How does knowledge of atmospheric gravity waves guide their parameterizations?

with a bias towards balloon observations

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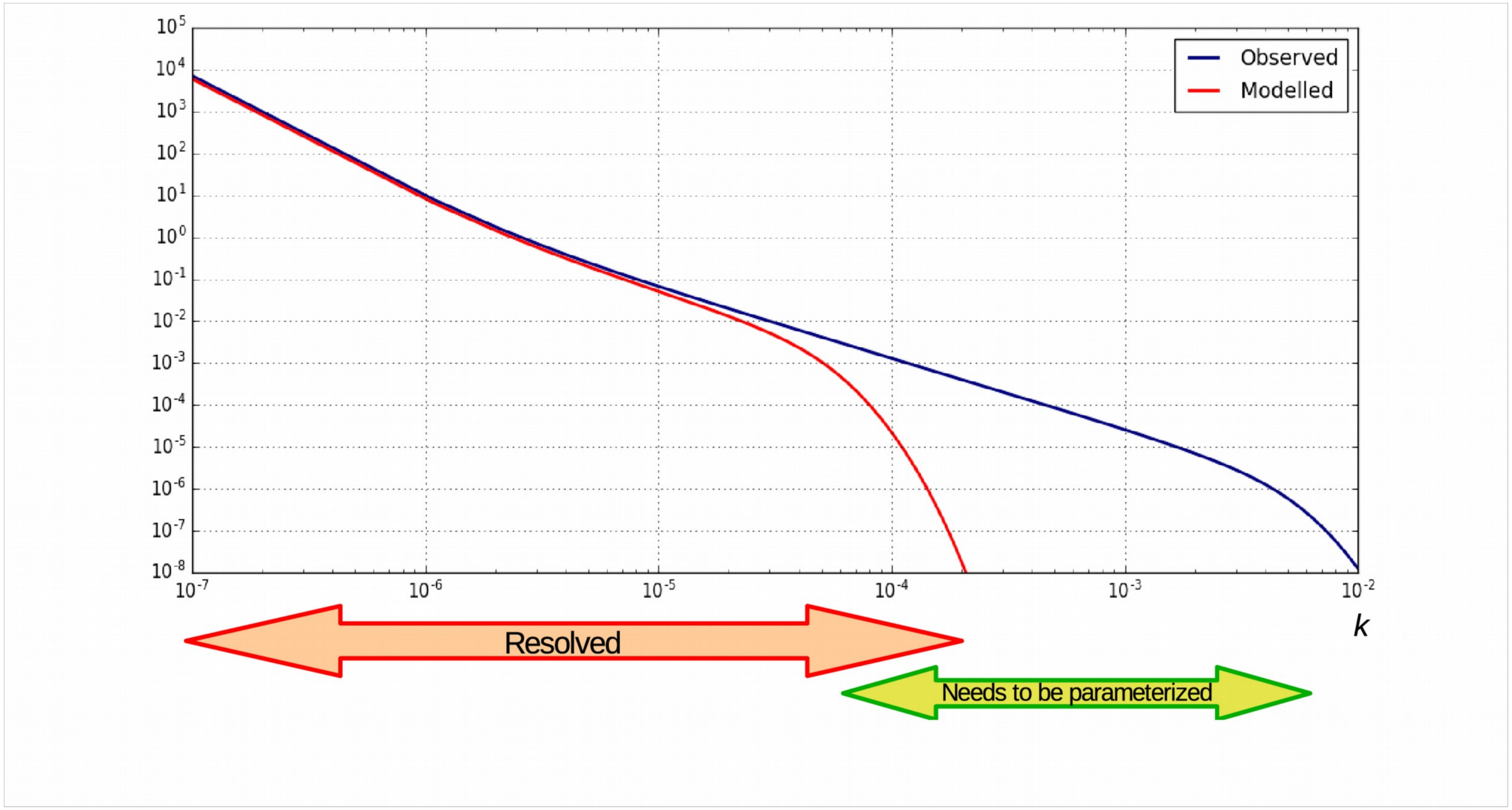
DISCLAIMER

No new work, no new results are presented.

This presentation discusses issues that are already well known.

Gravity waves need to be parameterized because *they are not resolved*



and this matters because models are sensitive to choices in the parameterizations :

Illustration of the **sensitivity of a model to GW parameterization parameters** :

Two simulations with the Whole Atmosphere Climate Model, **differing only by the non-orographic GW momentum flux at the source level :**

0.7 mPa or
1.0 mPa

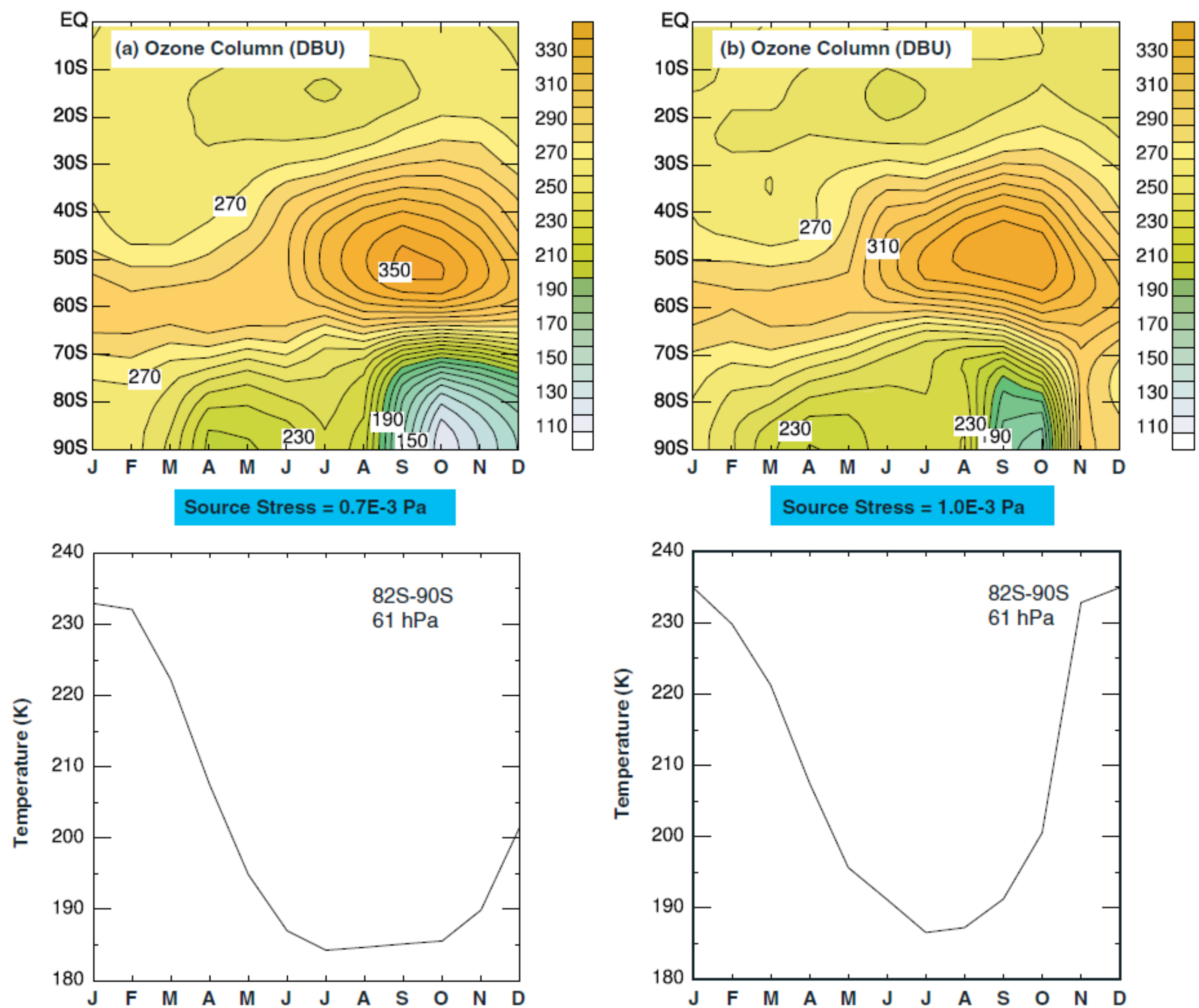


Figure 3. Top panels: time–latitude changes in Southern Hemisphere column ozone in WACCM simulations with slightly lower (left, 0.7 mPa) and higher (right, 1.0 mPa) values of NGWD source-level momentum flux. Bottom panels: time series of polar temperatures at the 61 hPa pressure level in the simulations. This figure is available in colour online at www.interscience.wiley.com/journal/qj

Garcia et al 2007

Alexander et al 2010

Encouraging, but there are difficulties :

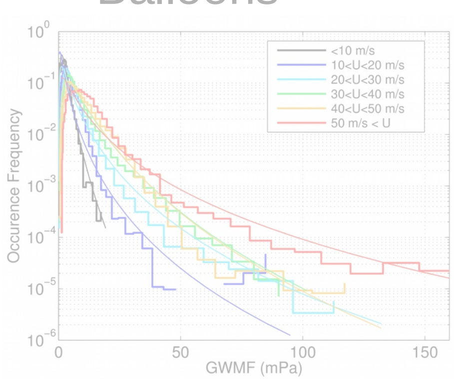
there are **several ways to obtain this forcing**
(orographic drag, convectively generated waves, transience?)

Rolando et al 2017, Choi & Chun 2013, poster by G. Böloni et al..

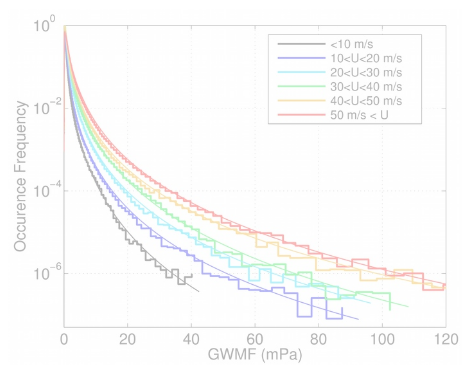
→ Still more to learn from observations + modelling etc...

Useful to obtain **flow-relative information**

Balloons



WRF



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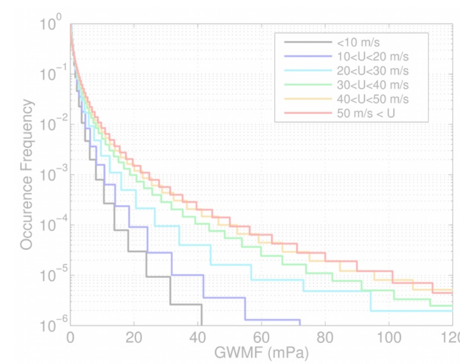
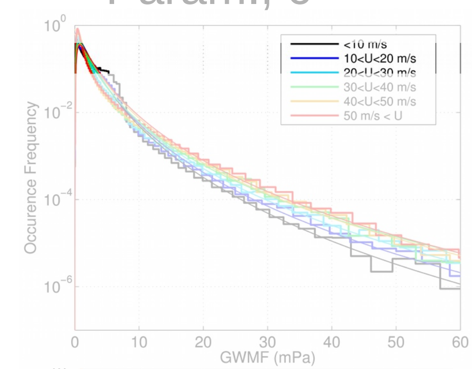
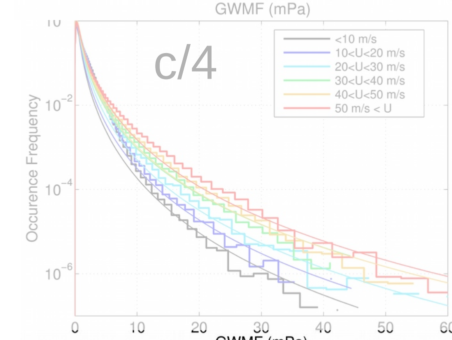


Param., c





Plougonven et al 2017

Fundamentals of GW parameterizations

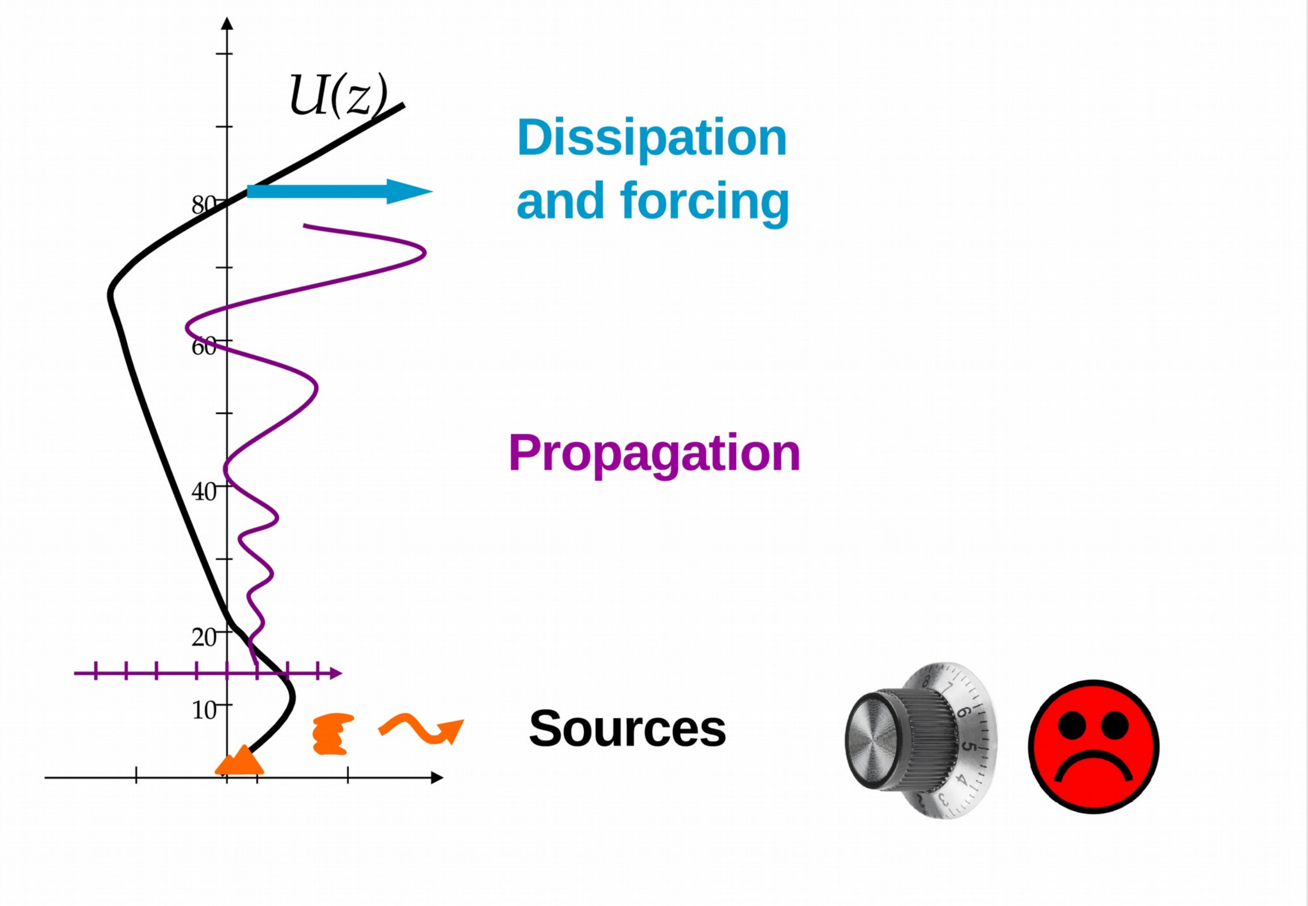
Based on robust features :

Strongest forcings (fast intrinsic timescales, vertical motions) in troposphere

Upward propagation

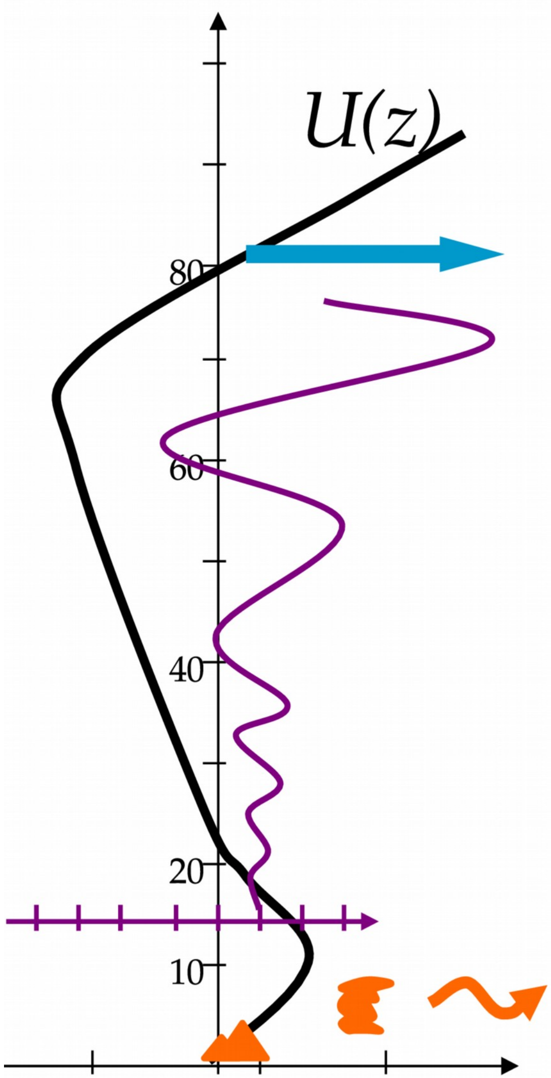
Critical level filtering

→ Standard parameterization framework :



How does knowledge of atmospheric gravity waves guide their parameterizations?

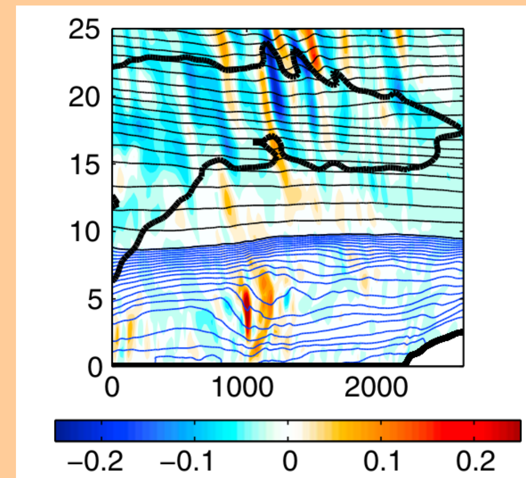
First thoughts



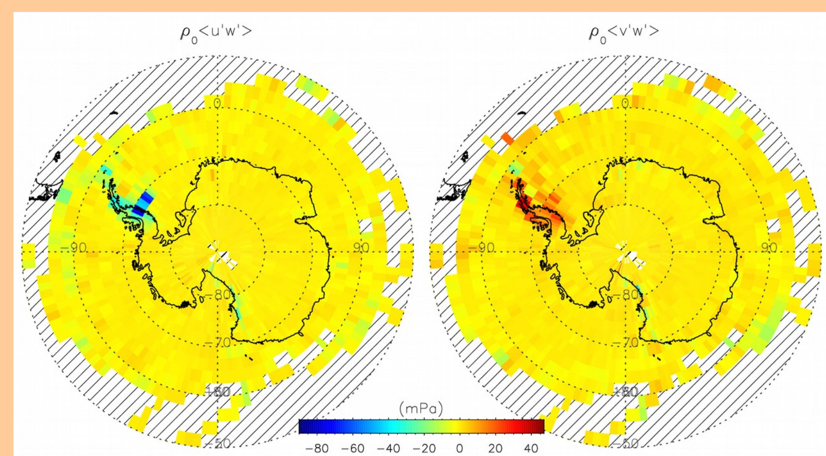
Theory

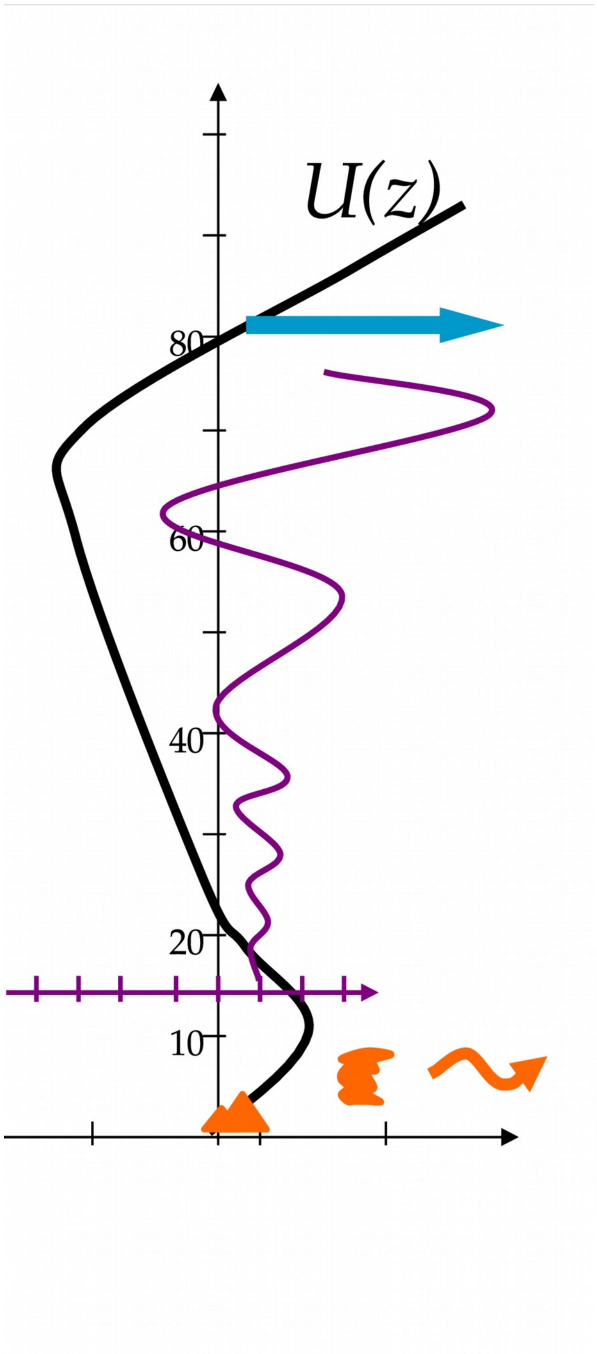
$$\overline{F}^z = -\rho_r\left(\overline{u'w'} - f\frac{\overline{v'\theta'}}{\theta_{0z}}\right) = \frac{\rho_r g^2}{f\theta_r^2 N^3}(\rho_r q_r \sigma_z)^2 \mathcal{F}^\xi\left(\frac{k_l\Lambda}{f}z\right)$$

Modelling



Observations





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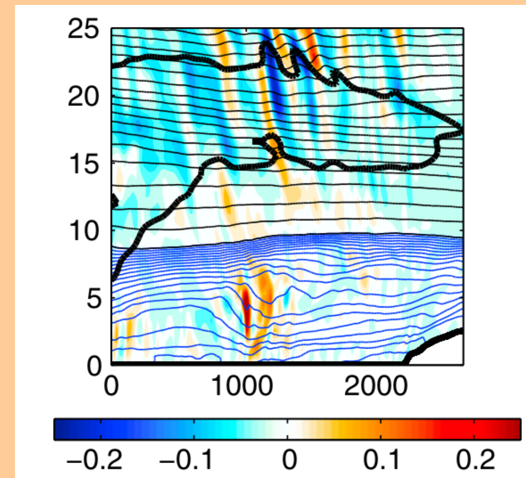

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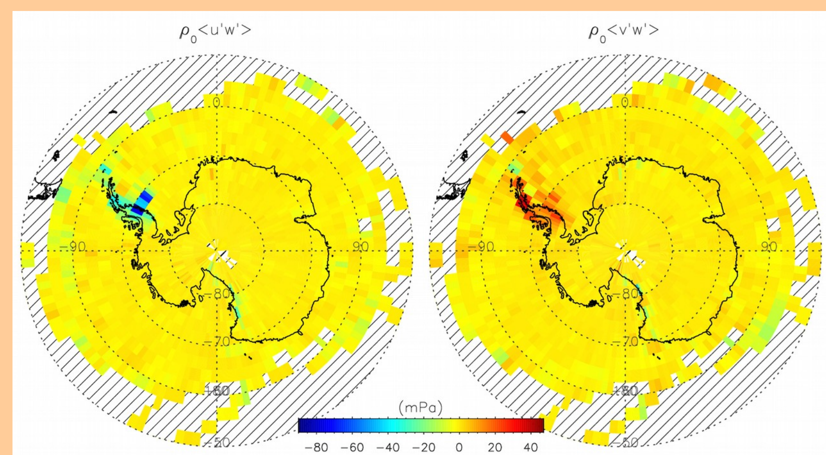
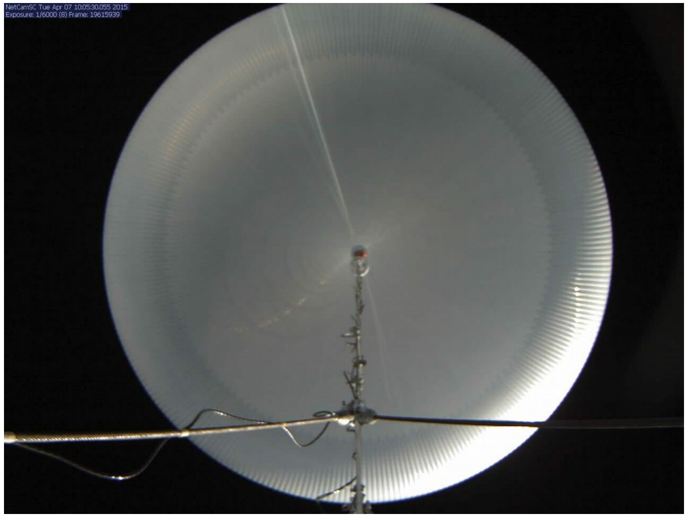


Super Pressure Balloons (SPB)

Preparing launch in McMuro station

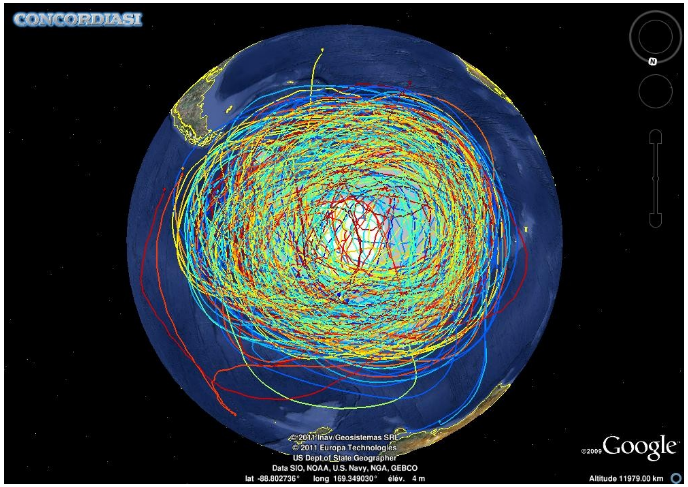


Spherical when fully inflated

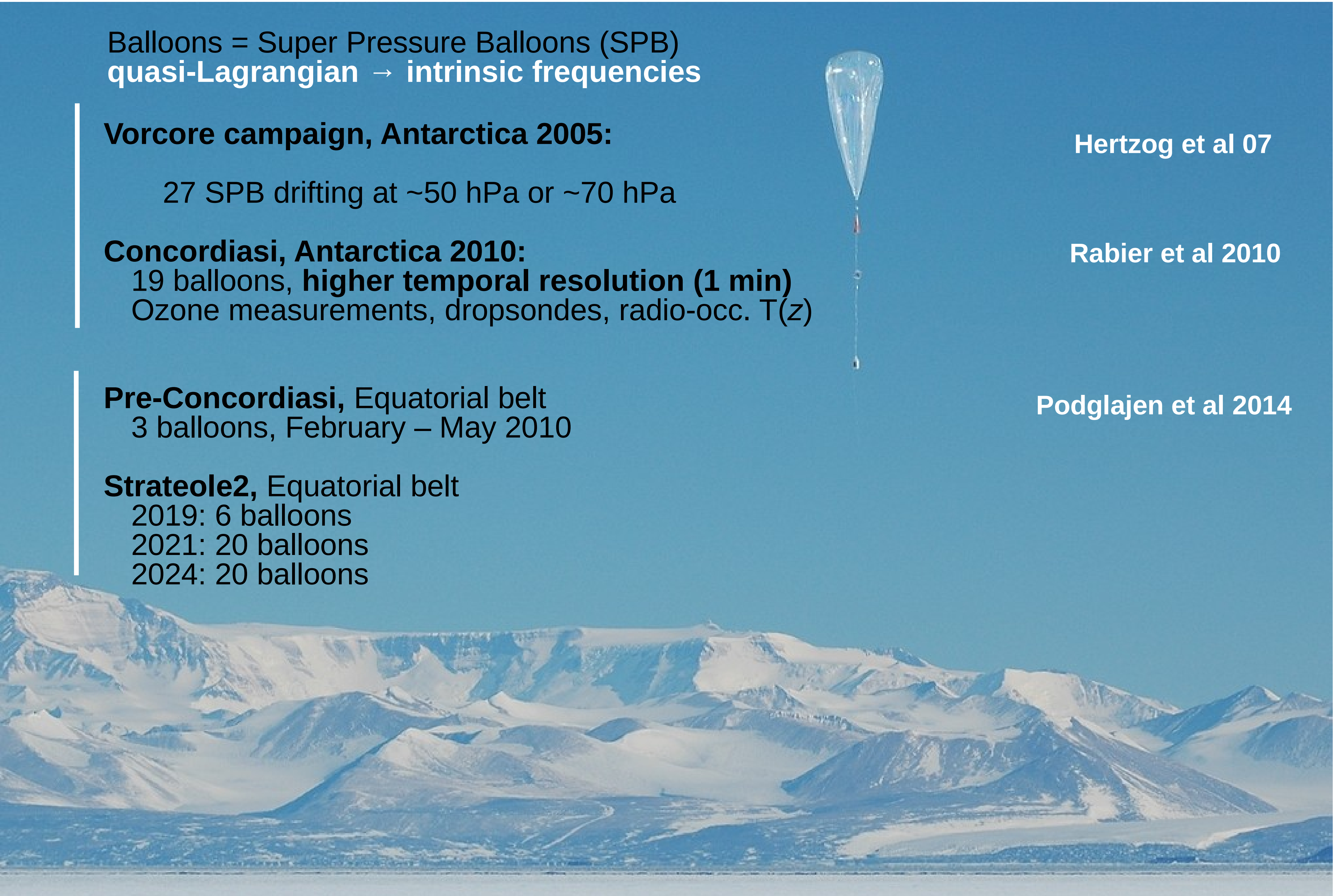
Closed, inextensible enveloppe
Balloons fly between 18 and 20 km, drifting on isopycnic surfaces

Launch of BP11

Trajectories from **Concordiasi**



Super Pressure Balloons campaigns



Balloons = Super Pressure Balloons (SPB)
quasi-Lagrangian → intrinsic frequencies

Vorcore campaign, Antarctica 2005:

27 SPB drifting at ~50 hPa or ~70 hPa

Hertzog et al 07

Concordiasi, Antarctica 2010:
19 balloons, **higher temporal resolution (1 min)**
Ozone measurements, dropsondes, radio-occ. T(*z*)

Rabier et al 2010

Pre-Concordiasi, Equatorial belt
3 balloons, February – May 2010

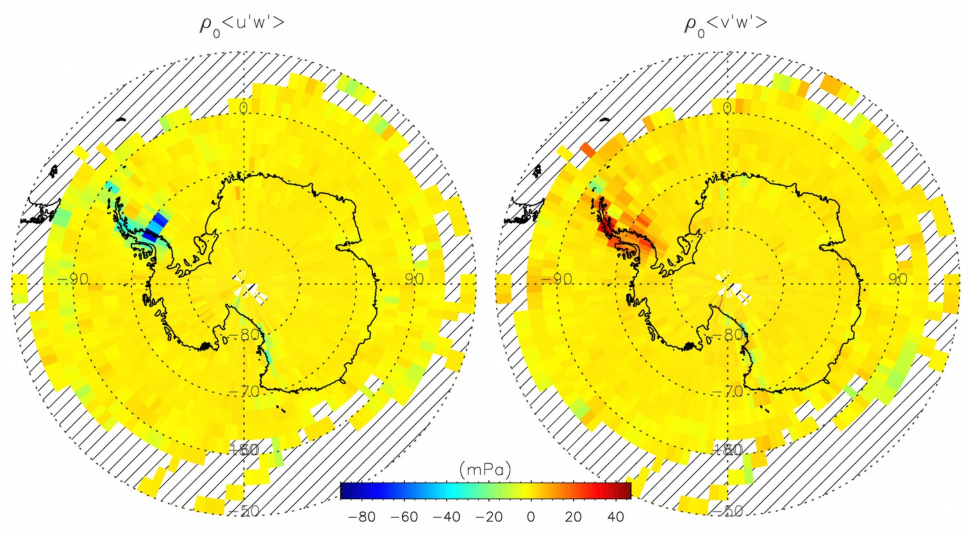
Podglajen et al 2014

Strateole2, Equatorial belt
2019: 6 balloons
2021: 20 balloons
2024: 20 balloons

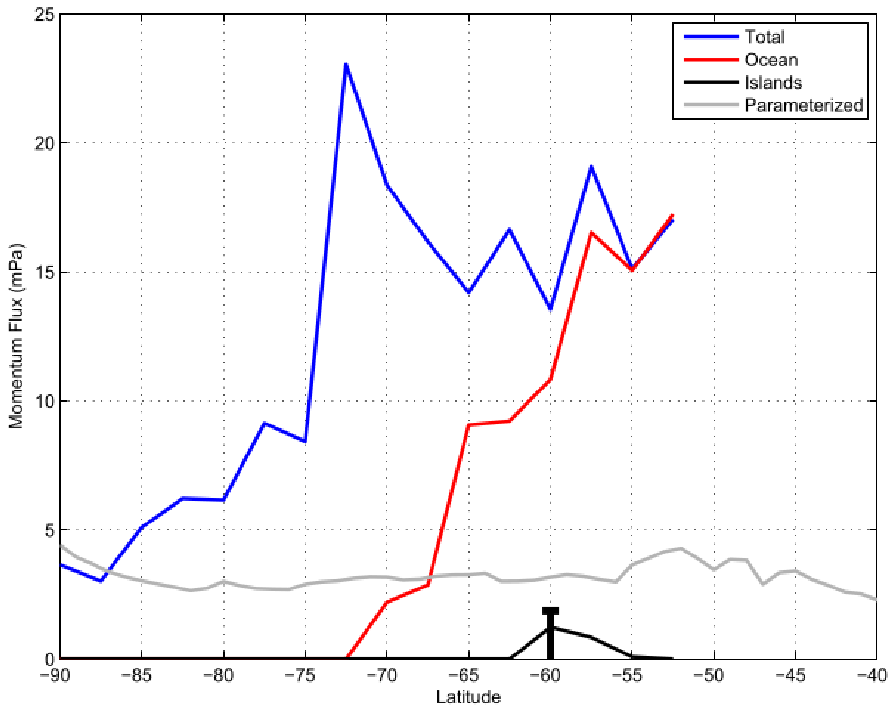
Quasi-Lagrangian behaviour

→ good quantification of GW

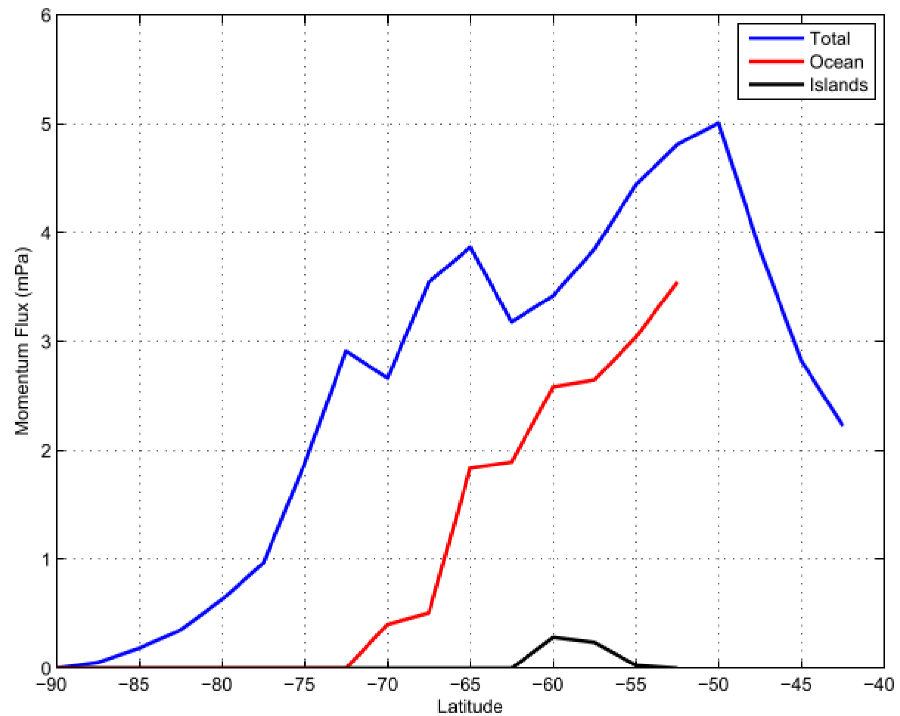
→ mean momentum fluxes :



Zonal average, separating orographic and non-orographic regions :



a)



b)

Criterion for determining GW parameterizations input parameters ?

Realism of **simulated middle atmospheric circulation**

e.g. Zonal mean winds
Variability of polar vortex

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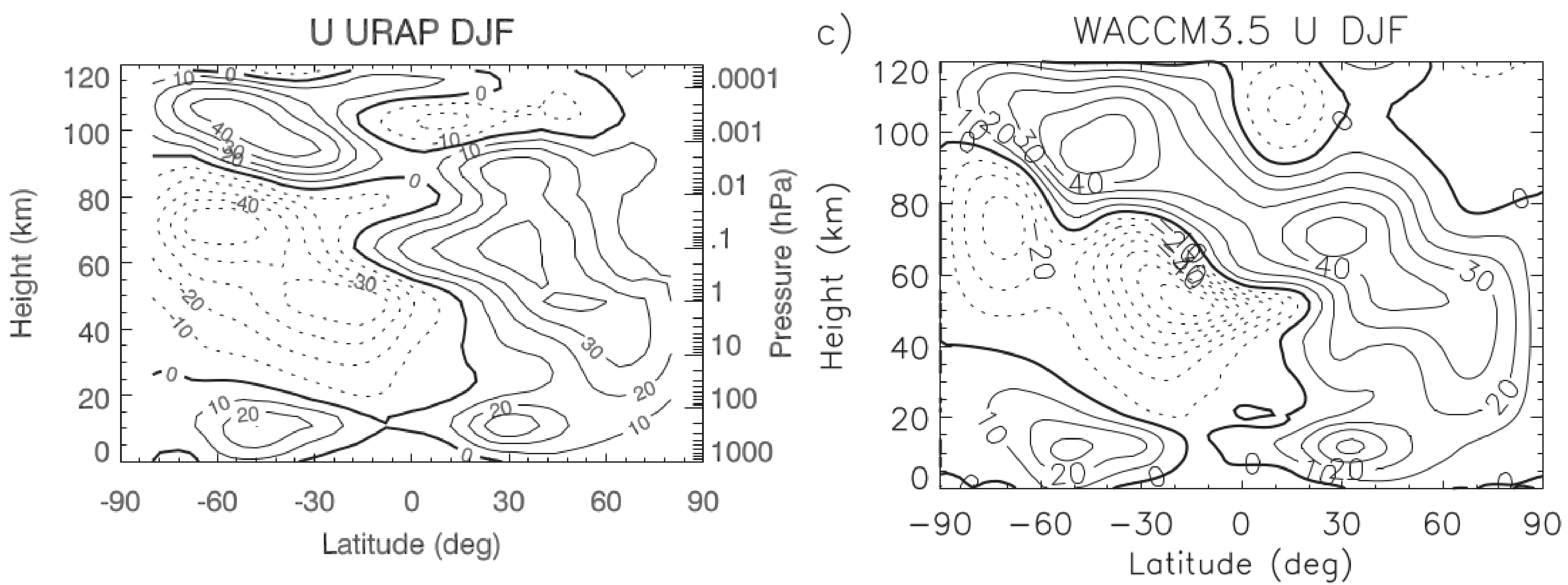


Richter et al 2010

Effects of GW param. **aggregated with all other models processes** and biases, and **interacting** with them

Tuning of GW param. Includes compensating for model biases

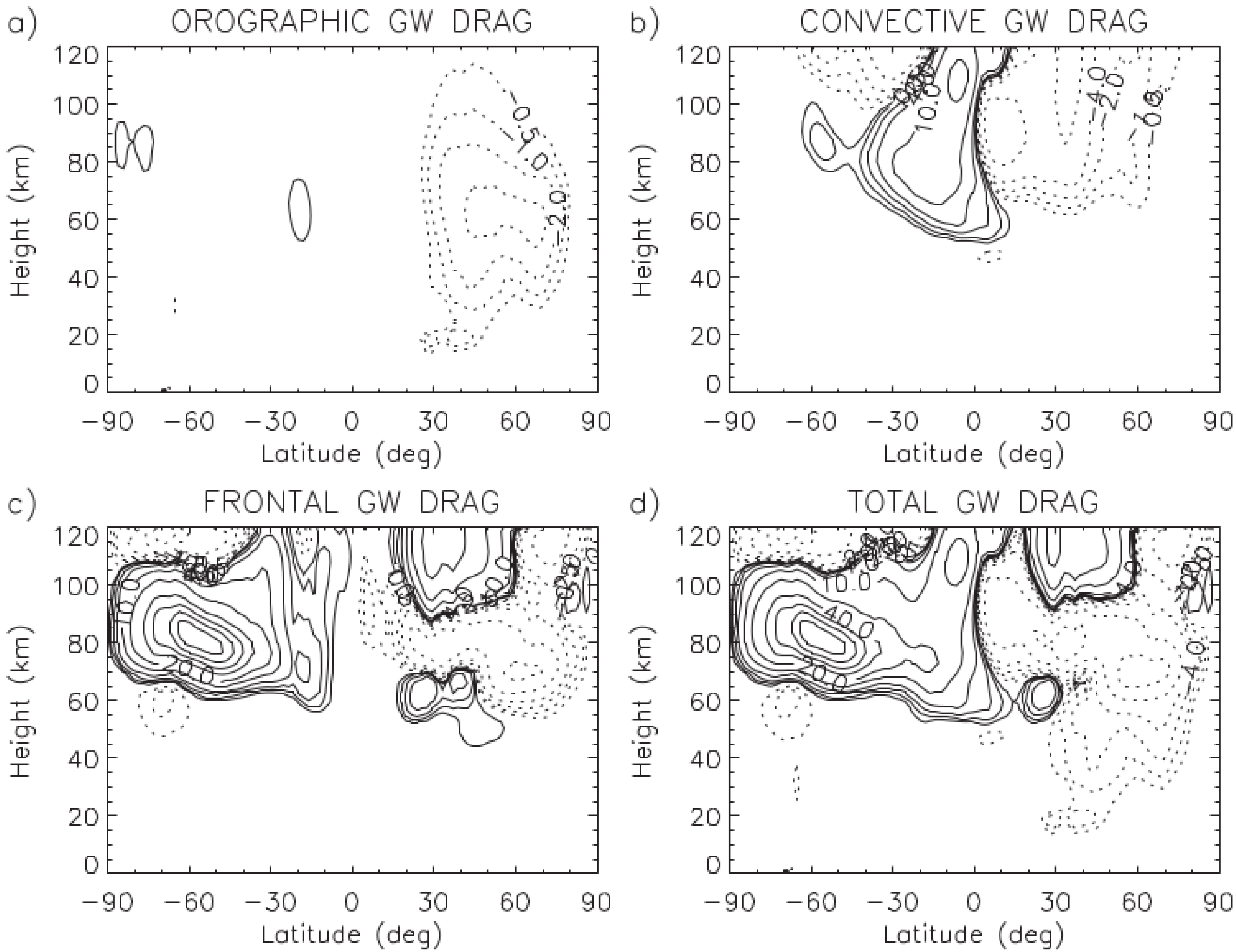


FIG. 6. (a) Orographic, (b) convective, (c) frontal, and (d) total GW drag averaged over DJF in WACCM3.5. Contour intervals are ±0.5, ±1, ±2, ±4, ±10, ±20, ±40, ±60, ±80, and ±100 m s^{-1} day^{-1}.

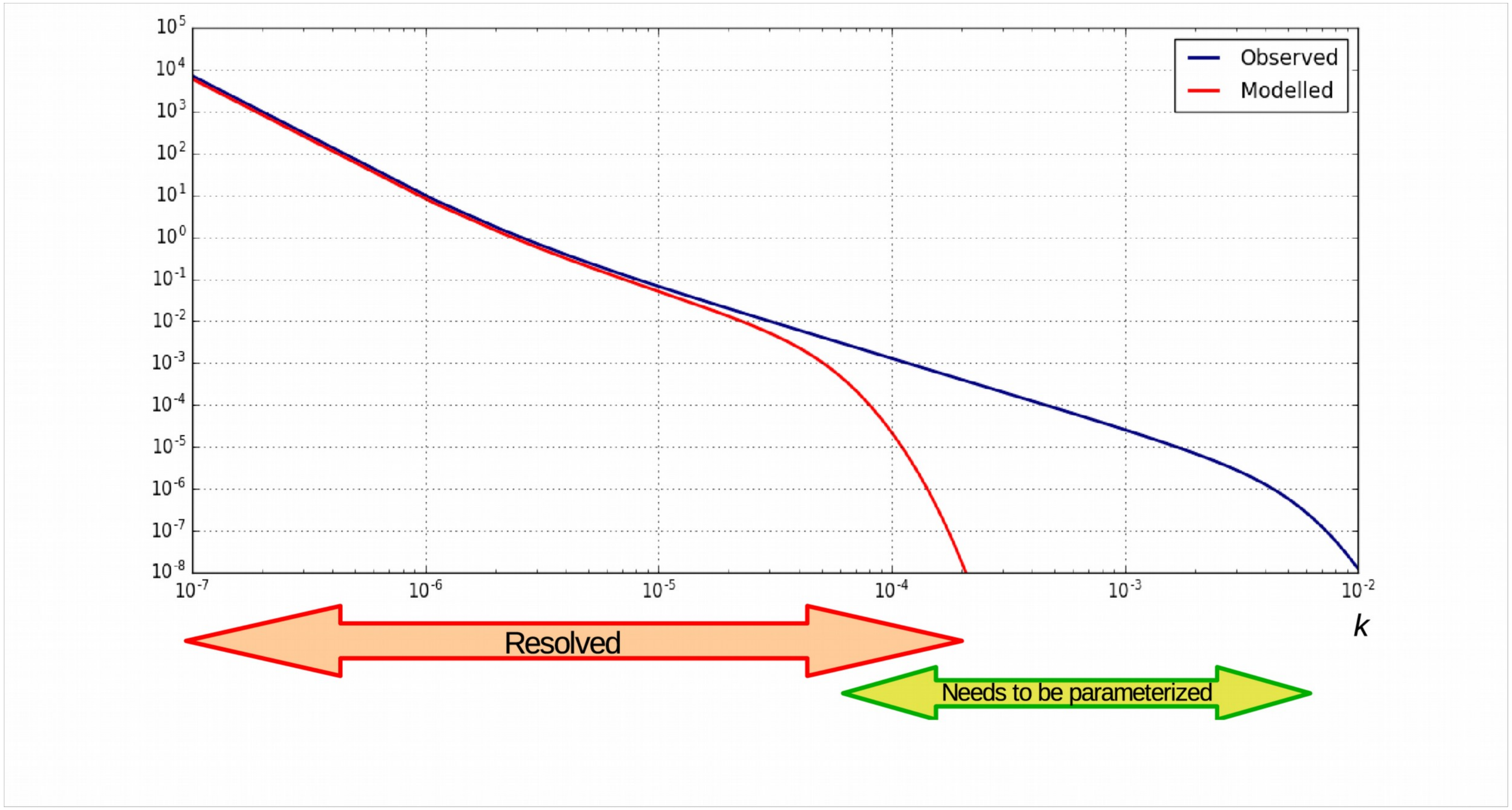
Richter et al 2010

The **major contribution** to the total GW drag comes from **frontal GW** (the least constrained)

→ GW parameterization largely set by tuning to compensate for other model biases..

Gravity waves need to be parameterized because ~~*they are not resolved*~~

they have **effects on the large-scale** flow which are **missing** otherwise



Gravity waves need to be parameterized because ~~*they are not resolved*~~

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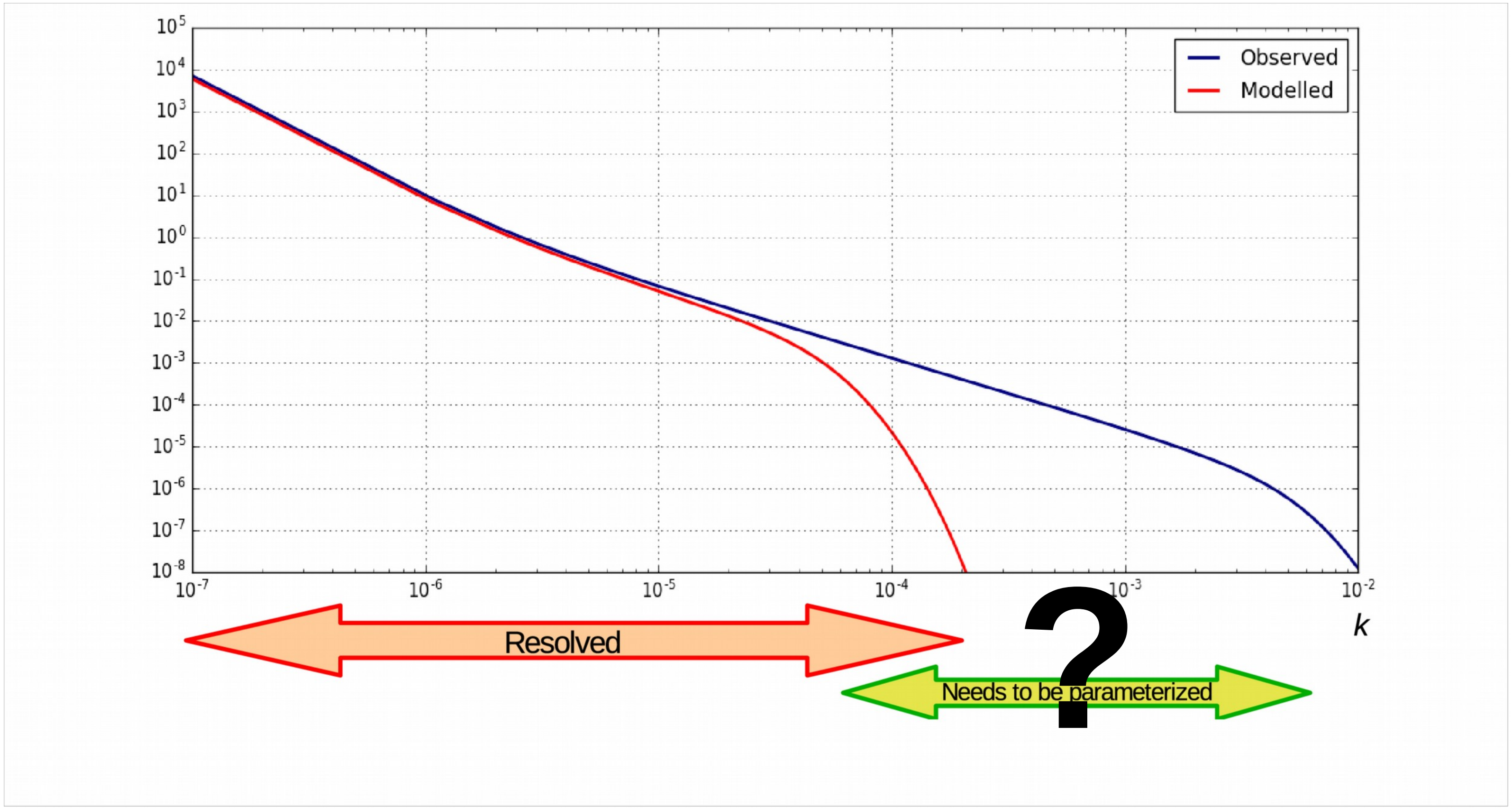
Relation between **resolution and parameterized GW**

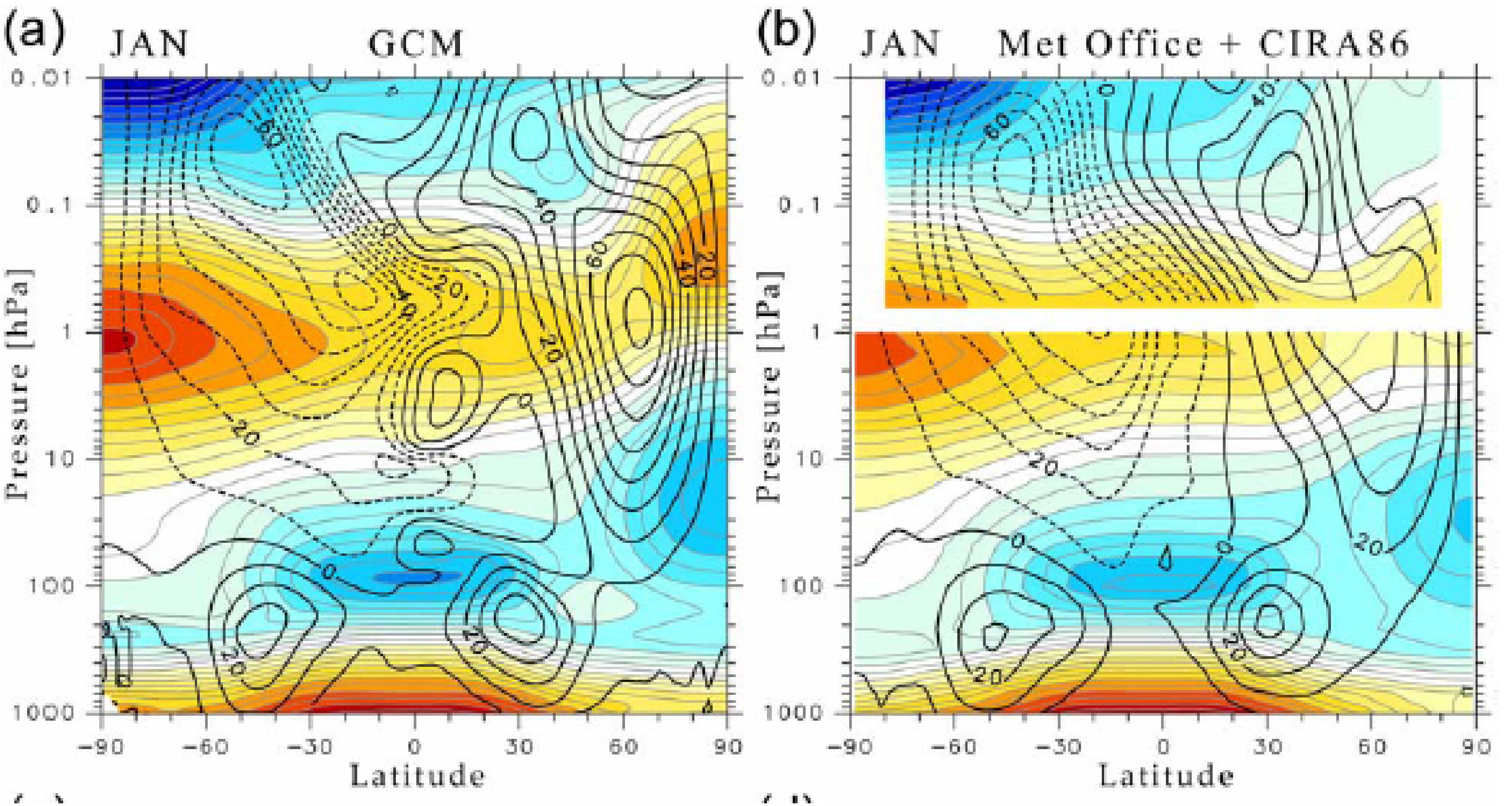


double-counting ?

Example of a moderate resolution model w/o GW param Watanabe et al 2008

Kanto model
0.5625° resolution, 256 levels up to 80 km, no GW parameterization
does not resolve GW with wavelengths < 200 km

yet the mean middle atmosphere mean winds seem rather satisfactory :

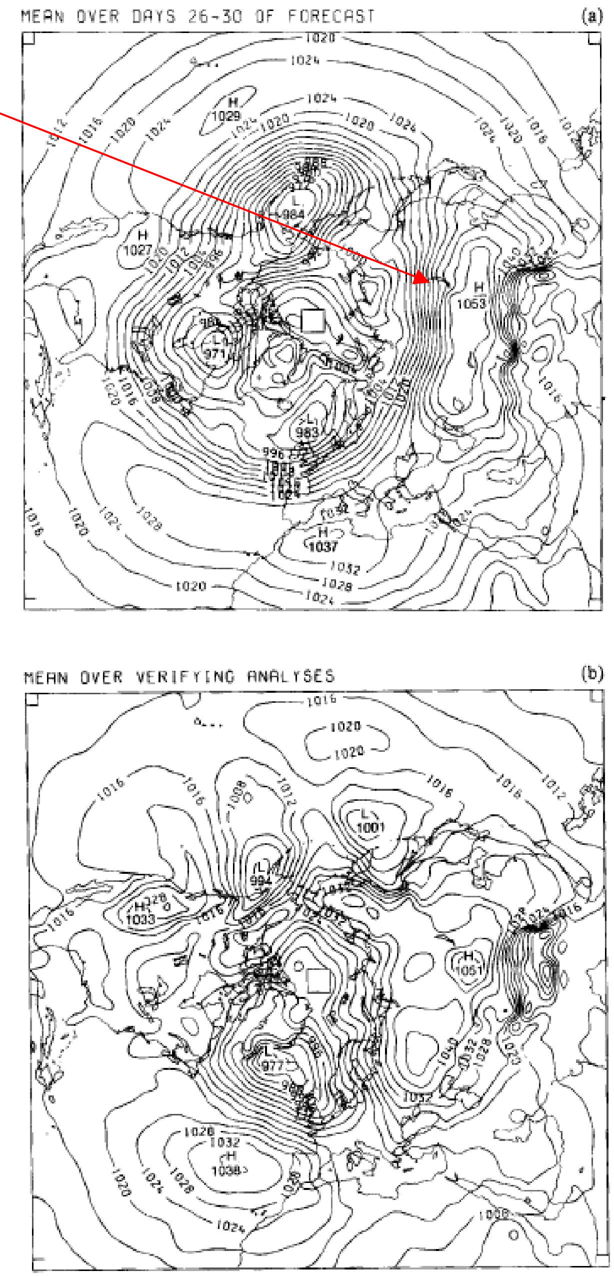


Example of a GW param. Becoming necessary because resolution increased

Example of early orographic GW parameterizations

Jet is too strong

Forecast of MSLP



Analysis

Figure 1. (a) Time-mean sea level pressure field from days 26–30 of a wintertime forecast with the Meteorological Office operational model (prior to the inclusion of gravity wave drag). (b) The verifying analysis.

Palmer et al 1986 introduced orographic GW parameterization **because the resolution of the model *increased***

Mid-latitude jet systematically too strong

Prior to that, **missing drag** from orographic GW was **compensated by the diffusivity** of the low-resolution model

[redacted]

Input parameters of **parameterizations are model-dependent**

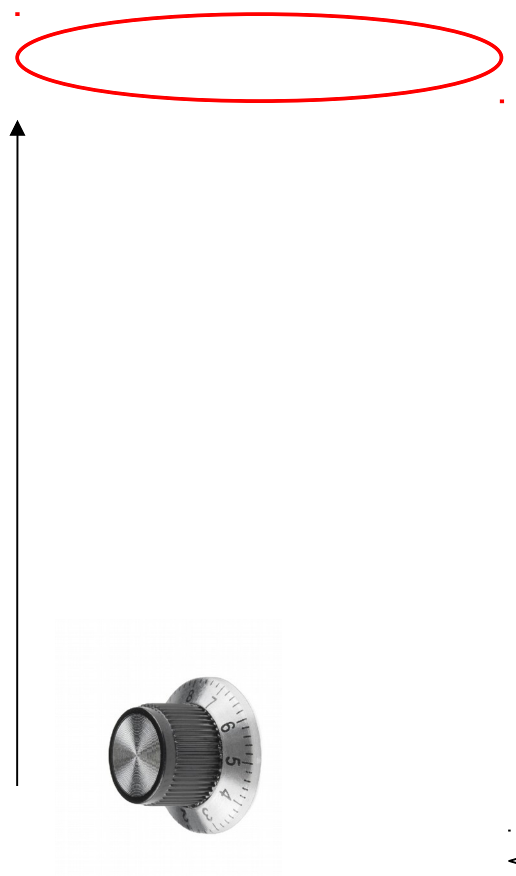
Relation to observations not straightforward

[redacted]

Discrepancy between :

Parameterizations

tuned so that the **resulting forcing produces the right climatology** at upper levels

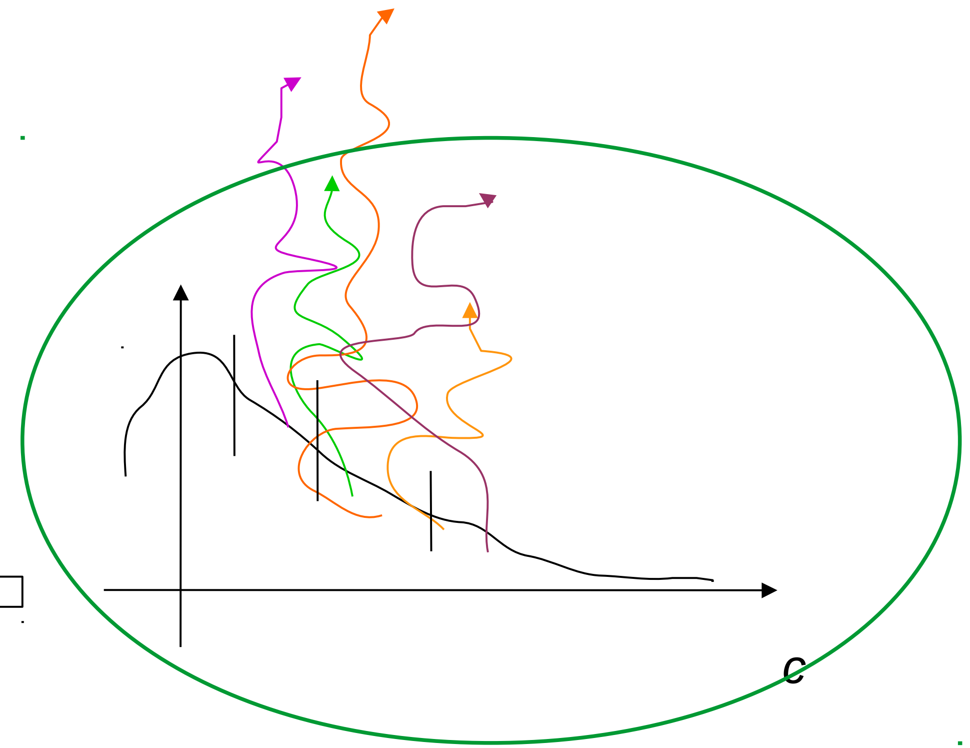


Sources *tuned* so that the **forcing** produces the right circulation

Constrain ?

Observations and hi-res models

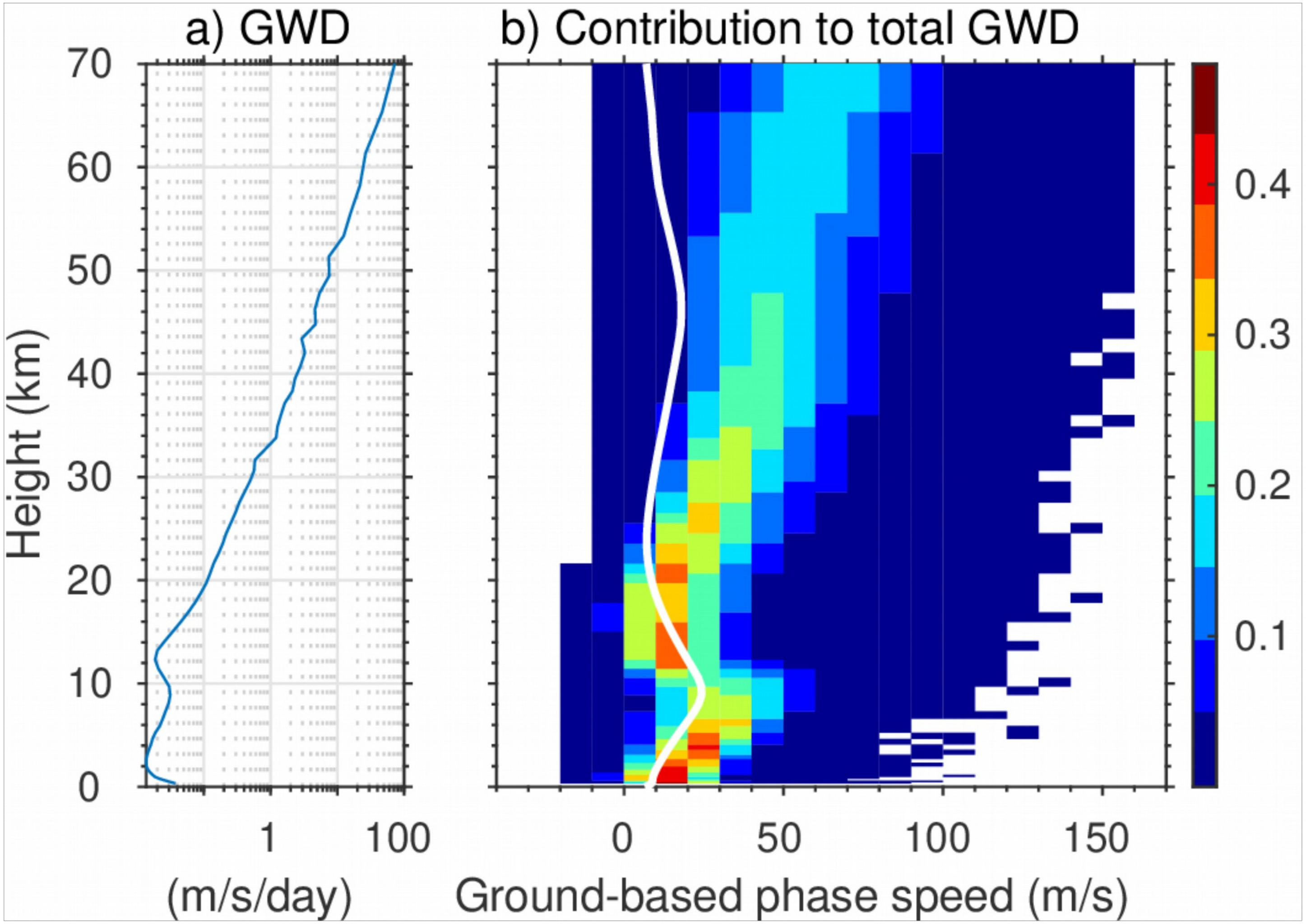
which describe a part of the population of GW mostly in the stratosphere, of which only a small fraction contributes to the forcing at mesospheric levels



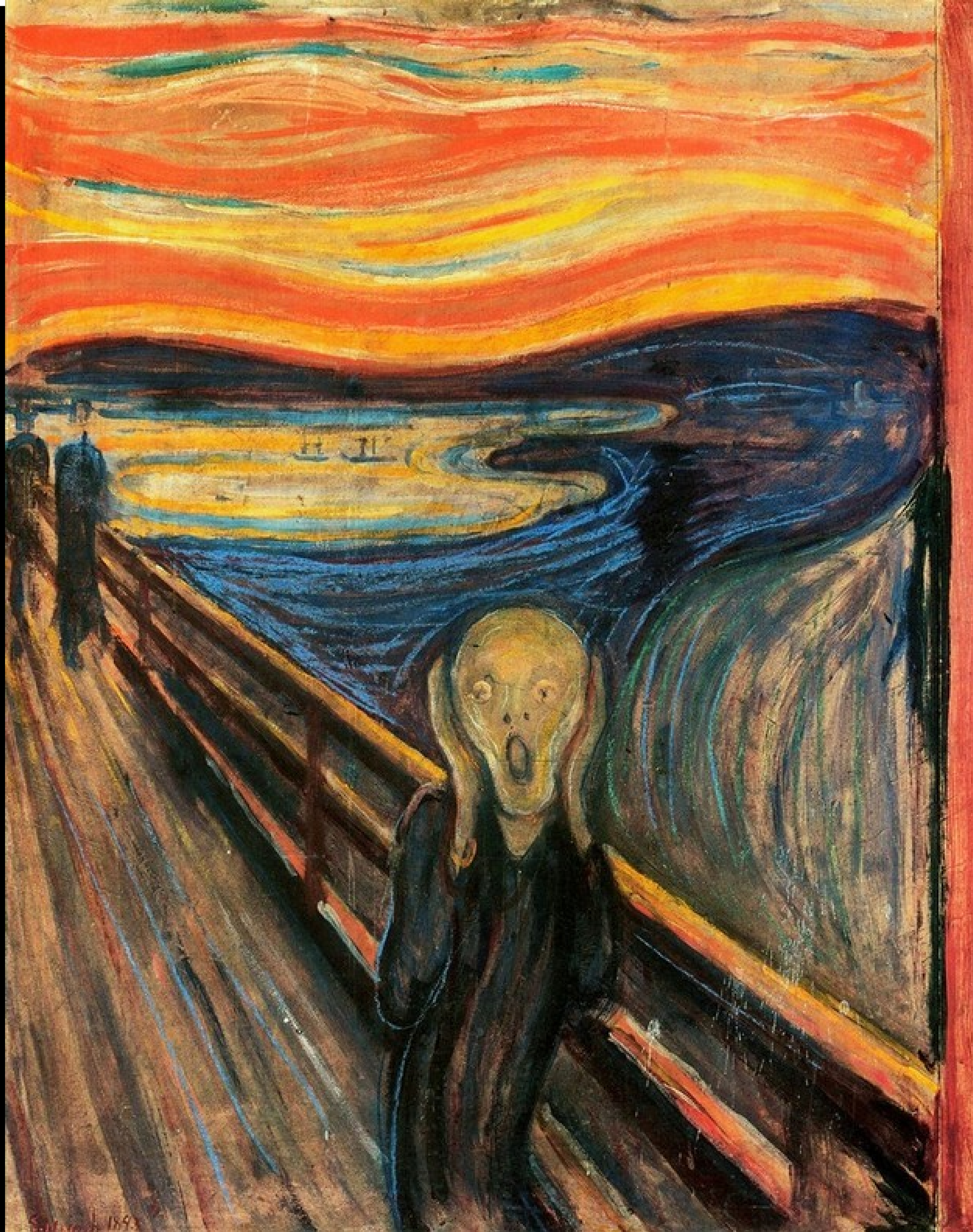
Offline calculations with the Non-Orographic GW parameterization of de la Camara and Lott (2015). Average forcing calculated for a month of October, averages between 45 and 75°N.

Total forcing from parameterized GW

Which waves are contributing to this Forcing ? (White line = Ū)



Much of the forcing results from just a ***fraction*** of the waves,
Moreover, these have high phase speeds (→ poorly constrained)



How does knowledge of atmospheric gravity waves guide their parameterizations?

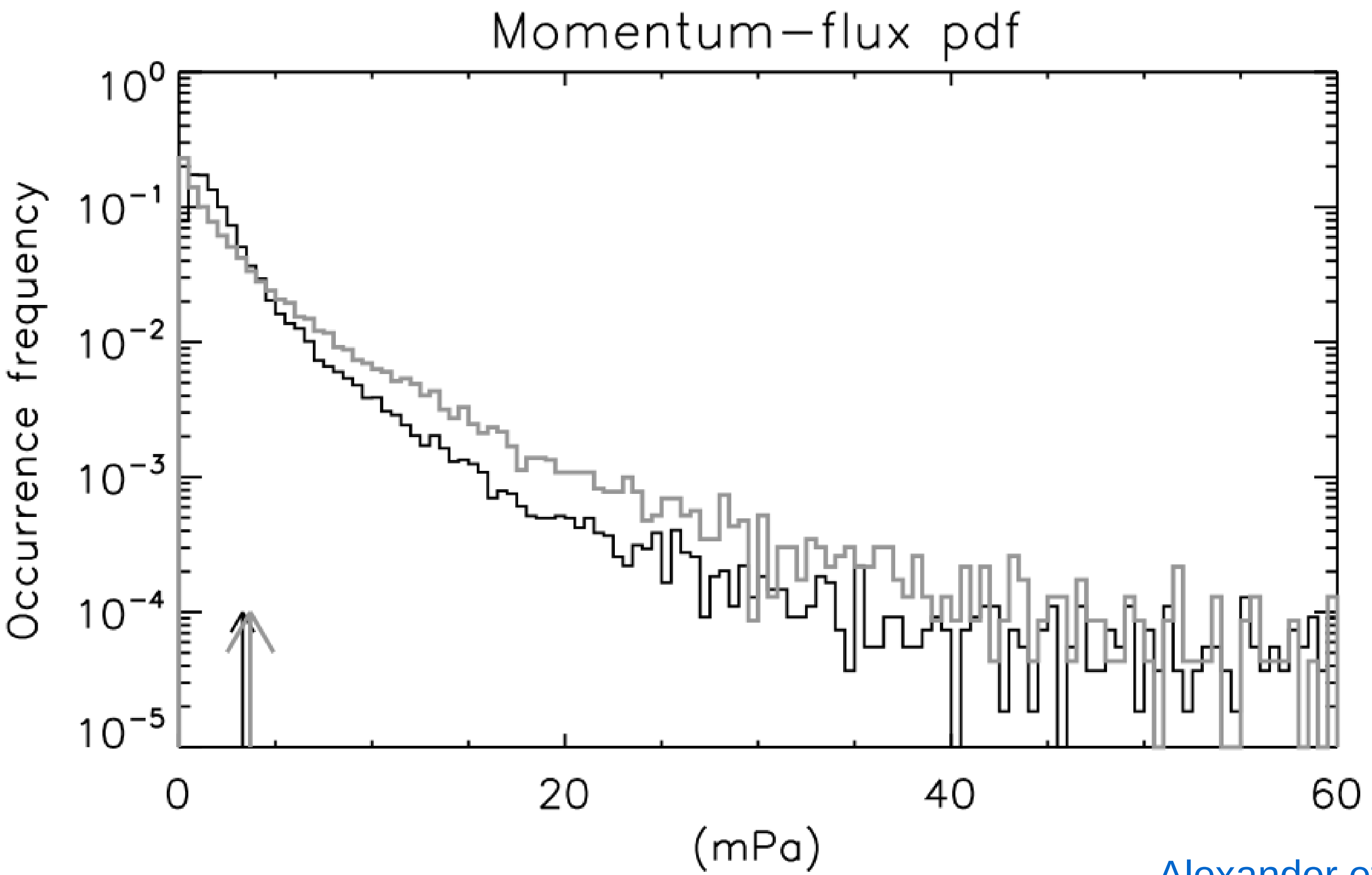
Informs us on robust features which influence the resulting interaction with the background flow

Example of intermittency

Gravity waves are **intermittent** ; it has long been known.

Of prime importance is the wave – mean flow interaction
(→ one can get away with a constant source :
think of the simplest QBO paradigm)

Past decade : observations allowing to **quantify intermittency**
and compare different sources of information



Alexander et al 2010

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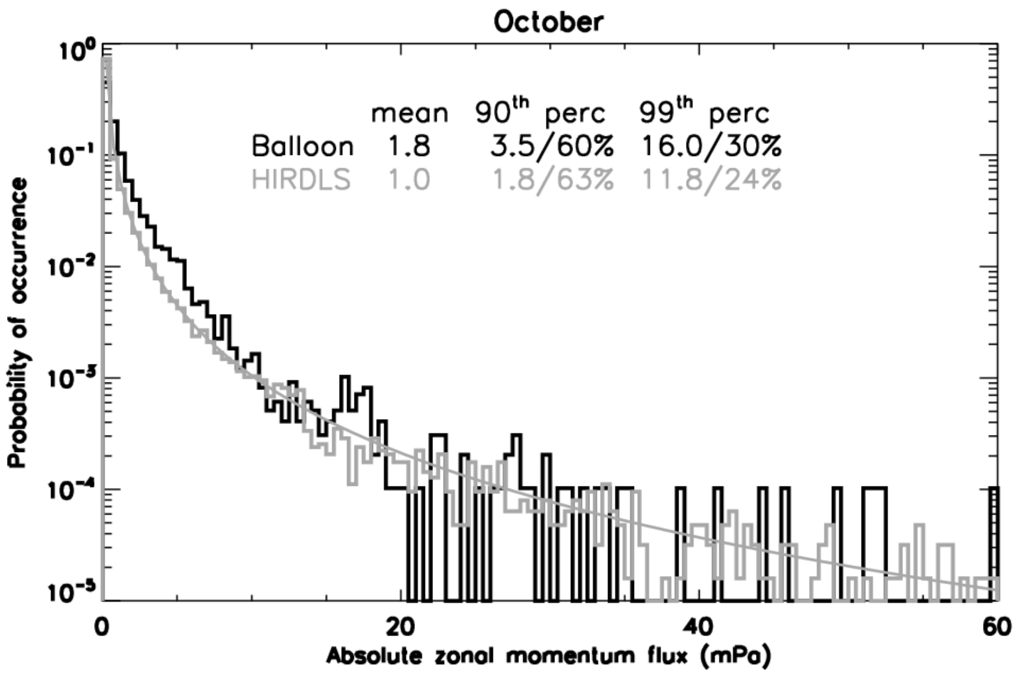
Systematic comparison → robust feature



Good agreement between two very different observational datasets (balloons and satellite obs.)

PDF akin to **lognormal distribution**

Hertzog et al 2012

Quantified also from other satellite observations and mesoscale simulations

Wright et al 2013,
Plougonven et al 2013

Use of intermittency to guide a parameterization

Non-orographic GW parameterization of LMD-Z

Stochastic formulation — Lott Guez 2013

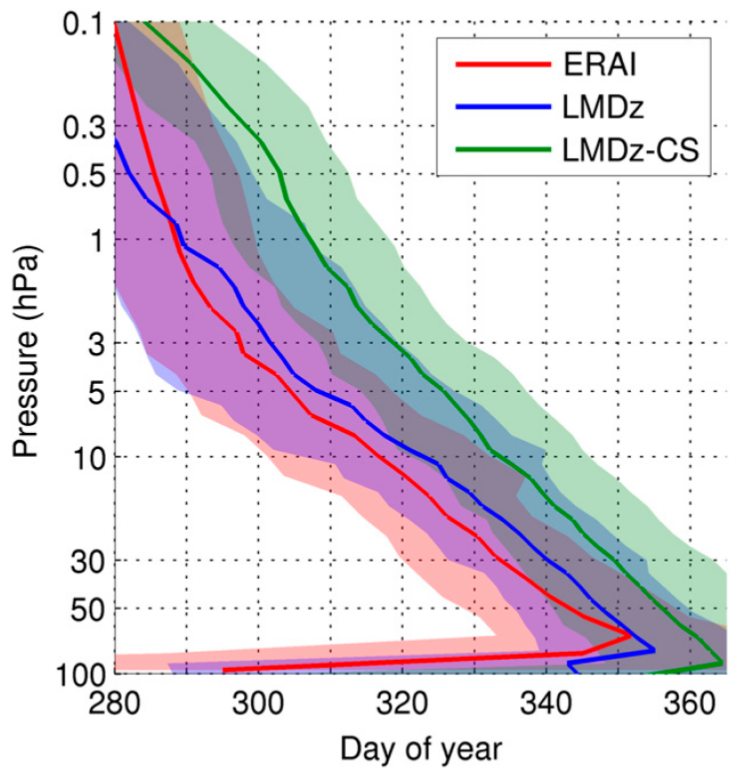
Jet / front sources based on theoretical studies — Lott et al 2010, 2012; de la Camara et al 2014, 2015

Resulting intermittency quantitatively compared with balloon observations

- changing the parameterized sources to be intermittent induced a major **improvement in the stratospheric circulation** :

Timely **breakdown of the Southern Polar Vortex**

→ Reduction of the ‘***Cold Pole***’ **bias**



Camara et al 2016

Intermittency in other parameterizations with beneficial impacts — Bushell et al 2015

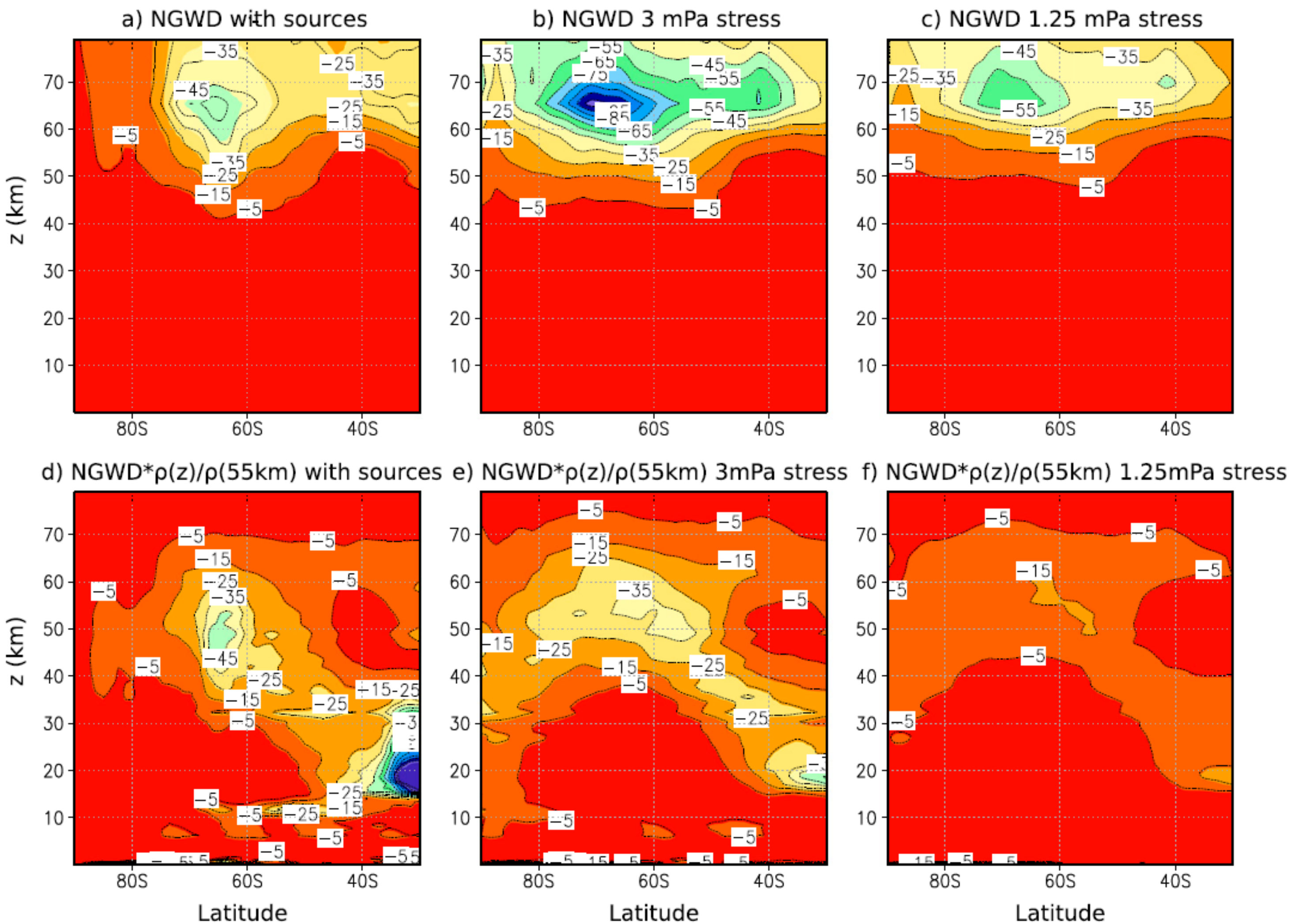
Impact : changes to the forcing of the large-scale circulation that could not be obtained with a constant source

Forcing in Southern high latitudes with intermittent source (left), and constant source (middle and right)

Reference, with LMDZ param. **with intermittency**	**Constant source**, equal to the mean in the reference	**Constant source, reduced** to obtain appropriate mesospheric forcing

Effect in mesosphere (drag) $(\mathrm{m\,s^{-1}\,day^{-1}})$

Effect in stratosphere (drag * ρ)



Encouraging, but there are **difficulties** :

there are **several ways to obtain this forcing**
(orographic drag, convectively generated waves, transience?)

Rolando et al 2017, Choi & Chun 2013,
Polichtchouk et al 2018, poster by G. Bölöni et al..

General issue with parameterizations (Mauritsen et al 2012...)

JOURNAL OF ADVANCES IN MODELING EARTH SYSTEMS, VOL. 4, M00A01. doi:10.1029/2012MS000154, 2012

Tuning the climate of a global model

Thorsten Mauritsen,[1] Bjorn Stevens,[1] Erich Roeckner,[1] Traute Crueger,[1] Monika Esch,[1] Marco Giorgetta,[1] Helmuth Haak,[1] Johann Jungclaus,[1] Daniel Klocke,[2] Daniela Matei,[1] Uwe Mikolajewicz,[1] Dirk Notz,[1] Robert Pincus,[3,4] Hauke Schmidt,[1] and Lorenzo Tomassini[1]

Received 27 January 2012; revised 22 June 2012; accepted 2 July 2012; published 7 August 2012.

[66] Climate models ability to simulate the 20th century temperature increase with fidelity has become something of a show-stopper as a model unable to reproduce the 20th century would probably not see publication, and as such it has effectively lost its purpose as a model quality measure. Most other observational datasets sooner or later meet the same destiny, at least beyond the first time they are applied for model evaluation. That is not to say that climate models can be readily adapted to fit any dataset, but once aware of the data we will compare with model output and invariably make decisions in the model development on the basis of the results. Rather, our confidence in the results provided by climate models is gained through the development of a fundamental physical understanding of the basic processes that create climate change. More than a

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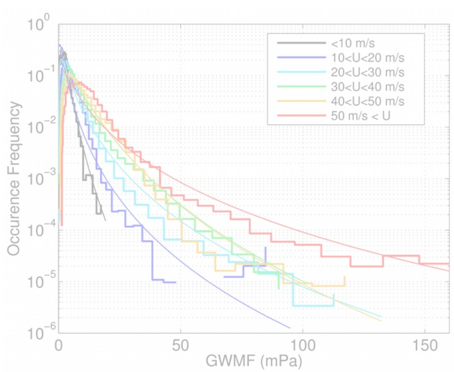
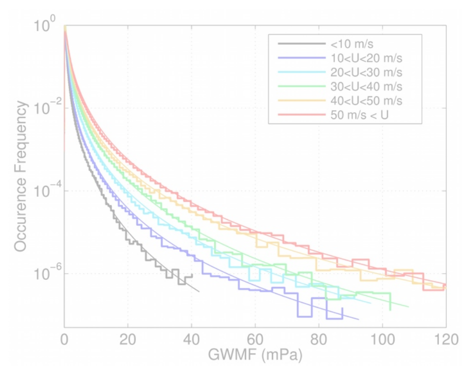
Useful to obtain **flow-relative information**

Balloons



WRF



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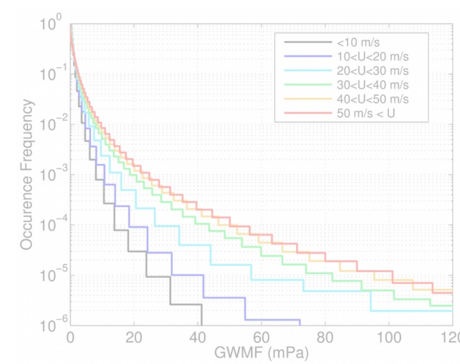

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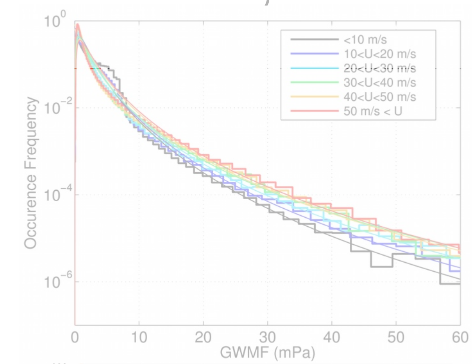

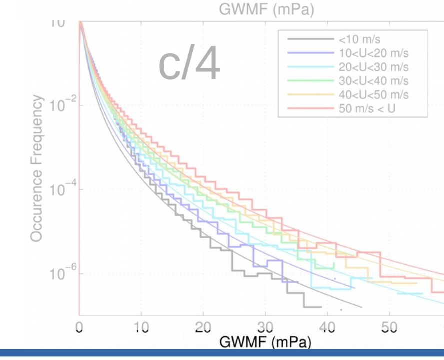

Plougonven et al 2017

How does knowledge of atmospheric gravity waves guide their parameterizations?

Other **possible discrepancies** between atmospheric GW and param.

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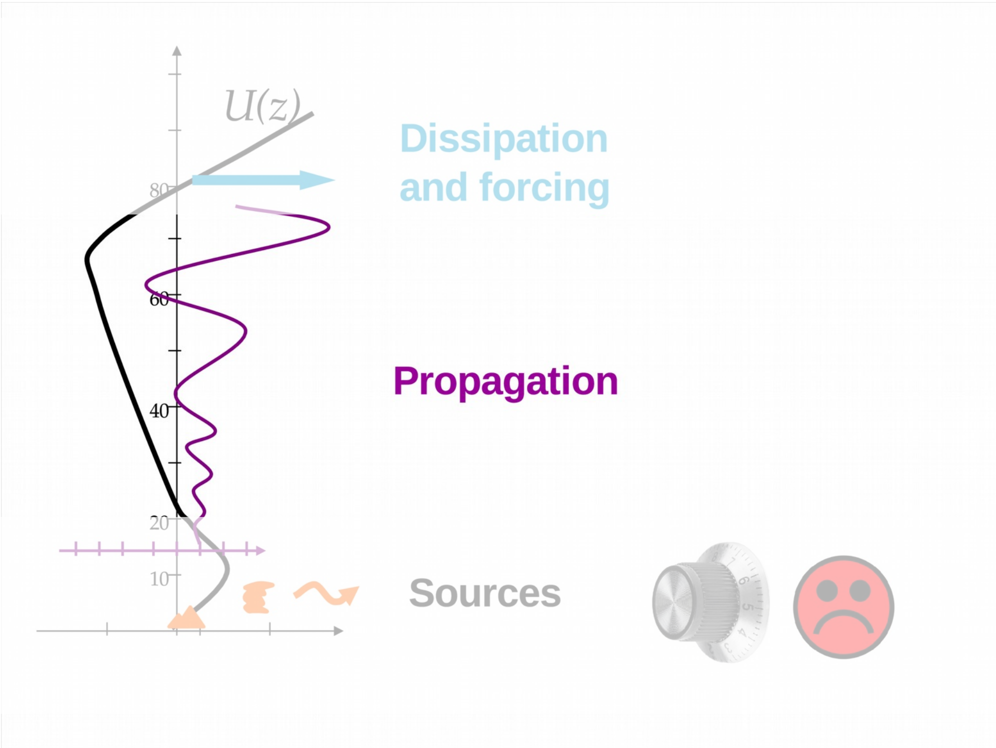


Columnar, instantaneous propagation

Only tropospheric sources

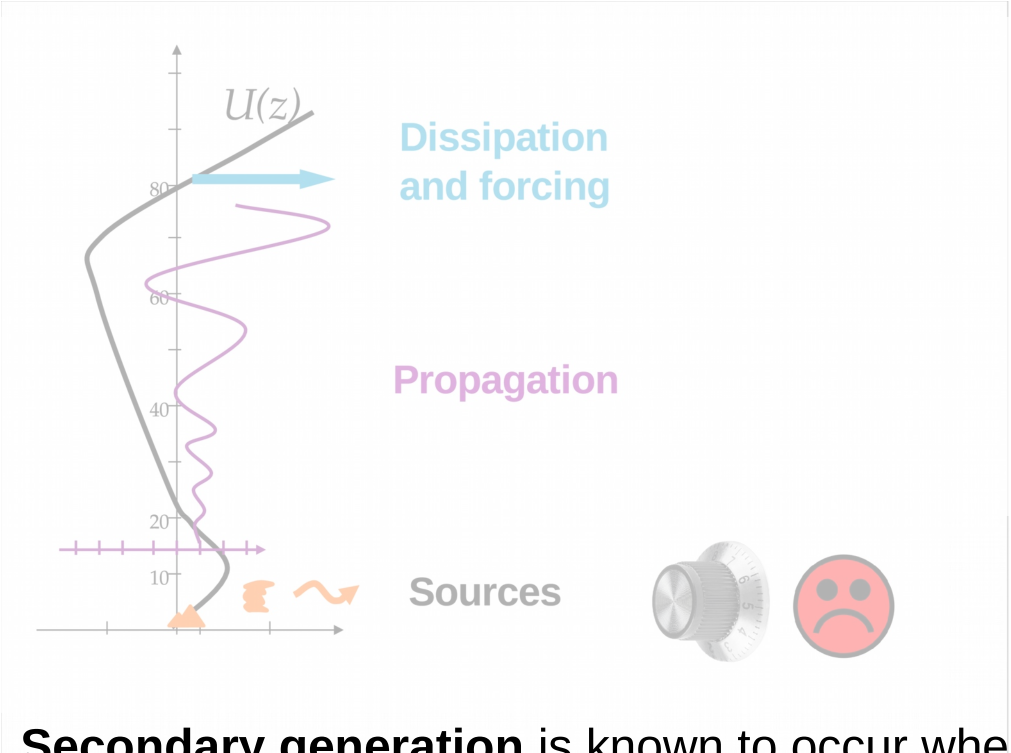
Lateral, transient propagation is seen to occur in the atmosphere

Convectively generated waves propagating into the stratospheric jet
Sato et al 2009, 2012, Thurairajah et al 2017

Propagation already in the lower stratosphere
Ehard et al 2017, Krisch et al 2017, Ern et al 2016, Plougonven et al 2017

Ray-tracing studies offline, and implementations of ray-tracing parameterizations
Hasha et al 2008, Achatz et al 2010, Senf and Achatz 2011, Bölöni et al 2016
Song and Chun 2008, Choi and Chun 2013, Amemiya and Sato 2016

Other **possible discrepancies** between atmospheric GW and param.



Columnar, instantaneous propagation

Only tropospheric sources

Secondary generation is known to occur when waves break

Observed from radiosondes during PyrEx and recent campaigns (DeepWave)
Scavuzzo et al 1998, Bossert et al 2017

Theoretical frame as response to localized body forces
Vadas et al 2001, 2003

High resolution simulations
Fritts et al 2015

GW permitting AGCM displaying active contribution from secondary generation
Becker and Vadas 2018

Summary

Relation between atmos. GW and their param. is ***not straightforward***

Observed waves : **upper bound** for what should be parameterized

Parameters set by ***tuning***, constrained by targeted features of middle atm.

Criterion not sufficient (Mauritsen et al 2012)
Multiple ways to satisfy comparison with a given dataset

Example of *intermittency* :
Incorporating ***robust features*** **which impact the resulting forcing** is a priori beneficial (e.g. intermittency : redistributes the forcing in the vertical in a way that can not be obtained with a constant source)

Importance of identifying **flow-relative relations**

Global observations allow to test ability of param. to reproduce obs. GWMF (e.g. Trinh et al 2016)

Sets **high expectations on process studies** to quantify GW processes in their full complexity ;
Understanding necessary to then decide which process needs to be retained in parameterizations (which **necessarily simplify** greatly)

Processes that lie outside of the usual GW parameterization framework :
lateral propagation, transience, secondary generation

Multiple activities to explore these :

- hierarchy of models/approaches to explore the effects of neglected processes

  Tools to quantify the effects of transience and **<u>lateral propagation</u>**

  MS GWaves

- following lifecycle of GW packets **from tropopshere to mesosphere**

  Campaigns like Deep Wave, SouthTrac

- high resolution simulations following breaking through scales

  exploration of **secondary generation**,
  rich, complex dynamics

  Fritts et al 2015

STRATEOLE 2

http://strateole2.aeris-data.fr/

- French-US initiative focused on equatorial UTLS
- **Science objectives**
    - **Dynamics** of TTL and tropical lower strat.
    - **Transport and dehydration**
    - Satellite cal/val: **Aeolus**
    - Improve **operational forecasts**
- Stratéole-2 campaign schedule
    - **Nov. 2019 – Feb. 2020 : rehearsal, 6-8 balloons**
    - Fall 2021: 1st main campaign, 20 balloons
    - Fall 2024: 2nd main campaign, 20 balloons

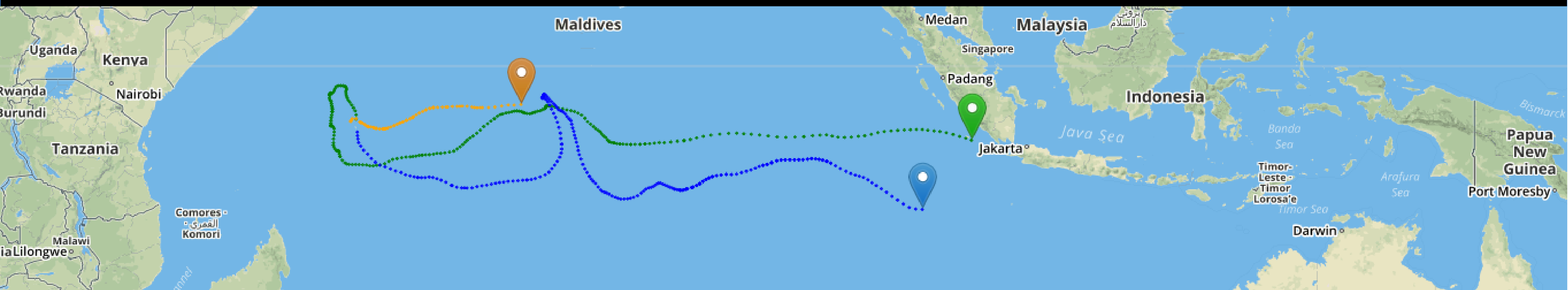
- Balloons launched from Seychelles Islands (5°S)

- Instruments developed or adapted for these campaigns to measure H20, O3, particles, cirrus, fine-scale temperature anomalies

Strateole 2 on Twitter

https://twitter.com/strateole_2/status/1194413435351683073

Thank you for your attention



How does knowledge of atmospheric gravity waves guide their parameterizations?, R. Plougonven, A. de la Cámara, A. Hertzog and F. Lott, in revision for Quart. J. Roy. Met. Soc.

Encouraging, but there are difficulties :

there are **several ways to obtain this forcing**
(orographic drag, convectively generated waves, transience?)

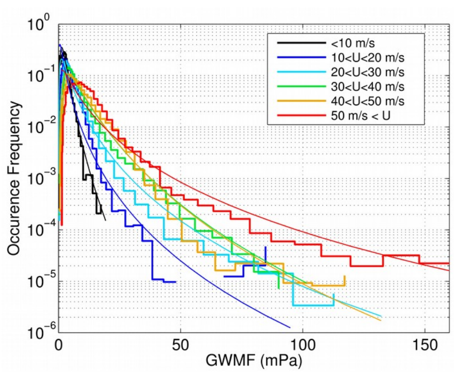
Rolando et al 2017, Choi & Chun 2013, poster by G. Bölöni et al..

Still more to learn from observations + modelling etc...

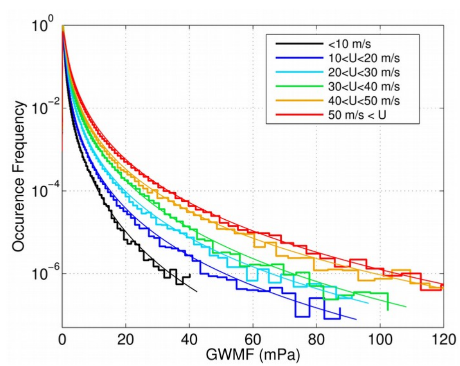
Useful to obtain **flow-relative information**

PDF of GWMF conditional on background flow :
Consistent, robust dependence in obs. And models. Params ?

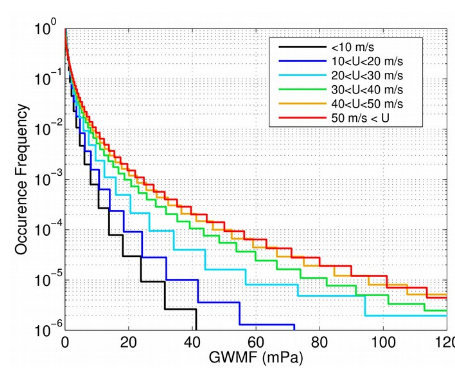
Balloons



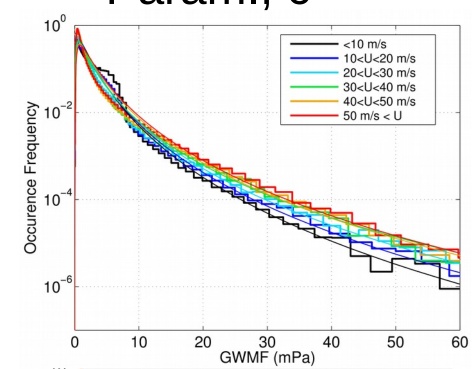
WRF

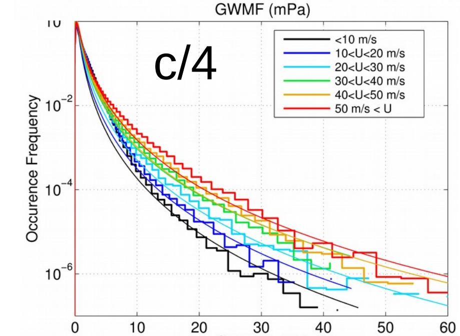


ECMWF Op.



Param., c





Plougonven et al 2017