At the edge of resolution: Earth System modelling at ECMWF

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Outline

• Pushing the limits of scalability with km-scale IFS atmosphere simulations

• Earth system benefits at higher resolution – the “Touring test of climate simulations” (Palmer, 2016)

• When do global climate models resolve non-hydrostatic flow features and why is it interesting for the intermediate goal of 1km weather & climate simulations?
ECMWF’s progress in degrees of freedom
(levels x grid columns x prognostic variables)

(Schulthess et al, 2018)

ECMWF’s progress in degrees of freedom
(levels x grid columns x prognostic variables)
Ocean – Land – Atmosphere – Sea ice
Ocean-coupling and local effects on sea surface temperature (SST)

Mogensen et al 2018

- The ECMWF Ocean-coupled (red) model is better simulate the cool wake after the passage of Tropical cyclone Neoguri. A more realistic response is observed comparing the 10-day forecast with an on-track DRIBU observation of SST, both for TC passage and diurnal cycle.
Impact of Ocean-coupling on Tropical Cyclones and relevance for 2018 season

Kristian Mogensen & Fernando Prates

Tropical Cyclones Intensity is generally improved when looking at recent cases (past 2-years)

Mean-sea-level-pressure, MSLP in hPa, of new 45r1 (red) & 43r3 (blue). The data sample includes about 750 cases at initial time, decreasing to about 200 at forecast day 5-6 and to about 50 at day 10. Bars indicate 95% confidence.

The red curve is for the ECMWF HRES Coupled as implemented on the 5th of June 2018
Earth surface monitoring & forecasting advance needs better use EO observations

Special Issue:
"Advancing Earth Surface Representation via Enhanced Use of Earth Observations in Monitoring and Forecasting Applications"

http://www.mdpi.com/journal/remotesensing/special_issues/earthsurface_RS
The problem of initialisation of the increased degrees of freedom
IFS KE spectra compared to altimeter observations

Cut-off where power is 50% of $k^{-5/3}$

→ true 1 km resolution needs at least $x6$ improvement = $x216,000$ for computing!

[Courtesy S. Abdalla]
Global KE - Spectra ~500hPa

Resolve rather than parametrize much of the crucial vertical transport of momentum and heat.
Non-hydrostatic (NH) or hydrostatic (H) ?

IFS 1km: strong scaling on PizDaint
The Erzgebirge, a case for NH at 2.5km resolution?
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Plotting with the correct aspect ratio!
Vertical velocity at 500hPa across Europe at 2.5km
BUT

Vertical velocity at 500hPa across Europe at 2.5km

The NH solution with smaller time-step excites (unwanted) gravity waves from the same orographic forcing, where as the H solution does not change, which raises the question if H equations are an effective filter in the limit of poorly resolved orographic flow?
Comparison of spectra at 2.5km

The spontaneous excitation of gravity waves can be seen in the global spectra.
Mean Orography spectra at different NWP centres

Scaled with $n^{5/3}$
Global 1.25km spectra: Mid-Troposphere 500hPa

Impact of orography + parametrization, (Malardel + Wedi, JGR 2016)
Upscale or downscale spectral energy fluxes?

(Augier and Lindborg, 2013; Malardel and Wedi, 2016)
Energy Fluxes in ECMWF’s IFS model

1) Impact of physical parametrizations
2) Divergent and interacting divergent and rotational motions (dashed lines)

(Malardel and Wedi, 2016)

(Augier and Lindborg, 2013)
500hPa horizontal kinetic energy spectra

log(horizontal KE) [m**2/s**2]

spherical wave number

IFS 1km
IFS 5km NoConv
IFS 5km Conv
ICON 5km NoConv
ICON 5km Conv

Daniel Klocke (DWD)
• 1 km simulation on reduced planet
• No convection parameterization!
• Same microphysics schemes
• Different numerics-physics coupling
• Different time steps

→ Imprinting of numerics?
Greyzone evaluations

1, 2.5, 5, ~9 km of Tropical Atlantic with ICON & IFS

Total water + ice content

Daniel Klocke and Nils Wedi
The IFS model grid

Integrated Forecasting System (IFS)

N24 reduced Gaussian grid

N24 octahedral Gaussian grid

A further \( \sim 20\% \) reduction in gridpoints

\Rightarrow \sim 50\% \text{ less points compared to full grid}

Physics-dynamics coupling vs different dynamical core

Surface pressure after 15 days evolution of the moist baroclinic instability with IFS microphysics and convection scheme

Christian Kuehnlein
TCo1279 (9km) + TCo1999 (5km) have the deep convection parametrization on, all runs hydrostatic.
Conclusions

• How long a time-step can be used in 1km simulations of weather and climate?
  – Less than 1 min seems to be the consensus, but a large spread due to the numerical methods used
  – Results with 2 min suggest temporal filtering effect may be desirable rather than a problem in the limit of poorly resolved but hardly filtered orographic forcing

• Global NH solutions become H with larger time-step
  – More general question on the behaviour of time-integration schemes in the limit of poor temporal resolution
Additional slides
The cost profile of a 1.25km IFS atmosphere simulation on Piz Daint

Example: TCo7999 L62 (~1.25km)

- 16% GP_DYNAMICS
- 34% SI_SOLVER
- 45% SP_TRANSLATIONS
- 75% physics + rad

Where do we spend the time?

- 75% comms
- 25% compute

4880 MPI tasks x 12 threads

69 FC/day ~ 0.19 SYPD

single precision / FLT

~85.21 MWh / SY

Based on the Piz Daint, Swiss Cray XC50 Haswell, Aries interconnect, ~5000 nodes total
The cost profile of a 1.25km (non-hydrostatic) IFS atmosphere simulation Piz Daint

Example: TCo7999 L62 (~1.25km)

Based on the Piz Daint, Swiss Cray XC50 Haswell, Aries interconnect, ~5000 nodes total

4880 MPI tasks x 12 threads
32 FC/day ~ 0.088 SYPD
single precision / FLT
~191.74 MWh / SY