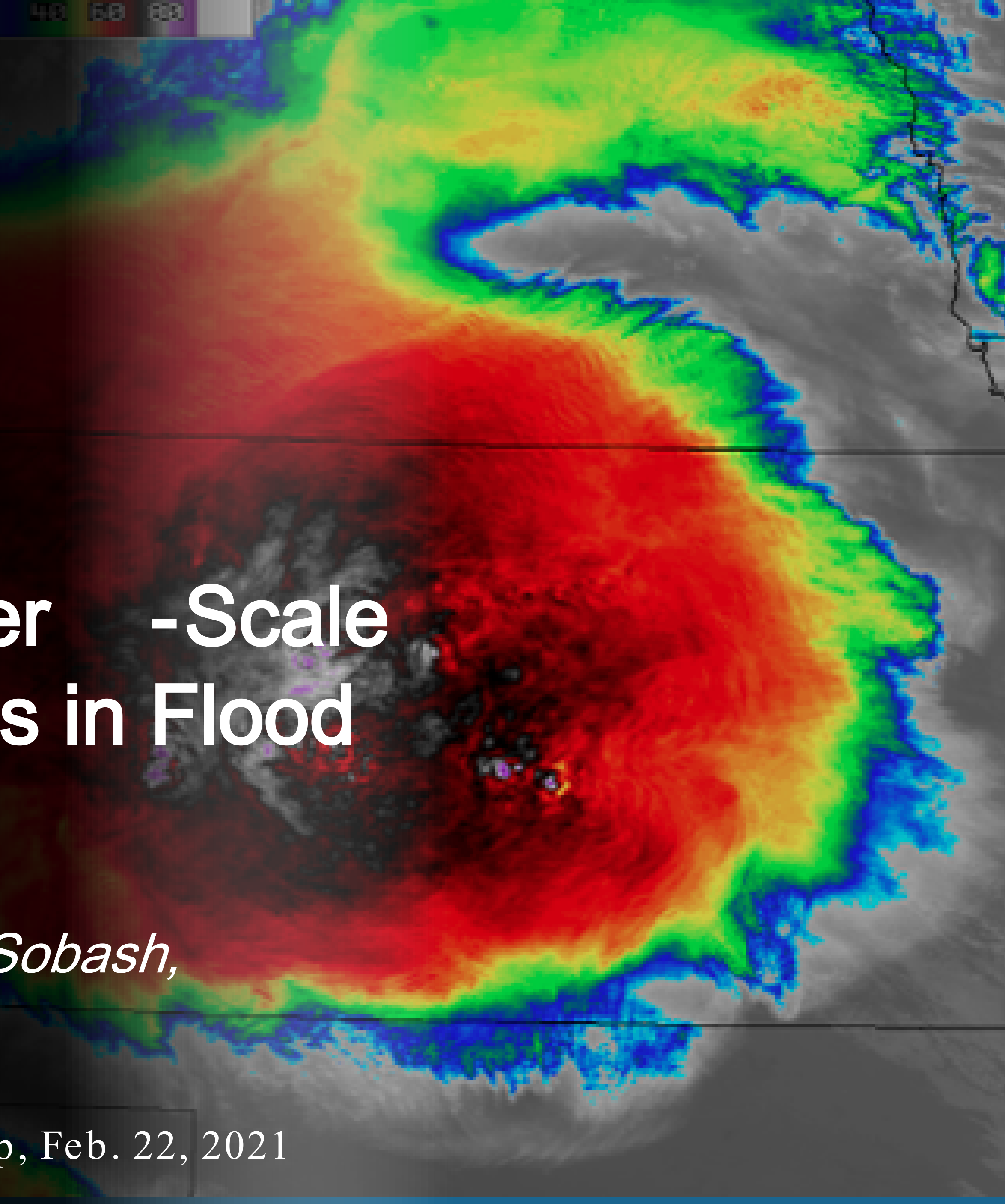

On the Applicability of Kilometer-Scale Heavy Precipitation Simulations in Flood Risk Assessments

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National Center for Atmospheric Research

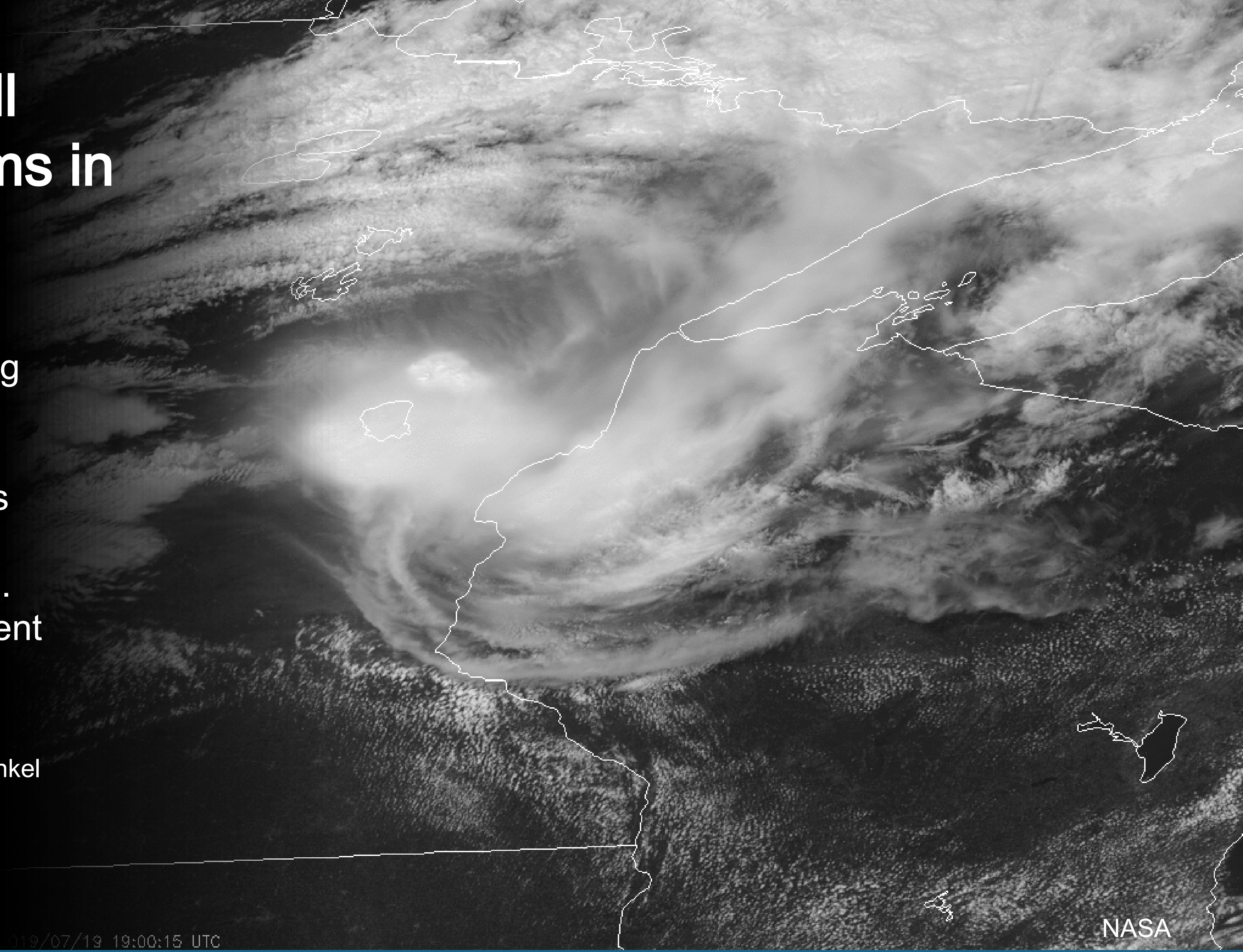
5th Annual Probabilistic Flood Hazard Assessment Workshop, Feb. 22, 2021

This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

Extreme Rainfall Producing Storms in the US

- Tropical Cyclones along the seaboard
- Mesoscale convective systems (MCSs), fronts and extratropical cyclones in central U.S.
- Orographic enhancement in Appalachian region

Schumacher and Johnson 2006, Kunkel et al. 2012, Prein and Mearns 2021



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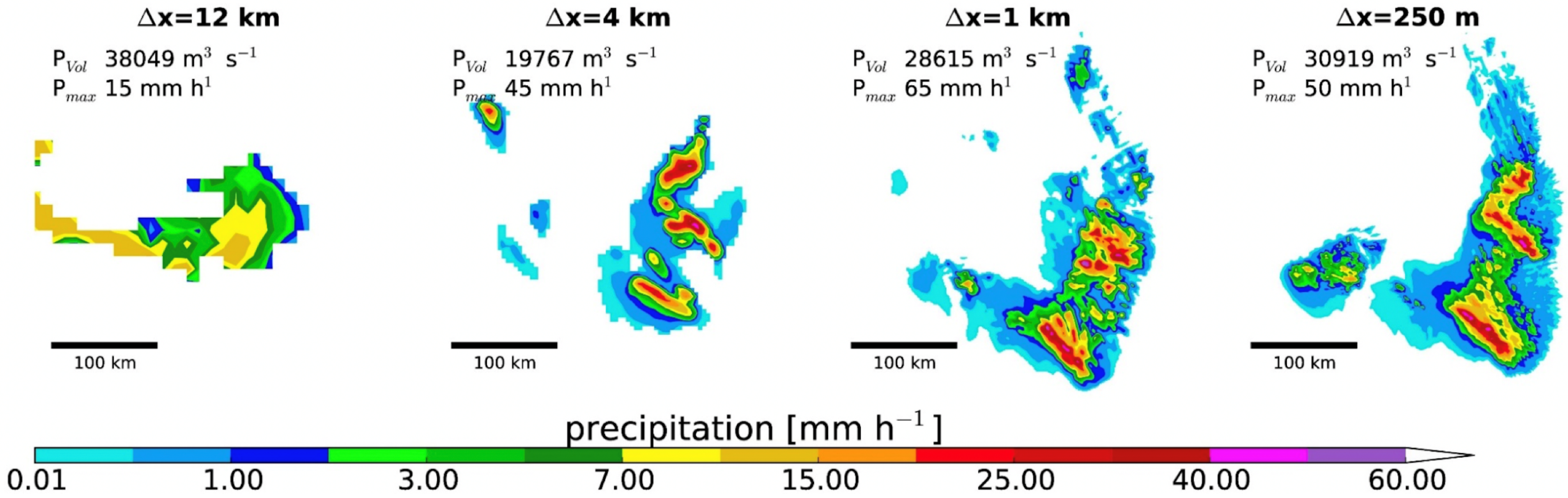
Model Resolution Dependence of Simulating Heavy Rainfall



Prein et al. 2021

Kilometer-sale (convection-permitting) models feature step improvement in simulating heavy rainfall.

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NRC project NR. 31310019S0015

”Convection-Permitting Modeling for Intense Precipitation Processes”

Probable Maximum Precipitation (PMP)

Does not allow quantification of uncertainties in hazard estimates in either a physical or a risk sense.

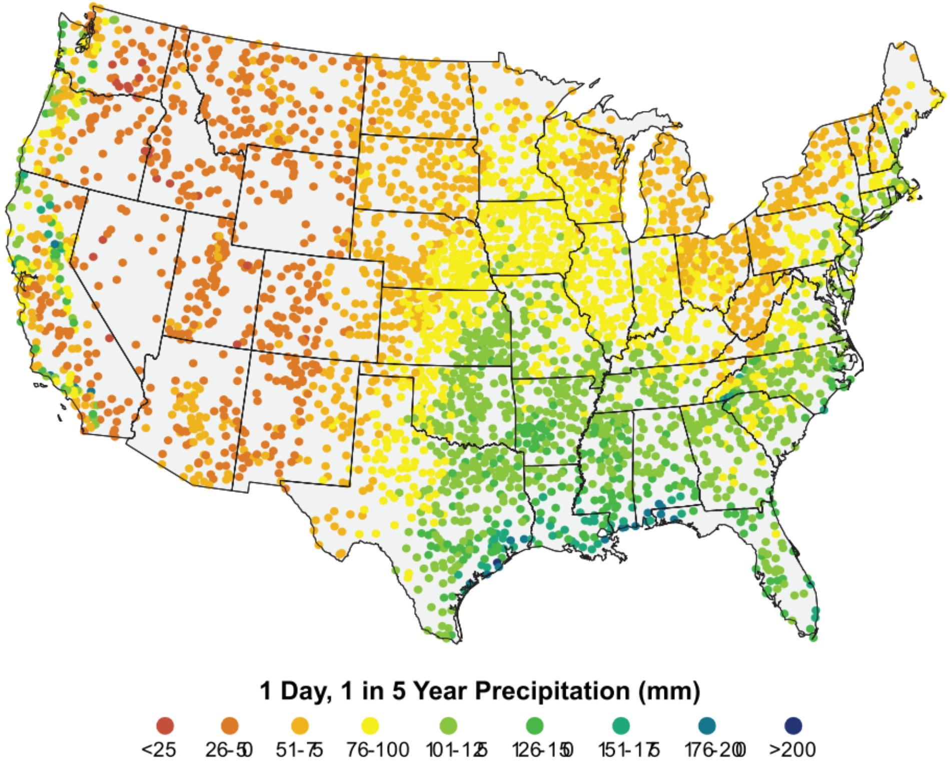
→

Convection-Permitting Models

Can they facilitate a more physically-based probabilistic flood risk assessments?

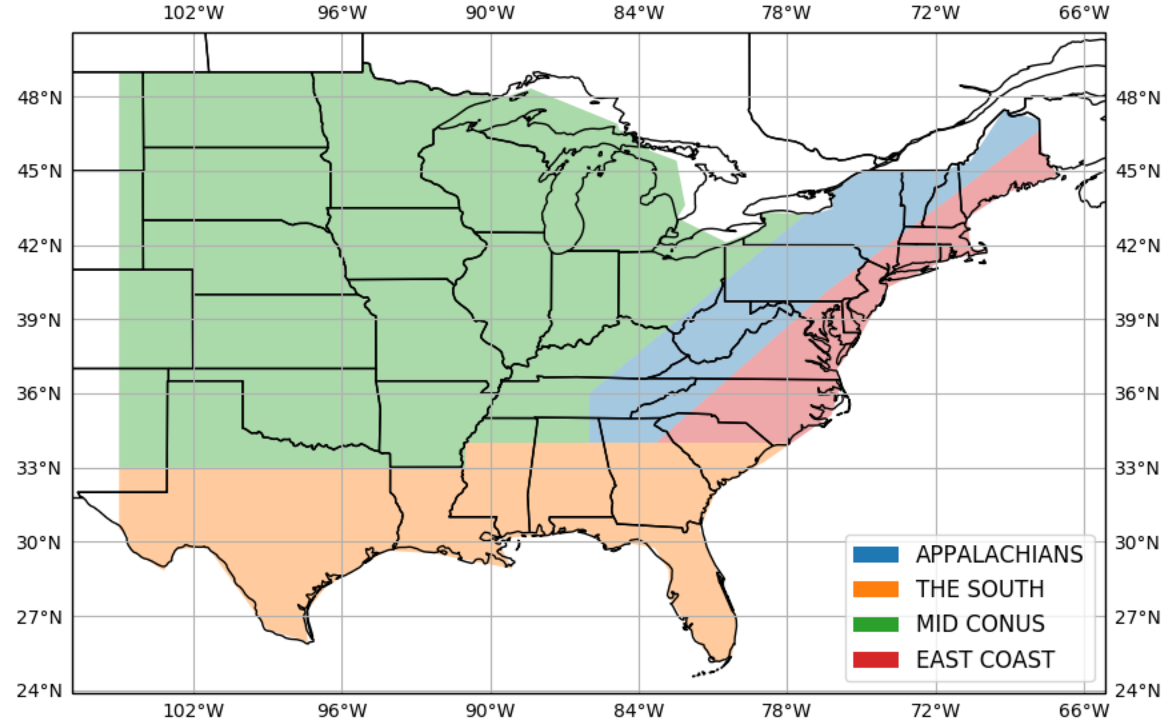
Intense Precipitation Events in Eastern CONUS

Daily, 1-in-5-yr precipitation amount for 3646 stations for the period of 1950–2010



Kunkel et al. 2012

Evaluation in Four Regions



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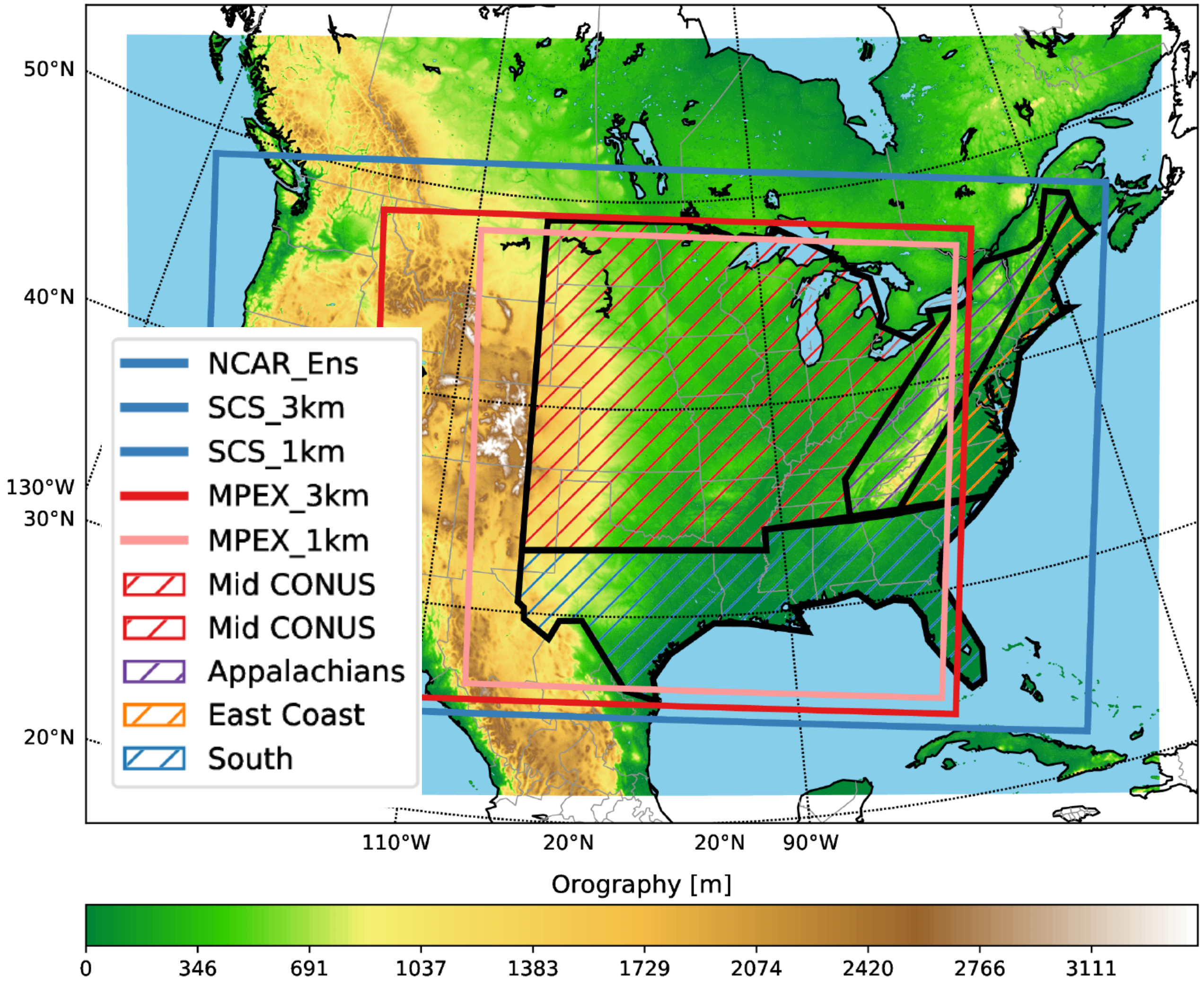
Analysis Region and Datasets

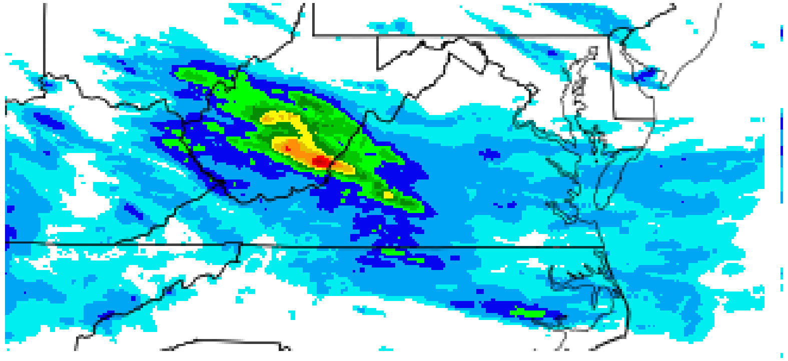


Dataset	Δx	Elements	Period	References
NCAR Real-time Ensemble	3 km	10-member ensemble forecasts	5/1/2015-12/31/2017	Schwartz et al. (2014, 2015a, 2015b), Romine et al. (2014)
NCAR MPEX Ensemble	3 km & 1 km	10-member ensemble forecasts	5/15/2013-6/15/2013	Schwartz et al. (2017)
NCAR Severe Weather Study	3 km & 1 km	Deterministic forecasts; 500 cases	2010-2017	Sobash et al. (2019), Schwartz et al. (2019)

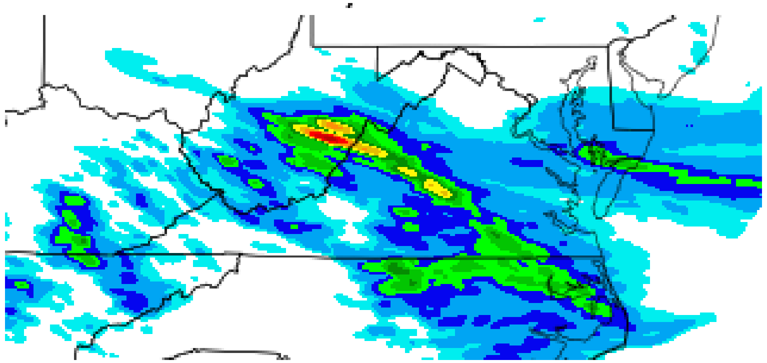
- 10,570 36-hour WRF simulations/forecasts at 3-km horizontal grid spacing (1.8 mi)
- 810 36-hour simulations at Δx=1 km (0.6 mi)

West Virginia Flooding of 2016

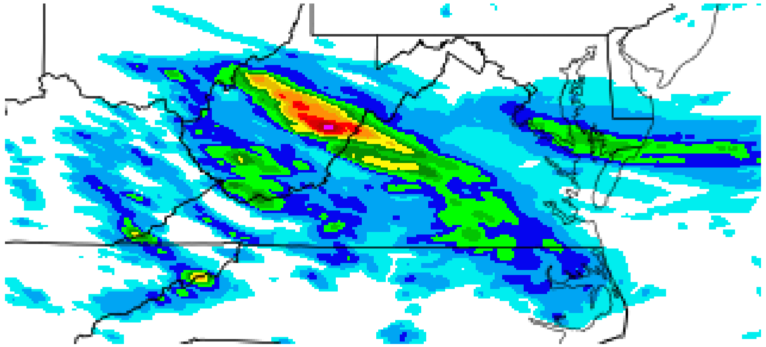
Observed Precipitation



3 km simulation

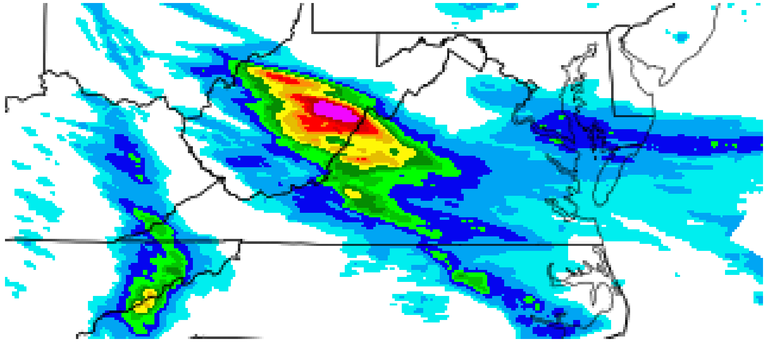


3 km simulation

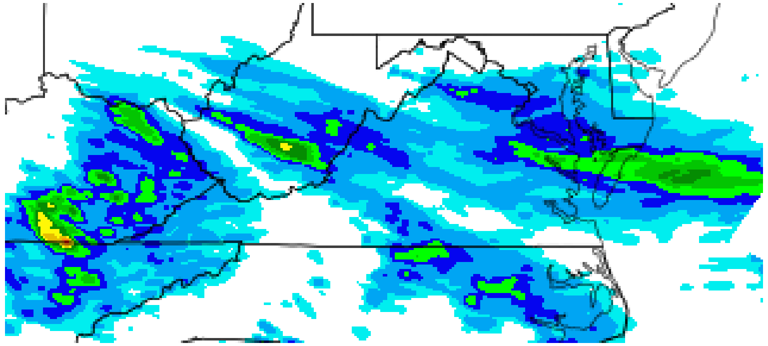


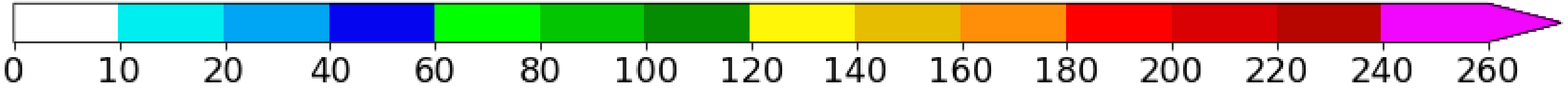
Ensemble approach generates a set of plausible heavy rainfall storms that could have occurred

1 km simulation



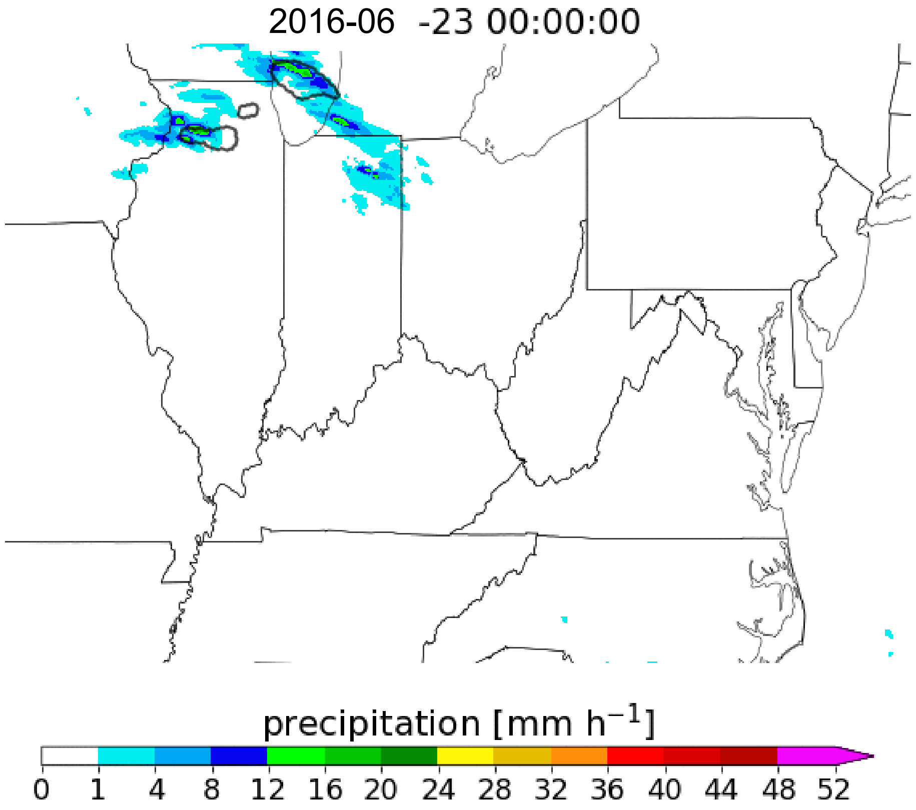
3 km simulation

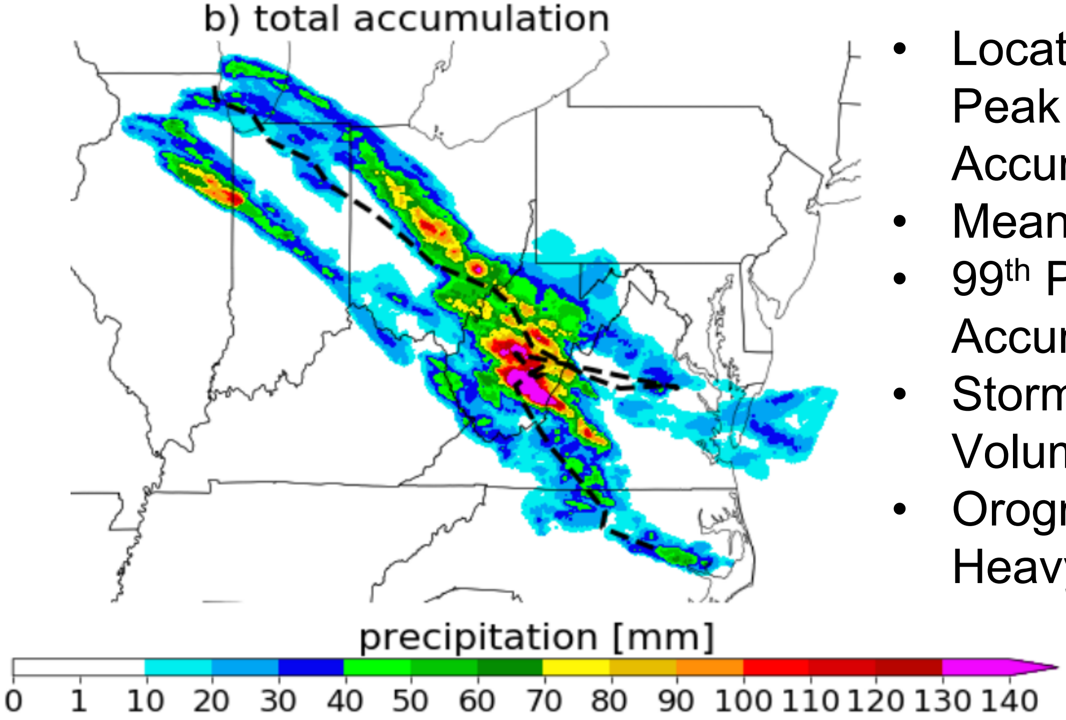




Lagrangian Evaluation Framework

West Virginia Flooding of 2016





Key Evaluation Metrics:

- Location of Peak Rainfall Accumulation
- Mean Hourly P99 Rainfall
- 99th Percentile Event Accumulation
- Storm Total Rainfall Volume
- Orographic Gradients of Heavy Rainfall

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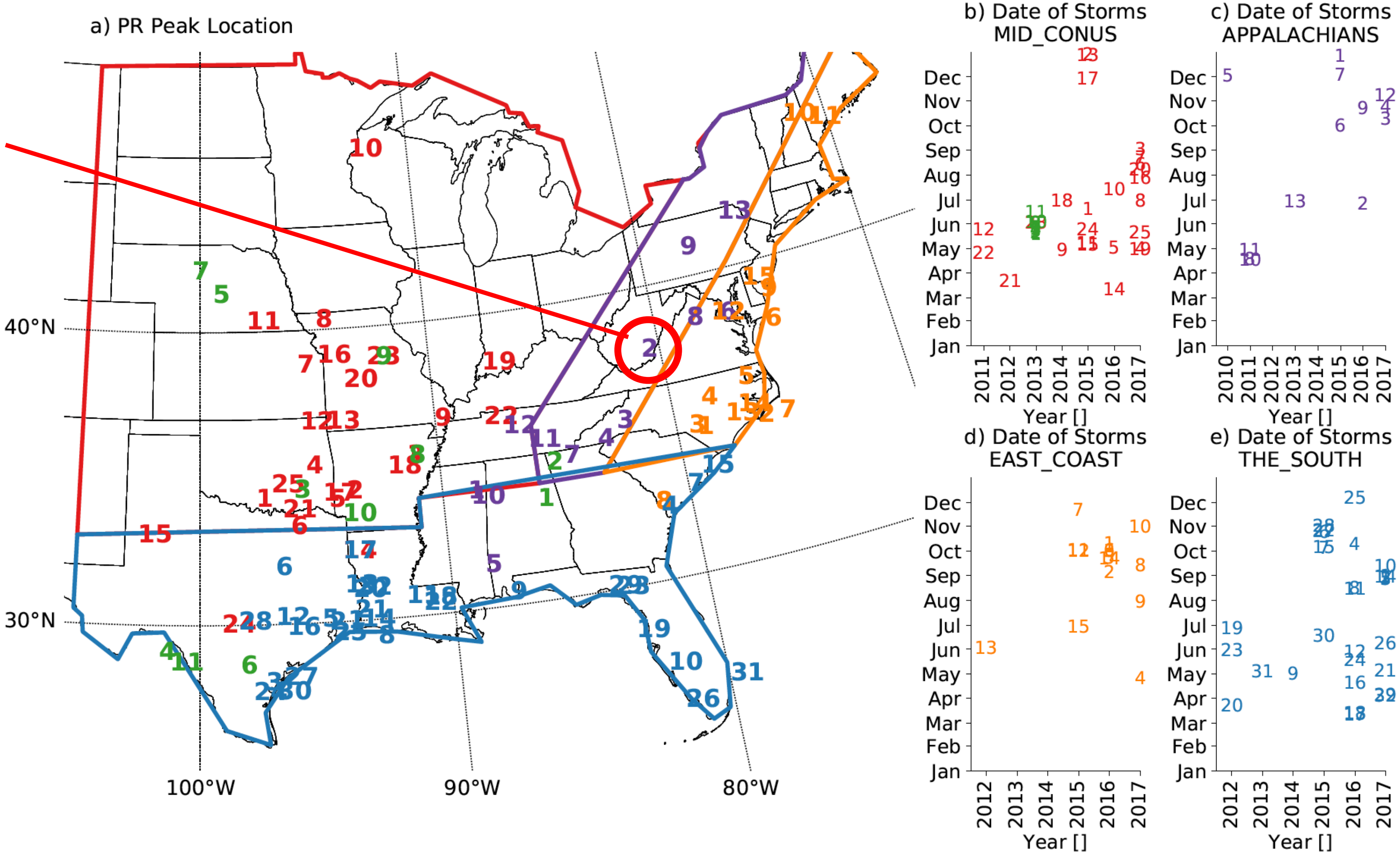
Selected Heavy Precipitation Events

West Virginia Flooding



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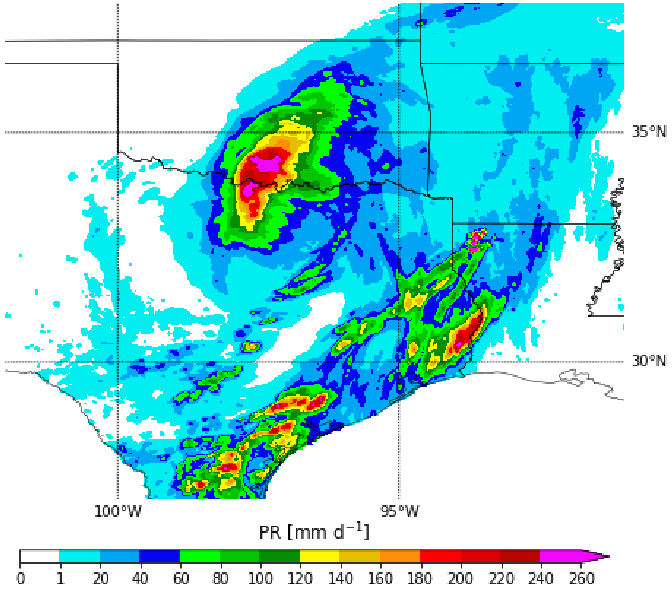
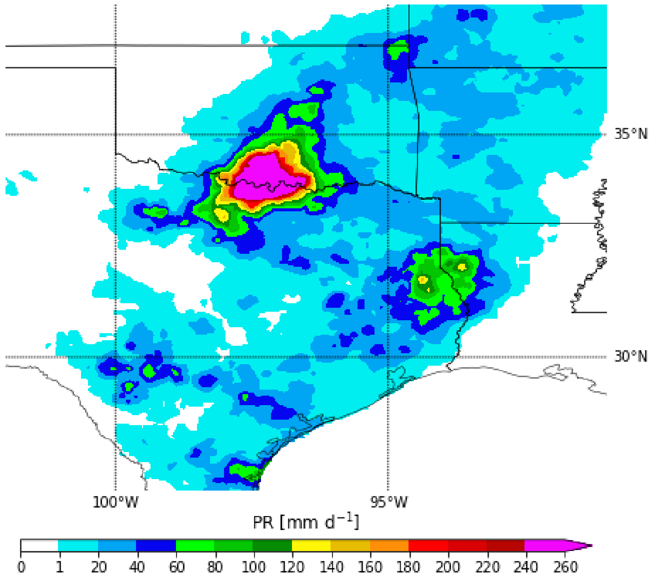
Observational Uncertainties

Data Name	Period	Δx/Δt	Ensemble size	Source
Stage IV	2001–present	4 km/ hourly	deterministic	159 radar stations, ~3,000 gauges
MRMS	2014–present	1 km/2.5 min.	deterministic	180 radar stations, gauges, NWP, lightning, satellite
PRISM	1982–present	4 km/ daily	deterministic	13,000 gauges and radar after 2002
GMET	1980–2016	12 km/ daily	100 members	12,000 gauges

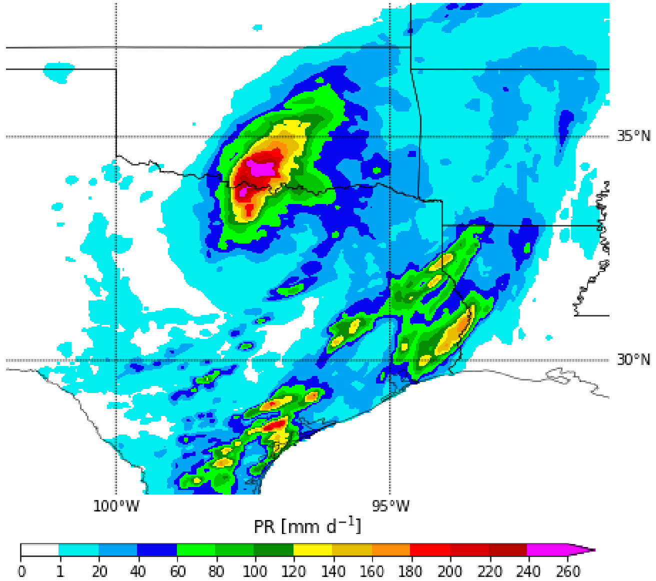
Stage-IV – radar & gauges



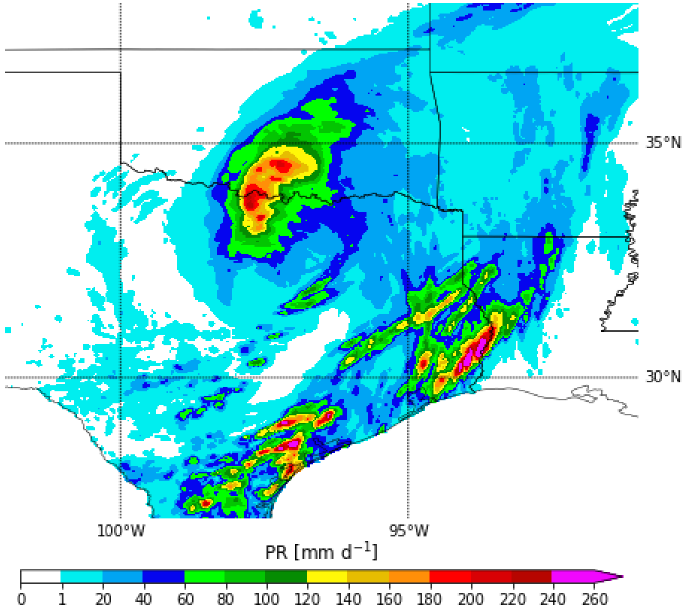
GMET – only gauges



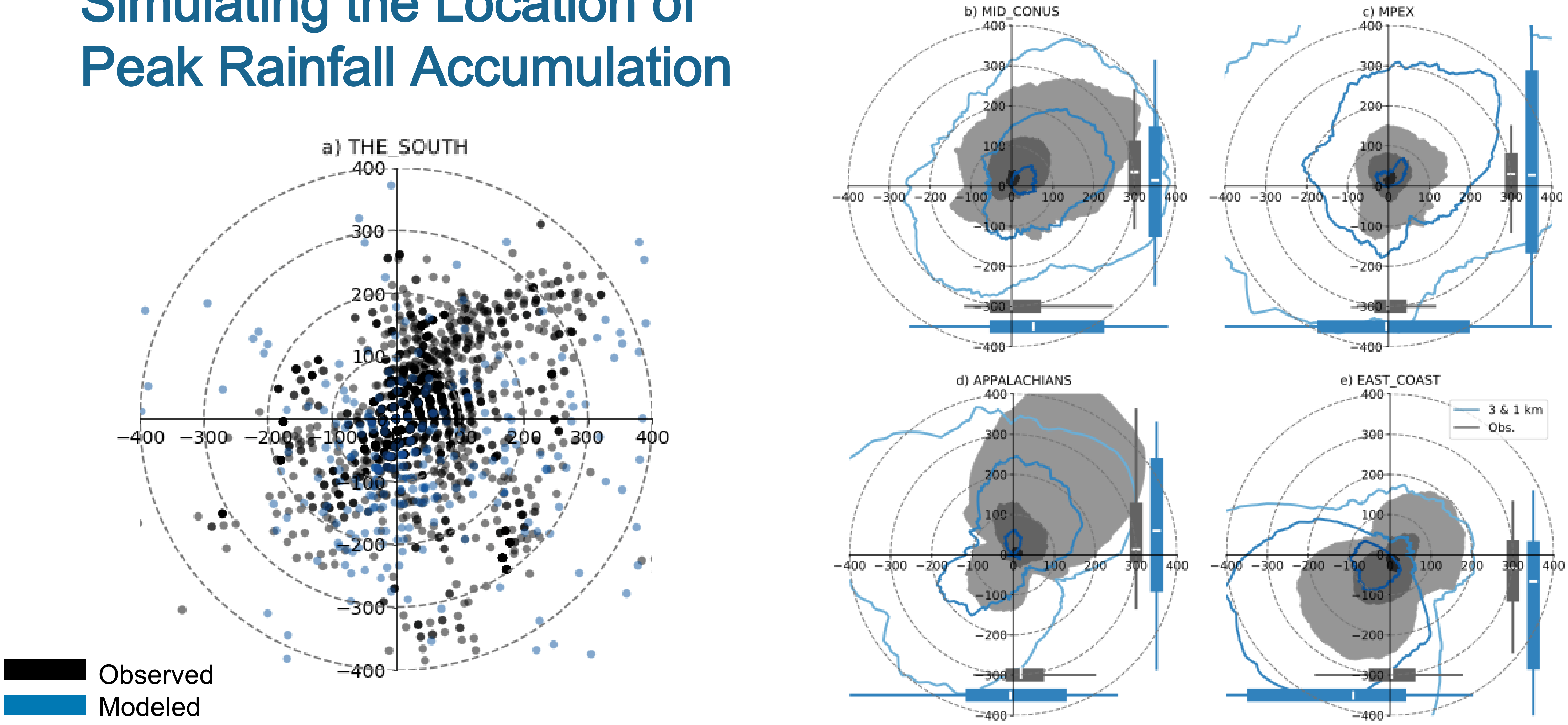
PRISM – radar & gauges



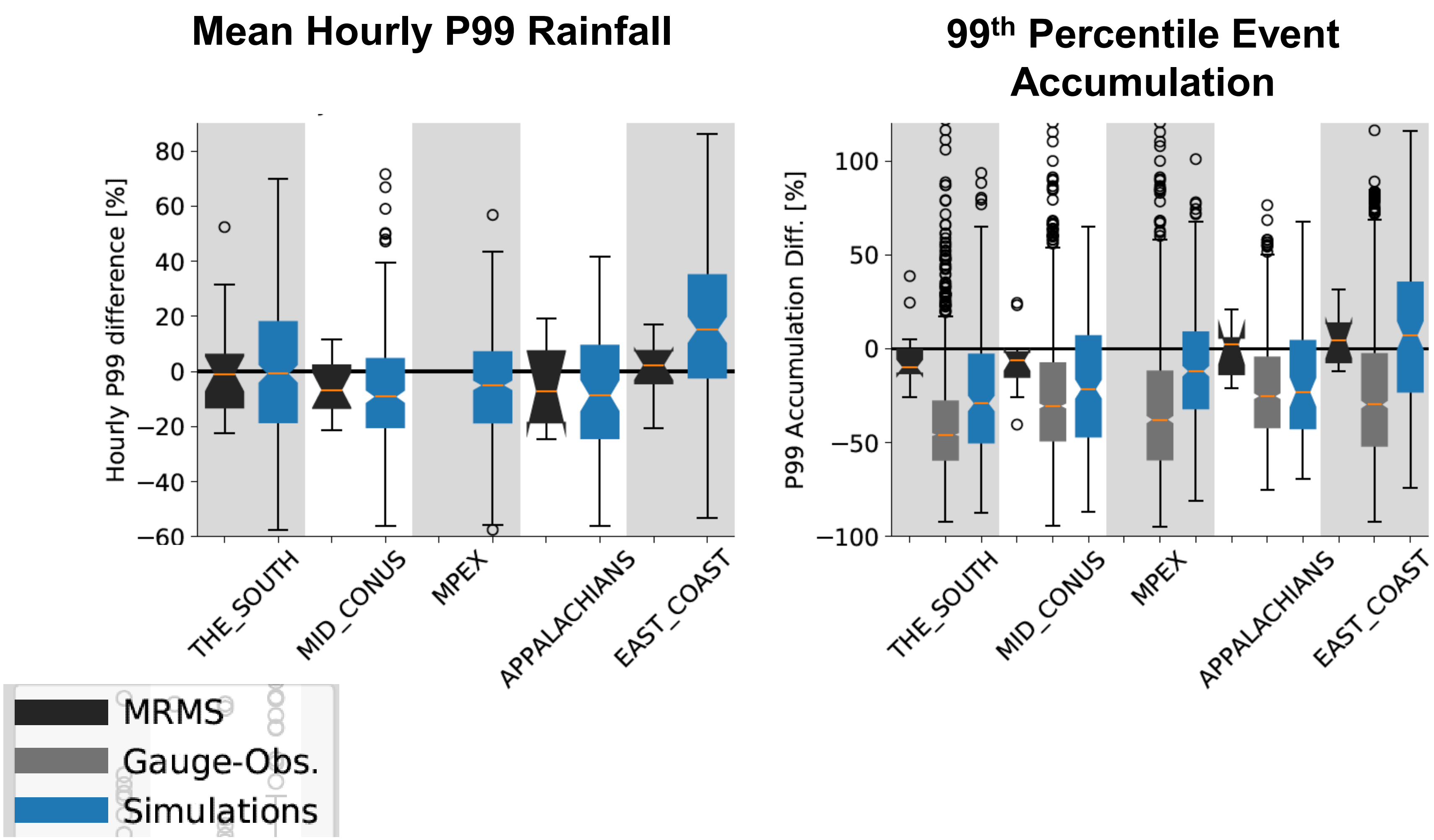
MRMS - multisensor



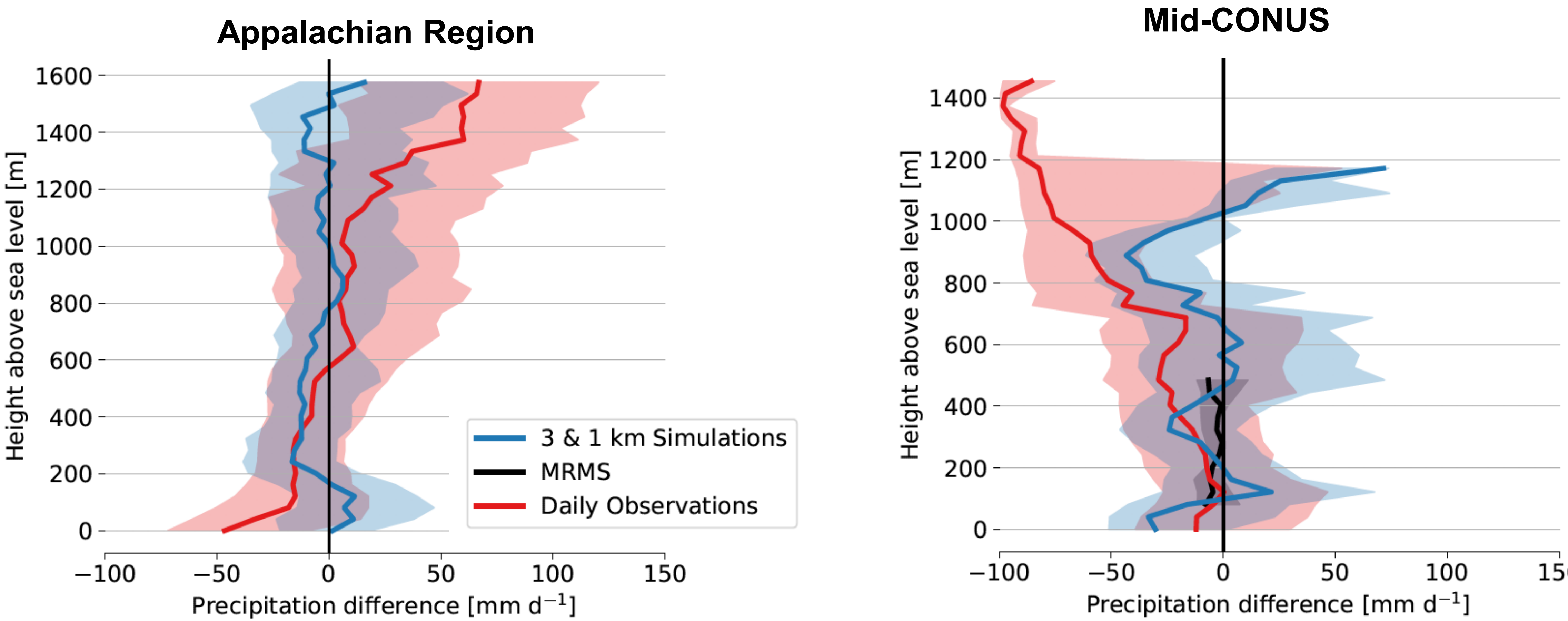
Simulating the Location of Peak Rainfall Accumulation



Biases in Simulated Heavy Rainfall Storms Compared to Stage -IV Observations

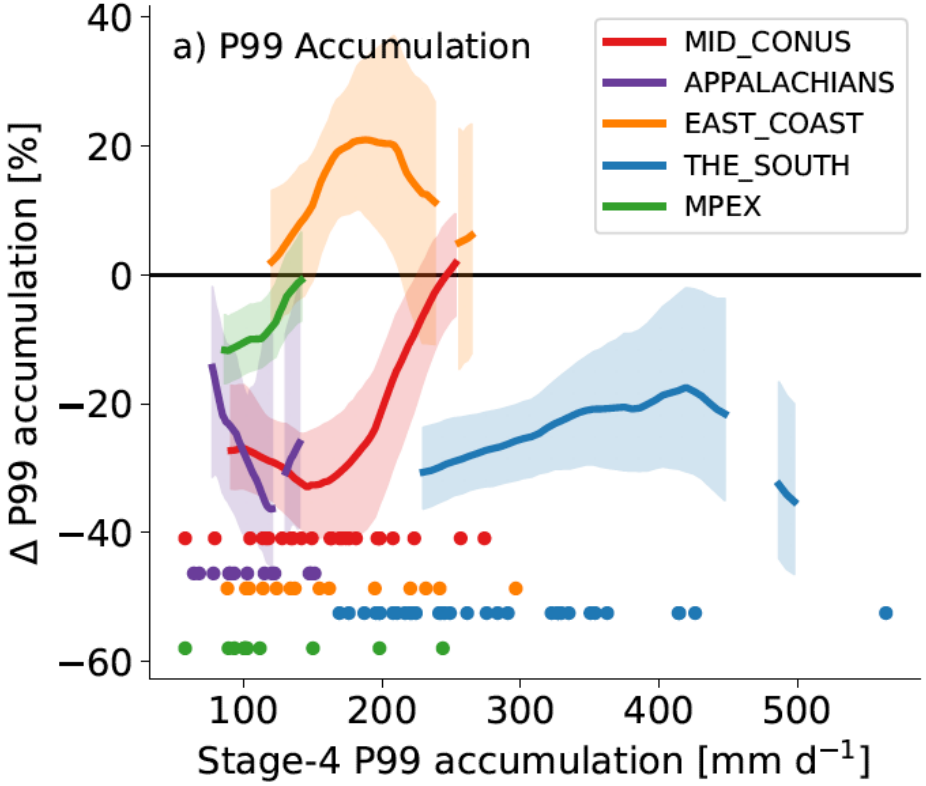


Kilometer Scale Simulations can Capture the Orographic Gradients of Heavy Rainfall Events

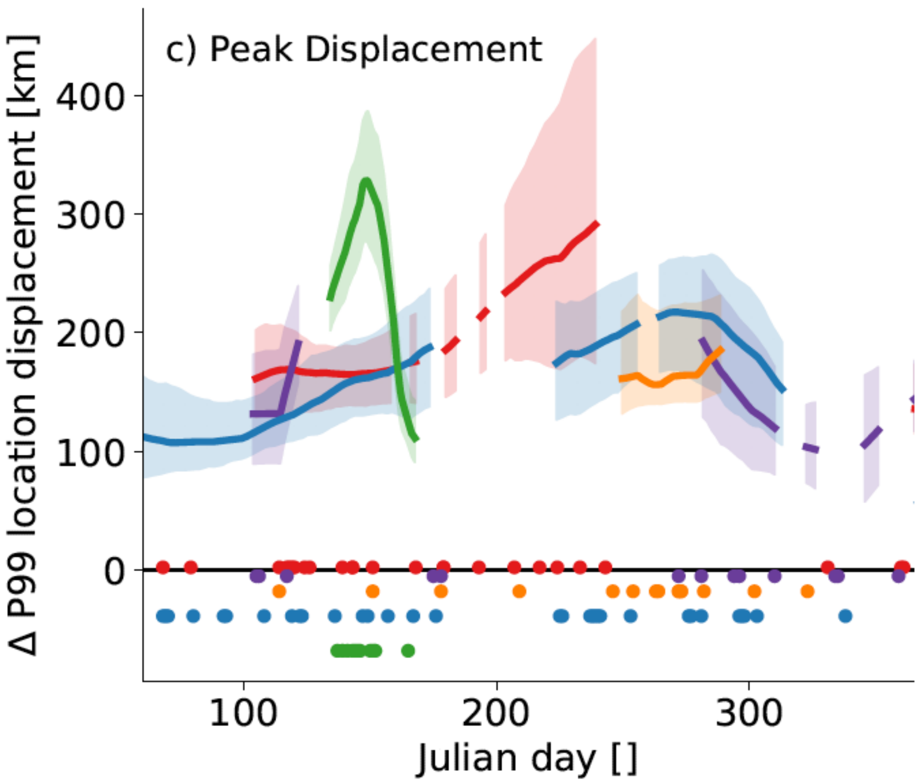


Biases Dependent on Storm Intensity and Season

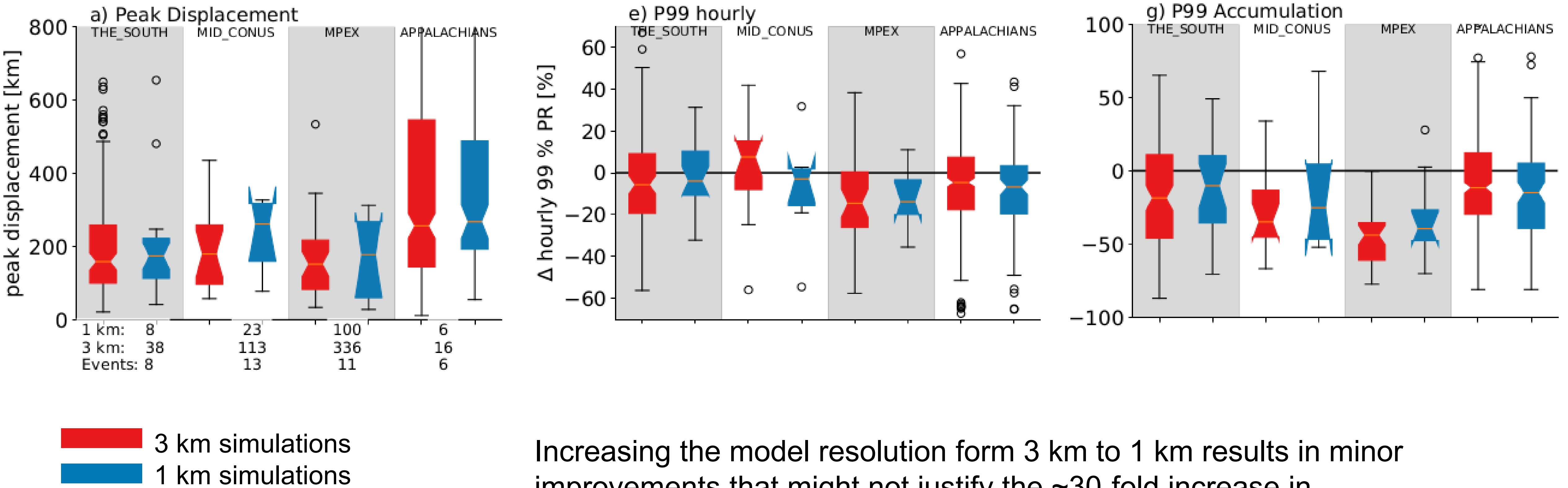
Biases in simulated peak precipitation decrease with storm intensity



Biases in the simulated location of the peak accumulation location are larges in late summer



The Benefit of Using 1 km Instead of 3 km Model Resolution



Increasing the model resolution form 3 km to 1 km results in minor improvements that might not justify the ~30-fold increase in computational costs.

Summary

- Convection-permitting models (CPMs) can capture recently observed intense rainfall events east of the Continental Divide
- CPMs can outperform purely station based datasets in capturing peak accumulations, orographic gradients, and storm total precipitation volumes
- Systematic biases exist (e.g., underestimation of peak accumulations) that need bias correction for usage in flood risk modeling

This work is sponsored by NRC under the Interagency Agreement Number 31310019S0015

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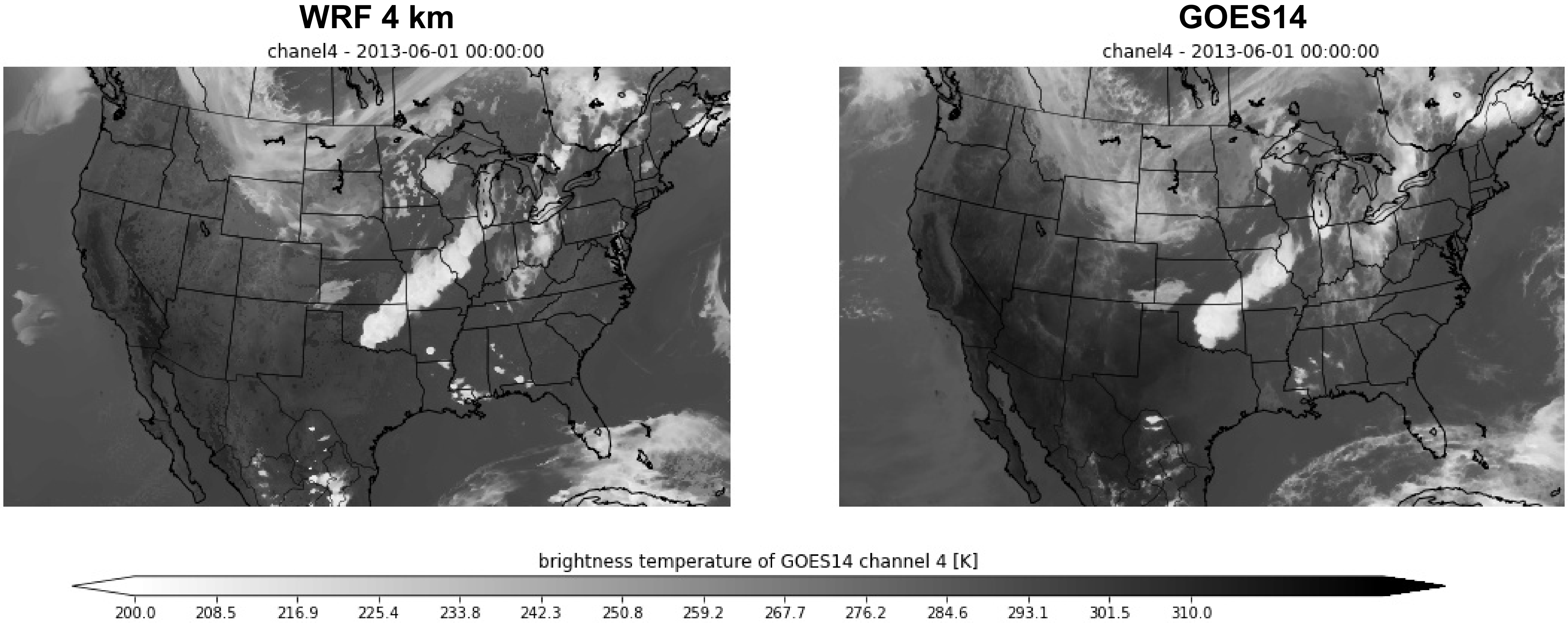
CPM rainfall simulation ratings for the criteria of realism, variability, and computational cost

	CPM Rainfall Simulations		
Source	Realism	Variability	Cost
Operational Forecasts			
Downscale Reanalysis			
Downscale GCMs			

40-Year 4-km WRF CONUS Simulation

Comparison of Simulated and Observed Cloud Brightness Temperature

USGS sponsored HyTEST project
1979 to present
Finished by Sept. 2021



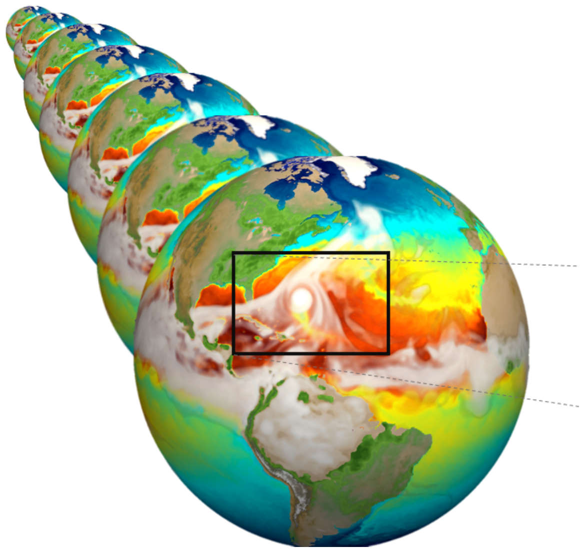
CPM rainfall simulation ratings for the criteria of realism, variability, and computational cost

	CPM Rainfall Simulations					
Source	Realism	Variability		Cost		
Operational Forecasts	High	Lower	Higher (if ensembles)	Lesser (if existing)	Greater (continuous)	Lesser (event-based)
Downscale Reanalysis	High	Lower		Greater (if new)		
Downscale GCMs	Med/High	Higher		Greater (if new)		

4 km 20-year current and future climate for CONUS

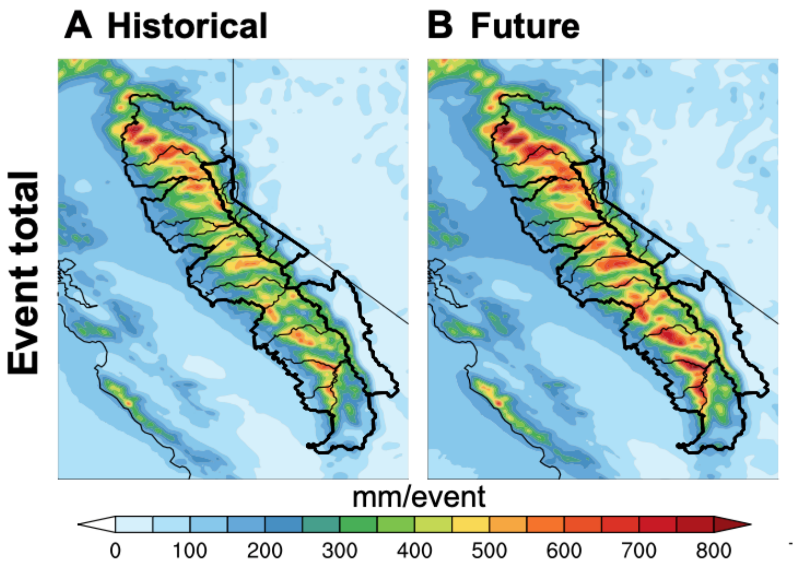
Framework for using CPM output in flood risk assessments

Search for Extreme Weather Conditions in Global Climate Models



- E.g., NCAR's Large Ensemble Simulations
- 40 runs covering 1920 – 2100
- Total of 7,200 modeling years

- Use NCARs Large-Ensemble Simulations
- Allows to simulate the ~400 year event explicitly
- Computational costs are ~0.1 % of continuously running simulations



Huang et al. 2020

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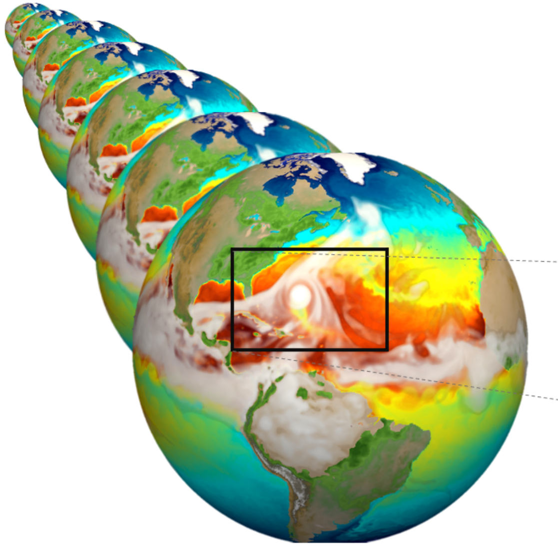
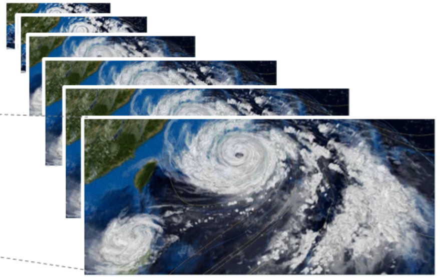
Search for Extreme Weather Conditions in Global Climate Models



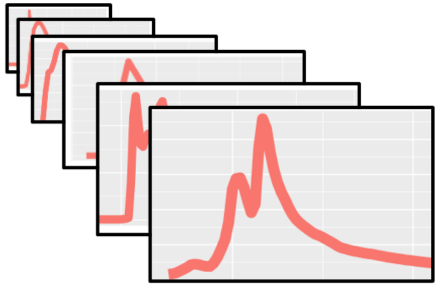
Step 1. Scan NCAR's Community Earth System Model Large Ensemble (LENS) to identify the top extreme environments for current and future periods.

Downscale These Conditions to 3 km Grid Spacing



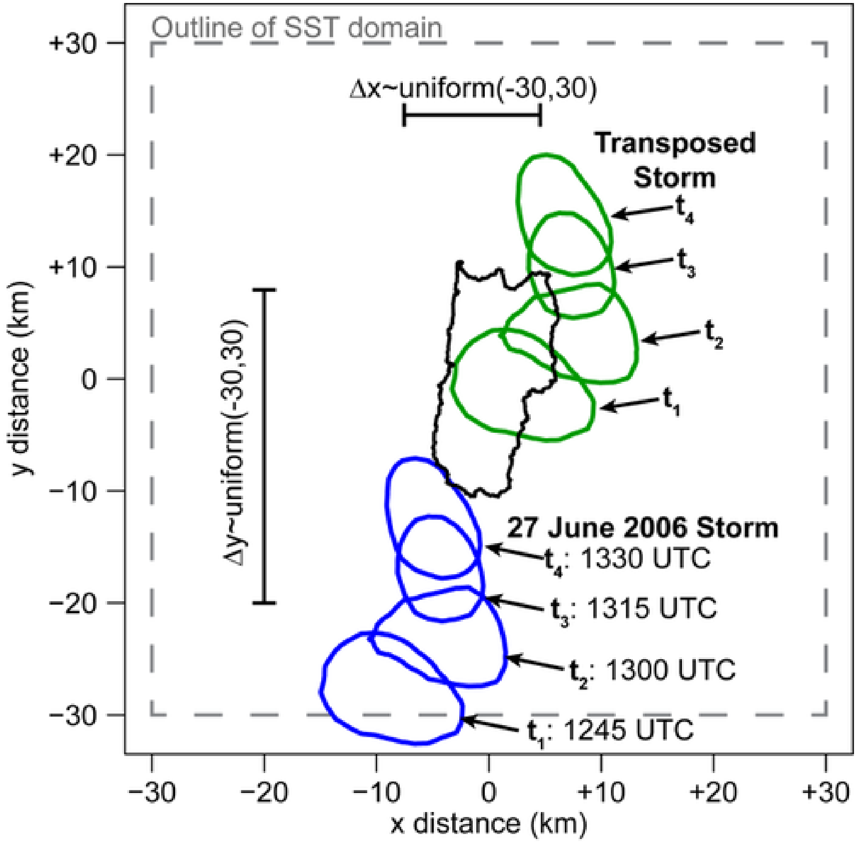
Step 2. Use 3-km WRF to simulate new precipitation events in target region.

Drive Hydrologic Models With 3 km Output



Step 3. Run 3-km WRF output through WRF-Hydro to simulate new flood events.

Stochastic Storm Transposition



[Wright et al. 2014]

Recommendations for using CPMs in Probabilistic Flood Risk Assessments

1. Collect CPM heavy precipitation events for the catchment of interest from existing weather forecasting and climate modeling efforts
2. Perform targeted downscaling for heavy precipitation days identified in global models to increase storm sample size
3. Remove systematic biases from simulated precipitation
4. Apply statistical methods (e.g., SST) to further increase the sample size
5. Use hydrologic model to simulate discharge and inundation

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