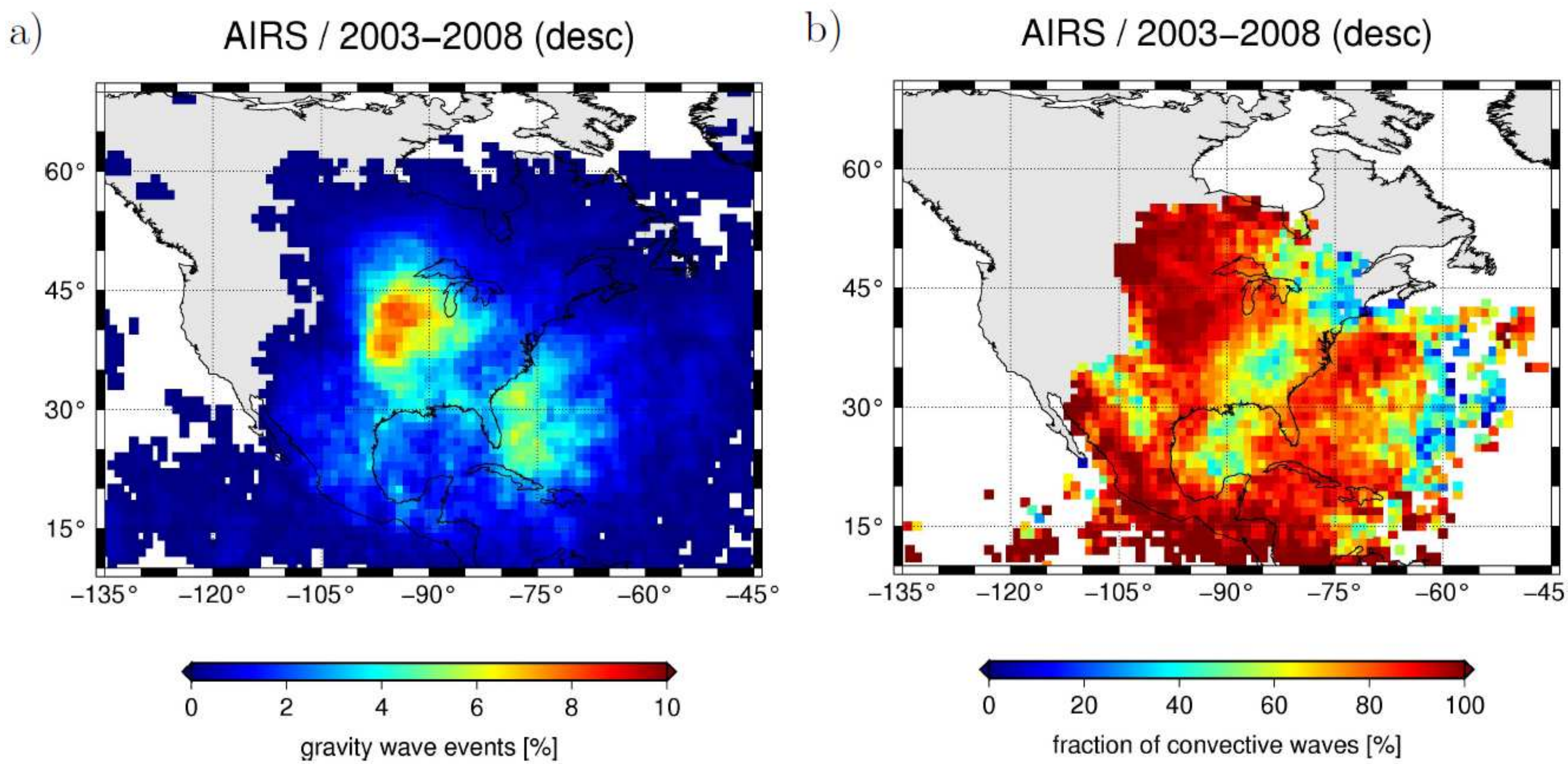

Jan 2006
Jul 2006
ECHAM 24.0 km
GISS 19.6 km
HadGEM 11.6 km
HIRDLS 1 9.1 km
HIRDLS 2 10.7 km
SABER 12.9 km
Kanto 22.1 km
CAM 5.3 km
ECHAM 24.8 km
GISS 24.0 km
HadGEM 12.4 km
HIRDLS 1 8.8 km
HIRDLS 2 12.4 km
SABER 11.9 km
Kanto 27.5 km
CAM 5.5 km
Height (km)
Normalized Abs Flux
Normalized Abs Flux

GWs above North America



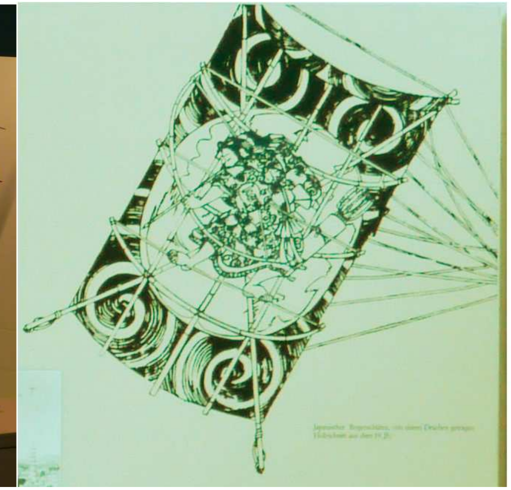
- Difference due to the prevailing winds?
- Missing spread due to merely vertical propagation of parameterized GWs?

Additional instruments: AIRS (IASI)

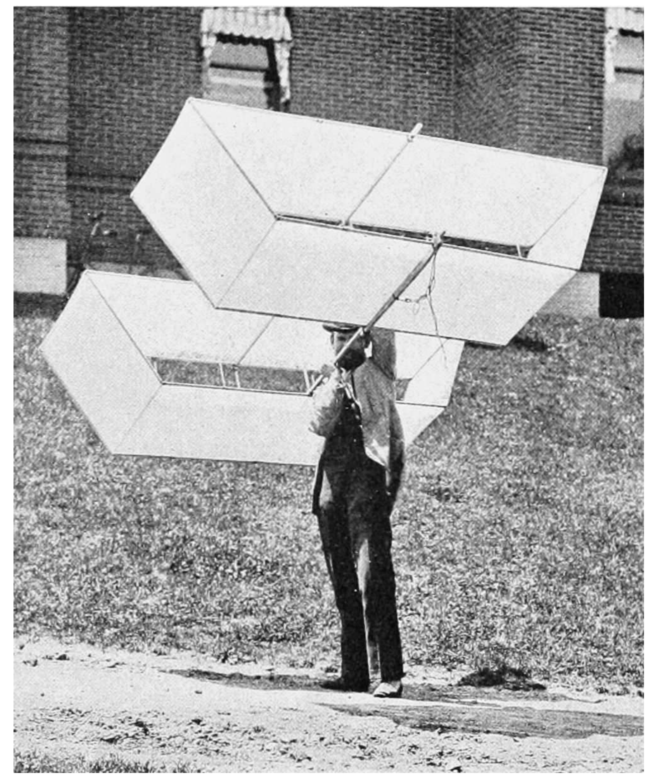


Gravity waves at 40 km altitude and correlation to convection at 500 km miss distance.

Hoffmann and Alexander, JGR, 2010

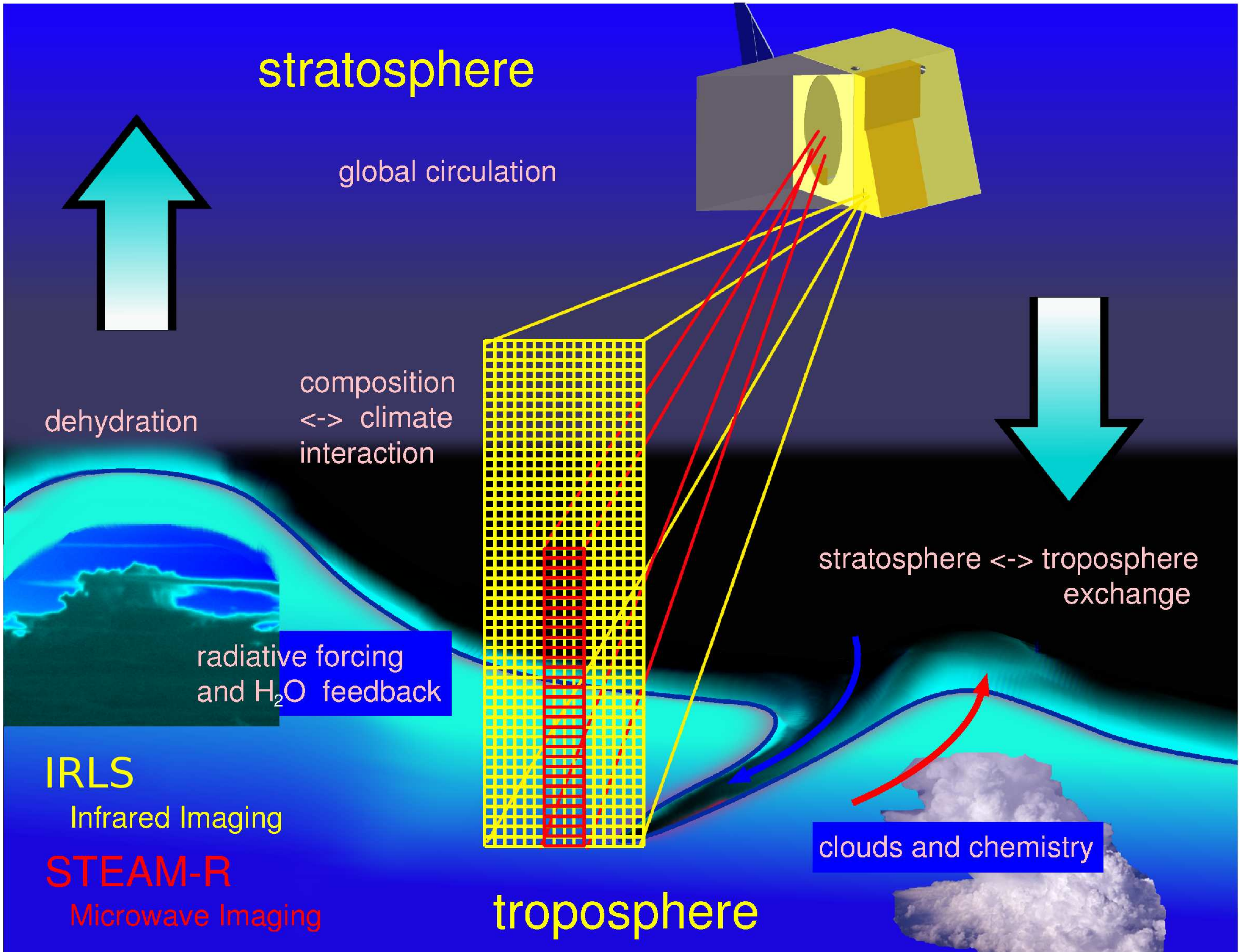


F. Trey, Meteorol. Z., 1919 : *We need more kite stations!*



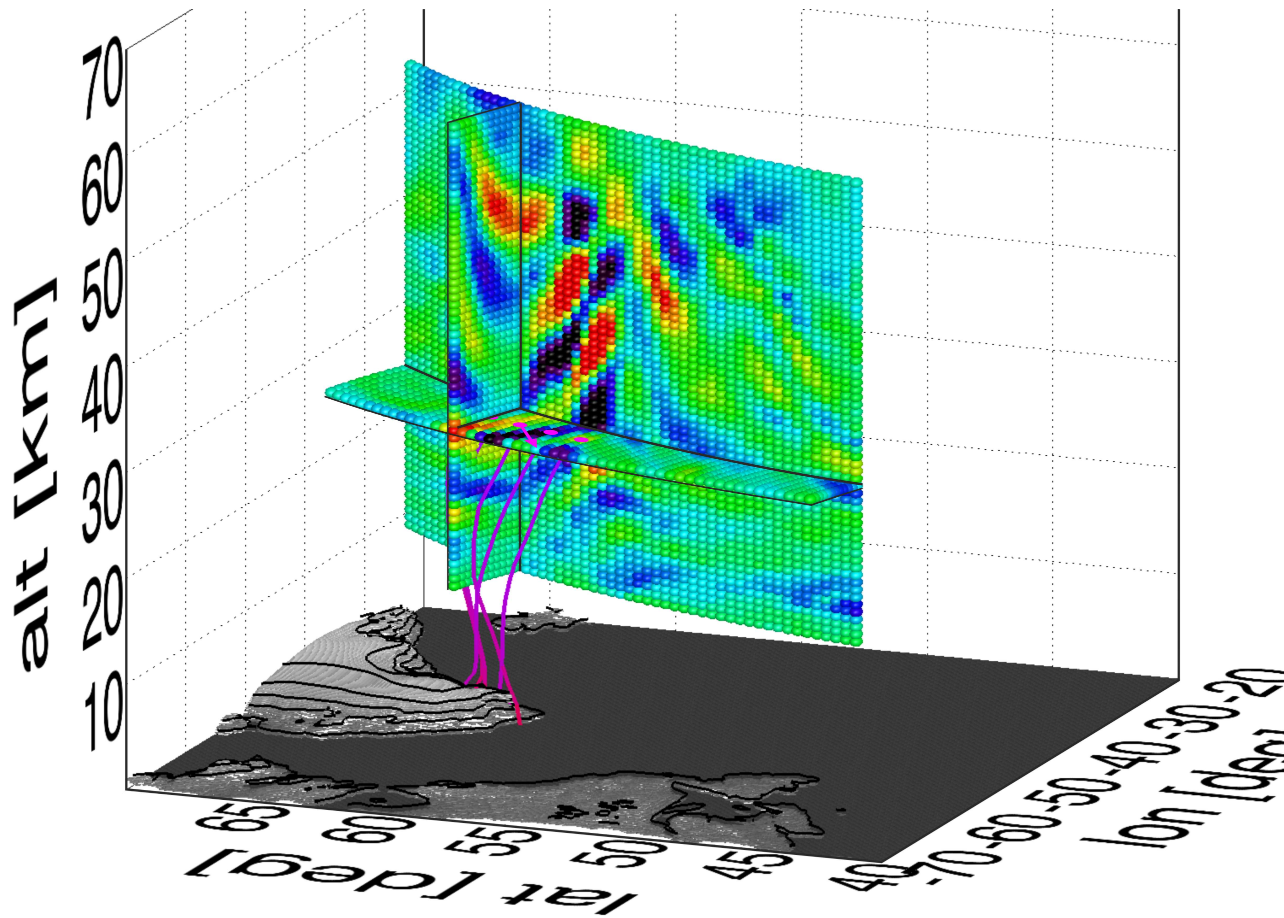
What are todays kites?

PREMIER → EE-9, ATMOSAT

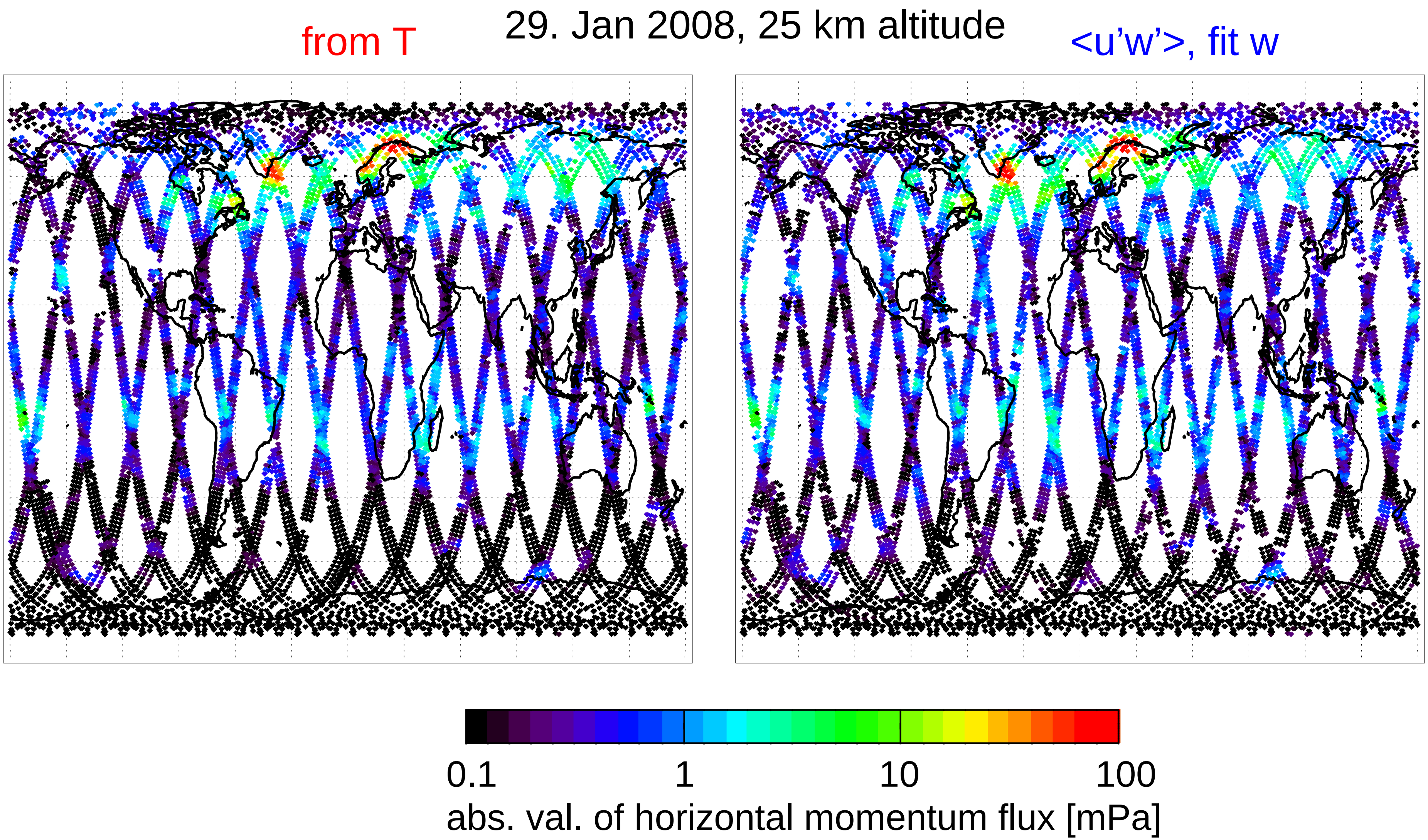


PREMIER IRLS parameters

- sampling:
  30 km x
  50 km x 0.7 km
- resolution:
  30 km x
  60 km x 1.0 km
- 12 tracks,
  360 km
  across-track
  coverage
- temperature
  precision
  0.5-1.0 K
- altitude coverage
  5-55 km



ECMWF: NH winter



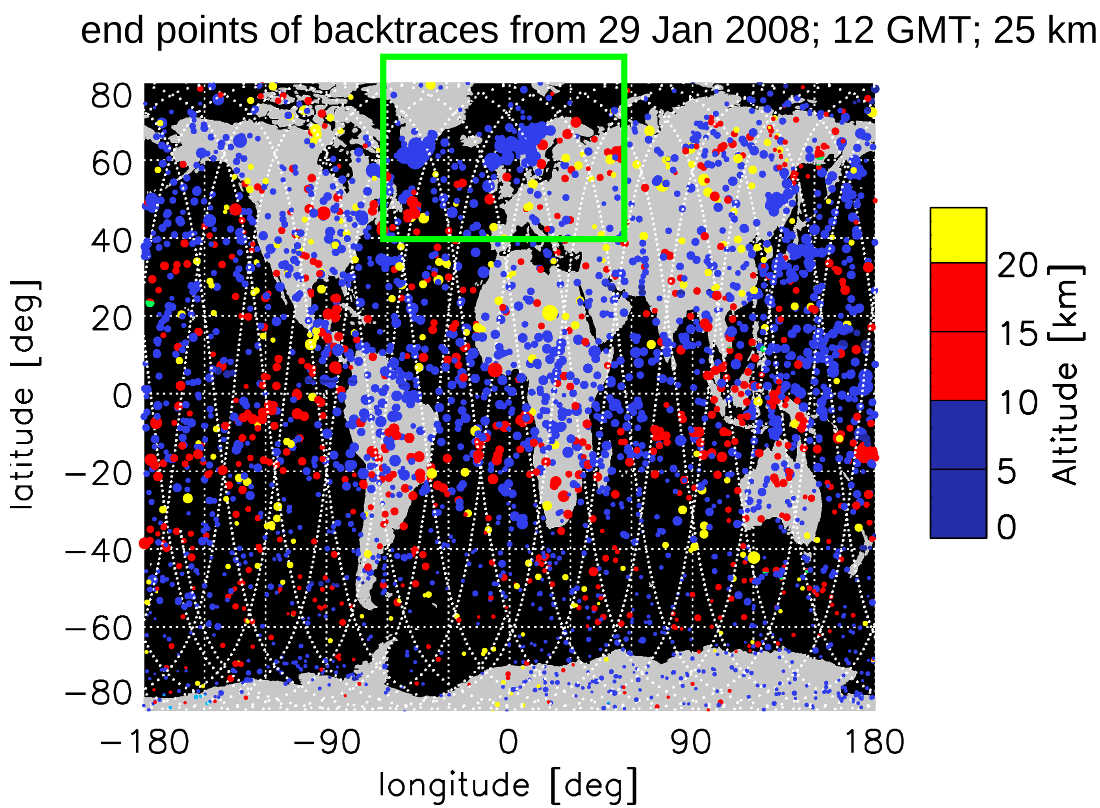
Good agreement of temperature-deduced GW-MF with reference

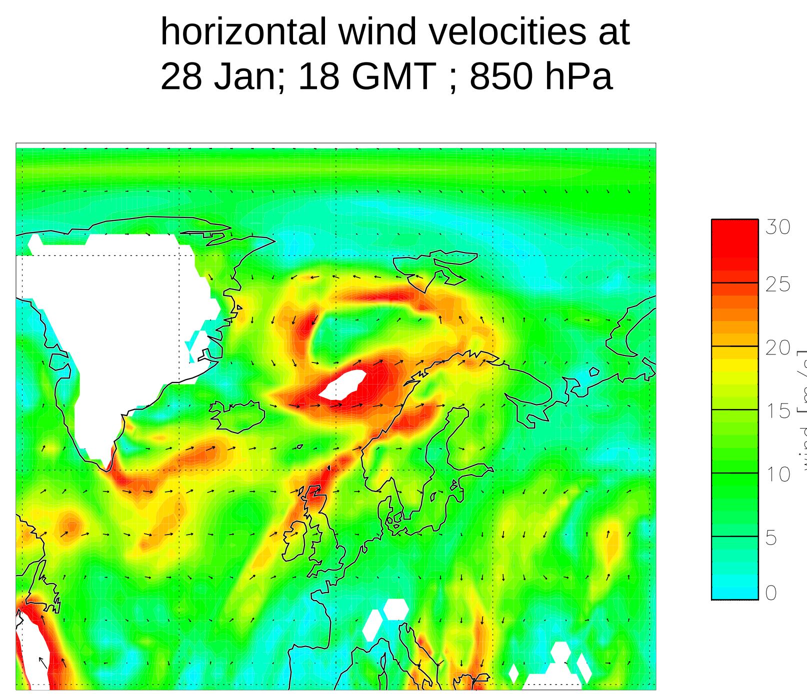
PREMIER assessment

By simulated measurements (limb soundings) through ECMWF data fields:

- PREMIER will be able to measure all three key quantities:
  - GW momentum flux
  - direction
  - phase speed (inferred)
- zonal mean net GWMF accurate to $\sim$30 %
- independent values at several altitudes throughout entire stratosphere

Backward ray-tracing

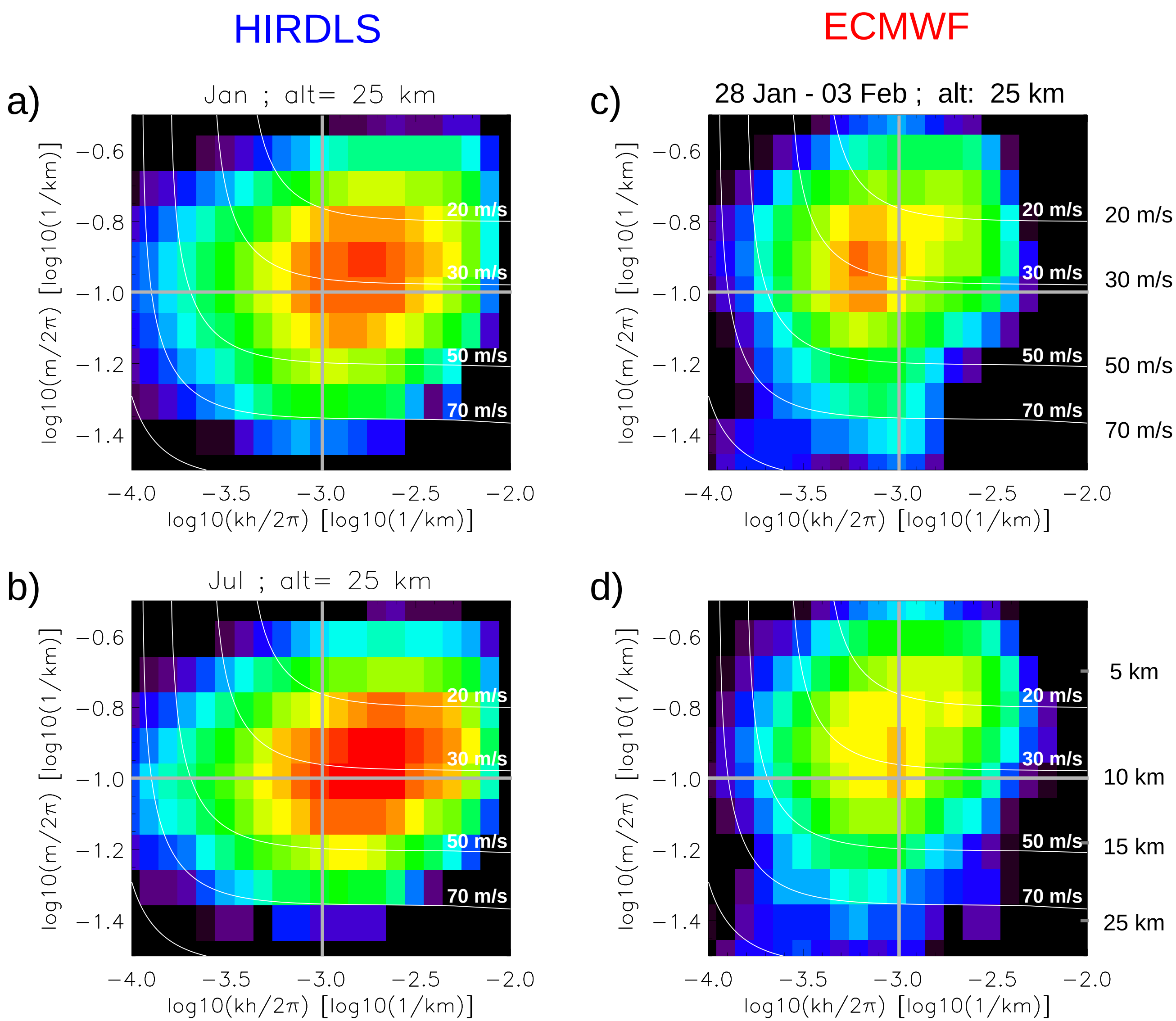




Preusse et al., ACP, 2014

- Orographic waves: Greenland
- Storm approaching Norway

Convective GWs too long



HITEC project on GWs in the ECMWF model

Still needed in 2025?

- Gravity waves are important for e.g. QBO and Brewer-Dobson circulation and thus for weather prediction and climate projection
- GWs in GCMs: oversimplified and ill-constrained
- Climatological information by IR limb-sounders (CRISTA, HIRDLS, SABER), superpressure balloons and radio sondes
- General distribution coarsely realistic
- Uncertainty ranges are large (factor 2-5).
- $\Rightarrow$ Synoptic-scale climate projections not reliable
- 3D distributions from limb imager would be most important break-through

$\Rightarrow$ Very likely!