A SPECTRAL VERTICAL REPRESENTATION IN CAM-SE

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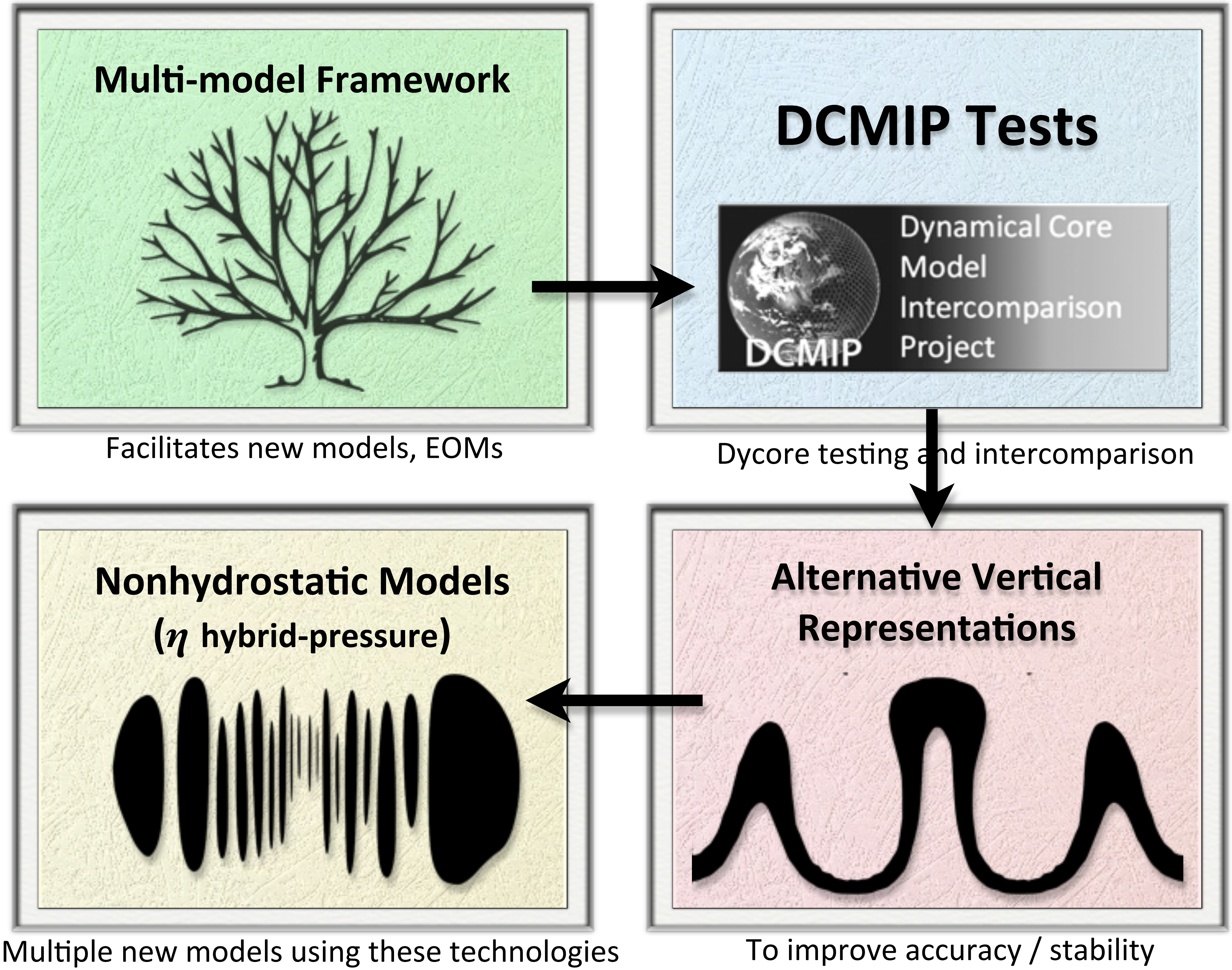
NEW TECHNOLOGIES IN HOMME

- Main thrust of project is nonhydrostatic model in η (hybrid-pressure)
- Enabling technologies: Multi-model framework, DCMIP, alternate vertical rep



NEW TECHNOLOGIES IN HOMME

- Focus today: alternative vertical representations
- (Nonhydrostatic update at the end)

Multi-model Framework

Facilitates new models, EOMs

DCMIP Tests

DCMIP Dynamical Core Model Intercomparison Project

Dycore testing and intercomparison

Nonhydrostatic Models (η hybrid-pressure)

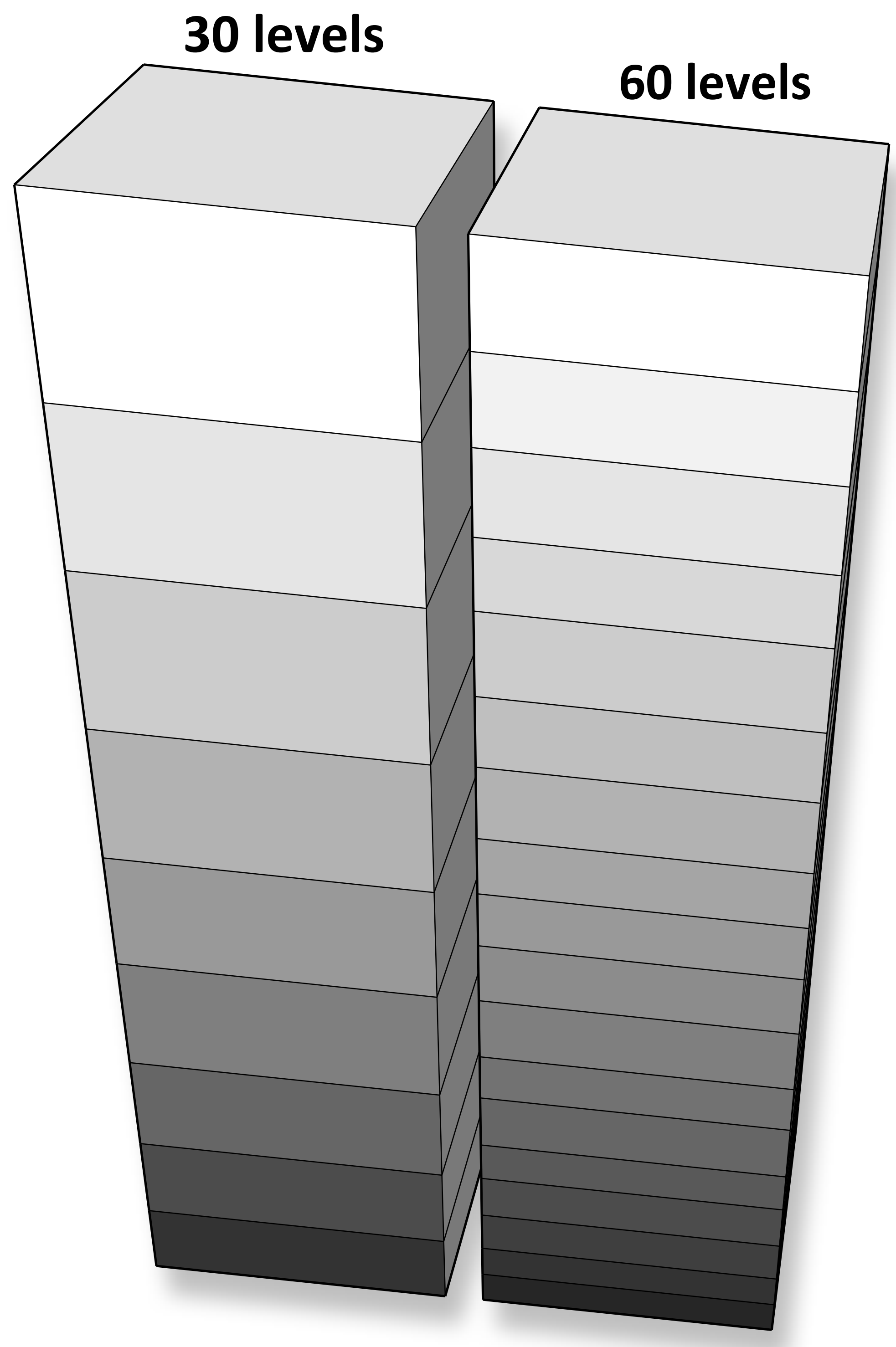
Multiple new models using these technologies

Alternative Vertical Representations

To improve accuracy / stability

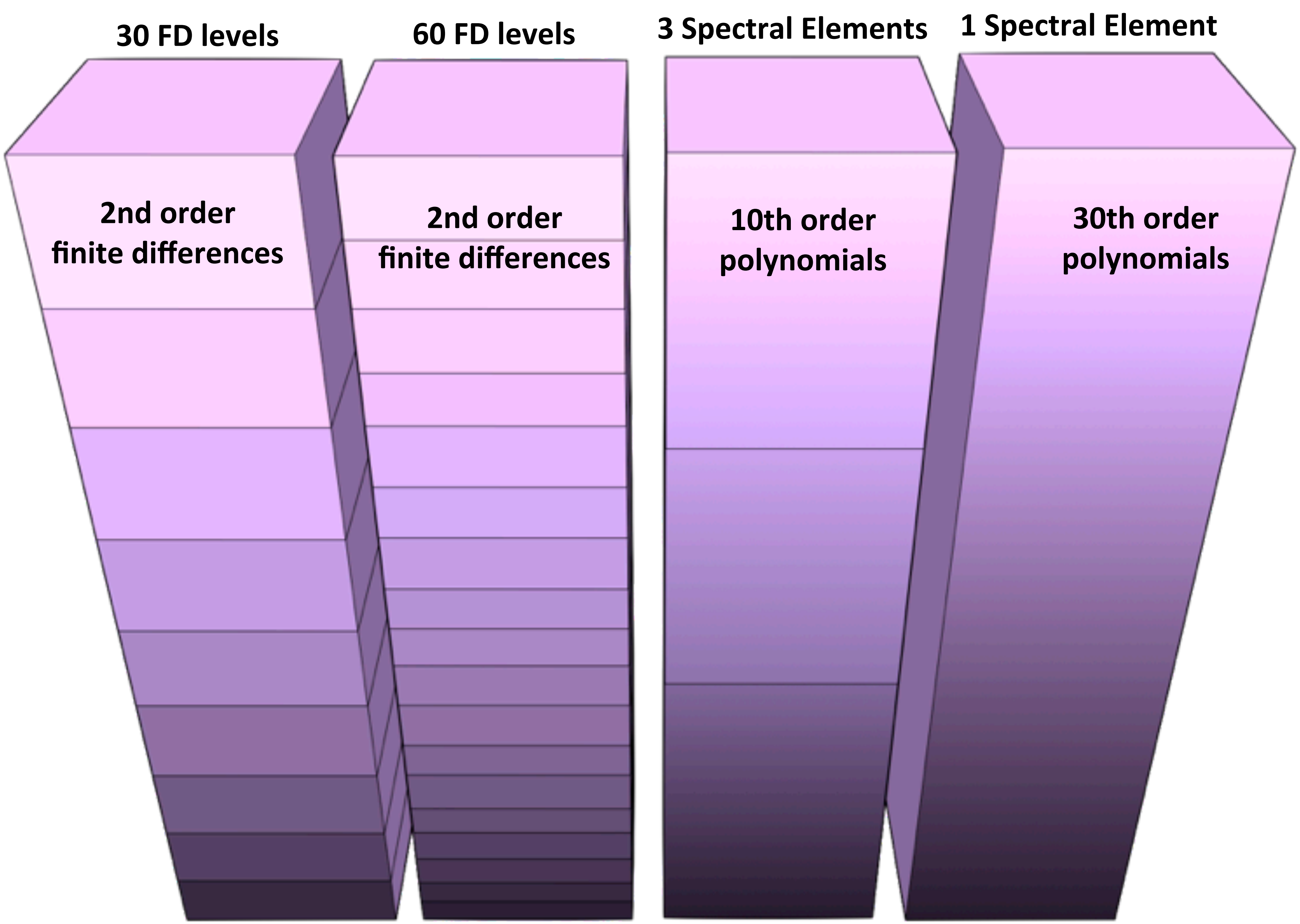
AMWG 2014: PROPOSED INCREASE IN VERTICAL RESOLUTION

- **Currently 30 vertical levels in CAM**
- **Upgrade to 60 levels?**
  - Increases accuracy
  - Increases detail
  - Doubles cost of all simulations
- **Alt: Replace it with spectral representation?**
  - Increases vertical accuracy
  - No additional communication costs
  - No additional memory demands
  - Makes optimal use of vertical DOFs



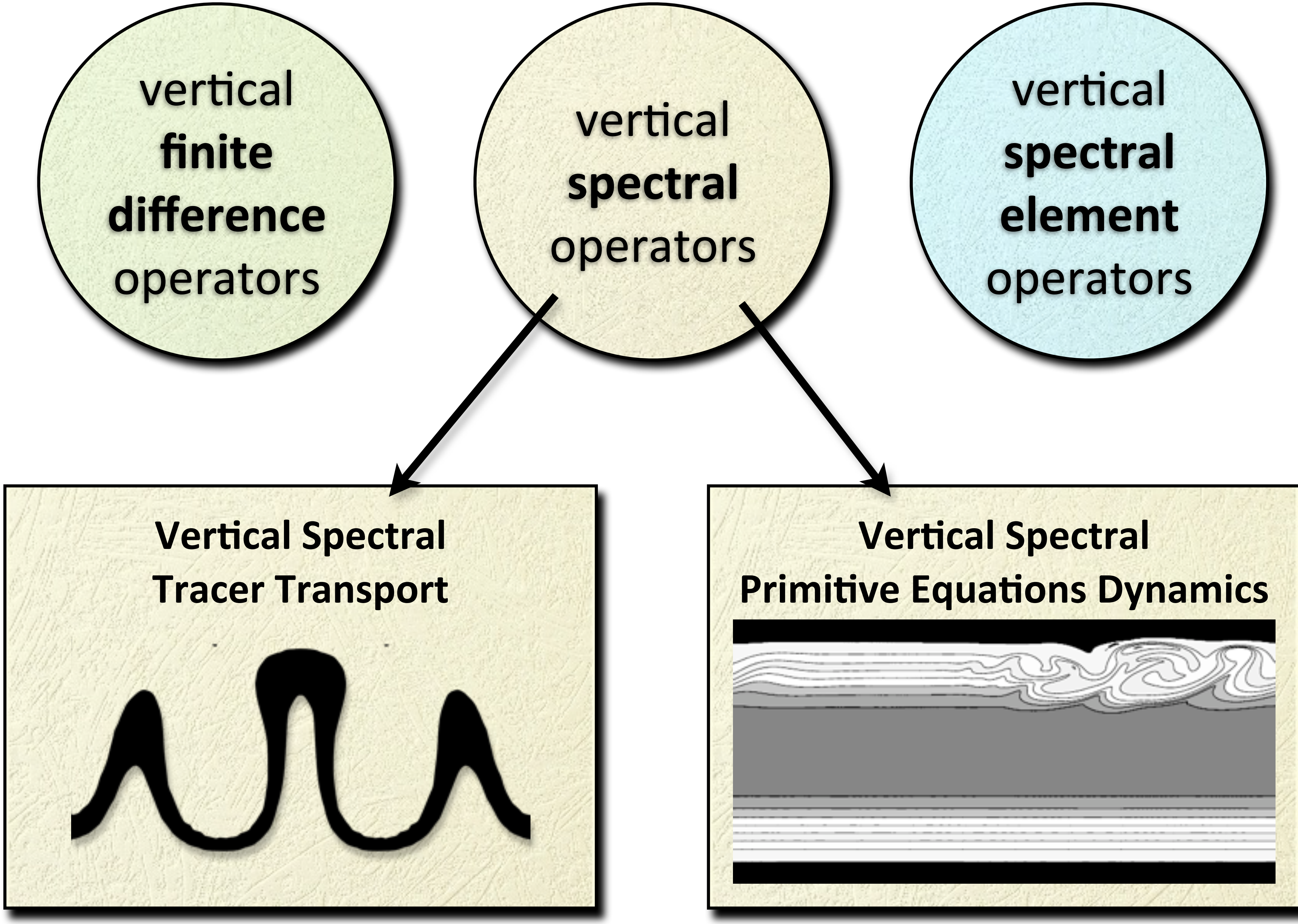
MANY POSSIBLE VERTICAL DISCRETIZATIONS

- 30 levels, 2nd order finite differences
- 60 levels, 2nd order finite differences (2x cost)
- 3 spectral elements, 10th order (1x cost)
- 1 spectral element, 30th order (1x cost)



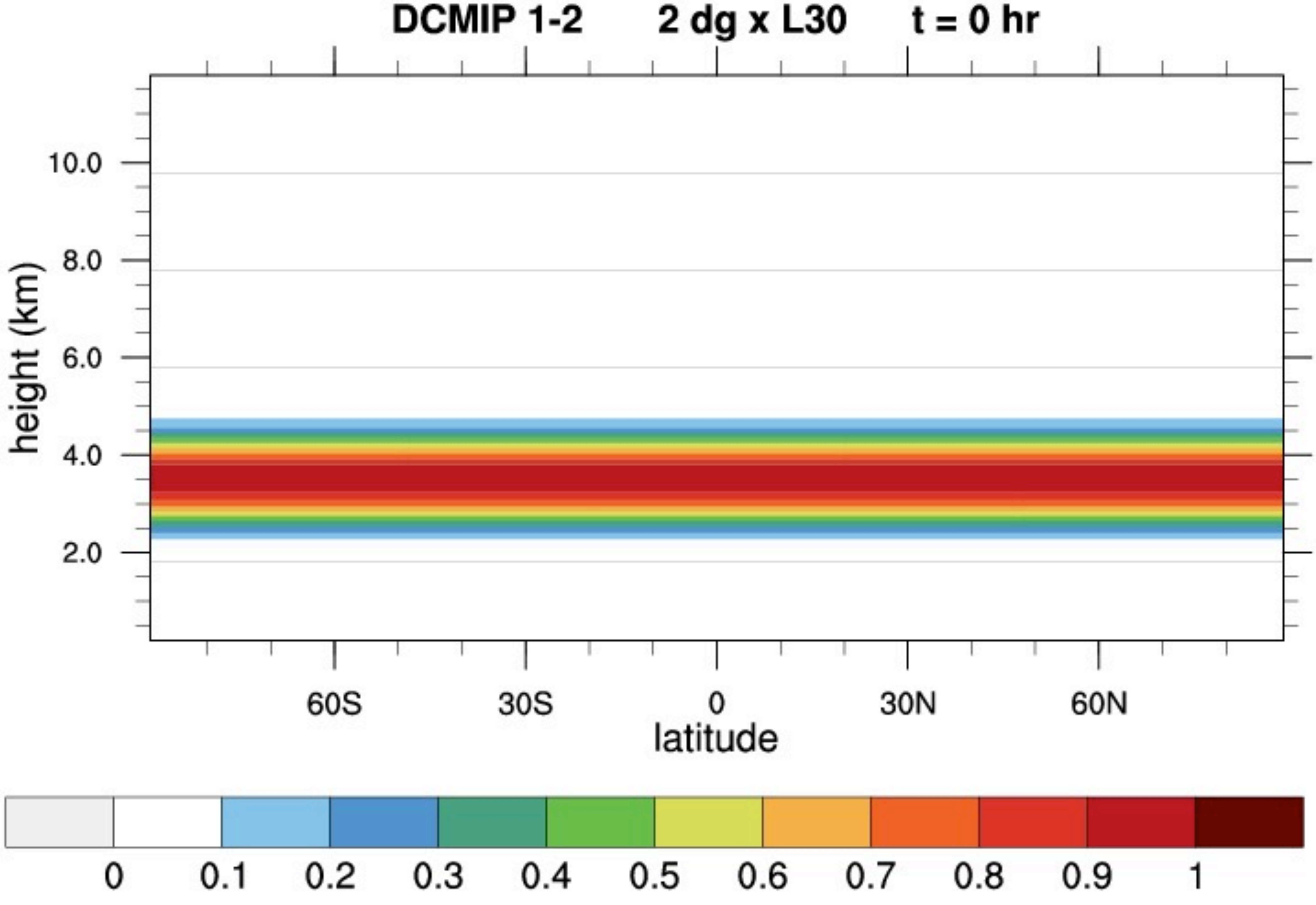
SPECTRAL TRANSPORT AND DYNAMICS

- Both **transport** and **dynamics** models developed using **vertical-spectral** routines
- Will show some **DCMIP test results** to evaluate their performance



DCMIP 1-2: DESCRIPTION

- Prescribed tracer transport, Hadley-like flow
- Examines impact of vertical representation on tracer transport routines
- No limiters, filters, or hyperviscosity



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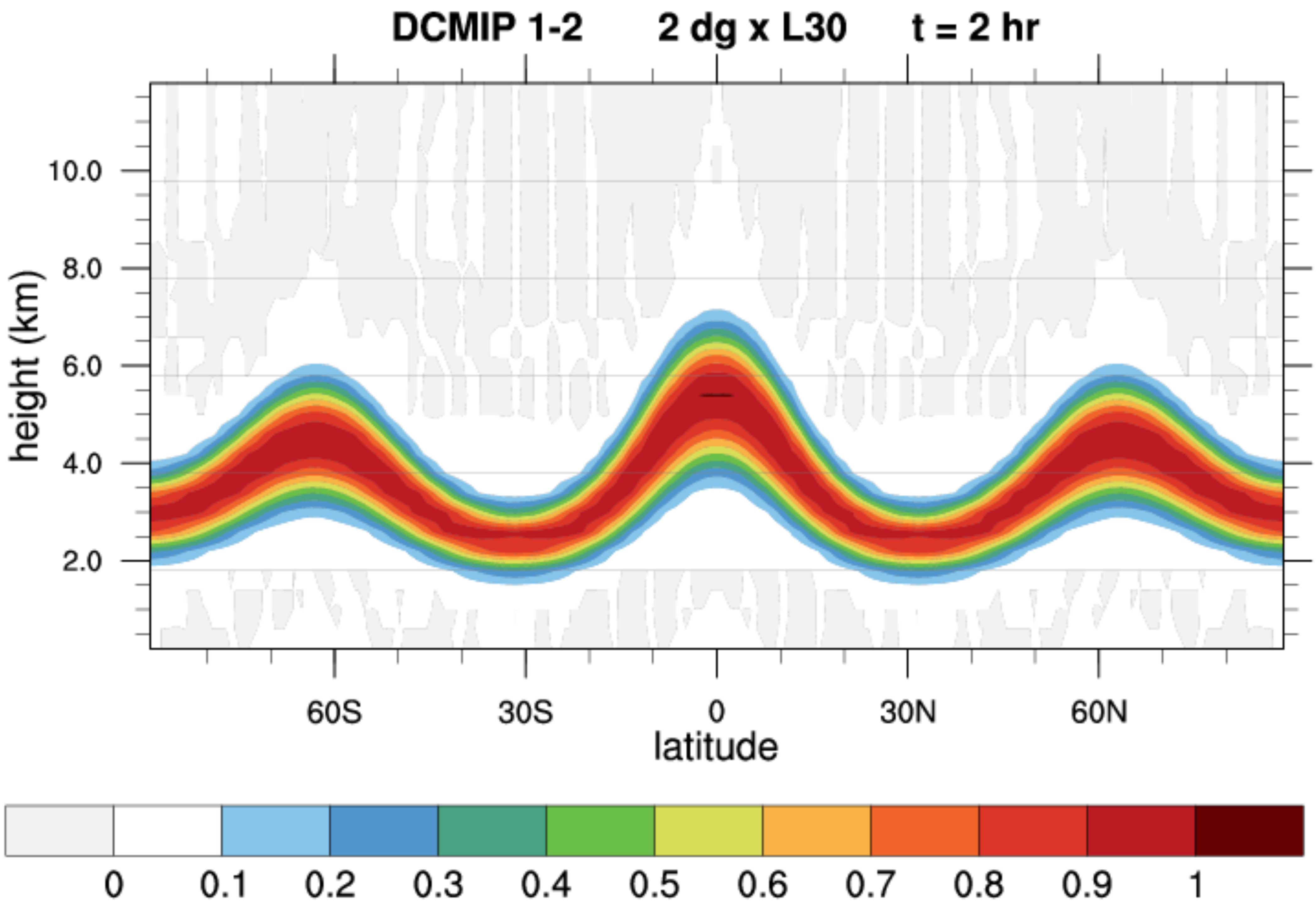

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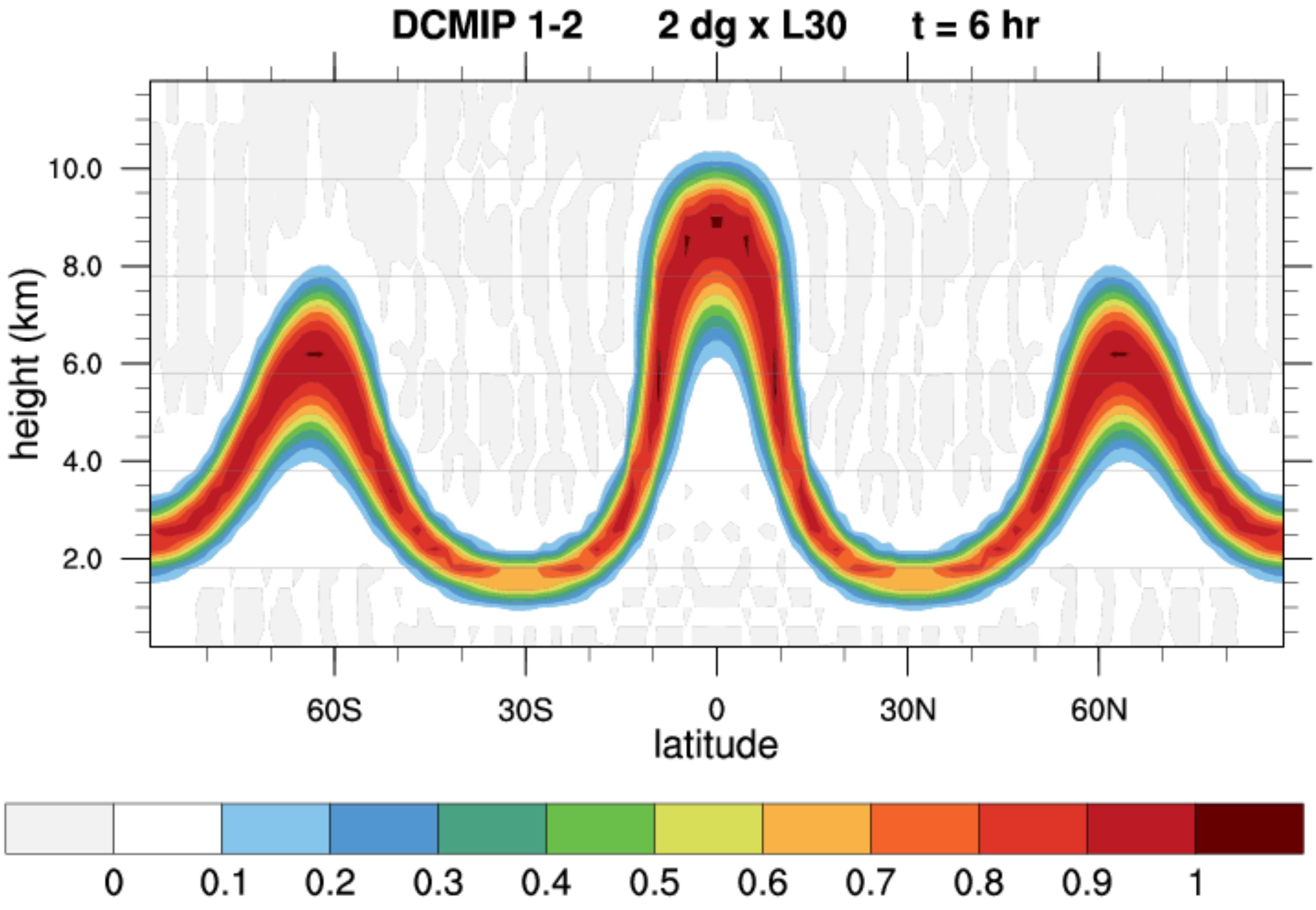

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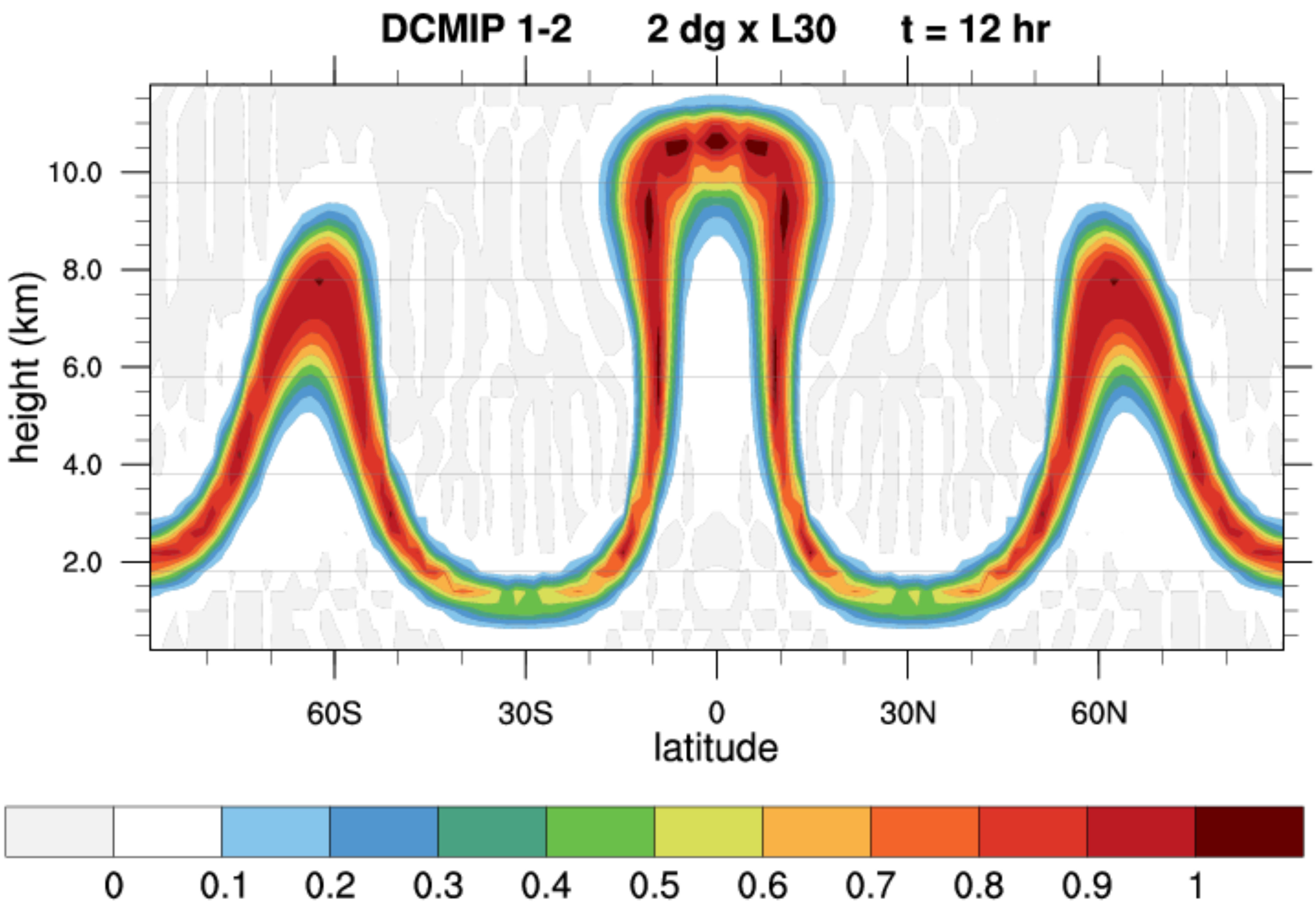

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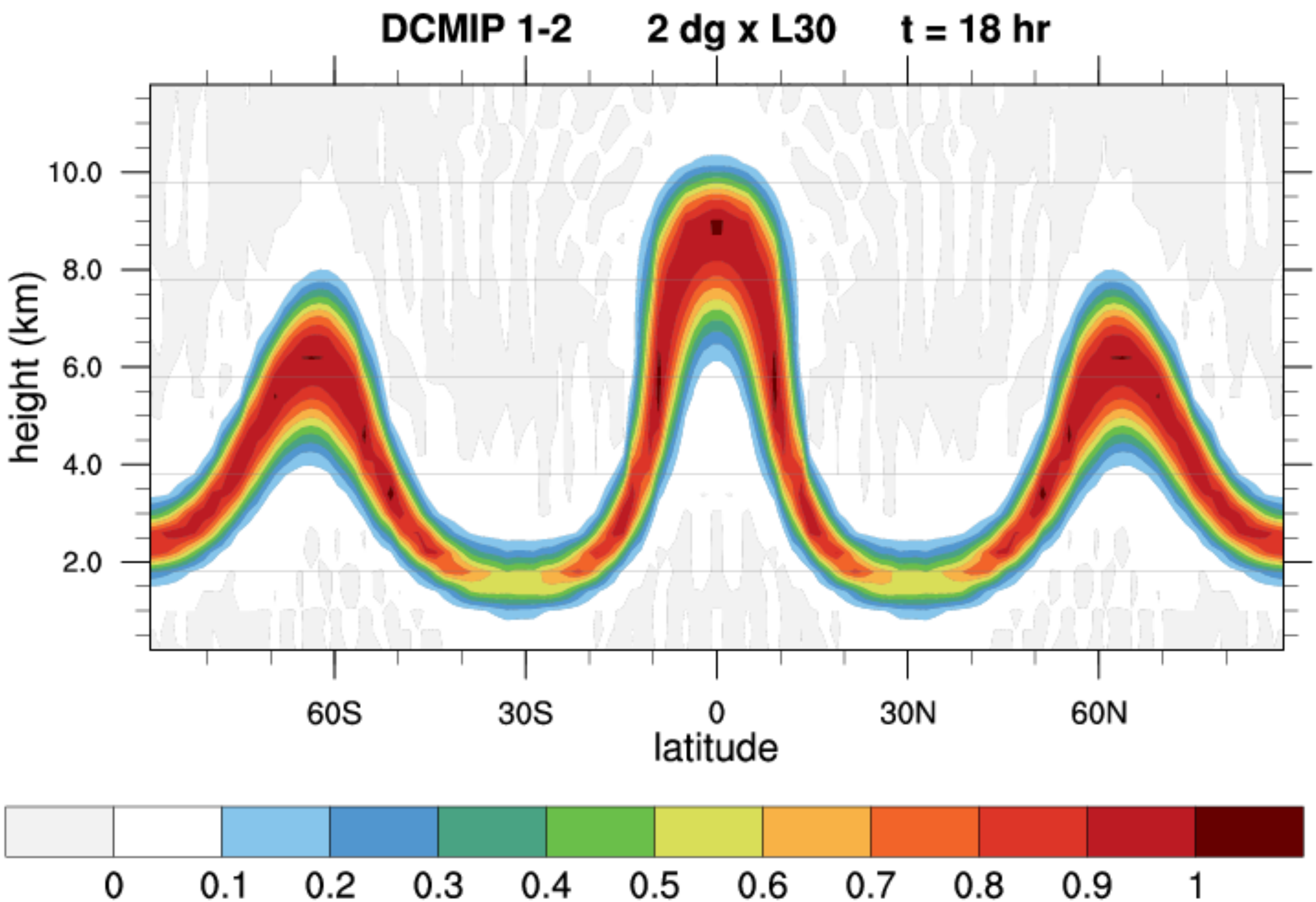

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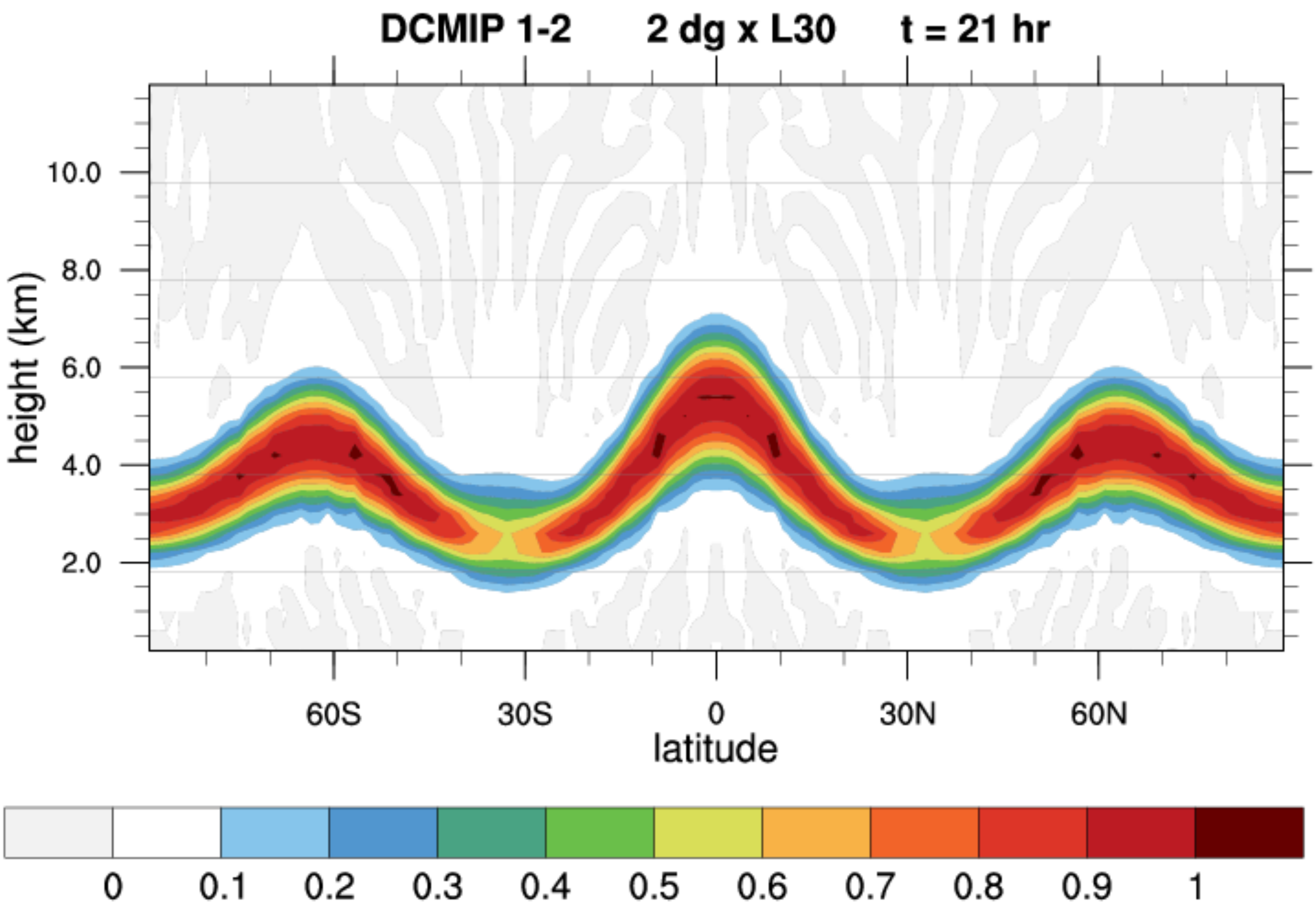

DCMIP 1-2: DESCRIPTION

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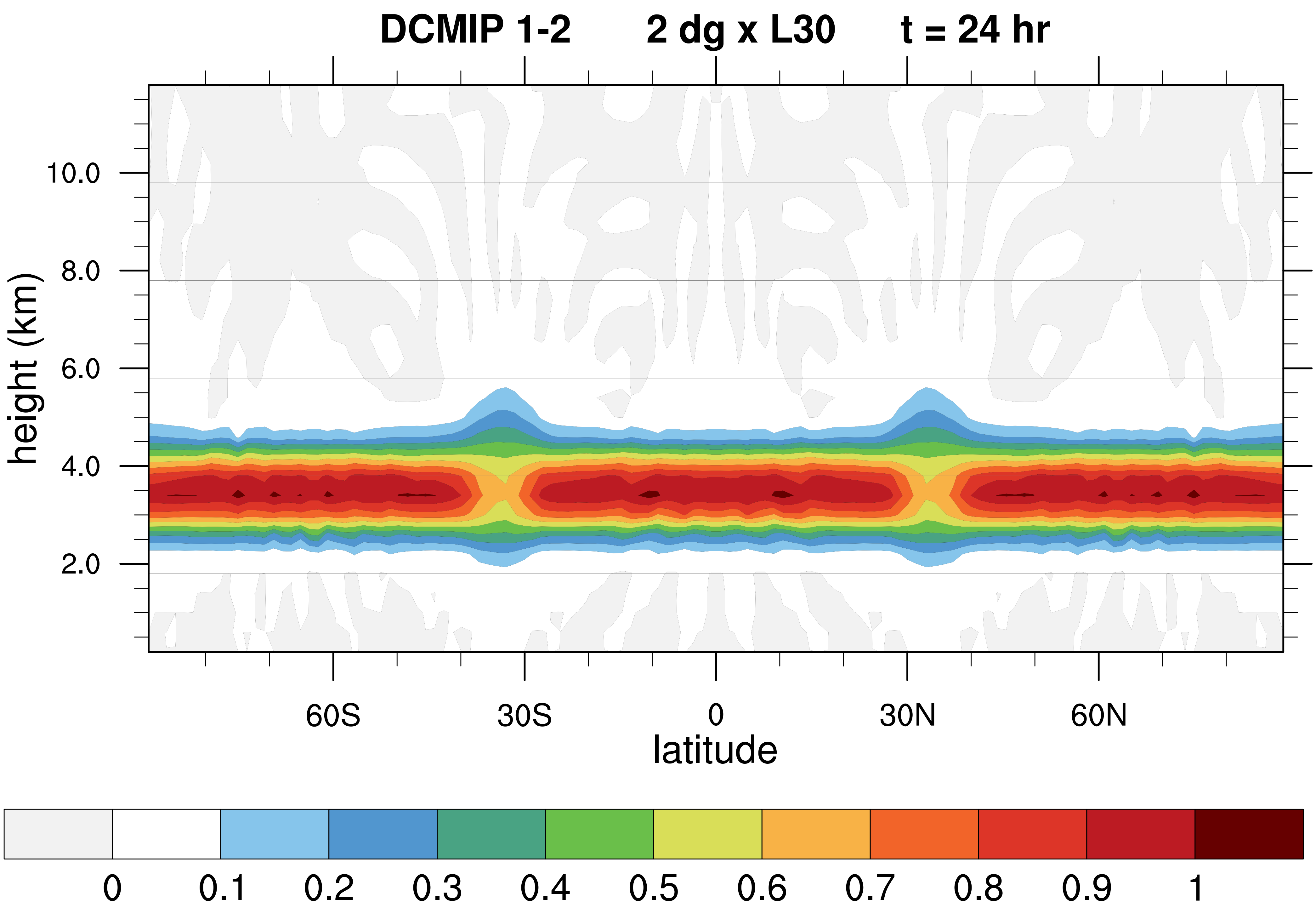
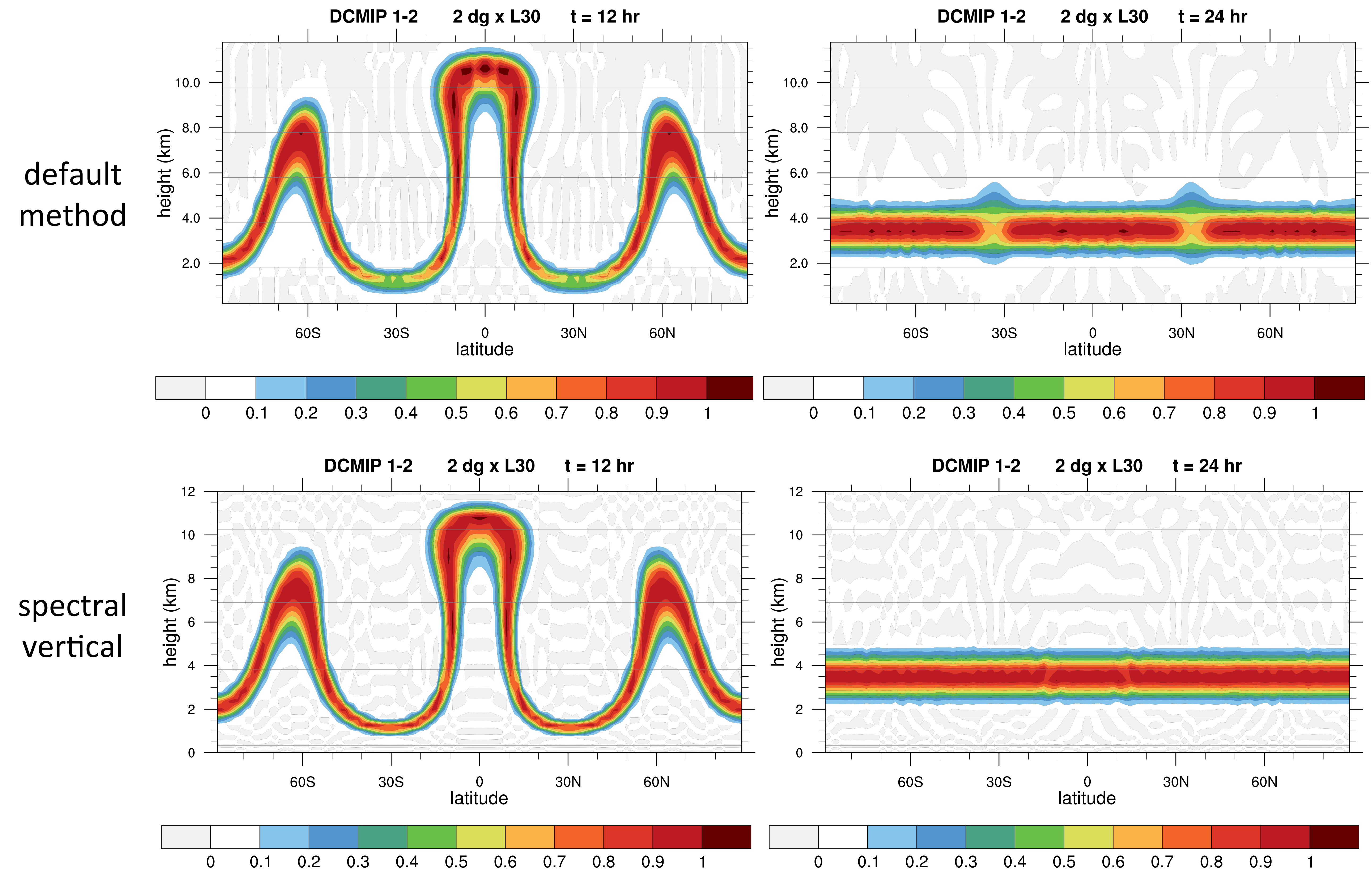
- No limiters, filters, or hyperviscosity (2°, 1°)



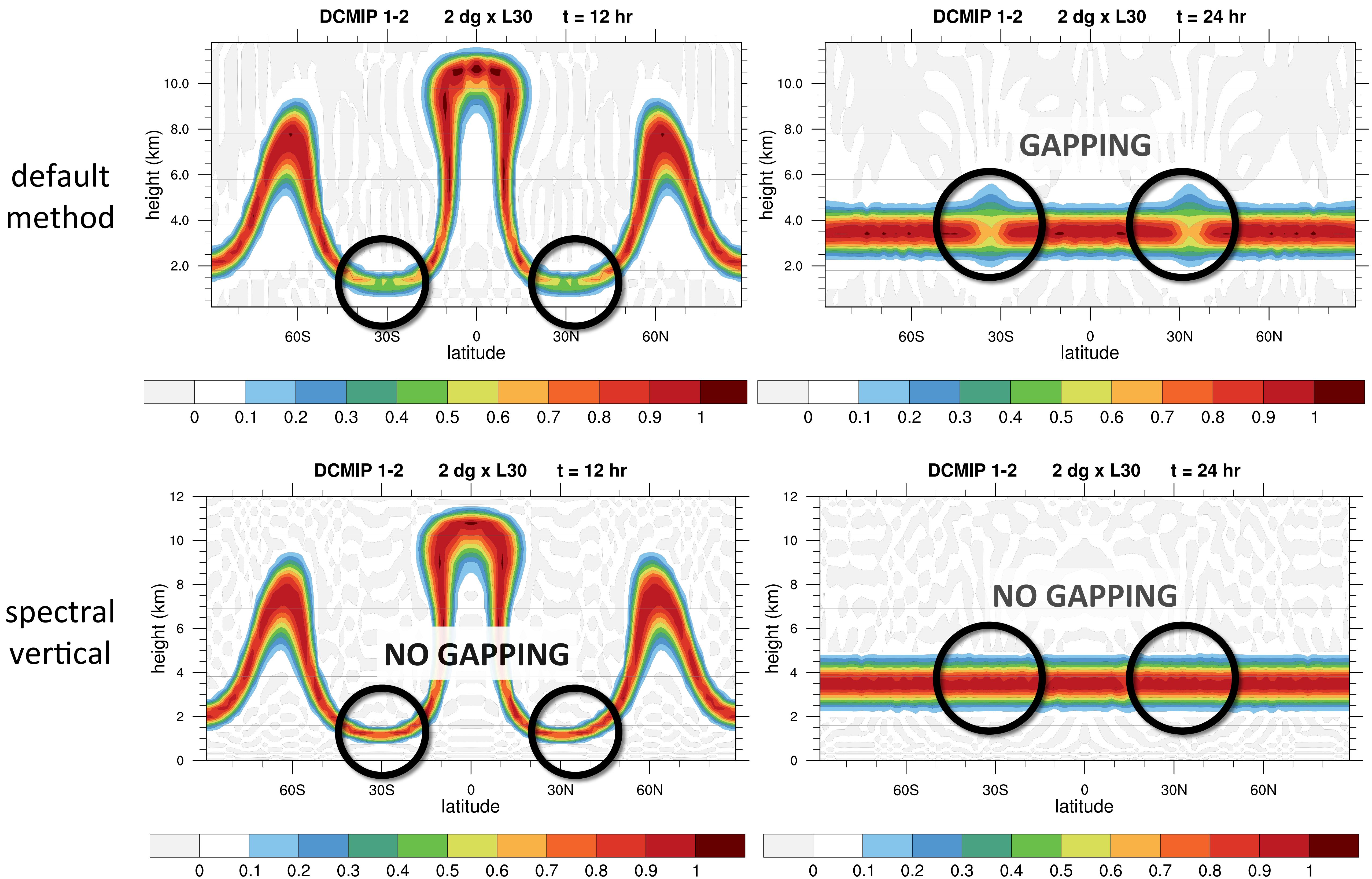
DCMIP 1-2: HADLEY-LIKE TRANSPORT, 2°

Vertical Cross-Sections at 12 and 24 hours



dt=5 sec, no limiter, no hyperviscosity

DCMIP 1-2: HADLEY-LIKE TRANSPORT



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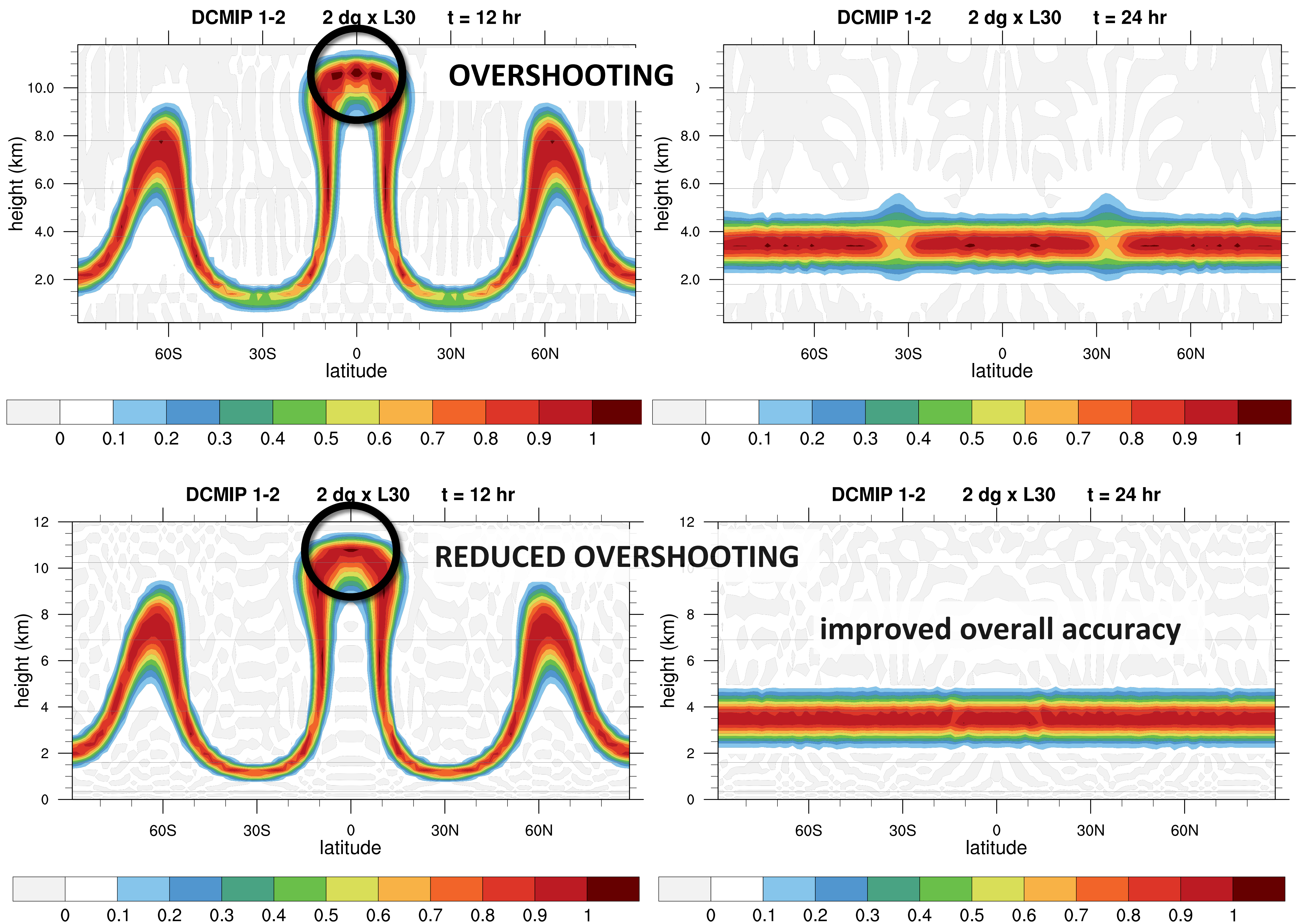
DCMIP 1-2: HADLEY-LIKE TRANSPORT

default method

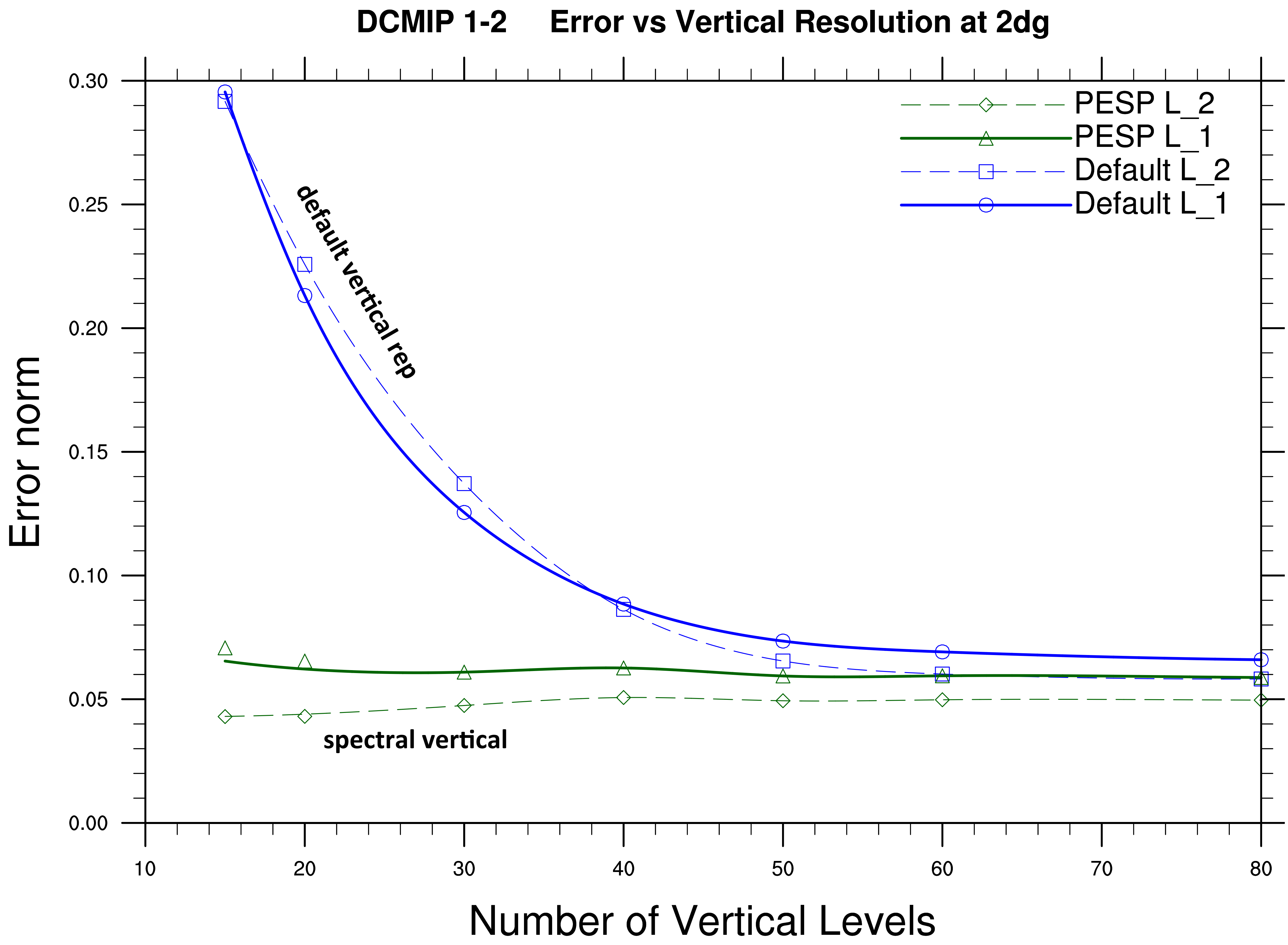
spectral vertical



dt=5 sec, no limiter, no hyperviscosity

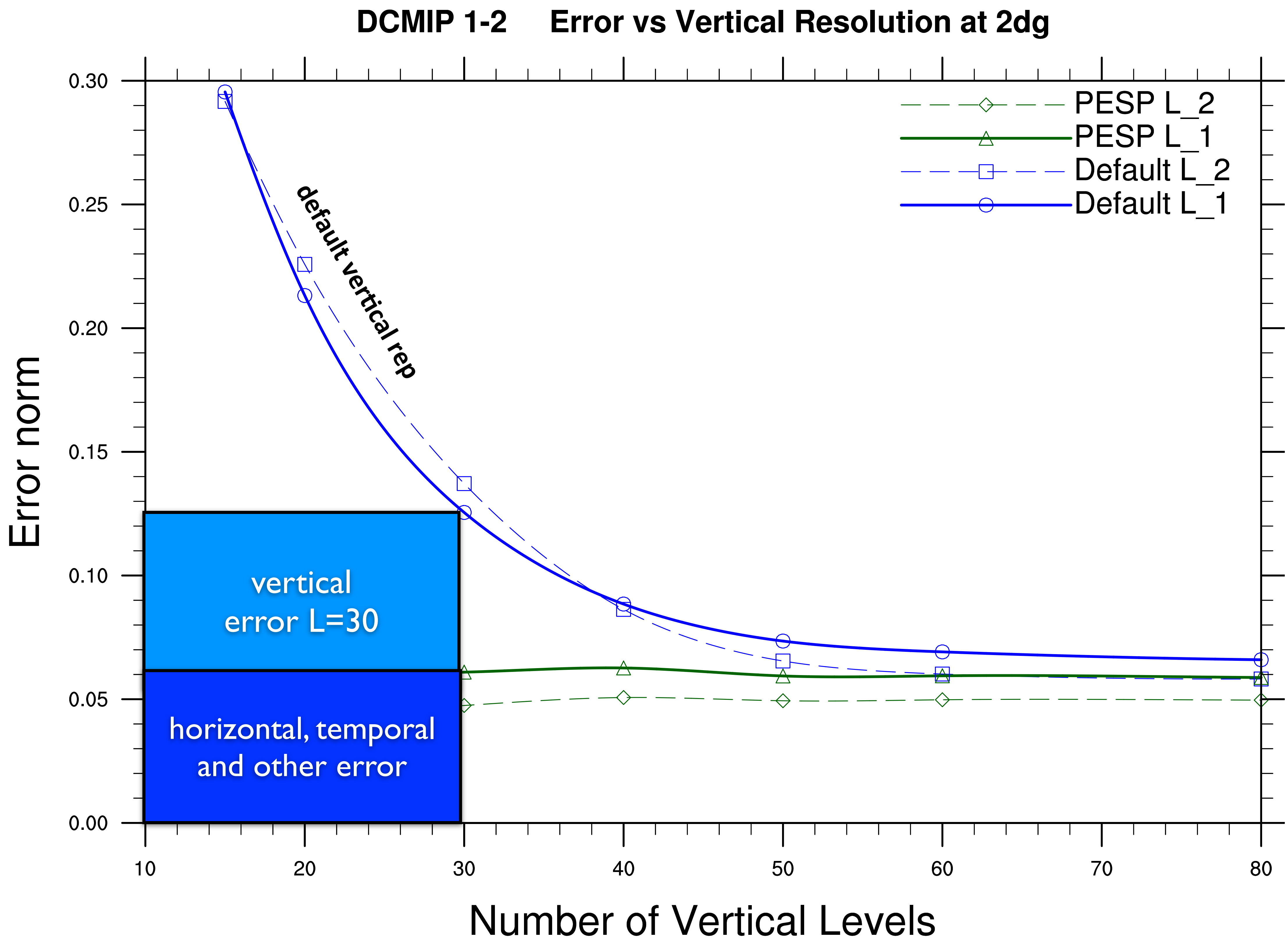
DCMIP1-2: ERROR NORMS AT 2°

- L1, L2 error computed by comparing initial and final states
- Vertical SP more accurate at all resolutions



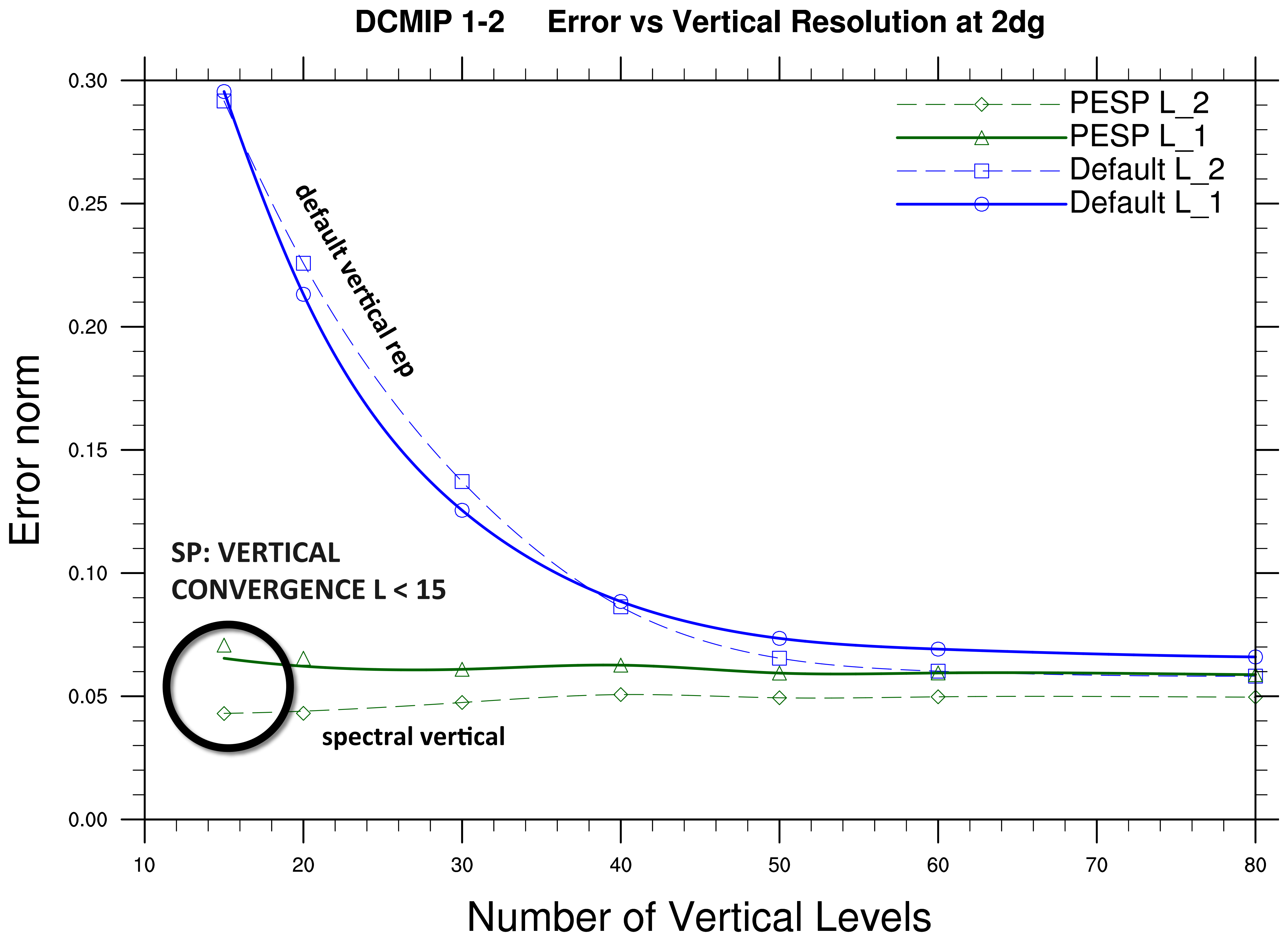
DCMIP1-2: ERROR NORMS AT 2°

- total error = sum(vertical, temporal, horizontal, other err)
- vertical err is reduced with greater L



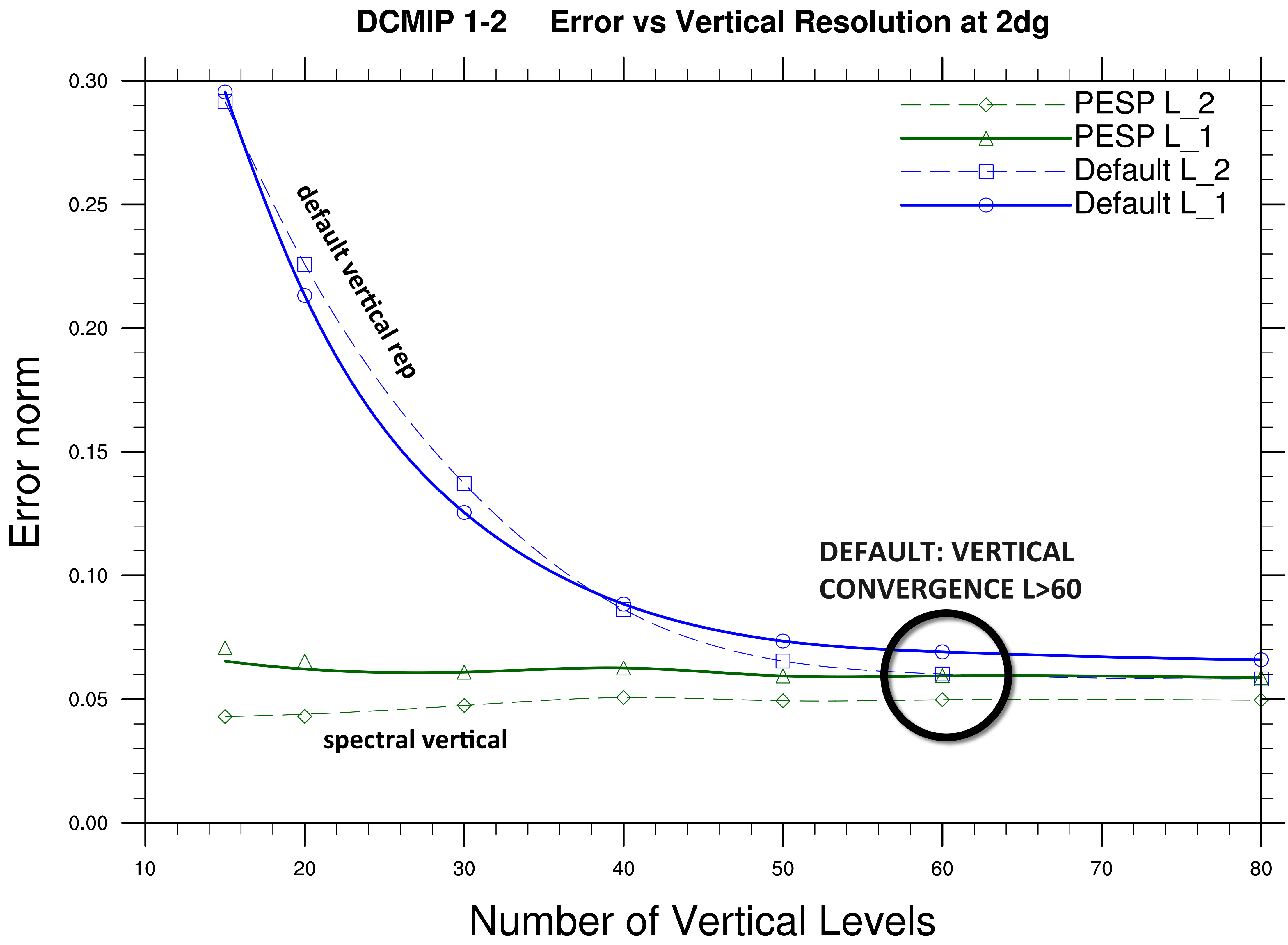
DCMIP1-2: ERROR NORMS AT 2°

- spectral vertical is converged L<15 (smaller than other error sources)



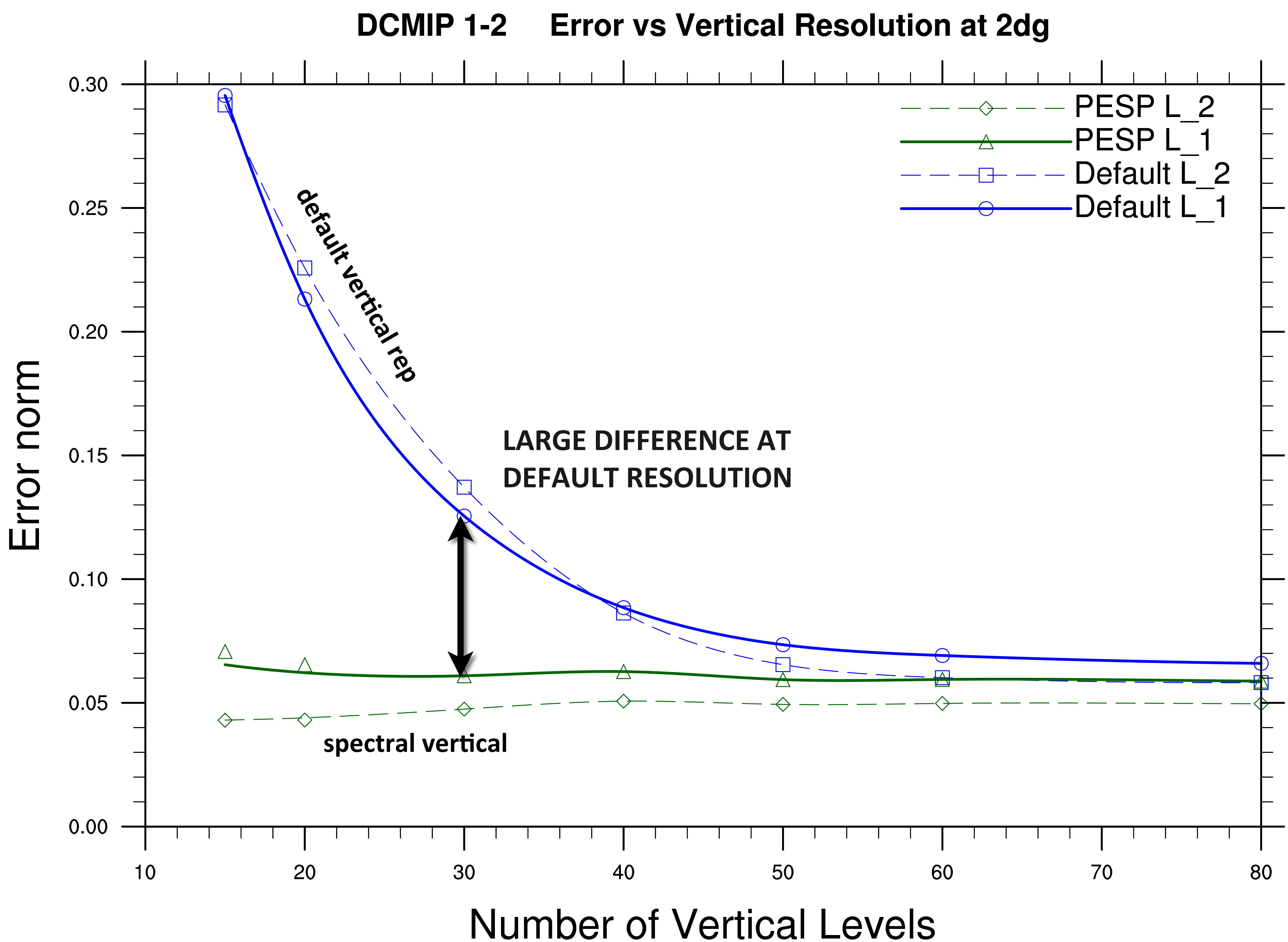
DCMIP1-2: ERROR NORMS AT 2°

- default converged at L>60
- asymptotic approach to vertical SP result



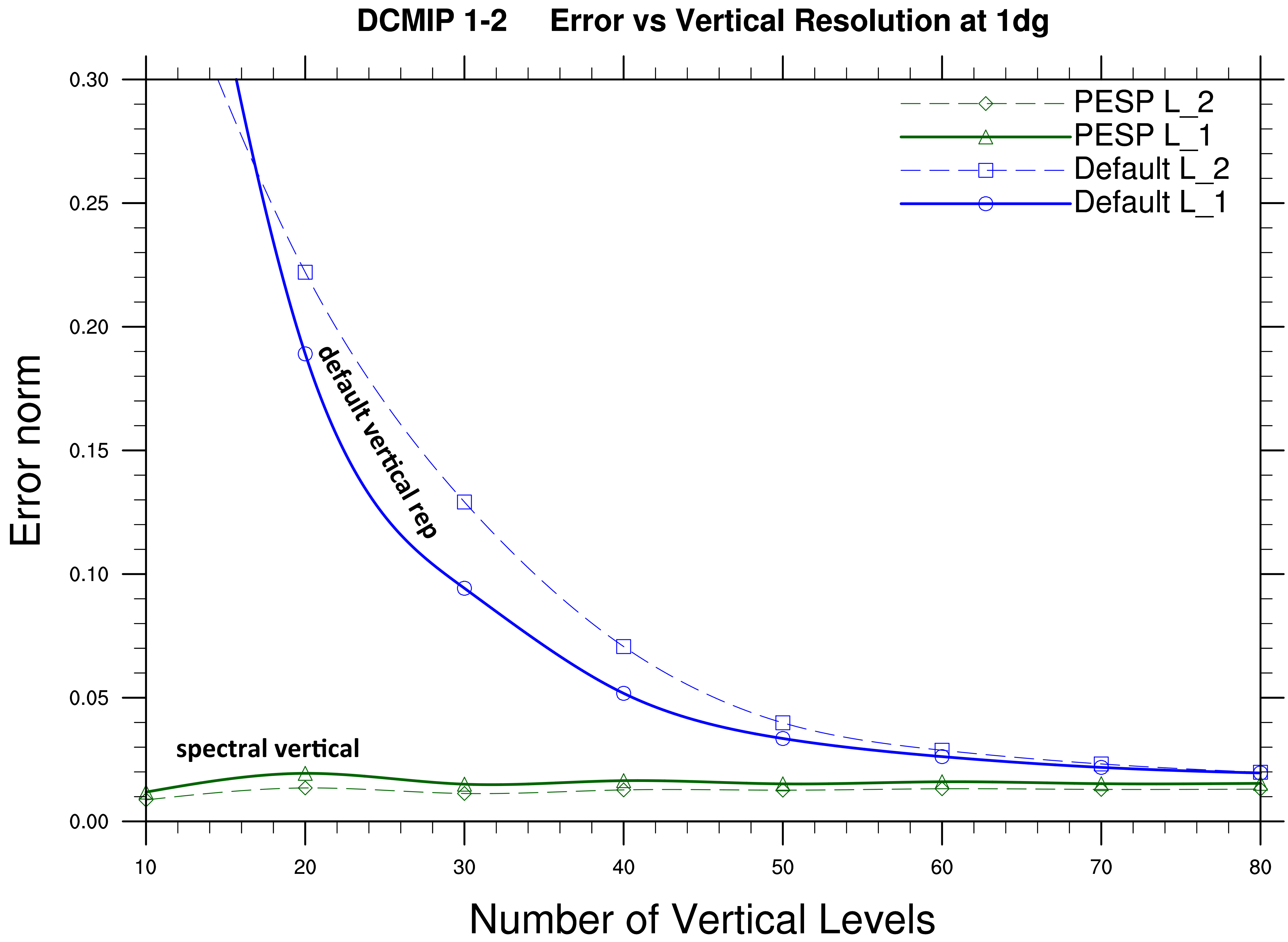
DCMIP1-2: ERROR NORMS AT 2°

- At default resolution, there is a large difference in vertical accuracy



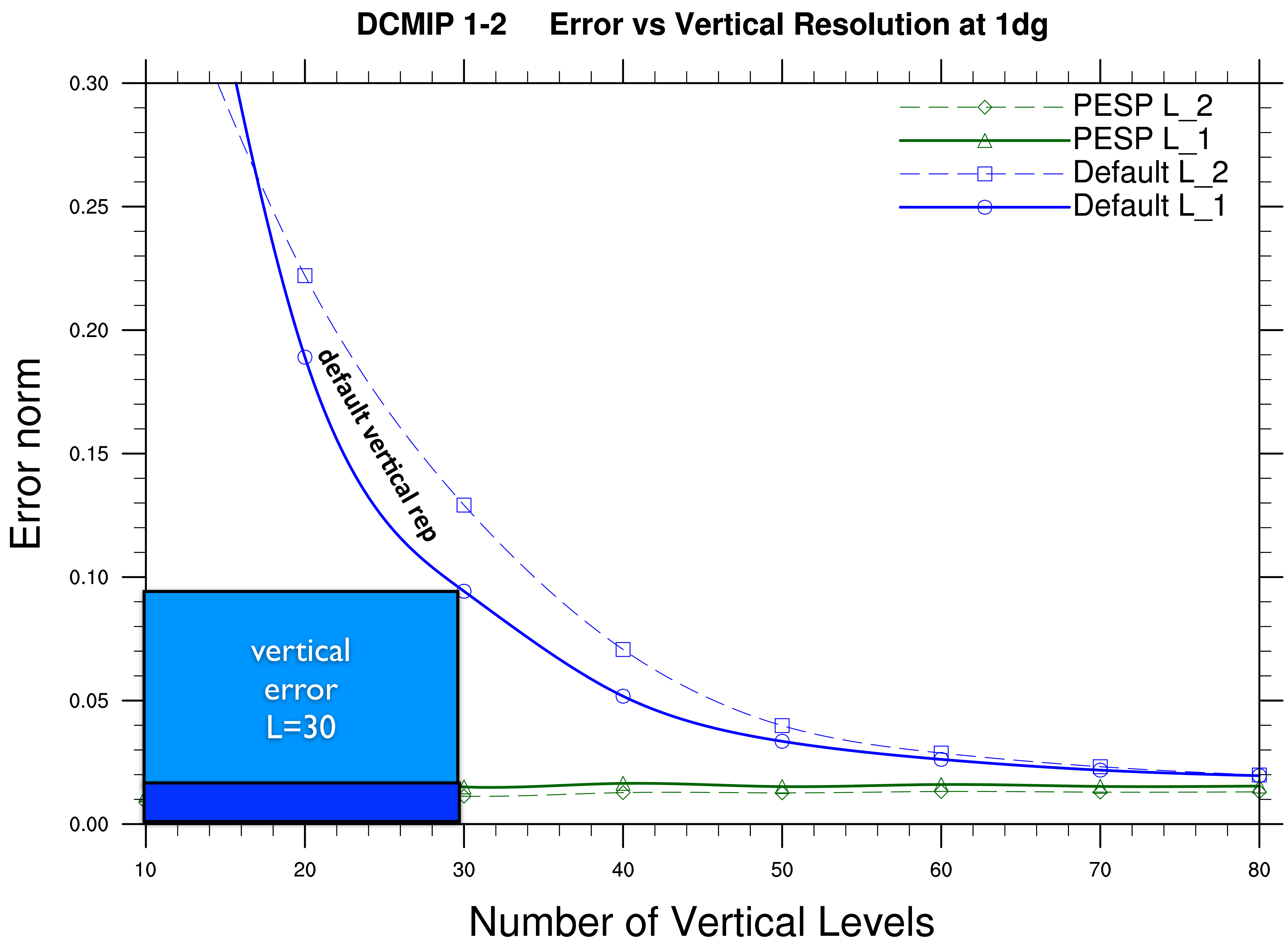
DCMIP1-2: ERROR NORMS AT 1°

- At 1° horizontal resolution, errors are shifted down
- Qualitatively the same relationship



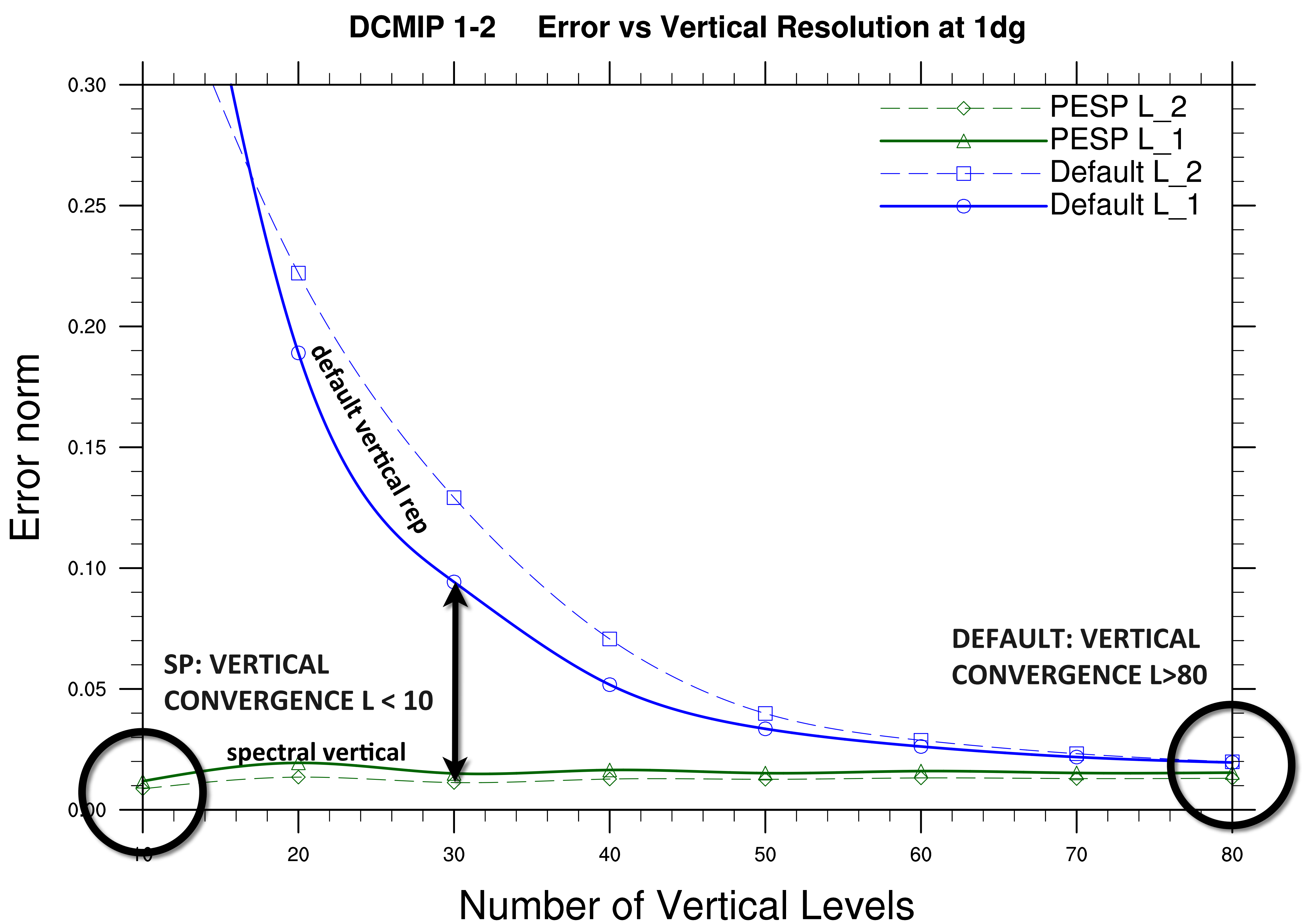
DCMIP1-2: ERROR NORMS AT 1°

- Horizontal error is greatly reduced
- Vertical error stays about the same



DCMIP1-2: ERROR NORMS AT 1°

- SP converged L<10 default L>80 large difference at L=30



DCMIP1-2: PERFORMANCE AT 2°

- Vertical SP is more accurate. What about its **computational cost**?
- Extract **prim_run walltotal**: isolates tracer and dynamic run time

DOE XSEDE Stampede supercomputer, 256 cores

DCMIP1-2: PERFORMANCE AT 2°

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timing: default method

name	processes	threads	count	walltotal	wallmax	wallmin
prim_run	256	256	4.423680e+06	**1.073763e+04**	42.070	41.068
prim_advance_exp	256	256	4.423680e+06	3.870625e+03	18.405	14.196
prim_advec_tracers_remap_rk2	256	256	4.423680e+06	3.936514e+03	17.003	10.629
vertical_remap	256	256	4.423680e+06	2.311321e+03	10.434	8.373
remap1	256	256	2.332800e+07	2.284787e+03	10.316	8.274

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9929 s / 10737 s = **0.92**

VERTICAL-SPECTRAL TRACER TRANSPORT IS **8% FASTER** AT **L=30**

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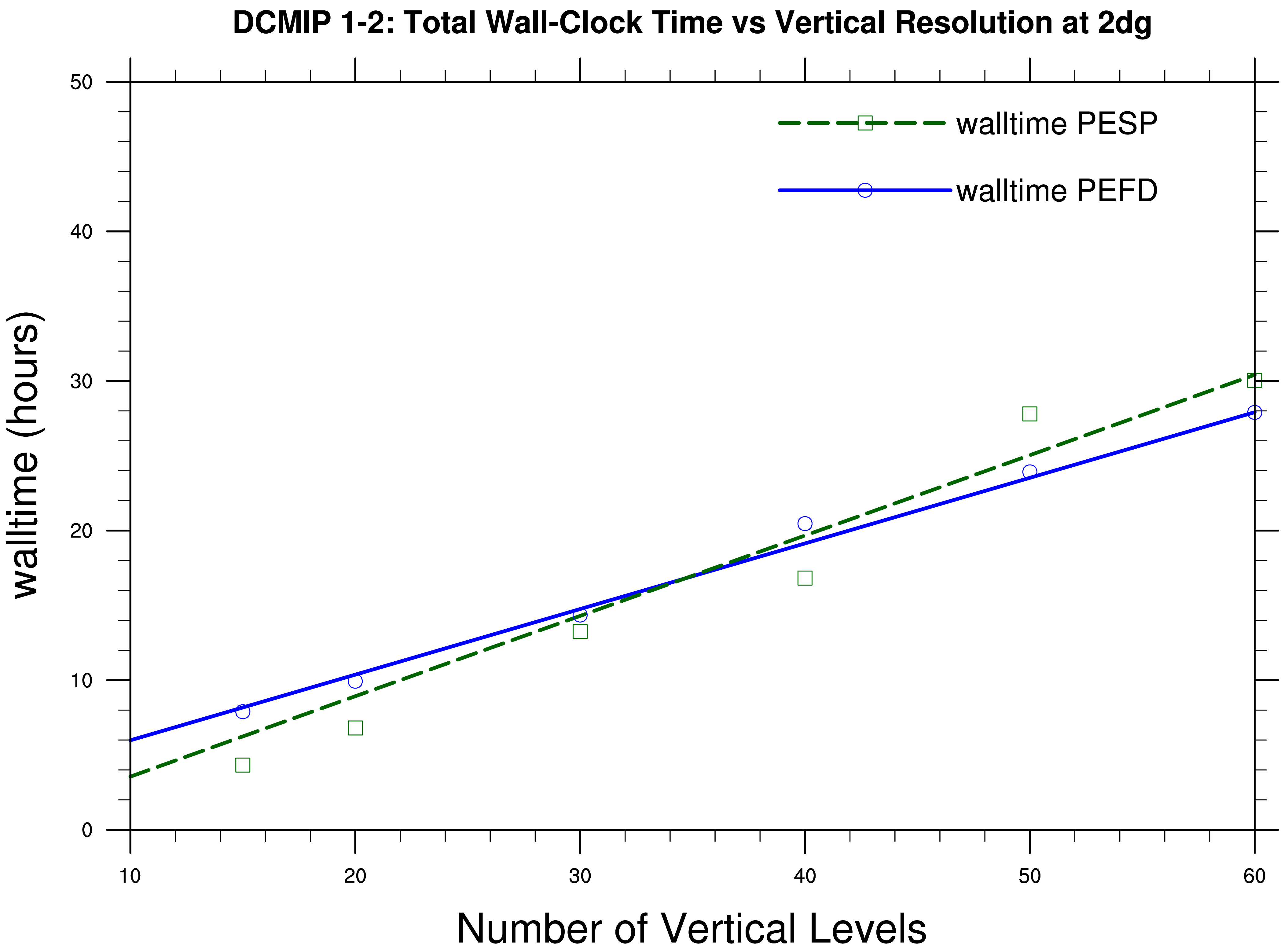
DCMIP1-2: PERFORMANCE VS VERTICAL RESOLUTION

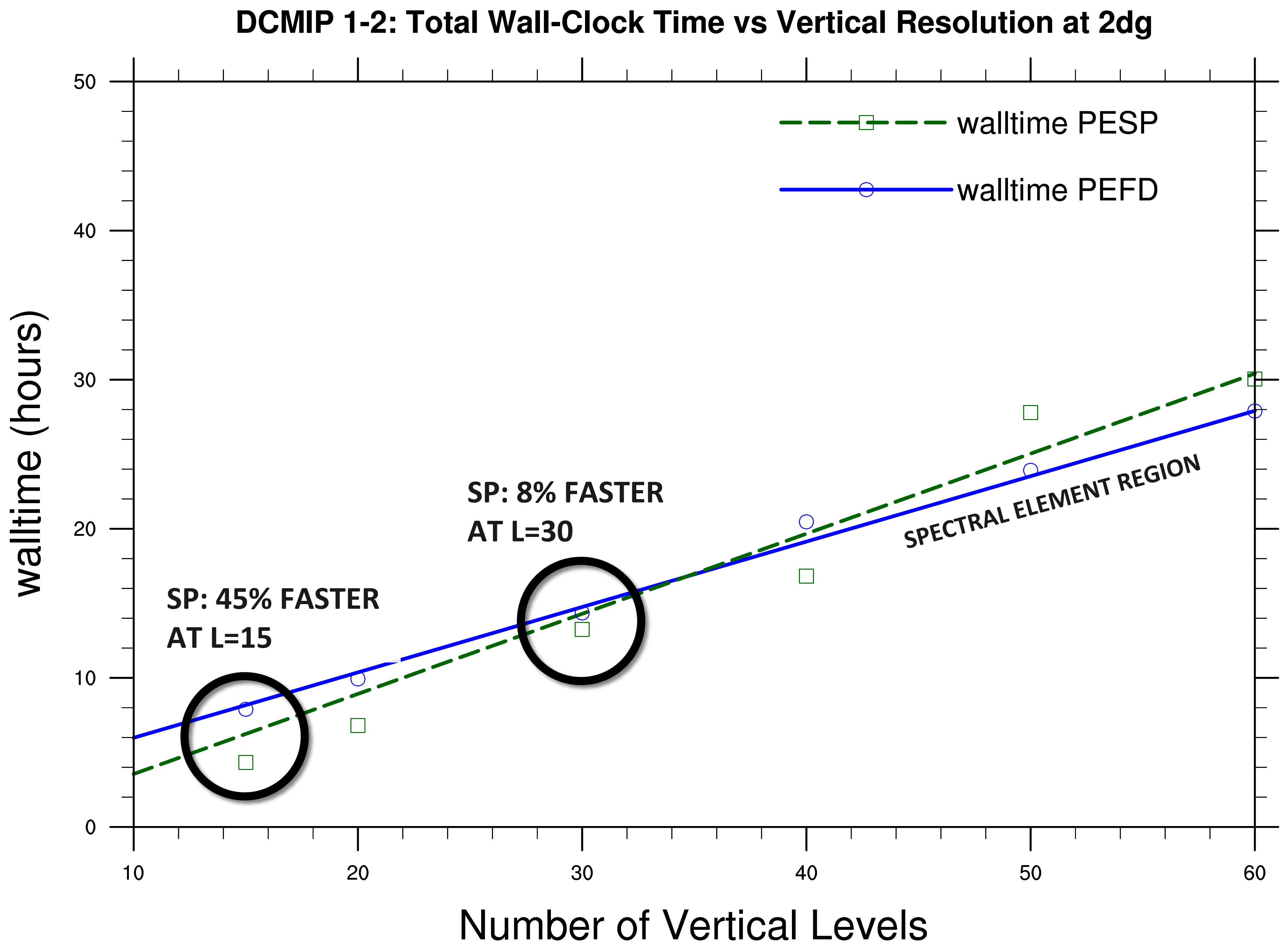
- Look at wallclock time vs L
- Near optimal scaling for both, all data on one node



DOE XSEDE Stampede supercomputer, 256 cores

DCMIP1-2: WALL-CLOCK TIME AT 2°

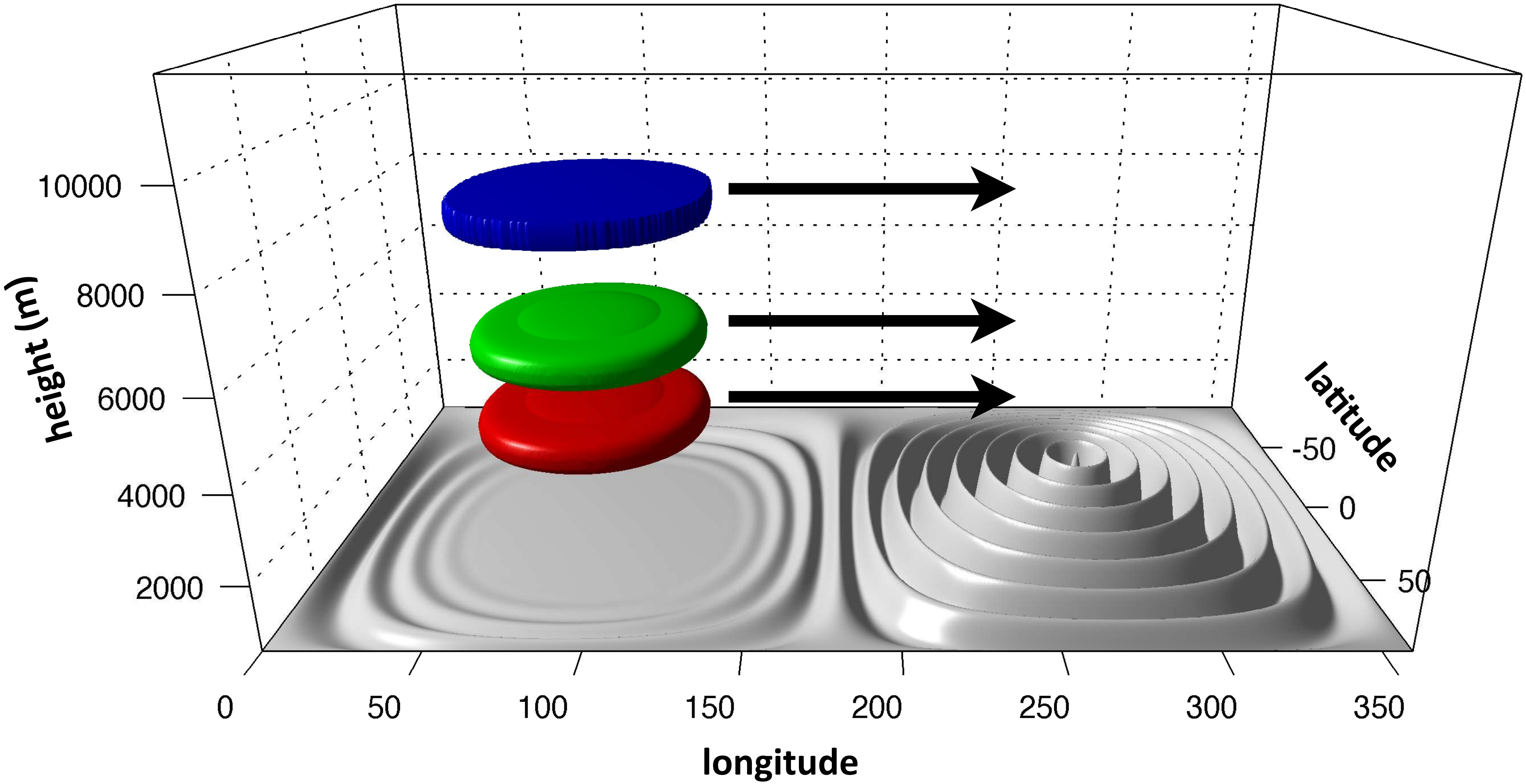
- SP much faster at low L. A bit faster at L=30
- SP is a bit slower at L=60, but here one would choose vertical spectral elements



DOE XSEDE Stampede supercomputer, 256 cores

DCMIP 1-3: DESCRIPTION

- Thin cloud tracer transport over Schär-type mountain range
- Tests impact of terrain following coordinates: numerical mixing, induced flux



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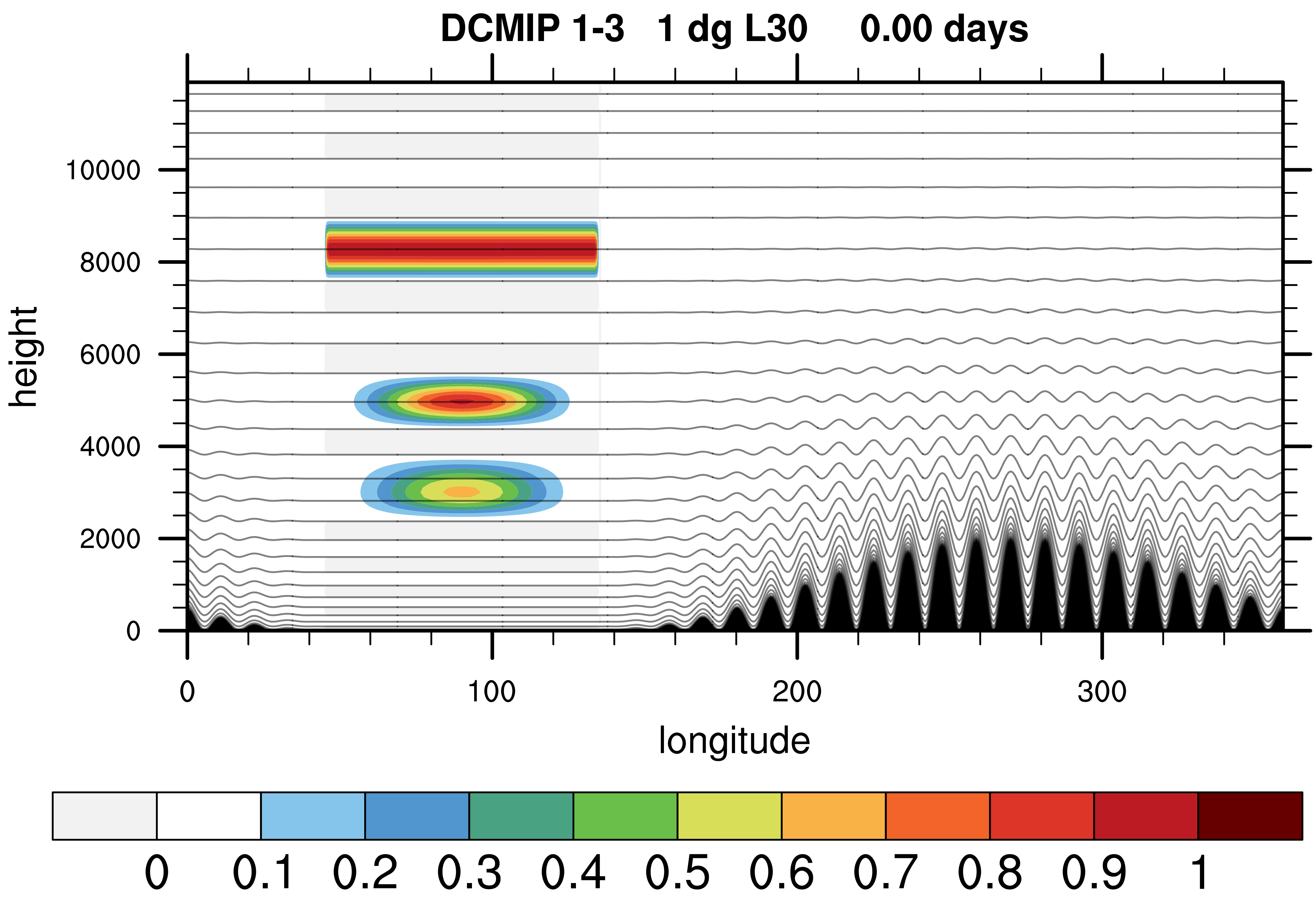

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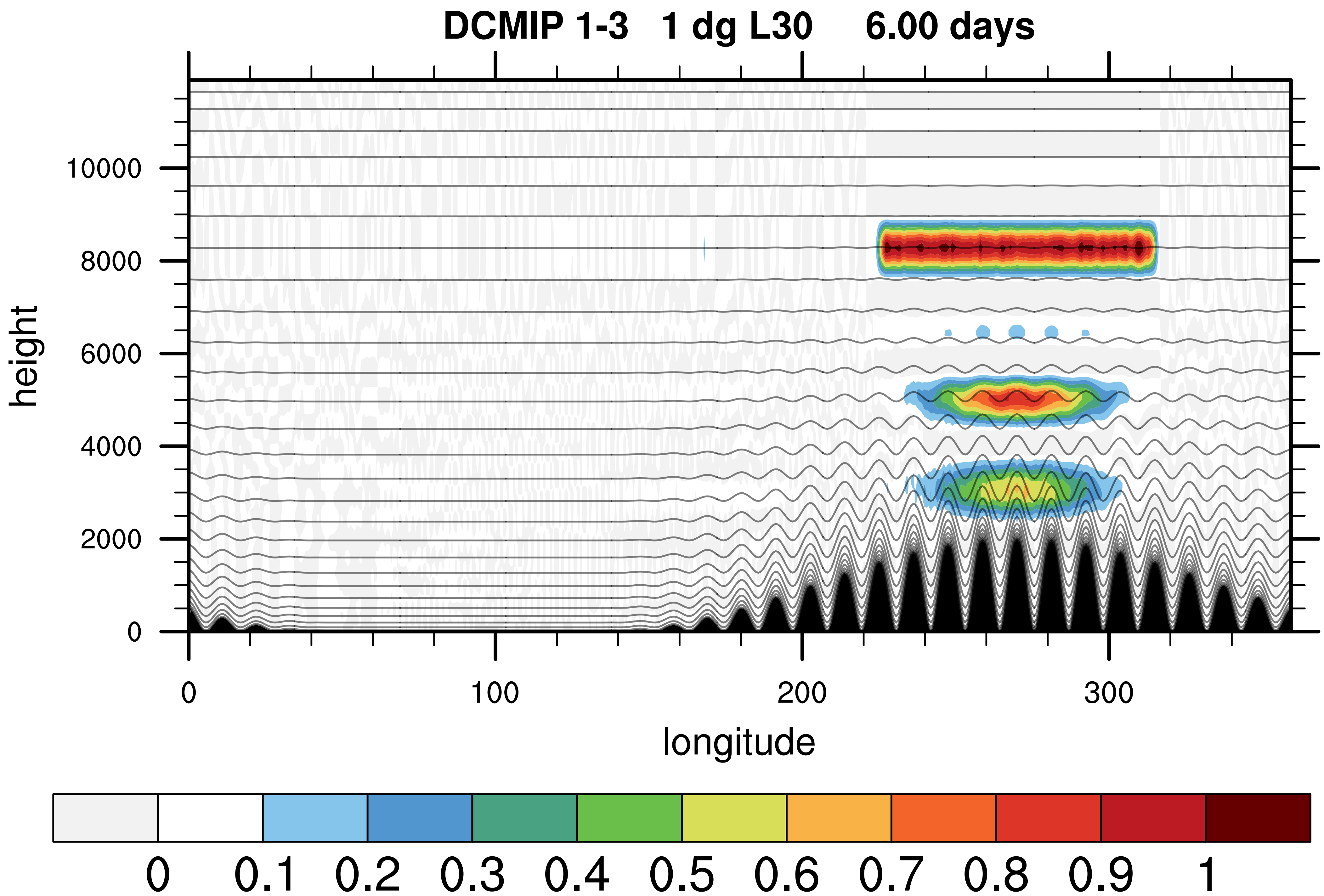

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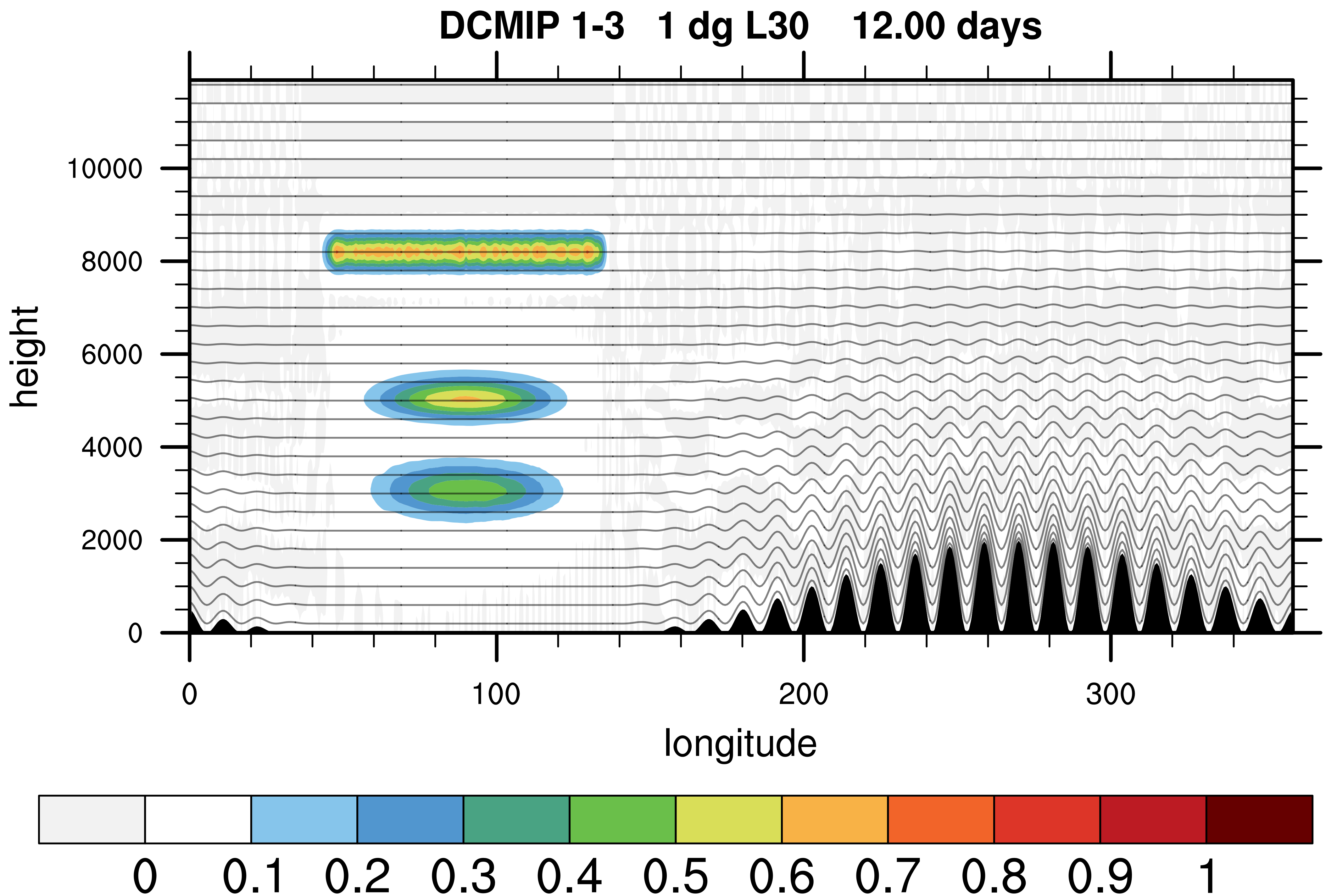
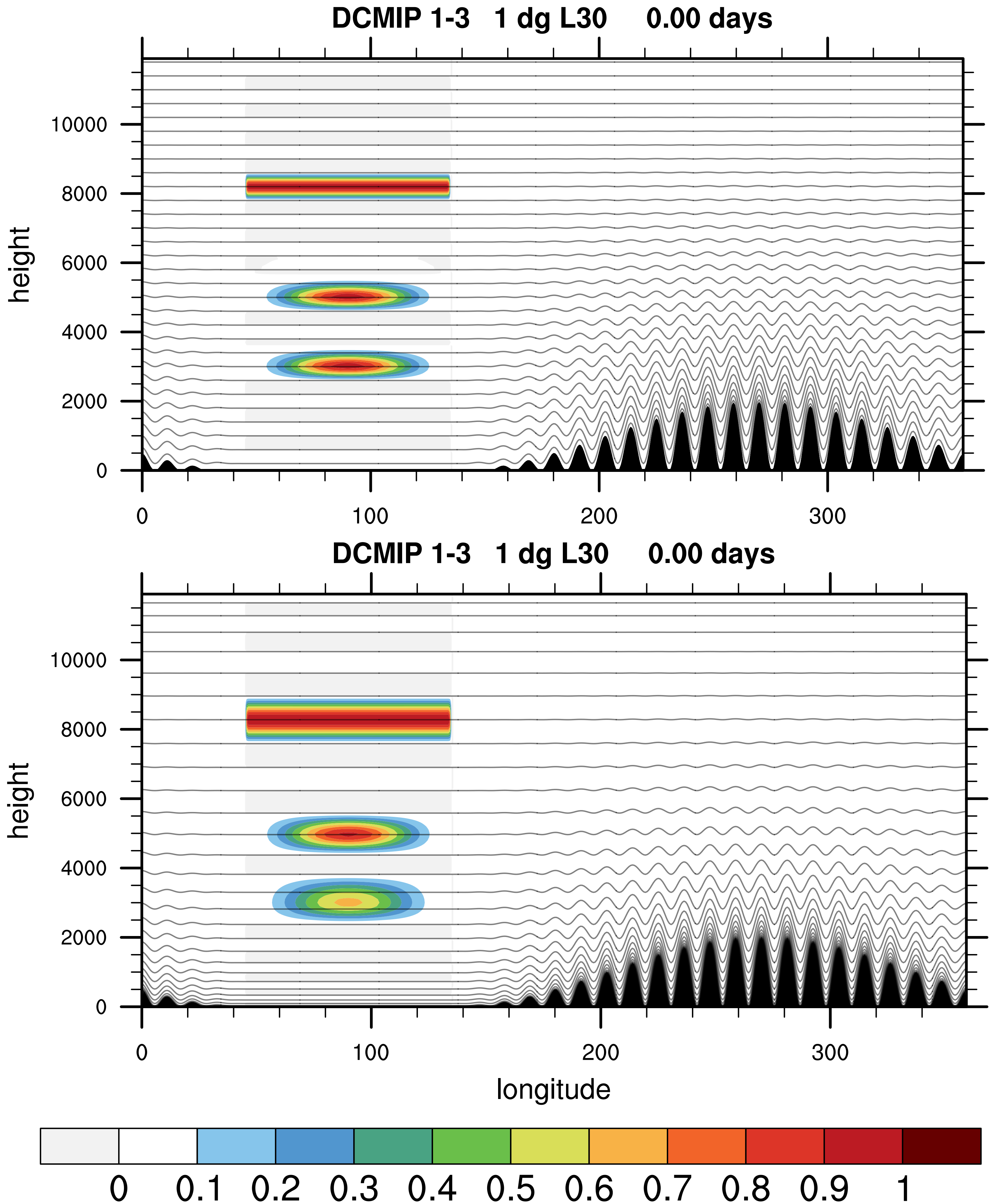


DCMIP 1-3: HORIZONTAL THIN CLOUD TRANSPORT

default method

INITIAL STATE

spectral vertical

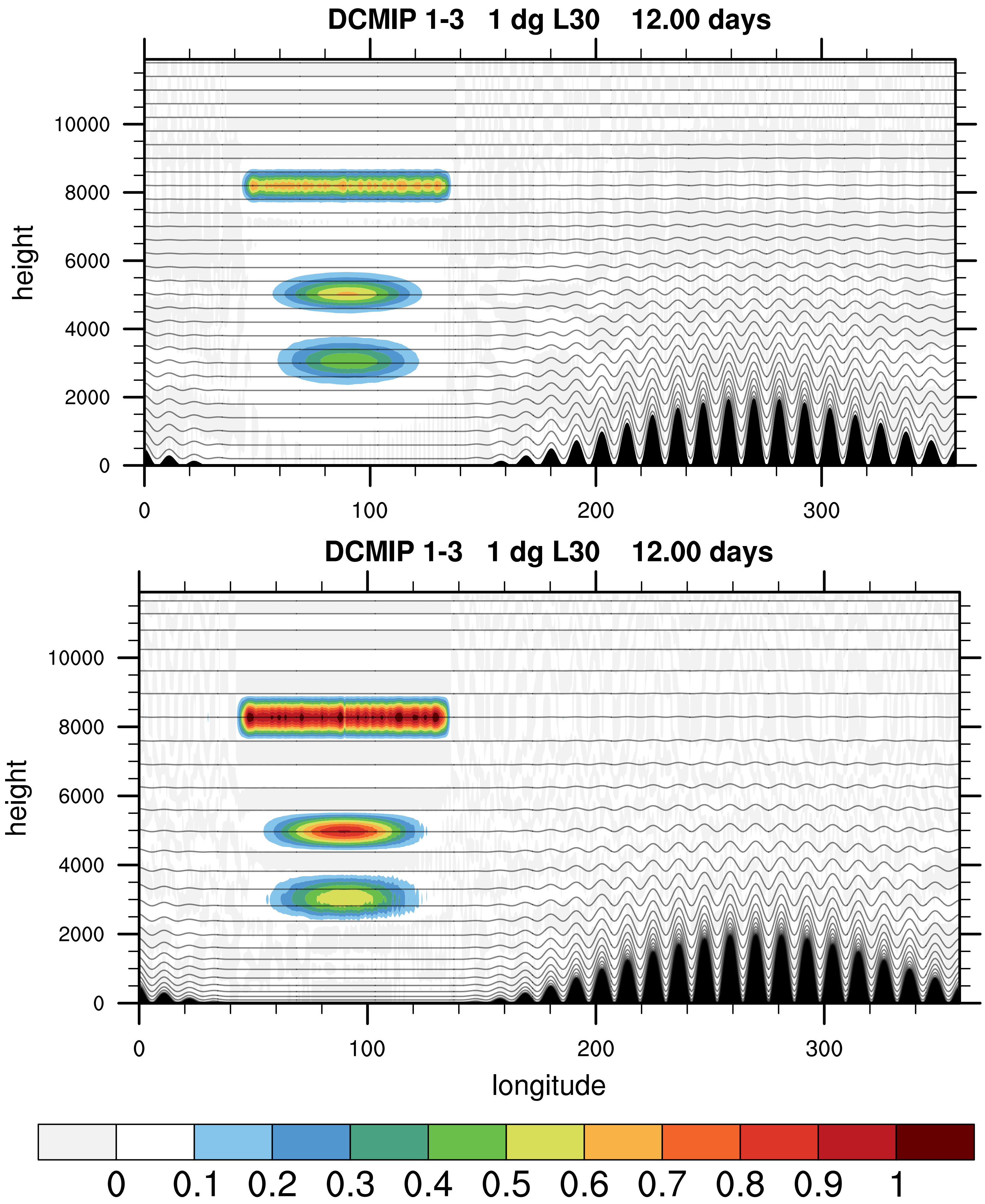


DCMIP 1-3: HORIZONTAL THIN CLOUD TRANSPORT

default method

FINAL STATE

spectral vertical



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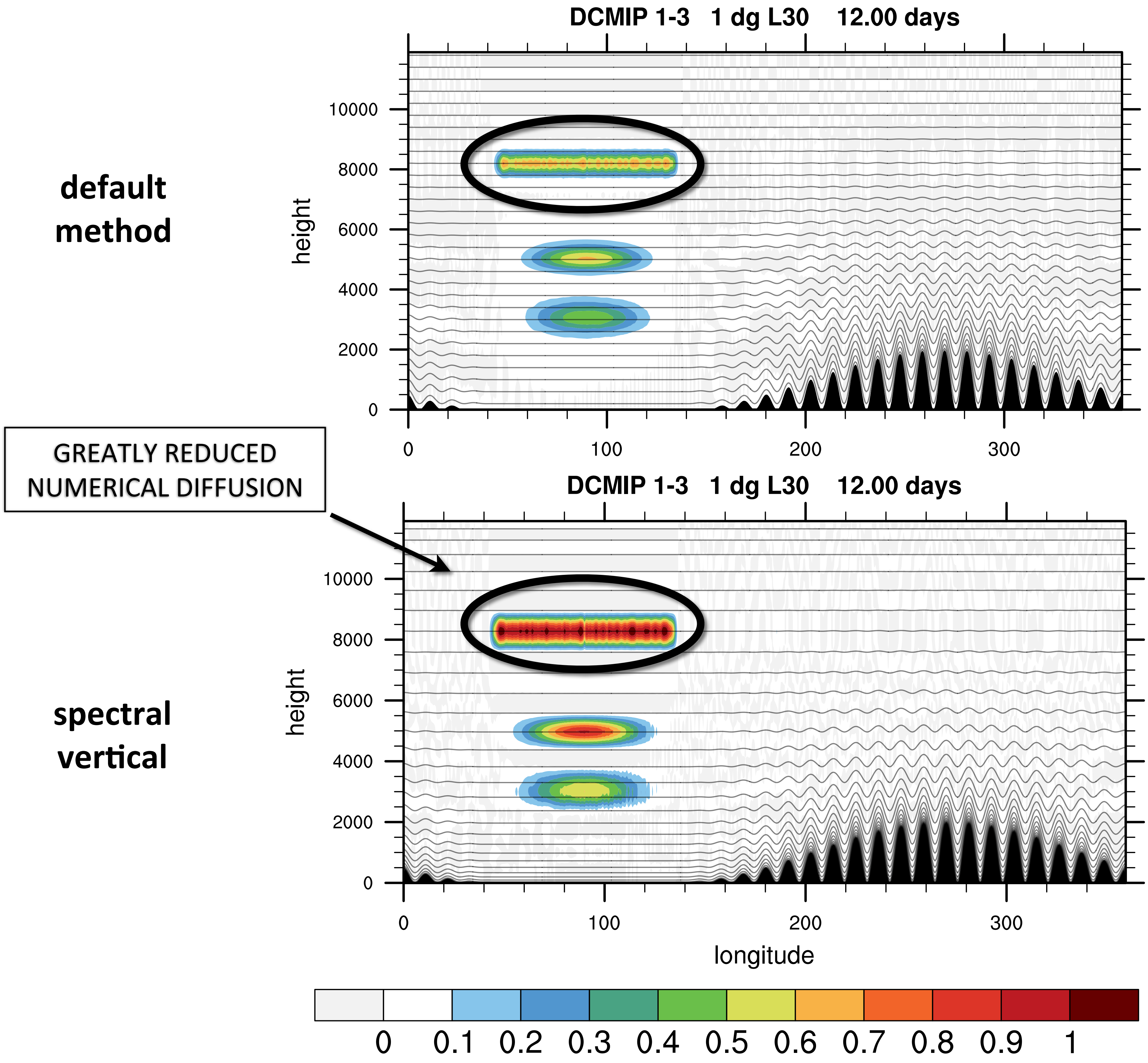
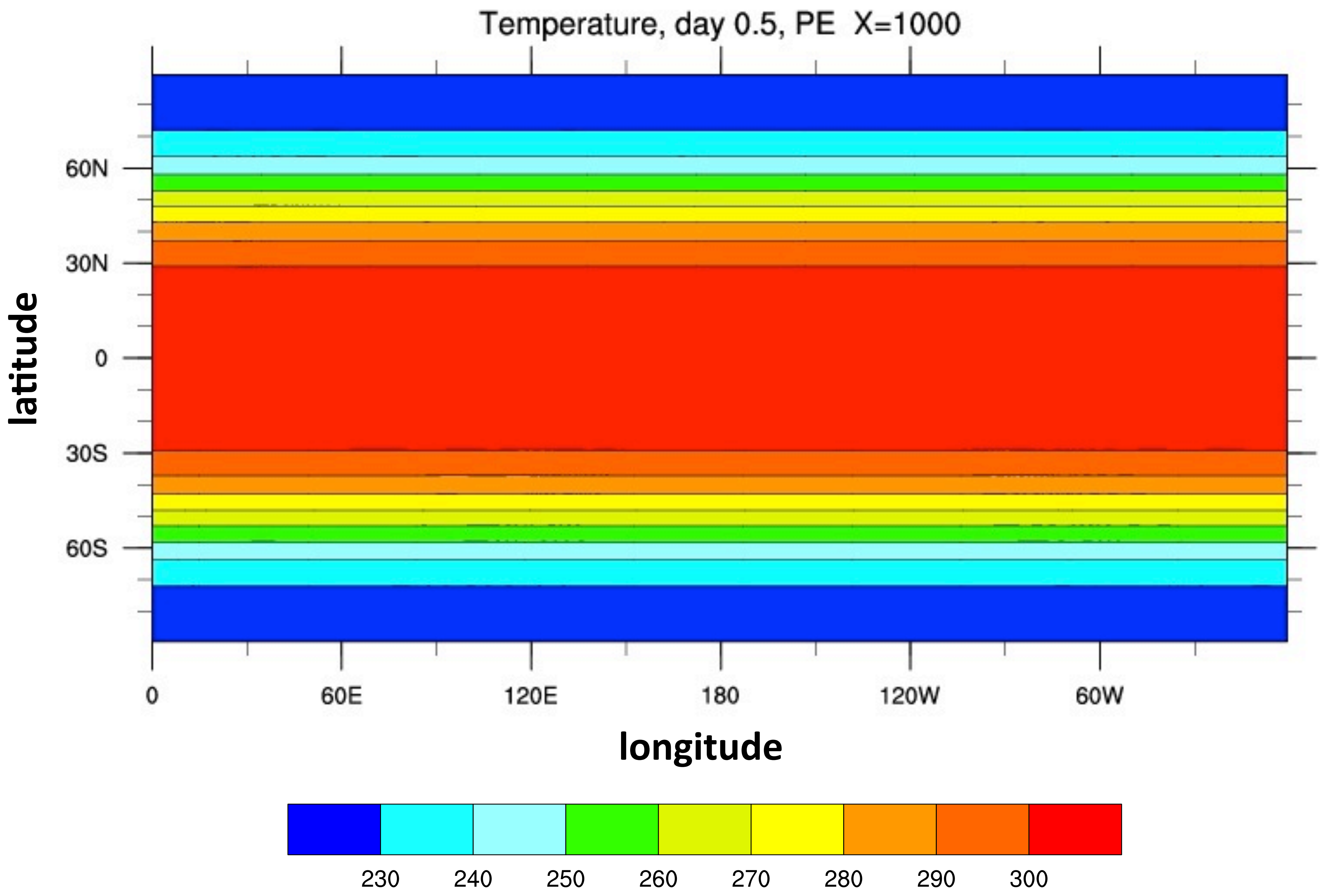


DCMIP 4-1: DESCRIPTION

- Development of a baroclinic instability over 30 days
- Tests **primitive equation** dynamics (not just tracer transport)
- **Horizontal cross-sections** shown here



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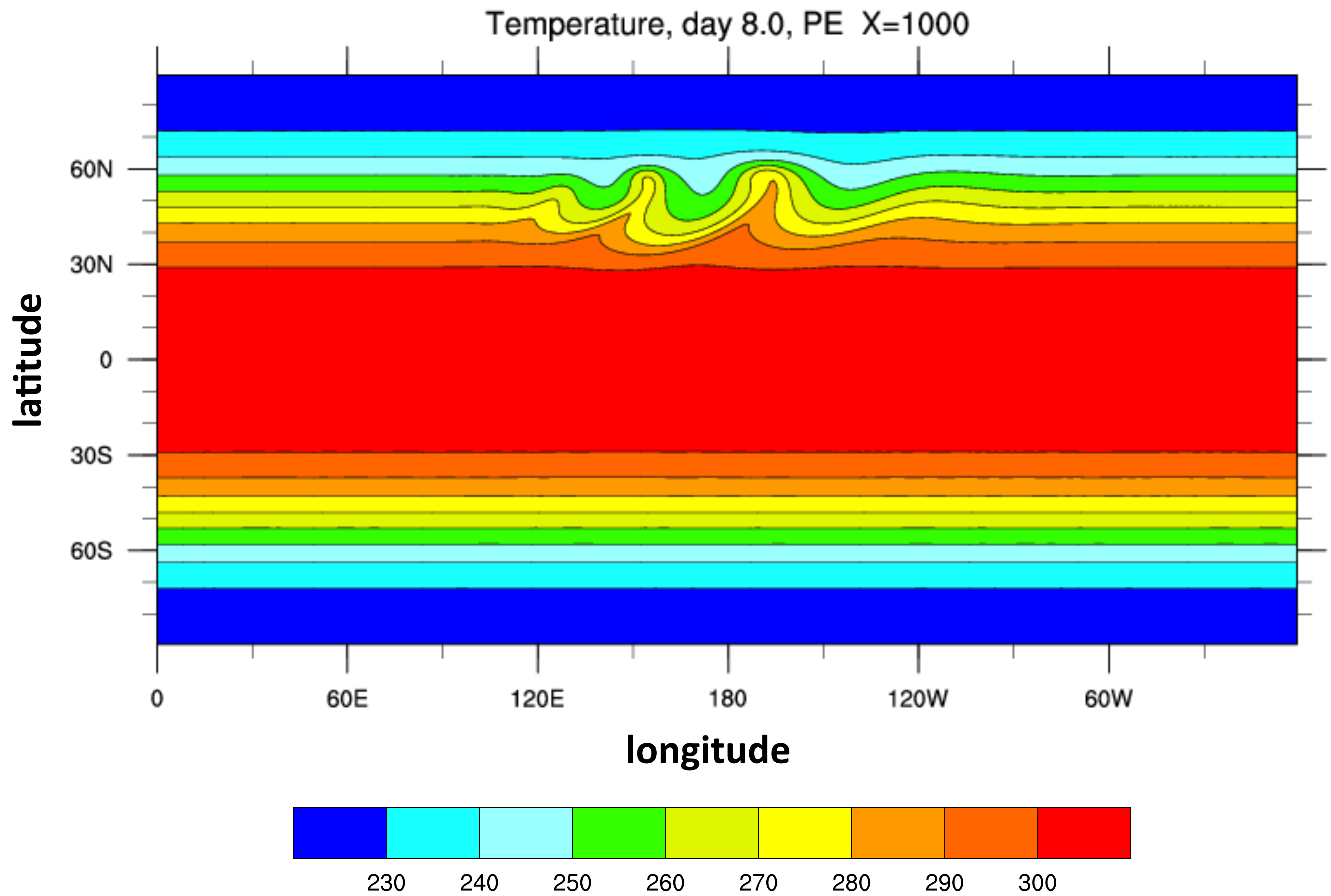

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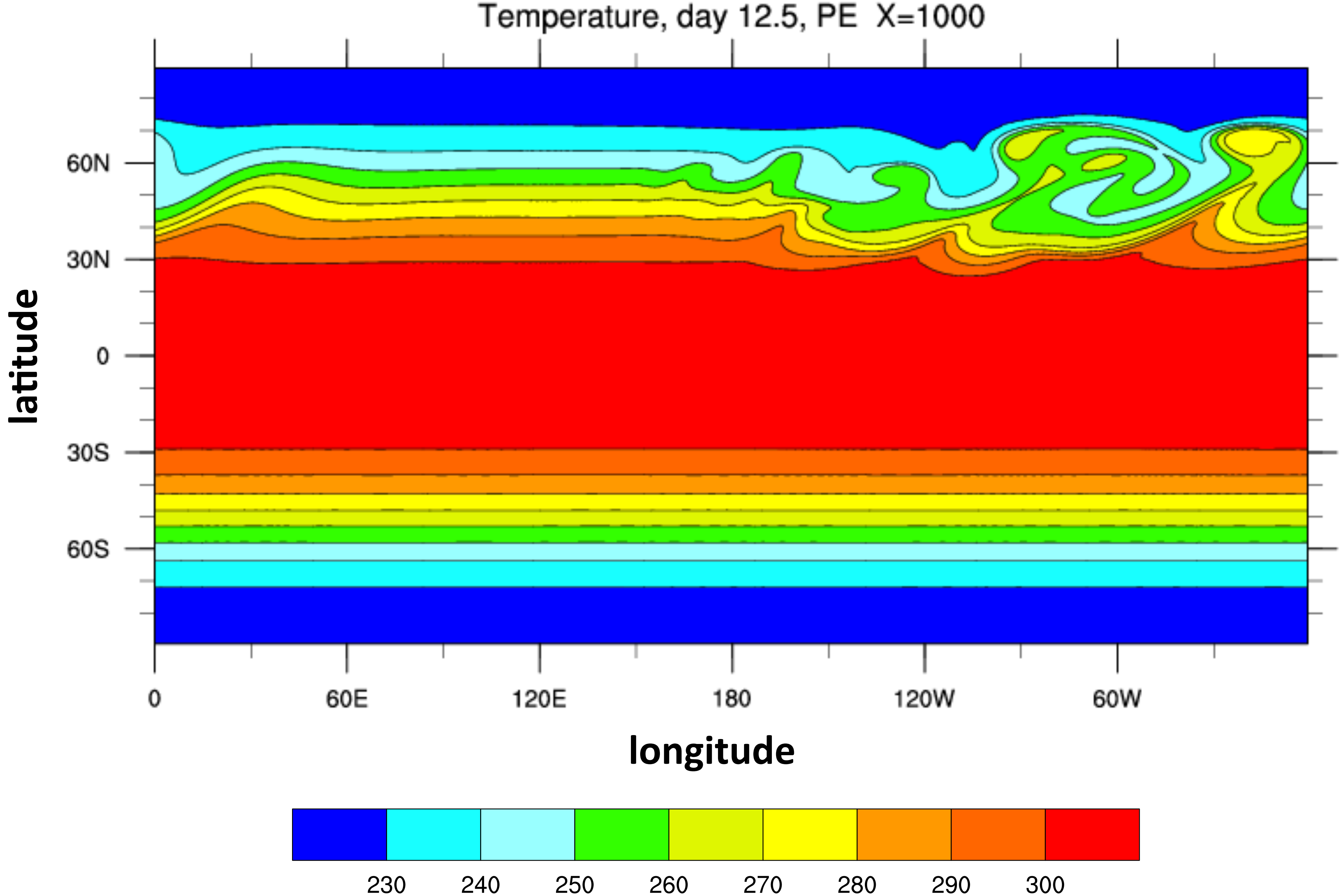

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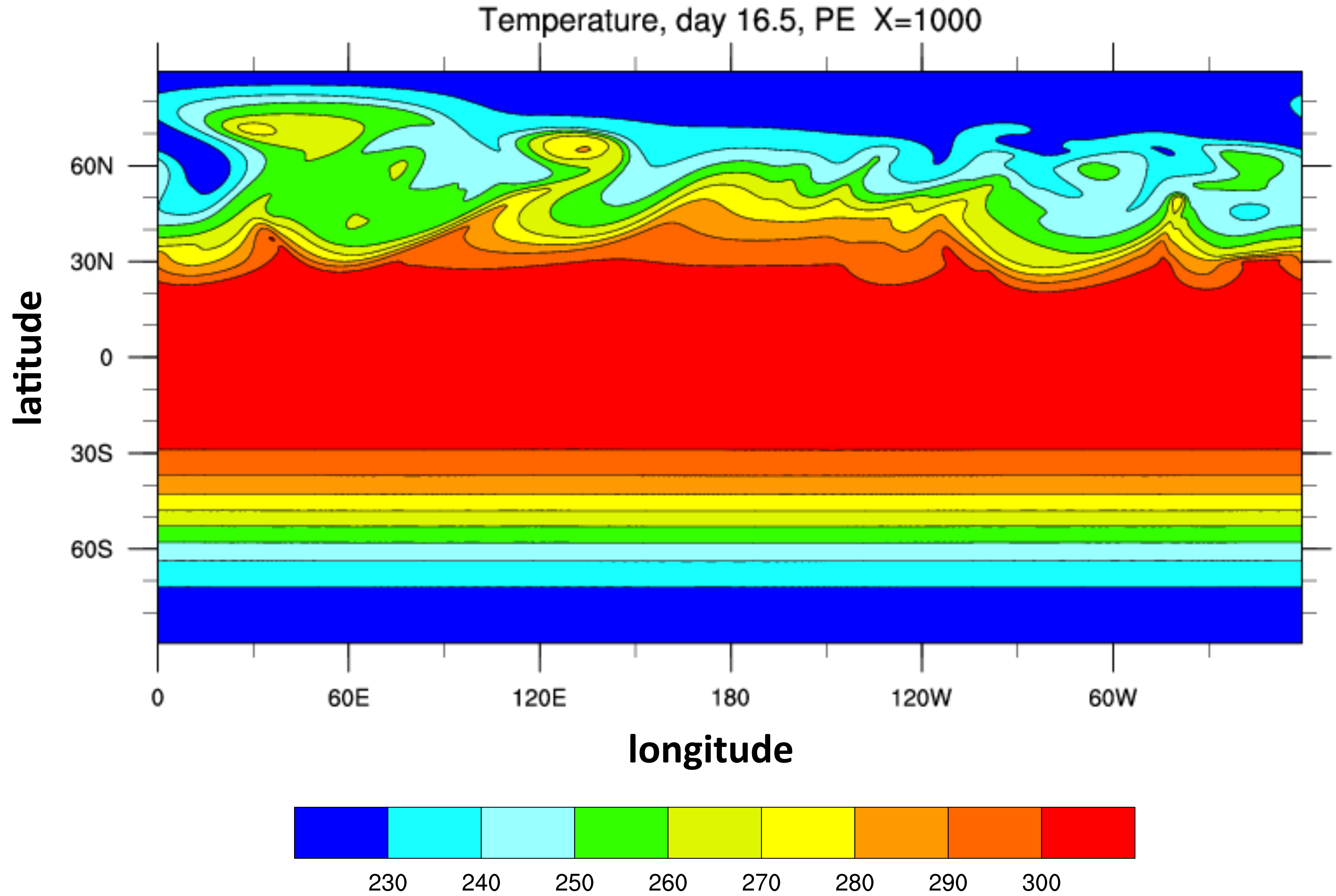

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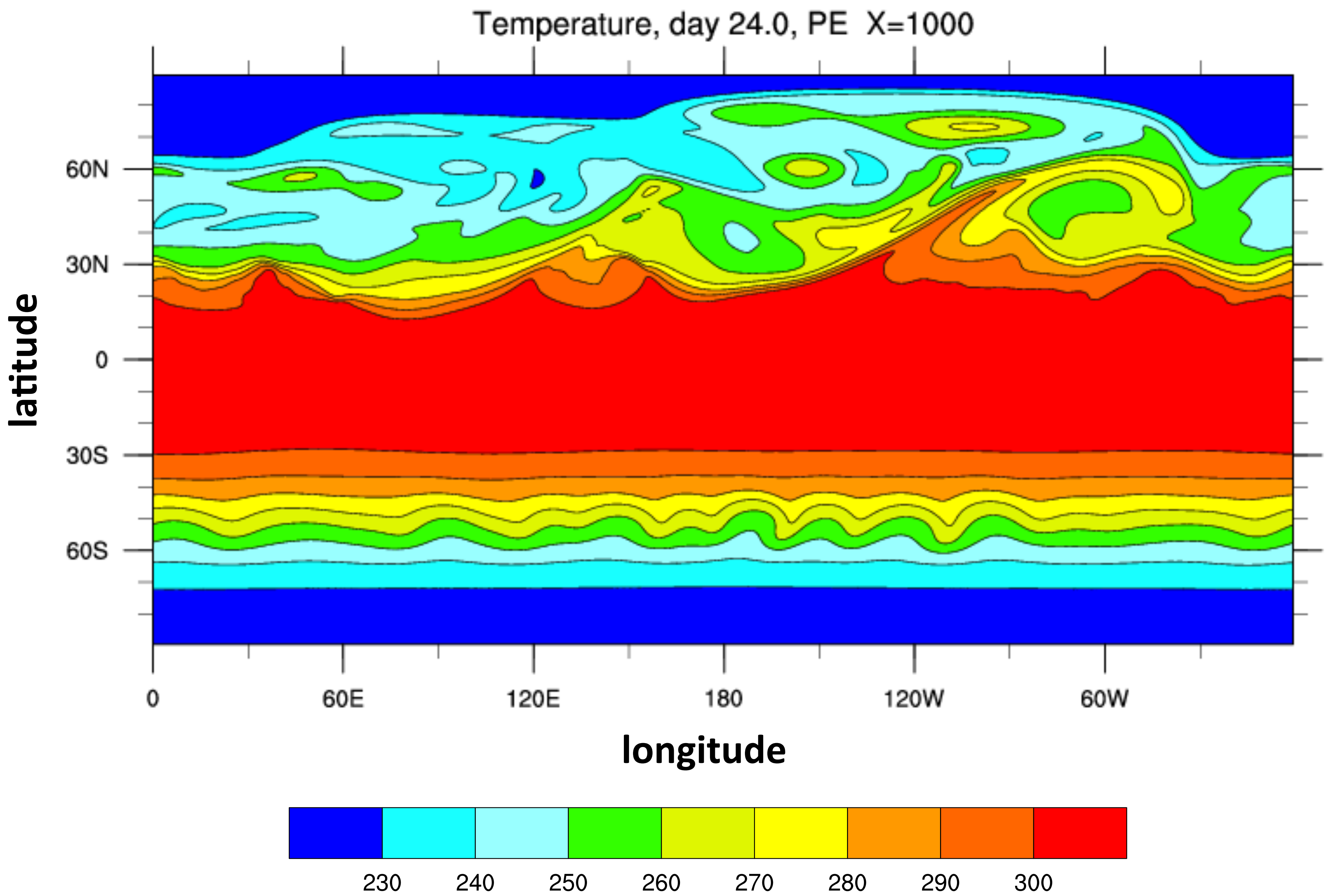

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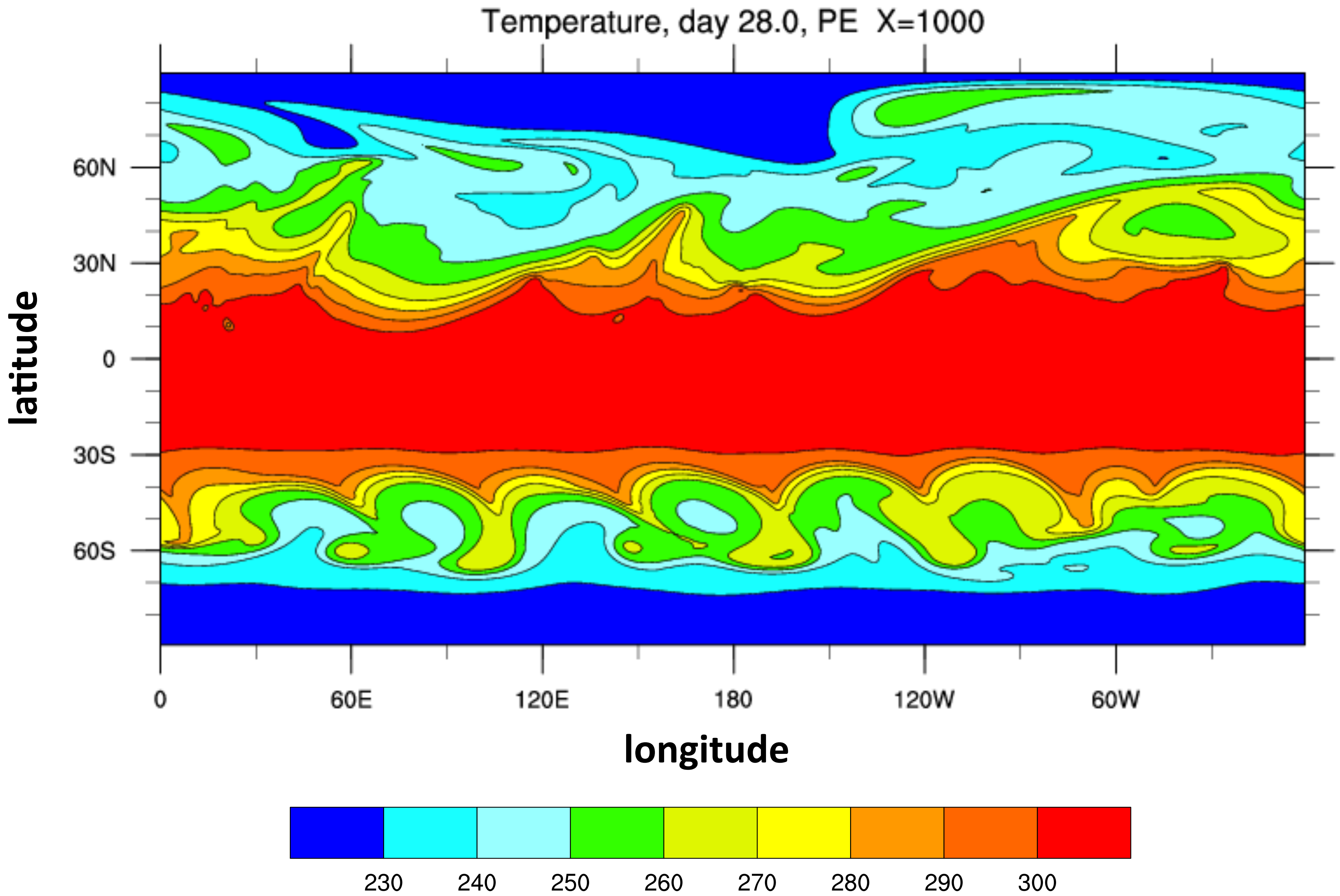
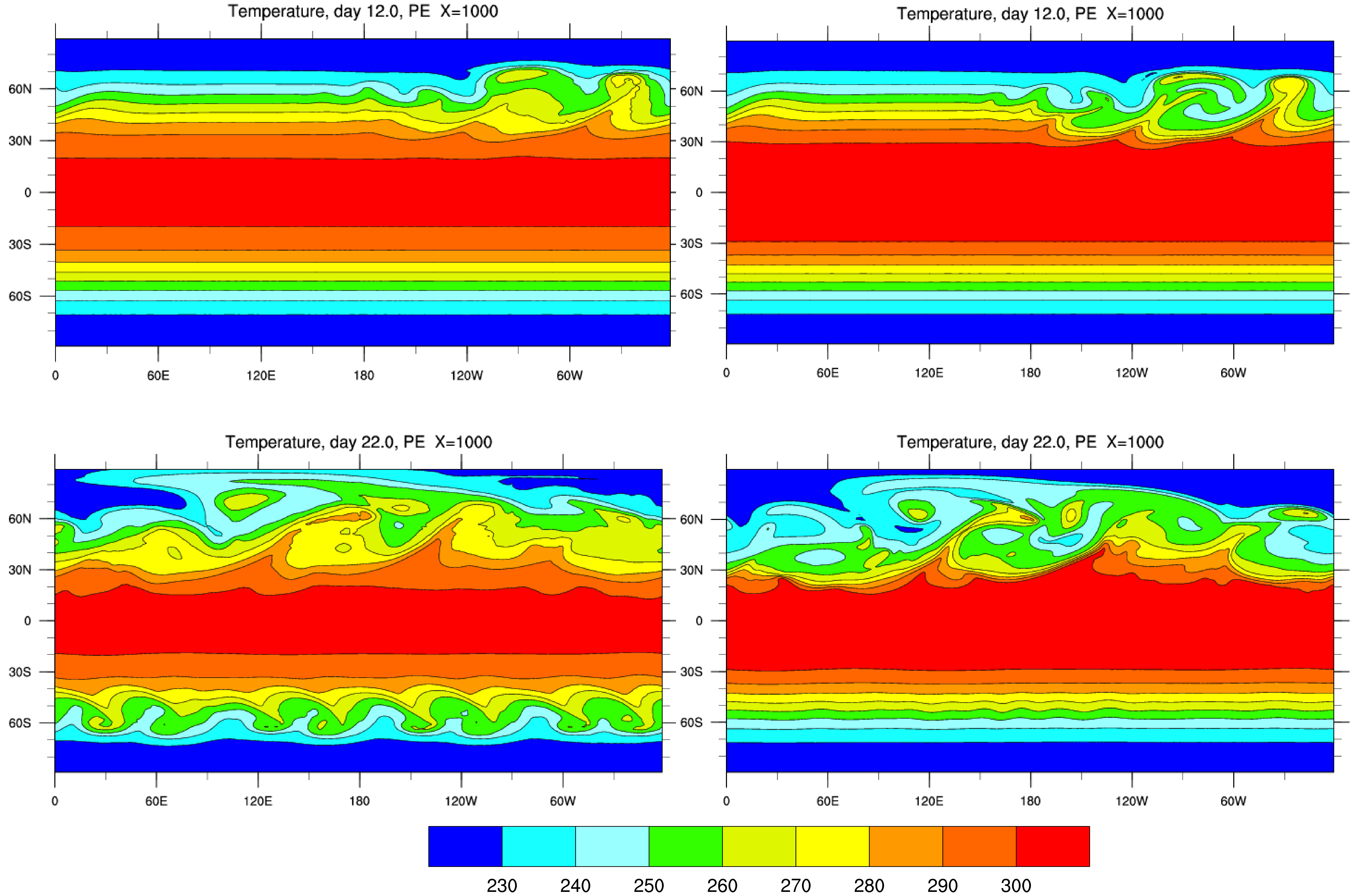


DCMIP 4-1

- **Vertical resolution** impacts **horizontal solution** quality

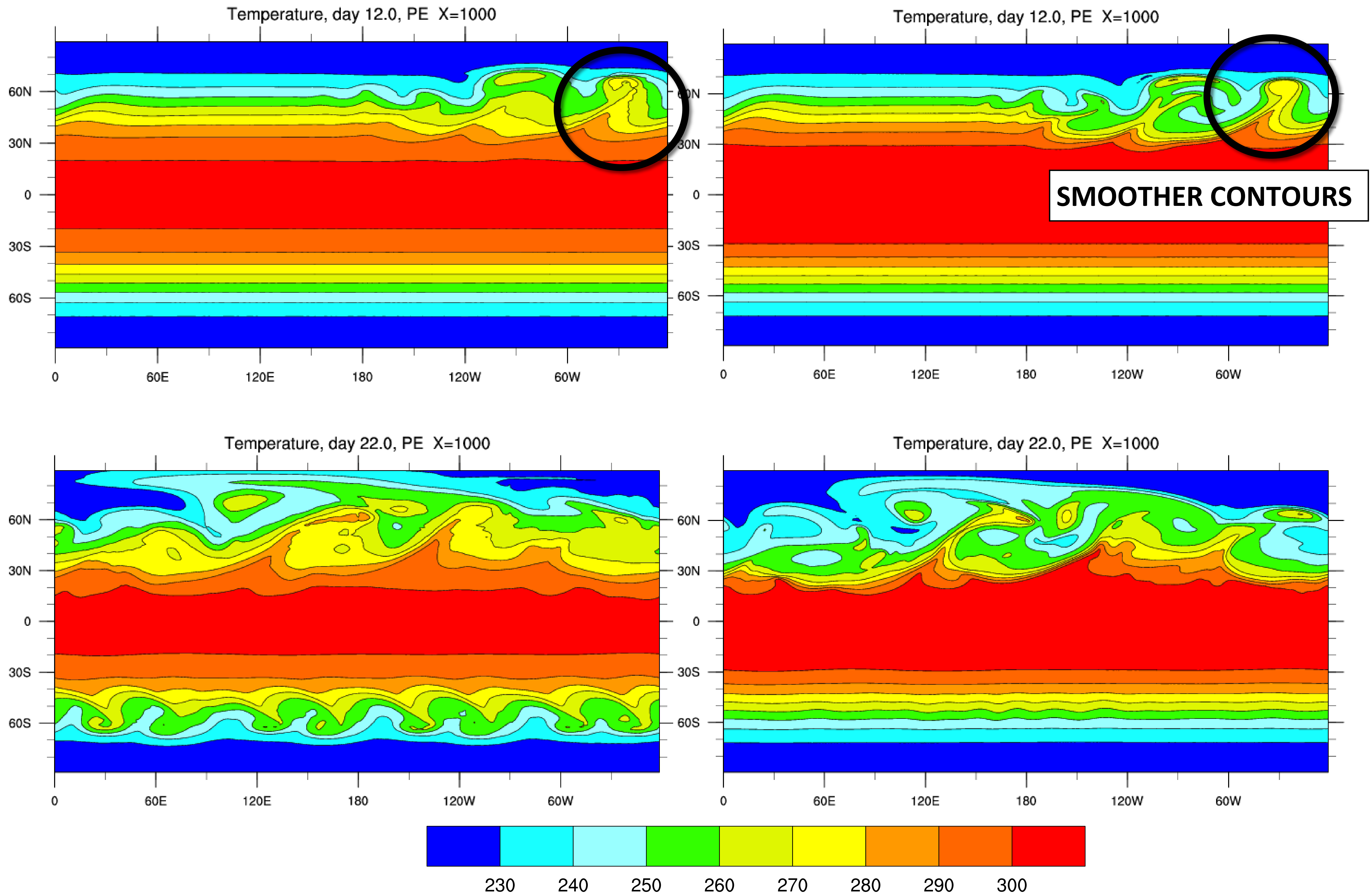
default method | **spectral vertical**



DCMIP 4-1

default method

spectral vertical



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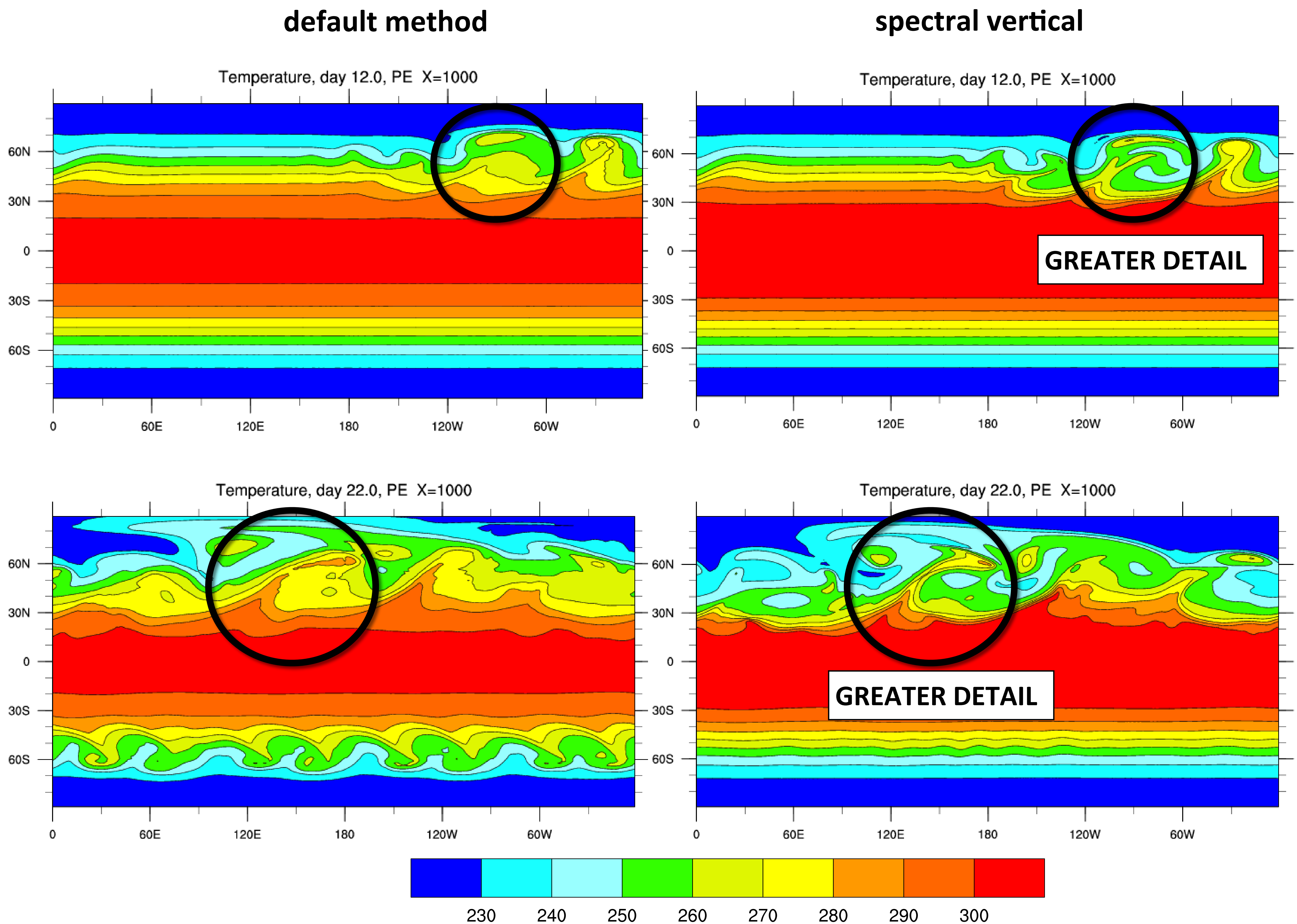
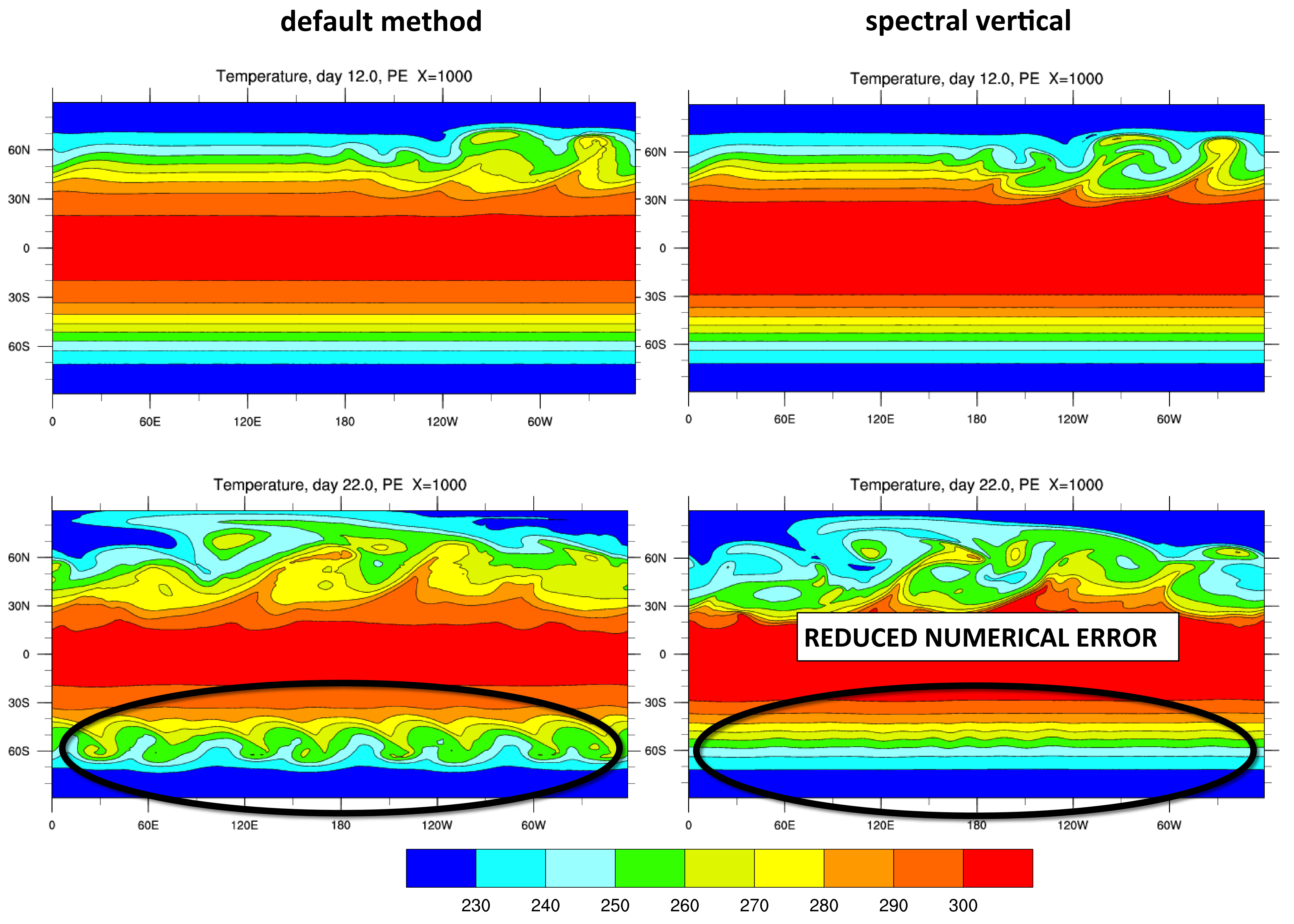


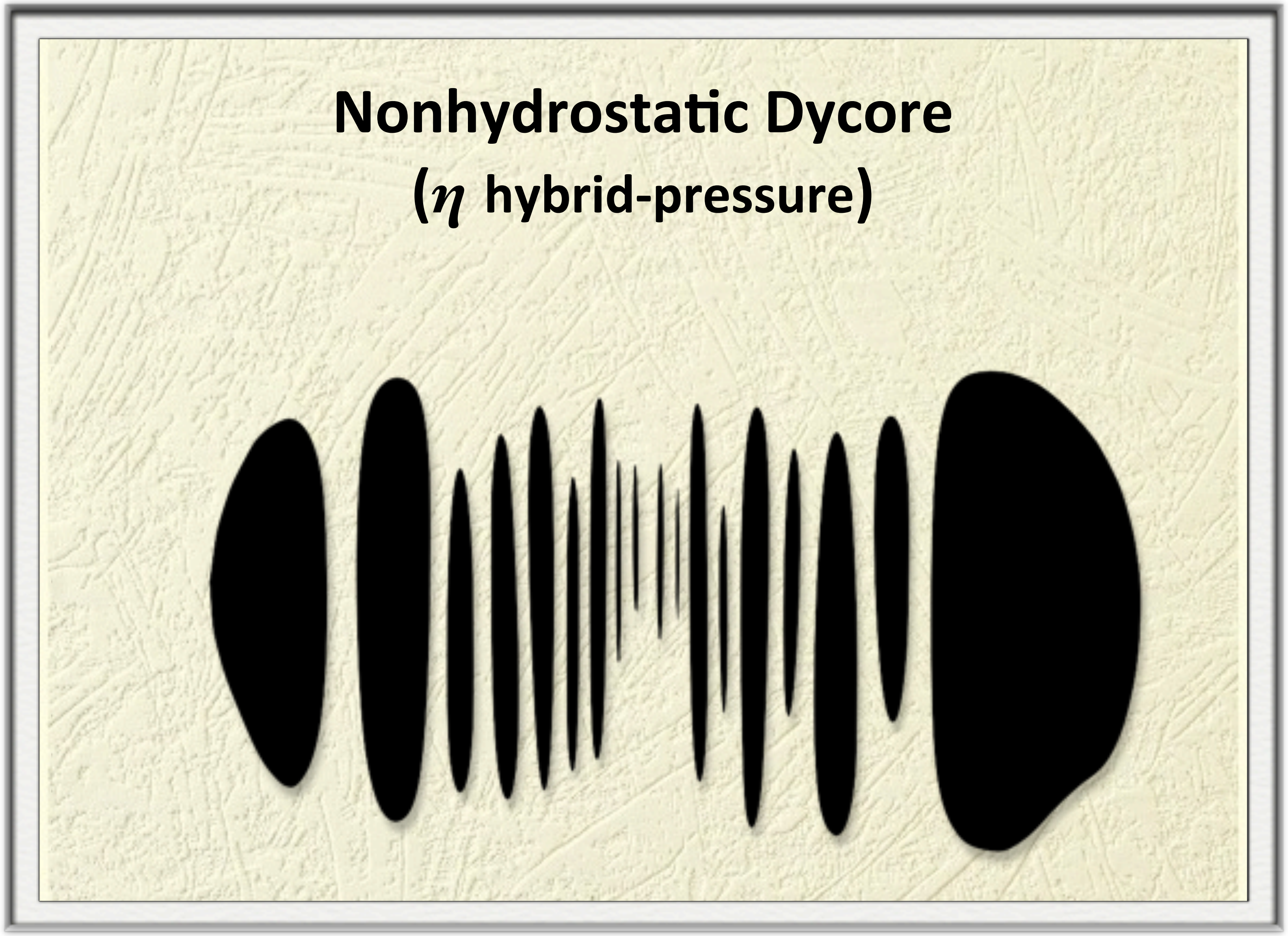
default method
spectral vertical
Temperature, day 12.0, PE X=1000
Temperature, day 12.0, PE X=1000
GREATER DETAIL
Temperature, day 22.0, PE X=1000
Temperature, day 22.0, PE X=1000
GREATER DETAIL
60N
30N
0
30S
60S
0
60E
120E
180
120W
60W
230
240
250
260
270
280
290
300

DCMIP 4-1



default method
spectral vertical
Temperature, day 12.0, PE X=1000
Temperature, day 22.0, PE X=1000
60N
30N
0
30S
60S
0
60E
120E
180
120W
60W
REDUCED NUMERICAL ERROR
230
240
250
260
270
280
290
300

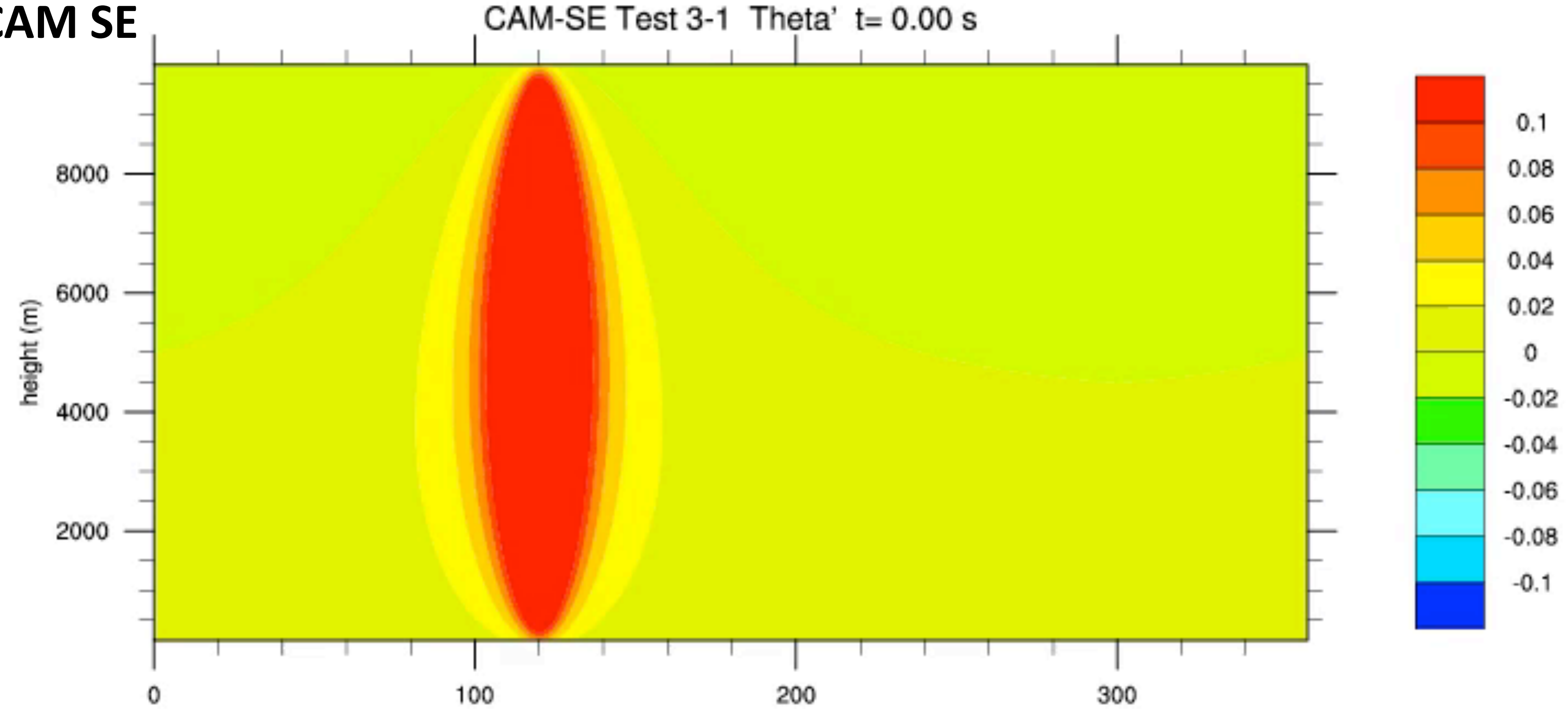
NONHYDROSTATIC MODEL IN PRESSURE COORDS



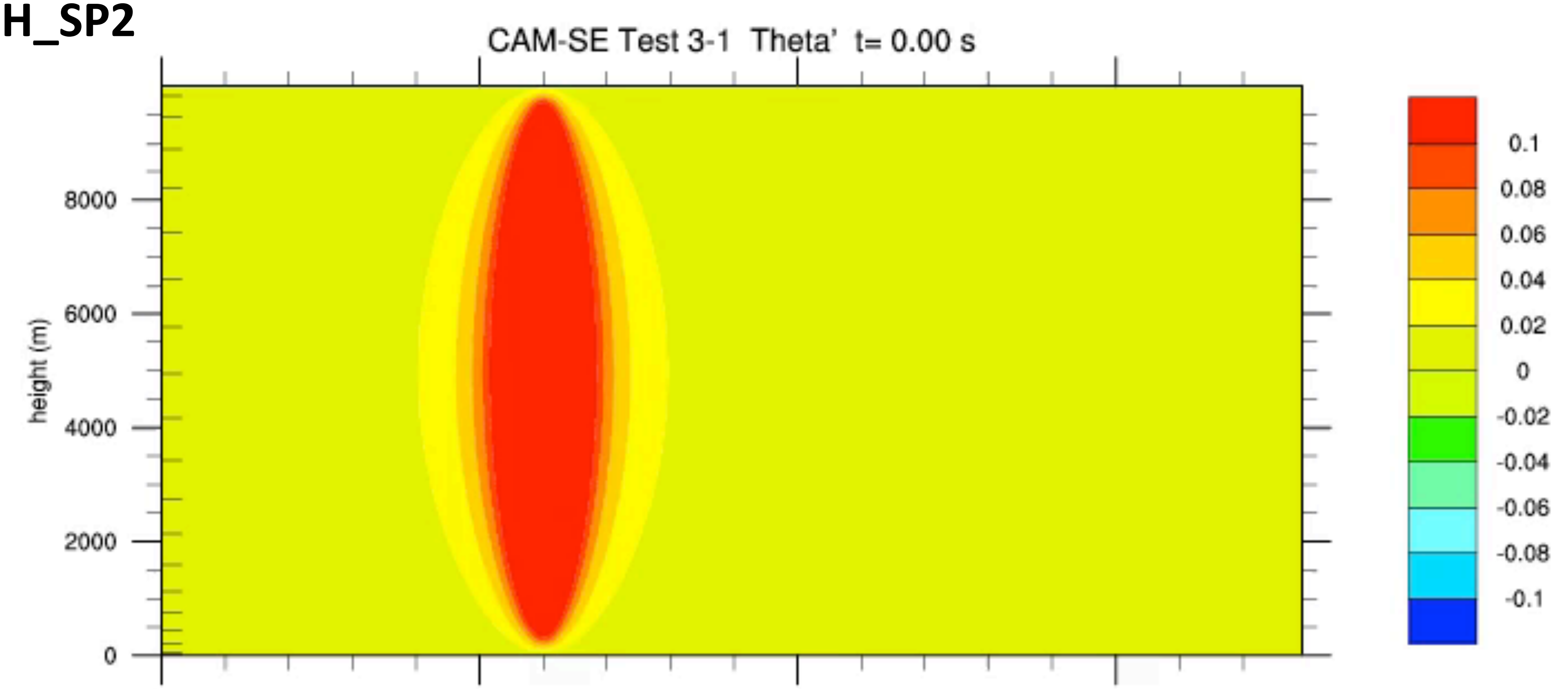
- Critical for horizontal resolutions finer than 10 km/cell
- Employs same spectral-vertical representation
- Works very well for orography-free simulations
- Orographic boundary conditions require further testing

DCMIP 3-1: PRIMITIVE VS NONHYDROSTATIC MODELS

CAM SE



NH_SP2



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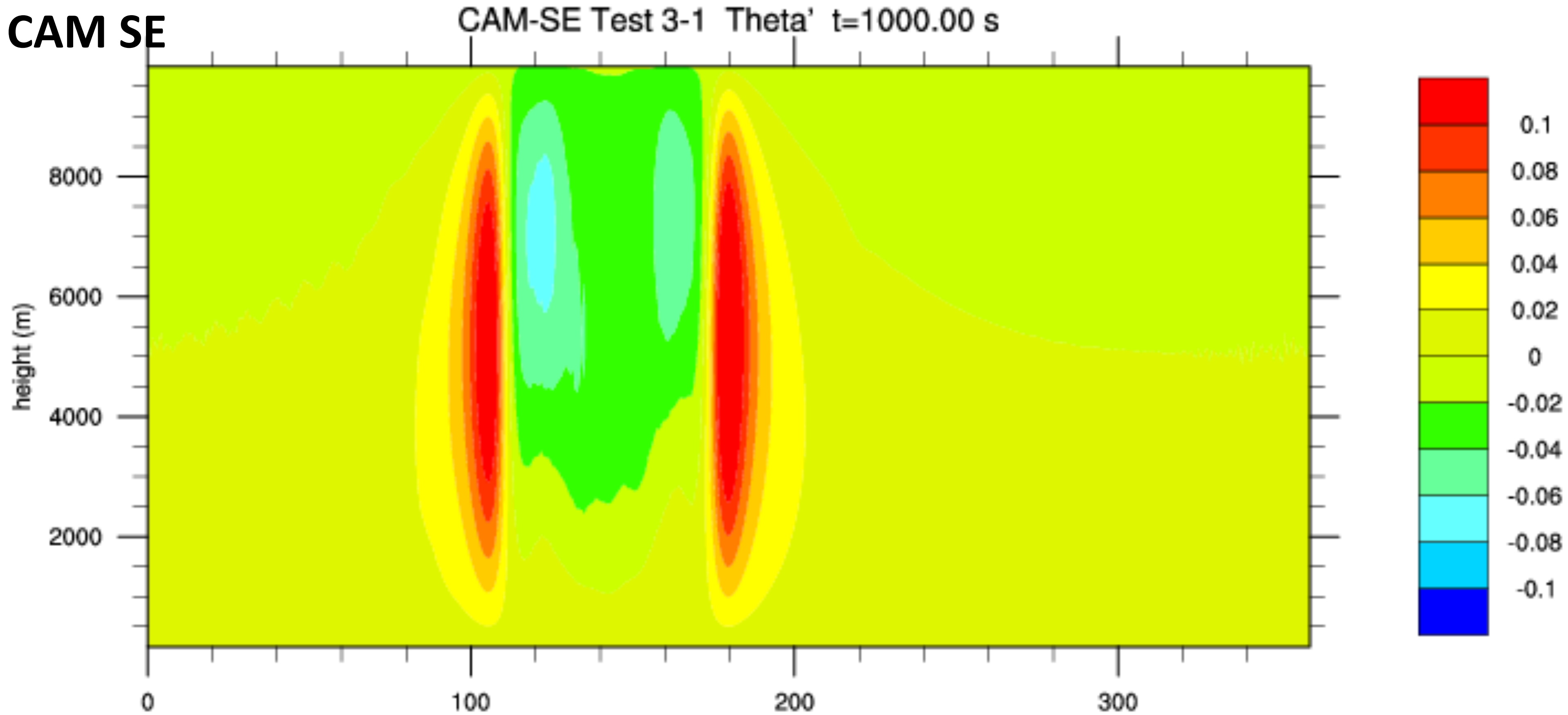
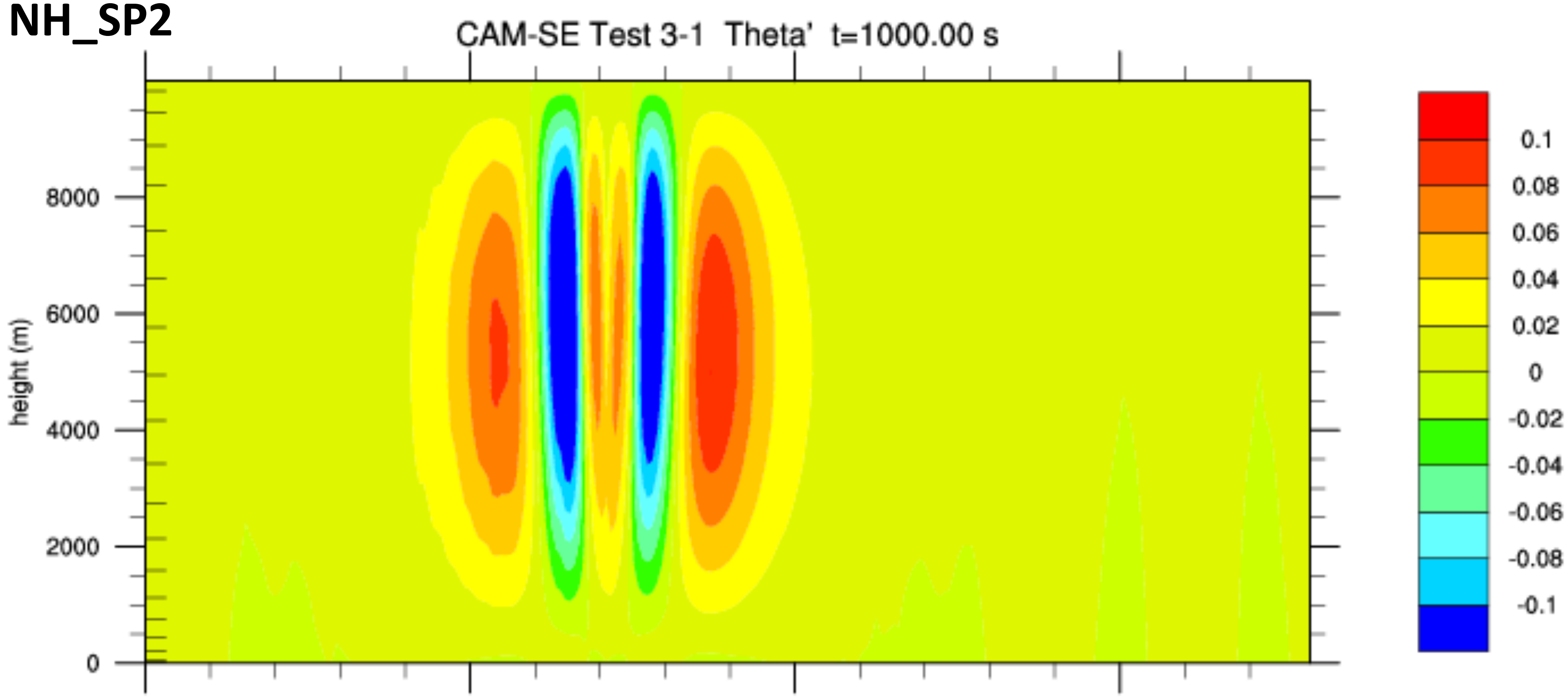
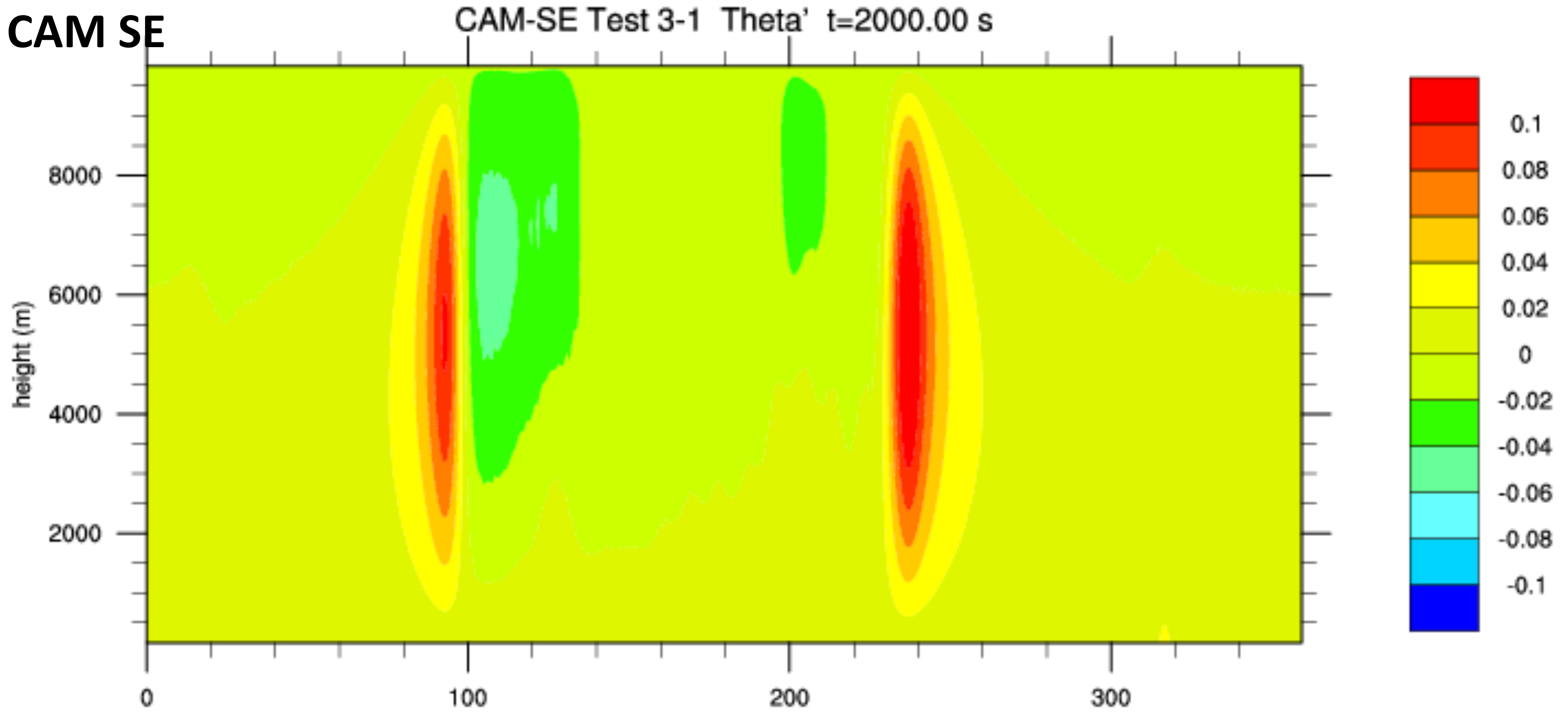


NH_SP2



DCMIP 3-1: PRIMITIVE VS NONHYDROSTATIC MODELS

CAM SE



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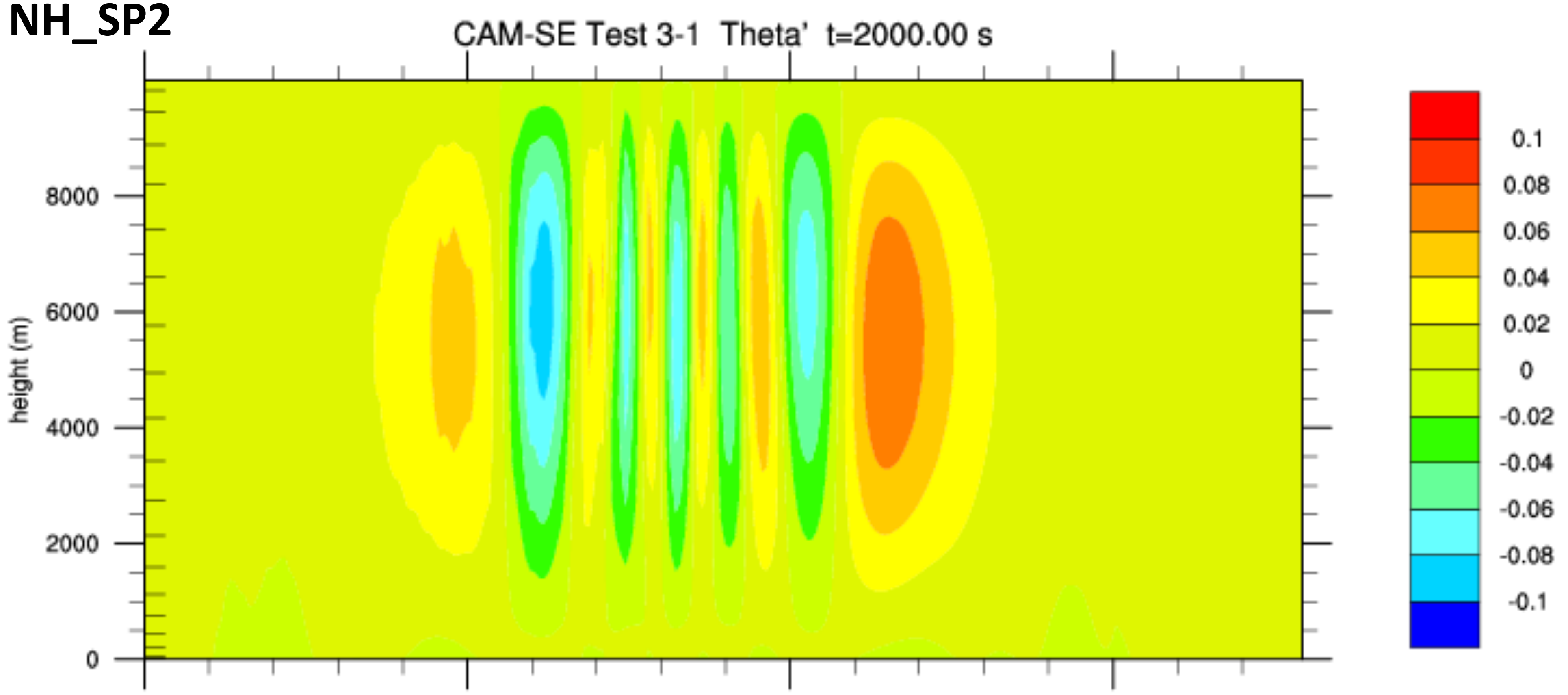
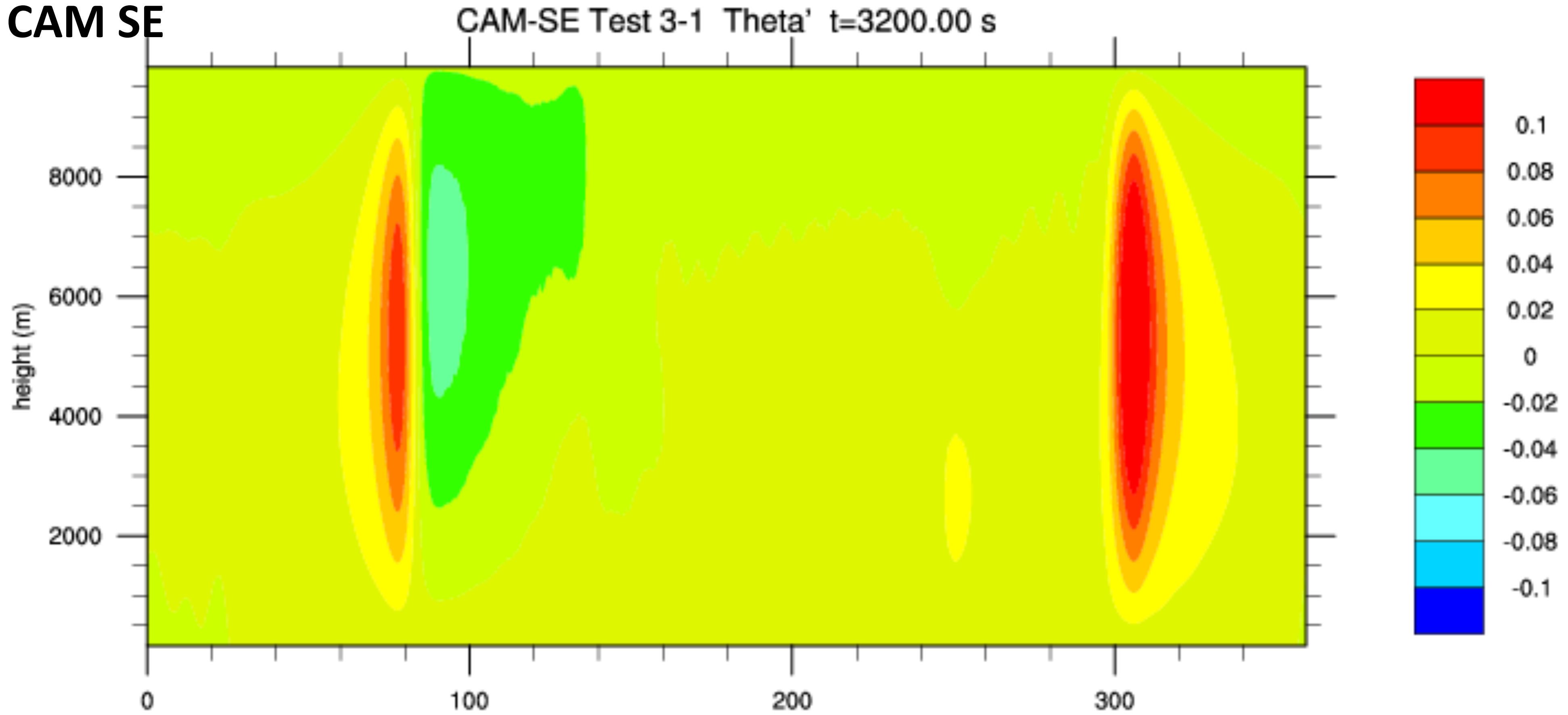


DCMIP 3-1: PRIMITIVE VS NONHYDROSTATIC MODELS

CAM SE



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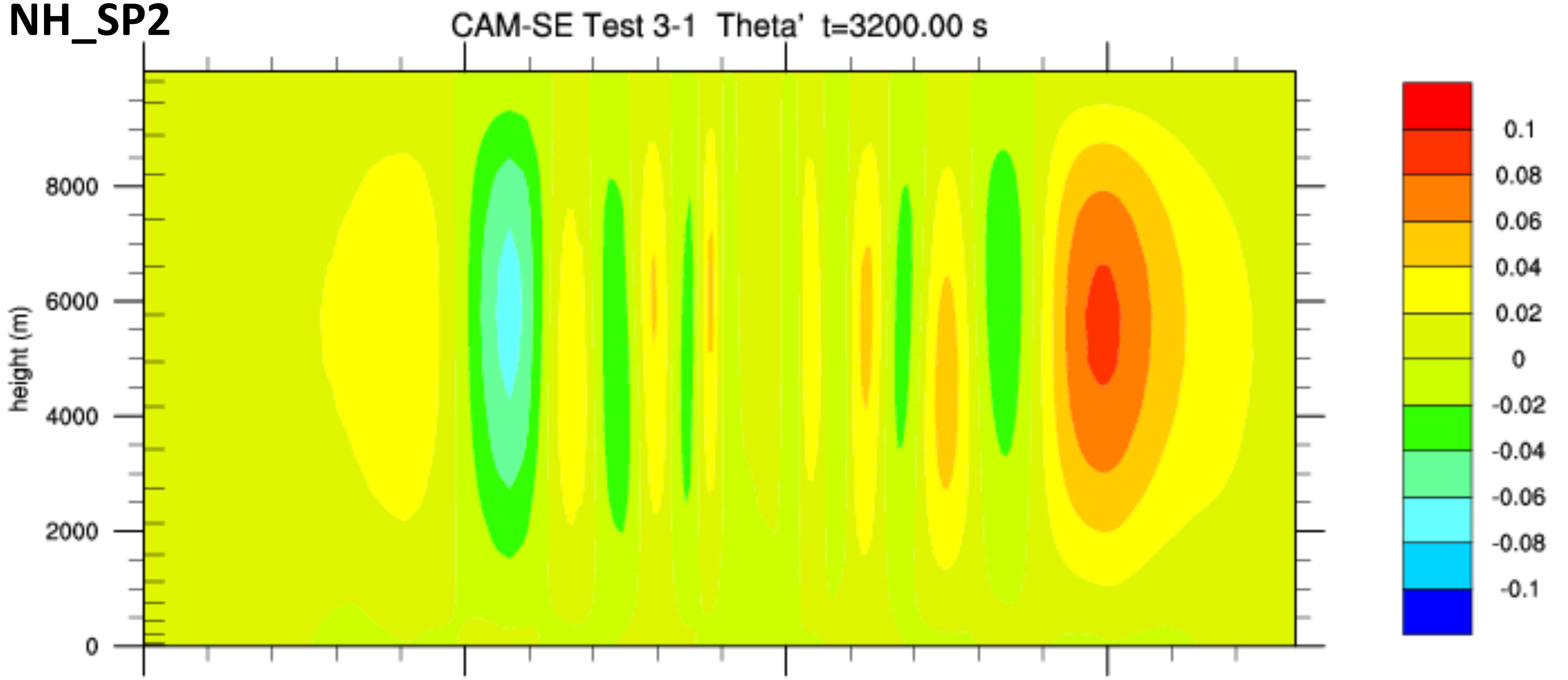
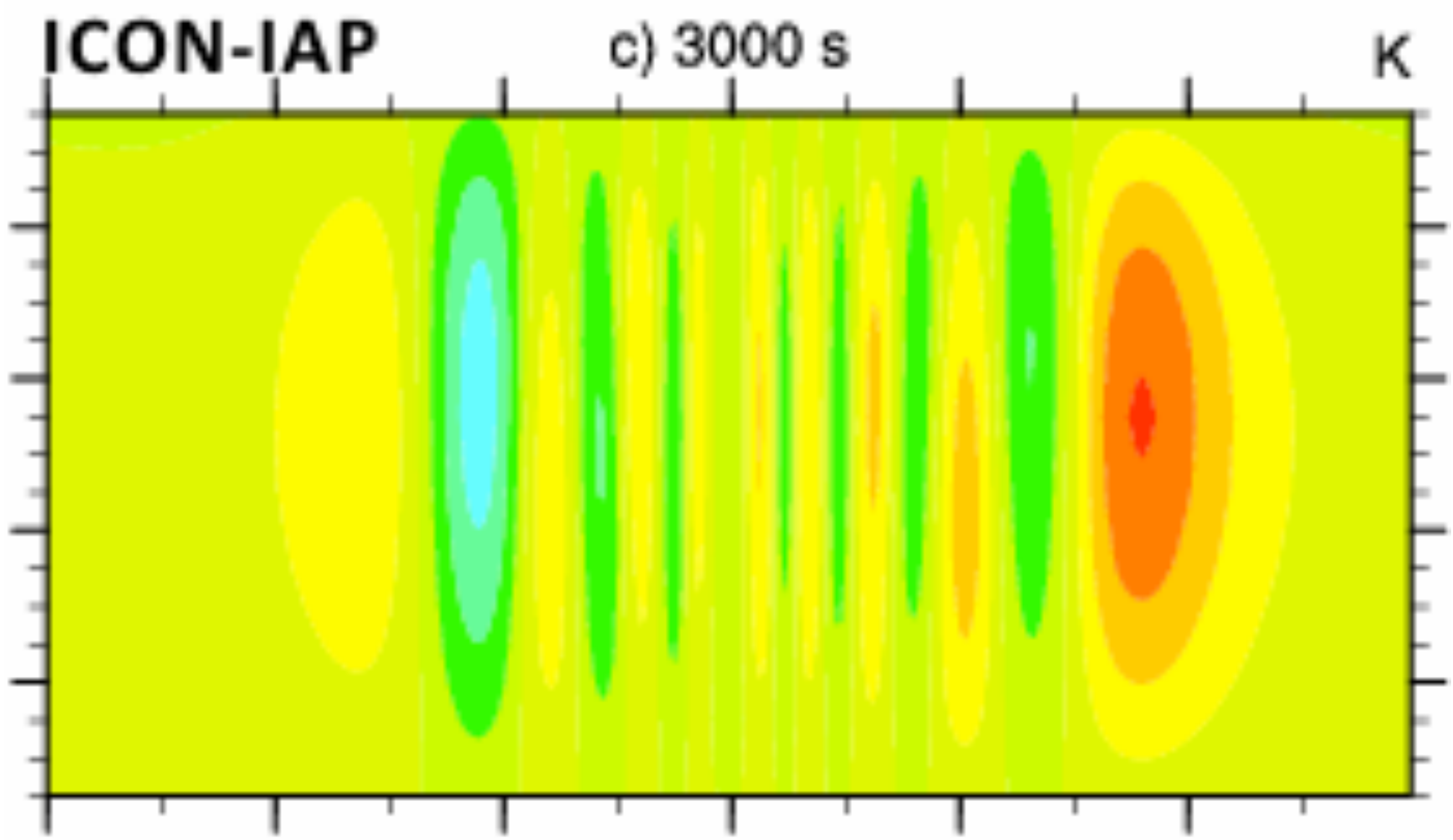
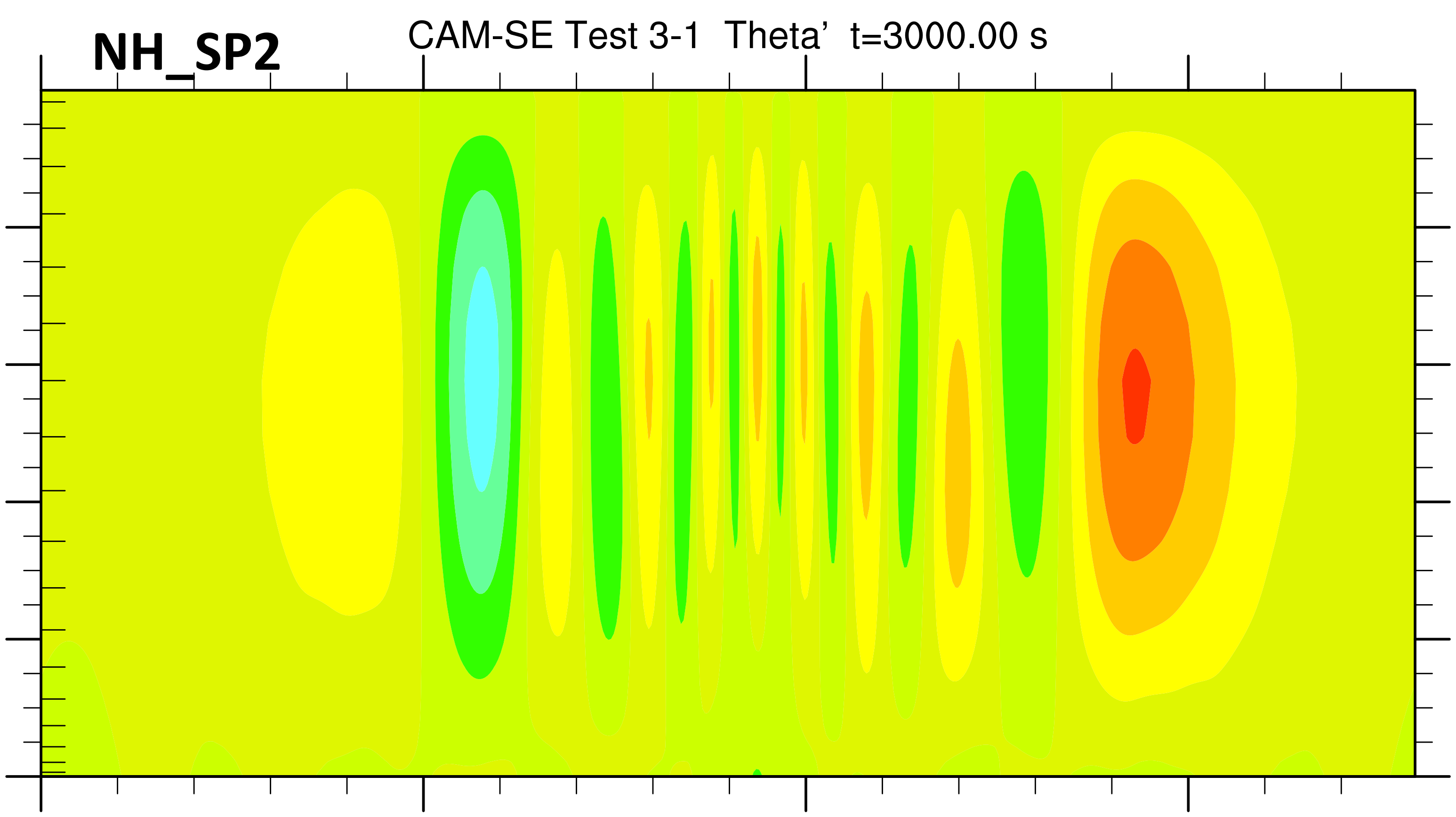


- Nonhydrostatic model results differ significantly from primitive equation results

DCMIP 3-1: COMPARISON WITH ICON NH MODEL





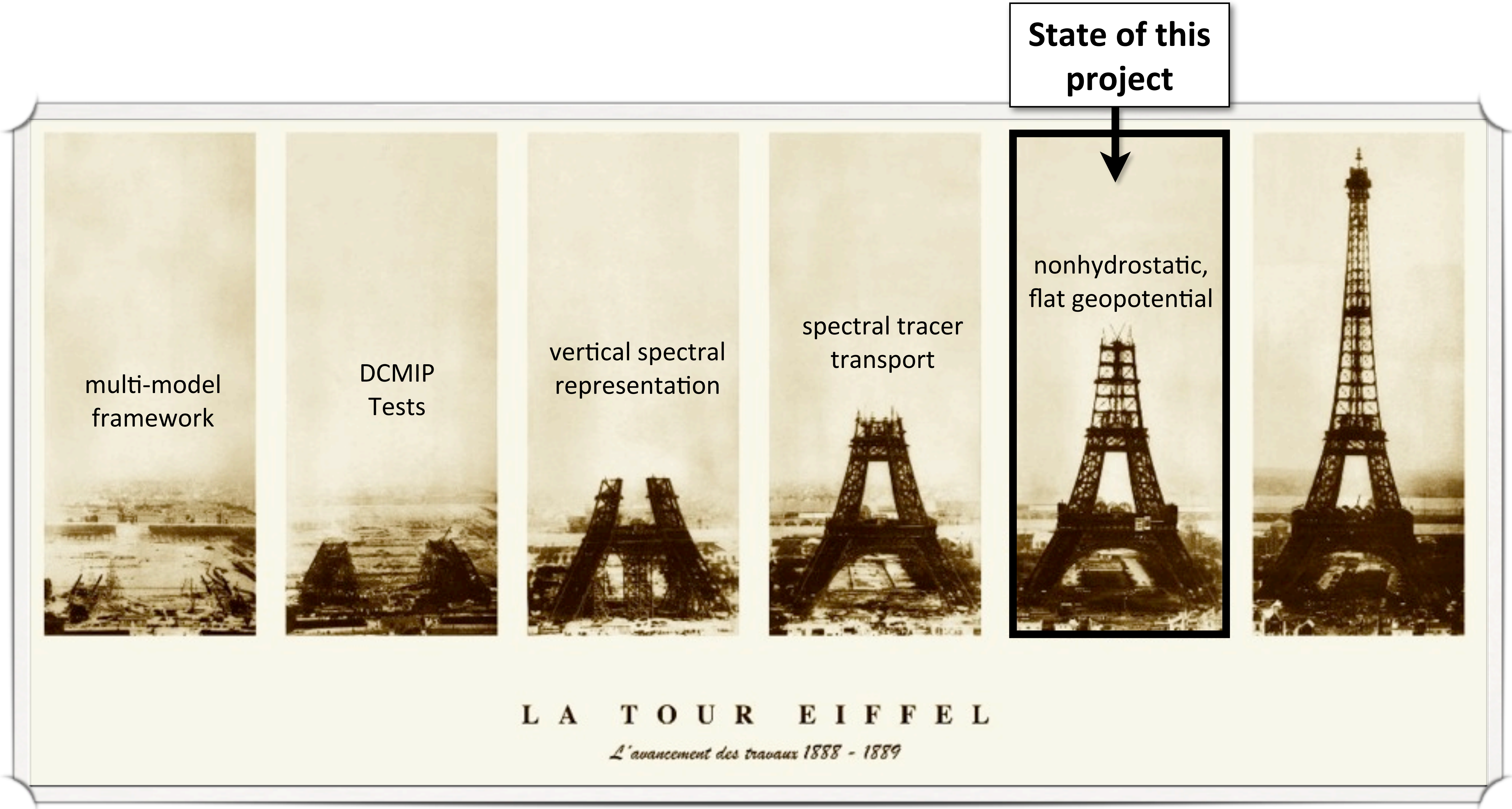
- Matches other nonhydrostatic models (it's working correctly)

IMPORTANT WORK REMAINS TO BE DONE:

- **Deliver** capabilities to **CAM trunk**
- Complete nonhydrostatic **orographic boundary condition** testing
- **Evaluate** both on Aqua-planet, AMIP

PROBLEM: FUNDING

- Funding for this project has run out.
- Ideally, I am seeking additional funding to finish / deliver new capabilities
- Alternatively: Anyone need a skilled climate-model developer?



SUMMARY

- **NEW SPECTRAL-VERTICAL REPRESENTATION**
- **SIGNIFICANTLY IMPROVES ACCURACY** IN CAM-SE **WITHOUT INCREASING THE COMPUTATIONAL COST**
- OBSERVED IMPROVEMENTS:
  - DCMIP 1-2: **REDUCED OVERSHOOTING**, **REDUCED GAPPING**
  - DCMIP 1-3: **REDUCED NUMERICAL DIFFUSION**
  - DCMIP 4-1: **GREATER DETAIL**, **SMOOTHER CONTOURS, REDUCED NUMERICAL ERROR**
- A PLAUSIBLE **ALTERNATIVE** TO **DOUBLING VERTICAL RESOLUTION**

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