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Using Variable Resolution Meshes to Model Tropical Cyclones in NCAR's CAM General Circulation Model

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University of Michigan

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***Acknowledgements**: Mark A. Taylor, Michael N. Levy, Sandia National Labs*

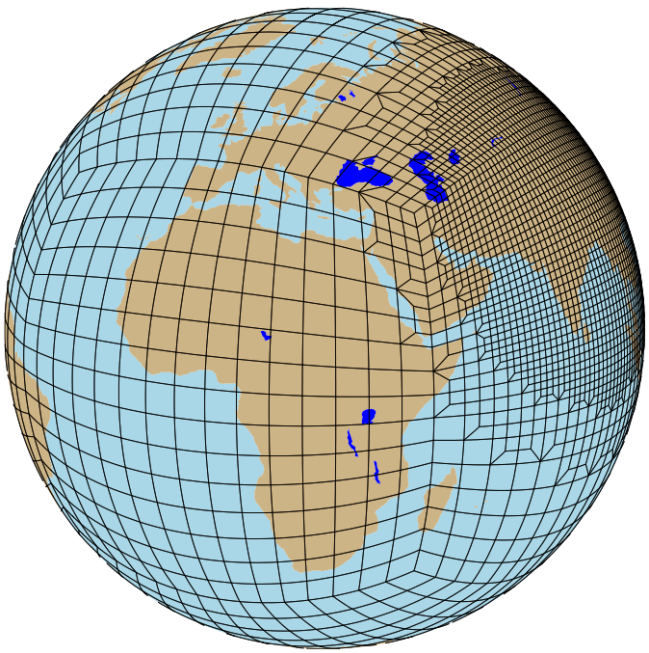
Outline

Tropical cyclones in GCMs

- Modeling of tropical cyclones in **G**eneral **C**irculation **M**odels (GCMs) historically difficult
  - Computing constraints -> low resolutions
  - Significant parameterization of sub-grid scale processes
    - Convection
    - Fluxes
- Higher resolution studies becoming more prevalent in hurricane research community
  - Many great examples during this week's talks

CAM SE variable-resolution dycore

- Variable resolution feature recently implemented in NCAR **C**ommunity **A**tmosphere **M**odel (CAM) **S**pectral **E**lement (SE) dynamical core
- 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



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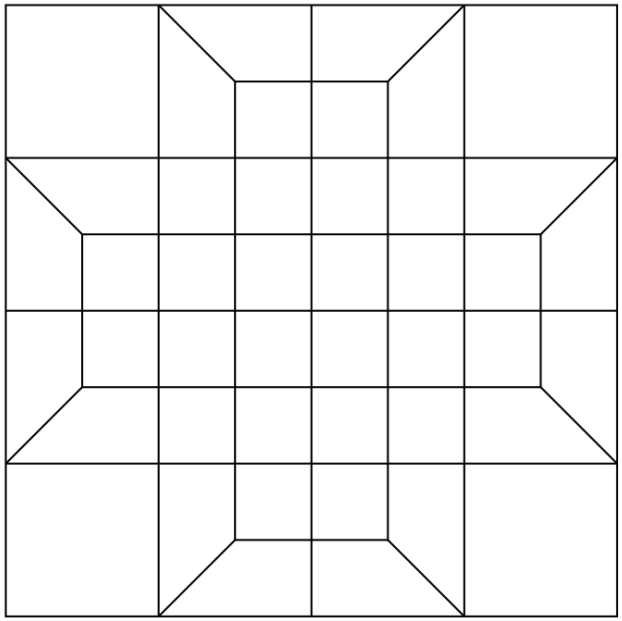

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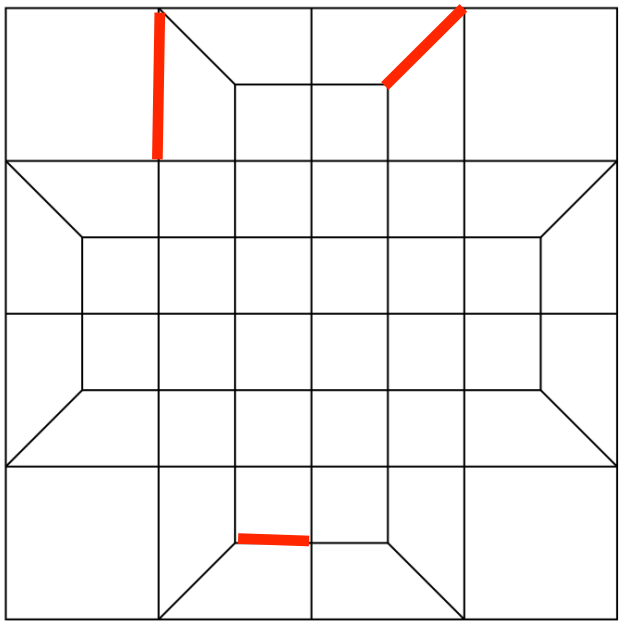

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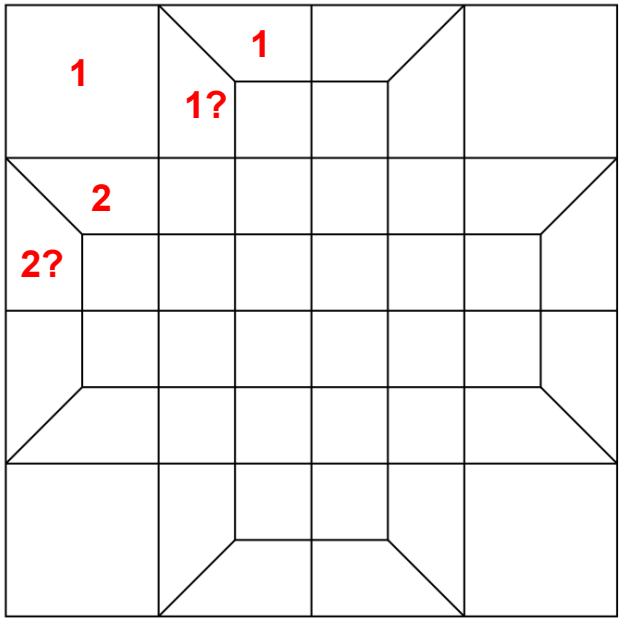

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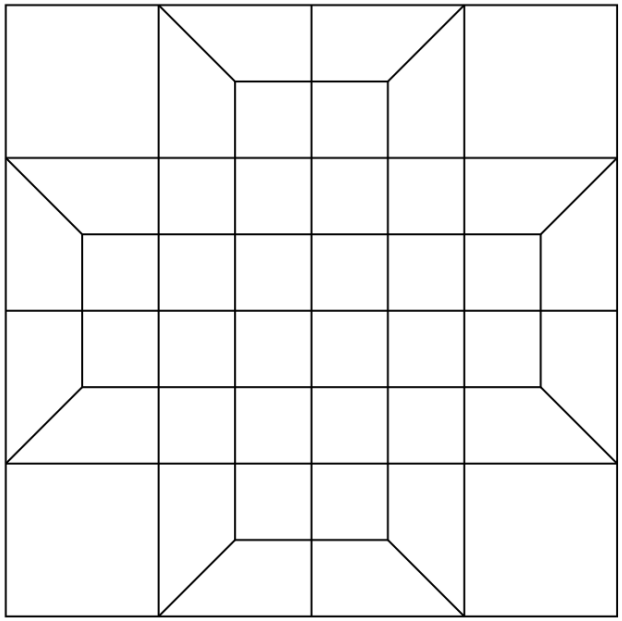

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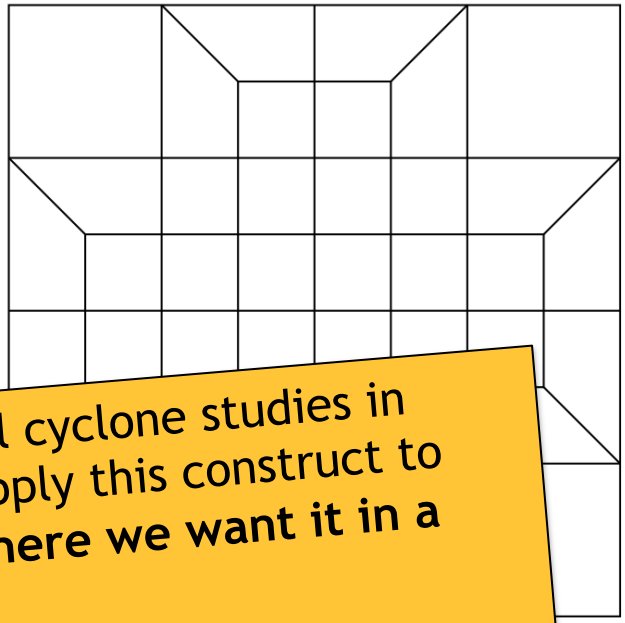
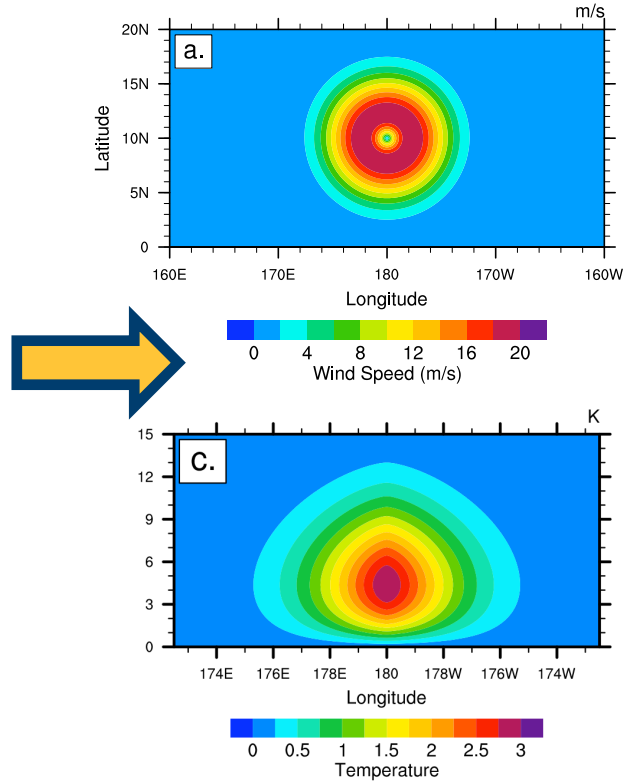


Variable resolution used for tropical cyclone studies in limited area models (LAMs), now apply this construct to GCMs > **focus computing power where we want it in a *global modeling framework***!

-- Setup eliminates need for **externally-forced** and possibly **numerically and physically inconsistent** boundary conditions

Short-term, seeded simulations

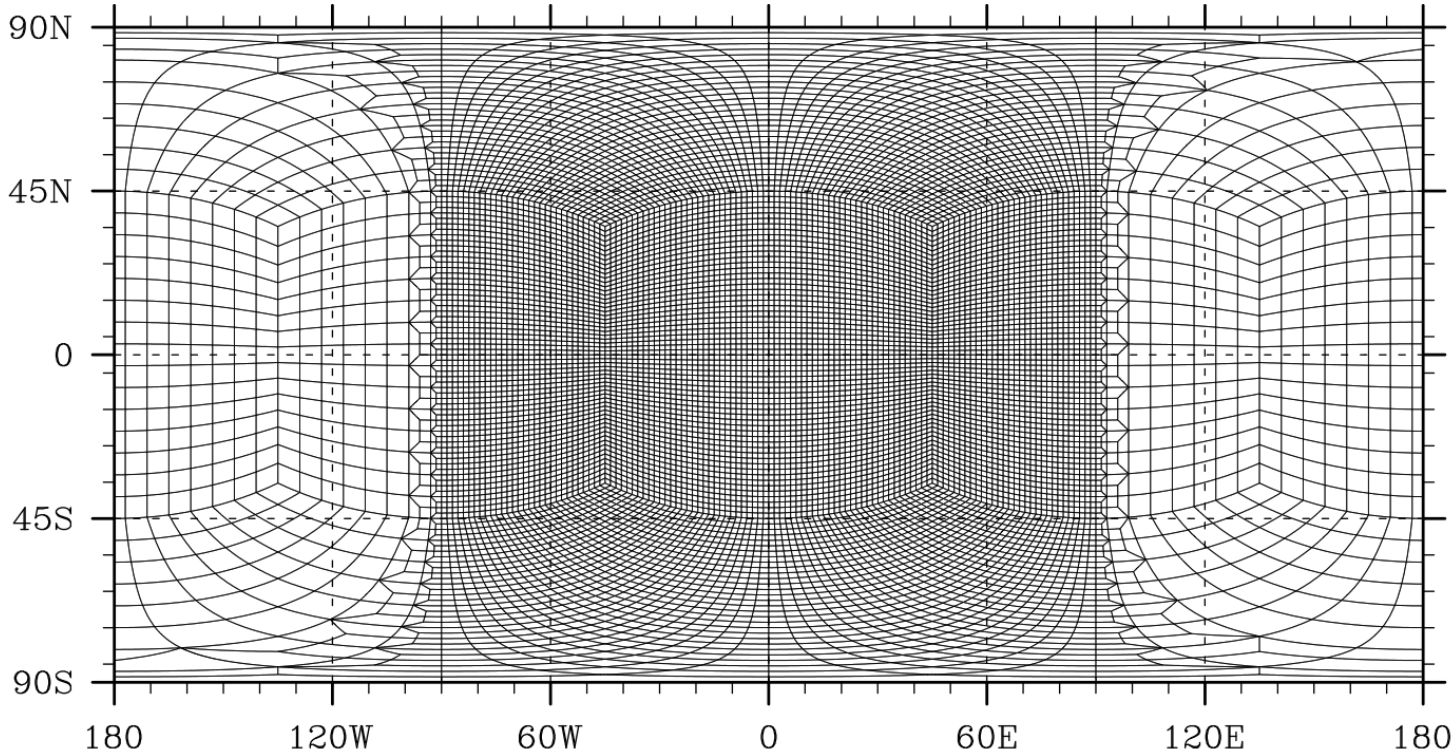
- *Analytically-derived, axisymmetric, weak, warm-core* vortex in hydrostatic and gradient wind balance on an aquaplanet (T = 29°C) [*Reed and Jablonowski*, 2011]
- CAM version 5.1.09, default CAM5 physics* (***parameterization scalability caveats apply!**)



Resolution	Grid spacing (equator) (km)	Analogous to…	Physics timestep (s)	Dynamics timestep (s)	Diff. coefficient (m4 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

Cyclone transition: coarse -> fine

- Important desirable property -> *satisfactory interaction of cyclone with transition region between different resolutions*
- Set up -> start with global ne15 (~2°) and refine x4 (fine = ne60 = ~0.5°) -> refine entire hemisphere
- Why? Simple refinement, transitioning along cubed sphere edges -> "aggressive" width



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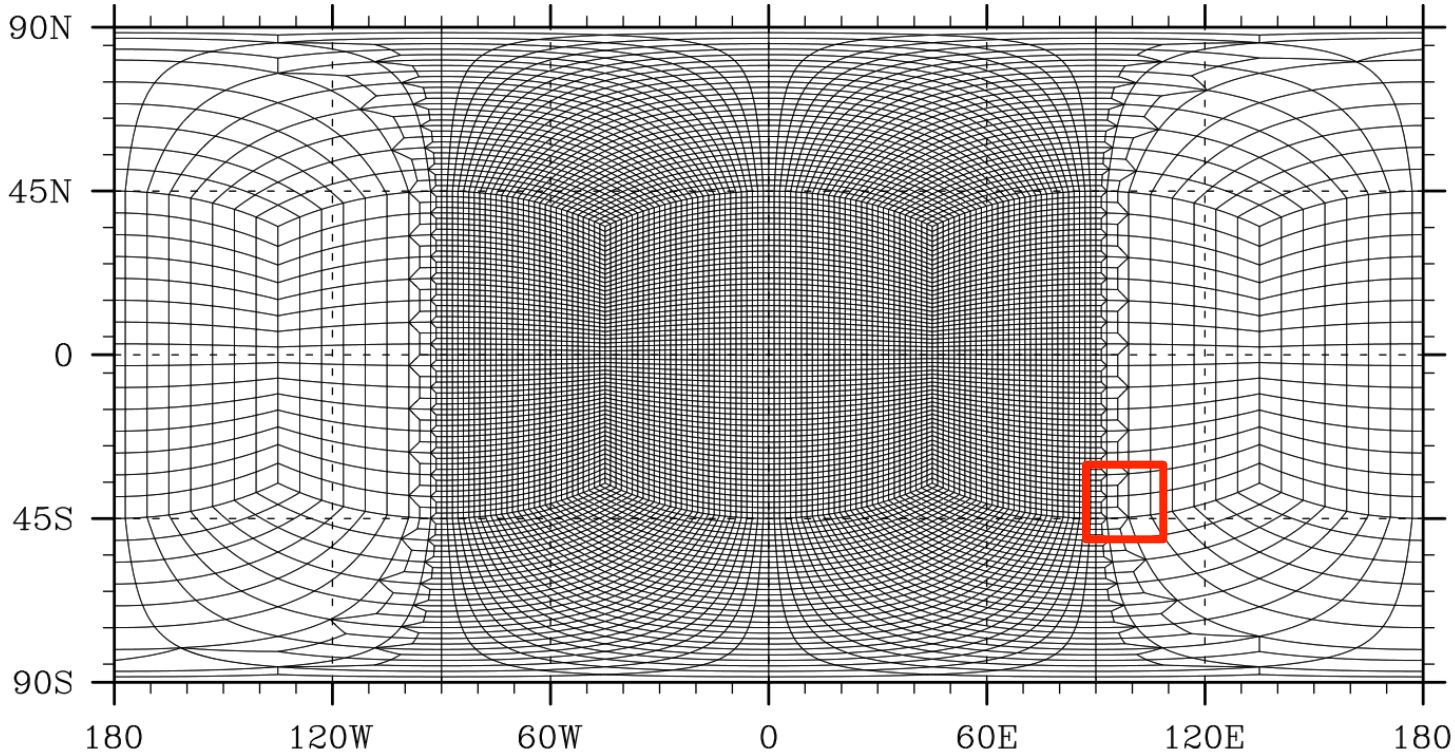

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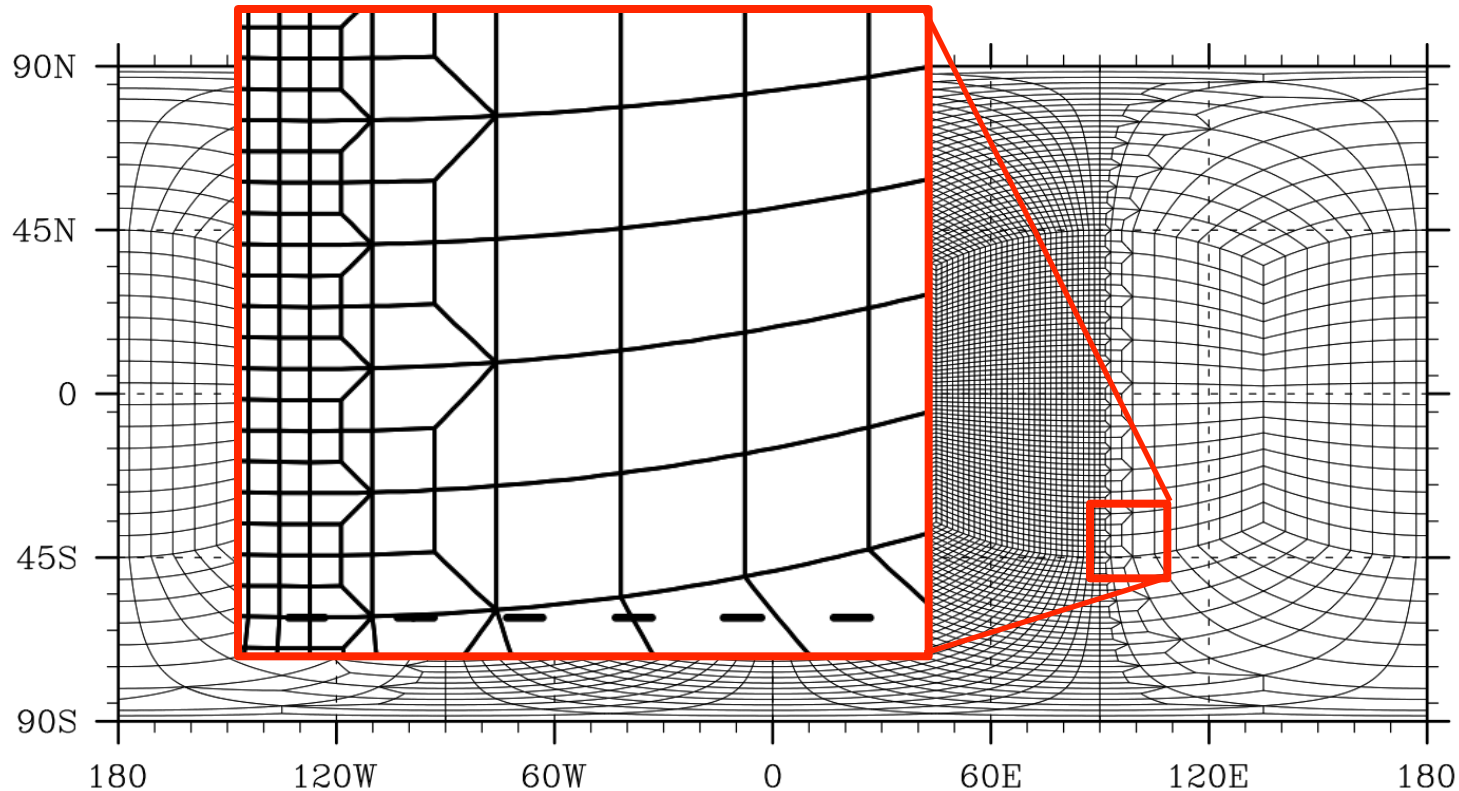

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Initial vortex:
v = 20 m/s
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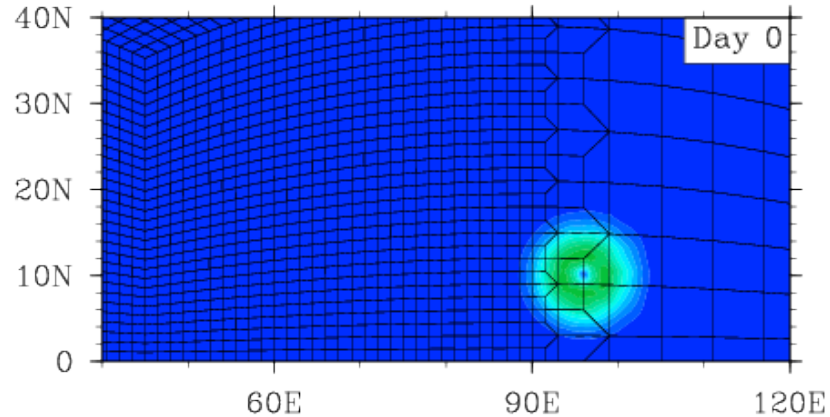
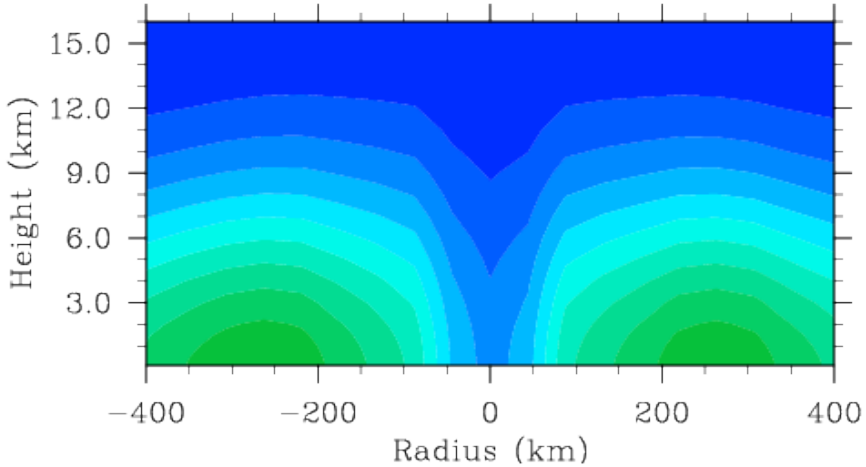


850 mb wind speed (m/s)

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



Latitudinal cross section wind speed (m/s)

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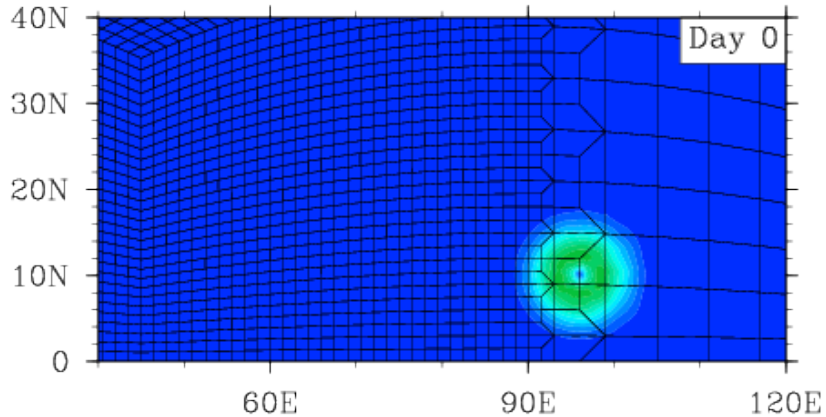
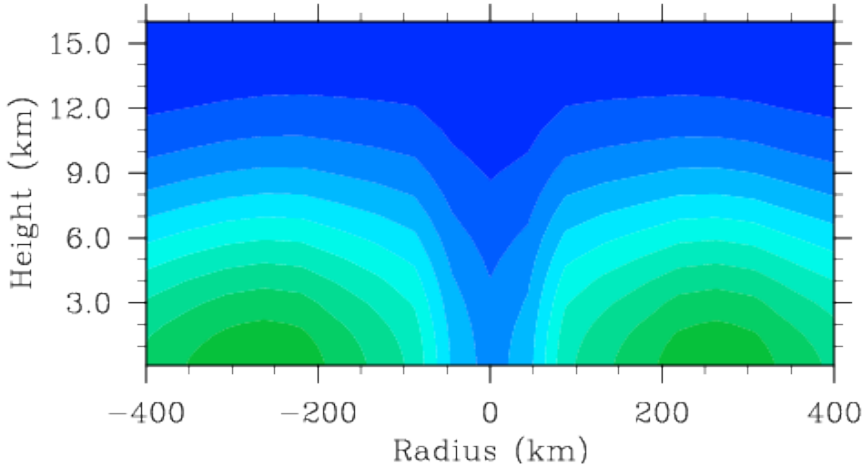


850 mb wind speed (m/s)

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



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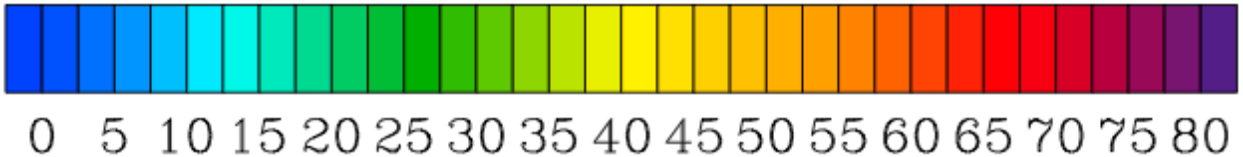

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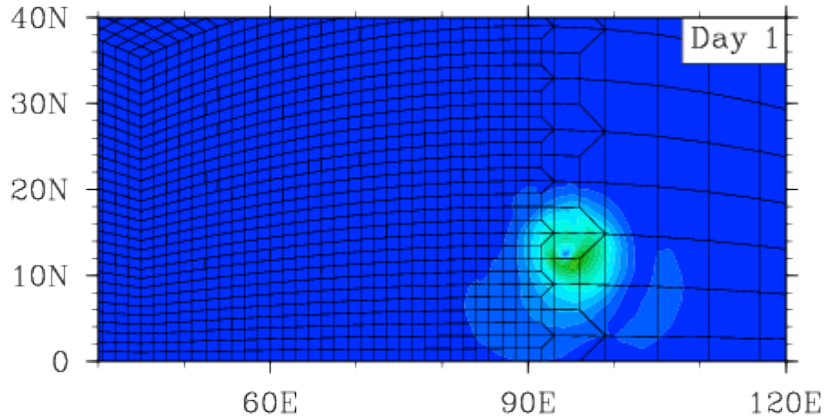

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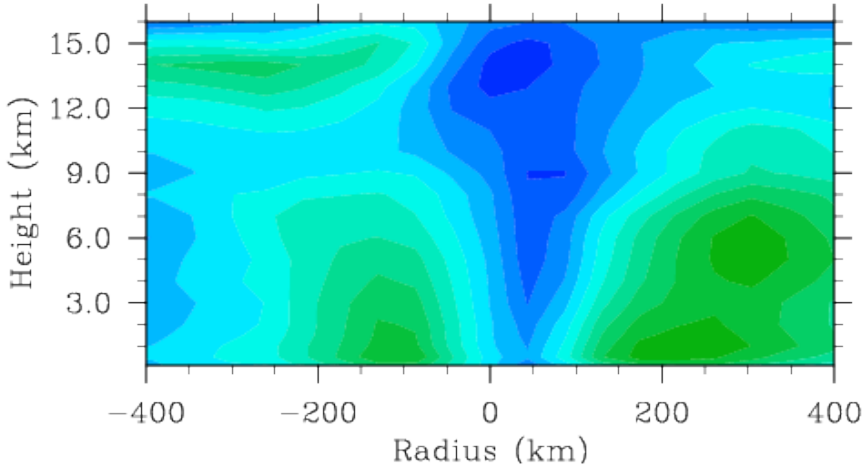

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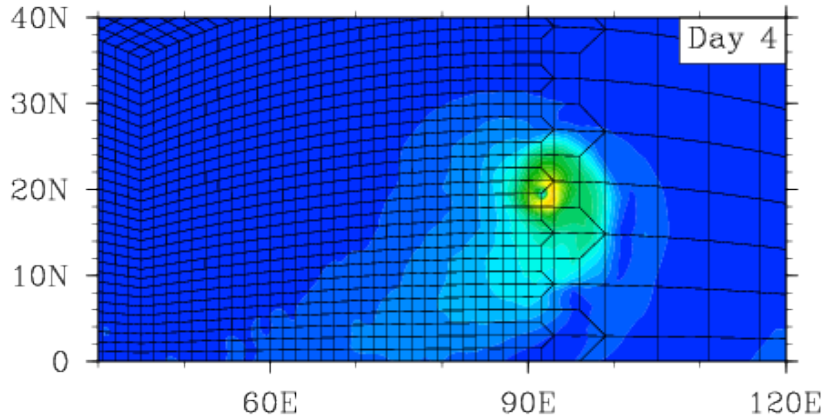

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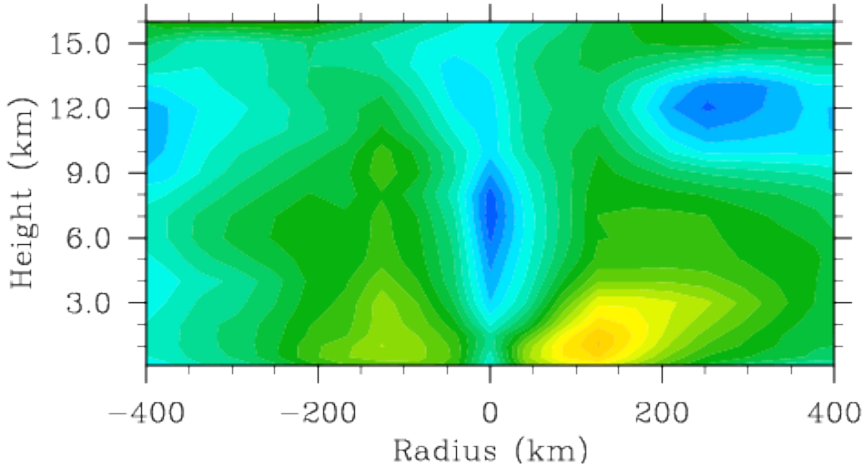

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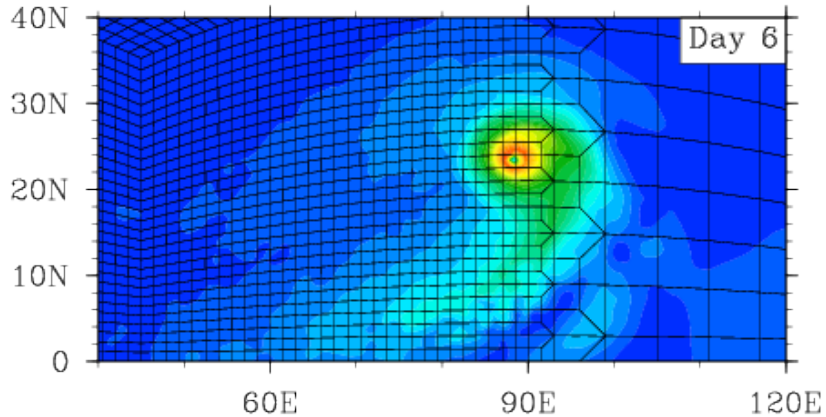

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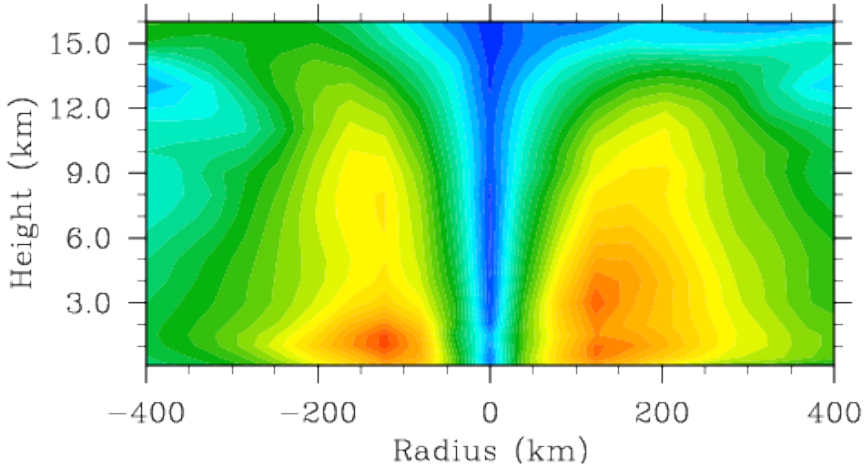

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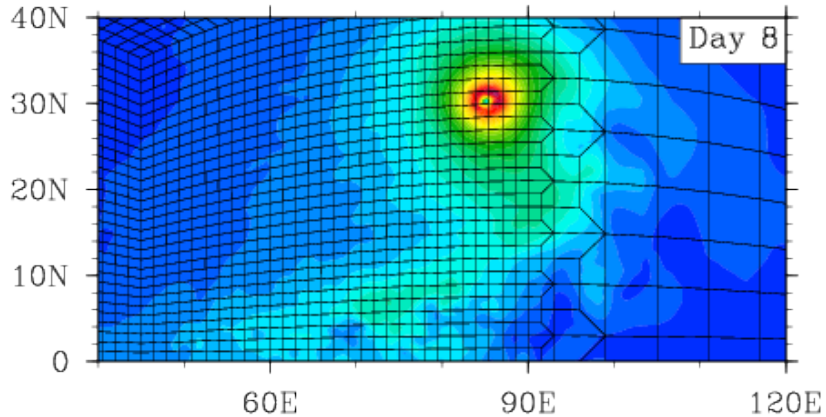

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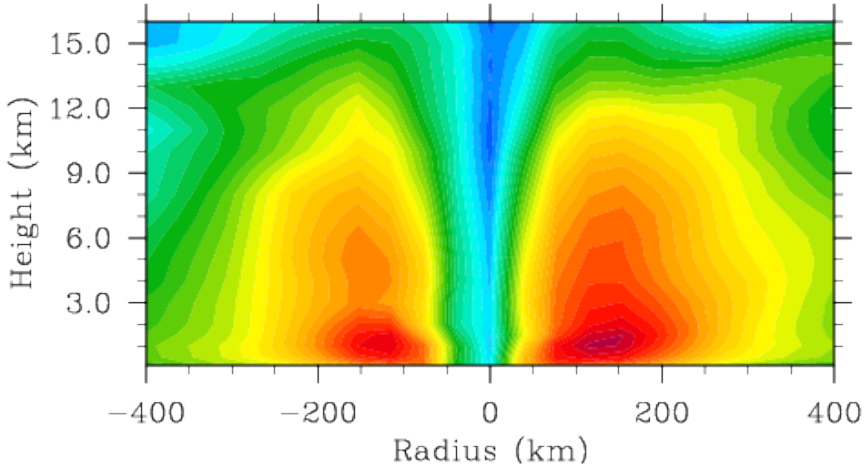

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Comparing “uniform” to “refined” meshes

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

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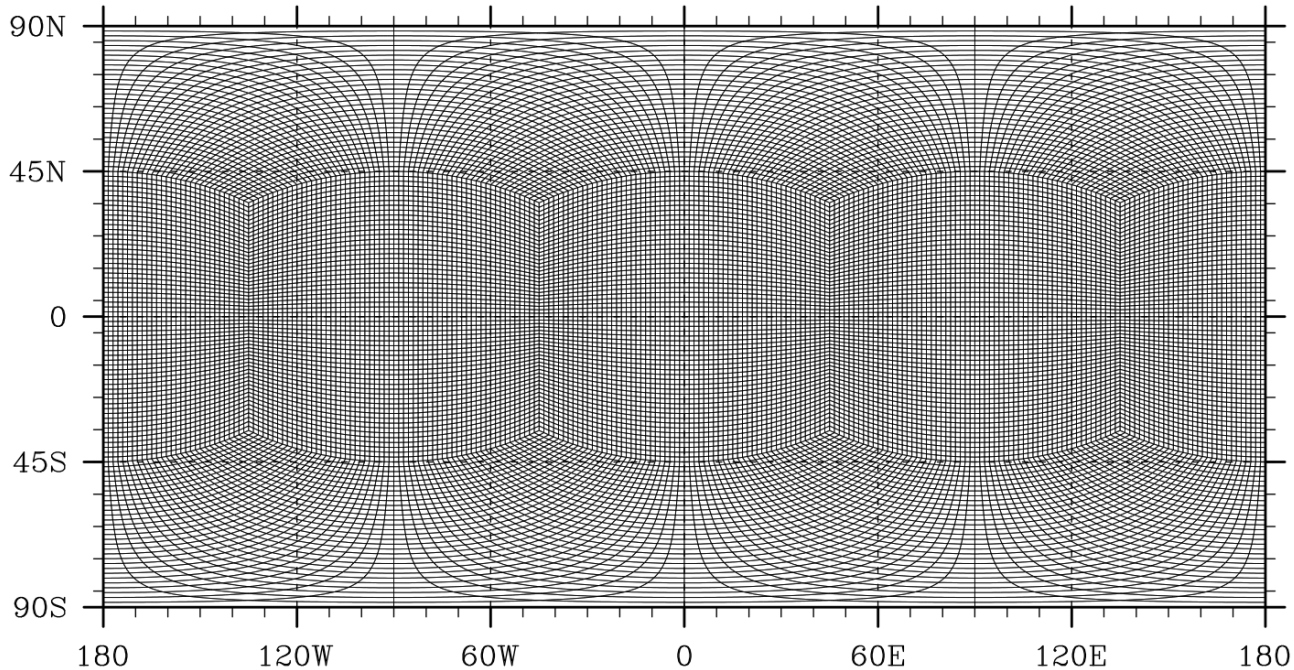

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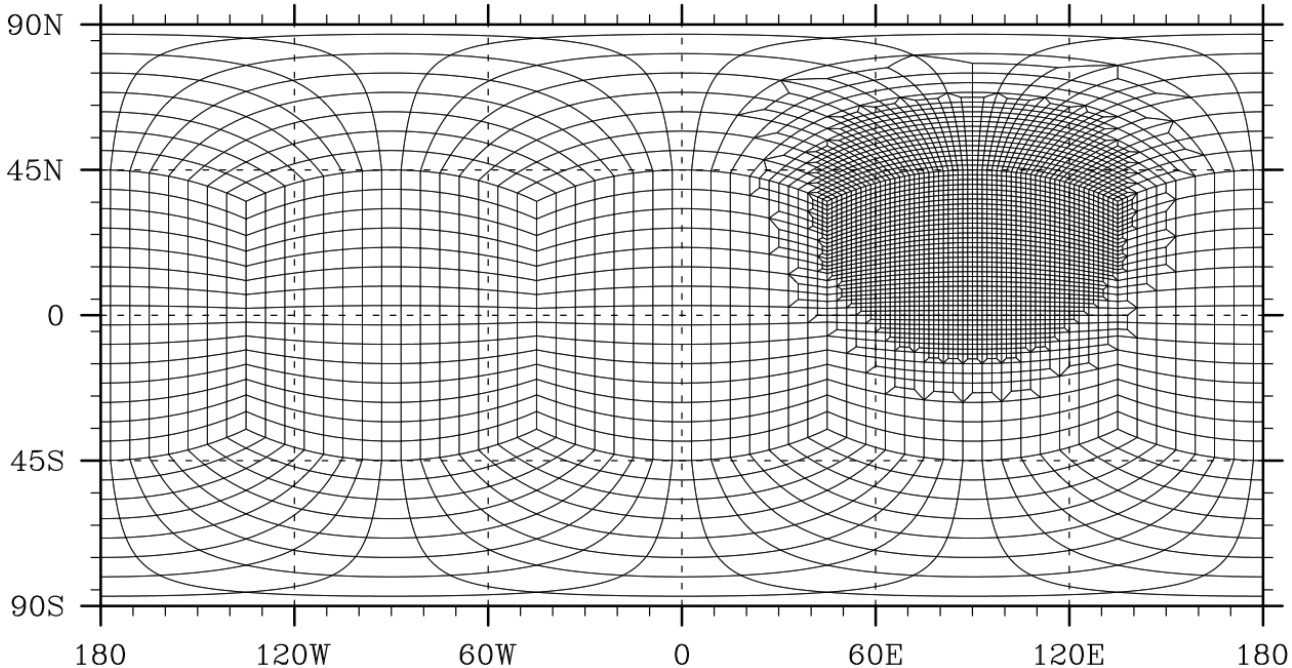

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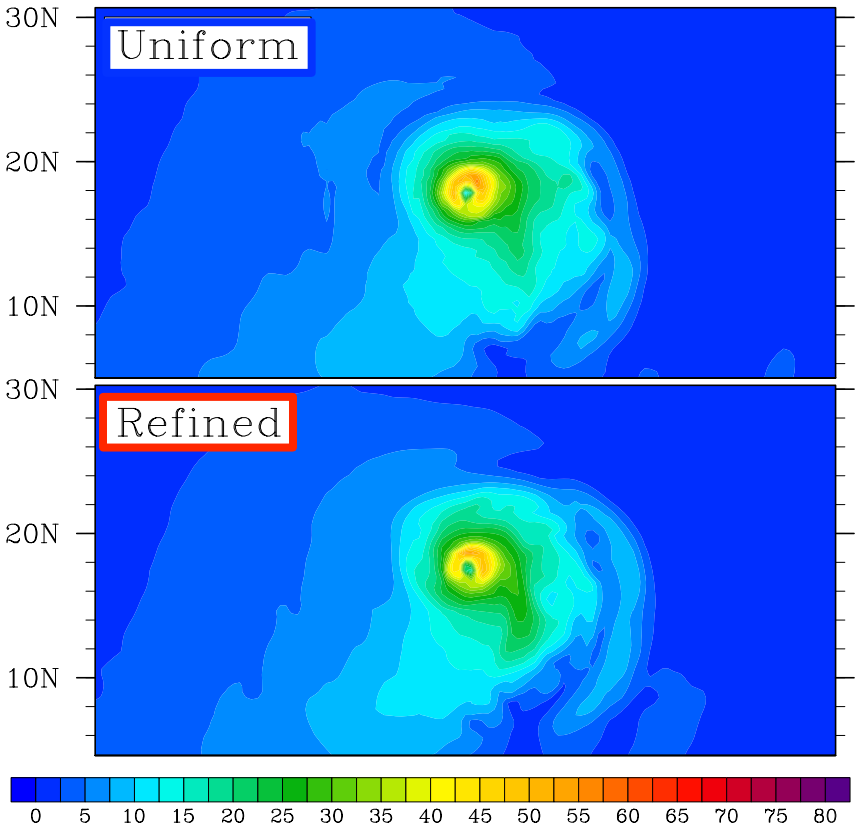

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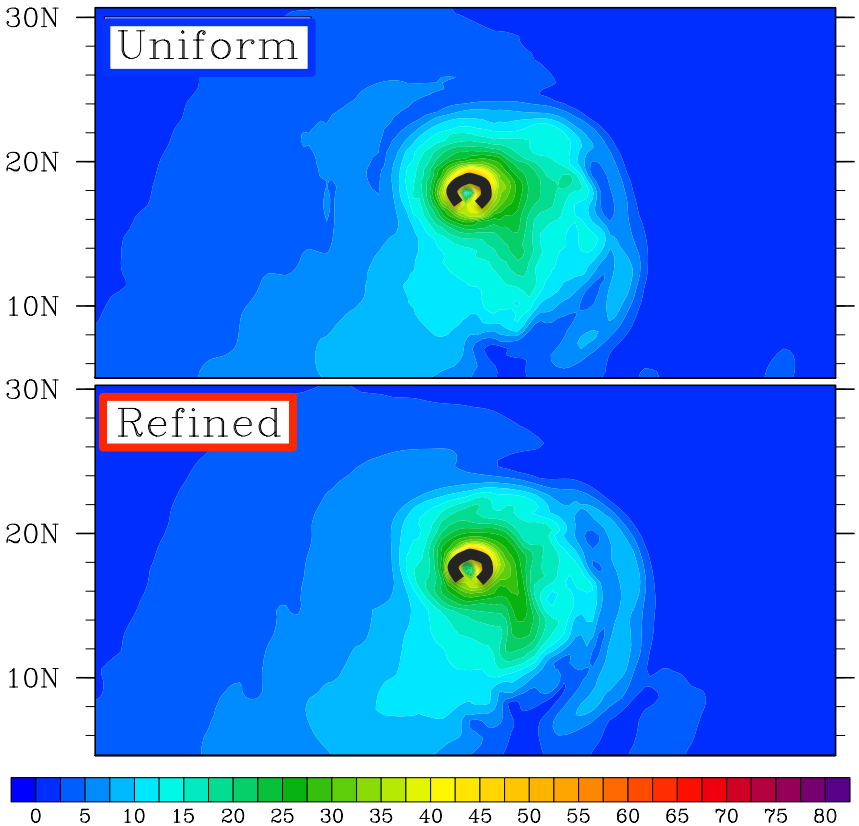

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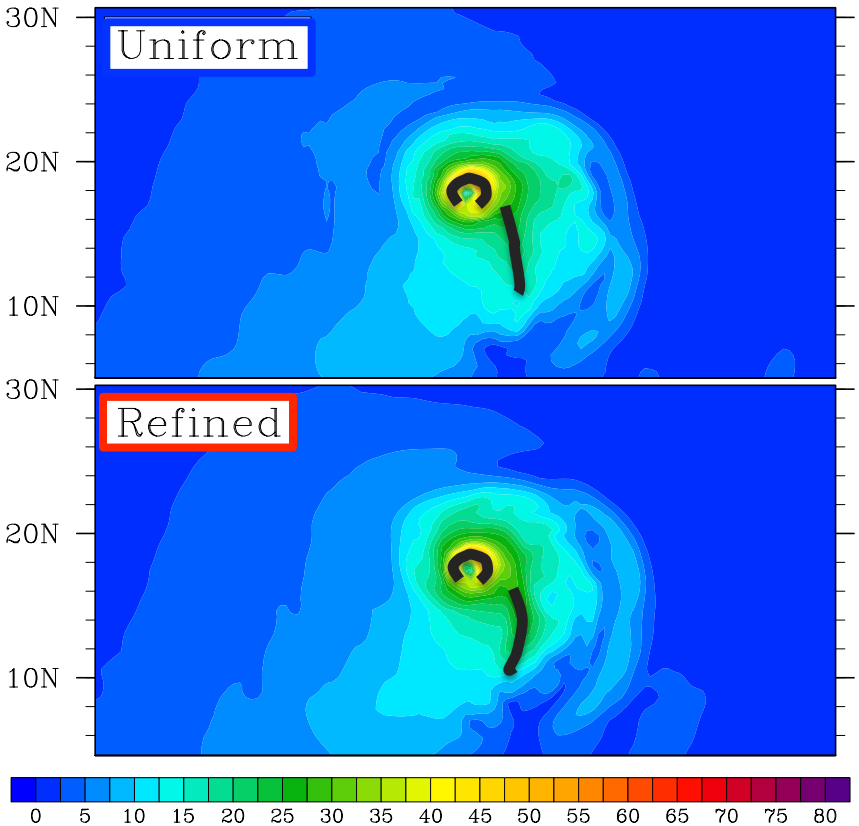

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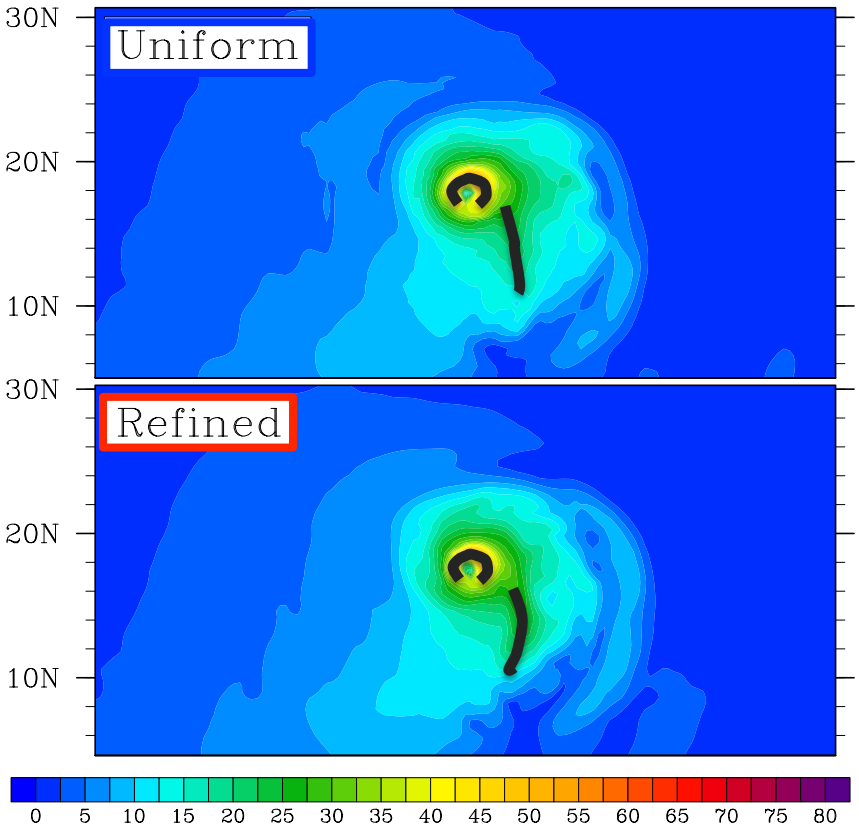

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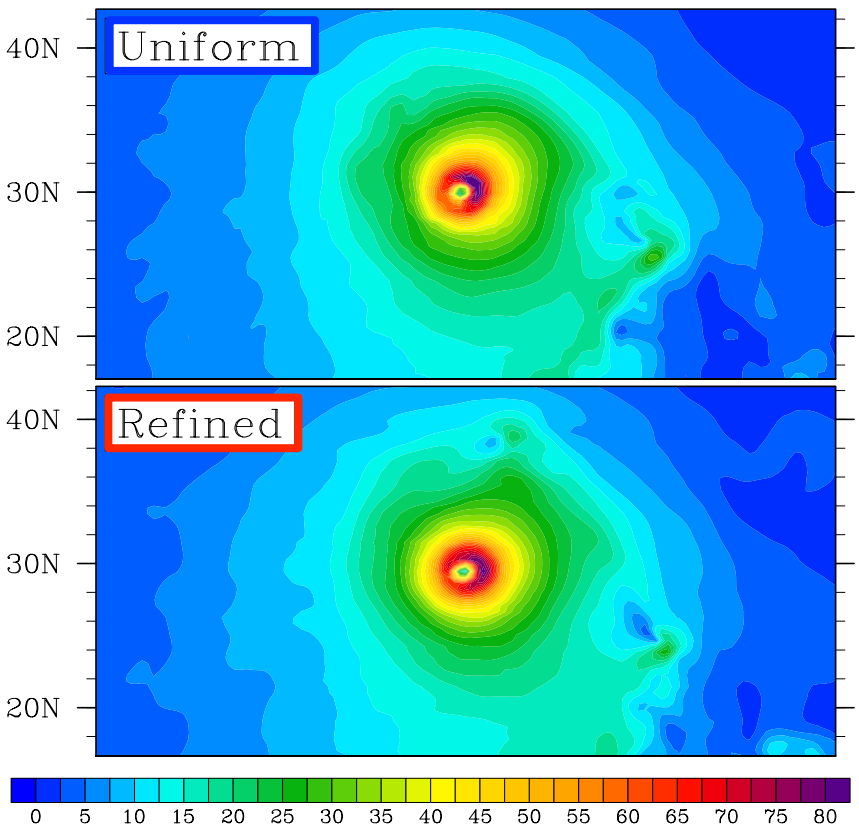

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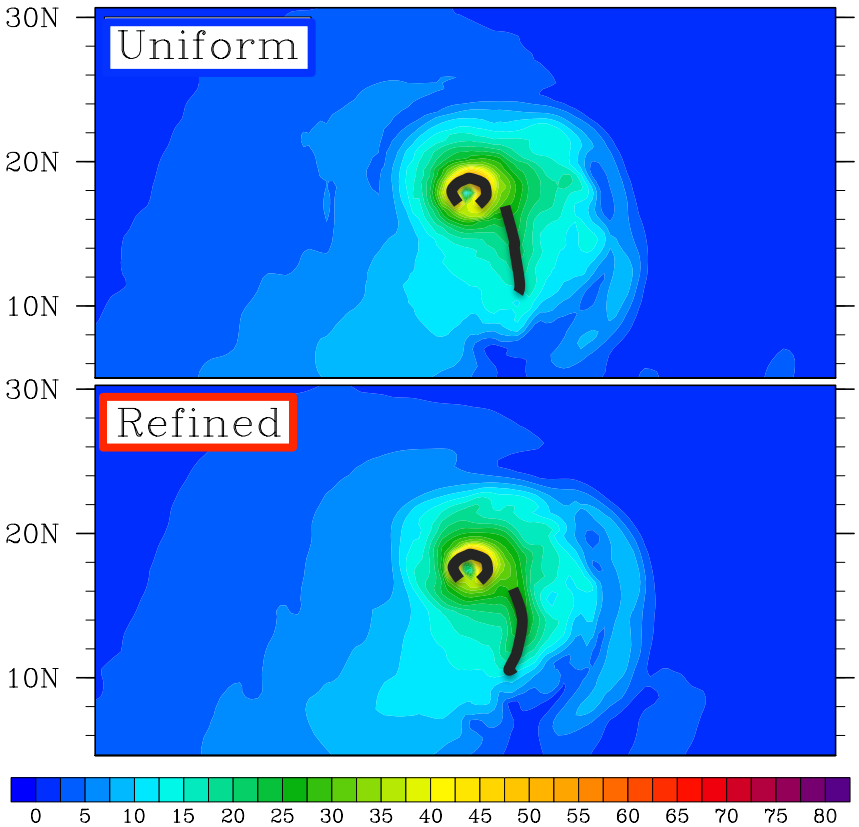

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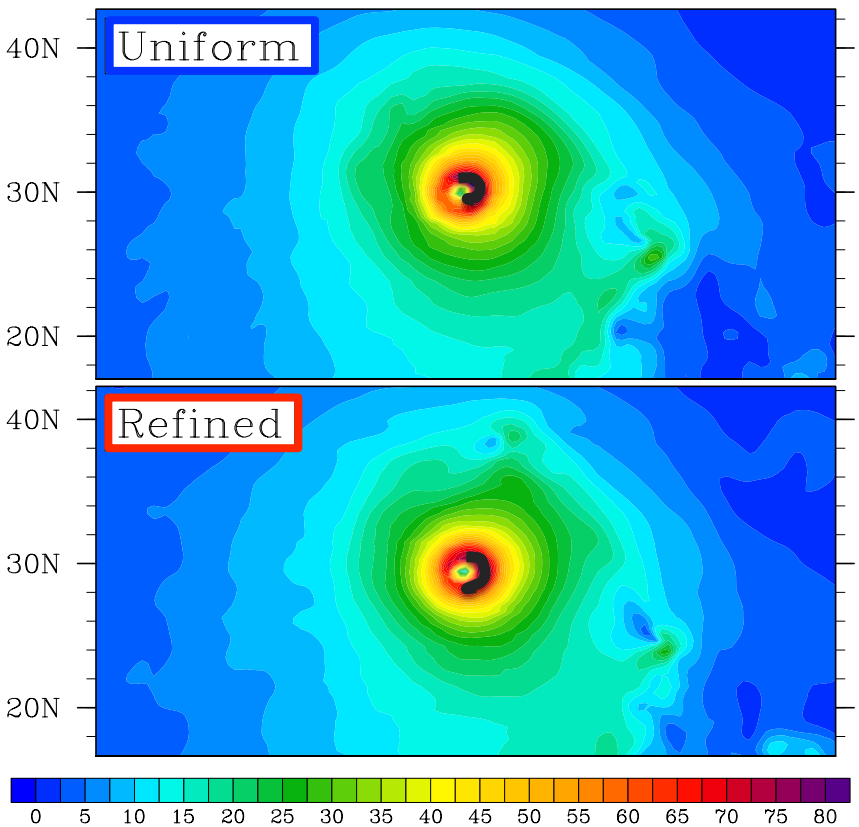

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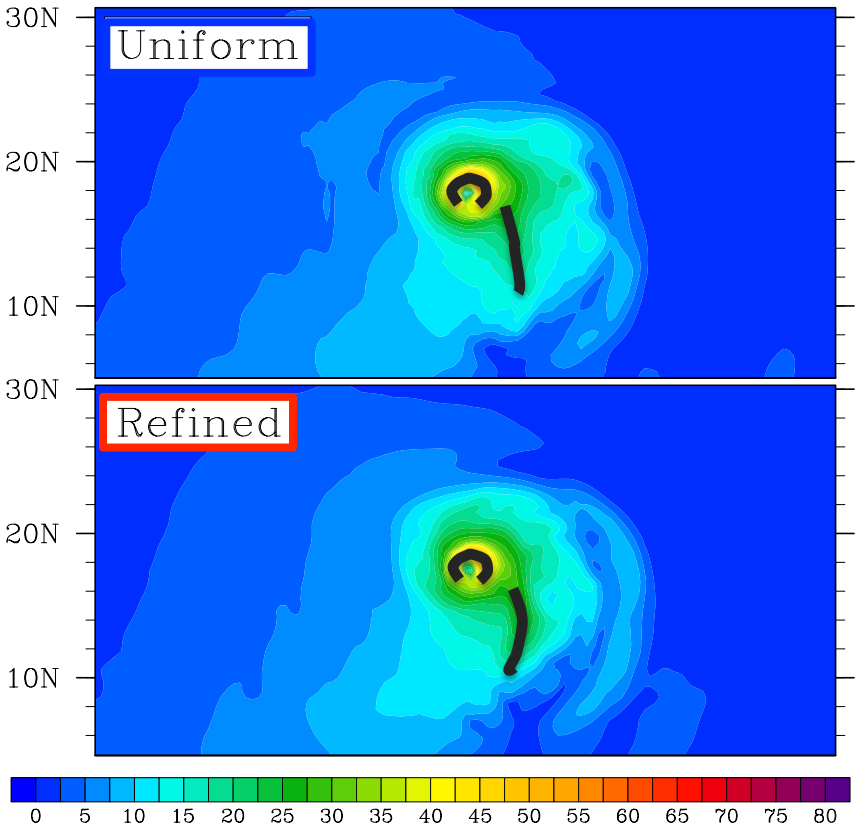

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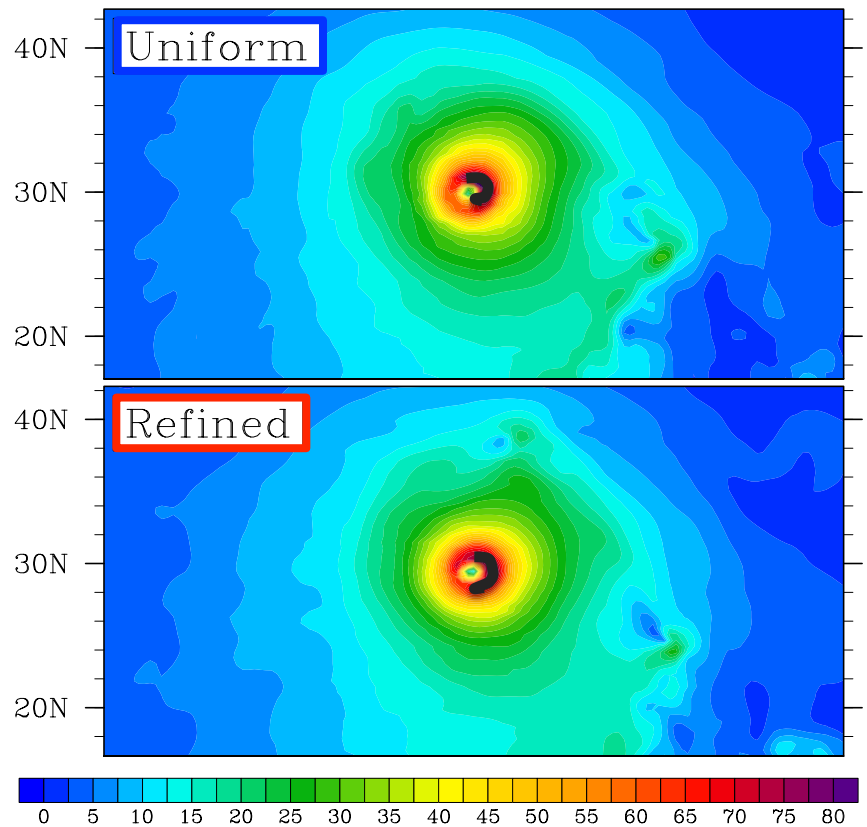

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- In reality? If **full uniform mesh** is equivalent to 1.0 "work units," **refined mesh** produces *essentially identical* results with **0.201** "work units"

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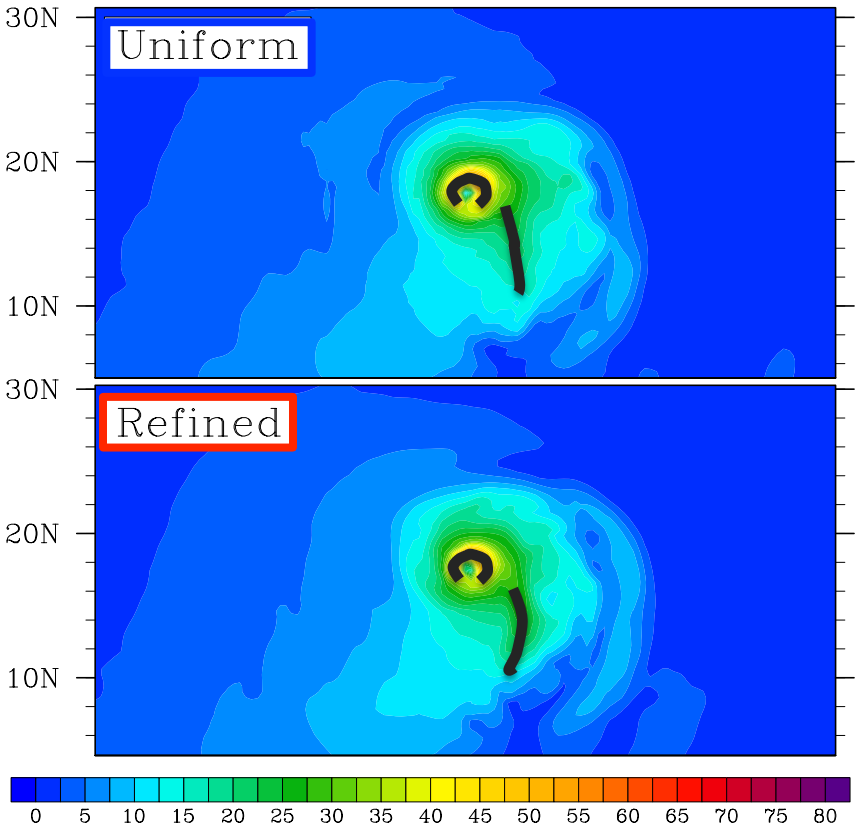

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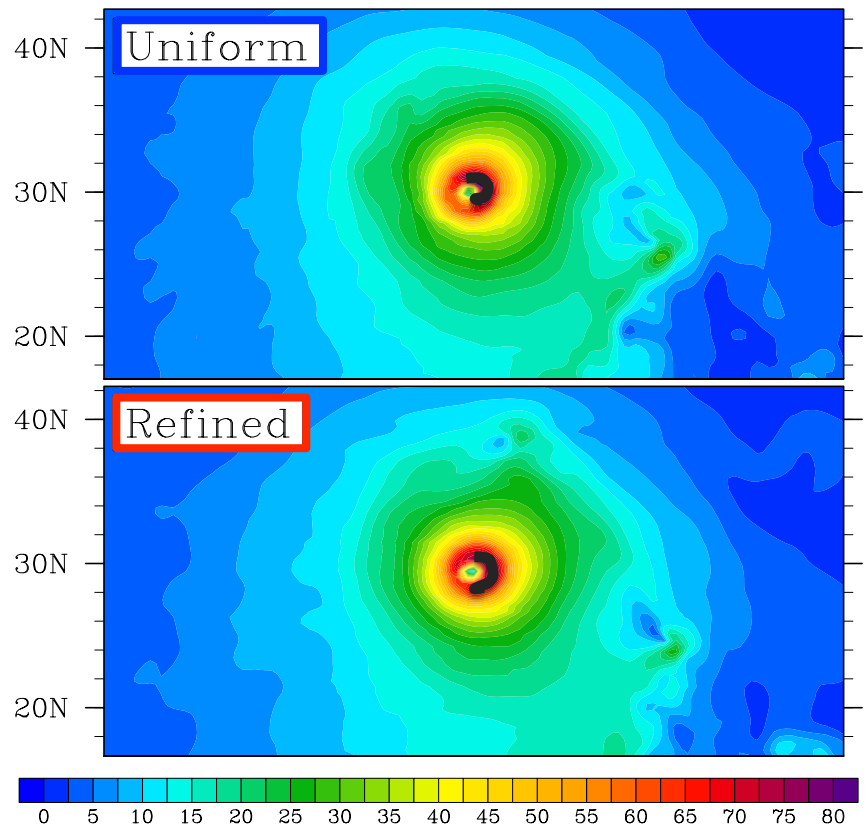

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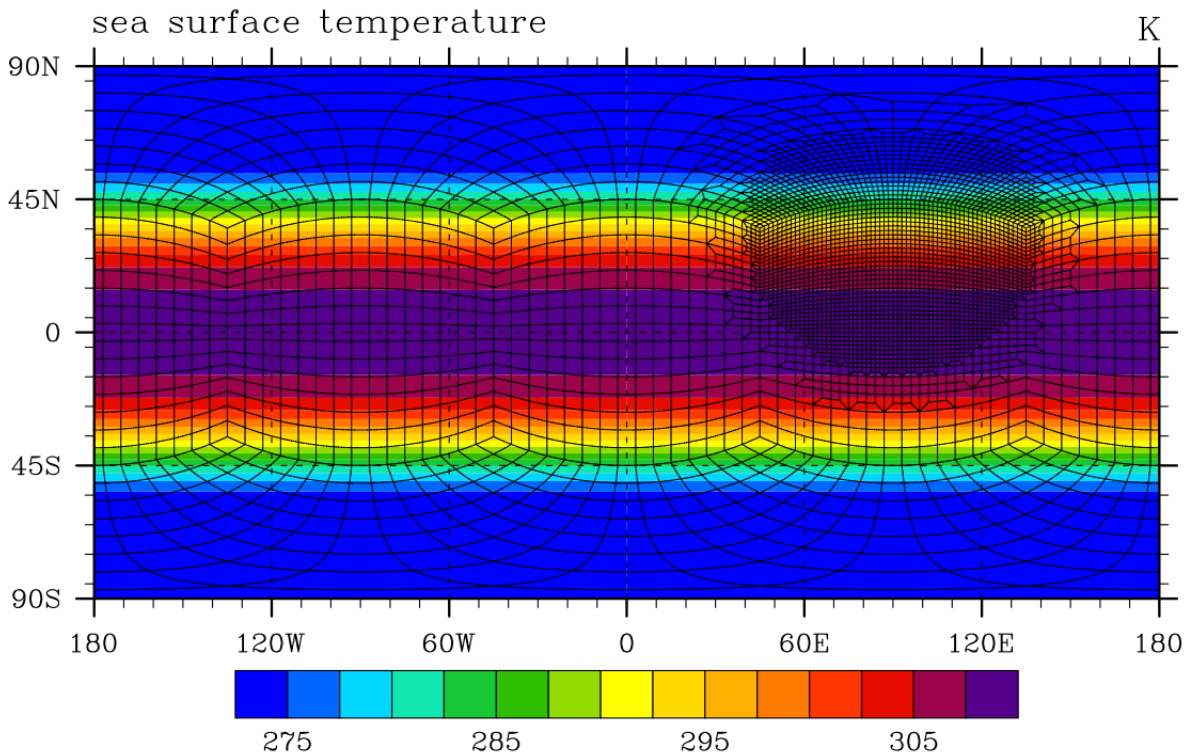
Year-long aquaplanet climate

- Use same refined mesh (~2° to ~0.5°) -> year-long aquaplanet climate
- Zonally-averaged SSTs, run for 14 months, discard first 2 as "spin-up"
- Simulation reaches steady state with features similar to observed climate system
- Provides **intermediate test** between short-term, deterministic studies (last few slides) and full-scale weather/climate simulations



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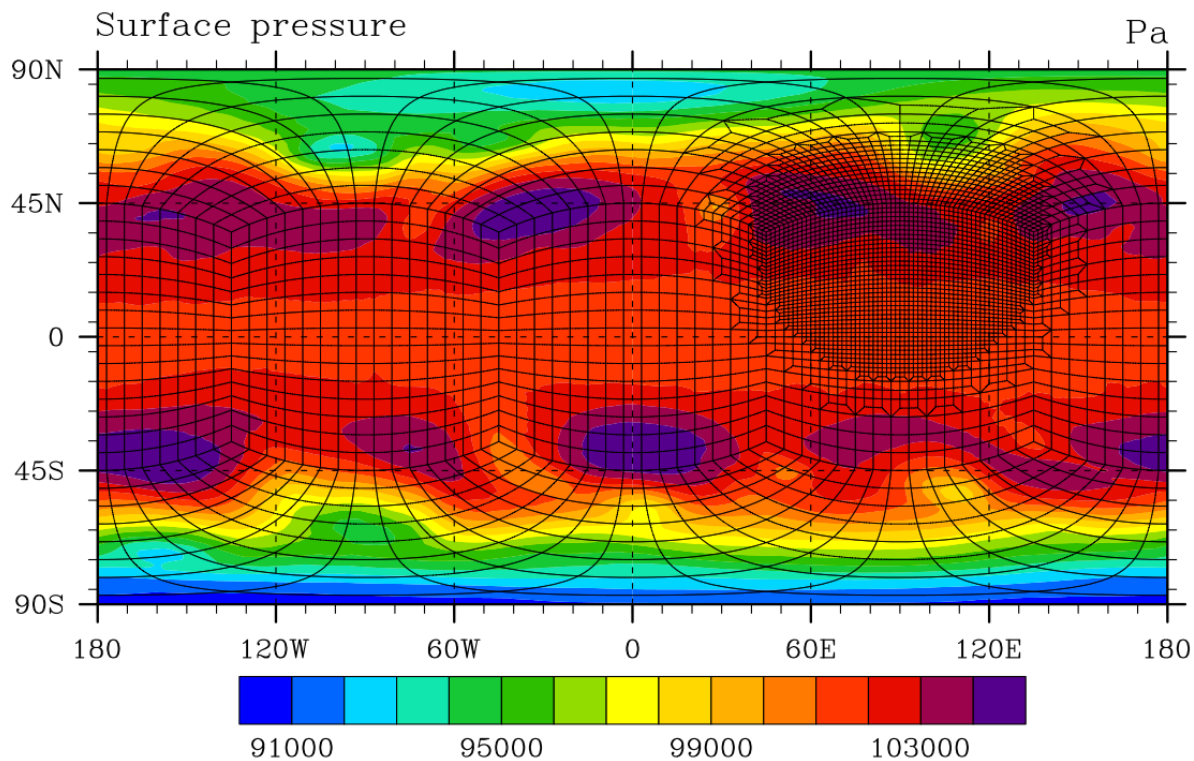

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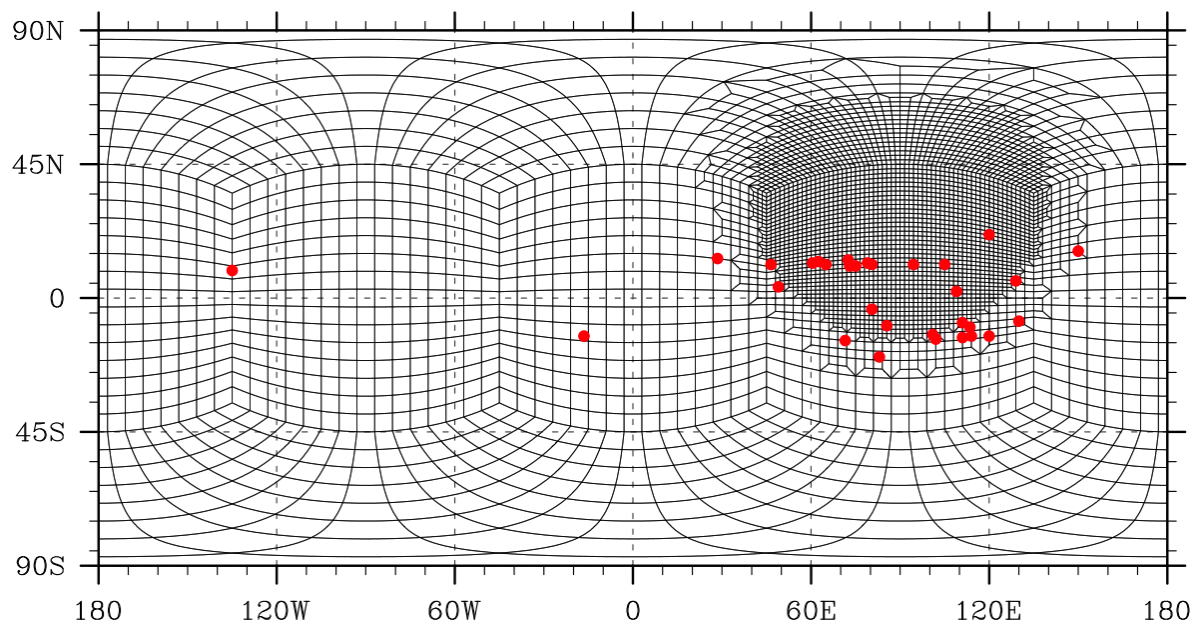
Red dots are cyclone origins. Detected using Vitart *et al.*, (1997) (GFDL) technique



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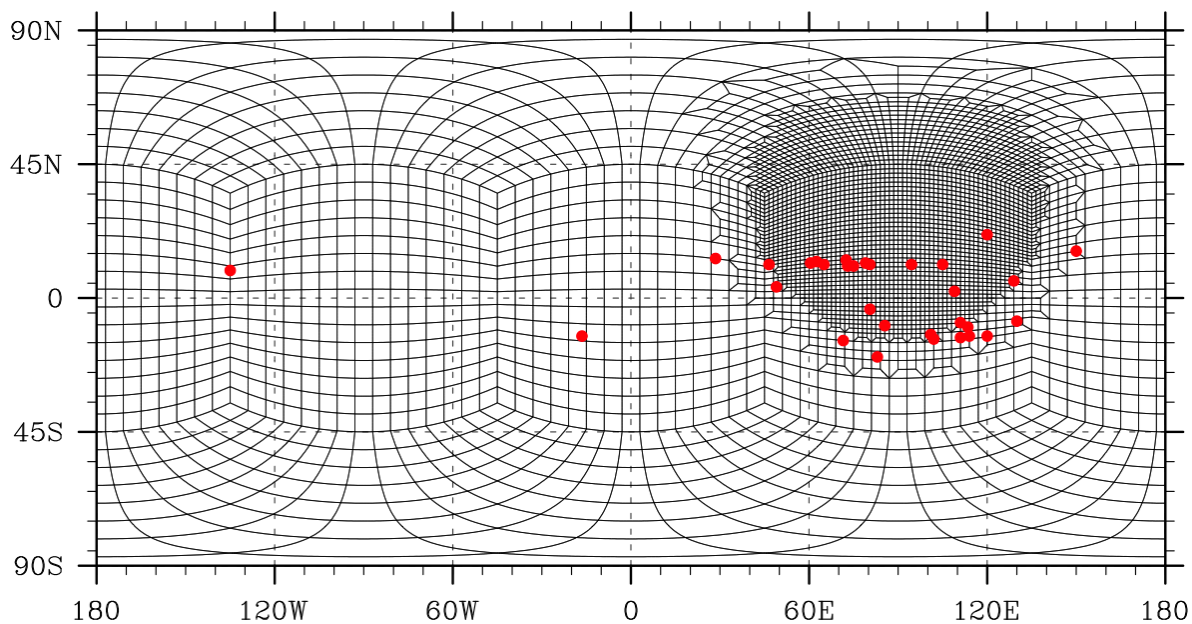
- Simulation reaches steady state with features similar to observed climate system
- Provides **intermediate test** between short-term, deterministic studies (last few slides) and full-scale weather/climate simulations

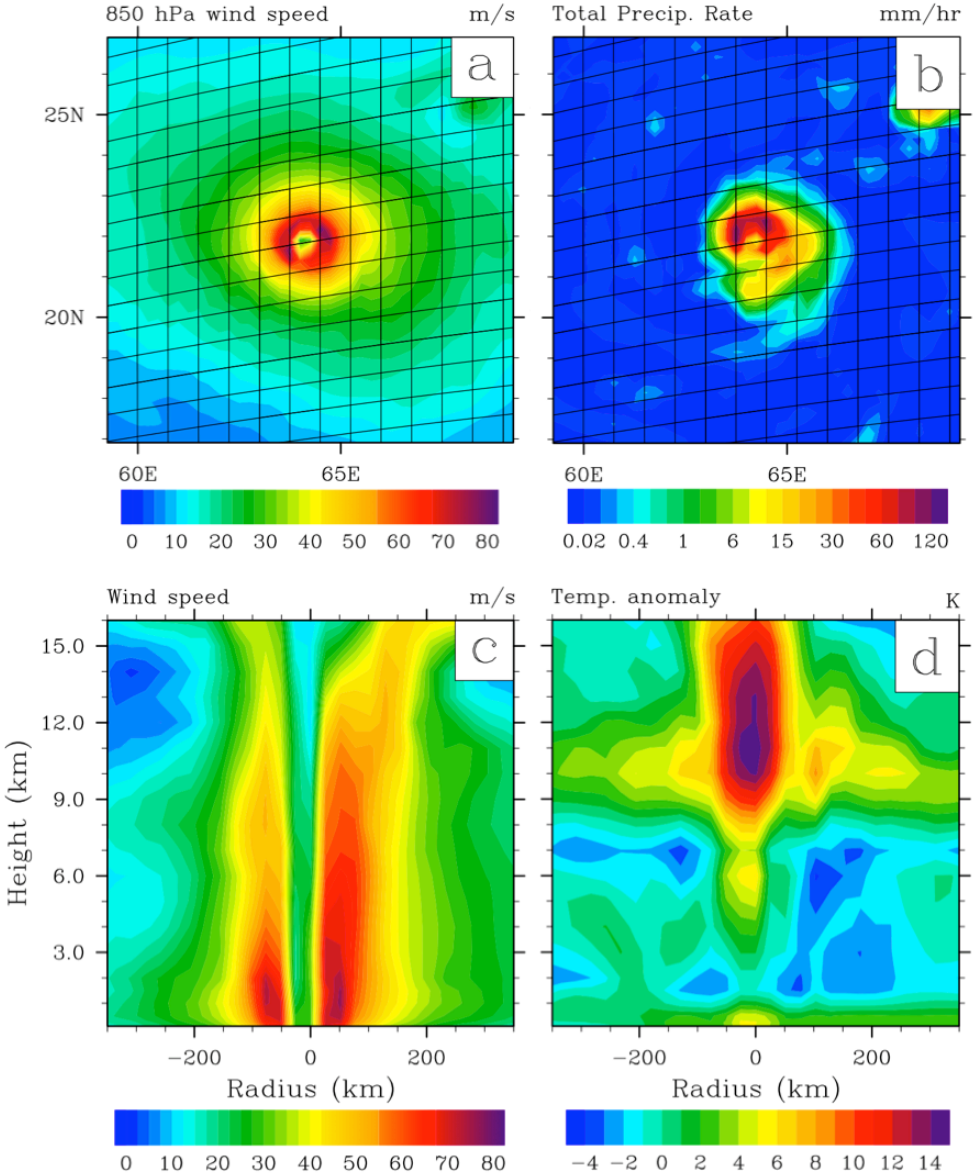
Red dots are cyclone origins. Detected using Vitart *et al.*, (1997) (GFDL) technique



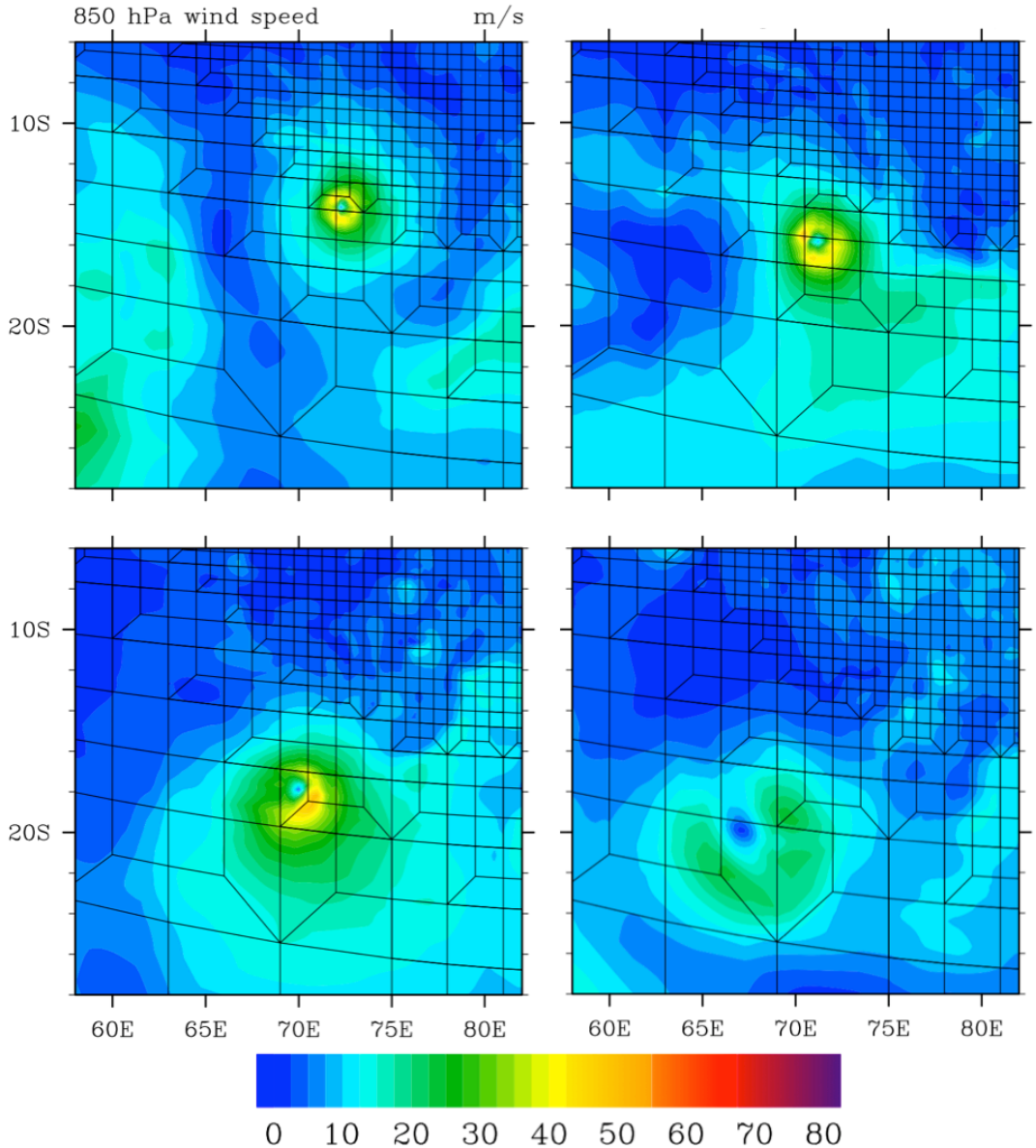
Spontaneous generation of cyclones in high resolution mesh

Aquaplanet cyclone in refined mesh

- Further refinement from ne15 -> ne120 (~0.25°)
- Example of one storm formed in northern hemisphere
- Category 4/5 equivalent cyclone - MSP: **911 hPa**, max near surface wind speed: **~75 m/s**
- **~25 km resolution** w/ computing power of **globally-uniform 50 km model**



Cyclone transition fine -> coarse



- Asymmetric mesh allows for development of TCs in southern hemisphere as well
- Pass out of mesh transition region as TCs, not extratropical systems
- **No numerical error or wave reflection back into refined domain**
- Cyclone expectedly weakens as grid spacing becomes larger

Summary

- Cyclones passing both in and out of mesh transition regions are **well-maintained** and expected storm intensity increases/decreases are observed when cyclones **move into/out of refined areas.**
- 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 realistic TC structure** and simulations are able to **generate TCs without vortex seeds** on an aquaplanet with regionally-refined nest
- Careful refinement selection can provide a **doubling (or more) of regional resolution for the same computational cost** when compared to a globally-uniform model

Thank you!