Vertical resolution, energetics and dissipation in high-resolution atmospheric simulations

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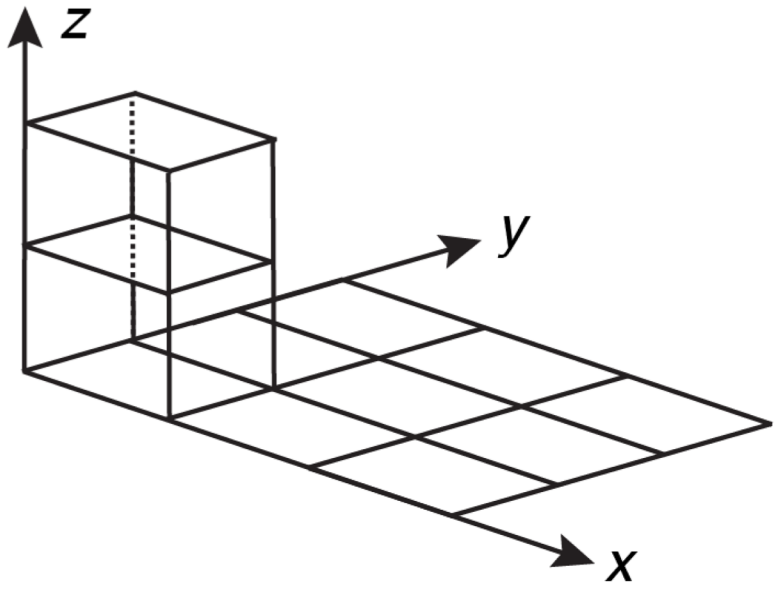
Resolution in Atmospheric Models

Horizontal grid spacing has decreased dramatically in the last several decades
($\Delta x \sim O(100)$ km to $\Delta x \sim O(10)$ km)

Vertical grid spacing has not decreased at a similar rate.

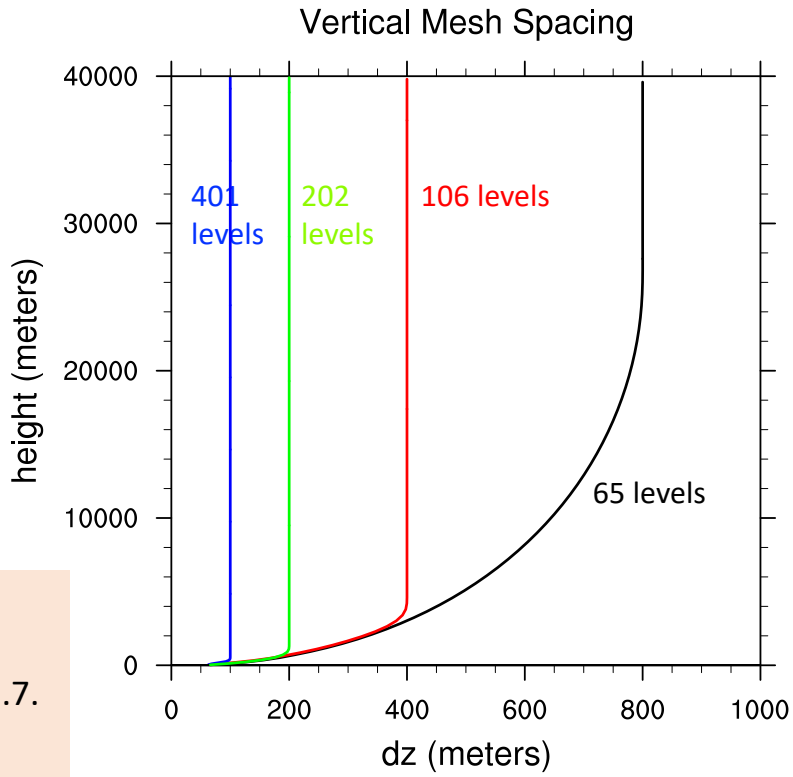
Is this appropriate?

One norm (or metric) to consider:
Kinetic energy



Numerical Tests – Configurations

- Global MPAS
- 7-day forecasts initialized 2016-12-20 and 2016-07-03
- Uniform 15 km global mesh (2.62 x 10^6 columns)
- 40 km model top, 4 different vertical meshes with 65, 106, 202 and 401 levels.

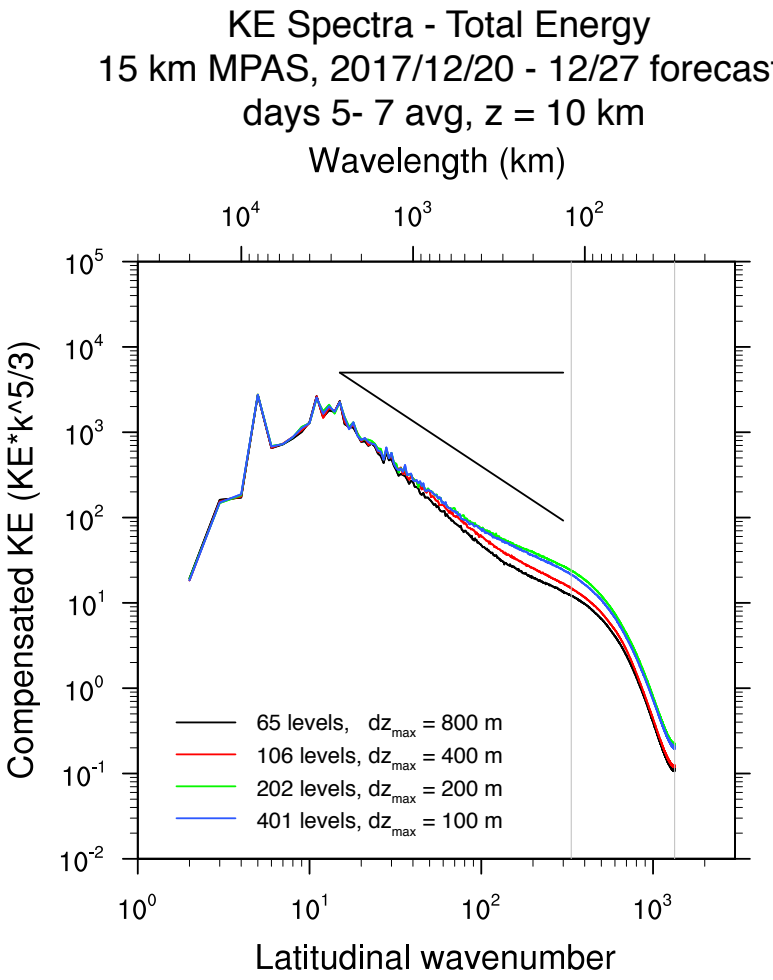


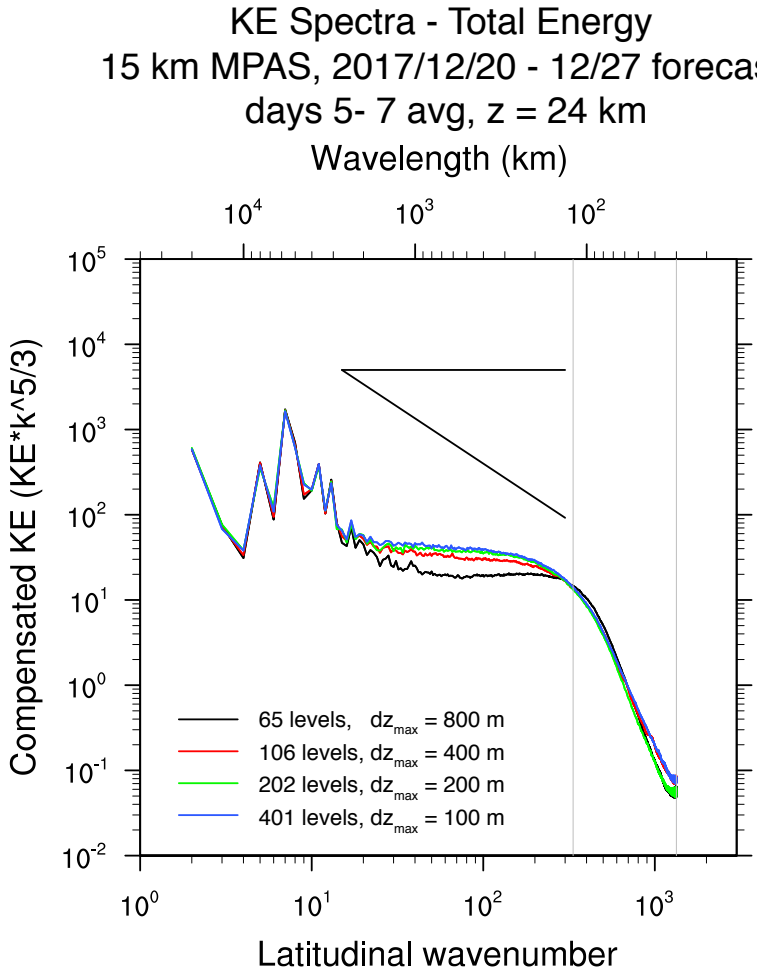
Mesoscale reference physics suite – MPAS V5.0

Surface Layer: (Monin Obukhov): module_sf_sfclay.F 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 as in WRF 3.4.1; RRTMG lw as in WRF 3.4.1
Ocean Mixed Layer: modified from WRFV3.6

Forecast KE spectra convergence

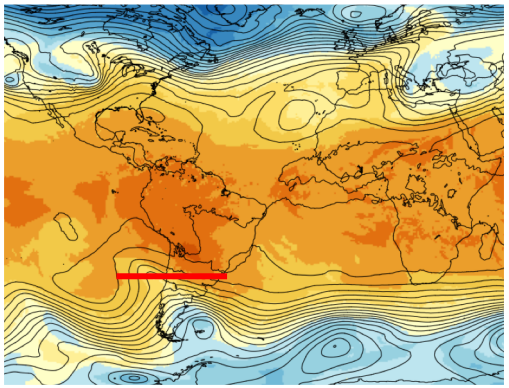
KE spectra at z = 10 and 24 km, hourly spectra averaged over 2 days

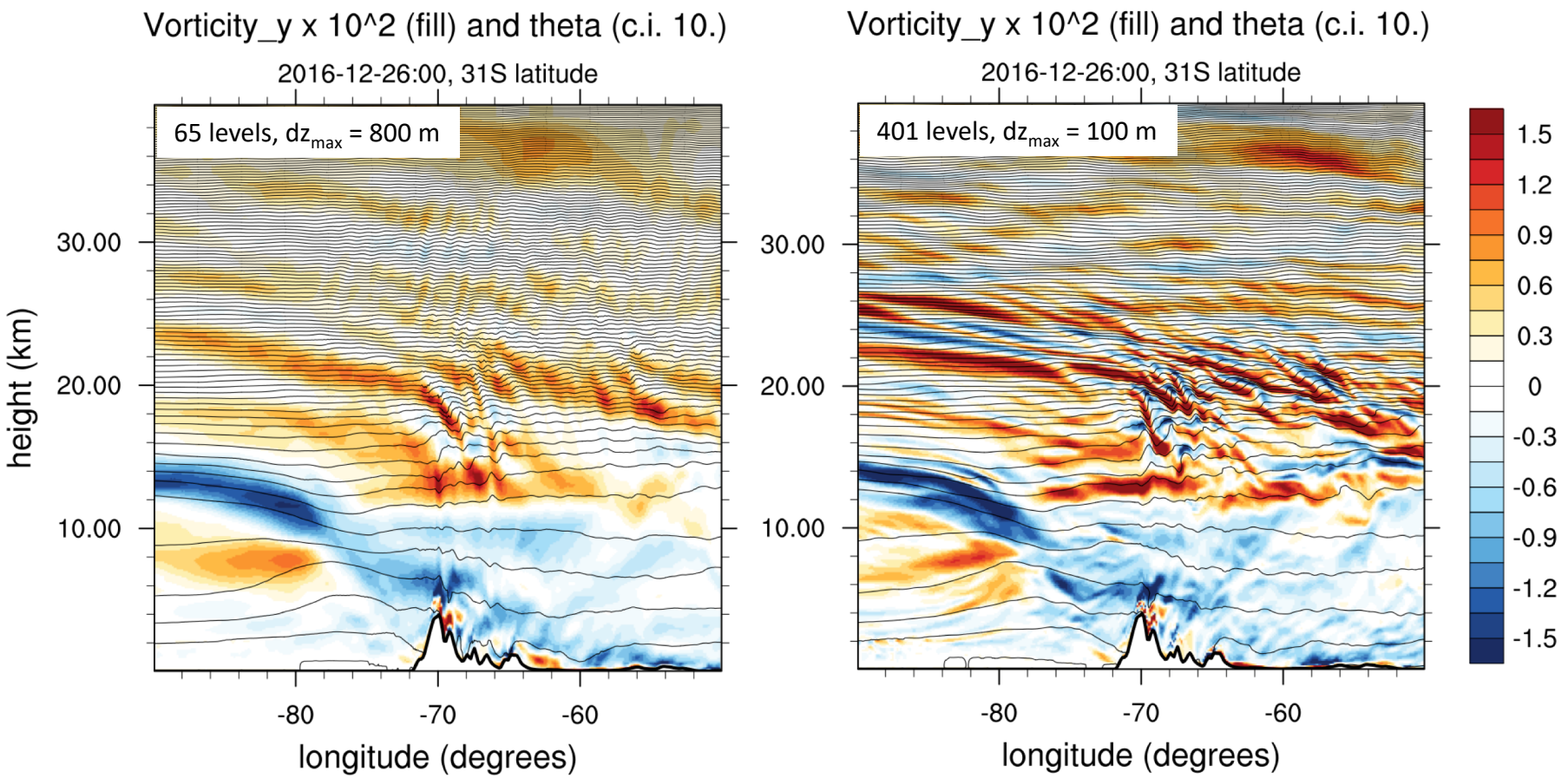


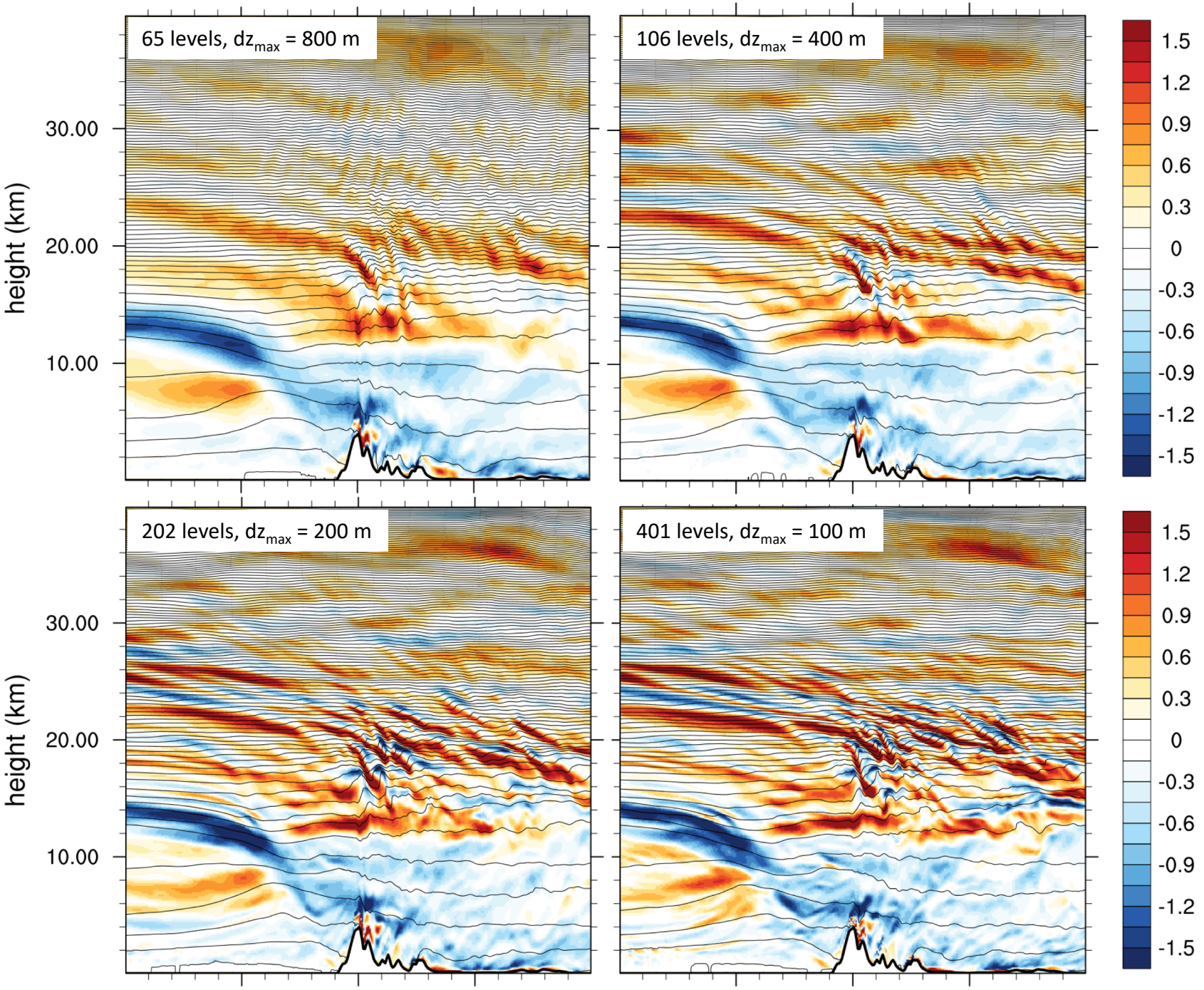


Mountain waves in South America

2016-12-26 00 UTC

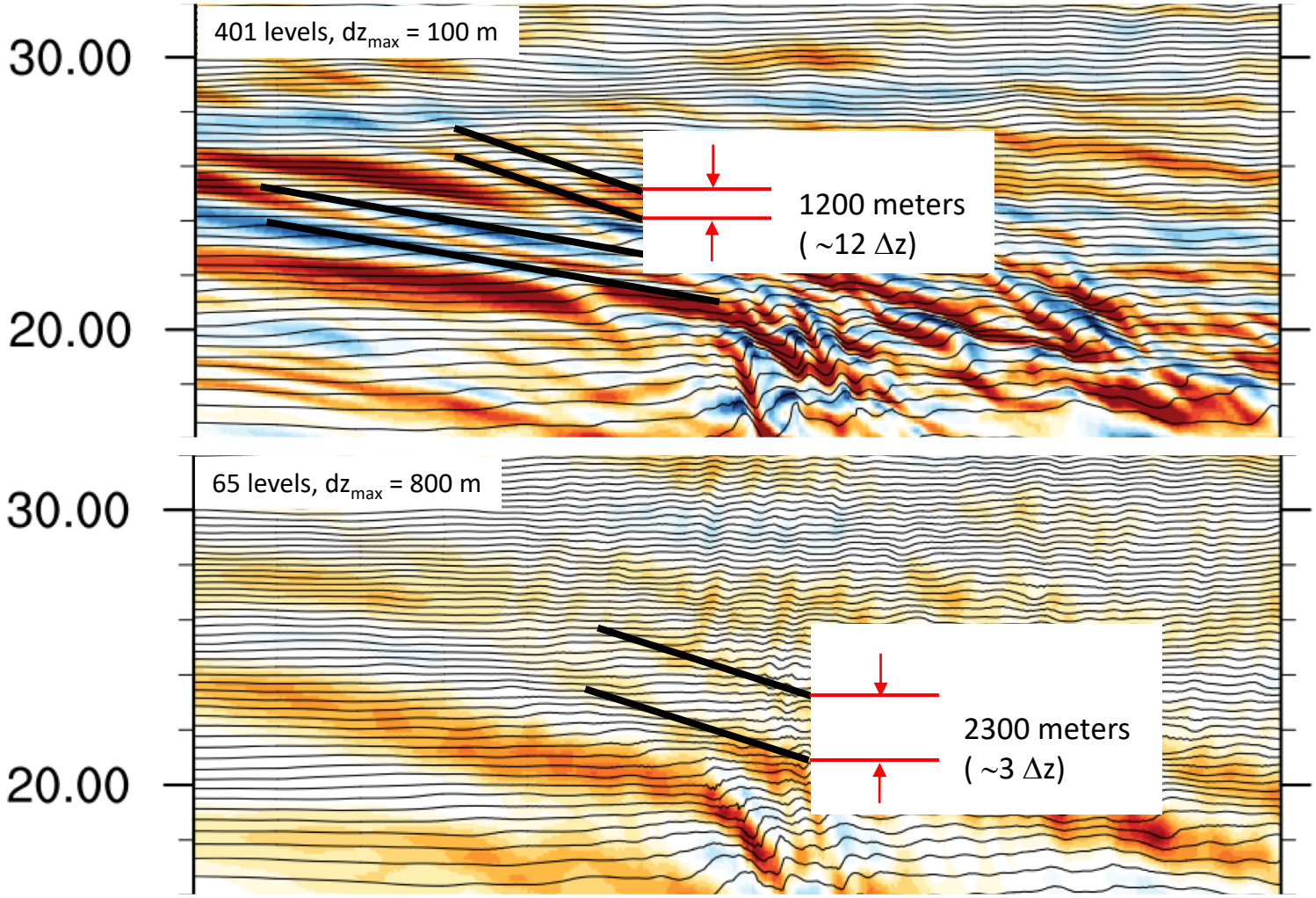





65 levels, dz$_{max}$ = 800 m
106 levels, dz$_{max}$ = 400 m
202 levels, dz$_{max}$ = 200 m
401 levels, dz$_{max}$ = 100 m
height (km)
30.00
20.00
10.00
1.5
1.2
0.9
0.6
0.3
0
-0.3
-0.6
-0.9
-1.2
-1.5

Mountain waves in South America

Vertical resolution…



Mountain waves in South America

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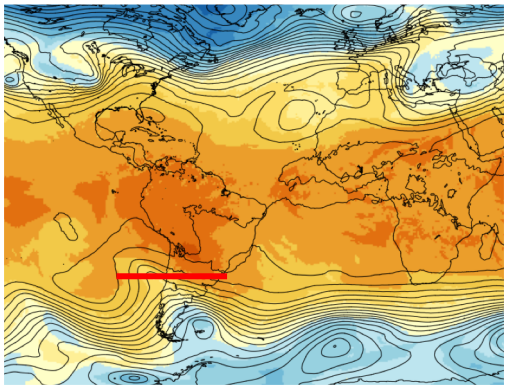

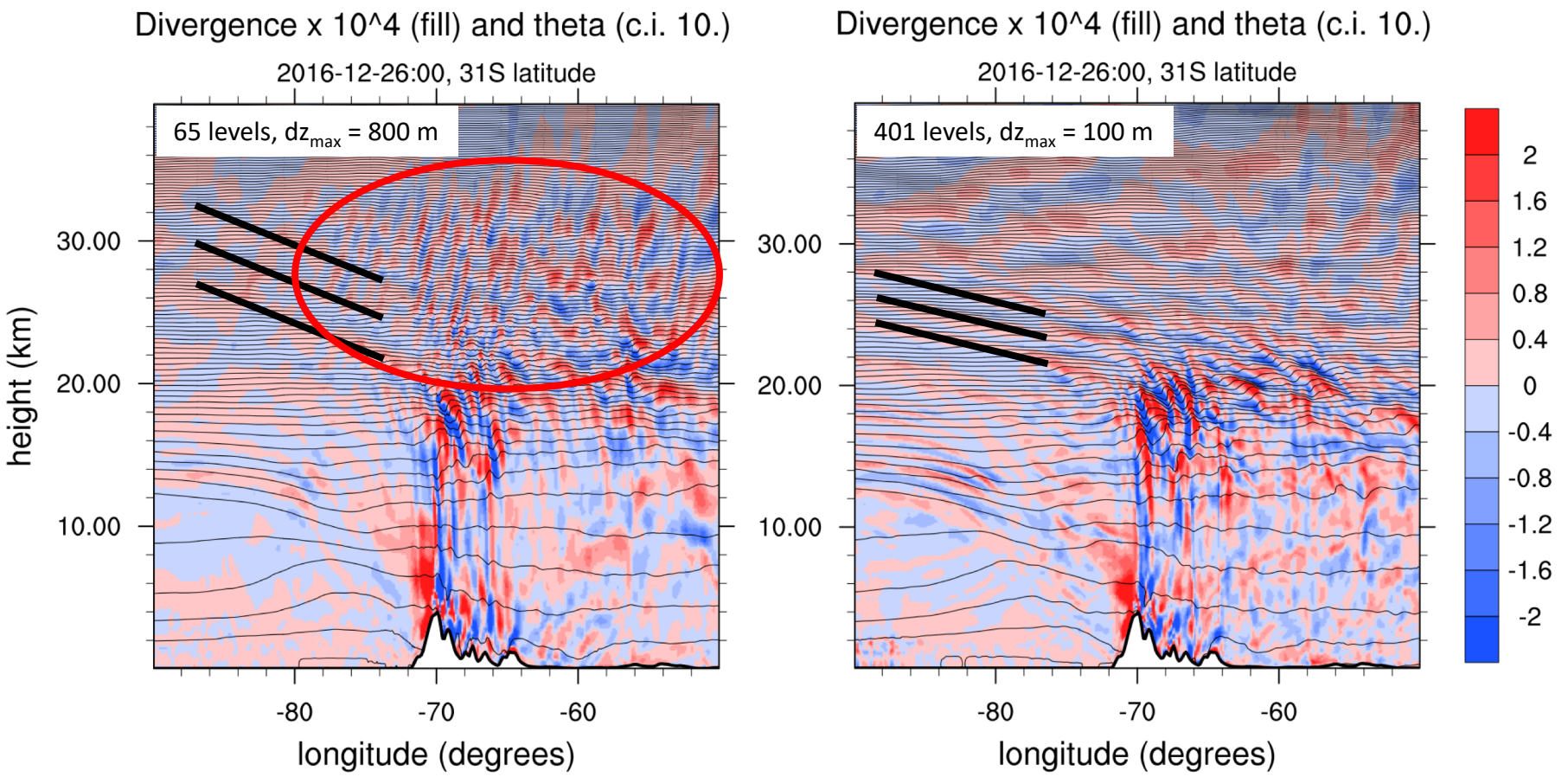

Mountain waves in South America

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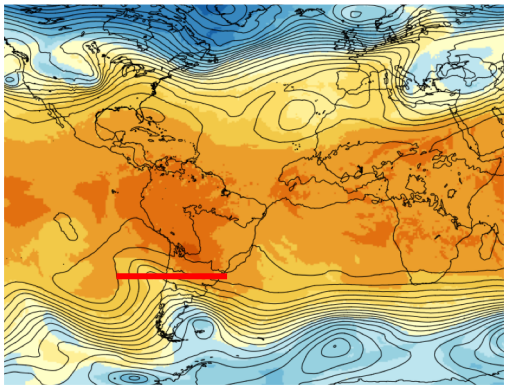
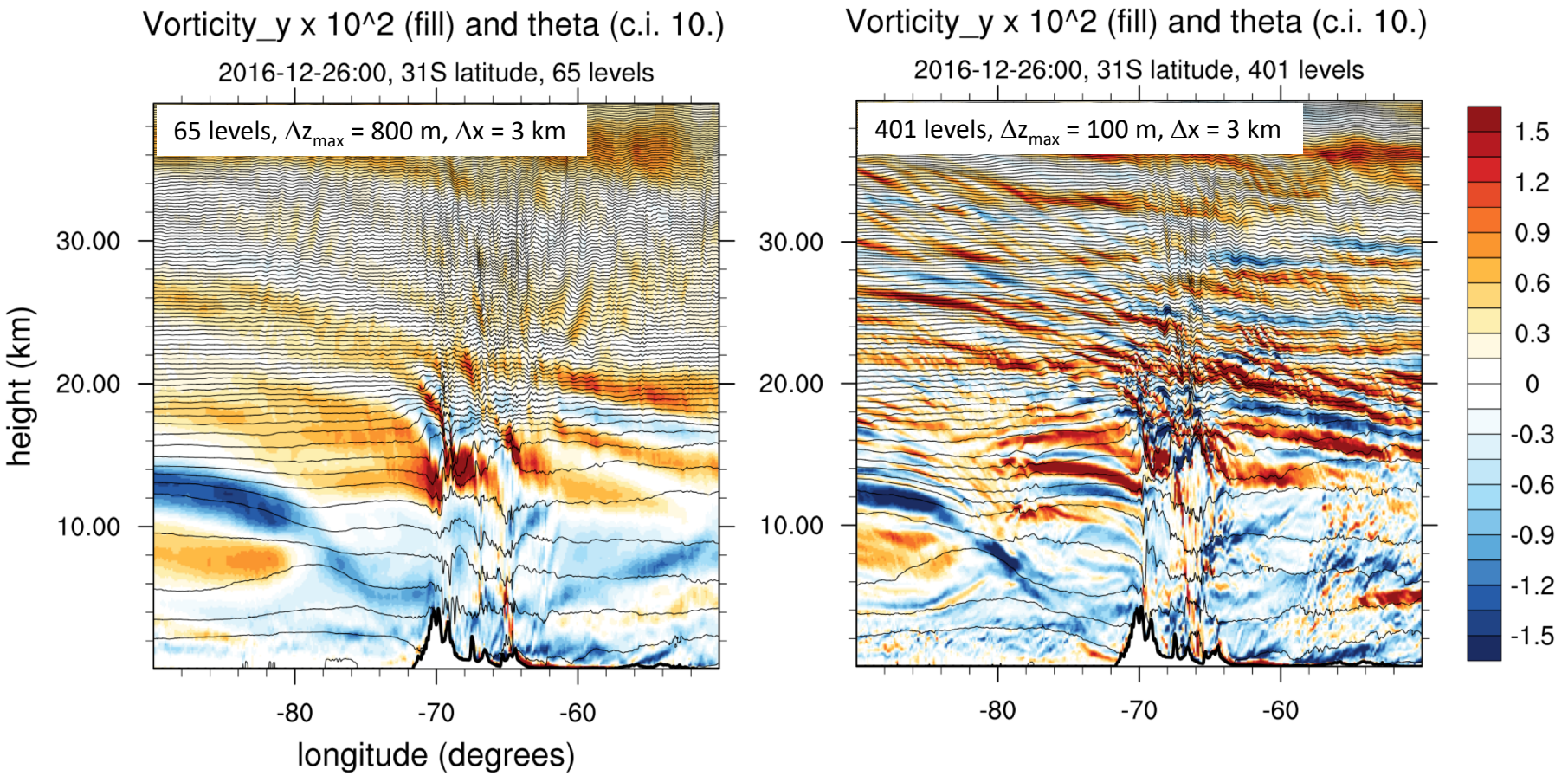
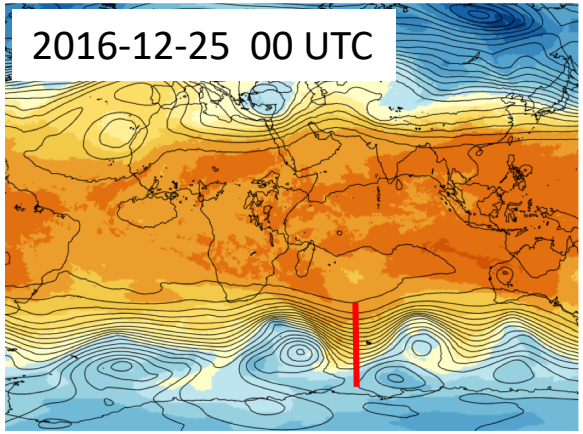
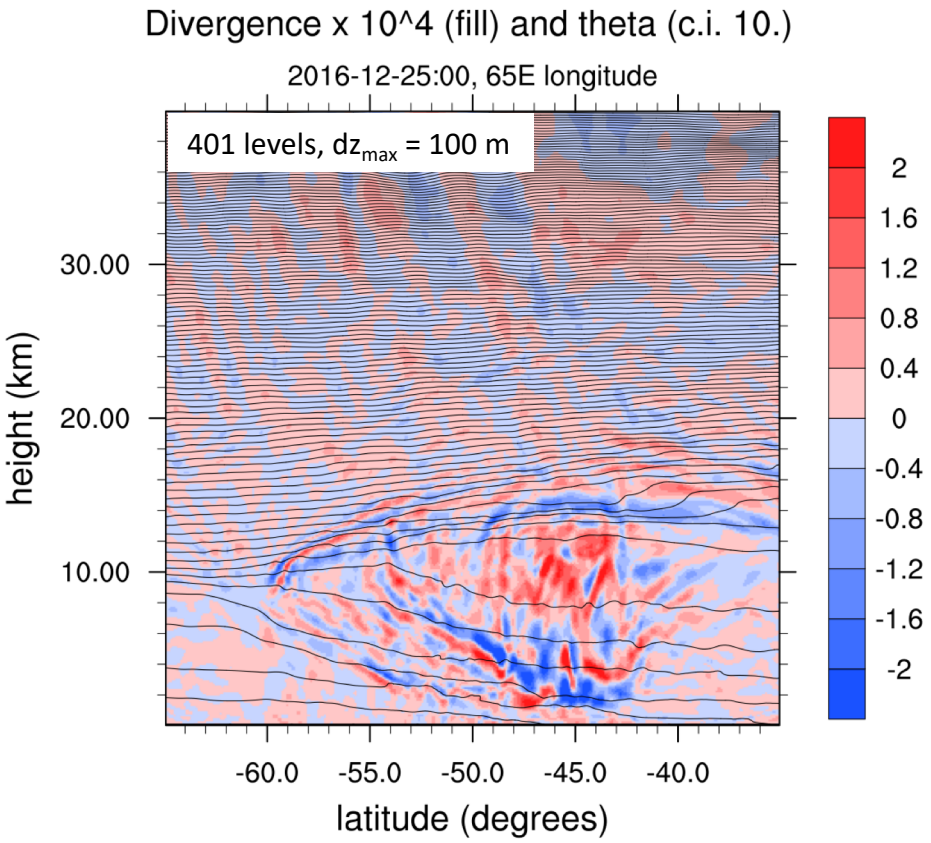
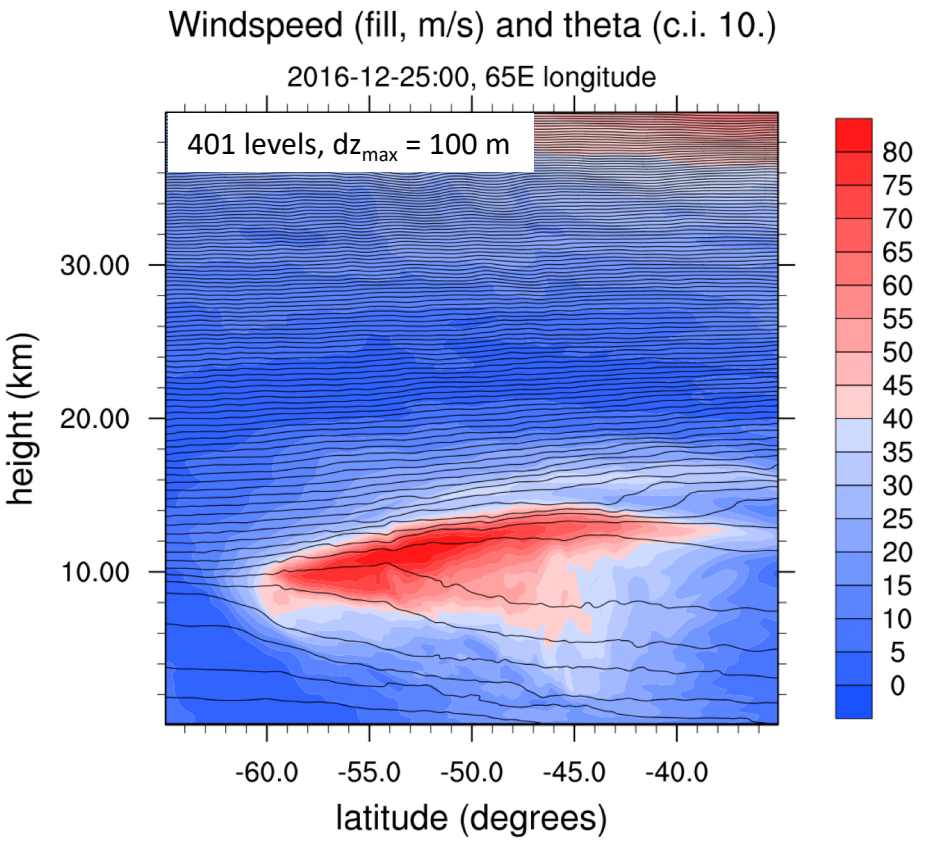


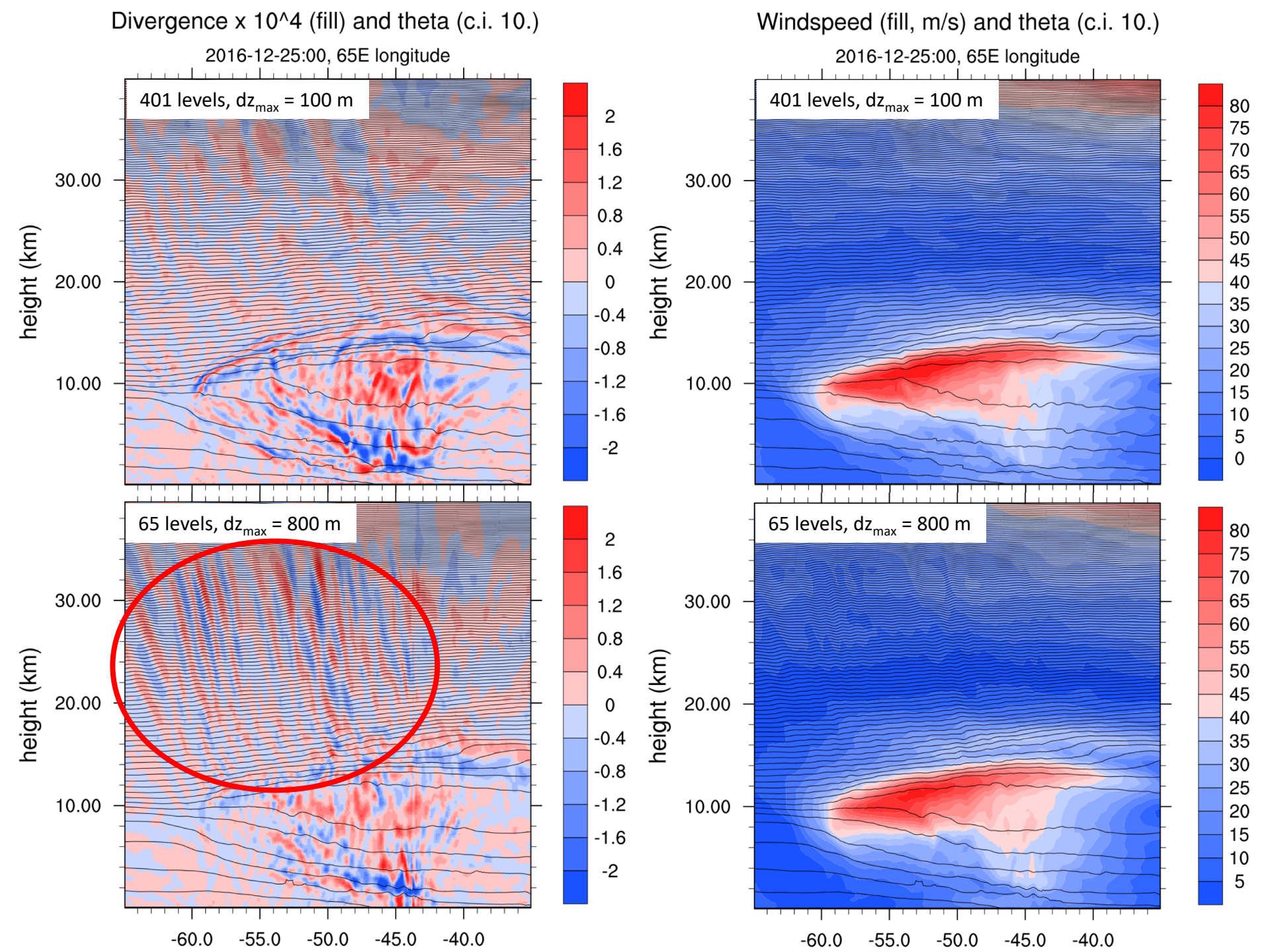


Baroclinic waves

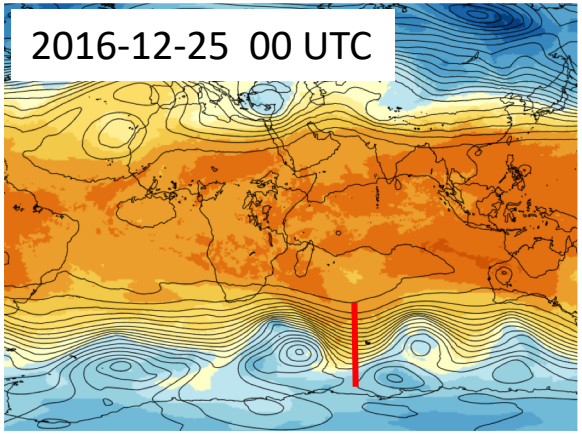


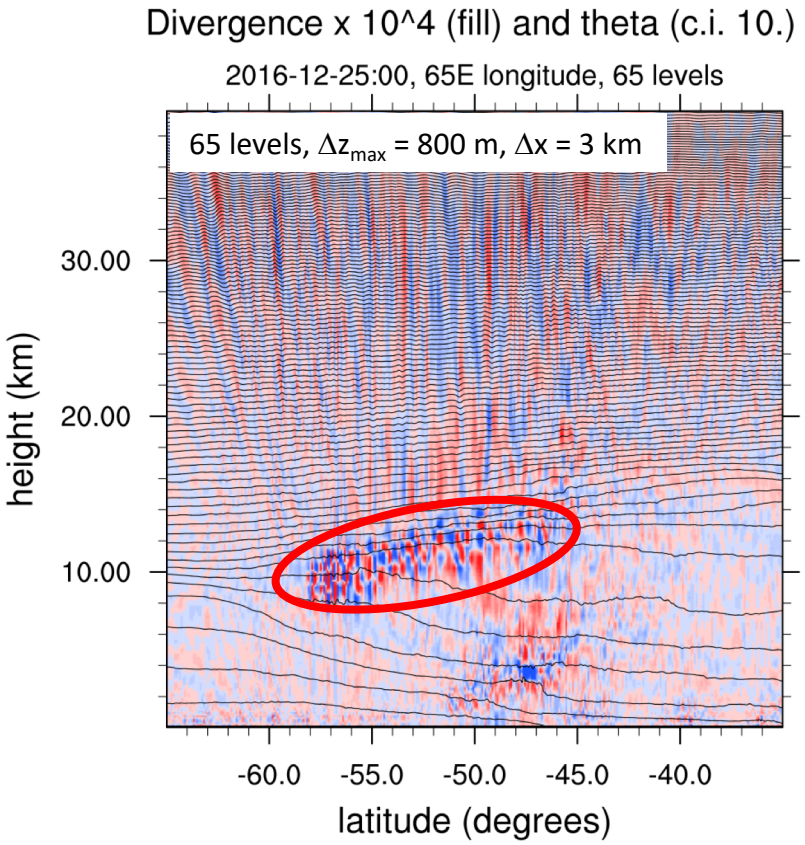


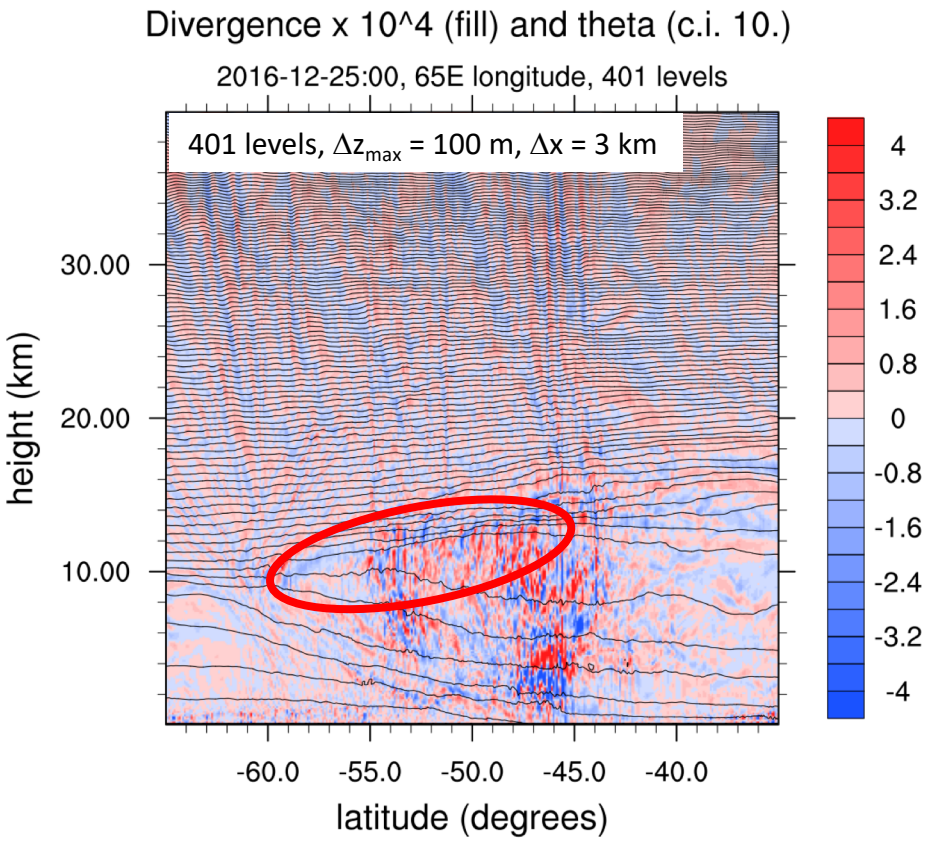



Divergence x 10^4 (fill) and theta (c.i. 10.)
2016-12-25:00, 65E longitude
401 levels, dz$_{max}$ = 100 m
65 levels, dz$_{max}$ = 800 m
height (km)
30.00
20.00
10.00
2
1.6
1.2
0.8
0.4
0
-0.4
-0.8
-1.2
-1.6
-2
-60.0
-55.0
-50.0
-45.0
-40.0
Windspeed (fill, m/s) and theta (c.i. 10.)
2016-12-25:00, 65E longitude
401 levels, dz$_{max}$ = 100 m
65 levels, dz$_{max}$ = 800 m
height (km)
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0

Baroclinic waves

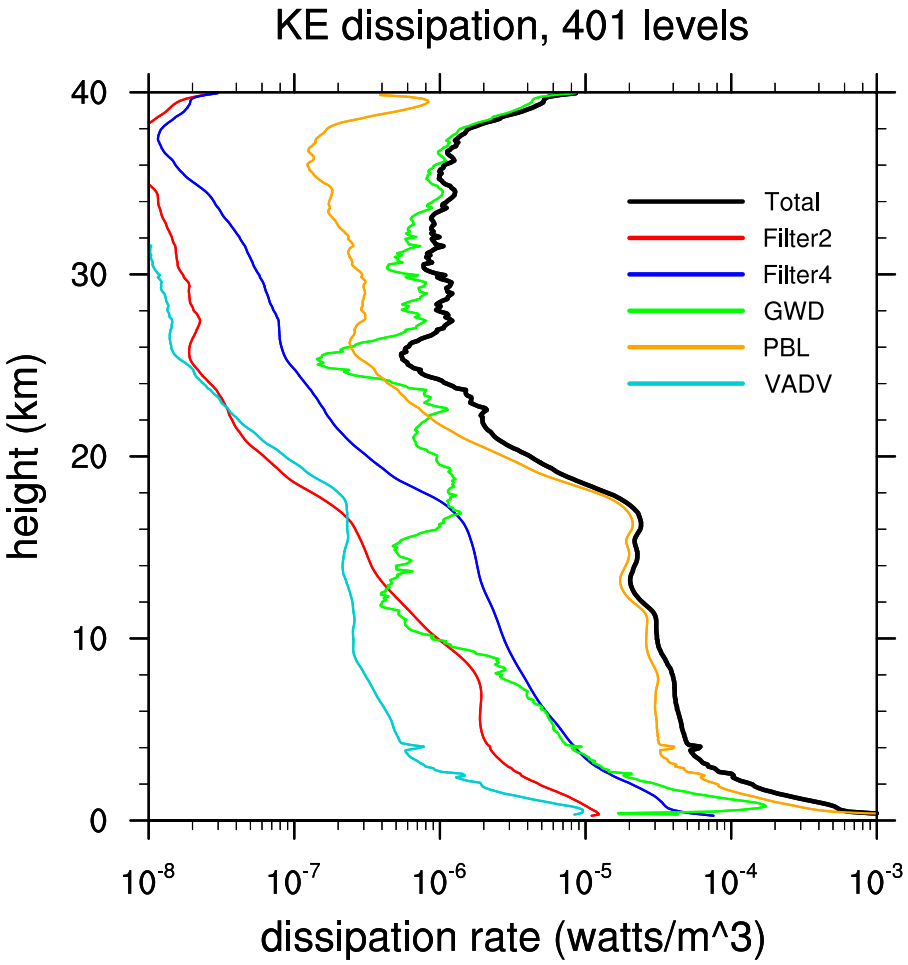






Horizontally-Averaged KE Dissipation

2016-12-20 simulation, horizontal average over model surfaces, forecast days 6 and 7

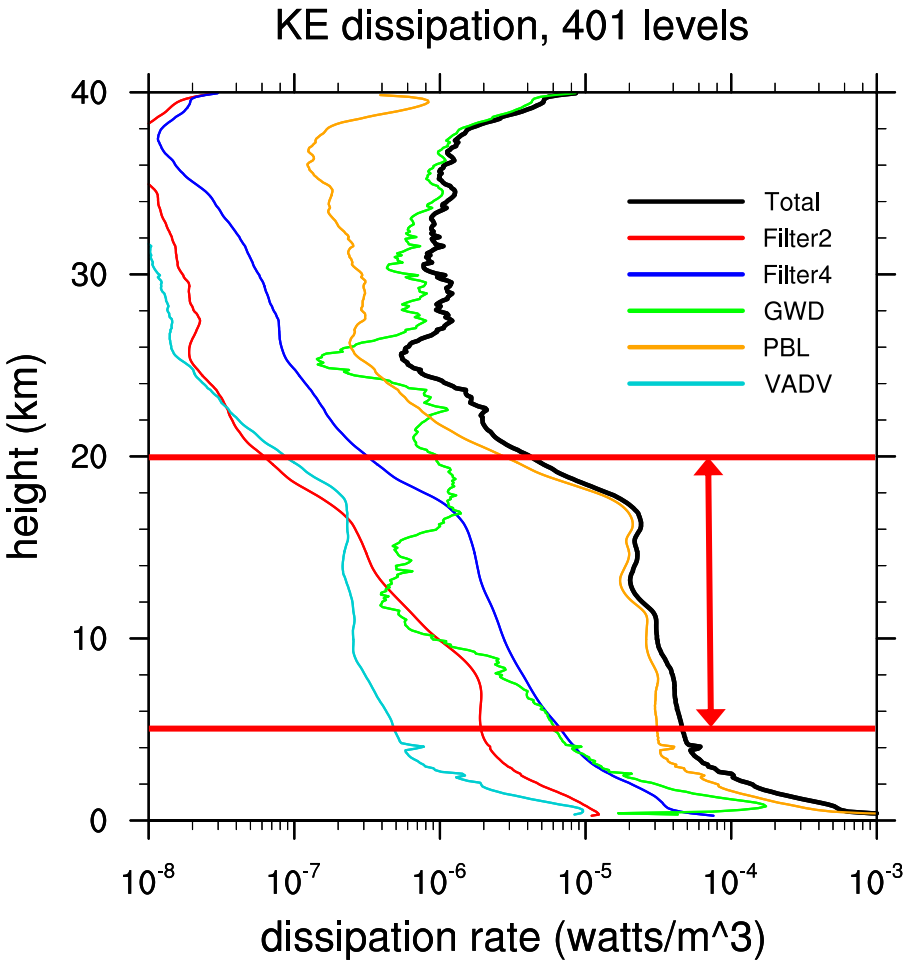


Mechanisms in MPAS that dissipate kinetic energy

- 2^{nd}-order horz. Smagorinsky
- 4^{th}-order horz. Filter
- Vertical advection
- Gravity-wave drag
- YSU PBL scheme
- Total

Horizontally-Averaged KE Dissipation

2016-12-20 simulation, horizontal average over model surfaces, forecast days 6 and 7



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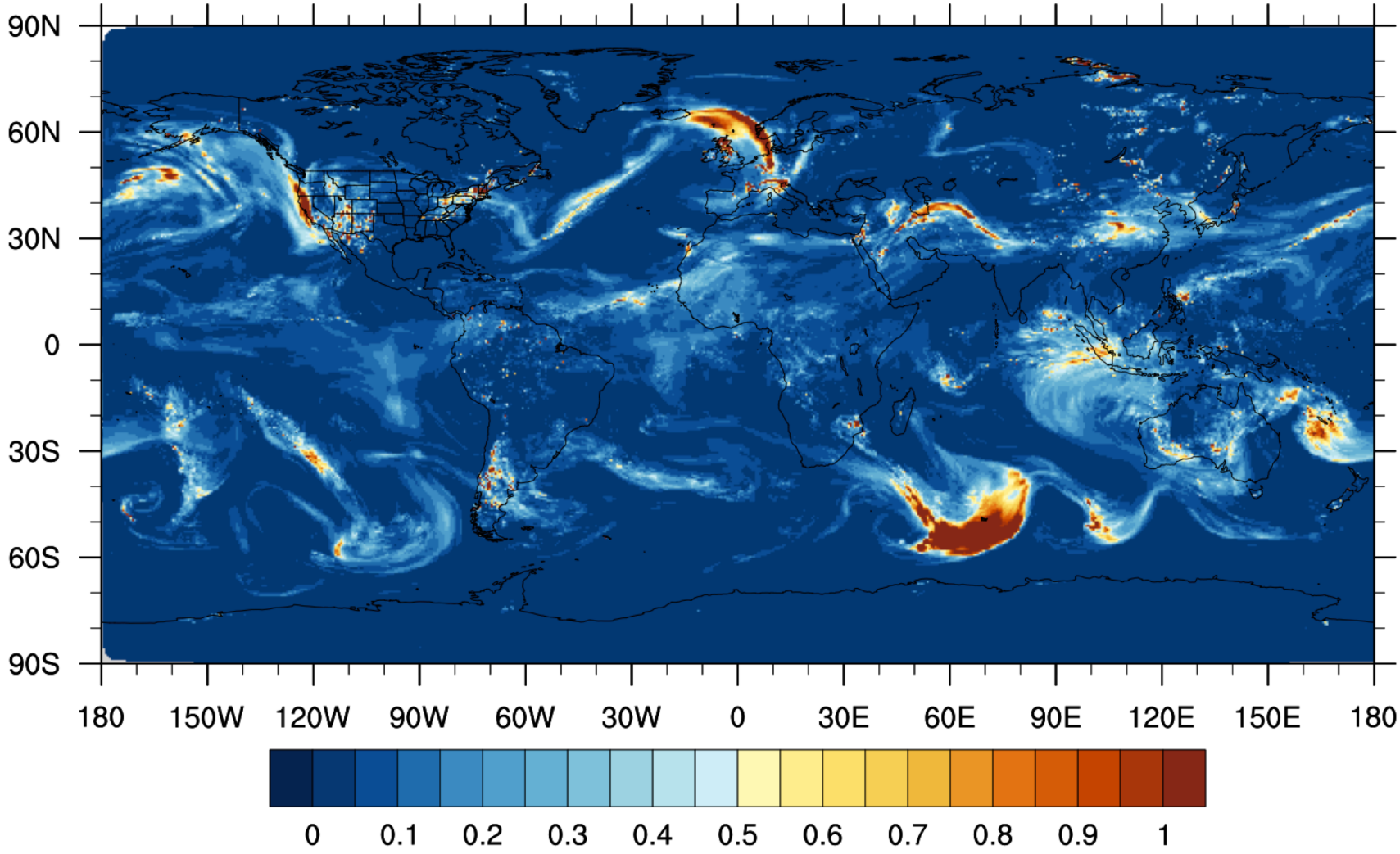
- Gravity-wave drag
- YSU PBL scheme
- Total

Next: vertical average from 5 to 20 km

Vertically-Averaged KE Dissipation

2016-12-20 simulation, vertical average from z=5 (AGL)-20 km, forecast day 5.



Implications for NWP and climate model applications?

- Vertical resolution with $\Delta z <= 200$ meters is required to converge KE spectra and resolve most IG waves for mesoscale and cloudscale applications.
- The primary KE dissipation in the free atmosphere in MPAS is driven by vertical mixing from the PBL scheme. Is this physically consistent with what the atmosphere is doing?
- Do resolving the IG waves and converging the KE spectrum matter for NWP applications, climate applications?