Atmospheric Sciences in Frankfurt

Institute for Atmospheric and Environmental Sciences
Prof. Dr. Ulrich Achatz

4. Februar 2022

Goethe University in Frankfurt

Frankfurt Region with ~3m inhabitants

- centrally placed in Europe
- very international by tradition
- history at work

Goethe University

full-scale university

16 departments

ca. 46.000 students

ca. 7.500 international students

5.000 employees

3 major campus sites across the city

Institute for Atmospheric & Environmental Sciences (IAU)

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Location

- Natural Sciences Campus (Riedberg)
- Geosciences/Geography department

Structure

- 5 professorships
- several senior researchers
- 8 research groups
- ca. 70 students (MSc & BSc Meteorology)

Department leader in research budget

- funding DFG, EU, DWD, VESRI etc.
- leading or contributing to various major coordinated projects (TPChange, MS-GWaves, CLOUD …)

What makes us special?

strong footing **in all** of

- **theory**
- **modelling**
- **experimental research**

emphasis on the **physical basis**

strong connection to **DWD**

Research Groups

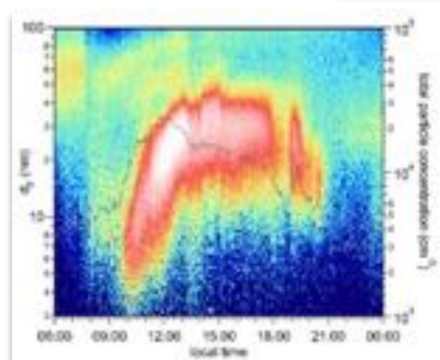
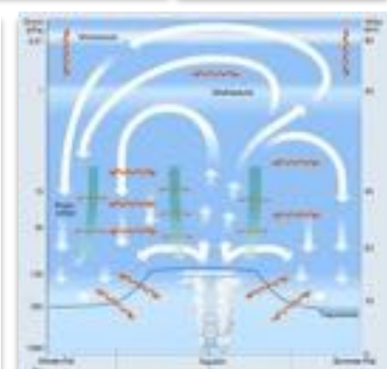

Atmospheric Environmental Analytics (A. Vogel)

Chemical characteristics of atmospheric aerosols

- Natural background
- Anthropogenic effects
- Health aspects


Experimental Atmospheric Research (J. Curtius & A. Engel)

- Aerosols
- Ice Nucleating Particles
- Atmospheric Circulation (Tracers)

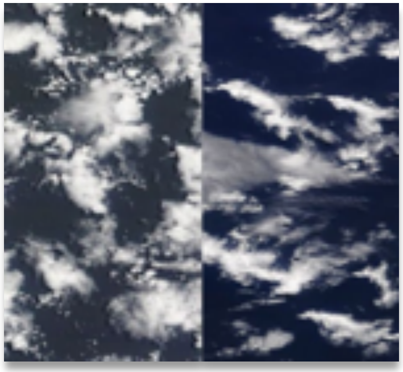
Research Groups

Atmospheric Physics and Climate (A. Possner)

physics and dynamics of clouds

cloud impact on radiation

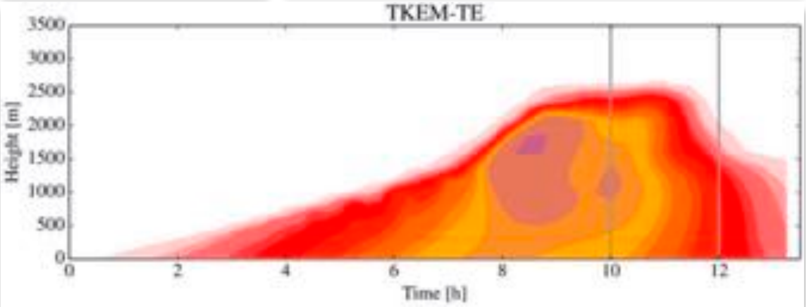
energy meteorology



Boundary-Layer Meteorology (J. Schmidli)

Turbulence & BL in weather & climate models

- BL over complex terrain
- Parameterization of
  - turbulence,
  - convection
  - small-scale orography



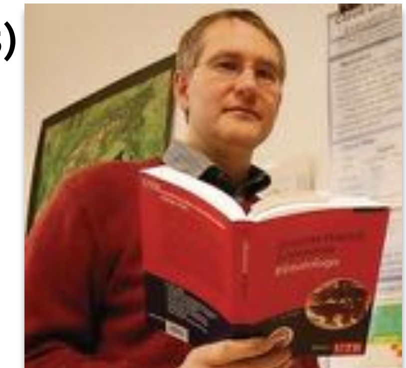
Research Groups

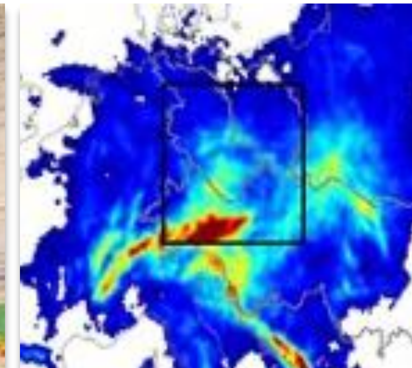
Mesoscale Meteorology & Climate (B. Ahrens)

interaction components of the climate system

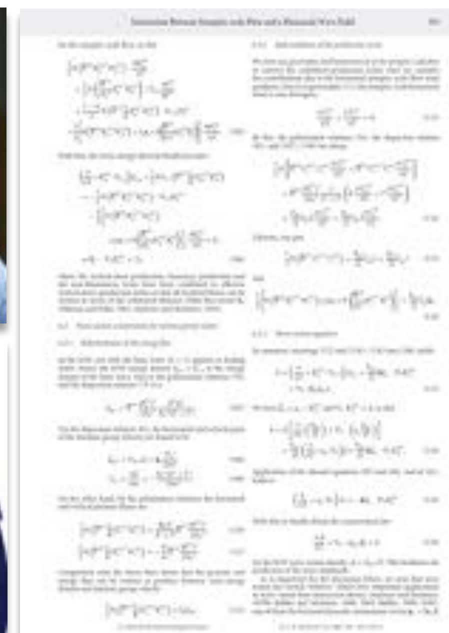
improvement climate projections

climate impact research





Theory Atm. Dynamics & Climate (U. Achatz)



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Modelling of atmospheric dynamics needs subgrid-scale (SGS) parameterization:

- Synoptic-scale eddies ($L < 5000$km) in planetary-scale model
- Mesoscale eddies ($L < 1000$km) in low-resolution climate model
- Turbulence ($L < 1$km) in LES

Robustness variation of external boundary conditions requires minimal tuning:

- Coupling ocean etc.
- Paleoclimatology
- Climate change

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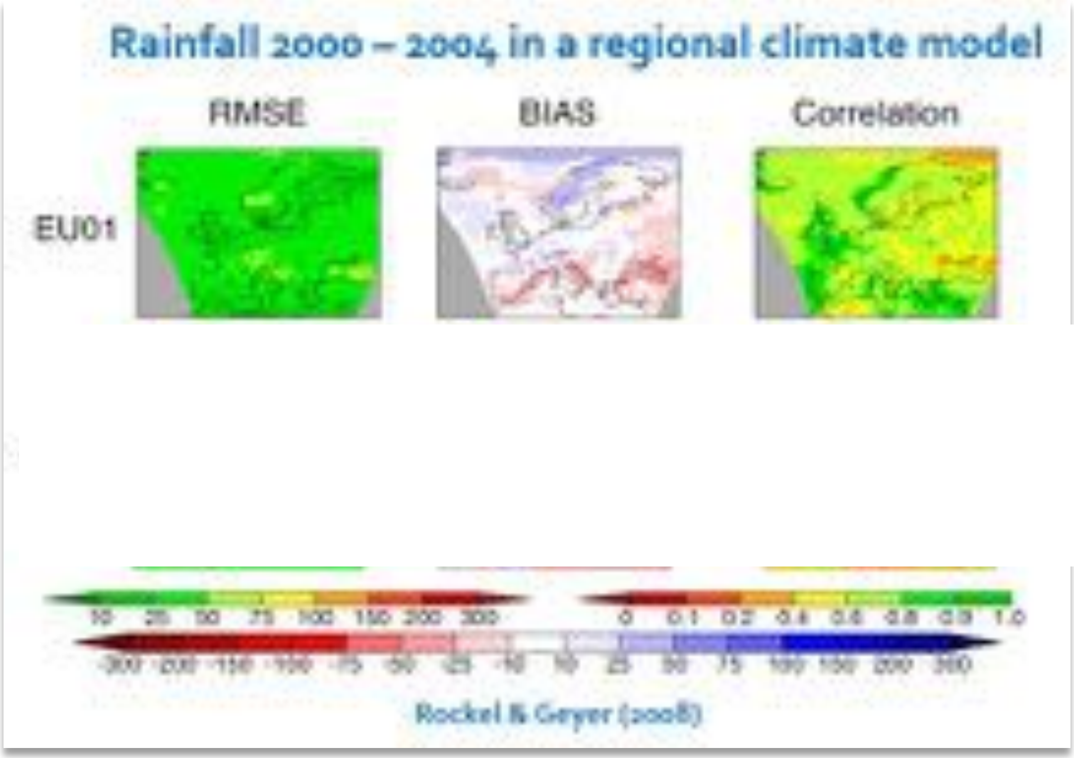

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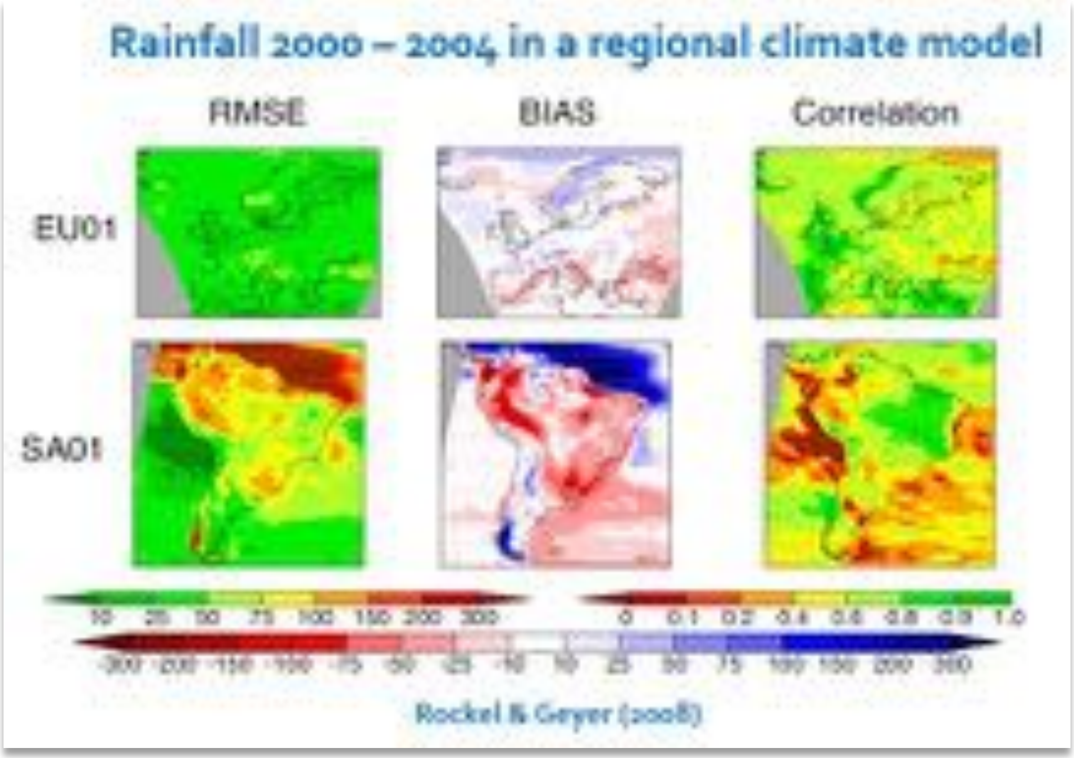
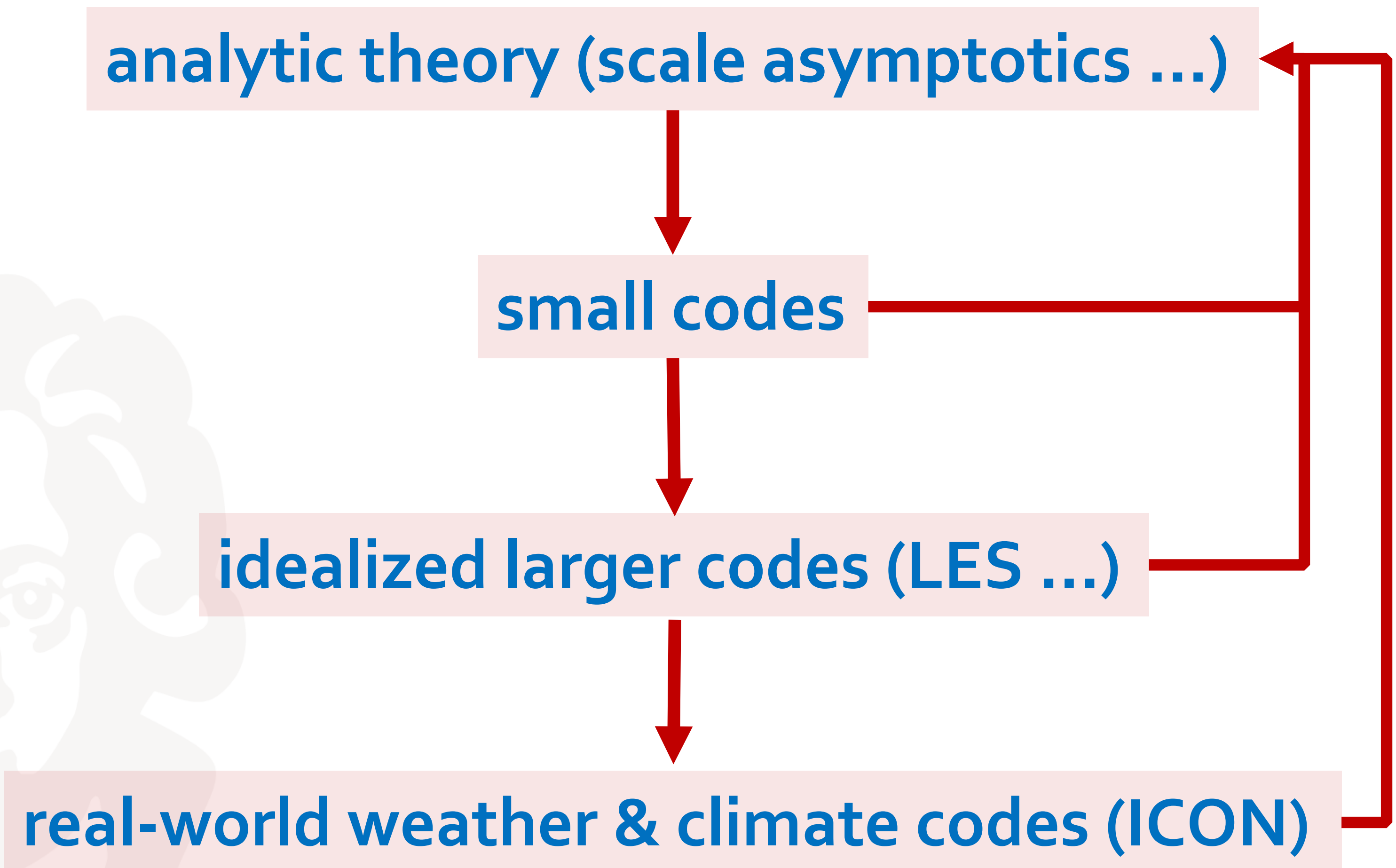
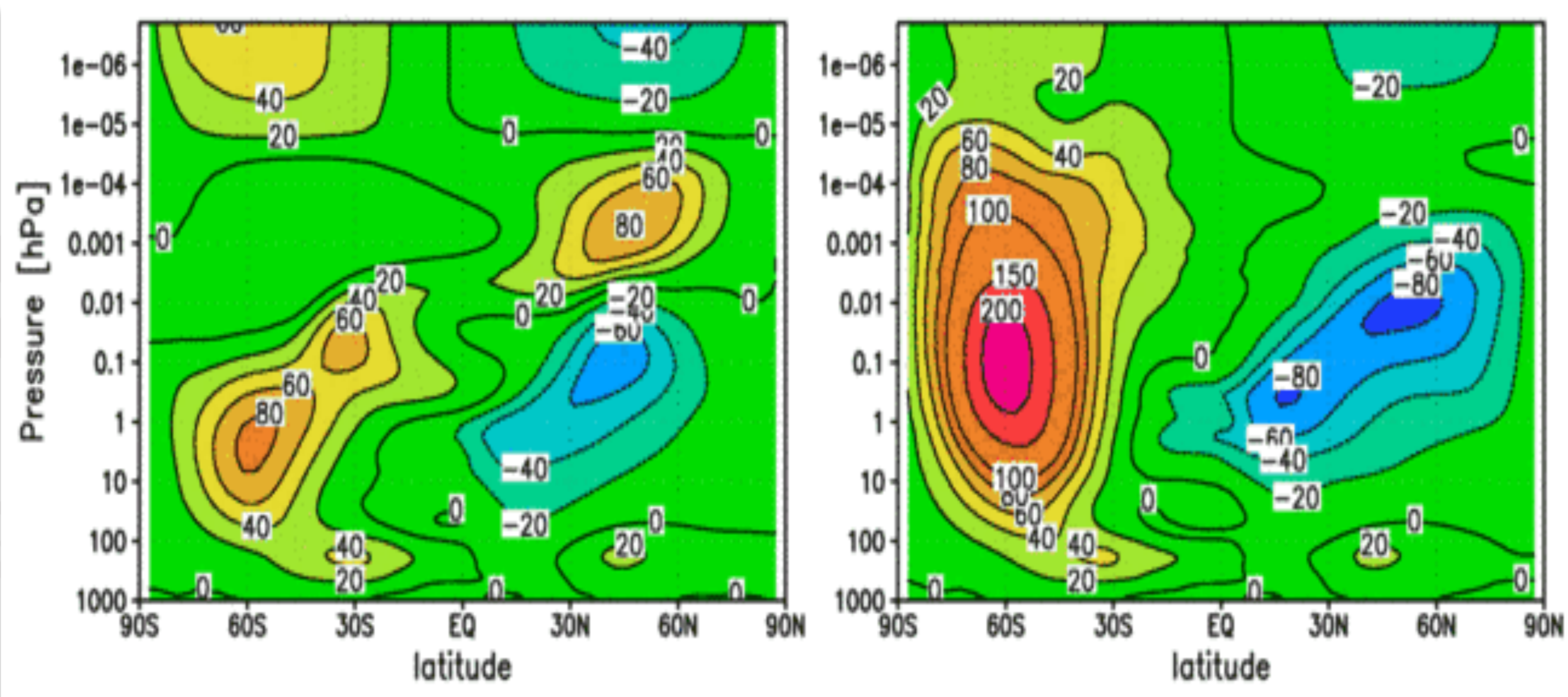


Theory Atmospheric Dynamics & Climate:
General Strategy



Zonal winds (westerlies)

Schmidt et al (2006)



With GW parameterization

Without GW parameterization

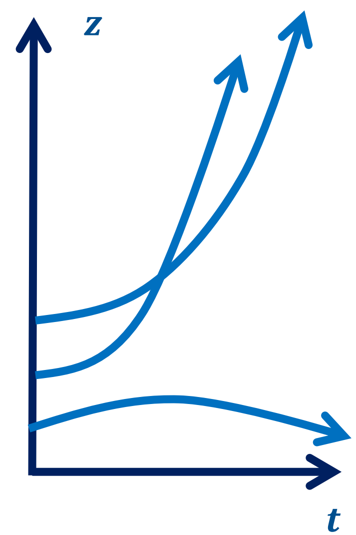
Spectral description (Dewar 1970, Dubrulle & Nazarenko 1997, Bühler & McIntyre 1999, Hertzog et al 2000, Muraschko et al 2015):
wave-action density $\mathcal{N}(m, z, t)$ so that (e.g.)

$$E_{GW}(z,t) = \int dm\, \mathcal{N}(m,z,t)\, \hat{\omega}(m)$$

Along **rays,** defined by $dz/dt = c_g$

$$\frac{dm}{dt} = -k\frac{\partial U}{\partial z}, \qquad \frac{d\mathcal{N}}{dt} = 0$$

Mean flow: $$\frac{\partial U}{\partial t} = -\frac{1}{\bar{\rho}}\frac{\partial}{\partial z}\left(\bar{\rho}\,\overline{u'w'}\right) = -\frac{1}{\bar{\rho}}\frac{\partial}{\partial z}\left(\int dm\, c_g k\, \mathcal{N}\right)$$



Generalization to 3D straightforward

Theory Atmospheric Dynamics & Climate:
e.g. Gravity Waves (Muraschko et al 2015)

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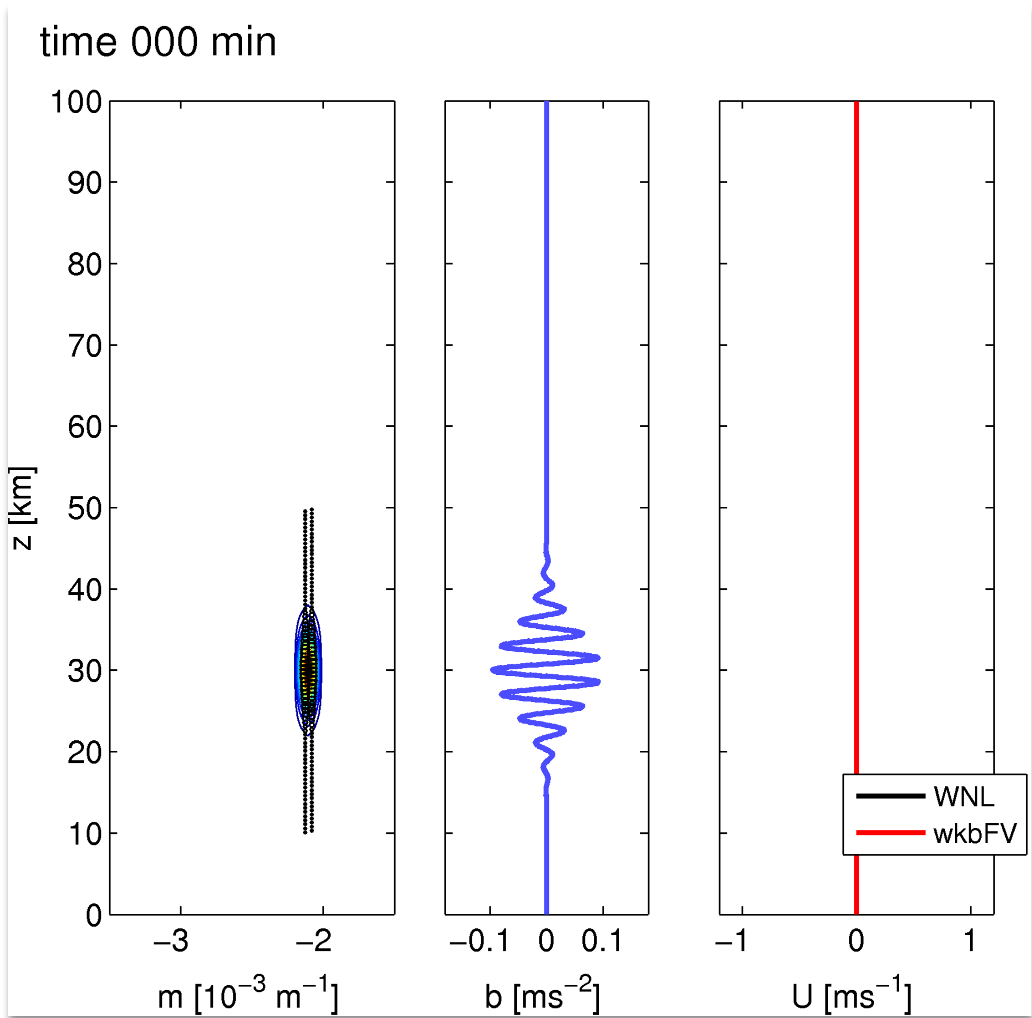
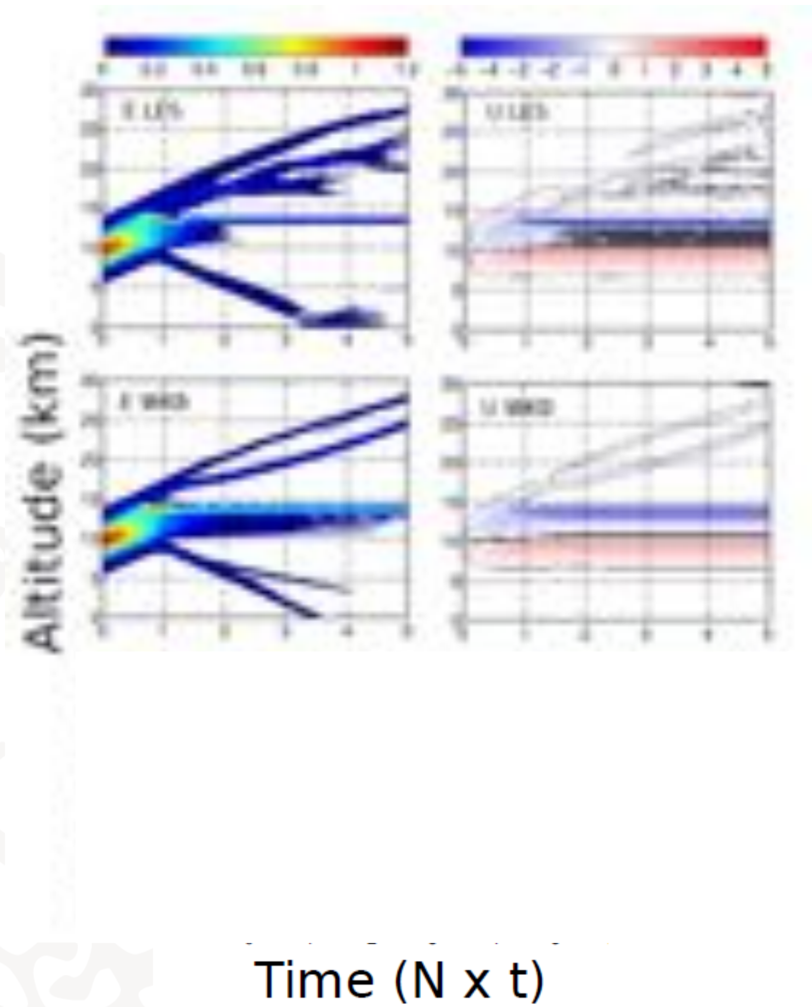
hydrostatic wave packet



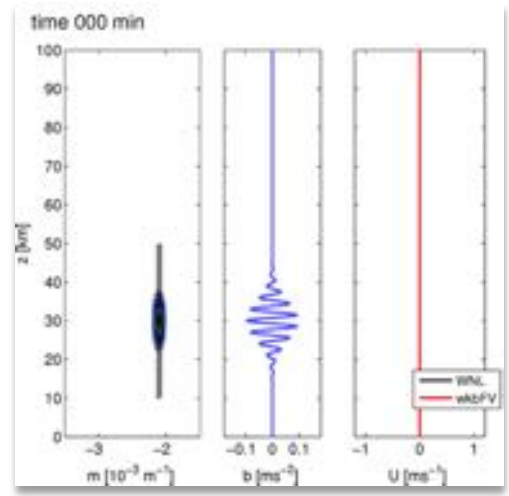
No turbulence taken into account!

Theory Atmospheric Dynamics & Climate:
e.g. Gravity Waves (Bölöni et al 2016)

static instability non-hydrostatic wave packet



LES
(wave-resolving)



MS-GWaM
(with turbulence param.)

Theory Atmospheric Dynamics & Climate:
e.g. Gravity Waves (Bölöni et al 2016)

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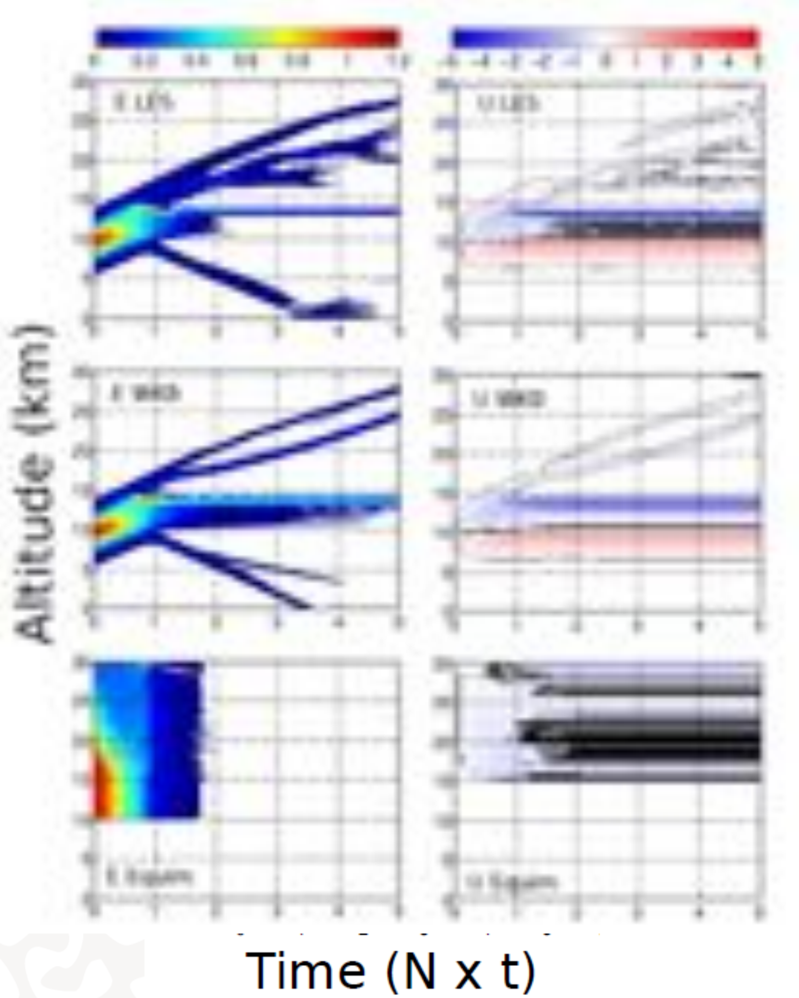

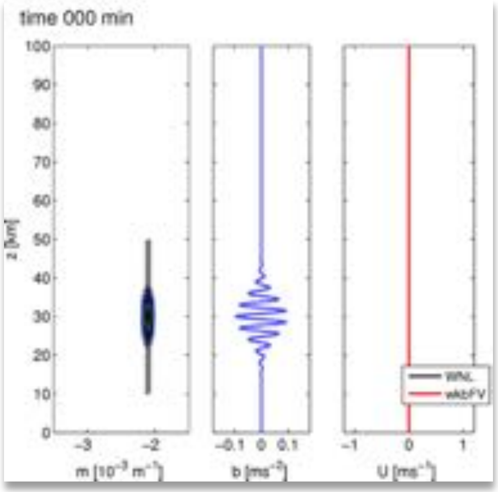

LES
(wave-resolving)

MS-GWaM
(with turbulence param.)

steady-state
(classic GW parameterization)

Theory Atmospheric Dynamics & Climate:
e.g. Gravity Waves (Böloni et al 2021, Kim et al 2021)

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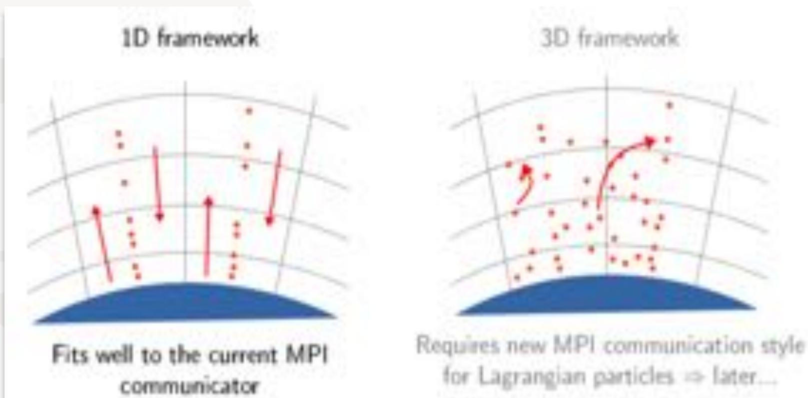
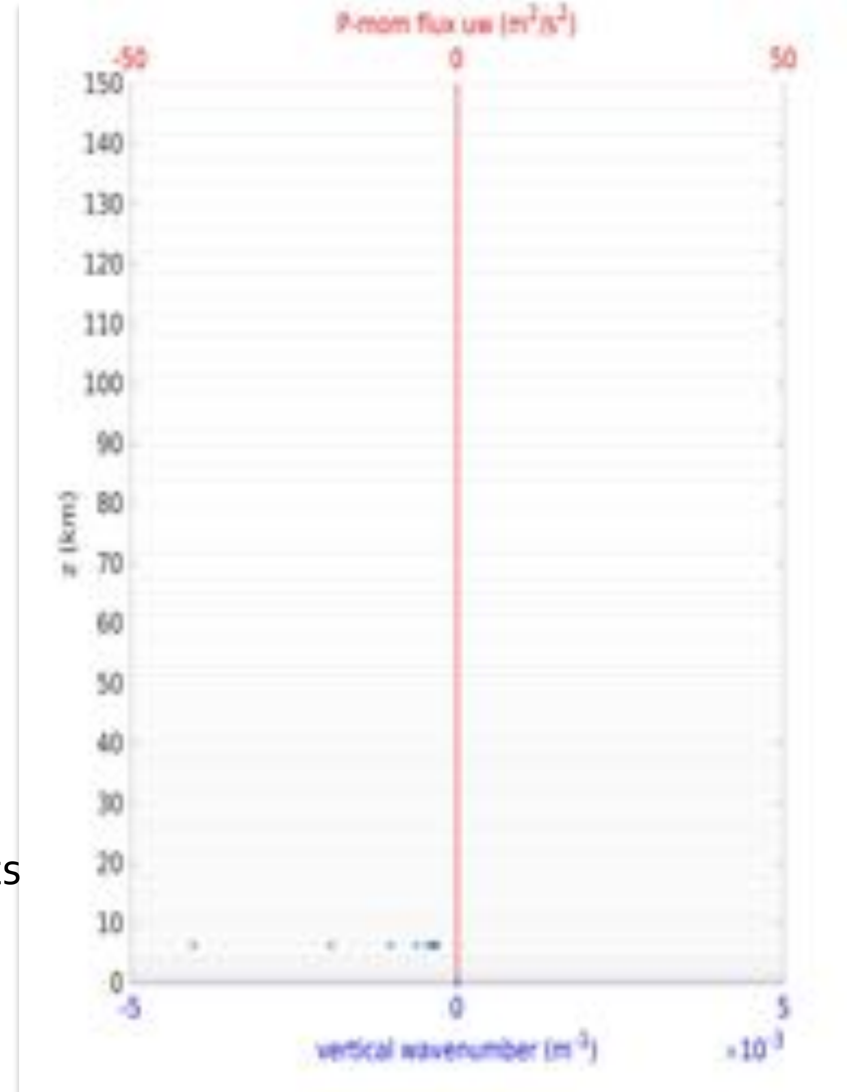
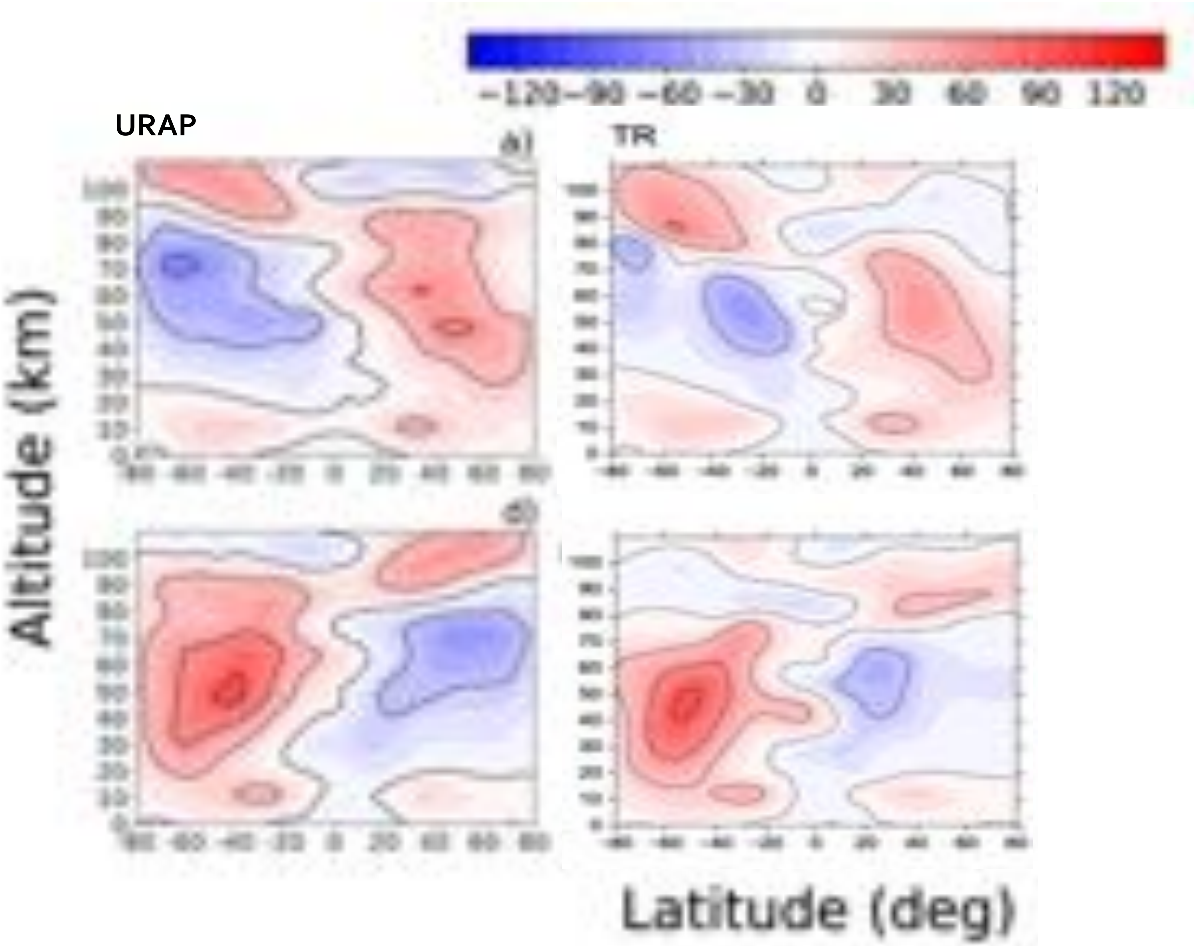
UA-ICON
(Borchert et al 2019)





- **constant launch-level source** for jets & fronts etc.
- **flow-dependent source for convection** (Song & Chun 2005)
- mountain waves via Lott & Miller (1997)

Theory Atmospheric Dynamics & Climate:
e.g. Gravity Waves (Bölöni et al 2021, Kim et al 2021)



Zonal-mean zonal wind

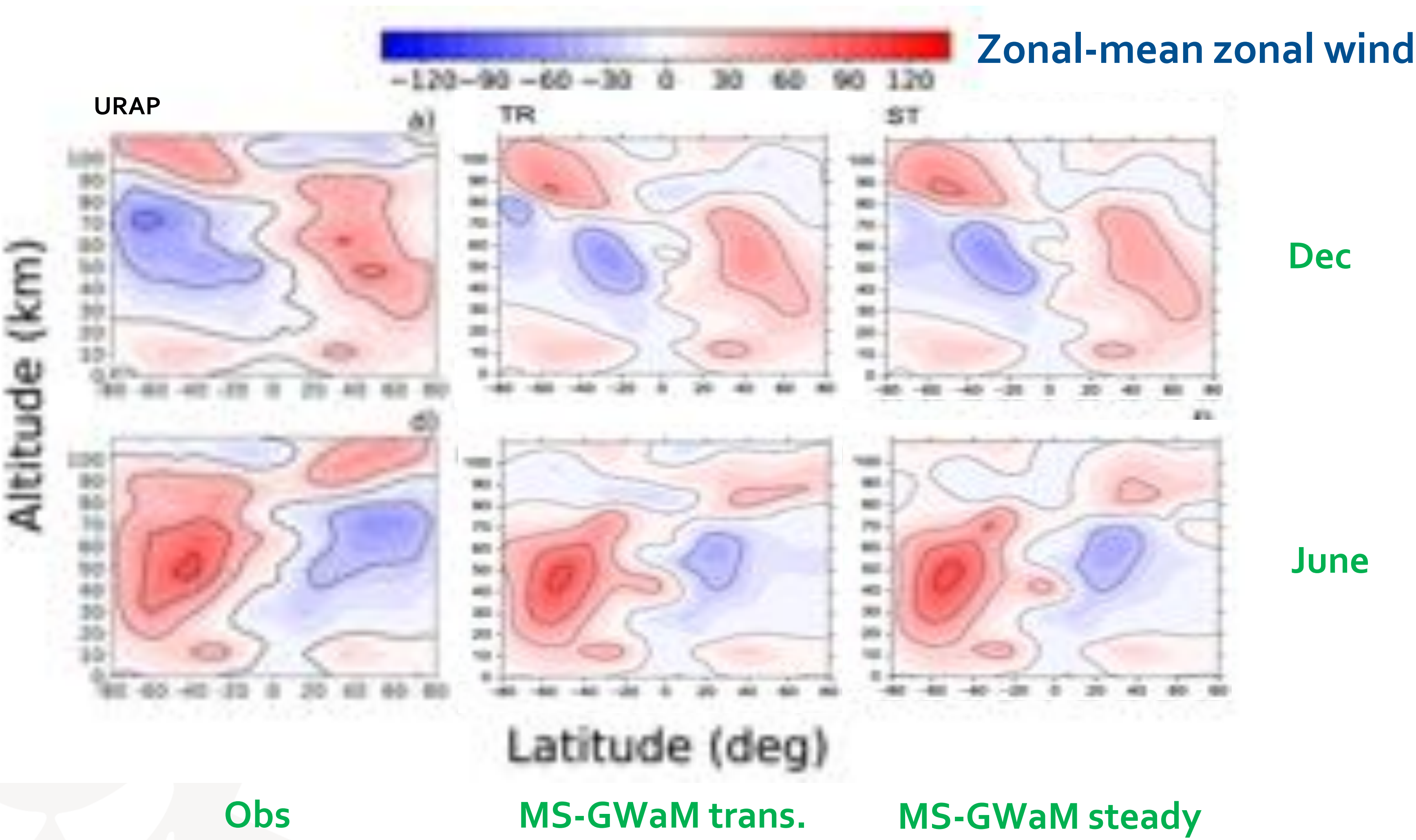
Dec

June

Obs

MS-GWaM trans.

Theory Atmospheric Dynamics & Climate:
e.g. Gravity Waves (Bölöni et al 2021, Kim et al 2021)



Theory Atmospheric Dynamics & Climate:
e.g. Gravity Waves (Bölöni et al 2021, Kim et al 2021)

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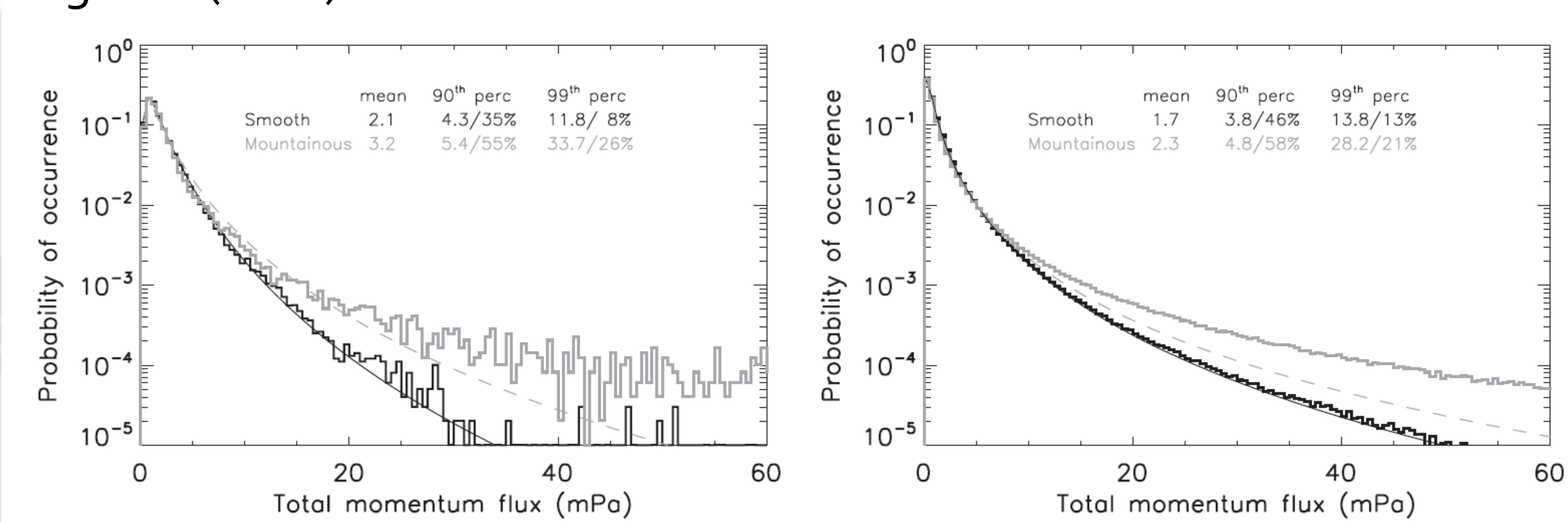
PDF GW momentum flux

Hertzog et al (2012) Vorcore WRF



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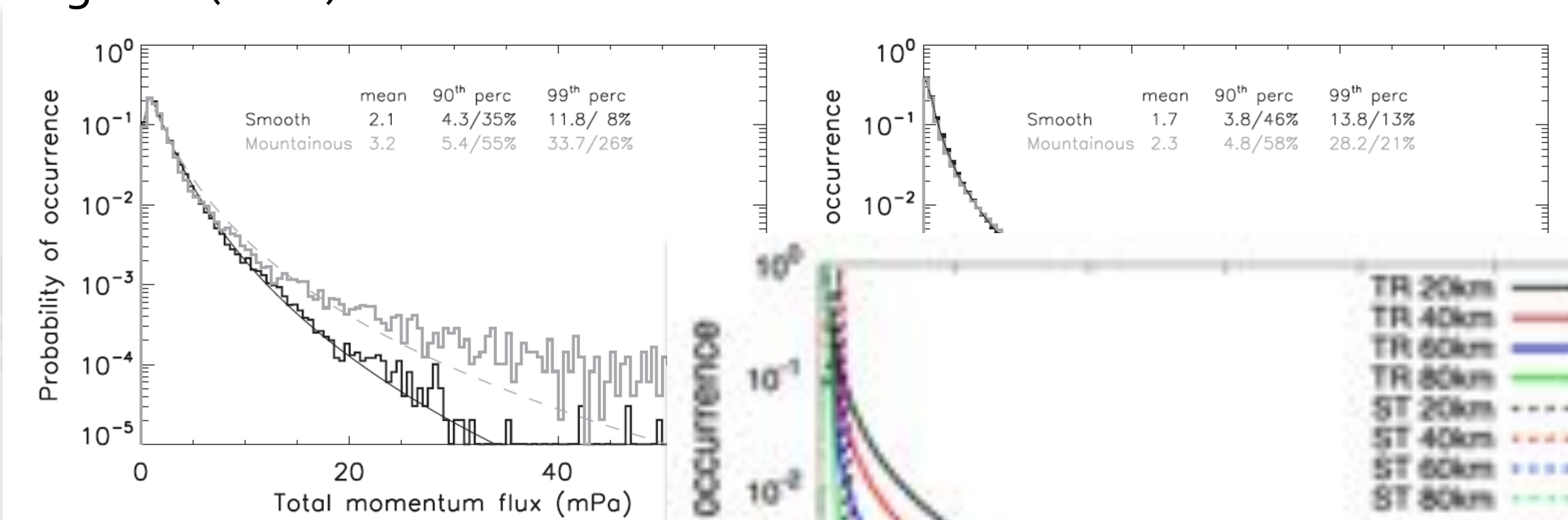

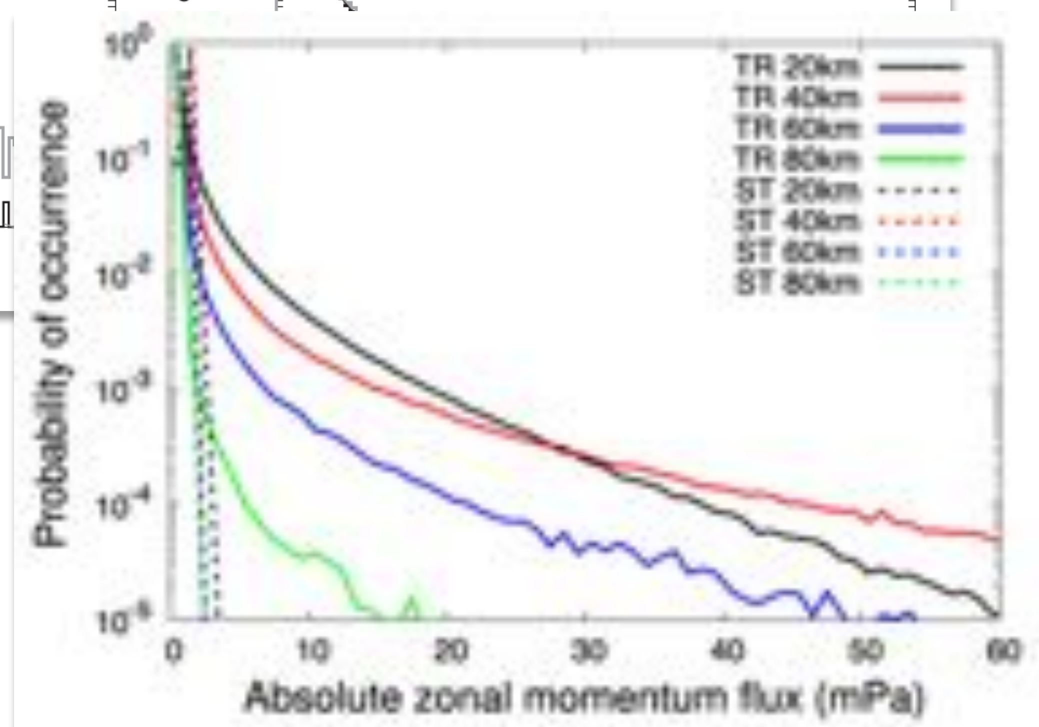

Bölöni et al (2021):
65°S – 50°S in Oct

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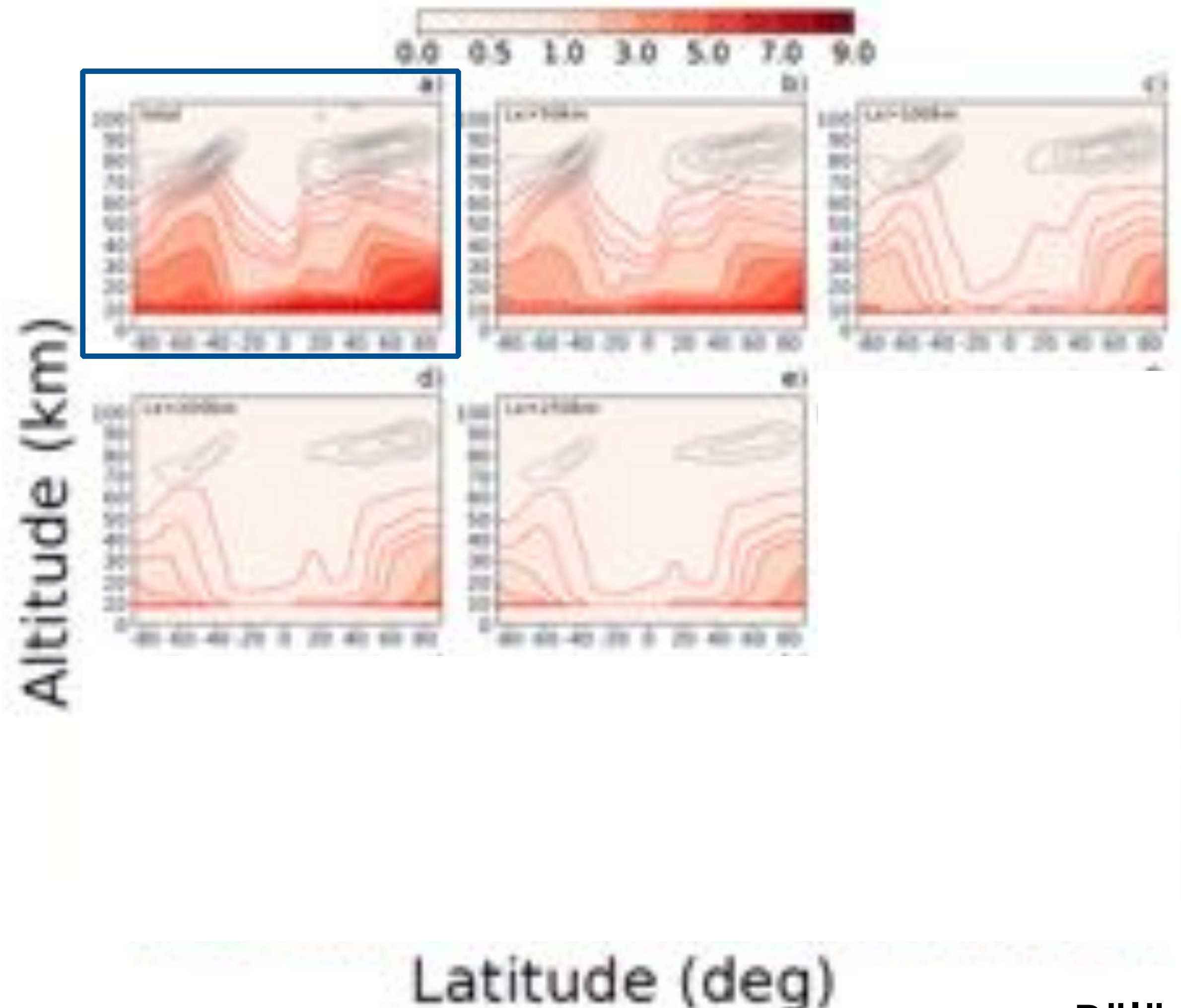
Which horizontal scales matter?

June

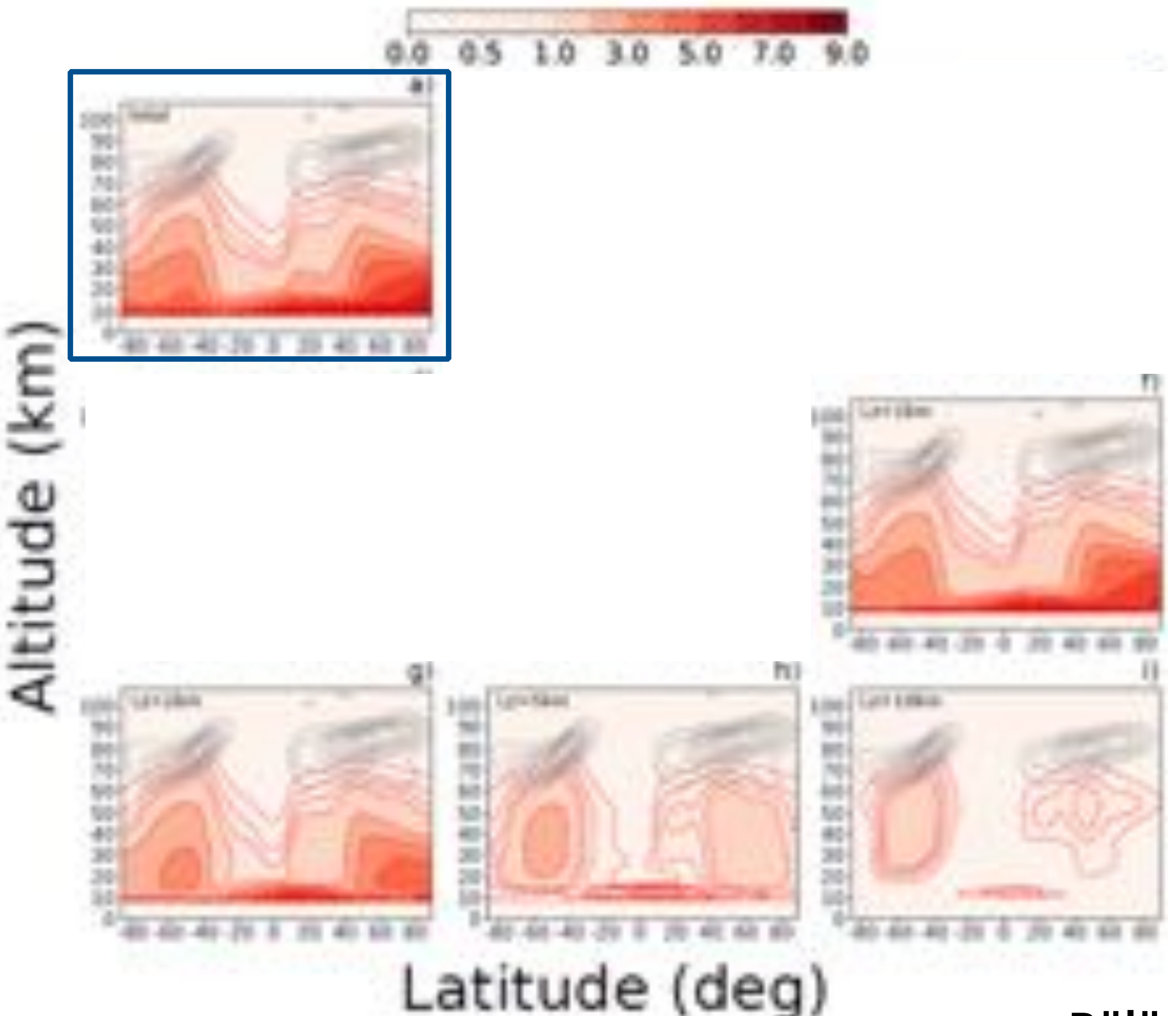


Bölöni et al (2021)

Theory Atmospheric Dynamics & Climate:
e.g. Gravity Waves (Bölöni et al 2021, Kim et al 2021)

Which verical scales matter?

June



Bölöni et al (2021)

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Is it worth the effort?

	UA-ICON / MS-GWaM (3D)
Δx/km	160
Δz/km	0.02 (BL) – 0.7 (ST) – 4.5 (top)
relative increase comp. time (compared to ICON with classic GWP - Orr et al 2010)	**10**

UA-ICON / MS-GWaM is

- **more expensive** than UA-ICON with **classic GWP**, but

Theory Atmospheric Dynamics & Climate:
e.g. Gravity Waves (Bölöni et al 2021, Kim et al 2021)

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Is it worth the effort?

	UA-ICON / MS-GWaM (3D)	UA-ICON GW resolving
Δx/km	160	5
Δz/km	0.02 (BL) – 0.7 (ST) – 4.5 (top)	0.02 (BL) – 0.2 (ST) – 0.2 (top)
relative increase comp. time (compared to ICON with classic GWP - Orr et al 2010)	**10**	**240000**

UA-ICON / MS-GWaM is

- **more expensive** than UA-ICON with **classic GWP**, but
- **much cheaper** than **wave resolving UA-ICON**

Theory Atmospheric Dynamics & Climate:
e.g. Gravity Waves: Planned and Present Work

DFG TRR 181 (HH& HB):
- Horizontal GW propagation
- Validation against measurements

DataWave (VESRI):
- Orographic GWs in MS-GWaM
- Efficiency increase by machine learning

DFG TRR TPChange (with J. Schmidli & …):
- GWs from jets & Fronts
- GW interaction with turbulence
- GW impact on tracers
- GW impact on ice clouds

BMBF ROMIC 2: GW impact on the QBO










Contact

https://www.uni-frankfurt.de/41121398/Institut_für_Atmosphäre_und_Umwelt (German)
https://www.goethe-university-frankfurt.de/45678073/Institute_for_Atmospheric_and_Environmental_Sciences? (English)

Questions?