Recent Developments at ECMWF

Nils Wedi

Contributions by Lars Isaksen, Peter Bechtold, Richard Forbes, Mats Hamrud, Thomas Jung, Martin Leutbecher, Martin Steinheimer, George Mozdzynski and Geir Austad

Overview

- The current operational cycle CY36R2
- Data assimilation and EPS developments
- (Ultra-)high resolution global simulations with IFS
- New prognostic cloud microphysics
- Revision of topographic fields
- Fast Legendre transforms
- Some technical developments of interest

The current operational cycle 36r2

- **Forecast/Assimilation system T1279 L91 (analysis inner loops with T159/T255/T255)**
- **EPS system T639 (10days)/T319(7days) + revised representation of uncertainty**
- **Ensemble of Data Assimilations (EDA) T399 L91 (analysis inner loops T95/T159)**

Data assimilation

- Ensemble of data assimilations (EDA) (to provide flow-dependent error variances to 4D-Var and input to EPS).
- Long window weak constraint 4D-Var (to account for model error and exploit additional parallelism).
- Ensemble Kalman Filter (EnKF) to explore alternative options for scalability and usefulness in the context of reduced availability of observations.

Ensemble of Data Assimilations (EDA)

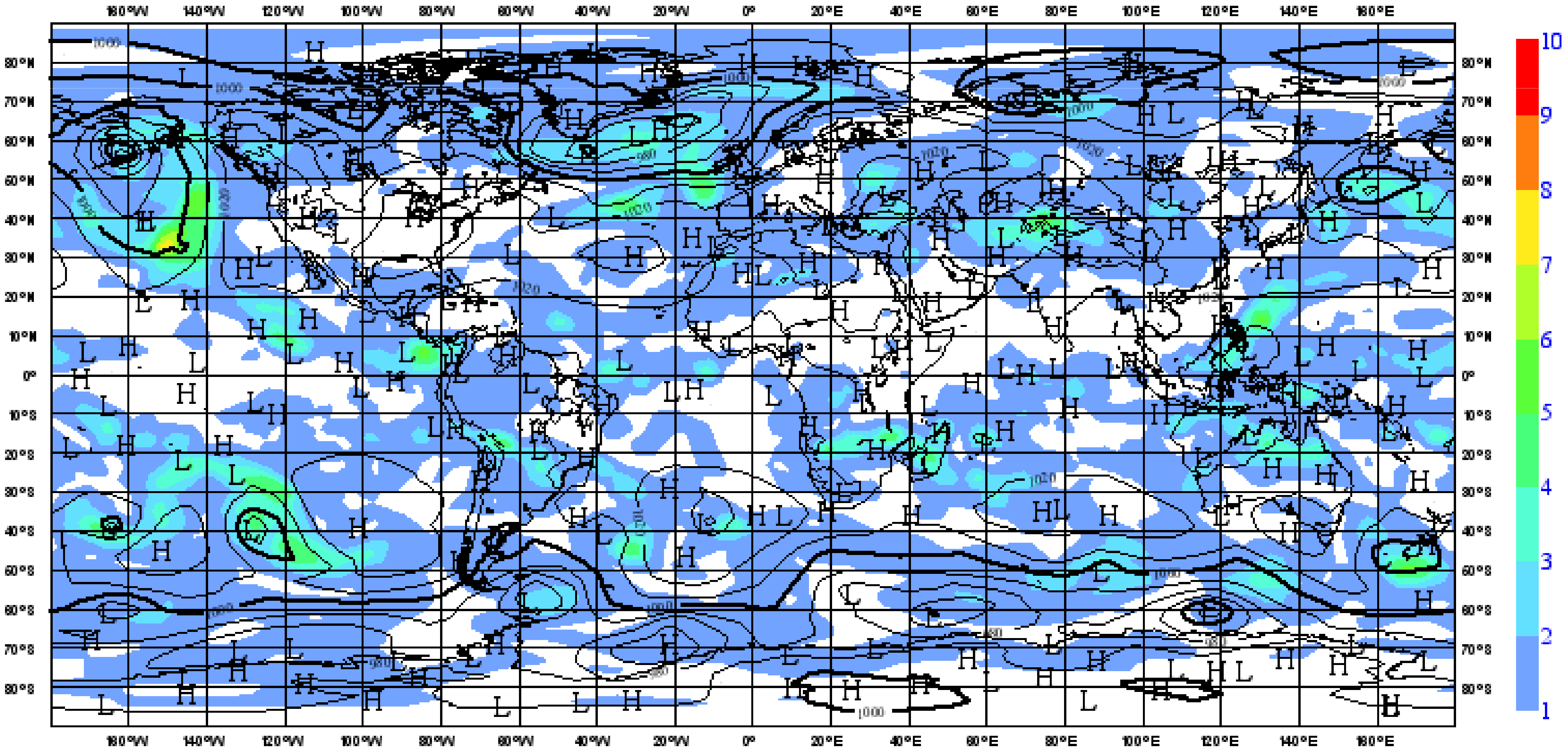
- Control + 10 ensemble members using 4D-Var assimilations
  - T399 outer loop
  - T95/T159 inner loop (reduced number of iterations)
- Model error
  - Stochastically Perturbed Parametrization Tendencies
- Randomly perturbed observations and SST fields

Example of flow-dependent (filtered) ensemble spread

(without filtering noisy with only 10 ensemble members)

Lars Isaksen

Vorticity at 500 hPa, +9h



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Reasons for Ensemble of Data Assimilations

- To improve the initial perturbations in the Ensemble Prediction
- To estimate analysis uncertainty
- To calculate static and seasonal background error statistics
- To estimate flow-dependent background error in 4D-Var - "errors-of-the-day" (expected operational late 2010)
- To improve QC decisions and improve the use of observations in 4D-Var (expected operational late 2010)

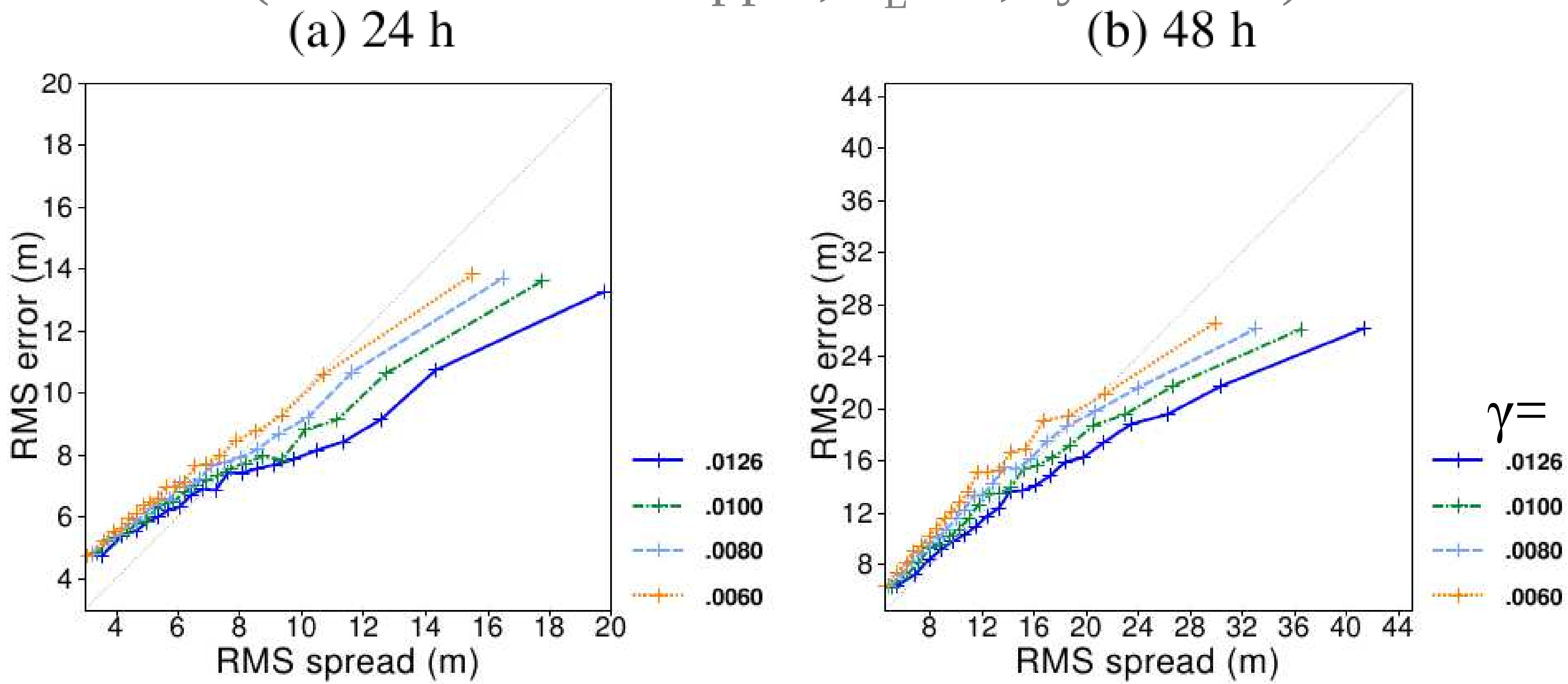
EPS representation of uncertainty

- Initial uncertainty using perturbations from the ensemble of data assimilations (EDA) in addition to perturbations based on singular vectors (SVs)
- Subgrid-scale uncertainty: Stochastically perturbed parametrization tendency scheme (SPPT) (temporal and spatial randomization)

spread-reliability and SV perturbation amplitude

Z500, N-Hem Mid-latitudes, 21 cases in Oct–Dec 2009

(EDA+init. SVs+ sppt1, T_L639, cycle 36r2)



Martin Leutbecher

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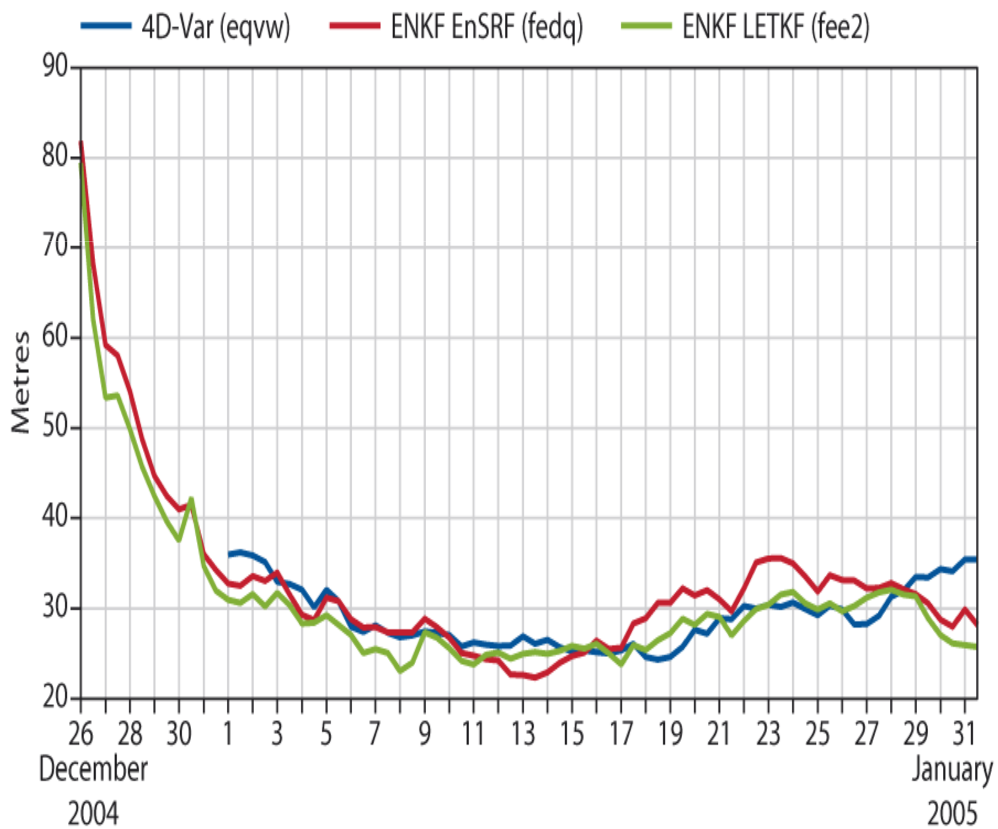
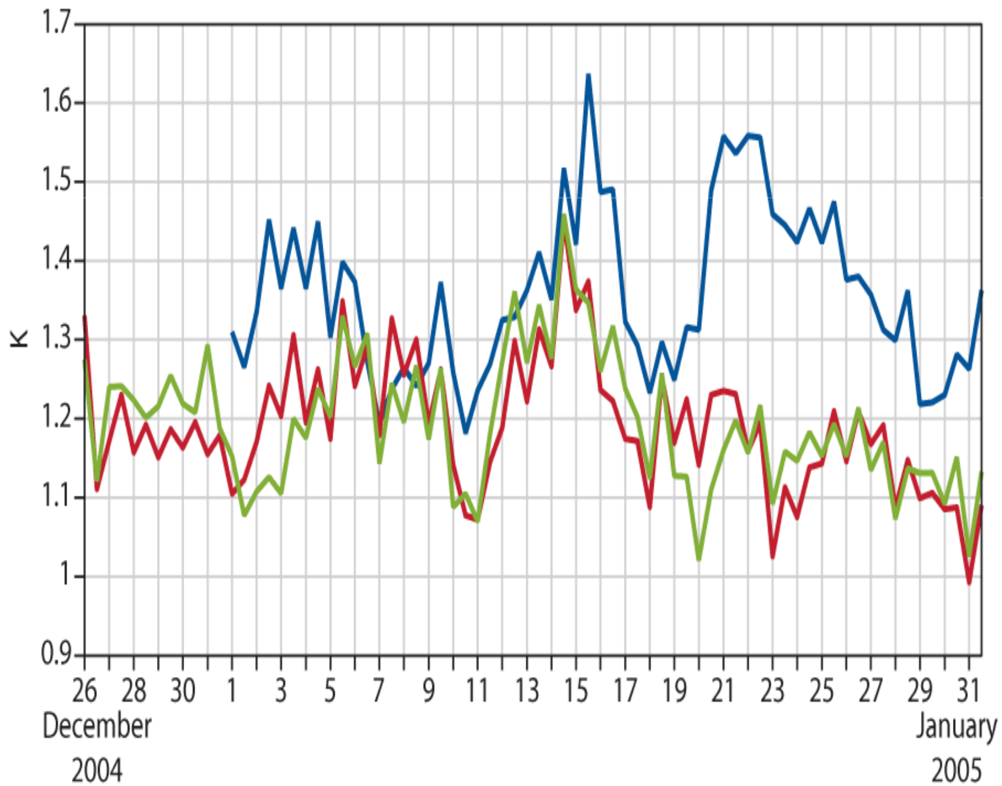
ENKF: Surface pressure data only comparison with control analysis

Mats Hamrud





The RMS errors of 4D-Var, EnSRF and LETKF using surface pressure observations only. Errors are relative to a control 4D-Var assimilation that used all observations. Left: N.Hemisphere 500hPa geopotential height. Right: Tropical 850hPa temperatures

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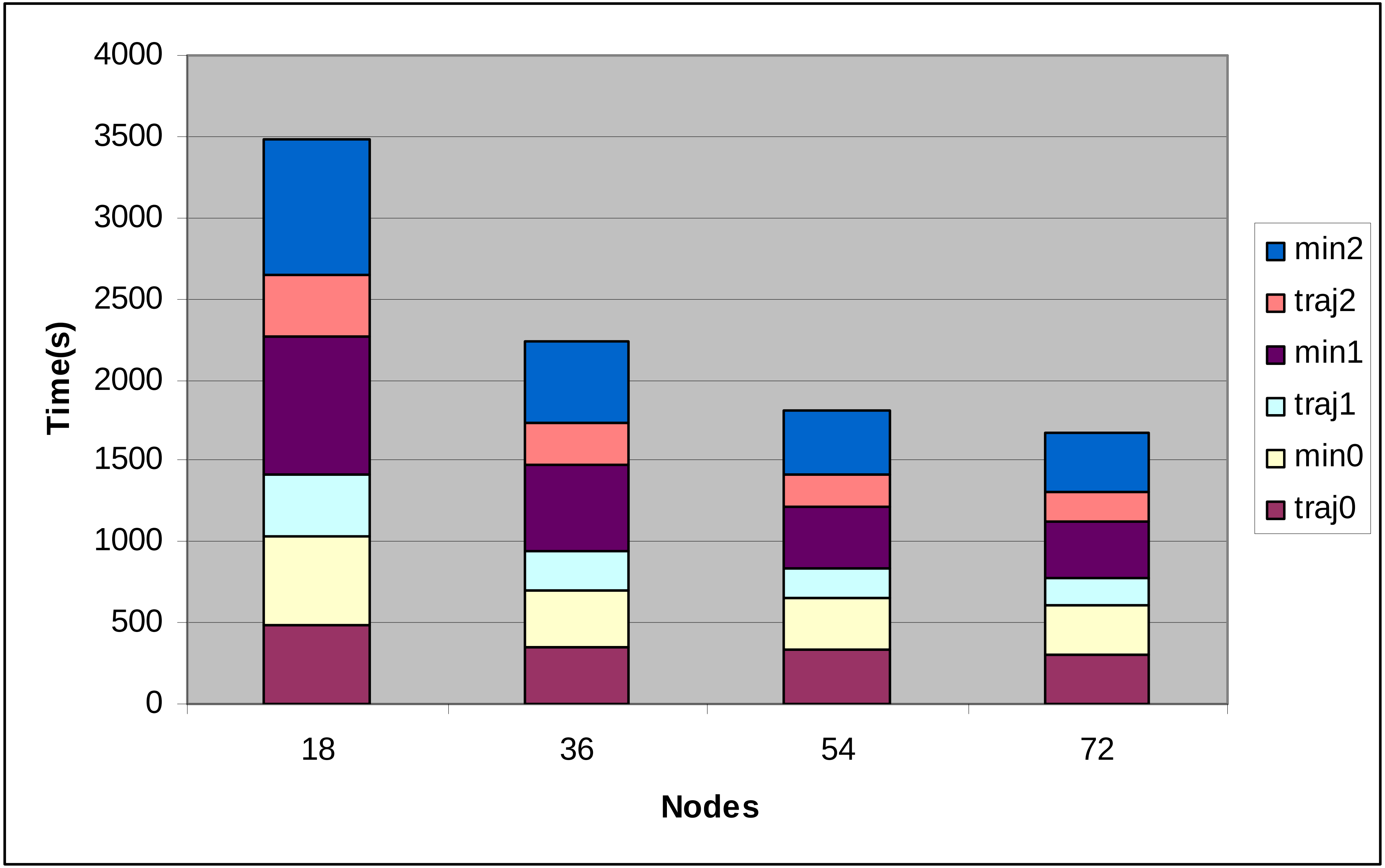
Computational cost of 4D-Var

Mats Hamrud



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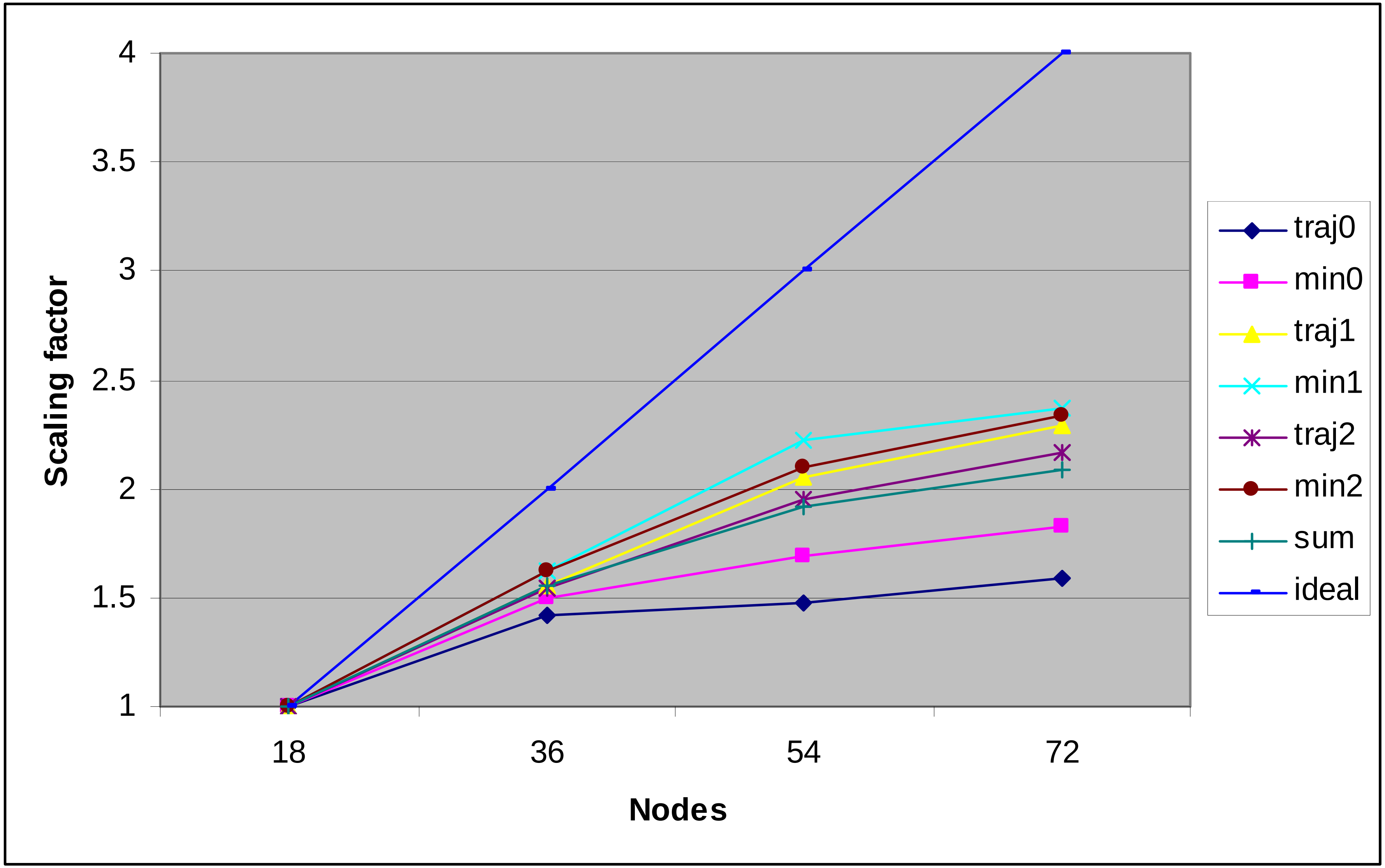
Scaling of 4D-Var

Mats Hamrud



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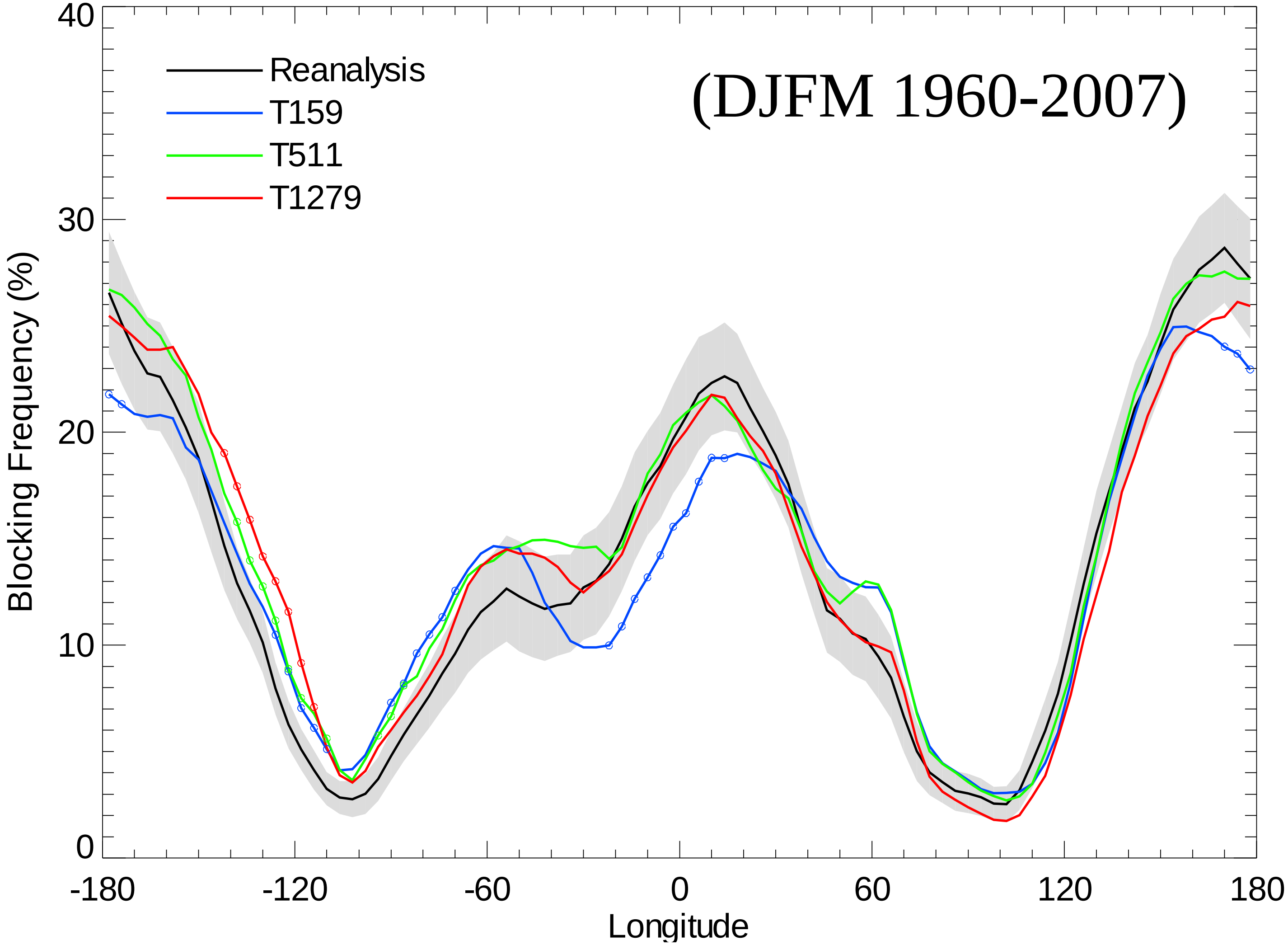
History of resolution changes

- **Resolution increases of the deterministic 10-day medium-range Integrated Forecast System (IFS) over ~25 years at ECMWF:**
  - **1987: T 106 (~125km)**
  - **1991: T 213 (~63km)**
  - **1998: T_L319 (~63km)**
  - **2000: T_L511 (~39km)**
  - **2006: T_L799 (~25km)**
  - **2010: T_L1279 (~16km)**
  - **2015?: T_L2047 (~10km)**
  - **2020-???: (~1-10km) Non-hydrostatic, cloud-permitting, substan-tially different cloud-microphysics and turbulence parametrization, substantially different dynamics-physics interaction ?**

The Athena Project: Experimental Setup

- IFS (latest cycle 36r1) atmosphere-only runs with prescribed lower boundary conditions (SST data from observations until 2007, 2070- A1B scenario SST forcing comes from CCSM simulation)
- Four different horizontal resolutions:
  - T_L159L91 (~125 km)
  - T_L511L91 (~ 39 km)
  - T_L1279L91 (~16 km)
  - T_L2047L91 (~10 km)
- Two different setups
  - Set of 13-months long integrations (1960-2007)
  - T_L1279 and T_L159 AMIP long runs (1960-2007 and 2070-2117)

Athena project: Blocking Frequency



Thomas Jung

Better representation of orography important factor !

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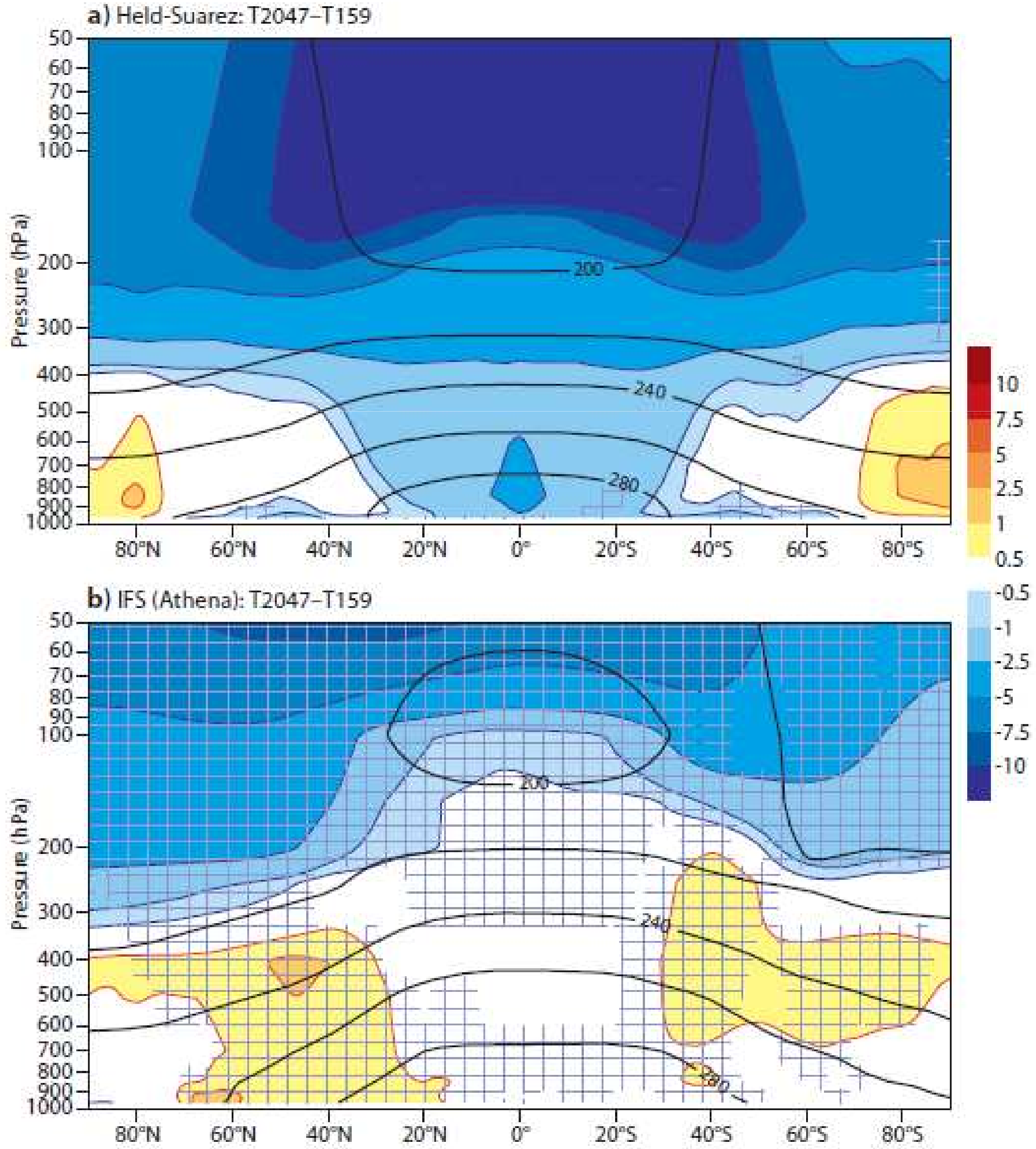
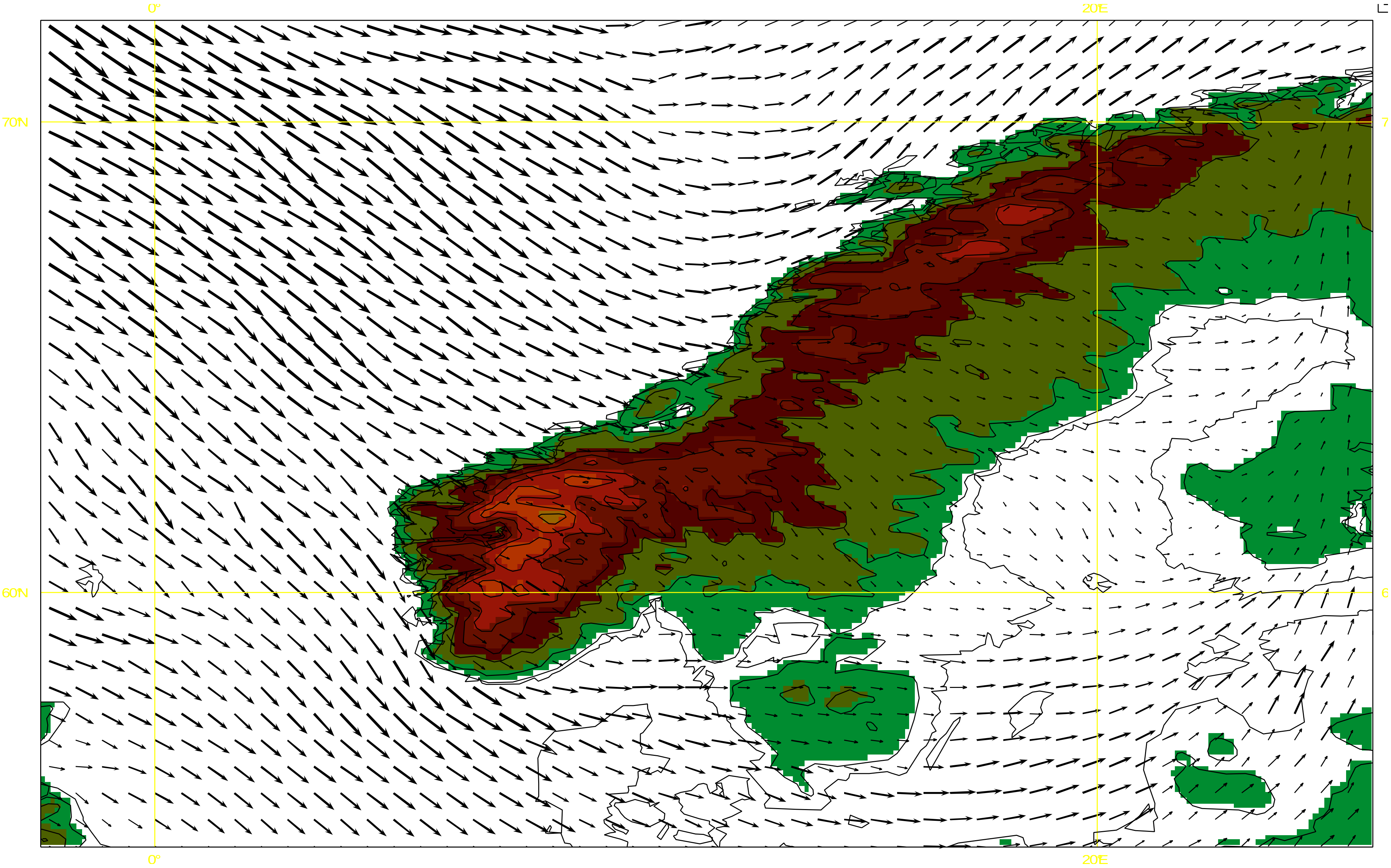
Increasingly colder stratospheric temperature with increased horizontal resolution



Ultra-high resolution global IFS simulations

- T_L0159 (~ 125km) >> 35,718 points per field/level
- T_L0511 (~ 39km) >> 348,528 points per field/level
- T_L0799 (~ 25km) >> 843,490 points per field/level
- T_L1279 (~ 16km) >> 2,140,702 points per field/level
- T_L2047 (~ 10km) >> 5,447,118 points per field/level
- T_L3999 (~ 5km) >> 20,696,844 points per field/level (world record for spectral model ?!)



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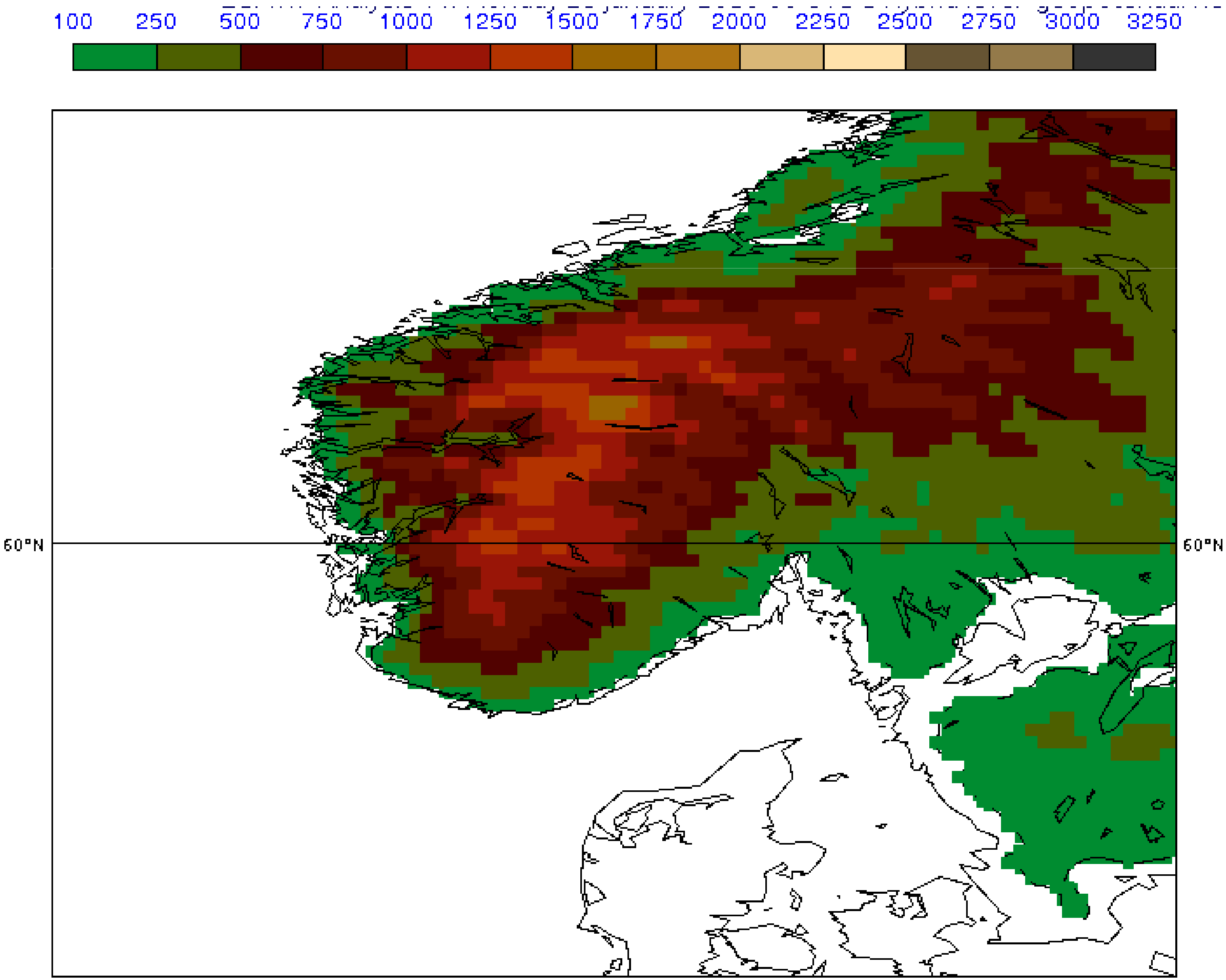
Orography – T1279



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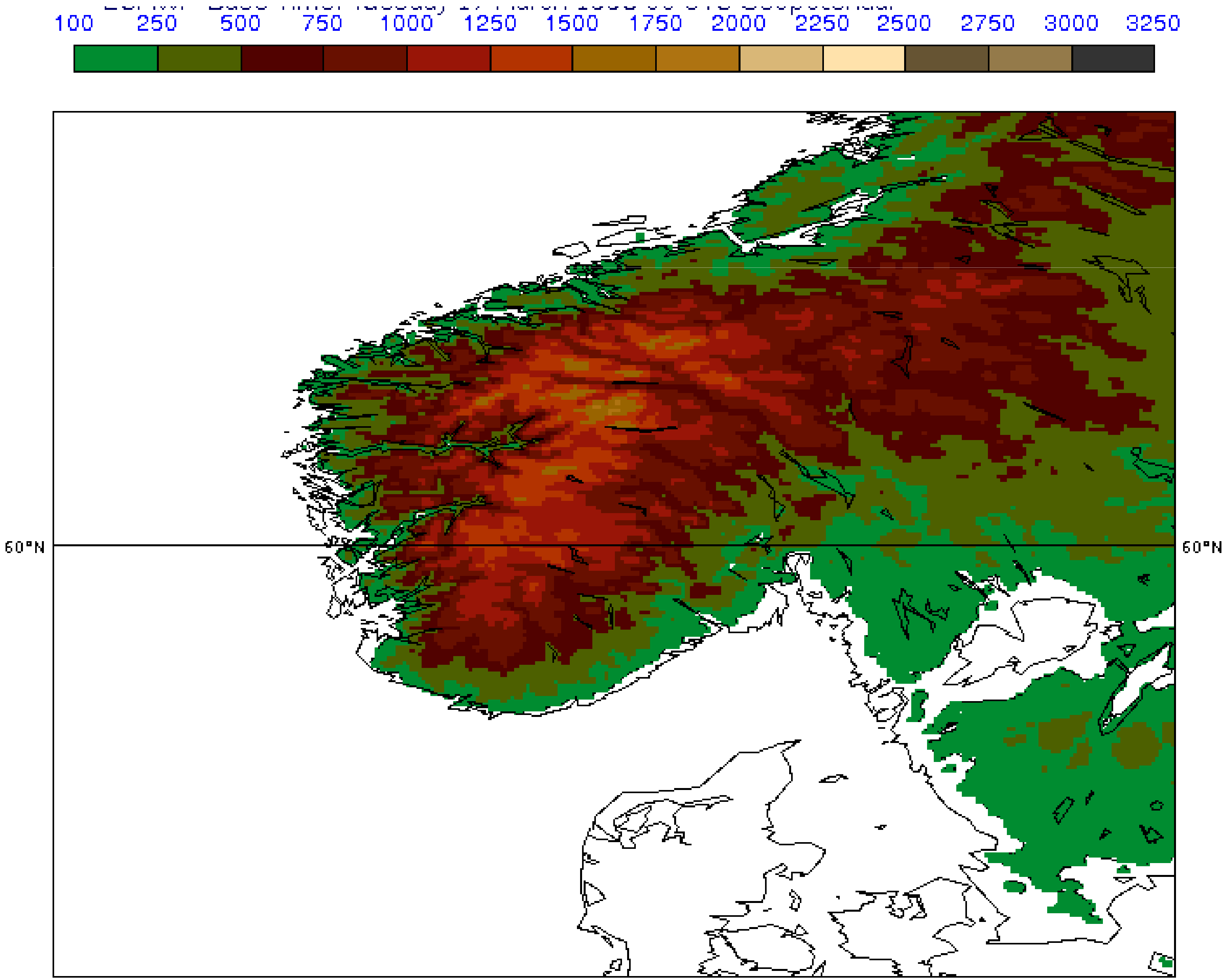
Orography T3999



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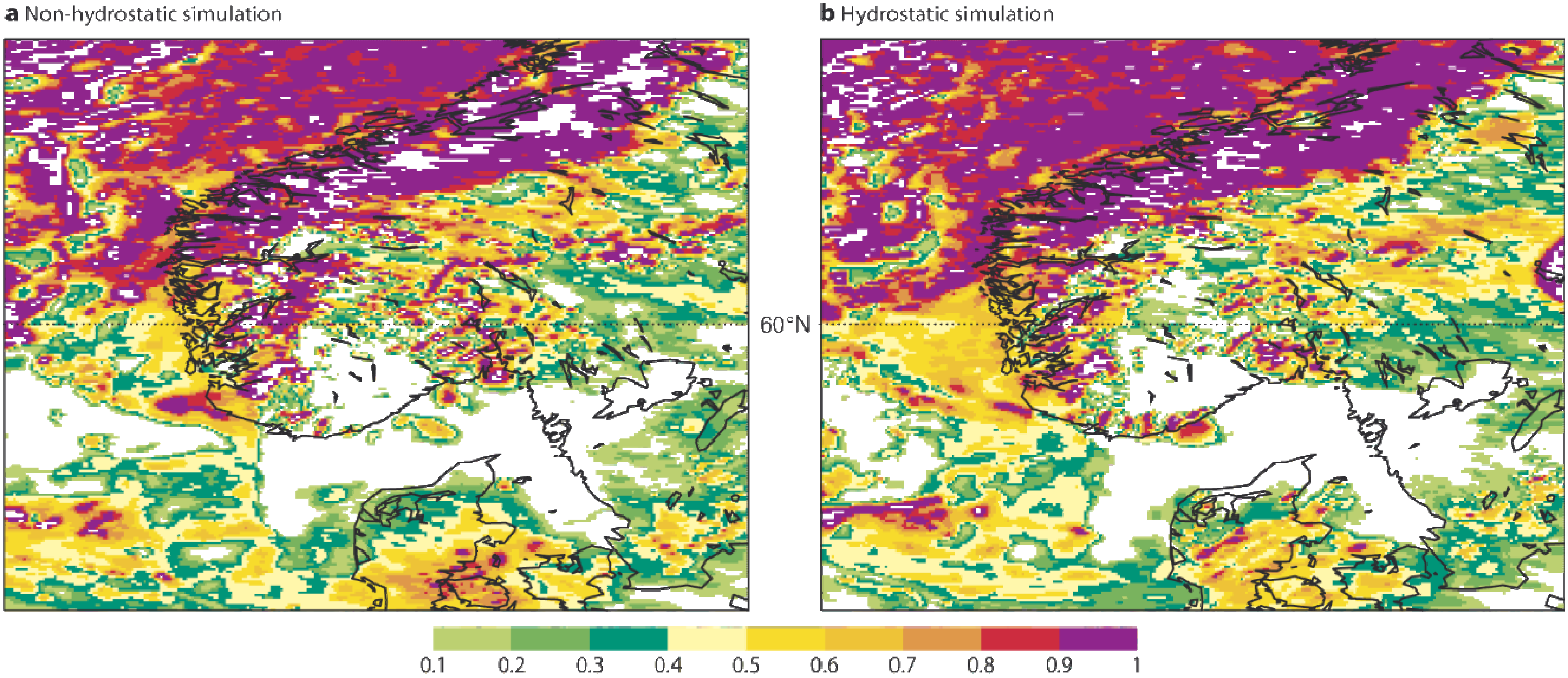
Cloud cover 24h forecast T3999 (~5km)



Era-Interim shows a wind shear with height in the troposphere over the region!

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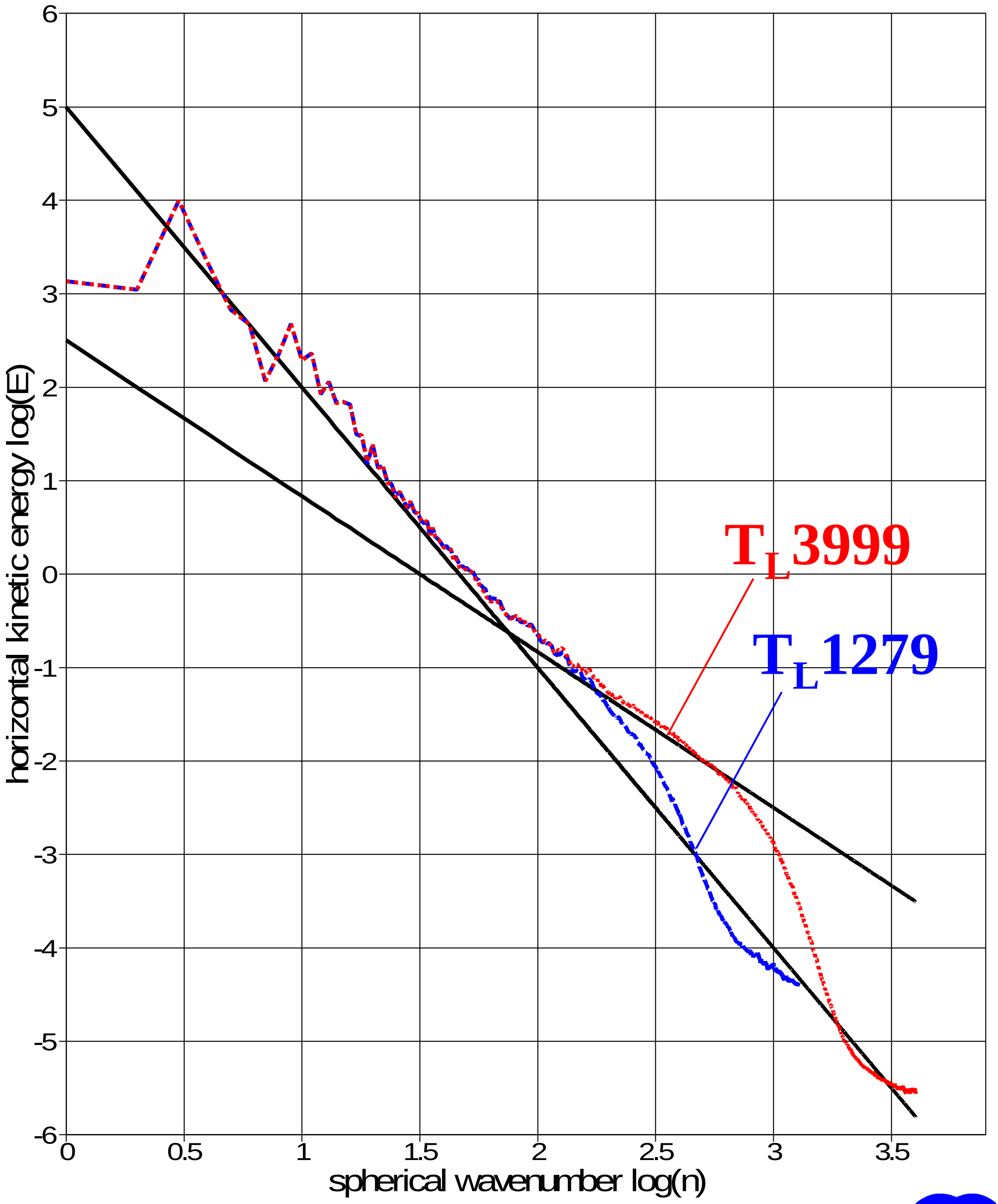
Kinetic Energy Spectra (10hPa) T3999 – T1279 H IFS



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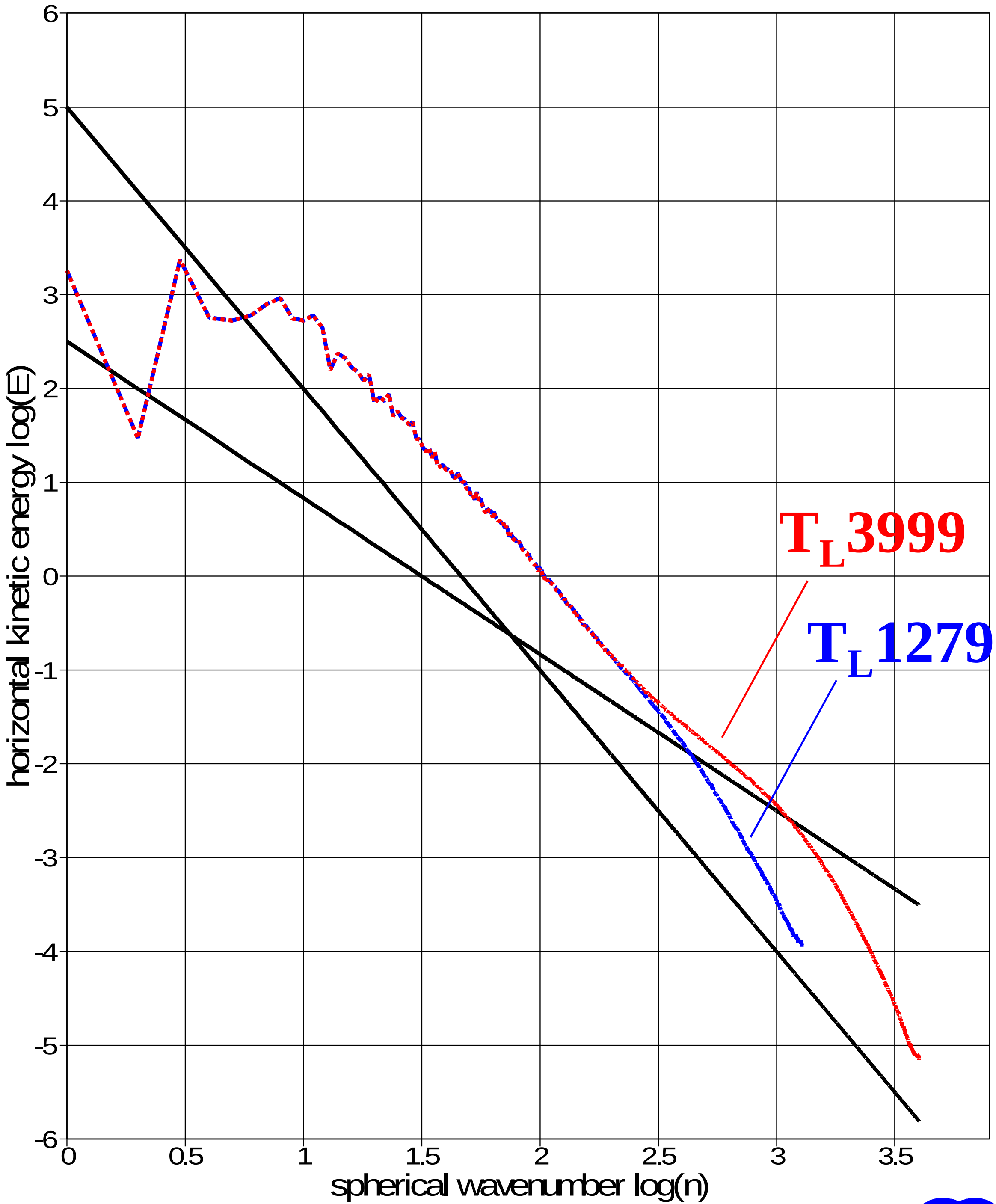
Kinetic Energy Spectra (500hPa) T3999 – T1279 H IFS



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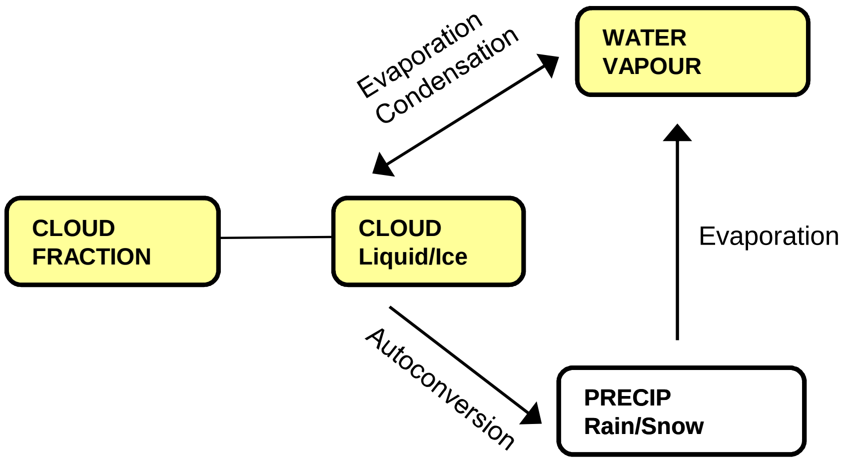
New prognostic microphysics scheme

Scheme description

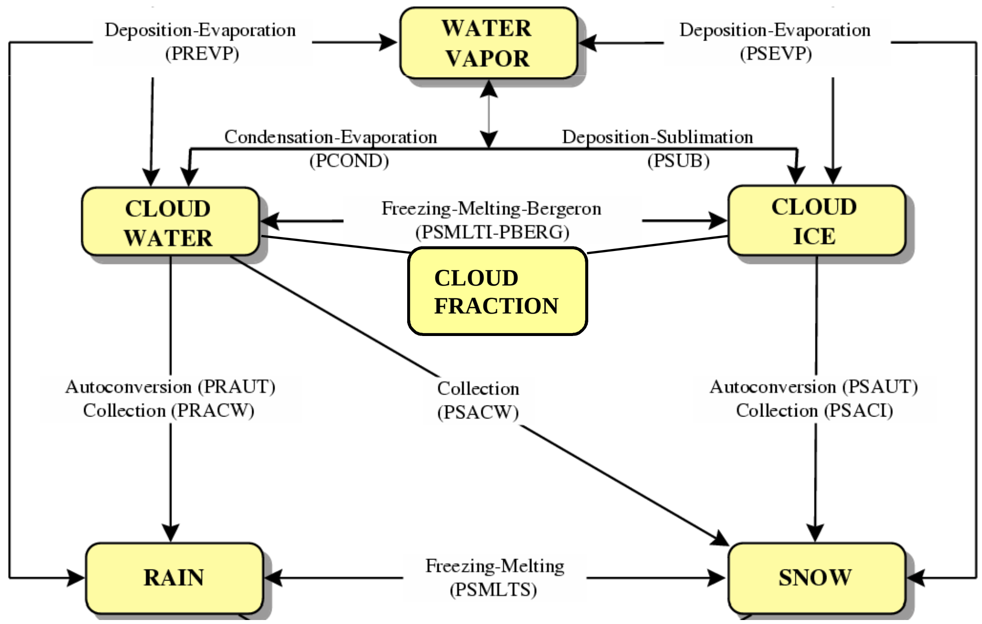
Richard Forbes

Current Cloud Scheme



- 2 prognostic cloud variables + w.v.
- Ice/water is a diagnostic function of temperature (0℃ to -23℃)
- Diagnostic precipitation (rain/snow)

New Cloud Scheme



- 5 prognostic cloud variables + water vapour
- Ice and water now independent in mixed phase temperature regime
- Prognostic (advected) precipitation

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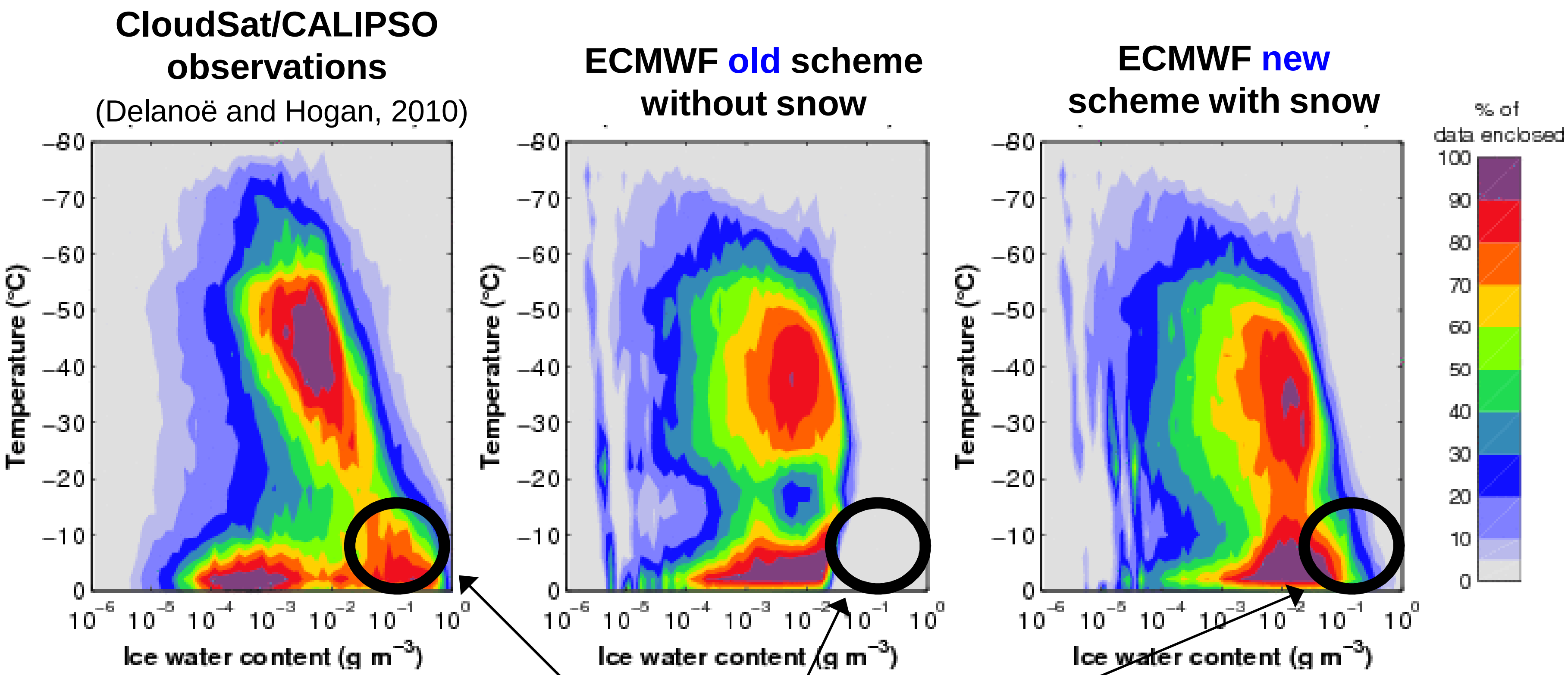
New prognostic microphysics scheme

Example: IWC vs. Temperature

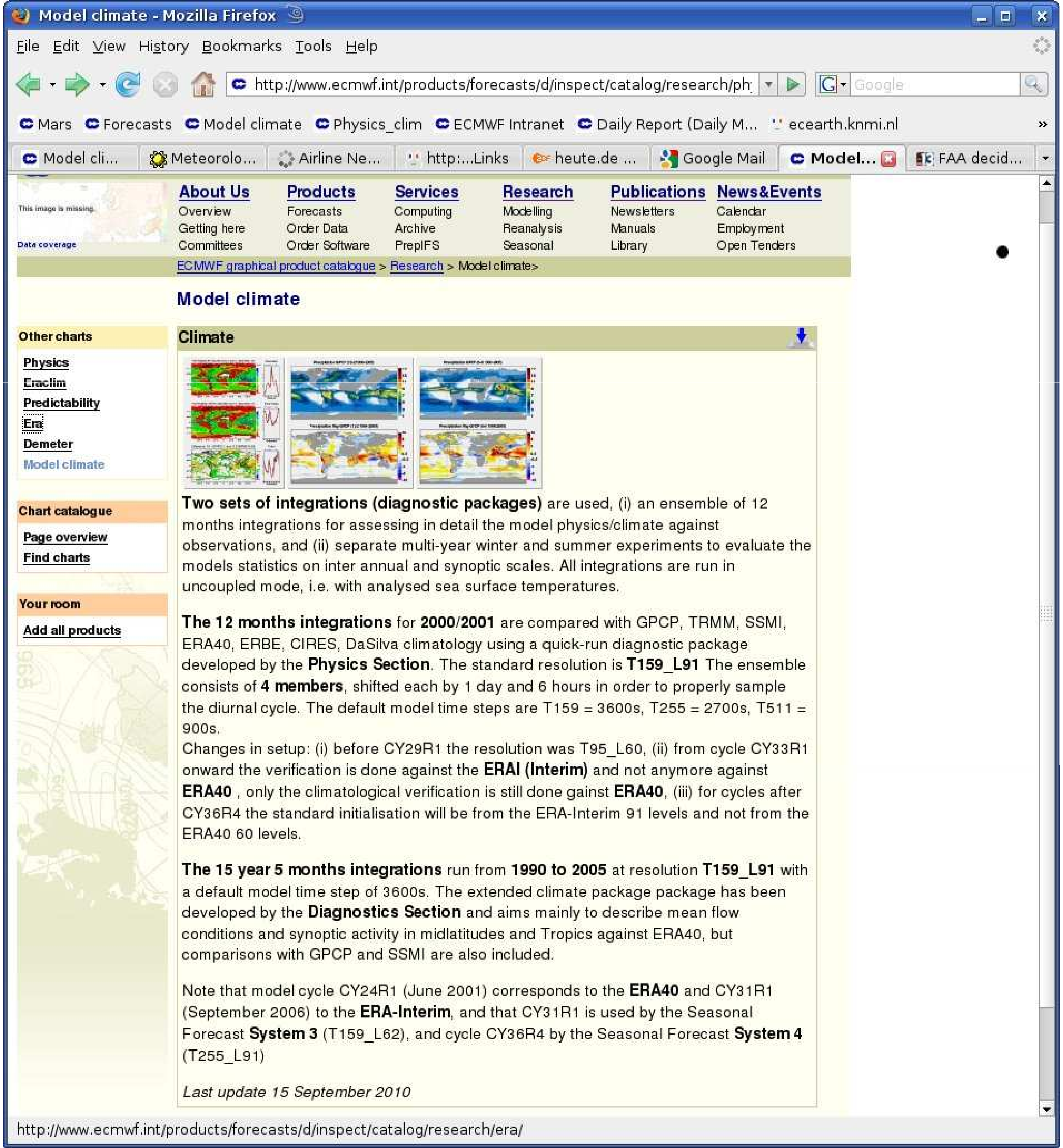
Relative frequency of occurrence of ice/snow for N. Hem. mid-latitudes June 2006



New scheme with prognostic ice in mixed-phase and prognostic snow precipitation allows much higher ice water contents (seen by the radiation scheme)

In collaboration with Julien Delanoë

New: www
IFS Model climate
publicly accessible



Model climate - Mozilla Firefox

http://www.ecmwf.int/products/forecasts/d/inspect/catalog/research/ph

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Climate

Two sets of integrations (diagnostic packages) are used, (i) an ensemble of 12 months integrations for assessing in detail the model physics/climate against observations, and (ii) separate multi-year winter and summer experiments to evaluate the models statistics on inter annual and synoptic scales. All integrations are run in uncoupled mode, i.e. with analysed sea surface temperatures.

The 12 months integrations for **2000/2001** are compared with GPCP, TRMM, SSMI, ERA40, ERBE, CIRES, DaSilva climatology using a quick-run diagnostic package developed by the **Physics Section**. The standard resolution is **T159_L91** The ensemble consists of **4 members**, shifted each by 1 day and 6 hours in order to properly sample the diurnal cycle. The default model time steps are T159 = 3600s, T255 = 2700s, T511 = 900s.
Changes in setup: (i) before CY29R1 the resolution was T95_L60, (ii) from cycle CY33R1 onward the verification is done against the **ERAI (Interim)** and not anymore against **ERA40** , only the climatological verification is still done gainst **ERA40**, (iii) for cycles after CY36R4 the standard initialisation will be from the ERA-Interim 91 levels and not from the ERA40 60 levels.

The 15 year 5 months integrations run from **1990 to 2005** at resolution **T159_L91** with a default model time step of 3600s. The extended climate package package has been developed by the **Diagnostics Section** and aims mainly to describe mean flow conditions and synoptic activity in midlatitudes and Tropics against ERA40, but comparisons with GPCP and SSMI are also included.

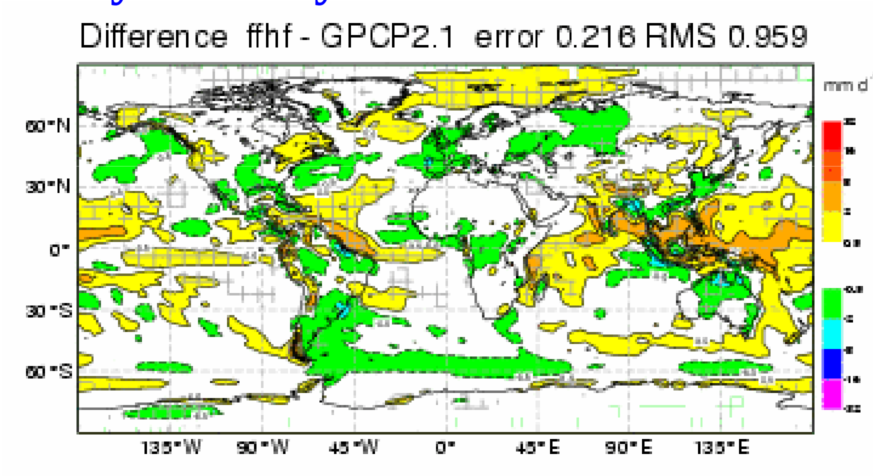
Note that model cycle CY24R1 (June 2001) corresponds to the **ERA40** and CY31R1 (September 2006) to the **ERA-Interim**, and that CY31R1 is used by the Seasonal Forecast **System 3** (T159_L62), and cycle CY36R4 by the Seasonal Forecast **System 4** (T255_L91)

Last update 15 September 2010

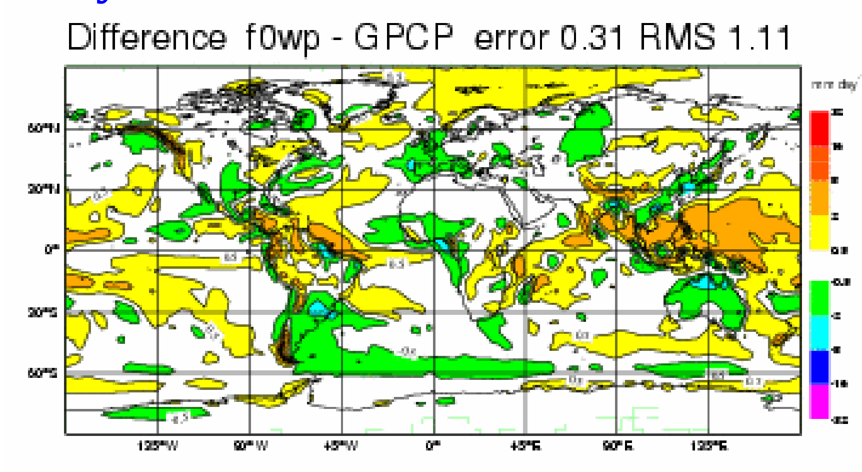
http://www.ecmwf.int/products/forecasts/d/inspect/catalog/research/era/

Improvements in Precipitation climatology in the last 10-Years Precipitation for 2000/2001 against GPCP

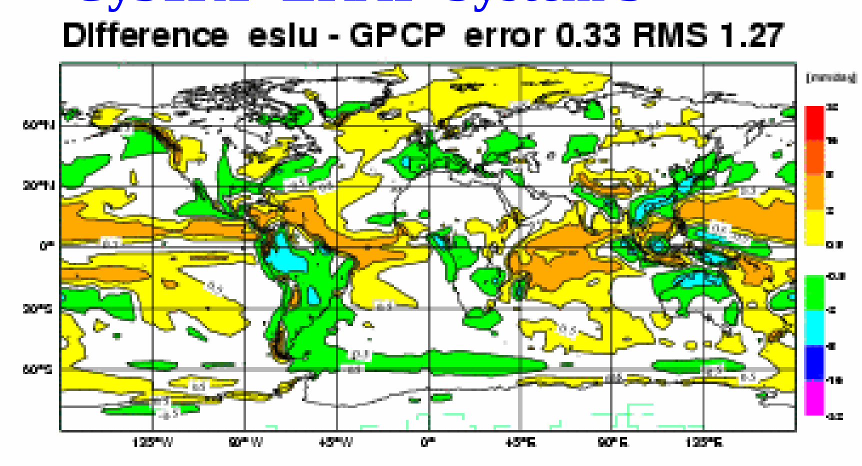
Cy36R4=System 4



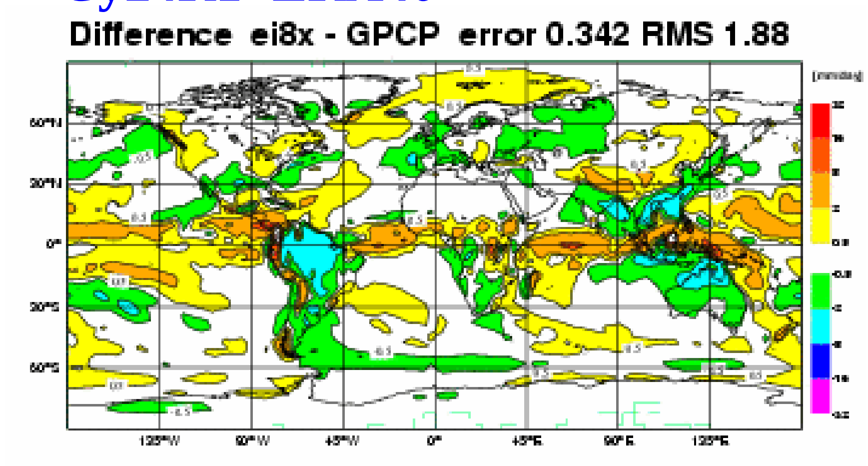
Cy33R1



Cy31R1=ERAI=System 3



Cy24R1=ERA40



Revision of high-resolution topographic fields

- Globe
- SRTM30
- Modis Mosaic of Antarctica (MOA)
- Globcover
- Global Land Cover Characteristics (GLCC)
- Harmonised World Soil Database (HWSD)
- Modis surface albedos

→ Create a database of grib-files at 1km from which the operational resolutions are consistently derived.

→ Input to the computation of subgrid-scale parameters.

Comparing GLCC and Globcover

- **Left picture is GLCC, right Globcover, both on a 1 km grid for a small area in Norway.**

Geir Austad

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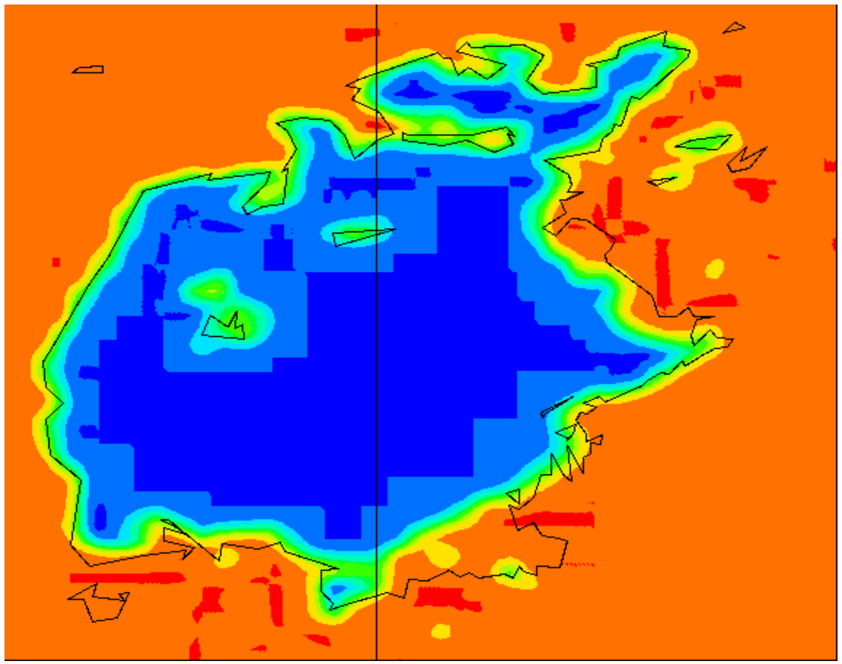
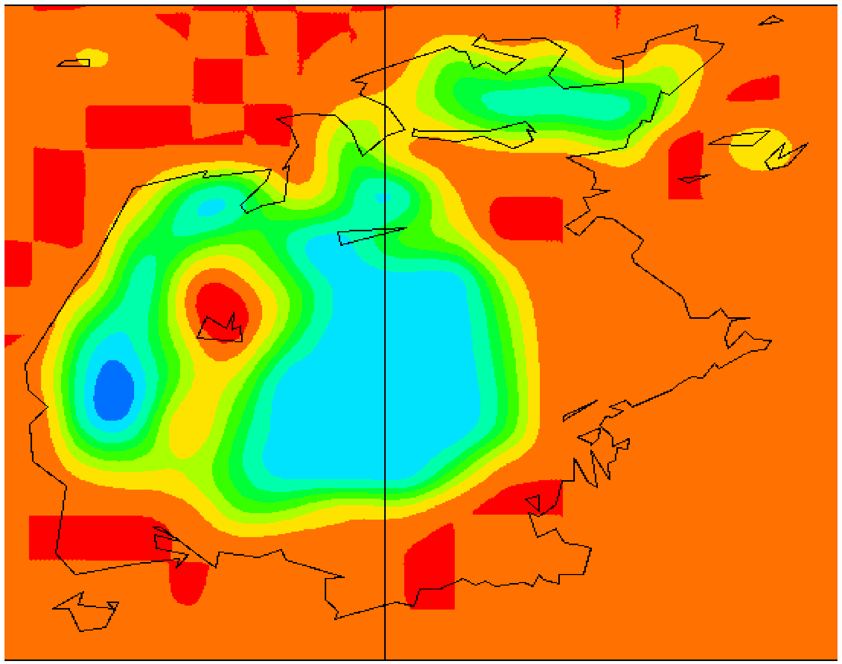
Comparison of lsm/lake mask from existing and new

Geir Austad





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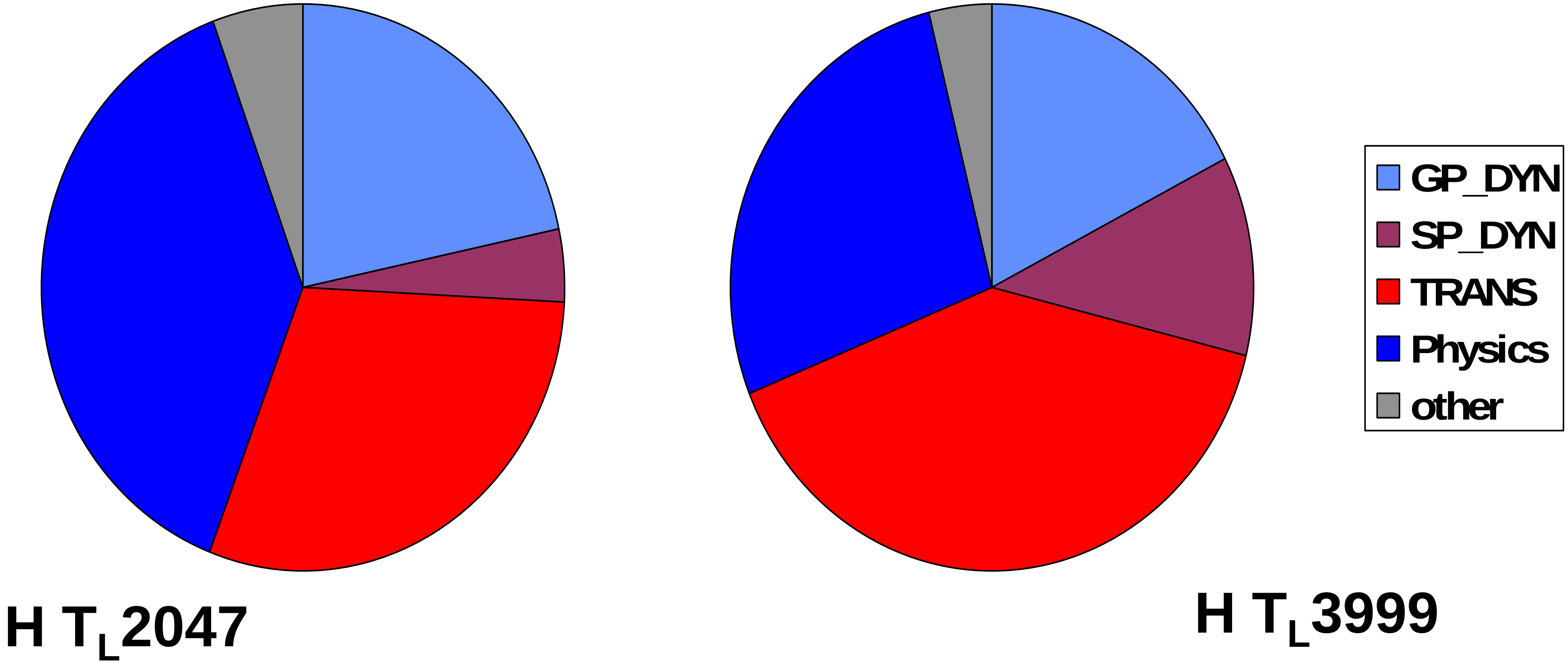
Computational Cost at T_L2047 and T_L3999 (with the hydrostatic IFS)



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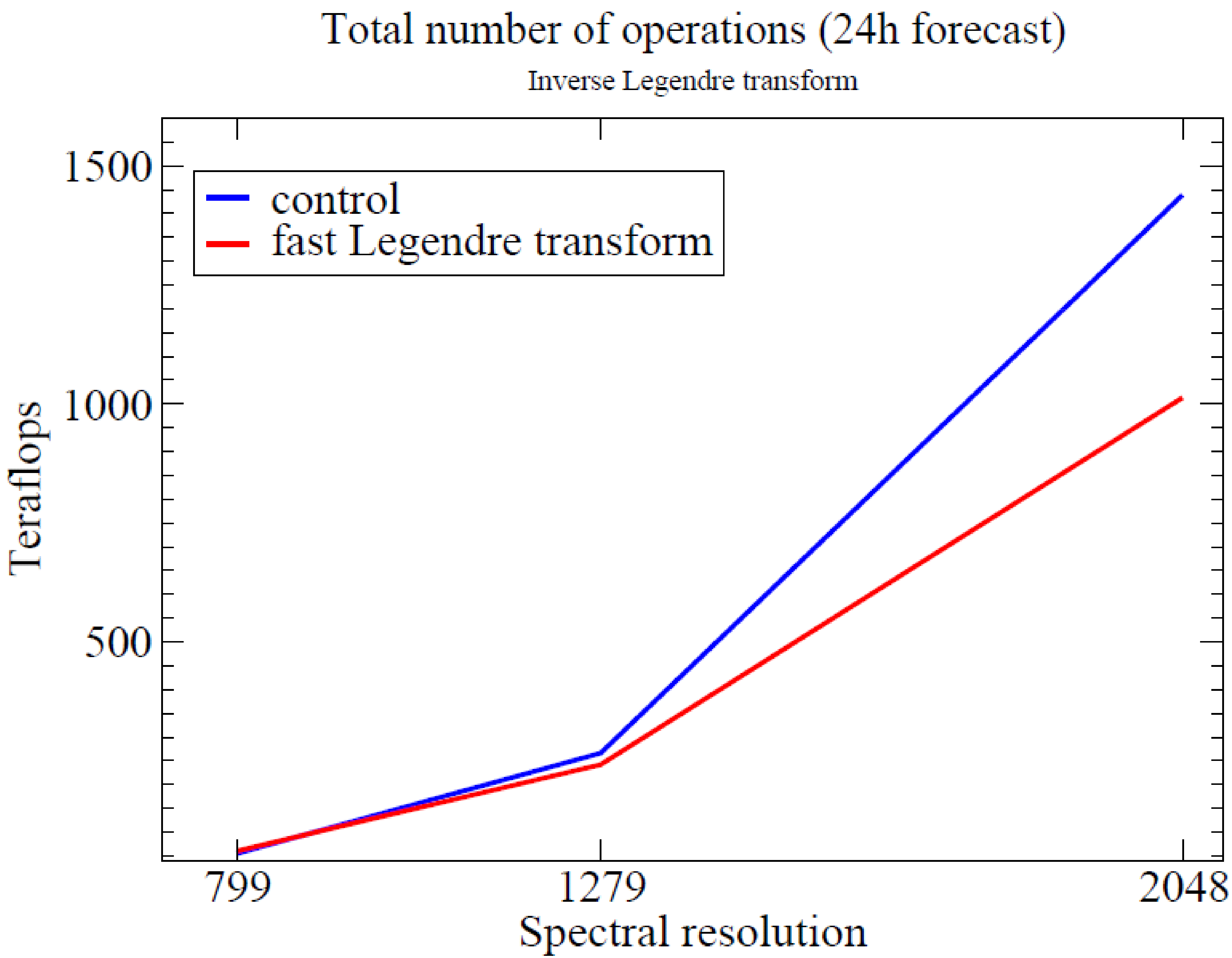
Cost of spectral transform method

- The Fourier transform can be computed at a cost of **C*N*log(N)** where C is a small positive number and N is the cut-off wave number in the triangular truncation with the Fast Fourier Transform (FFT).
- Ordinary Legendre transform is $O(N^2)$ but can be combined with the fields/levels such that the arising matrix-matrix multiplies make use of the highly optimized BLAS routine DGEMM.
- But overall cost of transforms is $O(N^3)$ for both memory and CPU time requirements.
- On top of the computational cost there is also the cost of message passing associated with the "transpositions" but likely $O(N^2)$

Desire for **a fast Legendre transform where the cost is proportional to C*N*log(N)**
and thus overall cost proportional to N^2*log(N)


Total number of operations (24h forecast)
Inverse Legendre transform
control
fast Legendre transform
Teraflops
1500
1000
500
799
1279
2048
Spectral resolution

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Other technical developments

- OOPS project and IFS code cleaning and modularisation
- IFS can be build with free tools and libraries using gfortran_v4.5
- GRIB_API → GRIB2 (also in preparation of increase of vertical levels to approximately 140 levels next year)
- Metview 4 released

BC project review

- ECMWF committed to provide quality boundary conditions to regional forecast, data assimilation and EPS applications
- Main points suggested by the TAC subgroup:
  - Hourly boundary conditions
  - Alternative timeliness scheduling needs further research
  - Possibility of BCs for LAM EPSs considered
  - Special topic BCs in LAMs user group workshop hosted at ECMWF within the next 18 months
  - Regular review (every 2-3 years) of BC requirements for the member states as these evolve

Additional slides

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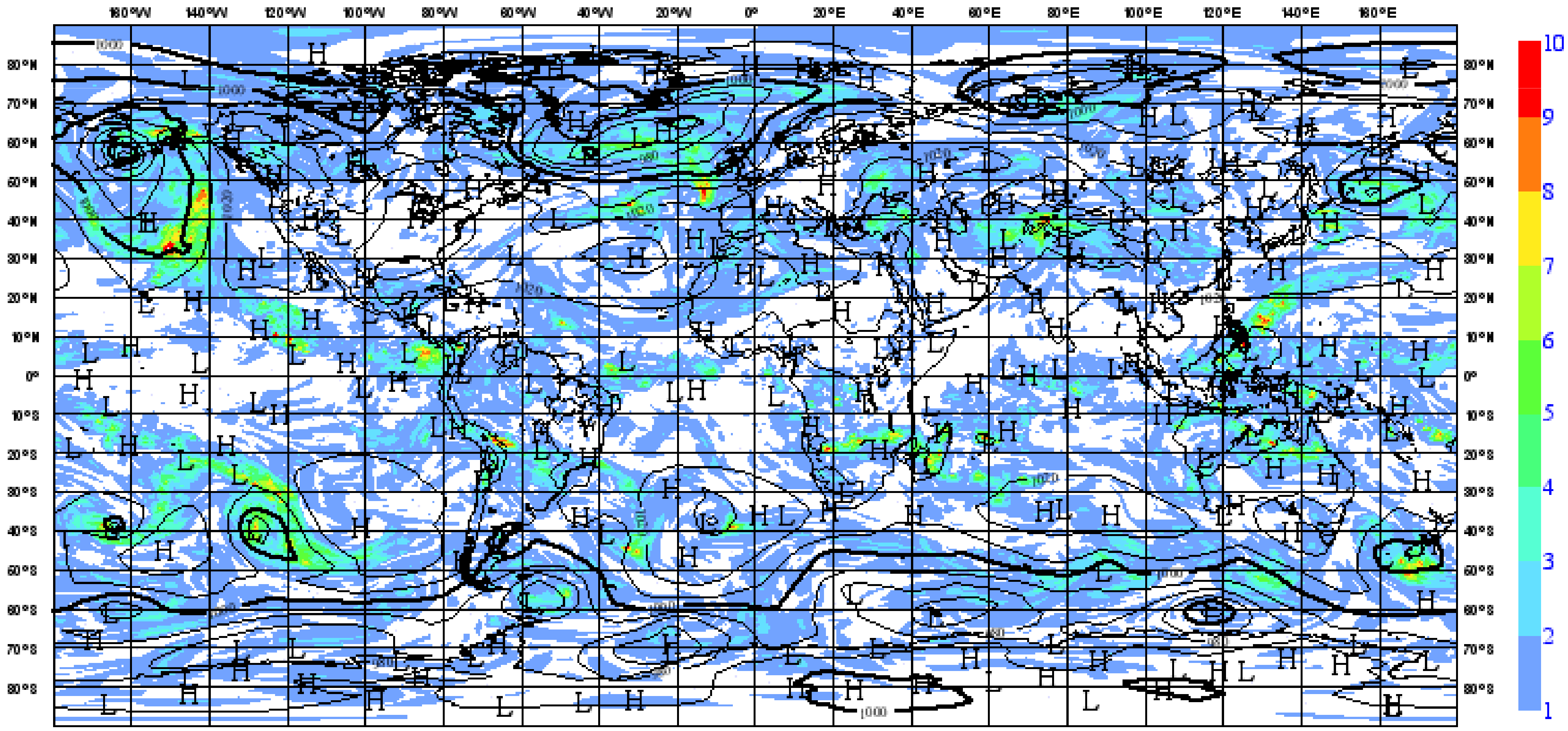
Example of ensemble spread that is flow dependent (without filtering noisy with only 10 ensemble members)

Vorticity at 500 hPa, +9h



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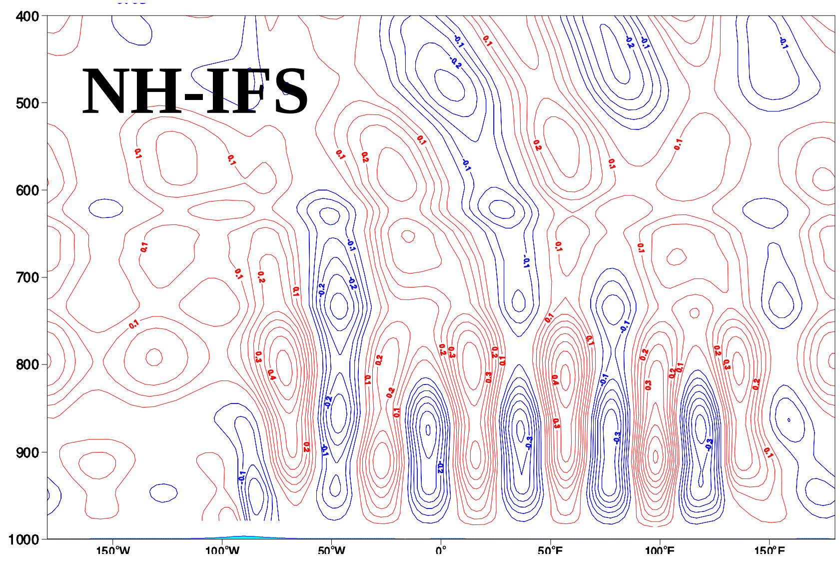
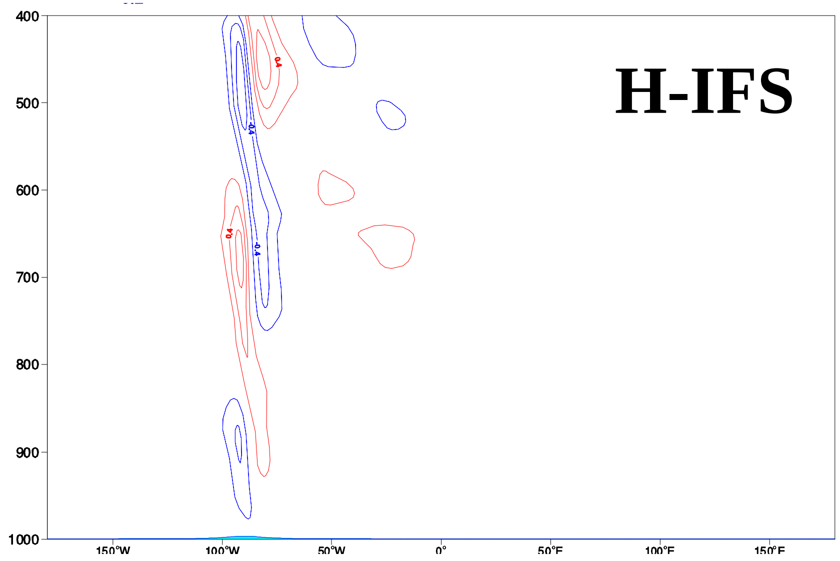
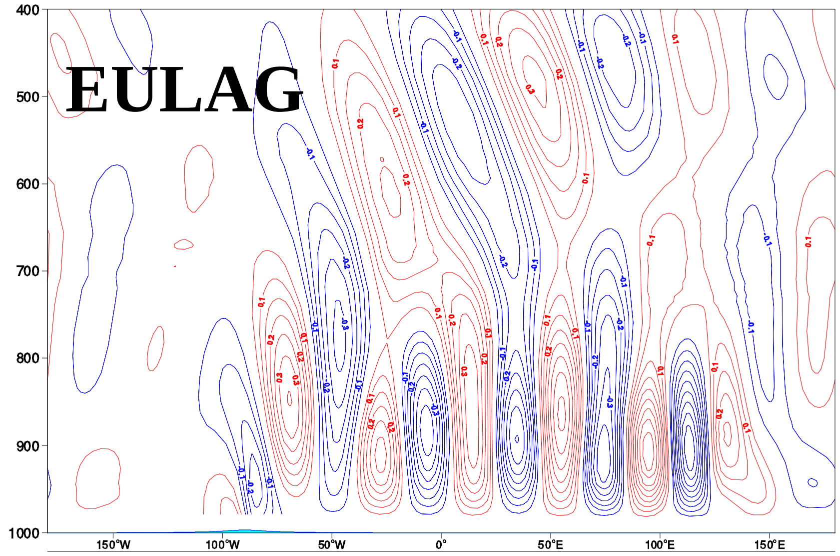
Quasi two-dimensional orographic flow with linear vertical shear







The figures illustrate the correct horizontal (NH) and the (incorrect) vertical (H) propagation of gravity waves in this case (Keller, 1994). Shown is vertical velocity.

(Wedi and Smolarkiewicz, 2009)

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