

Modeling Tropical Cyclones in NCAR's General Circulation Model with Variable-Resolution Meshes

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University of Michigan

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Sandia National Laboratories

Outline

Motivation

Model setup and overview

Cyclones in mesh transition regions

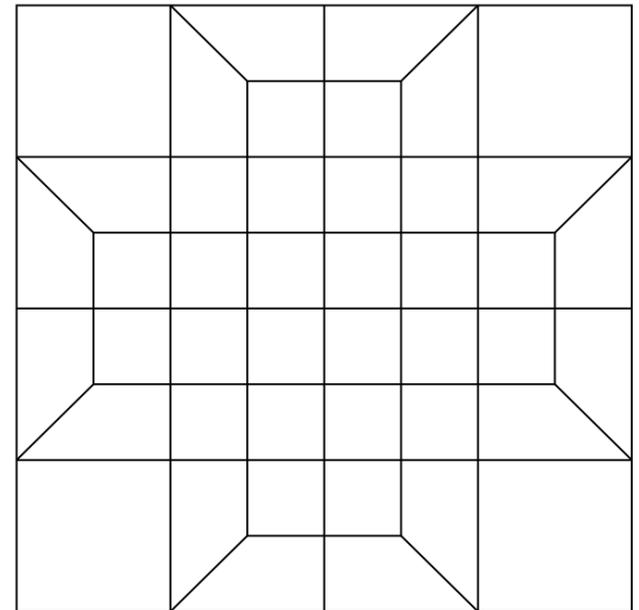
TCs embedded in uniform and refined meshes

Summary

- Modeling of tropical cyclones in General Circulation Models (GCMs) historically difficult
 - Computing constraints -> low resolutions
 - Heavy parameterization
 - Convection
 - Fluxes
- Higher resolution studies becoming more prevalent in hurricane research community
 - *Bengtsson et al., 2007*
 - *Gualdi et al., 2008*
 - *Zhao et al., 2009*
 - *Held and Zhao, 2011*

CAM SE variable-resolution dycore

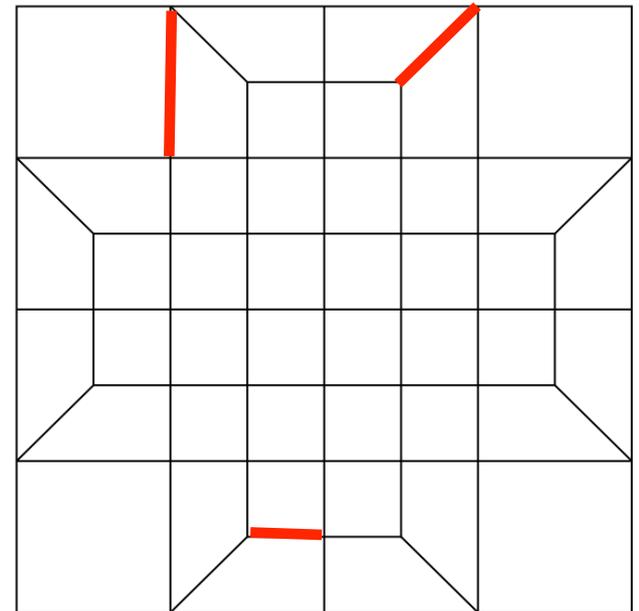
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- CAM-SE scheduled to be default in next CESM
- **Conforming refinement**
 - Every edge shared by only two elements
- **Unstructured**
 - Domain not tiled in (i,j) fashion
- **Static refinement**
 - Grid refined during initialization, does not follow atmospheric features



Levy et al., PDES, 2010

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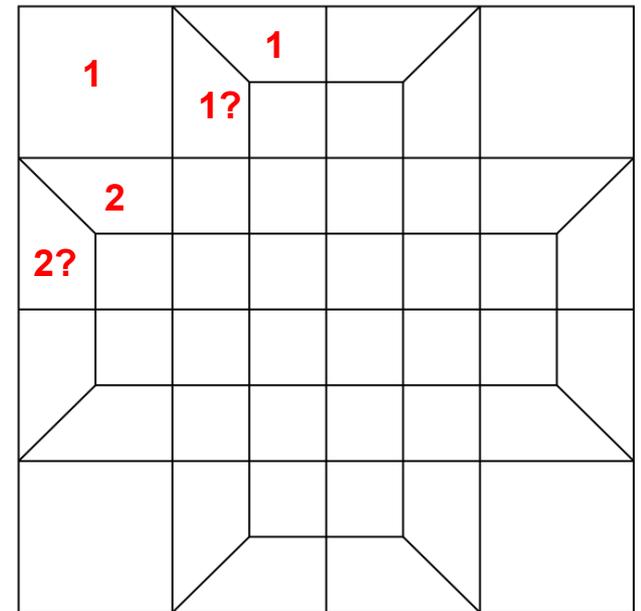
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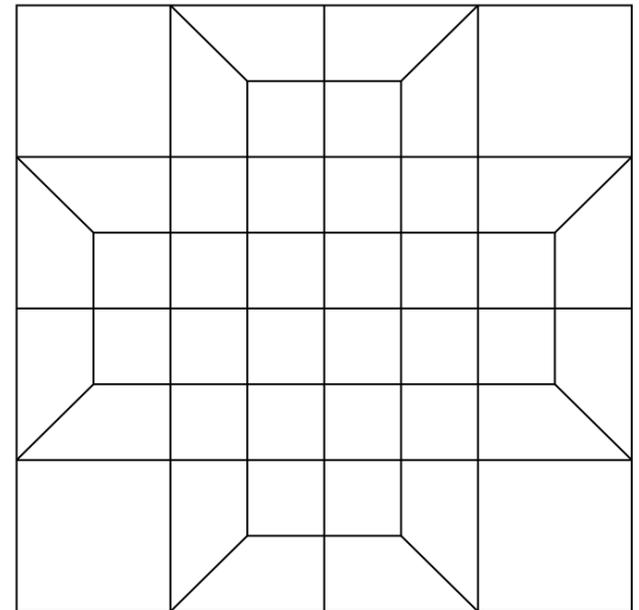
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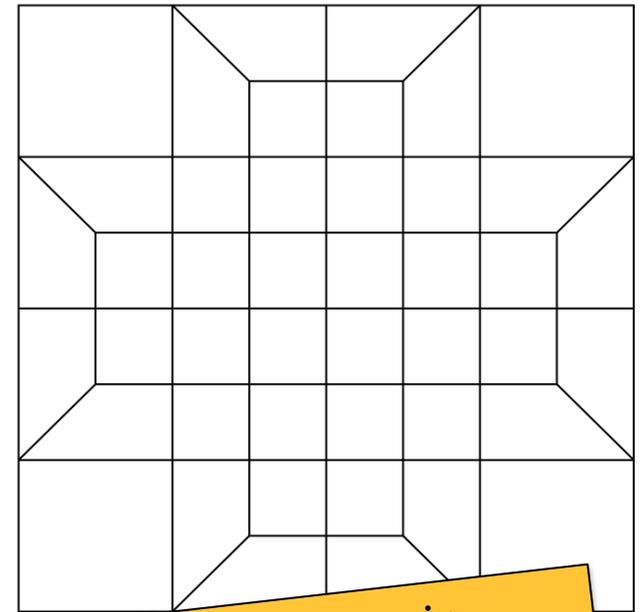
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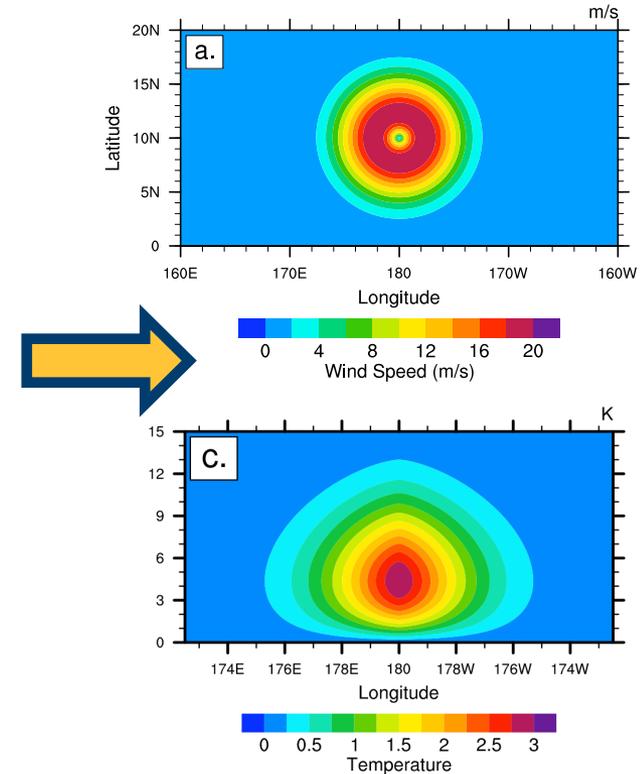
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Variable resolution used for tropical cyclone studies in limited area models (LAMs), now apply this construct to GCMs > focus computing power where we want it in a global modeling framework!

Tropical cyclone test case

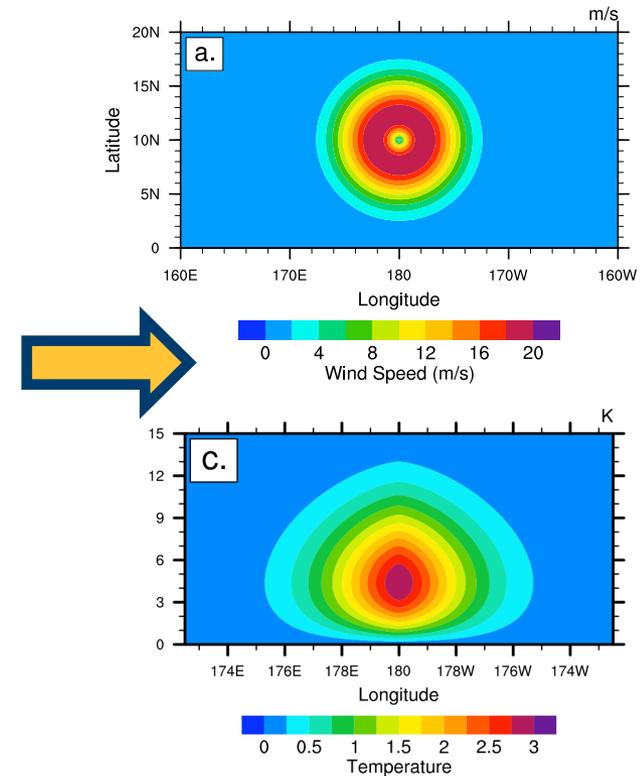
- Analytically-derived, axisymmetric, weak, warm-core vortex in hydrostatic and gradient wind balance on an aquaplanet ($T = 29^\circ\text{C}$) [Reed and Jablonowski, 2011]
- CAM version 5.1.09, default CAM5 physics* (*parameterization scalability caveats apply!)



Resolution	Grid spacing (equator) (km)	Analogous to...	Physics timestep (s)	Dynamics timestep (s)	Diff. coefficient (m ⁴ s ⁻¹)
ne15	222	2° x 2°	3200	640	1e16
ne30	111	1° x 1°	1600	320	1e15
ne60	55	0.5° x 0.5°	800	160	1e14
ne120	28	0.25° x 0.25°	400	80	1e13

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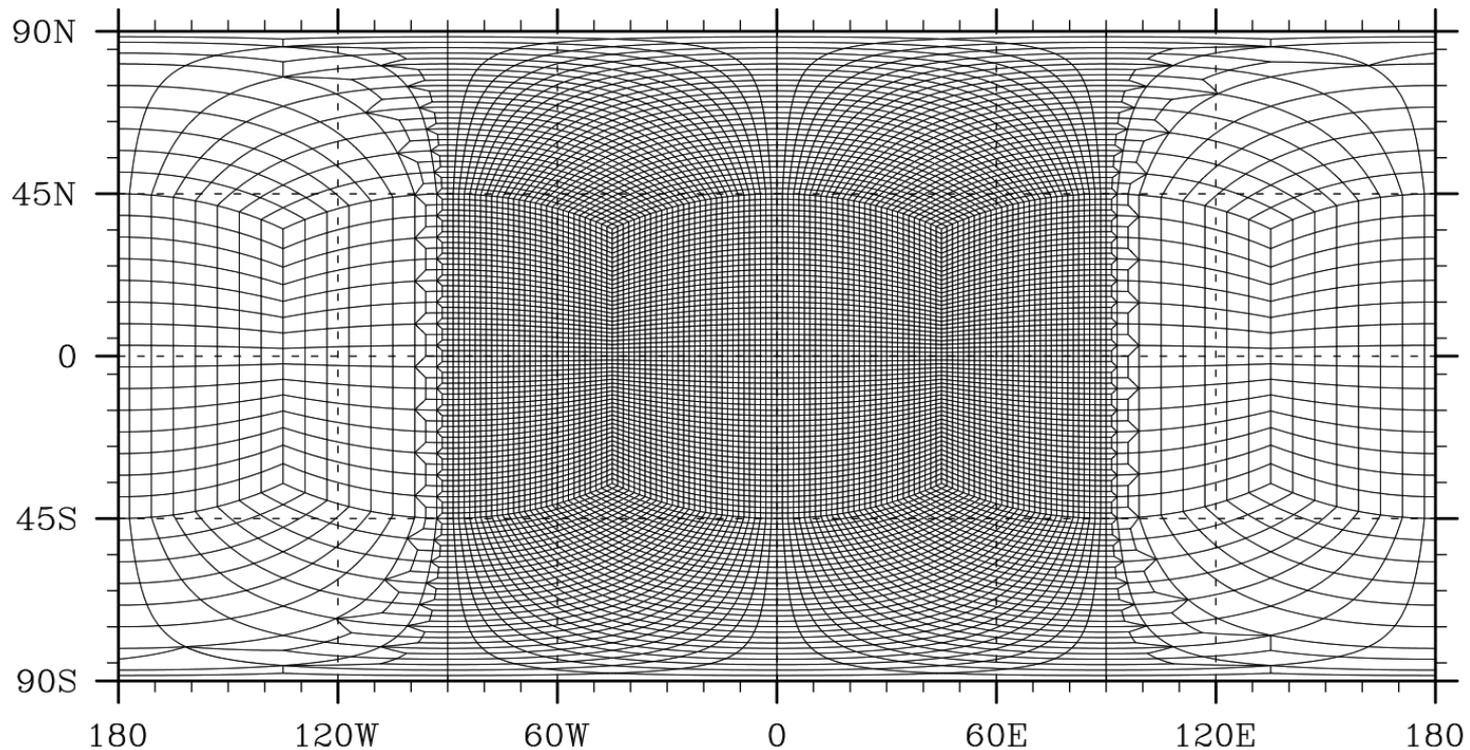
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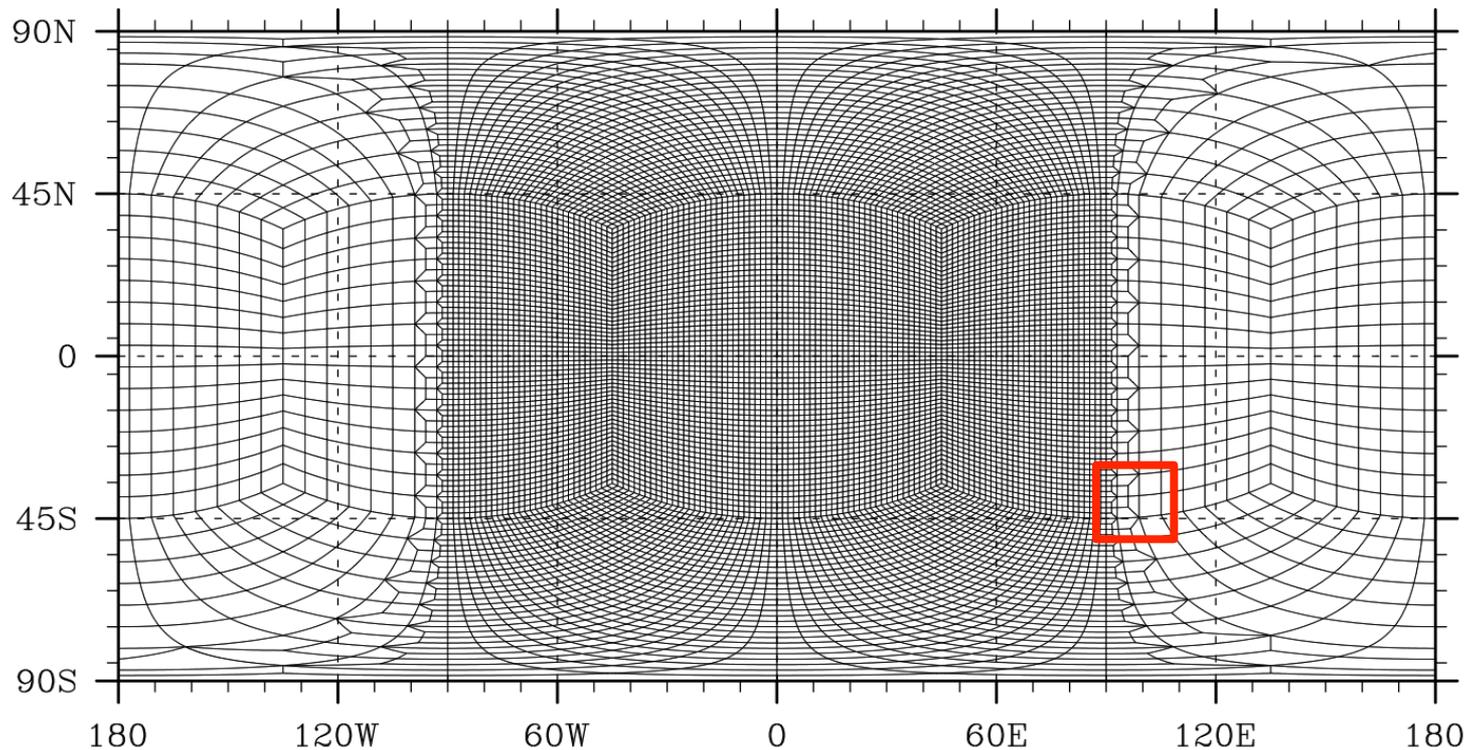
Cyclone transition from ne15 -> ne60

- First refinement ne15 x ($2^2 = 4$) (fine = ne60) - refine entire hemisphere
- Why? Simple refinement, allows for transitioning along cubed sphere edges -> “aggressive” width



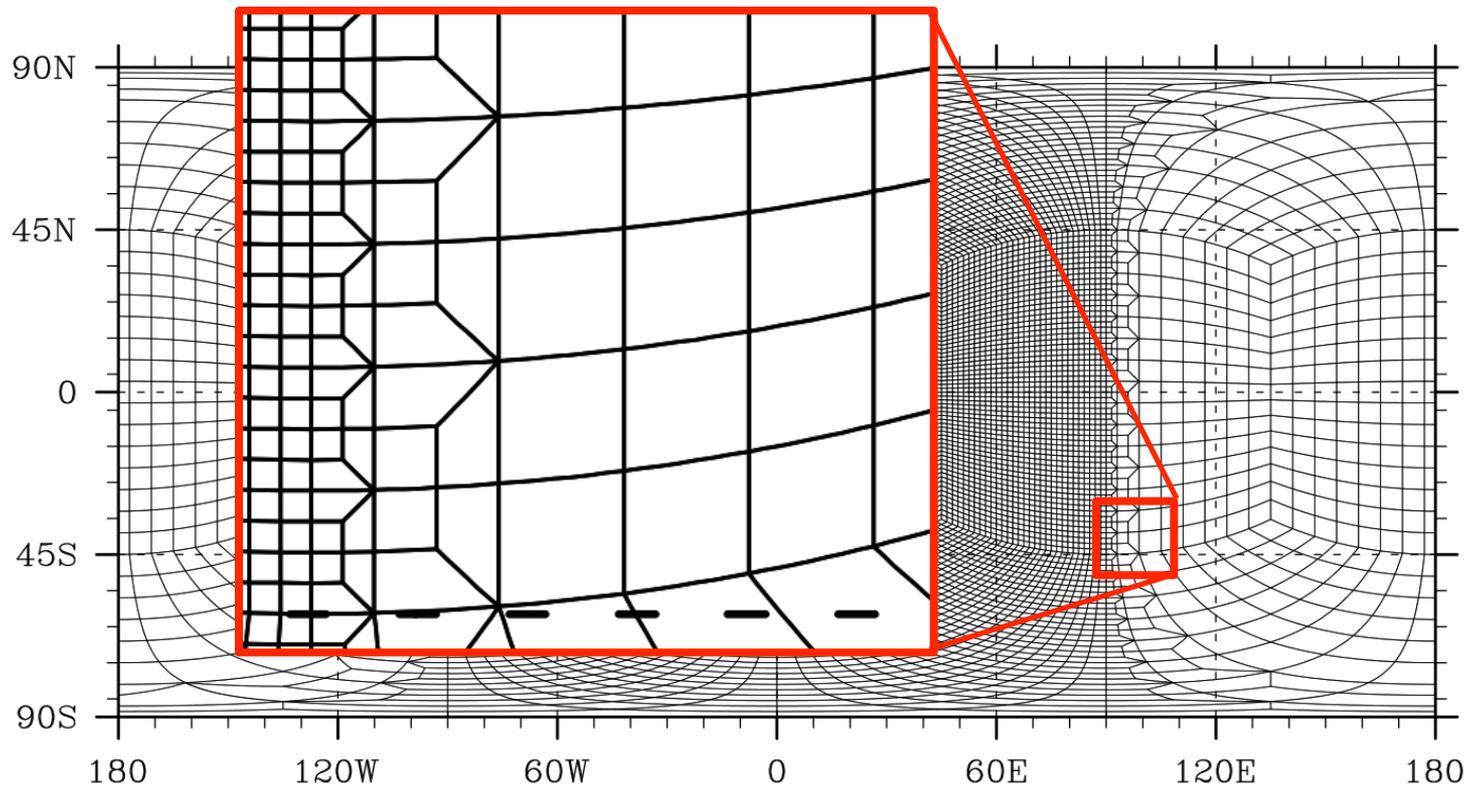
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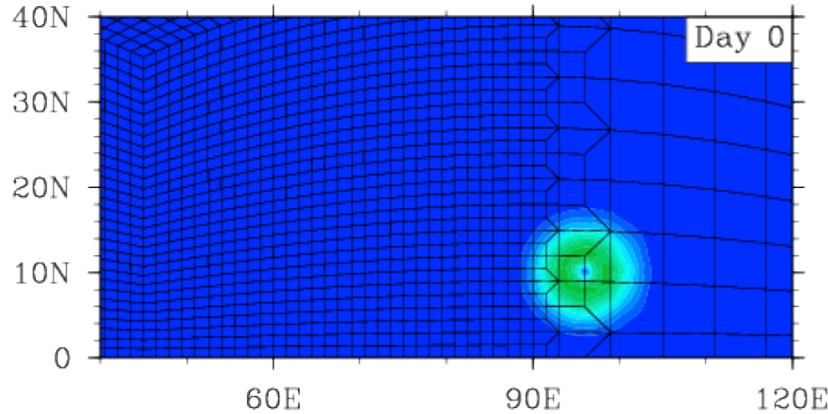
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Initial vortex:

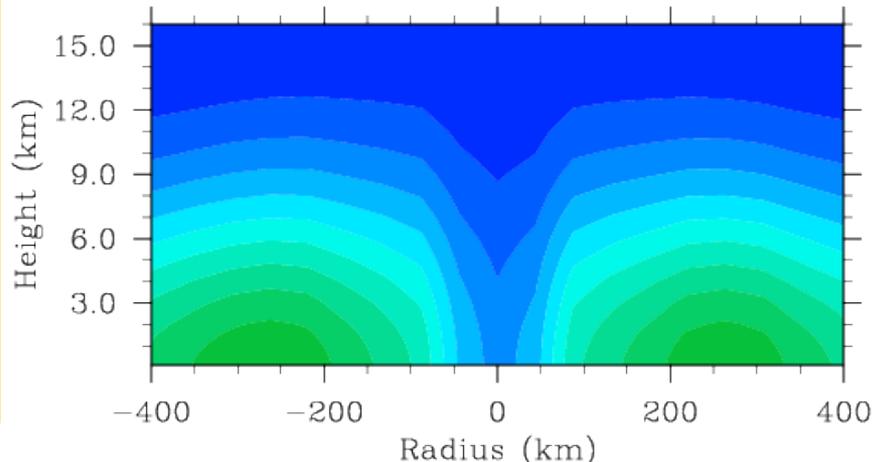
$v = 20 \text{ m/s}$

RMW = 250 km

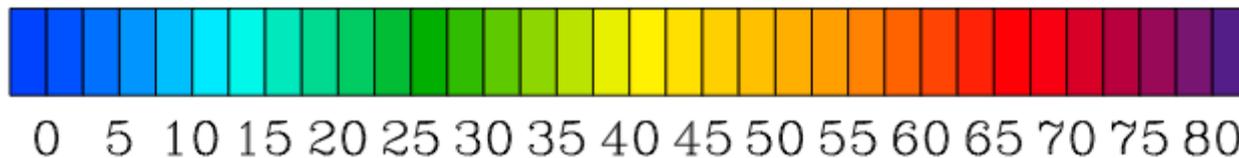
Difficulties: Ideally we'd compare cyclone vs. "control" -> virtually impossible given time scales used / lack of mesh transition analogs



850 mb
wind speed
(m/s)



Latitudinal
cross section
wind speed
(m/s)



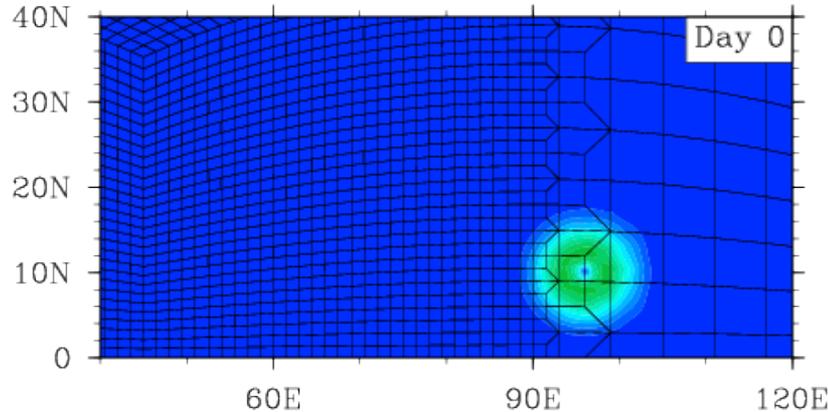
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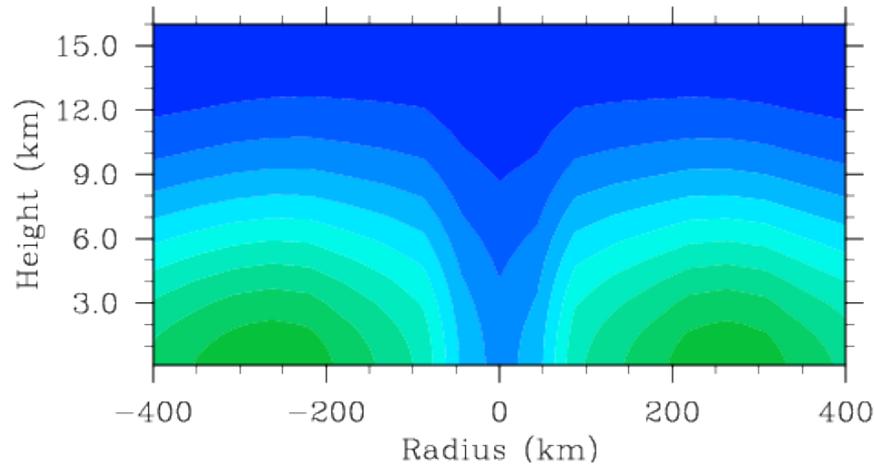
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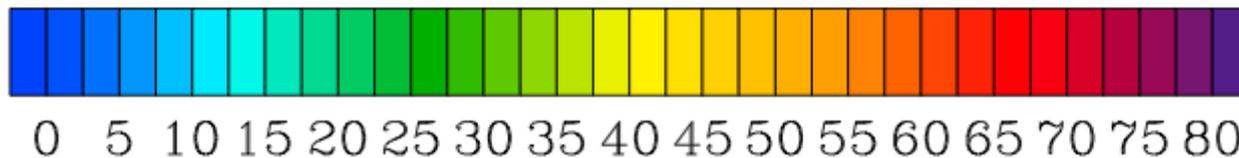
Key: Looking for relatively symmetric development; no stretching, no filamentation



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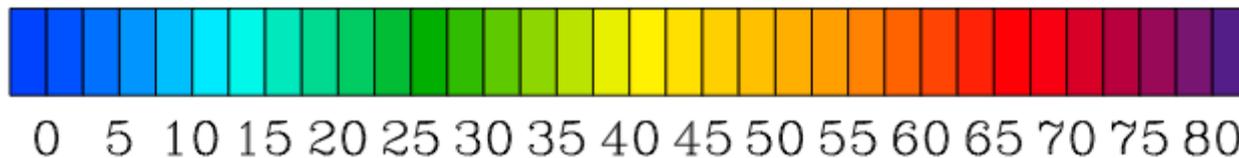
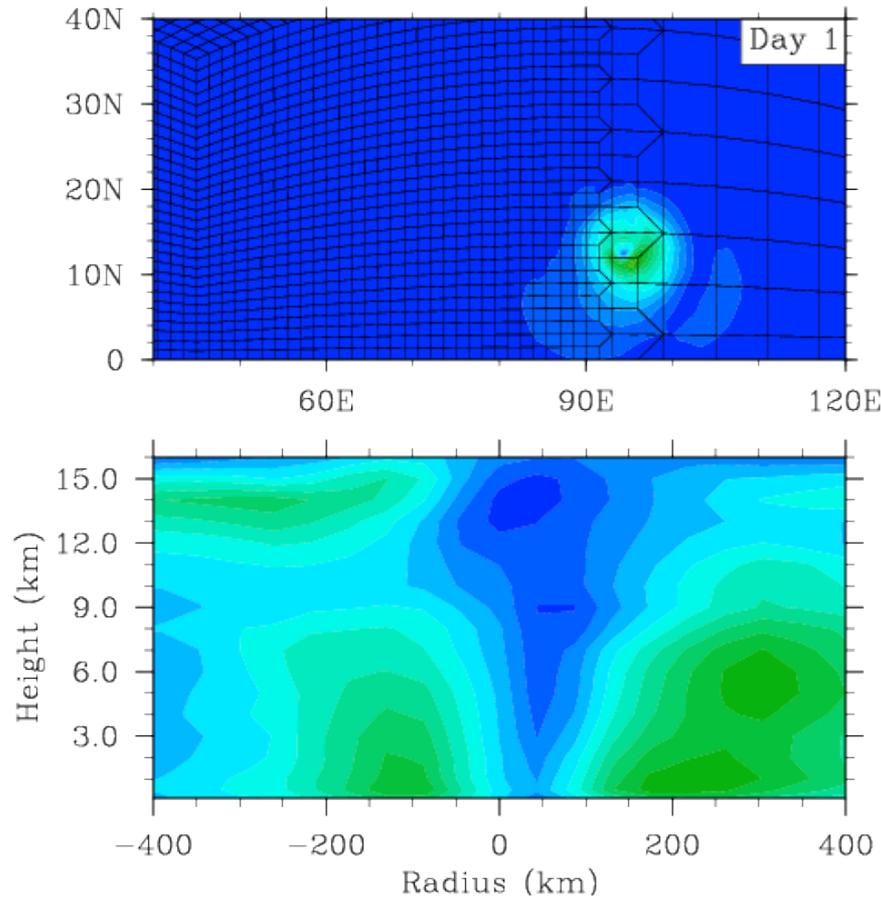
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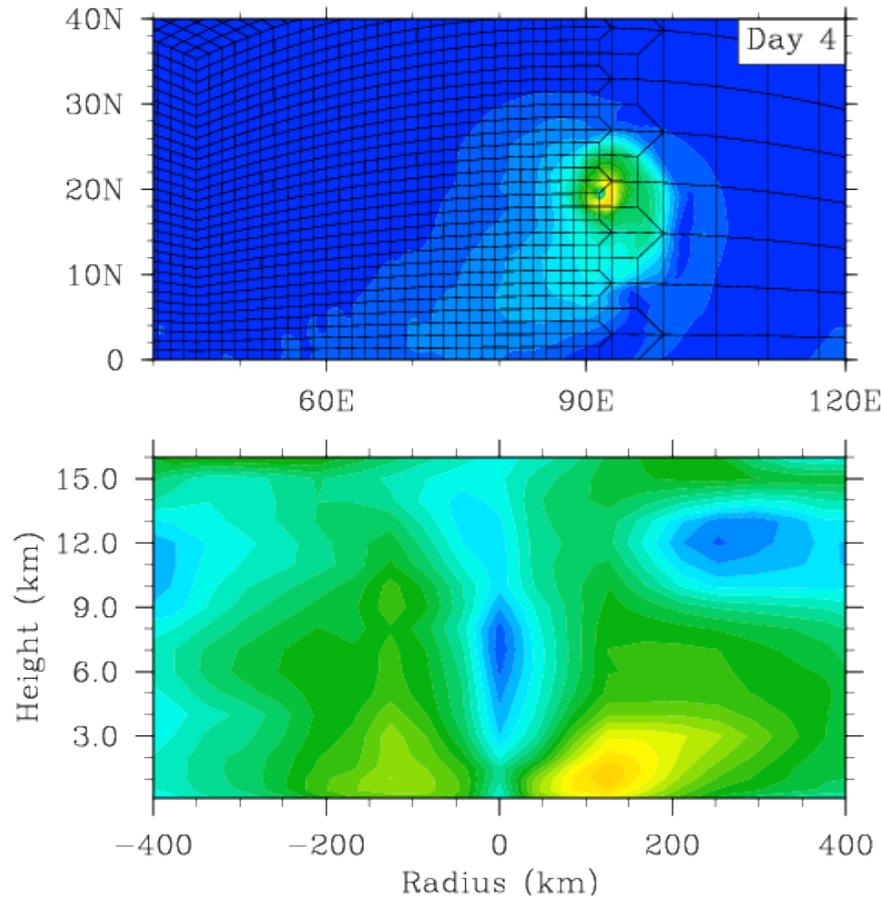
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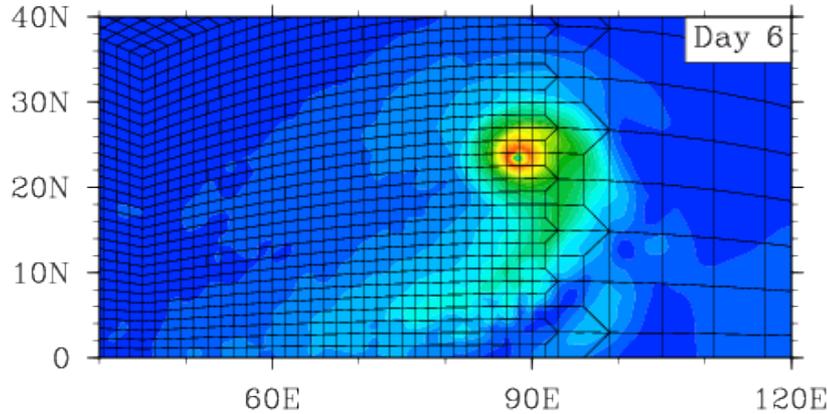
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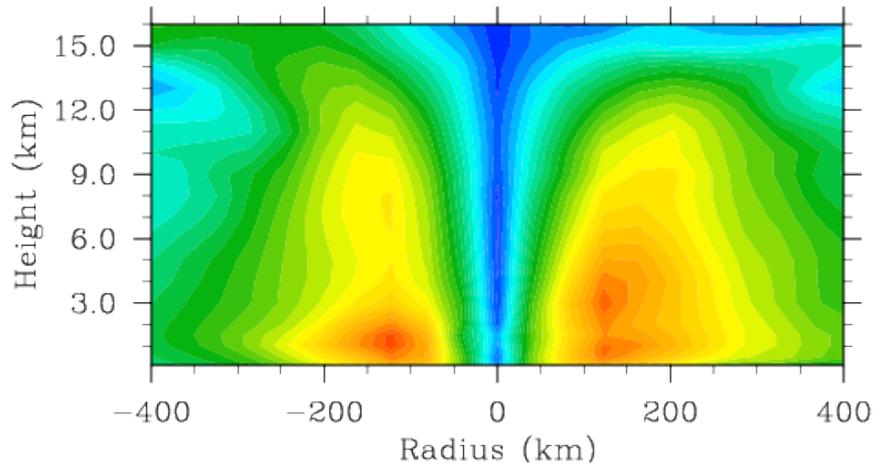
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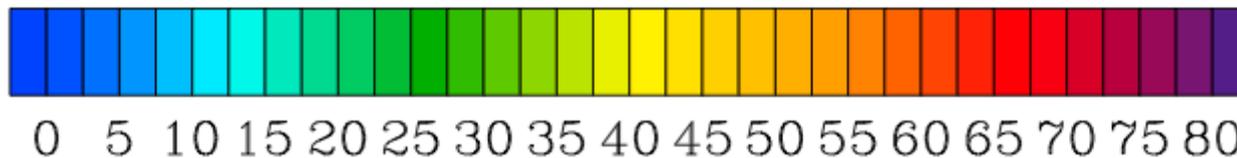


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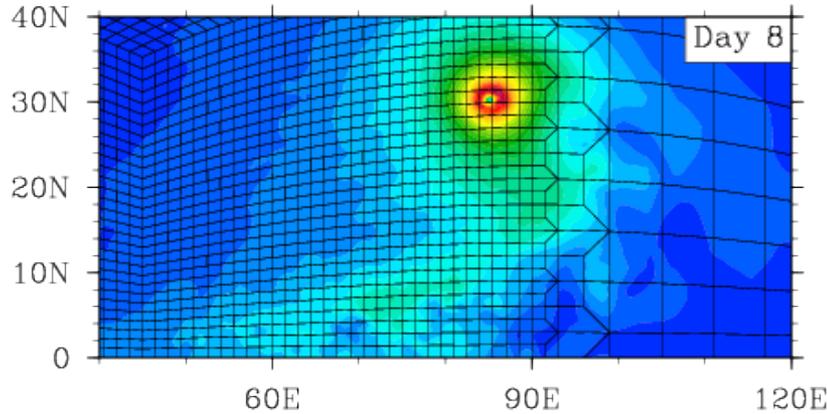


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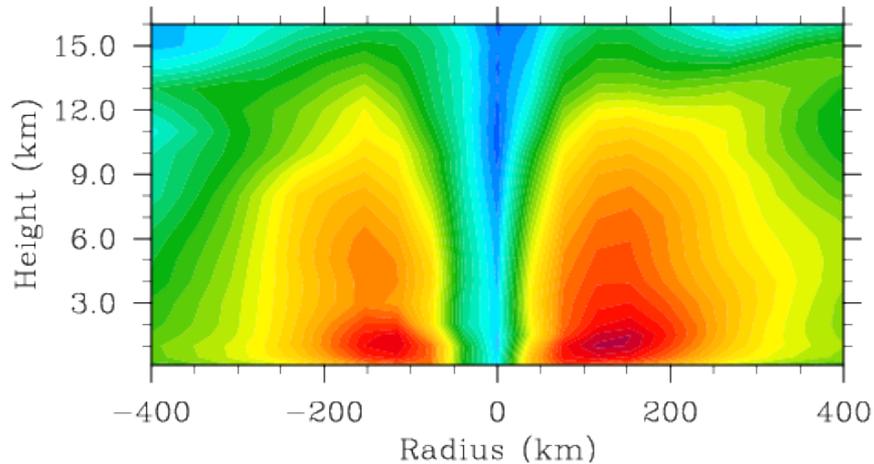
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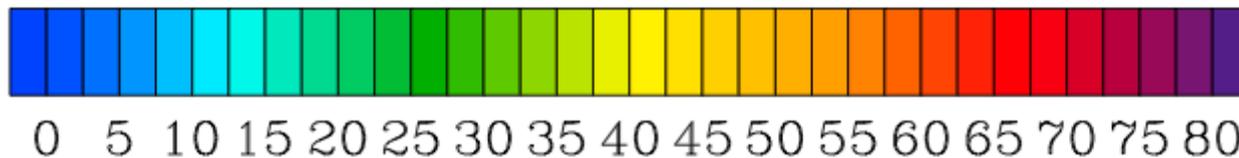


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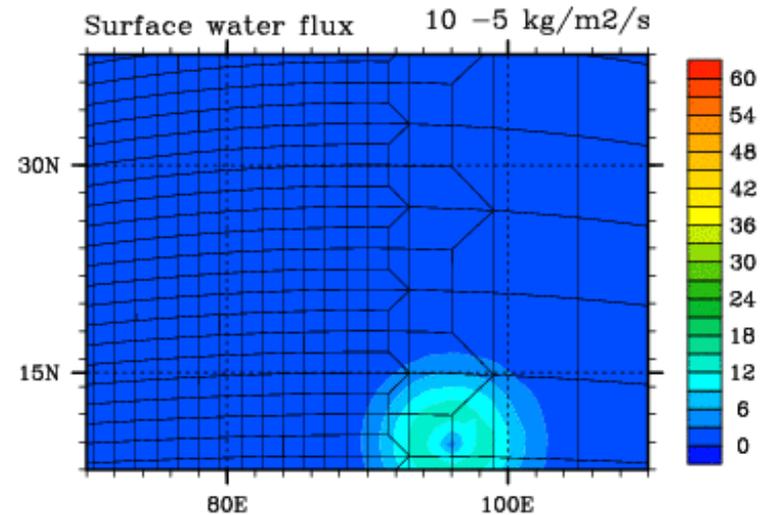
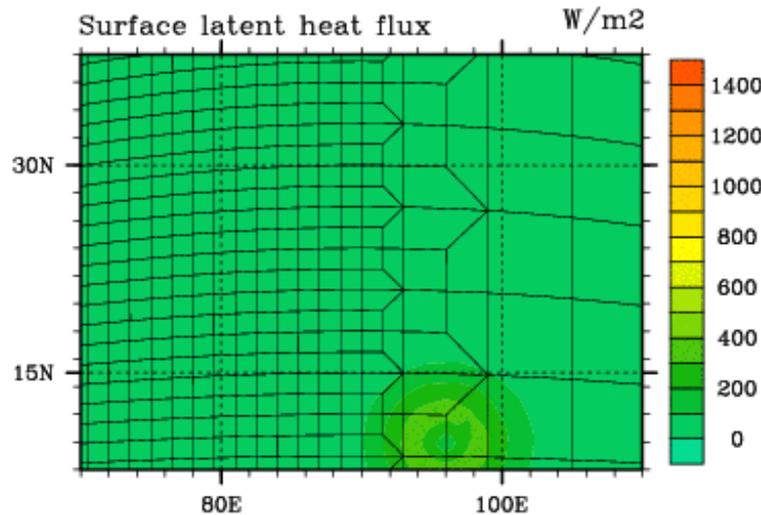
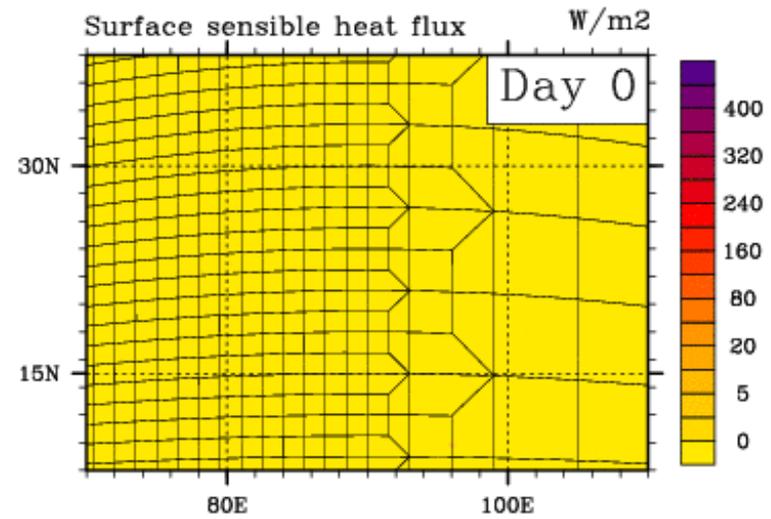
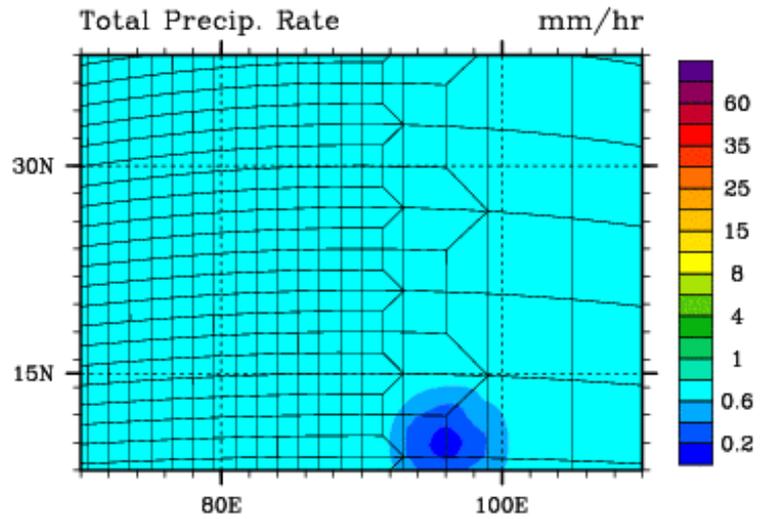
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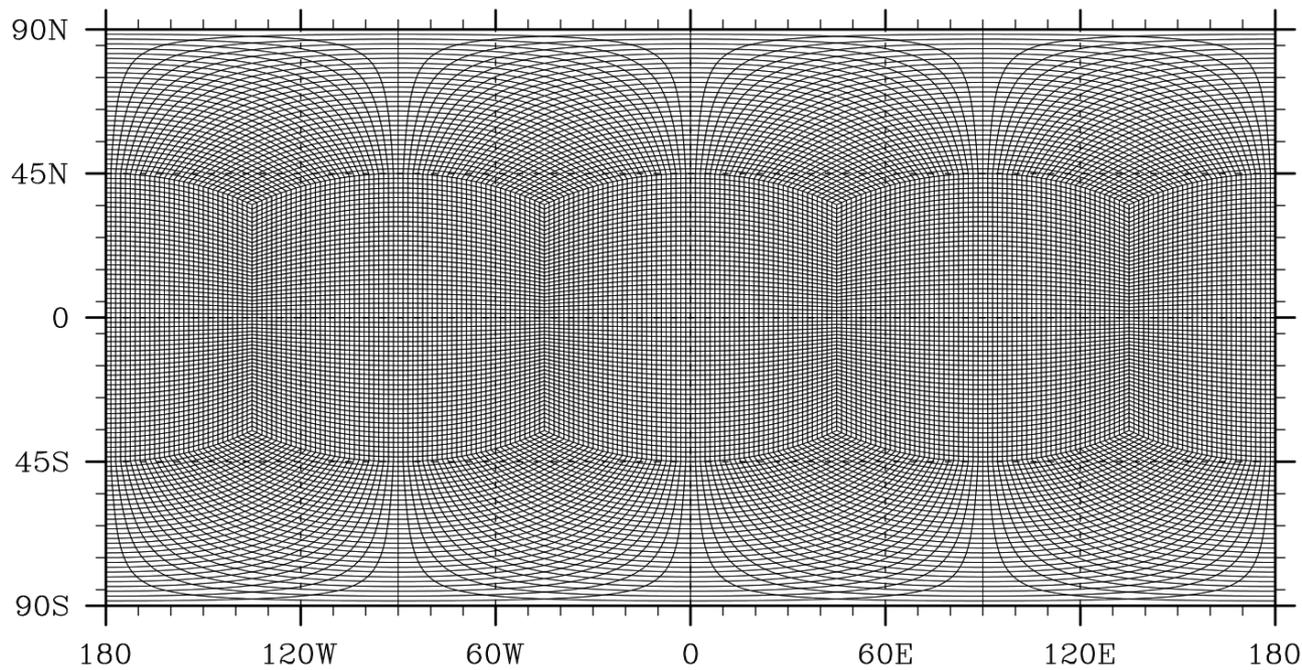


Comparing “uniform” to “refined” meshes

- Compare idealized cyclone in A) traditional **uniform** ne60 ($\sim 0.5^\circ$) mesh to a B) ne15 mesh ($\sim 2^\circ$) with a 4x **refined** area (ne60, $\sim 0.5^\circ$)
- Smaller refined region than hemisphere: analogous to size of north Pacific ocean

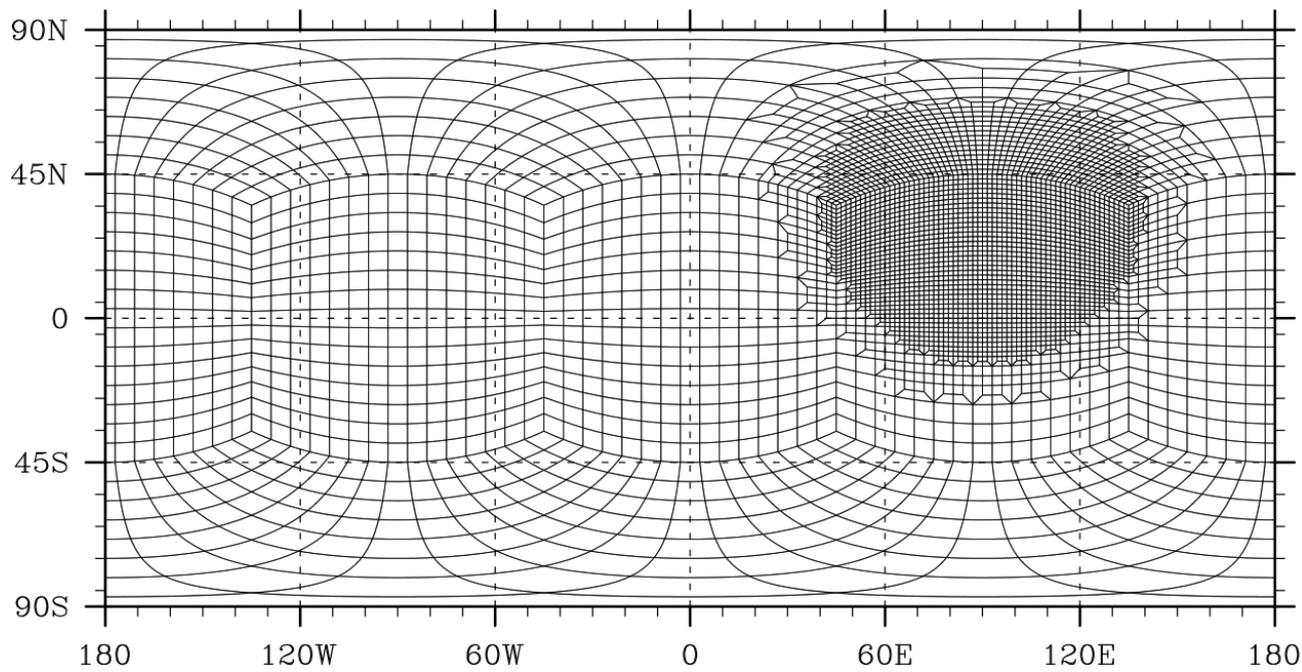
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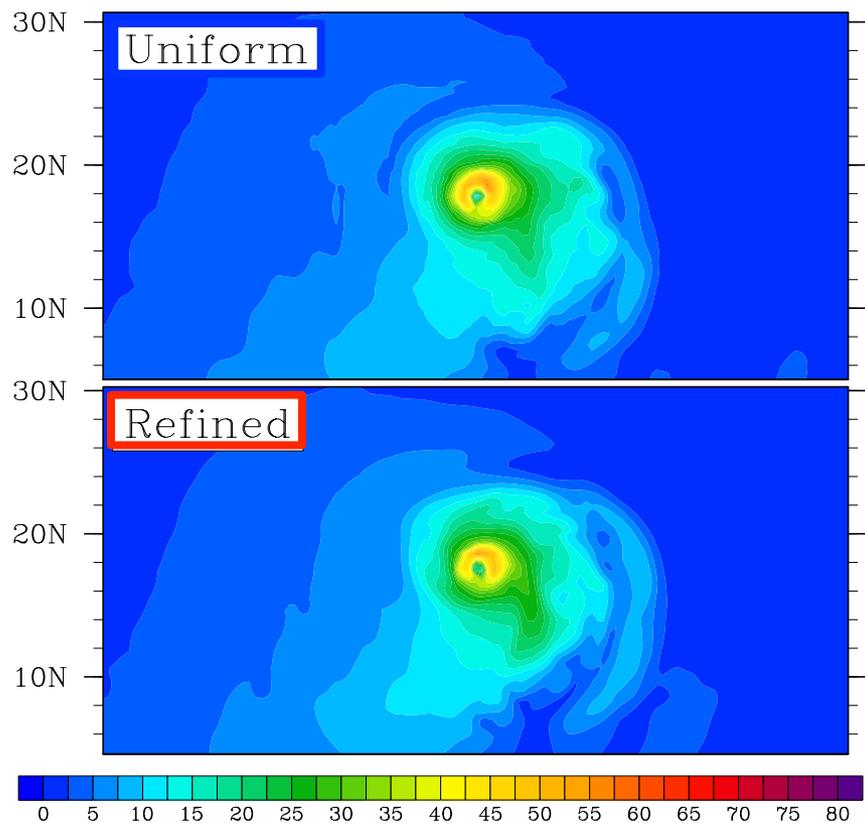
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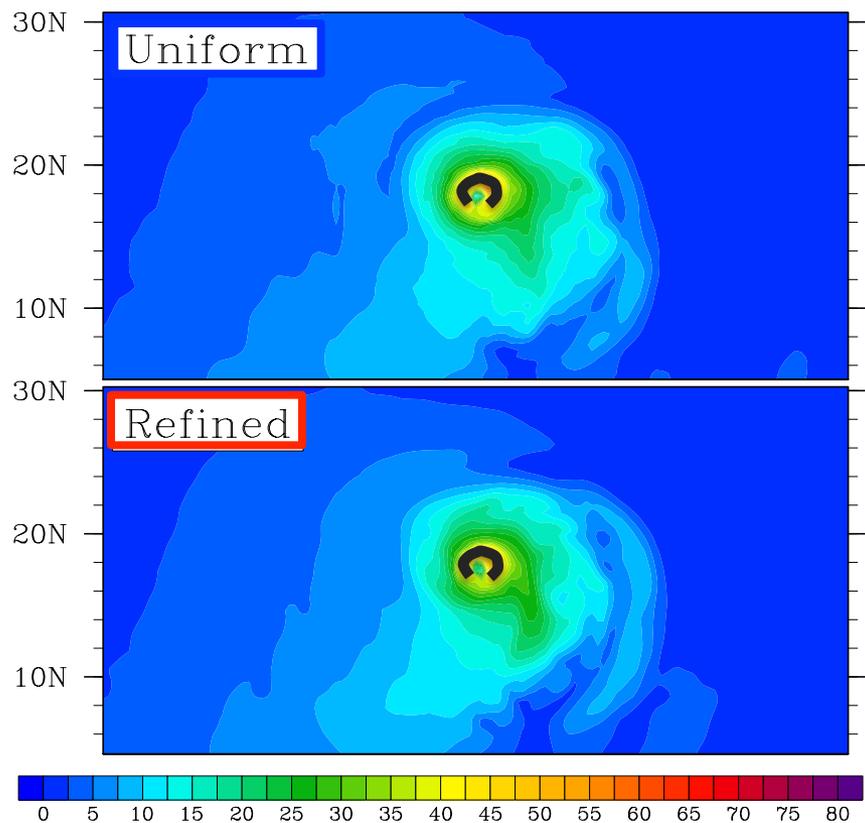
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Day 5 - 850 mb wind speed (m/s)



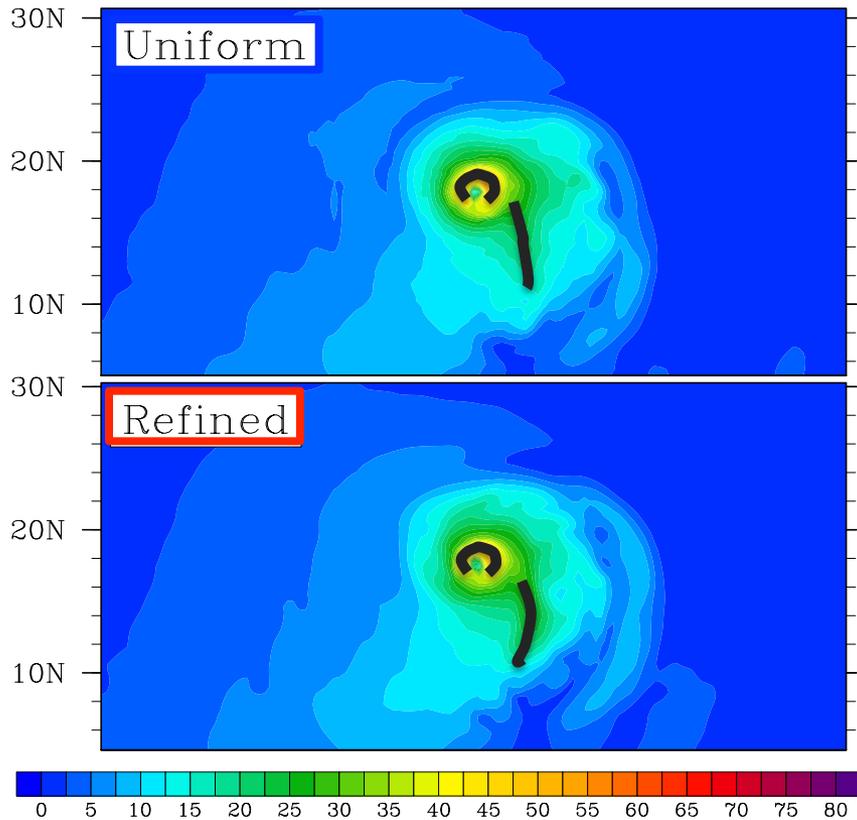
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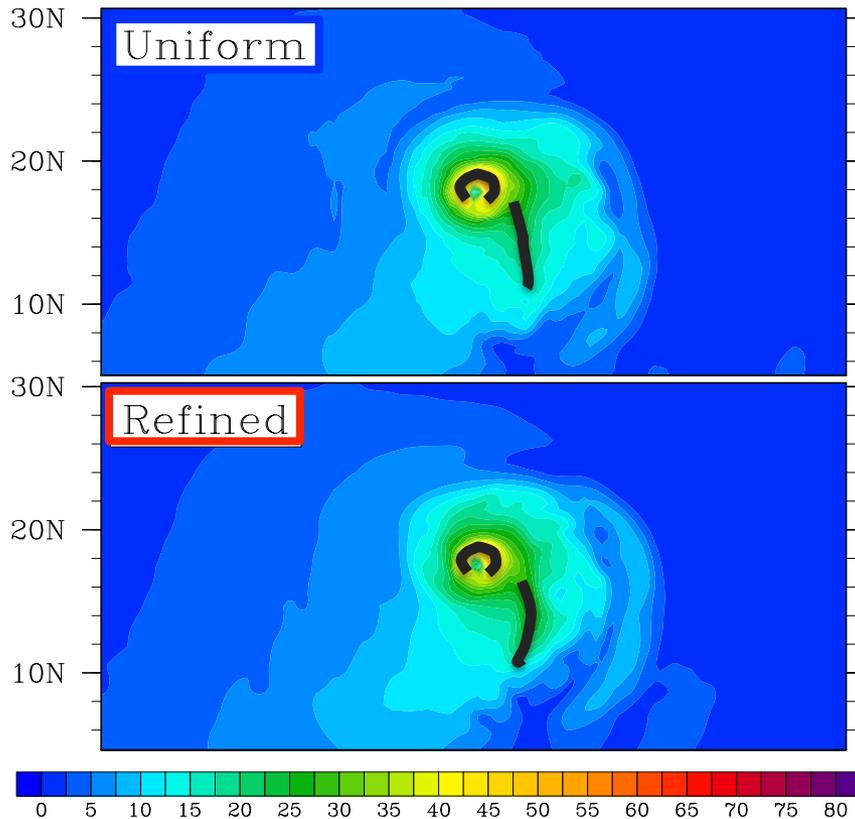
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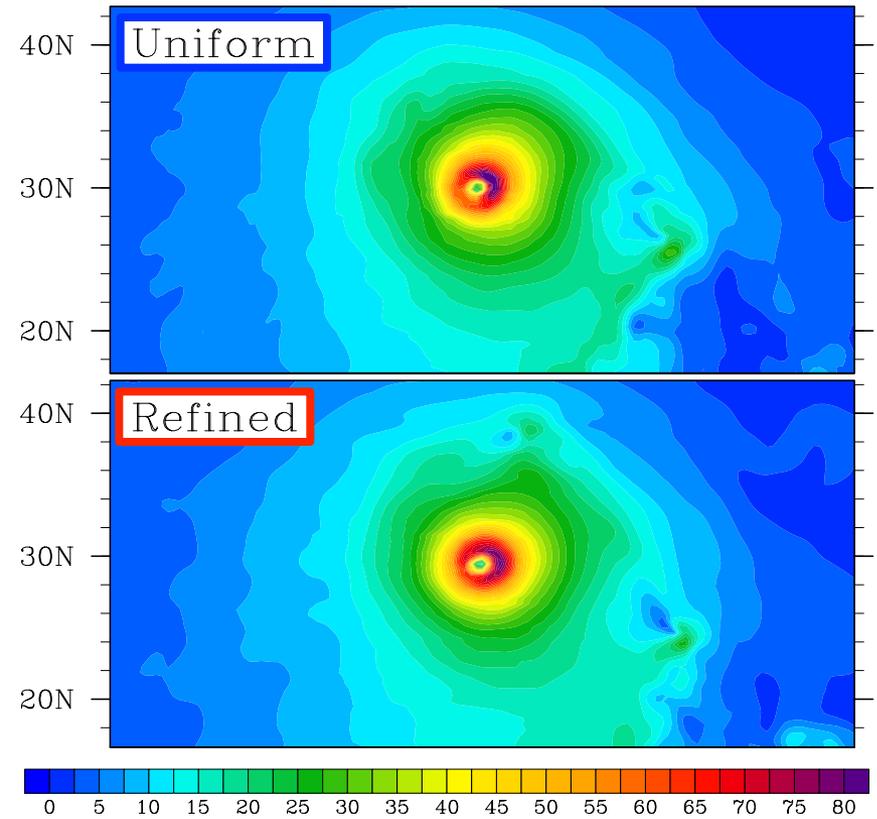


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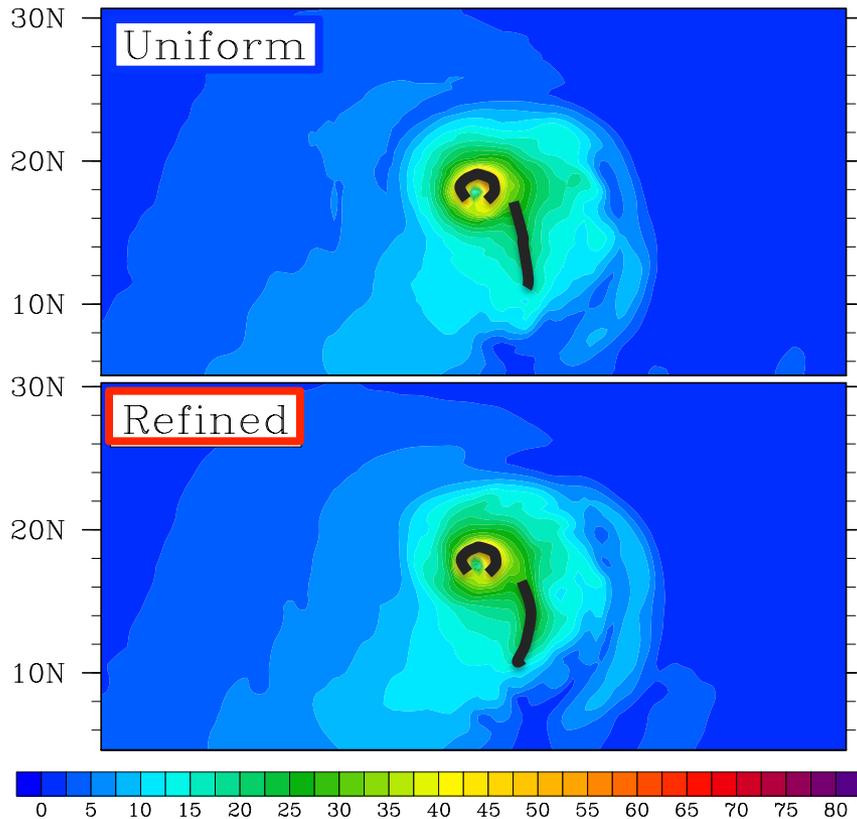


Day 10 - 850 mb wind speed (m/s)

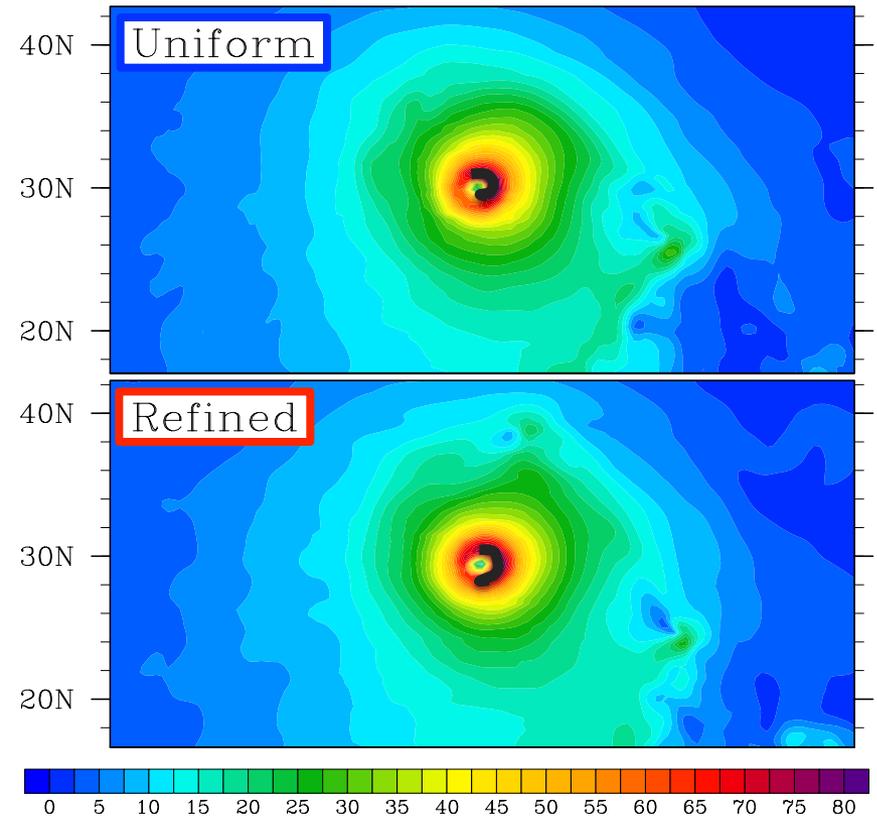


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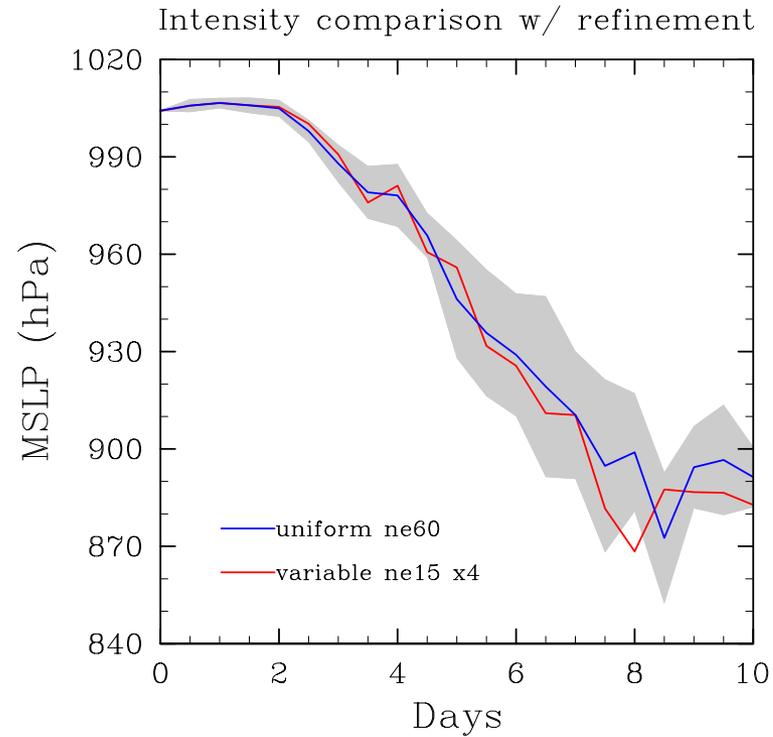
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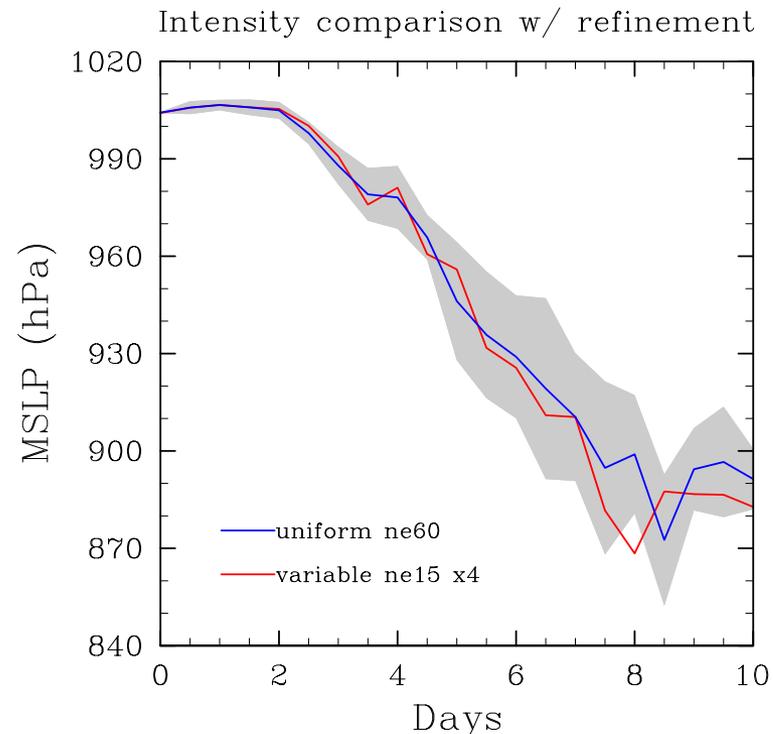
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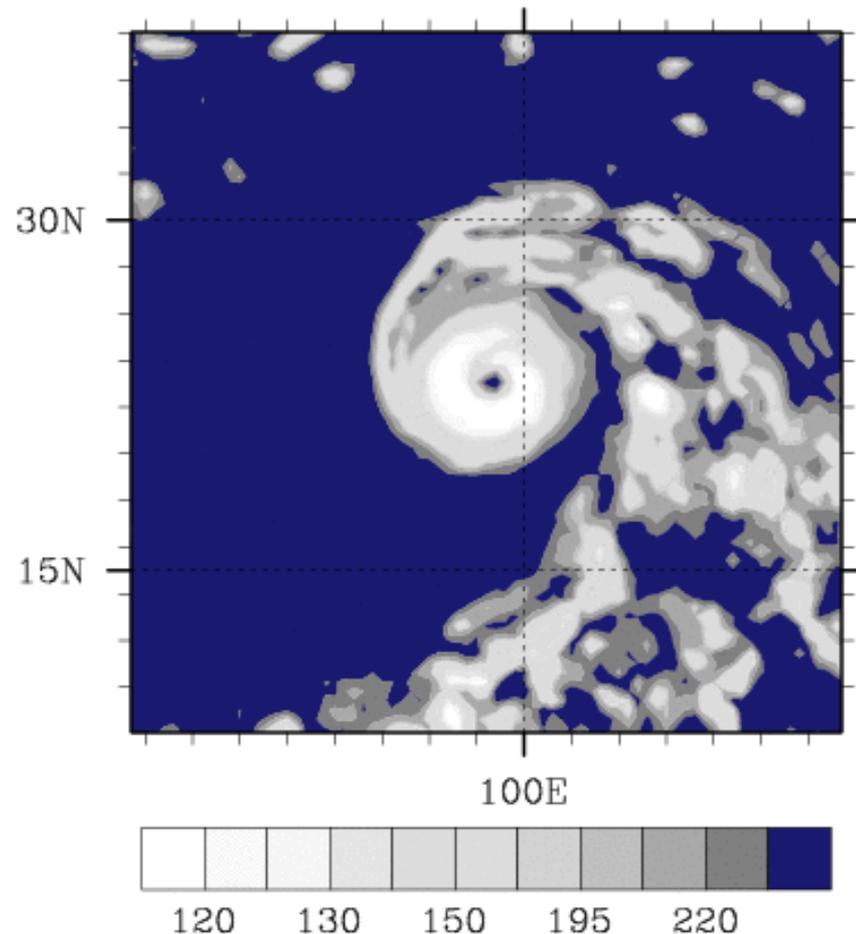


- 194,402 elements (**uniform**) vs. 38,666 elements (**refined**) = ratio of **0.199** -> *ideal scalability with SE dycore*
- In reality? Assume running **full uniform mesh** is equivalent to 1.0 “work units,” **refined mesh** produces similar results with **0.201** “work units”

More on the ability to simulate realistic TCs

- Refined grid -> ne120 (0.25°) on an aquaplanet
- Produce results visually comparable to observed cyclones

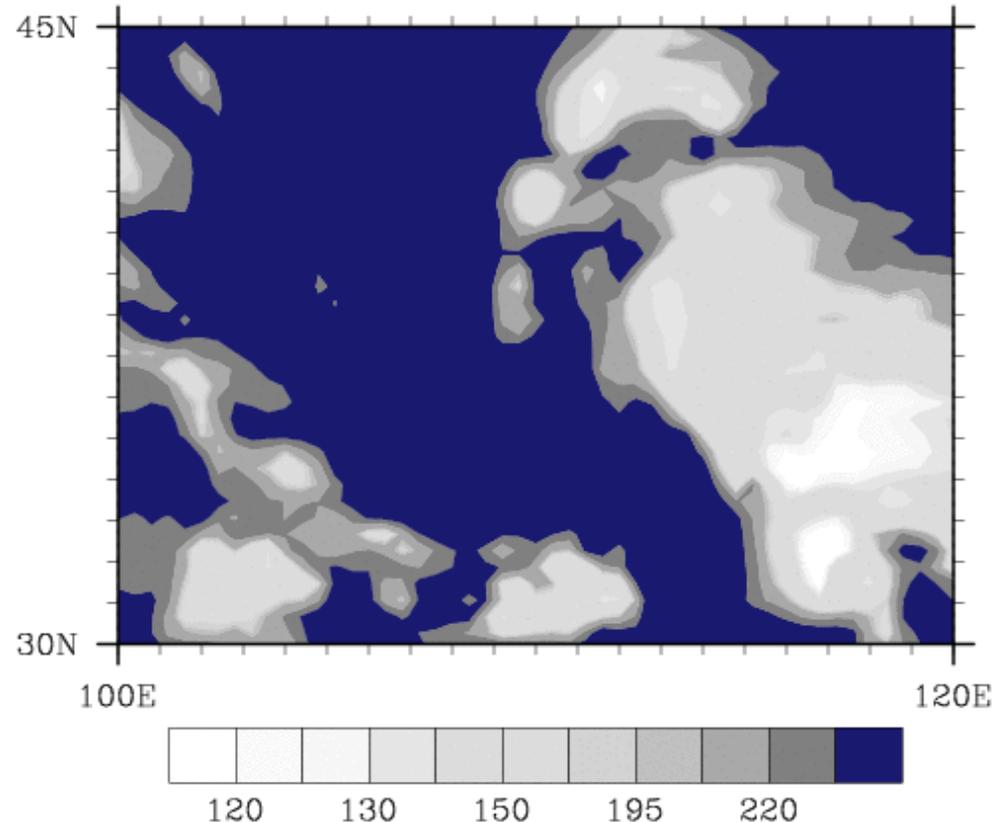
Hourly Outgoing Longwave Radiation (W/m^2)
(IR satellite proxy)



More on the ability to simulate realistic TCs

- Refined grid -> ne120 (0.25°) on an aquaplanet
- Produce results visually comparable to observed cyclones
- Simulations allowed to run beyond TC test lifetime
- Vortices in high-res domain spun up into additional cyclones without bogusing

Hourly Outgoing Longwave Radiation (W/m^2)
(IR satellite proxy)



- Variable resolution version of NCAR CAM-SE dynamical core presently being tested
- Using default CAM5 physics, variable resolution grids can develop/maintain TCs that **do not appear to suffer significant numerical errors when moving through grid transition regions**
- Identically-initialized ideal TCs can be simulated **significantly more efficiently in a refined grid when compared to a globally-uniform grid of the same resolution**
- High resolution nests **produce visually realistic TCs** and simulations are able to **generate TCs without vortex seeds** on an aquaplanet