Max Planck Society

Max Planck Institute for Meteorology

COSMOS1 ESM and ICON dynamics

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Content

- COSMOS model development
  - Recent developments
  - COSMOS model packages
- ICON dynamics
  - Intro
  - Shallow water model
  - Ongoing work
- Conclusions

Model development in the last 12 months

- Development of models and their coupling
  - Shortwave aerosol scattering (PhD work of Manu Thomas)
  - Shortwave gas absorption (Cagnazzo et al., ACP, 2007)
  - Cloud radiative forcing: Monte Carlo Independent Column Appr. (Räisänen et al., J. Climate, accepted)
  - Computation of CO2 fluxes: MPIOM ◊ ECHAM5
  - Land use change as external forcing of terrestrial carbon cycle Dynamical vegetation (DYNVEG)
- Model integration in the PRISM system
  - Usage of Standard Compile Environment and Standard Running Environment for configuration of models and generation of scripts for compilation and running.
  - Carbon cycle
- Technical improvements
  - Optimization of AO and carbon cycle models on NEC-SX6

Shortwave radiation

Based on implementations of the Fouquart&Bonnel schemes implemented in ECMWF models

ECHAM4:

- Discretization:
  - 250nm – 4000nm, 2 bands: 1UV/vis + 1 near infrared (NIR)
  - 1 vertical integration: all sky
- Problems:
  - Overestimation of NIR cloud and aerosol radiative forcing

ECHAM5 until version 5.3.02

- Based on IFS model Cycle 23 Release 1
- Discretization:
  - 250nm – 4000nm, **4** bands: 1UV/vis + **3** NIR
  - **2** vertical integrations: clear sky and cloudy sky subcolumns
    Simplified loop for clear sky radiative transfer
- Problems:
  - Overestimation of clear sky aerosol radiative forcing
  - Coarse representation of O3 absorption,
    Underestimated upper stratospheric heating and hence temperature

Shortwave radiation

Based on implementations of the Fouquart&Bonnel schemes implemented in IFS models at ECMWF

ECHAM5.4.00 (Release date: 29.05.2007)

- Based on SW6 scheme in current IFS
- Discretization:
  - 185nm – 4000nm, **6** bands: **3**UV/vis+3NIR
    Gas absorption as in IFS (Cagnazzo et al., ACP, 2007)
    Cloud optical properties of ECHAM5
  - 2 vertical integrations: clear sky and cloudy sky subcolumns
    Avoid simplifications for clear sky aerosol scattering
    (M. Thomas, PhD thesis on effects of the Mt. Pinatubo eruption)

Aerosol scattering

Scattering of aerosols in the clear sky sub-column is simplified.

☞ Radiative forcing by aerosols is overestimated.

PhD study of Manu Thomas lead to the following changes:

- Multiple reflection in clear sky conditions
- Interaction of gas absorption and scattering
- Proper summation of aerosol optical properties
- Single Delta transformation of aerosol optical properties
- Use Eddington approximation also in clear sky subcolumn

☞ Presentation on Supervolcanoe project Timmreck/Schmidt
(~50% reduction in Pinatubo aerosol temperature signal)

Spectral resolution

1 UV+vis + 3 NIR ◊ 3 UV+vis + 3 NIR

250nm to 4000nm ◊ 185nm to 4000nm

Improvements:

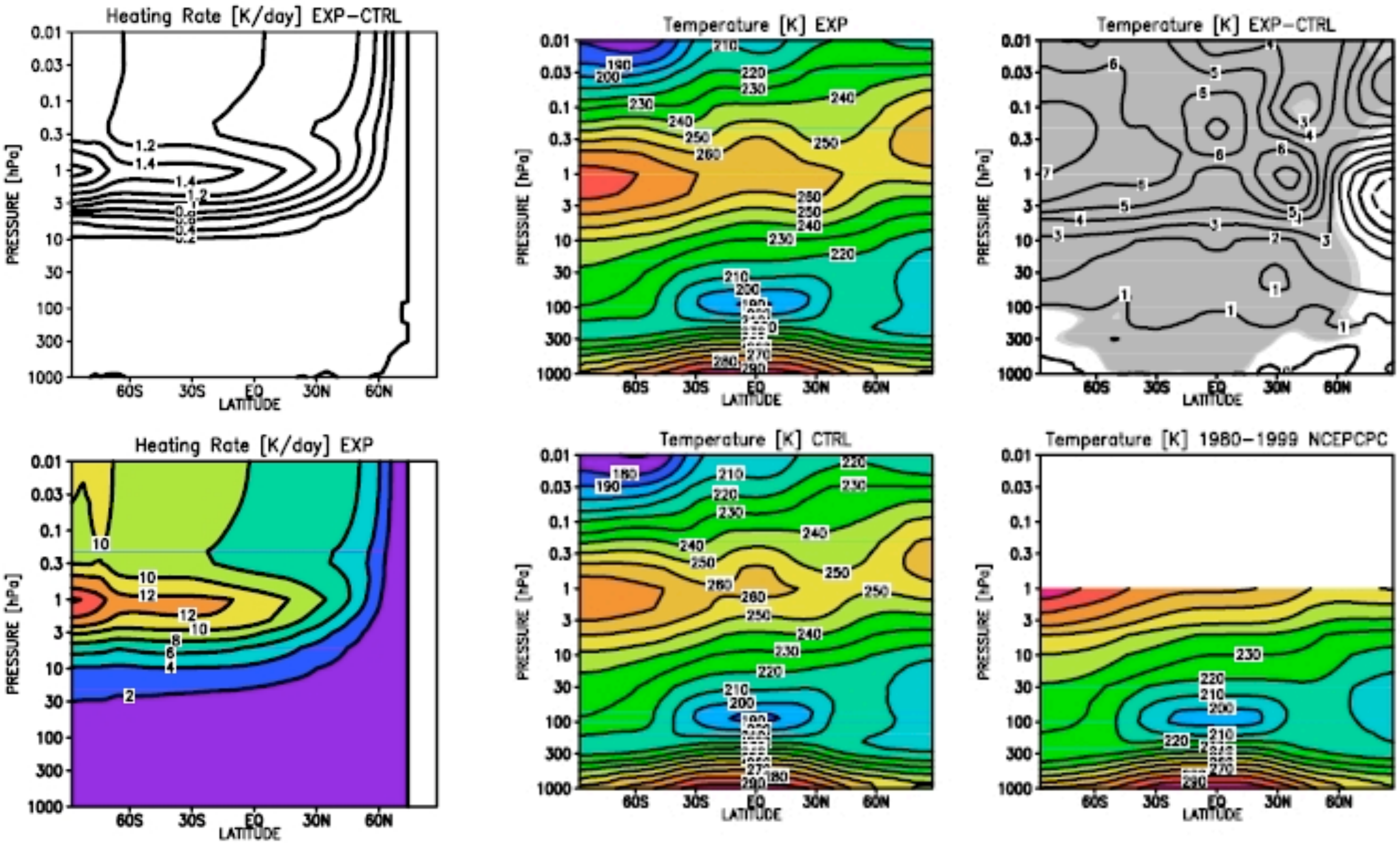
- Better differentiation of O3 absorption by strong Hartley bands (UV) and weak Chappuis bands (visible)
- Full spectral coverage of Hartley bands

Evaluation in Cagnazzo et al. (ACP, 2007)

- Comparison of stand alone model with line-by-line rad. scheme
- Comparison of ER-40 and MAECHAM5 simulations: SW4 vs. SW6

Spectral resolution

Evaluation in MAECHAM5 simulation, January climatology



COSMOS versions / developments

Start:

- Collection of ECHAM5 and MPIOM based models

COSMOS aims:

- Build integrated modelling system for Earth system studies
- Modularity for different model configuration
- Flexibility for different computing systems

Motivations:

- Science: Millennium, Supervolcanoe, …,
- Climate change assessments: IPCC-AR5, WMO/UNEP O3

COSMOSv0.9 (status at last COSMOS meeting)

COSMOSv0.9 package

- ECHAM5/MPIOM as used for IPCC-AR4 simulations
- OASIS coupler
- Scripts for running the coupled model on the NEC-SX6 at DKRZ

Separate models (and compile and run scripts)

- ECHAM5, ECHAM5-HAM, ECHAM5-JSBACH
- MPIOM, MPIOM-HAMOCC

Distribution by Model and Data Group

COSMOSv1.0 (Released Nov.2006)

New: Embedding of models in PRISM environments

- SCE+SRE configurations:
  - Models:
    - "cosmos-ao" = atmosphere ocean model
  - Resolutions:
    - T31L19/GR3L40
    - T63L31/GR1.5L40
  - Computers/Sites
    - NEC-SX6 at DKRZ
- Codes:
  - ECHAM5
  - MPIOM
  - OASIS3

COSMOSv1.1 (in work)

New: Includes carbon cycle, more model configurations

- SCE+SRE:
  - Models:
    - "cosmos-a" ◊ ECHAM5 = atmosphere
    - "cosmos-as" ◊ ECHAM5-JSBACH = atmosphere + land vegetation
    - "cosmos-o" ◊ MPIOM = ocean
    - "cosmos-ob" ◊ MPIOM-HAMOCC = ocean + biogeochemistry
    - "cosmos-ao" ◊ ECHAM5/MPIOM = atmosphere ocean
    - "cosmos-asob" ◊ ECHAM5-JSBACH/MPIOM-HAMOCC = carbon cycle
  - Resolutions:
    - T31L19/GR3L40
    - T63L31/GR1.5L40
  - Computers/Sites
    - NEC-SX6 at DKRZ
- Codes:
  - ECHAM5, ECHAM5J
  - MPIOM
  - HAMOCC
  - OASIS3

Later versions (v1.2 etc.)

COSMOS1.n

Aims:

Integrate HAM aerosol model:

- Replace ECHAM5 by ECHAM5-HAM
- “cosmos-ah...” configurations

1. Merge ECHAM5-HAM and ECHAM5-JSBACH
   - Only one ECHAM5 code in COSMOS package
2. Fast chemistry
   - Ozone chemistry in multidecadal experiments

COSMOS2

Aims:

- Integrate atmospheric chemistry
- Redesign of ECHAM software structure
  - Unify ECHAM5 and ECHAM5/MESSy software infrastructures
  - Interface for ICON dynamical core

Feedback from the COSMOS community

Welcome!

- Must be tested thoroughly and documented
- Radiative balance must be maintained
- Better overall performance
- Ideally removes known persistent biases
- No detrimental effects on computational efficiency

Request

- Please return the SCE and SRE settings for your computing system so that it can be incorporated in the COSMOS packages
- Included in following releases
- Available to others

The ICON Project: Development of a New Dynamical Core for a Unified Climate and NWP Model

A joint project of the Max Planck Institute for Meteorology (MPI-M) and the German Meteorological Service (DWD)

MPI-M: E. Roeckner, M.A. Giorgetta, ***L. Bonaventura***[(1)]***, H. Wan, P. Korn,*** L. Kornblueh, ***A. Gassmann***

DWD: D. Majewski, ***Th. Heinze, P. Ripodas,*** B. Ritter, H. Frank, D. Liermann, U. Schättler

(1) Now at MOX at the Politecnico di Milano

Motivation

Why to develop a new dynamical core

Goals of the ICON project

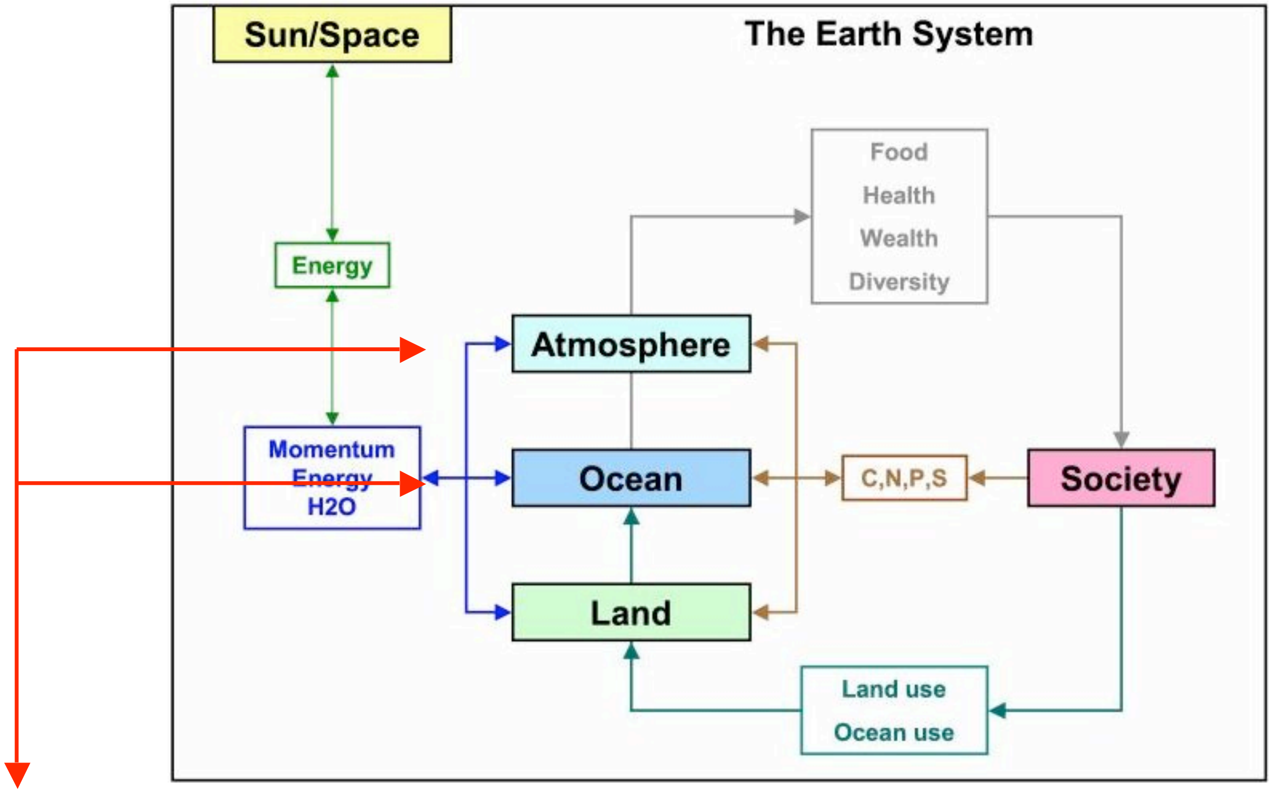
Development plan

The shallow water model

- Grid
- Numerics
- Tests: Flow over a mountain, Rossby-Haurwitz wave

Summary and outlook

Schematic view of the Earth System



Dynamical cores are at the base of the general circulation models and their properties determine the quality of the solutions

Original motivation at the MPI-M:

Inherent **problems with tracer mass conservation** in the existing **ECHAM5** atmospheric general circulation model.

ECHAM5:

- **Spectral transform dynamics** with semi-implicit time stepping, Asselin time filter and hybrid vertical coordinate, global mass fixer
- **Gridpoint transport scheme** (Lin&Rood) which is mass conserving provided winds are derived from a mass conserving dynamics
- Combination of both generates unbalanced mass sinks and sources, unless “corrected” winds were available
- No theoretical basis for correction of winds

◊ **Overcome the problem with a new dynamical core**

Motivation at DWD

- Include **more processes** in operational models as necessary for the increased use of satellite radiances, example: ECMWF has included a (linearized) ozone scheme ◊ **mass conservation** becomes an issue

- Extended forecasts / seasonal forecasts require **coupled atmosphere ocean system (EUROSIP)**

- Need for a model system more similar a climate model

- Current operational global model GME is neither mass conserving nor coupled to an ocean model

Goals of the ICON project

- Develop a mass conserving dynamical core
- Consistent discretized equations for dynamics and transport

- Discretize equations in grid point space
- Use icosahedron for grid construction to allow a quasi uniform horizontal resolution (Sadourny, 1968; CSU, ES, GME)

- Non-hydrostatic and hydrostatic cores

- Use the same core for global an regional atmospheric models
◊ unify codes for global and regional dynamics

- Local mesh refinement in selected regions + multi-scale solutions ◊ conservative 2 way interaction

- Use same grid structure + discrete operators for ocean model

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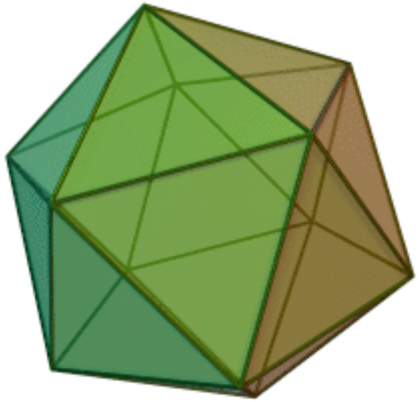
Icosahedron

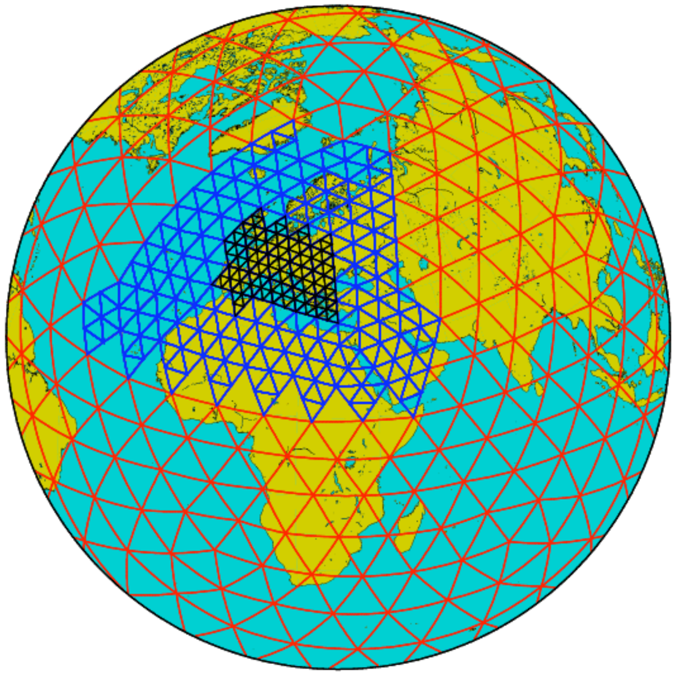
12 vertices

20 equilateral triangles



Example for local grid refinement

- Quasi uniform base grid:
  icosahedron edge ◊ 6 cell edges
- 2 step refinement in a lat-lon region over Europe by bi-section of edges:
  1 triangle ◊ 4 ◊ 16



Shallow water model prototype (ICOSWP) → **SWM + grid refinement (ICOSWM)**

Hydrostatic dyn. core → **HDC + refinement**

Hydrostatic atmosphere (ICOHAM) [1]

Non-hydrostatic atmosphere (ICONAM)

Non-hydrostatic ocean (ICONOM)

Done/Published / In work

[1] ICOsahedral Hydrostatic Atmosphere Model
ICON HDC + ECHAM physics

ICON Shallow water model (ICOSWM)

Numerical scheme in a nutshell:

Finite differences for normal velocity u_n

- Formaly O(1) because of asymmetric position of normal velocity points between adjacent cell centres. The asymmetry is however small
- In practice ~O(2)

Reconstruction of tangential velocity u_t

- By Raviart Thomas finite element of order 0
- By vector radial basis function

Finite volume for height

- Mass conservation

Semi-implicit time integration

- Two time level
- Three time level, leapfrog

Model evaluation: Williamson test cases 5 and 6

Compare results from ICON shallow water model with:

NCAR spectral transform shallow water model as reference
(T426 for case 5, T511 for case 6, 3-time-level scheme, dt=90 s)
(updated version, http://icon.enes.org/swm/stswm/index.html)

GME (current operational global model at DWD)
(semi-implicit 3-time-level scheme, dt=90 s)
(http://icon.enes.org/swm/gmeswm/index.html)

Sensitivity of L2 normalized errors to model parameters

Williamson test case 5 "Flow over an isolated mountain"

- semi-implicit 3-time-level, e-folding=480 s,
  Asselin parameter. 0.02, 0.05, 0.1, 0.2
- semi-implicit 3-time-level, Asselin parameter 0.1,
  e-folding time 240, 480, 960 s
- semi-implicit 2-time-level,
  off-centering parameter 0.6, 0.7

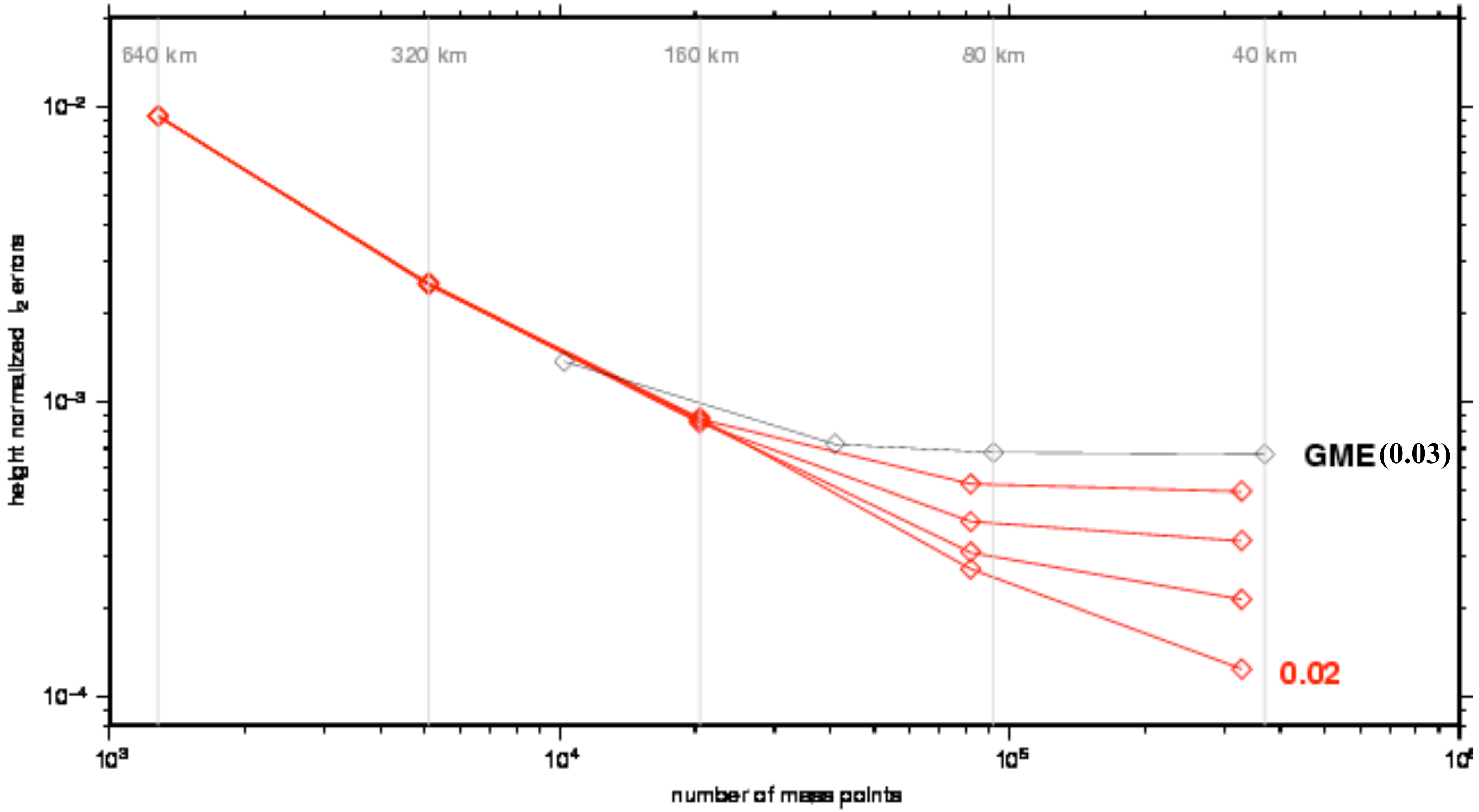
Williamson test case 6 " Rossby-Haurwitz wave"

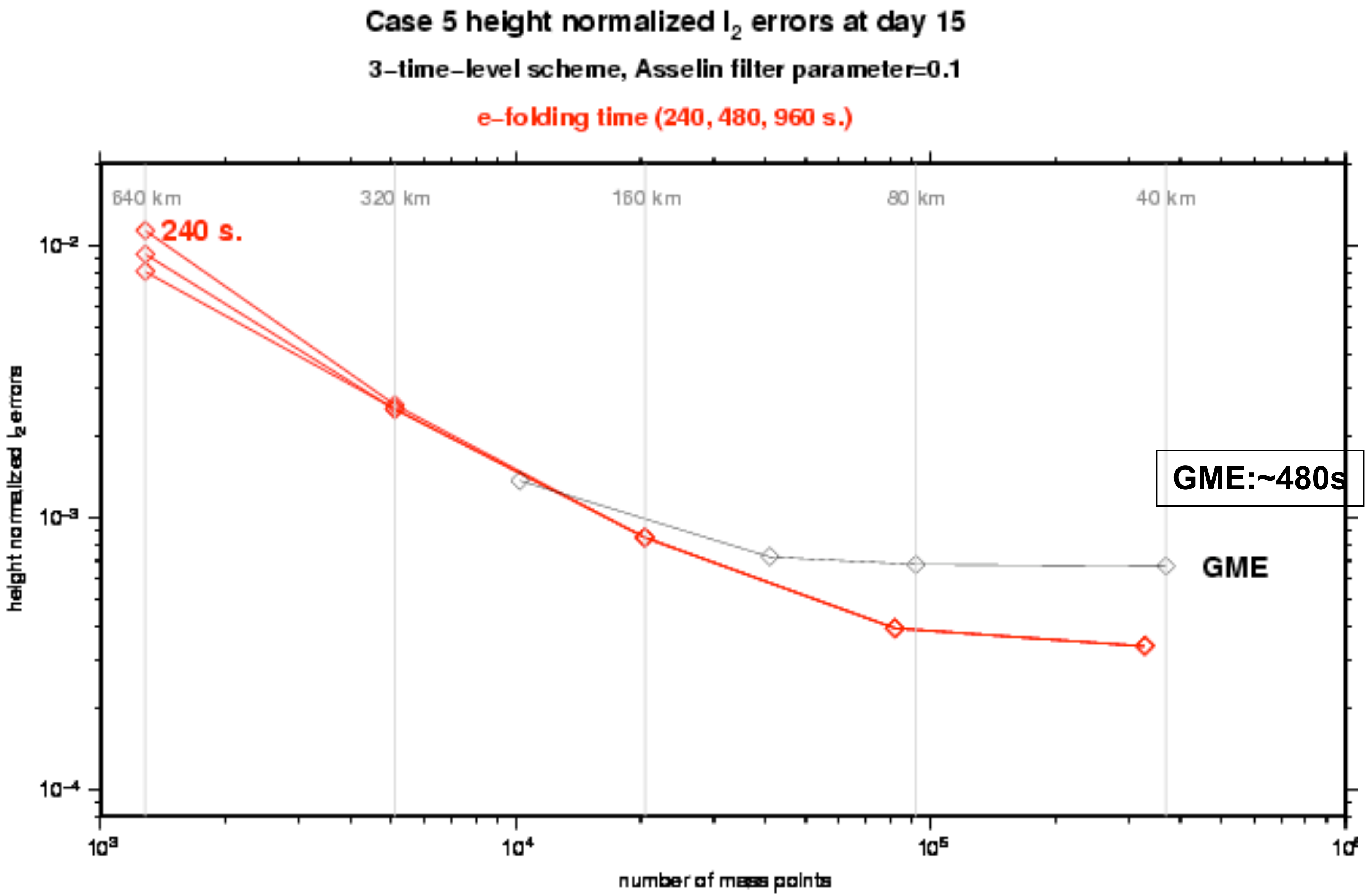
- semi-implicit 3-time-level, e-folding=480 s,
  Asselin parameter 0.05, 0.1, 0.2
- semi-implicit 3-time-level, Asselin parameter 0.05,
  e-folding time 240, 480, 960 s

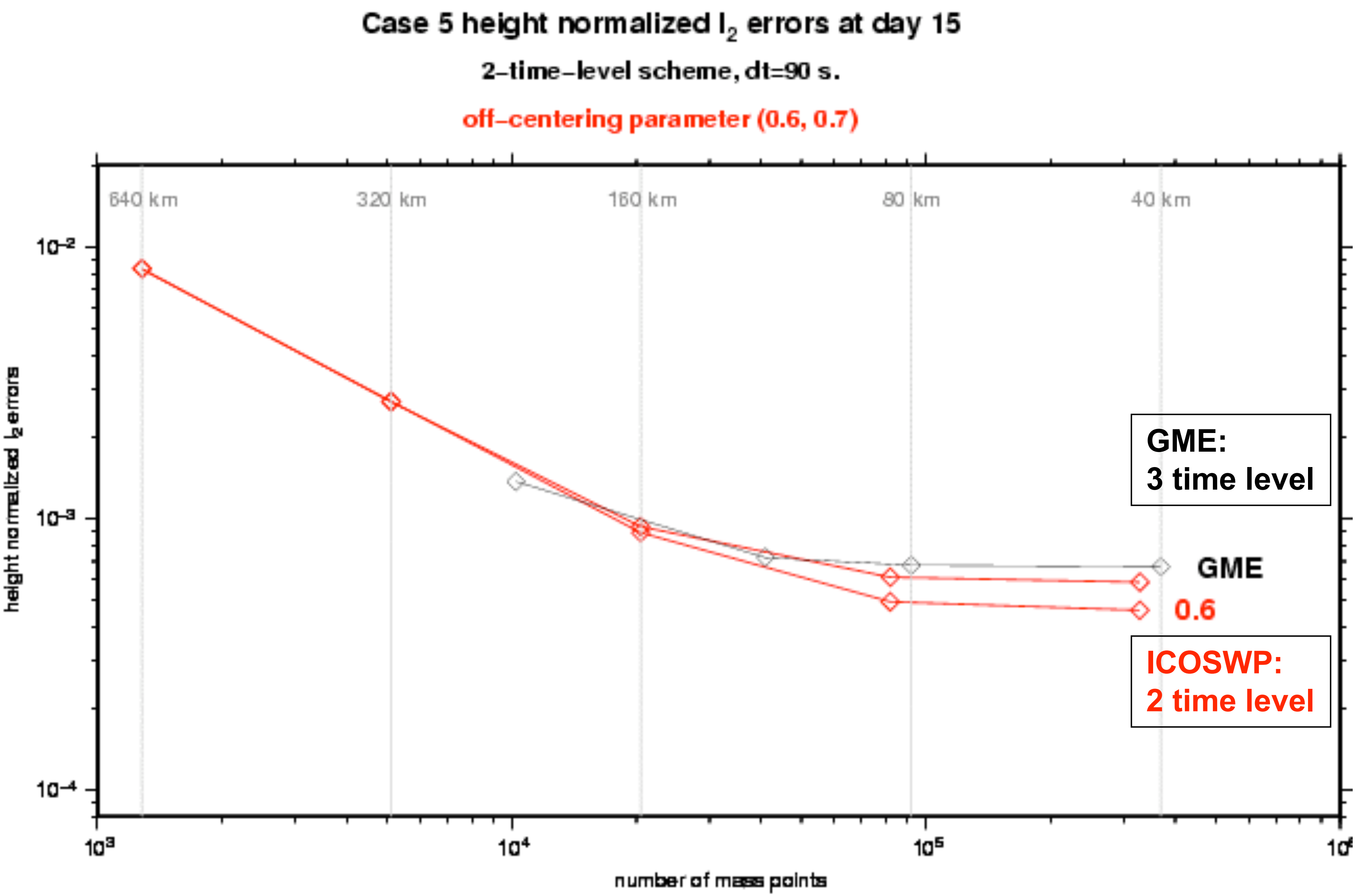
Case 5 height normalized l_2 errors at day 15

semi–implicit 3–time–level scheme, e–folding time=480 s.

Asselin parameter (0.02, 0.05, 0.1, 0.2)



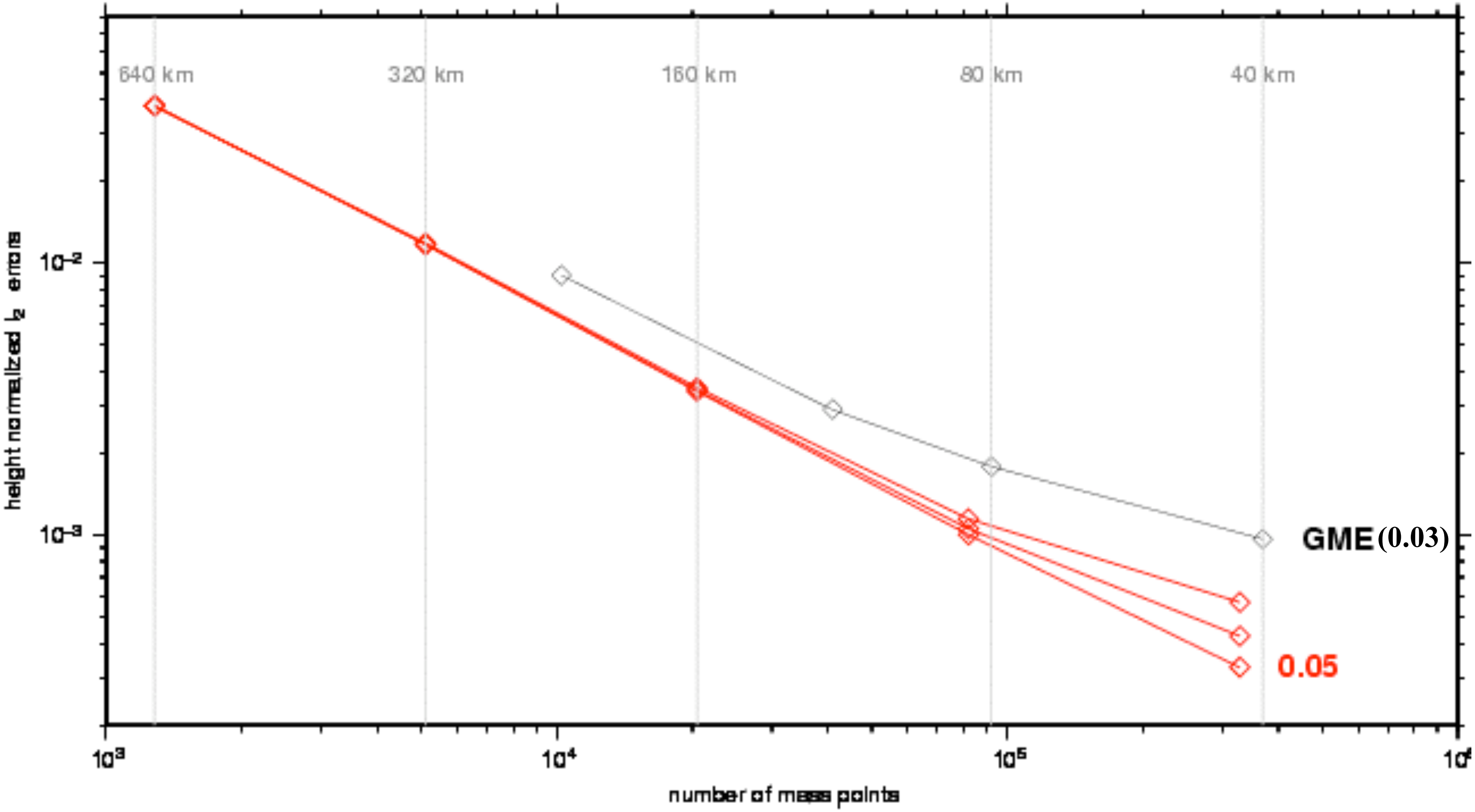

Case 5 height normalized l_2 errors at day 15
3–time–level scheme, Asselin filter parameter=0.1
e–folding time (240, 480, 960 s.)
640 km
320 km
160 km
80 km
40 km
240 s.
GME:~480s
GME
10^{-2}
10^{-3}
10^{-4}
height normalized l_2 errors
10^{3}
10^{4}
10^{5}
10^{6}
number of mass points


Case 5 height normalized l_2 errors at day 15
2–time–level scheme, dt=90 s.
off–centering parameter (0.6, 0.7)
640 km
320 km
160 km
80 km
40 km
10^{-2}
10^{-3}
10^{-4}
height normalized l_2 errors
10^{3}
10^{4}
10^{5}
number of mass points
GME:
3 time level
GME
0.6
ICOSWP:
2 time level

Case 6 height normalized l_2 errors at day 10

3–time–level scheme, e–folding time=480 s.

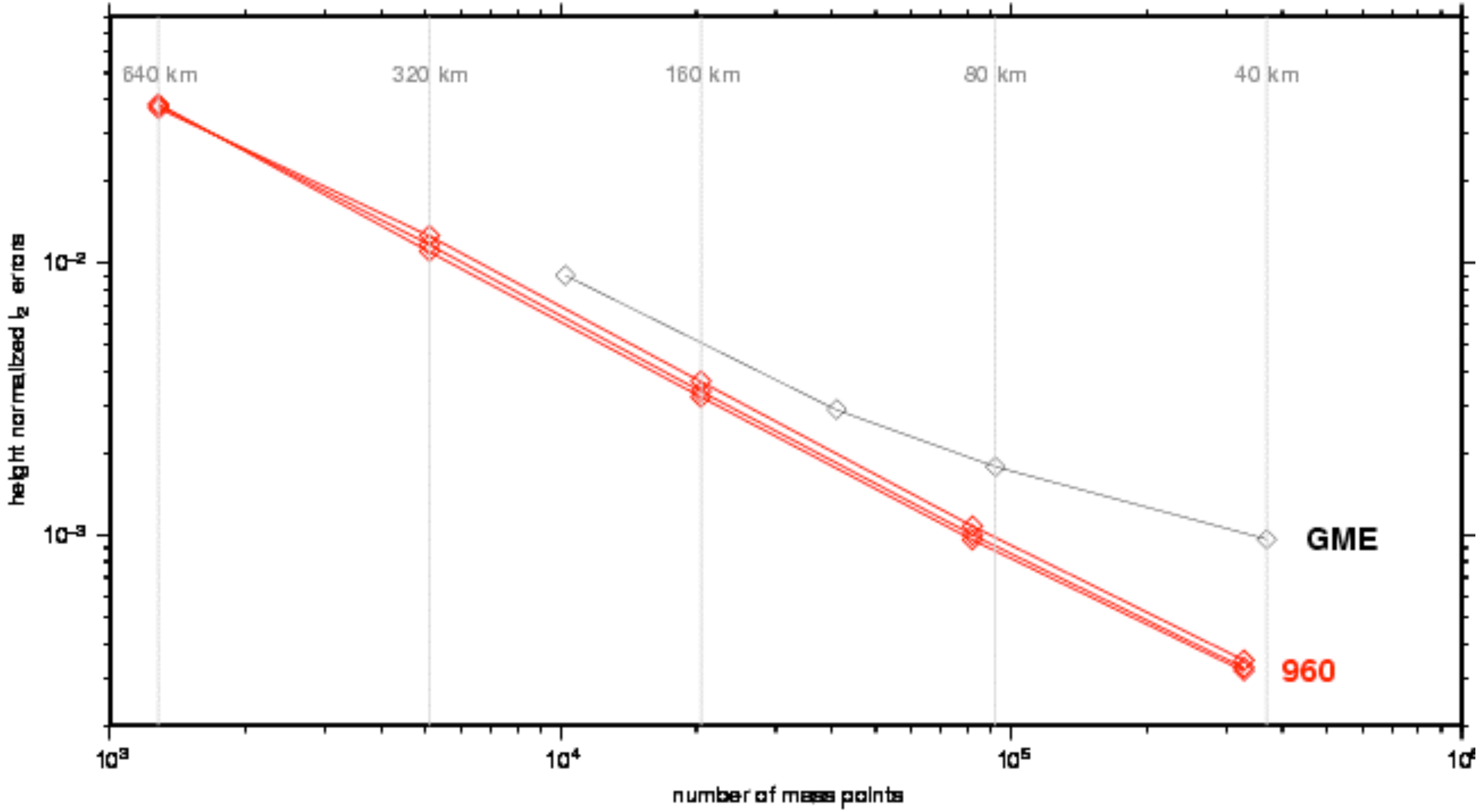
Asselin filter parameter (0.05, 0.1, 0.2)



Case 6 height normalized l_2 errors at day 10

3–time–level scheme, Asselin filter parameter=0.05

e–folding time (240, 480, 960 s.)



Conclusions for convergence tests with ICOSWP

3 time-level scheme, case 5+6
- ICOSWP outperforms GMESWM in both tests
- At low Asselin parameter: convergence also at high resolution

2 time level scheme, case 5
- Comparable to GMESWM with 3 time-level scheme
- Levelling off of convergence at high resolution

Little sensitivity of convergence on diffusion time scale

Conclusions

COSMOS1.0 distributed since 2006, November:

- ECHAM5/MPIOM (cosmos-ao)
- T63L31/GR15L40 and T31L19/GR30L40
- ca. 40 downloads

Ongoing integration of components:

- Carbon cycle model ◊ COSMOS1.1 ◊ Millennium Project
- Aerosol system model ◊ COSMOS1.2

ECHAM5.4 (release: 29.05.2007)

- Improved SW aerosol scattering and gas absorption (release: 29.05.2007)

ICON dynamics:

- Icosahedral shallow water model with new data structure tested in Williamson test suite
- Basis for icosahedral hydrostatic atmosphere dynamical core

Model documentation

Special Section on Climate Models at the Max Planck Institute for Meteorology, J. Climate, 19, Issue 16, 2006.

Atmosphere

- ECHAM5: Roeckner et al., Wild and Roeckner, Roesch and Roeckner, Hagemann et al.
- MAECHAM5: Manzini et al., Giorgetta et al.
- ECHAM5-HAM: Stier et al.
- HAMMONIA: Schmidt et al.

Atmosphere ocean

- ECHAM5/MPIOM: Jungclaus et al.
- ECHAM5/MPIOM-HAMOCC: Wetzel et al.
- ECHAM5-HAM/MPIOM-HAMOCC: Stier et al., ACP, 2006

Carbon cycle model:

- …

The End