Seamless seasonal to multi-decadal prediction and projection

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Representative phenomena that give rise to variability & predictability in the climate system

Physical Phenomena	Variability & predictability timescale	
Mid-latitude storms, general circulation	Daily to two-week weather forecast	
Madden-Julian Oscillation, etc	Subseasonal	
El Nino/Southern Oscillation	Seasonal to interannual	***Internal***
Volcanic aerosol forcing	Seasonal to interannual	***Forced***
Decadal-scale ocean-atmosphere variability (AMO, PDO, etc)	Interannual to multidecadal	***Internal***
Anthropogenic greenhouse gases, aerosols, ozone changes	Decadal to centennial	***Forced***

Components of a seamless seasonal to decadal to multidecadal prediction and projection system

- **Observing Systems**
- **Assimilation Systems**
- **Models**
- **Changing radiative forcing**

Initial Value Problem
(seasonal to decadal prediction)

Boundary Value Problem
(decadal to multidecadal projection)

Seasonal to Multidecadal Predictions and Projections

Benefits of a seamless system for predictions and projections:

- *Interactions among scales*
- *High relevance for understanding and attribution*

Desired capability:

Modeling system that can produce large ensembles of initialized predictions and projections for time scales ranging from one season to multiple decades in advance

Desired product:

Probabilistic predictions and projections of climate variations and change that have utility for planning across a range of time and space scales – including 2-30 years.

Examples:

- How will predictable changes in ocean temperature influence tropical storm activity?

- How likely is it that:
  - the AMO will change phase and alter Atlantic hurricanes and other climate features?
  - the PDO will change phase and impact North American hydroclimate?

- How will anthropogenic climate change alter the probability of extreme events over the US for the next decade, including rainfall/flooding and heat waves?

First Generation GFDL Seasonal to Decadal to Mutidecadal Prediction and Research System

Global coupled ocean-atmosphere climate models

	Atmosphere resolution	Ocean resolution
CM2.1	200 km	1°
FLOR	50 km	1°
HIFLOR	25 km	1°

- CM2.1 and FLOR: run as part of the North American Multi-Model Ensemble (NMME)
  - output to NCEP & others to inform seasonal outlooks (ENSO, hurricanes, precip, temp, sea ice, etc)
  - ocean reanalysis provided to NCEP for Multiple Ocean Reanalysis Project
- Decadal predictions as part of international coordinated program through UK Met Office
- Large ensembles of multidecadal climate projections in response to radiative forcing changes

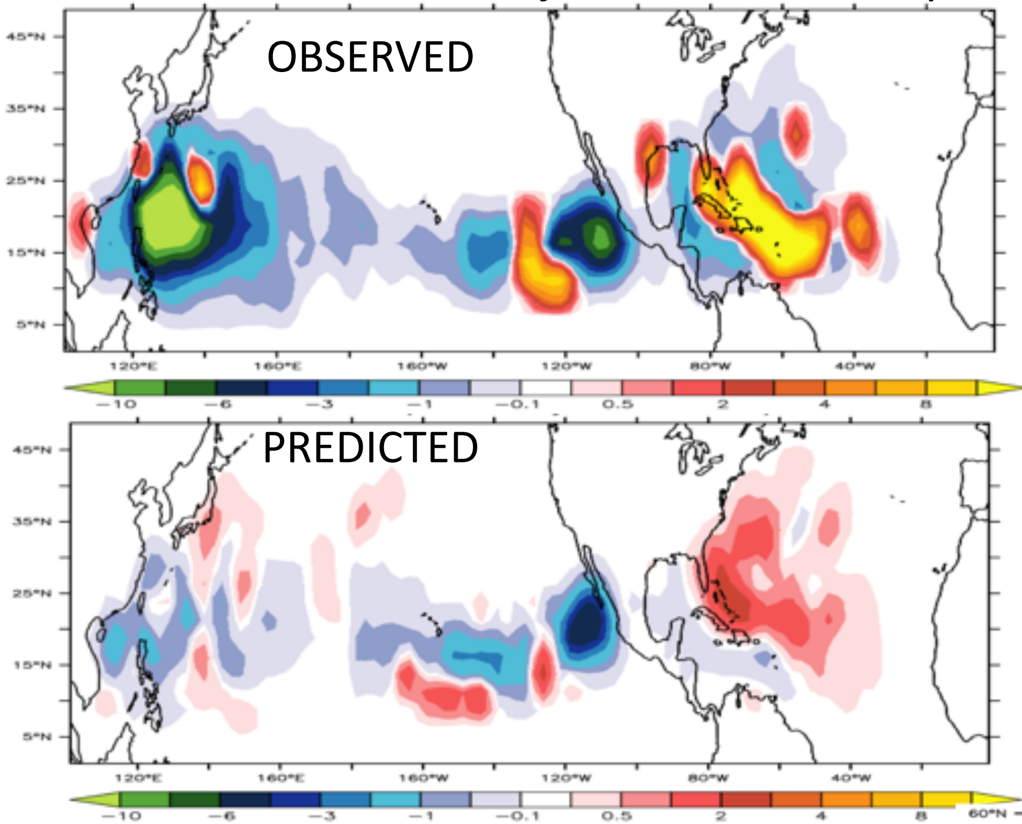
Key point: These prediction and projection systems are made possible through harvesting the fruits of a decades long research effort on INITIALIZATION SYSTEMS and MODEL DEVELOPMENT.

[1] *Due to computational cost, HIFLOR is run on a limited basis primarily for hurricane season*

Seamless prediction facilitates attribution of observed events

Dominant effect of relative tropical Atlantic warming on major hurricane occurrence
Murakami et al, 2018, Science

2017 anomalous major hurricane activity



(predictions based on 1 Jul, 2017 observations)
These predictions were provided to NCEP in real time.

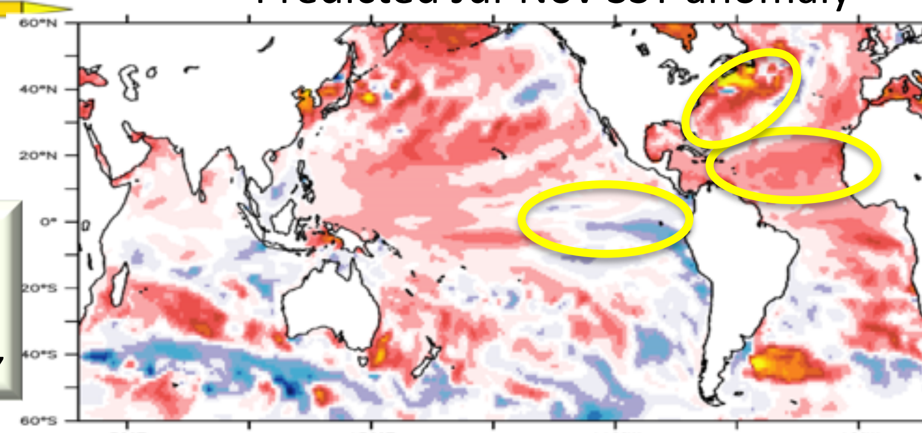
With this successful prediction, can perform additional simulations to diagnose what physical factors led to the extreme hurricane season.

We find:

a. Moderate La Nina was not responsible
b. Warming off US East Coast was not responsible
c. Tropical Atlantic warming played dominant role

➔ *Used these and additional results to make statements about future hurricane activity.*

Predicted Jul-Nov SST anomaly



2015 active season in eastern Pacific and Hawaii due to:
- ➢ Pacific Meridional Mode
- ➢ Subtropical warming from greenhouse gases

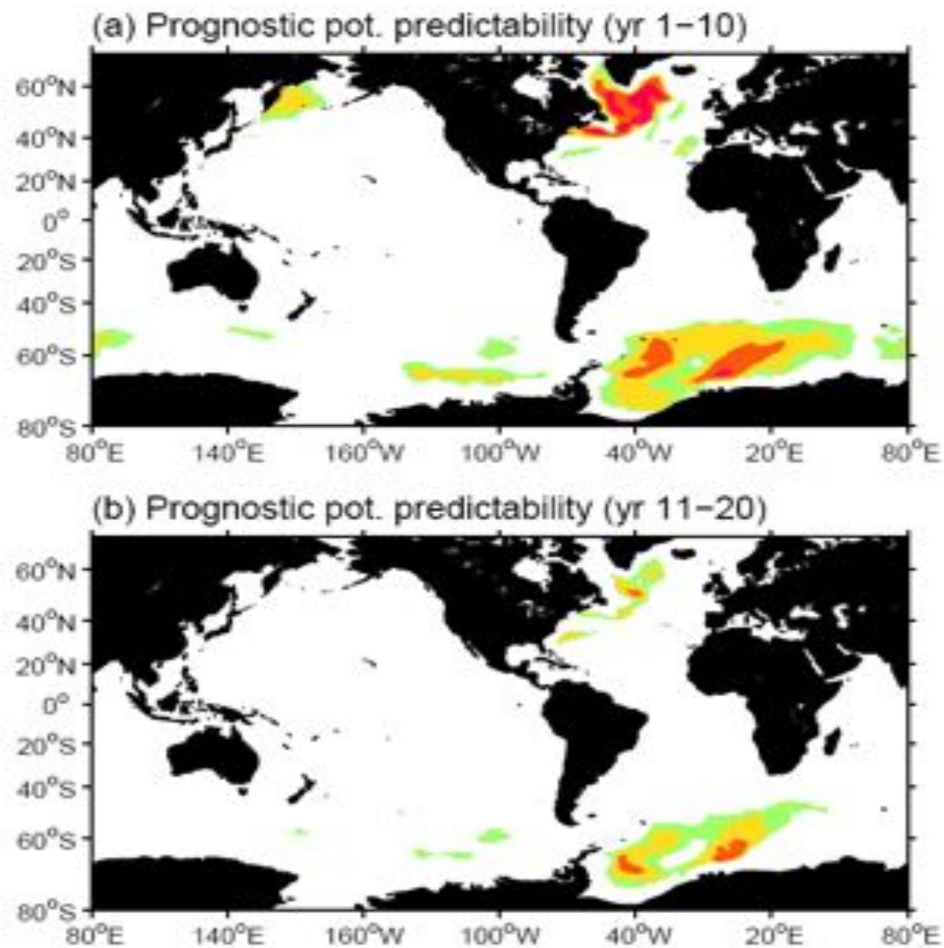
Murakami et al, 2017

There are a number of phenomena with decadal predictive skill from internal variability:

1. Atlantic Ocean surface and subsurface temperature (AMOC, ocean circulation)

2. Pacific Decadal Oscillation (less predictable than North Atlantic)

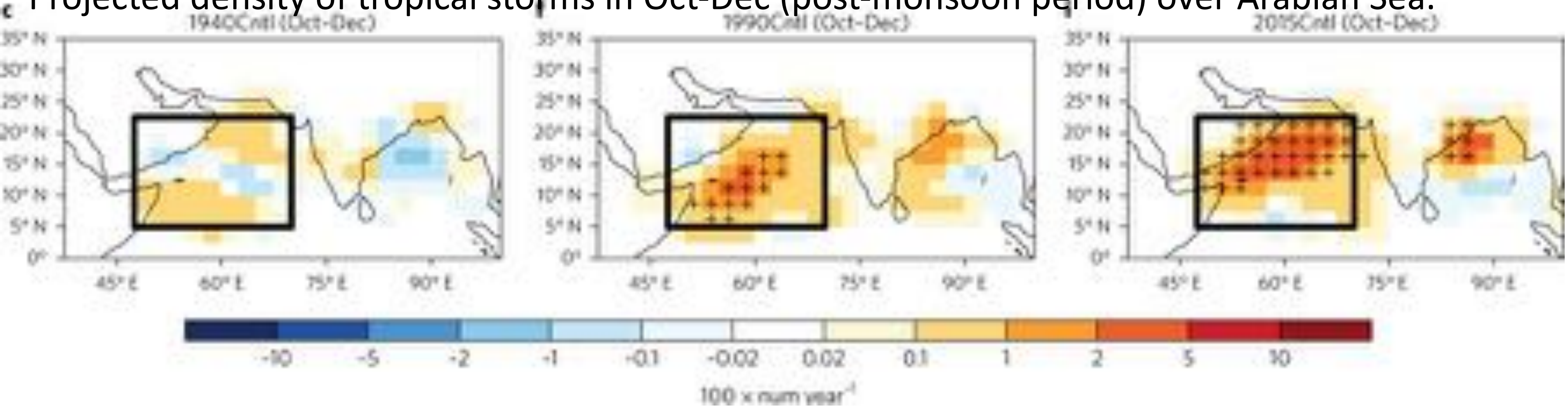
3. Southern Ocean – potentially predictable on long time scales



Seamless prediction systems may provide advance warning of emerging threats

Projected changes in SST and atmosphere lead to new threats of tropical storms in the Arabian Sea where previously there had been none.

Projected density of tropical storms in Oct-Dec (post-monsoon period) over Arabian Sea.



Increasing frequency of extremely severe cyclonic storms over the Arabian Sea

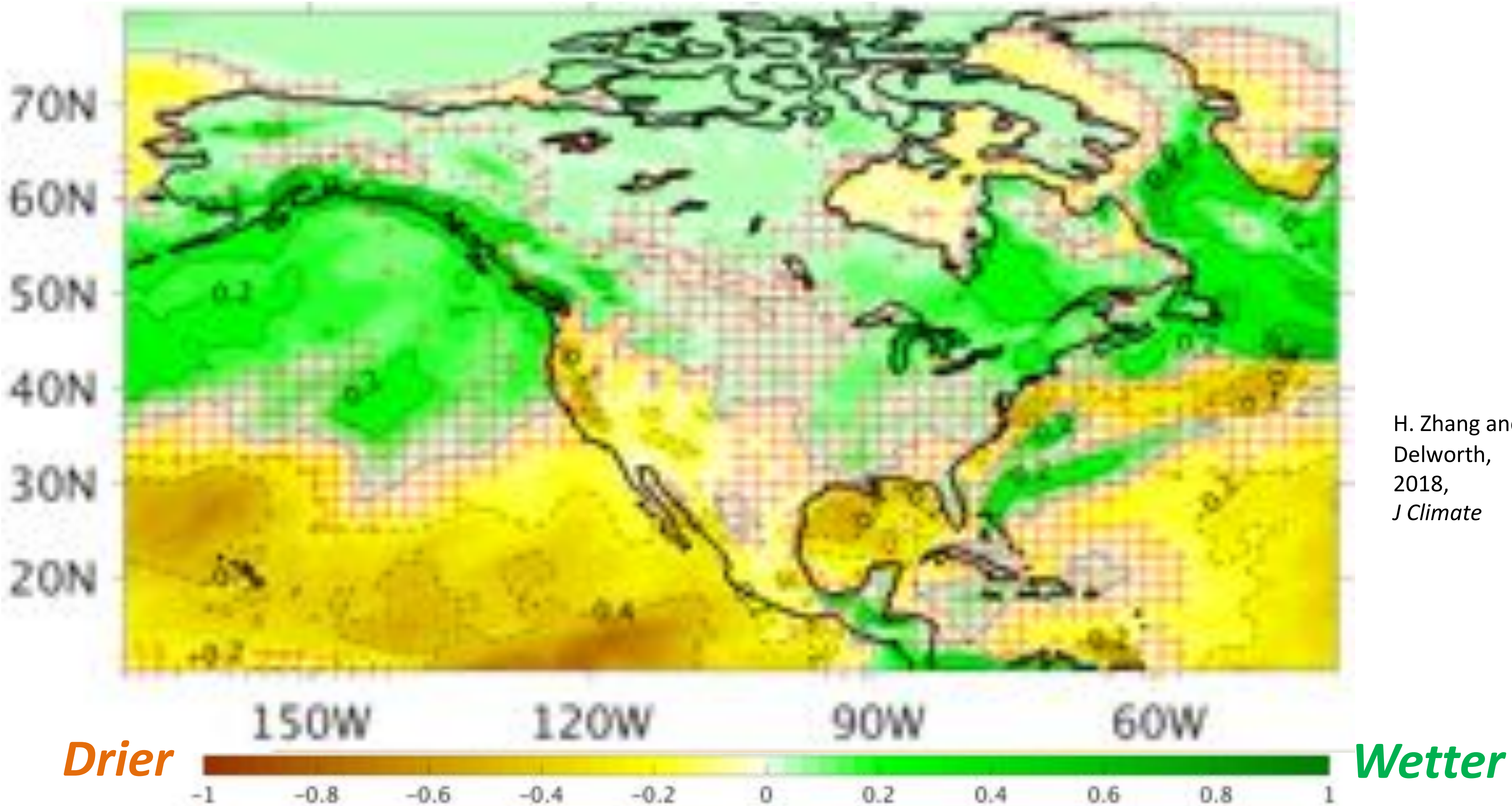
Murakami et al, 2017, Nature Climate Change

Projecting decadal scale changes in North American Hydroclimate

Key goal: Probabilistic assessment of decadal-scale changes in weather extremes over North America

- *Precipitation extremes and water resources, especially over North America*
- *Characteristics and impacts of changing tropical and extratropical storms*
- *Snowpack and western water resources*

Example: Projected change in P-E (winter, for decade of 2030s) using large ensembles with FLOR



Change in Precipitation minus Evaporation (mm day^{-1})

H. Zhang and Delworth, 2018, *J Climate*

Next Generation GFDL Seasonal to Multidecadal Prediction and Research System – SPEAR

(Seamless system for Prediction and EArth system Research)

➔ Using latest generation component models to build next generation seamless prediction system, consisting of: **AM4** (atmosphere), **MOM6** (ocean), **SIS2** (sea ice), **LM4** (land)

Drivers:

- Advances in scientific understanding, physics, and numerics
- User needs for improved predictions and projections on **seasonal to multidecadal time scales**, especially for extremes and regional scales

	Atmosphere resolution	Ocean resolution	Model Development Status	Reforecasts
SPEAR_LO	100 km	1^o	Completed	Underway
SPEAR_MED	50 km	1^o	Completed	Planned over next 6 months
SPEAR_HI	25 km	1^o	In development	Very limited set planned due to computational costs

Combined with next generation initialization system operating with MOM6 ocean code

Emerging capabilities for prediction of aspects of ocean biogeochemistry

Possible actions for a broader US perspective on 2-30 year predictions and projections:

- **Coordinated effort to**:
  - Bring together US institutions with capabilities for 2-30 year predictions and projections
  - Where is there skill? What is the potential for future skill? What is scientifically credible?

- **Continued coordination with international efforts already underway:**
  - The UK Met Office is a Lead Centre for Annual-to-Decadal Climate Prediction.
  - Growing number of large ensembles for climate change projections from centers around the world.

- **Iterative process (researchers and end users)** to better identify and understand desired products for predictions/projections on 2-30 year time scale
  - identifying what is feasible and what is not, what is useful and what is not

- **Need "translators"** to help make such model output useful to users; this was identified in the 2012 NAS report on Climate Modeling.