Center for Western Weather
and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY
AT UC SAN DIEGO

How do Spectrally Vast AR Thwart Attempts to Skillfully Forecast their Continental Precipitation?

International Atmospheric Rivers Conference

Modeling and Methods Session 1

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Collaborators
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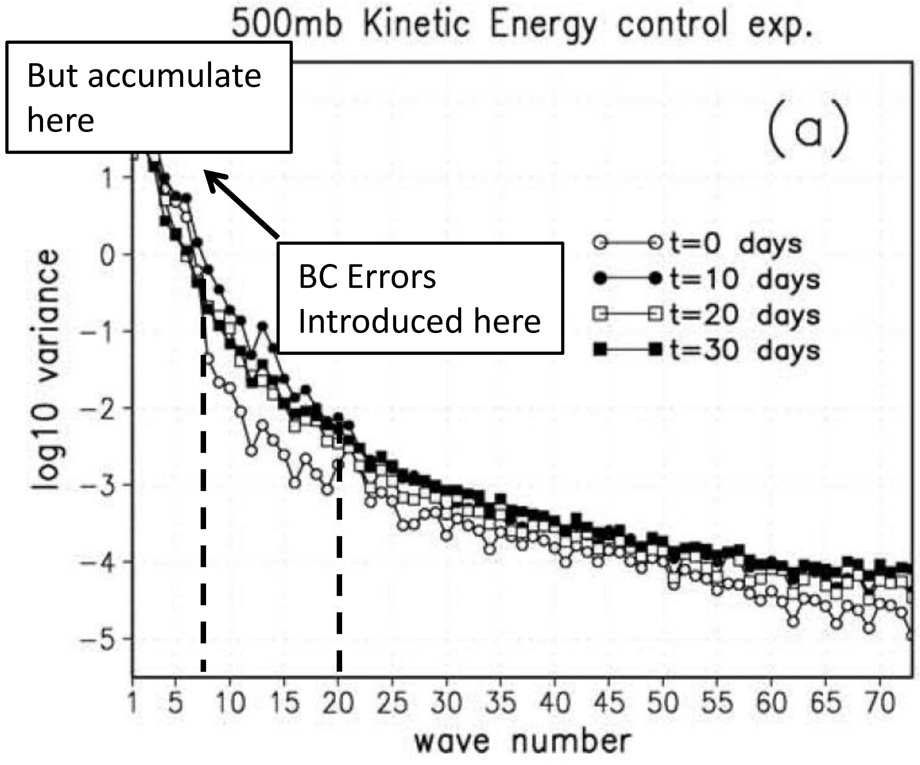
Outline

- Why do the Largest AR Scales Present a Problem to Limited Area Models?
- Results from Storm-Scale Configuration Tests
- Forecast Vapor Transport Structure Errors
- Why do the Scales Responsible for “Local Precipitation Response” Present an Additional Problem?
- Investigating Simulated Local Response in 2 NWP Systems
- Can Observed Linear Orographic Response Suggest Where to Invest Model Improvement?

AR Storm Scales Present a Problem for LAM



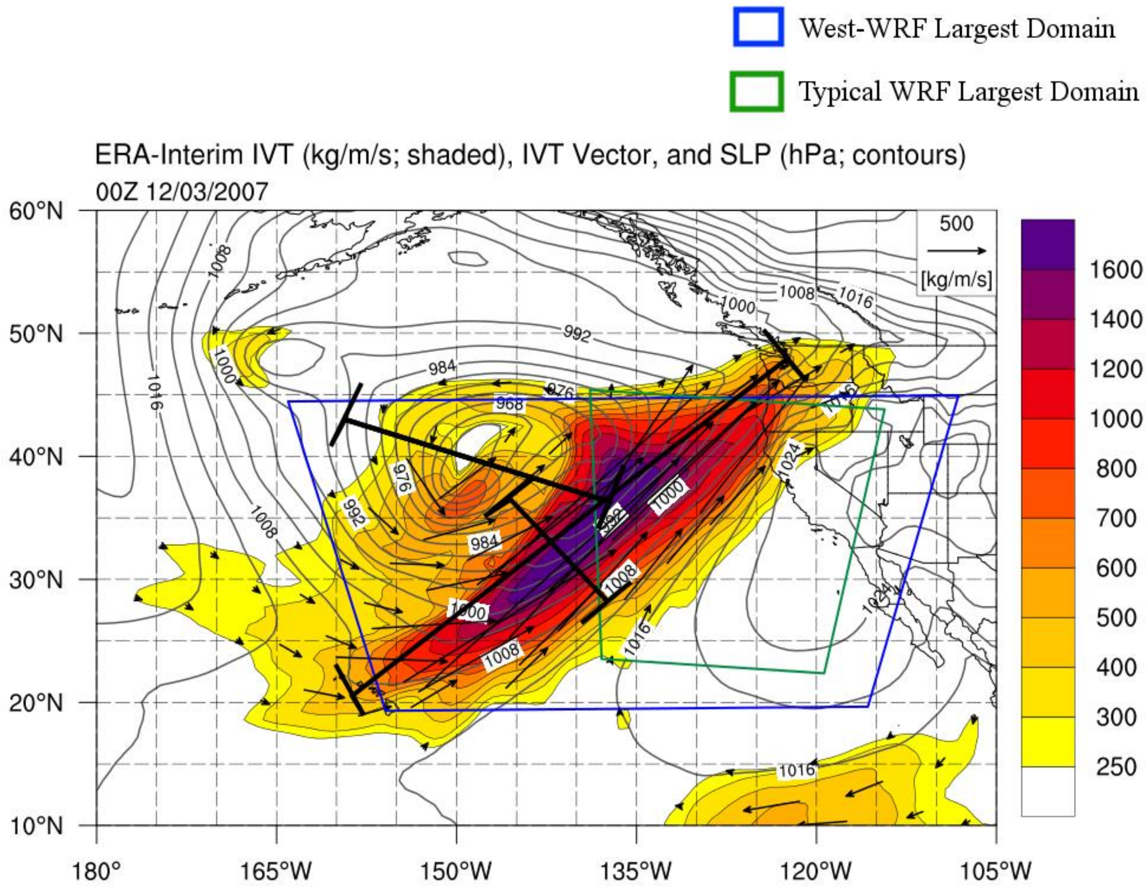
500mb Kinetic Energy control exp.

But accumulate here

BC Errors Introduced here

BC Δx

BC Δx/3



ERA-Interim IVT (kg/m/s; shaded), IVT Vector, and SLP (hPa; contours)

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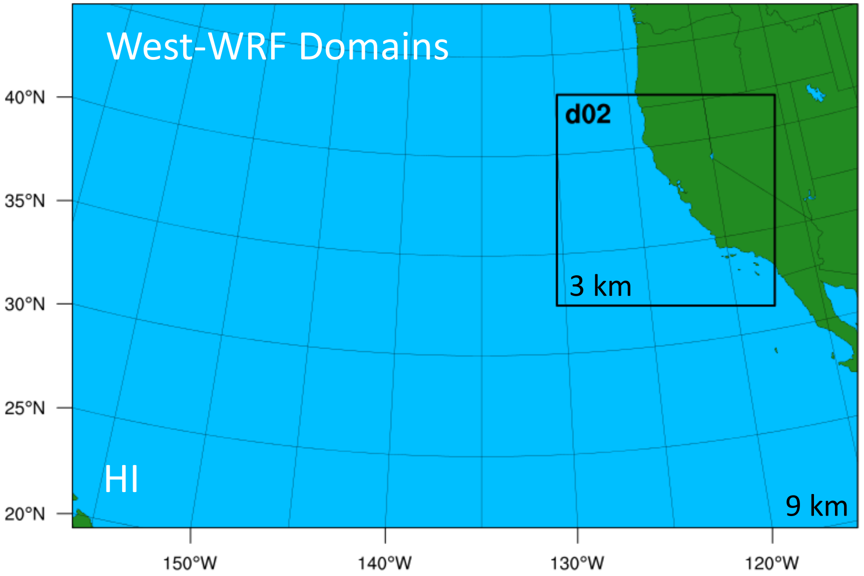
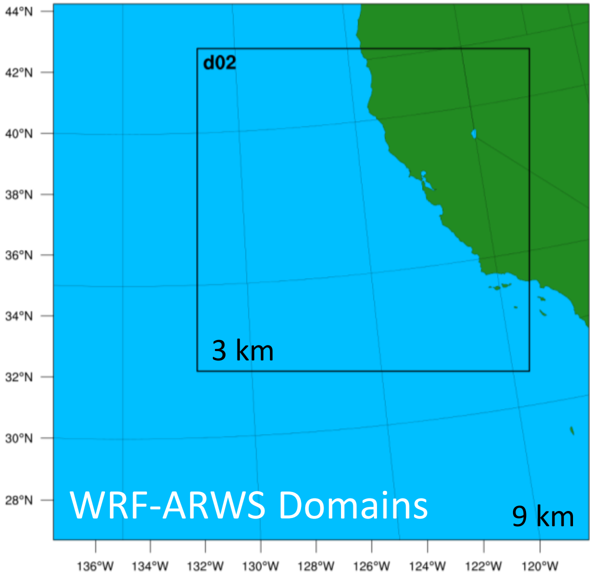
**Spectral Analysis from Miguez-Macho et al., *J. Geophys Res.* 2004

Models Investigated





Selected Physics:

- YSU BL
- Noah LSM
- MYJ Sfc
- Thomspon New MP
- Goddard SW
- RRTM LW
- GD 3D Cumulus (9 km only)

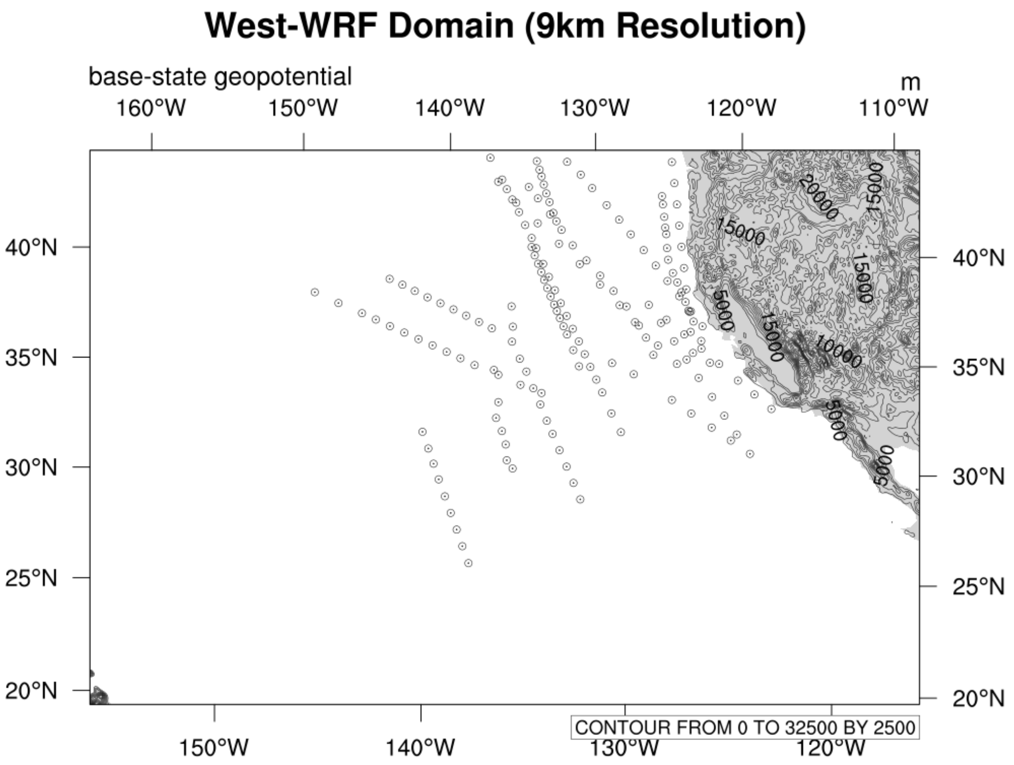
15 Oceanic AR and 10 Landfalling AR were simulated with 2 WRF configurations, both driven by GEFS 9.0.1 CTL member reforecast (GFSRe). Forecasts were run up to 7 days lead time with 24 hr lag.

West-WRF: 9 km / 3 km by 1-way nesting, 60 vertical levels, topographic wind correction.

WRF-ARWS: Identical to West-WRF except outer domain extent is smaller. Nested domains (used for precipitation verification) are identical.

**Martin et al., *J. Hydromet.*, In Prep.

West-WRF Verification Methods 1



Location of CalWater dropsondes used in study of forecast errors

15 Calwater flights completed AR Core transects during CalWater 2014 / 2015.

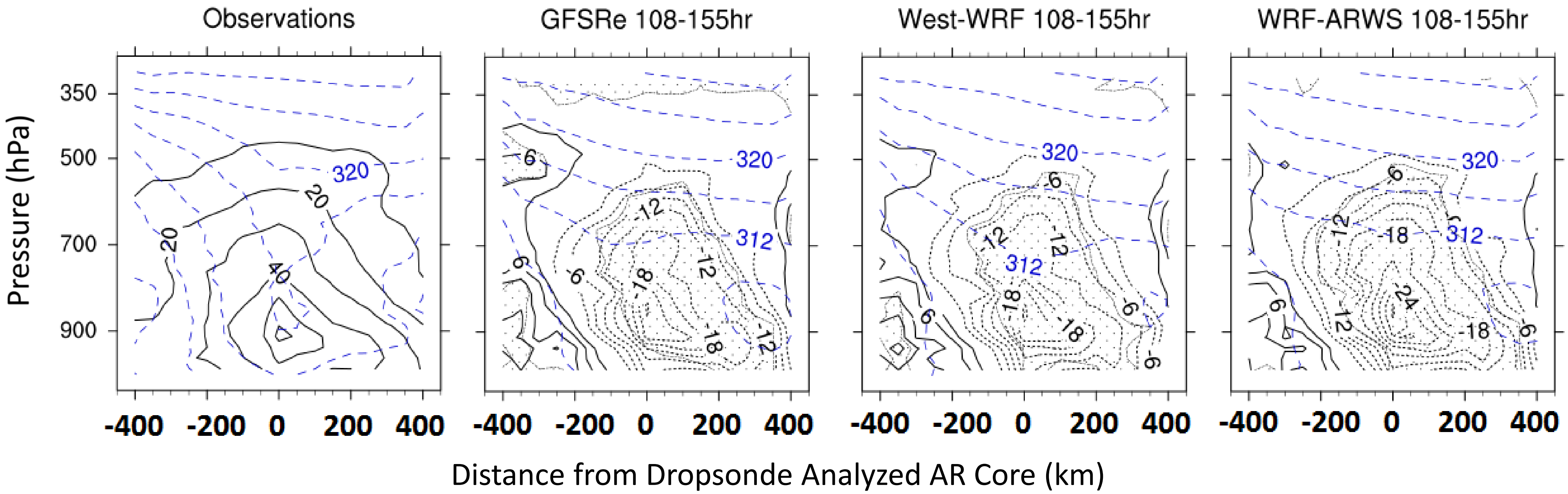
All transects crossed a moderate strength (IVT > 500 kg m^{-1} s^{-1}) core and were more than 1° from model boundaries.

Use these observations to investigate forecast accuracy at storm scales (Δx > 80 km)

**Martin et al., *J. Hydromet.*, In Prep.

CW3E

Performance in Capturing Structure

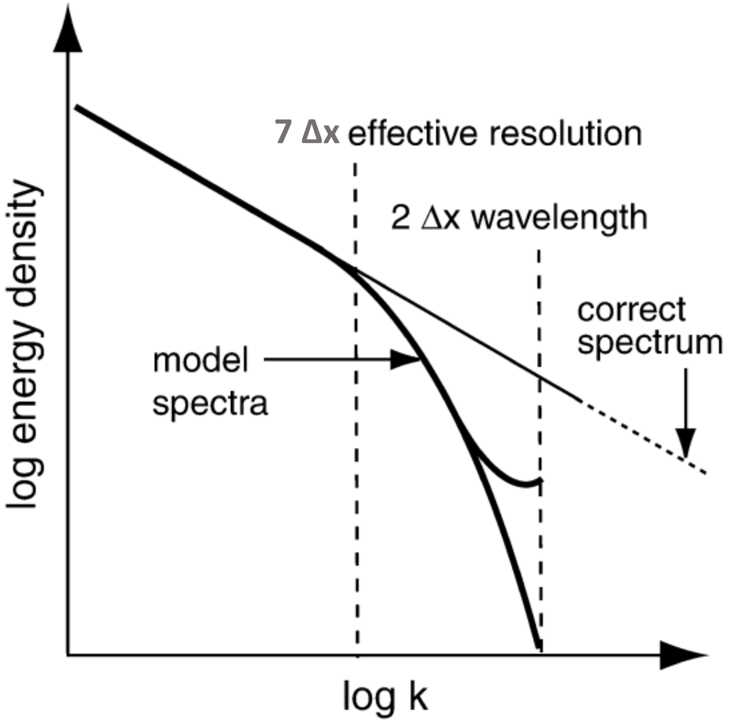


Left to Right: Partial IVT contours (kg m^{-2} s^{-1} - black) and θ_e (K - blue dashed) from Observations, GFSRe, West-WRF, WRF-ARWS

In panels showing model Partial IVT, quantity is model – obs. Negative contours are dotted.

**Martin et al., *J. Hydromet.*, In Prep.

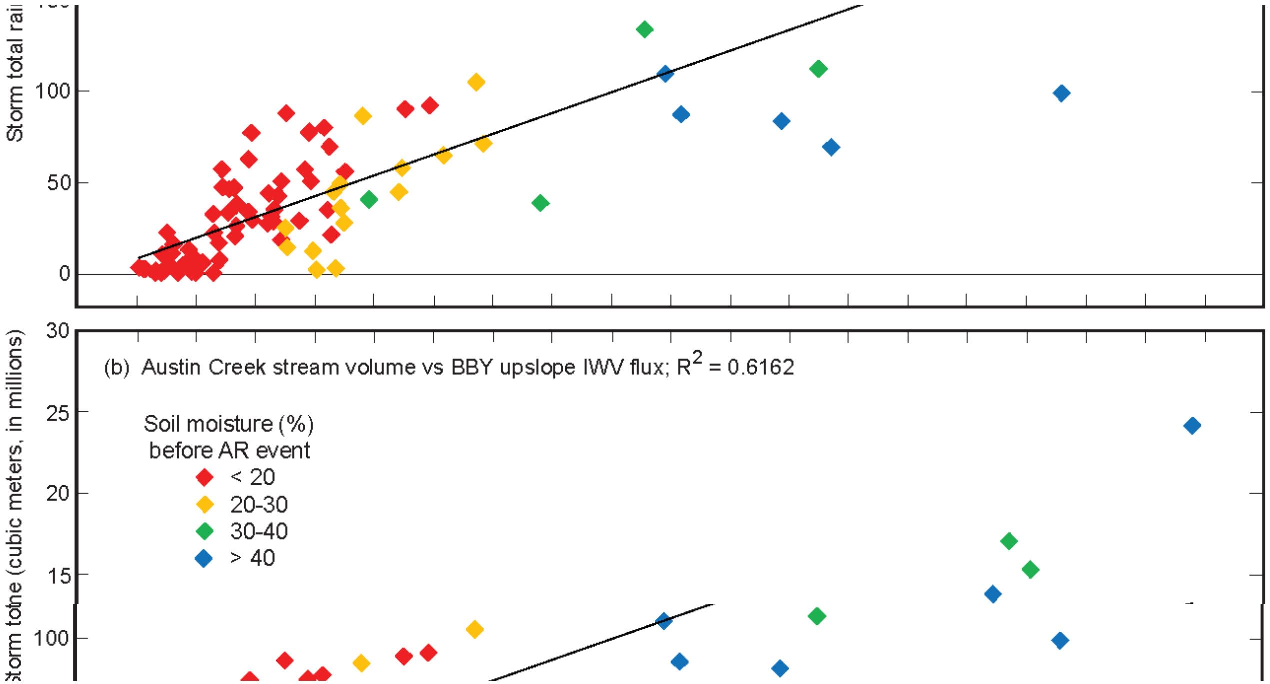
AR Precip. at Local Scale a Challenge for LAM and GCM



Δx ~ 1 km necessary to preserve energy density at local topographic scale

**Idealized Wavenumber Spectra from Skamarock, *Mon. Wea. Rev.*, 2004.

Direct Measurement of the Storm-Local Scale Relationship



Storm-total BUF (IVT Proxy, X Axis) is strong predictor of Storm-total rainfall (Y axis).

- BUF is determined primarily by storm scales (dx > 50 km)
- Rainfall response to BUF (slope, intercept, R^2) is controlled by local dx < 10 km scales.
- Model type determines whether BC, dynamics or physics most influences the error in the response.
- Least Squares can be used to derive a linear model Y = F(X) for observations and forecasts.

**Scatterplot from Ralph et al., *J. Hydromet.*, 2013.

West-WRF Validation Methods 2

Start Date	Start Time	Duration	Special Obs
12/10/2014	1500	32	
02/06/2015	0400	27	CalWater IOP
02/08/2015	0900	25	CalWater IOP
12/09/2015	1300	26	
12/20/2015	1400	47	
01/17/2016	0400	25	
01/28/2016	1700	32	
03/05/2016	2200	33	FIRO Soundings
03/09/2016	0800	42	FIRO Soundings
03/12/2016	1500	37	

10 “Moderate” or stronger AR that made landfall in the Russian River Watershed are used to build a database for verification.

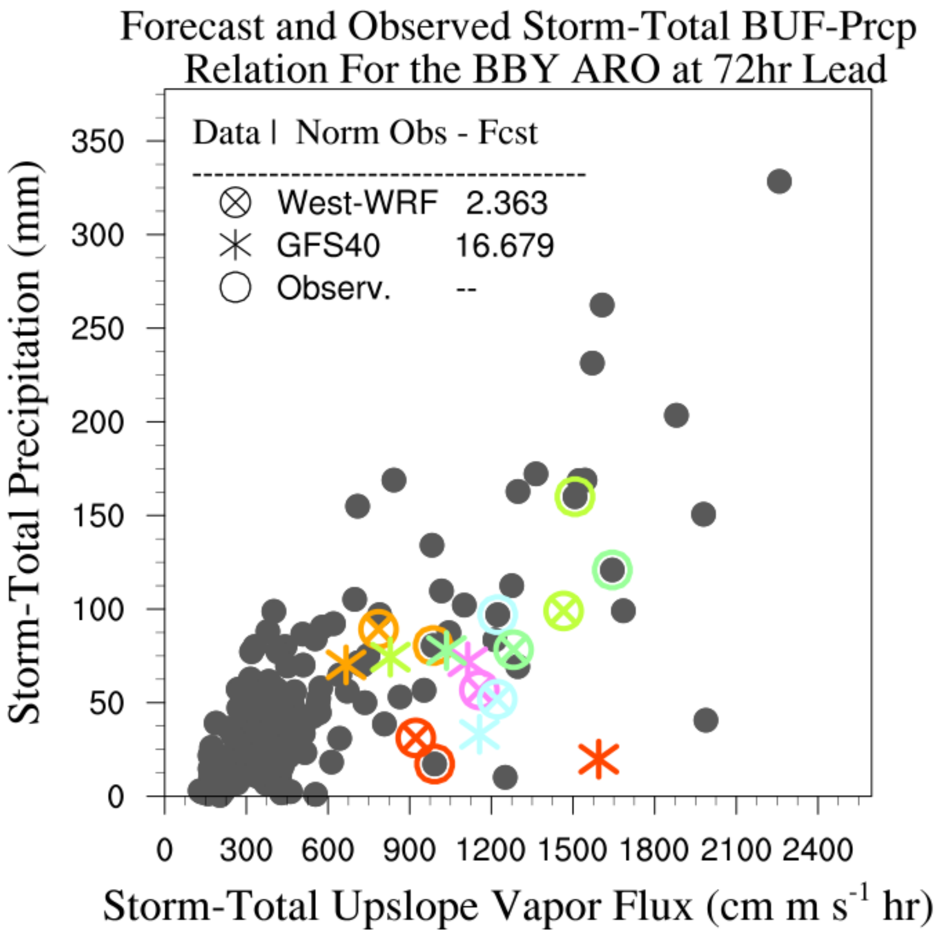
The NOAA Coastal ARO is used to investigate forcing and precipitation response.

Forecasts are generated for lead times up to 7 days every 24 hr.

West-WRF, WRF-ARWS
GFSRe is used for comparison

CW3E

Which model simulates the forcing-response relationship at local scale?



Normalized 2-dim. Error (e_{xy}): ARO - Model

Lead Time	West-WRF	GFS
12 - 59	1.285	12.68
60 - 107	3.524	10.50
108 - 155	9.275	18.33

$$e_{xy} = E\left[\left(X - X_0\right)^2 + \left(Y - Y_o\right)^2\right] \Big/ 2\sqrt{V\left[X_0\right]V\left[Y_0\right]}$$

**Martin et al., *J. Hydromet.*, In Prep.

Linearizing the Response Relationship

Normalized Error in ST Precip:

$$e_y = E\left[\left(f\left(X\right) - Y_o\right)^2\right] \Big/ V\left[Y_o\right]$$

If $F_o(\ )$; $F(\ )$ derived from linear LS fit obs. and modeled BUF-Prcp at ARO, then

$$de_{ypr} = E\left[\left(F_o\left(X\right) - Y_0\right)^2\right] \Big/ e_y \; - 1$$

$$de_{ypf} = E\left[\left(F\left(X_o\right) - Y_0\right)^2\right] \Big/ e_y \; - 1$$

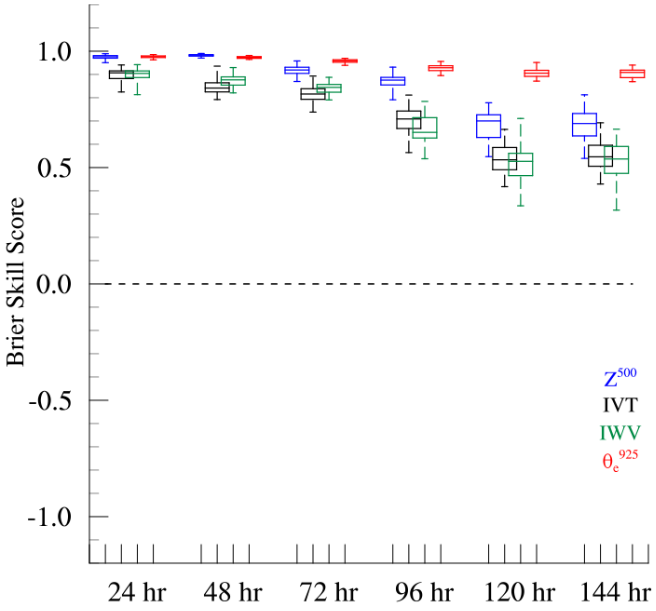
are the reduction in forecast ST Precip. by "perfect" local response (pr) and "perfect" storm scale forcing, respectively.

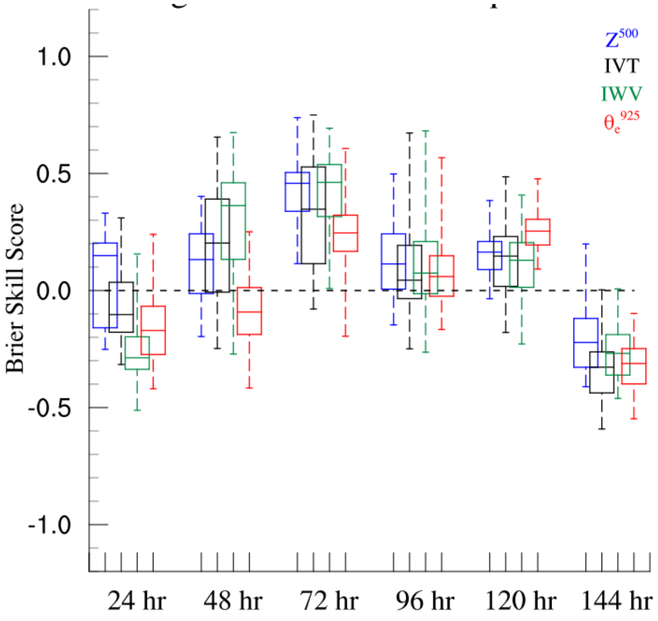
Error Measure		**Forecast Lead Time (hr)**		
		12 – 59	60 – 107	108 - 155
e_y	West-WRF	0.442	1.224	2.092
	GFSRe	15.753	24.094	41.176
e_{ypf}	West-WRF	--	-60.7%	-79.7%
	GFSRe	-33.7%	-35.3%	-25.0%
e_{ypr}	West-WRF	--	-43.4%	-51.4%
	GFSRe	-95.3%	-94.4%	-86.8%

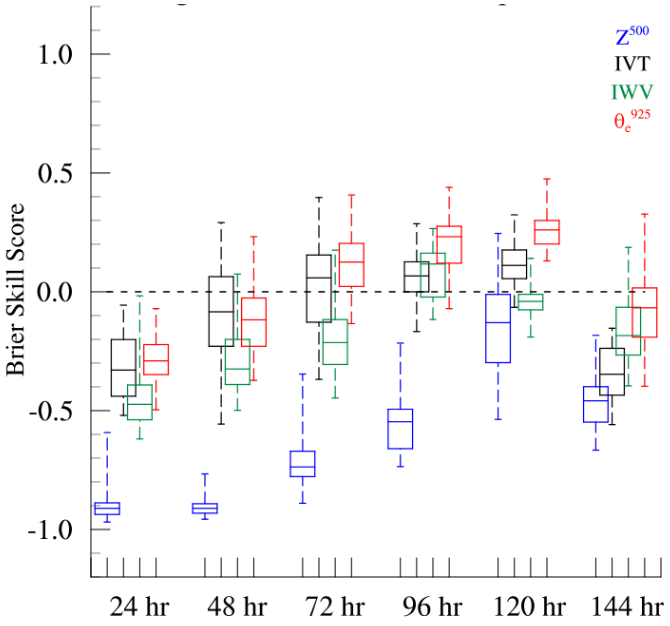
Summary and Conclusions

- Forecasting AR Requires Special Attention in Constructing LAM Domain.
- LAM (West-WRF) are able to forecast AR as accurately as GNWP at large scales up to 7 day lead times.
- If Storm-Scale forcing is as accurate, the reduction in dynamics and representativeness errors in high-res LAM offer big improvement in local scale precip. forecasting
- The dominance of local response relationship in driving GFSRe precip. errors was verified by a linearized model
- Linearized model demonstrated that West-WRF can be tuned for better precip. forecasts as well, at both local and storm scales.

NWP Performance at Storm Scales


GFSRe skill vs. GFSRe climatology

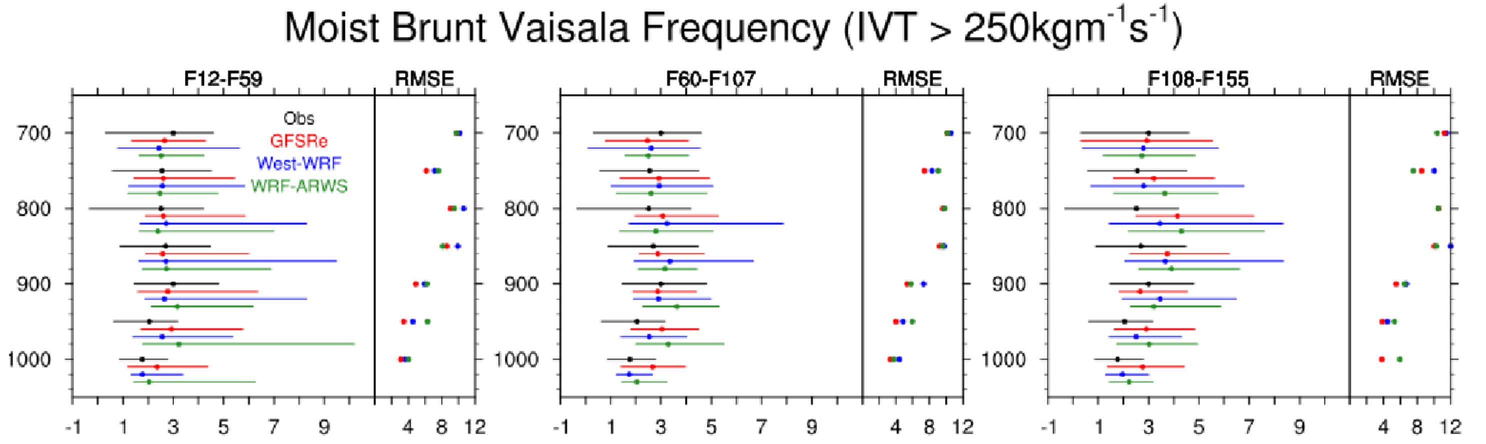

West-WRF skill vs. GFSRe

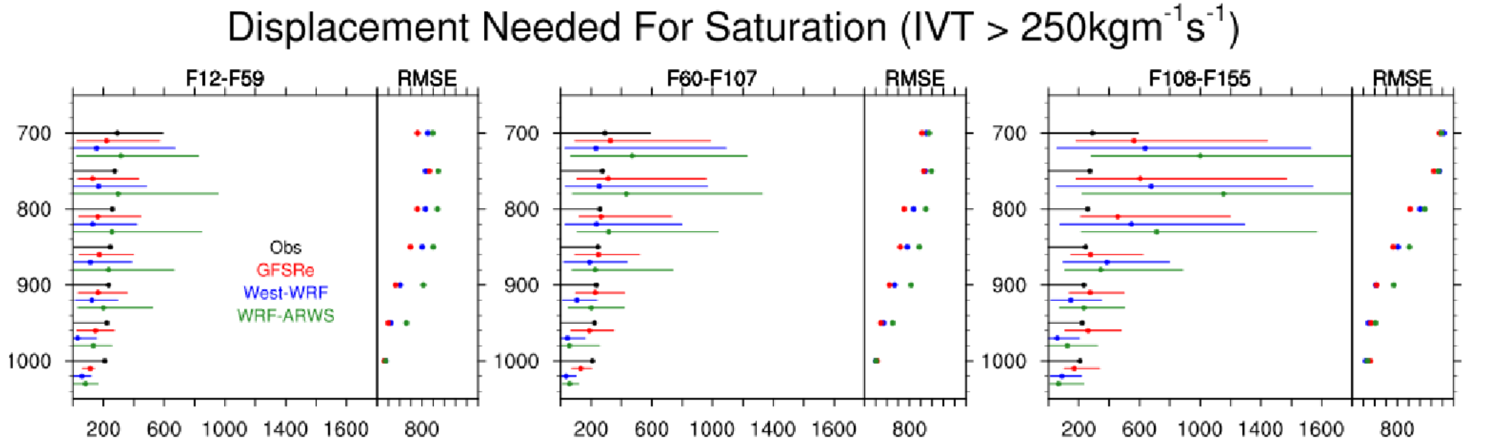

WRF-ARWS skill vs. GFSRe

Only Sondes for which IVT ≥ 250 kg m^{-1} s^{-1} used to compute BSS

**Martin et al., *J. Hydromet.*, In Prep.

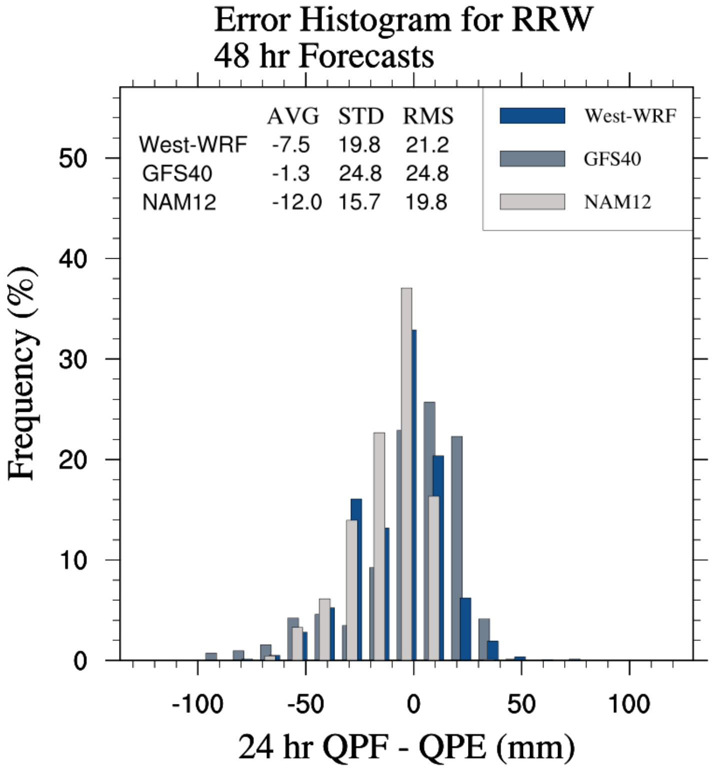
NWP Performance at Storm Scales


Moist Brunt Vaisala Frequency (IVT > $250kgm^{-1}s^{-1}$)


Displacement Needed For Saturation (IVT > $250kgm^{-1}s^{-1}$)

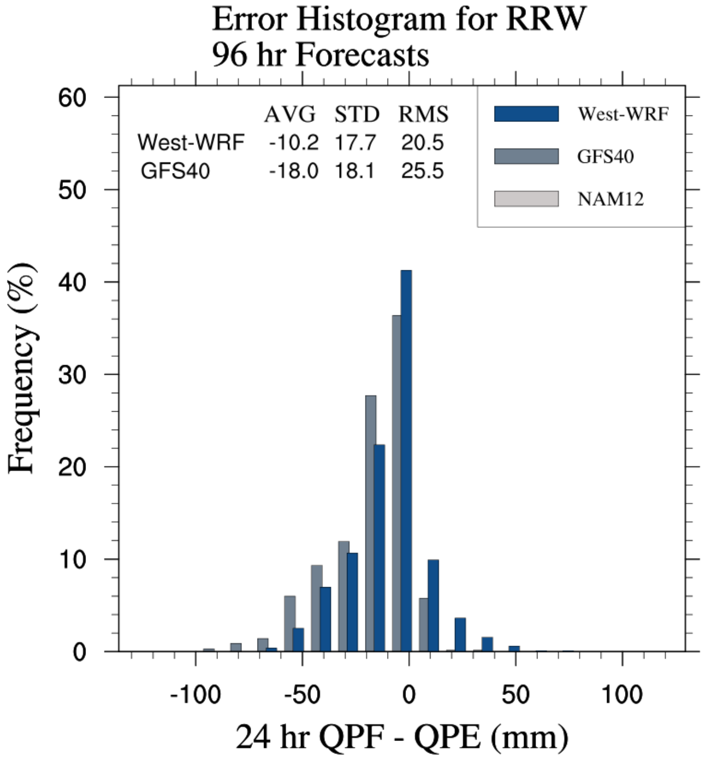
**Martin et al., *J. Hydromet.*, In Prep.

QPF Deterministic Skill During Landfalling AR



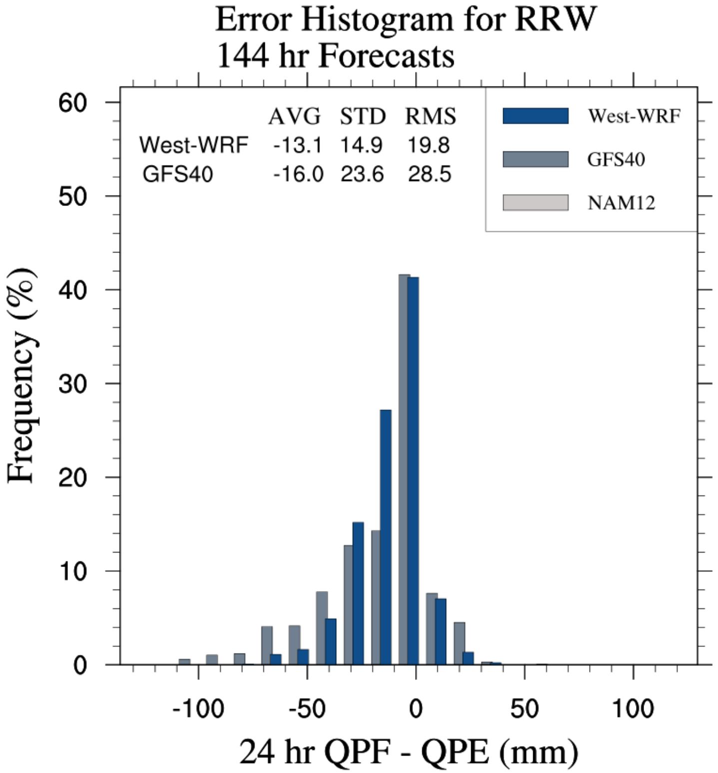
Error Histogram for RRW
48 hr Forecasts

	AVG	STD	RMS
West-WRF	-7.5	19.8	21.2
GFS40	-1.3	24.8	24.8
NAM12	-12.0	15.7	19.8



Error Histogram for RRW
96 hr Forecasts

	AVG	STD	RMS
West-WRF	-10.2	17.7	20.5
GFS40	-18.0	18.1	25.5



Error Histogram for RRW
144 hr Forecasts

	AVG	STD	RMS
West-WRF	-13.1	14.9	19.8
GFS40	-16.0	23.6	28.5

Validated Against NCEP Stage-IV 24 hr QPE. Models Linearly Interpolated to Stage IV Grid.

**Martin et al., *J. Hydromet.*, In Prep.