Multi-Seasonal Snowpack Prediction

(Ultimately: can we predict western U.S. water?)

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Developing a western U.S. prediction system

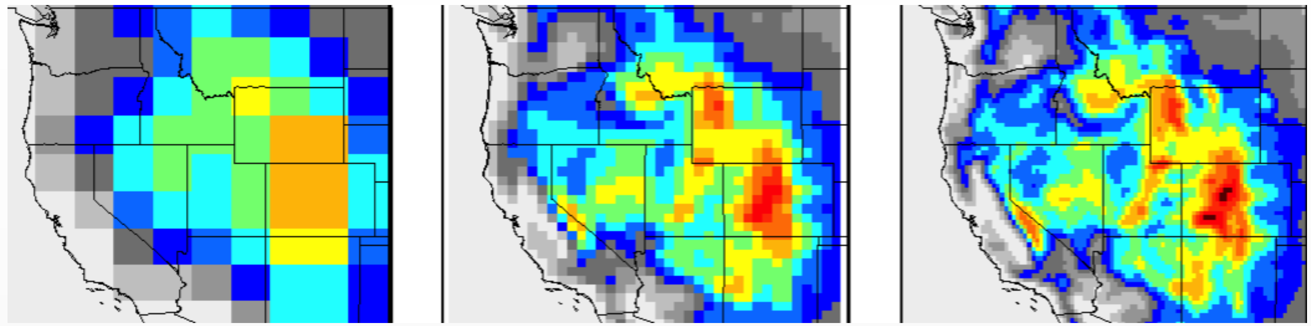
Scientific questions to ask

- *Why do we have mountain precipitation / snow?*
- *How does it vary?*
- *Can we predict it?*
- *What else are we missing?*
- *Are we asking the right prediction questions? (For science? For stakeholders?)*

BUILDING A SEASONAL CLIMATE PREDICTION SYSTEM

Current GFDL seasonal prediction models

Global coupled models with regional applications

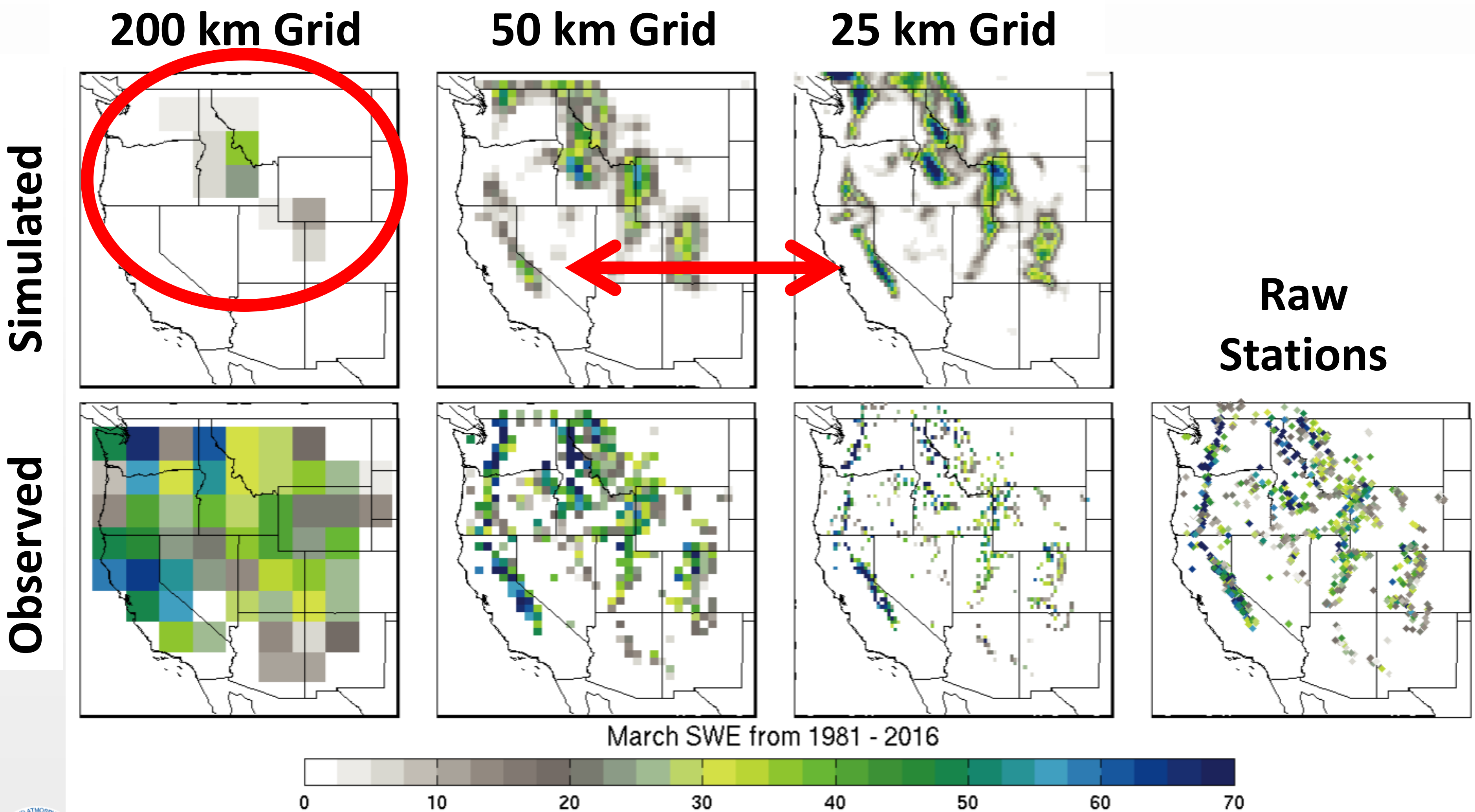


	CM2.1	FLOR	HiFLOR
Atmospheric/Land Grid Size	***200 km***	***50 km***	***25 km***
Ensemble members	*10*	*12*	*12*

"**Ensemble members**" provide individual solutions for the future

- Several members are produced on the 1st of the month and then left to run for 12 months total to provide a potential future (for 4 seasons)
- Collectively they provide a probabilistic forecast of the future—a likely solution but also a range of potential values and probabilities

Climatology of western U.S. Snowpack in March
1981-2016, simulated snowpack vs. station data

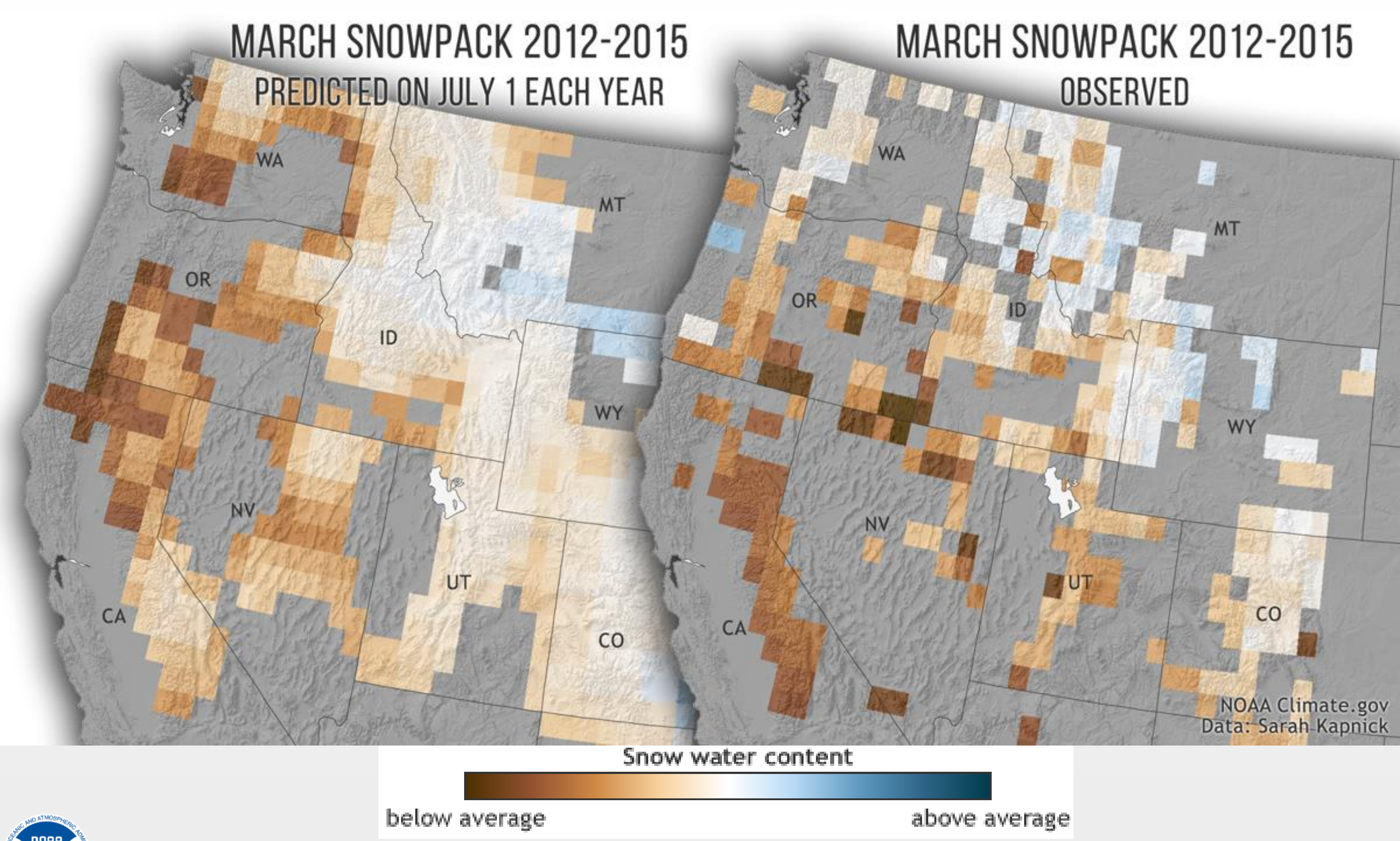


Source: Kapnick et al., PNAS, 2018

PREDICTION TESTS

Low March snowpack case study: 2012-15

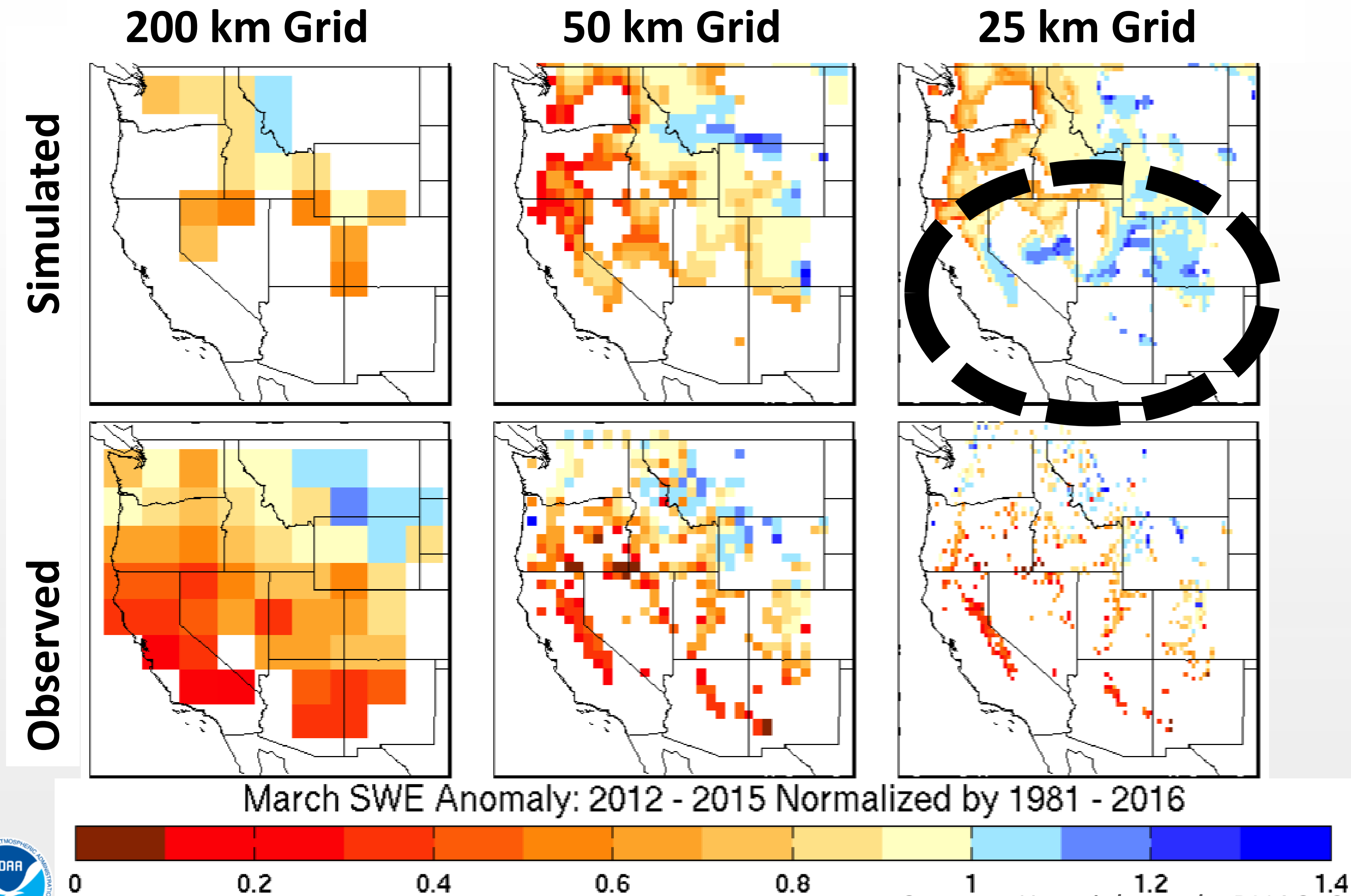
Yearly predictions made July 1 (50 km model) vs. observed



Source: Climate.gov image adapted from Kapnick et al., Proc. Natl. Acad. Sci. 2018

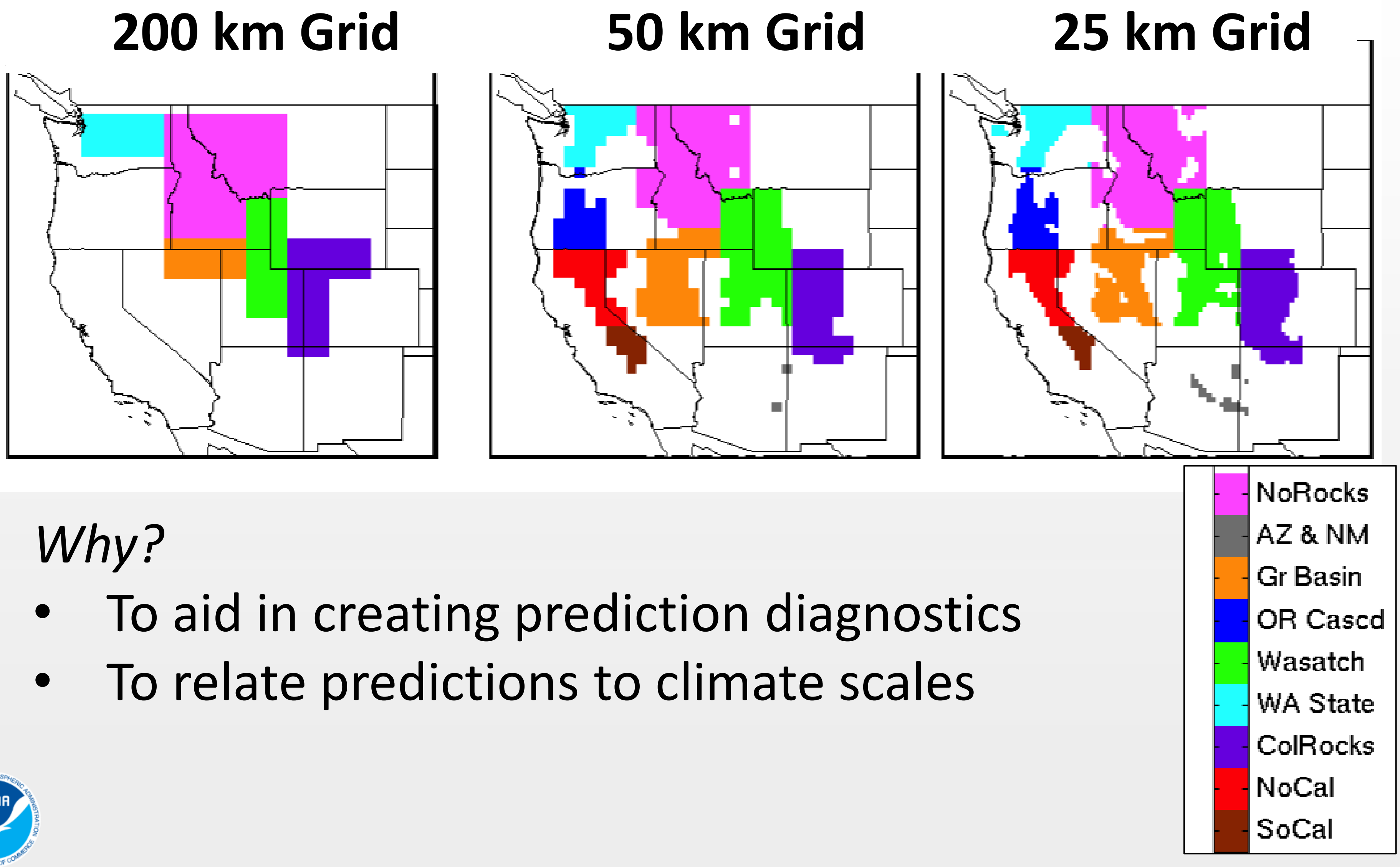
Low March snowpack case study: 2012-15

Yearly predictions made July 1 vs. observed



Source: Kapnick et al., PNAS, 2018

How well do we prediction regional snow?



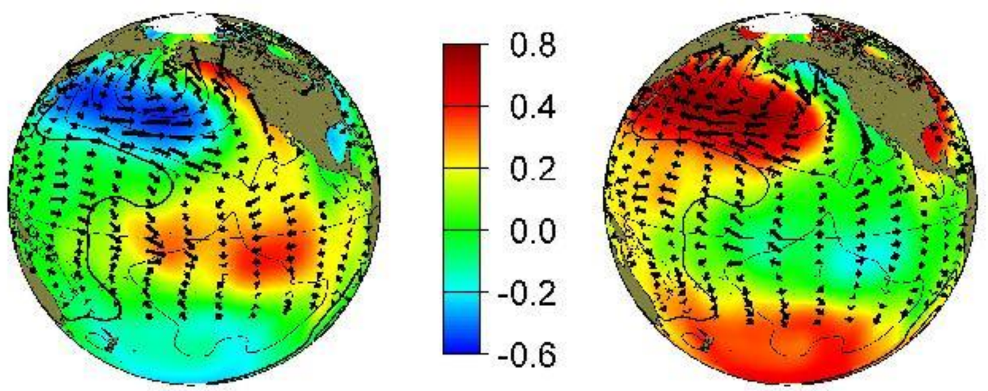
Why?

- To aid in creating prediction diagnostics
- To relate predictions to climate scales

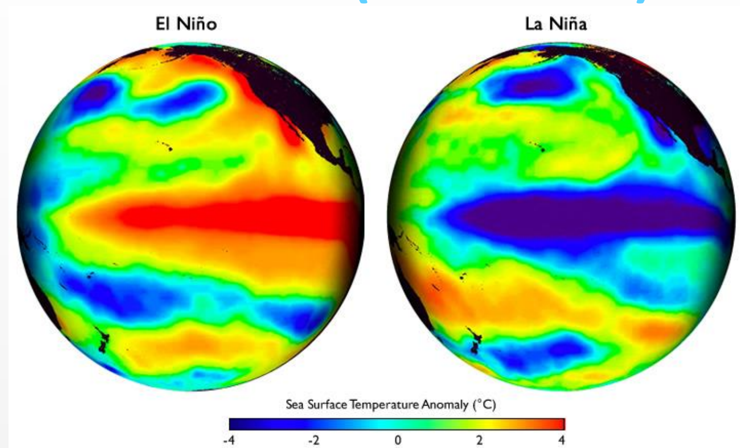
Climate Indices: Defined Climate States

Often used for seasonal prediction due to teleconnections

Pacific Decadal Oscillation (PDO)

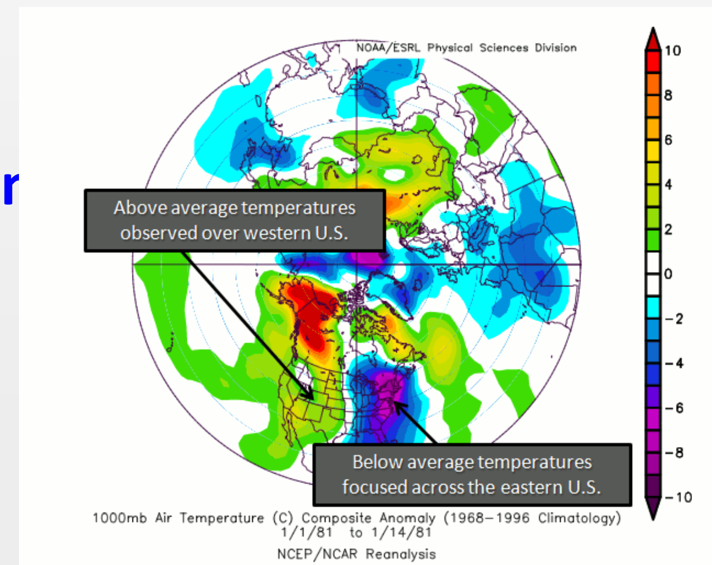


Multivariate El Niño Southern Oscillation (NINO MEI)



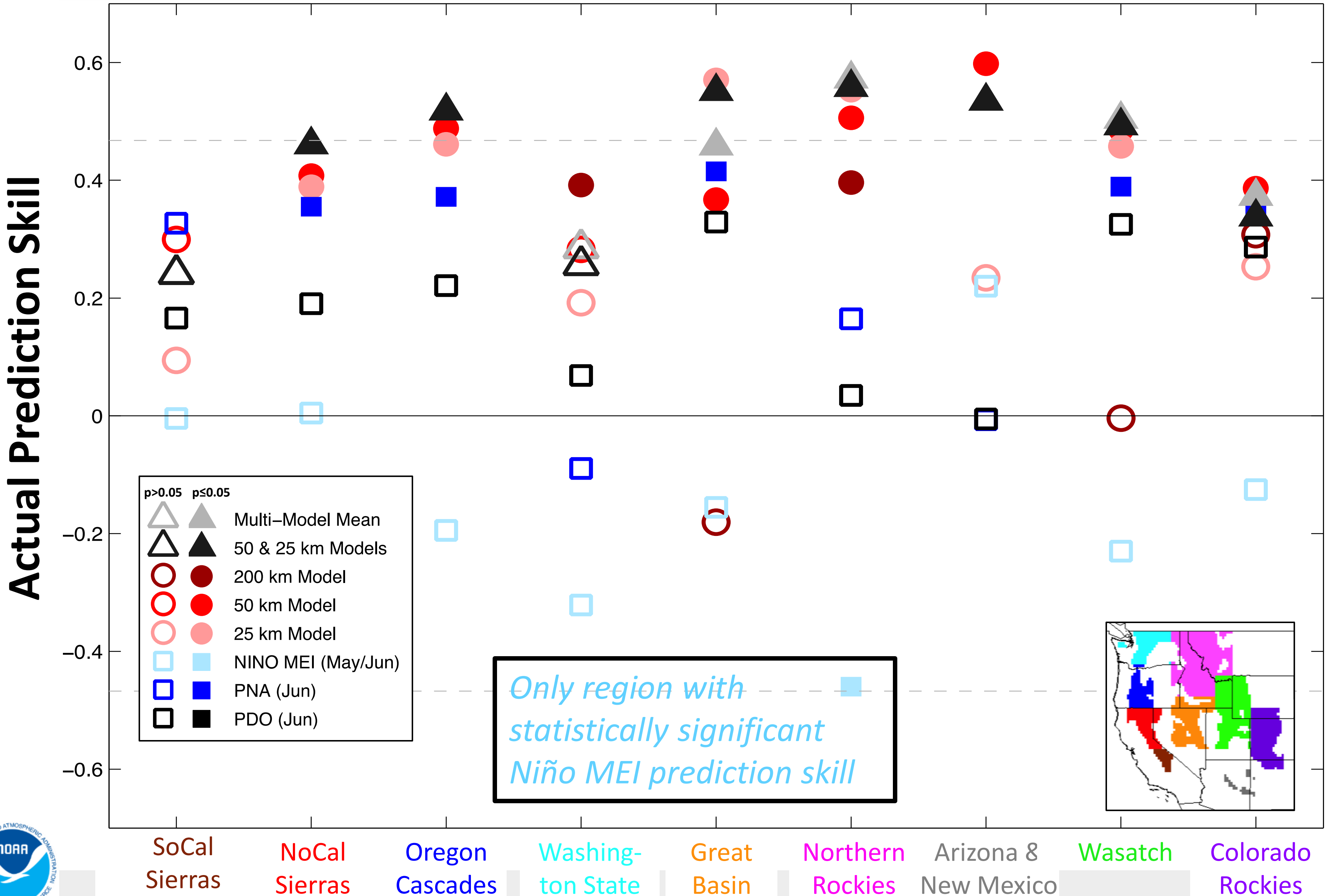
Pacific North American Pattern (PNA)

purely atmospheric



1981-2016 March prediction skill 8 months prior

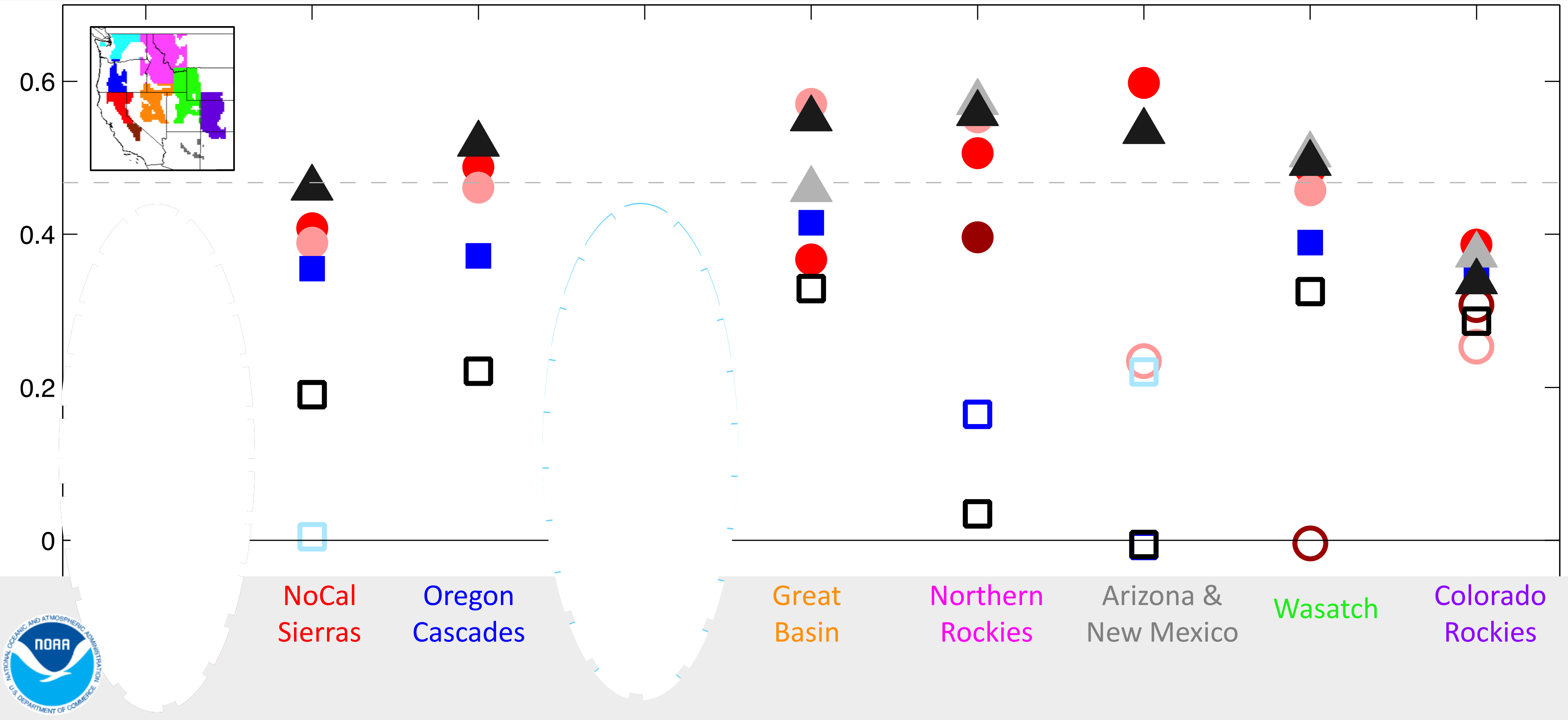
March snowpack predicted on previous July 1 (Kapnick et al. 2018)



Prediction success!

Broad skill in dynamic system (Kapnick et al. 2018)

- The high resolution models (▲) tend to be the best
- Climate mode with consistent predictive skill: **PNA (■)**
- **Southern California** elusive, **Washington** only in *200 km*



Why are coastal mnts difficult to predict?

1) **Trends:** Do trends in snowpack affect results?
2) **Size of mountains:** Did we chose narrow ranges that scale to be significantly smaller than storms?
3) **Frequency of storms:** Do coastal ranges tend to have fewer storms than the interior?
4) **Fundamental modeling issue:** Is there a model bias in specific regions? Perhaps a fundamental dynamical issue? Narrow mountains?
5) **Elevation/resolution:** Do we need even higher resolution for elongated maritime mountains?

Short answer: YES! *We have researched these points & use them to feed back on prediction system R&D. Ultimately, stakeholder engagement can foster research for user needs.*

Multi-month to multi-seasonal to…

A case for dynamical global coupled model predictions

Days → Weeks → Months → Seasons → Years → …

Initial Value Problem

- Why "damped persistence" has skill)
- Statistics based on initial value have skill

Boundary Value Problem

- Uncertainty from knowledge of the future forcing the system
- Global climate models can simulation the evolution of the system & produce various futures with different boundary conditions

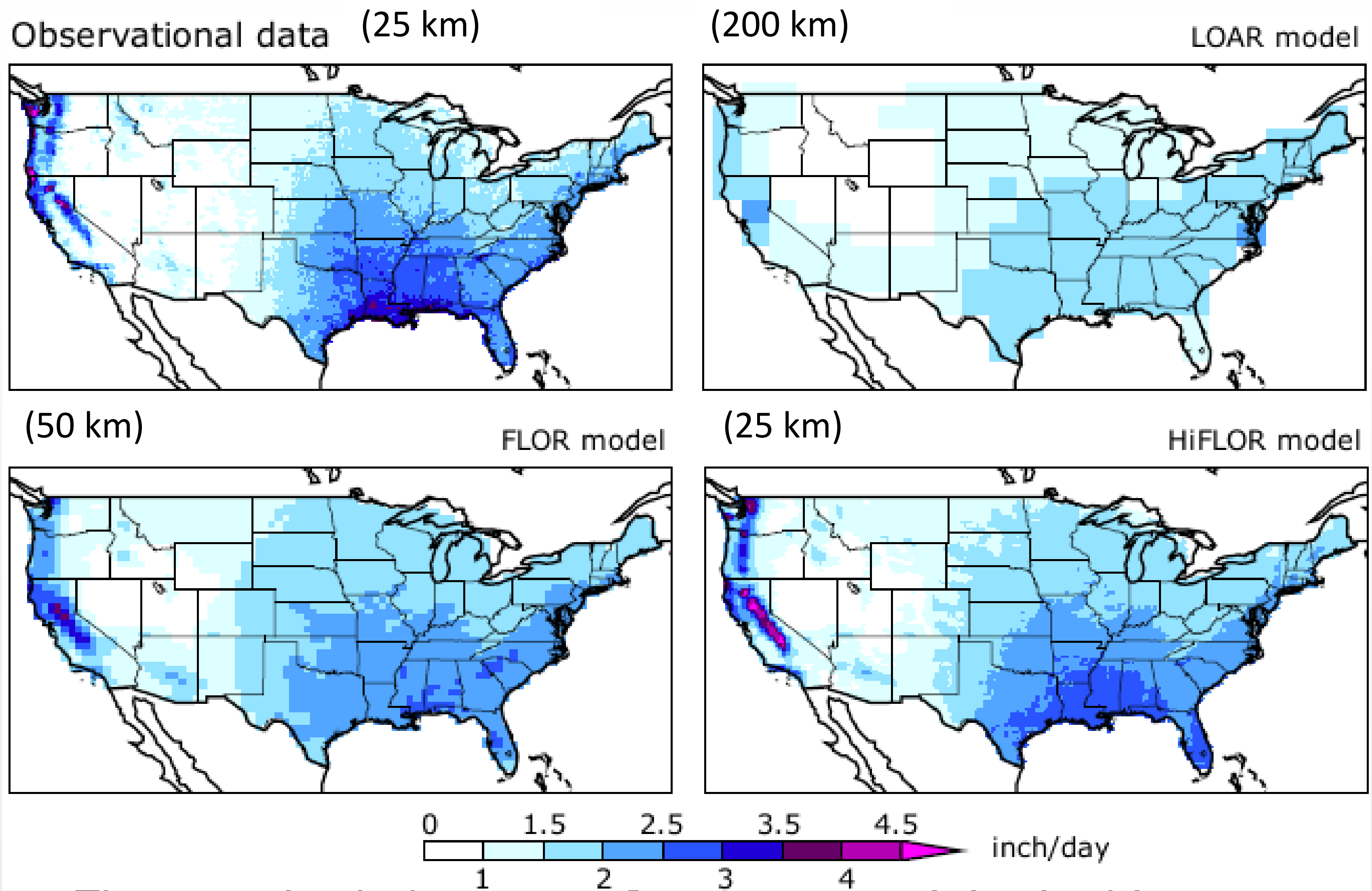
Where are the limits???

Key snowpack prediction takeaways

- **Snowpack prediction skill exists 8 months in advance** in a dynamic coupled modeling system
  - Prediction in this system comes from the initial state (initialization) & dynamic coupled evolution (GCM prediction)
- **Climate indices lack prediction skill at 8 months**
  - Dynamic models outperform their climate index counterparts & may be necessary at longer time scales
- **California remains elusive** with lowest skill in coastal mountains. We can reframe the question to test the boundaries of skill (e.g. Nov or Jan predictions of March snowpack?) –and/or– work to improve our prediction systems for this problem

WHAT CAN BE DONE TO IMPROVE PREDICTIONS?

Improve resolution: U.S. Precipitation Extremes Example

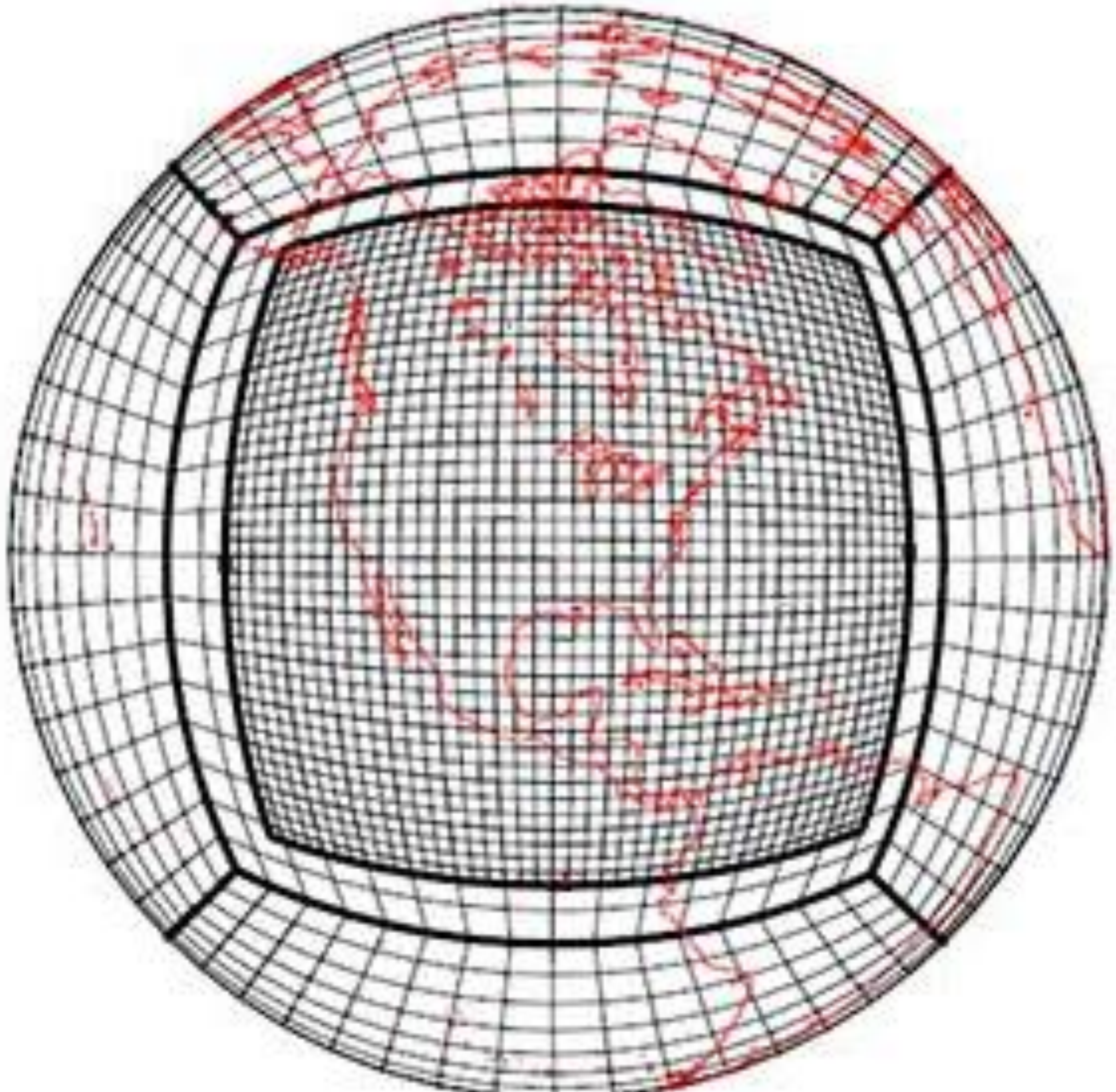


The magnitude (amount of extreme precipitation) improves with resolution

Source: Van der Wiel et al., 2016

Model development: non-uniform global models

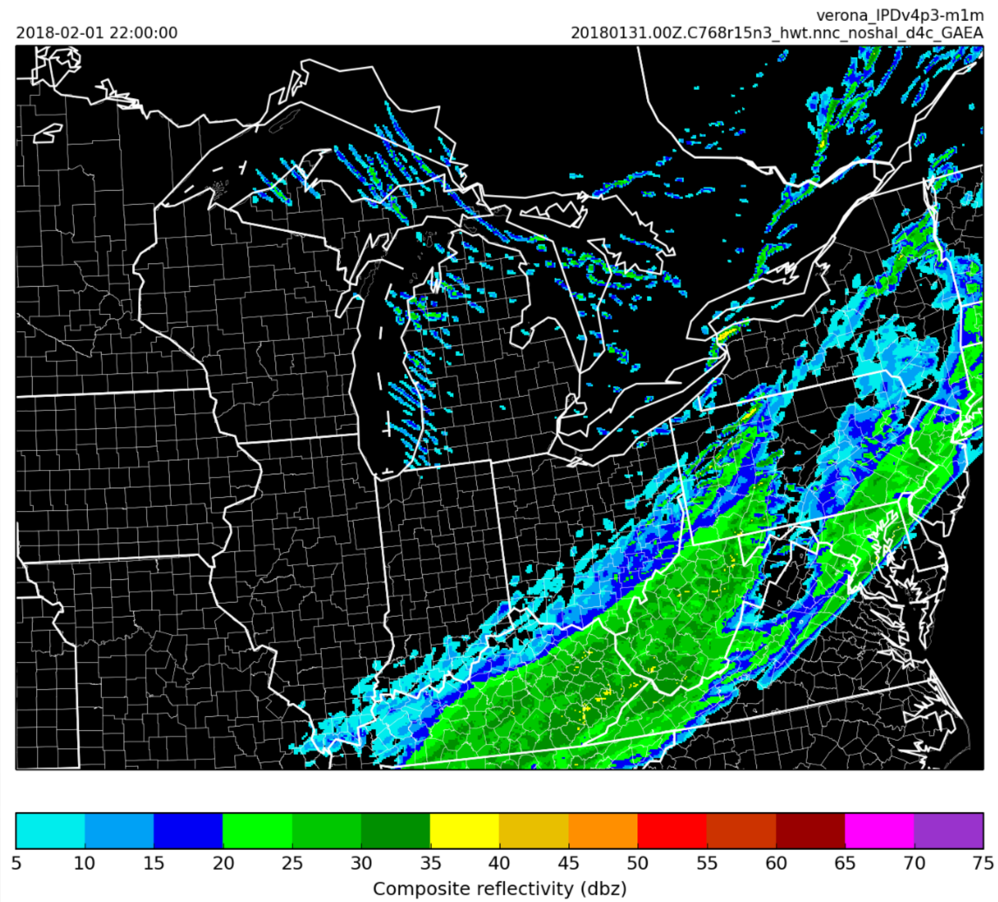
For: orographic precip, hurricane intensity, large-scale climate statistics

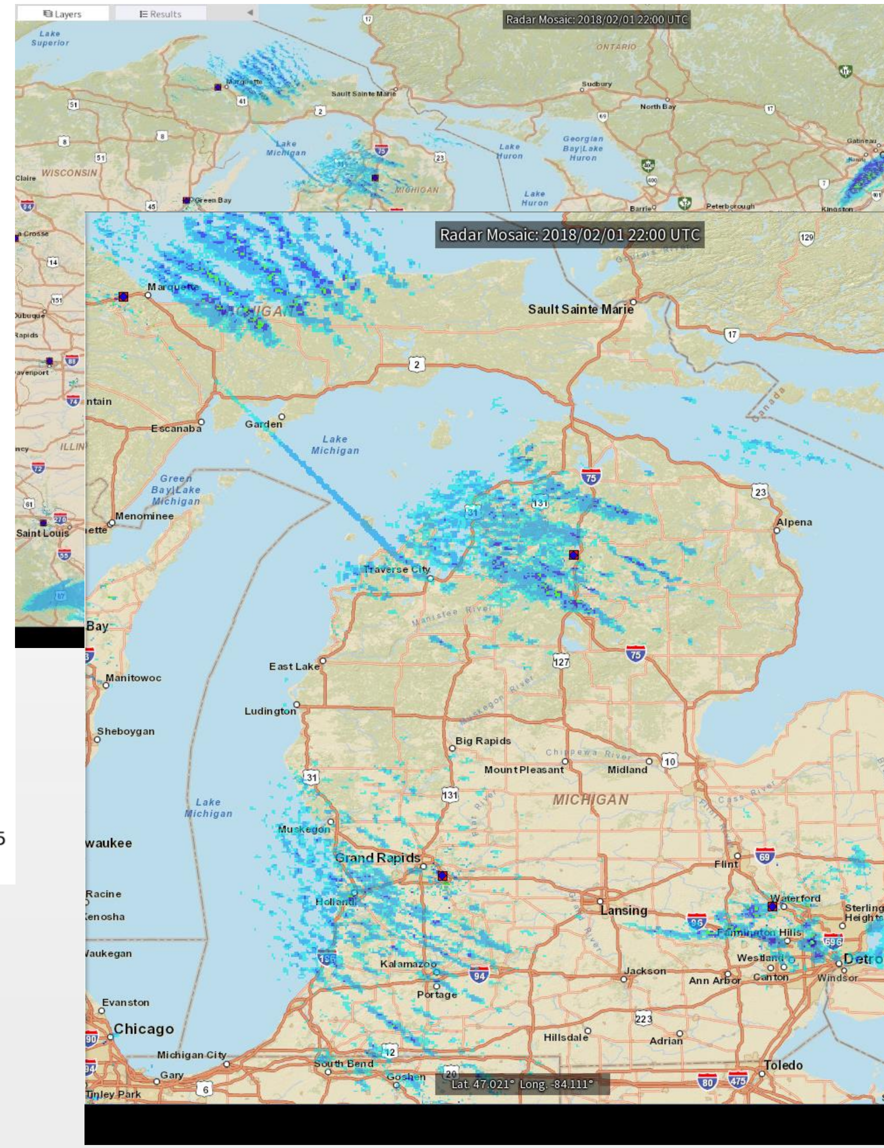


- A high resolution nest inside a global model allows for consistent physics, boundary conditions
- Computational resources can be focused on the region of interest (North America)

10 km over North America in Harris et al. 2016; 25 km in Harris et al. 2014

Snow bands in 22 hr forecast





3-km global-to-regional CONUS nest
Initialized 1 Feb 2018

Courtesy Lucas Harris

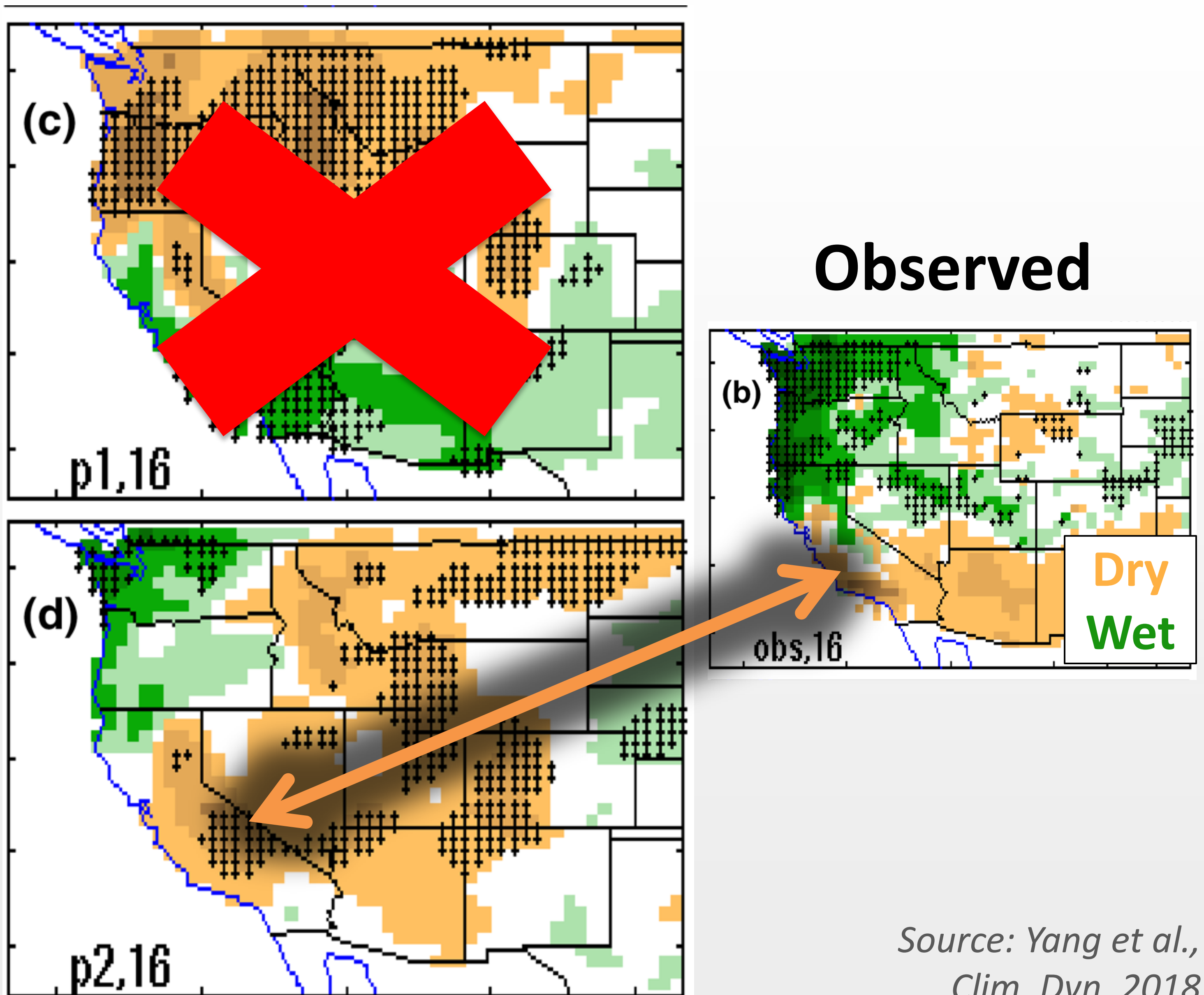
Improve our initialization system (model jump-start)

Case study: Dec 1 prediction for DJF precipitation, 2015-16 El Niño

Ocean

Ocean
+ Land
+ Atmos

Observed



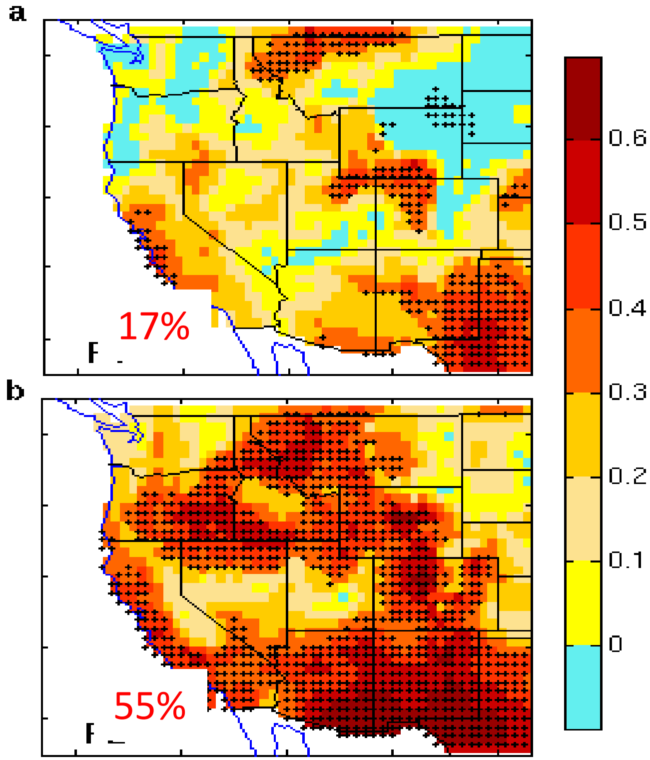
Source: Yang et al., Clim. Dyn. 2018

Improving initialization can improve prediction skill

Winter precip skill

Initialization with only ocean data

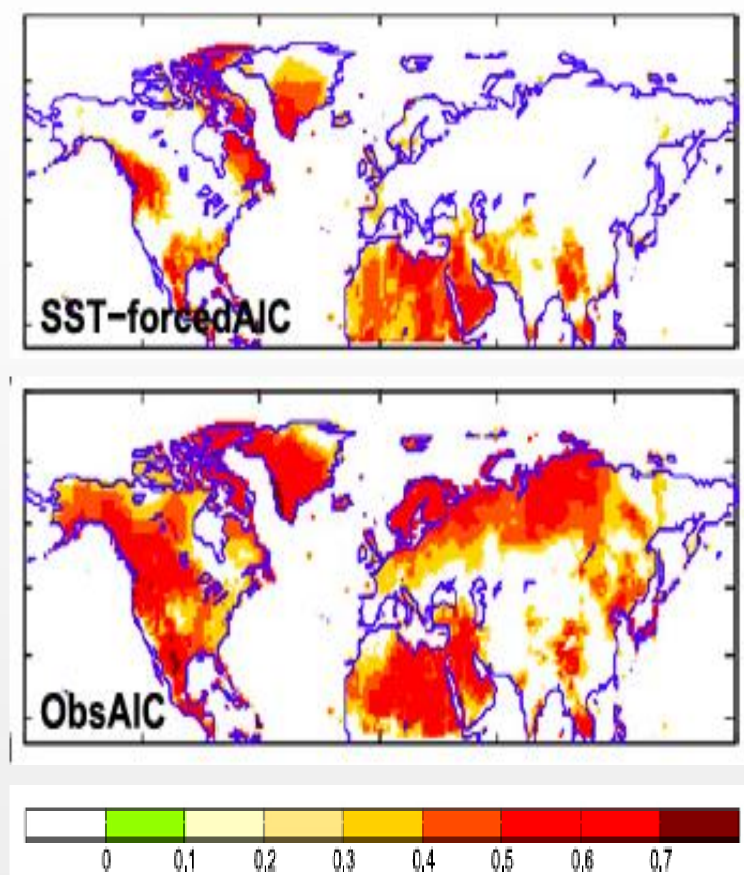
Initialization with ocean & atmos data



Winter sfc temperature skill

Initialization with only ocean data

Initialization with ocean & atmos data

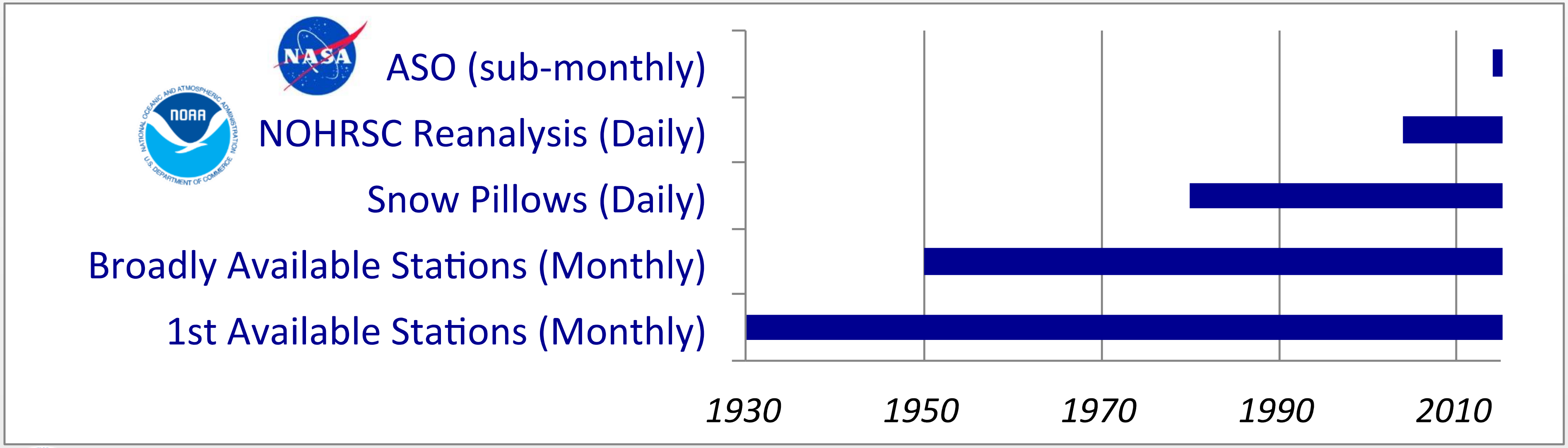


Atmospheric initial conditions are important for successfully predicting the unusual 2015/16 winter precipitation pattern.

Jia et al. (2017, J. Clim.)
Yang et al. (2018, Clim. Dyn.)

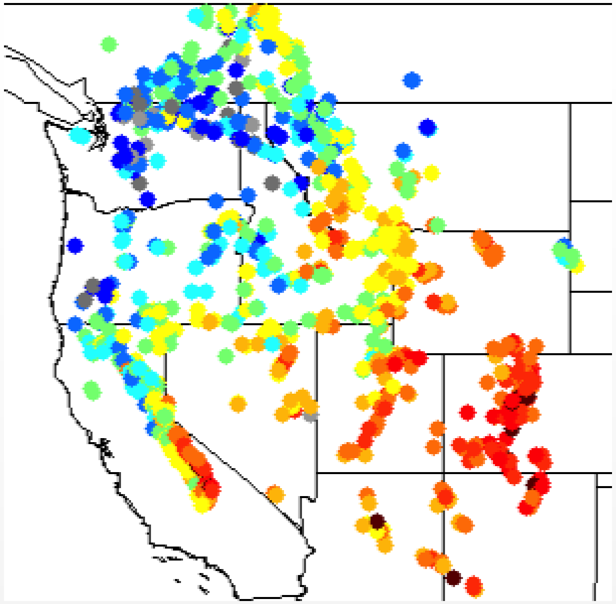
Challenges: Observations critical

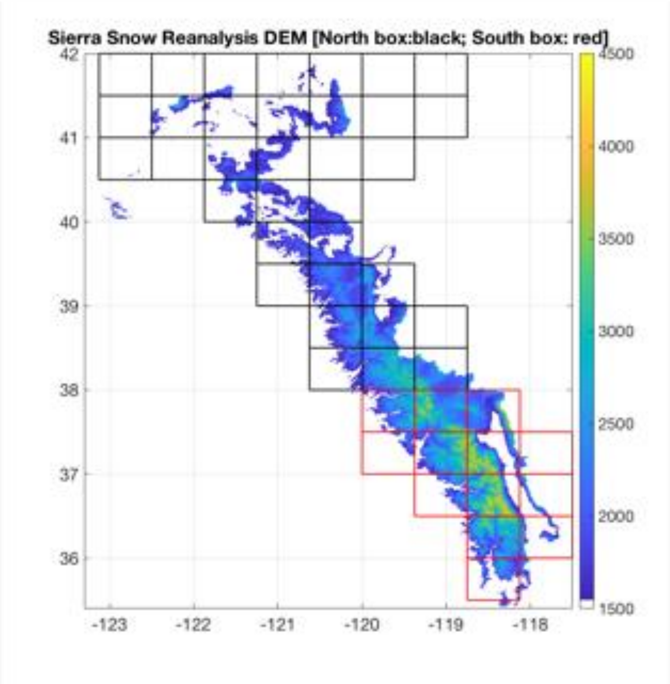
- Observations are critical for model prediction verification
- Snow point observations provide the best data source for analyzing mountain snowpack (and total winter precipitation) for multiple decades



Observational data sets for validation

Prediction systems do not emerge from a vacuum





- March & April snow:
  - Point: National Resource Conservation Service & California Cooperative Snow Surveys
  - Gridded: UCLA Snow Reanalysis (Margulis et al. 2016)
- U. East Anglia CRU (Climate Research Unit) gridded temperature / total precipitation (0.5 degree)
- ERA-Interim reanalysis winds

How do we improve weather-to-climate predictions?

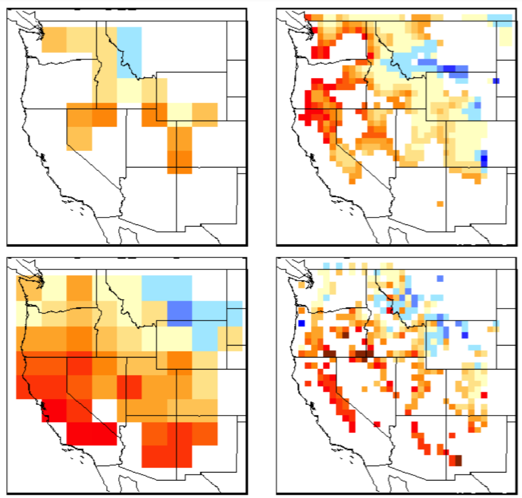
Kapnick et al. 2018; Yang et al. 2018

① Improve the **models** (i.e. physics, resolution, processes) for total records & case studies

200 km 50km

Simulated

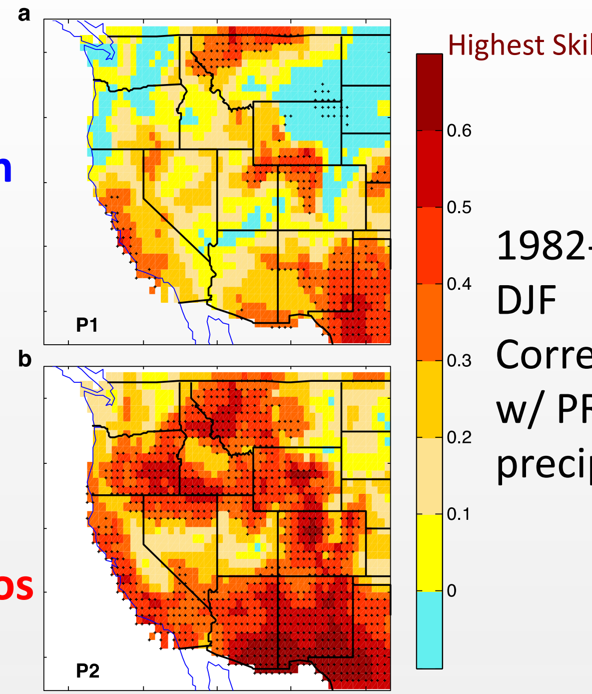
Observed



② Improve **initialization system** (i.e. info to start prediction)

Ocean

Ocean
+ Land
+ Atmos



1982-2016
DJF
Correlation
w/ PRISM
precipitation

③ Improve **observations** for model development, initialization, verification

Is California snowpack simply unpredictable at 8-mon leads?
What problems can we solve (e.g. for leads, variable, region)?

WHERE DO WE GO FROM HERE?

GFDL Research on Prediction Systems

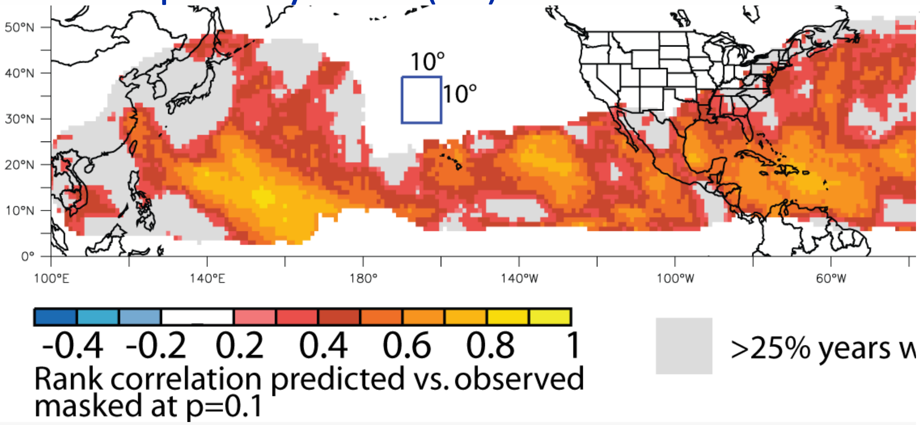
CM2.1	FLOR	HiFLOR
2004	**2012**	**2014**
Low Res Atmos (200 km)	Medium Res Atmos (50 km)	High Res Atmos (25 km)
Low Res Ocean (100 km)	Low Res Ocean (100 km)	Low Res Ocean (100 km)

- CM2.1 and FLOR are run each month as part of the North American Multi-Model Ensemble (NMME)
- Output provided to the National Hurricane Center and the Climate Prediction Center to inform their seasonal outlooks
- Ocean reanalysis also provided to NOAA

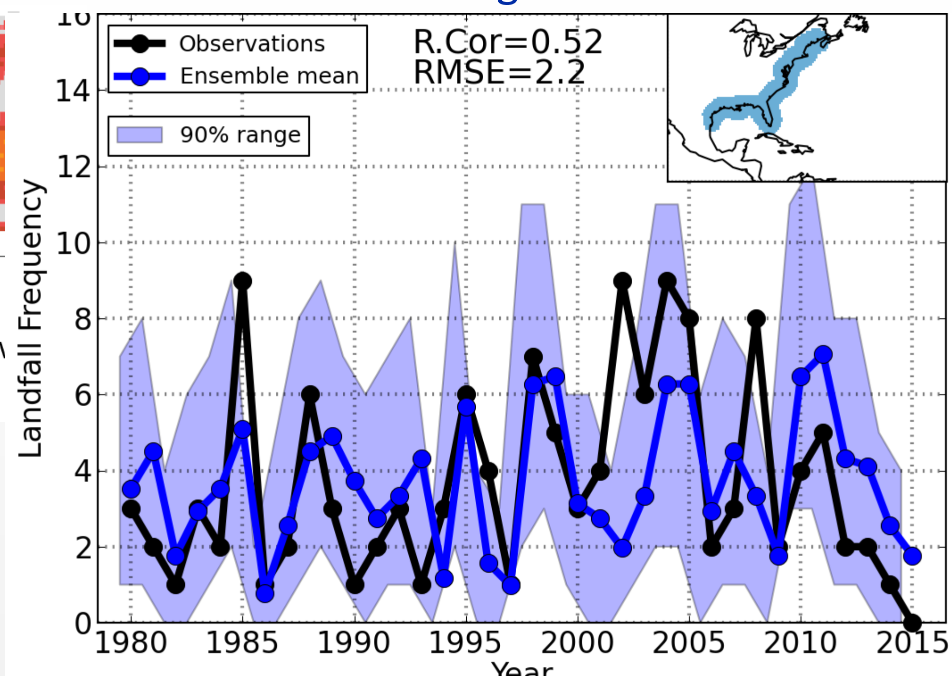
These prediction systems are made possible through harvesting the fruits of a decades long research effort on **INITIALIZATION SYSTEMS** & **MODEL DEVELOPMENT**

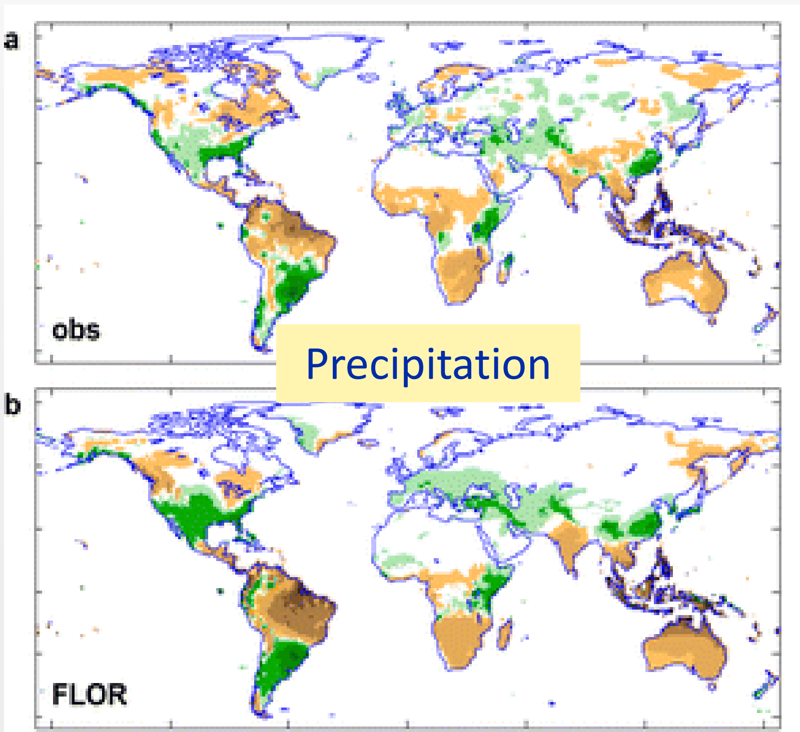
Select Research Advancements from Current Suite

Tropical Cyclone (TC) Distribution



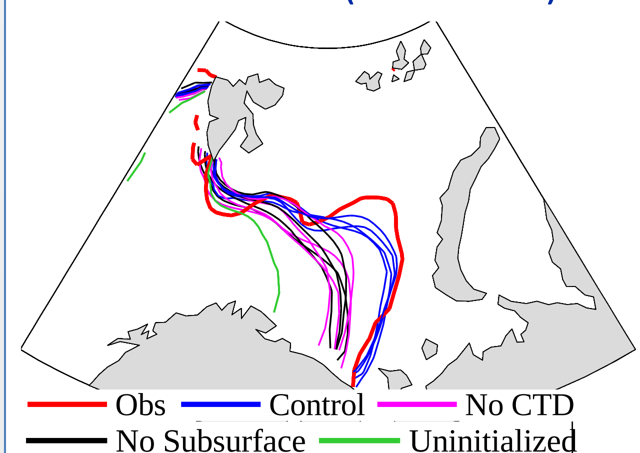
Landfalling TCs



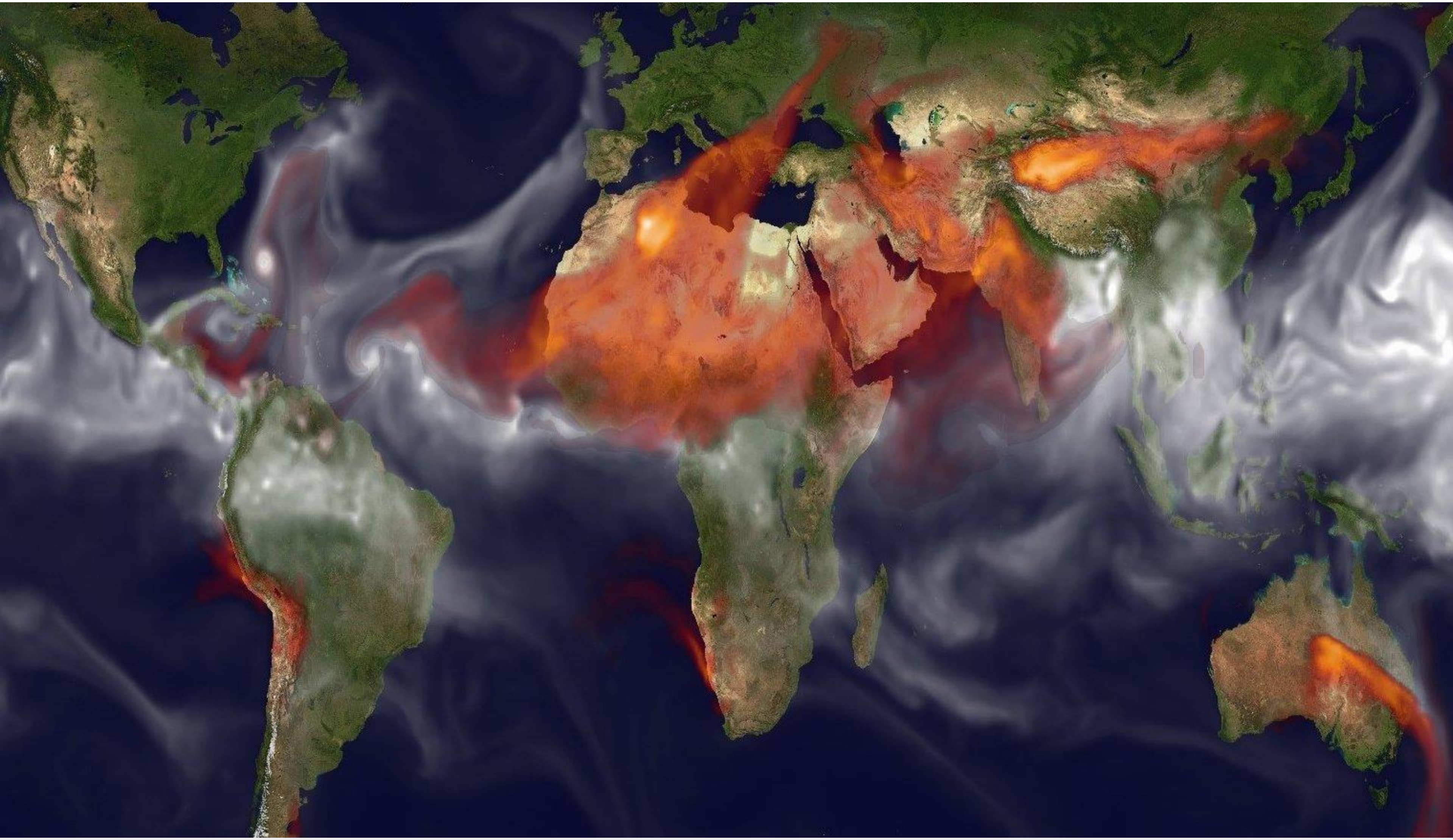


- Spatial distribution TCs (Vecchi et al. 2014)
- Landfalling TCs (Murakami et al. 2014, 2015, 2016)
- Sea ice prediction (Bushuk et al, 2016, 2017)
- Temperature & precip (Jia et al. 2015, 2017)

Sea Ice Extent (Mar 2007)



GCM Global Dust



P. Ginoux, GFDL/NOAA

Building a new prediction system: Design with purpose

Model design / computation:
Resolution (granularity)
Ensemble size
Computational time

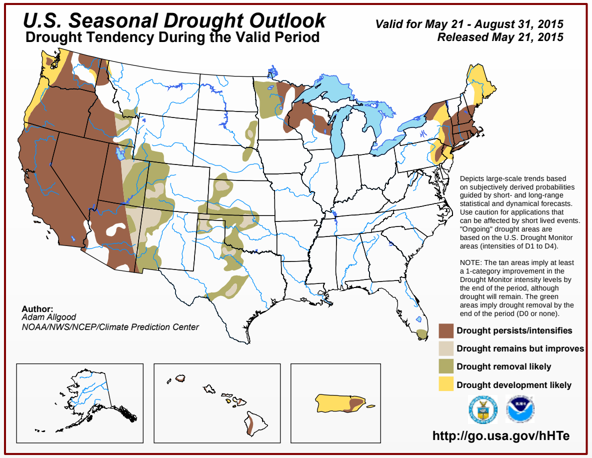
User needs:
Who will use this data?
Scientific needs vs. societal applications

Seamlessness:
Can a system be designed in a way where it can be adapted across time scales (seasonal to decadal to multidecadal) and users?

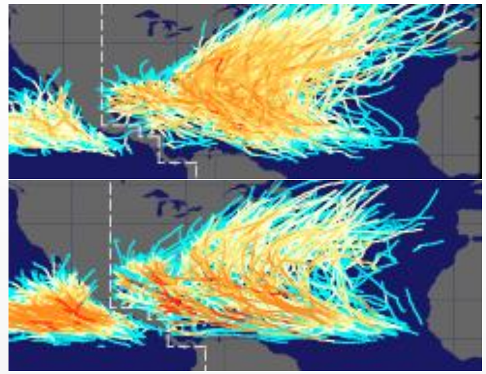
Seamless System for Prediction and EArth System Research

"SPEAR"

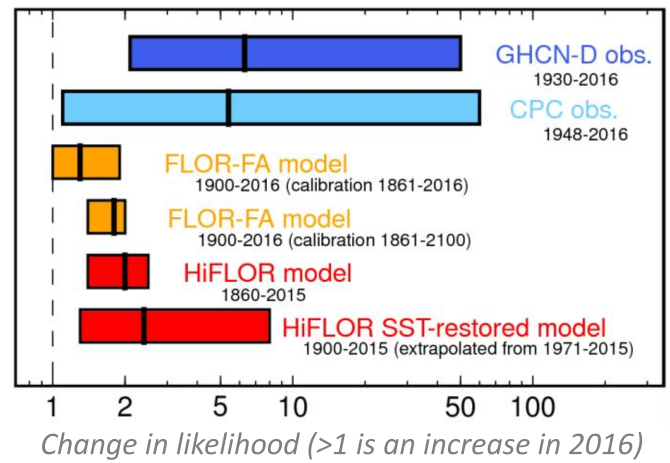
Climate Risk Management Across Timescales



Simulated & Observed Tropical Cyclones



1900 vs. 2016 Risk of Extreme Central U.S. Gulf Rains



- **Subseasonal to seasonal to decadal prediction:**
  - Improve advanced warning of events
  - Make decisions to avert financial losses, aid decision making and protect lives
- **Long term data sets (100s or 1,000s of years):**
  - Before an event happens: Reduce uncertainty in calculating risks (due to the ability to generate additional data than available in observations-blue bars) planning
  - After a major event happens: Can isolate causes for specific events and potential for reoccurrence in general or under identified conditions

Asking the right questions

Feedback we've received

- We have questions to advance the science of S2S & questions to advance the usability of S2S science for stakeholder needs
- **Western Water Targets:**
  - November 15 prediction for winter precip/March snowpack (*What will the winter be like?*)
  - January 15 precip/snow (*What will there rest of winter be like?*)
- **Fisheries Targets:**
  - Snowpack amount; streamflow timing, flow, temperature
- **Long-term Extreme Planning Targets:**
  - What is the likelihood of event X (*historical or statistical storm*)?
  - Is the likelihood of that event or causes of such an event changing or predictable?

What problems can we solve (e.g. for leads, variable, region)?
What questions are we missing?

THANK YOU!

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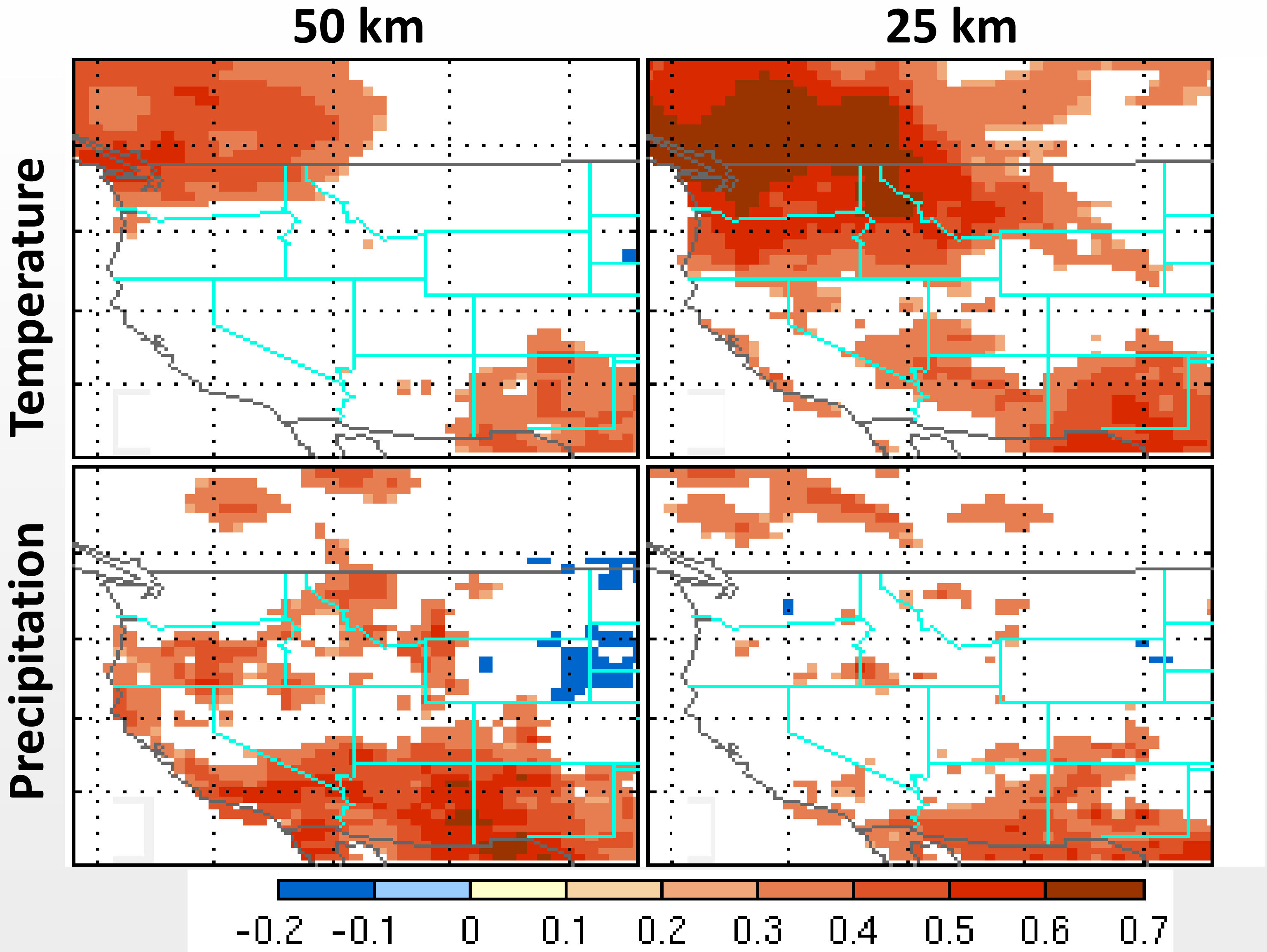
Test 4: Fundamental Bias

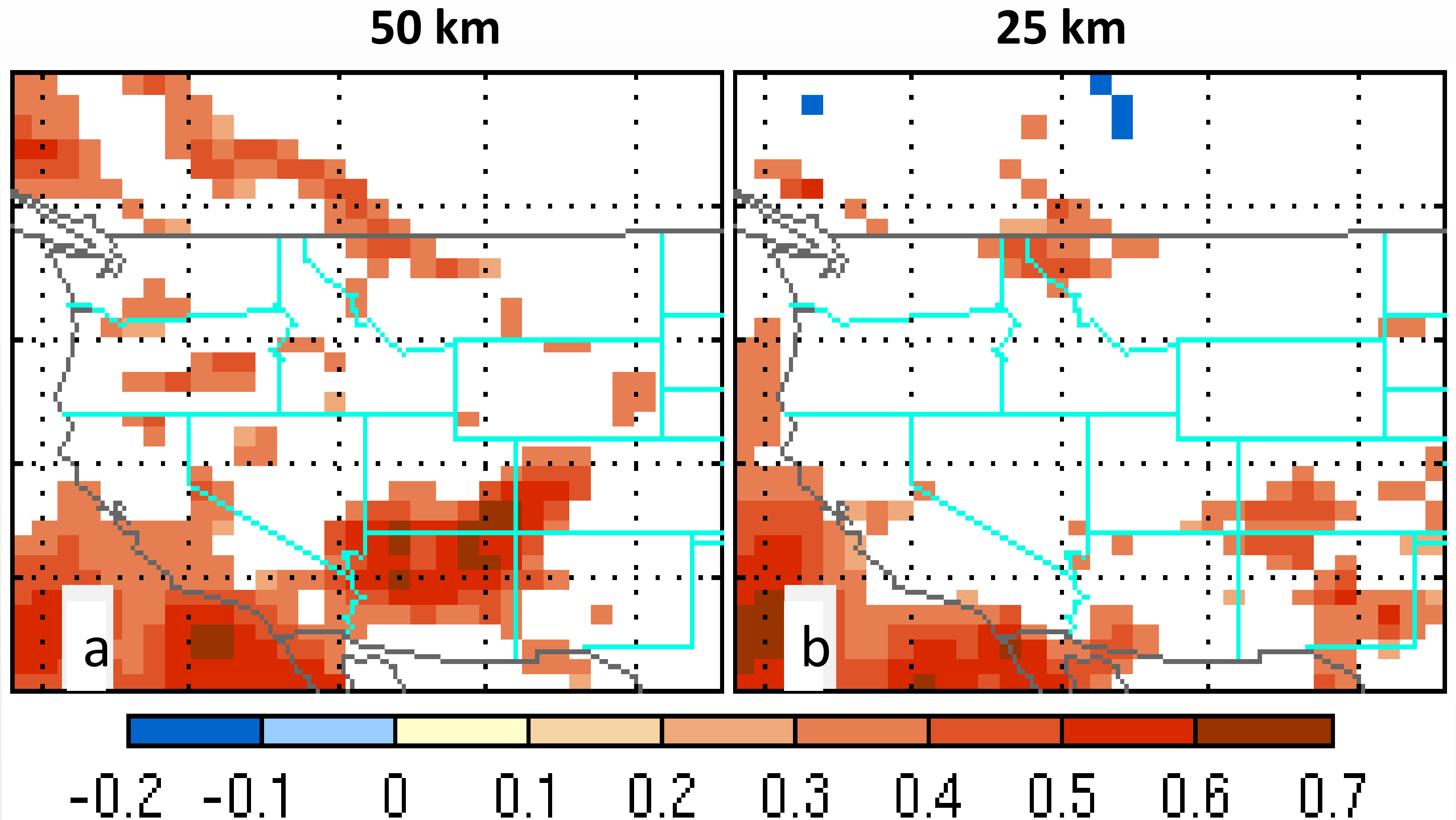
Temperature and precipitation skill alone (July 1 for Nov-Dec-Jan-Feb)



Correlation CRU observations vs. ensemble mean

Test 4: Fundamental Bias

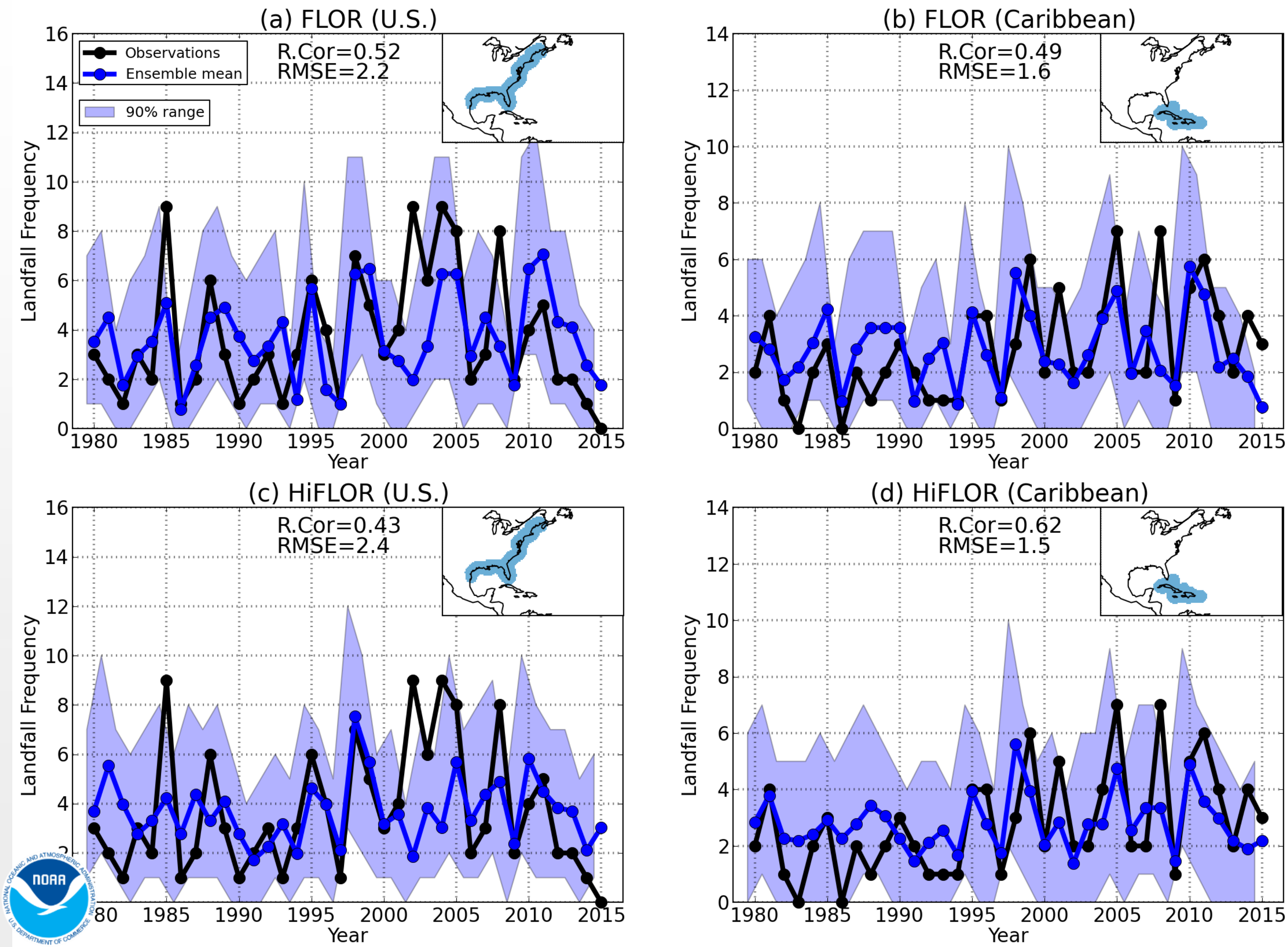
Storm track skill from windspeeds aloft (July 1 for Nov-Dec-Jan-Feb)



Correlation ERA-Interim vs. ensemble mean

Can we predict tropical cyclone landfall in advance?

Seasonal predictions: July through November

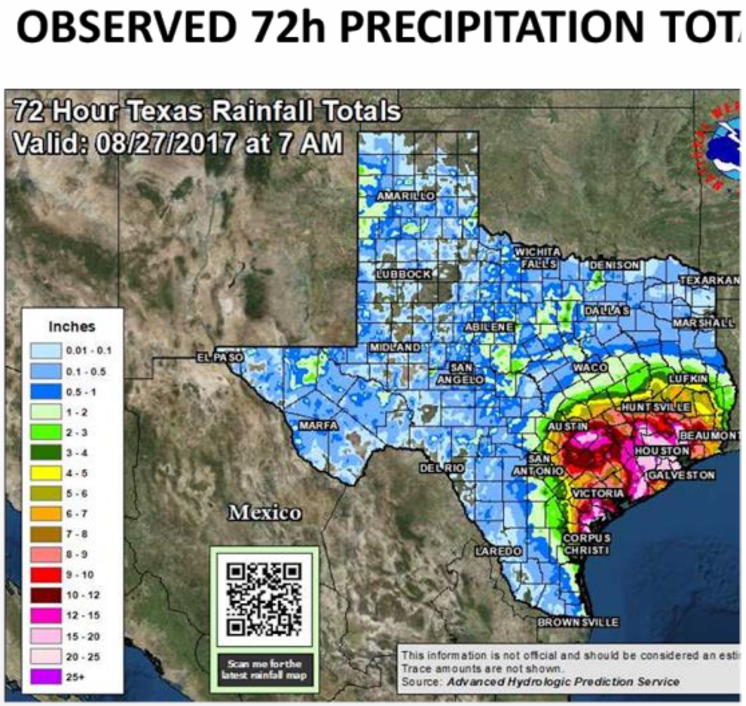


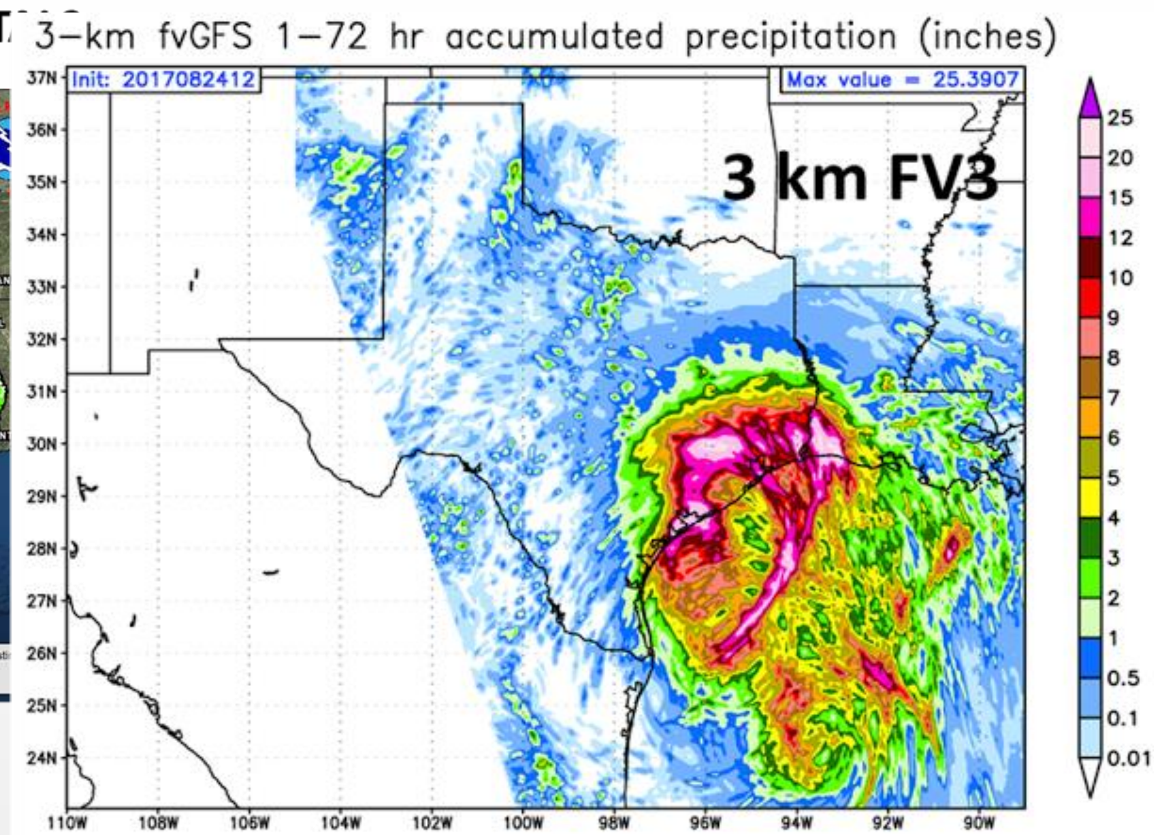
<u>50 km</u> model, currently operational

<u>25 km</u> model, presently used to develop next generation

Murakami et al. (2016, JC)

fvGFS: Hurricane Harvey Precipitation





- Nested fvGFS captured the double max structure with the core near Corpus Christi & the band trailing into Houston
- Slightly too far east due to motion bias
- 5-day precip shows continued accumulations near Houston & SW Louisiana

Courtesy Matt Morin, Andy Hazelton and Morris Bender