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University of Michigan

Evaluating the Impact of Localized GCM Grid Refinement on Regional Tropical Cyclone Climatology and Synoptic Variability

Colin M. Zarzycki, Christiane Jablonowski
University of Michigan

Motivation

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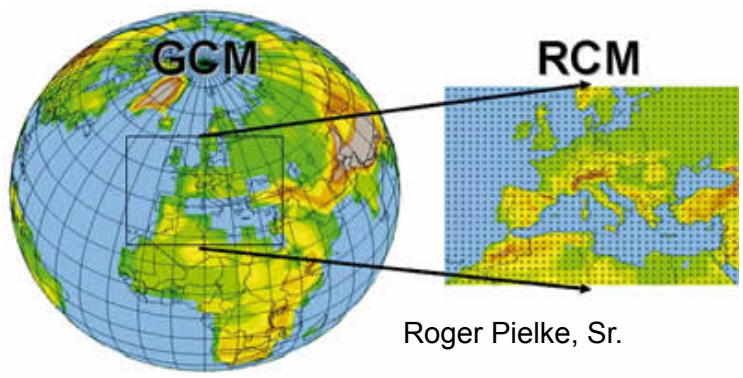
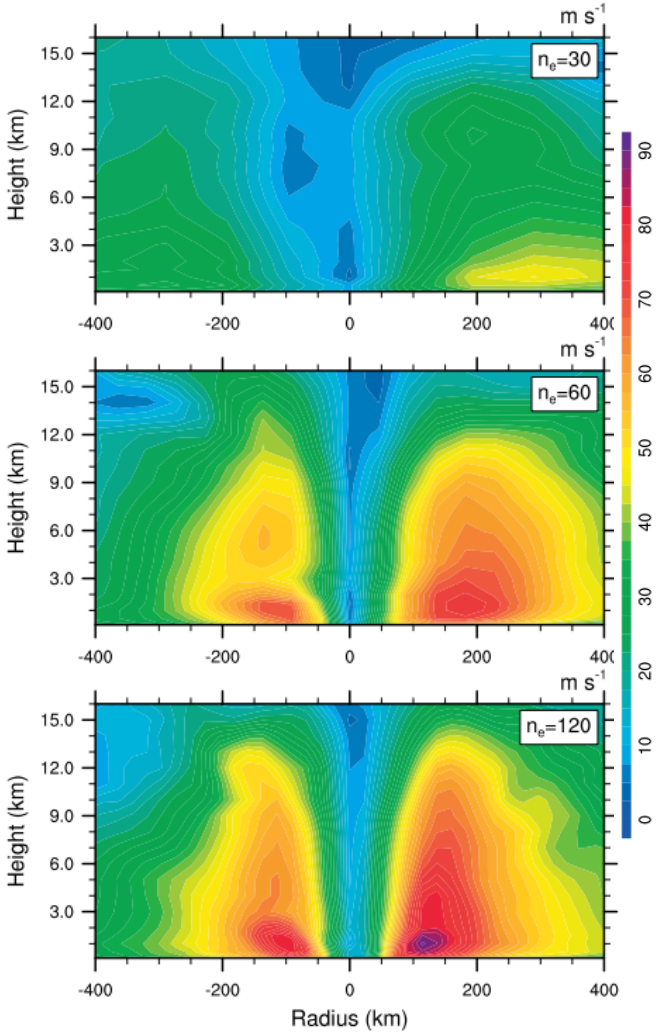
- Modeling sub-synoptic scale features in *global* numerical models requires **high horizontal resolution**
  - Largely function of computational ability
  - Examples:
    - Tropical cyclones
    - High-intensity precipitation events
- Can improve resolution through use of *limited area* models
  - "Target" computing resources by only simulating specific region
  - Some issues requiring addressing…
    - Lateral boundary conditions
    - One-way vs. two-way nesting



Roger Pielke, Sr.



Reed et al., 2012

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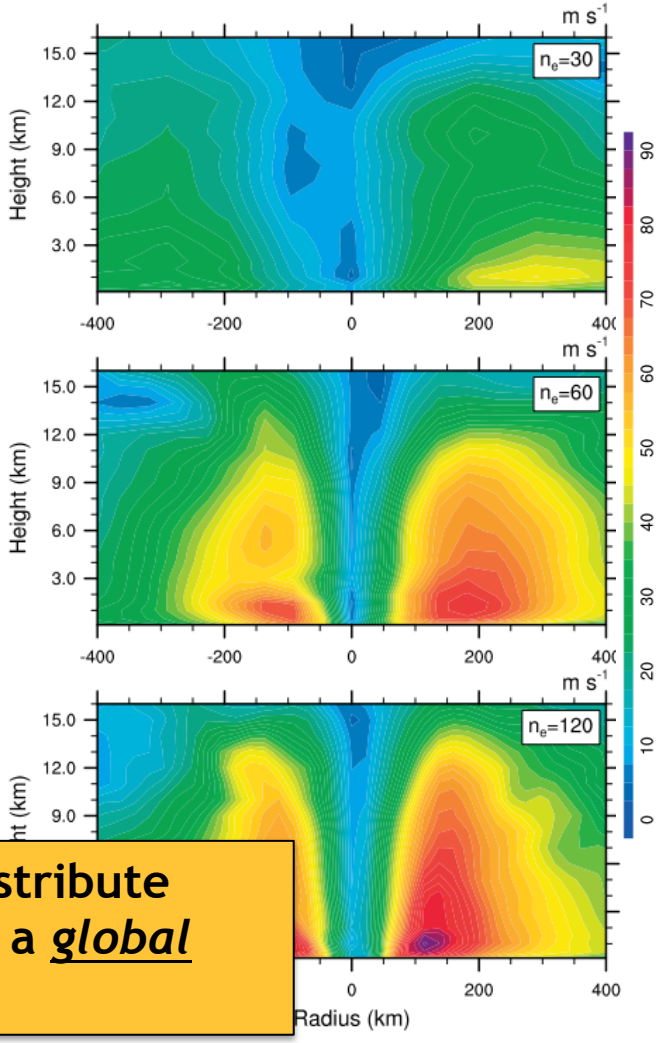

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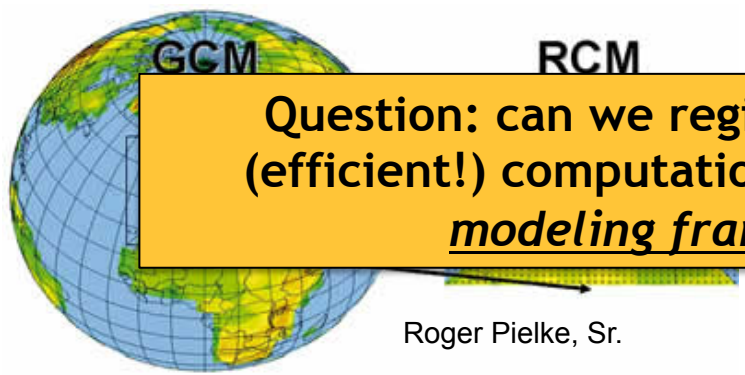

Question: can we regionally distribute (efficient!) computation load in a *global modeling framework*?

Roger Pielke, Sr.

Variable-resolution CAM-SE

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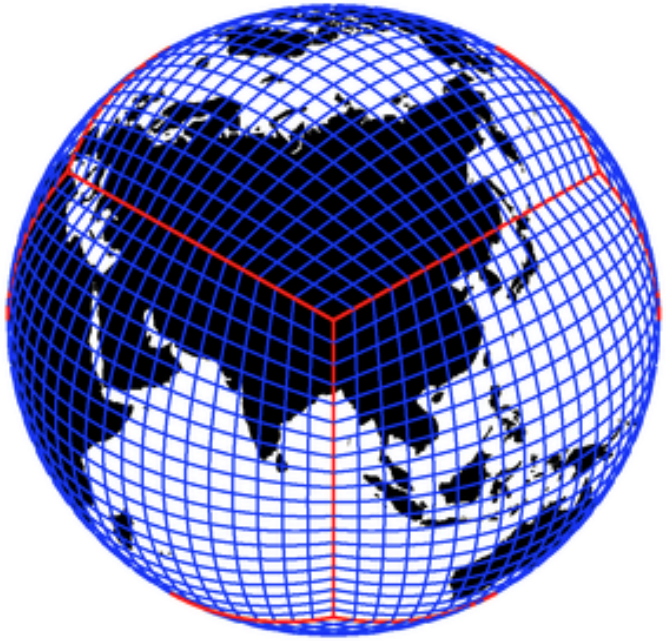
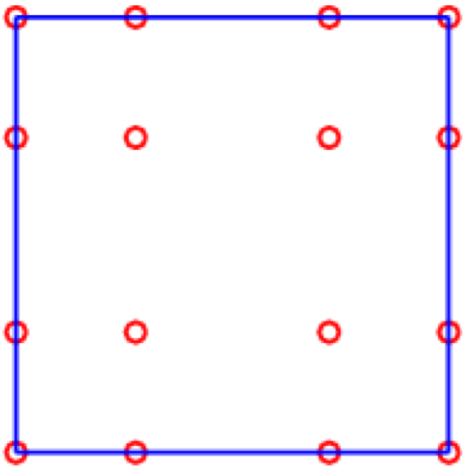
- NCAR **C**ommunity **A**tmosphere **M**odel **S**pectral **E**lement (CAM-SE) dynamical core
  - ***Cubed-sphere grid***
    - Quasi-uniform, no pole convergence
  - Solve primitive eqns in local spectral space
    - Only nearest neighbor communication required
    - Highly scalable
  - **Provide flexible framework for static grid nesting**





Variable-resolution CAM-SE

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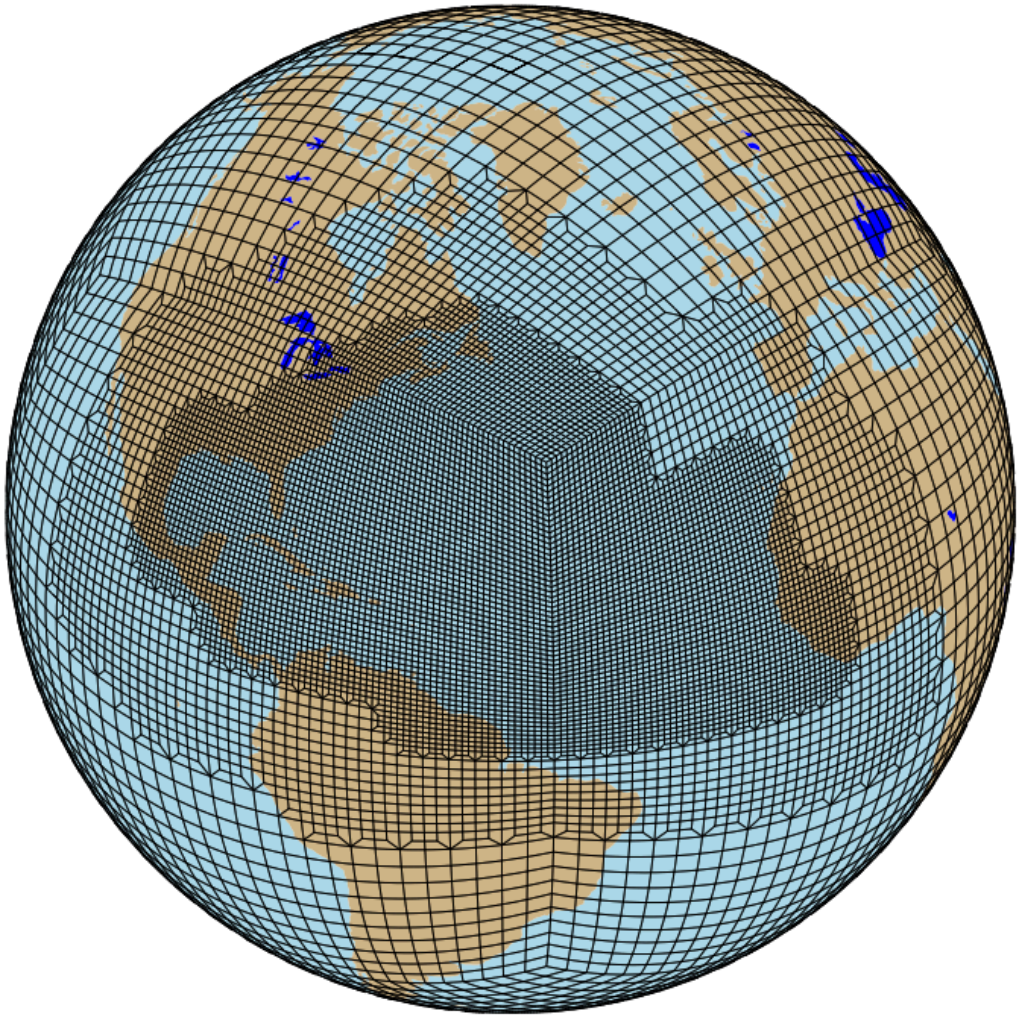
- Atlantic refinement: 1° (~110 km) x 4 (2^2) (fine = 0.25° = ~26 km)
- Refinement done in CUBIT (Sandia) software package



- Timestep globally restricted to finest grid scale
- Fourth-order hyperviscosity (explicit diffusion)
  - Scaled by "longest" element axis (scalar)
  - New formulation being tested in shallow-water (tensor)

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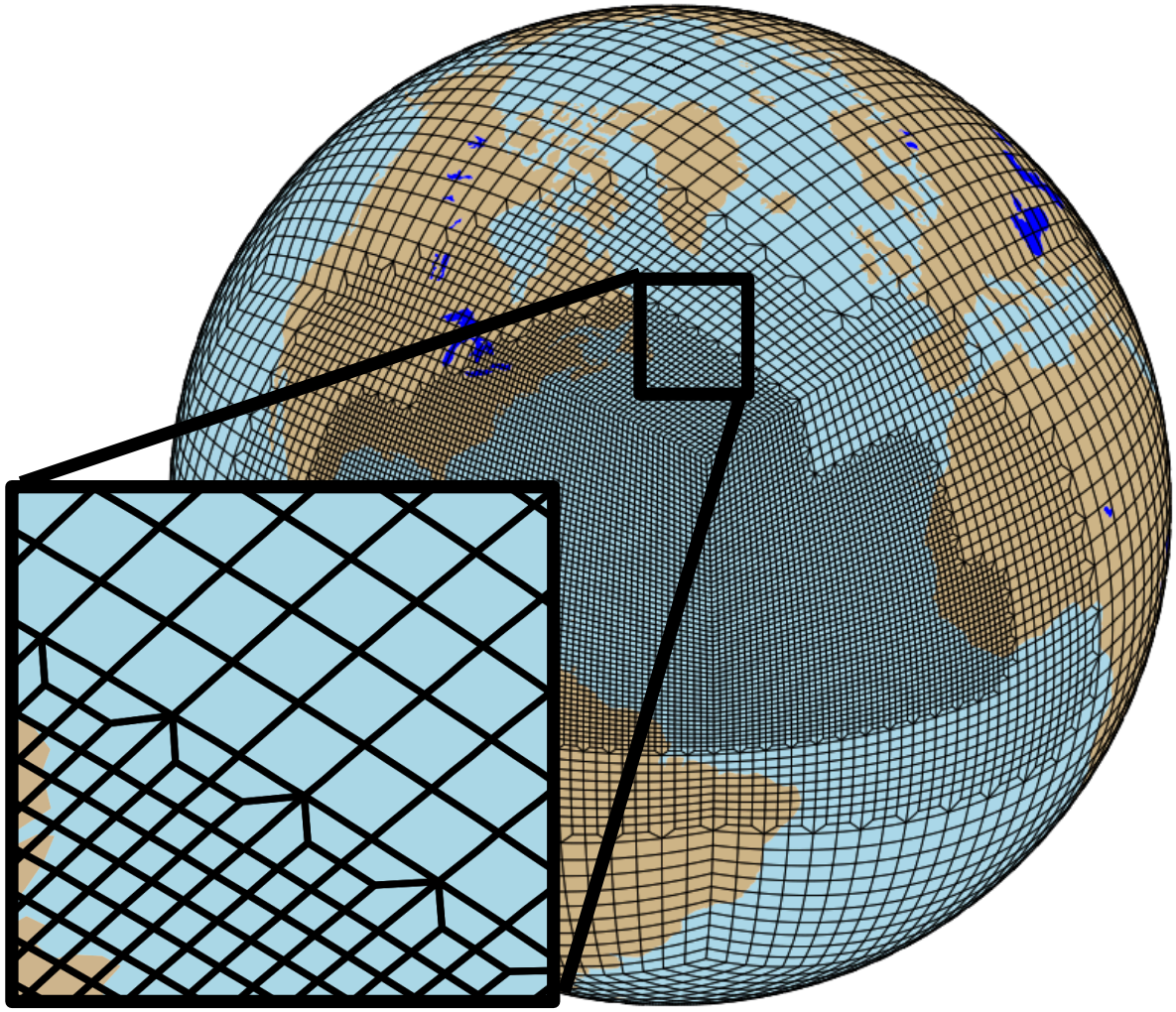

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Climate simulations

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- **A**tmospheric **M**odel **I**ntercomparison **P**roject (AMIP) protocols
  - 1980-2002 (23 years)
  - Observed SST, O_3, aerosol, solar forcing, etc.
- Two different atmosphere grids
  - Globally uniform 1° (**UNI**) (~110 km)
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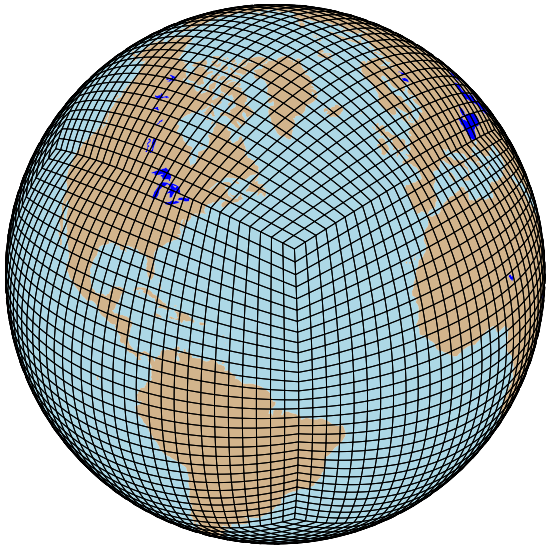

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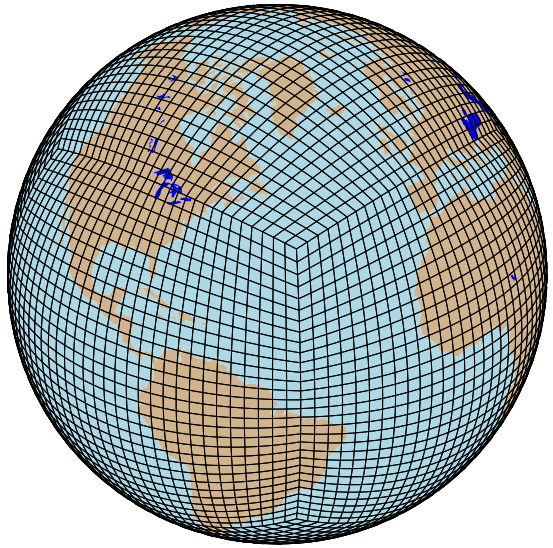

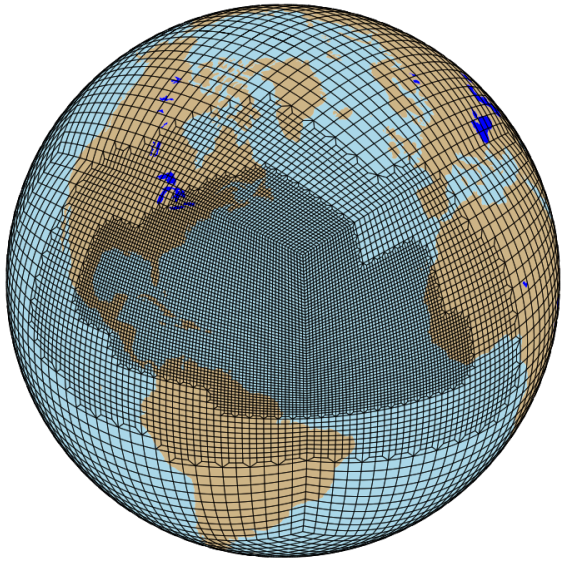

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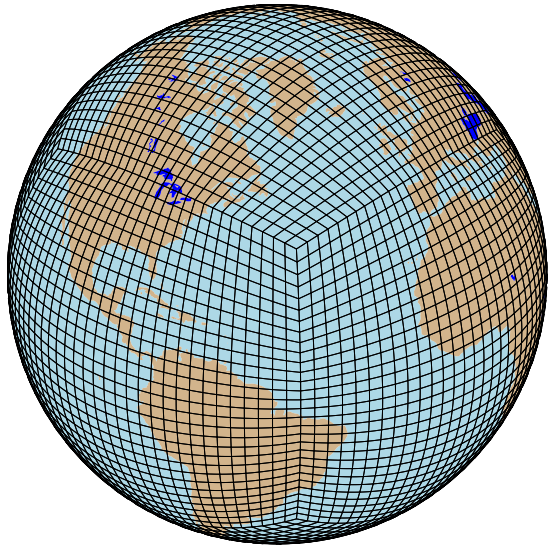

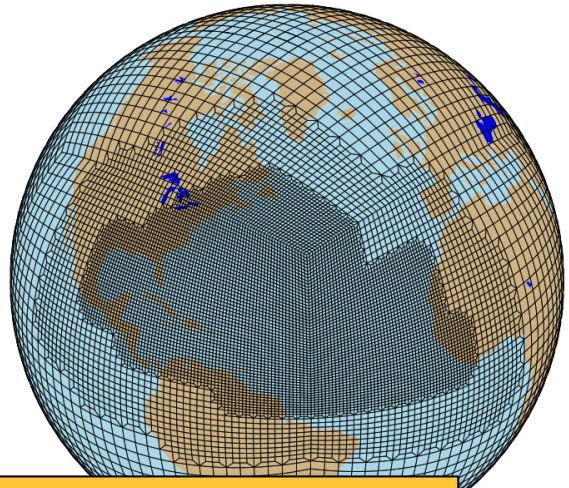

Goal: Resolve "fine-scale" systems in Atlantic Ocean while doing "no harm" to global solution

Uniform global simulation

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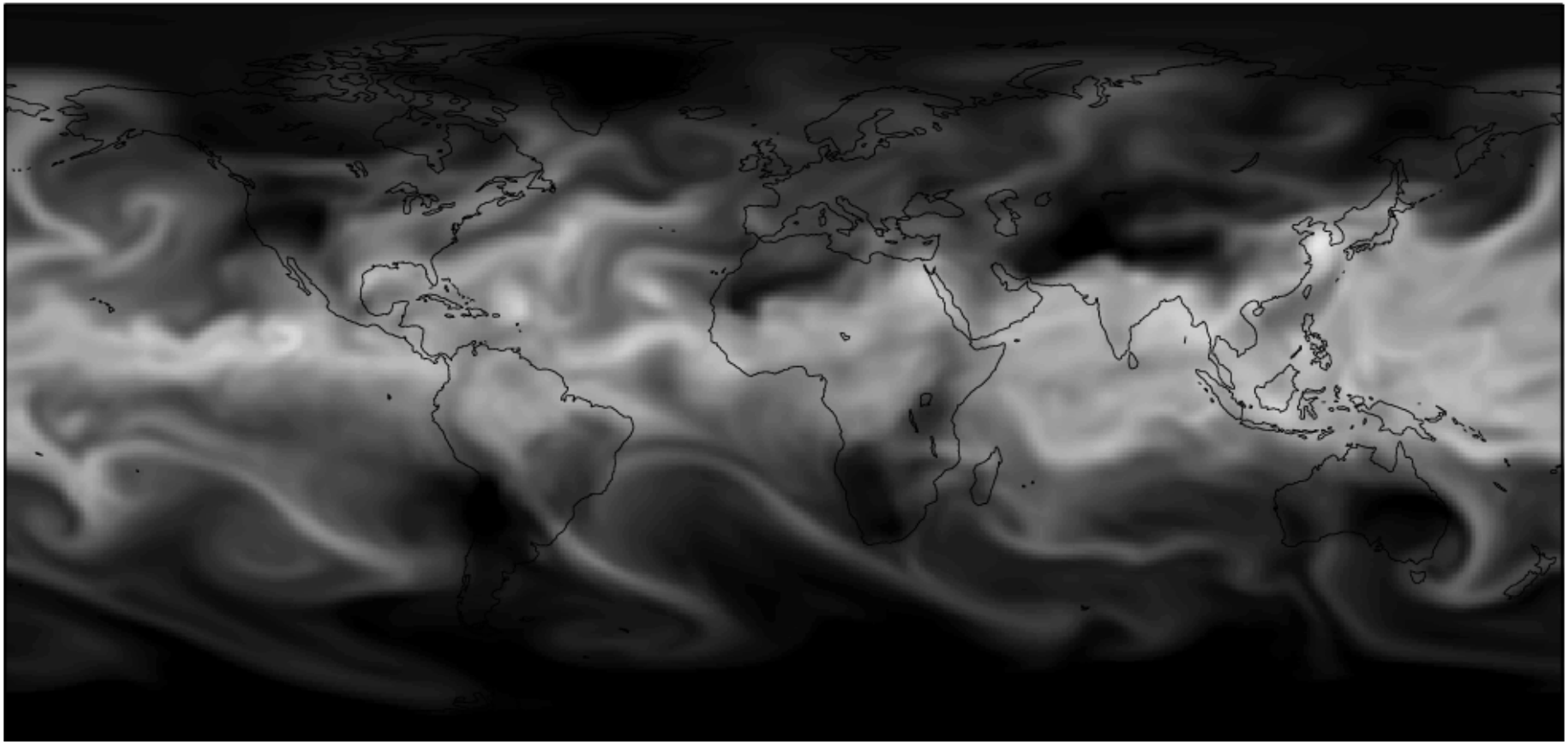

TPW, Sept 1-16

Multi-resolution global circulation

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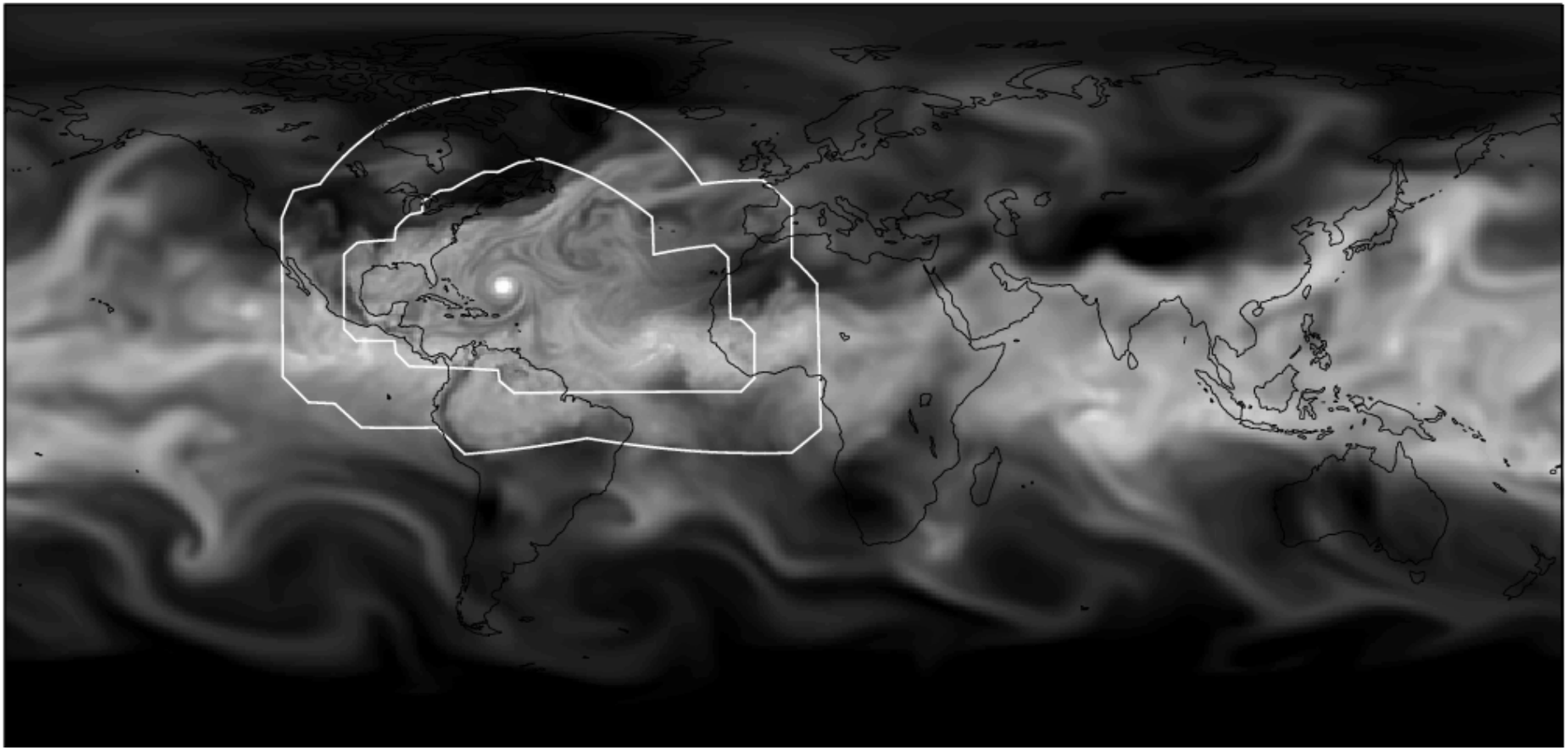

TPW, Sept 1-16

Observed TC distribution

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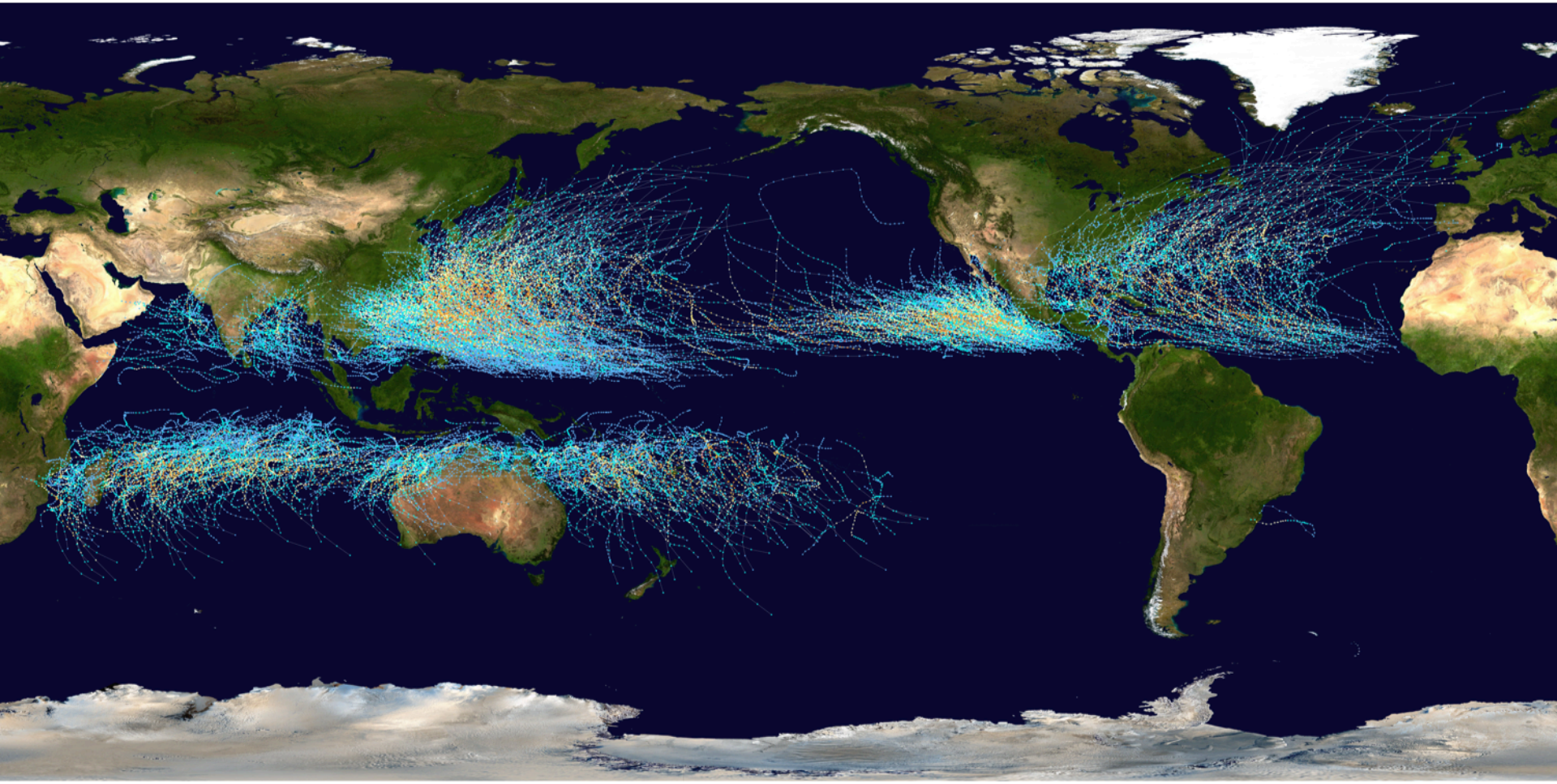

Wikipedia

What does resolution buy?

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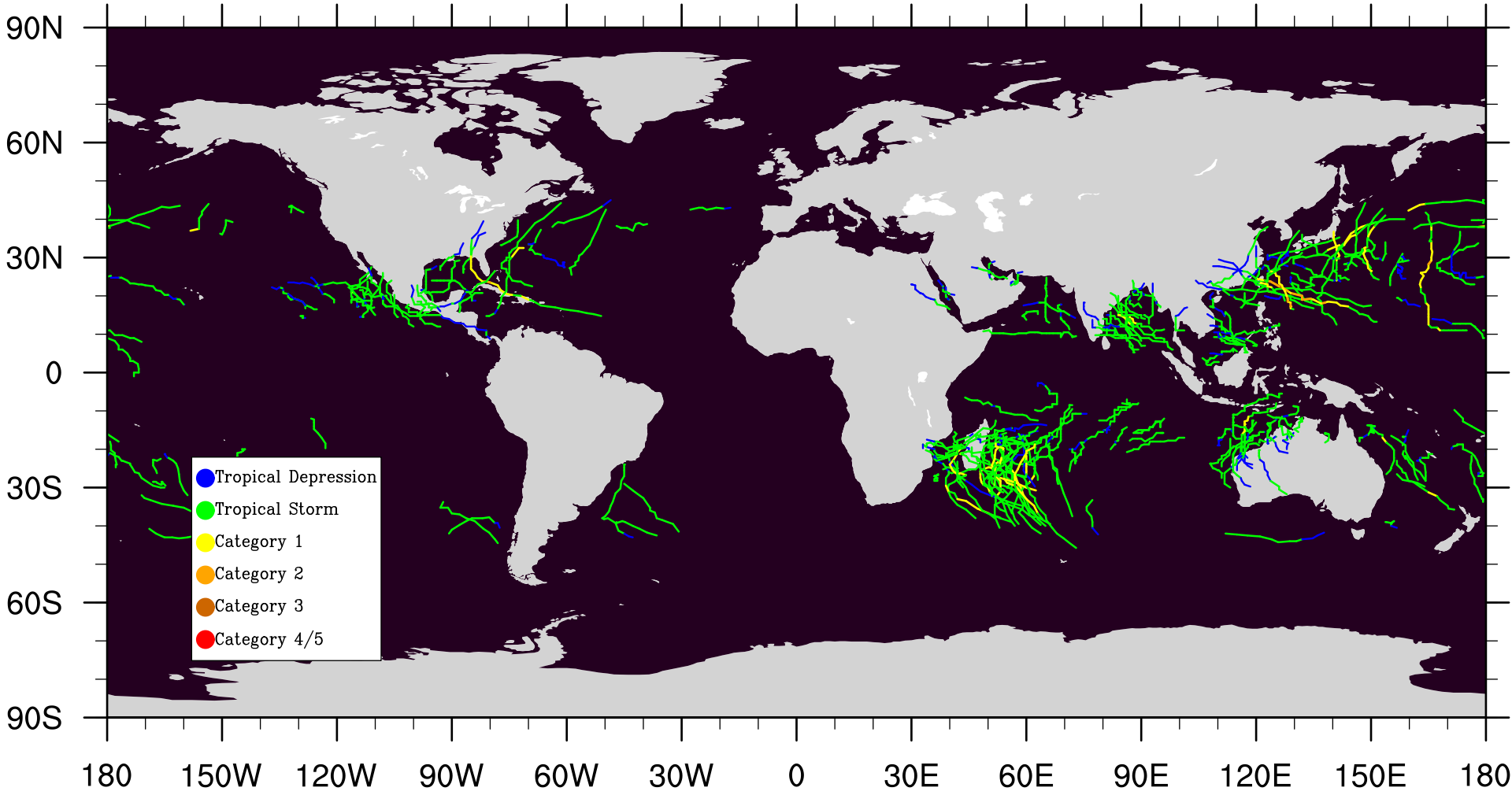

Uniform 1 degree

1980-2002 tracks

What does resolution buy?

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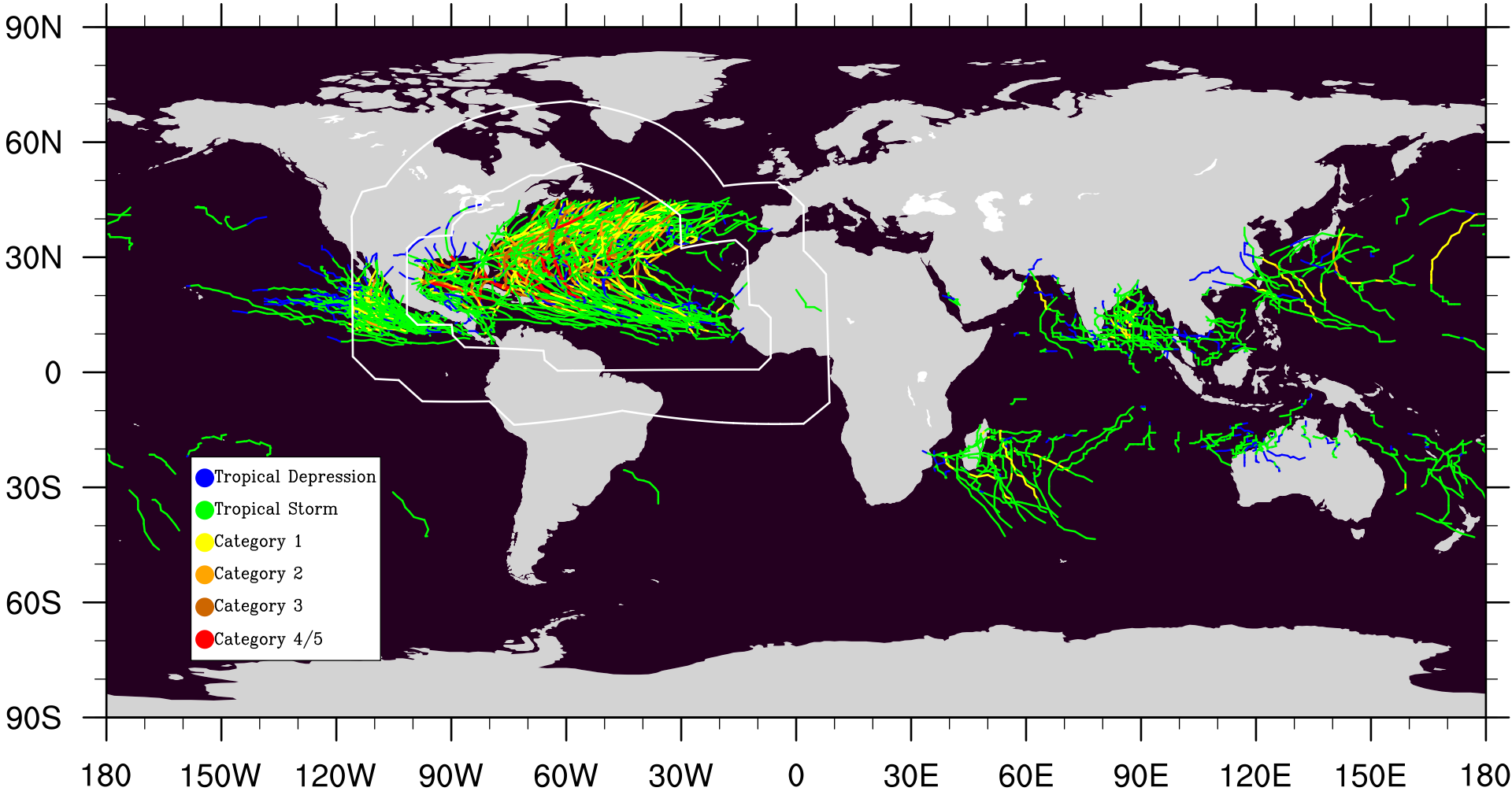
University of Michigan



Variable-resolution

1980-2002 tracks

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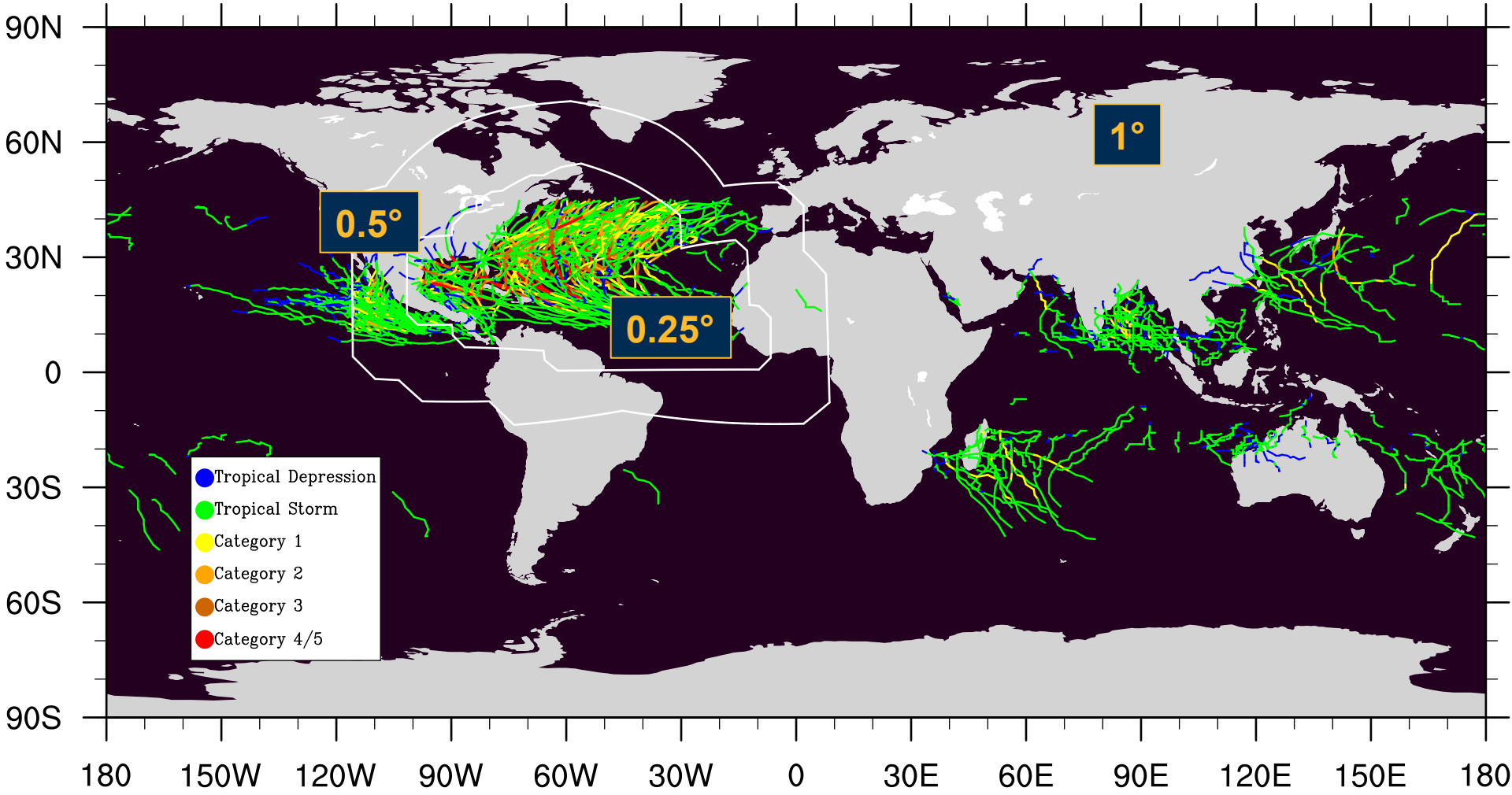
University of Michigan



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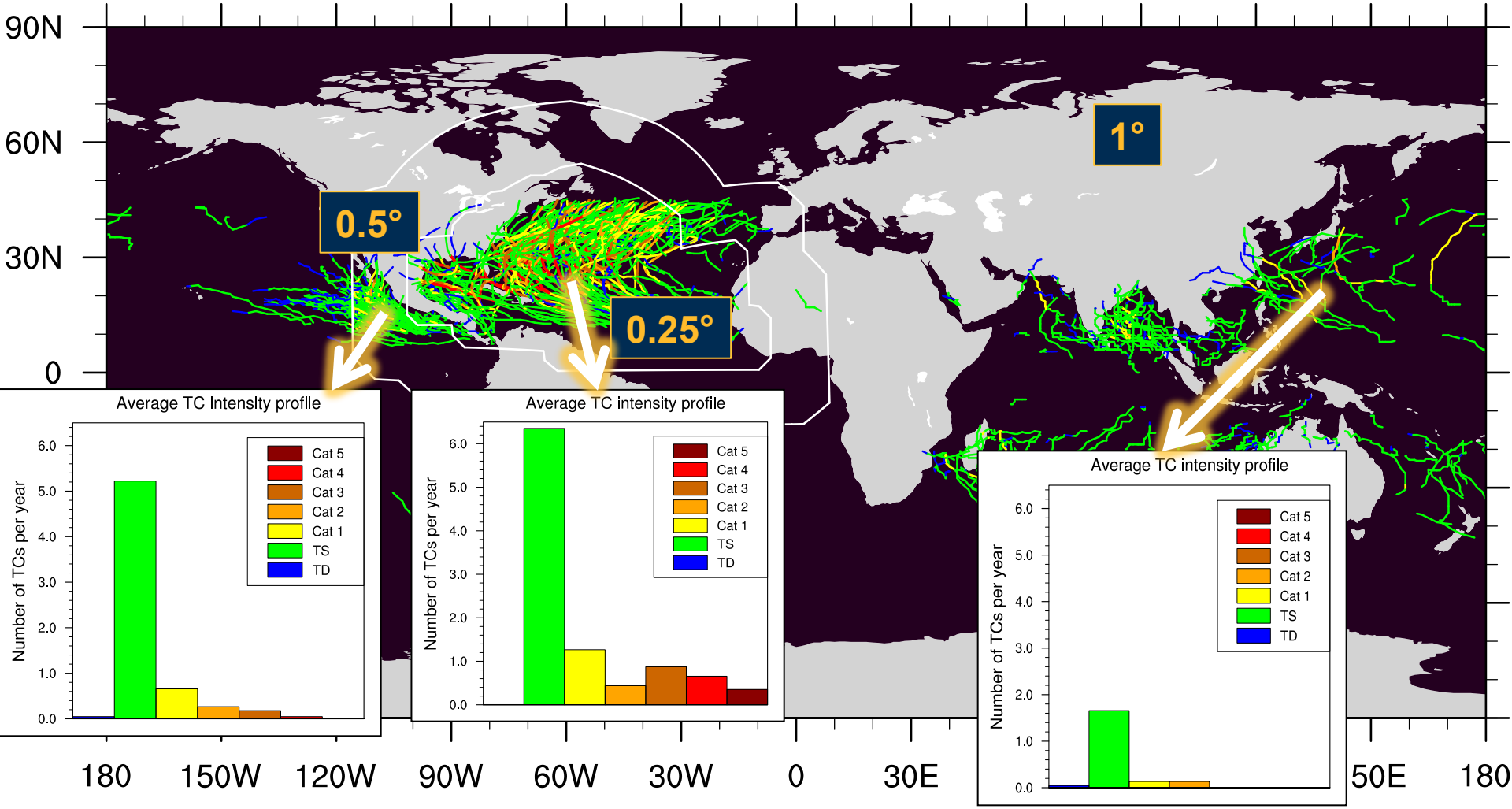

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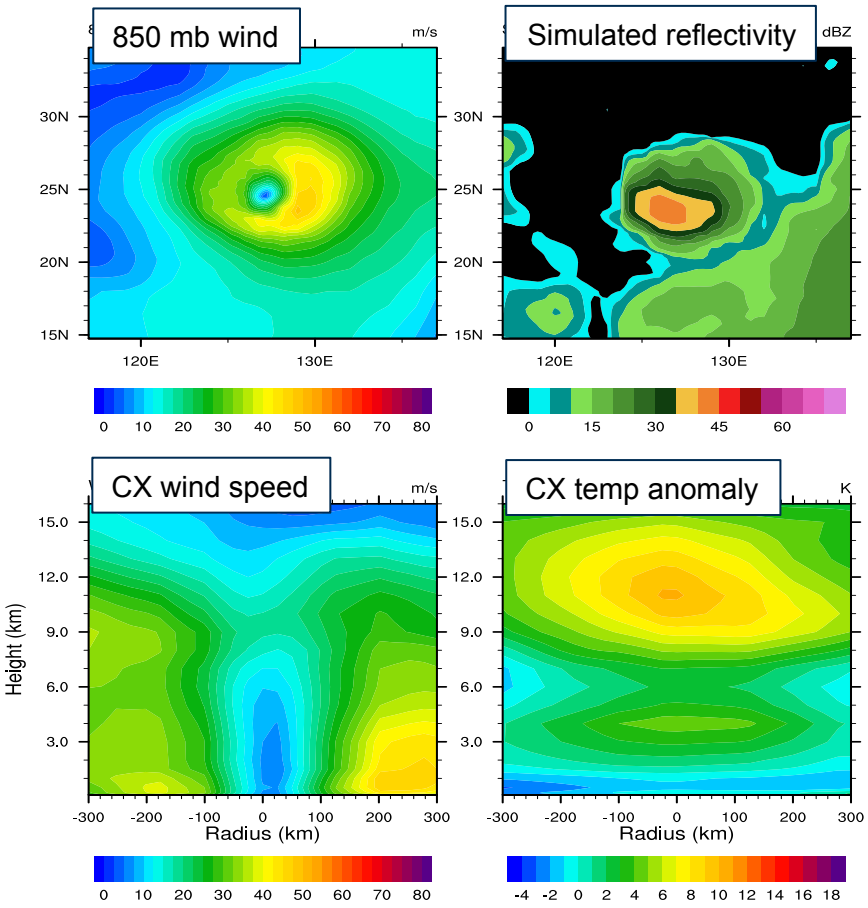
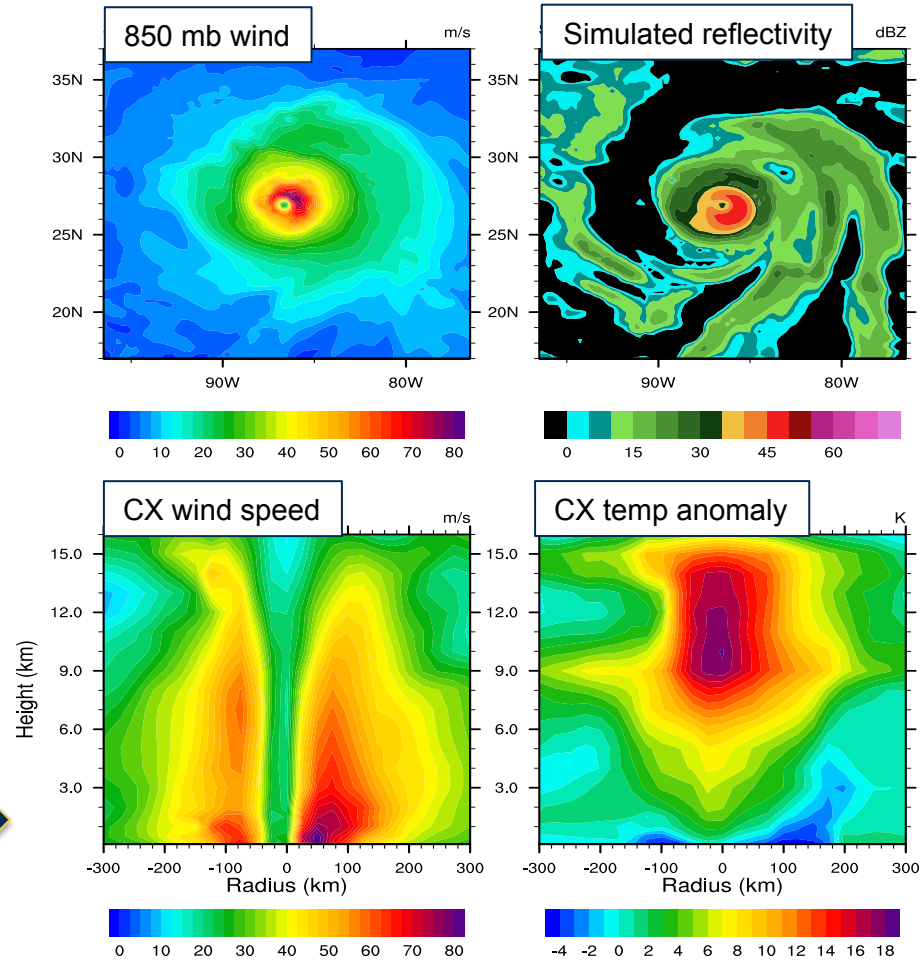


WPAC (1°)



NATL (0.25°)

African Easterly Wave activity

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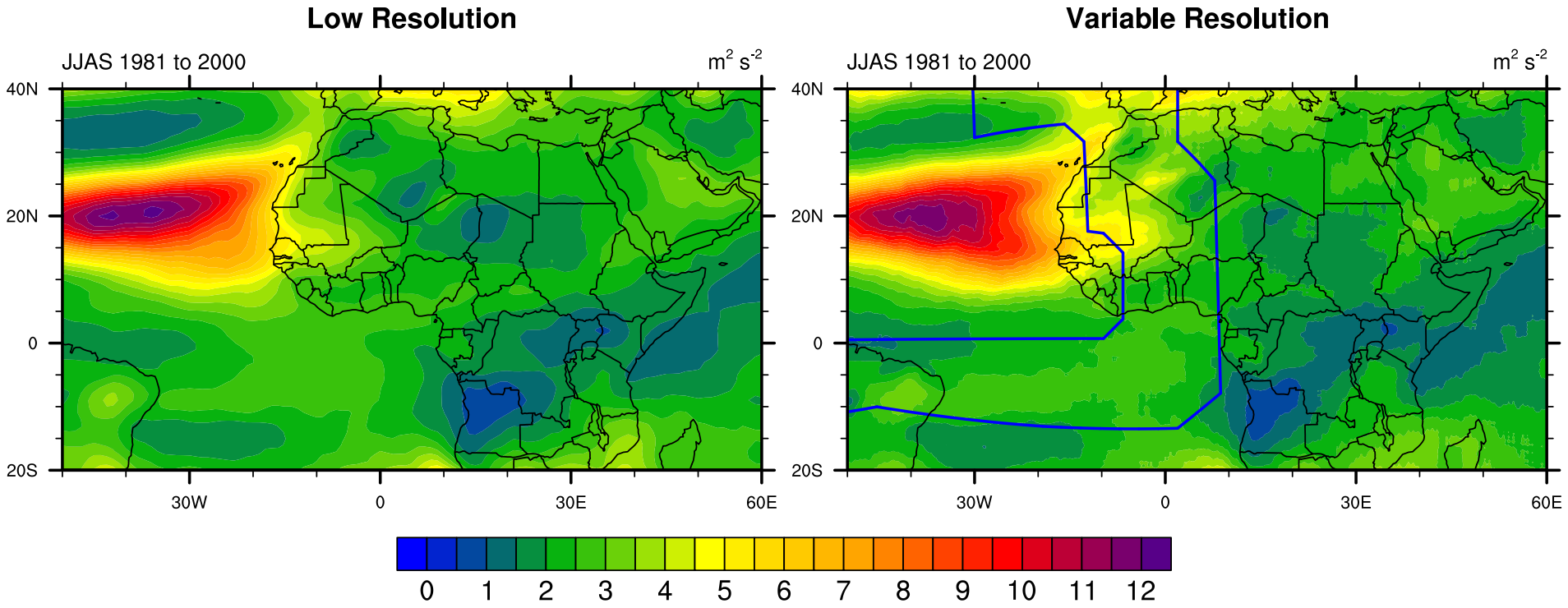
CAM-SE Meridional Wind Variance at 700 hPa



Figures from *Diana Thatcher* (UMich), technique from *Skinner and Diffenbaugh*, 2013

Differential topography smoothing

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$$\Phi_{VR} = \Phi_U + cK_o(\Delta x)\nabla^o\Phi_U$$

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Hyperviscosity order

Var-res topo

High-res topo

Tunable constant

Diffusion coefficient (scale selective!)

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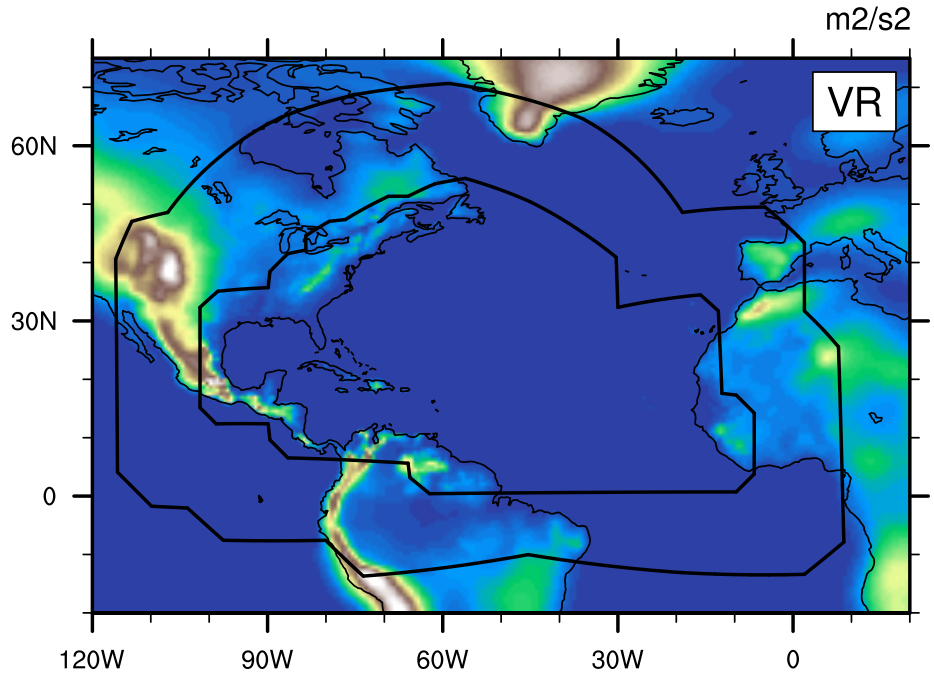

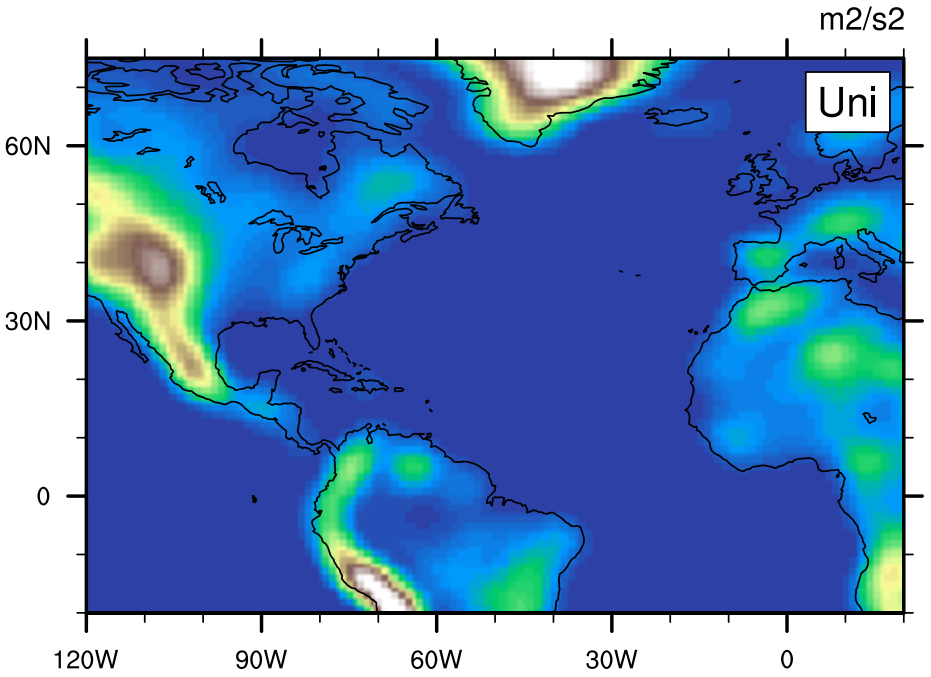

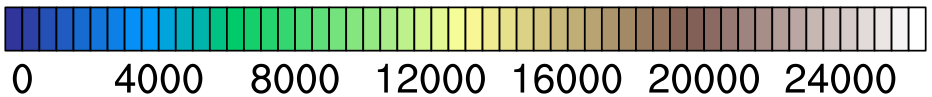

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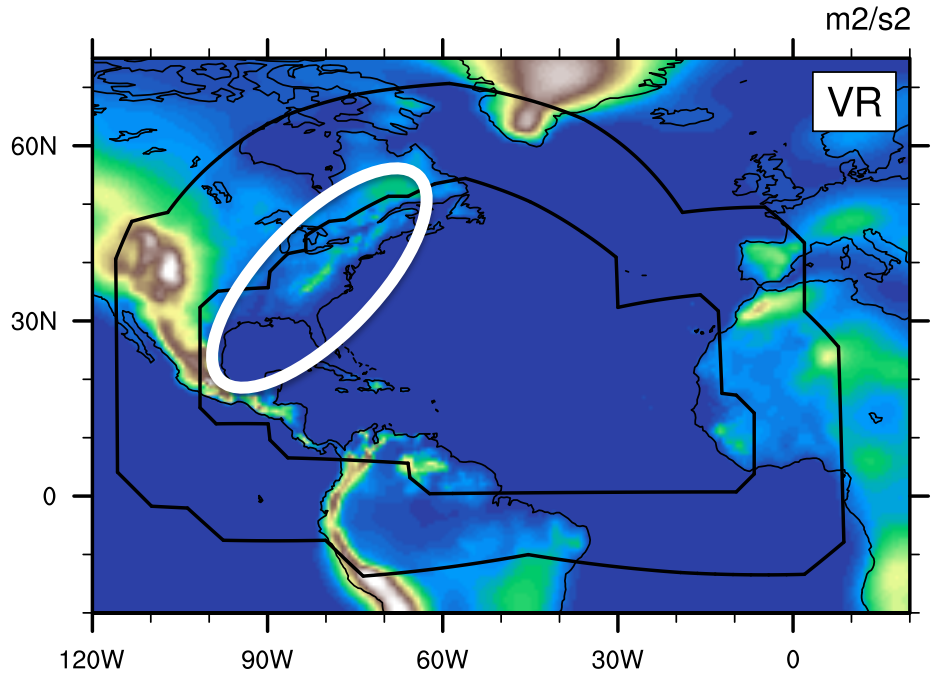

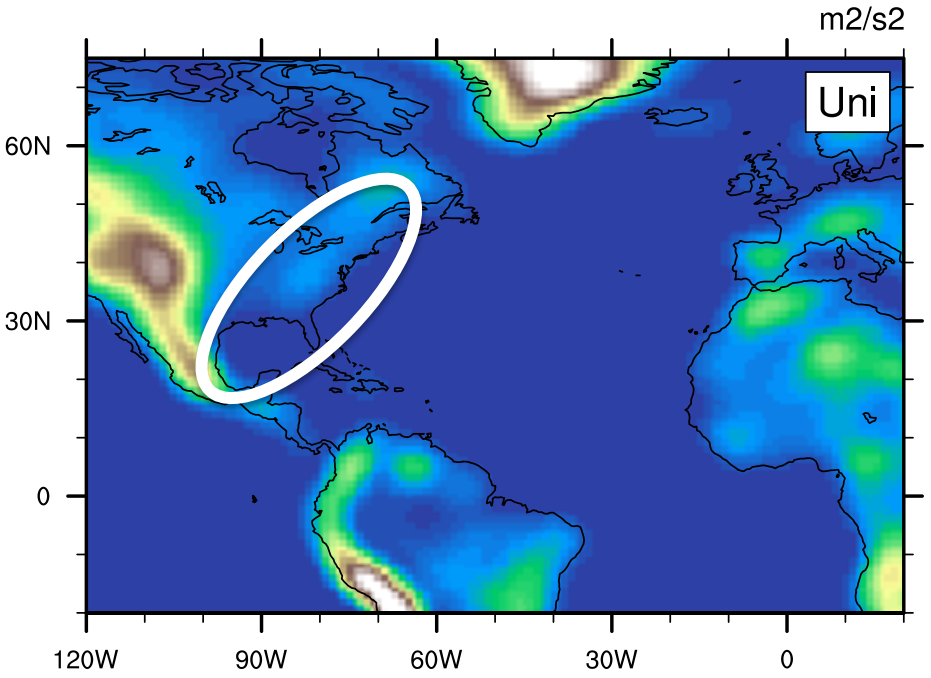

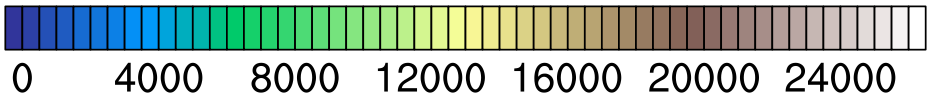

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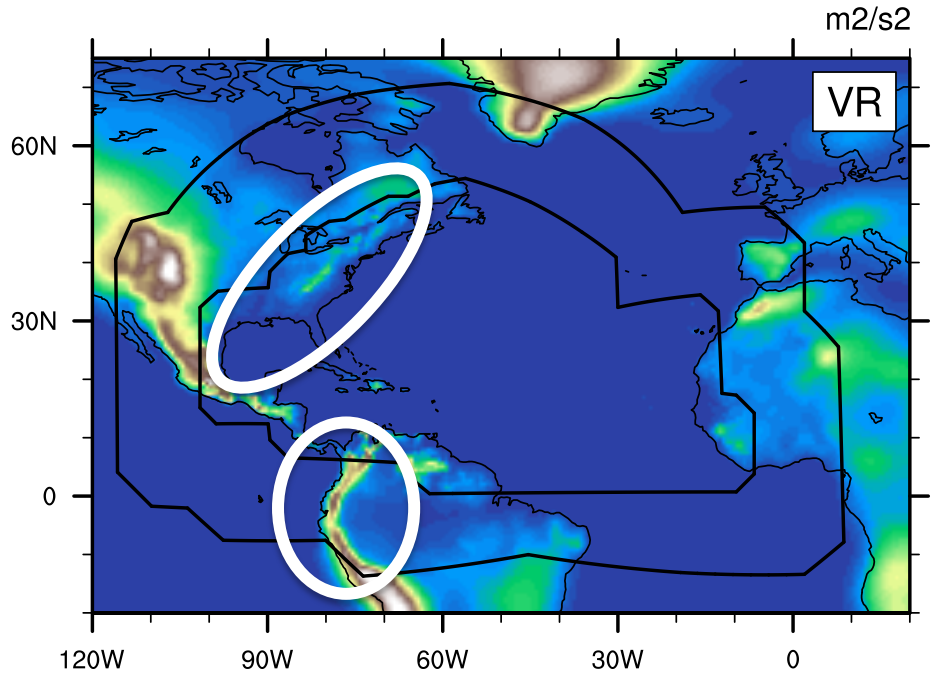

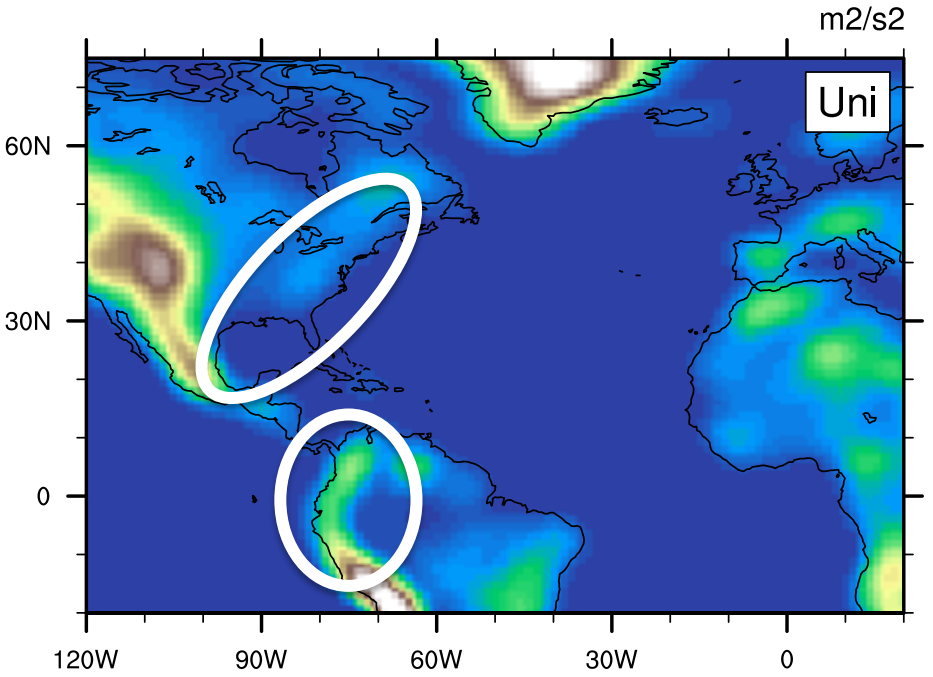

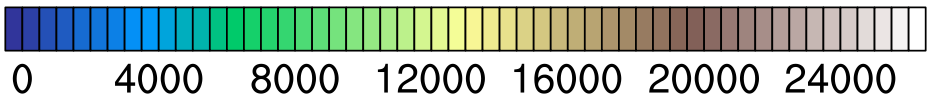

Topographical effects

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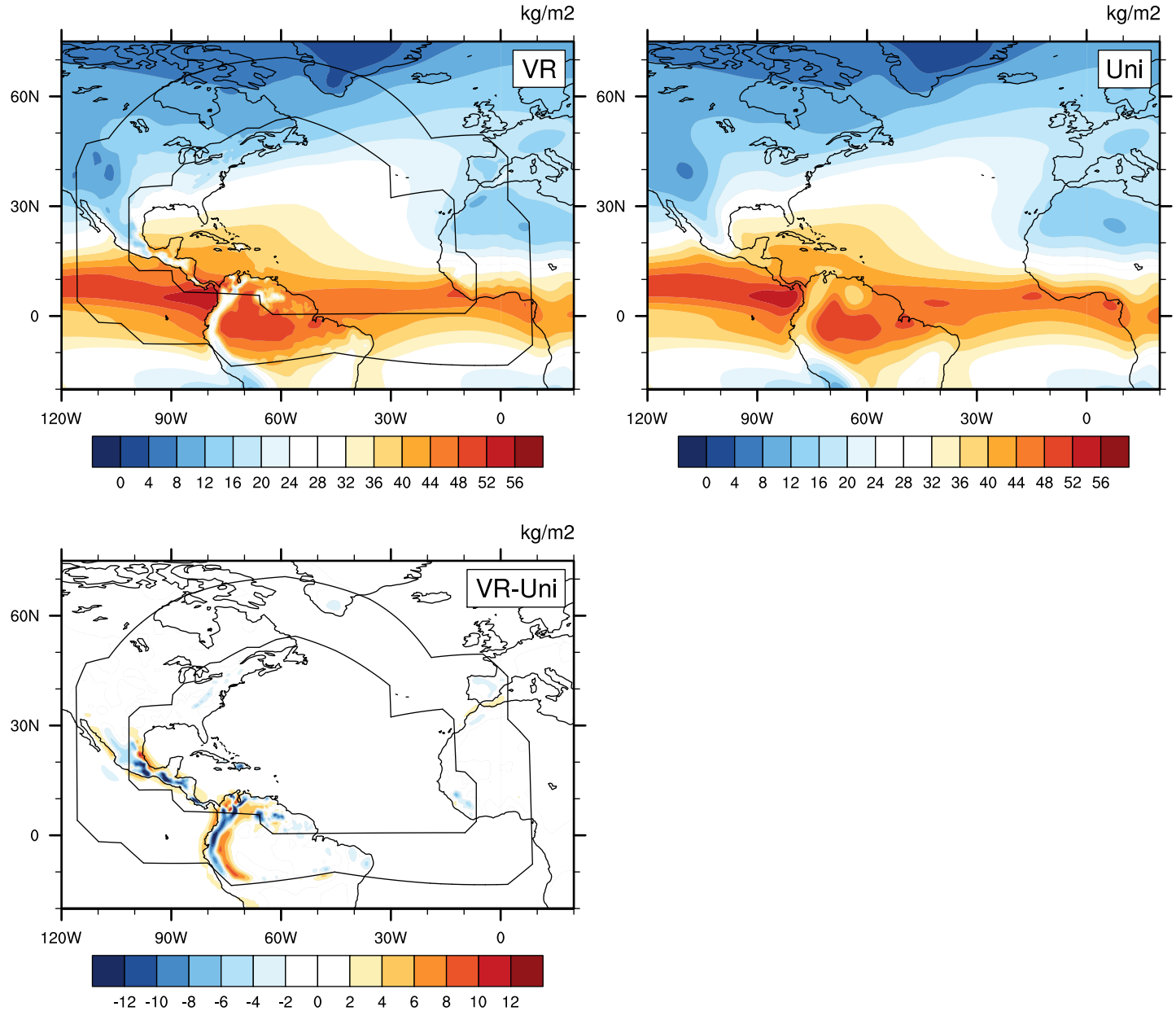
Total Preciptable Water



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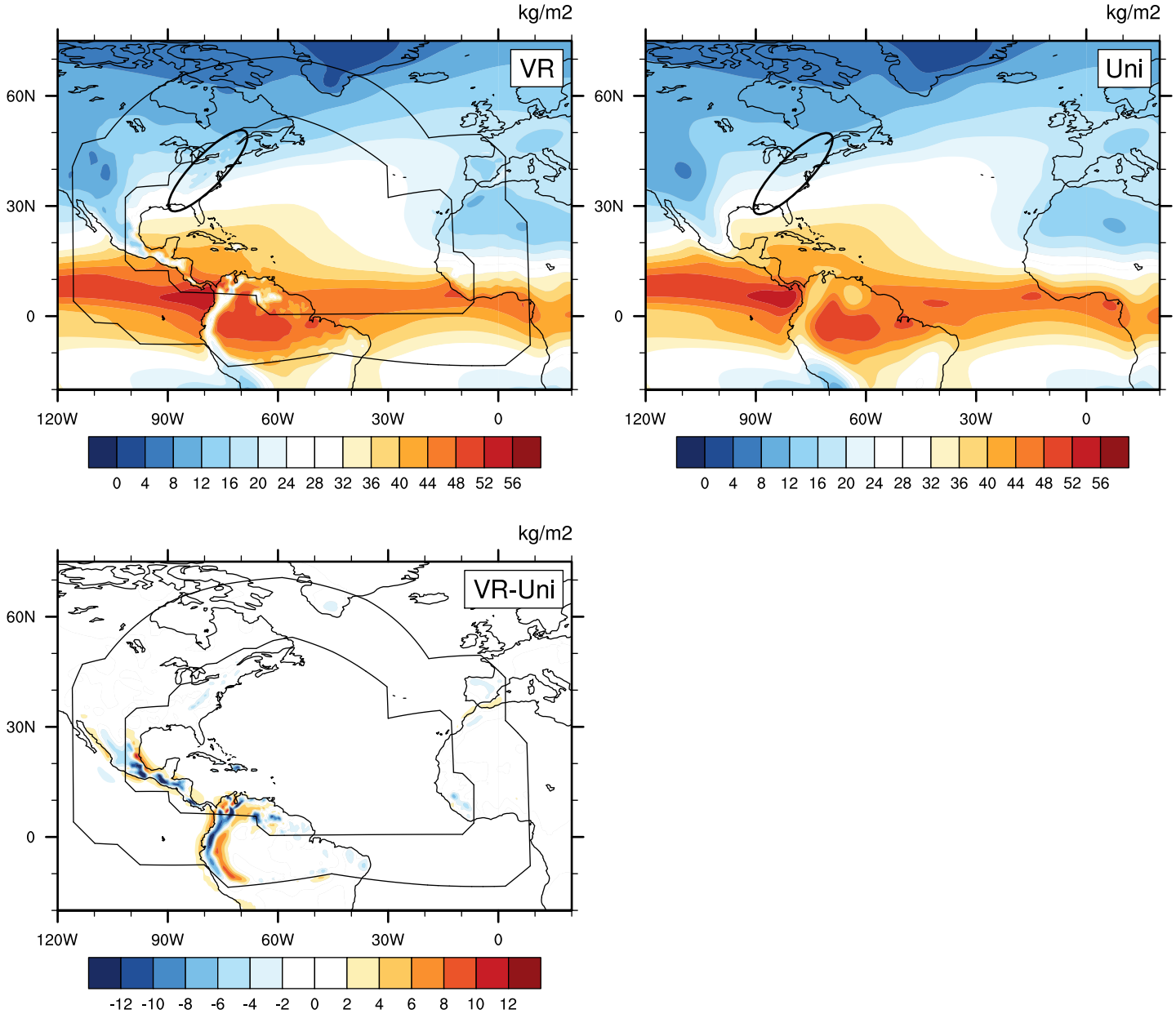

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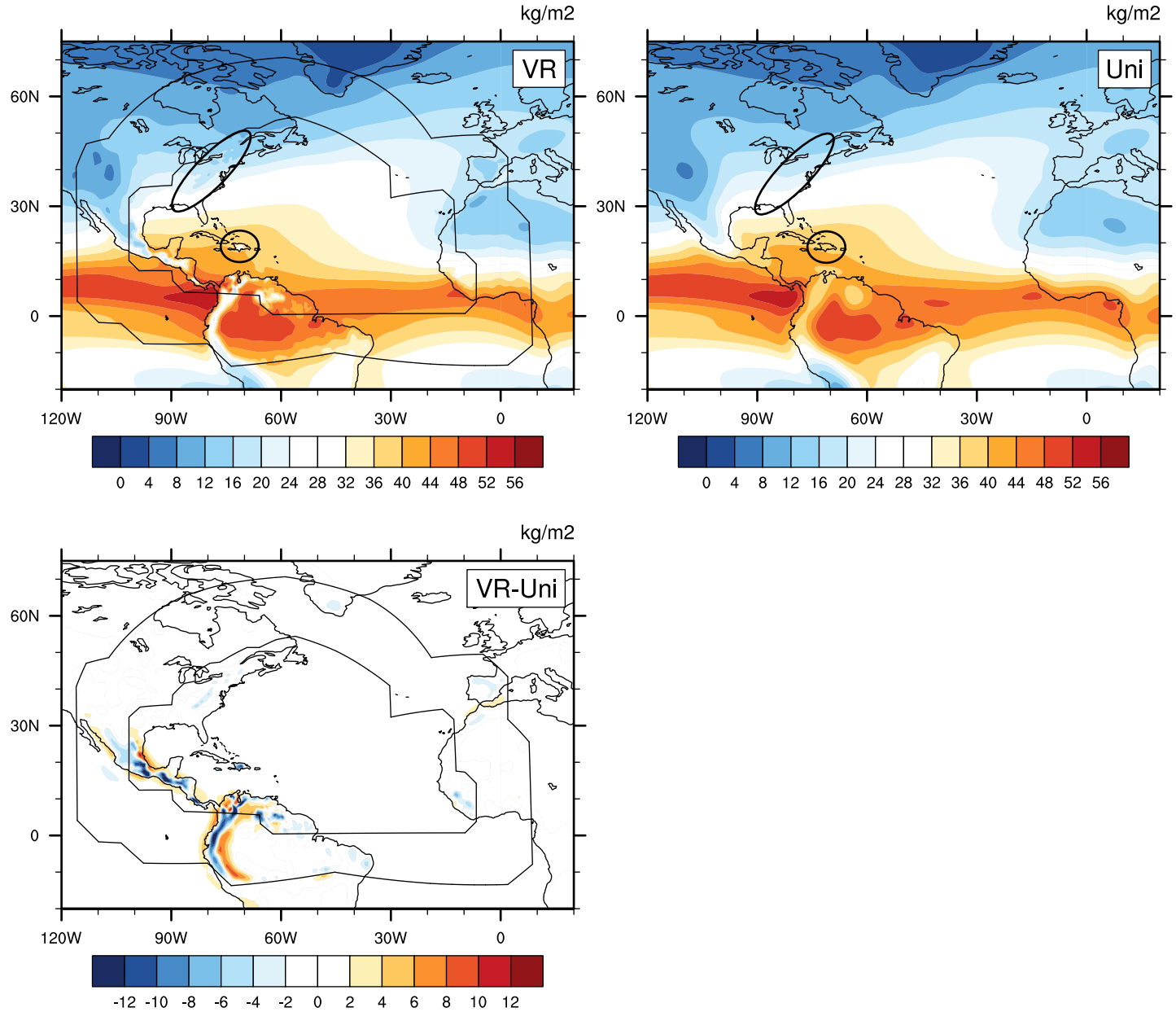

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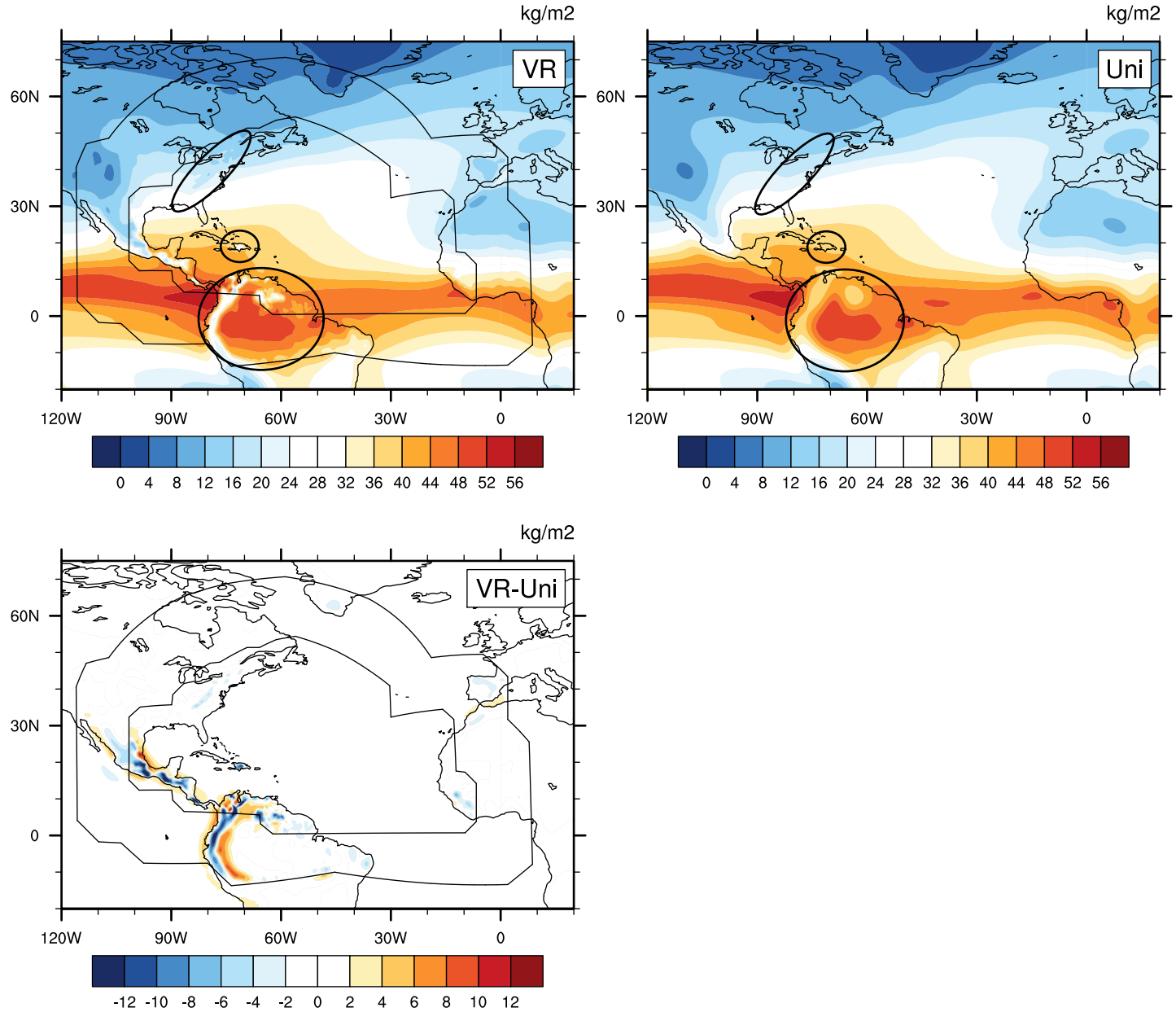

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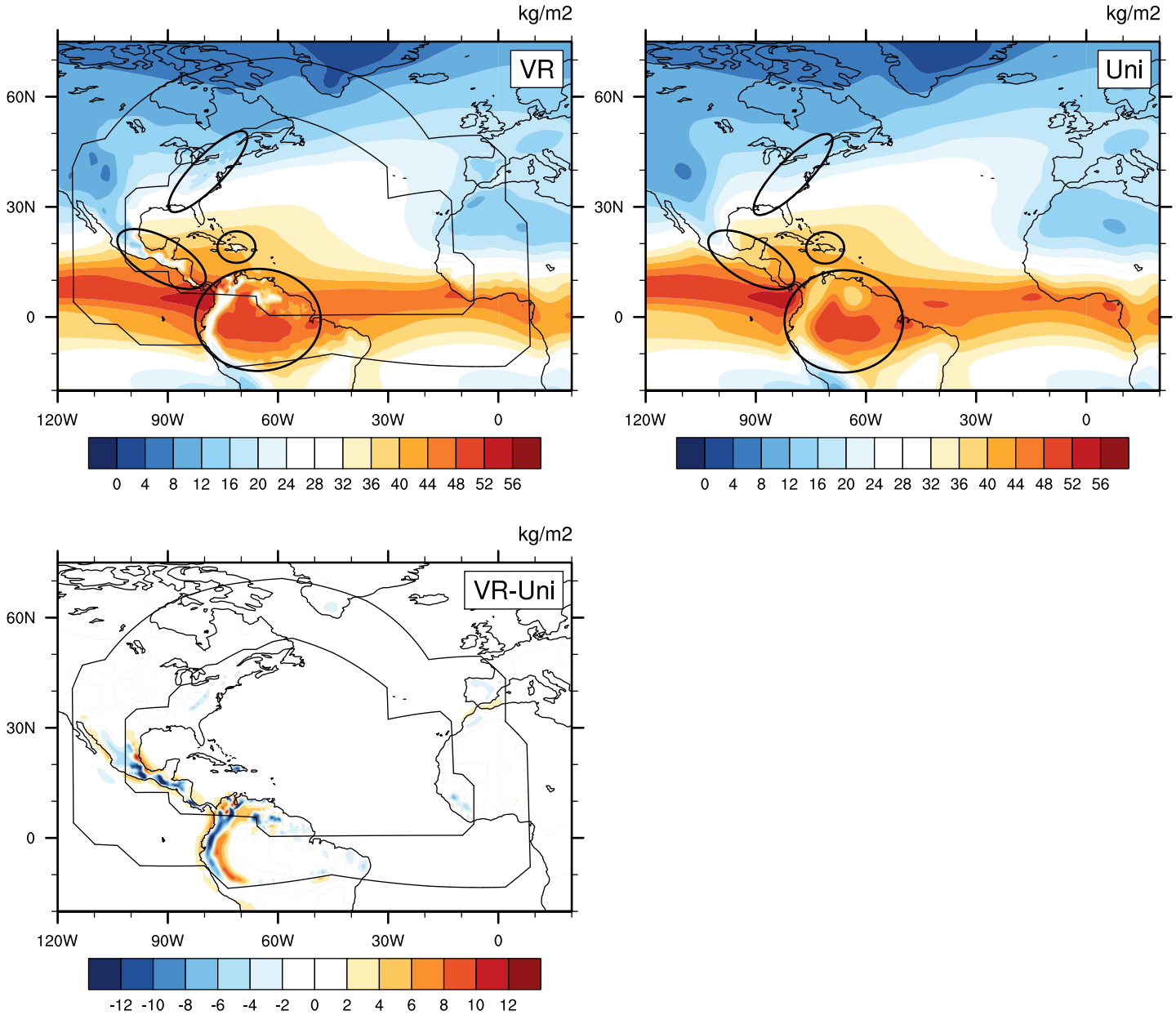

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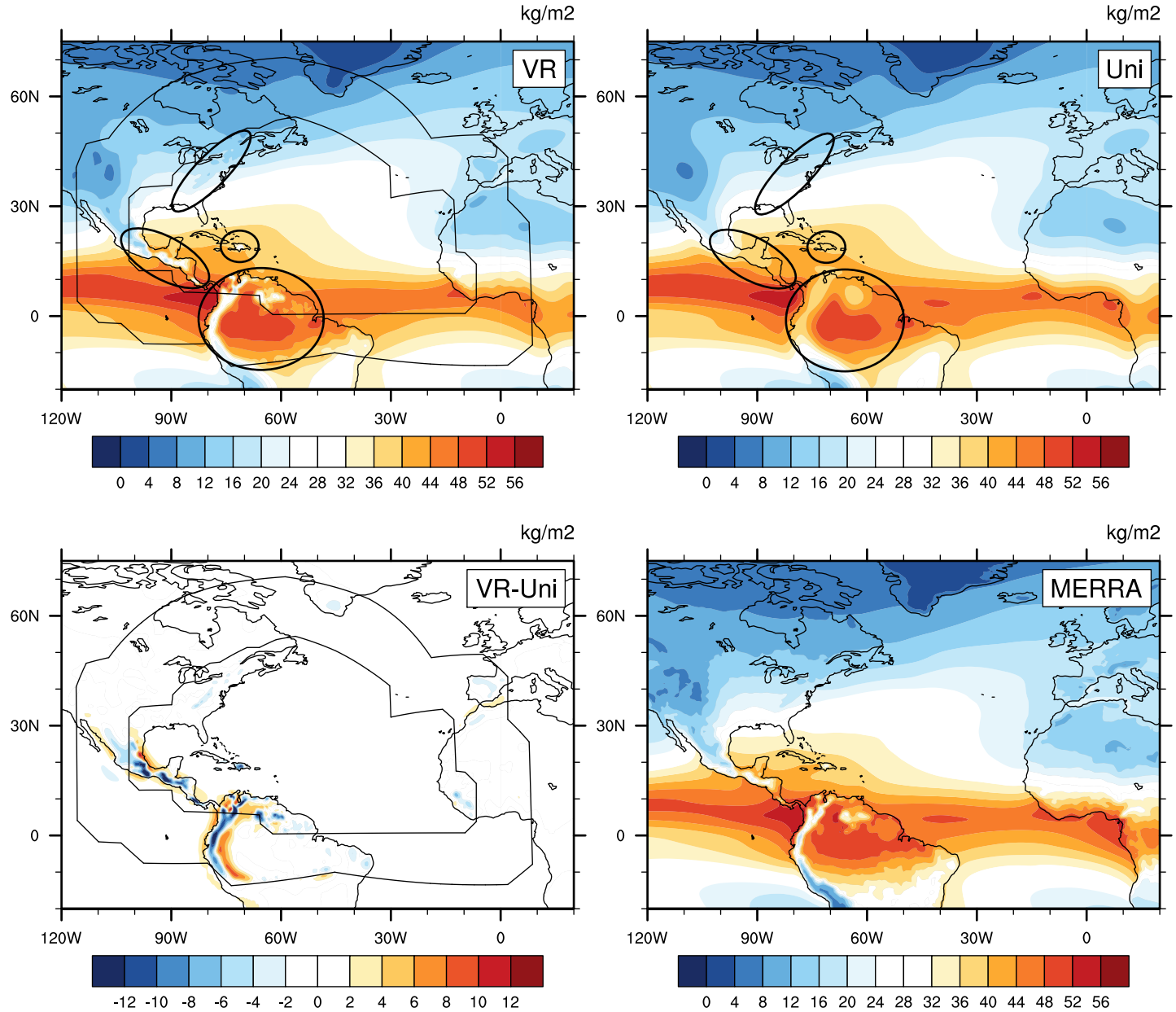

Climatology

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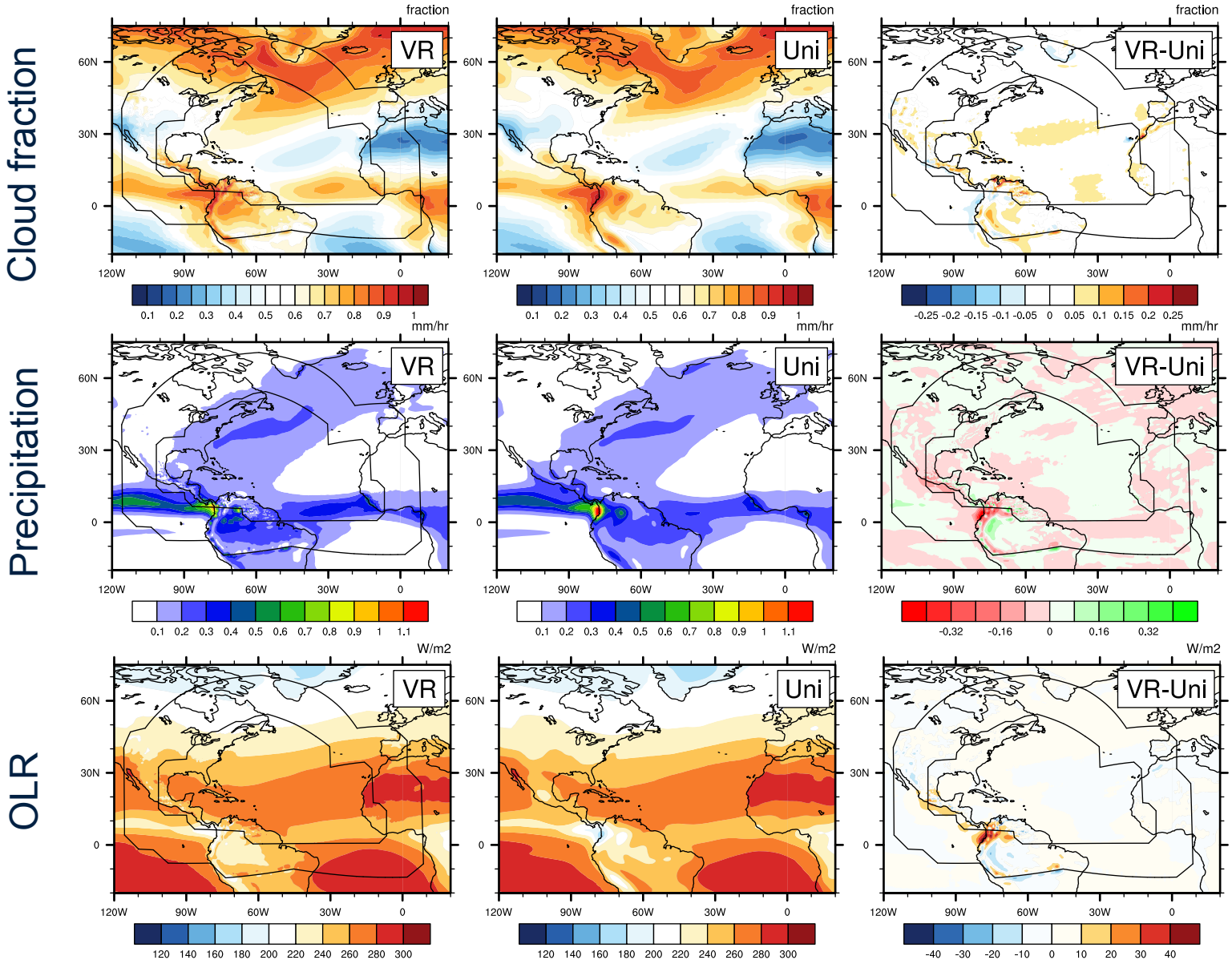

Computational benefits

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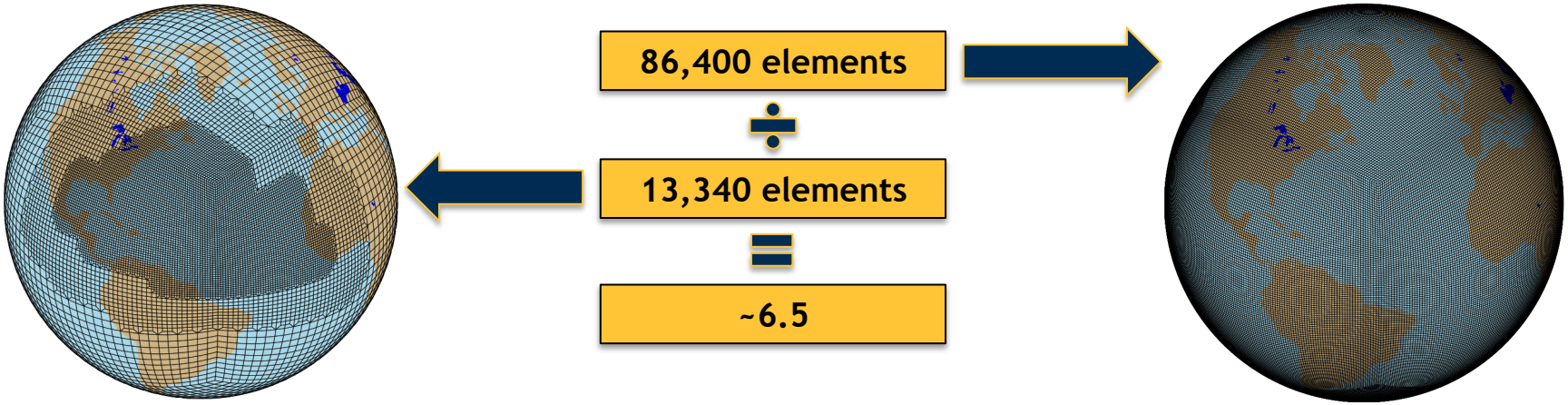

- Atm: ~**6-7x speedup** with variable-resolution vs. 1/4° uniform grid
  - Scales with number of elements and fixed compute load
- For same cost of global uniform/quasi-uniform…
  - **Higher regional resolution**
  - **Additional ensemble simulations**
  - **Longer model runs**

Summary

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- **Multi-resolution, highly-scalable dynamical cores (such as CAM-SE) may provide opportunities to improve regional climate assessments**
- Tropical cyclones
  - Refinement produces (more) realistic tropical cyclone counts, spatial distribution, and intensity
- Topography
  - Topographical effects in time-averaged climatology improved
- Large-scale circulation
  - Synoptic patterns do not appear to be significantly harmed by addition of resolution