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Finding the Right Cadence: Pairing Compute, Ambition, and Realities to Create Decision-Relevant Climate Data across Central Asia

Presenting: Stefan Rahimi

University of Wyoming | CISL | NSF NCAR Operated by UCAR | KBTU Kazakh-British Technical University | CORDEX Coordinated Regional Climate Downscaling Experiment

Forward

- Context
- Central Asia: **A climate data desert**
- The Central Asia Climate Transitions Initiative (**CACTI**)
  - *Activities*
  - *Realities*
- Next steps

Some context

I am an Earth System Modeler studying regional climate change across the United States.

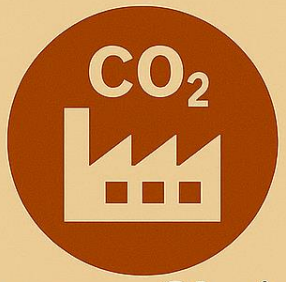
Earth System Models, or **Global Climate Models**, are the main tools used to project forward in time the earth's climate state.

Earth System Models

- Along with drug discovery & astrophysical modeling, climate modeling amongst most computationally expensive problems
- **ESMs cover the entire planet**; computational power limits their resolution

Three climate change uncertainty sources

Internal Variability



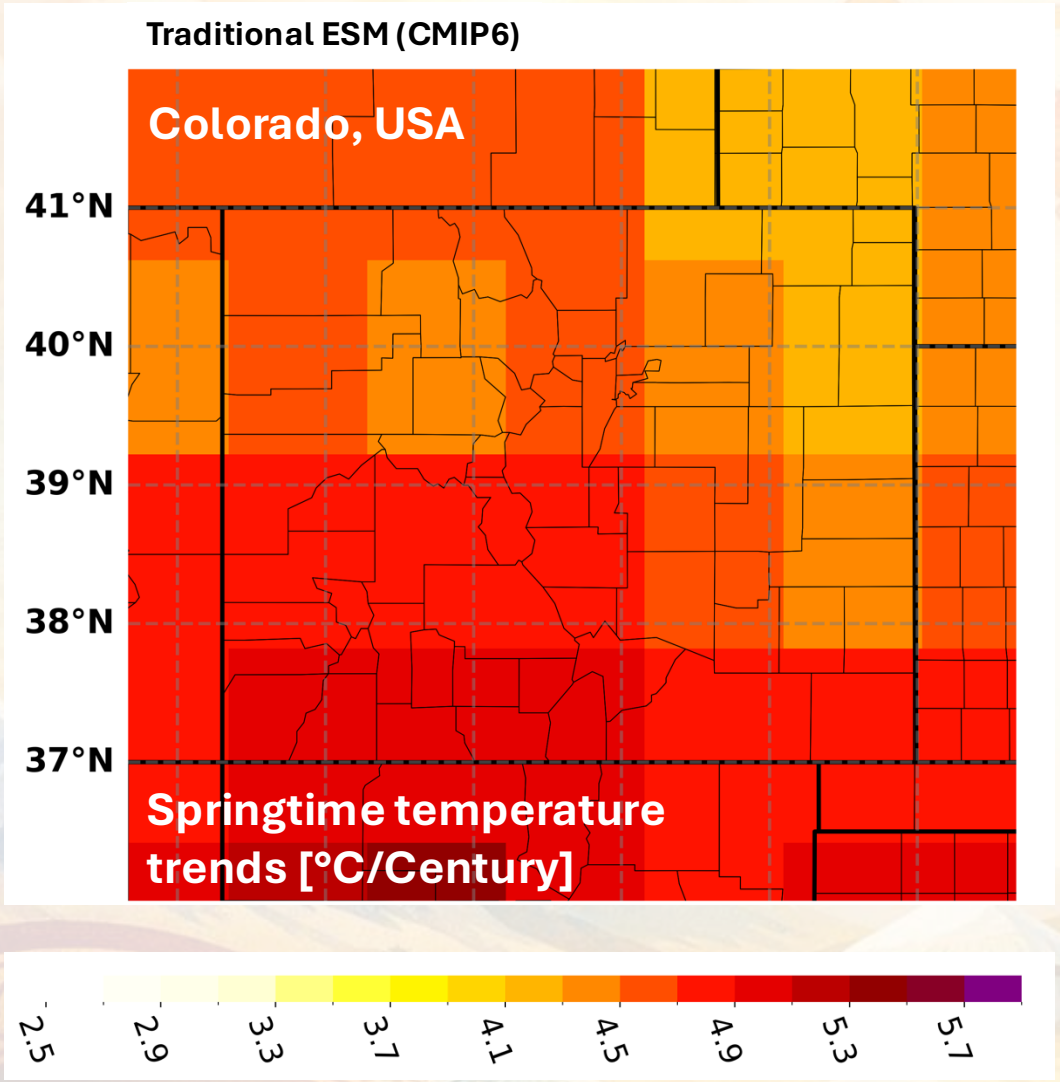
Human Choices & Future Emissions

Model Uncertainty

- Internal variability: Natural earth-system variations add “noise” and either attenuate or enhance anthropogenic trends. ***Limited historical duration reduces reliability of rare event statistics.***
- Future emissions: Trends can be altered by how much humans pump into the atmosphere, as well as other human behavior
- ESM differences: Different modeling centers across the planet have their own ESM: Like Ferraris and Lambos, different choices relating to components lead to different performances.

- **Quantifying these uncertainty sources is a big challenge.**

Earth System Models and downscaling

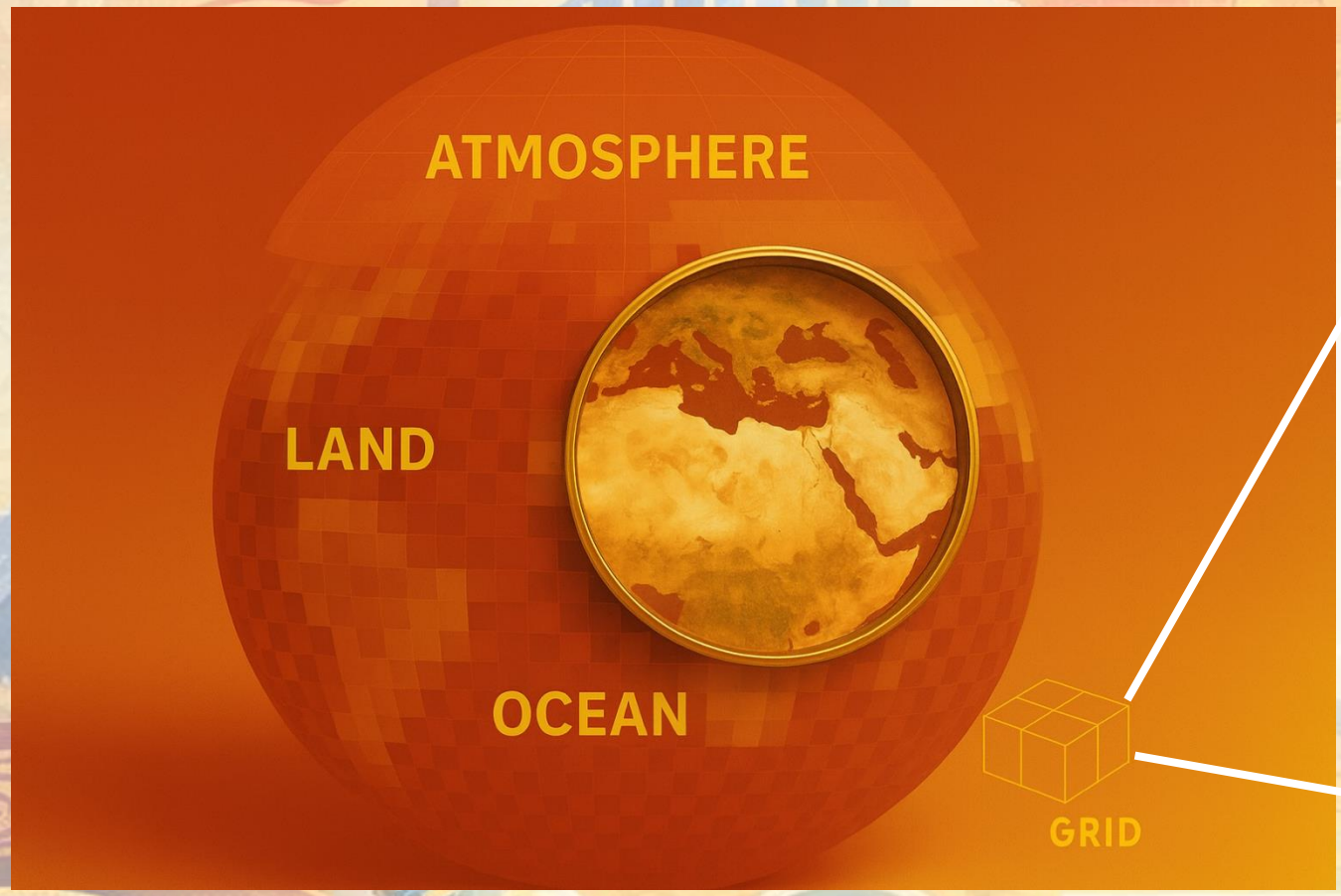


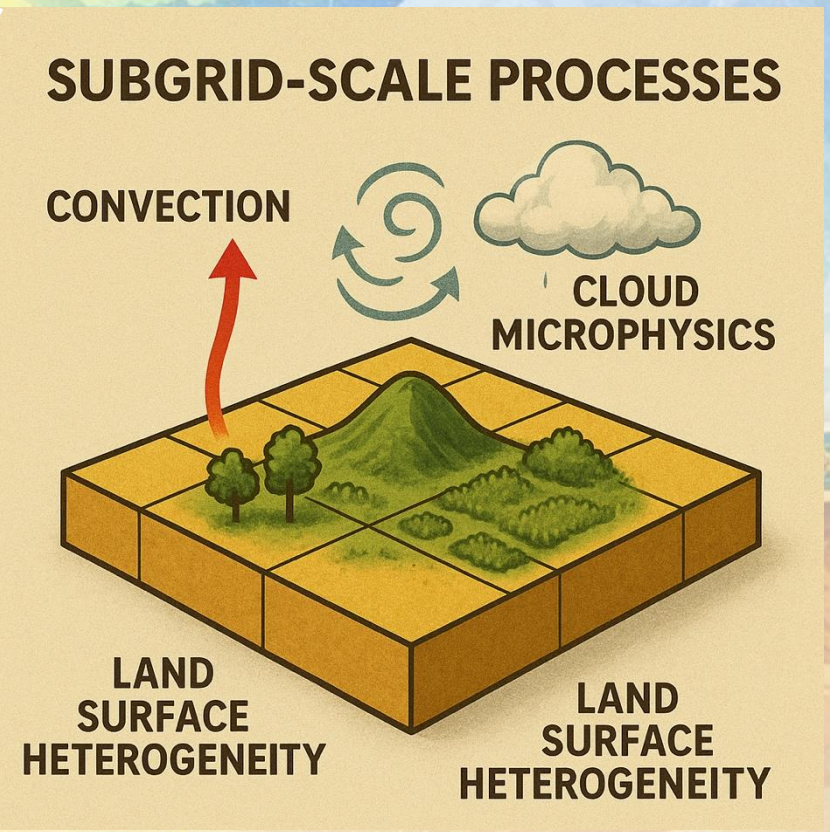
Like high-mountain Asia, the Western USA has complex terrain that meaningfully impacts national water security; **Traditional ESMs cannot resolve this**

Water, agricultural, and infrastructure **plans cannot be made at local scales** using this type of information

Zooming into a single grid box

Within ESMs, the weather as we know it evolves ‘sub-grid’

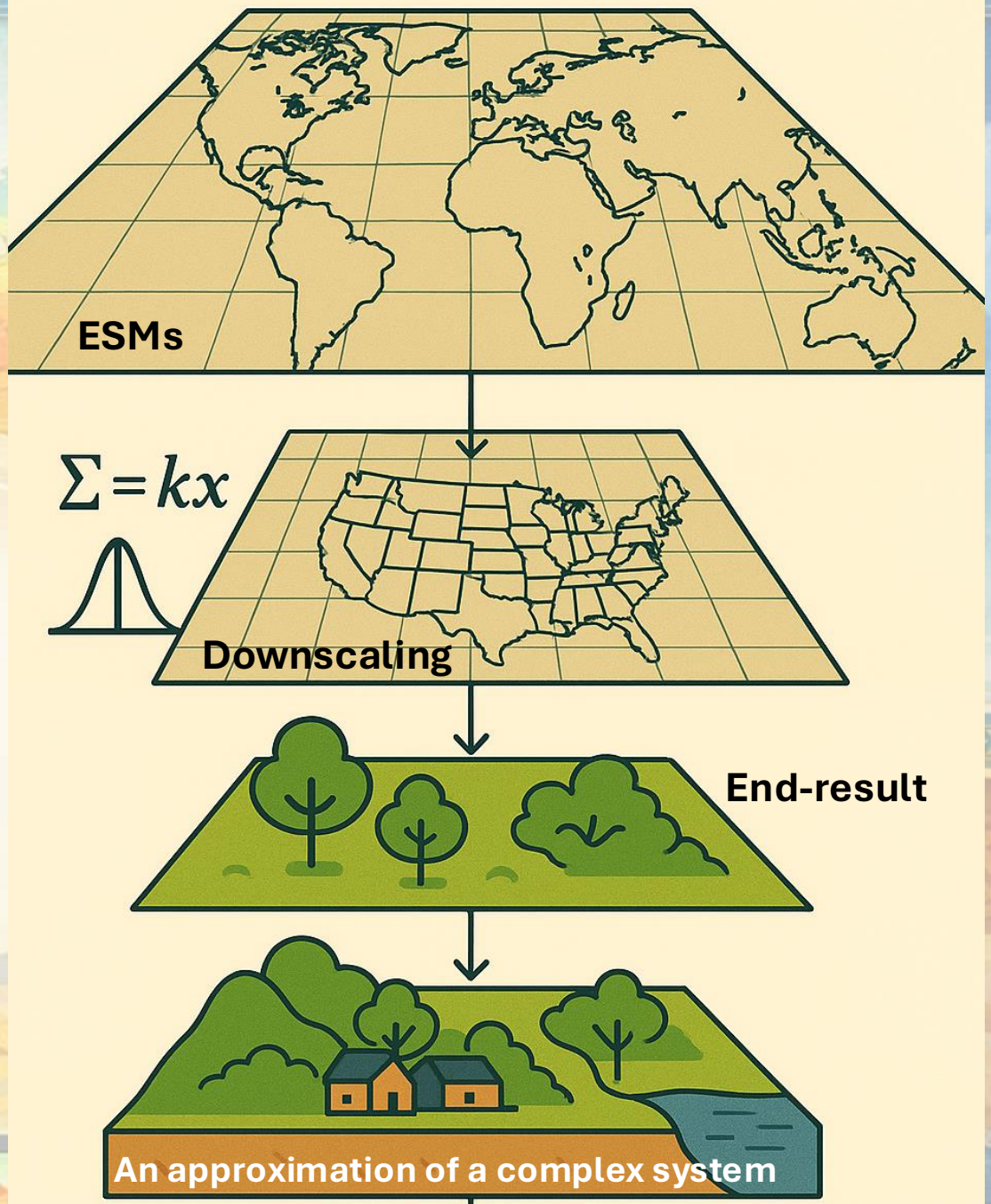




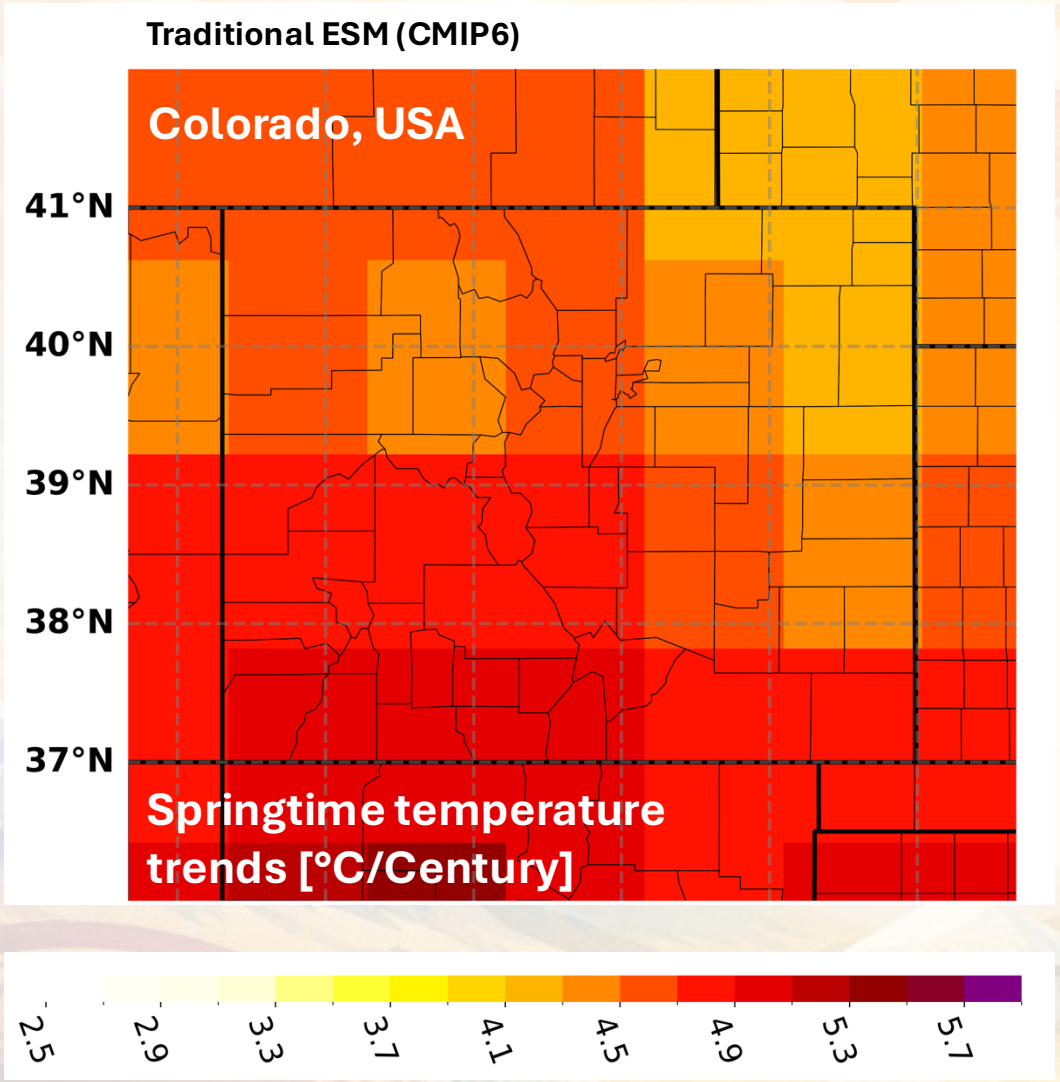
Bridging this resolution gap: Downscaling

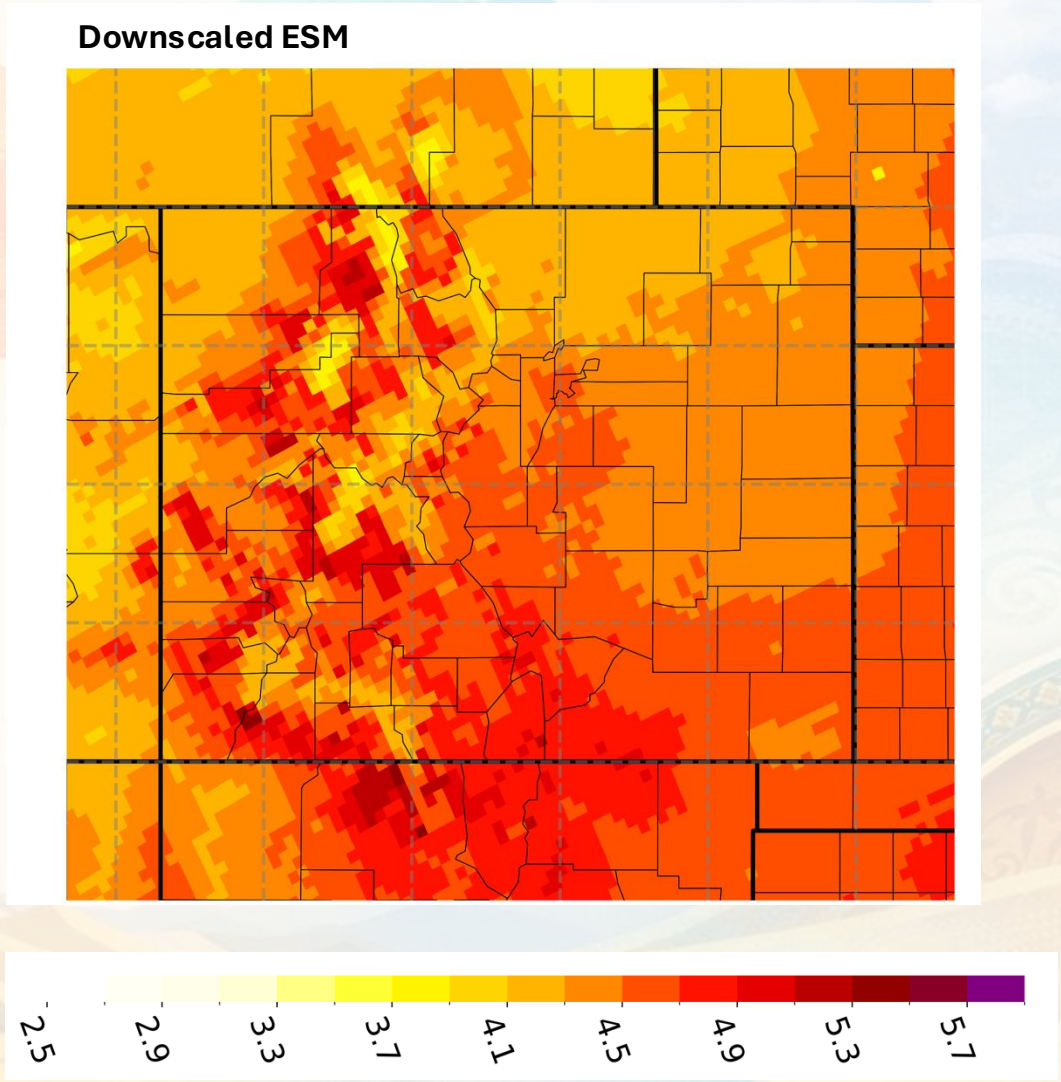
The transformation of ESM outputs to high-resolution via the use of **statistics** or **physics**

1. **Dynamical:** Regional ESM (**RESM**) embedded within an ESM, primitive equations solved in high-resolution
2. **Statistical**: Develop relationships between low- and high-resolution targets
   - **ESM trend preservation assumed**
   - **Bias adjustment ubiquitous**



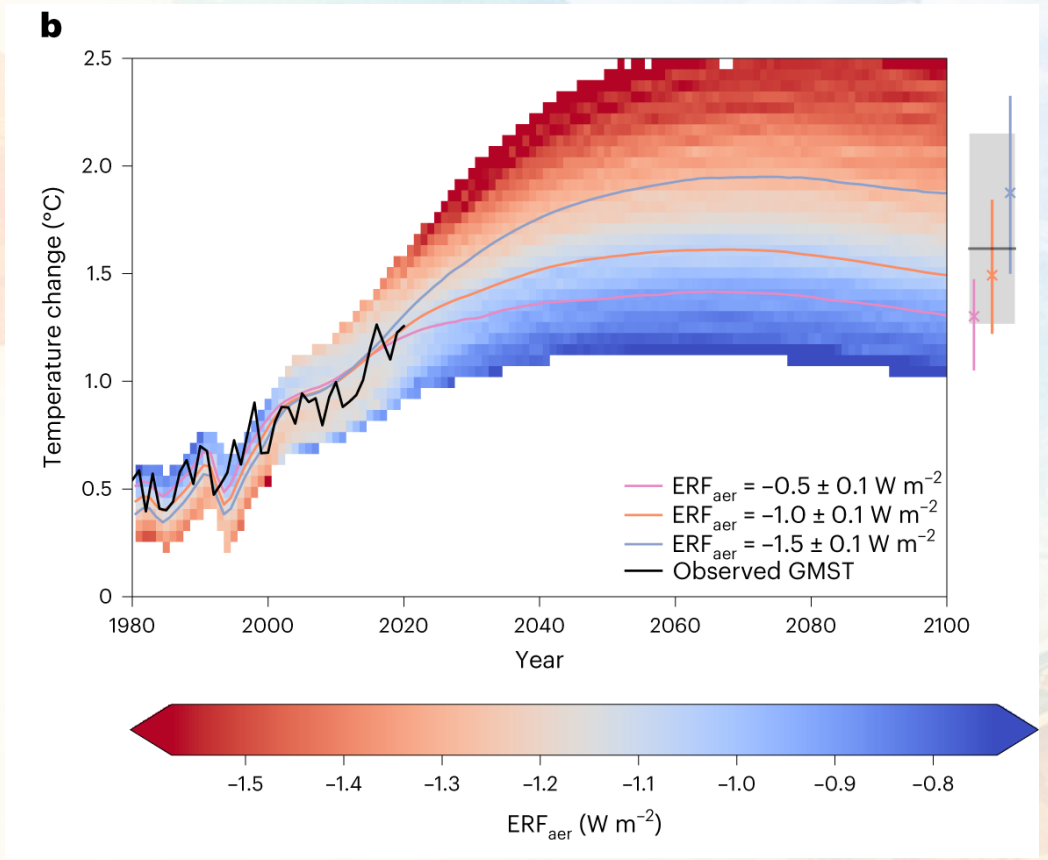
Earth System Models and downscaling





Earth System Models: It's not just about high resolution

We need to run **many simulations** under different future emissions pathways and from different centers globally to build an **envelope of uncertainty**



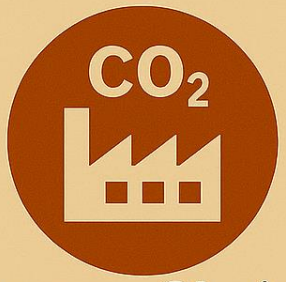
Projected global warming under SSP1: One of 5 future scenarios, this is the scenario under which the planet warms the least

A truth about **decision-relevant climate data**

It is too **computationally expensive** to run ESMs at resolutions sufficient for resolving **local-scale weather and climate** patterns whilst accounting for **full range of uncertainty**

Three climate change uncertainty sources

Internal Variability

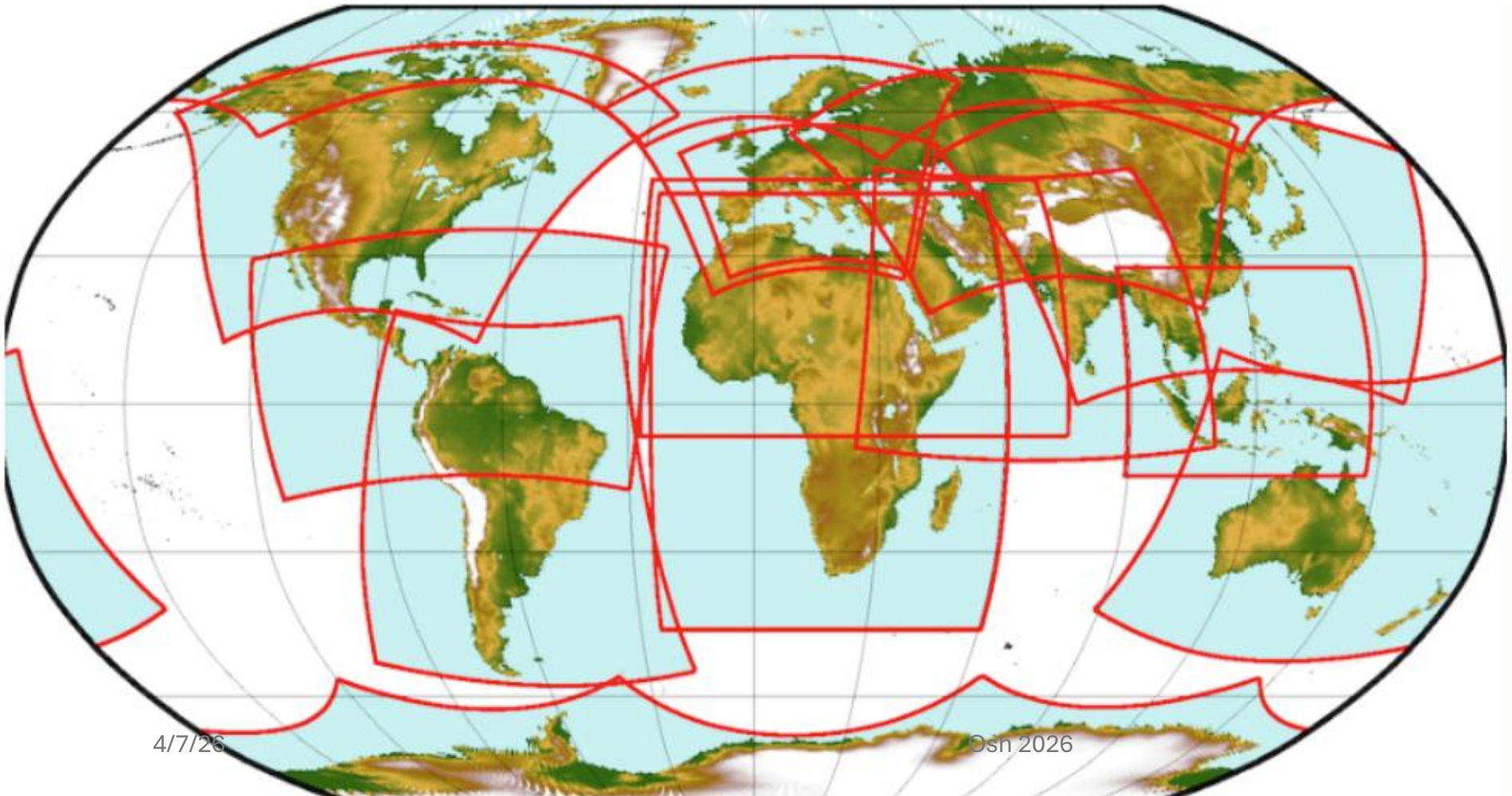


Human Choices & Future Emissions

Model Uncertainty

The Coordinated Regional Climate Downscaling Experiment (**CORDEX**) is a WCRP framework which creates and evaluates regional climate projections, advances regional climate knowledge, and aids in vulnerability, impact, and adaptation studies

CORDEX
Coordinated Regional Climate Downscaling Experiment



- Region 1: South America
- Region 2: Central America
- Region 3: North America
- Region 4: Africa
- Region 5: Europe (EURO)
- Region 6: South Asia
- Region 7: East Asia
- Region 8: Central Asia
- Region 9: Australasia
- Region 10: Antarctica
- Region 11: Arctic
- Region 12: Mediterranean (MED)
- Region 13: Middle East North Africa (MENA)
- Region 14: South-East Asia (SEA)

Pivoting back to Central Asia

Despite **its strategic importance as a headwaters region and agricultural hub**, Central Asia has access to a relatively **limited** datastream of future **climate information**, especially data which are **physics-** rather than statistically-based

An opportunity?

DERECHO

University of Wyoming: A computational powerhouse

- **UWyo** enjoys a **14% access** to the NCAR-Wyoming Supercomputing Center
- This resource has allowed our team to produce one of the most comprehensive downscaled ensembles ever created across the western United States for IPCC AR6.
- **The resource has traditionally been underused**
- **Let's use this resource to create projections across Central Asia!**

2024: Kazakhstan, Kyrgyz Republic, & Uzbekistan

UWyo's **Center for Global Studies** provided Callie and I a small seed grant to visit Central Asia over the course of two weeks

Tashkent: Green University & TIAME Irrigation

Almaty: Geologikal and Mineralogikal Sciences, Academy of Science Institute

Almaty: Al-Farabi Kazakh National University

Almaty: Kazakh-British Technical University

Almaty: KazNARU, KazNu

Astana: Kaz HydroMet & Nazarbayev Universtiy

Osh: GEWEX meeting on Central Asia climate & Osh State University

2024: Kazakhstan, Kyrgyz Republic, & Uzbekistan

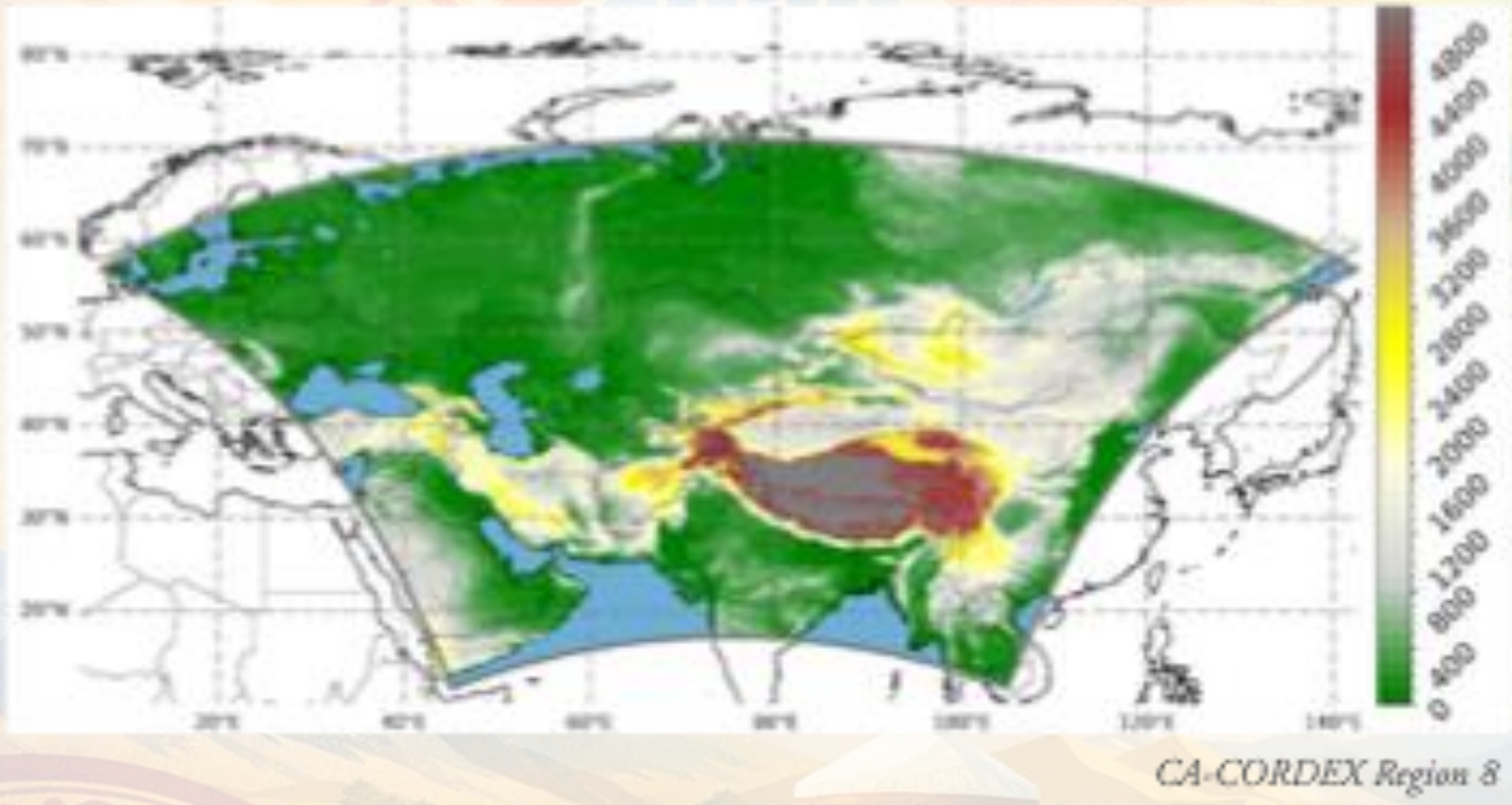
So, it is May 2024….

- Lots of enthusiasm
- Let's find funding to do this….**not so easy**

2024 ends and 2025 begins, still no progress…

Let's do something anyways: Callie connected us with students at KBTU, Central Asia University (Uzbekistan). I connected with fellow CORDEX representatives (Michelle & Shaukat), to organize **a volunteer downscaling activity across Central Asia**

The Central Asia Climate Transitions Initiative (CACTI)



Phase 1: Produce advanced downscaled datasets using same techniques as used here in U.S.

Phase 2: Integrate these **datastreams** into **decision-making** frameworks to support climate planning

The Central Asia Climate Transitions Initiative (CACTI): Phase 1

Beginning in March 2025, a group of about a **dozen** began to meet **twice per week** from 1500-1530 UTC

Gained access to the NCAR HPC

Learned the basics of **Linux**

Learned how to operate a regional downscaling **pipeline**, **managing 100s of TB of data**

Group exercise

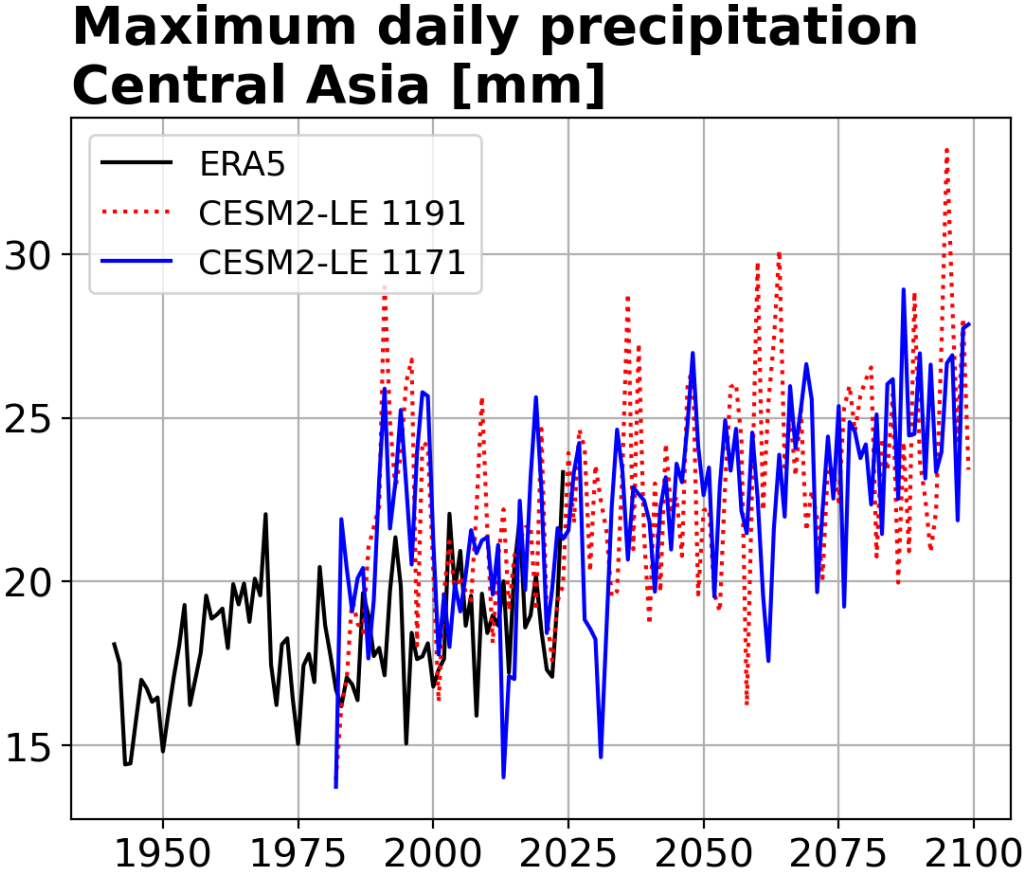
- Let's visualize the domain using python
- Copy `/glade/u/home/srahimi/outgoing/entralAsiaDomain.ipynb` to your ho space
- Navigate to jupyterhub.hpc.ucar.edu and login/authenticate
- Select 'Casper login node'
- Open the newly copied notebook and run using the NPL 2025a kernel

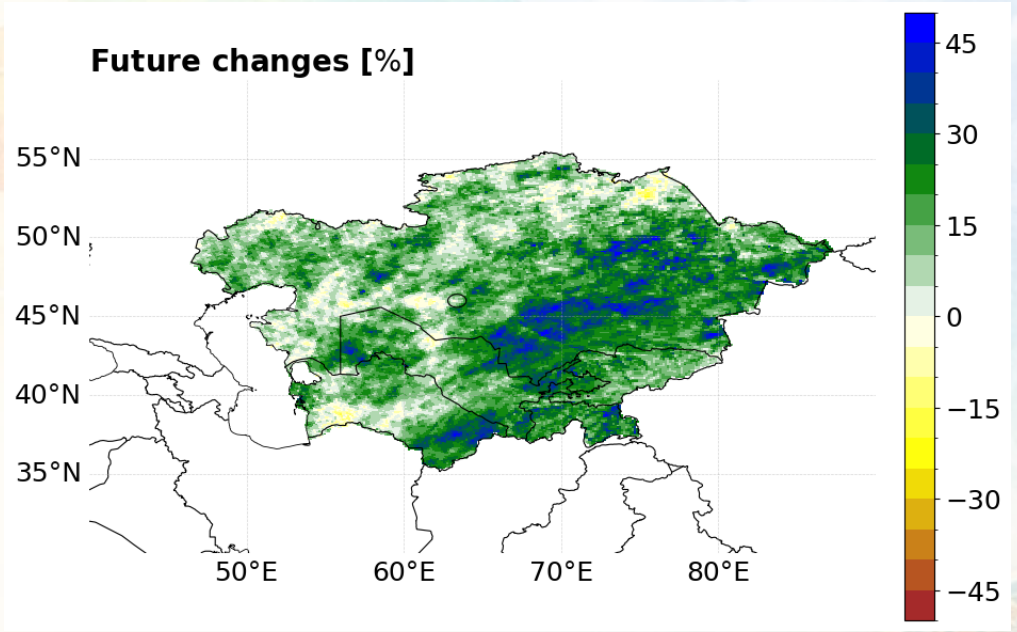
Many recordings saved in shared Google Drive

Distributed computing

Data processing

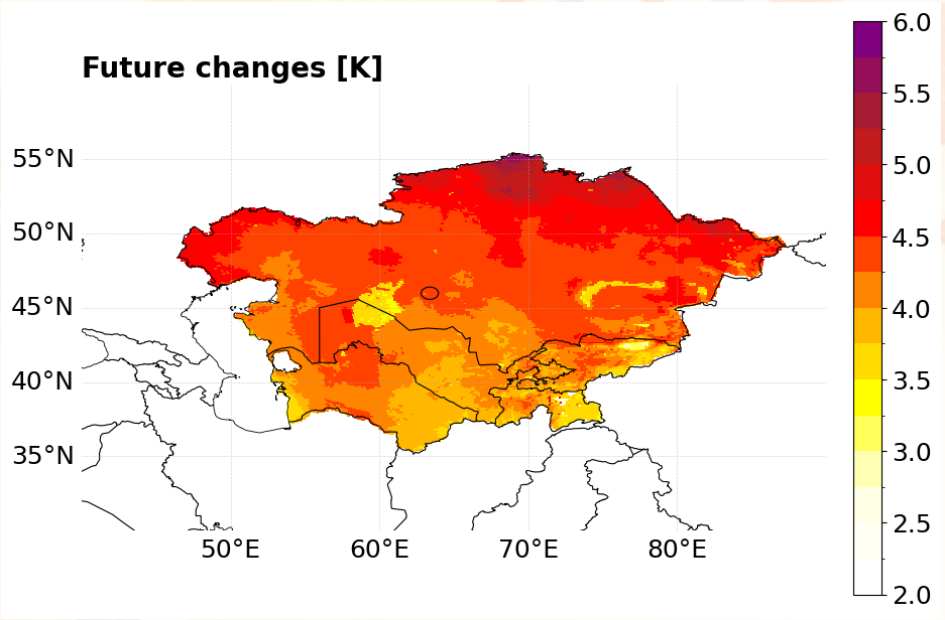
Some early results: Extreme rainfall



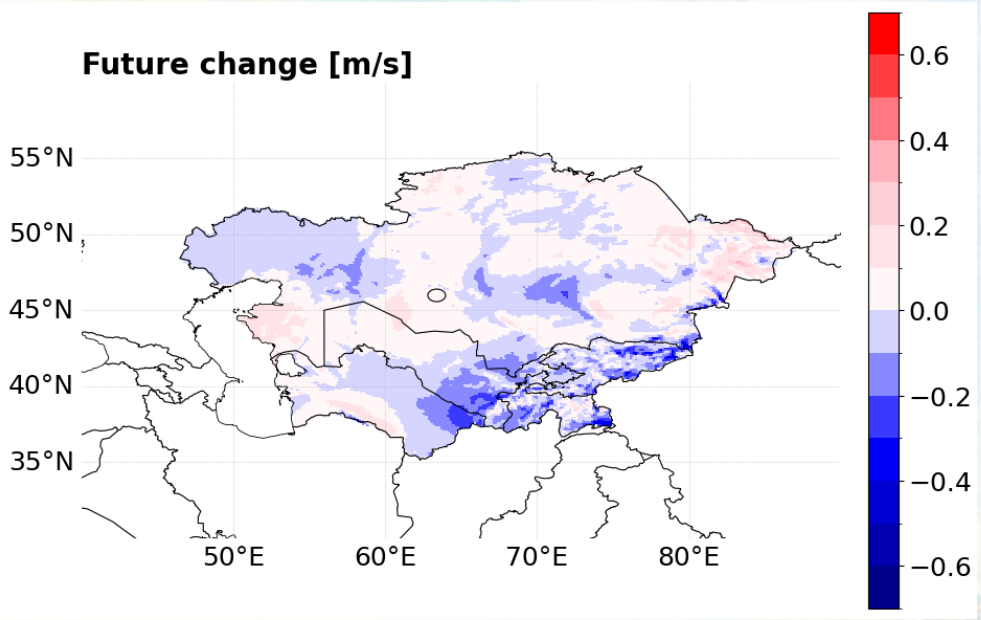


Extreme rainfall events will continue to rise **rise** across Central Asian countries **despite increasing aridification**

Some early results

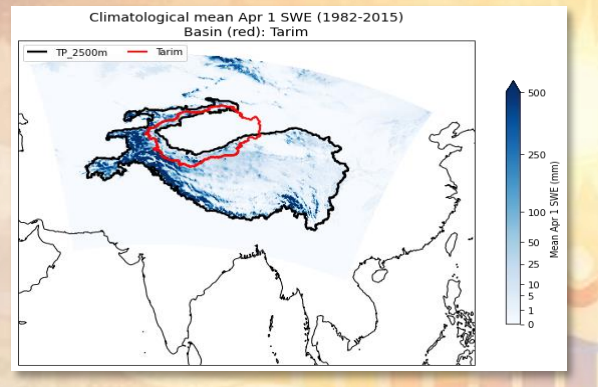


It **warms**….with depressed amounts of warming across the mountainous Kyrgyz Republic due to retained snow cover

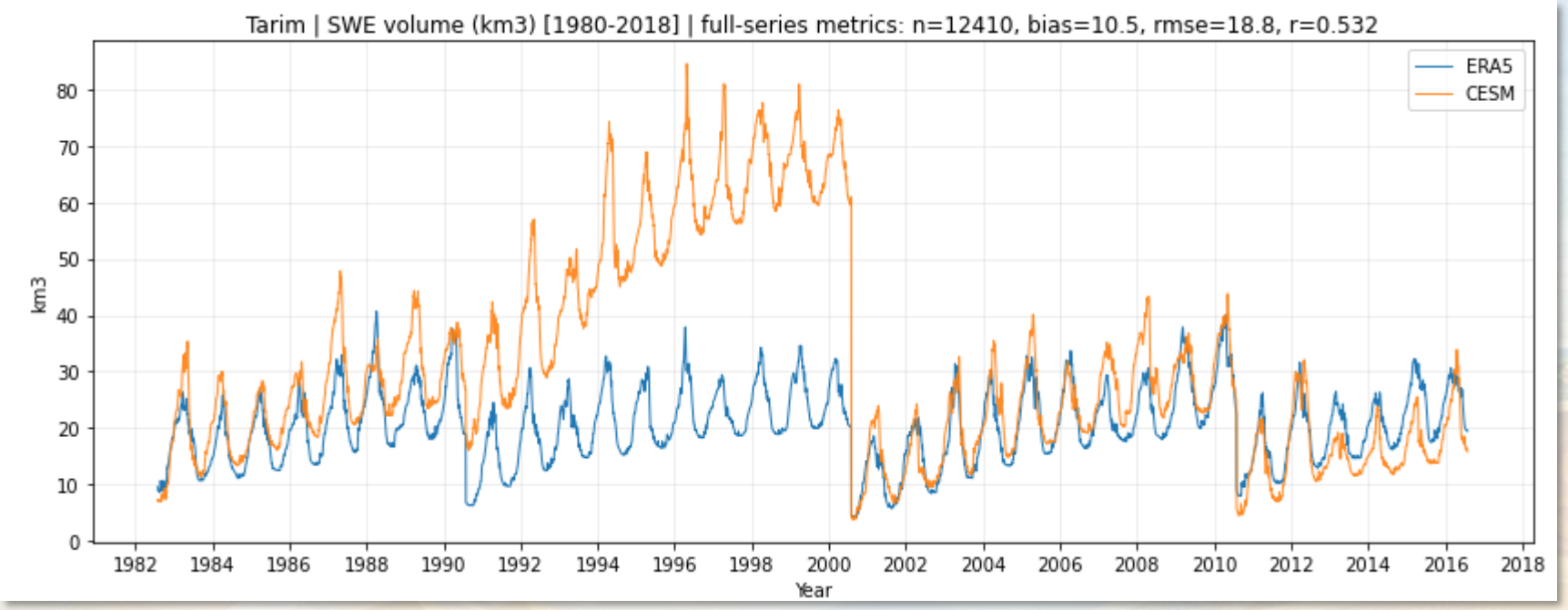


Unlike the western U.S., h**ub-height** wind declines are minimal, but they do decline more across the high mountains of Kyrgyz Republic

Some early results: An eye sore across the Tarim Basin



We are still working out the bugs; **more eyes/hands help this along**



Next steps and the next IPCC

- **With access to compute continuing,** we have a powerful opportunity to produce comprehensive ensembles of downscaled climate data across Central Asia; **accelerated with AI**
- **We need consistent engagement;** This means we need to secure consistent funding for a graduate student or two
- **Simulation nucleus** is actively being used to train a climate emulator that can be used to efficiently downscale **hundreds of Earth System Models across emissions scenarios**
- **Once downscaled ensemble matures;** we can use data to support geospatial analysis by students, connect with agroecon and hydro modelers, etc., with sites set on IPCC AR7.