Ocean Salinity and Machine Learning for Improved S2S Forecasts on Land

RAY SCHMITT

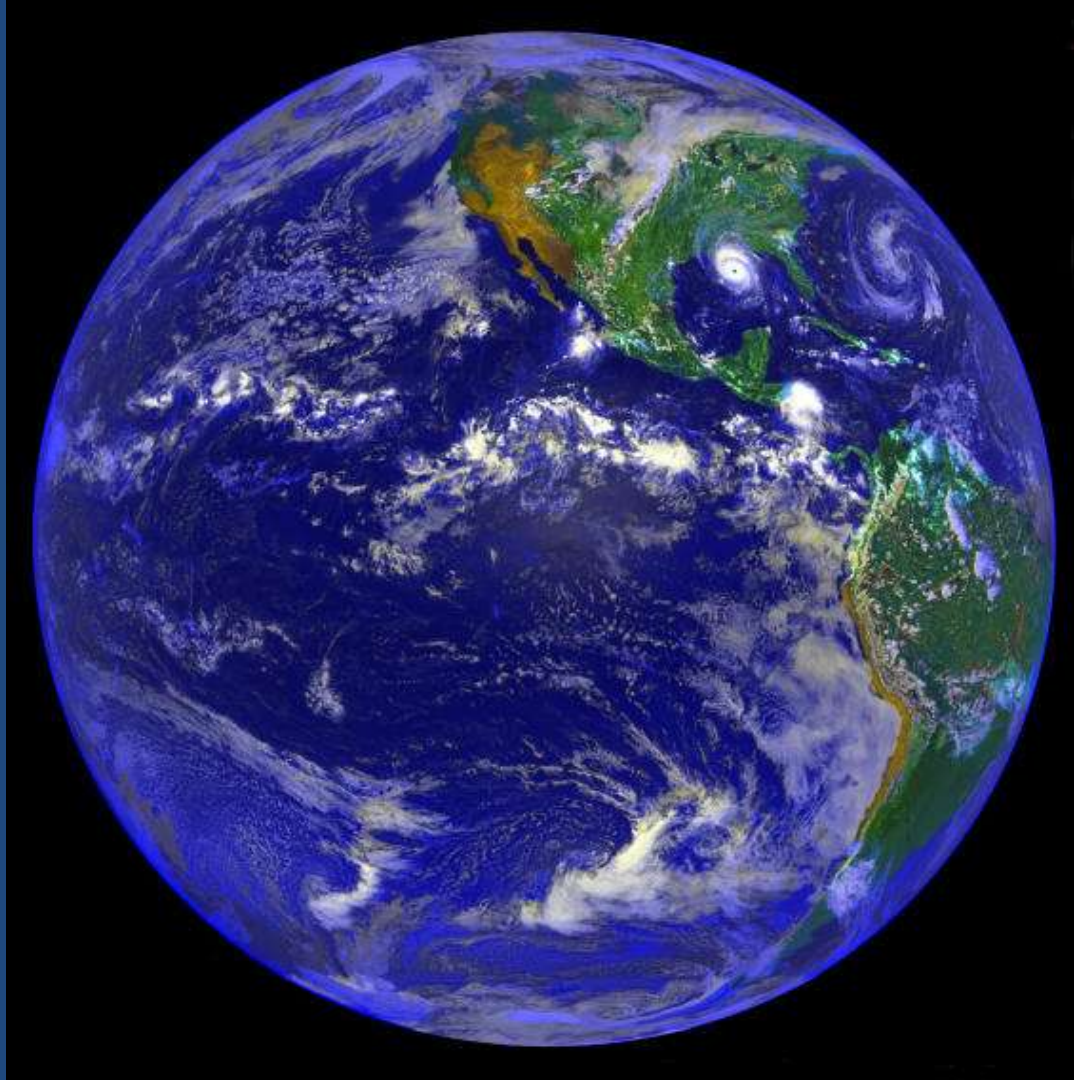
Woods Hole Oceanographic Institution

rschmitt@whoi.edu

"How inappropriate
to call this planet Earth when
clearly it is Ocean"

- - Arthur C. Clarke
Nature, 1990

The Oceans have low albedo and thus absorb most of the solar radiation incident on the planet. They also have over 1000 times the heat capacity of the atmosphere and 97% of the free water on the planet.



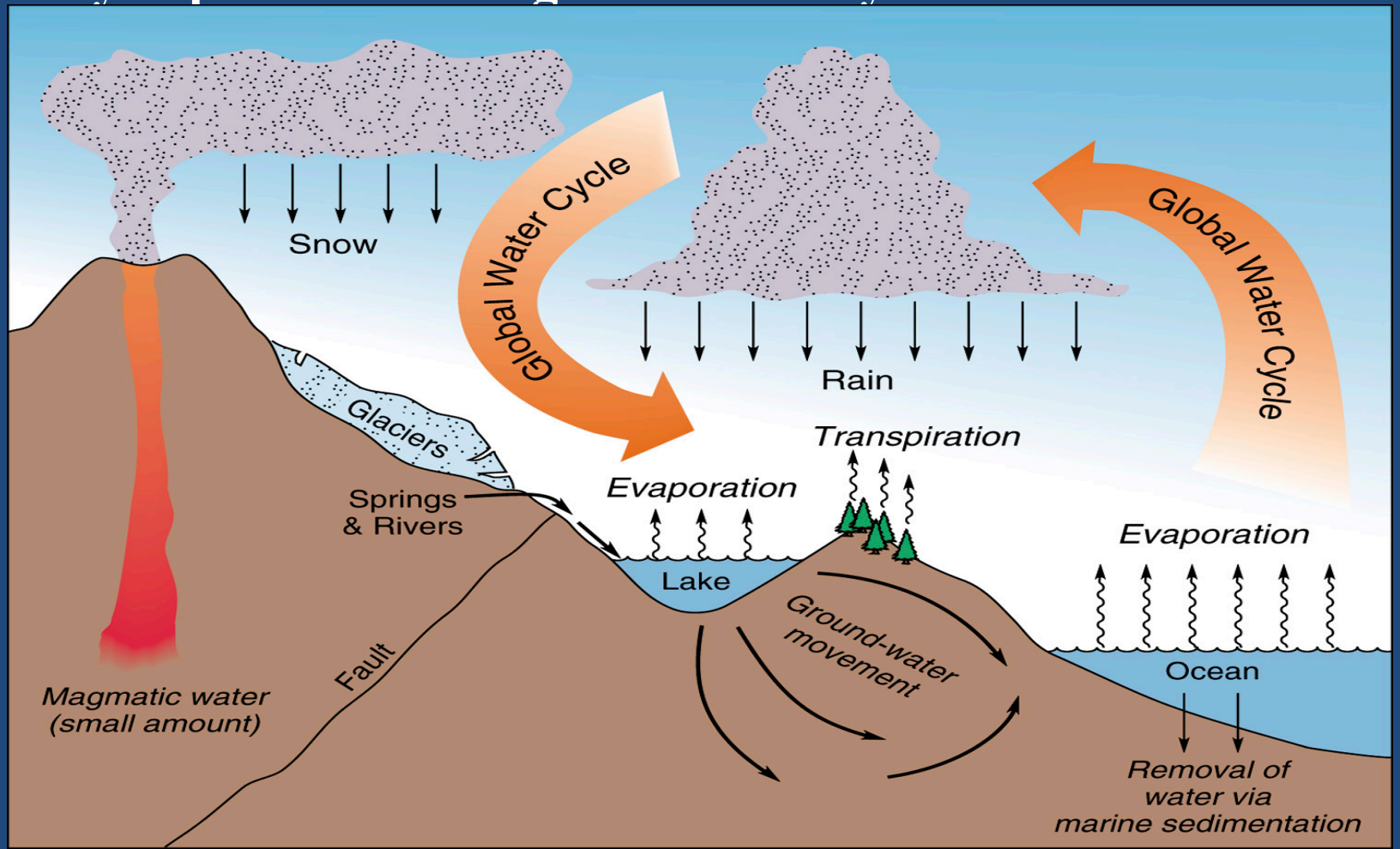
Background: I have been studying the global water cycle since the 1980s, but found funding difficult: Who cares if rains on the ocean?

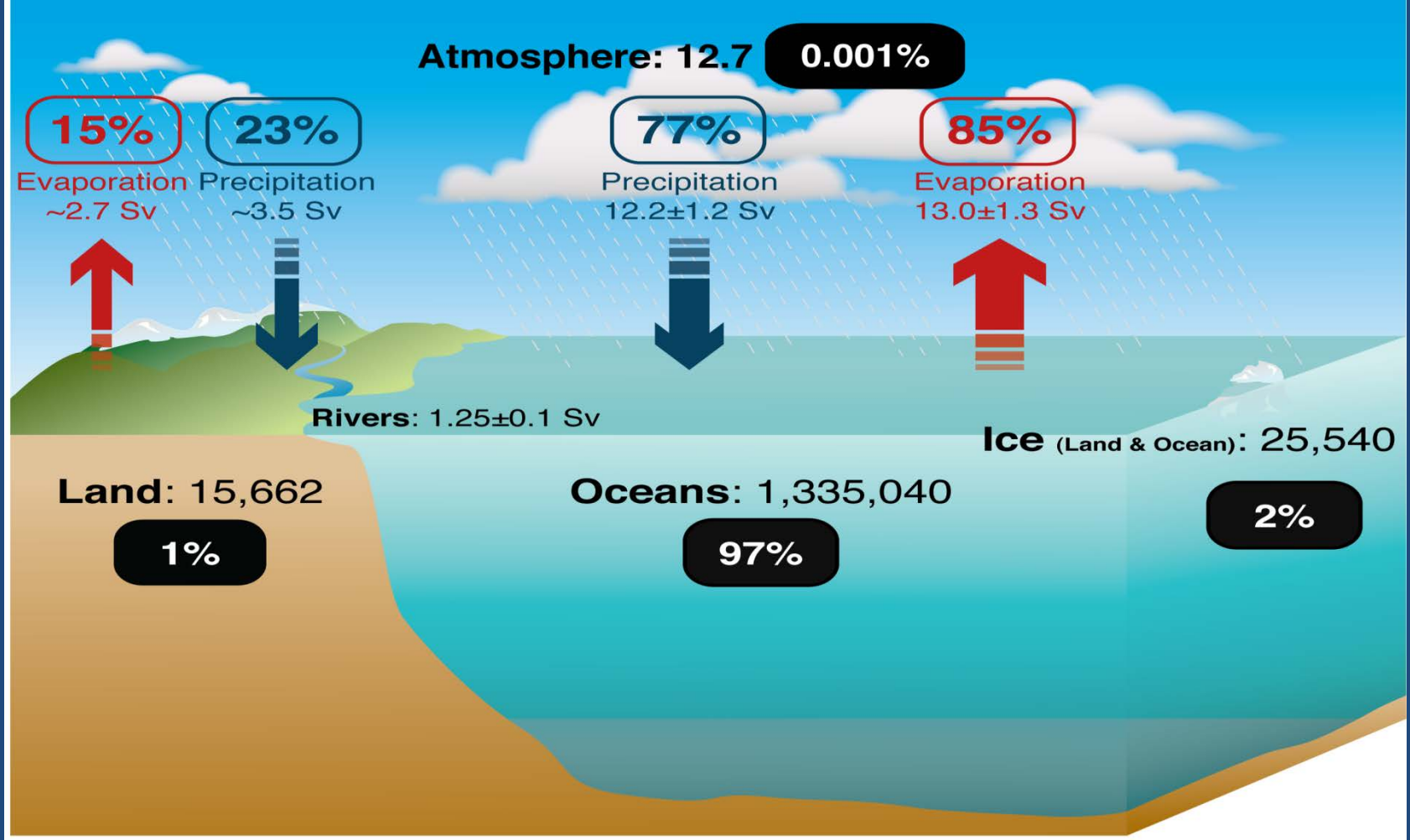
“GEWEX is not for Oceanographers”

- *GEWEX Steering Committee Meeting, 1991*

Oceanographers considered the oceanic water cycle too small, Hydrographers thought it too big.

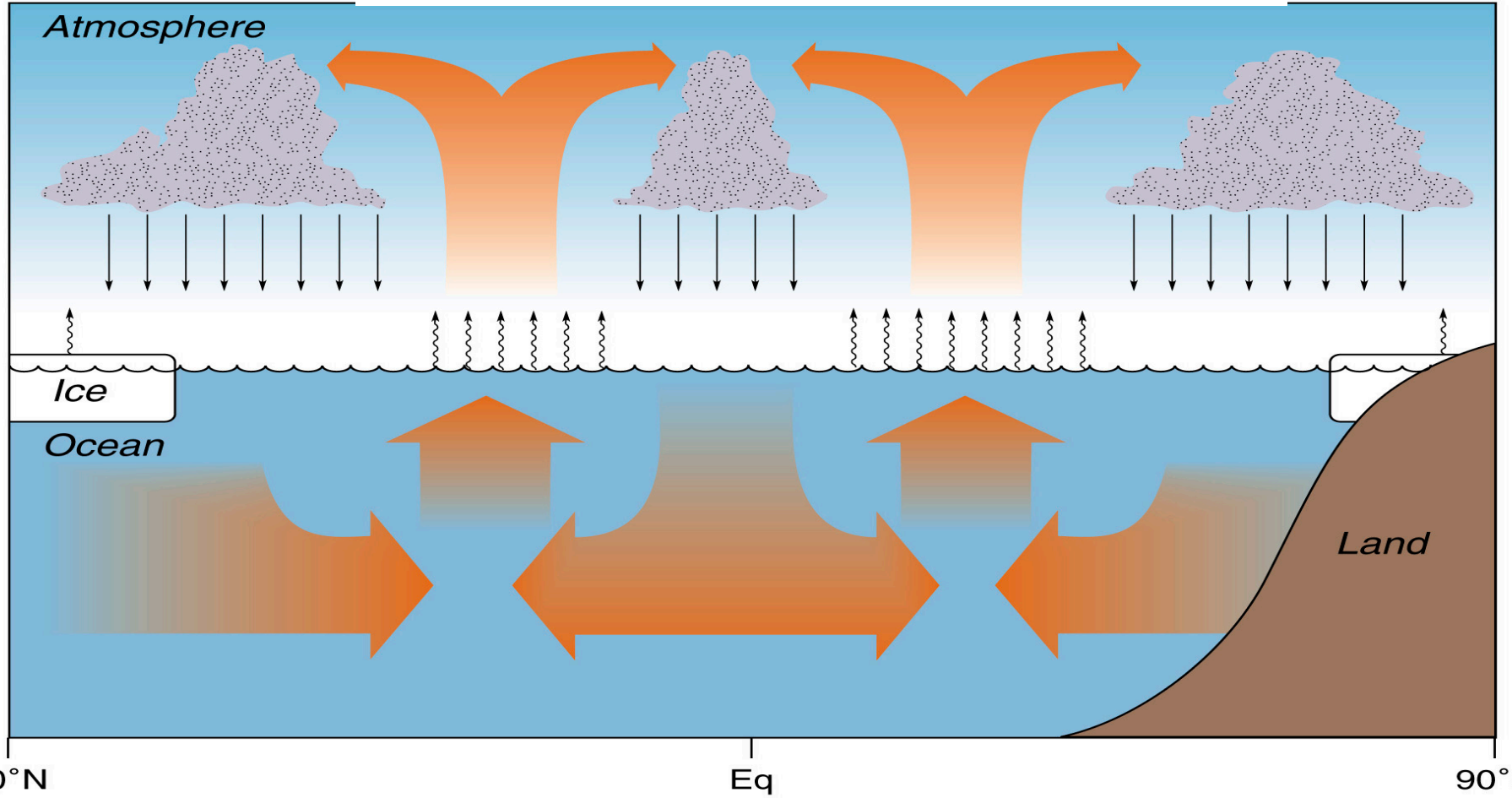
Many depictions of the global water cycle minimize the ocean!



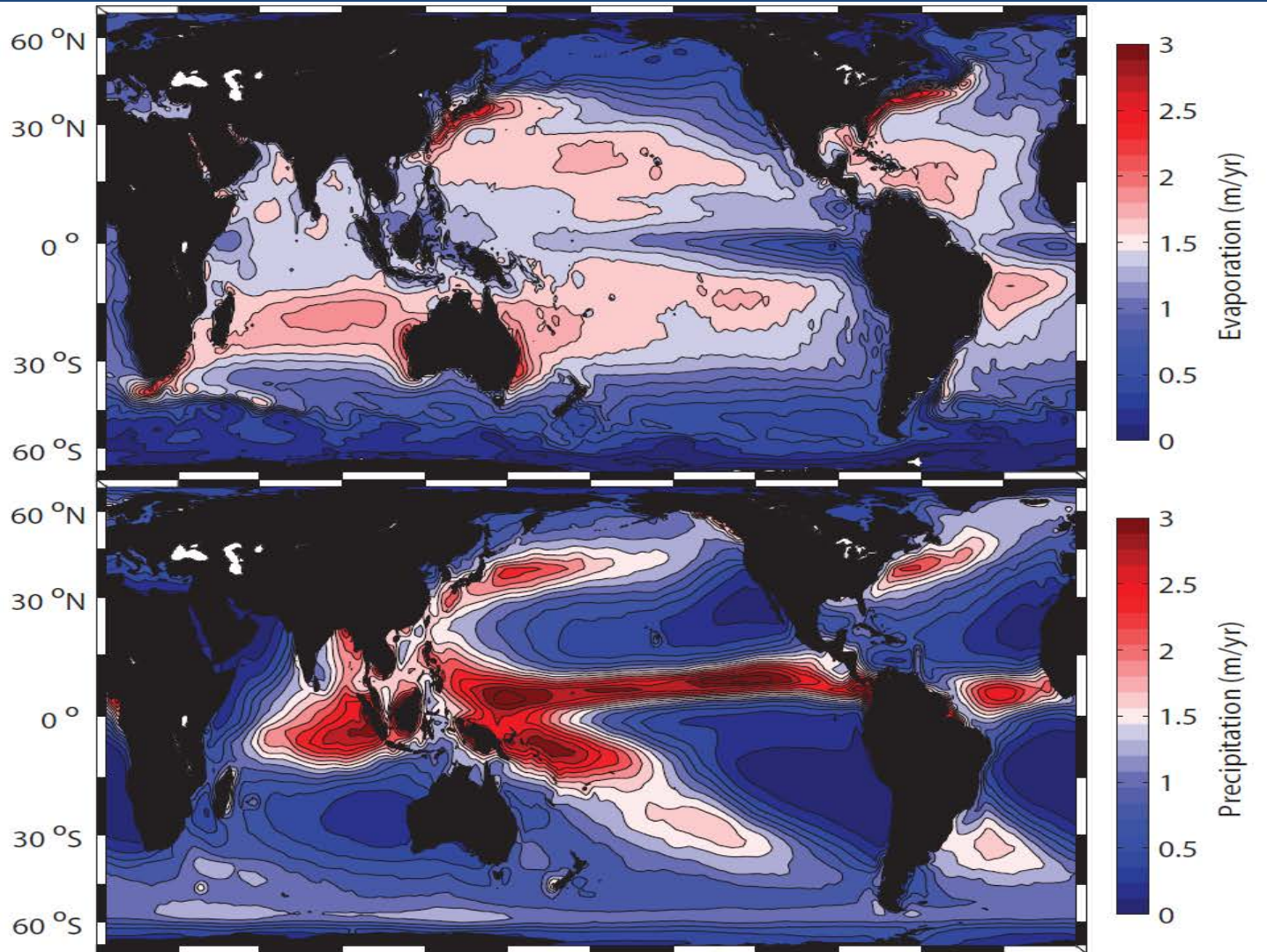


Reservoirs represented by solid boxes: 10^3 km^3, fluxes represented by arrows: Sverdrups (10^6 m^3 s^{-1})
Sources: Baumgartner & Reichel, 1975; Schmitt, 1995; Trenberth et al., 2007; Schanze et al., 2010; Steffen et al., 2010

The Oceanographers Water Cycle

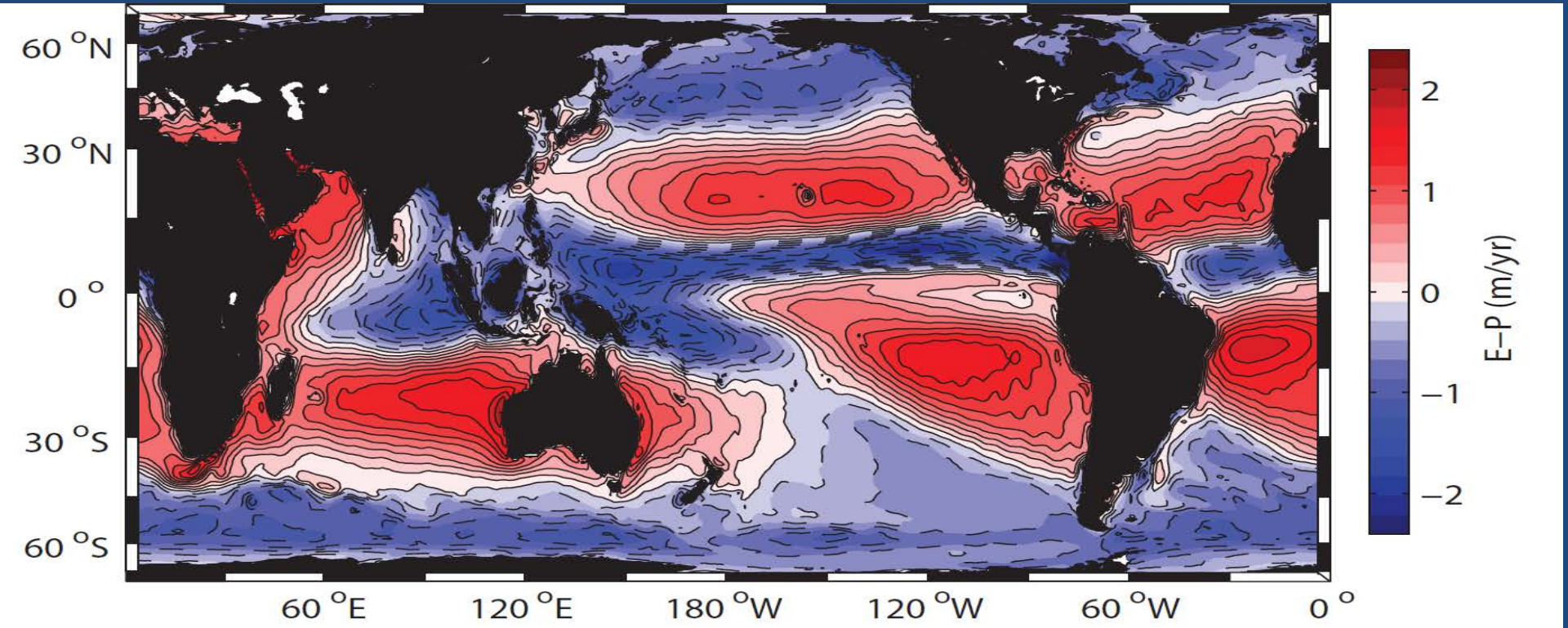


From:
Schanze,
Schmitt &
Yu, 2010
(J. Mar. Res

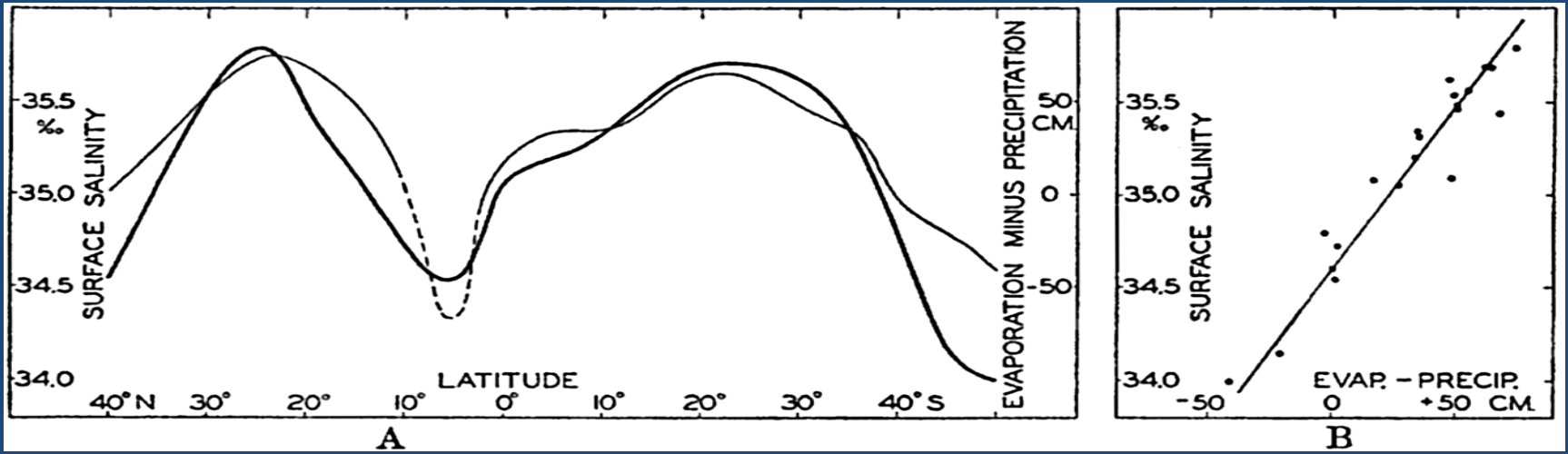


Net Evaporation –Precipitation

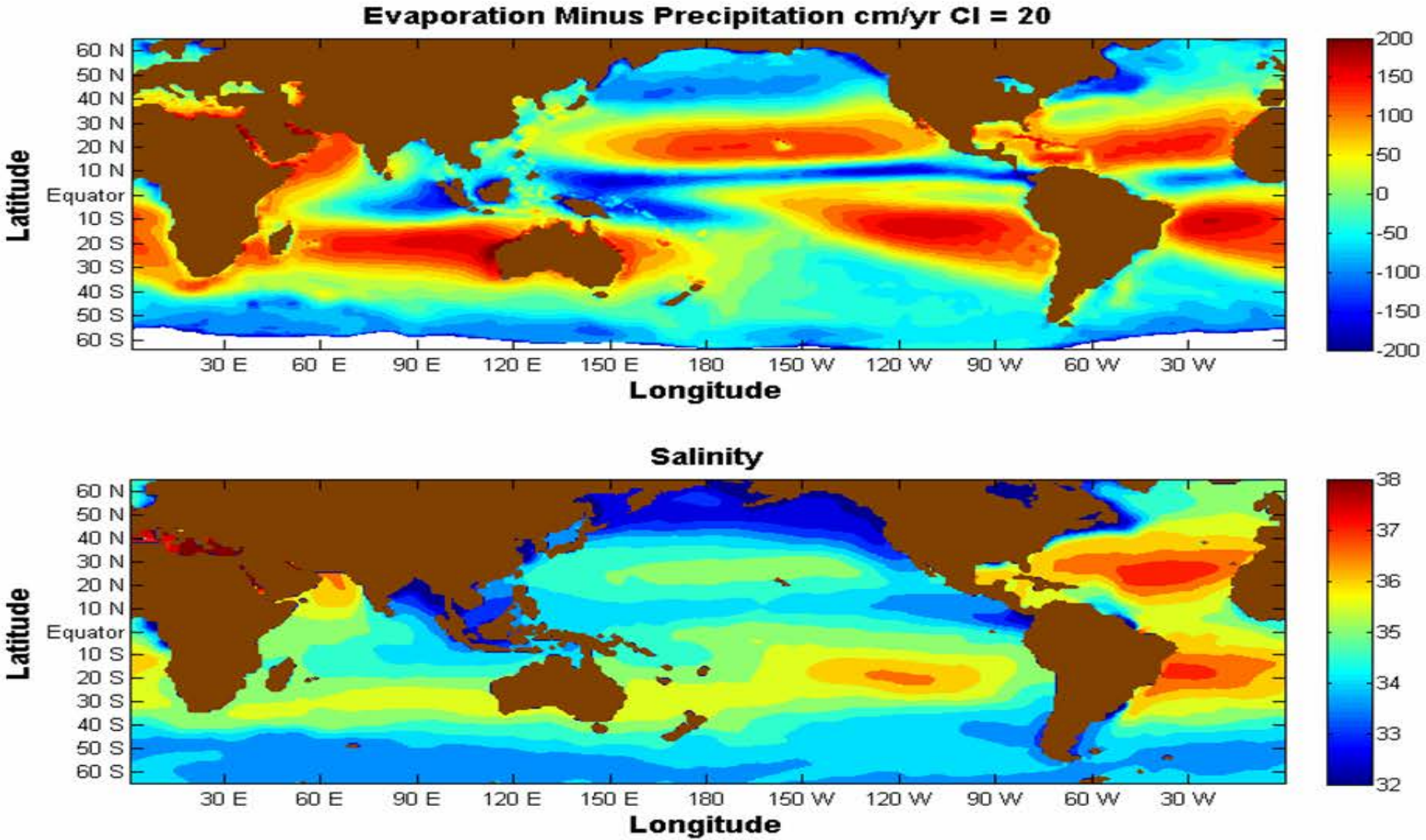
Schanze, Schmitt and Yu, 2010 (*J. Mar. Res.*)



Wüst, 1936



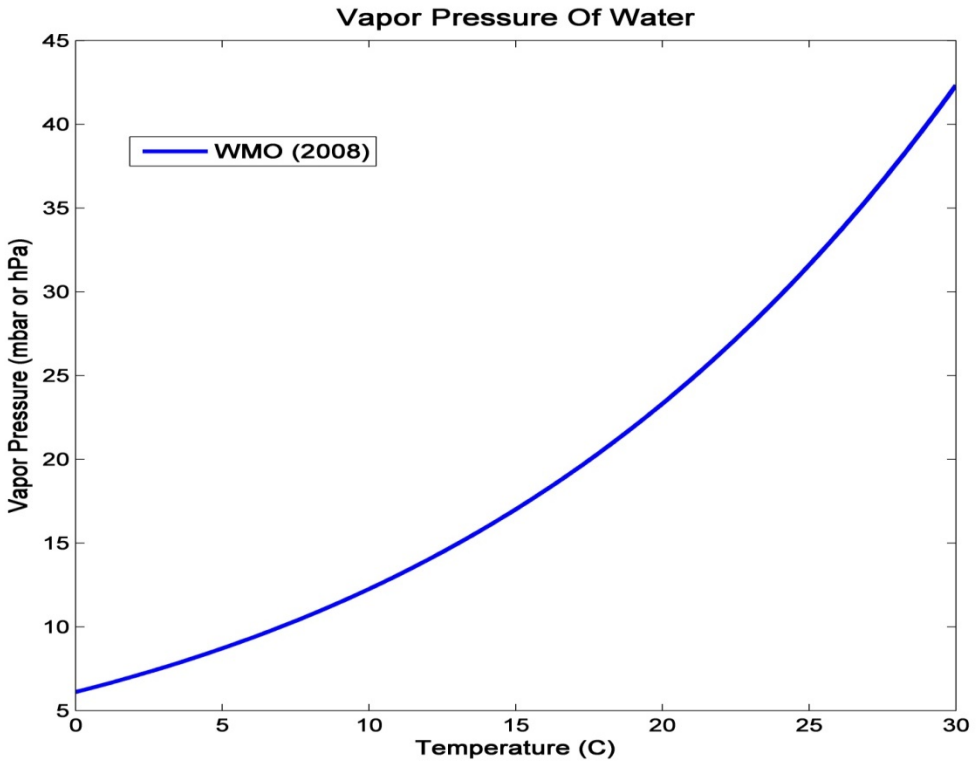
$$S = 34.60 + 0.0175(E - P).$$


Evaporation Minus Precipitation cm/yr CI = 20
Latitude
60 N
50 N
40 N
30 N
20 N
10 N
Equator
10 S
20 S
30 S
40 S
50 S
60 S
30 E
60 E
90 E
120 E
150 E
180
150 W
120 W
90 W
60 W
30 W
Longitude
200
150
100
50
0
-50
-100
-150
-200
Salinity
Latitude
60 N
50 N
40 N
30 N
20 N
10 N
Equator
10 S
20 S
30 S
40 S
50 S
60 S
30 E
60 E
90 E
120 E
150 E
180
150 W
120 W
90 W
60 W
30 W
Longitude
38
37
36
35
34
33
32

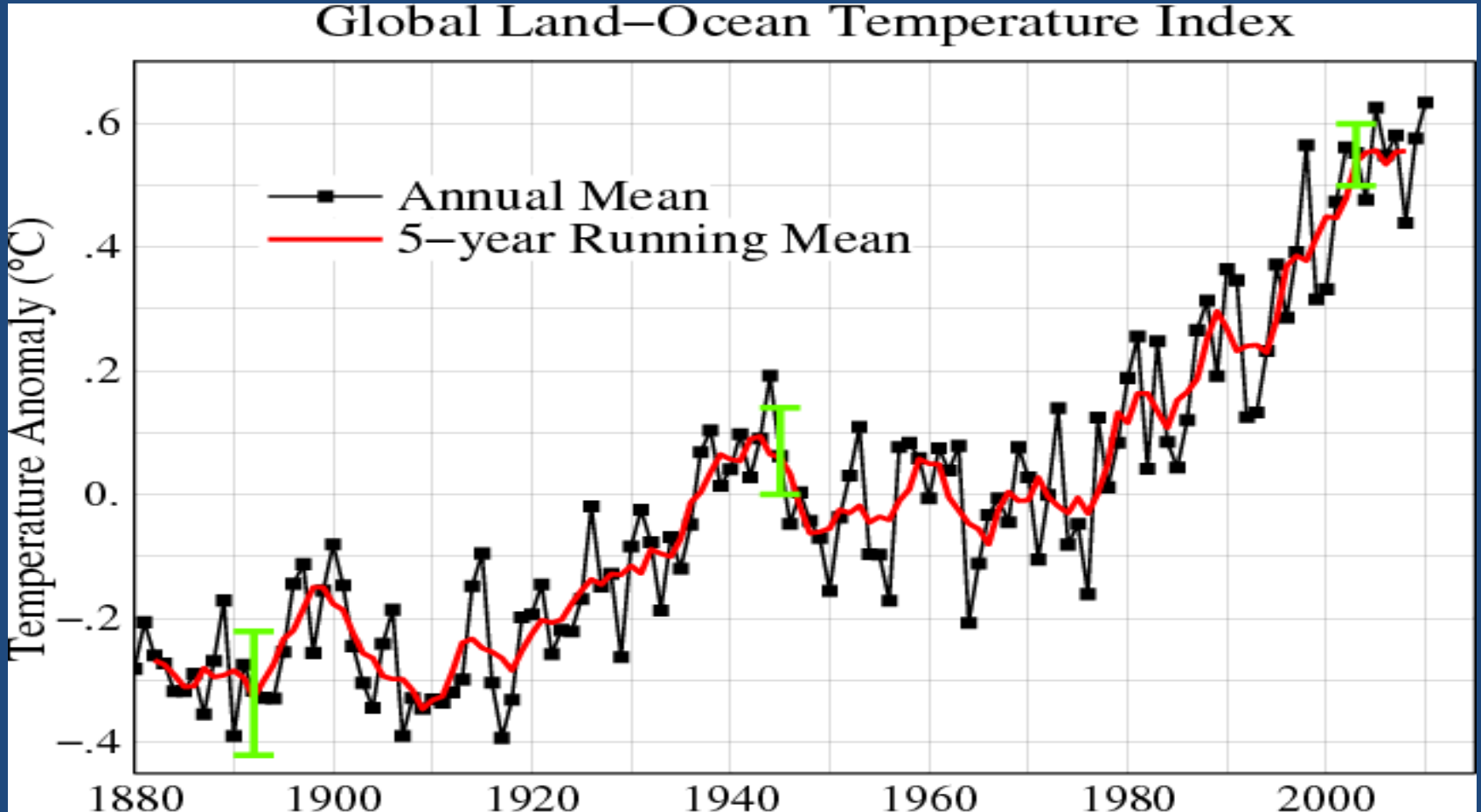
The Water Cycle Will Accelerate With Global Warming

A warmer atmosphere will carry more water vapor, because of the exponential increase of vapor pressure with temperature.

An enhanced water cycle will change the distribution of salinity in the upper ocean.

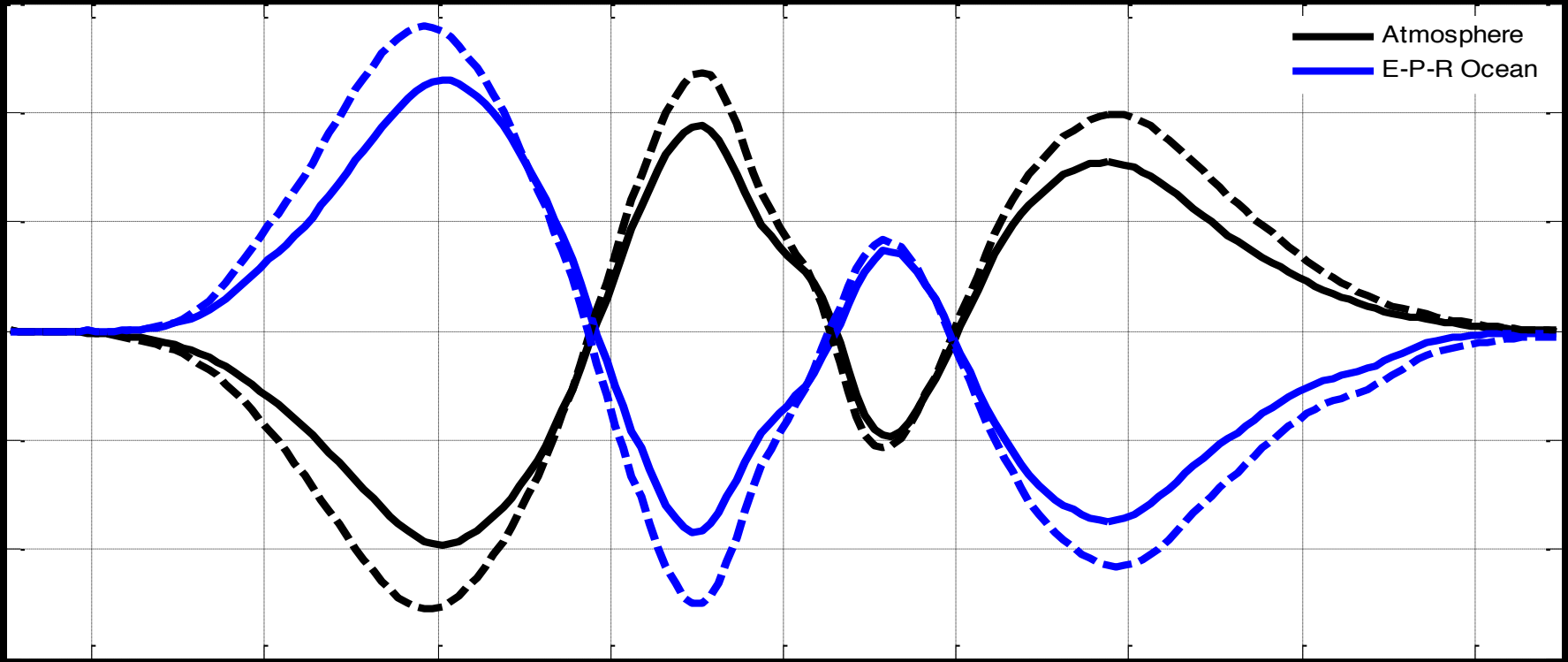


Temperatures are rising…..



Net Meridional Water Transport by Atmosphere and Ocean

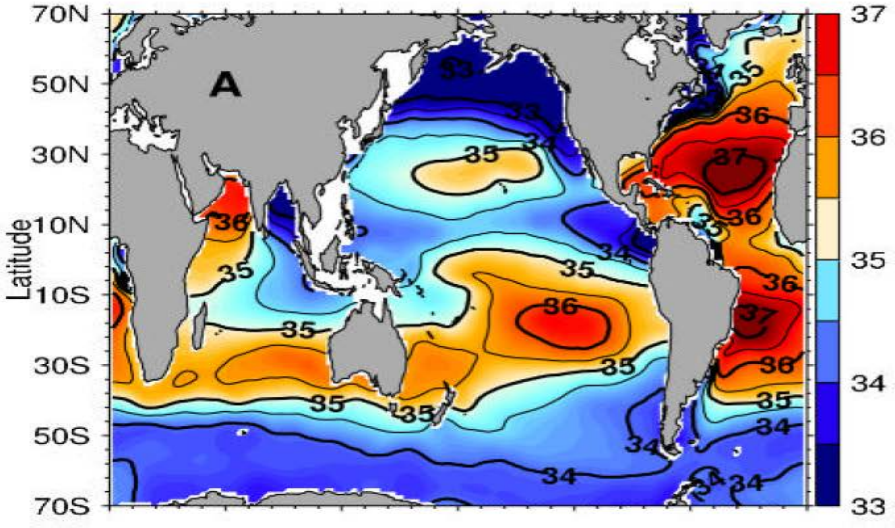
Solid = 2000, Dashed = 2100 from CMIP5 models



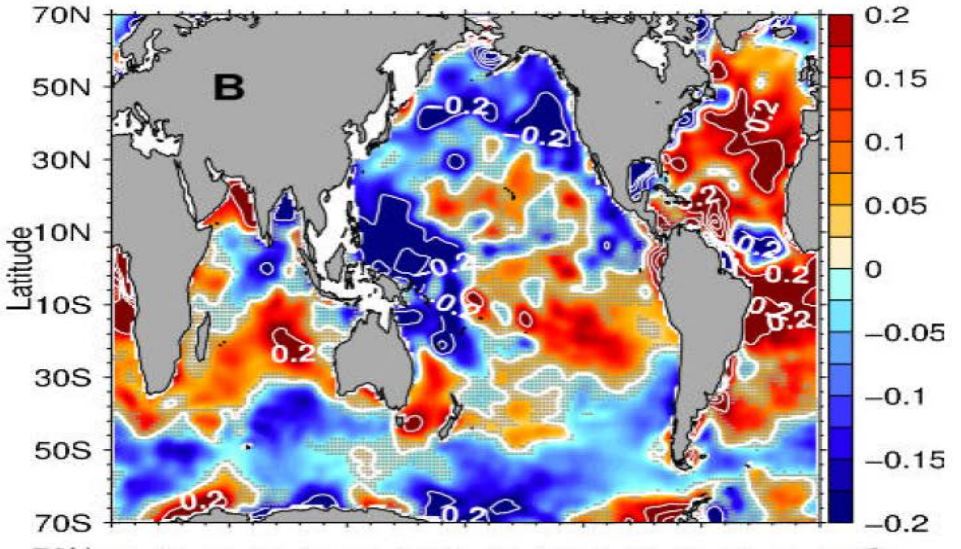
Durack and Wijffels, 2010

J. Climate

Mean SSS

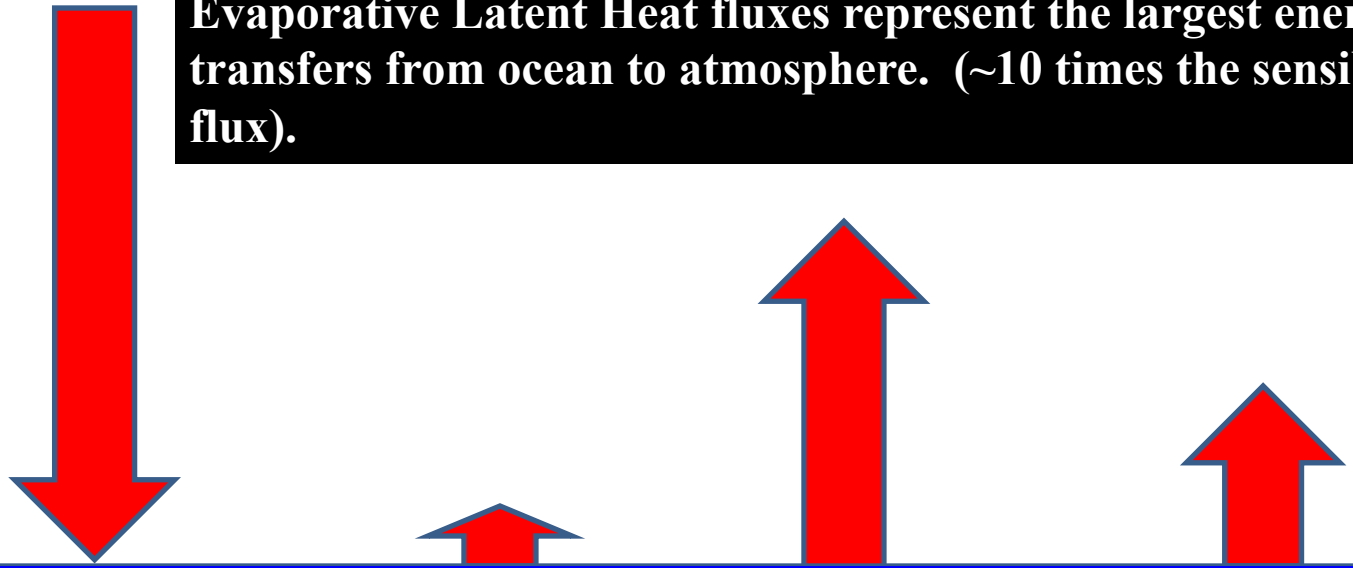


50 yr trend in SSS



Surface Ocean Heat Budget -- Modified from Stephens et al. (2012) to show ocean only.

Evaporative Latent Heat fluxes represent the largest energy transfers from ocean to atmosphere. (~10 times the sensible heat flux).



Net Short Wave Gain 165 W/m^2

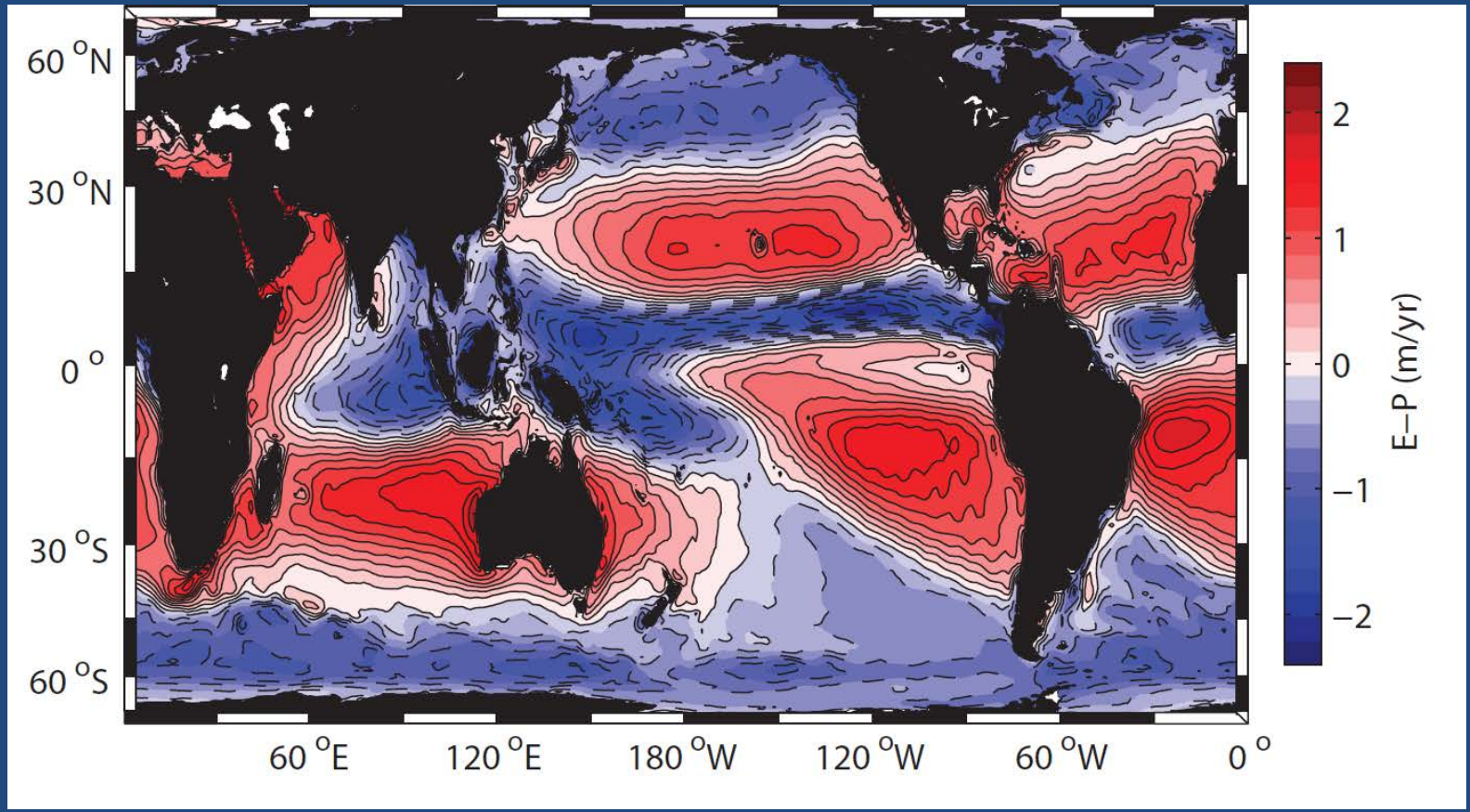
Sensible Heat Loss 10 W/m^2

Latent Heat Loss 98 W/m^2

Net Long Wave Loss 53 W/m^2

Note: Evaporation of 1 m/yr = 75 W/m^2

Evaporation minus Precipitation (E-P)



Schanze, Schmitt and Yu, (2010, *J. Mar. Res.*)

Water Cycle Facts:

Ray's Rules:

Area with E > P ≅ Area with P > E

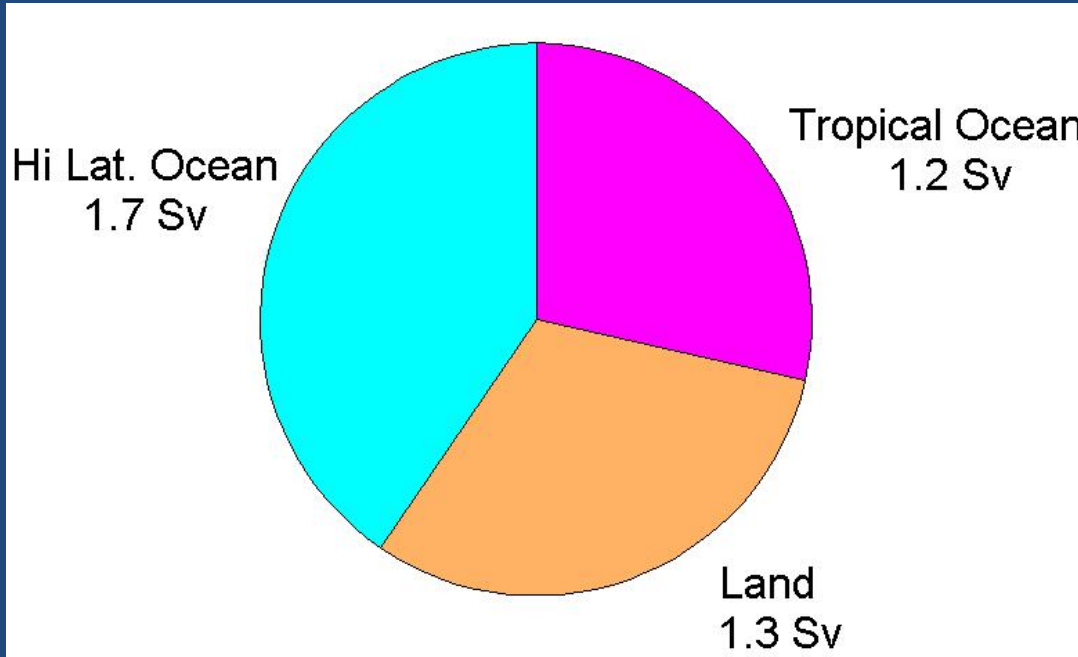
- E ≅ 2P where E > P
- P ≅ 2E where P > E

E = evaporation

P = precipitation

Subtropical water sources
= 4.2 Sv

Sinks:

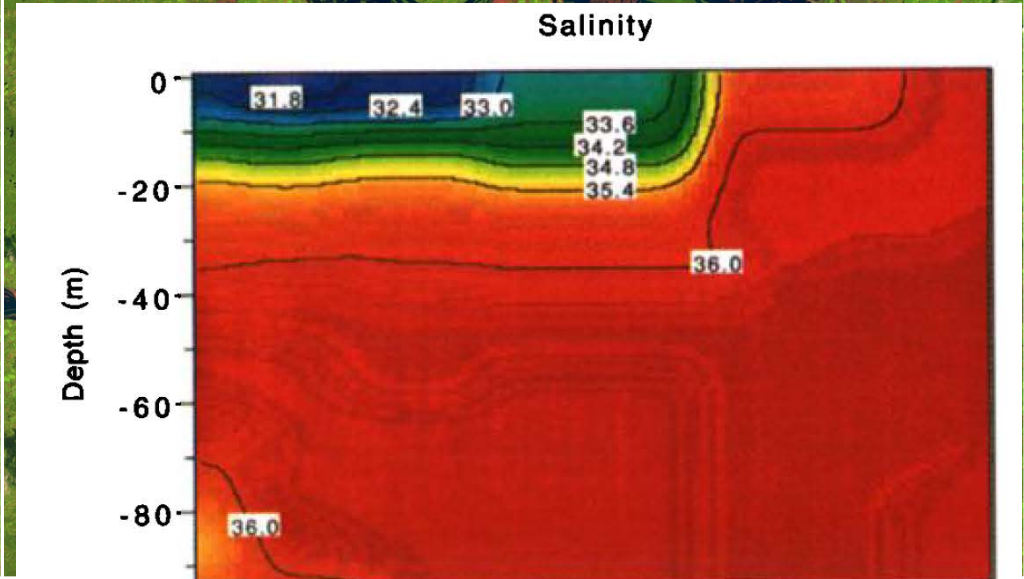


August 1991

August 1993

In 1993, heavy rains produced massive flooding along the Mississippi

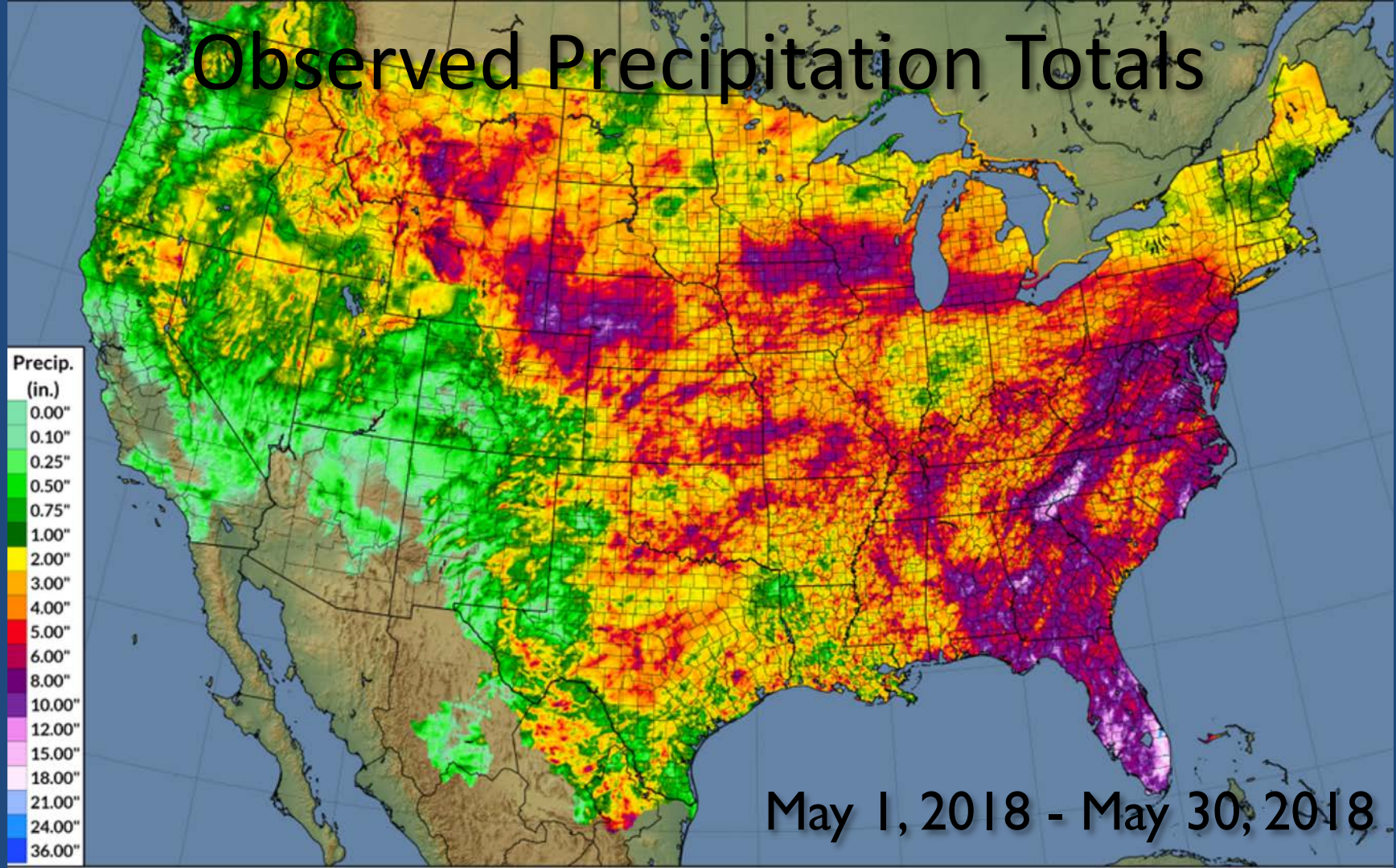
And strong fresh anomalies in the Gulf Stream!



Obvious inferences:

- No watershed floods by recycling its own water, the extra moisture must come from the ocean
- There must have been high salinity anomalies that preceded the heavy rains
- Can Sea Surface Salinity (SSS) variability be used to predict rainfall on land?

Observed Precipitation Totals

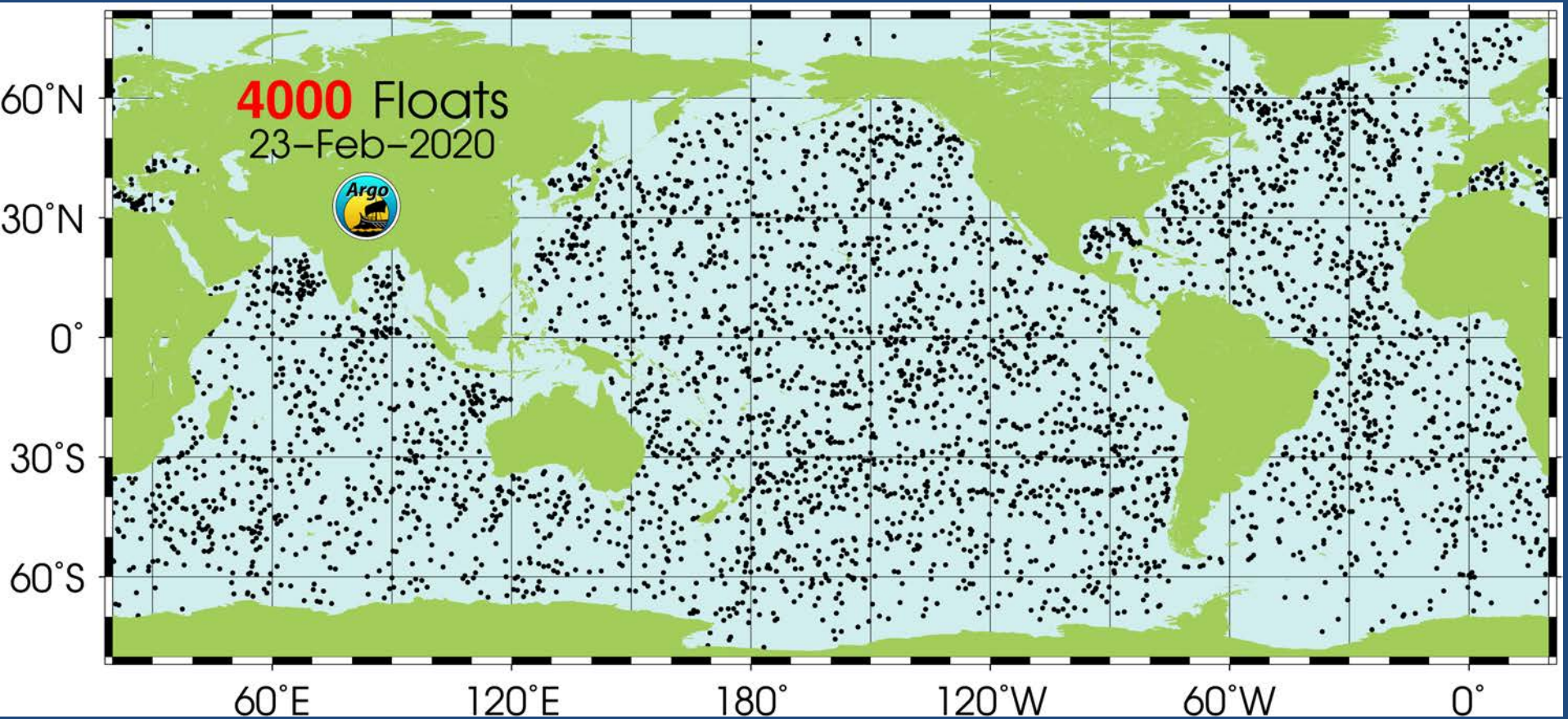


By Ray's Rules:

If 12 inches of rain falls over a large area of the US in a month, then:

- **A comparable area of ocean must have lost 12 inches of water**
- **If surface mixed layer depth is 100 ft, the SSS anomaly is 1% or ~0.35 PSU.**
- **This can be detected by satellites or ARGO floats.**

ARGO Floats Feb. 23, 2020



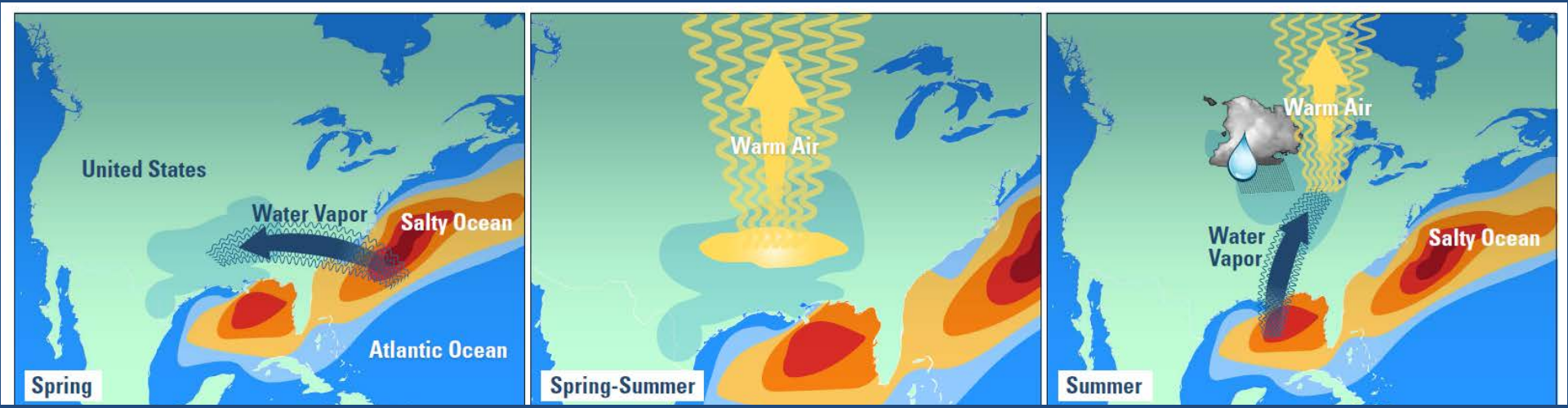
Background #2:

Unpopular proposals for SSS and water cycle

- **Several NSF proposals declined**
- **Continued resistance from Hydrology community**
- "…**we need to stop the simple extrapolation of results from ocean studies to land**…" Roderic al, (2012) ***Science***, **336,** p1230-1231.

- **But new opportunity in 2014…**
- **Laifang Li won a WHOI Postdoctoral Fellowshi**

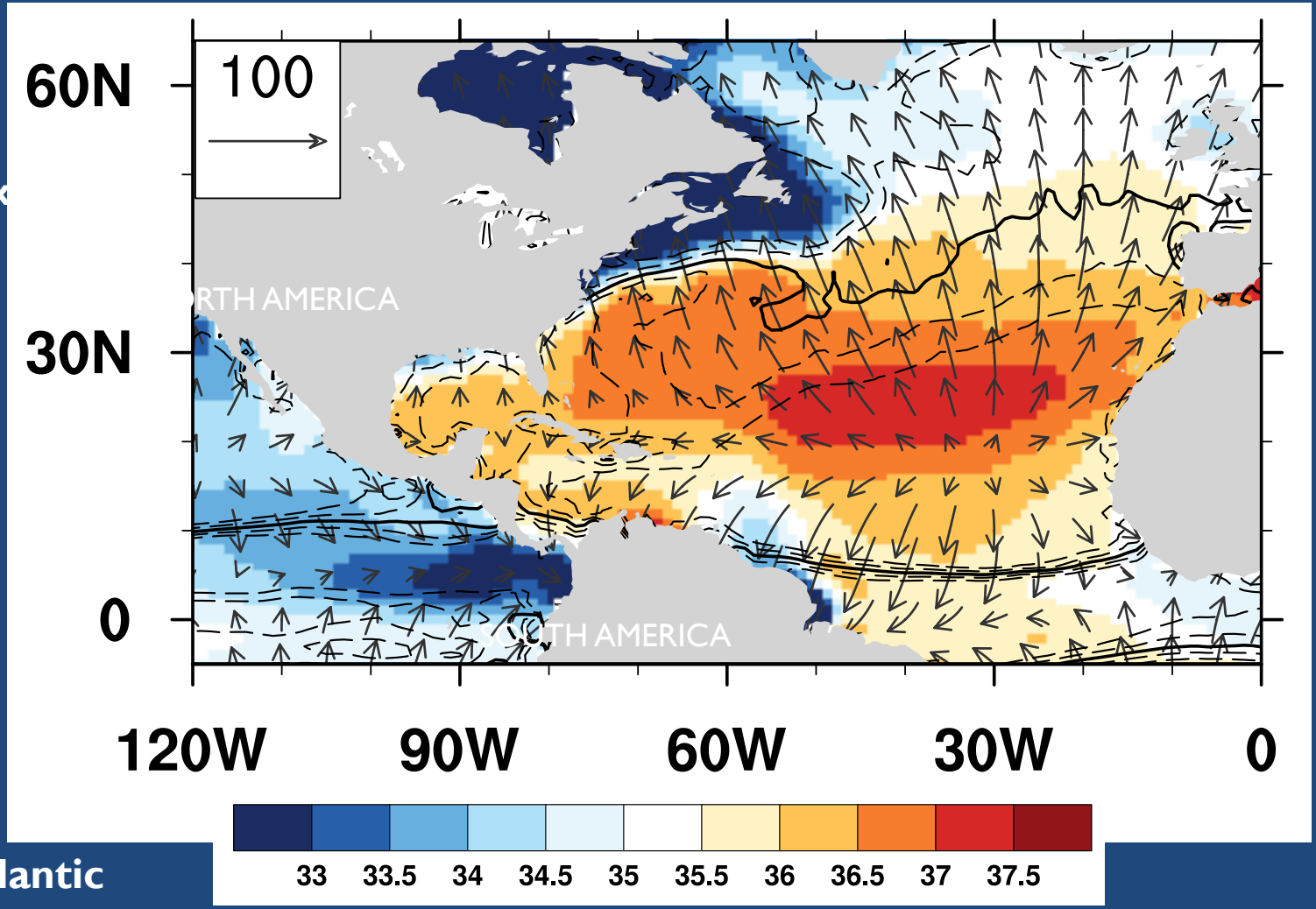
(2016) Journal of Climate, **29**, 3143-3159



Laifang Li, Raymond W. Schmitt, *and* Caroline C. Ummenhofer
Department of Physical Oceanography, Woods Hole Oceanographic Institution

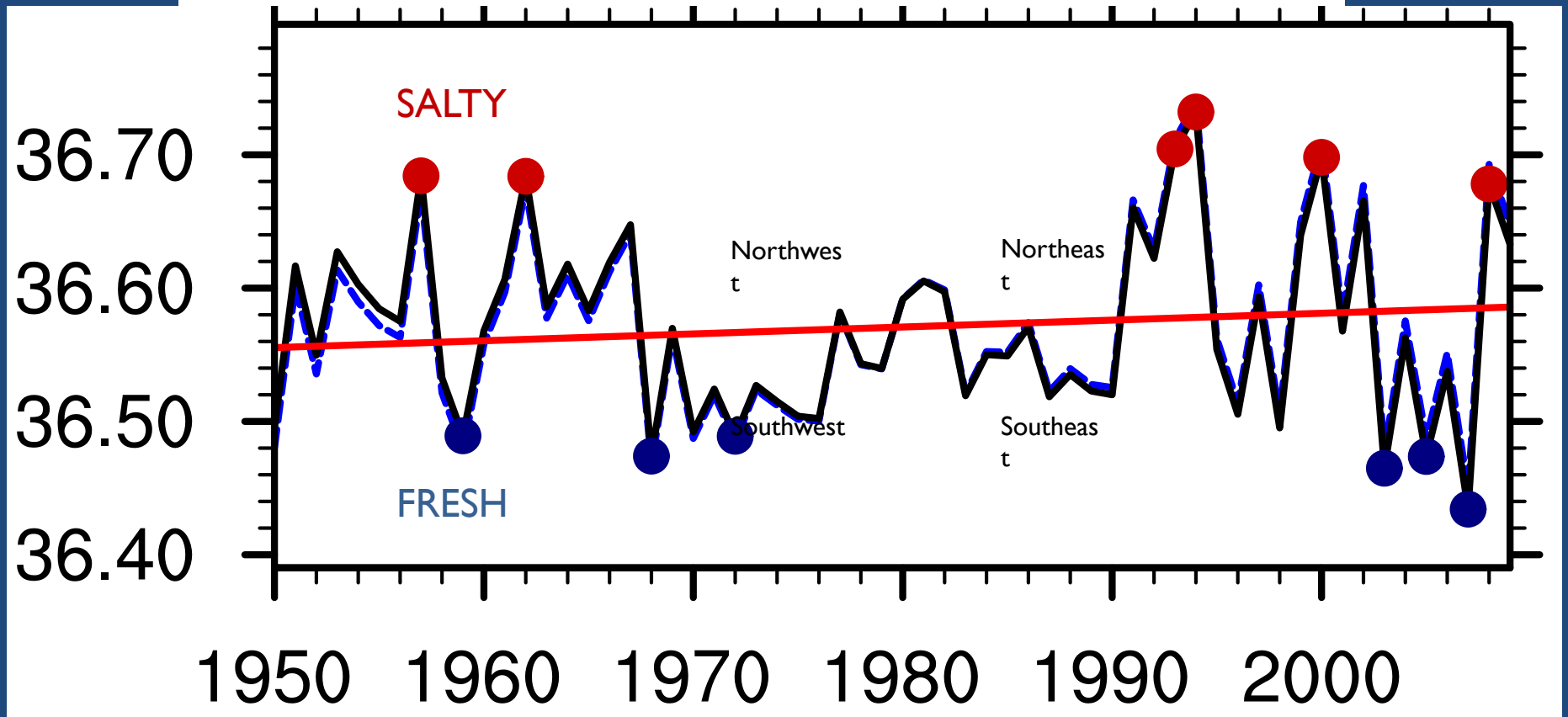
Kristopher B. Karnauskas
Department of Atmospheric and Oceanic Sciences, and Cooperative Institute for Research in Environmental Sciences, University of Colorado

Divergent
Moisture flux
→



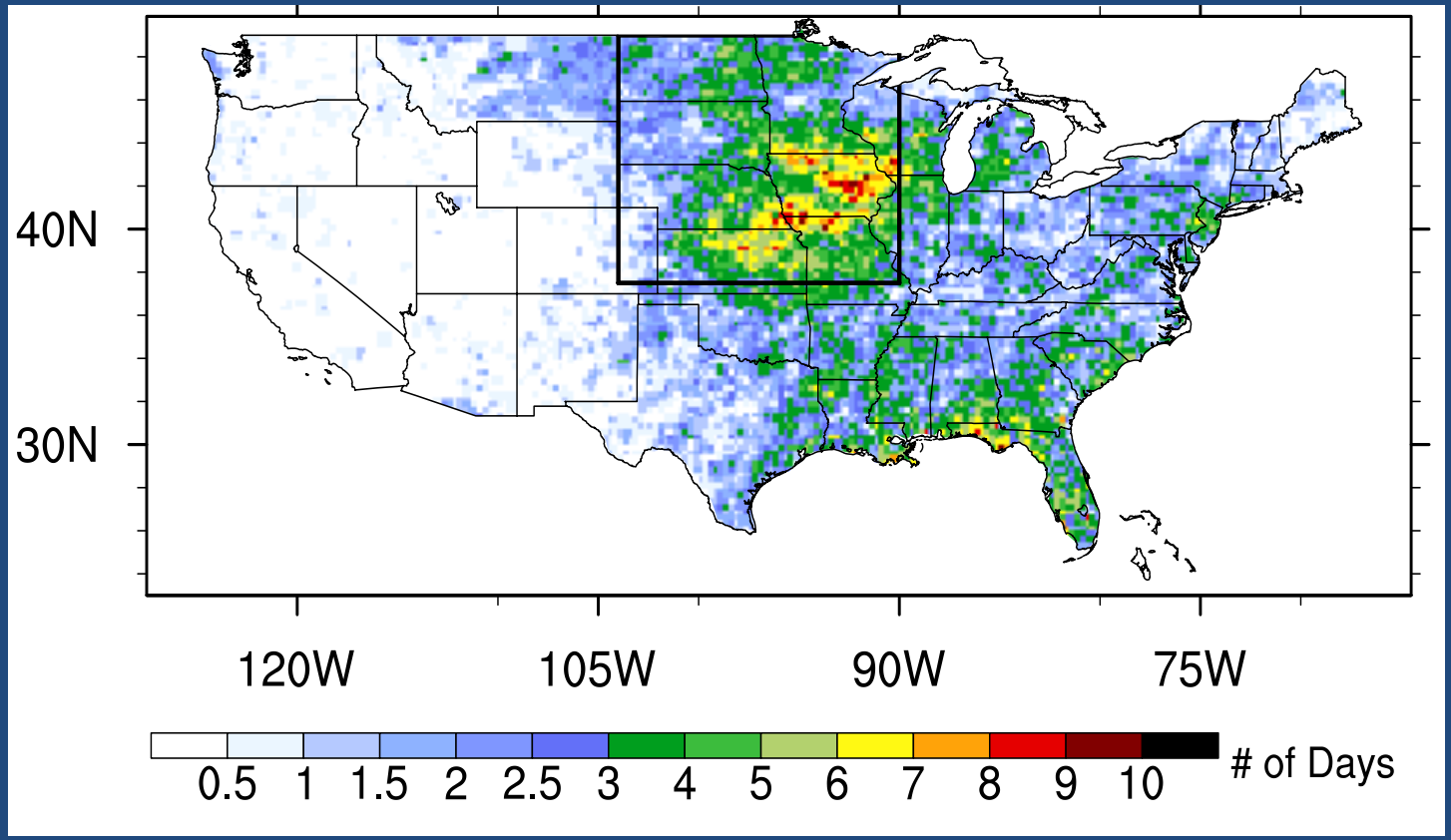
SSS in N. Atlantic

Spring SSS variability and trends for the Northwest sector



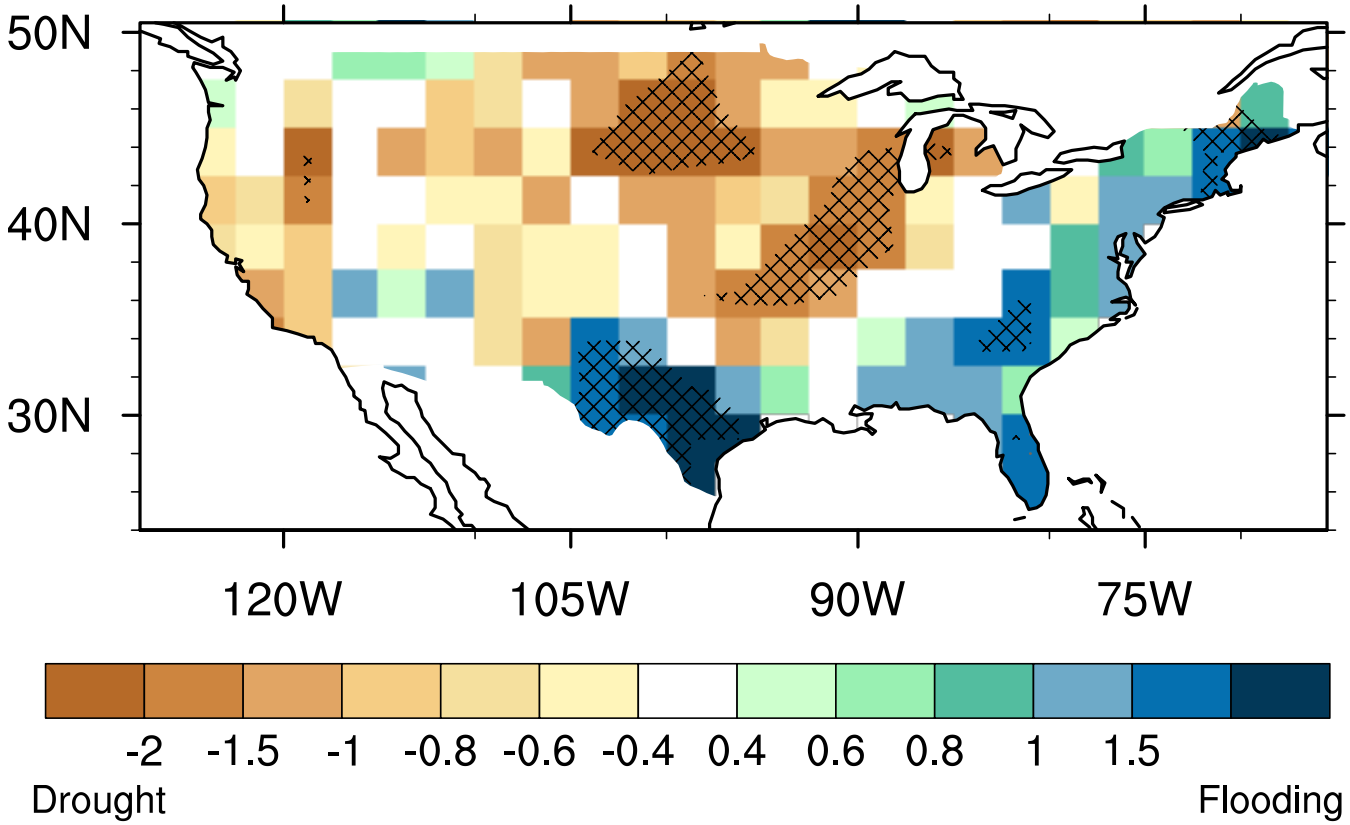
High spring salinity and summer rain > 1”/day

6 saltiest springs in NW Atlantic

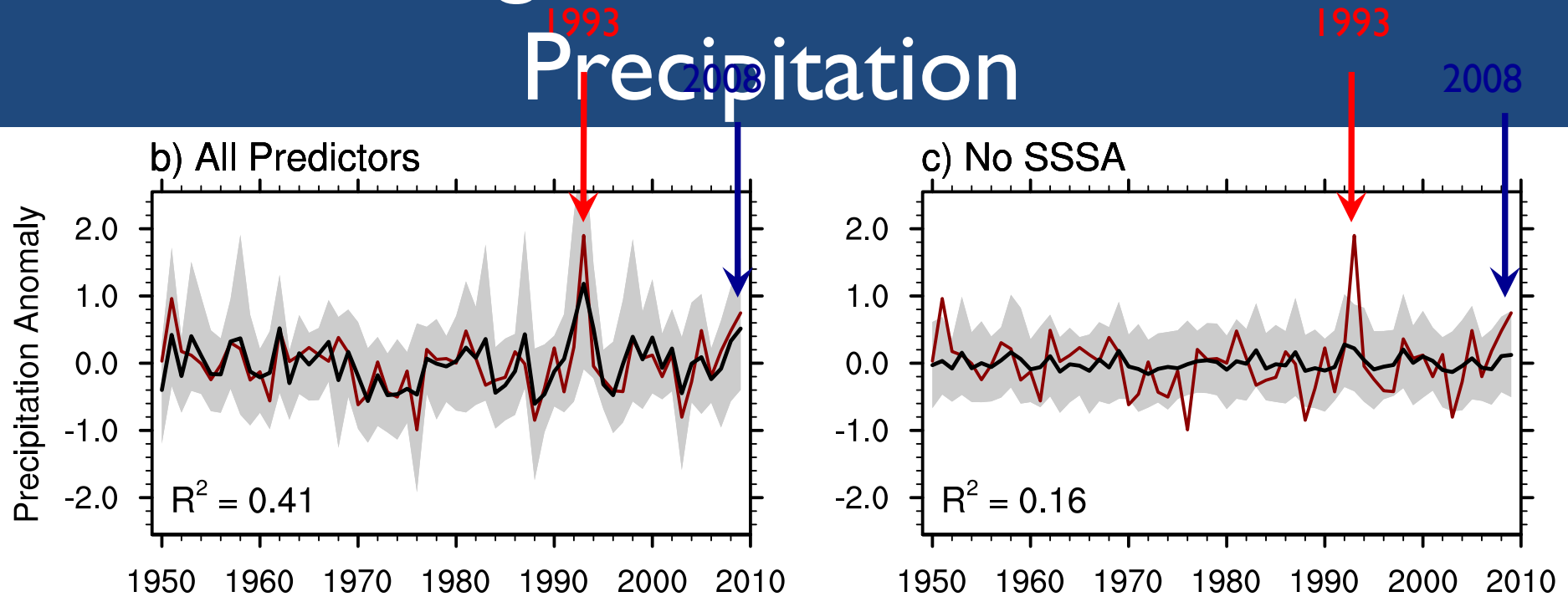


Low spring salinity and summer drought

6 freshest springs in NW Atlantic

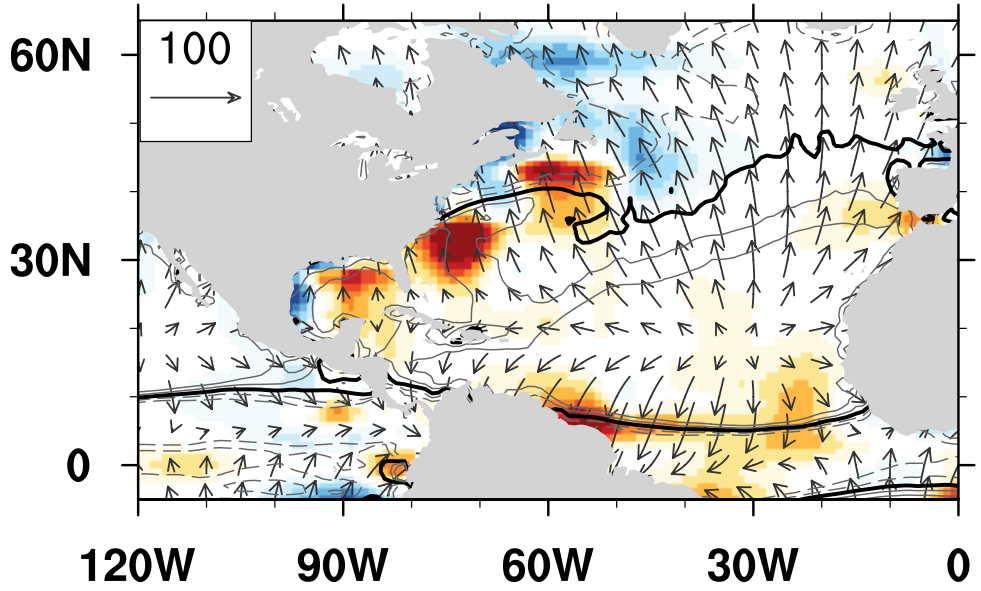


Predicting US Midwest Summer Precipitation

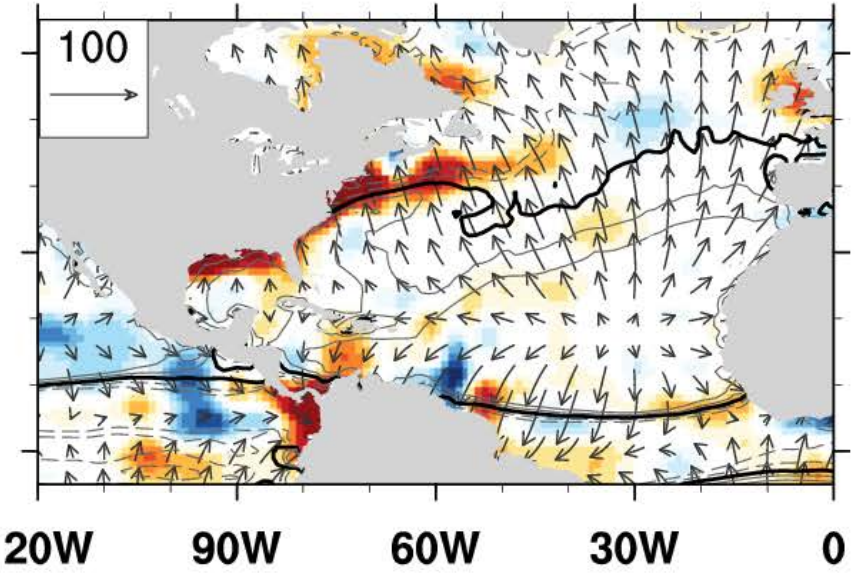


Li et al. (2016, *J. Climate*) Random Forest AI predictions

1993 Case Study
Spring Salinity Anomalies



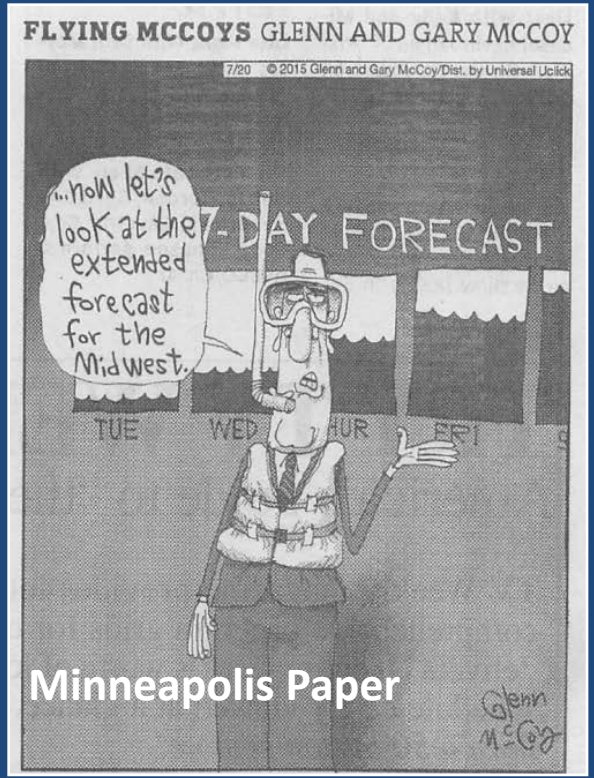
2015 North Atlantic
March Salinity Anomalies



A successful prediction was made at an AMS meeting in June 2015…

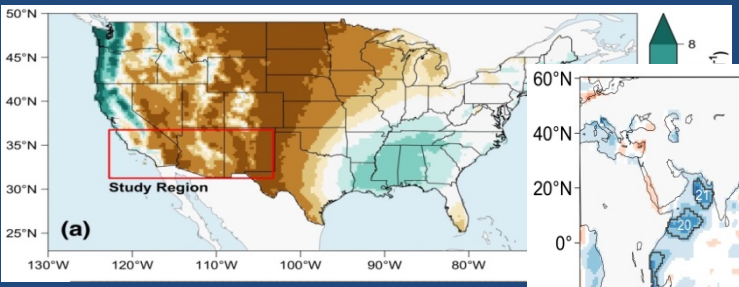
July Floods in Ill

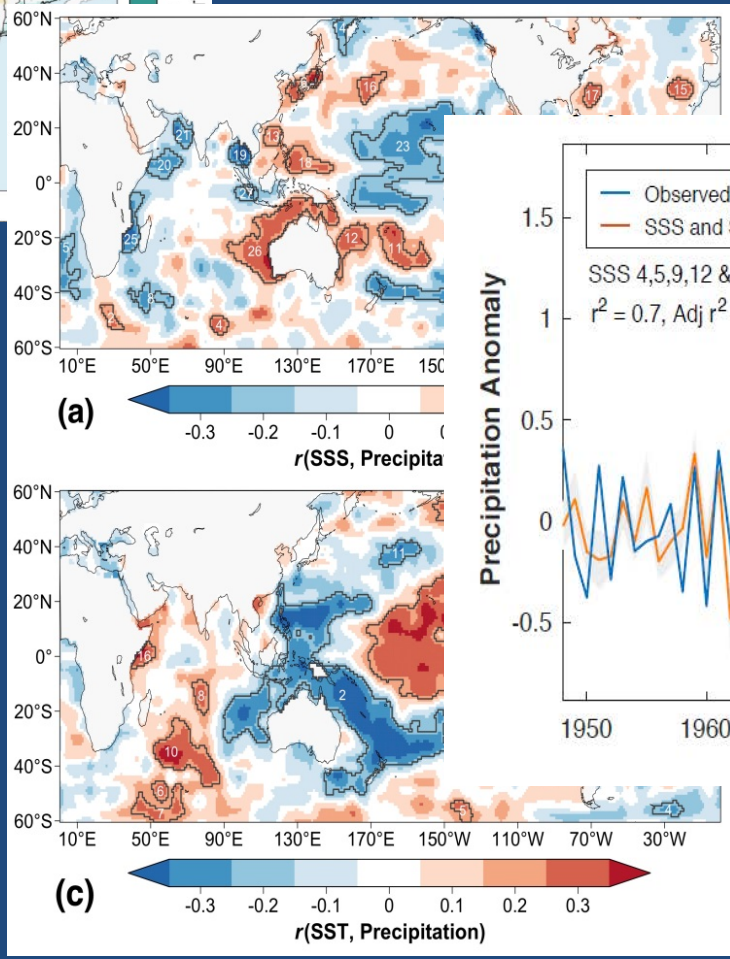
Great Lakes levels restored after a long drought

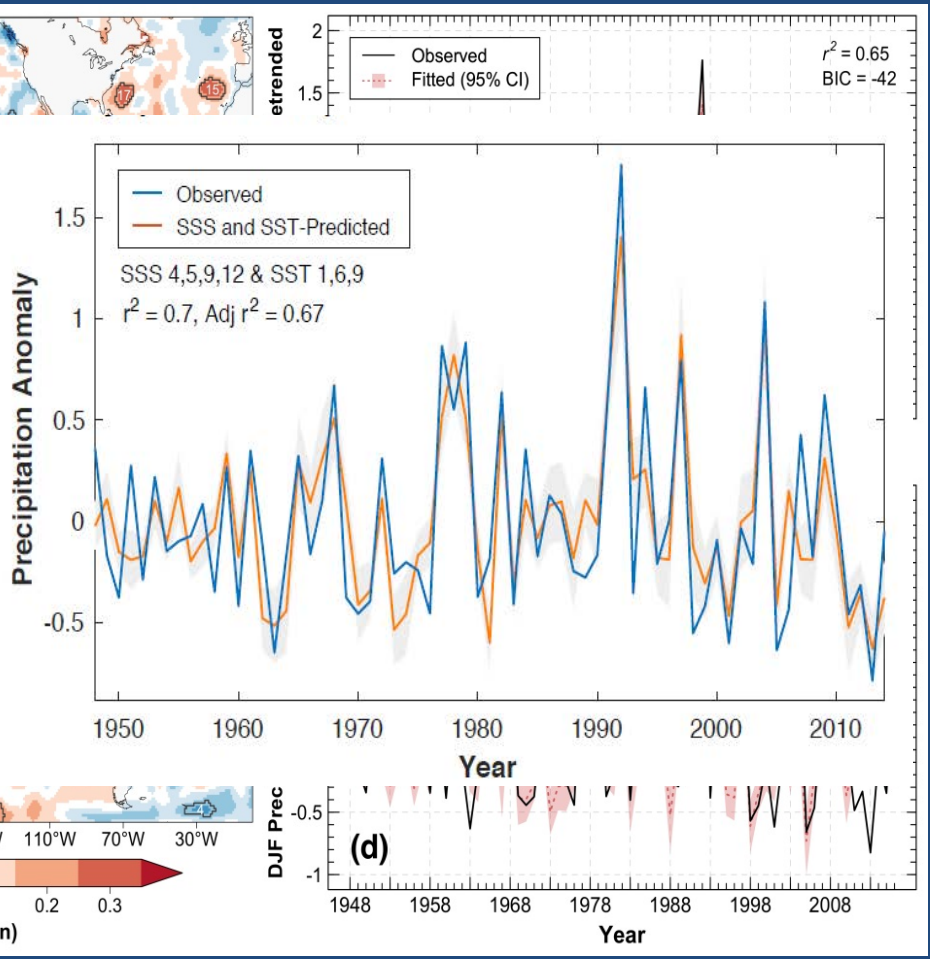


Minneapolis Paper

Global search for SSS and SST fall (SON) lead predictors for winter (DJF) precip in the US Southwest







Predictions for Southwest winter 2015-2016?

(Strong El Nino but no rain!)

	Precipitation (mm/day)
SSS-only	(0.71,1.4)
SST-only	(1.3,1.61)
Combined	(0.6,1.06)
Observed	0.73

←67% of Variance!

% Variance Explained

Niño 3.4	14
Niño 4	12
NAO	2
AMO	5
PDO	7

Liu, Schmitt and Li (2018, GRL)

Background #3:

Despite successful predictions and 3 publications,
More proposals were declined.
Again. And Again.
No funding and no team…

But then on December 23, 2016….

I got a email from colleague Steve Elgar
about a contest by the Bureau of Reclamation
The "Sub-Seasonal Climate Forecast Rodeo"

"Hey Ray, maybe you could win this"

https://www.drought.gov/drought/sub-seasonal-climate-forecast-rodeo

RECLAMATION
Managing Water in the West

U.S. Department of the Interior
Bureau of Reclamation

WATER PRIZE COMPETITION CENTER

Category	First Place	Second Place	Third Place
Weeks 3&4 Temperature	$100,000	$50,000	$25,000
Weeks 3&4 Precipitation	$100,000	$50,000	$25,000
Weeks 5&6 Temperature	$100,000	$50,000	$25,000
Weeks 5&6 Precipitation	$100,000	$50,000	$25,000

Forecasts at 3&4 and 5&6 week leads for the West every 2 weeks for a year

Twin Gamers!

December 25, 2016

Stephen
BS Com. & Elec. Eng. Northeastern

Eric
BS M.E. BU
MS M.E. Tufts

Using Neural Networks to play computer games!

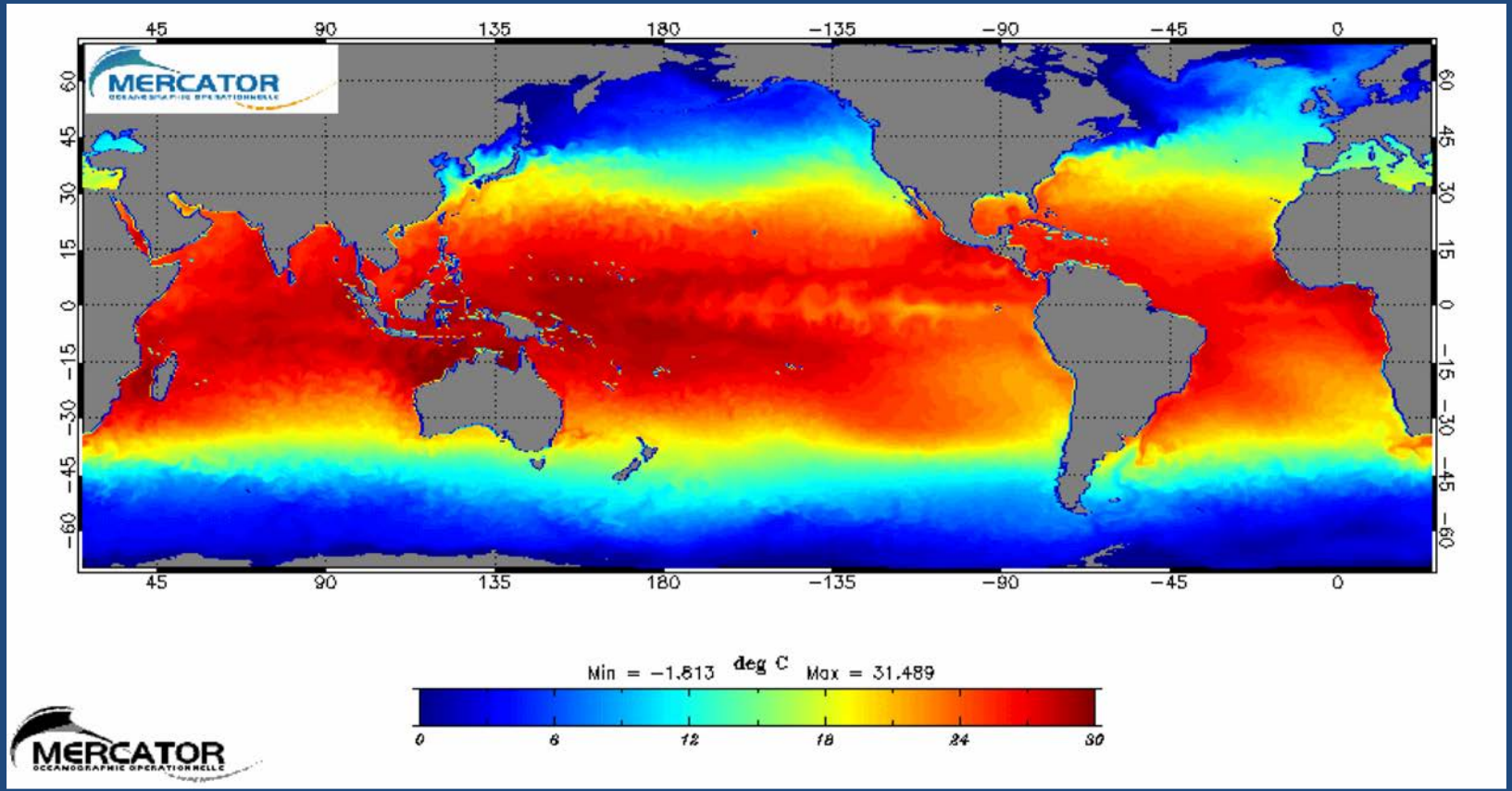
Predicting Dota 2 Game Outcomes

Neural Networks for Predicting Dota 2 Game Outcomes

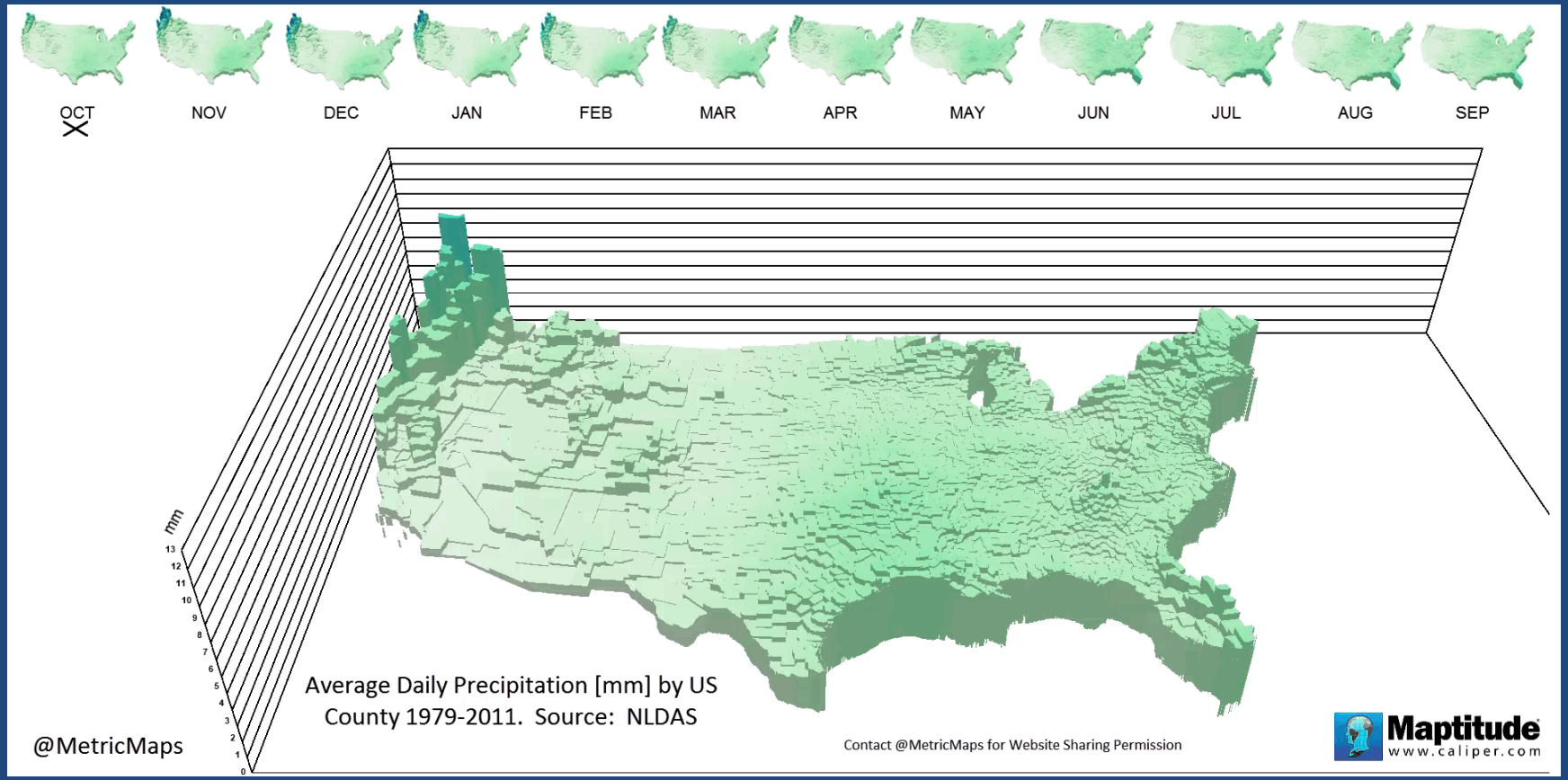
Team “Salient” enters the competition

- Use fully connected neural network trained on historical data in the US West from 1990-2017
- 50 test networks initialized with random parameters with wide exploration of parameter space
- 10% of the dataset is held out for validation
- Forecasts were ensembles of 10 best models

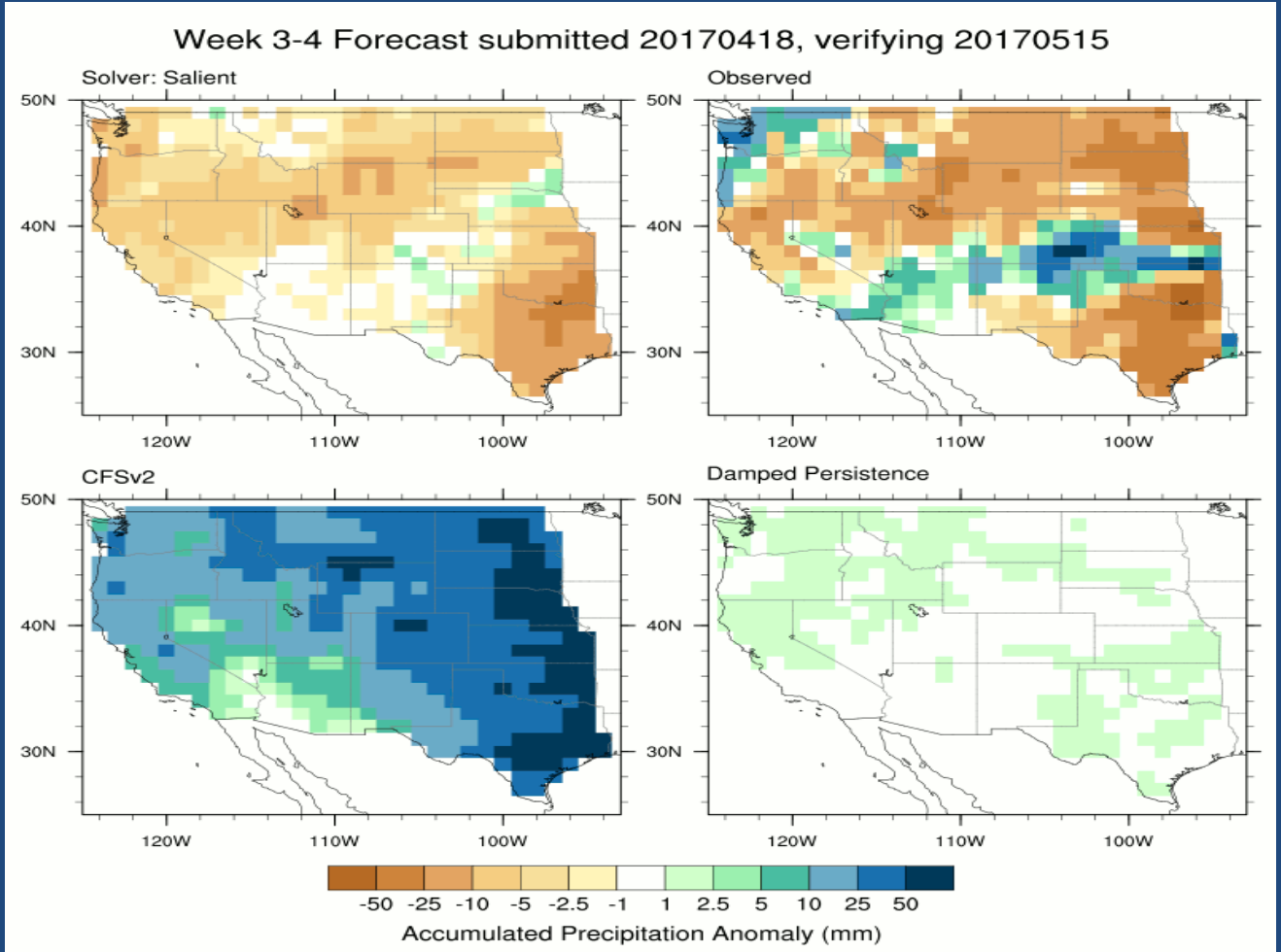
Sea Surface Temperature



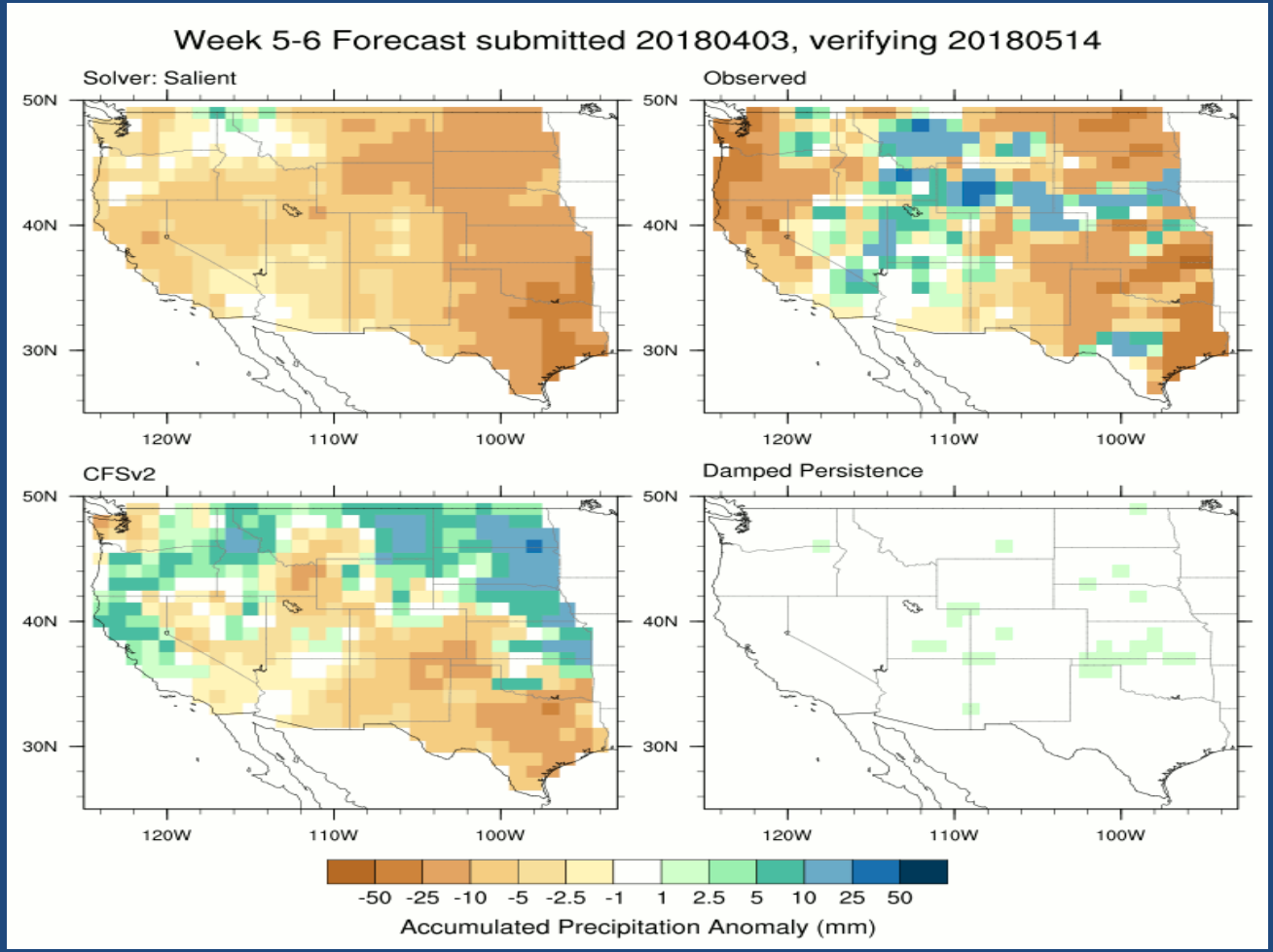
US Precipitation



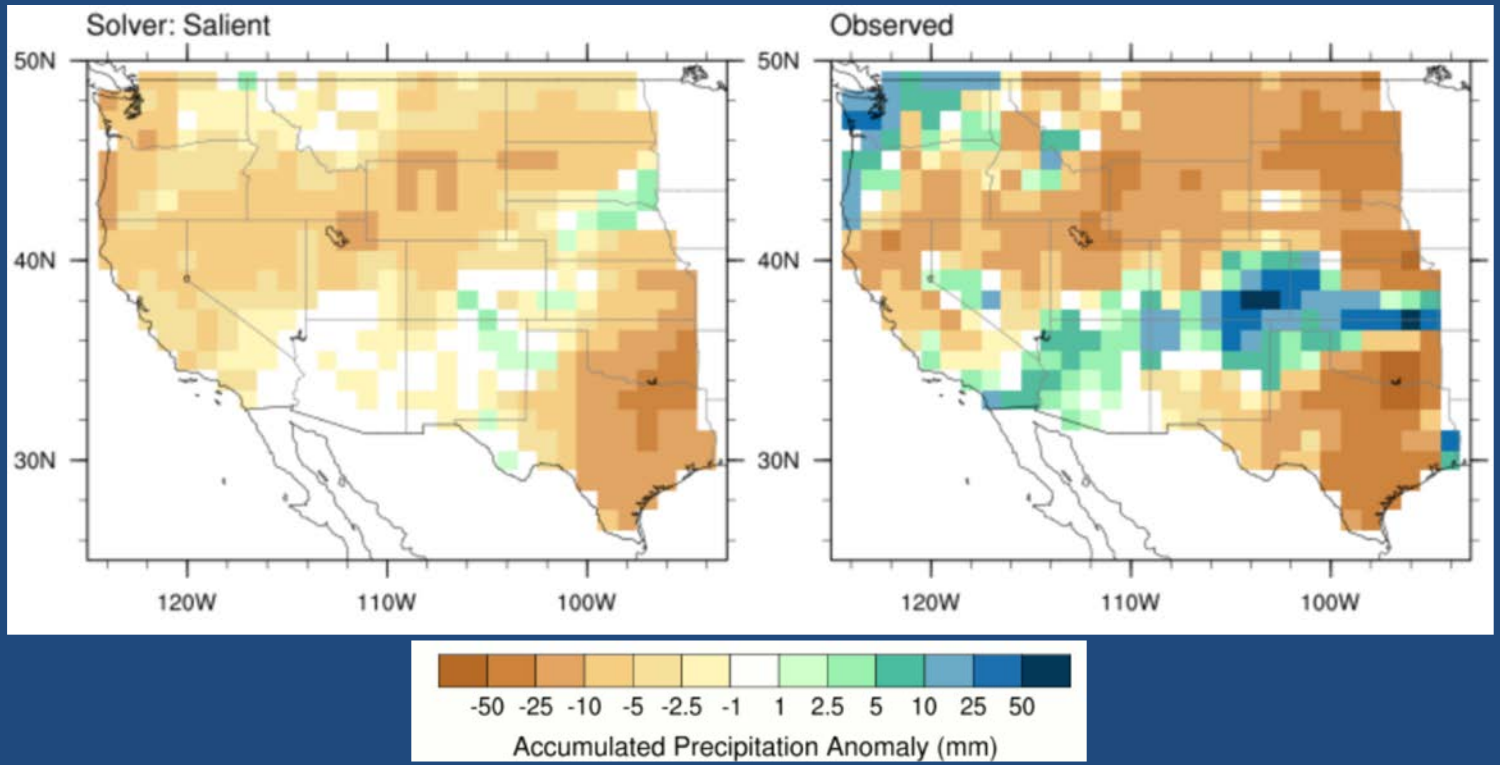
3-4 Week Forecasts



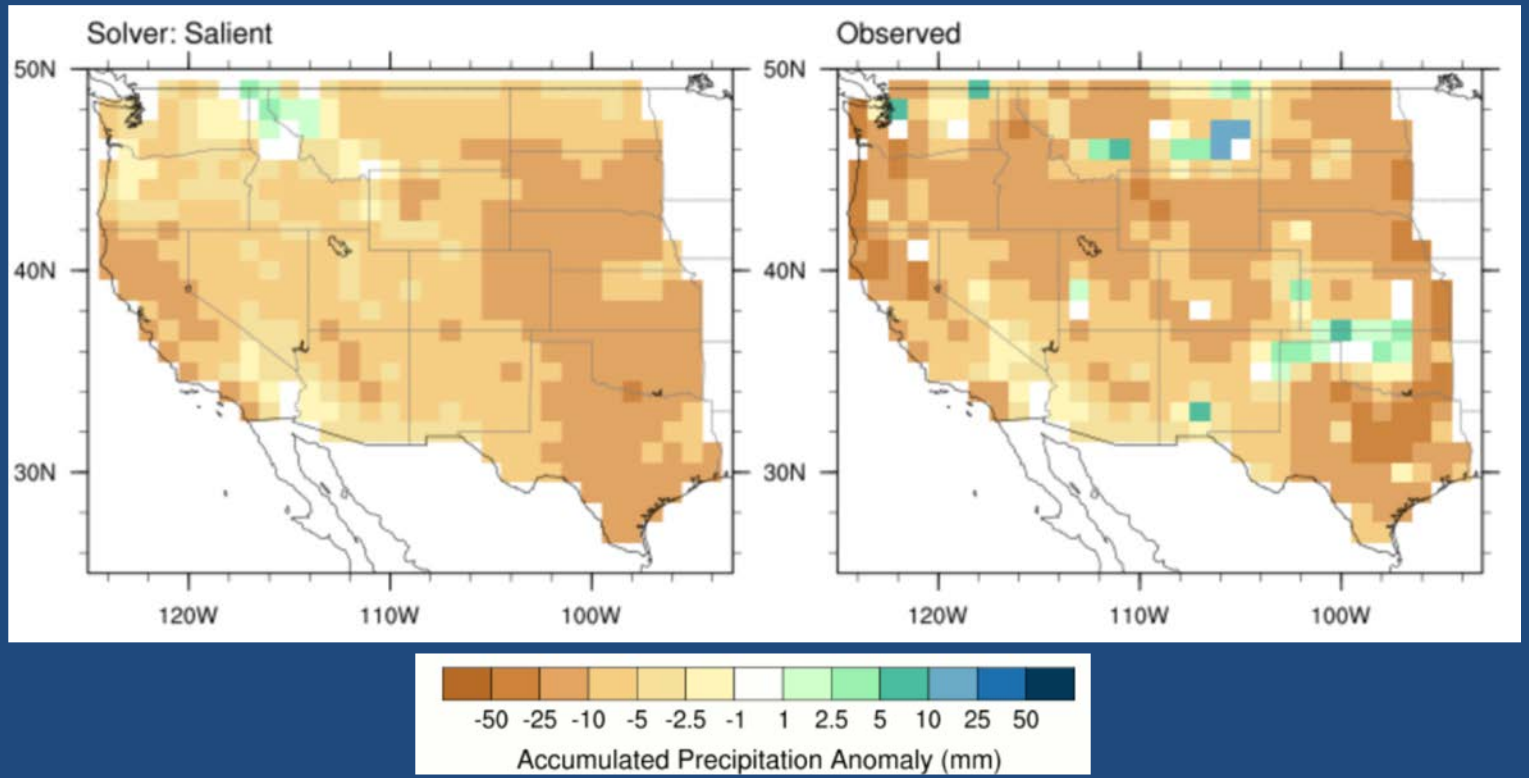
5-6 Week Forecasts



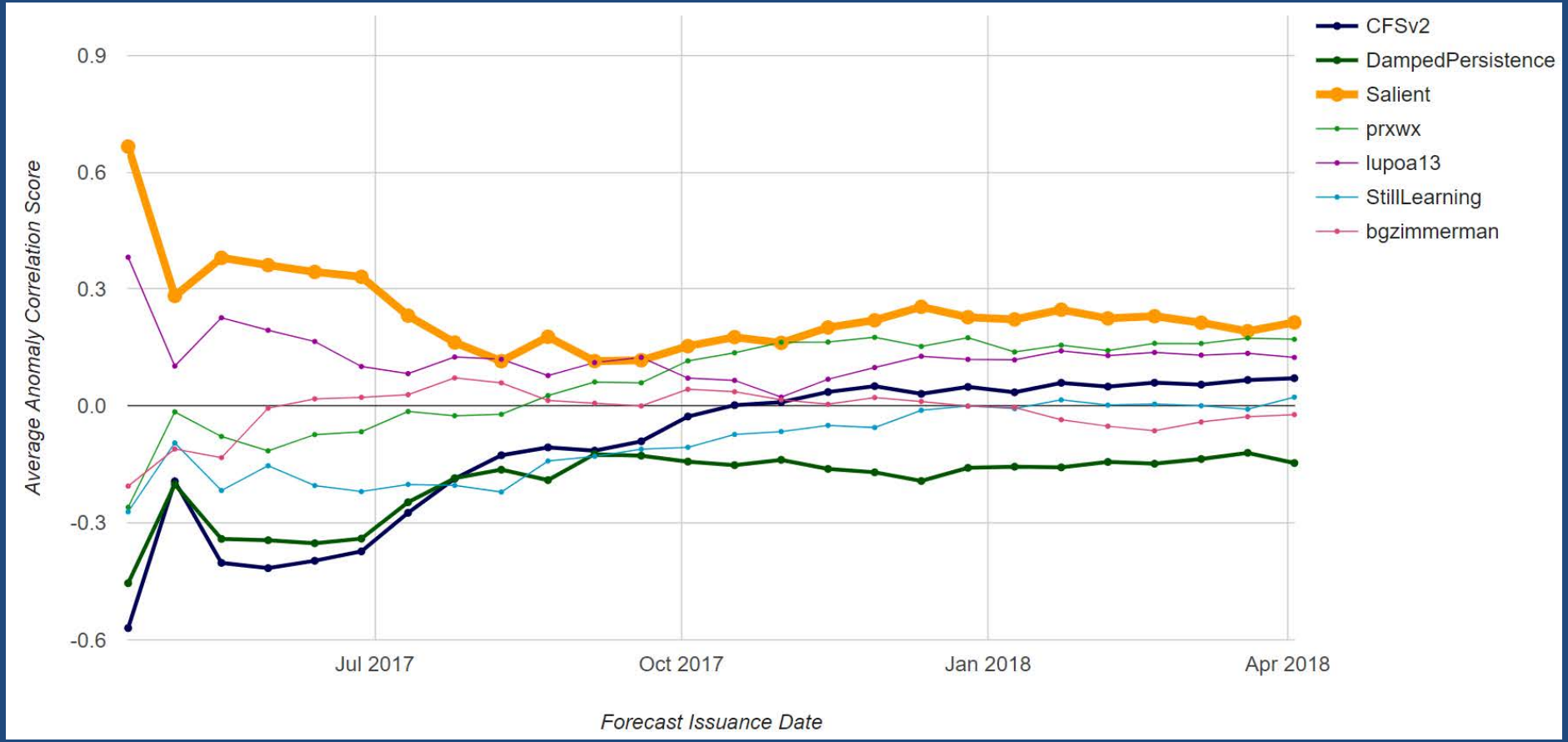
First 3-4 Week Forecast, Cor. =0.6654



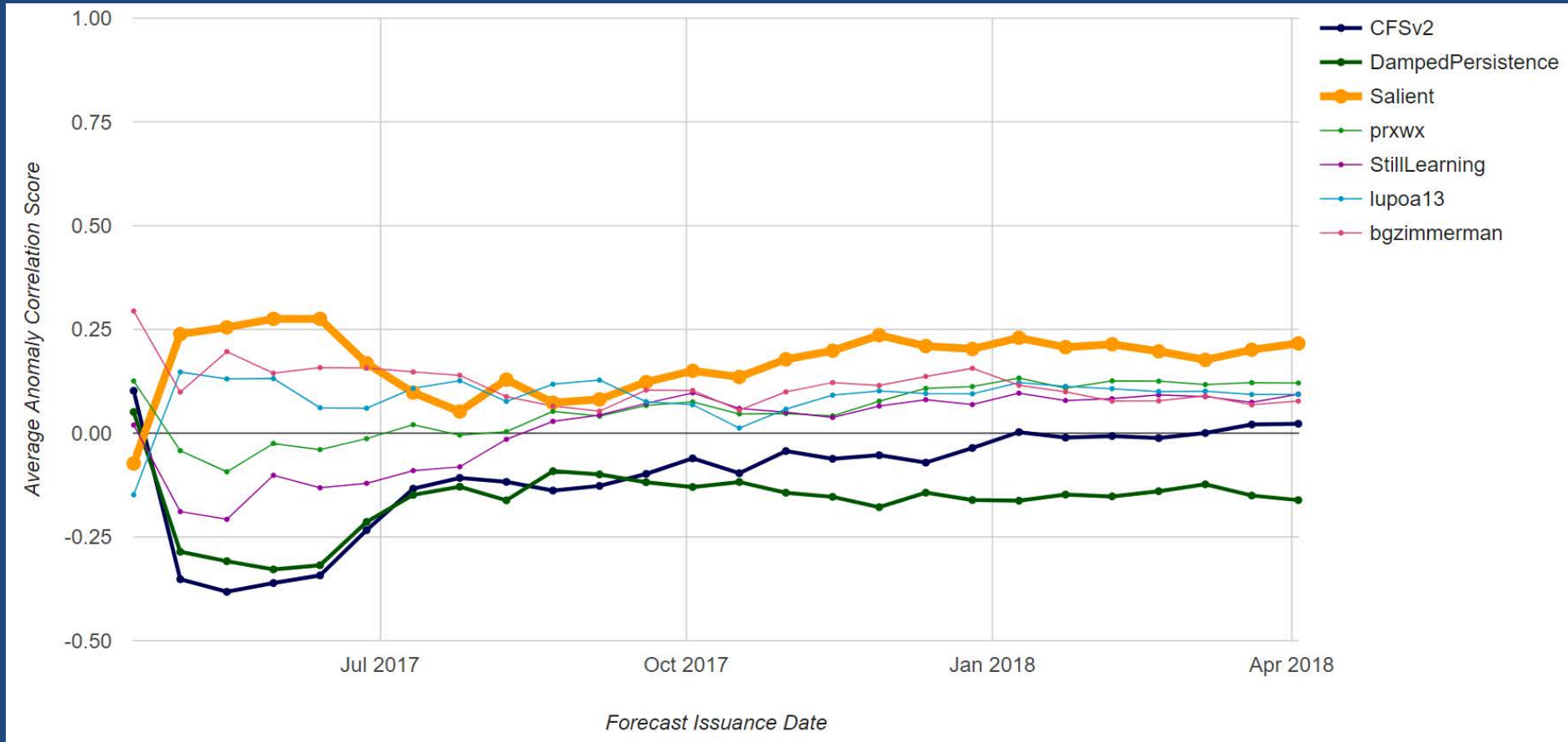
Last 3-4 Week Forecast, Cor. = 0.7758



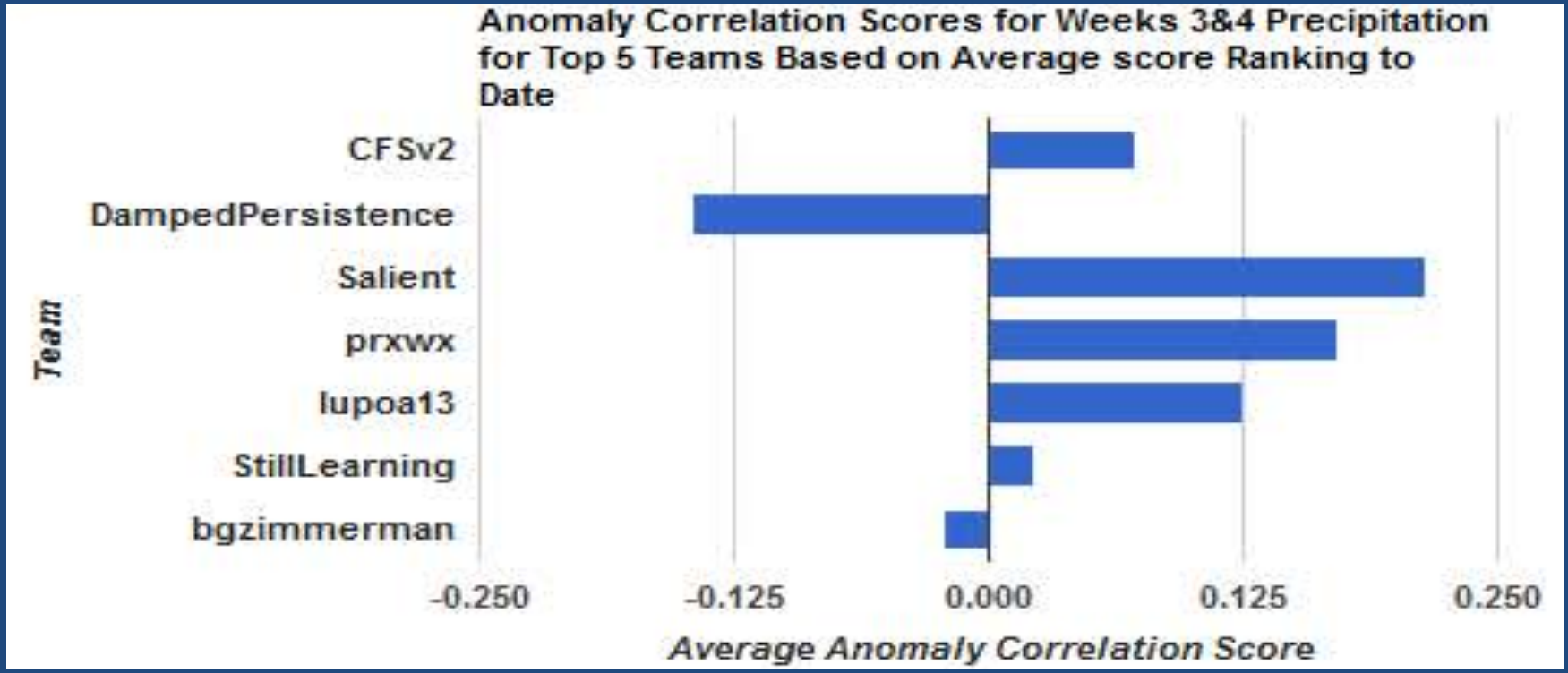
3-4 Week Precipitation



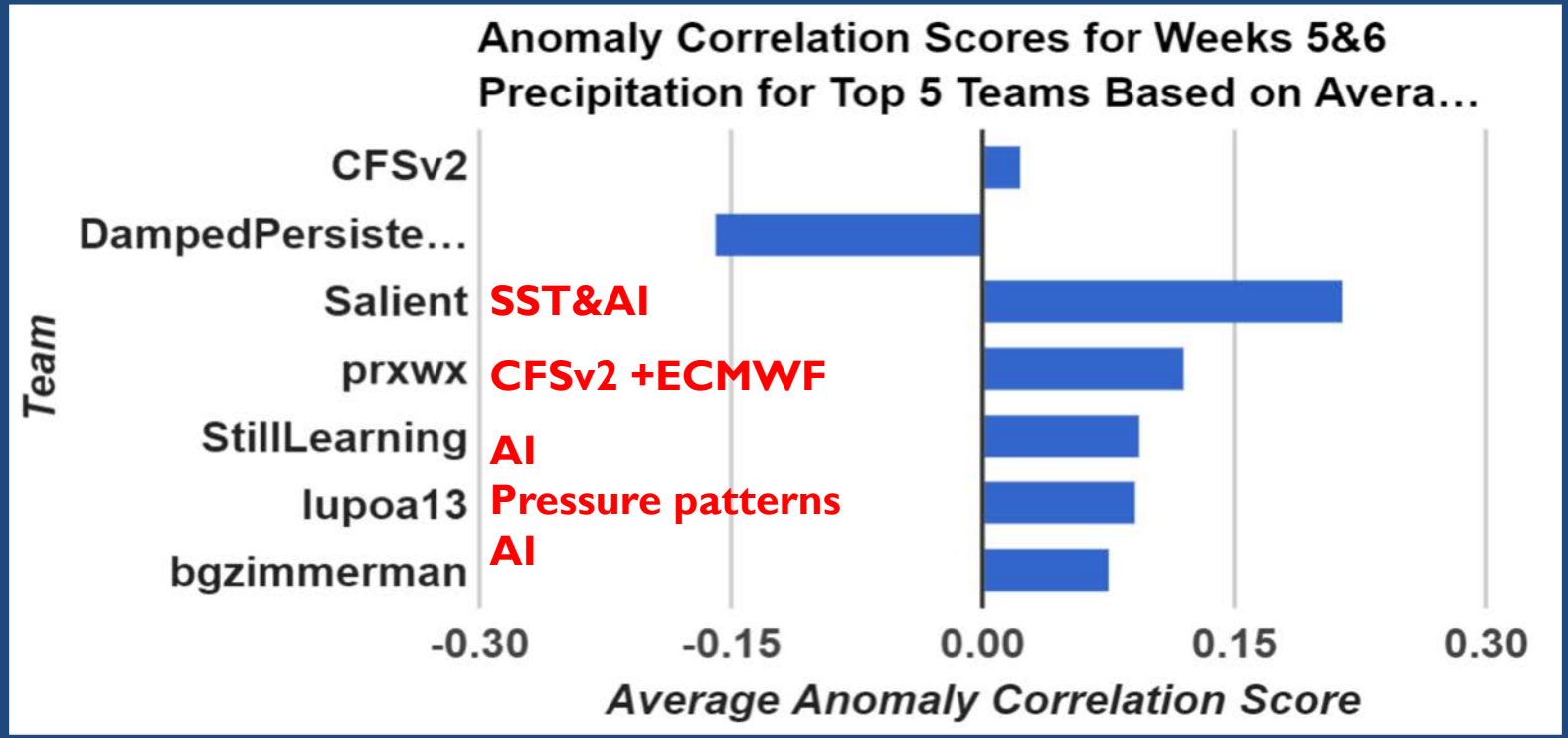
5-6 Week Precipitation



3-4 Week Precipitation



5-6 Week Precipitation



We led in the two precipitation categories AND the hindcast bonuses!

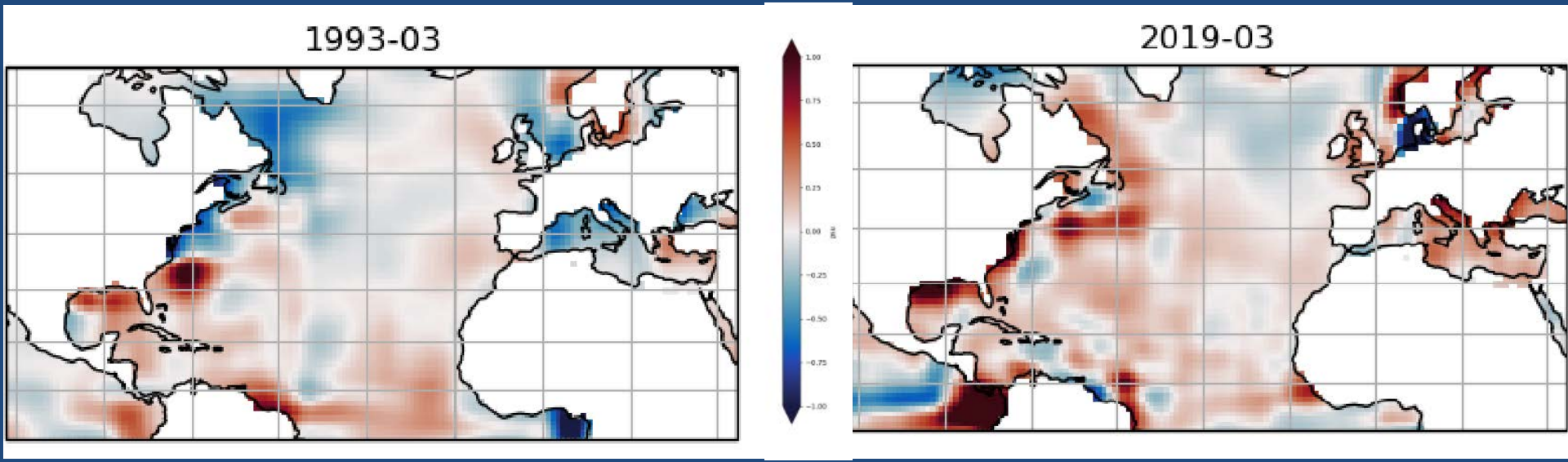
October 25, 2018 email:

“Dear Ray…You will be awarded $250,000.”

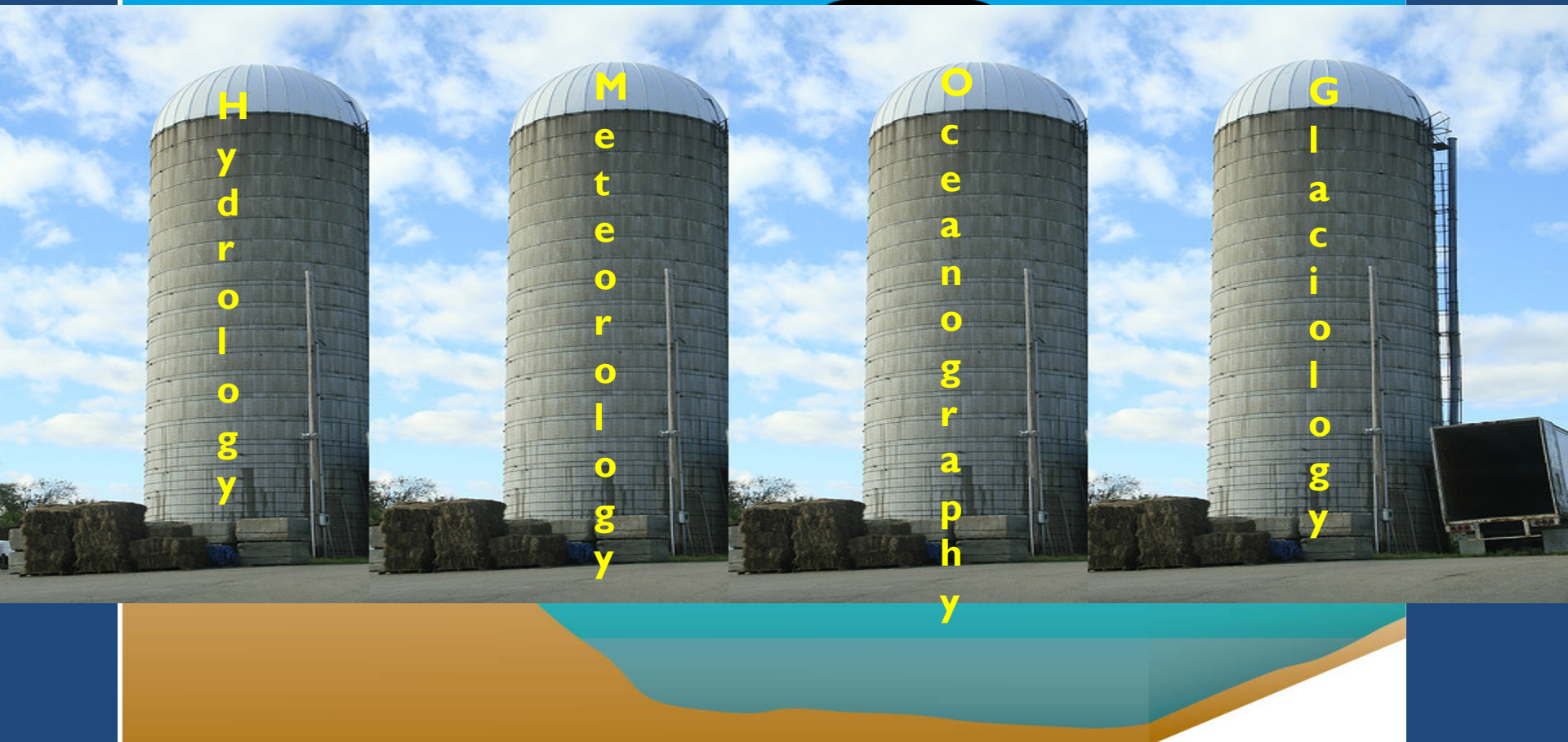
Successful Applications:

- Sahel Summer Monsoon, Li et al (2016, Sci. Advances)
- US Midwest Summer, Li et al (2016, J. Climate)
- Midwest Extremes, Li et al (2017, Climate Dyn.)
- US Southwest, Liu et al (2018, Geophys. Res. Let.)
- Yangtze River Valley Summer, Zeng et al (2019, Cliimate Dyn.)
- US Northeast Jan. Precip., (Fall AGU Poster NH 31C-0991)
- US West (Team Salient, Forecast Rodeo)
- Available from Salient Predictions: CONUS, Brazil, SE Asia

2019 Midwest floods are comparable to 1993. Did North Atlantic SSS anomalies in March foreshadow the 2019 floods? Yes!
Use SSS for Seasonal predictions,
SST for Sub-Seasonal predictions.



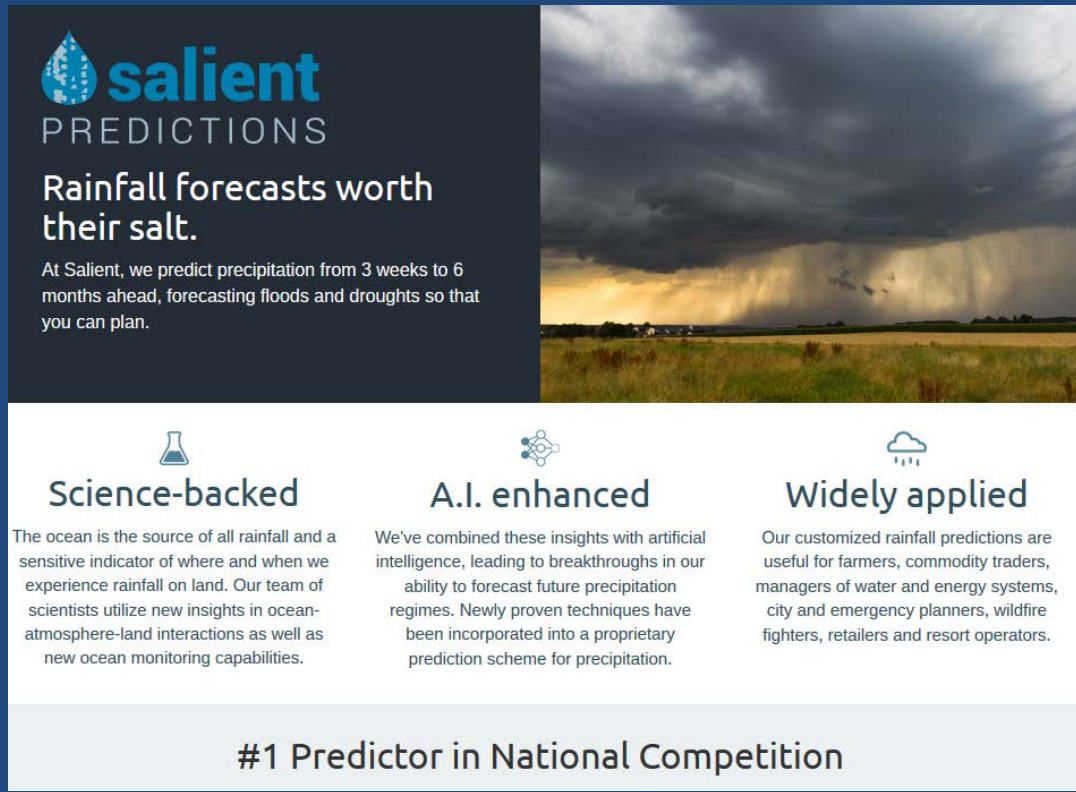
Disciplinary silos are blocking progress in developing understanding of the Global Water Cycle!



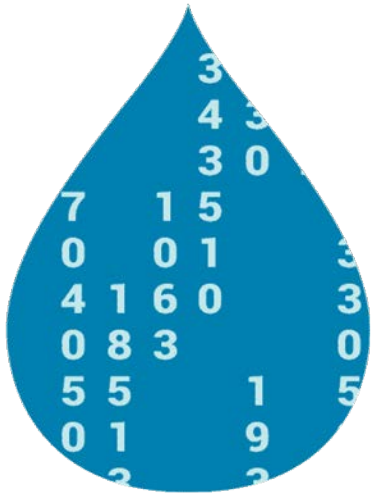
Given the lack of funding for interdisciplinary research on the global water cycle, team Salient has formed a company and is seeking venture capital to continue its work.

http://salientpredictions.com/

Why is the U.S. Global Change Research Program's Interagency Integrated Water Cycle Group still excluding the oceans?



Salient Predictions



Weather Predictions Worth their Salt

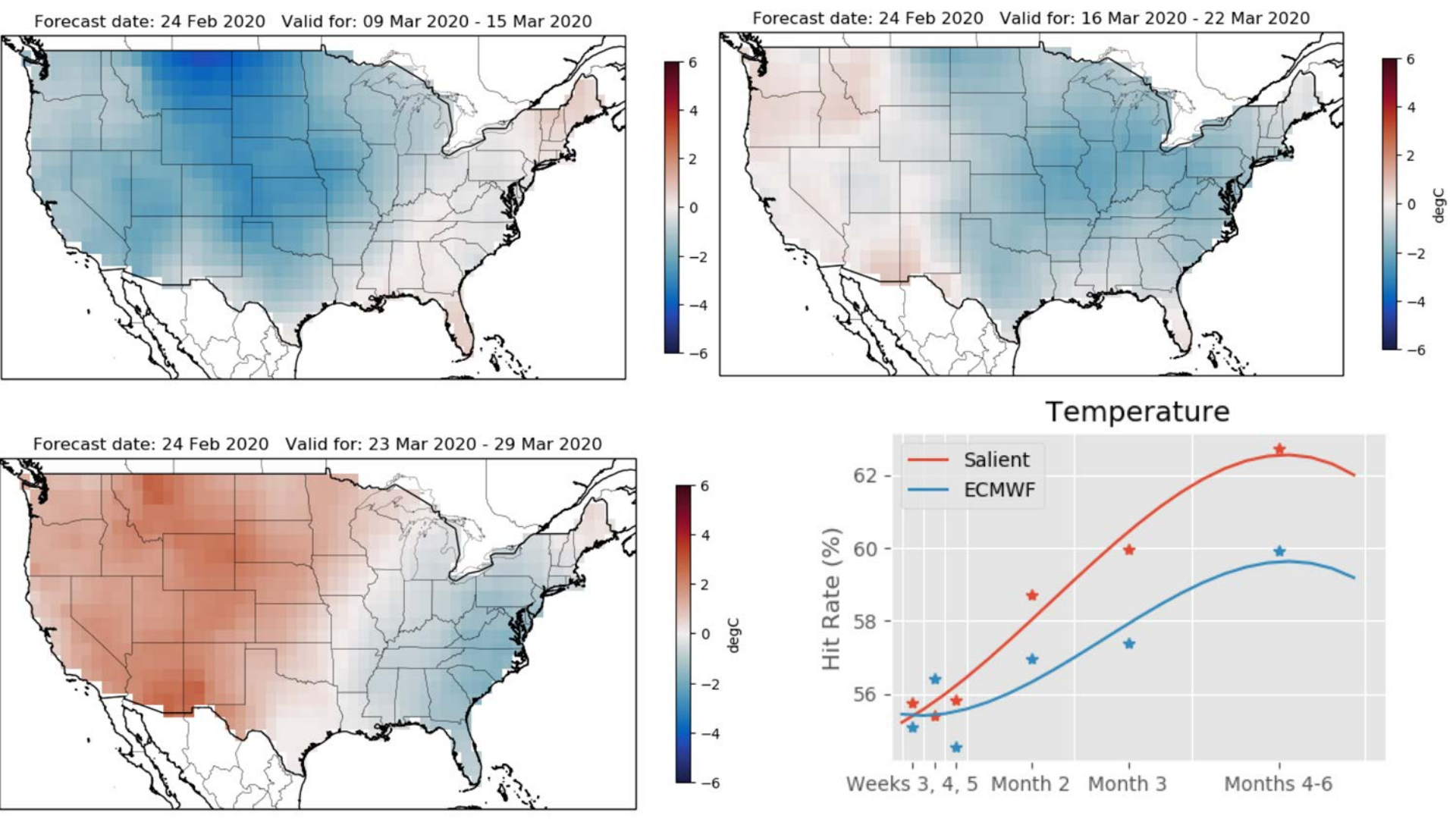
CURRENT PRODUCTS.

Continental US temperature and precipitation at 1° resolution, for 3 different timescales:

- **Sub-seasonal (Weeks 3, 4, 5)**
- **Seasonal (Months 1, 2, 3, 4)**
- **Long-range (Months 1 - 3, 4 - 6)**

Models are currently in development for global regions including South America, Europe, Asia, and Australia.

Have a particular application? Let us know - our algorithms are highly flexible and can offer skillful forecasts for all your seasonal weather needs.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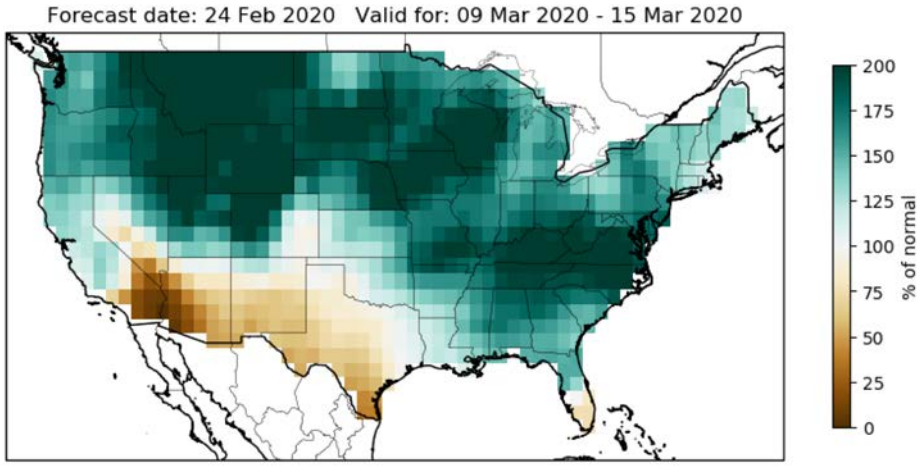
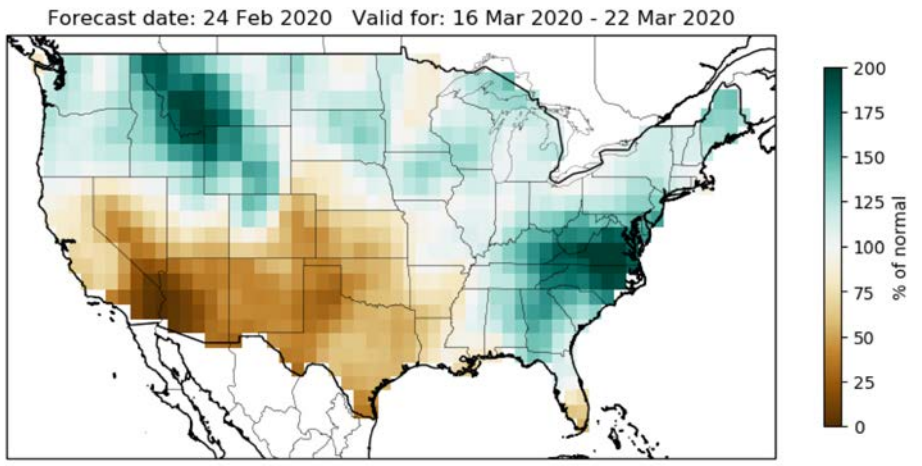
Forecast date: 24 Feb 2020 Valid for: 16 Mar 2020 - 22 Mar 2020
Forecast date: 24 Feb 2020 Valid for: 23 Mar 2020 - 29 Mar 2020
6
4
2
0
−2
−4
−6
degC
Temperature
Salient
ECMWF
Hit Rate (%)
62
60
58
56
Weeks 3, 4, 5
Month 2
Month 3
Months 4-6


Forecast date: 24 Feb 2020 Valid for: 09 Mar 2020 - 15 Mar 2020
200
175
150
125
100
75
50
25
0
% of normal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200
175
150
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100
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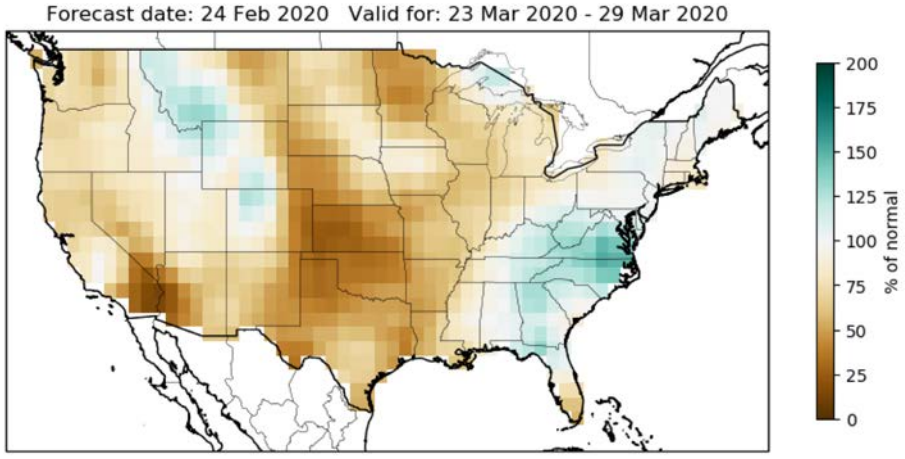
0
% of normal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200
175
150
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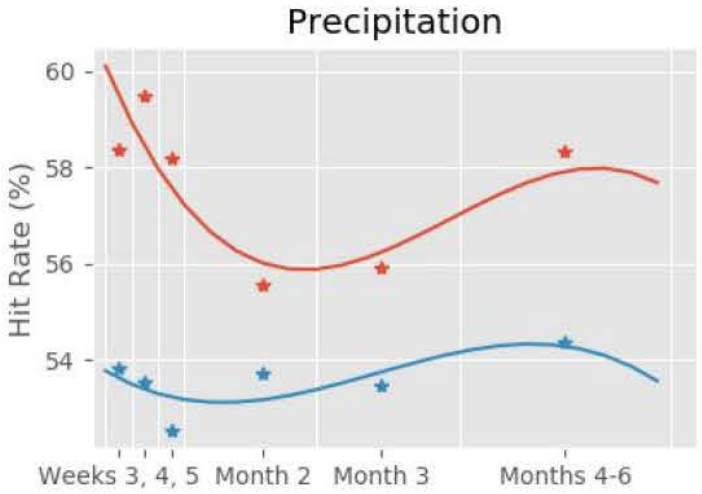
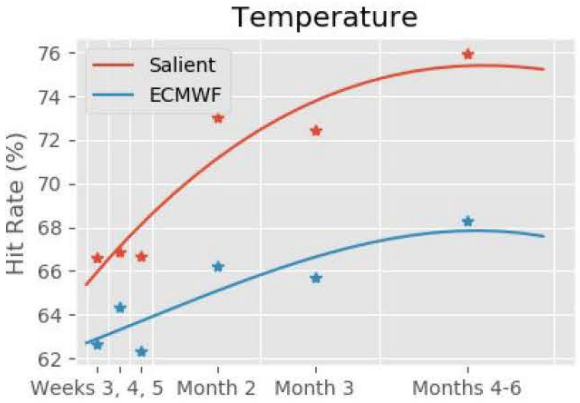
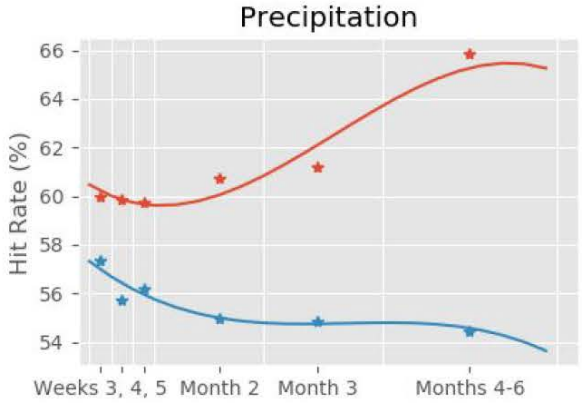
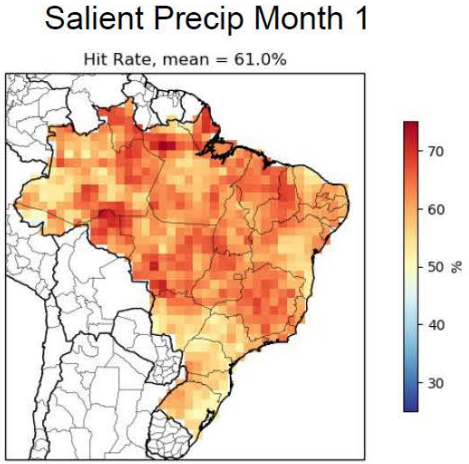
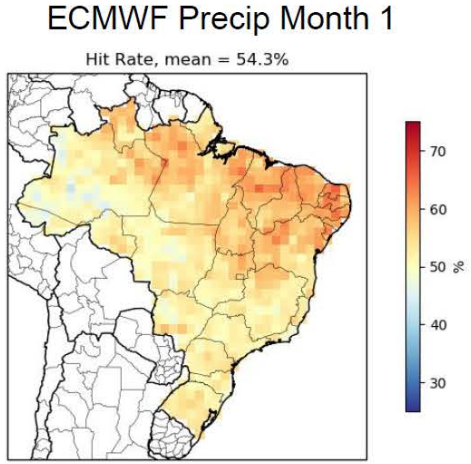

Precipitation
60
58
56
54
Hit Rate (%)
Weeks 3, 4, 5
Month 2
Month 3
Months 4-6

Average skill over Brazil for 1990-2020

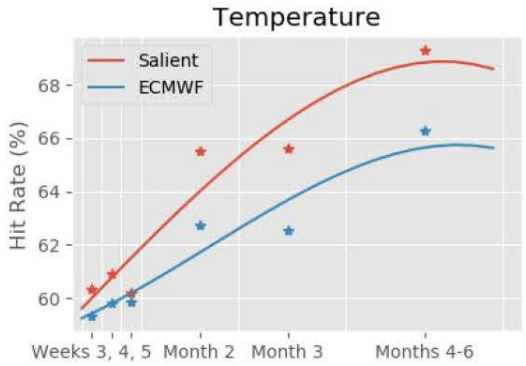


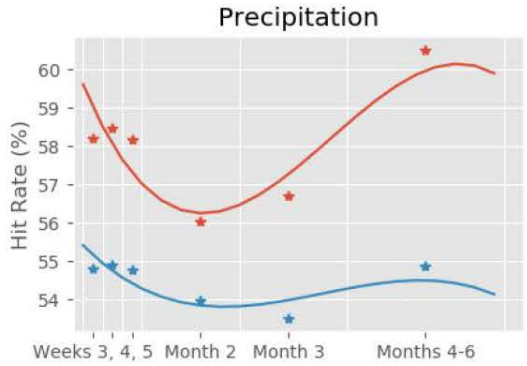




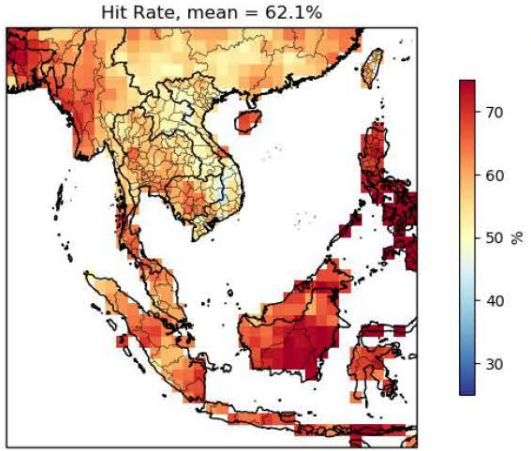


Average skill over SE-Asia for 1990-2020

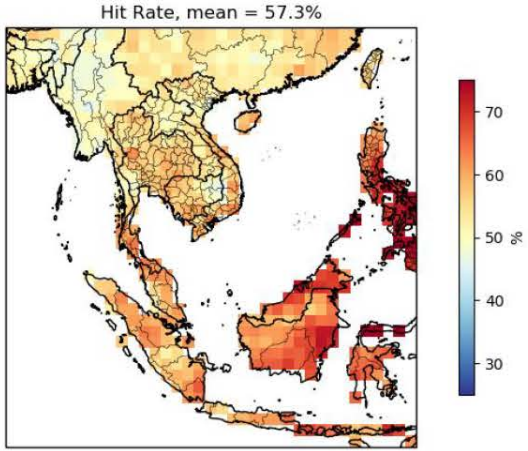




Salient Precip Month 1-3



ECMWF Precip Month 1-3



Dr. Ray Schmitt, PhD

President

- 40 year career in physical oceanography research and technology
- Woods Hole Scientist Emeritus
- NASA Earth Science Advisory Committee
- >100 refereed publications, >10k citations, h-index 48

Dr. Sam Levang, PhD

Chief Scientist

- Ph.D. Climate and Ocean Science, MIT/WHOI Joint Program
- NASA Earth and Space Science Fellow (NESSF)
- Internal Research, 3M
- B.S. Physics, Macalester College
- Expert in the global water cycle and its shifts with climate change

Eric Schmitt

AI Development

- Senior Engineer, Veryst Engineering
- Engineer, Neil Brown Ocean Sensors
- M.S. Mech Eng, Tufts

Stephen Schmitt

Lead Engineer

- Technical Lead, NetApp
- MIT Lincoln Laboratory
- B.S. Elec and Comp Eng, Northeastern

Engineering

Susie Riley

- Experienced founder, board member, tech executive
- Founder/CEO, Aquto (acq. Mavenir)
- Founder/CTO, Camiant (acq. Tekelec)

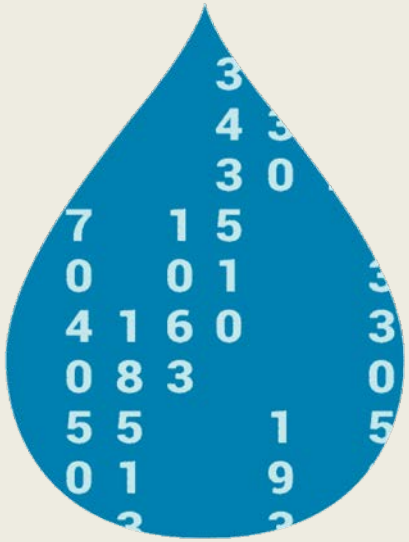
Drew Volpe

- Experienced CTO/VP Dev data and ML (Endeca, Locately, Semantic Machines)
- Founding Partner, First Star
- Harvard CS

First Star Ventures

Investors & Advisors

CONTACT:



Questions about our products?

Interested in a pilot?

Please get in touch:

info@salientpredictions.com

- The ocean has 1,000 times the heat capacity of the atmosphere and 100,000 times as much water . It is the ultimate source of all rainfall.
- Improved terrestrial rainfall predictions at seasonal and sub-seasonal leads can be derived using Machine learning on Ocean Salinity and Temperature data.
- Take Away: The Ocean is the long term memory of the climate system and is the key to S2S predictions.

RAY SCHMITT

rschmitt@whoi.edu