Earth System Predictability Across Timescales (ESPAT)

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Introduction

- Every country, region, and community is progressively more impacted by **effects of extreme weather** and climate change
- 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 c**ommunity workshop in April 2024** to identify grand challenges, key science questions and potential solutions
- This talk: **summary of key takeaways** & items of most relevance to the CESM community

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 & enabling University Community + UCP

Including UCAR Members

Integration across US Agencies

Including NSF, DOE, NOAA, NASA, USGS

Serving as a community nexus and fostering collaborative research

ESPAT External Advisory Committee

Newsha Ajami
Lawrence Berkeley National Laboratory

Magdalena Alonso Balmaseda
ECMWF

Elizabeth Barnes
Colorado State U.

Ping Chang
Texas A&M U.

Ben Kirtman
U. of Miami

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Slava Merkin
John Hopkins U.

Brad Pierce
U. of Wisconsin

Zhaoxia Pu
University of Utah

Zeljka Stone
New Mexico Tech U.

Dan Seaton
Southwest Research Institute

Colin Zarzycki
Penn State U.

ESPAT Year 1:

Engagement:

Internal WGs
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: to be submitted Feb 15
SP Priority Objectives: in draft plan
First investment: S2S

Synthesis & Societal Needs

Predictions on **weather, S2S, S2D, and climate** timescales

Climate Change is global: Impacts are local

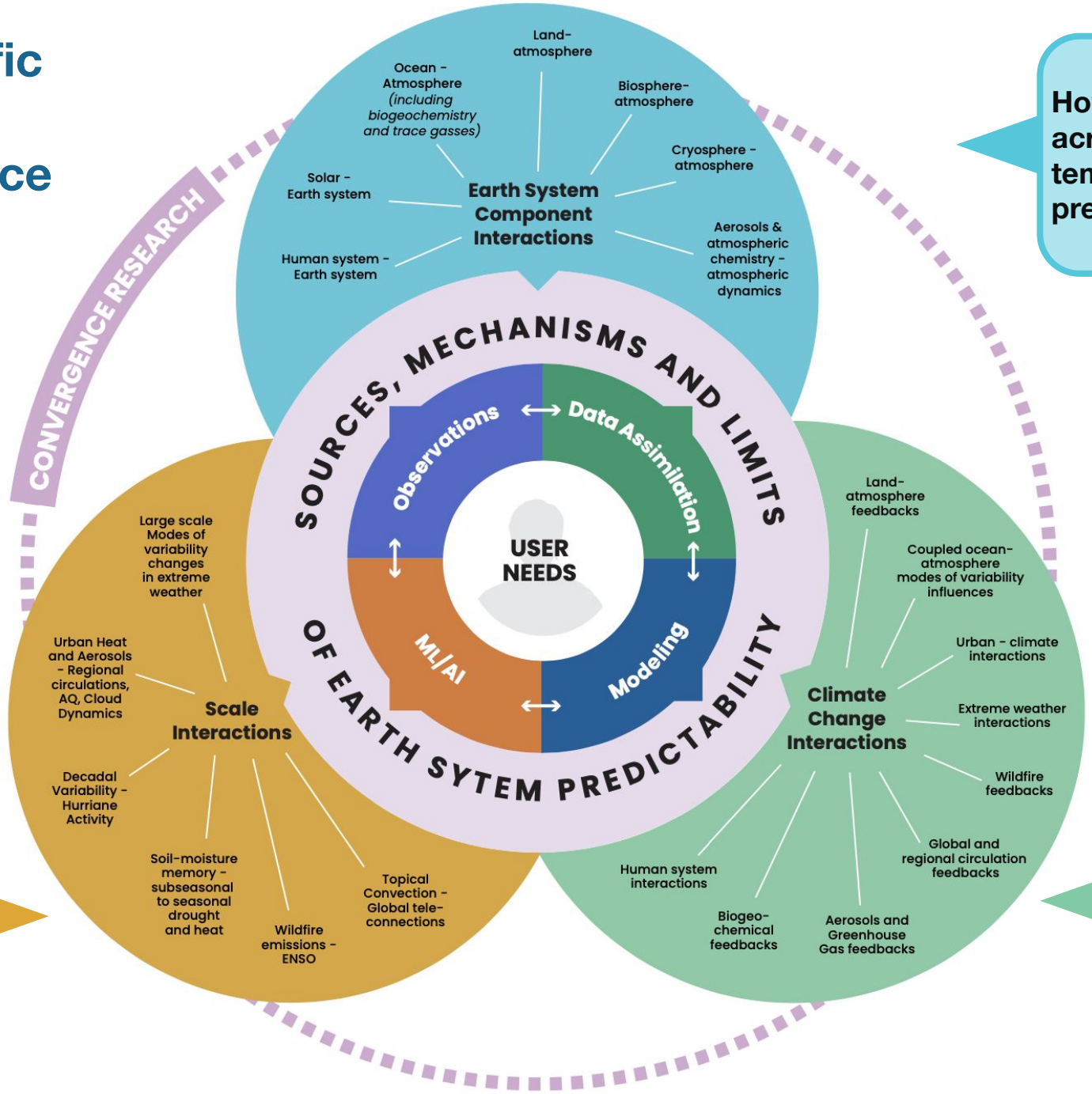
Interdisciplinary, across time and spatial scales approach is needed

Science needs to be done with community needs in mind

Trustworthy and actionable information on scales of communities **(1 to 25 km)**

Bi-direction feedback between users and scientists/tool developers

Summary of Scientific Grand Challenges & Overarching Science Questions



How do interactions across spatial and temporal scales affect predictability?

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

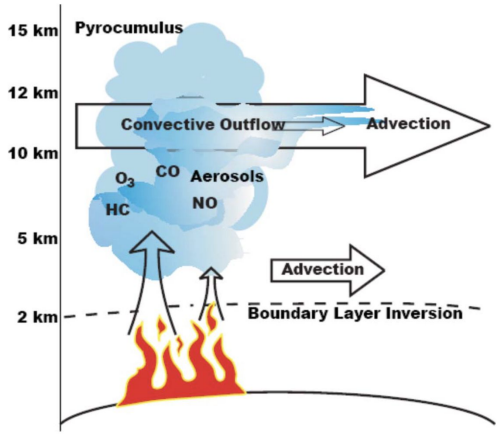
How does changing climate affect predictability across the Earth system?

ESPAT Modeling Needs:

Advancing **coupled data assimilation** (DA)

Coupled regionally-refined models or global high-resolution models (3 to 5 km horizontal resolution)

Fully coupled models with **interactive chemistry**: **1 km or less** horizontal resolution for **urban** applications



Unifying, **highly modular framework** enabling seamless development and exchange of components among organizations

Frequently updated **emission inventories**, including from wildfires

More Detailed Science Questions & Modeling Needs

Across timescales:

Key Questions:

How do human activities, such as land-use changes, influence regional climate variability and extreme weather events across timescales?

How can models more effectively represent urban-scale and human-environment interactions?

Modeling Needs:

ESMs with interactive land-use and land-cover changes, including urbanization and agricultural practices. Nested or regionally refined models.

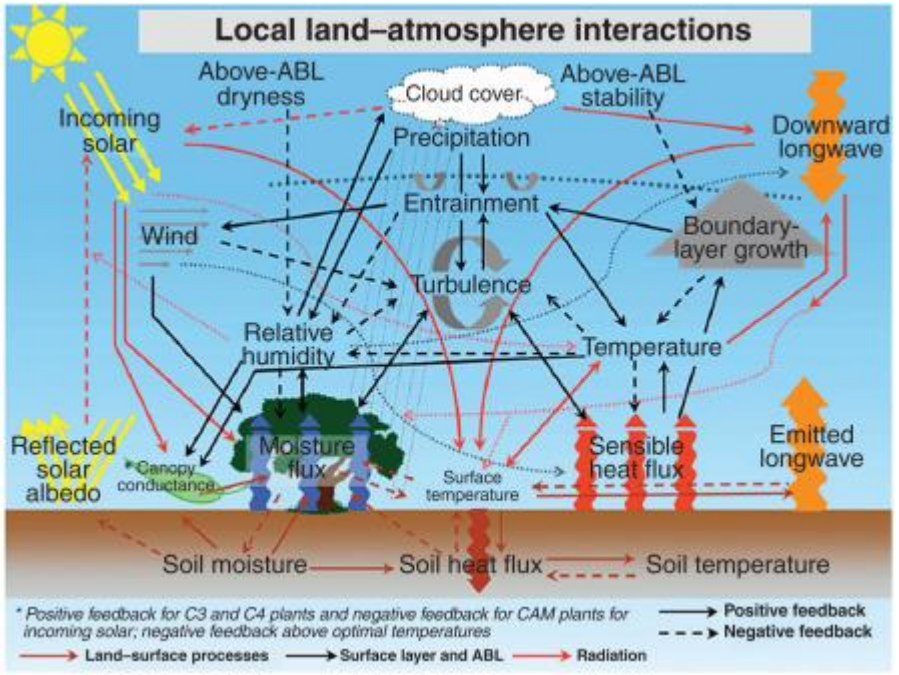
Incorporate urban-scale models coupled with ESMs. Develop frameworks to include human-decision making and its feedbacks on the Earth system.

More Detailed Science Questions & Modeling Needs

Key Questions:

- **How do models need to evolve to capture Earth system component interactions?**

Representing and verifying cross-component interactions



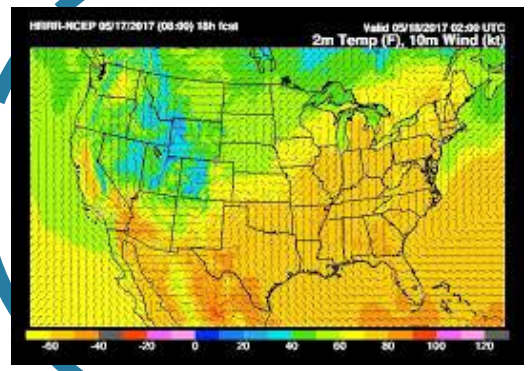
- Focus on improving critical processes such as l**and-atmosphere feedbacks, ocean-atmosphere coupling**, and cryosphere dynamics.
- **Strengthen verification** using process-level observations and historical data.

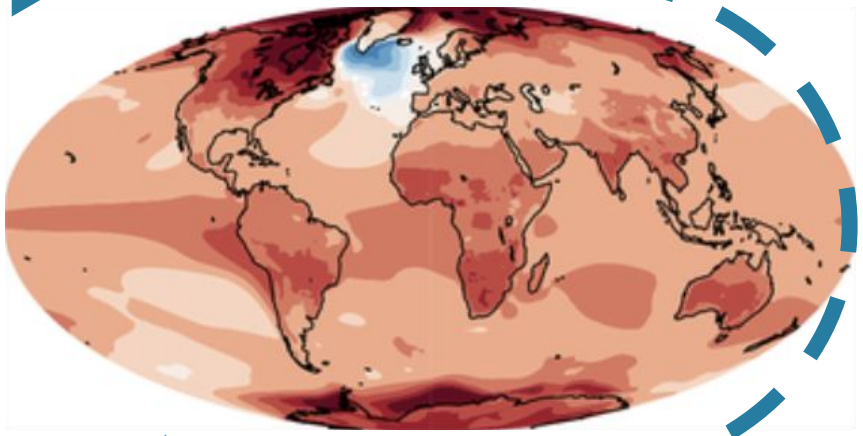
ESPAT Modeling Needs:

Key Questions:

- **Can we develop a common and consistent framework for harnessing and assessing predictability across scales, systems and applications?**

Use same model across timescales

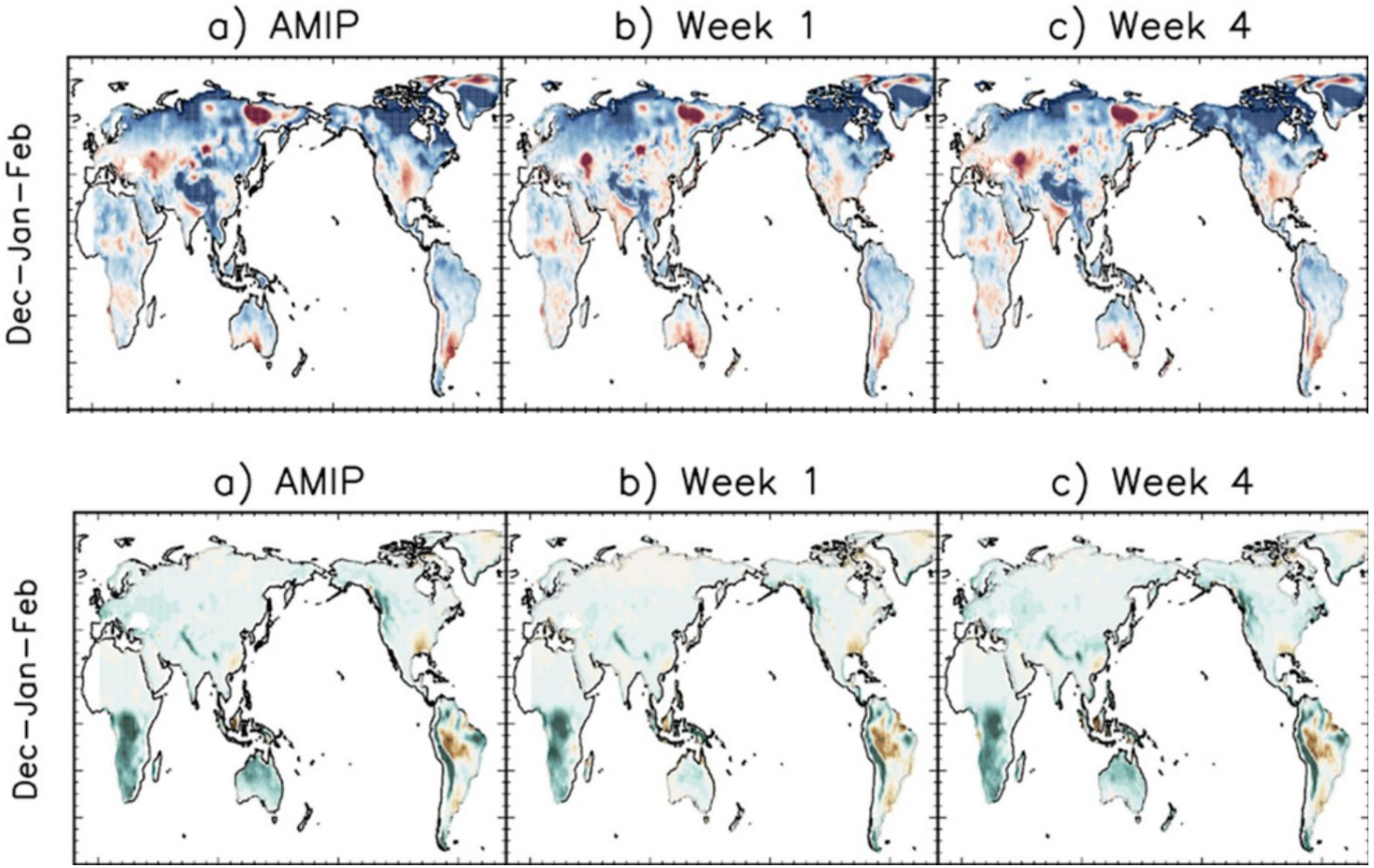


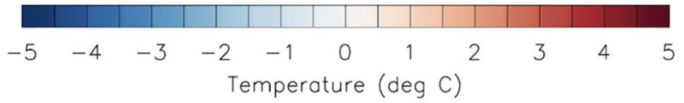


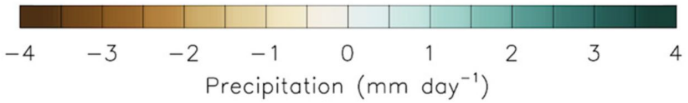
- Apply the **same models across timescales**. Ensemble approaches for reducing uncertainty and improving confidence. **Scale-aware and globally applicable parameterizations.**

Application of models across scales

Biases in physics evolve very quickly: same on timescales of days as decades



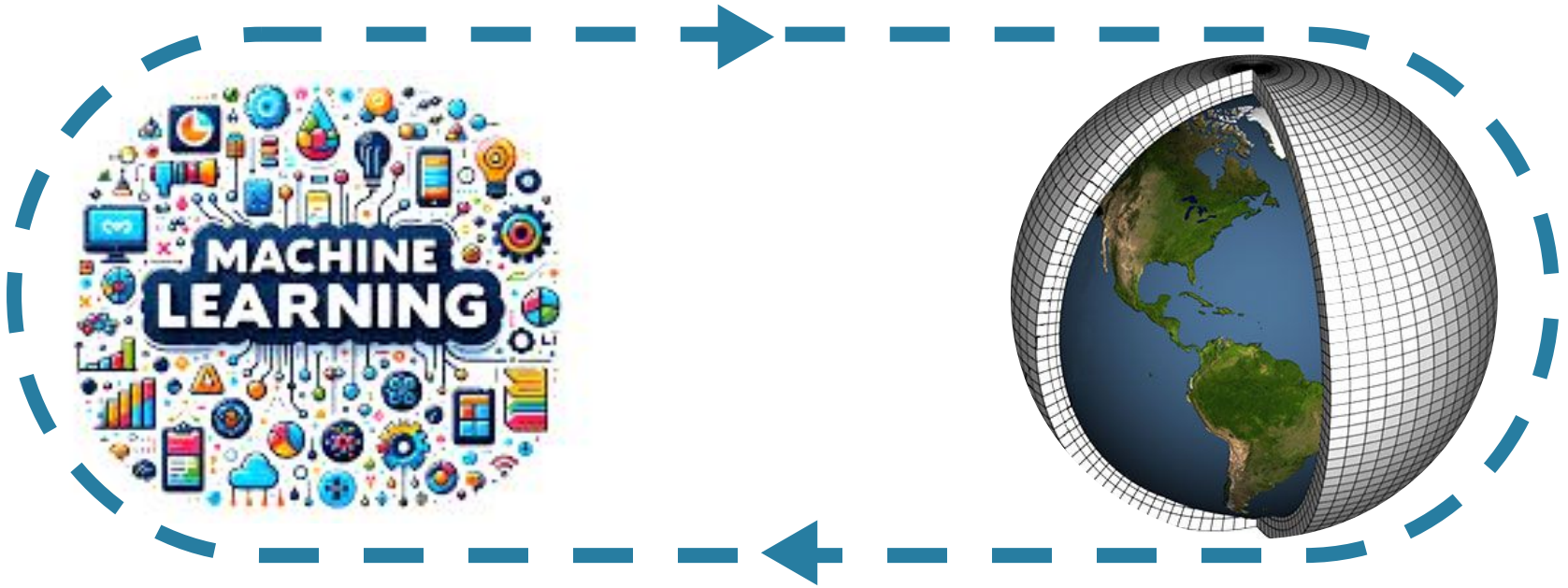




Richter et al. 2020

Opportunity for weather/S2S communities to work more closely with climate modeling community

ML/AI: Needs to be part of the solution



- **ML-based models/emulators** of key impactful phenomena & their impacts: floods, droughts, heatwaves, storm damage, health impact **at the community level**
- ML-improved **model bias**
- ML used for **understanding processes**
- ML for understanding **windows of and sources of predictability**
- **ML replacement** for certain parameterizations

Approach that is needed:

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

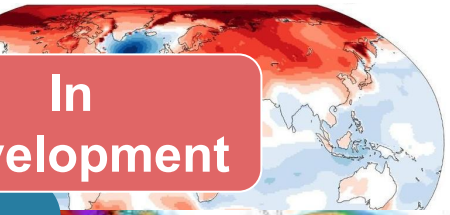
ESPAT Focus Areas:

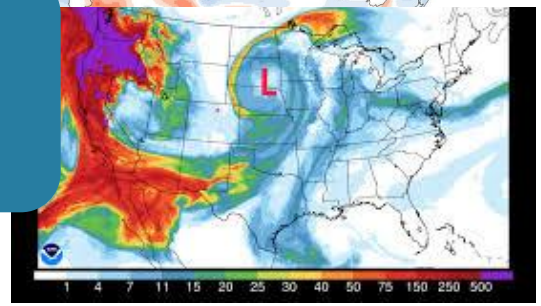
Seeded and growing

Subseasonal to seasonal predictability

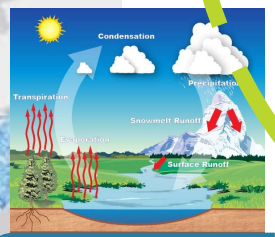
Atmospheric Composition & Emissions

In Development





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



In Development

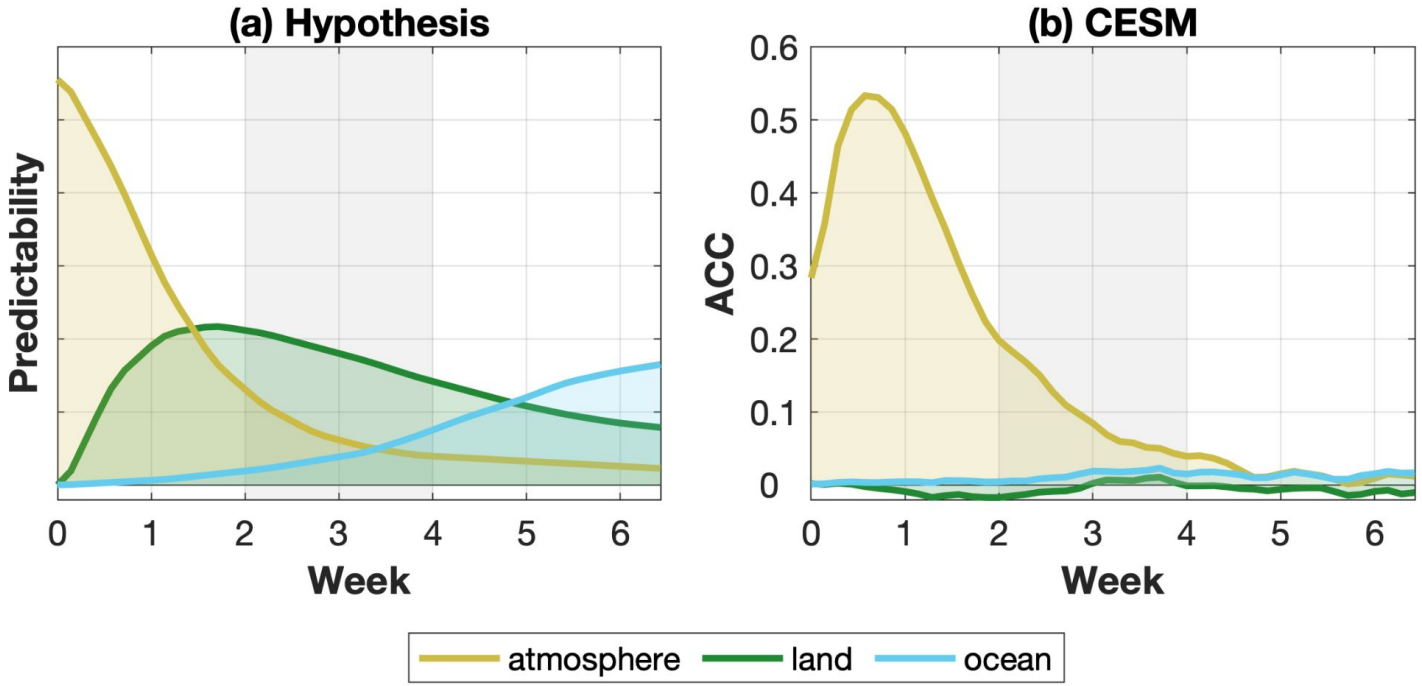
Hydrological Predictability

Space Weather

Getting close to seeding

ESPAT S2S: Motivated by findings from CESM

Not seeing benefit of land initialization: is coupling represented correctly?



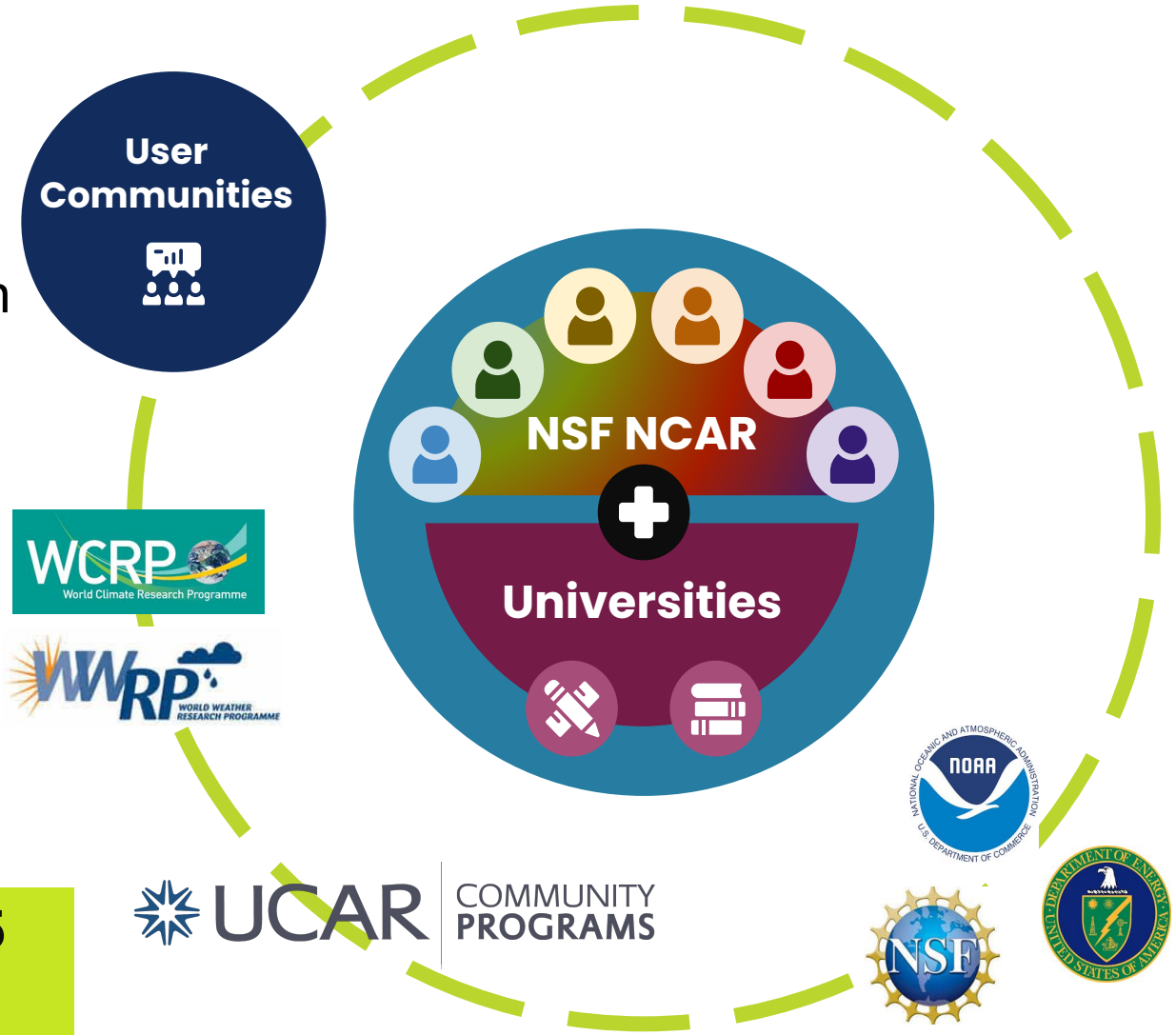
Based on a unique set of S2S reforecasts sets with realistic & climatological initial conditions with CESM2

Richter et al. (2024): NPJ Climate & Atmospheric Science:
https://www.nature.com/articles/s41612-024-00595-4

Limited observations to verify fluxes; Several tunable parameters in models; Need detailed process diagnostics.

ESPAT: S2S Working Group

- Focus on **land-atmosphere interactions**
- Utilizing **CESM, MPAS-NoahMP**, E3SM
- Invitation for U collaboration in Feb/early March
- **Contact: Meg Fowler**
- **Focus on S2S: but it will inform longer timescales** (Same model! Same physics!)
- **Leveraging CESM ESPWG** as much as possible

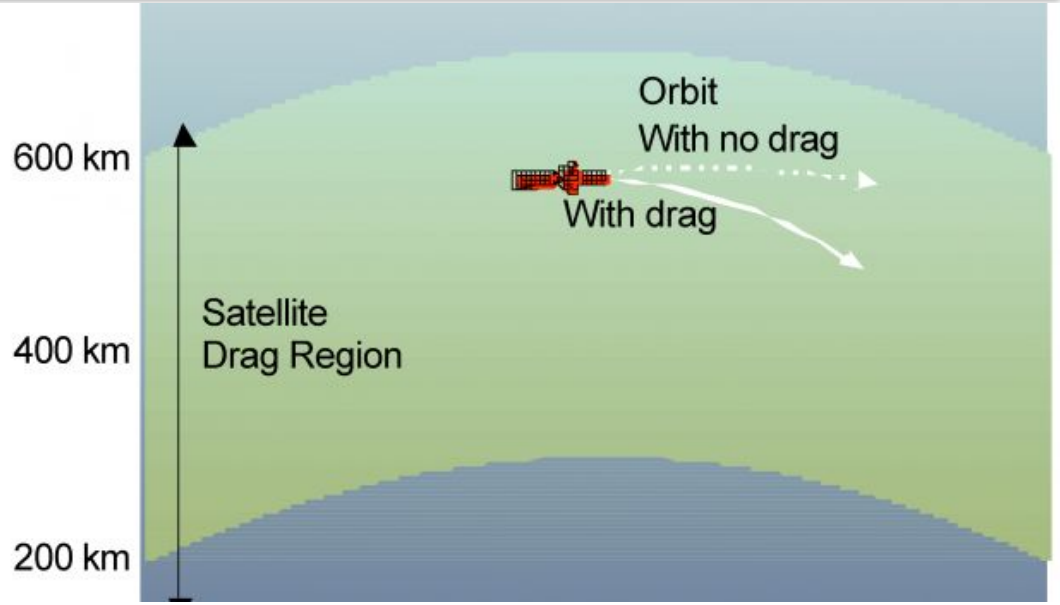


Cross-agency workshop: June 16 - 18, 2025 @ NCAR

ESPAT: Focus Area: Space Weather

- Solar activity affects power-grid industry and satellites. Key phenomena: **geomagnetic storms** and **CMEs:**

- **Coronal Mass Ejections (CMEs):** significant ejection of magnetic field and accompanying plasma mass from the Sun's corona into the heliosphere. Often associated with solar flares.



- Feb 2022: **CME** from the Sun caused a **geomagnetic storm.** The storm **heated and expanded Earth's upper atmosphere**, **increasing air density at low Earth orbit (LEO)**

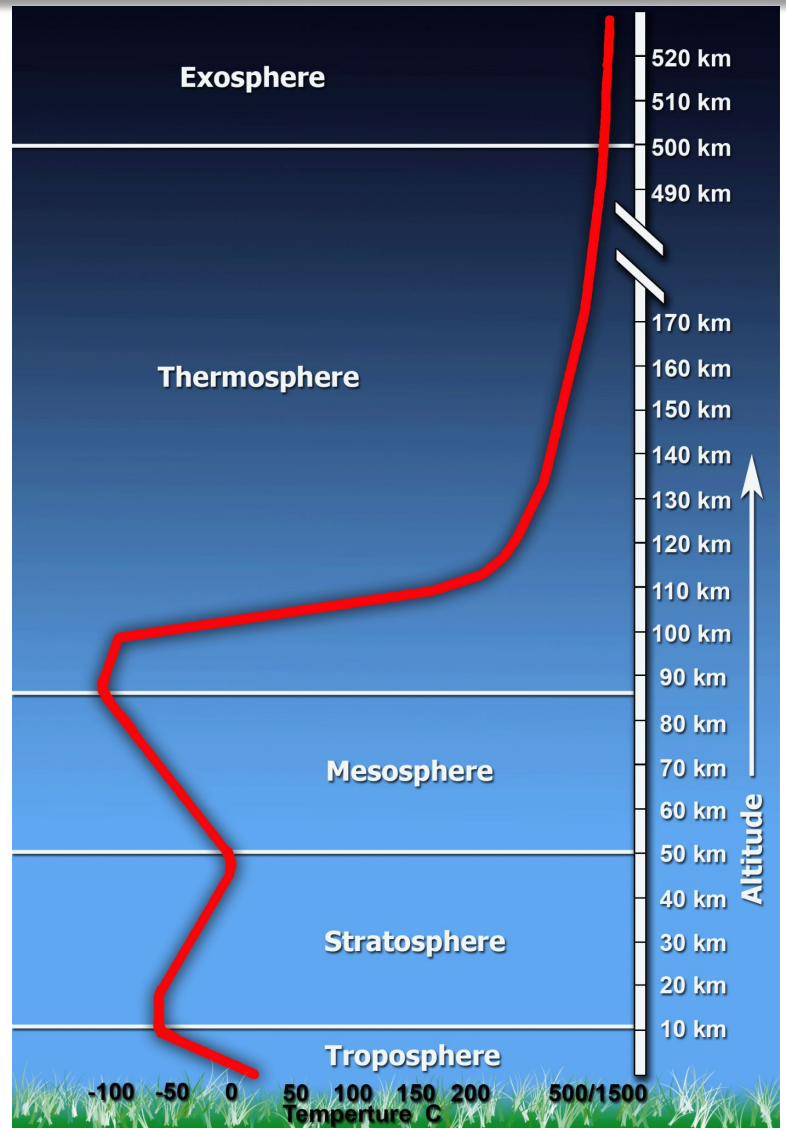
- The increased density **enhanced drag**, slowing the satellites and preventing them from reaching their operational orbits.

- **Led to 38 out of 49 SpaceX satellites lost due to enhanced neutral density ($20 Million)**

ESPAT: Focus Area: Space Weather

Opportunity space for WACCM-X:

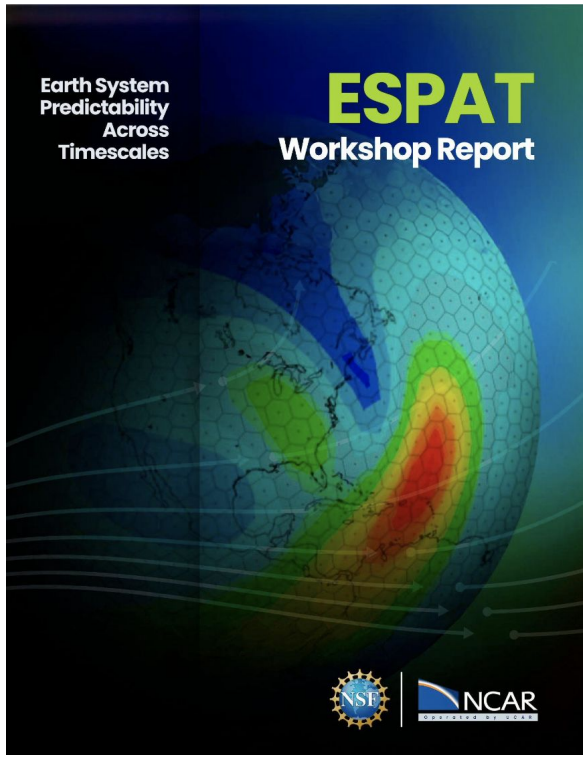
- Can be used to perform **fundamental research** to inform space weather forecasting & make scientific advancements
- Predicts thermospheric density variations under different solar and geomagnetic conditions, which are critical for satellite drag calculations.
- These fields are then used to estimate **drag forces on satellites** at various LEO altitudes.
- **Opportunity spaces:** Advancement of DA with WACCM-X;
  Improving **high-resolution coupling** between lower atmosphere and thermosphere
  Developing **ML-based hybrid model for thermospheric** density forecasting



Atm Chemistry & Emission & Hydrological Predictability in development

Key Takeaways

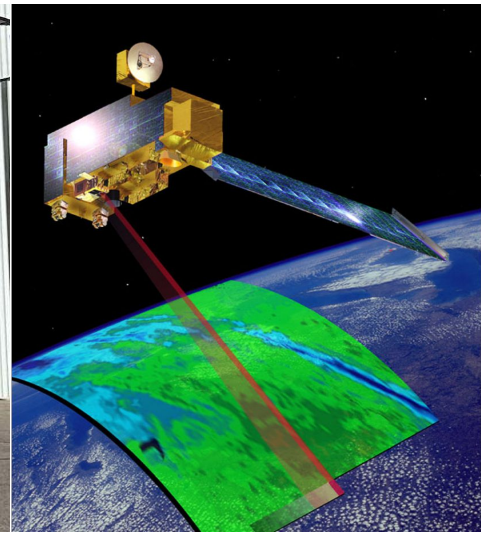
- Advancing Earth system predictability is essential for **societal resilience**
- A **multi-scale, interdisciplinary** approach is crucial. **Bridging** Weather, S2S, S2D, and climate communities is key
- **High-resolution or RR coupled models** are required for regional predictions, while urban-scale applications demand even f**iner resolutions + chemistry (~1 km). Development of parameterizations**, especially scale-aware
- **Integrating AI/ML** can revolutionize predictability
- **S2S:** CESM/ESPWG general: Sasha Glanville; Land-atmos interactions (Meg Fowler)
- Atm Chemistry/Composition & Hydrological predictability in dev



https://bit.ly/3PuVKI4

BAMS Article to be submitted in February

ESPAT Observational Needs:



Atmosphere:

high-resolution observations, aerosols, boundary layer, clouds, free troposphere and lower stratosphere

Land:

soil moisture, runoff, vegetation, land-surface fluxes

Ocean:

deep ocean measurements, air-sea fluxes

Human system:

data on human behavior and decision making