Assessing the Fidelity of Dynamical Downscaling with the NASA Unified-WRF Model

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17 June 2015
16th WRF Users Workshop
Boulder, CO

Computational Demands of Climate Projection

I. Spatial grid resolution – typically about 100 km for today's climate models. For some processes it is thought that resolutions of at least 10 km and maybe 1 km are needed. This requires 1000 to 10,000 times the computational capacity that we presently apply.

II. Model Complexity & Earth System Science – accurate depiction of climate variability and change involves representing the interactions between the ocean, atmosphere, land, vegetation, cryosphere, etc., accounting for physical, chemical and biological processes.

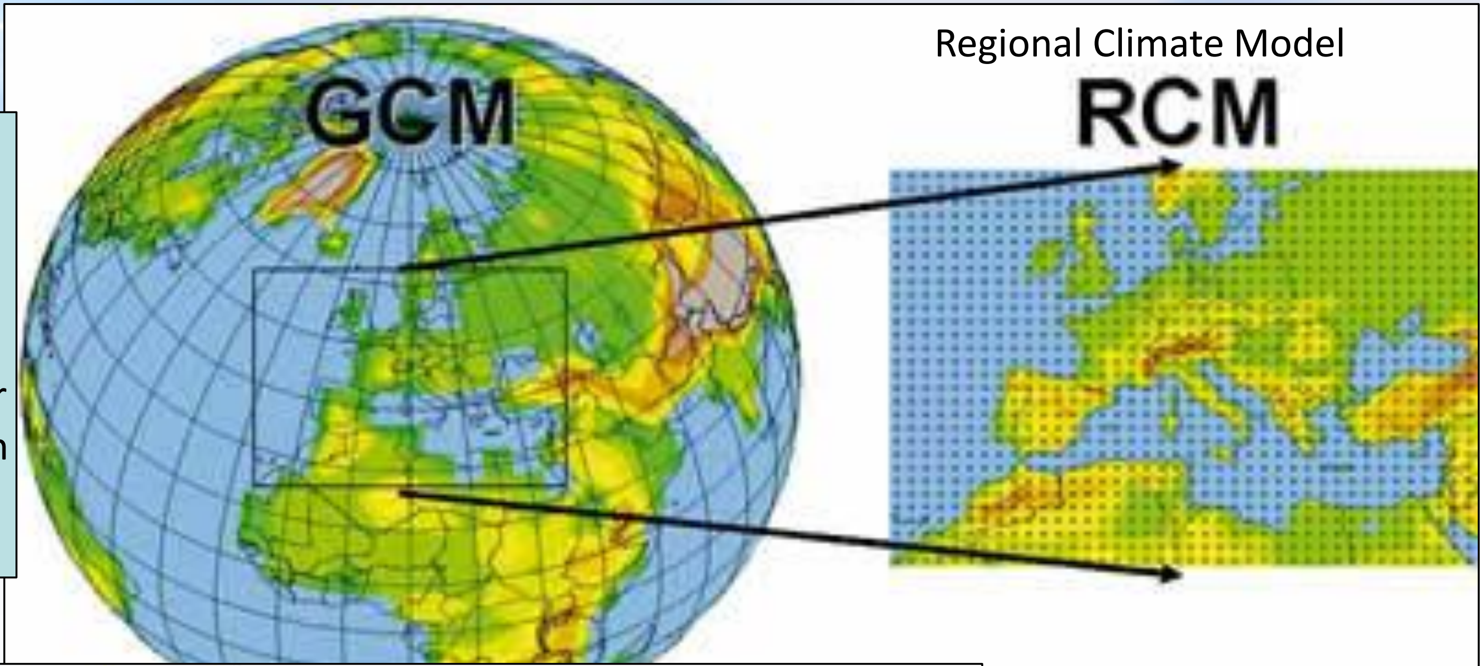
III. Complex and Demanding Experimental Design – the science and assessment demands associated with providing an accurate and well characterized projection are increasing over time.

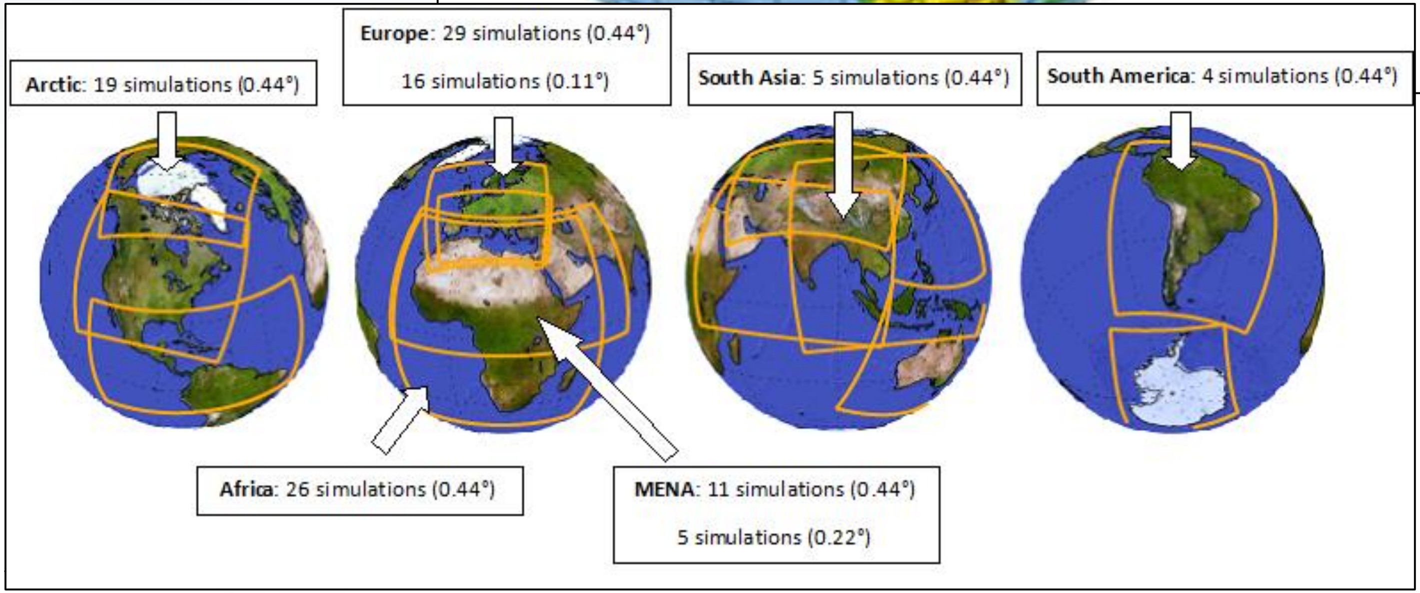
Assessments for Decision Makers require only a few variables but with challenging characteristics

- Surface: Rainfall, Temperature, Wind, Solar
  - O(10 km) or better, Hourly values
  - Realistic underlying "weather" variability (e.g., atmospheric rivers, central plains MCSs, tropical cyclones, northeast winter storms)
  - Quantification of uncertainty - requires (big) ensembles accounting for anthropogenic drivers/uncertainty, model structure uncertainty, initial condition/natural variability uncertainty

Dynamic Downscaling : One Common Solution

Use a 2nd model with much higher spatial resolution and possibly improved physical process representation over the area desired for impacts assessment with the boundary values from the GCM





CMIP5 includes the Coordinated Regional Downscaling Experiment (CORDEX)

Downscaling Assessment

Scoping the NASA Effort

Downscaling Assessment Questions

- Under ideal forcing conditions (e.g., high-quality re-analyses), how good is the RCM at replicating important weather and climate processes/phenomena?
- Under what conditions does downscaling (RCMs driven by GCMs) give valid results?
- Do high-resolution RCMs (5 km or finer) offer anything that can’t be obtained via today’s “high” but coarser resolution GCMs (25-50 km or coarser)?

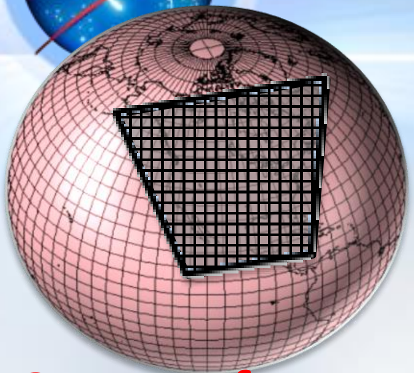
High-level methodology

(1) GCM & RCM Simulations

(2) Observation-based model performance metrics

(3) Methodology: 3-Step process for combining 1 & 2

Types of Simulations Needed



I. RCM with Observed BCs. Characterize fidelity of fine-grid RCM for important processes/phenomena.
Boundary Conditions from global reanalysis (e.g., MERRA, ERA-INTERIM).
A) Evaluate fine-grid RCM against Observations. Score = RO

Re-Analyses | Coarse-Grid GCM | Fine-Grid GCM

Current focus

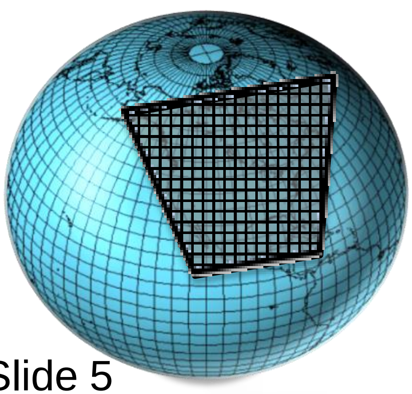
II. Fine- & Coarse-Grid GCM. Identify important processes/phenomena that **are** & **are not** represented well by the **coarse-grid** & **fine-grid** GCMs.

A) Evaluate fine-grid GCM against Observations Score = fG

B) Evaluate course-grid GCM against Observations Score = cG

C) Compare A) and B) Compare fG and cG

**Note: fine-grid GCM and RCM are meant to have similar resolutions*



III. RCM with Coarse-Grid GCM BCs. Dynamic downscaling simulations using fine-grid RCM with boundary conditions from the coarse-grid GCM.

A) Evaluate fine-grid RCM against Observations Score = RG

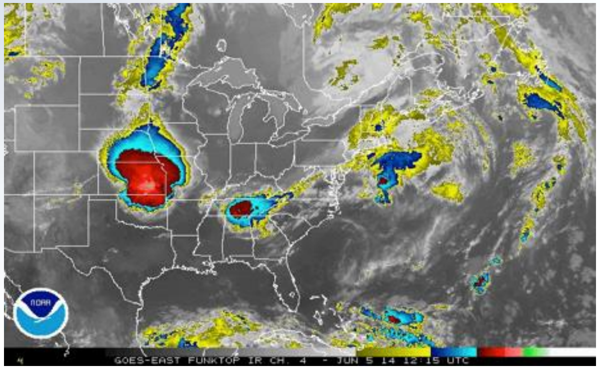
B) Compare III.A) and II.C) Compare RG, fG, and cG

Downscaling Assessment

Narrow Scope – Focus only on 3 Impactful Phenomena

Northeast Wintertime Storms (NESs)

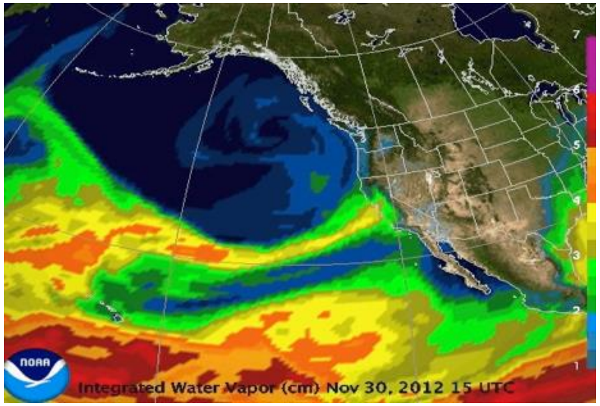
- Extreme precipitation/snowfall events
- Extreme wind events



Midcontinent Summertime MCSs

- Warm / Dry Climate Model Biases
- Extreme weather events

Resolution May Matter To The Proper Representation of The Impacts Of These Phenomena



West Coast Wintertime Atmospheric Rivers (ARs)

- Crucial for water resources/availability
- Associated with most flooding events

Downscaling Assessment

Simulation Framework

Modeling components & setup:

Regional Model: NASA Unified-WRF (based on ARW v3.5.1)

Initial/boundary conditions: MERRA-2 six-hourly re-analyses

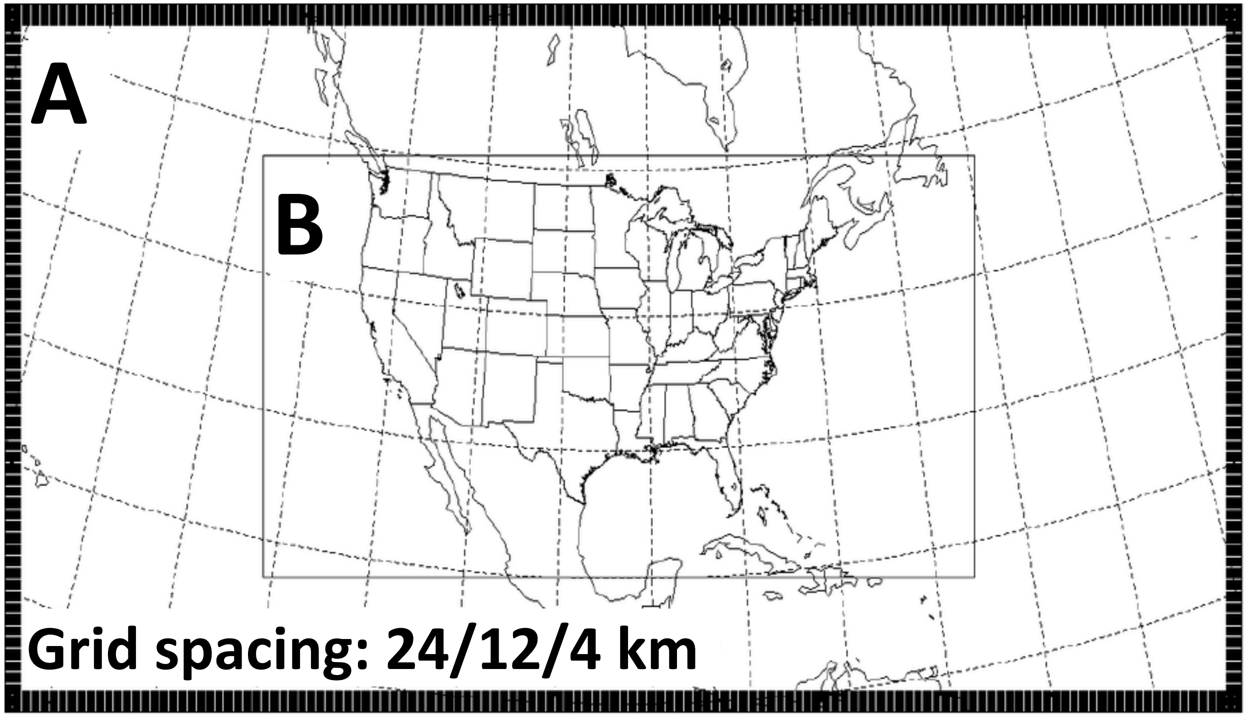
Land IC: Land Information System (LIS) 10-yr spin-up of Noah LSM

Period of Record: Nov 1999 to Oct 2010 (11 years)

Nudging: Simulations both **with and without** spectral nudging above PBL (no q nudging)

Domain (right):

- Pilot study examined 10-mo simulations on domains A and B
- Full study only on B



Downscaling Assessment

Domain and run-time details

Domain	nx	ny	total cores	cumulus	shallow cumulus	Quilting cores	Wall-clock time*
B-24 km	332	157	245	Grell 3D	Bretherton & Park	5 x 5	10.9 days
B-12 km	663	313	865	Grell 3D	Bretherton & Park	5 x 5	25.8 days
B-4 km	1987	937	6083	–	–	5 x 40	(ongoing)

*for spectral nudging run

Common grid characteristics:

- 41 vertical levels; p-top: 10 hPa
- <u>Radiation physics</u>: NASA/GSFC SW and LW schemes
- <u>Microphysics</u>: NASA/GSFC 3-ice scheme with graupel
- <u>PBL</u>: MYJ; <u>LSM</u>: Noah with 10-yr LIS spin-up on each grid
- <u>Five output streams</u>: wrfout, wrfdiag, wrf2dout, wrfpress, wrfrst
- All simulations made on NASA Center for Climate Simulation "Discover" supercomputer

Bug Fixes in WRF v3.5.1 Community Code

Spectral Nudging and Sea Ice in Restarts

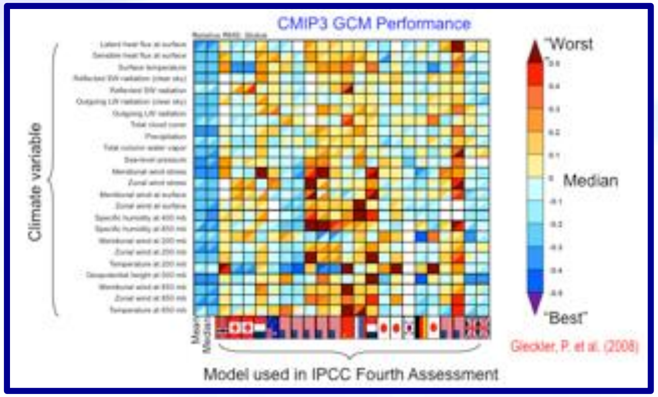
- Spectral nudging slow-down on large 4-km domain
  - Spectral nudging ran ~ **10-20 TIMES slower** than the control run without nudging; worse performance on large number of cores since each CPU calls the spectral nudging routine
  - FIX: zero-padding added to grid dimensions prior to calling spectral nudging to make grid dimensions a multiple of 10
- Sea ice re-initialized incorrectly during restarts
  - Resulted in solutions diverging immediately after restart
  - FIX: Revised Registry to include TSK_SAVE in Restart files, which is needed to update TSK correctly when sea ice is present
- Both fixes passed on to wrf-help at NCAR

Downscaling Assessment

Composite Metric Score

In the spirit of a “portrait diagram”, we are developing a set of scalar metrics that:

1) score model for representing our target process/phenomena
2) use observation-based data (satellite, reanalysis, in-situ),
3) focus on impact not underlying physics
4) “combine” them into a composite performance score.



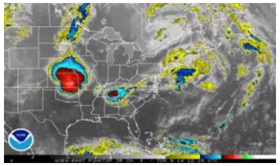
For each target process/phenomena

Model Composite Metric

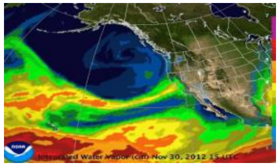
=

$\sum$ TBD Method to Combine Individual Scores

NES



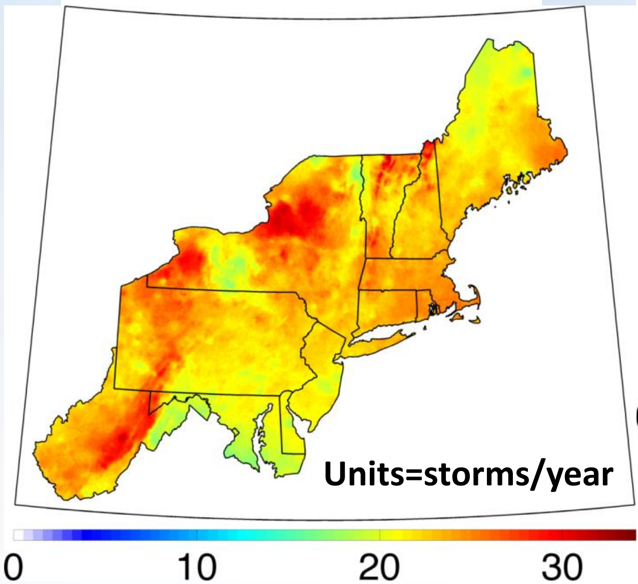
MCS



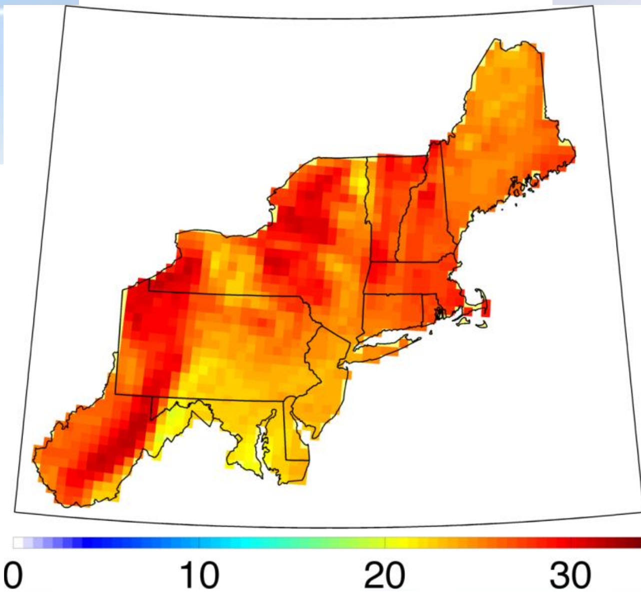
AR

NE Winter Storms: Storm Frequency

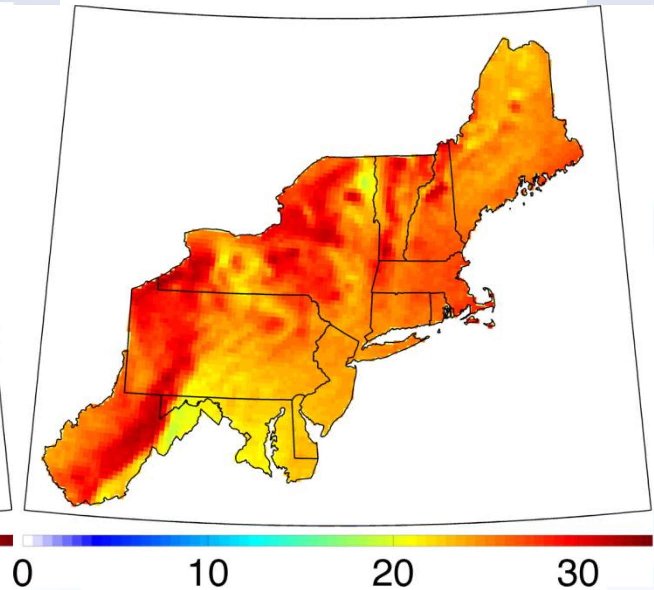
PRISM



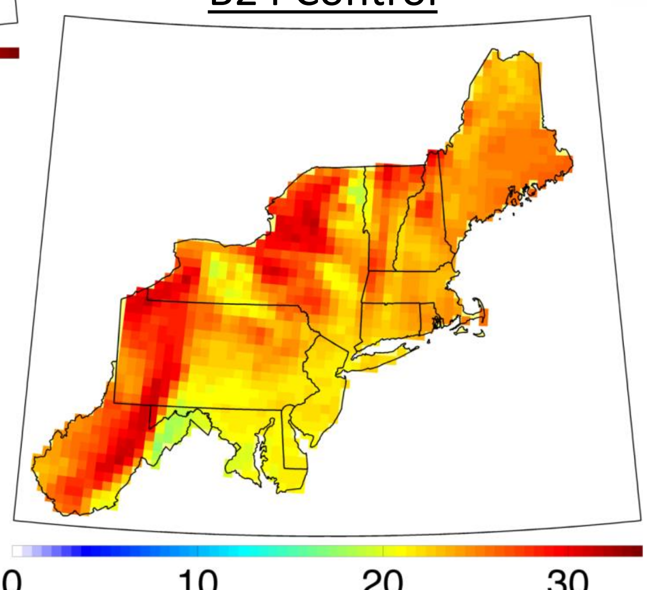
B24 Nudging



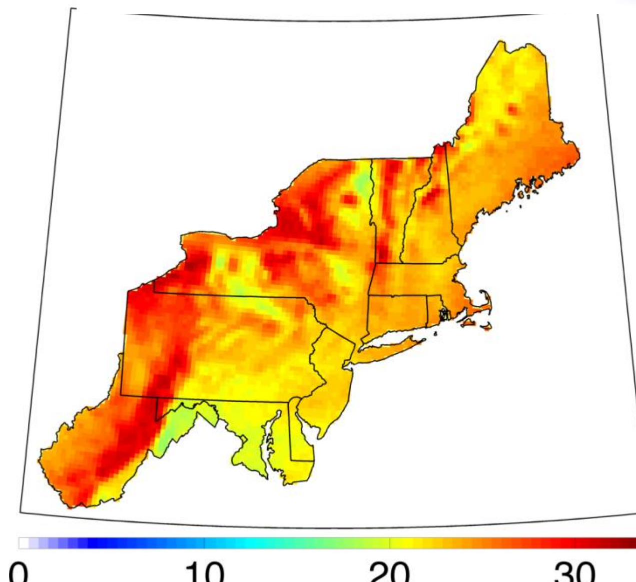
B12 Nudging



B24 Control



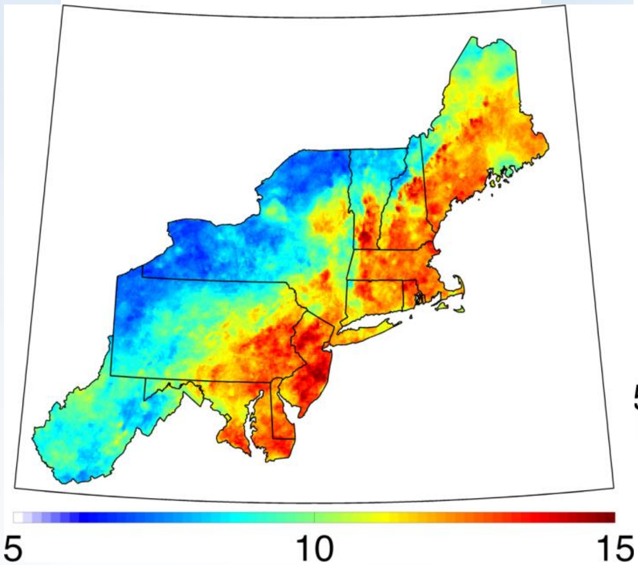
B12 Control



Storm = 1 or more consecutive days with daily precip >2.5 mm over NDJFM

NE Winter Storms: Median Storm Intensity

PRISM



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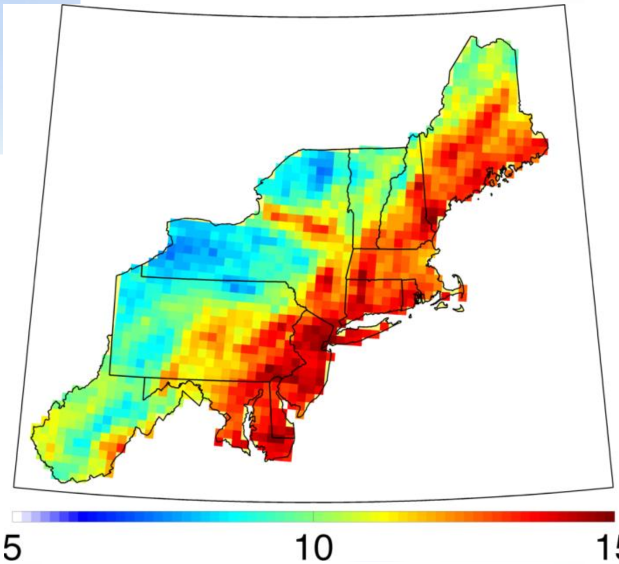

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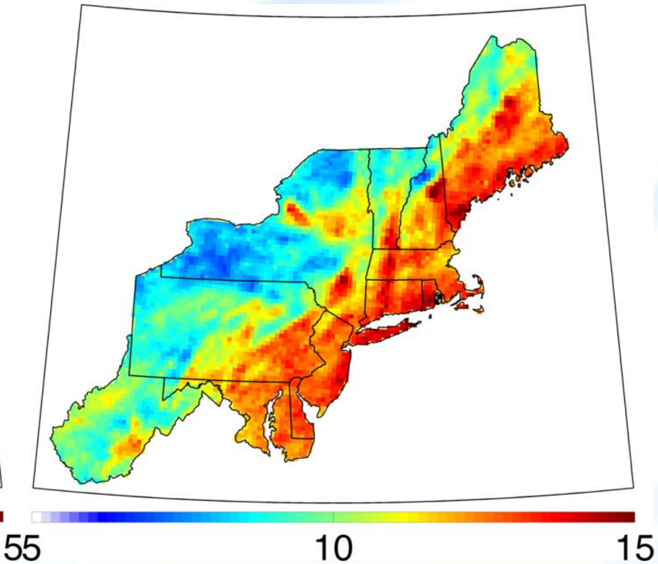
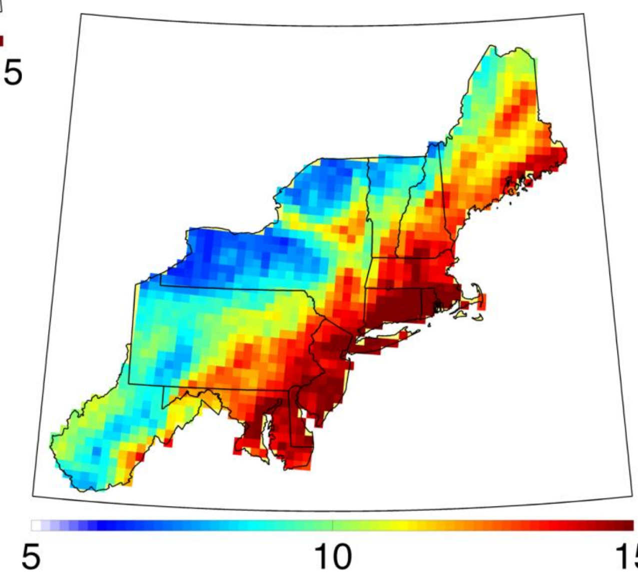
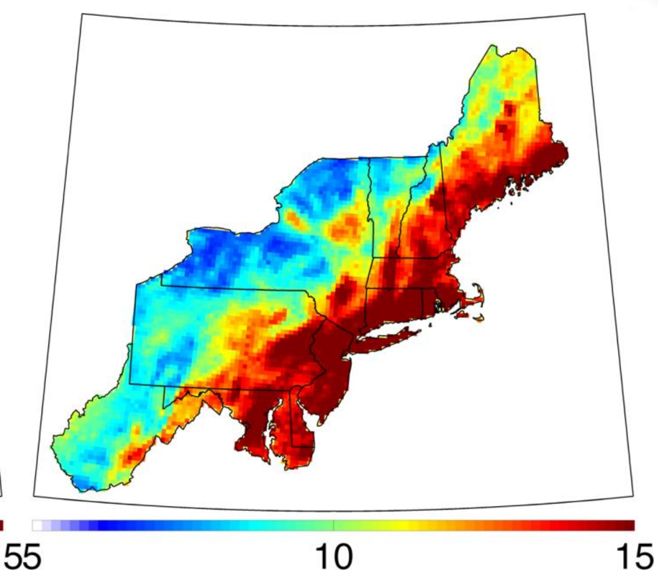


B24 Control



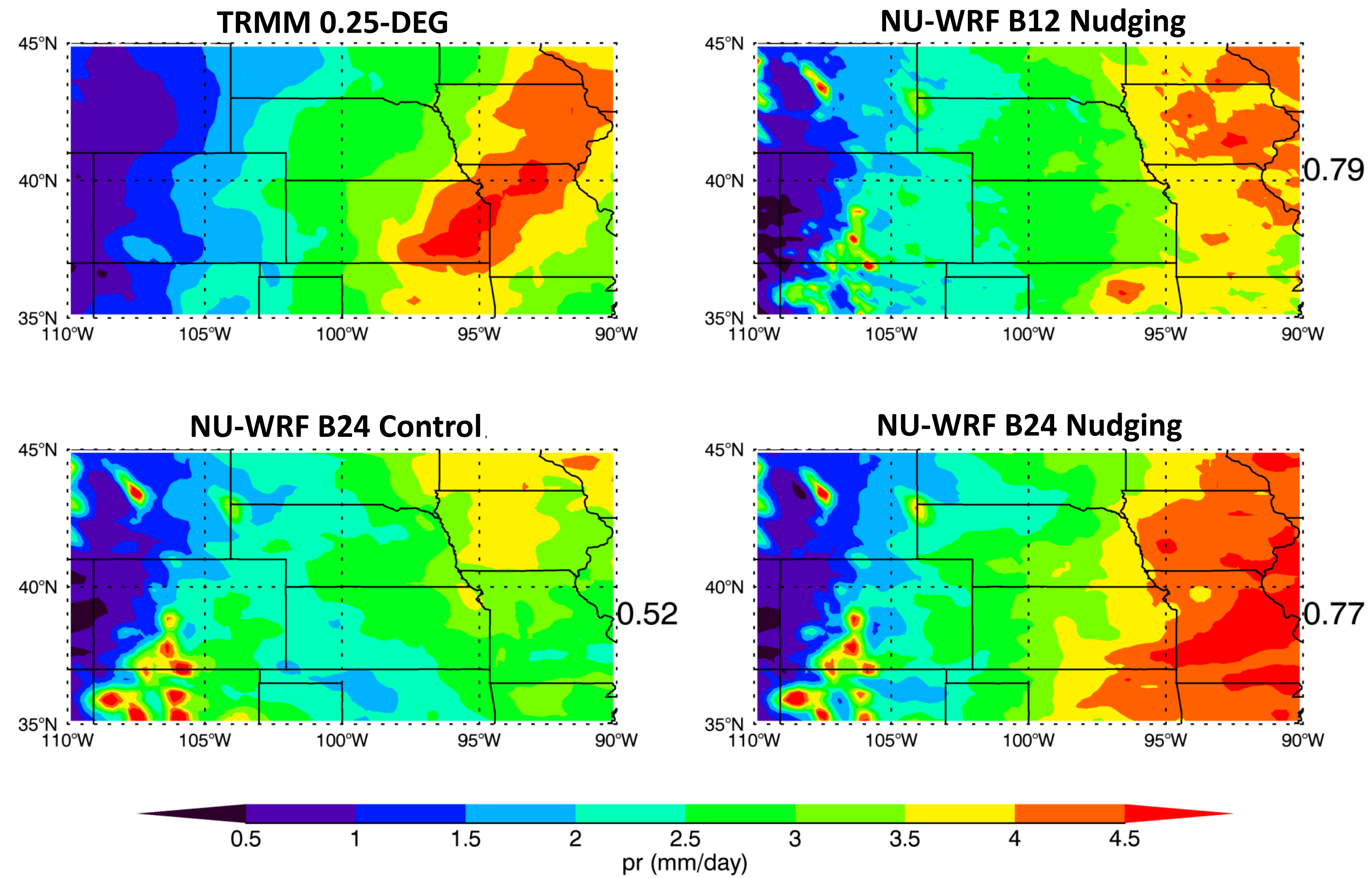
B12 Control



Intensity=maximum daily precipitation during a storm.

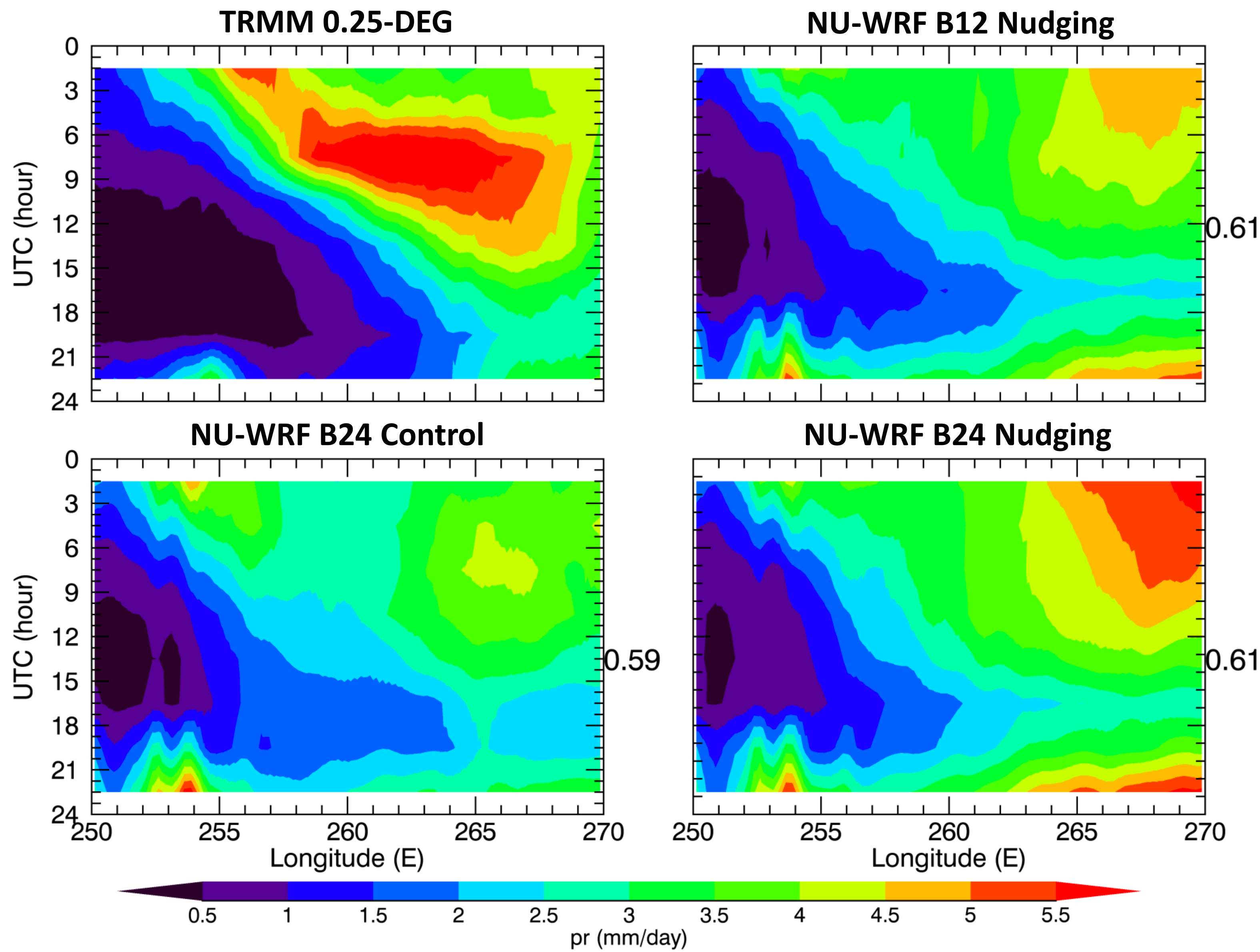
Summer MCS: JJA Mean Rainfall

****NOTE: Will be examining STIV QPE next!**



Summer MCS: JJA Mean Eastward Propagation

****NOTE: Will be examining STIV QPE next!**



West Coast Winter Atmospheric Rivers (AR)

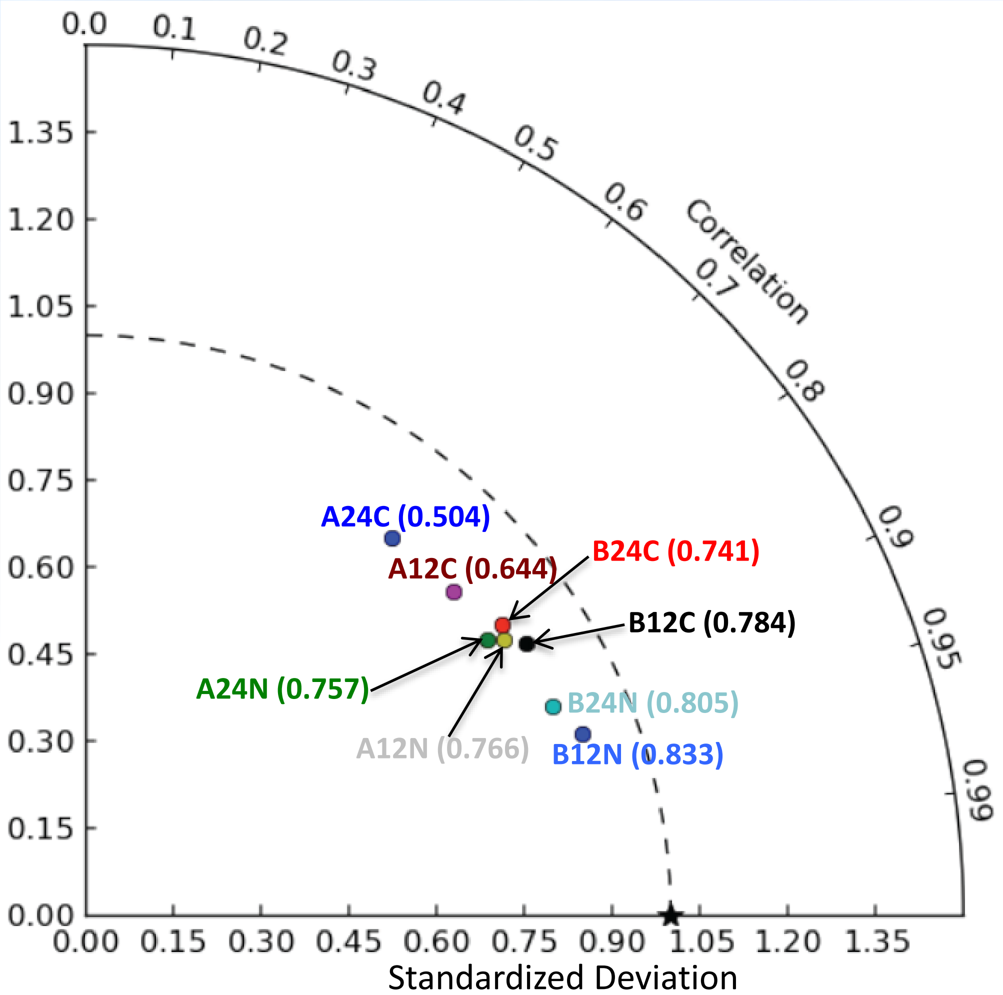
IVT-based AR Detection for Global and Regional Studies

- Pixel-wise IVT thresholding → AR shape
- Location of max. IVT → AR axis
- Additional considerations (length, width, etc.)

(IVT=Mean, time-averaged Vertically Integrated Water Vapor Transport; Zhu and Newell 1998 [MWR])

West Coast Winter Atmospheric Rivers

Evaluation of AR Precip Spatial Variability vs. NLDAS



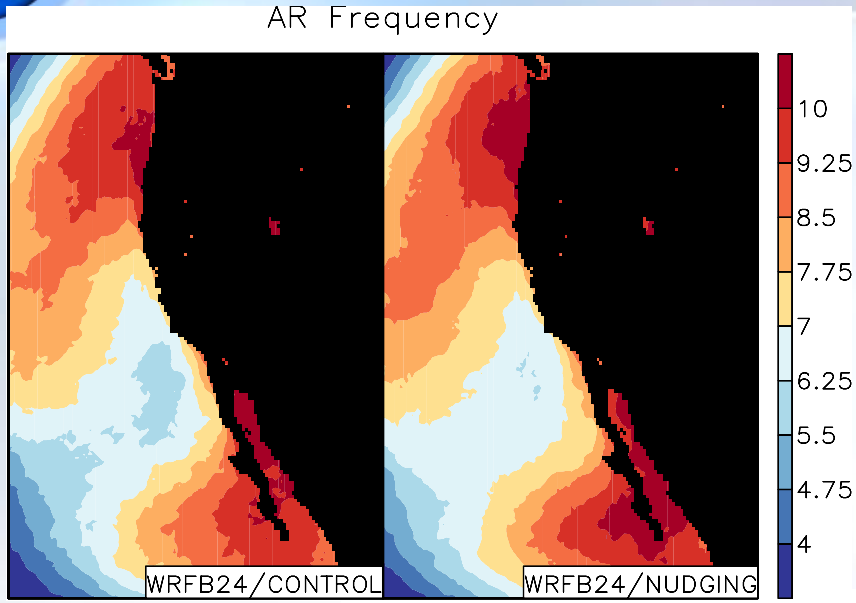
Spatial variability of the AR-precipitation fraction over WUS in the eight NU-WRF runs is evaluated using the Taylor diagram and "Tian" score

Performance varies widely, but a general pattern emerges.

- Smaller domain (B) out-performed larger domain (A)
- Finer resolution runs perform better than coarser resolution runs.
- Runs with spectral nudging outperforms runs w/o it.

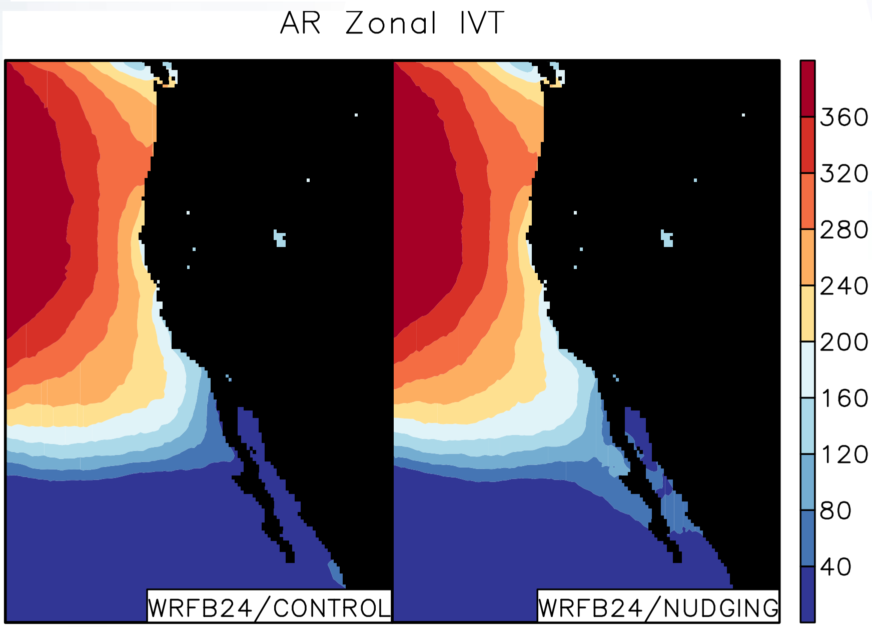
- *Using smaller domain, finer spatial resolution, and spectral nudging yields better results*.

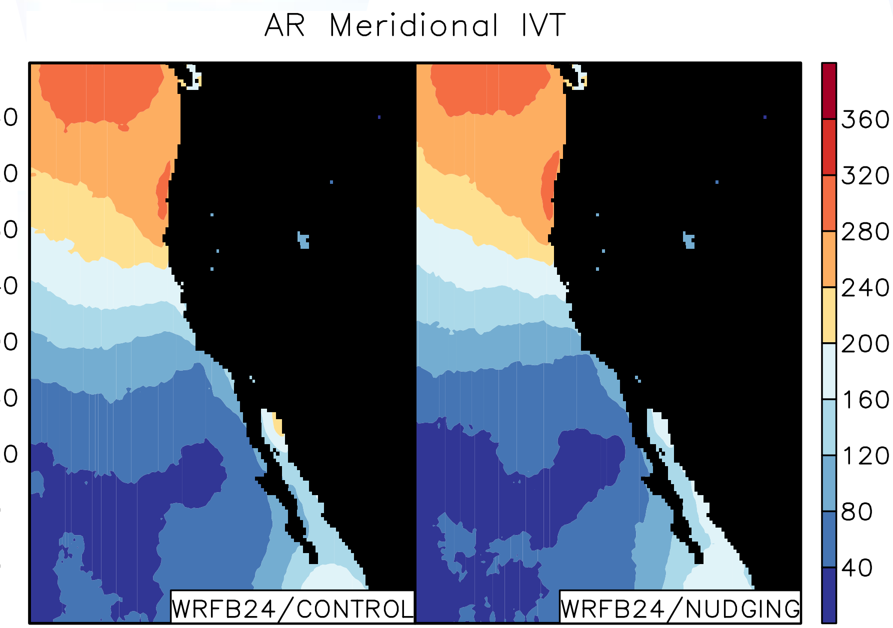
West Coast Winter Atmospheric Rivers



B24 Control vs. Nudging:

- Similar AR frequency and AR IVT, 1999-2010
- Probably due to close proximity of western lateral boundary





Ongoing and Future Efforts

- Complete domain B 4-km spectral nudging and Control (non-nudged) runs
- Perform “true” downscaling experiment of NU-WRF driven by GEOS-5 simulations
- Inter-compare NU-WRF downscaled runs to GEOS-5 high-res global simulations
- Summarize results using our developed metrics and compare against traditional downscaling metrics
- Make simulation data available to community

NASA Team Acknowledgement

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Kyo Lee	JPL	Di Wu	UMD/GSFC
Weile Wang	CSU/ARC	Brad Zavodsky	MSFC
Wei-Kuo Tao	GSFC	Bin Guan	UCLA/JPL
Kim Whitehall	JPL	Christa Peters-Lidard	GSFC
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