Progress Towards a GEWEX Regional Hydroclimate Project over the CONUS

Tim Schneider[1], Sarah Tessendorf[1], Peter van Oevelen[2]
[1]NCAR, [2]Director IGPO & GMU

Presentation to the SAIL/SPLASH Community
17 April 2023

Outline

I. **A Couple of 'Science Teasers'**

II. Brief Introduction:

  i. What is an RHP?

  ii. Why do we need one?

III. Highlights from Science Plan (Draft)

IV. Next Steps – Discussion

"How can we know the dancer from the dance?"

From the poem Among School Children, by W. B. Yeats

A Science Teaser

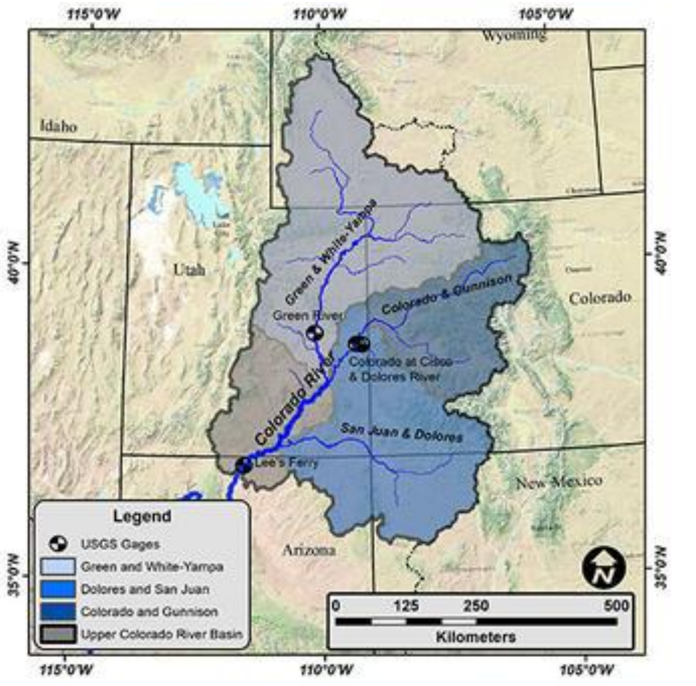
Water in the West – The Headwaters

The Upper Colorado River Basin (i.e. above Lee's Ferry, AZ) produces the majority of water in the Colorado River Basin, which is the source of water for 40 million people across seven states of the Southwestern United States, and two states in Mexico.

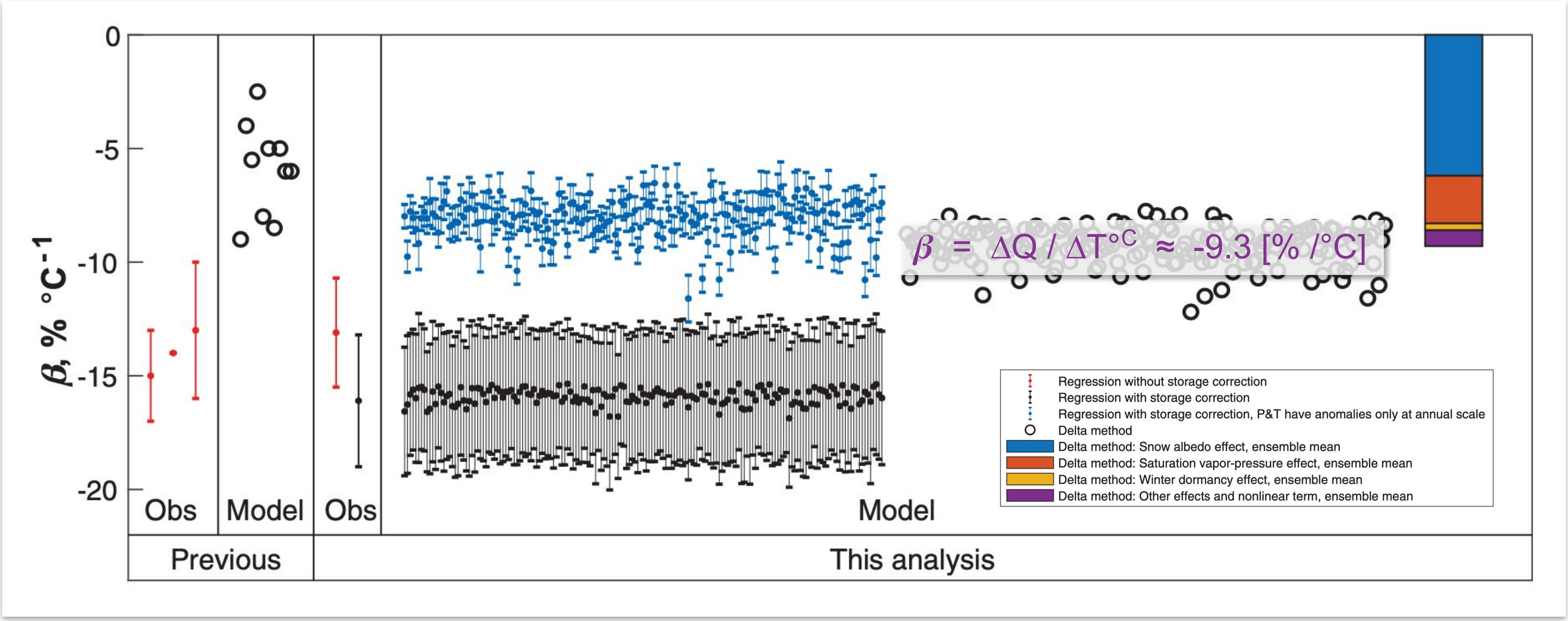
Colorado River water irrigates over 5 million acres of cropland, and it supports an estimated economic activity that exceeds one trillion dollars annually.

All of the water in the Colorado River Basin has been allocated – there is no wiggle room in this system.

And, streamflows in the basin have been declining…
(Naturalized flows in the CRB have declined 20% over the past century or so)



Sensitivity (β) of River Runoff due to a Changing Climate



This sensitivity (β) is attributed to changes in snowpack/albedo and ET. **Precipitation remains a big "?"** Factoring in future climate-driven changes (RCP8.5) to precipitation, Milly and Dunne estimate that the range in β is from +3% to -40%.

From: Milly, P. C. D. and K. A. Dunne , 2020: Colorado River flow dwindles as warming-driven loss of reflective snow energizes evaporation. *Science,* **367** (6483), pp. 1252-1255. DOI: 10.1126/science.aay9187.

Another Science Teaser

Impacts of Water and Energy Processes on Temperature & Precipitation Biases at the Surface

In the U.S.' Great Plains, mesoscale convective systems (MCSs) produce a significant portion of the annual precipitation in this region.

The sharp precipitation gradient across the Great Plains is shifting: the "100th meridian" is moving east; and seasonal relative peaks of precipitation and temperature are **fluctuating** in unexpected ways (Jeff Basara, personal comm.).

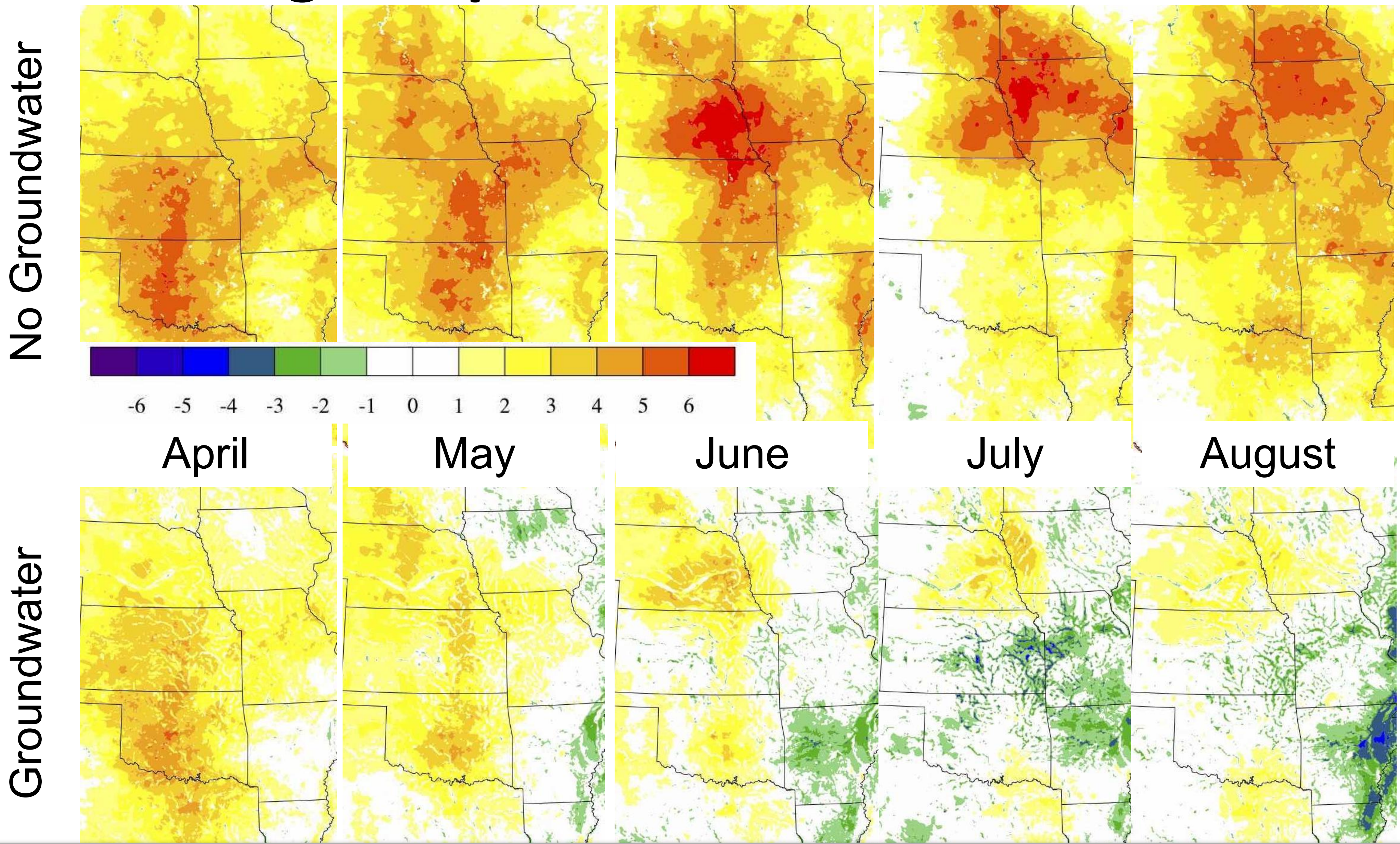
Modeling the fluxes of energy and moisture across the land-atmosphere interface are crucial to getting the temperature and precipitation biases right.

Recent work has shown that high spatial model resolution and a coupled groundwater model are important factors (coupled groundwater – land surface – and atmosphere models).

The image on the following slide shows a reduction in T_{2m} warm biases in the WRF model (a story of coupling and resolution):

The Great Plains before the native grasses were ploughed under, Haskell County, Kansas, 1897, showing a man sitting behind a buffalo wallow.
Source: USGS

Evolving Temperature Bias over Central U.S.



See: Barlage, M., Chen, F., Rasmussen, R., Zhang, Z., & Miguez-Macho, G. (2021). The importance of scale- dependent groundwater processes in land-atmosphere interactions over the central United States. *Geophysical Research Letters*, *48*, e2020GL092171. https://doi.org/10.1029/2020GL092171

Outline

I. A Couple of ‘Science Teasers’

II. Brief Introduction:

- **i. What is an RHP?**
- **ii. Why do we need one?**

III. Highlights from Science Plan (Draft)

IV. Next Steps – Discussion

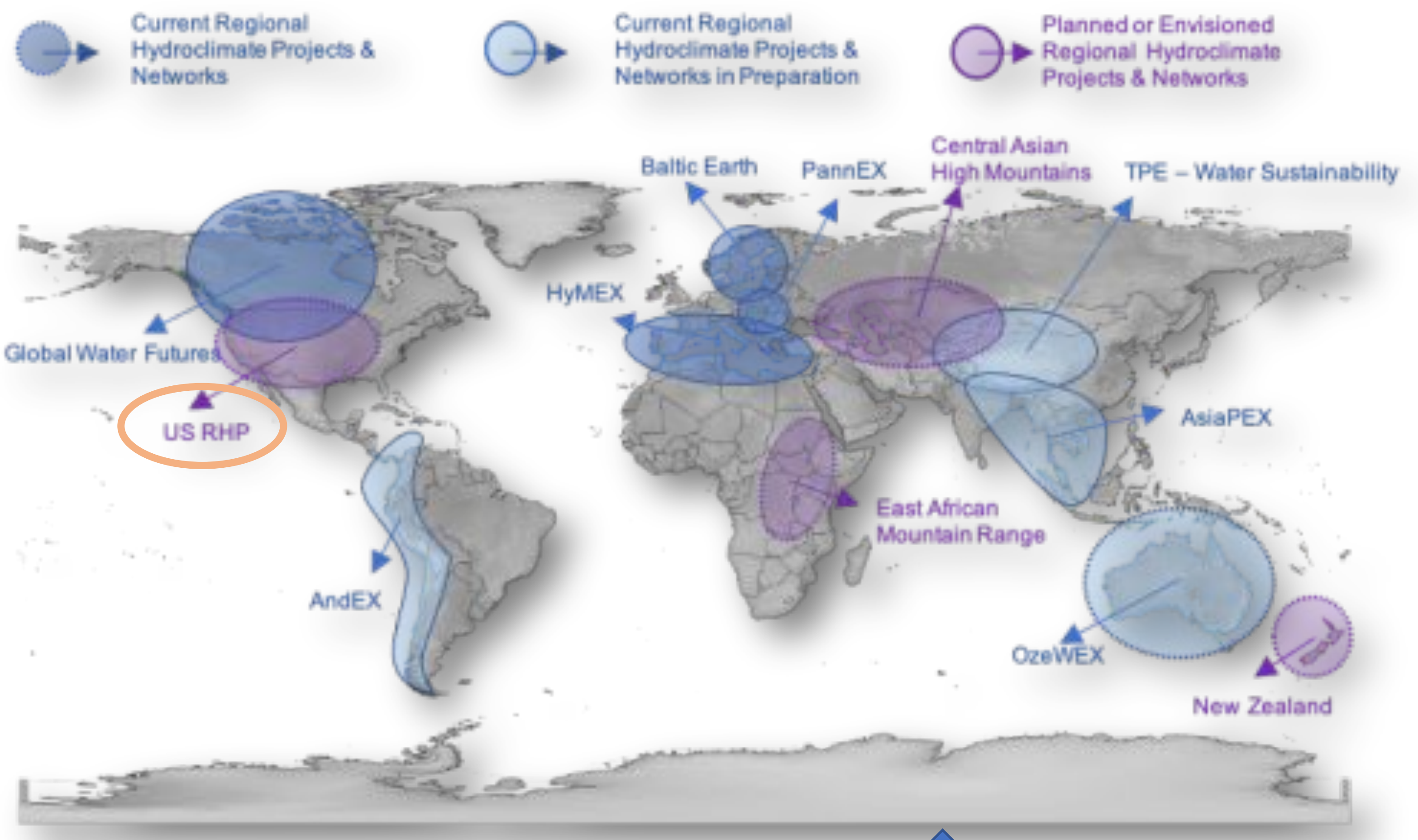
“How can we know the dancer from the dance?”

From the poem Among School Children, by W. B. Yeats

GEWEX Regional Hydroclimate Projects (RHPs)

RHPs are generally large, regionally-focused, multidisciplinary projects that aim to improve the understanding and prediction of that region's weather, climate, and hydrology.

All RHPs address the physical processes surrounding water and energy exchanges within a region, thus addressing the GEWEX Science Questions. Most RHPs are broader than this, often addressing questions related to the biosphere and carbon cycle, human interaction in the landscape, and even socio-economic factors.



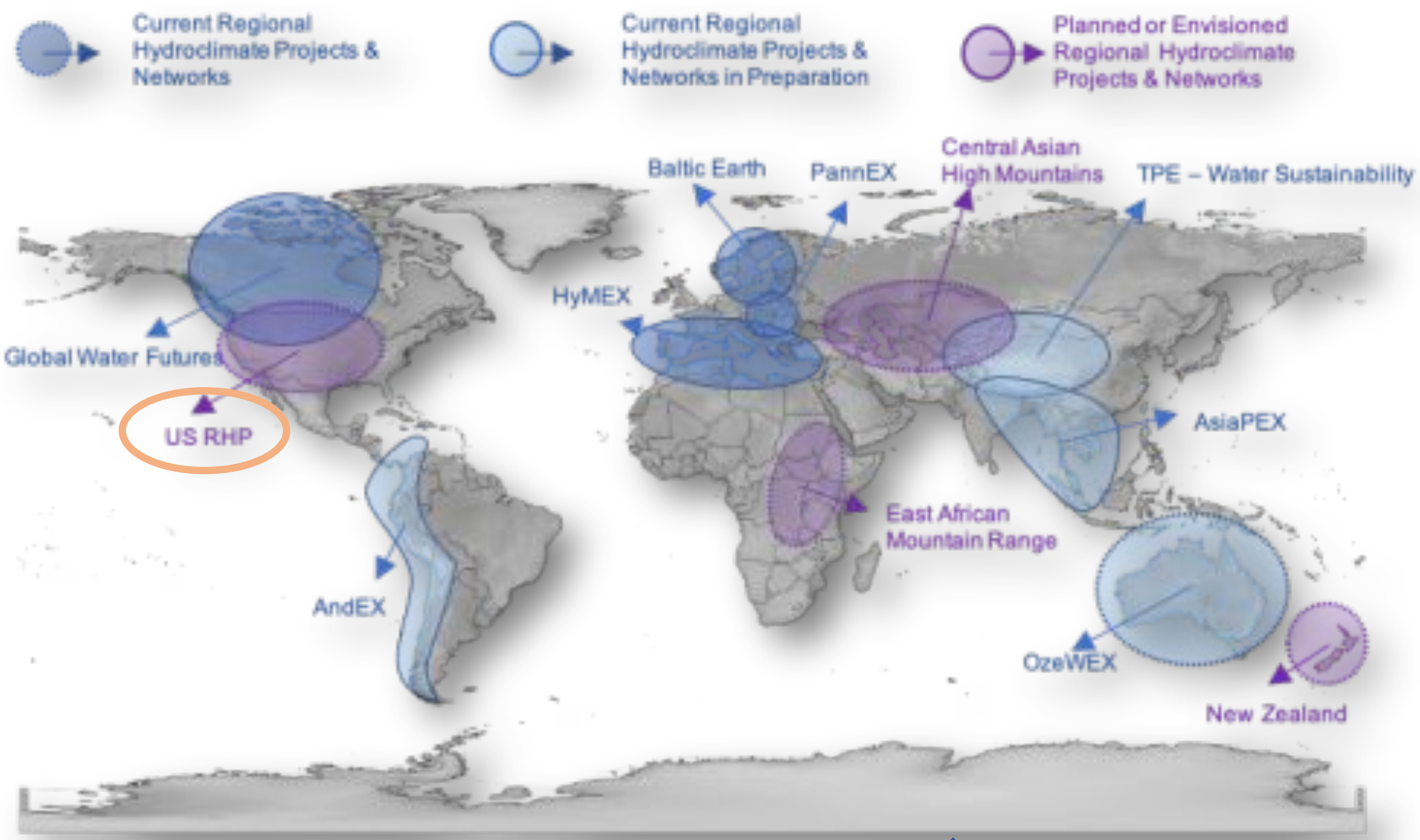
WCRP World Climate Research Programme → GEWEX Global Energy and Water Exchanges → GHP GEWEX Hydroclimatology Panel

GEWEX Regional Hydroclimate Projects (RHPs)

The US initiated GCIP about 30-years ago, and we were the world leaders in this scientific area at that time.

Today, other countries are leading the way; such as GWF in Canada and Baltic Earth in northern Europe.

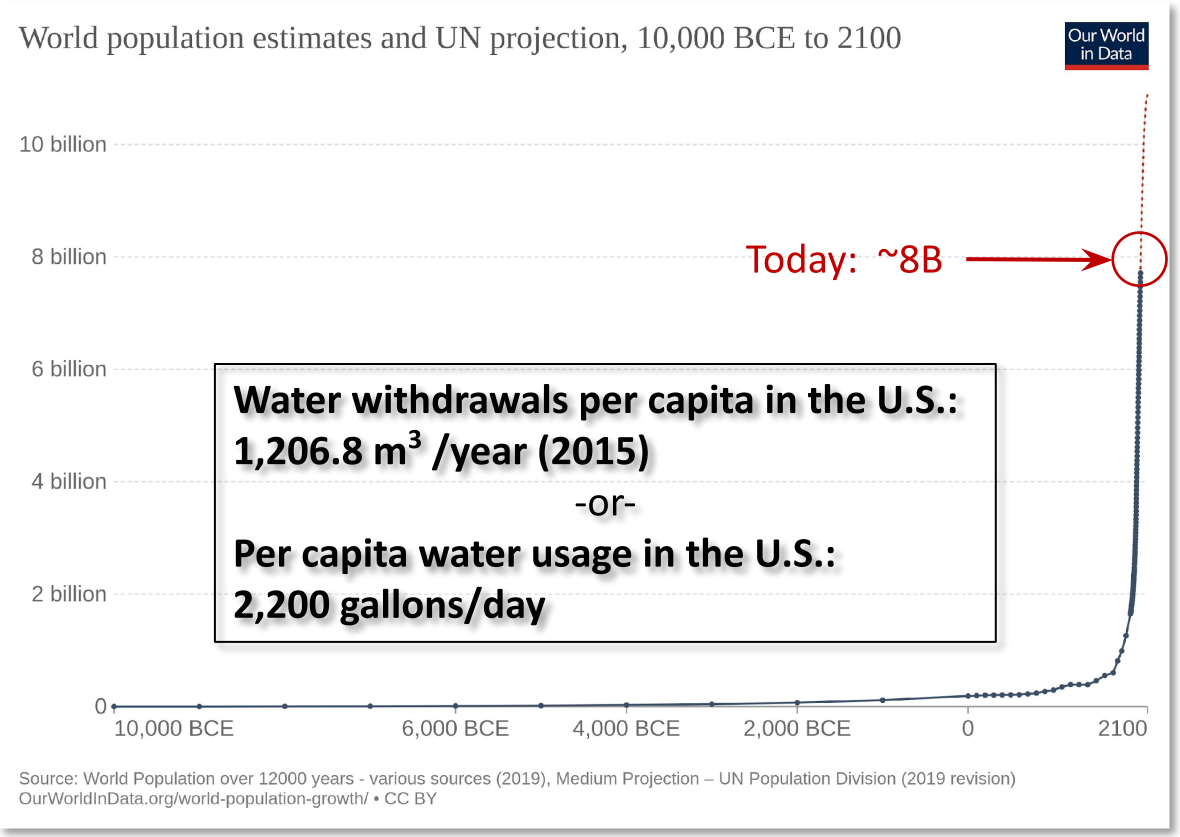
Building from our lesson's learned over the past decades and leveraging current investments, the US-RHP is poised launch the US to re-take our scientific leadership, for the benefit of our citizens.



WCRP World Climate Research Programme → GEWEX Global Energy and Water Exchanges → GHP GEWEX Hydroclimatology Panel

US-RHP: Why do we Need One?

The Anthropocene is here: Humanity's impacts are growing; so too is the need for accurate and robust environmental information at the appropriate scales.



Water withdrawals per capita in the U.S.:
1,206.8 m^3 /year (2015)

-or-

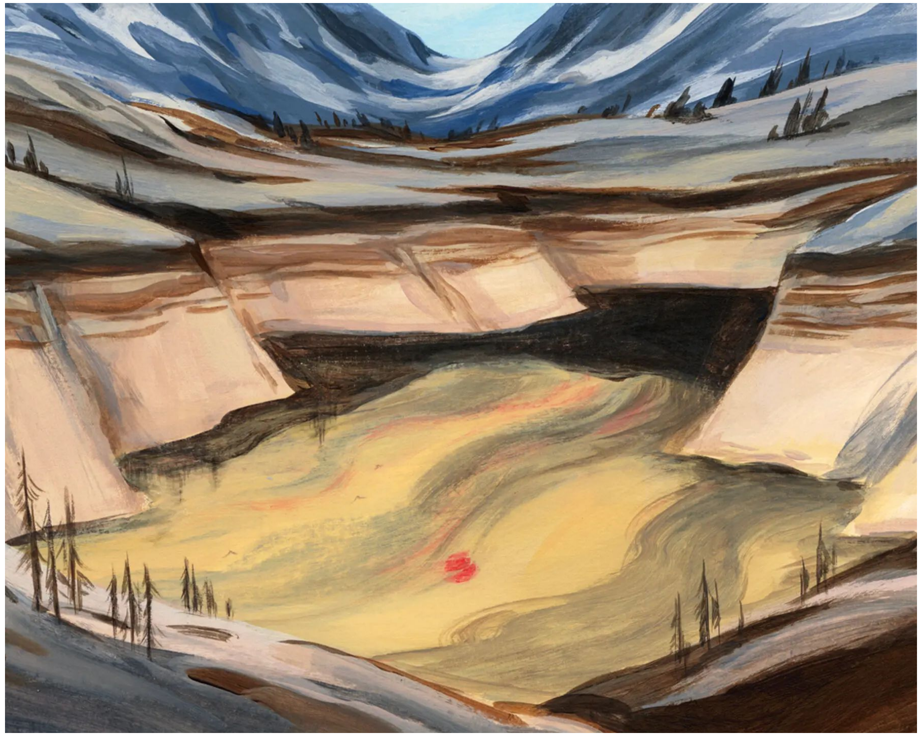
Per capita water usage in the U.S.:
2,200 gallons/day

https://commons.wikimedia.org/wiki/File:World-population-1750-2015-and-un-projection-until-2100.png

The New York Times

I'm a Scientist in California. Here's What Worries Me Most About Drought.

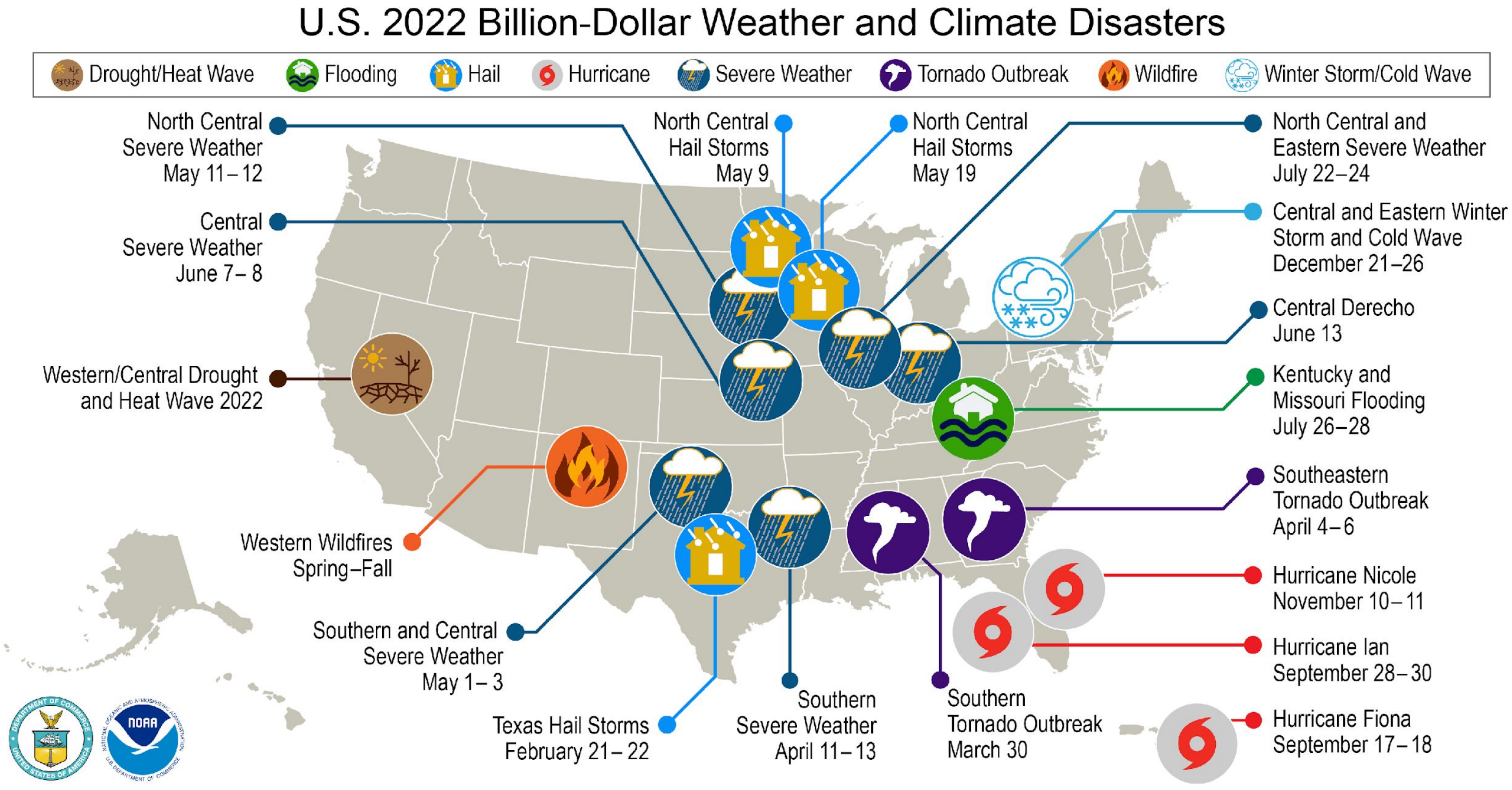
April 4, 2022



By Andrew Schwartz
Dr. Schwartz is the lead scientist and station manager at the University of California, Berkeley, Central Sierra Snow Lab.

https://www.nytimes.com/2022/04/04/opinion/environment/california-drought-wildfires.html

US-RHP: Why do we Need One?



This map denotes the approximate location for each of the ***18 separate billion-dollar weather and climate disasters that impacted the United States in 2022.***

“The U.S. has sustained 348 weather and climate disasters since 1980 where overall damages/costs reached or exceeded $1 billion (including CPI adjustment to 2023). **The total cost of these 348 events exceeds $2.510 trillion**.”

Source: https://www.ncei.noaa.gov/access/billions/

US-RHP: Why do we Need One?
The Science Case

- Despite GCIP & GAPP, our observations still cannot close the water and energy balances.
  - These were the last RHPs hosted in the U.S.
  - GCIP: GEWEX Continental-Scale International Project (1993-2000).
  - GAPP: GEWEX Americas Prediction Project (2001-2007).

- Our models are "outstripping" the observations; but are the models right?
  - We are now capable of modeling the CONUS at "high" resolutions over multiple decades.
  - Emerging observational capabilities; e.g. the GEWEX Land Atmosphere Feedback Observatory (GLAFO) & the USGS Next Generation Water Observing System (NGWOS).

- **<u>We need action now as a community</u>**, to close the energy, water and carbon balances in regional human-natural systems; to address the pressing science questions of the day.

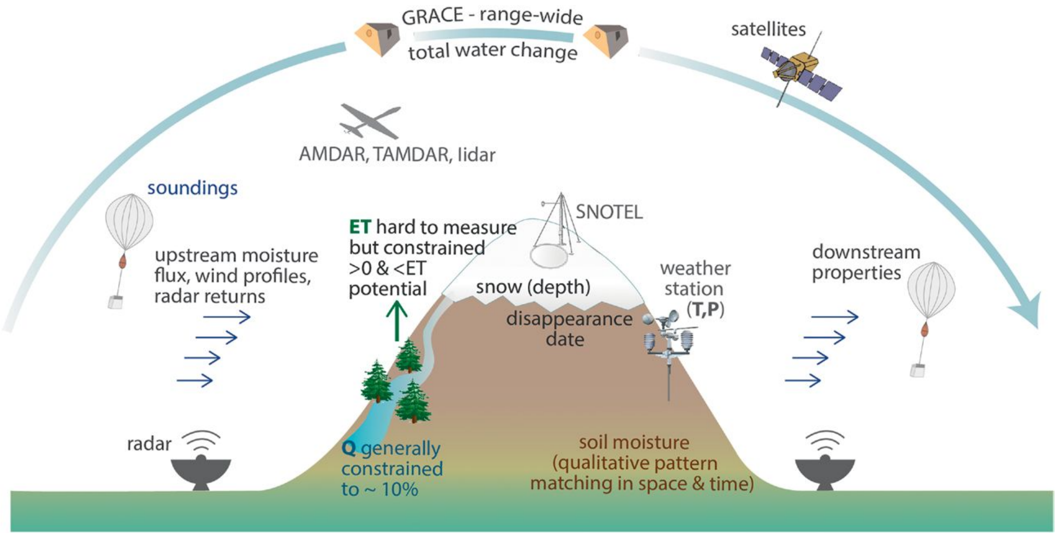
It is a complex, coupled system:

Water: $P + Q_{in} = ET + \Delta S + Q_{out}$
Energy: $R_n + G = \lambda ET + H$

Refine estimates of these terms; quantify their uncertainties; understand how will they change.

The *<u>Carbon Cycle</u>* most directly ties in through the "R_n" (energy) and "ET" terms.

<u>Anthropogenic influences</u> are manifold and impact all of these cycles through GHG emissions; land use/land cover change; and water resource management.



Lundquist et. al., 2019: Our Skill in Modeling Mountain Rain and Snow is Bypassing the Skill of Our Observational Networks. Bull. Amer. Meteor. Soc., ***100****, <u>https://doi.org/10.1175/BAMS-D-19-0001.1</u>*

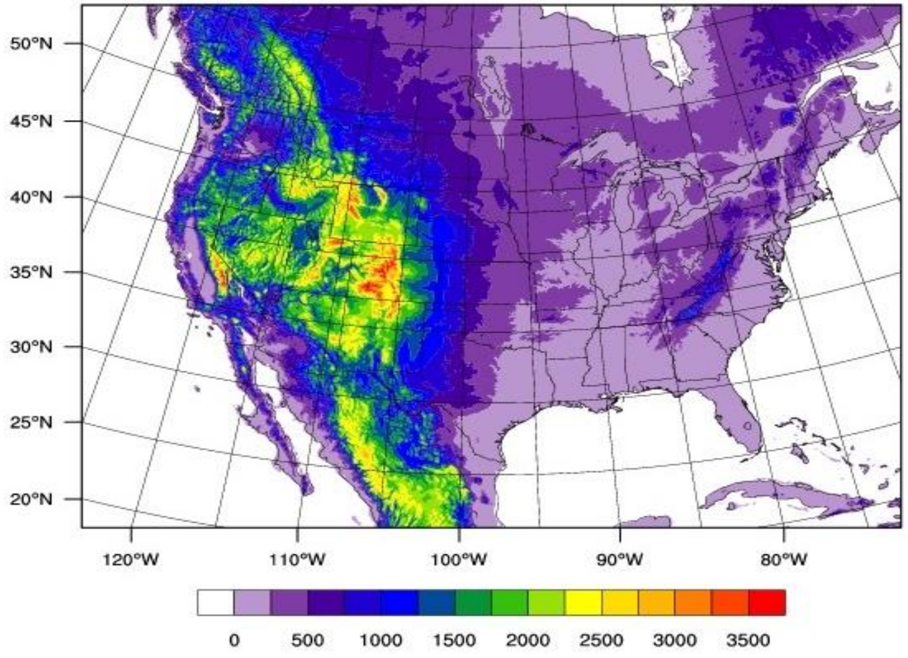
CONUS 404 Retrospective (1979-2022)

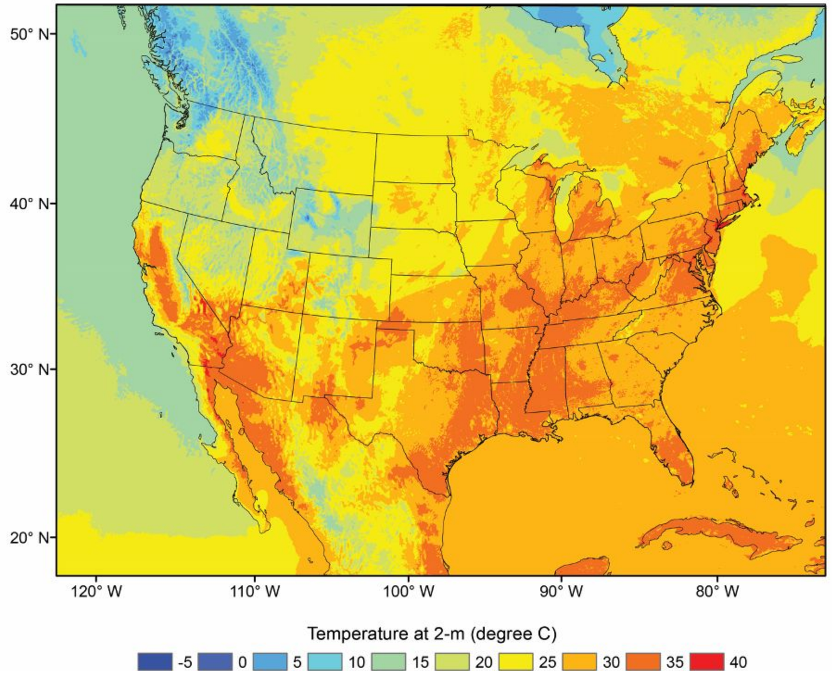
Top right: modeling domain with terrain height (m).

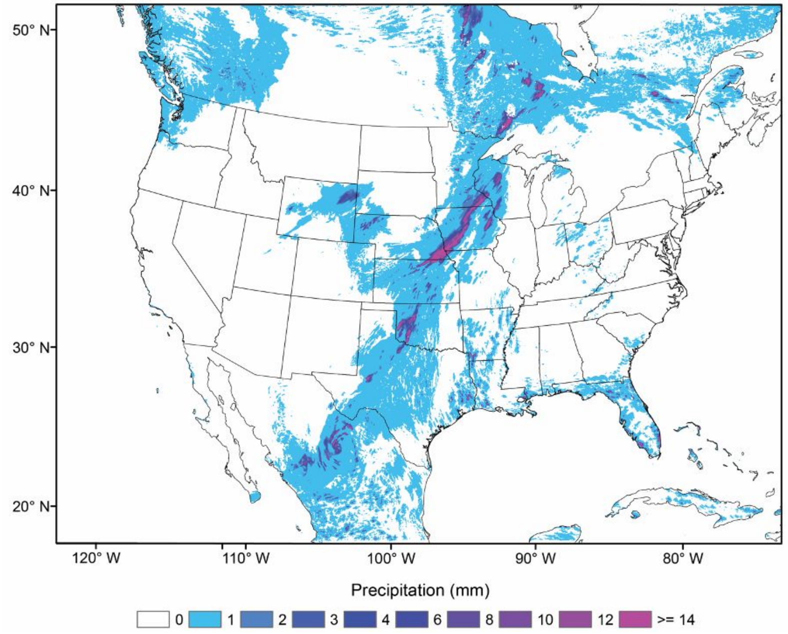
Clockwise examples of CONUS 404 generated fields: 2-m temperature, hourly precipitation, and volumetric soil moisture at 0-10 cm below the land surface.

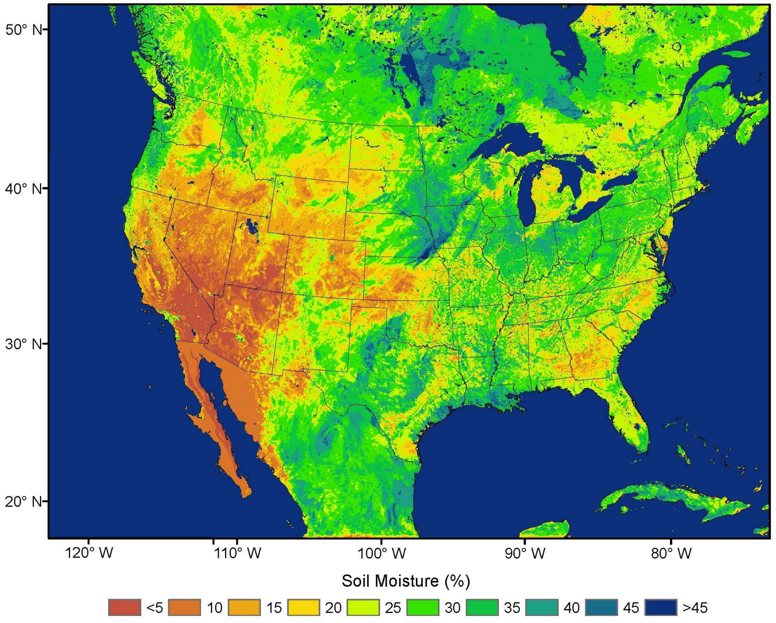
Valid at 18 UTC 4 July 2010.

Slide Source: Fei Chen, NCAR



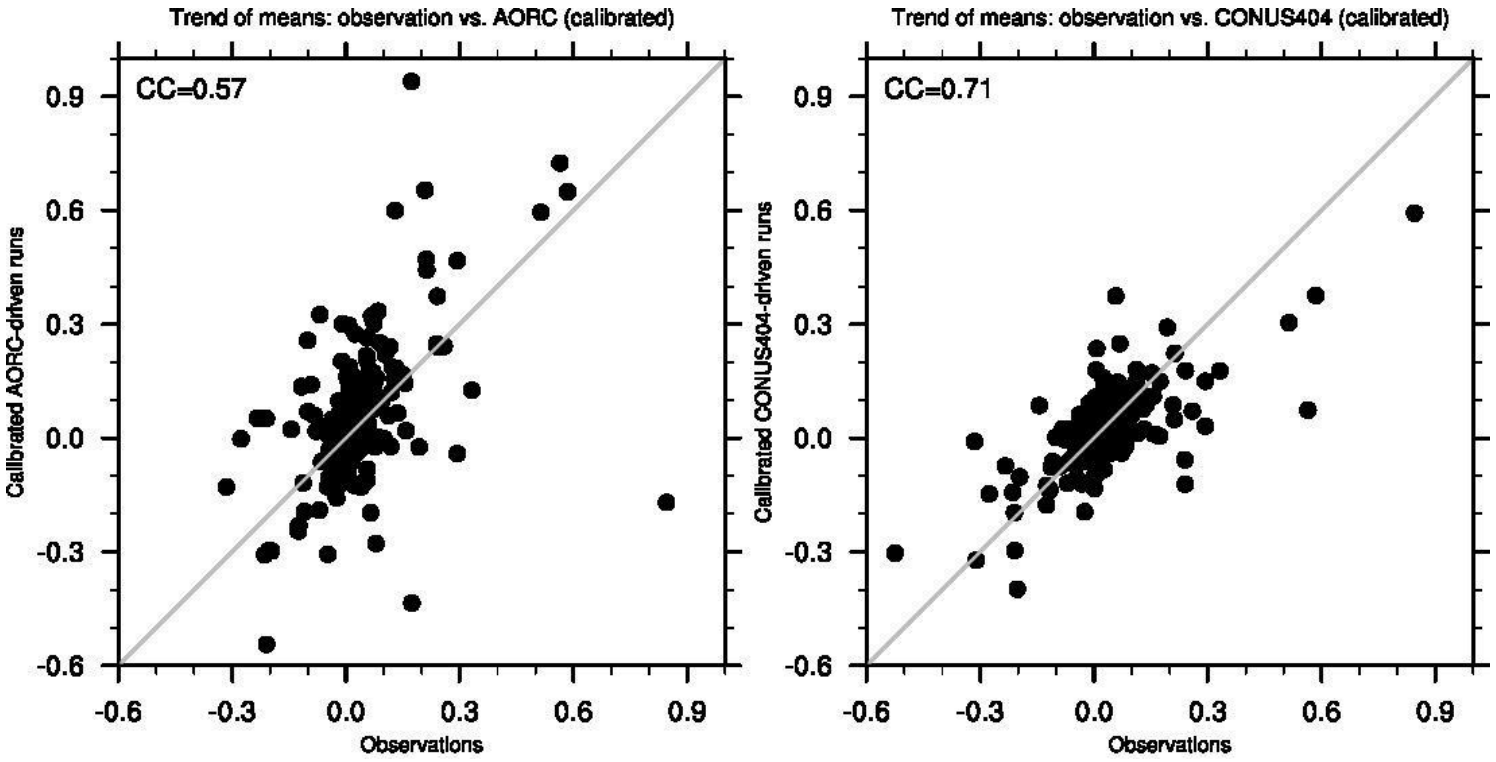






Hydrologic Response to CONUS404 Forcings

Trends of streamflow means [cms/year]



OBS vs. WRF-Hydro (NWM2.1)
forced with **AORC**
(calibrated by AORC)

OBS vs. WRF-Hydro (NWM2.1)
forced with **CONUS404**
(calibrated to AORC)

CONUS404 = NCAR's (with USGS) 40-year (now 43), 4 km resolution retrospective over the CONUS
AORC = NOAA "Analysis of Record for Calibration" used by the National Water Model

Courtesy of *Yongxin Zhang*

US-RHP: Why do we Need One?

The Programmatic Case

- Focus:
  - Provides a focal point for engagement
  - There has not been a major land-atmosphere project in the US for a long time and we still have a lot to learn
- Leveraging:
  - No one agency can do it all
- Engagement:
  - US-RHP as an agent for ‘Open Science’
  - Brings the international community to the table
- Economy/Effectiveness
  - More efficient use of tax payer dollars
  - The whole is greater than the sum of the parts

GEWEX US-RHP Proposal

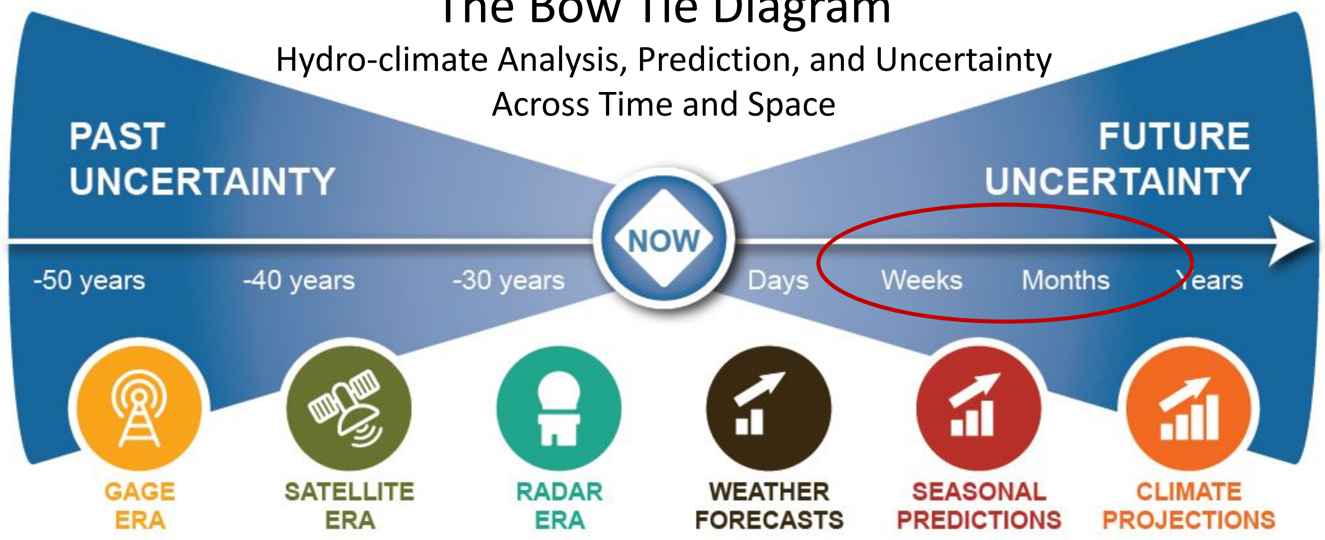
A ten-year effort to understand and characterize the Water, Energy*[1], and Carbon Cycles in the Anthropocene: driven by a need for usable modeling tools and actionable products developed in collaboration with stakeholders to address climate justice, and support water, food, and energy*[2] security for natural and human systems in a changing future.

*[1] In the sense of the Earth's (natural) energy cycle.

*[2] In the sense of human energy production/consumption.

The Bow Tie Diagram

Hydro-climate Analysis, Prediction, and Uncertainty Across Time and Space



Outline

I. A Couple of 'Science Teasers'

II. Brief Introduction:

  i. What is an RHP?

  ii. Why do we need one?

III. Highlights from Science Plan (Draft)

IV. Next Steps – Discussion

Partial Outline From: ***A GEWEX US-RHP FOR FOOD, ENERGY, AND WATER SECURITY IN THE ANTHROPOCENE***

II. US-RHP Scientific Strategy

2.1 Human Dimensions

2.2 Mountain Hydroclimate

2.3 Land-Atmosphere Processes and Coupling

2.4 Impactful Extremes

2.5 Organized Convection and Precipitating Systems

2.6 Advancing Observational Systems

~~2.7 Coastal Processes and Coupling~~

III. Digital Earth for the US (DEUS)

"How can we know the dancer from the dance?"

From the poem Among School Children, by W. B. Yeats

US-RHP *Notional* Scope

Modeling across scales:
global → **CONUS** → watershed

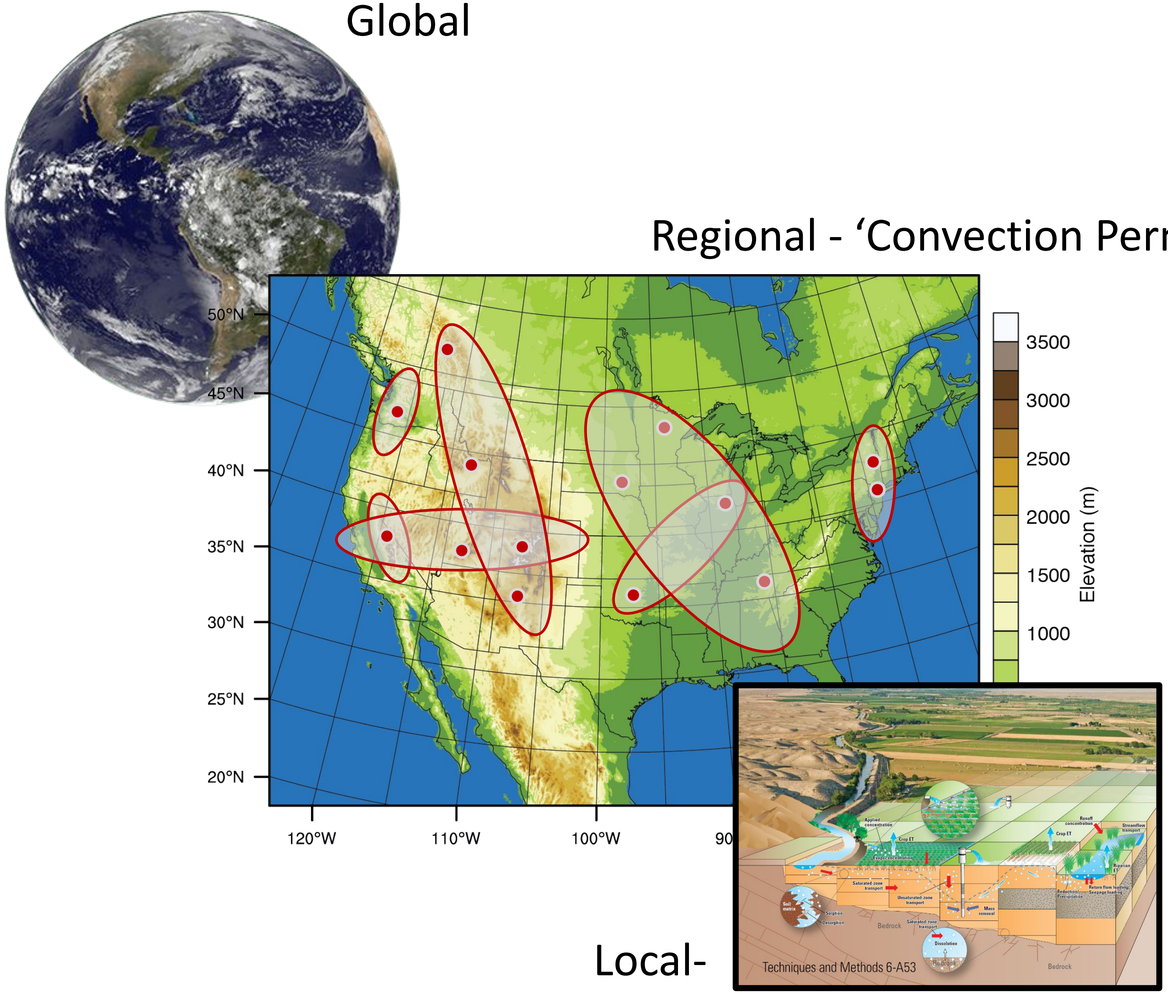
Coordinated intensive studies, supported by Regional Focal Studies with embedded observational transects

New and leveraged observations, e.g:

- USGS-NGWOS
- AmeriFlux
- NEON
- DOE/ARM (SAIL)
- NOAA (SPLASH)
- Global Water Futures
- Airborne missions
- Satellites
- GEWEX Land-Atmosphere Feedback Observatories (GLAFOs)
- etc.

Global

Regional - ‘Convection Permitting’



Local-
Watershed

Working Groups (Science Plan)

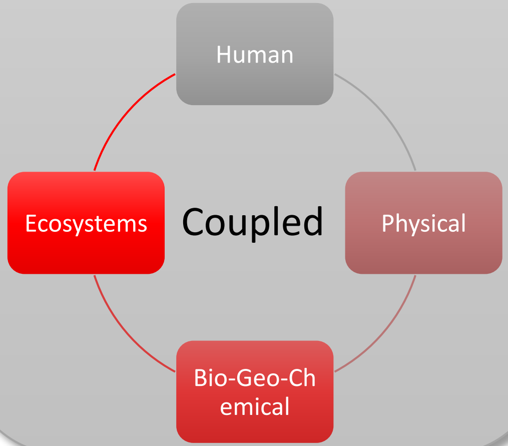
Human Dimensions	• Christine Kirchoff, Penn State Univ. • Diamond Tachera, NCAR ASP Post Doc
Mountain Hydrology	• Mimi Hughes, NOAA • Dan Feldman, DOE/LBNL
Land-Atmos Processes	• Cenlin He, NCAR • Rachel McCrary, NCAR
Impactful Extremes	• Jeff Basara, Univ. of OK • Natalie Thomas, NASA
Organized Convect. & Precip Systems	• Steve Nesbit, Univ. of IL • TBD
Advancing Observational Systems	• Craig Ferguson, SUNY-Albany • TBD
Coastal (TBD)	• TBD (T. Schneider to coord., e.g. with • RVCC-Hub (NSF Project), Haskell Indian Nations U.
"Digital Twin"	• Mike Bosilovich, NASA • Andrew Gettleman, DOE/PNNL

Our **foundation**: a diverse, 165 member strong (and growing), Affinity Group

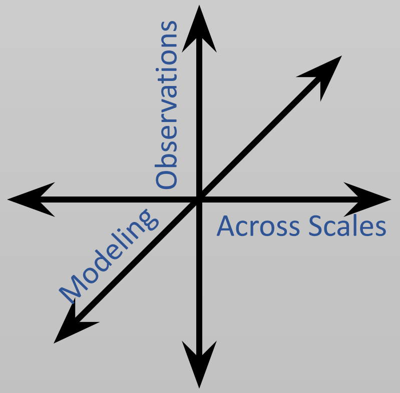
Updated" 4/13/2023

Select Emergent Themes

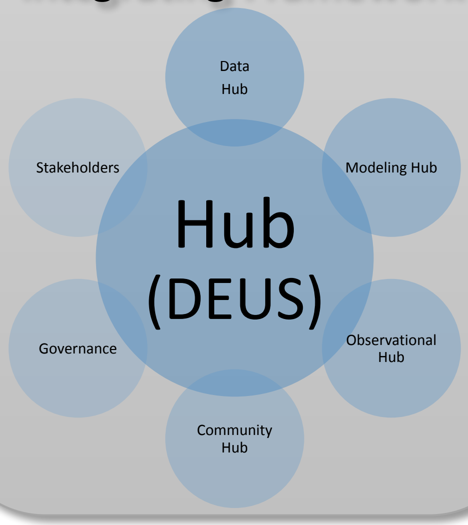
Convergent Modeling



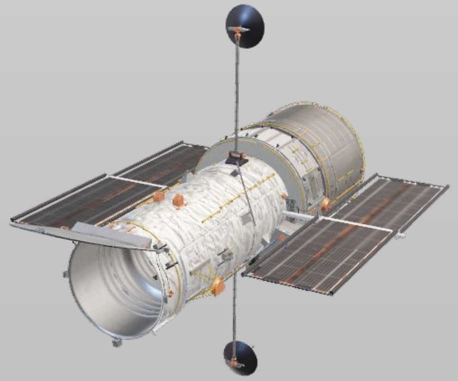
Intersections & Scales



Integrating Framework



Convergent Observations



2.1 Human Dimensions

Gaps

1) **Integration and Scales:** There are gaps in how we bridge our understanding of what makes hydroclimate and integrated carbon-water-food-energy knowledge actionable from continental to local scales
2) **Co-Production:** Gaps remain on the co-production of actionable knowledge with Indigenous and other communities that are historically underrepresented

Science Questions

1) How do we include humans (e.g., population characteristics, adaptive behavior, practices, local knowledge) in continental scale models and aggregate measures?
   - **Sample Activity:** Conduct experiments to understand trade-offs in how humans and behavior are included in continental scale models.
2) How does the scale of the science and the scope of the scientific enterprise affect our ability to produce actionable knowledge, particularly with emphasis on Indigenous and other communities that have been historically under-represented in research?
   - **Sample Activity:** Conduct ethnographic or observational studies to track how question identification, data identification, scenario development and modeling, and co-created outputs are used by communities and are revised over time in response to community feedback
3) How can we improve transparency and communication of scientific research to improve reciprocity and build (or repair) relationships with Indigenous and other communities?
   - **Sample Activity:** Conduct ethnographic or observational studies to understand what engagement and research practices improve reciprocity and repair relationships with Indigenous communities

2.2 Mountain Hydroclimate

Gaps

1) **Complex Terrain:** observations in complex terrain are insufficient to support model development, evaluation, and process understanding
2) **Partitioning:** Understanding the distribution and partitioning of precipitation, and a quantitative consensus of the complex fate of this moisture once it is on the ground
3) **Uncertainties:** uncertainties associated with anthropogenic hydroclimatic change are large in complex terrain because of the interaction between large scale climate and the terrain

Science Questions

1) What are the dominant sources of uncertainty in mountain hydrometeorology for state estimates, and sources of predictability on various predictive timescales?
   - **Sample Activity:** Observations of precipitation amounts and types [or insert your favorite variable here], at high enough spatial/temporal resolution to quantify "how much water falls" for at least a few large western US basins
2) What are the most significant impacts to mountain hydroclimate under anthropogenic climate change?
   - **Sample Activity:** High-resolution modeling experiments to elucidate the mechanisms of orographic precipitation response to anthropogenic climate change
3) What constitutes sufficient scientific support infrastructure for mountain hydrometeorology that ensures all federally-funded observations, modeling, and scientific insights from satellite- to field-scale activities are readily accessible for researchers?
   - **Sample Activity:** Western US hydrometeorology prediction testbed: a strategy to create an organized focus of effort for evaluation of alternatives (methods, observational data, models)

2.3 Land-Atmosphere Processes & Coupling

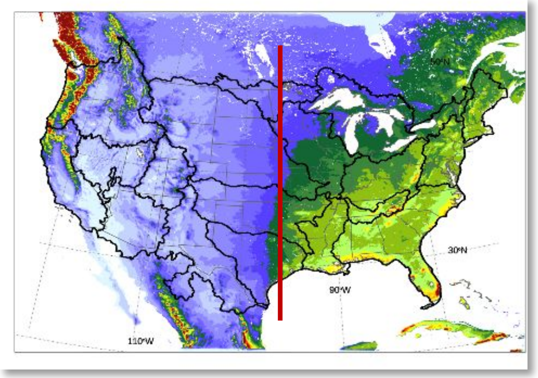
Gaps

1) **Extremes:** There is a lack of knowledge about the role that L-A coupling plays in influencing the evolution of US hydroclimate extremes on S2S to decadal timescales
2) **Coupled systems:** There is a lack of knowledge about how L-A feedback affects the coupled snowpack-drought-fire-heatwave system in the US, particularly under climate change
3) **LU/LC change:** There is a lack of knowledge in understanding how land use land cover (LULC) change will alter L-A interactions and hence the US hydroclimate under climate change

Science Questions

1) What roles do local and regional L-A interactions play in controlling the evolution and prediction of US hydroclimate extremes on S2S timescales?
   - **Sample Activity:** combining convection-permitting models that are enhanced in physical parameterizations with observations through data assimilation and adding model isotopes/tracers will be particularly useful for understanding and modeling L-A interactions
2) What are the L-A feedback mechanisms controlling interactions between snowpack, drought, heatwave, and fire in the US, and how will they respond to changing climate?
   - **Sample Activity:** Measurements of PBL quantities are needed to improve model parameterization of turbulence. This would require an expansion of flux tower networks in mountainous and diverse climate regions, where GLAFOs could provide valuable data.
3) How will LULC change affect local/regional hydroclimate through L-A interactions under climate change?
   - **Sample Activity:** Implement better representations of processes like groundwater, frozen soil, plant hydraulics, fires, canopy turbulence, wetland, irrigation, crop evolution, biogeochemical cycles, and ecosystem evolution. Update and optimize existing model parameters according to specific applications. Employ a Hierarchical System Development approach

2.4 Impactful Extremes



Gaps

1) **Cascading/compounding events:** extreme events and their impacts can and do interact with each other in complex and challenging ways that are are not necessarily well understood, and are intertwined with heightened societal impact and feedback
2) **Definitions:** defining what an extreme event is, and we do not understand how these definitions may or may not apply in a changing future, nor how we integrate an understanding of how humans adapt to changing extremes
3) **Understanding and predictions:** disentangling the local and remote mechanisms driving impactful extremes can be a challenge; limitations of key observations exacerbate these challenges; and many open questions remain regarding the main drivers of prediction skill and predictability, especially at S2S time scales

Science Questions

1) How should impactful extreme events be defined spatially and temporally in a non-stationary climate, and how can current definitions be applied to future climate projections?
   - **Sample Activity:** Case studies on sensitivity of quantification of and trends in extremes to different definitions and thresholds
2) What are the primary physical mechanisms associated with different impactful extreme events, and what is the role of climate change in driving extremes in the present and future climate?
   - **Sample Activity:** Large-ensemble experiments to explore the role of forced climate change in extreme events
3) What are the sources of predictability for different types of extreme events at various prediction timescales, and how well do current models represent these sources?
   - **Sample Activity:** Examination of S2S reforecasts to identify times and places where extremes are predictable

2.5 Organized Convection and Precipitating Systems

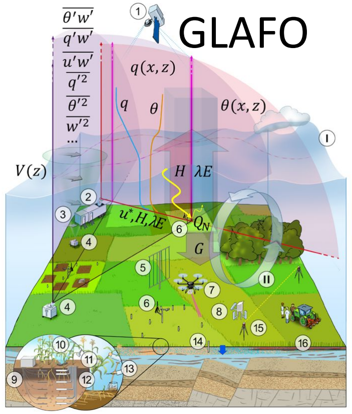
Gaps

1) **Changing precipitation:** a major challenge is understanding how precipitation accumulation as well as the distribution of instantaneous rainfall rates will change in the future
2) **Multi-scale nature of convection:** biases exist as a function of the models' spatial scale and their parameterizations of cloud microphysics, turbulence, and planetary boundary layer and surface parameterizations; improvement in models has been hampered by observational or reanalysis-based datasets that were too coarse in resolution or contained large uncertainties
3) **Frameworks:** frameworks, model intercomparisons, and evaluation datasets at high resolution will be needed to advance hydroclimate modeling capabilities, as well as assess societal risks associated with hydroclimate extremes

Science Questions

1) What are the sources and limits of predictability for the initiation, growth, and track of organized convective systems and precipitation? To what extent are they connected to atmospheric, land, ocean, and coupled processes? To what extent do these limits impact our ability to predict changes and extreme events of precipitation from organized convection?
   - **Sample Activity:** We will include novel approaches: to data analysis, such as cloud tracking and Lagrangian moisture tracking in the atmosphere and land surface; such as oxygen and hydrogen isotope observations in the atmosphere, precipitation, surface, and water bodies that provide estimates of origin, fluxes, and residence times of moisture in the system
2) What are the shortcomings of models in representing organized convective systems, extreme precipitation, and societal impacts of precipitation from organized convection?
   - **Sample Activity:** We will strive to develop and improve end-to-end risk assessment tools for hydroclimate extremes associated with organized convection
3) What are the potential climate change effects on organized convection, and how do these operate in different convective regimes (atmospheric and surface forcing differences)?
   - **Sample Activity:** In addition to traditional modeling, we will use machine learning techniques to test whether machine learning can break the convective parameterization improvement deadlock

2.6 Advancing Observational Systems



Gaps

1) **Thematic topics:** each of the thematic sections in the plan, from Human Dimensions (§2.1) to Organized Convection and Precipitating Systems (§2.5), have identified observational gaps that need to be addressed
2) **Observations of L-A processes:** observations of bedrock to boundary layer processes are insufficient in quantity, comprehensiveness, and geospatial/temporal coverage; new instruments and approaches are available and should be employed

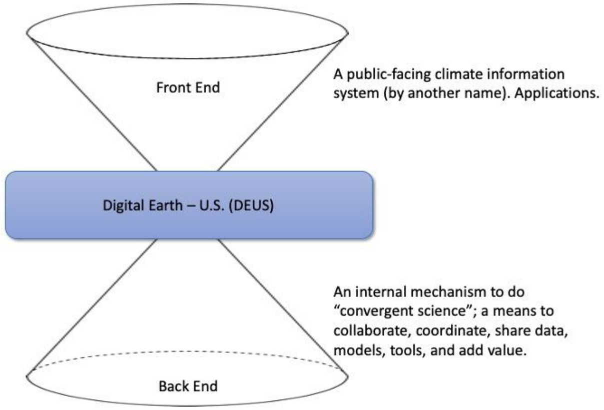
Science Questions

1) How can we best observe, analyze, and model the impacts of human land management (i.e., agriculture, wind and solar farms, deforestation, urbanization) on subsurface - surface - atmosphere coupling of water-energy-carbon cycle processes, and do these impacts represent a significant source of subseasonal-to-seasonal hydroclimatic predictability?
    1) What is the impact of landscape-scale surface energy flux partitioning on planetary boundary layer height, clouds, and precipitation across diurnal and seasonal cycles?
    2) How do critical zone processes influence evapotranspiration, streamflow, and their short and long-term climate patterns?
    3) What is the partitioning of evapotranspiration between transpiration and evaporation, and what is the partitioning of streamflow between subsurface runoff and groundwater?

Activities

Some initial activities will be to identify observational requirements for the project (especially based on observational needs identified in the other themes), and then to assess and compile available resources. This will then allow the US-RHP team to develop a detailed plan and strategy, and to propose new observations to fill in gaps, and innovative new observational strategies and instruments.

3.0 Digital Earth for the US (DEUS)



Gaps

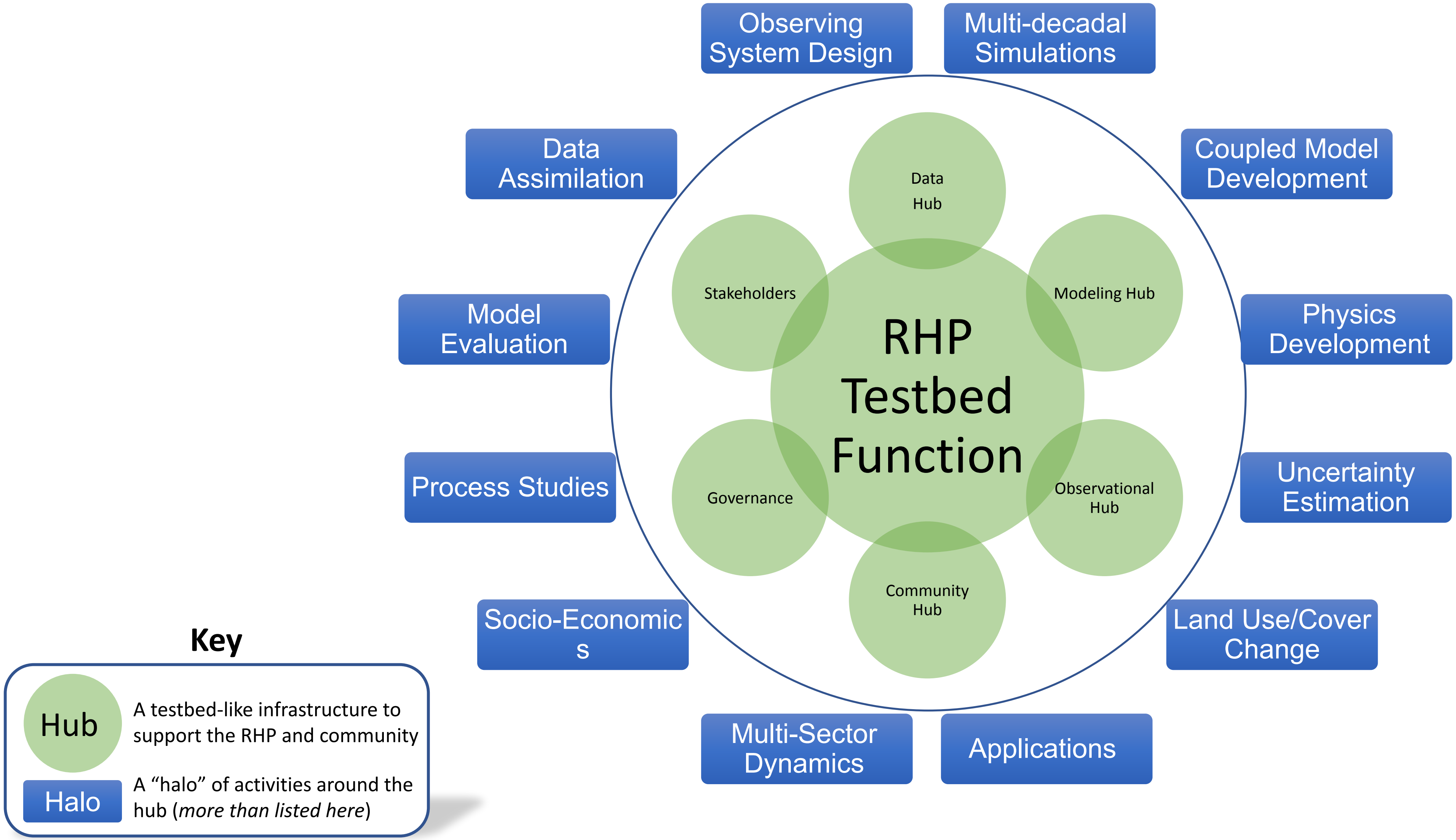
1) **Thematic topics:** The science plans and questions in this document require a prediction and analysis system of the scale of an integrated Digital Earth to effectively meet the needs identified herein.

Science Questions

1) What are current risk factors for flooding in the US? How will they change under climate extremes?
   - **Sample Activity:** Conduct stakeholder engagement and collaborations (e.g., water resource managers, urban and transportation planners, Indigenous communities and institutions)
2) What strategies can be used to adapt human systems (including agriculture) to the new water environment under climate change and to be resilient to water stress?
   - **Sample Activity:** Support interdisciplinary sciences coordination and collaboration
3) How do we optimally couple data of the physical and human system with transient weather and climate data and predictions to enable predictions of hydrology across a number of scales?
   - **Sample Activity:** Build a data management framework (combination of a data center and distributed centers)

US-RHP Strategic Elements

A Hub and Halo Approach



Outline

I. A Couple of 'Science Teasers'

II. Brief Introduction:

   i. What is an RHP?

   ii. Why do we need one?

III. Highlights from Science Plan (Draft)

IV. Next Steps – Discussion

"How can we know the dancer from the dance?"

From the poem Among School Children, by W. B. Yeats

US-RHP Timeline

It’s a marathon – not a sprint

2019-Present
- Foundation Building

June 2021
- Affinity Group Established

July '22
- Pan-GEWEX / SSG / GHP Meetings

Fall '22
- Working Groups Established

March ’23
- Draft Science Plan (~30 pp.) / Basic Governance

April '23
- Brief to USGCRP

June ’23
- Final Draft of Summary Level Plan

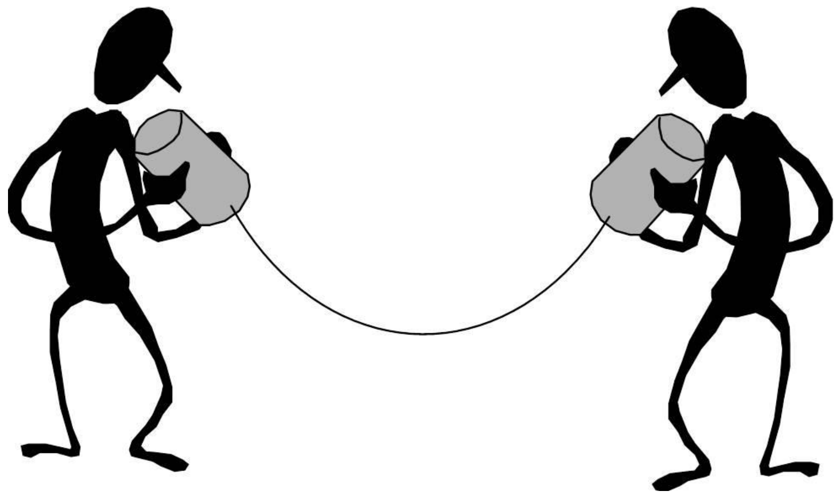
July '23
- Propose to become Initiating RHP

FY2024
- Establish Project Office
- Workshop(s)

FY2025
- Finalize Implementation Plan

Some Thoughts for Discussion

- [Tactical] Are there opportunities to collaborate now?
- [Tactical] How can the US-RHP community engage with you?
- [Strategic] How can the US-RHP build from your current efforts?
- [Strategic] How can the US-RHP partner with your community to make more campaigns like SAIL and SPLASH happen?
- You are welcome to join us:
  - Planning is in progress and ongoing
  - Help us shape our plans…



An Opportunity to Coordinate: The US-RHP Affinity Group

Format:

- Began July, 2021
- Meets every other Thursday @ Noon MT
- Usually a 20-30 minute technical/scientific presentation, including reflections on the nature of the RHP, followed by 30-40 minutes of robust discussion
- Google Shared Drive to share materials/recordings
- As of 4/2023: 165 members (~25-30 typically attend a biweekly meetings)

- A Sampling of Technical Presentations:
  - Ruby Leung (DOE) – "*North American Hydroclimate Research*"
  - Jeff Basara (OU) – "Living in a World of Extremes and Extreme Transitions – The North American Hydroclimate (Research Examples and Identifying Gaps/Opportunities)"
  - Kirsten Findell (NOAA) – "GFDL Research Highlights* of Relevance to the GEWEX US Regional Hydroclimate Project Affinity Group"
  - Craig Ferguson (SUNY Albany) – "Self-Introduction and Prospective on a GEWEX-organized U.S. Regional Hydroclimate Project"
  - Fei Chen (NCAR) – "*Improved Convection Permitting Modeling Through Capturing Fine-Scale Land-Atmosphere Interactions*"
  - Christine Kirchhoff (U. Conn) – "*Learning from Science of Science and Decision Making and Water Governance Research*"
  - And more… Francina Dominguez (U. IL), Drew Story (USGCRP), Rick Lawford (NOAA, ret.), Andy Wood (NCAR), Jin Huang (NOAA), Julie Vano (AGCI), Dan Feldman (DOE), Mimi Hughes (NOAA), Andreas Prein (WCRP LH/NCAR), Seth McGinnis/Linda Mearns (NCAR), Andrew Schwartz (UC-Berkley), Tammy Weckwerth (NCAR), Stephen Sebestyen (USDA), Tim Lahmers (NASA); etc.

- We invite you to join us – sign up form:
  - https://forms.gle/wFrAFajxwSMqV499A
- More Info: Tim Schneider - tls@ucar.edu

Thank You!

We look forward to our discussion.

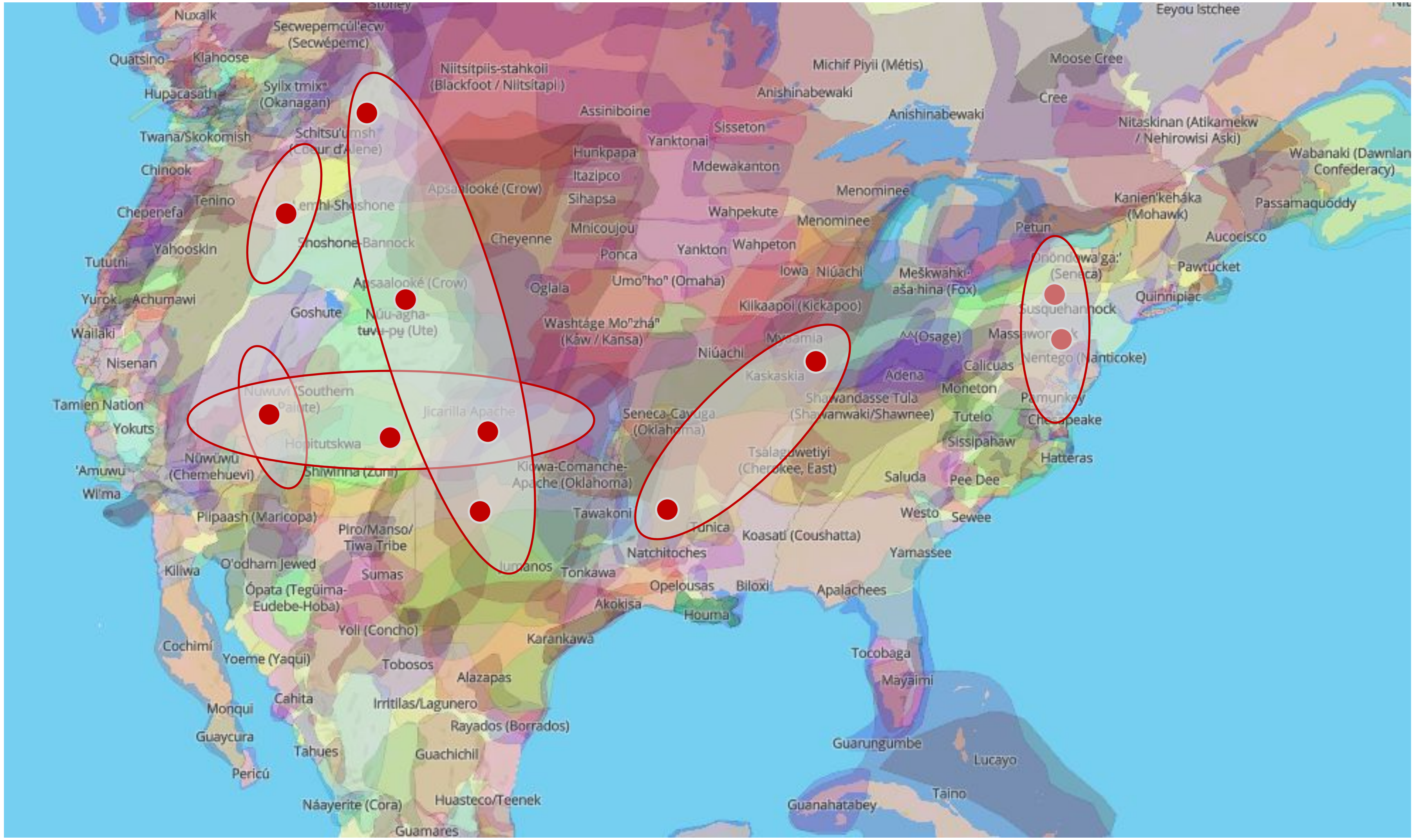
Contact: Tim Schneider / tls@ucar.edu / m: 720-725-3745

US-RHP *Notional* Scope (à la GWF)

Indigenization: we recognize, respect, and embrace the millennia of place-based knowledge and wisdom of those who were here first.

Global Water Futures (GWF; a Canadian RHP, nearing completion) effectively and productively engaged with Indigenous people on the “co-creation of water research”. We seek to learn from their successful approach.

GWF: https://gwf.usask.ca/

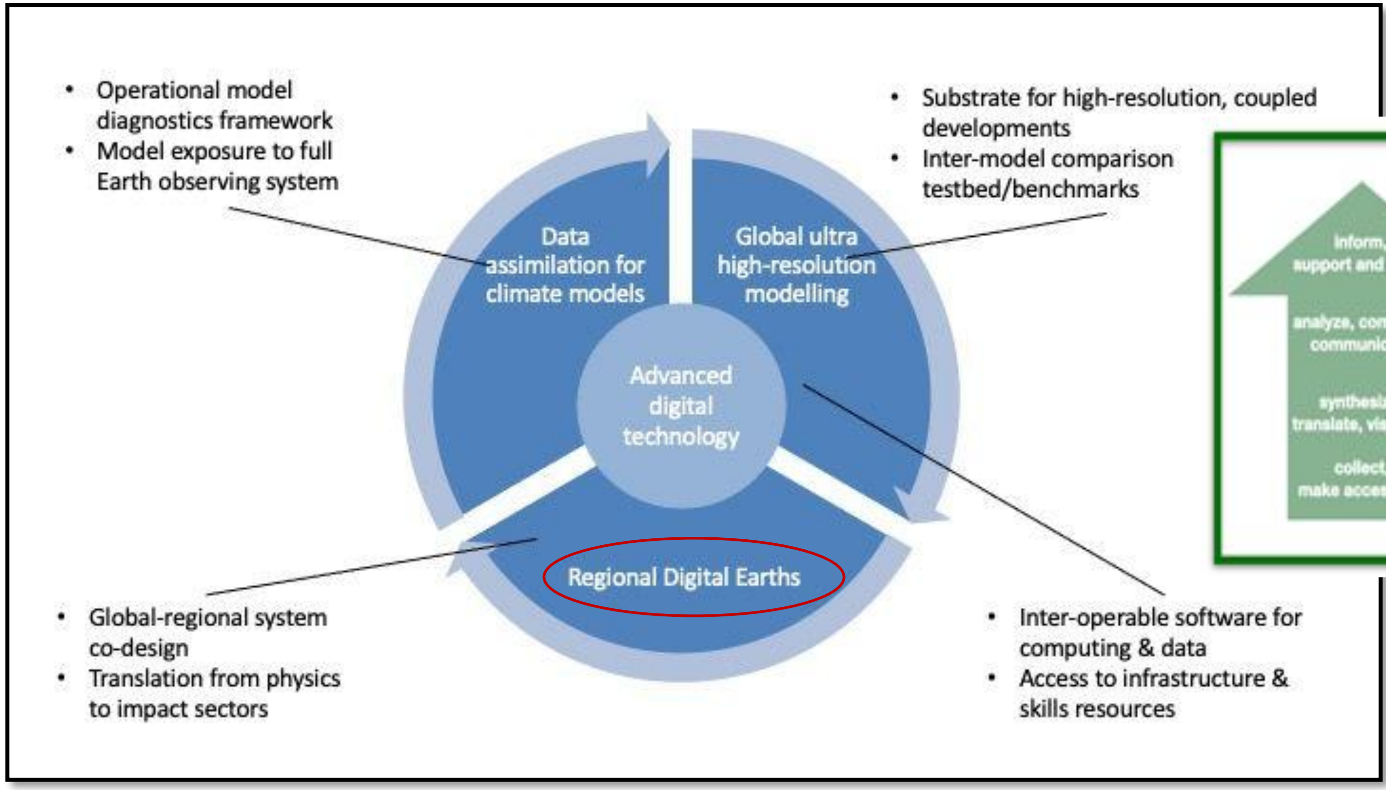


Traditional Native Lands (https://native-land.ca/)

A Digital Twin of the CONUS?

A topic for consideration. Aligns with the WCRP Digital Earths Lighthouse Activity

- https://www.wcrp-climate.org/digital-earths



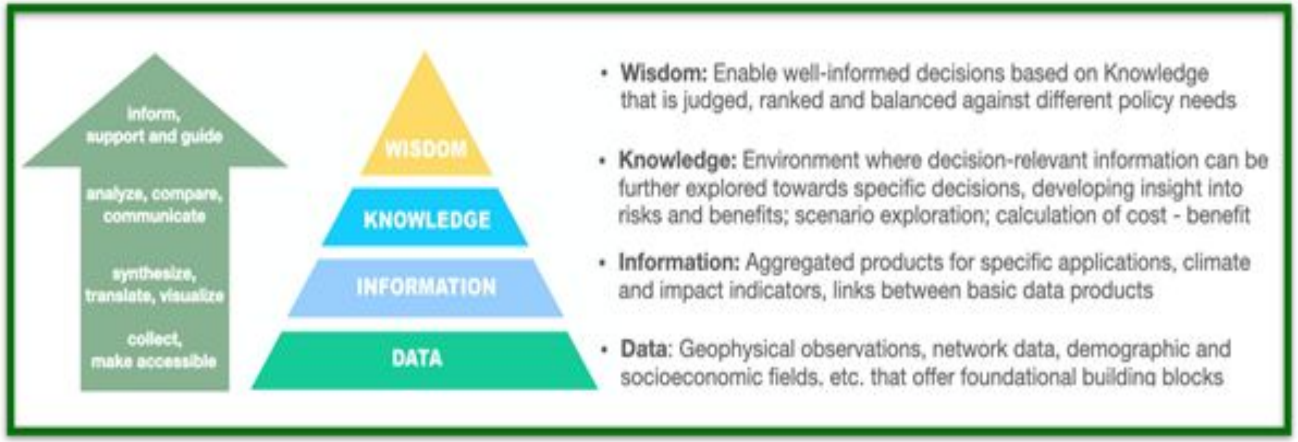


Figure (above): Knowledge Pyramid concept of systematic value-add from basic data to context-enabled knowledge that then provides the input for decision-making. Borrowed from D. Yates.

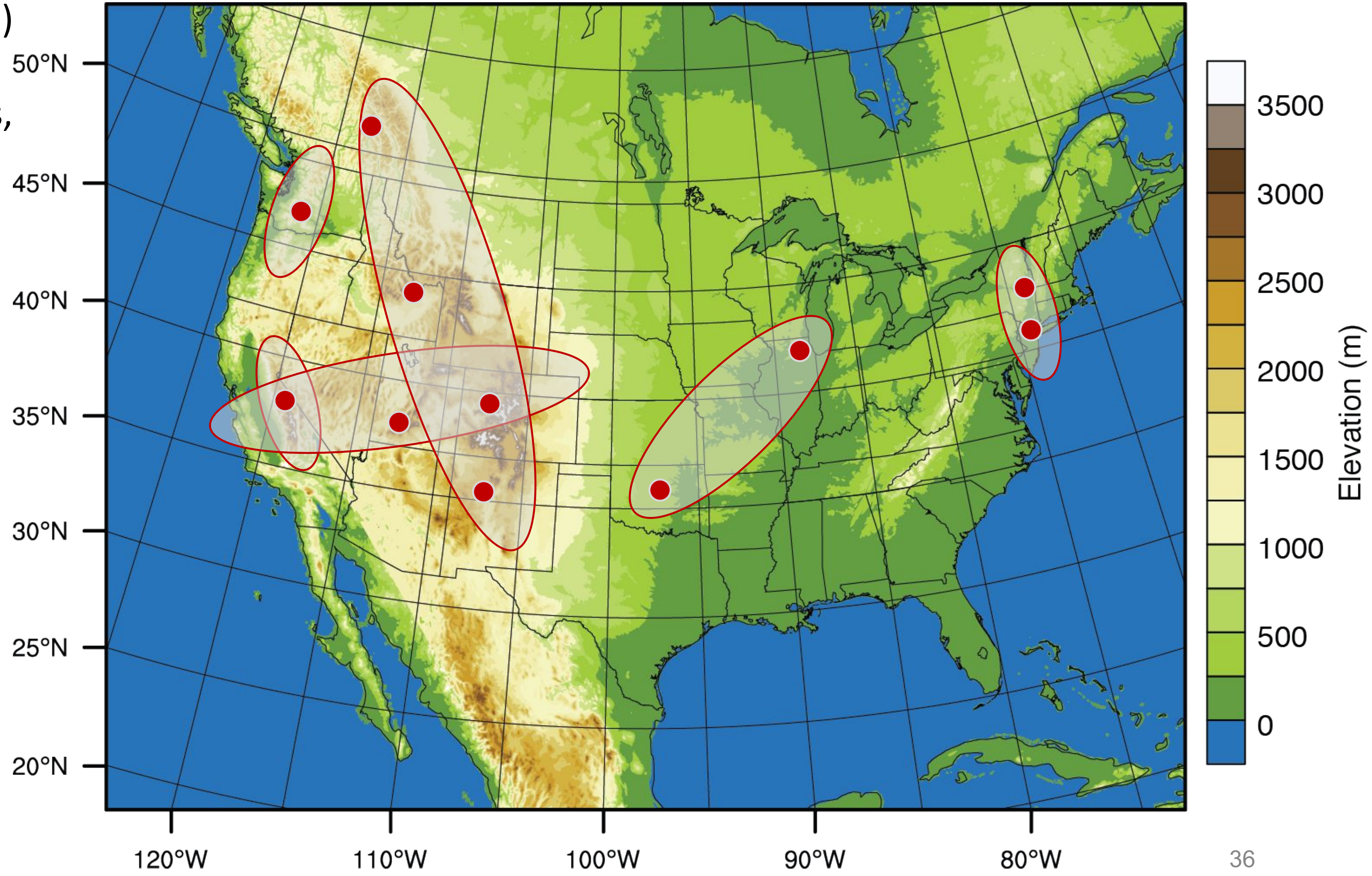
US-RHP Notional Scope

Modeling across scales (global→CONUS→watershed)

Coordinated intensive studies, supported by observational transects

New and leveraged observations, e.g:

- USGS-NGWOS
- AmeriFlux
- NEON
- DOE/ARM (SAIL)
- NOAA (SPLASH)
- Global Water Futures
- Airborne missions
- Satellites
- GLAFO
- etc.



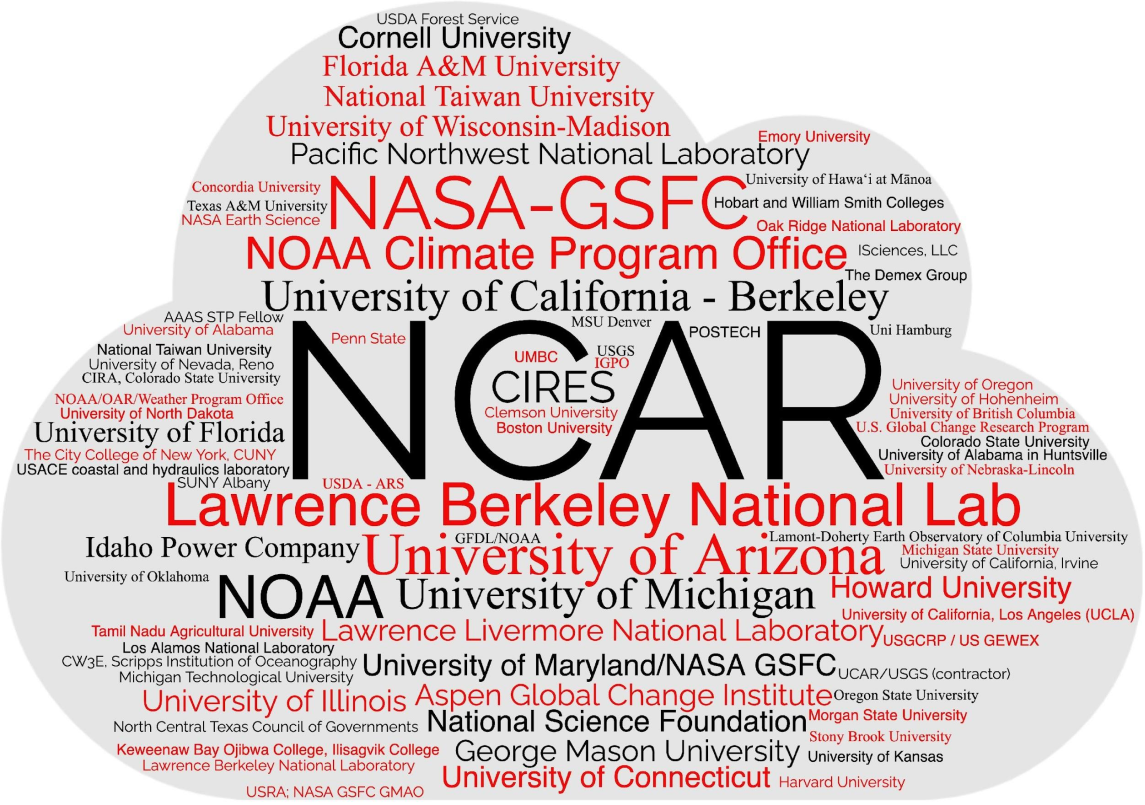
Plan Outline:

A GEWEX US-RHP FOR FOOD, ENERGY, AND WATER SECURITY IN THE ANTHROPOCENE

https://docs.google.com/document/d/1WBJY6vTi2tdzc6uOnSGh2Qm1aEWGQBkF_w0OBYPAuFc/edit#heading=h.g9vmjxcjwg4t

A Caricature of our Affinity Group

By Affiliation



By Expertise