Grid Anisotropy in High-Resolution Global Nonhydrostatic Models

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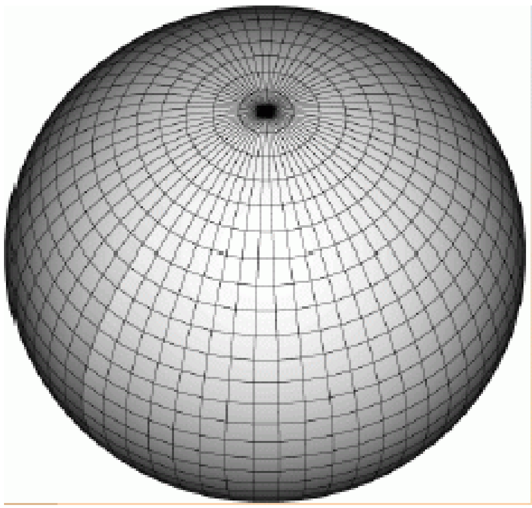


lat-long grid

(GEM model, Cote et al, MWR 1998)

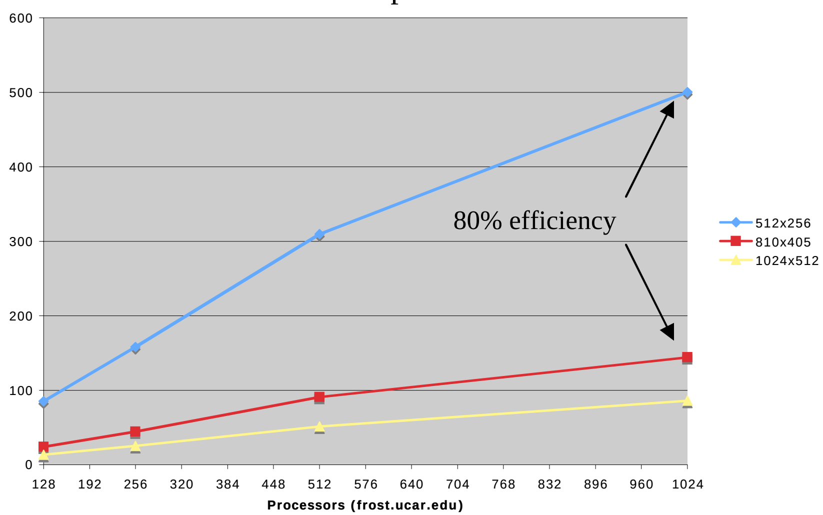
Some issues concerning grid anisotropy and filtering

WRF Global Model

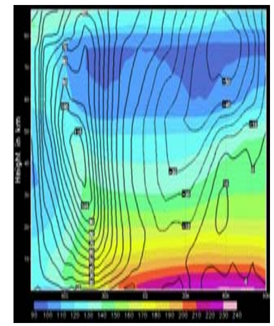
Global WRF on a lat-long grid

- Adapted from community development at Cal Tech for planetary atmospheres
- Functional system for nested nonhydrostatic global simulations
- Baseline for future nonhydrostatic global model development

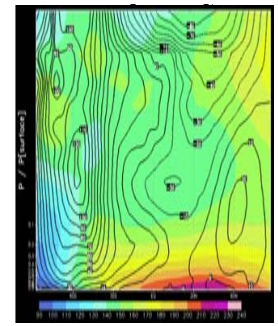
Simulation speed



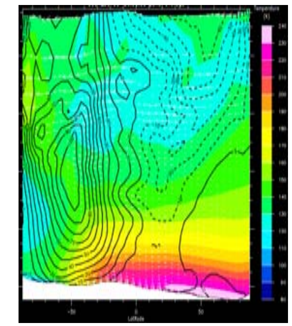
Mars at northern summer solstice (temperature and



GFDL MARS GCM



Oxford Mars GCM



Global WRF

10 day precipitable water forecast, initialized 7-11-2007 12Z

810 x 405 x 41 (x,y,z), ~50 km grid at the equator, 200 second timestep

QuickTime™ and a
BMP decompressor
are needed to see this picture.

Latitude-Longitude Grids

(GEM model, Cote et al, MWR 1998)

Advantages: Conformal (orthogonal)

Disadvantages: Highly anisotropic,
significant resolution
variance,
pole singularities.

Existing solutions: Reduced grids,
polar filters, careful definition
of vector quantities at the poles.

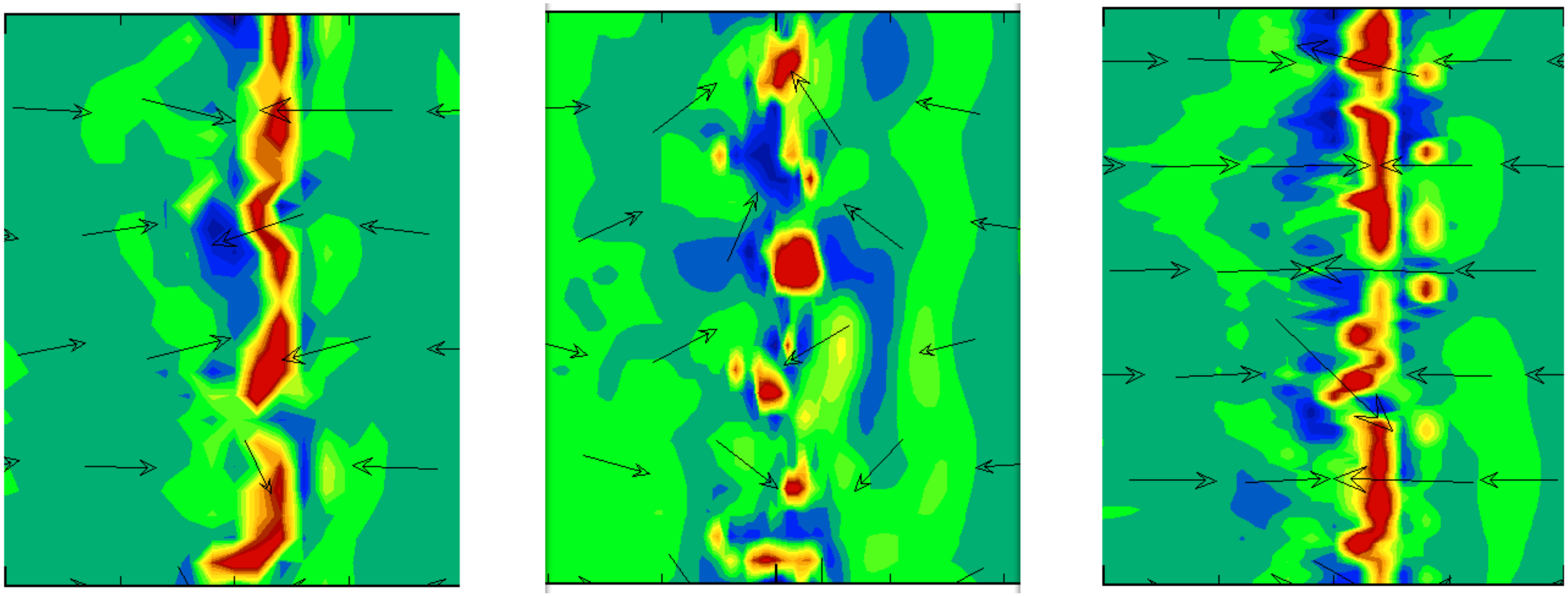
Most *operational* global weather and
climate models use this grid.

Anisotropic Grids Idealized Tests in Cartesian Domains

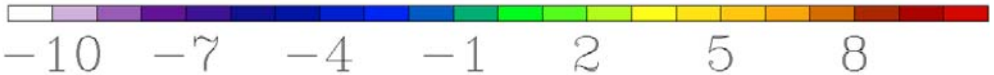
Squall-Line Test

Open bc (x), periodic (y), 200 km x 50 km domain

Vertical velocity (m/s) at z = 4 km, 2 hours



dx = dy = 2 km | dx = 500 m, dy = 2 km | dx = 2 km, dy = 500 m



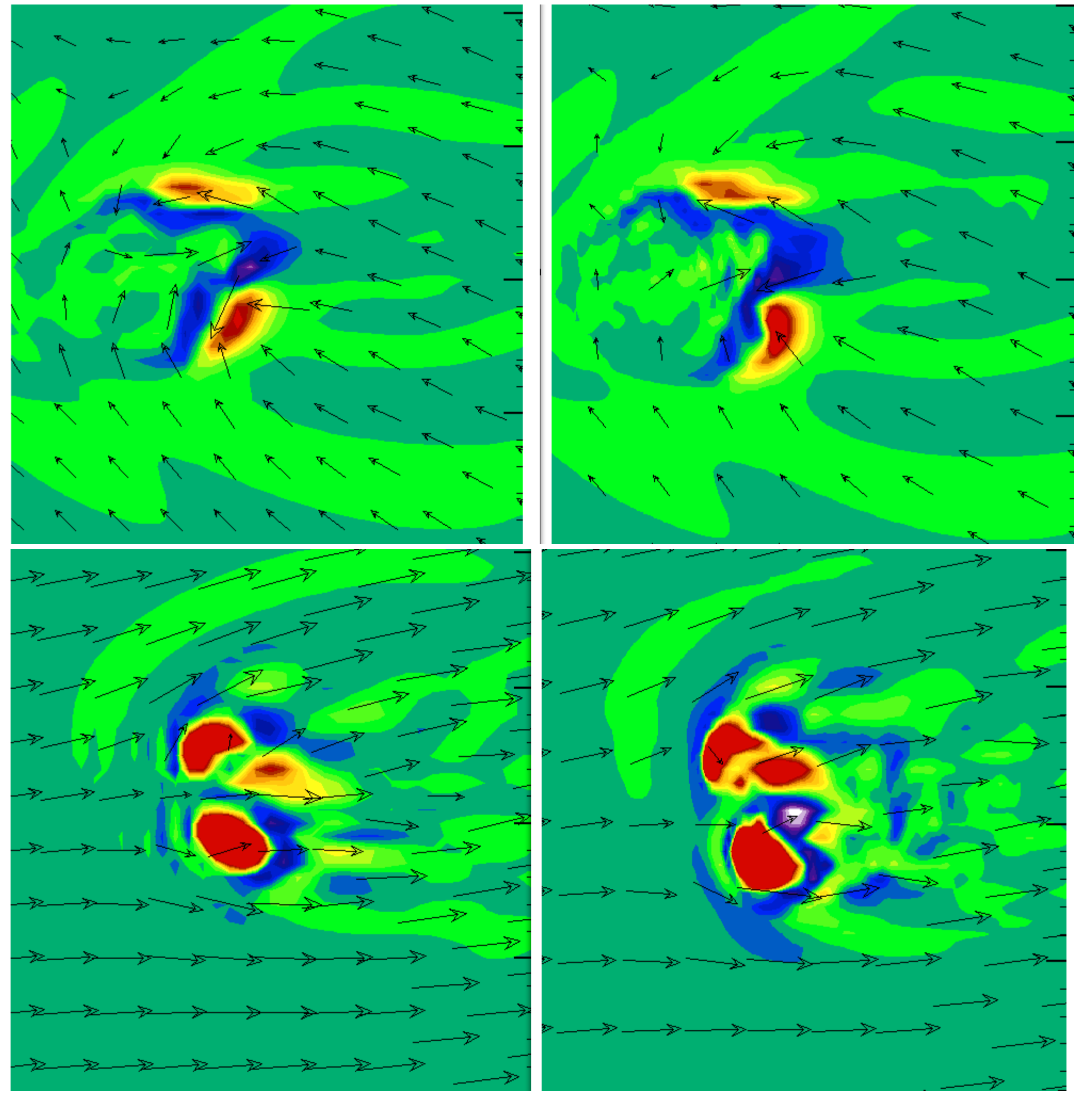
Supercell Test

Periodic (x,y),
120 x 120 km domain
w (m/s), 1 hour

dx = dy = 2 km | dx = 500m, dy 2 km

Z = 1.5 km

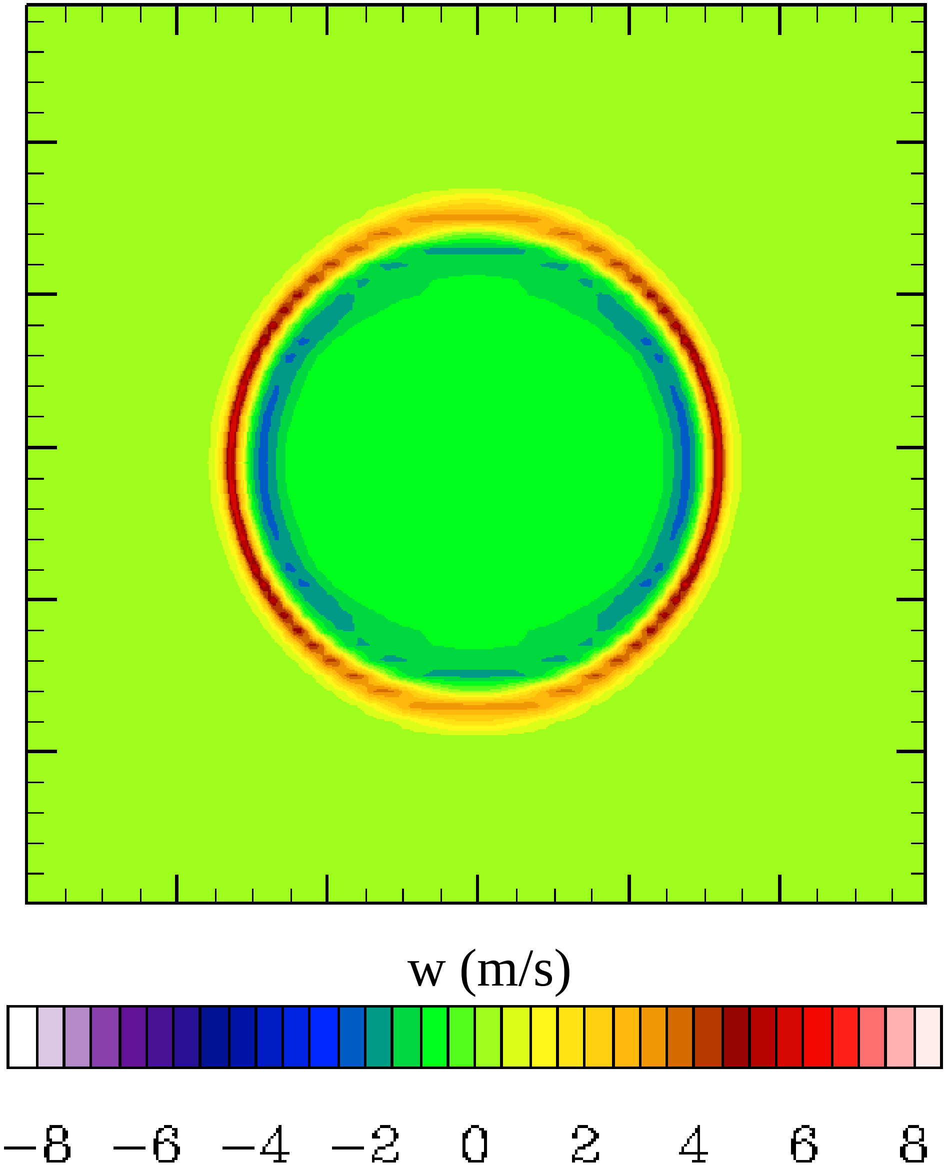
Z = 4 km



3D gravity current

dx = 500 m, dy = 2 km
120 x 120 km domain
Periodic bc's
w (m/s) at 30 minutes
z = 750 m

Observation: Unfiltered anisotropic grids are problematic (consider wave propagation, flow instability, model physics).



The Role of Filters

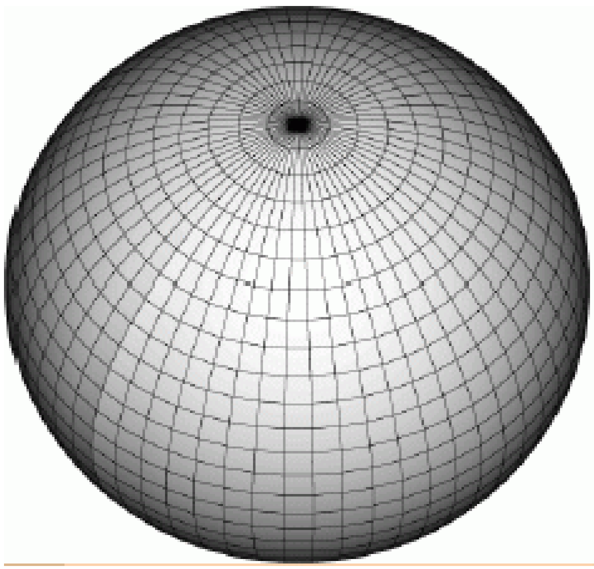
When filters are scaled to the grid-length, anisotropic grids lead to anisotropic solutions.

Filters can be used to render the solution (and effectively the grid) isotropic.

In global models, polar filters should produce isotropic solutions.

Latitude-Longitude Grids
Polar Filters

lat-long grid



Polar filters: After 40+ years, still more *art* than *science*.

Needed to stabilize schemes limited by Courant or Lipschitz conditions (i.e. all schemes).

General approach - 1D filter applied on latitude circles with increased filtering as the poles are approached.

WRF ARW Model Integration Procedure

Begin time step

Runge-Kutta loop (steps 1, 2, and 3)

(i) advection, p-grad, buoyancy, physics

Acoustic step loop

(i) advance U,V (Fourier Filter U,V)

(ii) advance ❍📭 ✈ (Fourier Filter ❍📭 ✈)

(iii) advance w, ♐ (Fourier Filter w, ♐)

End acoustic loop

Advance scalars (Fourier Filter Sc)

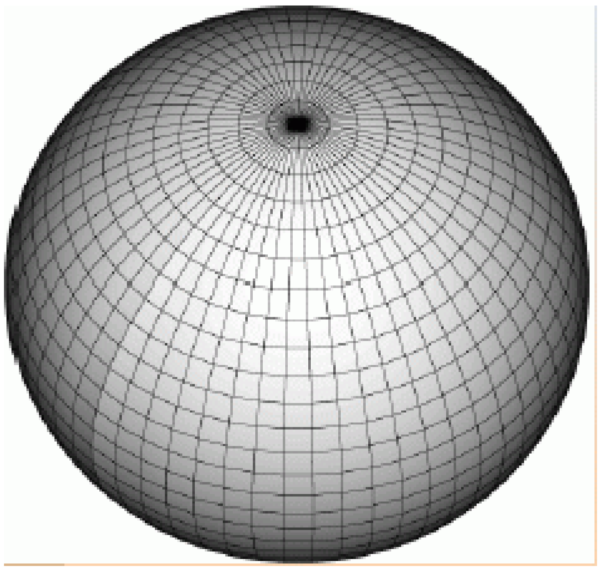
End Runge-Kutta loop

Adjustment physics (currently microphysics) (Fourier Filter Sc)

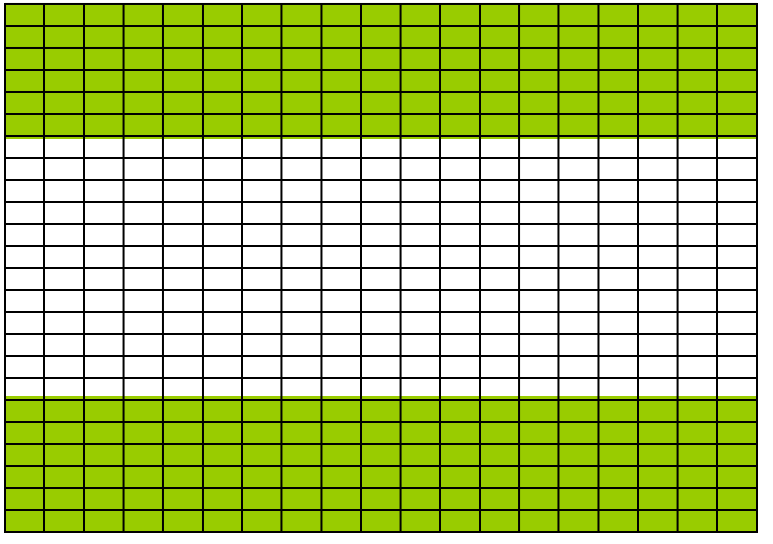
End time step

Latitude-Longitude Grids
Polar Filters

lat-long grid



computational grid



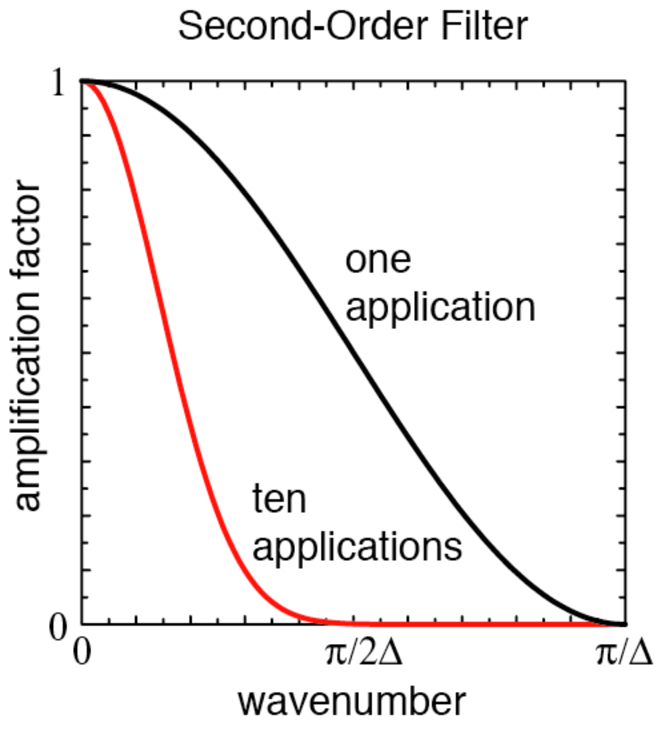
Polar filter application typically covers about half the computational grid, and much less than 1/2 the earth's surface.

Both Fourier and local filters have problems with isotropy (Purser, 1988)

Latitude-Longitude Grids
Polar Filters

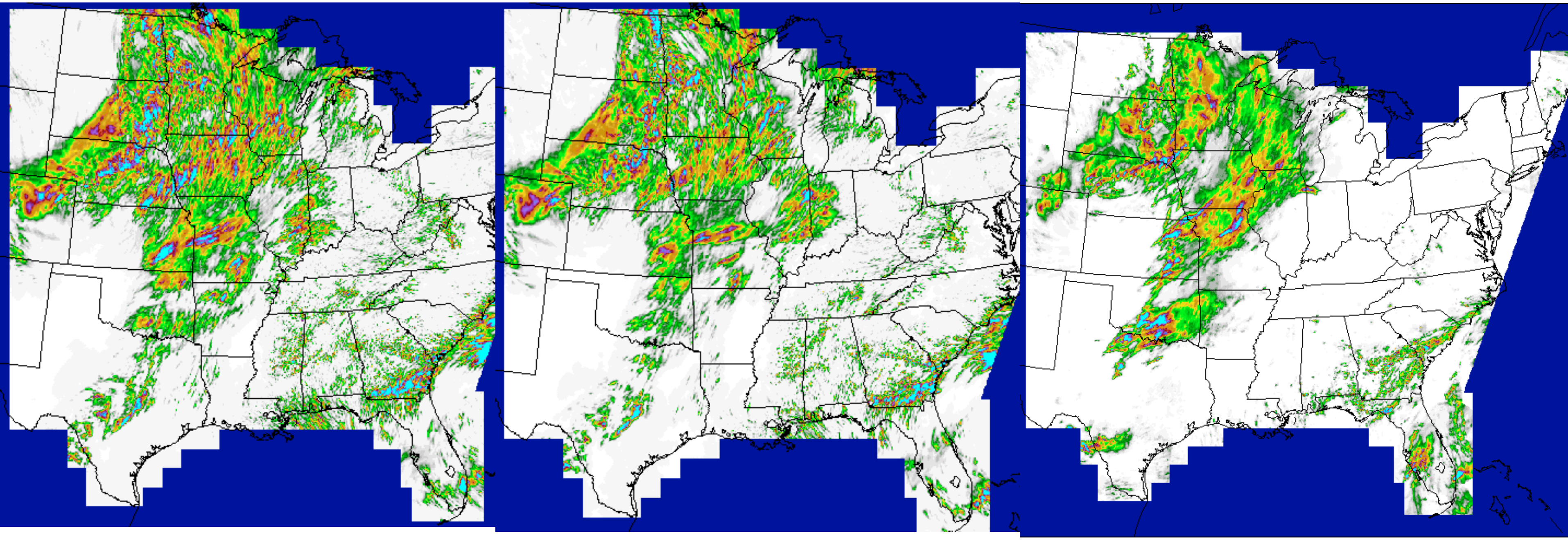
Fourier Filtering: Requires forward and back Fourier transforms on latitude circles, with a specified wavenumber truncation.
Strengths: Direct control of truncation.
Weaknesses: Essentially global communications. Not positive definite.

1D Local Filters: typically 1D Laplacian on latitude circles, with repeated applications as the poles are approached.
Strengths: Local - but less so with repeated applications. Positive definite.
Weaknesses: less control of truncation.

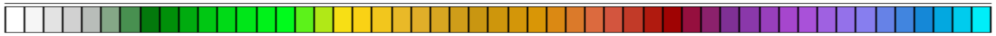


Positive-Definite Transport

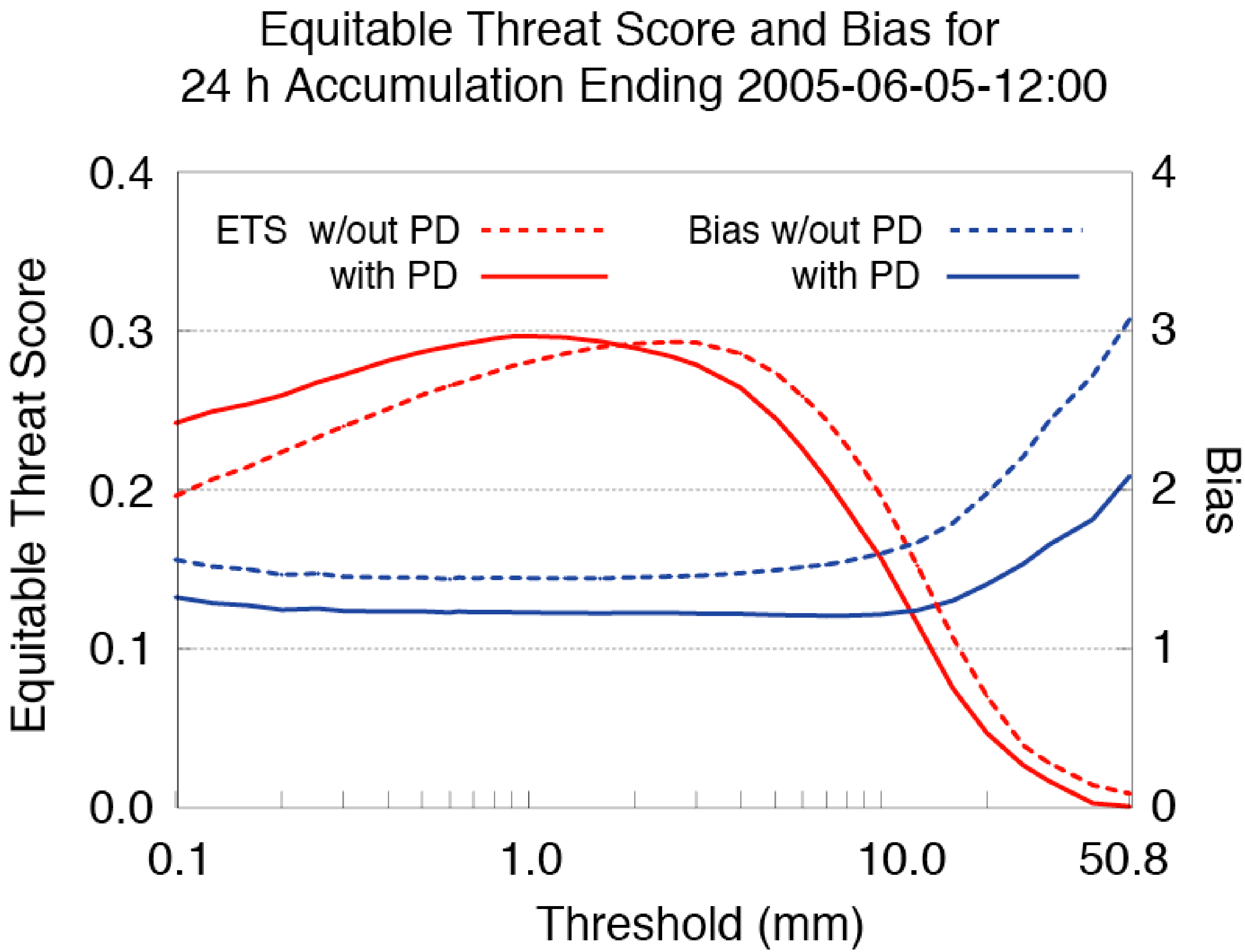
24 h accumulation ending 2005-06-05-12:00
WRF forecast, 4 km grid



no pd transport | pd transport | verification



Accumulated rainfall (mm)



Equitable Threat Score and Bias for
24 h Accumulation Ending 2005-06-05-12:00
ETS w/out PD
with PD
Bias w/out PD
with PD
Equitable Threat Score
Bias
0.4
0.3
0.2
0.1
0.0
4
3
2
1
0
0.1
1.0
10.0
50.8
Threshold (mm)

Summary

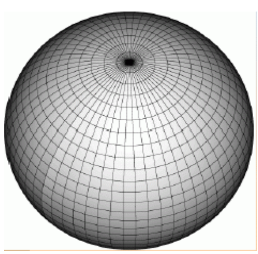
Filtering is needed on latitude-longitude grids for stability and solution isotropy.

Existing filters have problems.

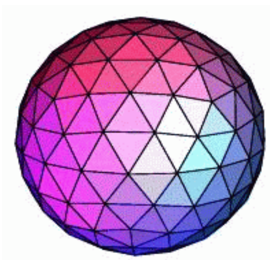
- Isotropy (Purser 1988)
- Positive definiteness (Fourier filtering)
- Damping characteristics (local filters)

New model designs are incorporating more-isotropic grids that do not need special filters.

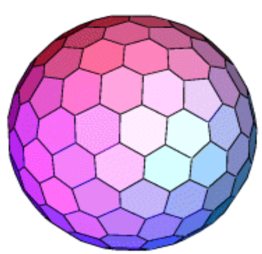
What is the long-term solution?



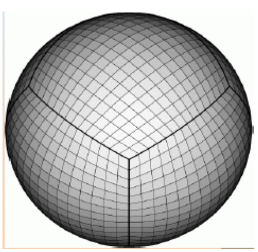
lat-long



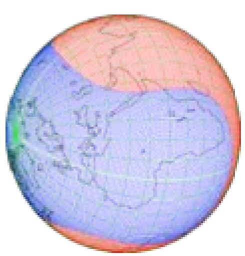
triangular



icosahedral



cubed sphere



yin-yang