Understanding Hydroclimatic Changes in Western USA Mountain Ranges using the Variable-Resolution CESM Multiscale Method

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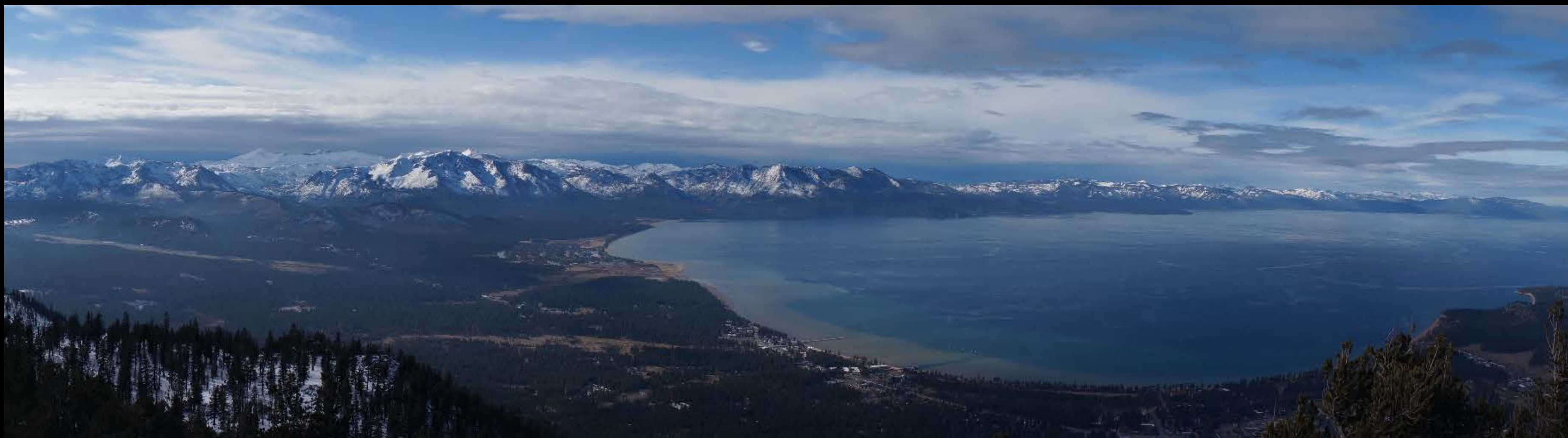
Western USA
Why Snowpack?



Provides Water Security **-** 75% of freshwater supply in western USA ***(Cayan, 1996)***

Alleviates Water Scarcity **-** Essential for entire water network during dry season

CA Agricultural Production **-** 400 commodities, 50% of fruit, nut, and veg. in USA ***(CDFA)***

Hydroelectric Power **-** 22% of energy in western USA ***(NHA.org)***

Western USA Tourism **-** Billion $ ski industry, 100,000 jobs, ~30 million visits/yr ***(NSAA.org)***

Hydroclimate Connector – Connects climate forcing (T, Pr, albedo) to hydrologic response

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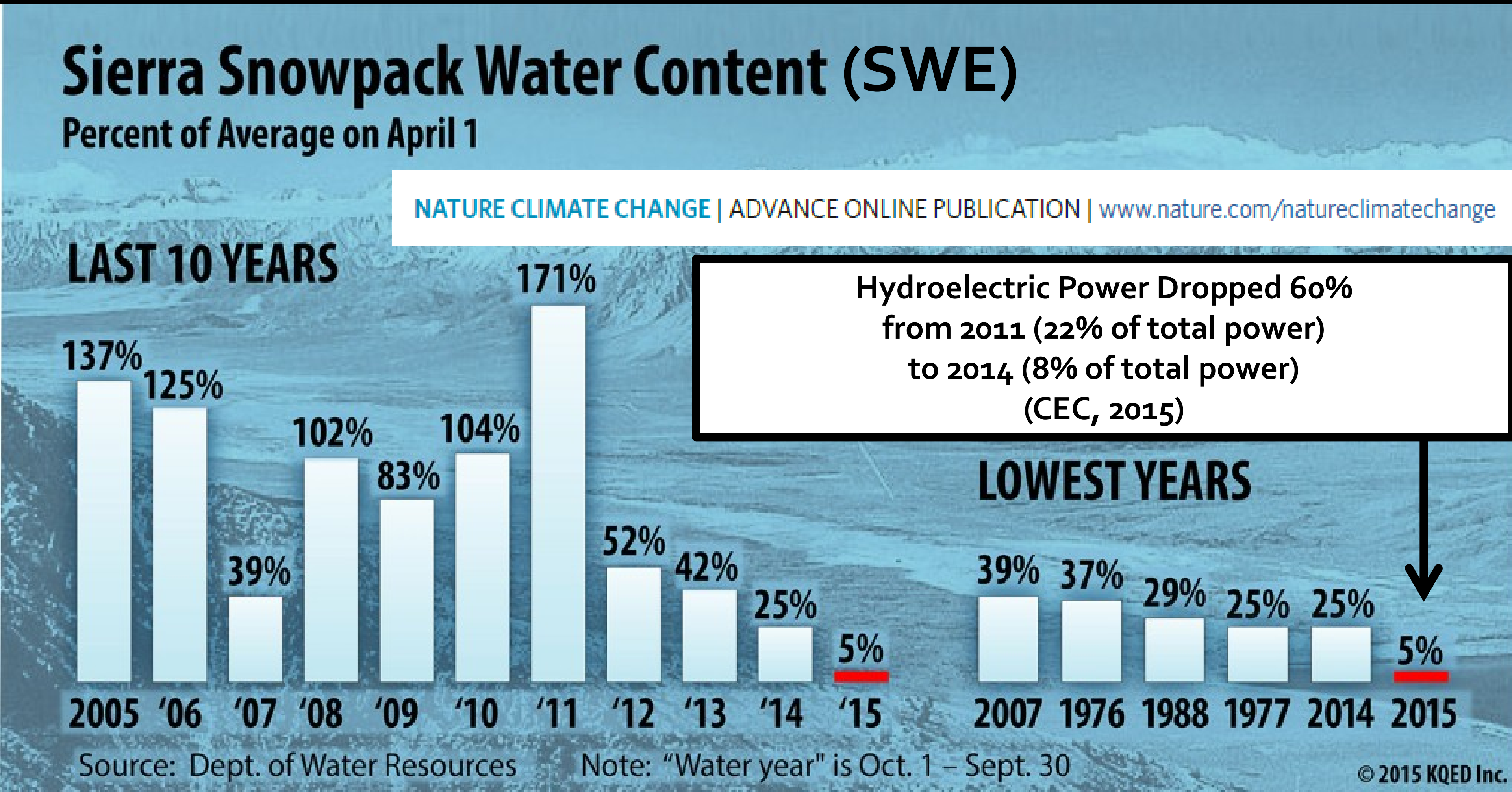
Observed Trends – Western USA

Recent Snowpack Trends in CA



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Observed Trends – Western USA
Water Supply Uncertainties

Climate change is creating uncertainty in ¾ of the water supply…

Peak Snowpack Supply

Decreasing by upwards of 1/3 in mountainous regions in western USA (Mote et al., 2005)

Timing of Peak Snowpack Supply

Shifting a week earlier for every 1 $^{\circ}$C of warming (Kapnick and Hall, 2012)

Source of Snowpack Supply

Precipitation is seasonally variable (20-45% due to teleconnections) (Cayan et al., 1998)
Precipitation is driven by extremes (5-15 days for 50% of precipitation) (Dettinger, 2011)

Temperature Sensitivity of Snowpack Supply

Annual Temperature +1.4 to +5.4°C (2041-2099) (National Climate Assessment, 2014)
Phase of precipitation will change (20-40% of storms at -3 to 0 $^{\circ}$C) (Bales et al., 2006)

…how can we better understand regional trends in water supply?

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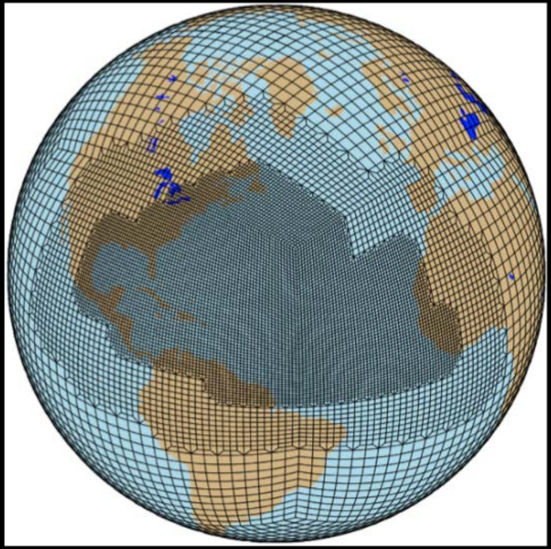
A Next-Generation Regional Modeling Technique

Variable-Resolution in the Community Earth System Model (VR-CESM)

Benefits of a New Dynamical Downscaling Approach…

- Global simulation (atmosphere-ocean teleconnections)
- Increased resolution in specified areas (better topography)
- Increased efficiency in model runtime and data storage (suited for "smaller" server usage)
- Eliminates multi-model lateral boundary conditions (bias propagation)
- More dynamic upscale and downscale effects on simulation
- Merges regional and global modeling communities



Courtesy of Colin Zarzycki

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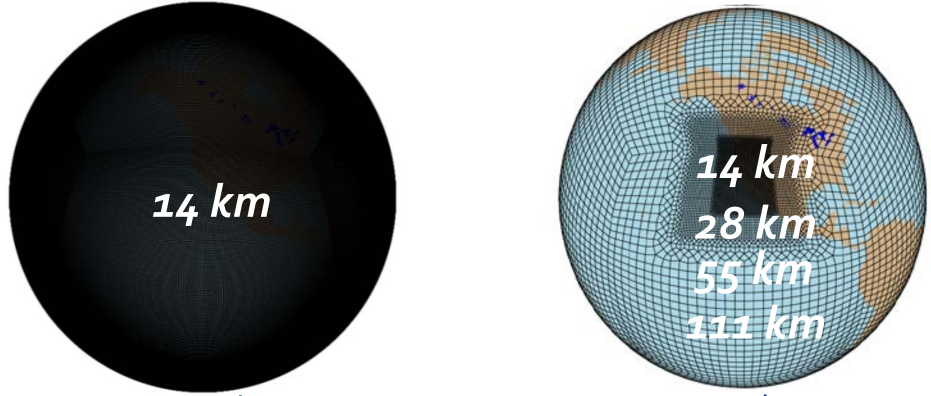
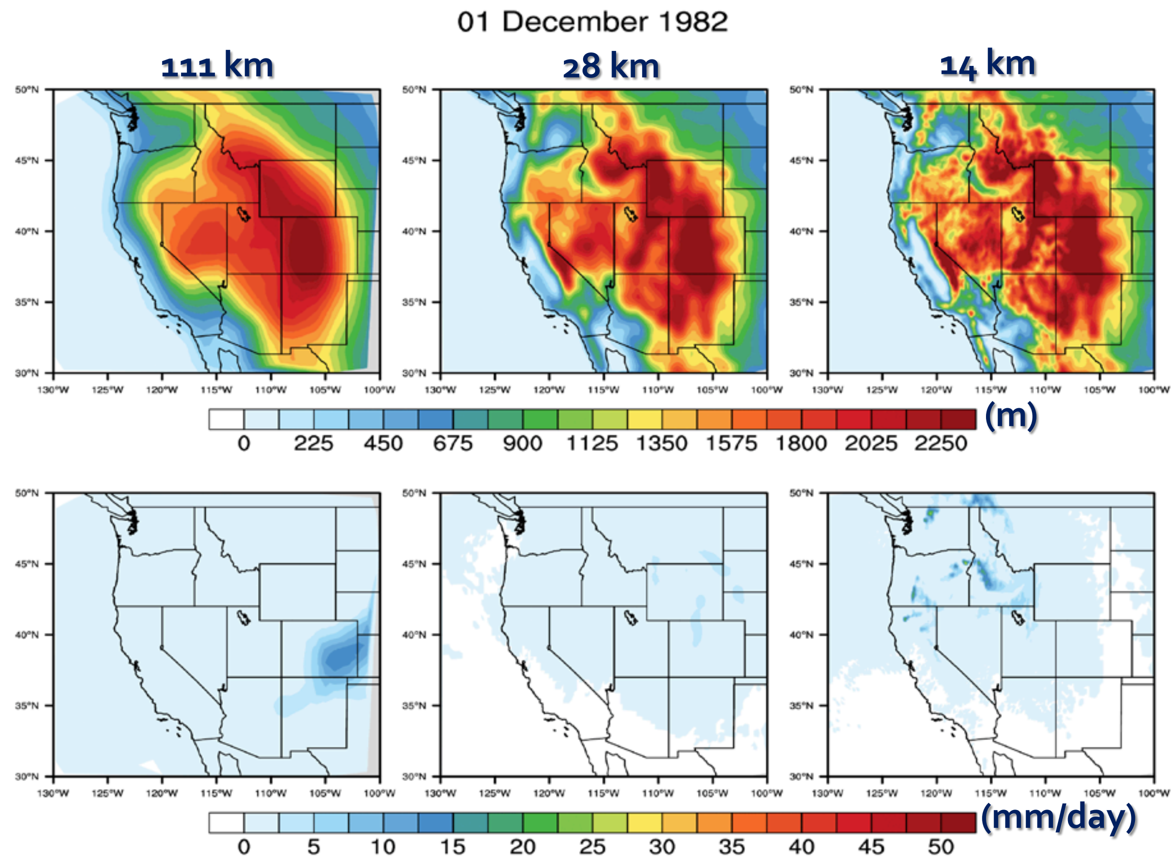
VR-CESM Benefits

30X
Computational Speedup Over Uniform Resolution





Topographical Representation

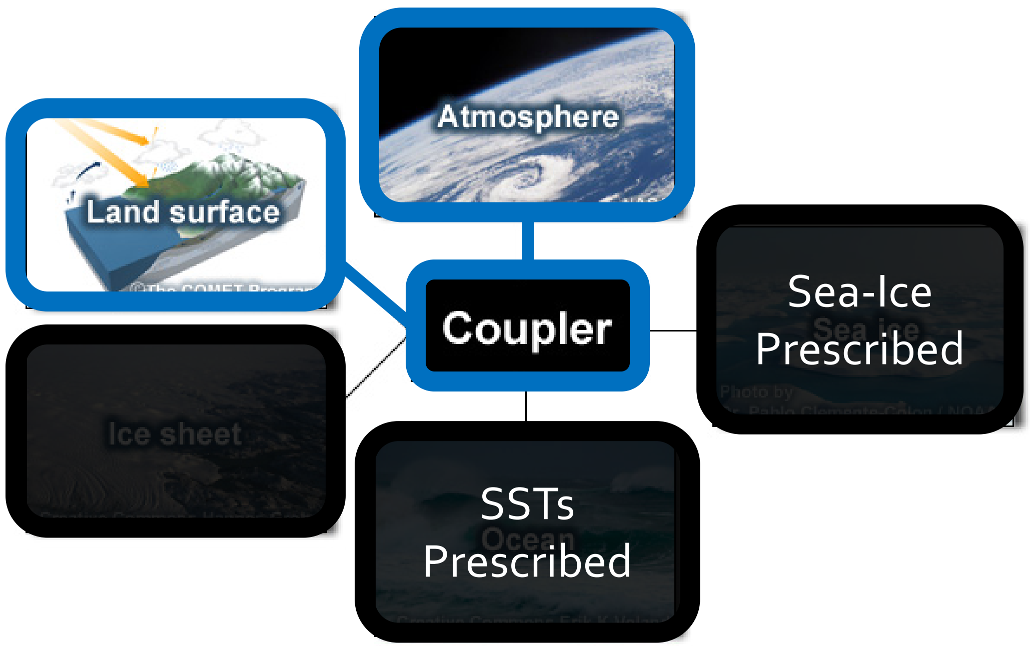
Orographically Driven Snowfall

Variable-Resolution in the Community Earth System Model (VR-CESM)

Configuration

Compset
- F_AMIP_CAM5
- Spectral Element DyCore
- AMIP Protocols

CESM Components



Grid Generator and Dataset Remap
(Dr. Paul Ullrich)
- SQuadGEN
- TempestRemap
- More info at climate.ucdavis.edu

VR-CESM Runtime/Throughput
- 1980-2005, 2025-2100 - Daily Average Output
- 28km – 25 yrs ~ 40 days to simulate (600 processors or 25 nodes)

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Variable-Resolution in the Community Earth System Model (VR-CESM)
Overview – Historical Validation

"Characterizing Sierra Nevada Snowpack Using Variable-Resolution CESM"
Rhoades et al., (2016)
J. Appl. Meteor. Climatol., DOI: http://dx.doi.org/10.1175/JAMC-D-15-0156.1

- VR-CESM at 14km/28km on seasonal/climatological time scales for the Sierra Nevada was well represented for SWE and SNOWC compared to observations/reanalysis/WRF
- VR-CESM still needs improvement in snowmelt rate and timing
- Topographical smoothing had most influence on VR-CESM snowpack, even when compared to ~2x model resolution
- For ~2x the computational cost of standard IPCC models, vastly better SWE statistics are shown for the Sierra Nevada
- KEY OUTSTANDING FINDING: early snowmelt timing and fast snowmelt rate biases shown across resolutions

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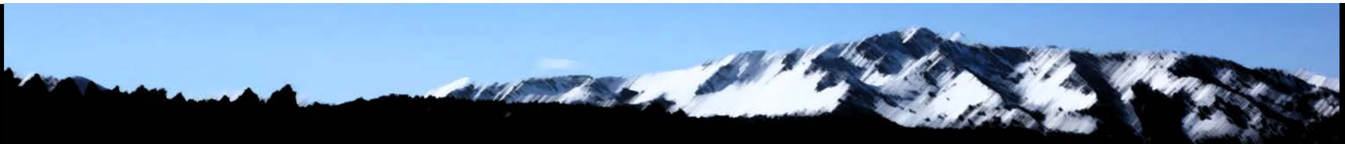
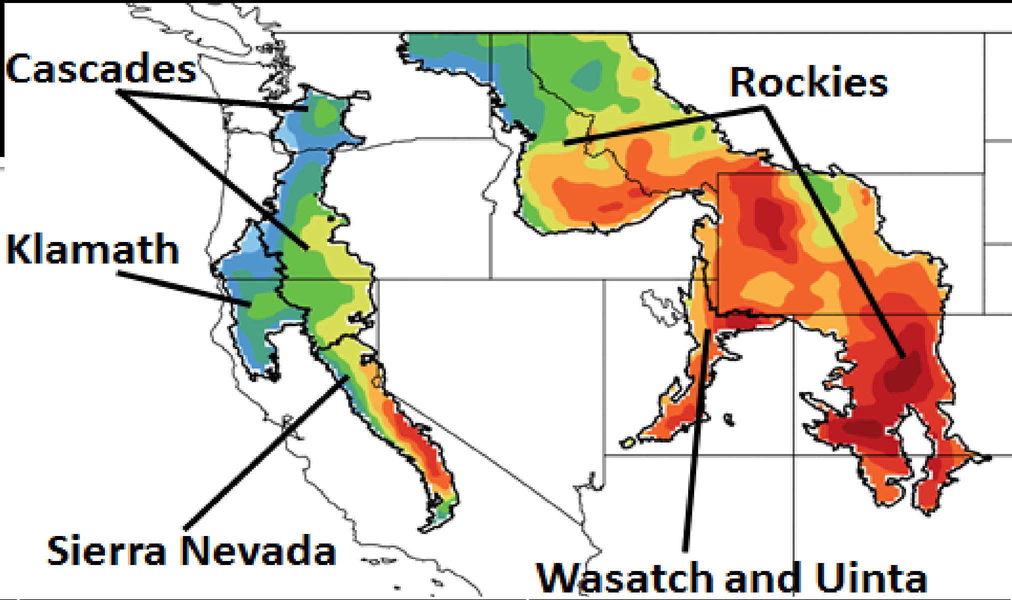


Model Datasets

For brevity, this talk will only cover TOTAL western USA mountain impacts. Individual mountain range AND seasonal (DJF) analysis has/will been done too.



Dataset	Downscaling	Resolution	DJF Seasons
VR-CESM	Dynamical	28 km	1980-2005 2025-2100
BCSD-CMIP5 (3 members)	Bias-Corrected Statistical	14 km	1975-2000 2040-2065
NARCCAP (9 members)	Dynamical	55 km	1975-2000 2040-2065
CMIP5 (8 members)	None	111 km	1980-2005 2040-2065

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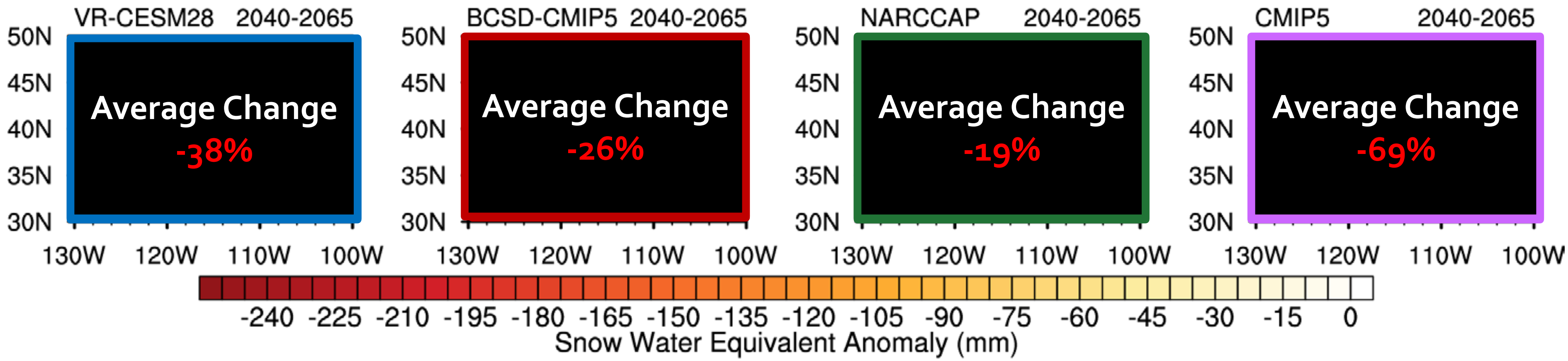
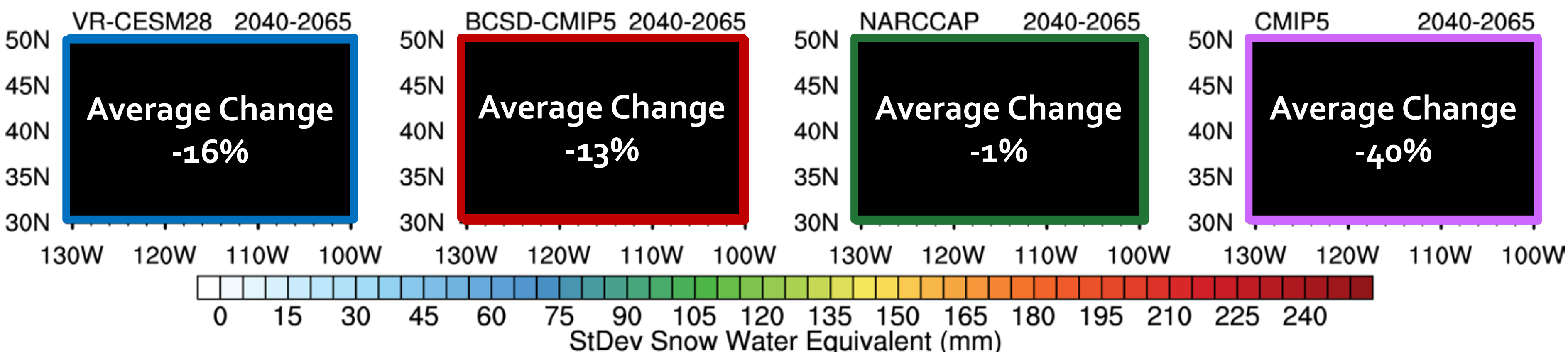
Preliminary Findings – All Datasets

Climatological DJF SWE (mm) RCP8.5 Historical vs 2040-2065





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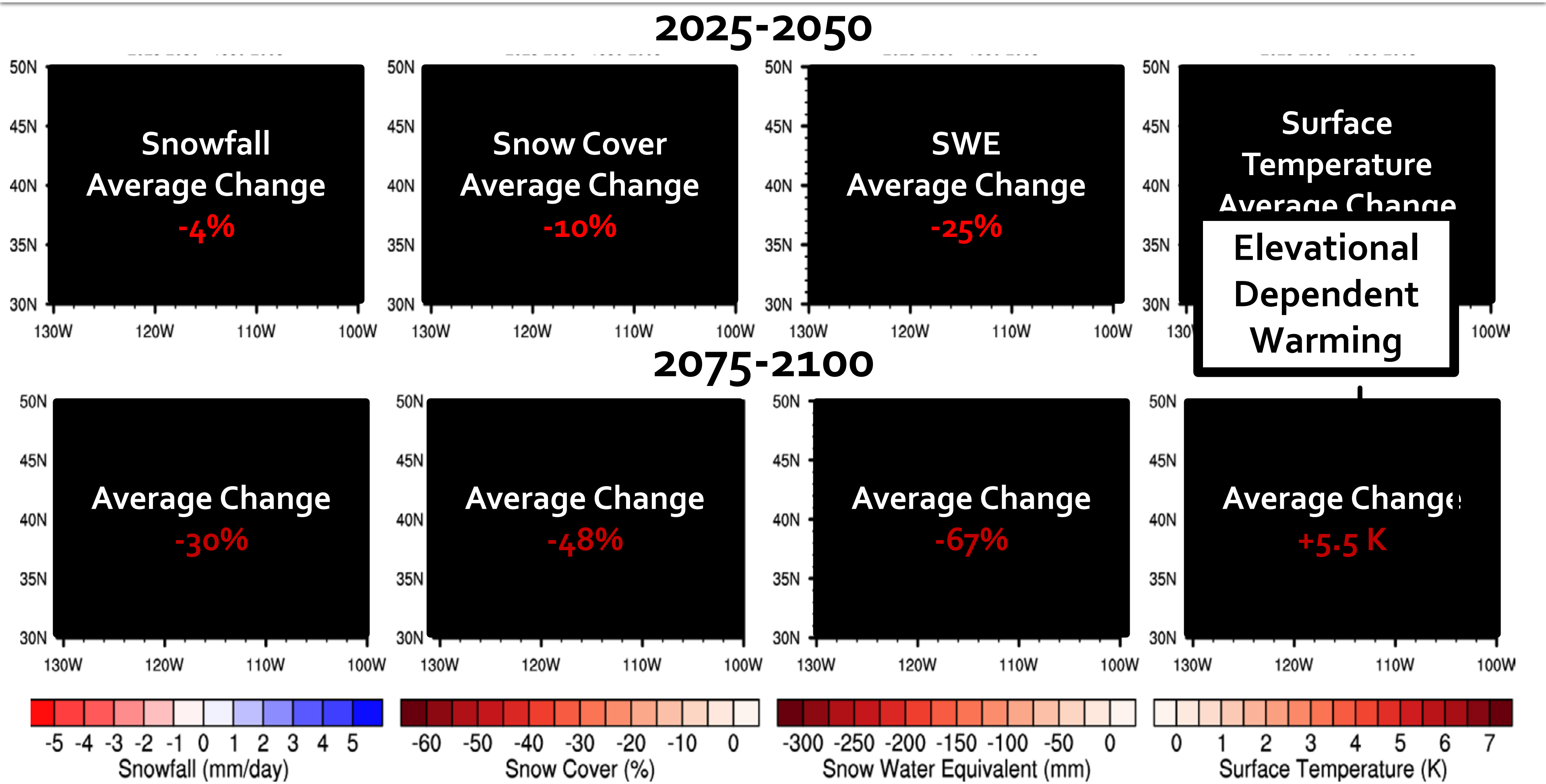
Preliminary Findings – VR-CESM28

Climatological DJF RCP8.5 1980-2005 vs 2025-2050 & 2075-2100



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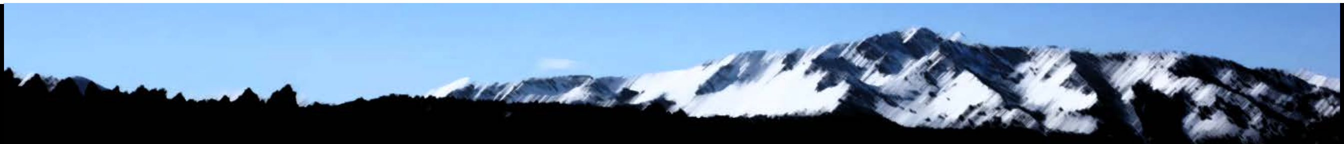

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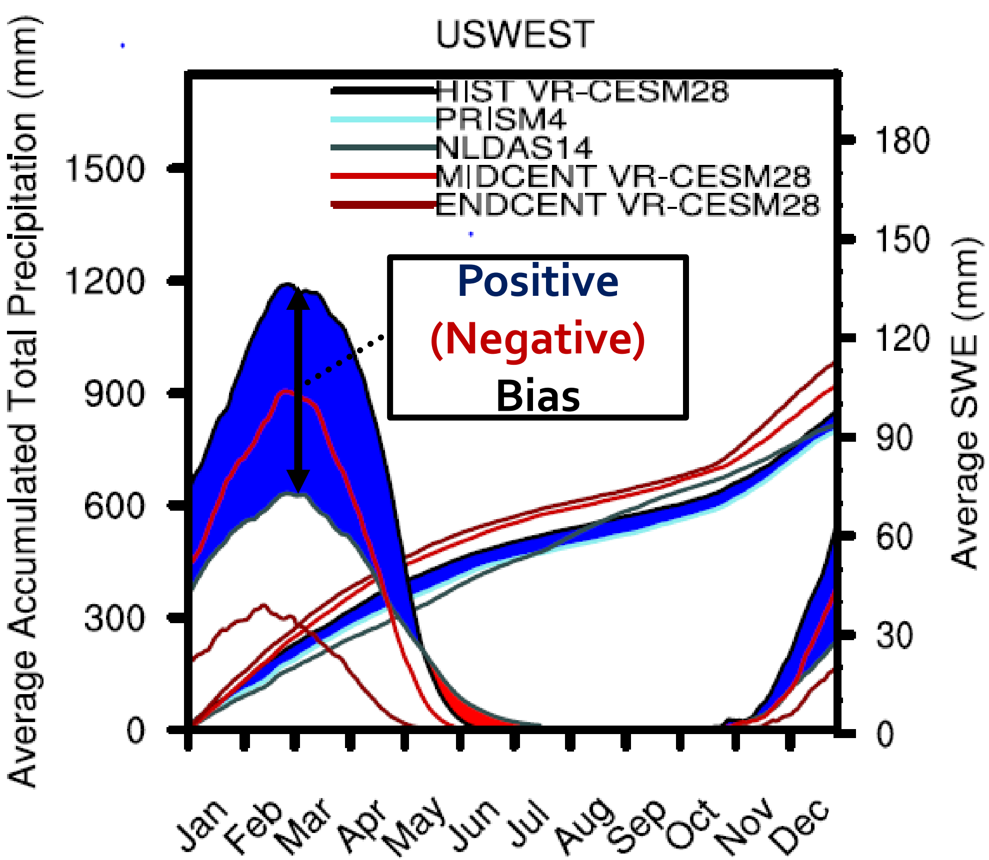
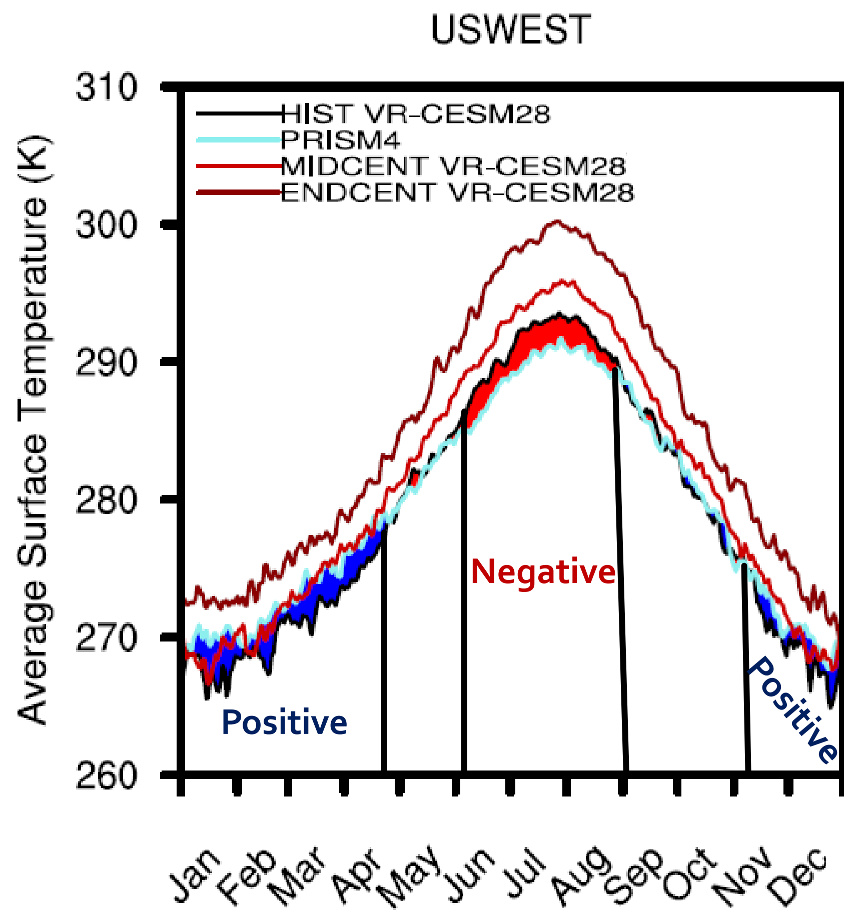
Preliminary Findings – VR-CESM28

Daily Climate RCP8.5 1980-2005 vs 2025-2050 & 2075-2100





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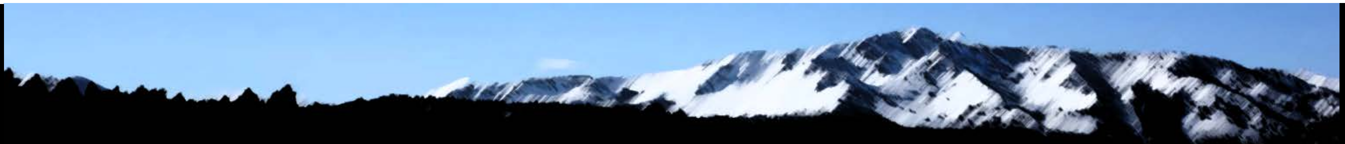

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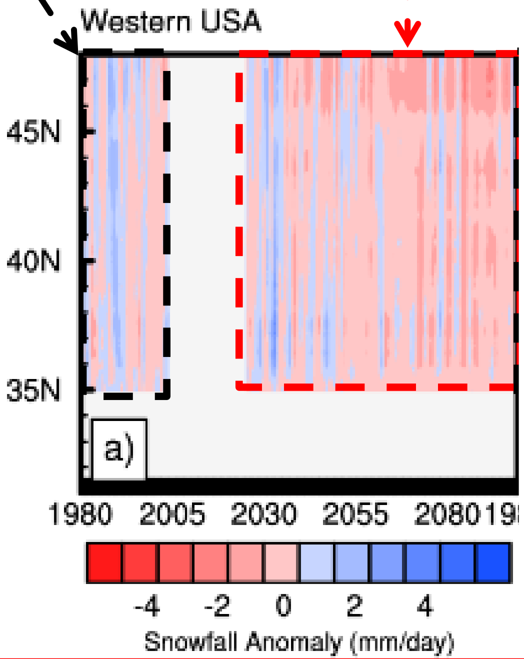
Preliminary Findings – VR-CESM28

Seasonal DJF RCP8.5 1980-2005 vs 2025-2100

Natural Variability

RCP8.5 2025-2100



More SWE/SNOWC Decline (Northern Latitudes)
Decrease Positive Anomaly (All Latitudes)

By 2050s, 2mST is Consistently Above Historical Normal (All Latitudes)

More Below Average Snow Storms (Northern Latitudes)

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Understanding Hydroclimatic Changes in Western USA Mountains

Conclusions

- ***Multi-model analysis of Winter Season SWE shows that by 2040-2065…***

  …mean SWE could decrease between -19% **(NARCCAP)** to -38% **(VR-CESM)**

  …regional downscaling ensemble average seasonal medians -37% & IQRs -20%

- ***Winter Season VR-CESM28 results indicate that by 2025-2050 and 2075-2100…***

SNOWF	-4%	to	-30%
SNOWC	-10%	to	-48%
SWE	-25%	to	-67%
2mST	+1.3 K	to	+5.5 K

- **Evidence of Elevational Dependent Warming, especially in the Rockies**
- **Interior mountain ranges have more resiliency to climate change than coastal ranges**
- **The spatial distribution of change indicates that…**

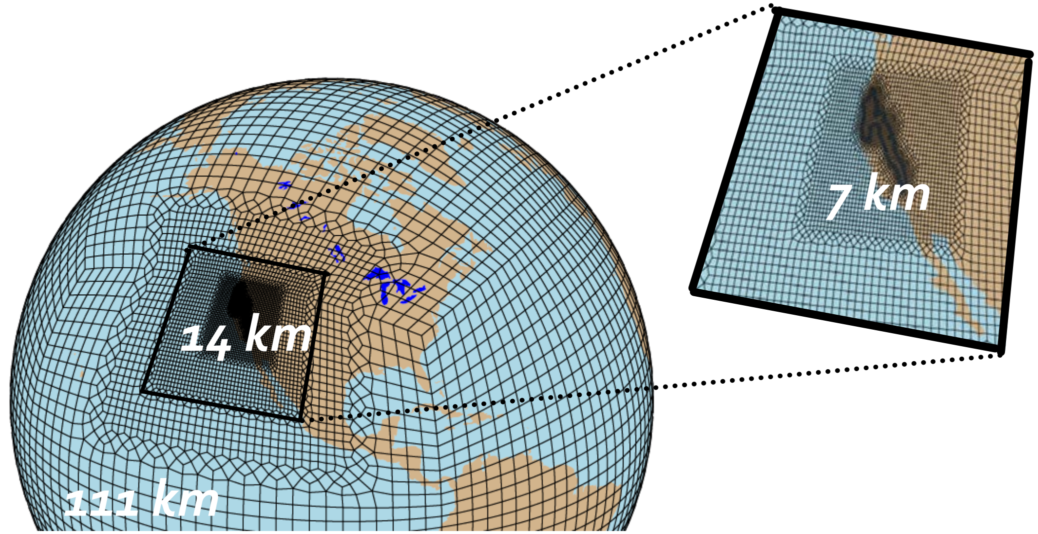
  Northern latitude mountain ranges may experience more dramatic shifts

  By 2050s, 2mST is consistently above normal by +2 K to +7 K

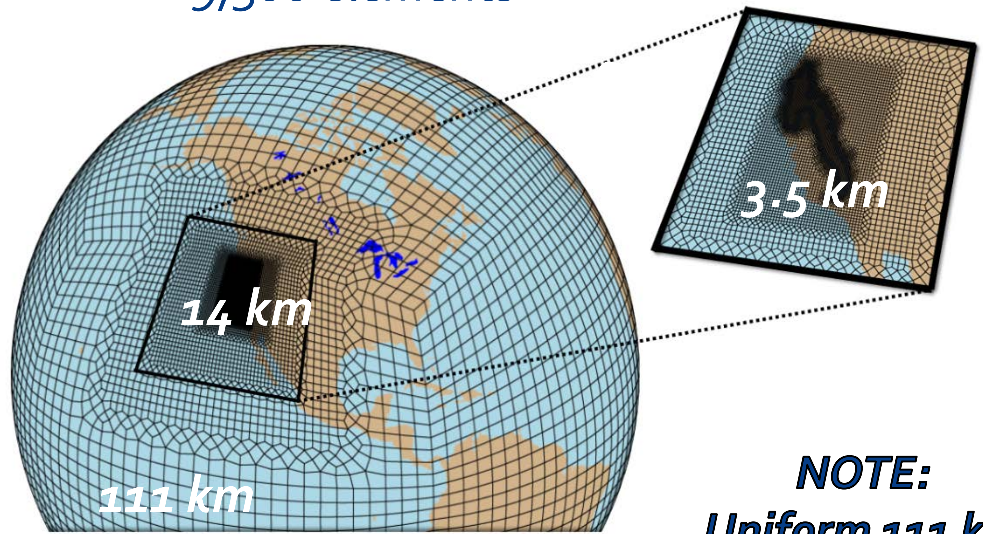
Future Work

Idealized VR-CESM Exploratory Experiments over California's Complex Topography

1. Resolution Dependence of CAM/CLM
2. Exploratory Dry Dynamics in CAM
3. Precipitation Sensitivity to Physics Time Step



9,500 elements



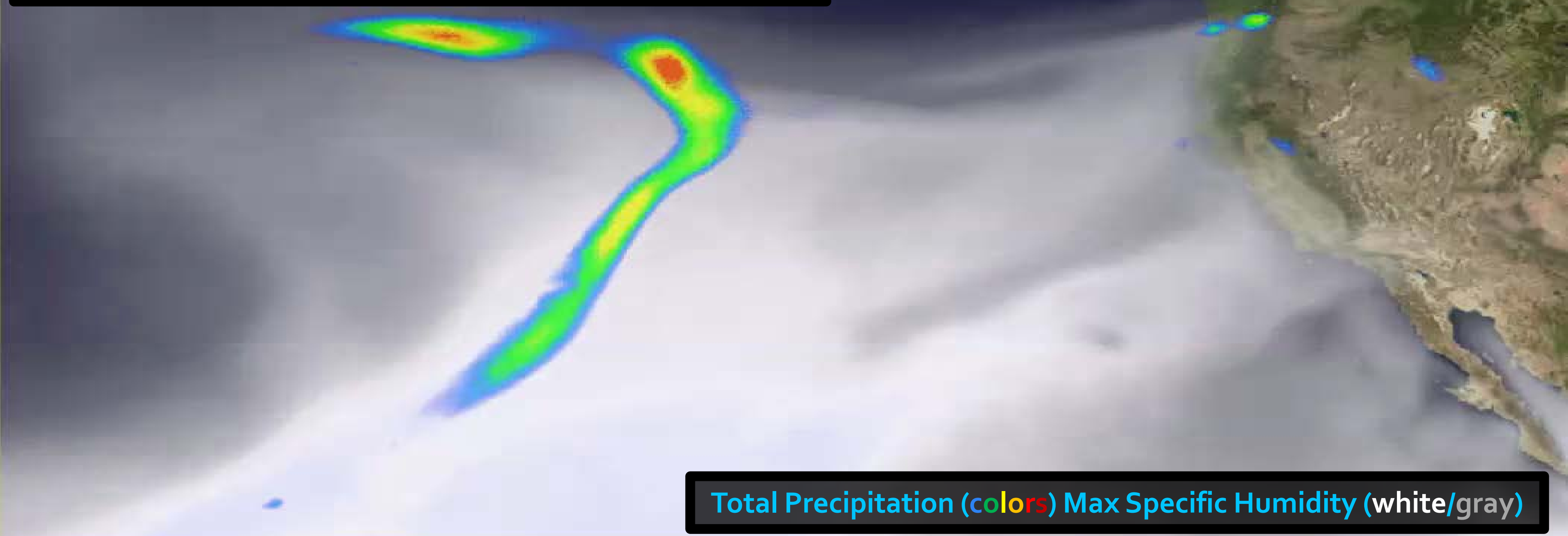
13,400 elements

NOTE: Uniform 111 km 5400 elements

Future Work
Atmospheric Rivers

Thank you for your time!

Project Funding
NSF Climate Change, Water, and Society IGERT
Leland and Roy Saxon Fellowship
DoE Multiscale Methods



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