Vertical Resolution Requirements for NWP models

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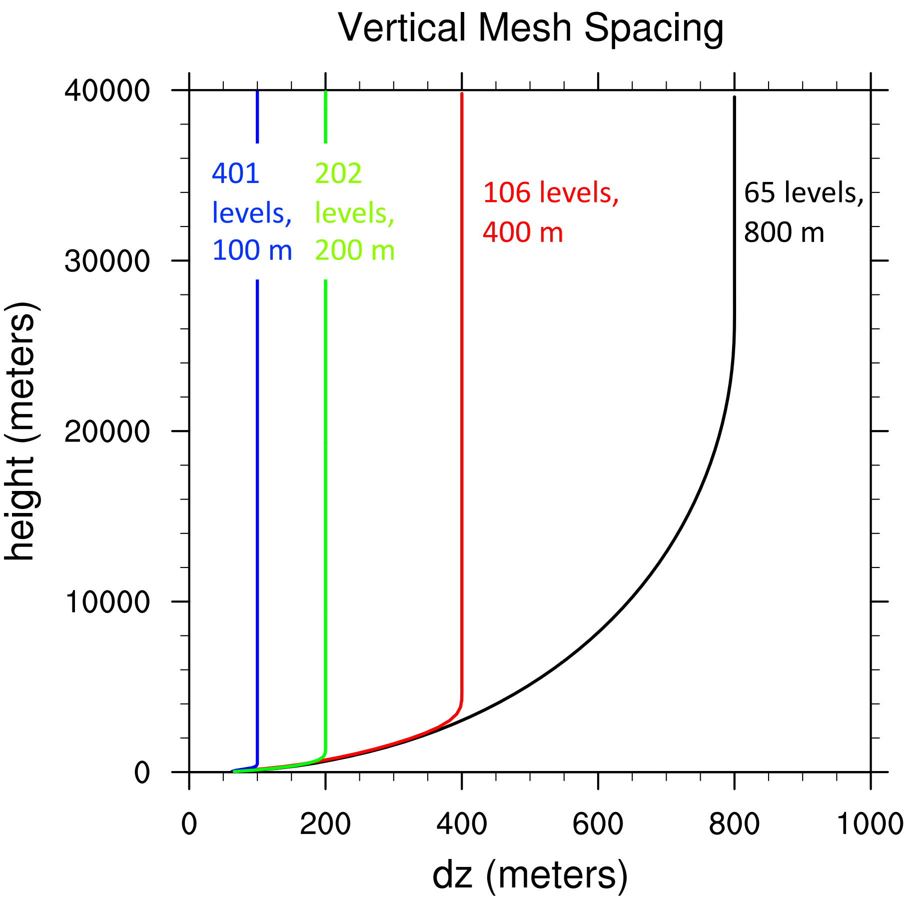
Numerical Tests – Configurations

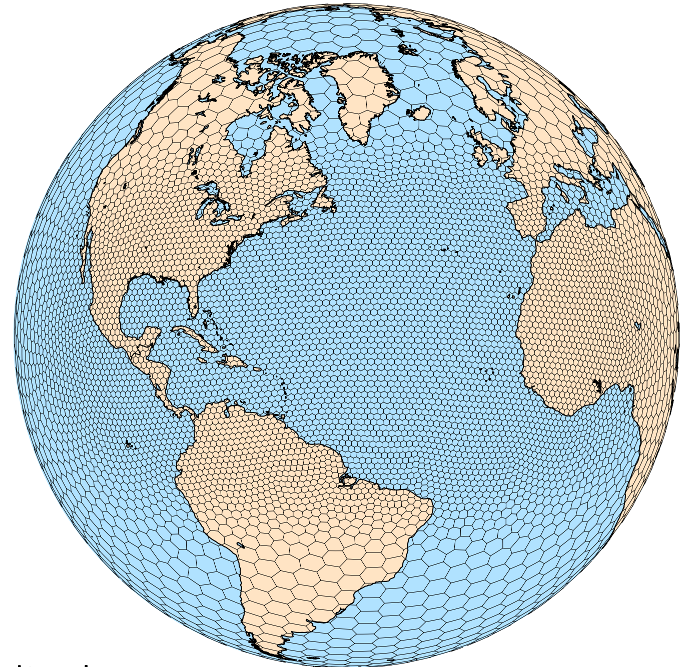
- Global MPAS
- 7-day forecasts initialized 2016-12-20
- Uniform 15 km global mesh (2.62 x 10^6 columns)
- 40 km model top
- 4 different vertical meshes with max Δz = 100, 200, 400 and 800 meters (65, 106, 202 and 401 levels)

Mesoscale reference physics suite – MPAS V5.1

Surface Layer: (Monin Obukhov): as in WRF 3.7.
PBL: YSU as in WRF 3.8.
Land Surface Model (NOAH 4-layers): as in WRF 3.3.1.
Gravity Wave Drag: *YSU gravity wave drag scheme.*
Convection: *new Tiedtke (nTiedtke), as in WRFV3.8*
Microphysics: WSM6: as in WRF 3.5
Radiation: RRTMG sw, lw as in WRF 3.4.1



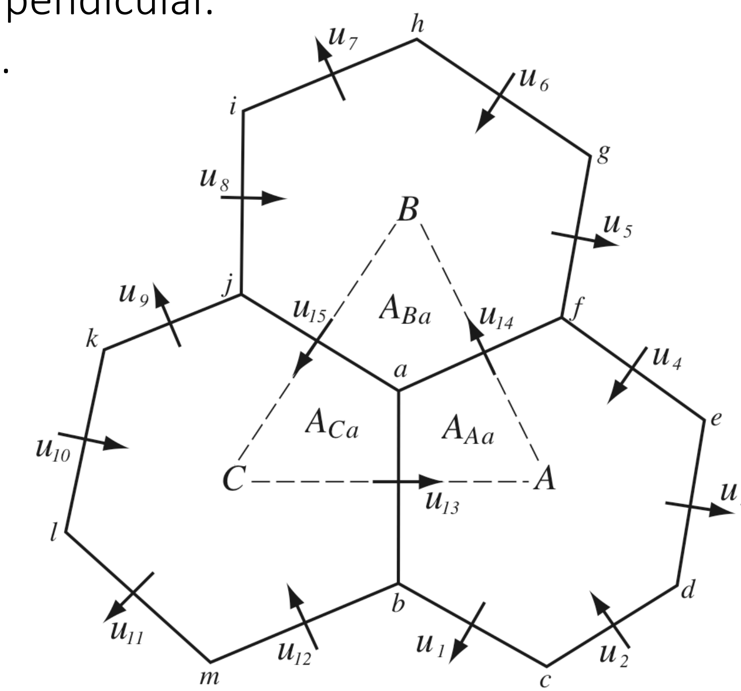
MPAS
Model for Prediction Across Scales



MPAS-Atmosphere solves the fully-compressible nonhydrostatic equations

Unstructured spherical centroidal Voronoi meshes

- Mostly *hexagons*, some pentagons and 7-sided cells
- Cell centers are at cell center-of-mass (centroidal).
- Cell edges bisect lines connecting cell centers; perpendicular.
- Uniform resolution – traditional icosahedral mesh.



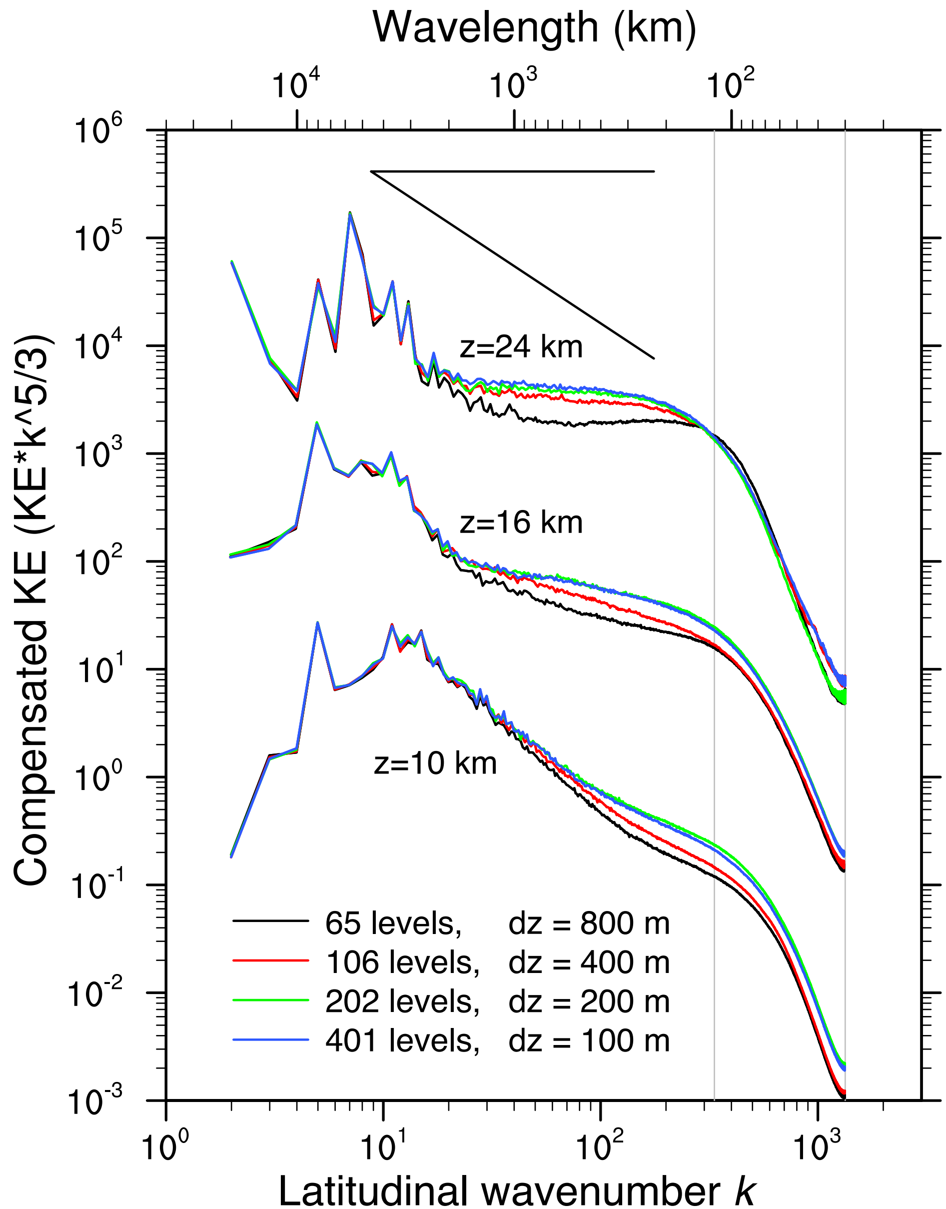
Time integration scheme as in Advanced Research WRF: Split-explicit Runge-Kutta (3rd order)

- Prognostic equations for coupled variables.
- Generalized height coordinate.

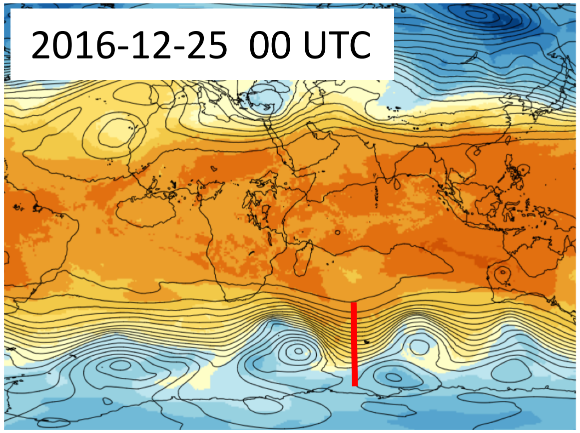
KE spectra convergence

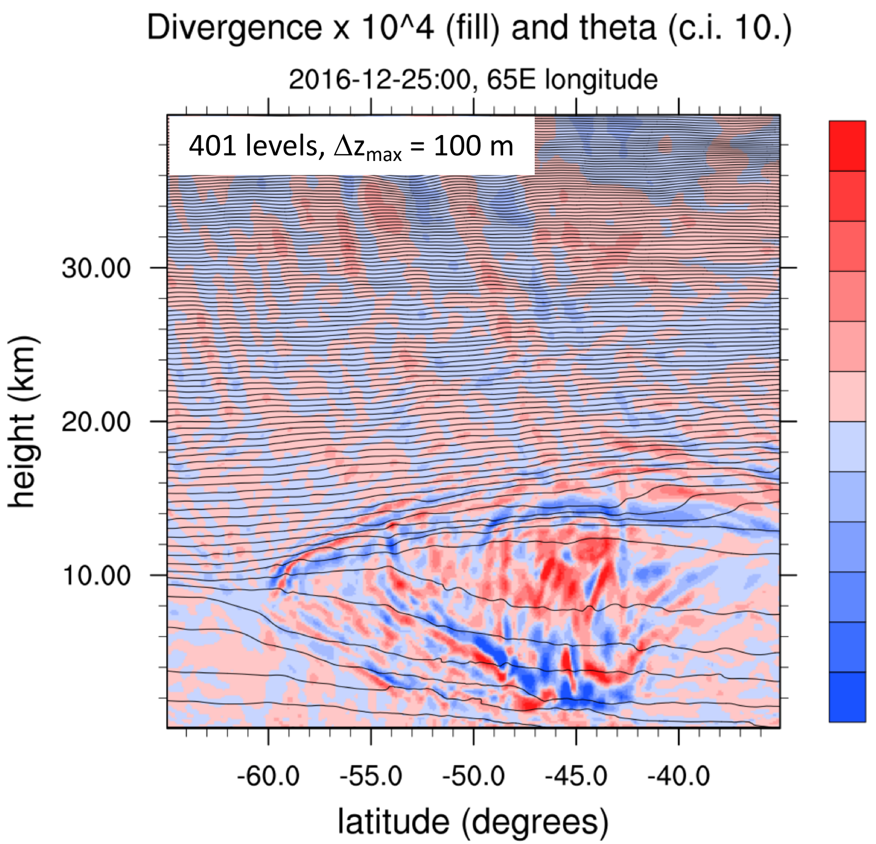
KE spectra at
z = 10, 16 and 24 km,
hourly spectra averaged
over the final 2 forecast days.
15 km uniform mesh

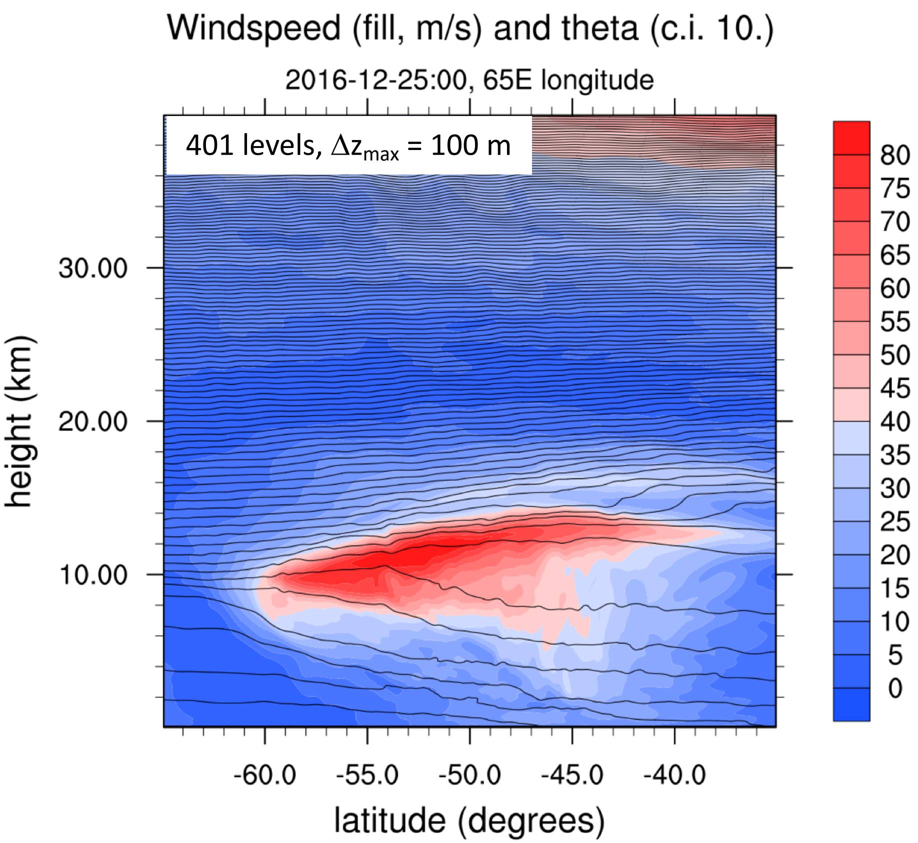
z=10/24 km
spectra shifted 2 decades
down/up
for clarity



Baroclinic waves







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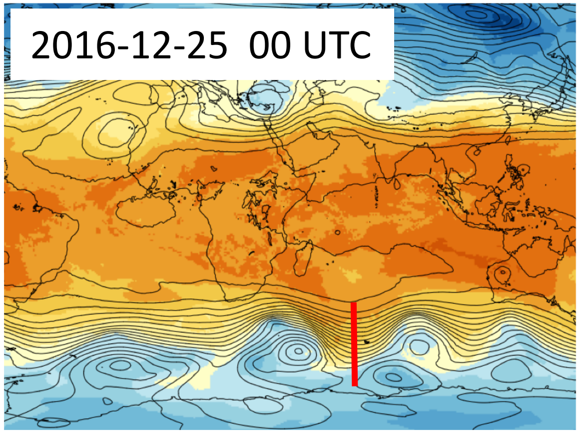
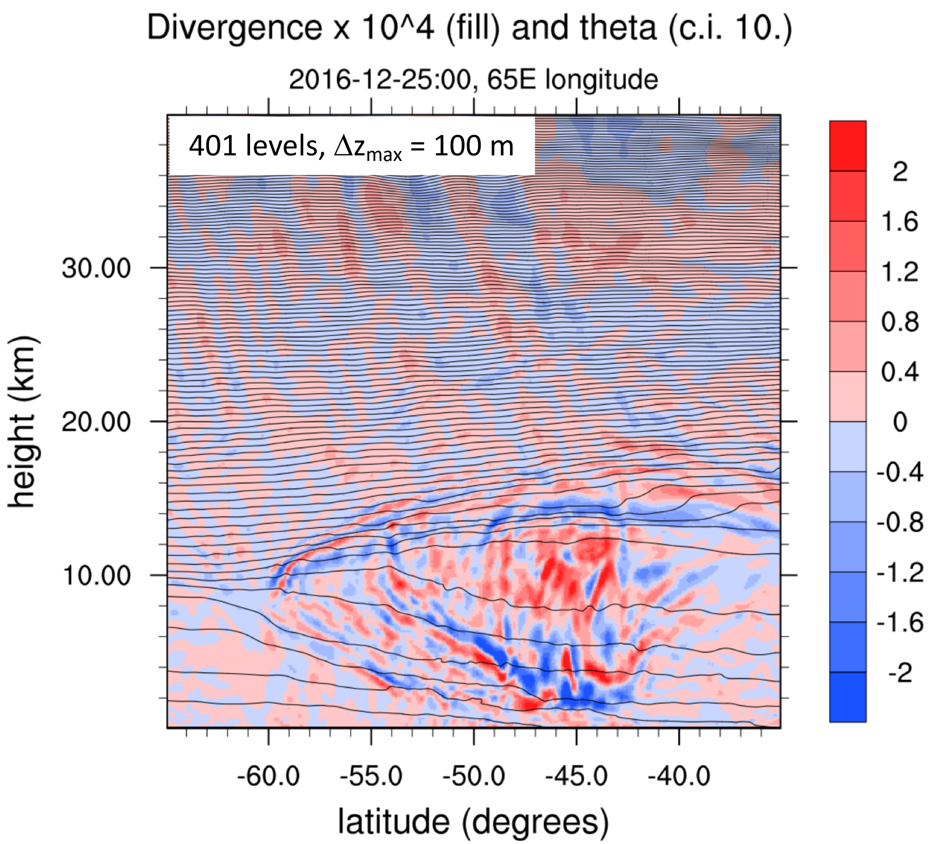
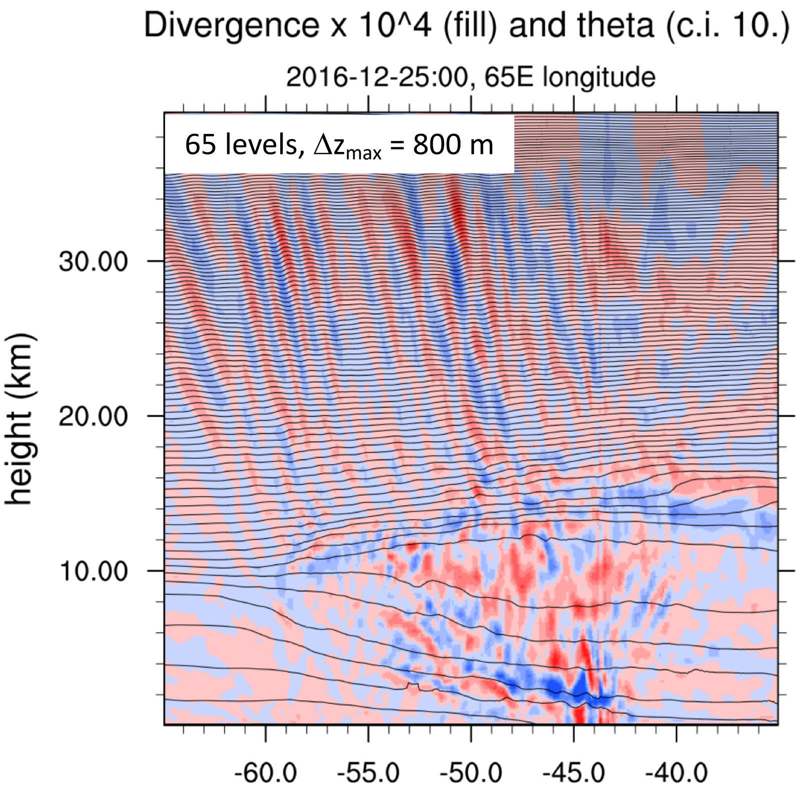
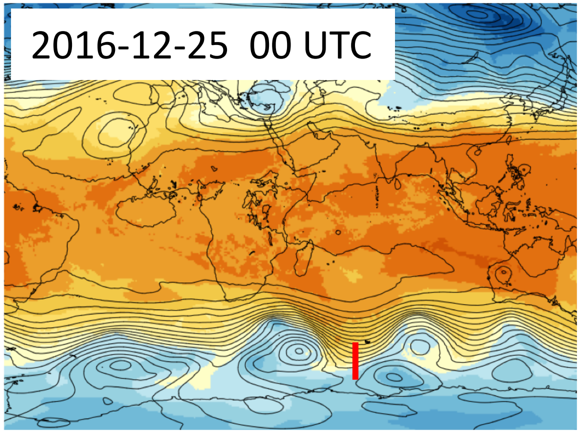
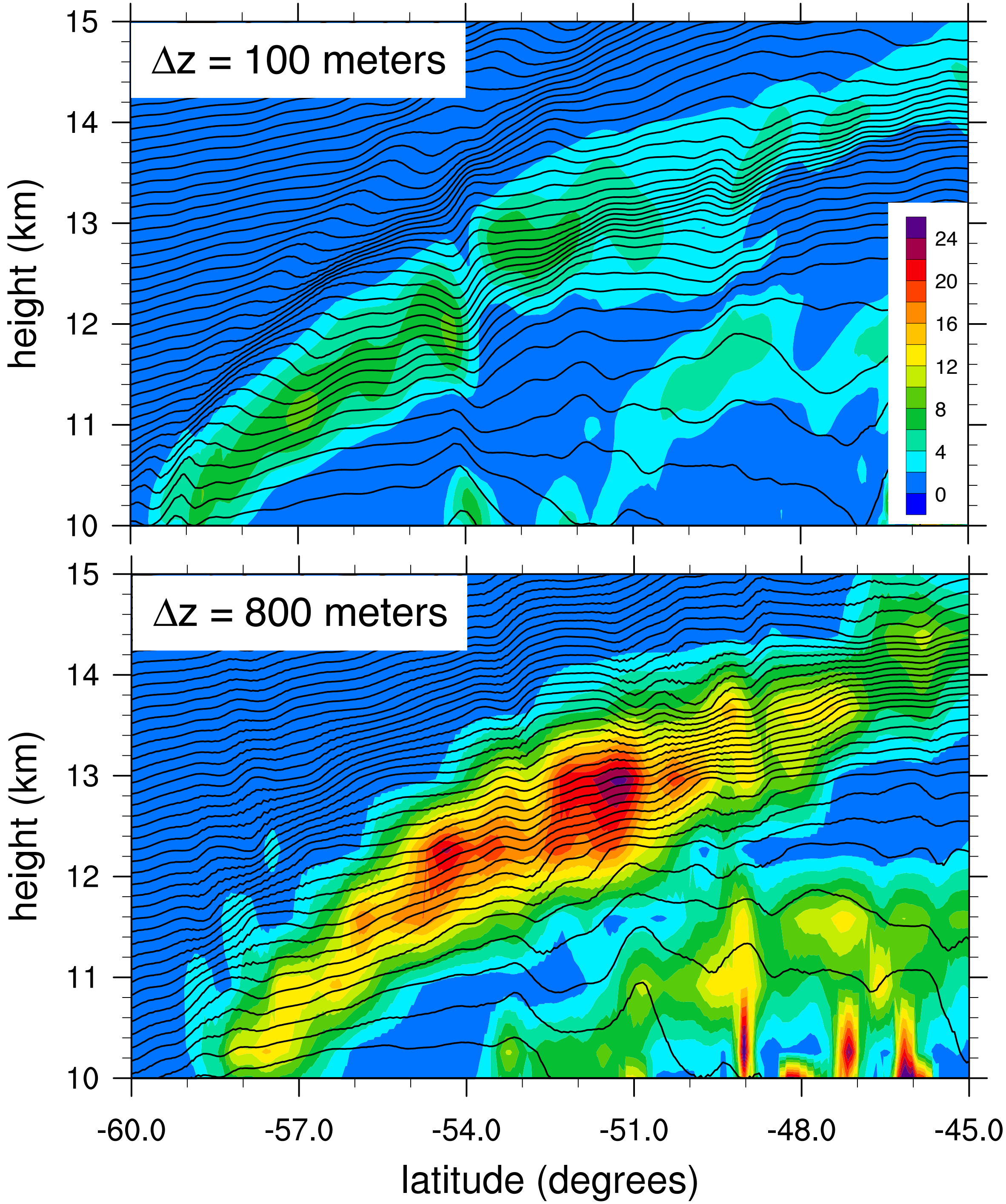




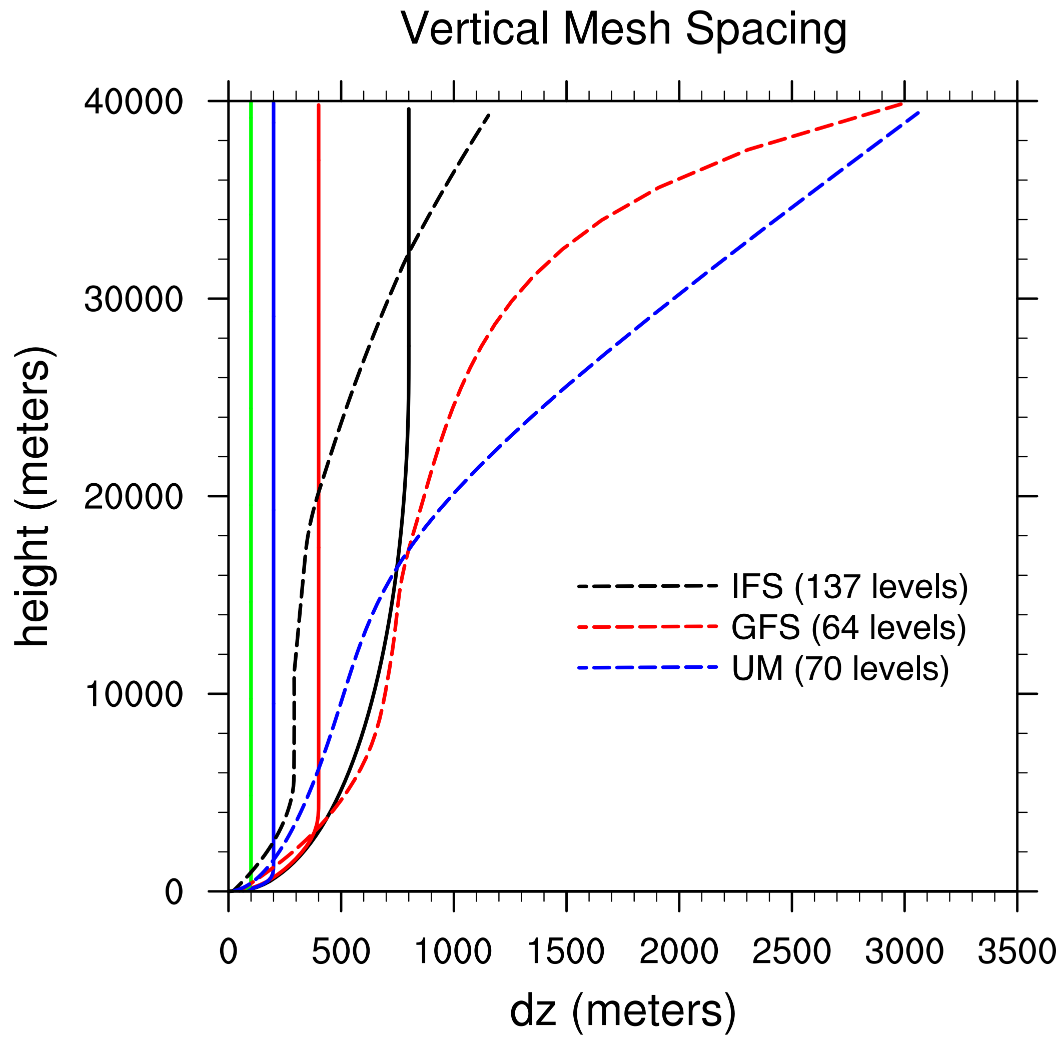






YSU PBL:
eddy viscosity for momentum
K_m (m^2/s) (color),
potential temperature
(c.i. = 2 K)

Vertical Meshes for Applications



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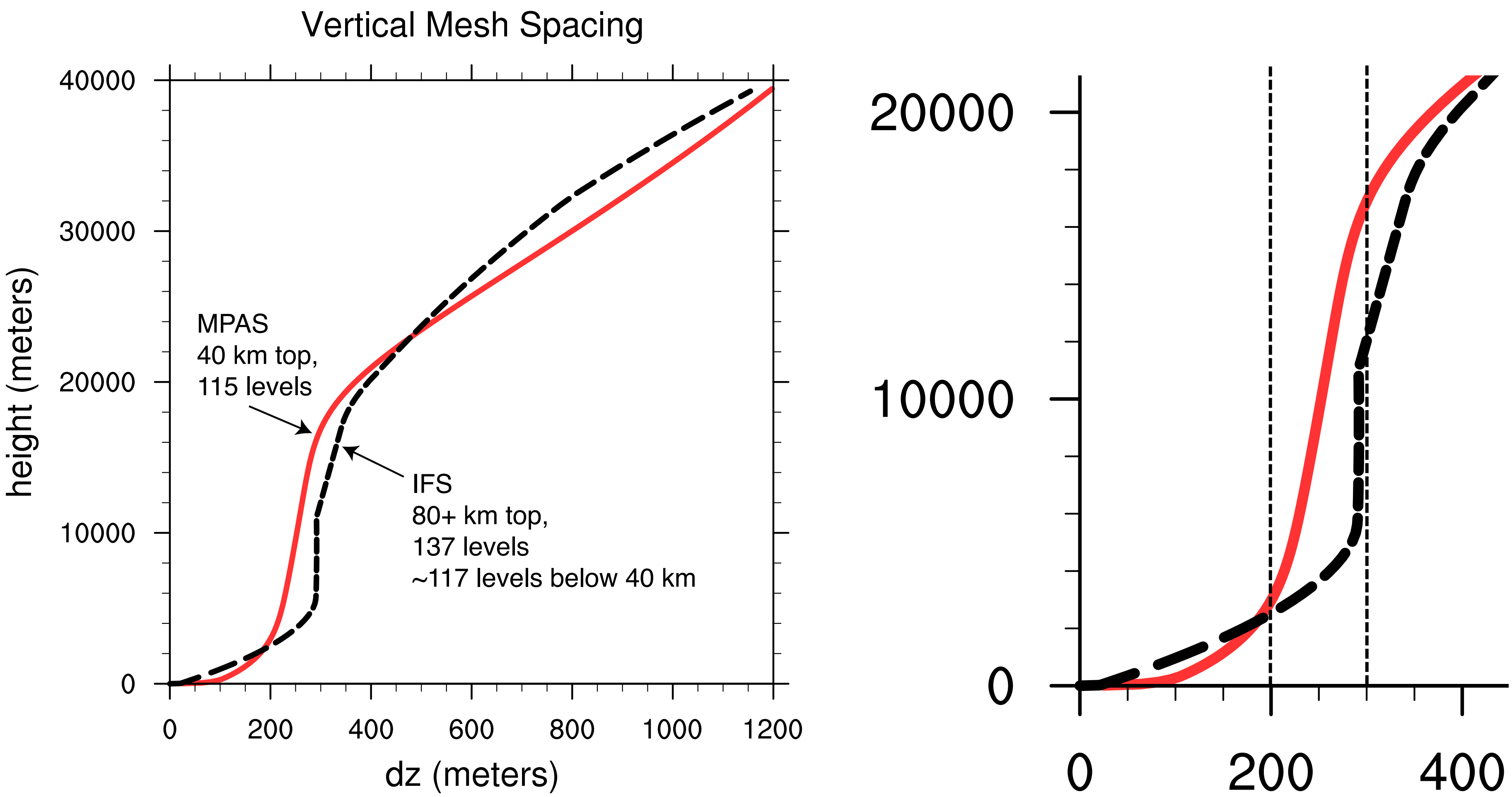
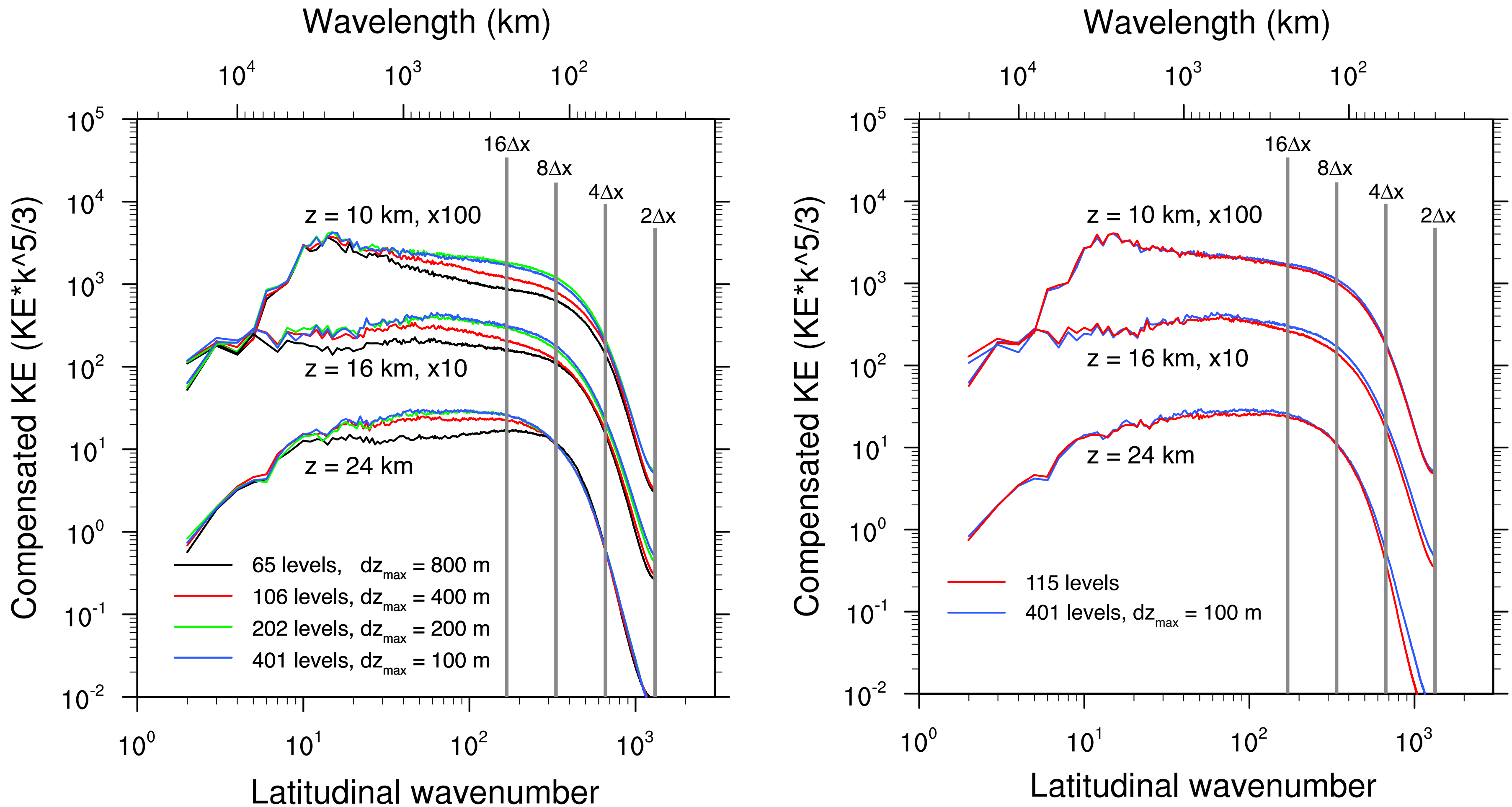


KE Spectra Convergence

Divergent component of the KE
2016-12-20 – 2016-12-27 forecast
Average over days 6 and 7



4^{th}-Order Filter Configuration

Horizonal momentum dissipation

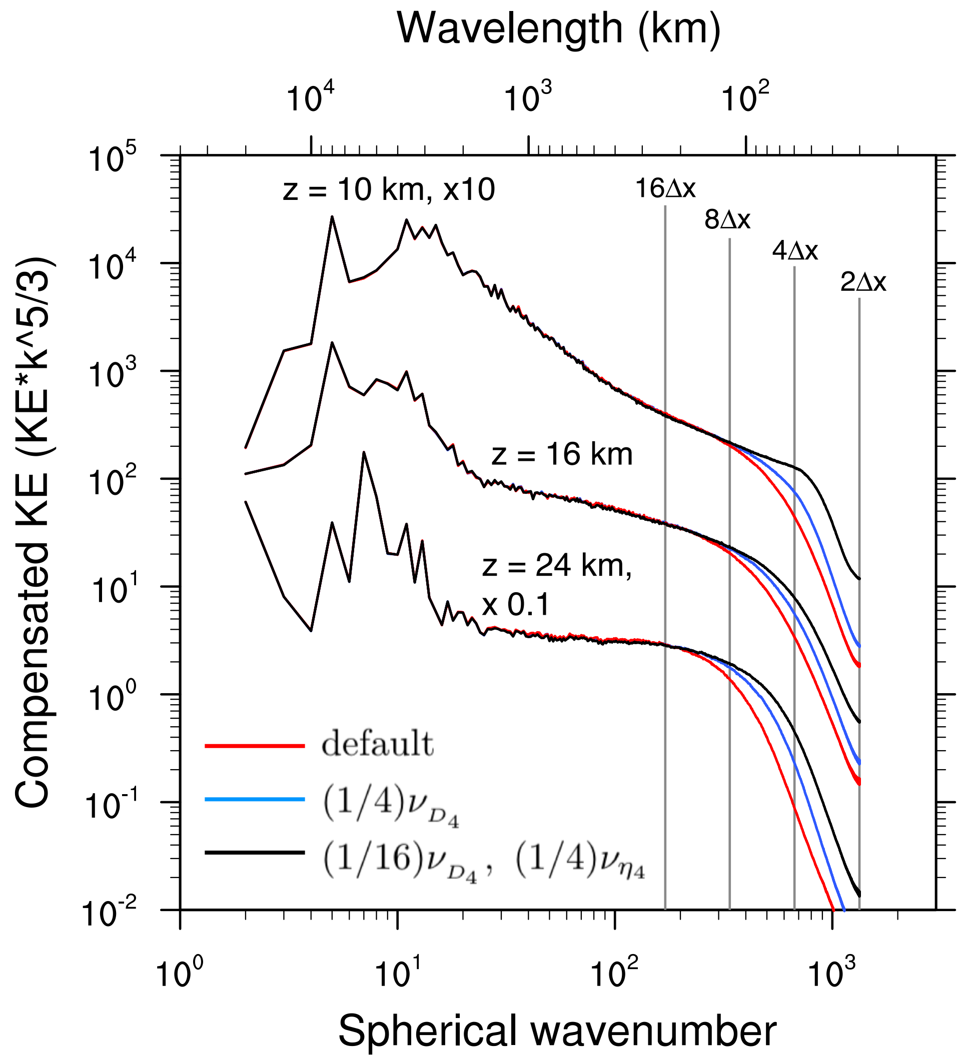
$$\nu_2 \nabla_\zeta^2 u_i \rightarrow \nu_D \frac{\partial}{\partial x_i} \nabla_\zeta \cdot \mathbf{v} - \nu_\eta \frac{\partial \eta}{\partial x_j}$$

$$\nabla_\zeta^4 u_i = \nabla_\zeta^2 \left(\nabla_\zeta^2 u_i \right)$$

Default hyperviscosity values for MPAS-Atmosphere 15 km mesh

$$\nu_{D_4} = 1.675 \times 10^{12}\, \mathrm{m}^4 \mathrm{s}^{-1}$$
$$\nu_{\eta_4} = 1.675 \times 10^{11}\, \mathrm{m}^4 \mathrm{s}^{-1}$$

KE, Total Energy



4th-Order Filter Configuration

$$\nu_2 \nabla^2_\zeta u_i \rightarrow \nu_D \frac{\partial}{\partial x_i} \nabla_\zeta \cdot \mathbf{v} - \nu_\eta \frac{\partial \eta}{\partial x_j}$$

$$\nabla^4_\zeta u_i = \nabla^2_\zeta \left(\nabla^2_\zeta u_i \right)$$

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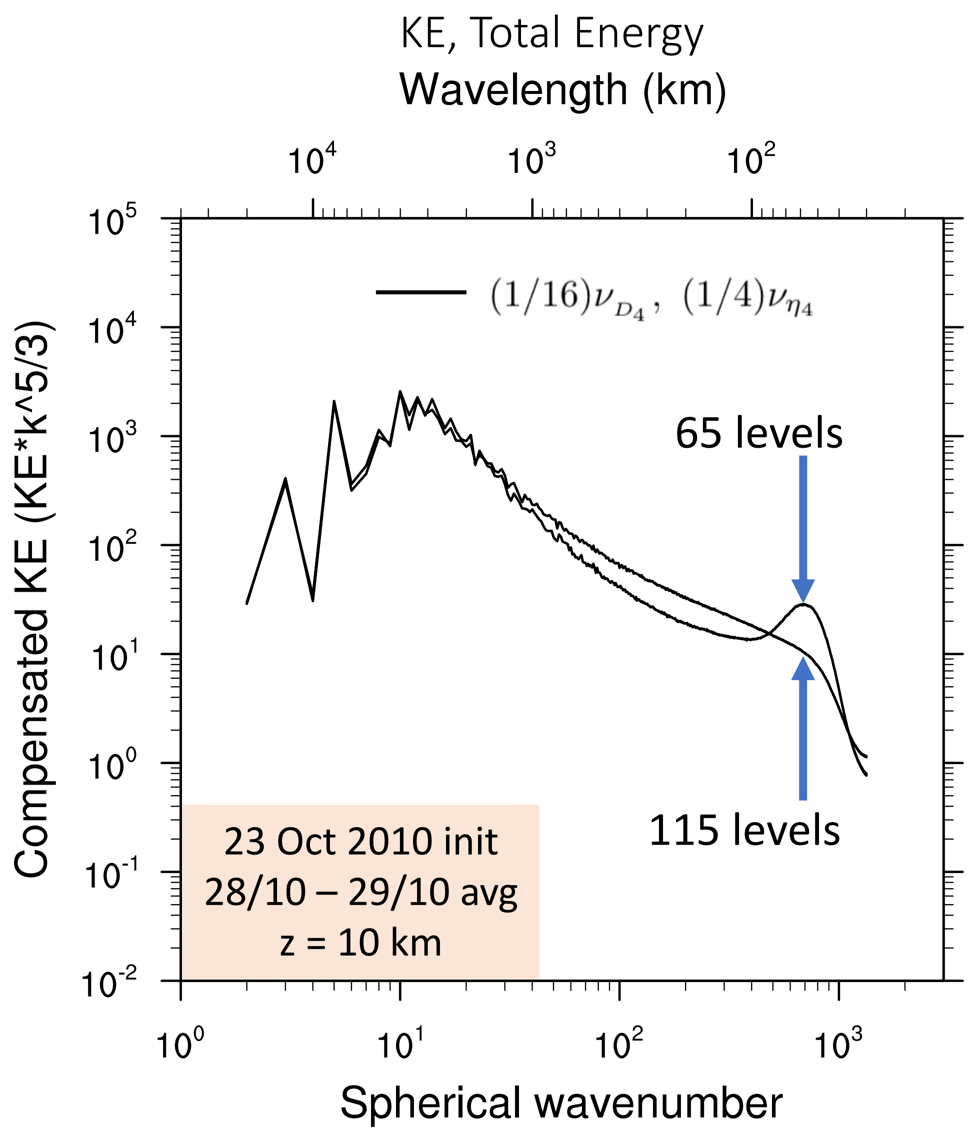
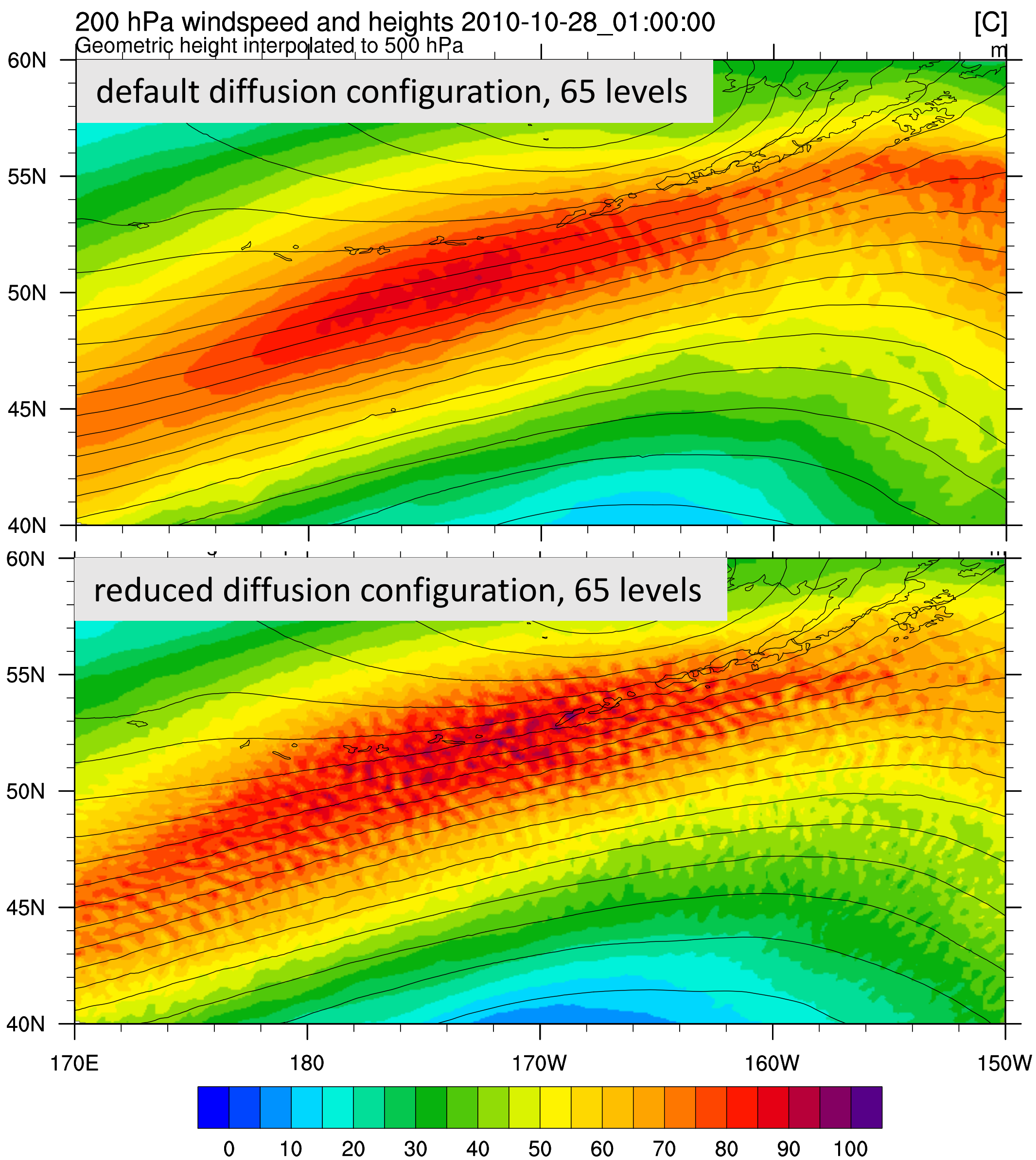


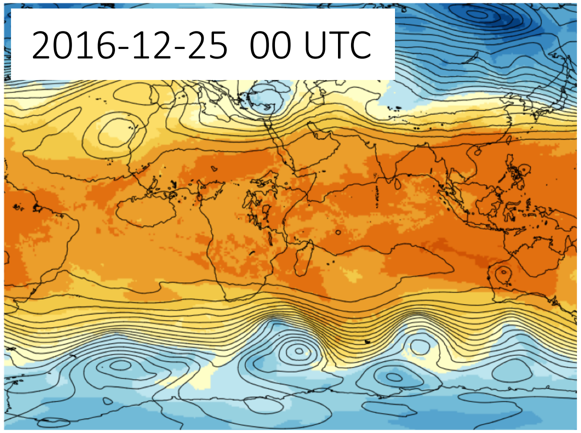
4th-Order Filter Configuration



Reducing the horizontal diffusion in the 65-level MPAS configuration leads to unacceptable noise in the jets in regions of strong winds and strong wind shear.

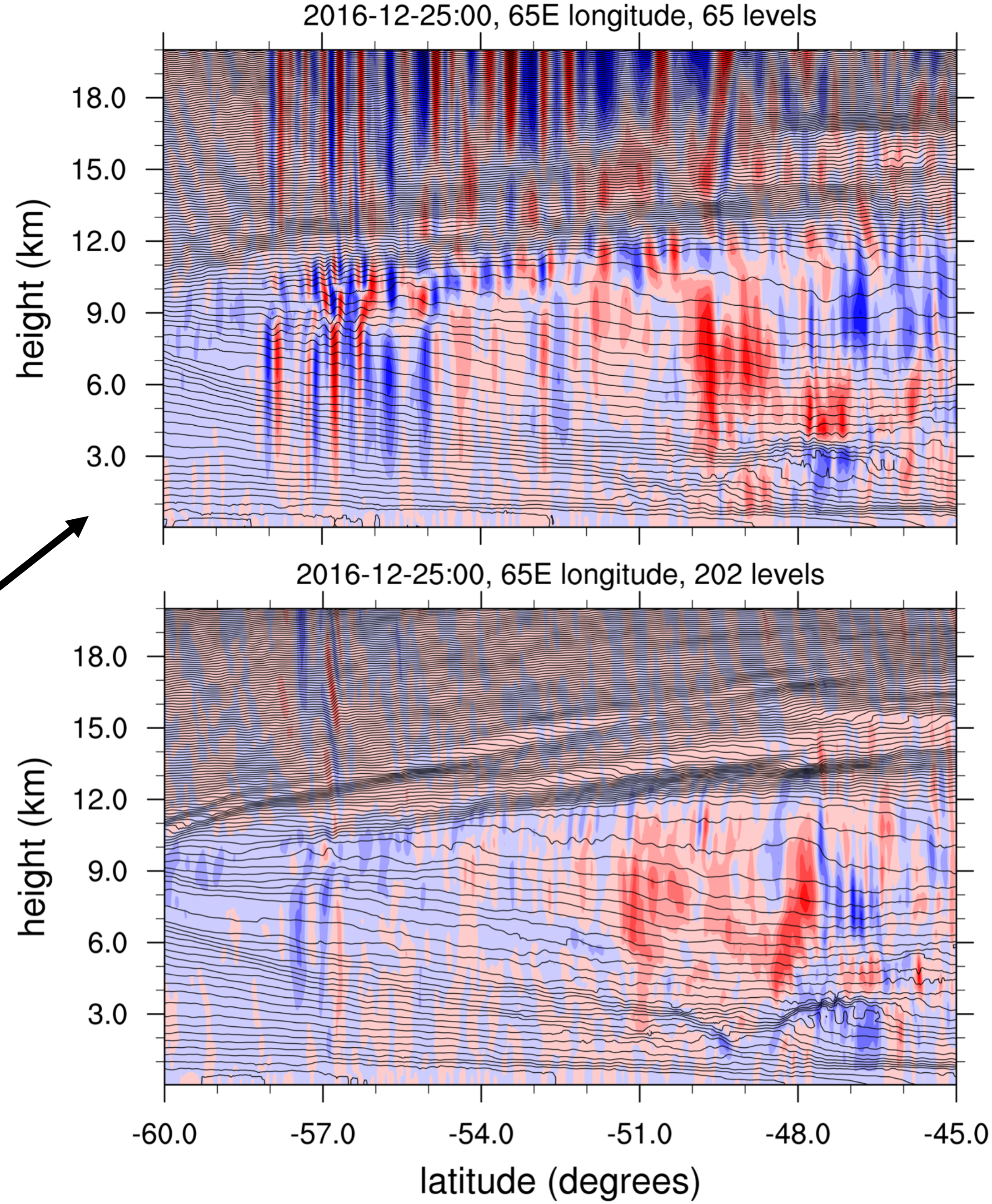
The reduced horizontal diffusion in the 115-level configuration produces acceptable levels of small-scale structure in the jets and increased effective resolution as indicated in KE spectra.

Based on the KE spectra, the 115 level configuration is more efficient than the 65 level configuration.



15-3 km mesh centered over the ridge

w (m/s, fill) and theta (c.i. 2.)



Default MPAS configuration

Dz < = 200 m configuration

Summary

- Δz approx. 200-300 meters is required for solution convergence at Δx = 15 km.
- Increasing vertical resolution allows for reduced horizontal filtering, increased effective resolution, and more efficient modeling.
- Preliminary results suggests Δz = 200 meters is adequate at Δx = 3 km (CAM mesh spacing).
- Vertical resolution: Does it matter for most NWP forecast metrics?