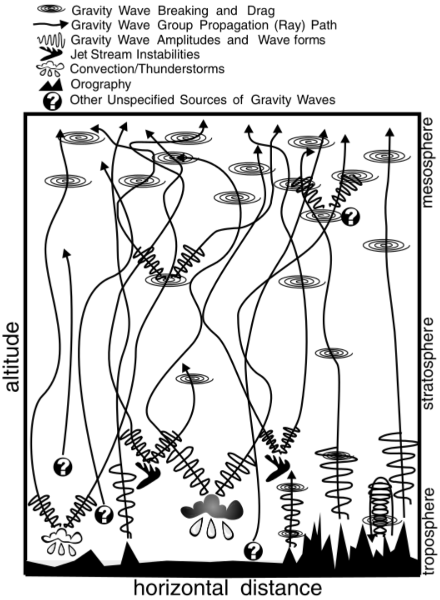
Towards the implementation of a transient gravity wave drag parameterization in ICON

Gergely Bölöni, Yong-Ha Kim, Sebastian Borchert, Ulrich Achatz

Motivation



Atmospheric gravity waves (GW)

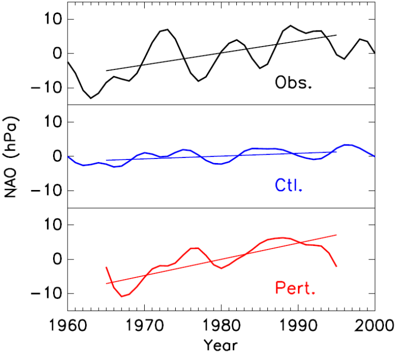
- main sources: orography, convection, jets/fronts
- mainly vertical energy (momentum) transport with $\vec{c}_g$ $\Rightarrow$ interaction with the large scale flow ("drag")
- wave breaking $\Rightarrow$ turbulence, dissipation, energy transfer to large scale flow ("drag")
- impact: GWs drive the middle atmosphere (stratosphere & mesosphere) $\Rightarrow$ feedback on the troposphere

(Kim et al., 2003)

Motivation

Importance of atmospheric gravity waves (GW) in weather & climate

- Mesospheric jet reversal, summer cold pole (Holton, 1983)
- Quasi Biennual Oscillation (QBO) (Butchart, 2014)
- Sudden Stratospheric Warmings (Northern Hemisphere)
- North Atlantic Oscillation (NAO) (downward control)



Obs

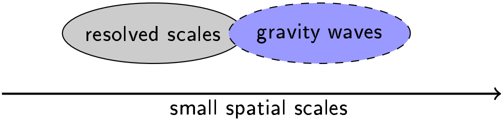
Model with poor MA

Model with improved MA

Scaife et al. (2005)

Motivation for a transient GW scheme

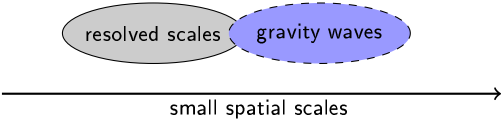
Parametrization of atmospheric GWs



- GWs are not fully resolved by GCMs and NWP models $\Rightarrow$ parametrization $\Rightarrow$ (Wentzel–Kramers–Brillouin) WKB theory

Motivation for a transient GW scheme

Parametrization of atmospheric GWs



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  ⇒ (Wentzel–Kramers–Brillouin) WKB theory
- Current parametrizations: **steady state** approximation
  ⇒ instantaneous propagation till breaking/critical layer
  ⇒ instantaneous drag via wave breaking only!

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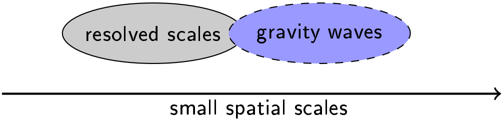

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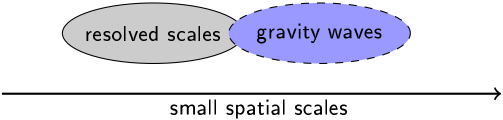

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  ⟺ transient propagation

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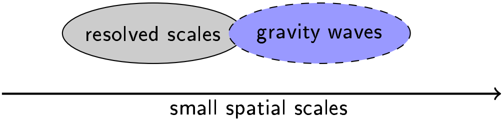

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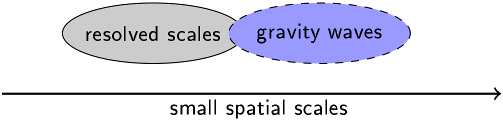
  $\Rightarrow$ instantaneous drag via wave breaking only!
- Proposed improvement: **transient** (direct) GW-meanflow interaction
  $\Longleftrightarrow$ transient propagation $\Longleftrightarrow$ continuous drag and feedback on the wave field

Motivation for a transient GW scheme

Parametrization of atmospheric GWs



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- Proposed improvement: **transient** (direct) GW-meanflow interaction
  ⇐⇒ transient propagation ⇐⇒ continuous drag and feedback on the wave field + drag through wave breaking

Motivation for a transient GW scheme

Wave field

Transient parametrization (Achatz et. al, 2017)

$$\frac{\mathrm{d}z}{\mathrm{d}t} = \mp \frac{Nkm}{(k^2+m^2)^{3/2}} \equiv c_{gz}$$

$$\frac{\mathrm{d}m}{\mathrm{d}t} = \mp \frac{k}{(k^2+m^2)^{1/2}} \frac{\mathrm{d}N}{\mathrm{d}z} - k\frac{\mathrm{d}u_b}{\mathrm{d}z} \equiv \dot{m}$$

$$\frac{\mathrm{d}\mathcal{A}}{\mathrm{d}t} = -\mathcal{A}\frac{\partial c_{gz}}{\partial z} \quad \left(\frac{\mathrm{d}}{\mathrm{d}t} = \frac{\partial}{\partial t} + c_{gz}\frac{\partial}{\partial z}\right)$$

Mean flow

$$\frac{\partial u_b}{\partial t} = -\frac{1}{\bar{\rho}}\frac{\partial}{\partial z}(kc_{gz}\mathcal{A})$$

z	:	vertical position
c_{gz}	:	vertical group velocity
m	:	vertical wavenumber
k	:	horizontal wavenumber (const)
$\mathcal{A}$	:	wave action density
u_b	:	background (resolved) wind
N	:	Brunt-Väisälä frequency

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Steady state parametrization

$$\frac{\mathrm{d}z}{\mathrm{d}t} = \mp\frac{Nkm}{(k^2+m^2)^{3/2}} \equiv c_{gz}$$

$$\frac{\partial m}{\partial t} = 0$$

$$\frac{\partial \mathcal{A}}{\partial t} = 0 \Longleftrightarrow c_{gz}(z)\mathcal{A}(z) = const.$$

Mean flow

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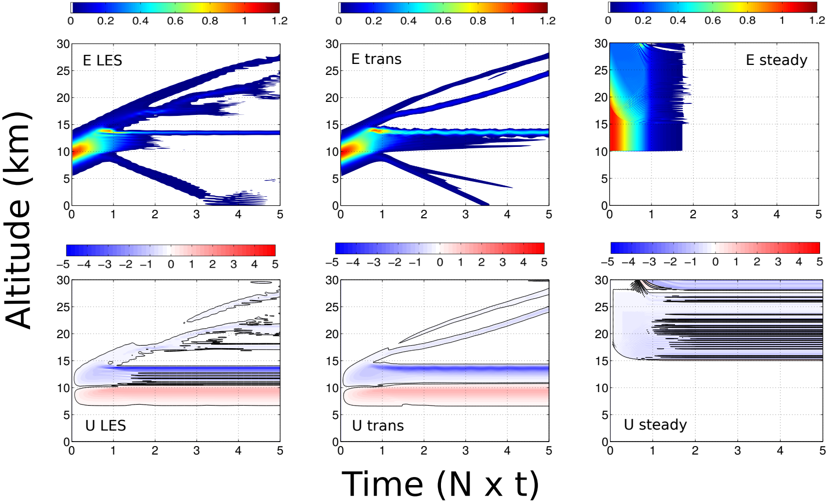
Motivation for a transient GW scheme

Idealized Toymodel (Bölöni et al., 2016)



Implementation in UA-ICON: MS-GWaM

ICON

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Max-Planck-Institut für Meteorologie

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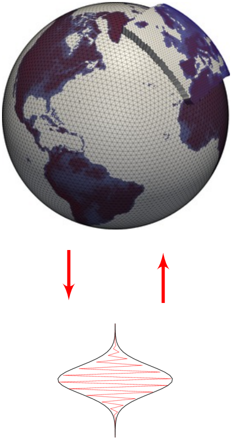


MS-GWaM: Multi Scale Gravity Wave Model

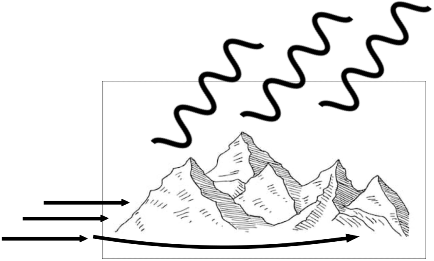
GOETHE UNIVERSITÄT FRANKFURT AM MAIN

MS-GWaves

Implementation in UA-ICON: MS-GWaM

Concept

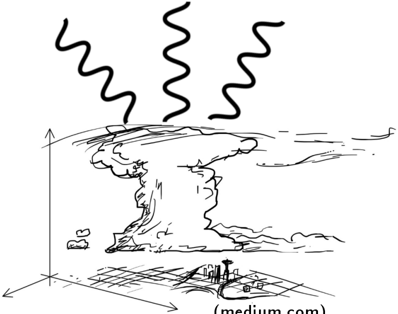
Orographic GWs



(shutterstock.com)

Lott and Miller (1996)
⇒ untouched

Non-orographic GWs



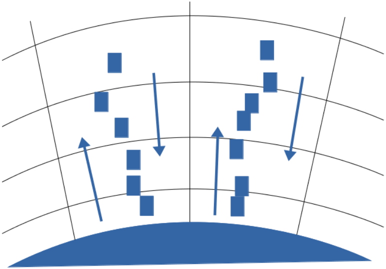
(medium.com)

Warner and McIntyre (1996), Orr et. al (2010), Scinocca (2003) ⇒ WKB (MS-GWaM)

Implementation in UA-ICON: MS-GWaM

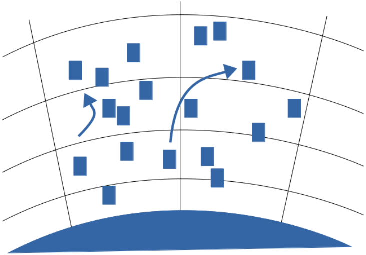
Concept

1D framework



Fits well to the current MPI communicator

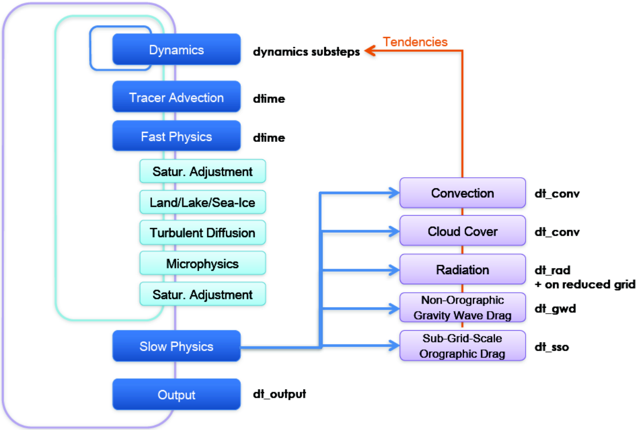
3D framework



Requires new MPI communication style for Lagrangian particles ⇒ later...

Implementation in UA-ICON: MS-GWaM

Concept



(Original courtesy: DWD, ICON Training 2015)

Implementation in UA-ICON: MS-GWaM

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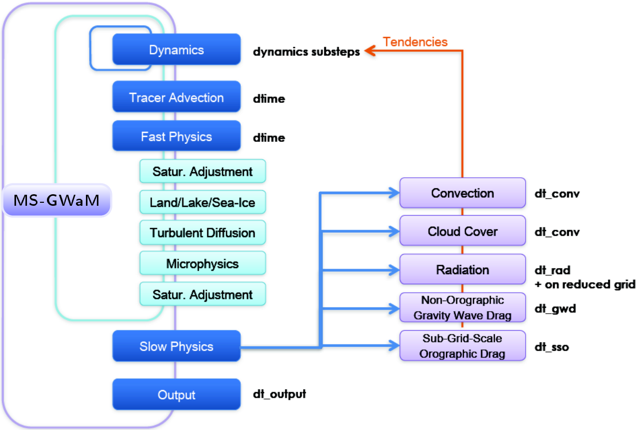

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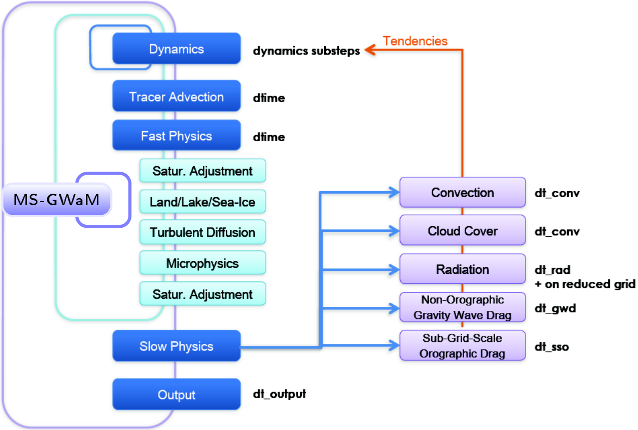


(Original courtesy: DWD, ICON Training 2015)

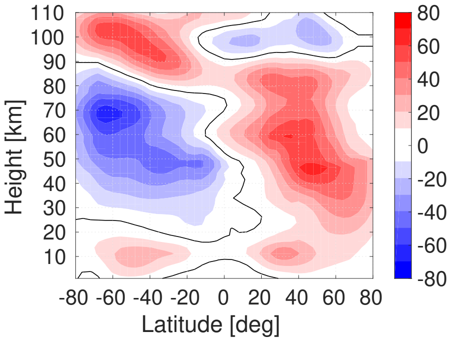
UA-ICON MS-GWaM: zonal mean circulation

- Winter (Nov-Dec) and summer (May-June) simulations for 6 years (2010-2015)
- UA-ICON: deep atmosphere dynamical core, NWP physics + upper-atmospheric physics
- Domain: Global, $z_{top} = 150km$, "Δx" $= 160km$, $\overline{\Delta z} = 1.25km$
- IFS initial conditions (operational ECMWF analysis) extrapolated in vertical
- Experiments:
  - **noGW**: non-orographic GWD parametrization switched off
  - **Orr**: state of the art non-orographic GWD parametrization (Orr et al., 2010)
  - **MS-GWaM**: MS-GWaM used as non-orographic GWD parametrization
- Stability measures: $z_{sponge} = 110km$, GWD limiter $|\frac{du}{dt}, \frac{dv}{dt}| \leq 0.05ms^{-2}$

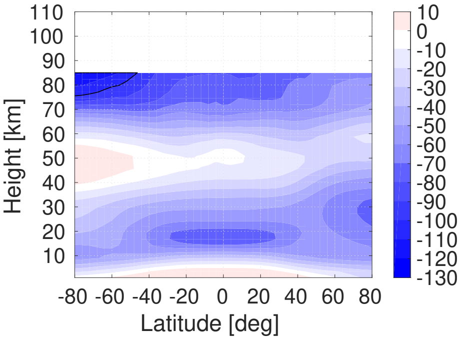
UA-ICON MS-GWaM: zonal mean circulation

The reference: **URAP** climatology 1992-1997
(Swinbank et al., 2003)

December u_b zonal mean $[ms^{-1}]$



December T zonal mean $[C^o]$



UA-ICON MS-GWaM: zonal mean circulation

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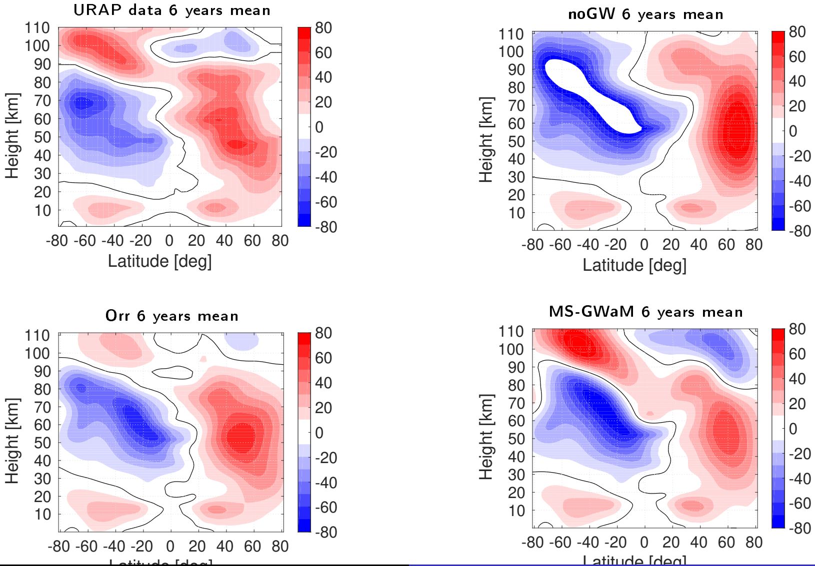

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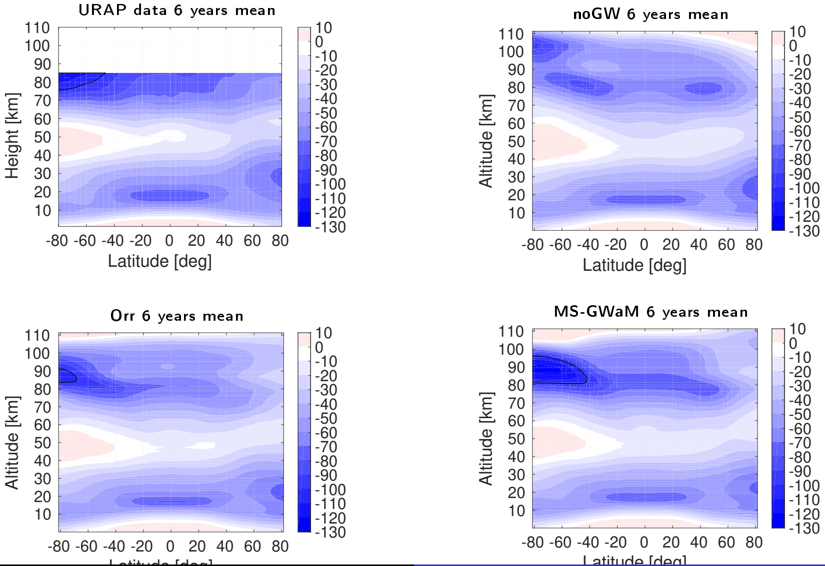
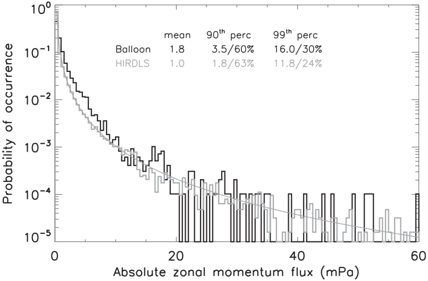


UA-ICON MS-GWaM: intermittency

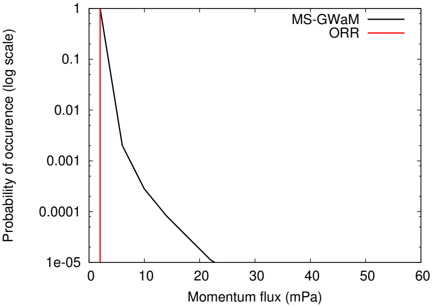
Intermittency: spatio-temporal variability of gravity wave activity

Observations

(Hertzog et al., 2012)



ICON simulations



(Sampling: $-180^o > \lambda > 180^o \quad ; \quad -50^o > \phi > -70^o \quad ; \quad 25km > z > 15km$)

UA-ICON MS-GWaM: intermittency

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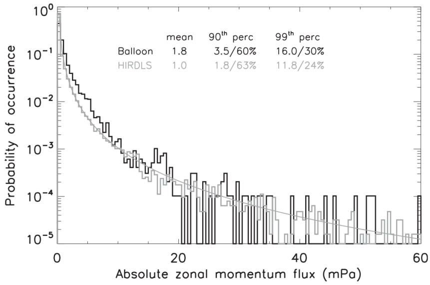
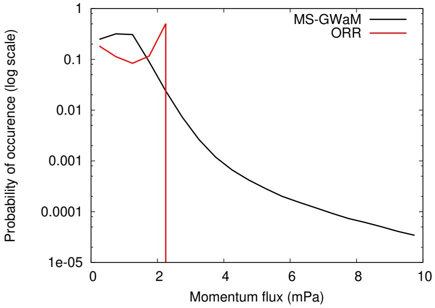


ICON simulations

(zoom)



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Summary

- A new **transient GW drag parametrization proposed: MS-GWAM**
- **MS-GWAM** is **implemented in UA-ICON** and became a useful research tool to study GW dynamics in a global framework.
- Based on climatological zonal averages **MS-GWAM is producing a realistic circulation** and captures some aspects better than steady state GW schemes.
- Due to its transient propagation scheme **GW intermittency is largely improved by MS-GWaM** as compared to steady state schemes.
- But there is still a long way to go... **real sources, horizontal propagation, etc.**

References

Achatz U., B. Ribstein, F. Senf, R. Klein, 2017: The interaction between synoptic-scale balanced flow and infinite-amplitude mesoscale wave field throughout all atmospheric layers: weak and moderately strong stratification, *Q. J. R. Meteorol. Soc.*, *143*, 342–361, DOI:10.1002/qj.2926

Lott, F. and M. Miller, 1997: A new subgrid-scale orographic drag parametrization: Its formulation and testing, *Q. J. R. Meteorol. Soc.*, *123*, 101–127

Bölöni, G., B. Ribstein, J. Muraschko, C. Sgoff, J. Wei, and U. Achatz, 2016: The interaction between atmospheric gravity waves and large-scale flows: an efficient description beyond the non-acceleration paradigm, *J. Atmos. Sci.*, 4833–4852, DOI:10.1175/JAS-D-16-0069.1

Orr A., P. Bechtold, S. Scinocca, M. Ern, M. Janiskova, 2010: Improved Middle Atmosphere Climate Forecasts in the ECMWF model through a Nonorographic Gravity Wave Drag Parametrization, *J. Climate*, *23*, 5905–5926, DOI:10.1175/2010JCLI3490.1

Scinocca J.F., 2003: An accurate Spectral Nonorographic Gravity Wave Drag Parameterization for General Circulation Models *J. Atmos. Sci.*, *60*, 667–682

Warner C.D., M.E. McIntyre, 1996: On the propagation and dissipation of gravity wave spectra through a realistic middle atmosphere, *J. Atmos. Sci.*, *53*(22), 3213–3235