S2S Predictability: First Focus Area of NCAR's ESPAT initiative

Cenlin He (NSF NCAR; cenlinhe@ucar.edu)

Jadwiga (Yaga) Richter (NSF NCAR; jrichter@ucar.edu)

& ESPAT Community

ESPAT: Earth System Predictability Across Timescales

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Introduction to NSF NCAR's ESPAT Initiative

- Every country, region, and community is progressively more impacted by **effects of extreme weather** (e.g., extreme precipitation, flood, drought).
- There is an urgent **need for more research** in Earth system prediction and predictability and **development of tools to empower communities** to become more resilient.
- In October 2023, NSF NCAR launched the **Earth System Predictability Across Timescales (ESPAT) initiative** to accelerate research in Earth system predictability across timescales to enhance societal resilience.
- Held **community workshop in April 2024** to identify grand challenges, key science questions and potential solutions.
- **S2S predictability** is the first focus area of ESPAT.

ESPAT Goal: Resilient Society Empowered by Science

Deeper understanding of the Earth system through coordinated and collaborative research integrated across disciplines and timescales to enhance societal resilience

Earth System Predictability Across Timescales (ESPAT)

Integration across NCAR

Including convergence research + EO

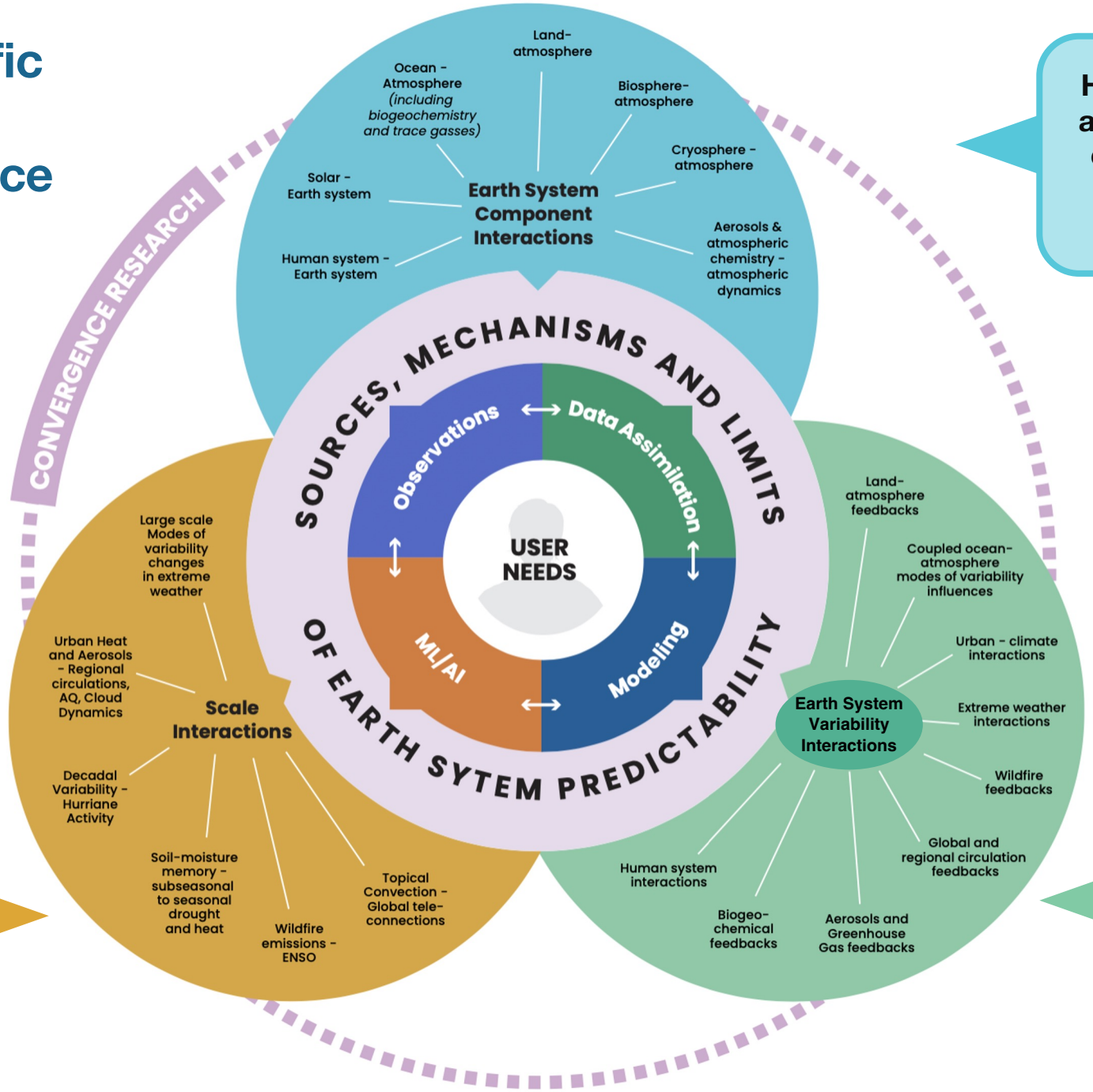
Integration with & supporting University Community

Integration across US Agencies

Including NSF, DOE, NOAA, NASA, USGS

Serving as a community nexus and fostering collaborative research

Summary of Scientific Grand Challenges & Overarching Science Questions



How do interactions across Earth system components affect predictability?

How do scale interactions influence predictability from short-term forecasts to long-term projections?

How does Earth system variability affect predictability across the Earth system?

Richter et al. (2025) BAMS Submitted

ESPAT Approach

- Multiscale and multidisciplinary approach
- Integration of modeling, observations, data assimilation, and ML/AI
- Intentional convergence research
- Bridging fundamental science and user needs

Partnership with various stakeholders and communities is welcome and needed!

ESPAT Year 1 (2024):

Engagement:

Internal Working Groups
Lab townhalls
University Visits
AGU/AMS

Workshops:

Feb 2024: Internal -> NCAR strengths & interests
Apr 2024:
Community Workshop
Sep 2024: mini Wkshp Space Weather

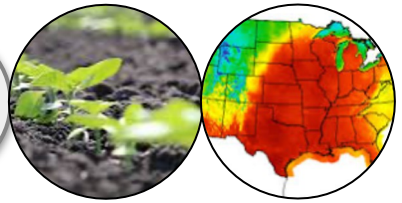
Outcomes:

Draft Roadmap: Key science questions, tools & capabilities
Focus Areas: identified
Workshop Report: complete!
BAMS article: Submitted Feb 16, 2025
SP Priority Objectives: in draft plan
First investment: S2S predictability

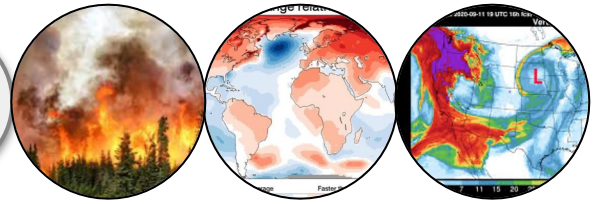
ESPAT Focus Areas

Closer integration of DA, modeling, observations, & ML & AI

- Launched — **Subseasonal to seasonal predictability**

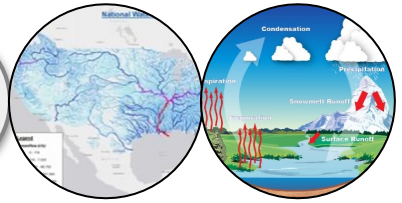


- In Development — **Atmospheric Composition & Emissions**



- In Development — **Space Weather**

- In Development — **Hydrological Predictability**



Dedicated community working groups formed to accelerate progress

S2S Research Topics

- DART
- CESM
- MPAS
- SIMA

- ML/AI
- JEDI
- OBS

First focused S2S Effort

Scientific Topics

- Land-atmosphere interactions
- Ocean-atmosphere interactions
- Reduction of model error, resolution
- Data assimilation for all Earth system components
- Tropical-extratropical interactions
- Convection Representation

Topics integrate & leverage existing programs

ESPAT: S2S Land-Atmosphere Interactions

MPAS:

Model for Prediction Across Scales

MPAS-A-NoahMP investigating land-atmosphere coupling processes & sensitivity experiments
Lead: Cenlin He and Zhe Zhang

MPAS-A-NoahMP-S2S setting up workflow to use MPAS as and S2S model: weekly reforecasts following same protocol as CESM
Lead: Judith Berner and Abby Jaye

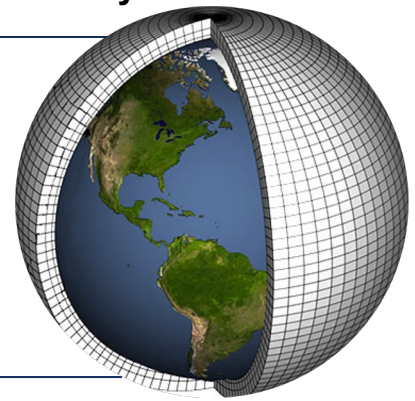
Started Oct 2024

CESM investigating land-atmosphere coupling processes and role of tunable parameters
Lead: Meg Fowler

Leveraging CESM ESPWG as much as possible

CESM:

Community Earth System Model



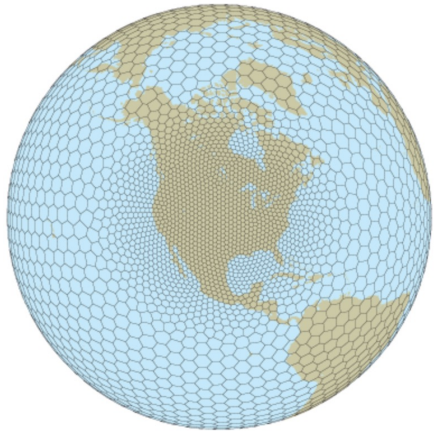
ESPAT: S2S Land-atmosphere Interactions: Seeking More Partners

- Established Community Liaison: **Meg Fowler** (mdfowler@ucar.edu)
- Sent out information to community in March 2024
- **23 University participants**
- **April 1**: had first Working Group meeting with introductions on what everyone was working on & discussion next steps
- Sent **survey out to group** after meeting to shape next steps

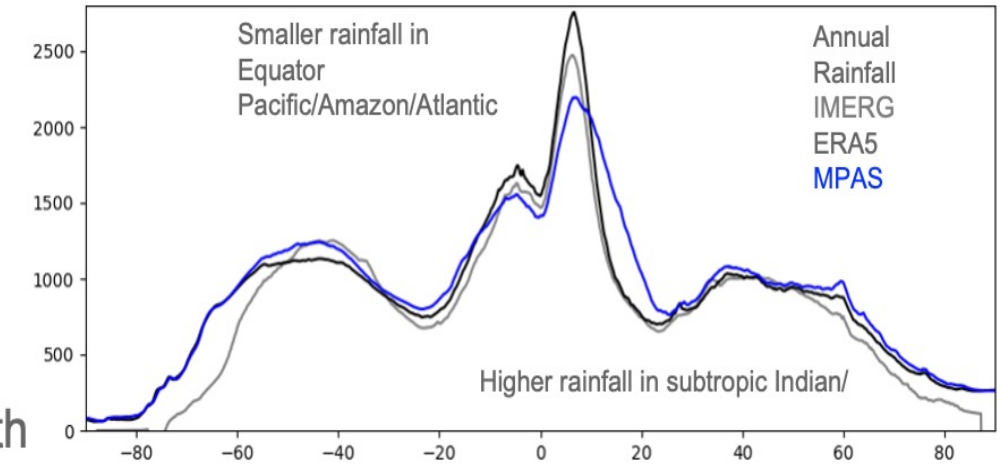
Partnership with various stakeholders and communities is welcome!

MPAS Model Performance for Global Precipitation

Model for Prediction Across Scales (MPAS)

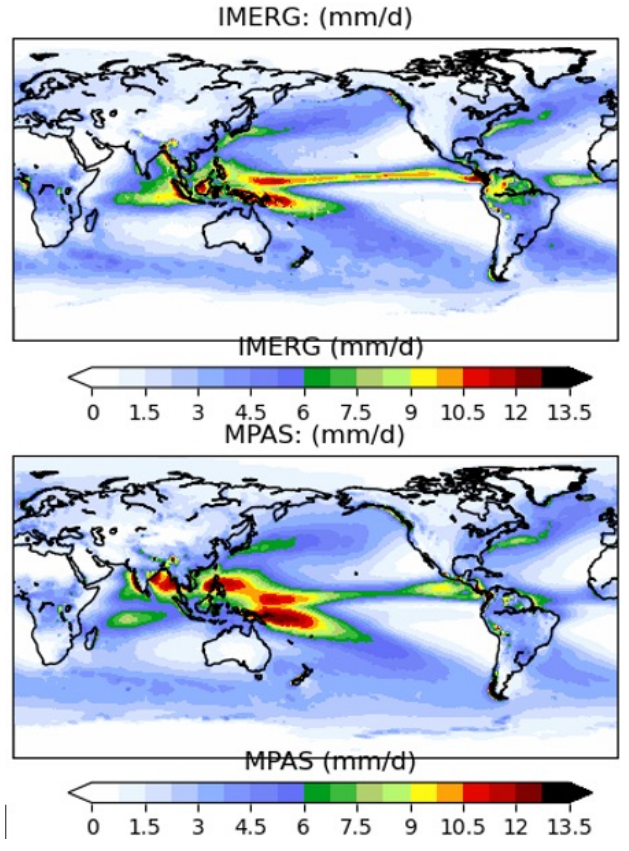


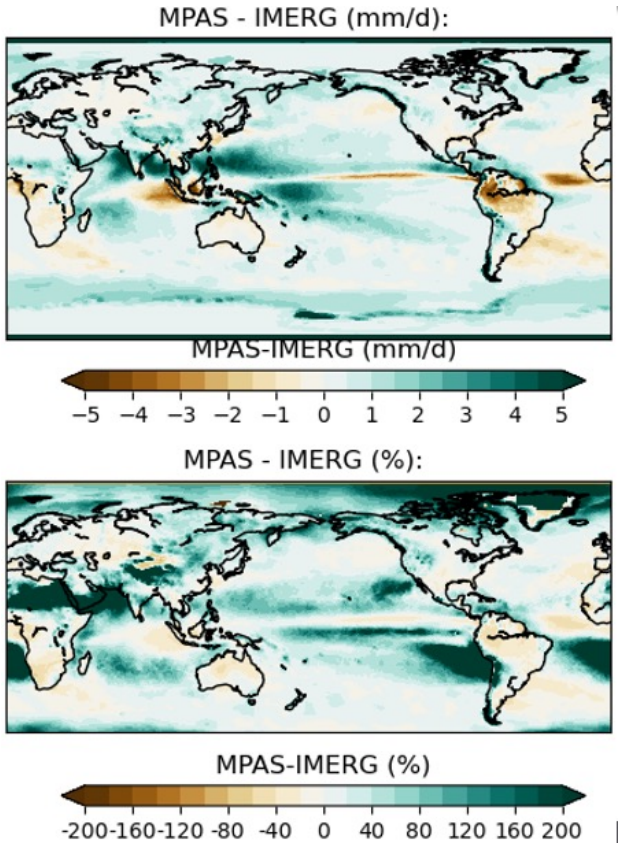
1999-2018 (20 year) precipitation



South North

Model Error in Precipitation

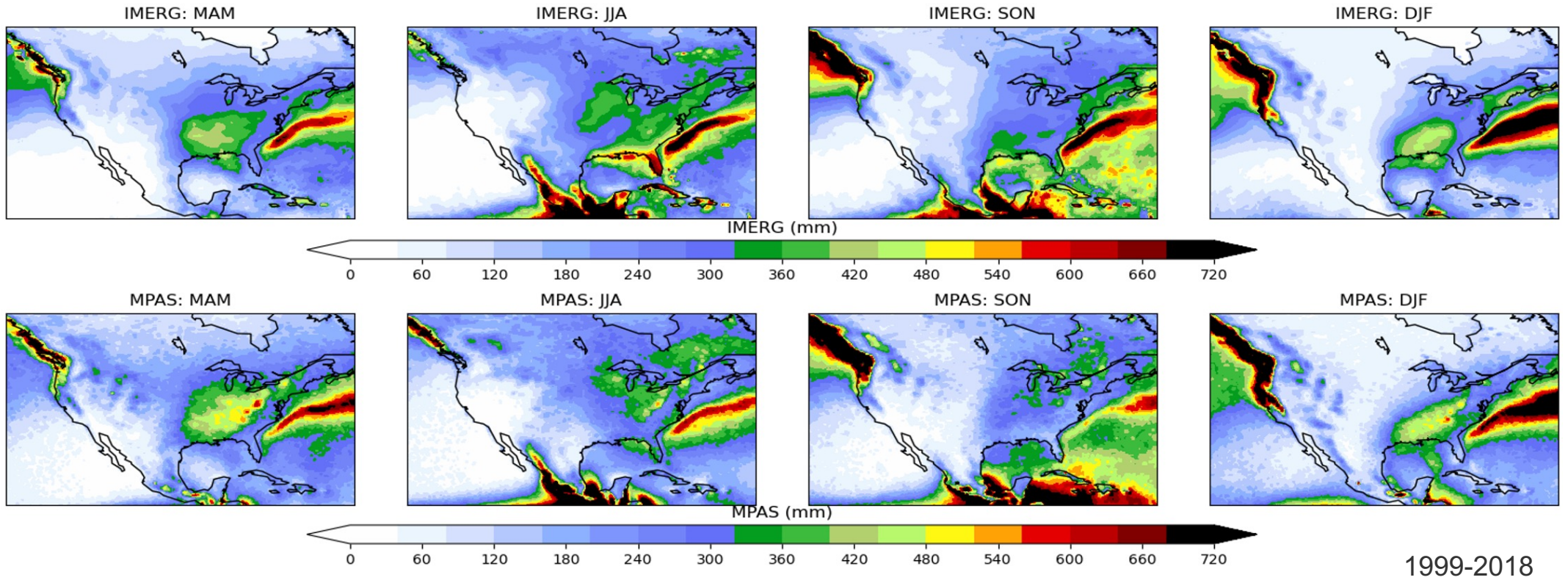




MPAS Model Performance for Precipitation in the Continental U.S.

Satellite

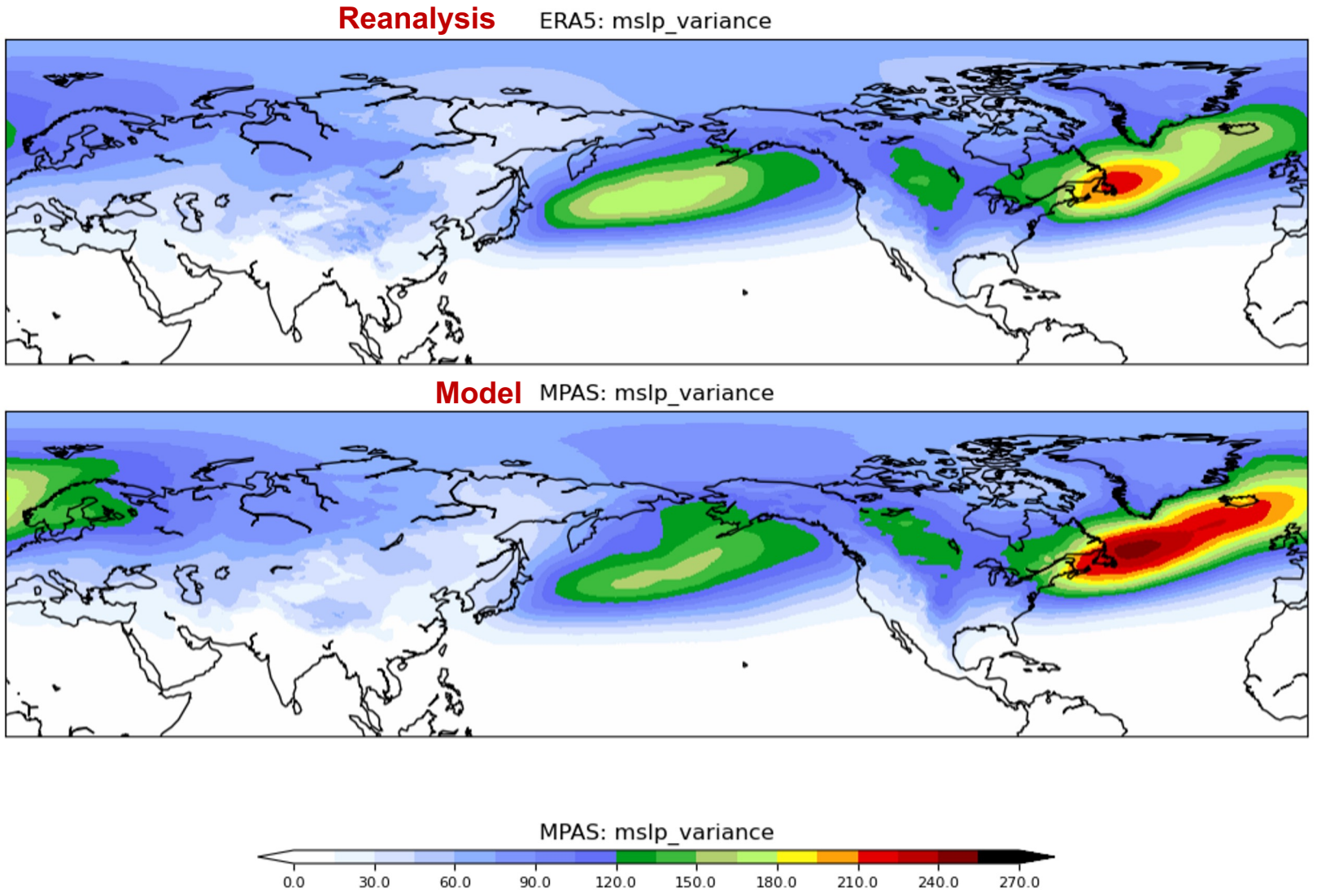
Model



1999-2018

- Seasonal precipitation pattern is reasonably captured over the continental U.S.
- Underestimated rainfall in central US in summer (mesoscale convective systems)
- Underestimated rainfall in Gulf of Mexico and Southeast U.S. coastal regions in summer (hurricane)

MPAS Model Performance for Storm Track

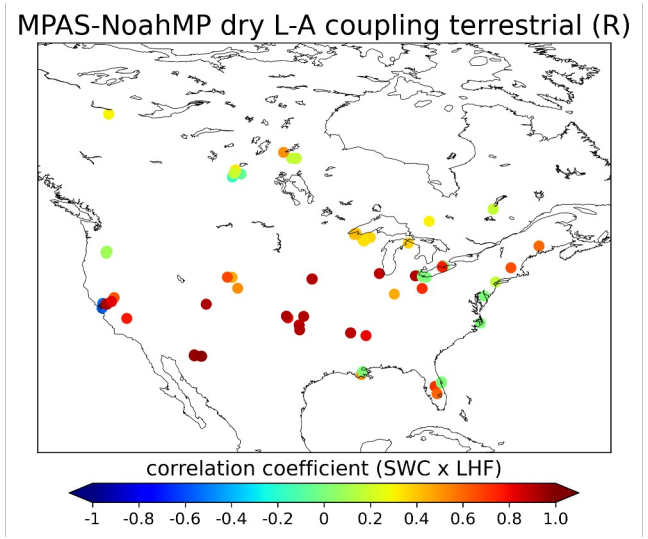
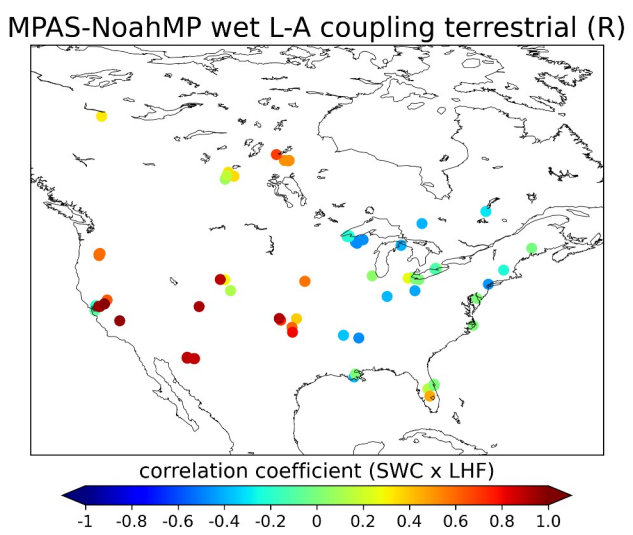
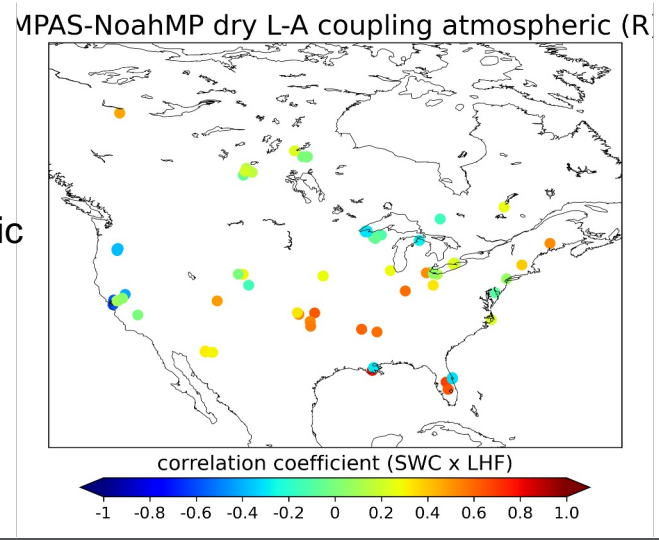
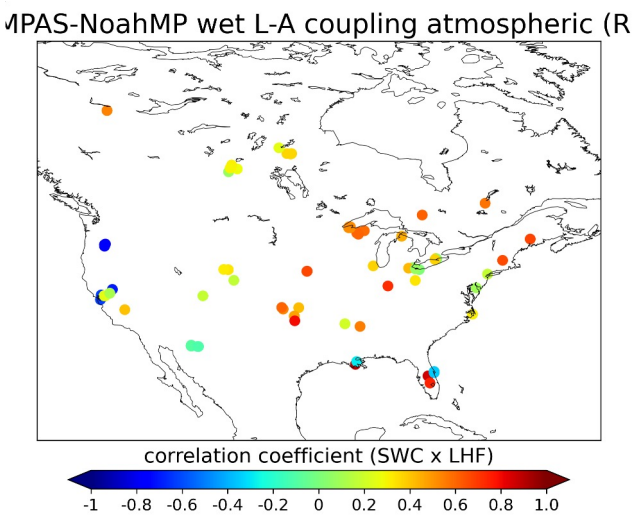


MPAS DJF winter storm track:

- Reasonably capture the spatial pattern
- Too strong in Atlantic Ocean
- Weaker in Pacific Ocean

Winter storm track (by mslp daily variance=$\overline{(slp(t) - slp(t+24))^2}$ over DJF)

Land-Atmosphere Coupling Diagnosis in MPAS: important for Soil Moisture-Precipitation Feedback in S2S prediction

	Dry Condition	Wet Condition
Terrestrial Leg		
Atmospheric Leg		

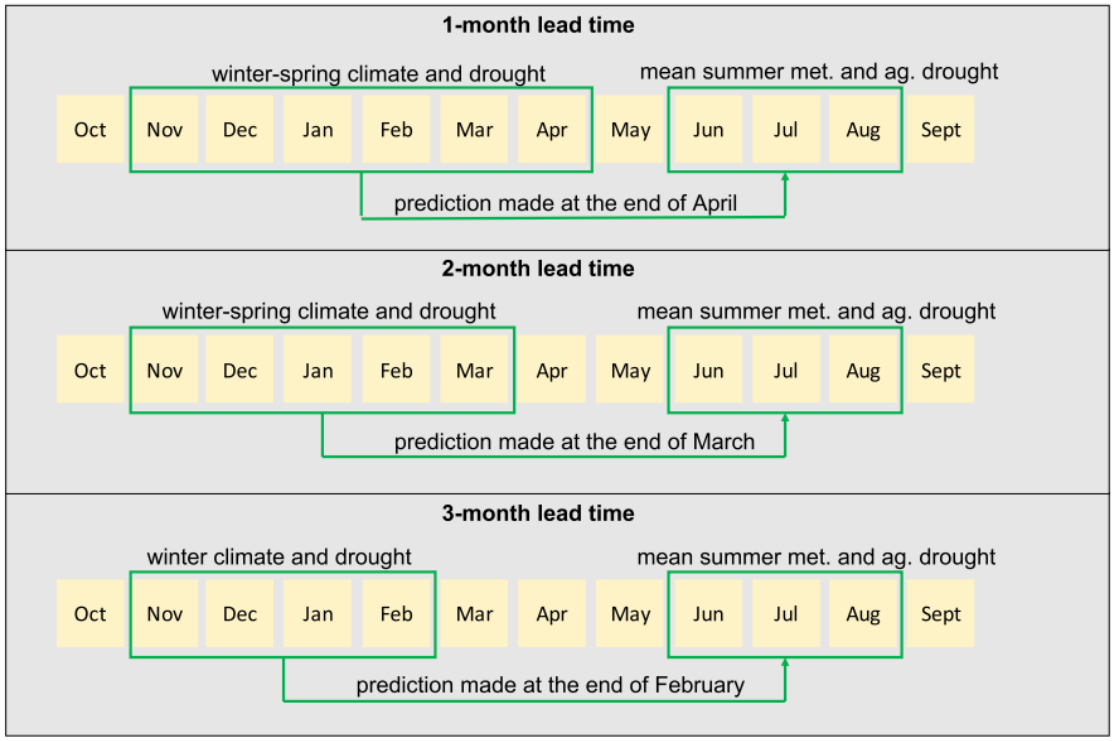
On Terrestrial leg:
Dry soil:
Strengthening L-A terrestrial leg

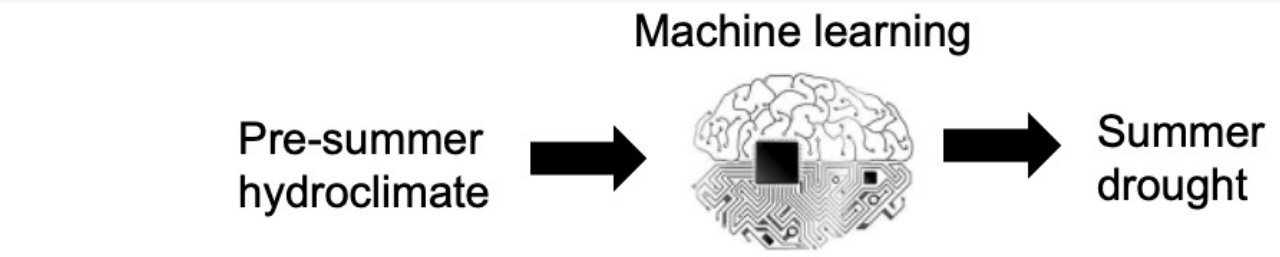
Wet soil:
Reduce L-A coupling strength
Eastern US shows negative correlation
Could be related to changing rainfall

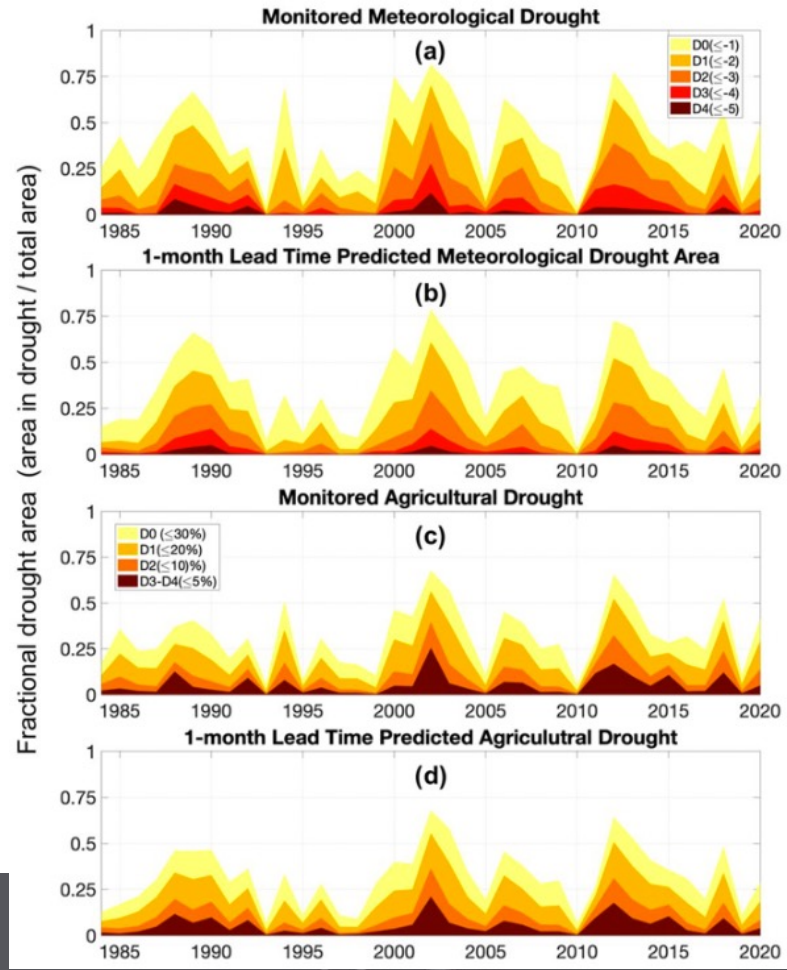
On Atmospheric leg:
Wet soil moisture strengthens atmospheric coupling in Eastern US

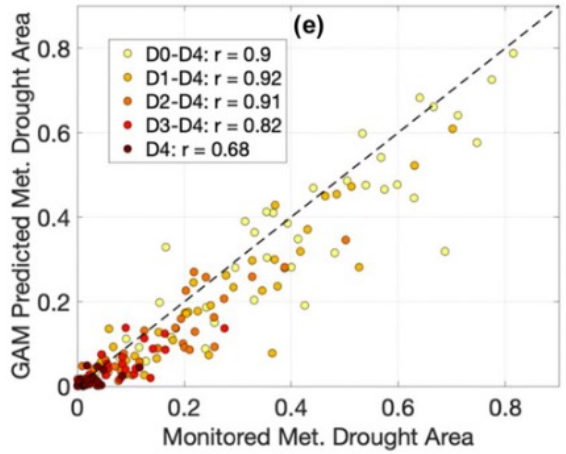
AmeriFlux Tower sites

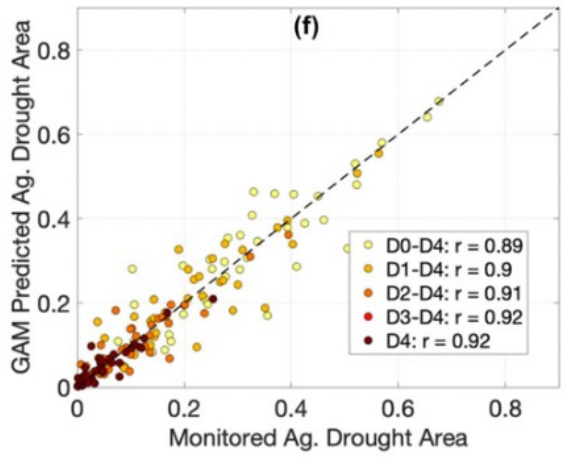
Machine learning-based high-resolution (4-km) S2S drought forecasts over the western U.S.









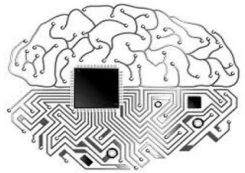


Abolafia-Rosenzweig, R., He, C., Chen, F., Ikeda, K., Schneider, T., & Rasmussen, R. (2023). High resolution forecasting of summer drought in the western United States. *Water Resources Research*, *59*, e2022WR033734. https:// doi.org/10.1029/2022WR033734

Machine learning-based S2S prediction of fire from snow droughts in the western U.S.

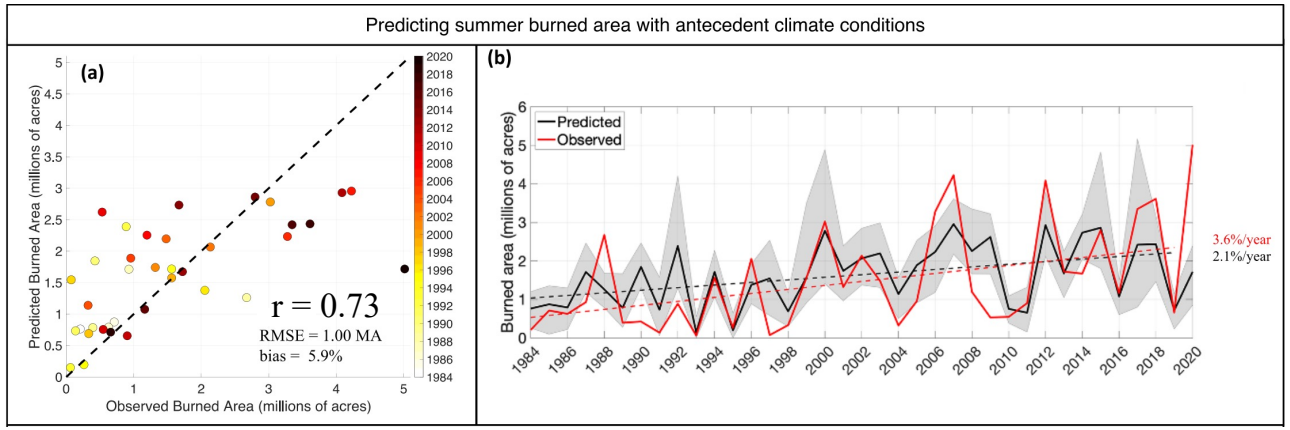
Winter & Spring Predictors:
(Observation-based when available)
Precipitation
Temperature
Vapor Pressure Deficit (VPD)
Evapotranspiration (ET)
Potential ET (PET)
Soil moisture
Snow drought (SWEI)
Palmer Drought Severity Index (PDSI)

AI/ML

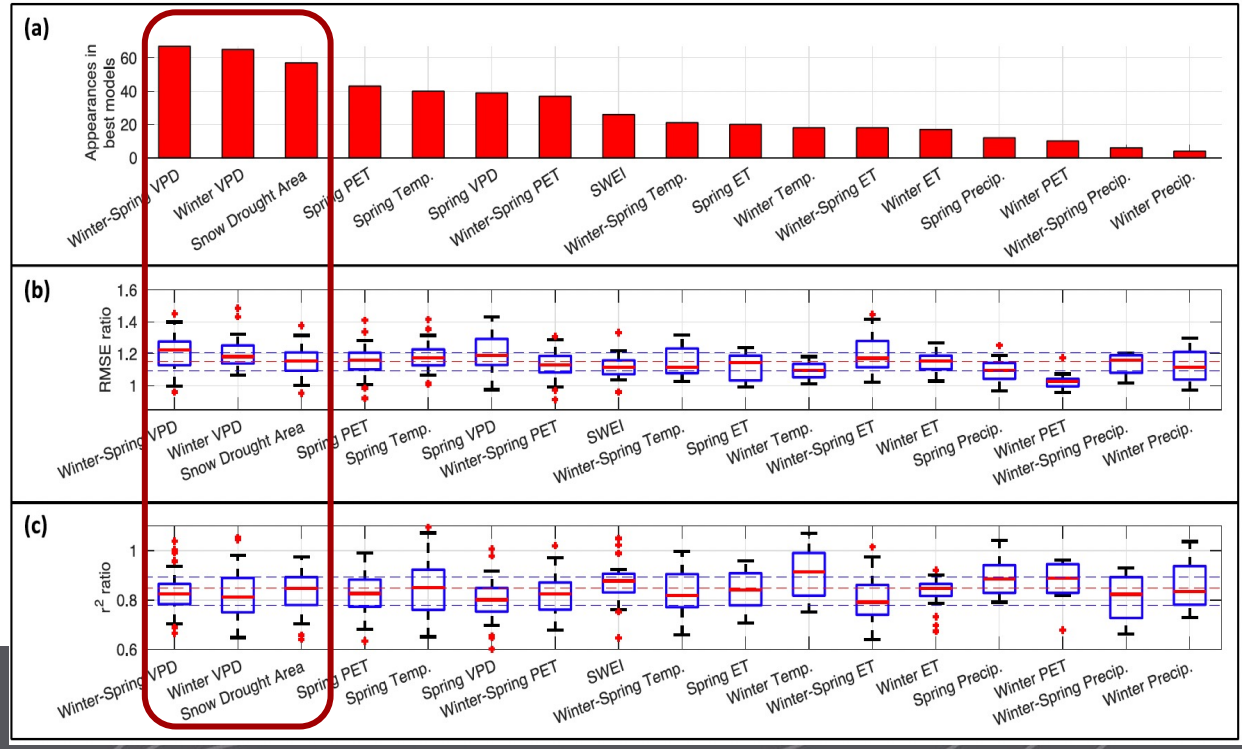


Observed fire burned area and drought

Seasonal fire burned area predictions



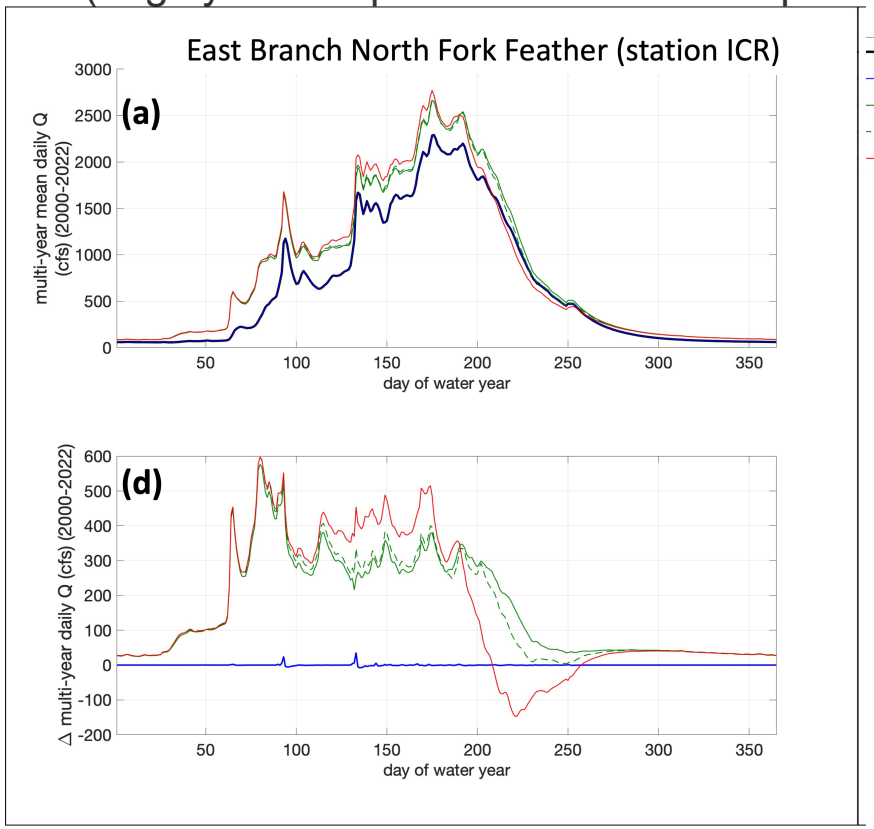
VPD and snow drought are the most important predictors



Abolafia-Rosenzweig, R., He, C., & Chen, F. (2022). Winter and spring climate explains a large portion of interannual variability and trend in western US summer fire burned area. *Environmental Research Letters*, *17*(5), 054030.

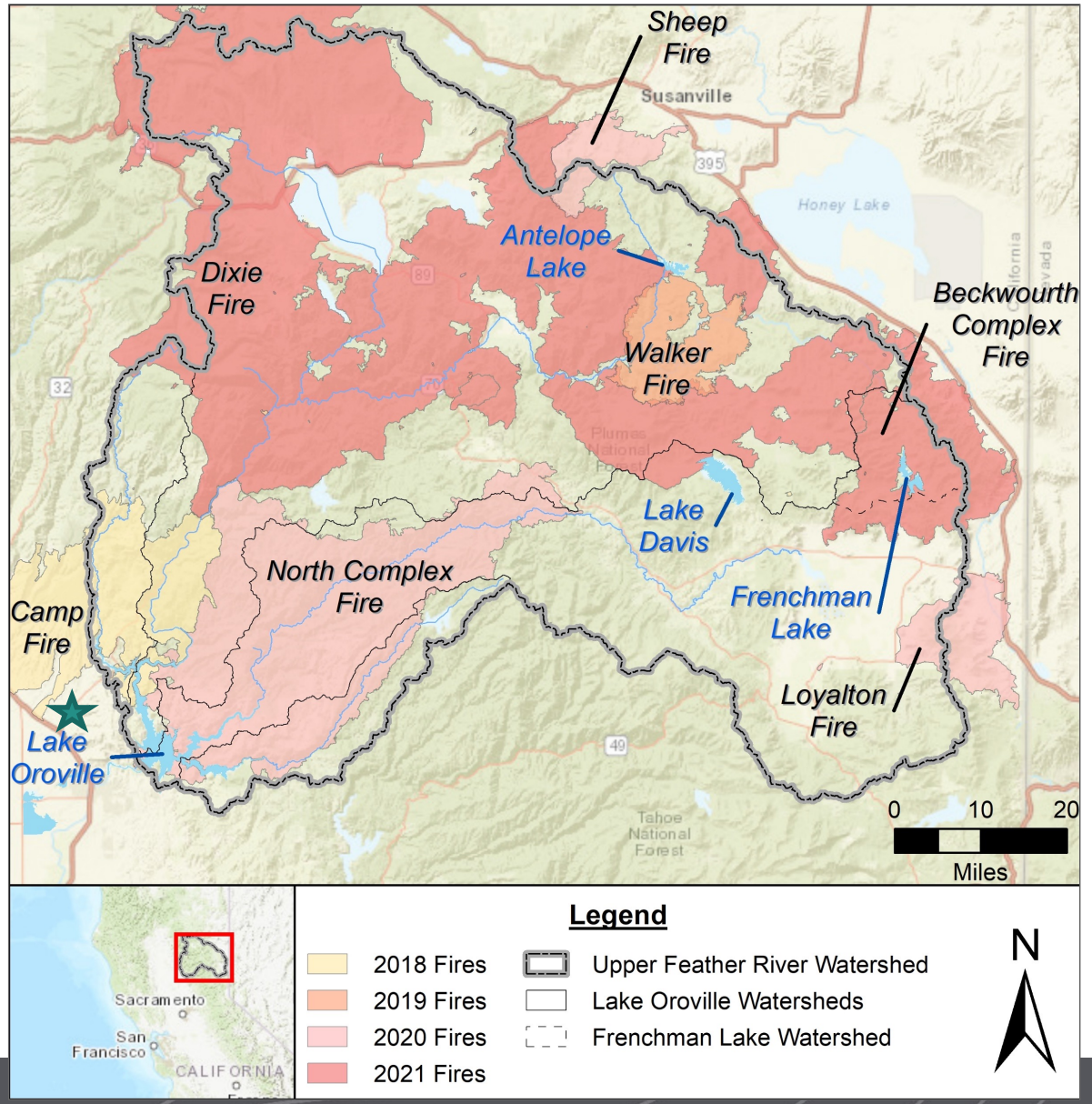
Model predictions of postfire streamflow in the Upper Feather River Watershed

- **57%** of the Upper Feather River Watershed has burned since 2018
- **27%** burned at high severity (75% tree mortality)
- The majority of shoreline around Lake Oroville has burned (largely in Camp Fire and North Complex Fire)



California State Water Project

Collaboration with ASO Inc.



Watershed Area Above Lake Oroville Approx. 2.3 million acres

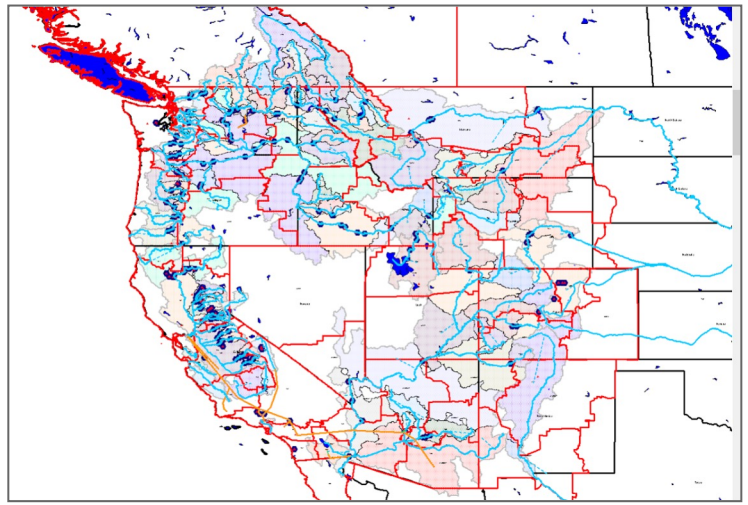
Abolafia-Rosenzweig, R., et al. (2024). Quantifying the Impacts of Fire-Related Perturbations in WRF-Hydro Terrestrial Water Budget Simulations in California's Feather River Basin. *Hydrological Processes*, *38*(11), e15314.

Electricity & Water systems in the Western US are closely connected: Water resources model + electricity model

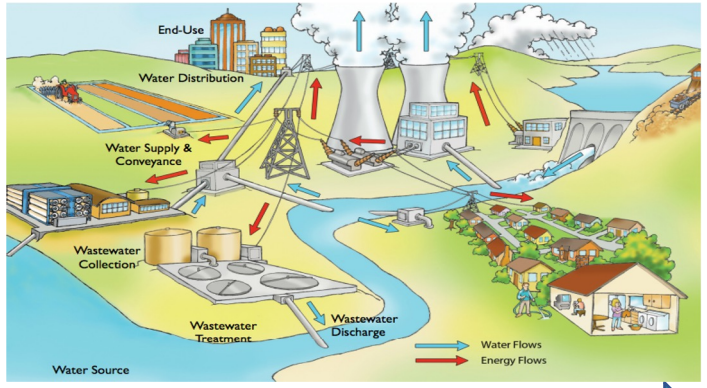
WECC (Western Electricity Coordinating Council)

WEAP: hydrology + water management

- Integrated water supply and demand
- Simulates hydropower and energy use for water with different scenarios

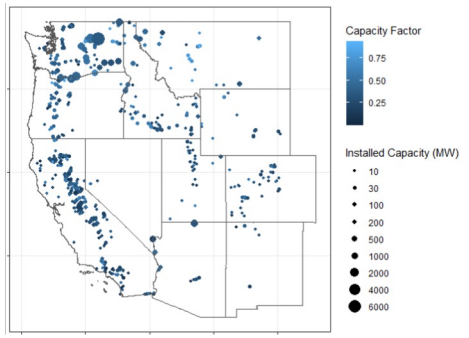


WEAP WECC Model (Yates, Szinai, and Jones, Earth's Future, 2024)



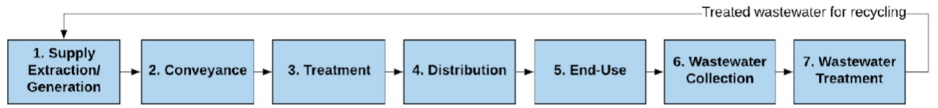
Changes in hydropower

WECC hydropower >30 MW



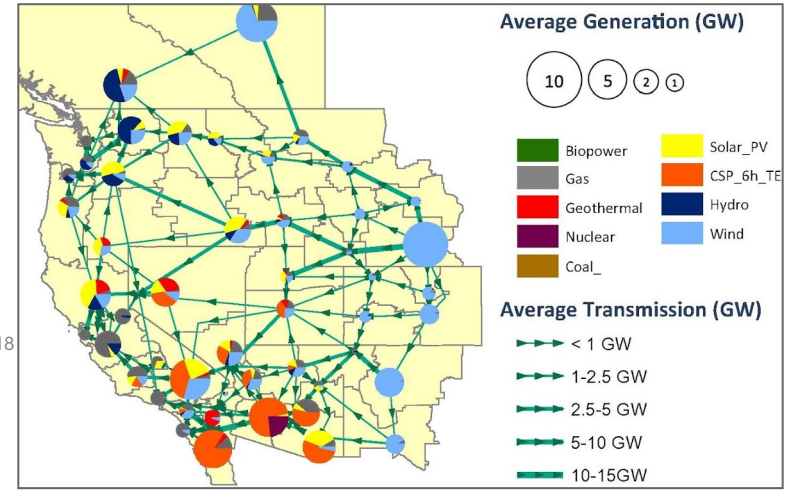
Changes in energy for water

Energy for water cycle



SWITCH: electricity capacity planning

- Optimization minimizes power system cost
- WECC-wide zero carbon generation by 2050

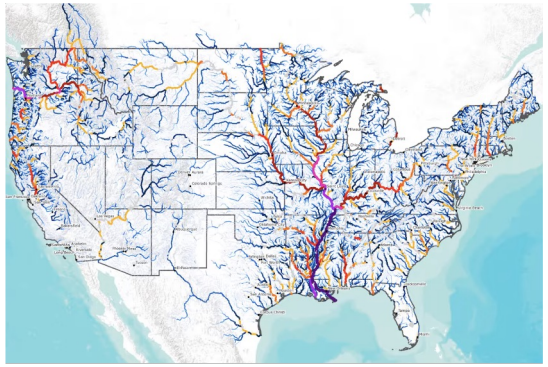


SWITCH WECC model (Nat Comm, Szinai, Yates, et al, 2024)

Courtesy of David Yates (NSF NCAR)

ESPAT's Next Planned Focus Area: S2S Hydrological Predictability

WRF-Hydro®



Hydrologic modeling

- WRF-Hydro model is a physically-based hydrologic model that accounts for streamflow within river channel
- Used as a basis for the US National Water Model

Key questions:

- How does **hydrological predictability** change as a result of coupling?
- Which hydrological processes are better represented when atmospheric **observations are assimilated** into land and hydrological models?
- Can integration of **ML/AI techniques** with physical models improve prediction skill?
- How are humans changing the global water balance, and what are the dominant **human-water feedbacks** driving these changes?
- How do human interactions with the hydrologic cycle at the **local scale** accumulate into **water budget** changes at larger scales?

Working now on what could be a seed effort

ESPAT S2S: Future coordination with GEWEX H_2US Mission

Immediate area of potential collaboration

H2US L-A Science Question:

What roles do local and regional L-A interactions play in controlling the evolution and prediction of US extremes on S2S timescales?

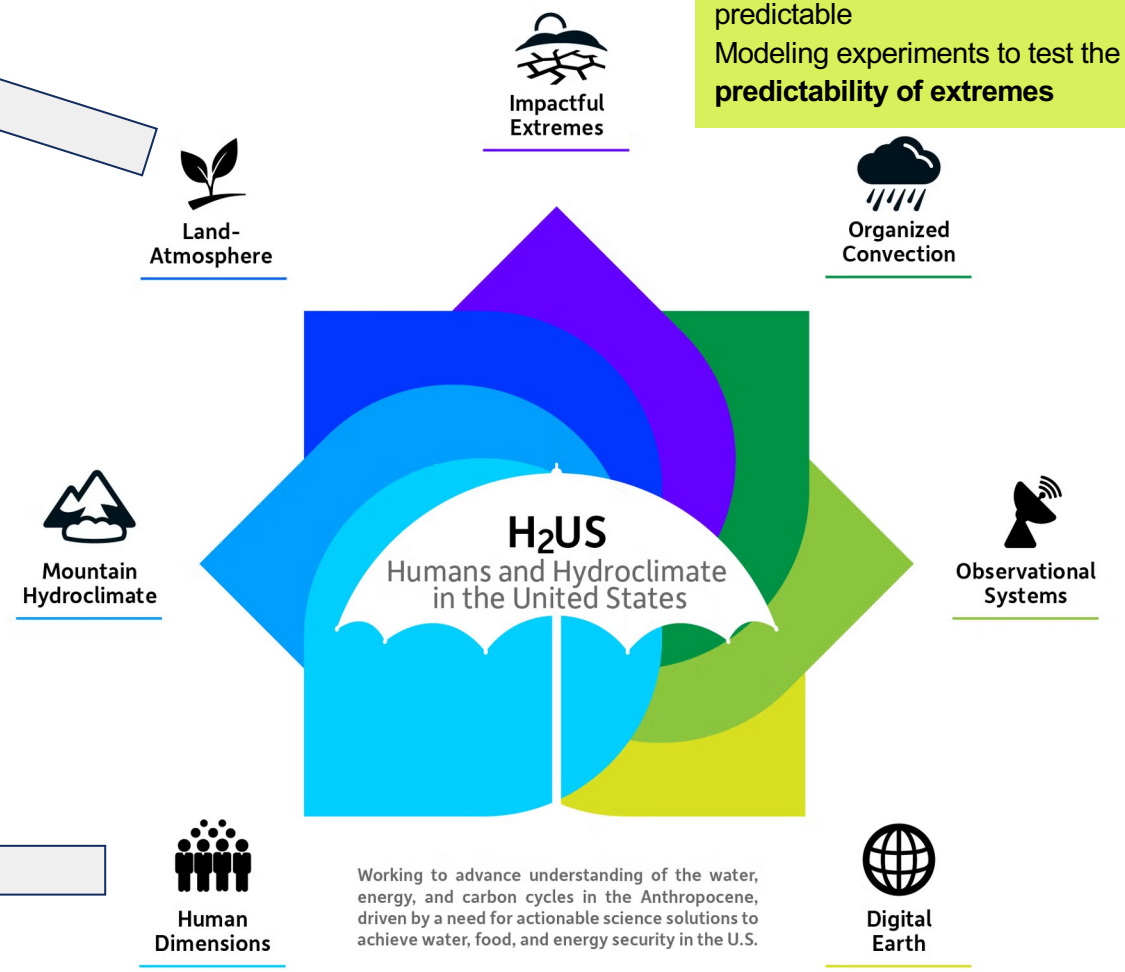
Immediate area of potential collaboration:

H2US Impactful Extremes: Science question 3:

Examination of S2S reforecasts to identify times and places where extremes are predictable

Modeling experiments to test the **impact of resolution, initialization on predictability of extremes**

Global Energy and Water Exchanges (GEWEX) program

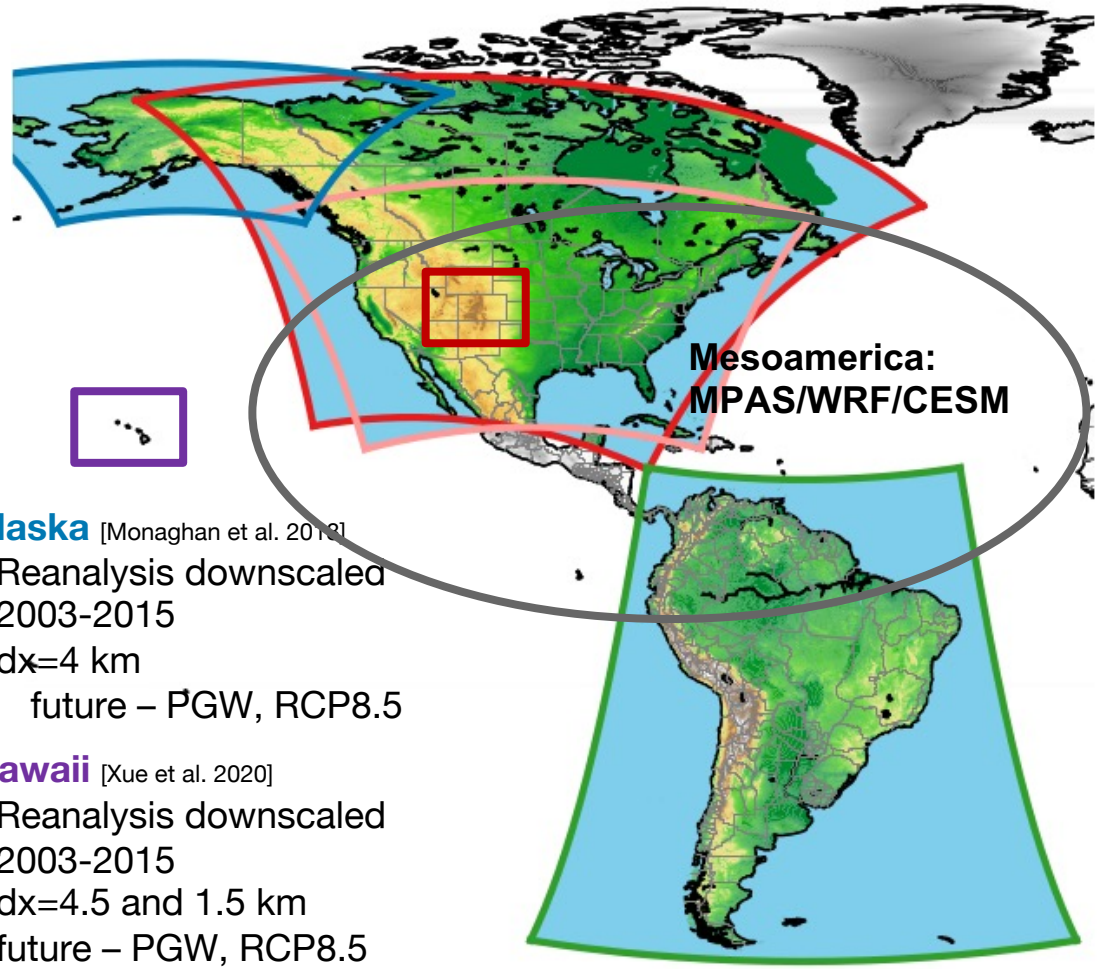


Once hydrology theme is up

Courtesy of Tim Schneider (NSF NCAR)

ESPAT S2S: Future coordination with NCAR Water System Program

Decades of NCAR Convection-Permitting Simulation Experiences



Alaska [Monaghan et al. 2018]
- Reanalysis downscaled
- 2003-2015
- dx=4 km
- future – PGW, RCP8.5

Hawaii [Xue et al. 2020]
- Reanalysis downscaled
- 2003-2015
- dx=4.5 and 1.5 km
- future – PGW, RCP8.5

NCAR/RAL Kilometer-Scale Climate Simulations

CO-Headwaters [Rasmussen et al. 2014]
- Reanalysis downscaled
- 2001-2008
- dx=4 km
- future – PGW, RCP8.5

CONUS-1 [Liu et al. 2017]
- Reanalysis downscaled
- 2001-2013
- dx=4 km
- future – PGW, RCP8.5

CONUS-2 [in progress]
- GCM downscaled
- 1995-2014
- dx=4 km

CONUS404 [Rasmussen et al. 2023]
- Reanalysis downscaled
- 1979-2021
- dx=4 km

South America [in progress]
- Reanalysis downscaled
- 20-years
- dx=4 km
- future – PGW, RCP8.5

Courtesy of Lulin Xue (NSF NCAR)

ESPAT S2S Future Plans: possible shared deliverables/actions

Shared resources	Special Issue	Conference Session	1 -2 Week Science Retreat @NCAR	Joint $ proposals
Evaluation datasets Metrics Simulations	Land-atmos interactions in S2S 	AMS American Meteorological Society Annual Meeting	NCAR Operated by UCAR  Summer 2026	UCAR/PACUR Community Engagement Fund NSF/DOE/NASA /NOAA

S2S working group meetings in May-June 2025

Outcomes:

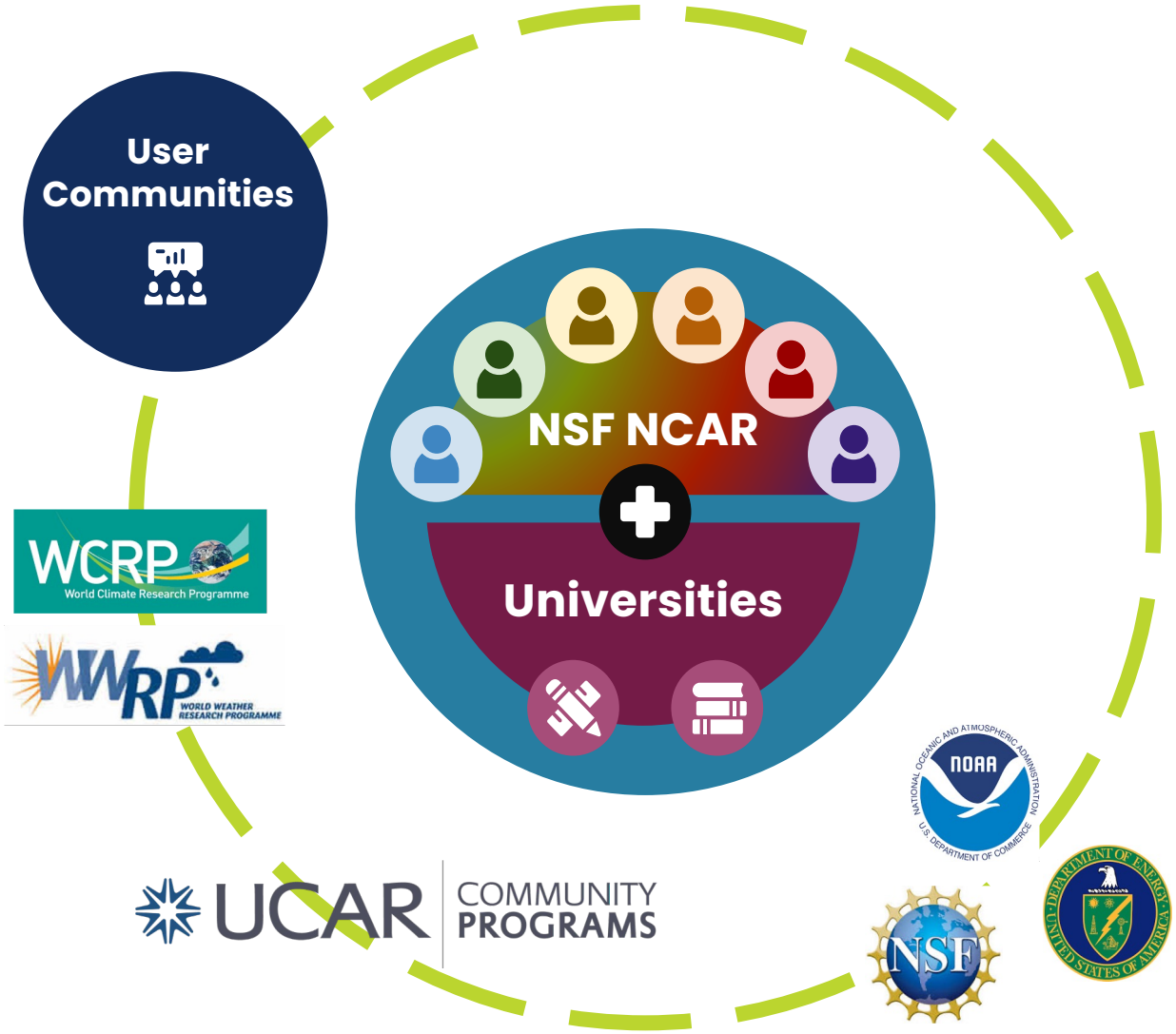
- S2S model simulations with regional refinement over some specific region(s)
- Central U.S., Gulf Coasts, Maritime Continents, Western U.S. (?)

S2S Community Workshop on Land-Atmosphere Interactions

Community workshop:
June 16 - 18, 2025 @ NCAR + online

- Multi-agency organization (NSF NCAR, NOAA, NASA, and DOE) with University Community shaping agenda/scope
- Hybrid workshop with **concrete outcomes**
- **Outcomes:**
  Process-oriented and operational metrics
  Co-ordinated experimental protocols

Registration is open through May 28:
https://ncarprojects.ucar.edu/S2S-workshop-2025



Anticipating 9 months - 1 year for experiments to be carried out; Bring group together Summer 2026

Join ESPAT S2S Working Group

Opening Group to Broader Scientific & Stakeholder Communities
Collaborate with us!

- **Contacts:**

ESPAT Lead: Jadwiga (Yaga) Richter: **jrichter@ucar.edu**

S2S Land-Atmos co-Lead: Cenlin He: **cenlinhe@ucar.edu**

Community Liaison: Meg Fowler: **mdfowler@ucar.edu**

Key Takeaways:

- ESPAT is a new NSF NCAR initiative focused on advancing Earth system predictability for **societal resilience**
- A **multi-scale, interdisciplinary** approach is crucial. **Bridging** Weather, S2S, S2D, and Earth system communities is key.
- First on-going theme: **S2S predictability**
- Planned themes: **Hydrological predictability and more**