An Assessment of Variable-Resolution Climate Modeling in CAM

Paul Ullrich
Alan Rhoades
Xingying Huang
Colin Zarzycki

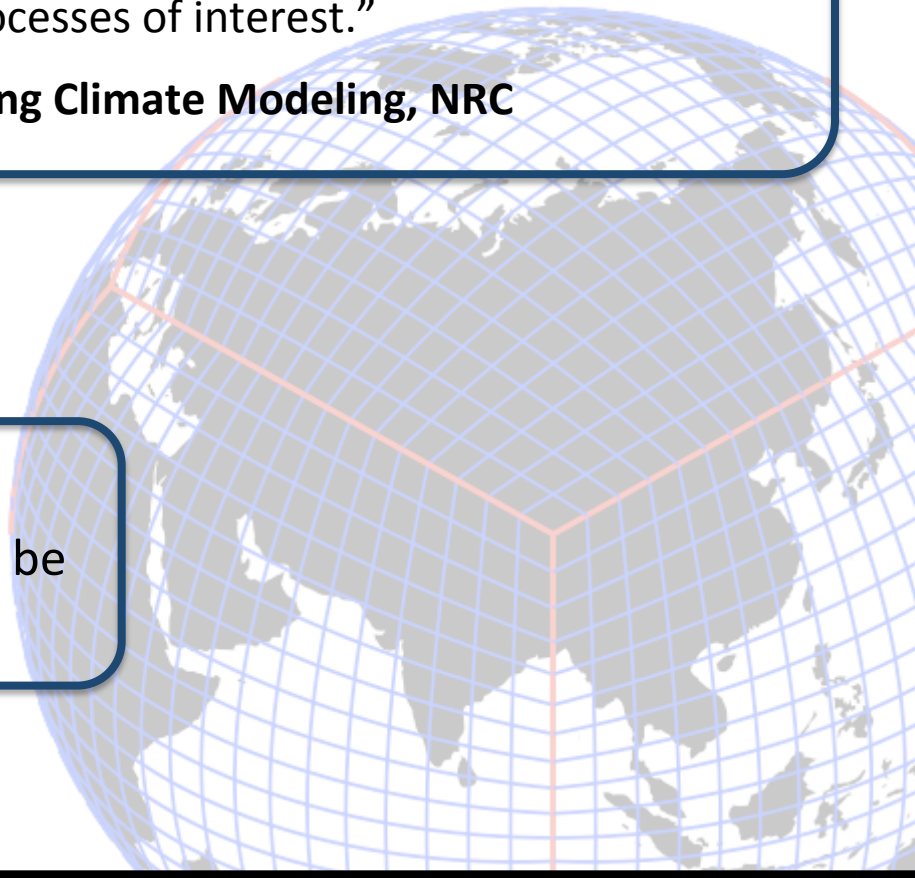
Atmospheric Model Working Group

February 18th, 2014

Variable-Resolution Modeling

"To enable higher resolution within computational constraints, alternative approaches such as regional climate models and global models with variable resolution, stretched grids or adaptive grids have been developed to provide local refinements for geographic regions or processes of interest."

- A National Strategy for Advancing Climate Modeling, NRC



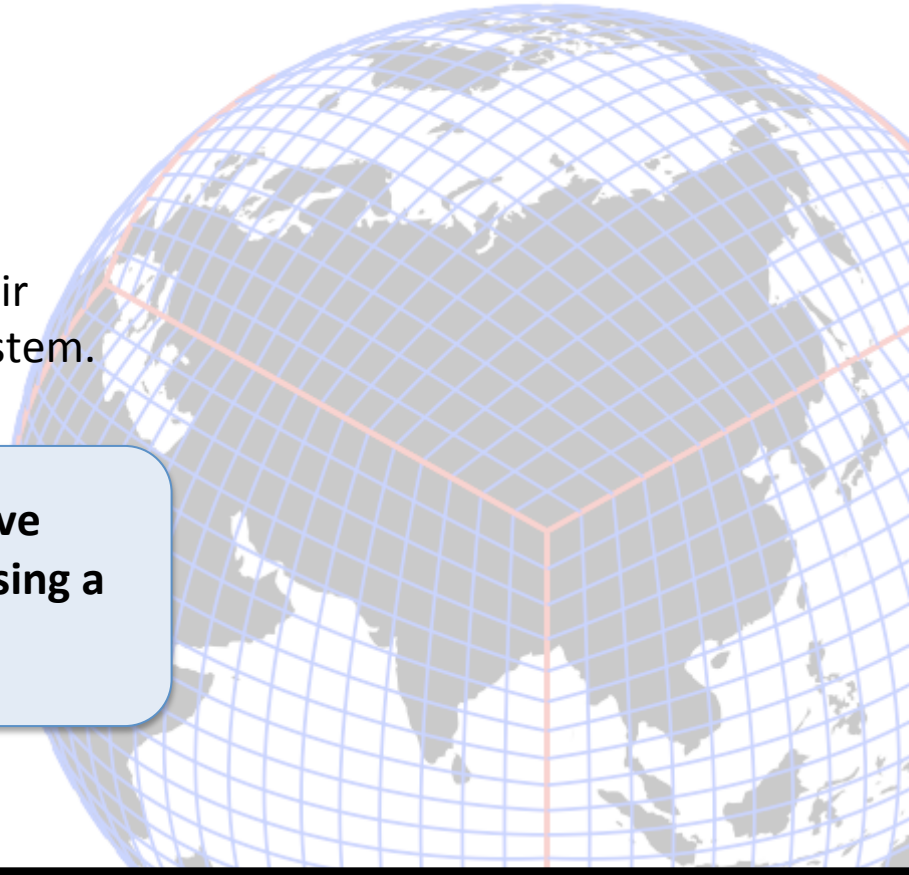
I'd like to argue that the next generation of regional models will be variable-resolution global models.

Variable-Resolution Modeling in CESM

It is widely acknowledged that pressing questions on regional climate change requires **higher model resolution**.

Variable-resolution modeling systems offer a promising method for reaching these scales.

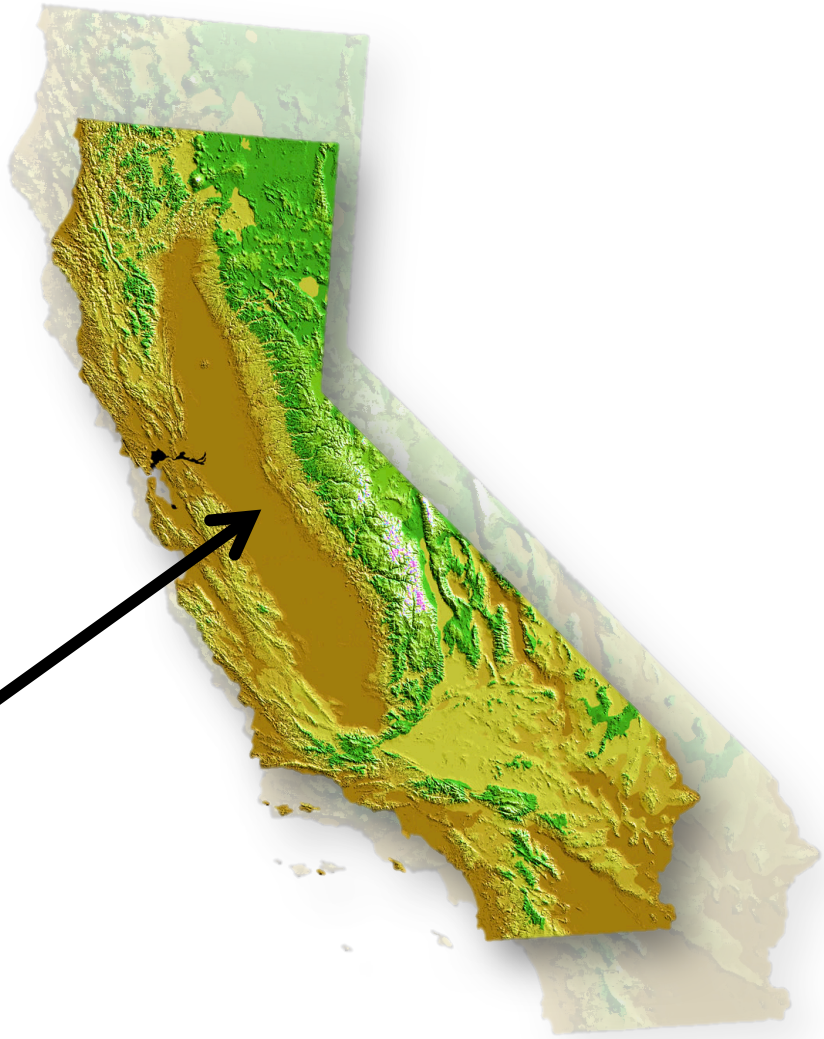
The new variable-resolution capabilities introduced in the Community Earth System Model (CESM) have been evaluated for their capability to resolve California's climate system.



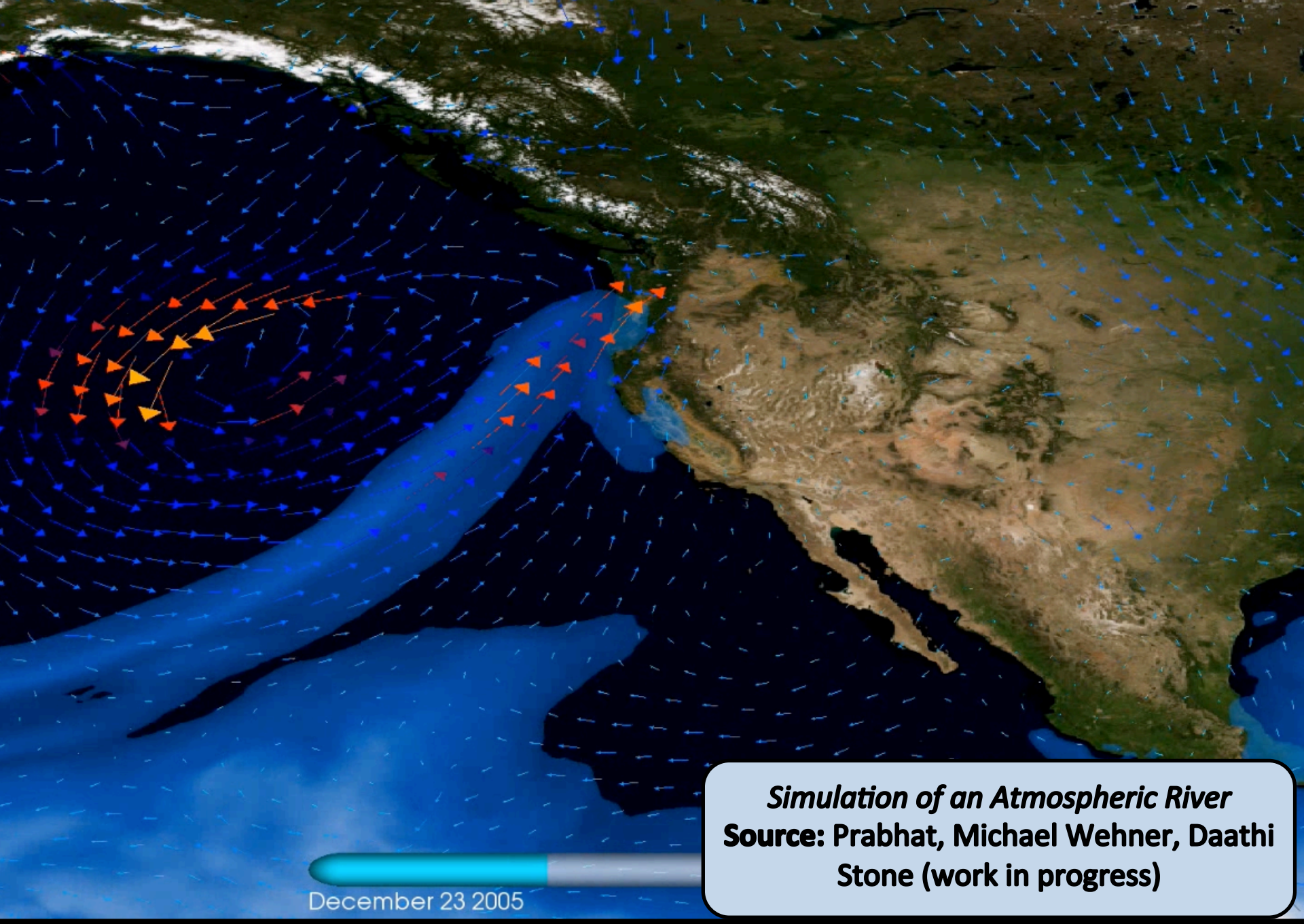
Our results suggest that **CESM is competitive with dynamical downscaling techniques using a regional climate model** (such as via WRF).

Why Higher Resolution?

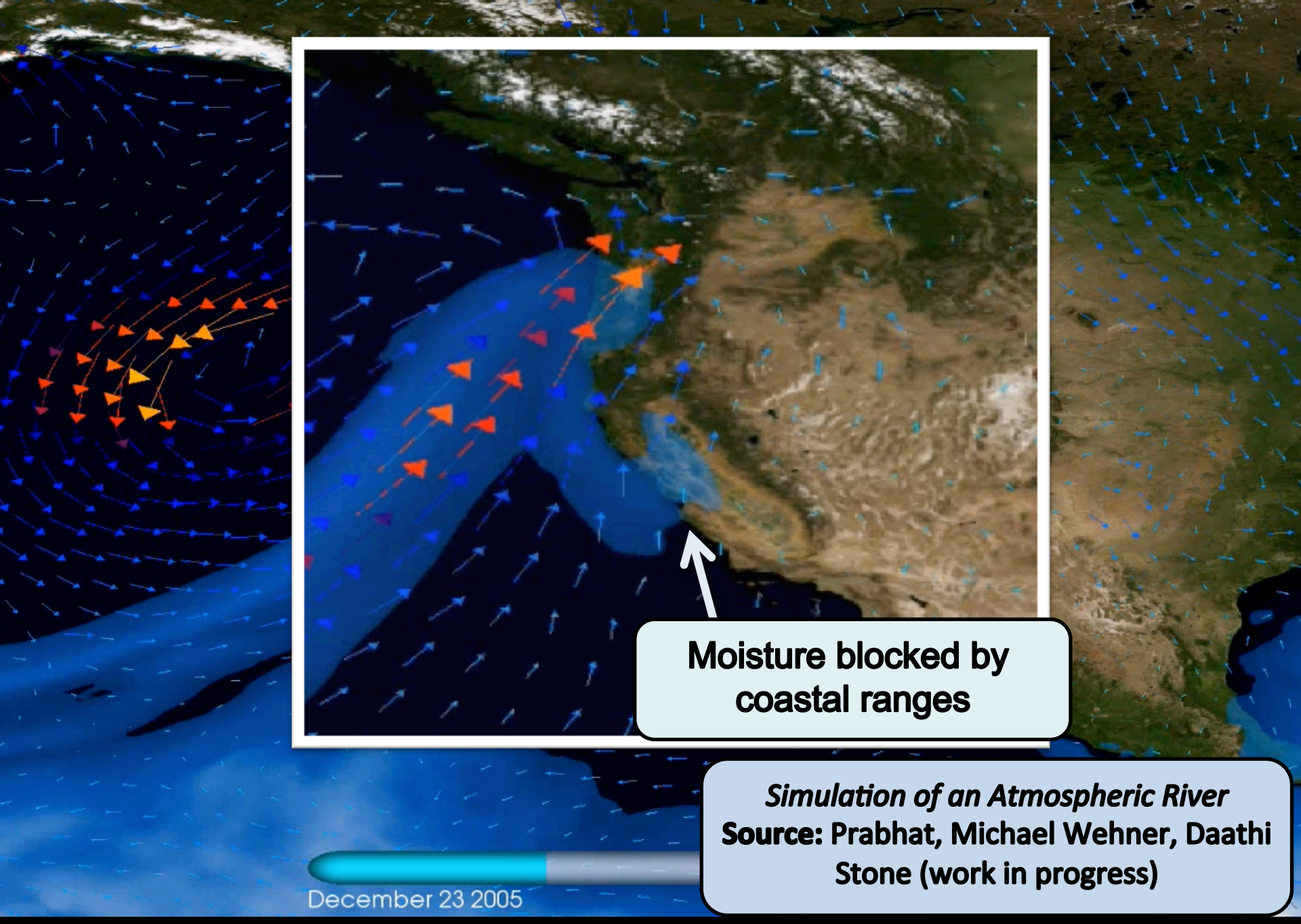
- Improved resolution of land-surface processes (snowpack, runoff)
- Resolution of transient eddies (synoptic-scale frontal systems, local convective systems)
- Resolution of extreme weather events
- Improvement in representation of geographic features (mountain ranges and islands)



The California coastal ranges have a dramatic effect on regional climate which is poorly captured in current climate models.



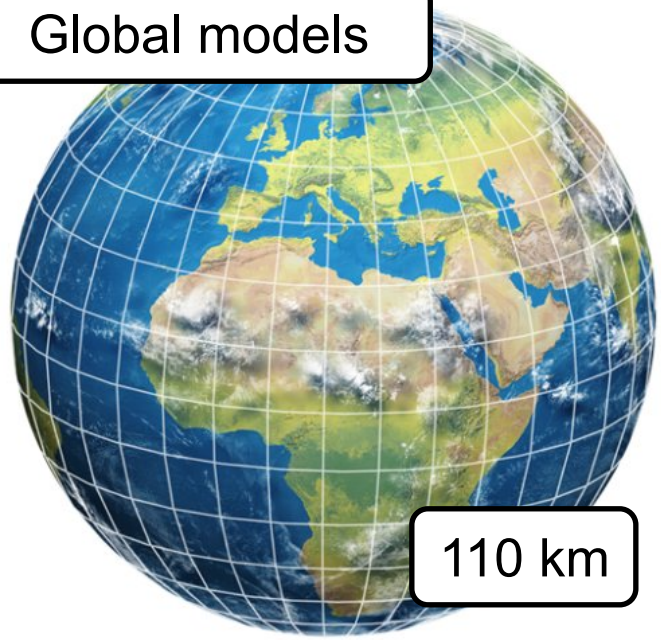
Simulation of an Atmospheric River
Source: Prabhat, Michael Wehner, Daathi Stone (work in progress)



Simulation of an Atmospheric River
Source: Prabhat, Michael Wehner, Daathi Stone (work in progress)

Global vs. Regional?

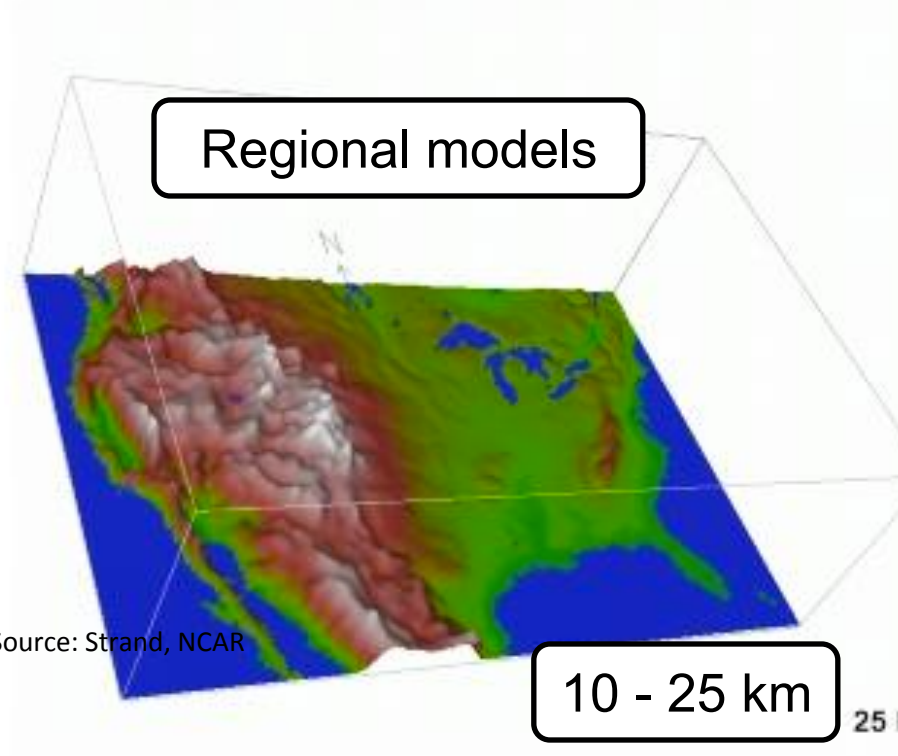
Global models



110 km

No explicitly driven boundary conditions

Regional models



Source: Strand, NCAR

10 - 25 km

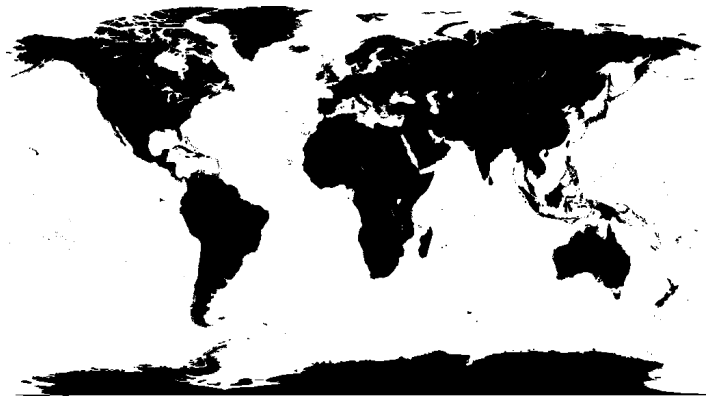
Boundary conditions must be specified by a global model or reanalysis data. Can lead to mismatch in boundary conditions and interior.

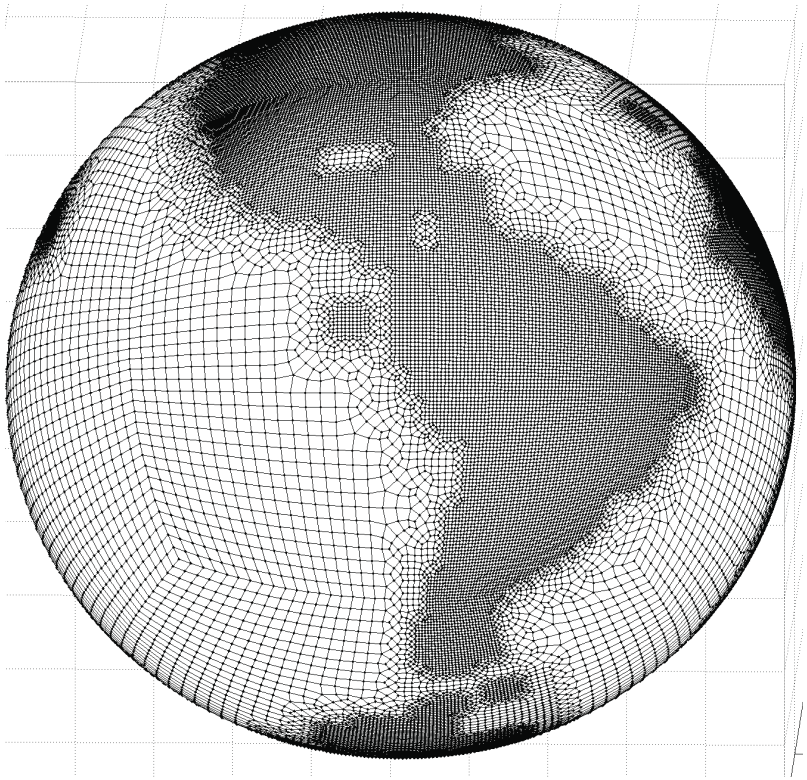
SQuadGen Mesh Generator

A new **meshing utility** for easy generation of conformal quadrilateral grids.

http://climate.ucdavis.edu/squadgen.php

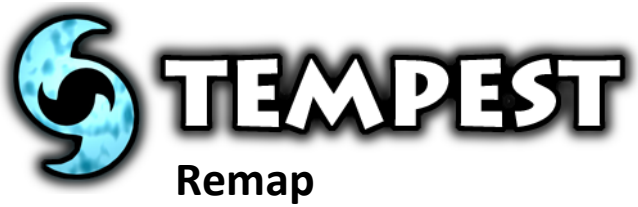
Below: Input in the form of a greyscale PNG image in latitude/longitude space.





Above: Output mesh with the low connectivity template showing enhanced resolution over land.

TempestRemap



A new **conservative**, **consistent** and/or **monotone** remapping scheme for arbitrary meshes, with built-in finite-element support. Analogous to ESMF functionality.

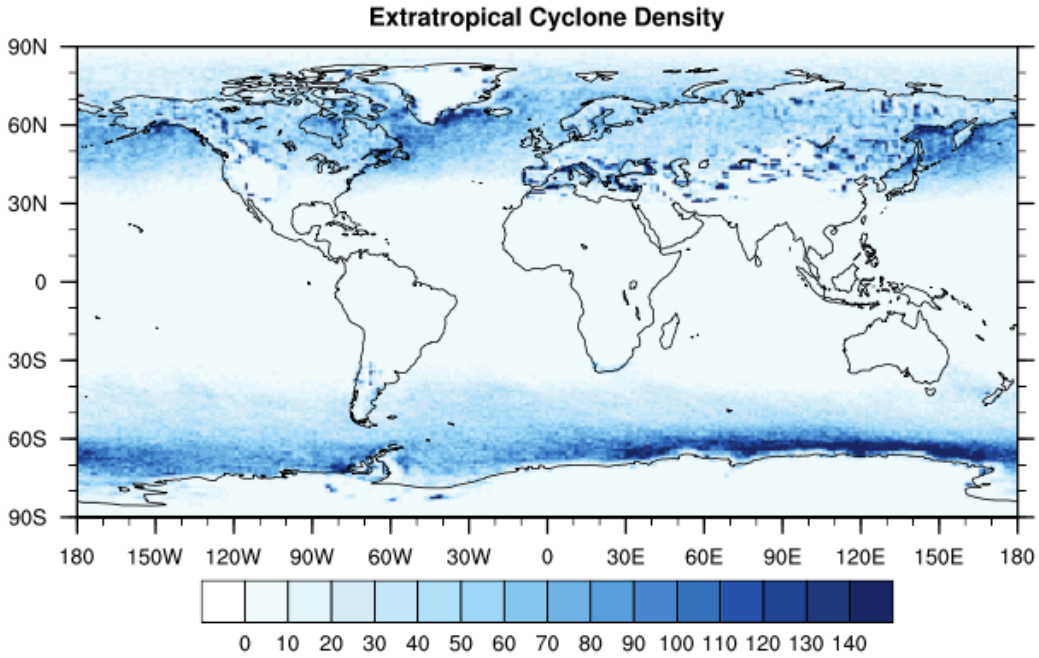
Improves significantly on existing ESMF / SCRIP maps, particularly when mapping between finite-elements and finite-volumes.

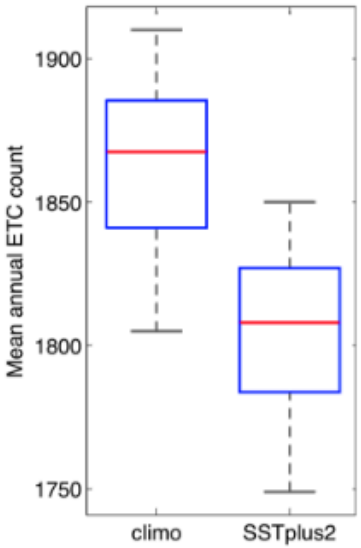
Reference: Ullrich, P.A. and M.A. Taylor (2014) "Arbitrary-Order Conservative and Consistent Remapping and a Theory of Linear Maps, Part 1." *Monthly Weather Review*, In Press.

TempestExtremes

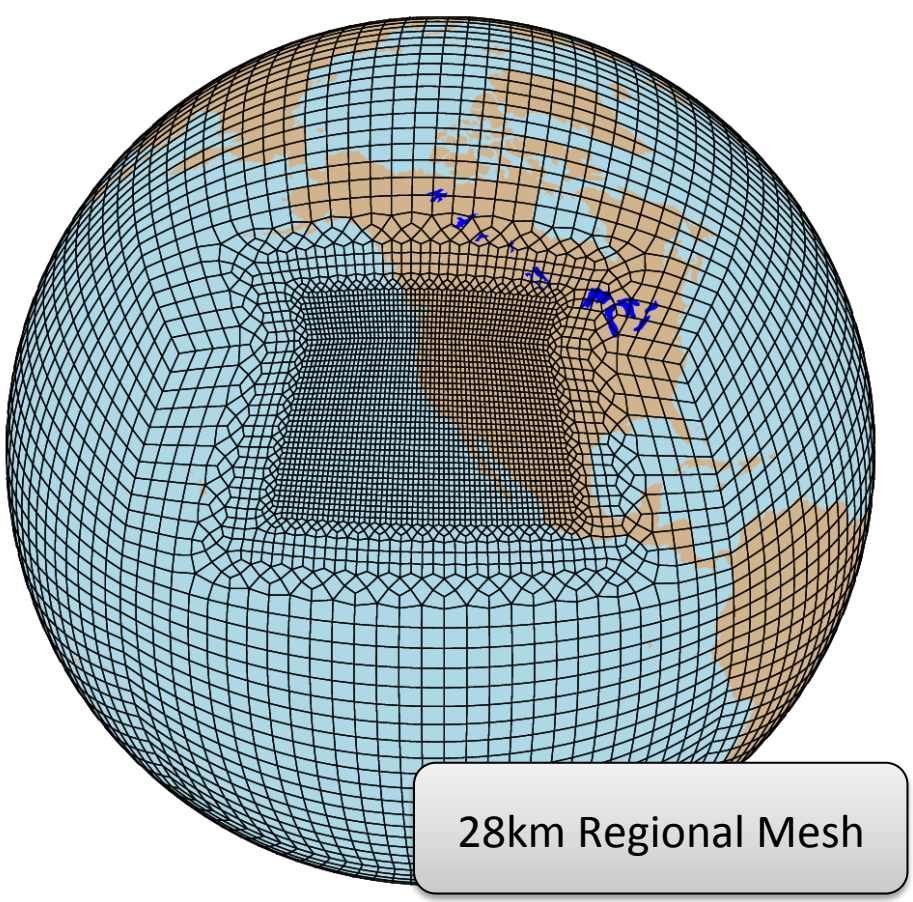
TEMPEST
Extremes

Automated detection and characterization of extreme weather events. Current support for **tropical cyclones**, **extratropical cyclones** and **atmospheric blocks**. Work underway for **atmospheric rivers**, **temperature extremes** and **precipitation extremes**.

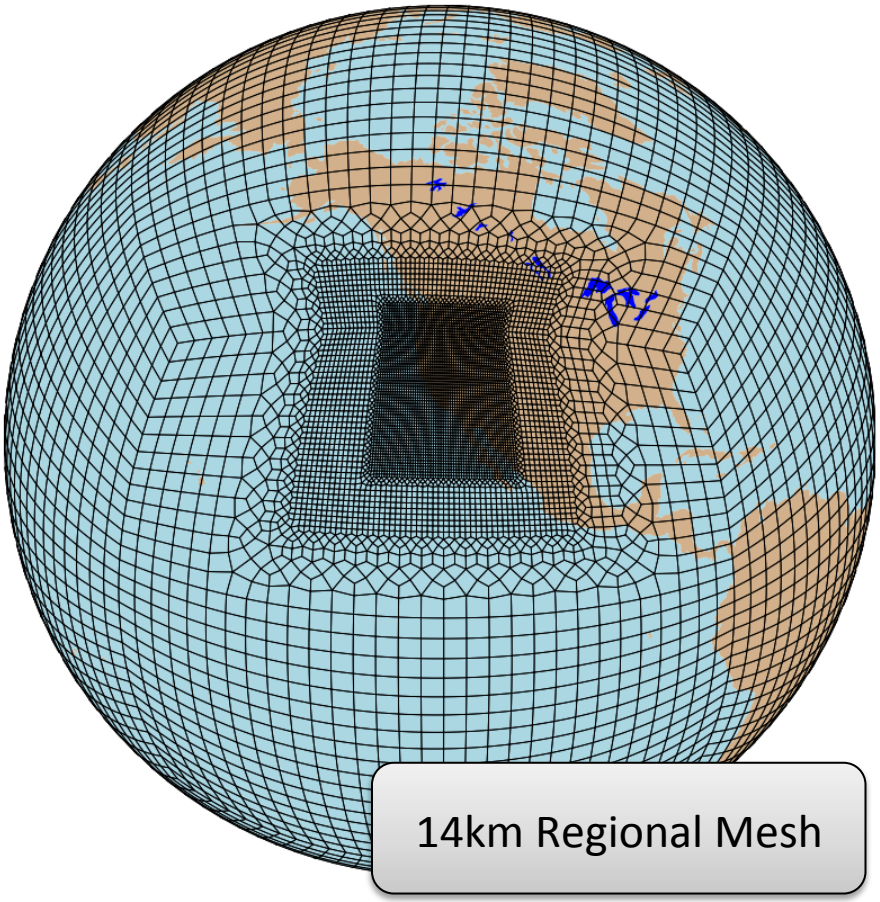




Two West Coast Regional Meshes



28km Regional Mesh



14km Regional Mesh

Variable-Resolution Simulations

Variable resolution simulations (AMIP):

- 4 x 28km 1980-2005 Variable Resolution CESM ensemble
- 1 x 28km 1980-2005 Variable Resolution CESM with rougher topography
- 1 x 14km 1980-2005 Variable Resolution CESM

Dynamically downscaled simulations (from ERA-Interim Reanalysis):

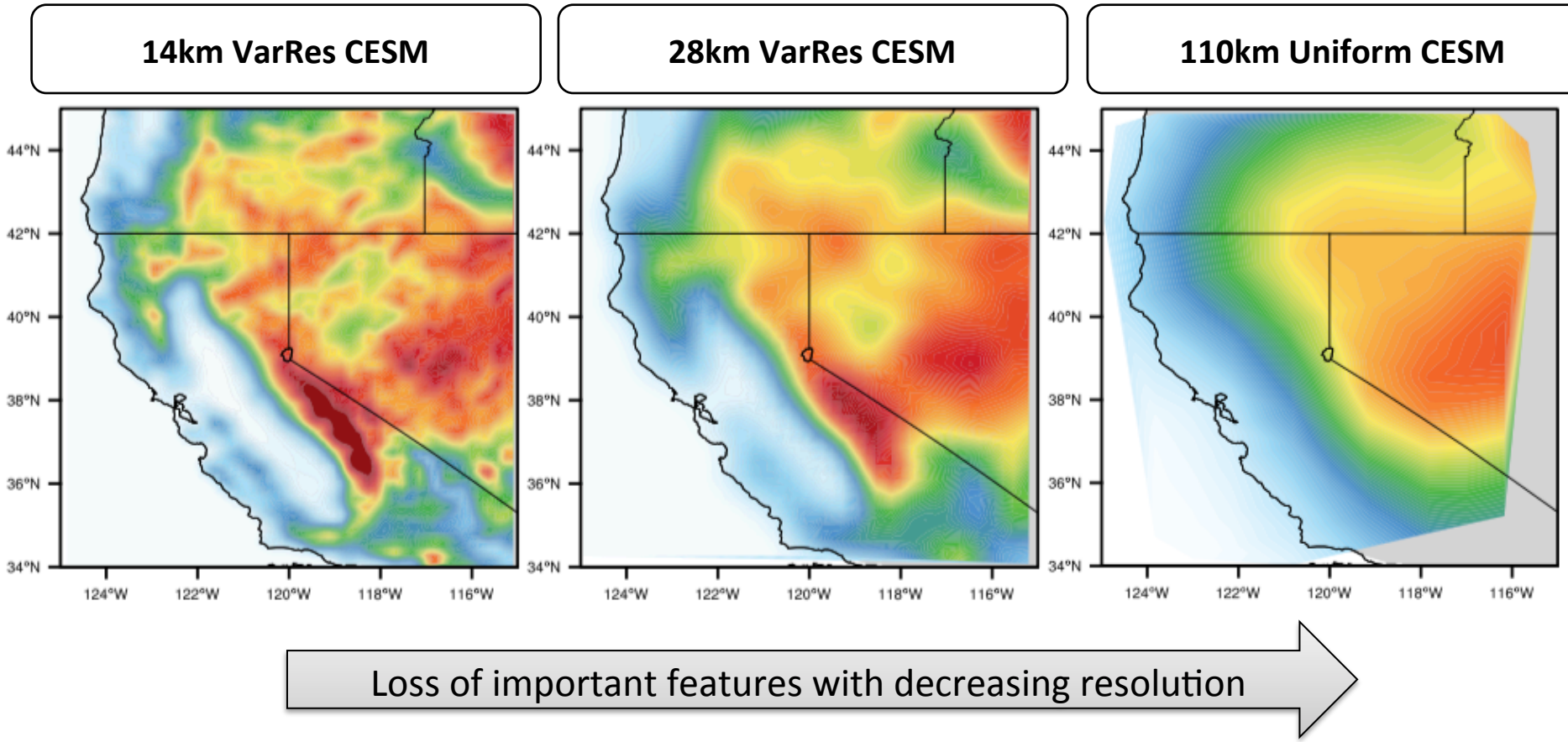
- 1 x 27km 1980-2005 Downscaled WRF
- 1 x 9km 1980-2005 Downscaled WRF
- 1 x 3km 1980-1983 Downscaled WRF (selected seasons)

Climate of the 20th century dataset (AMIP, courtesy Michael Wehner, LBNL):

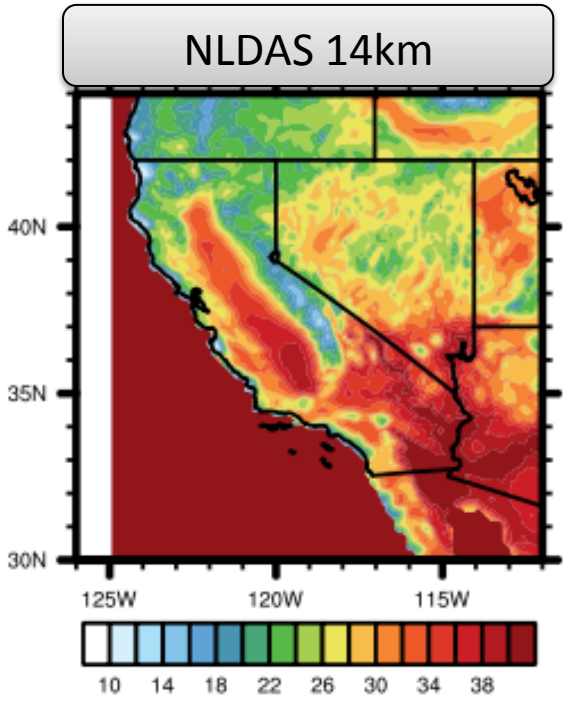
- 40 x 110km 1950-2010 Uniform Resolution CESM ensemble
- 1 x 28km 1950-2010 Uniform Resolution CESM (finite volume dycore)

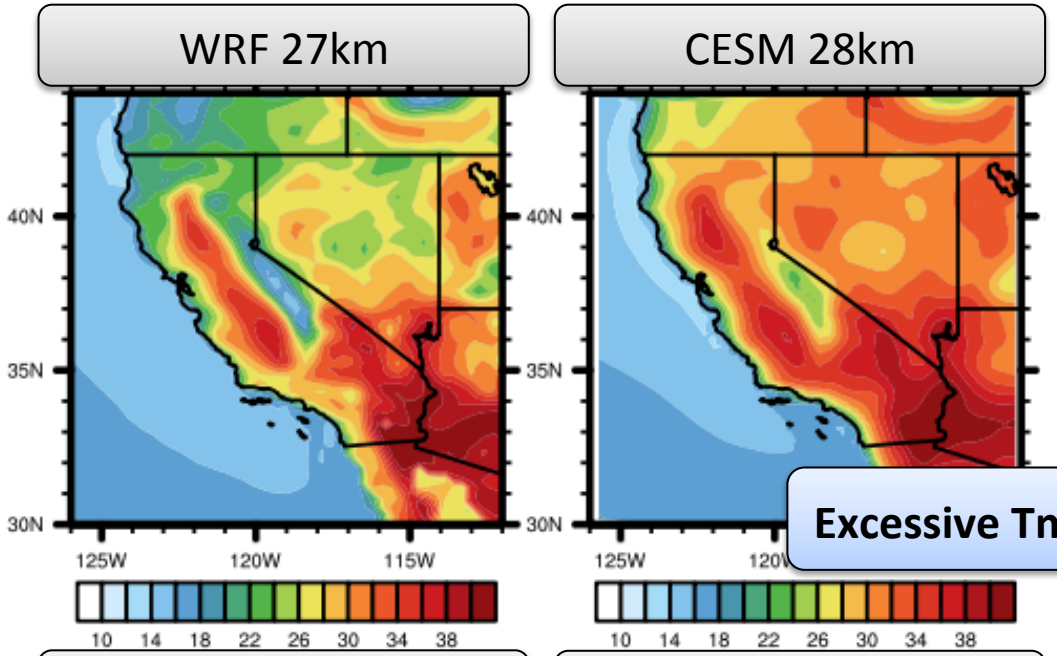
14km Variable Resolution, June 2003 (30 min output)

Topography Height

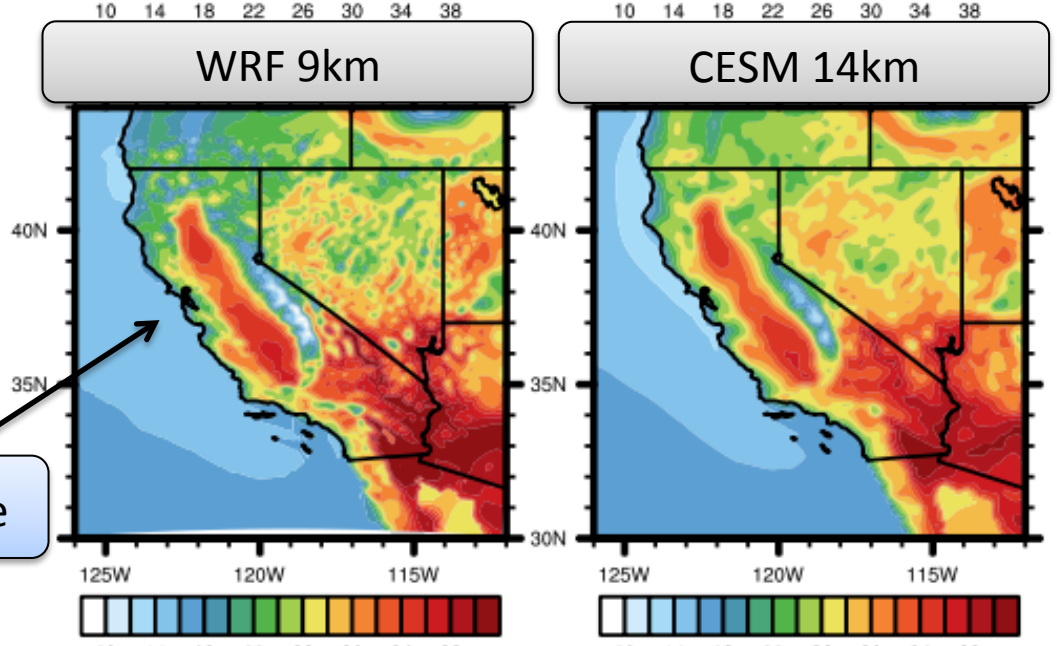


JJA Daily 2m Maximum Temperature





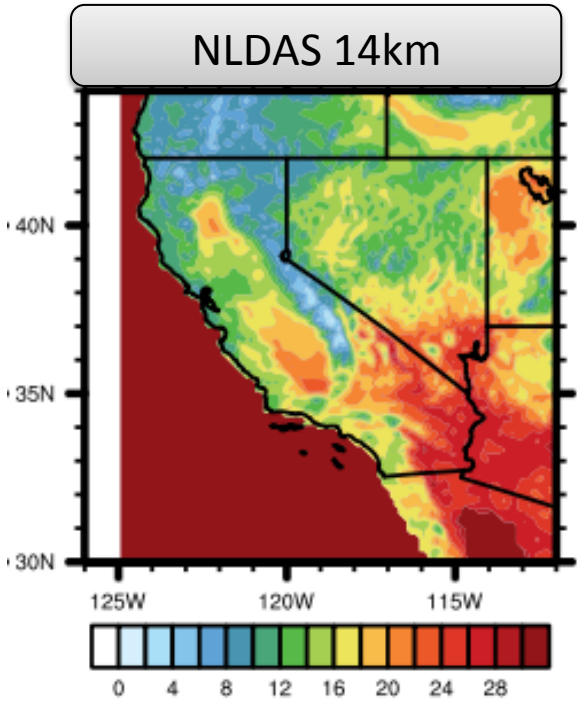
Excessive Tmax

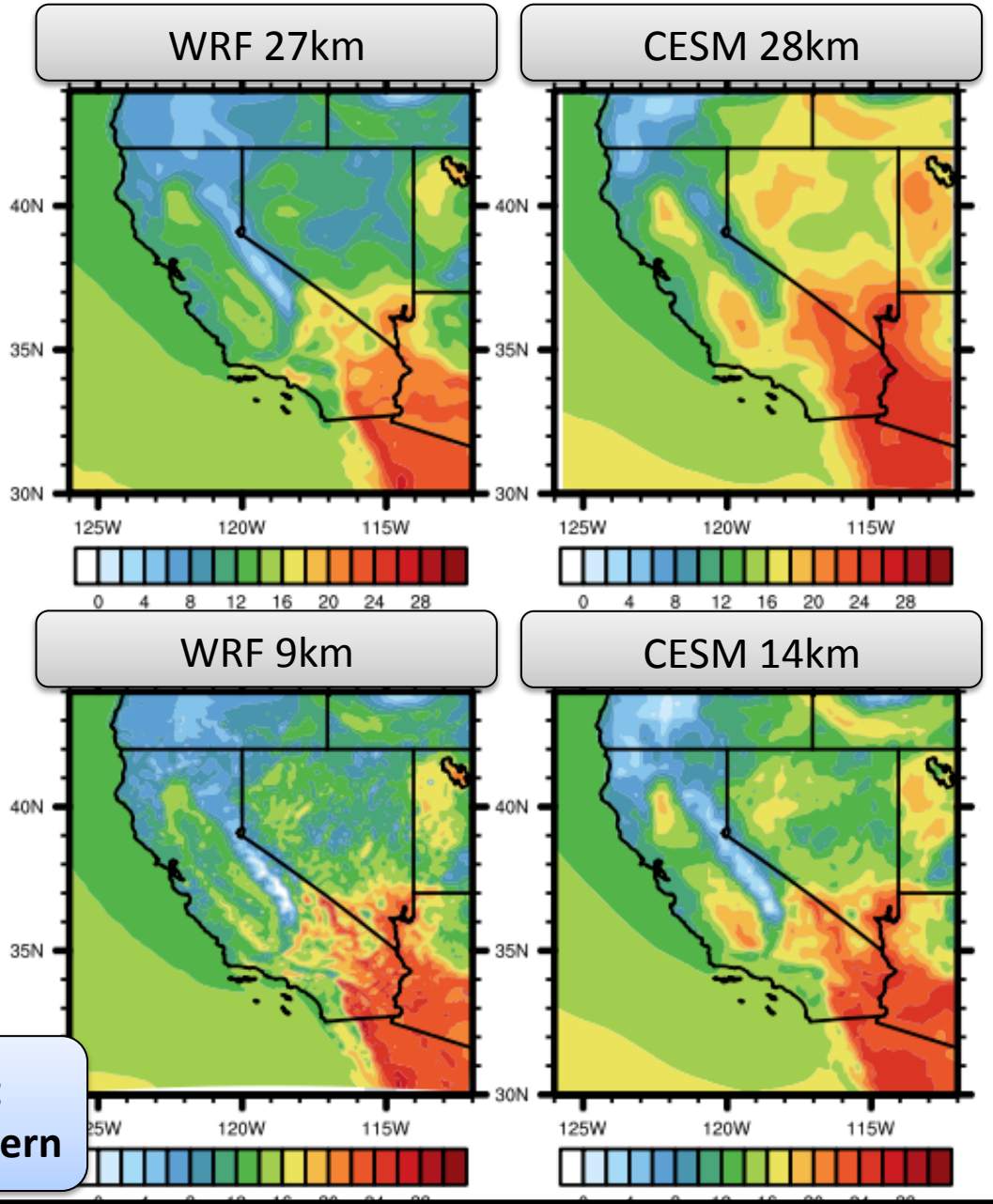


Sea Breeze

NLDAS: NOAA Land Data Assimilation System

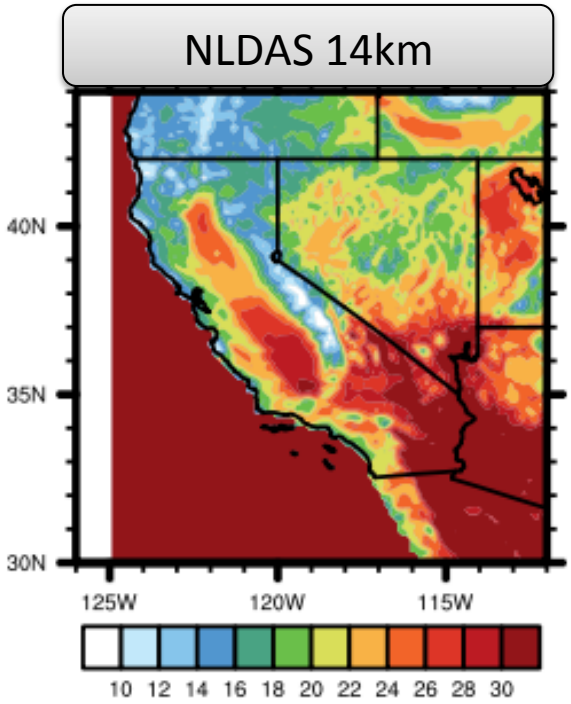
JJA Daily 2m Minimum Temperature



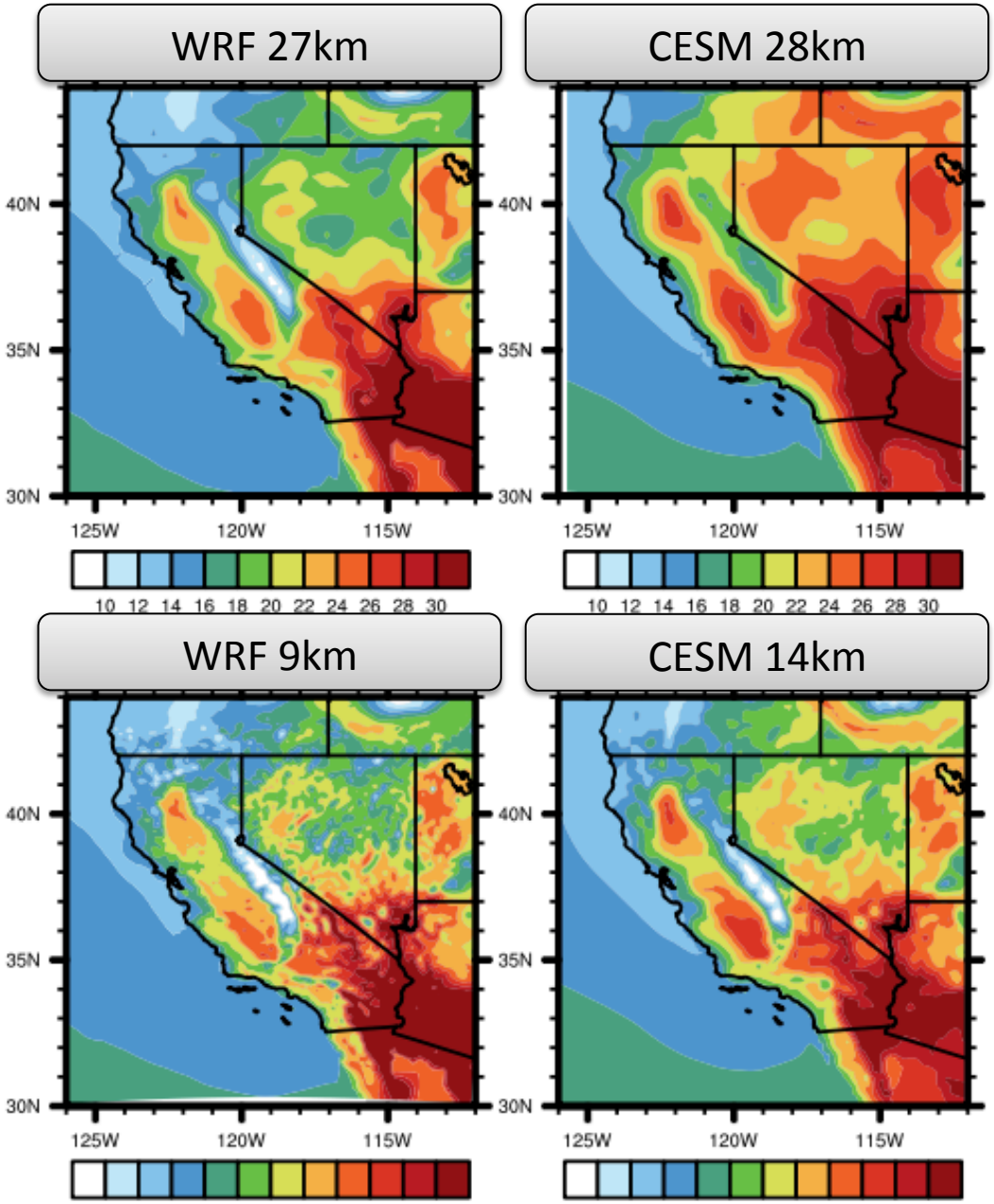


WRF: Incorrect central valley pattern

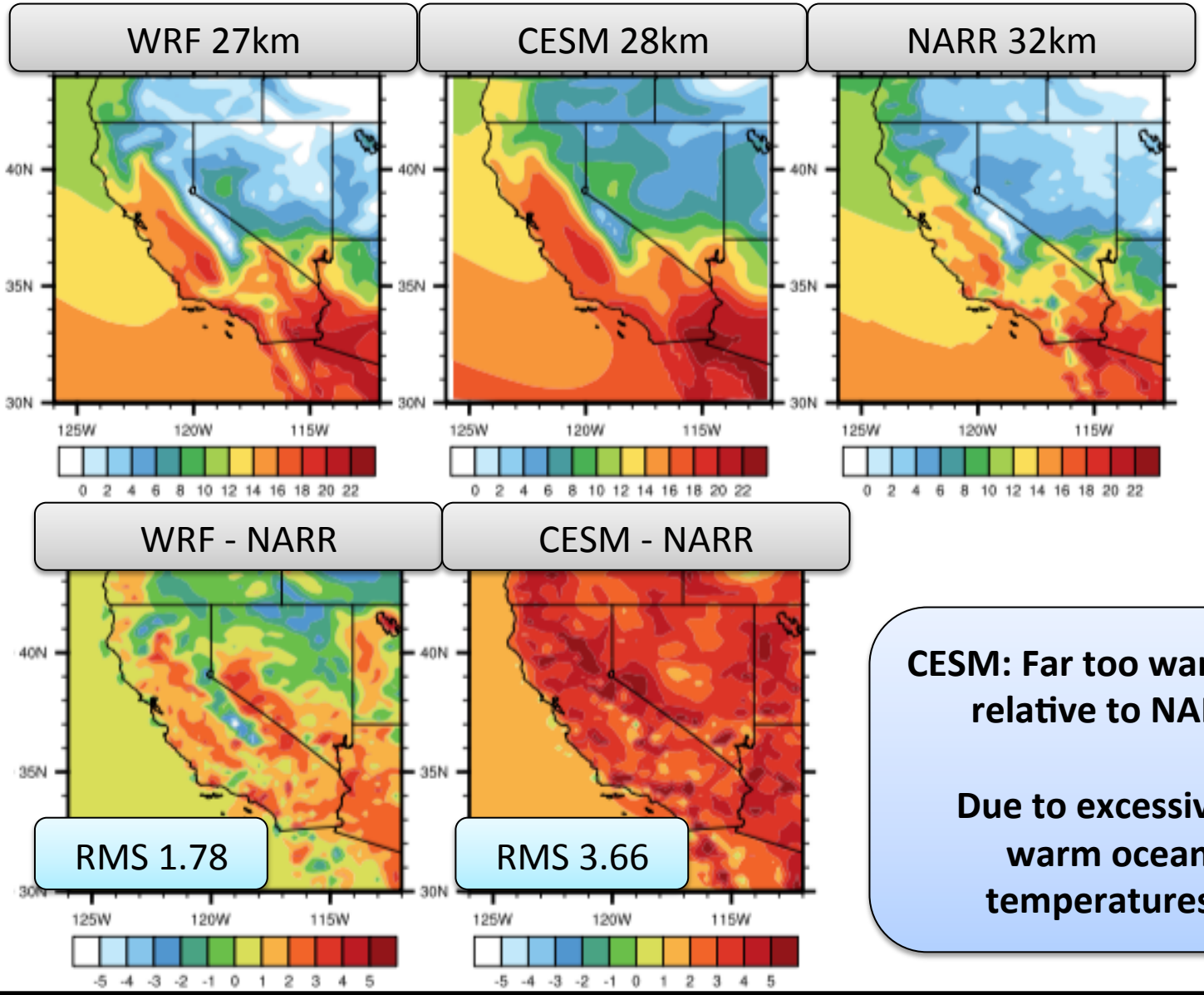
JJA Daily 2m Average Temperature



Overall: Better agreement from CESM



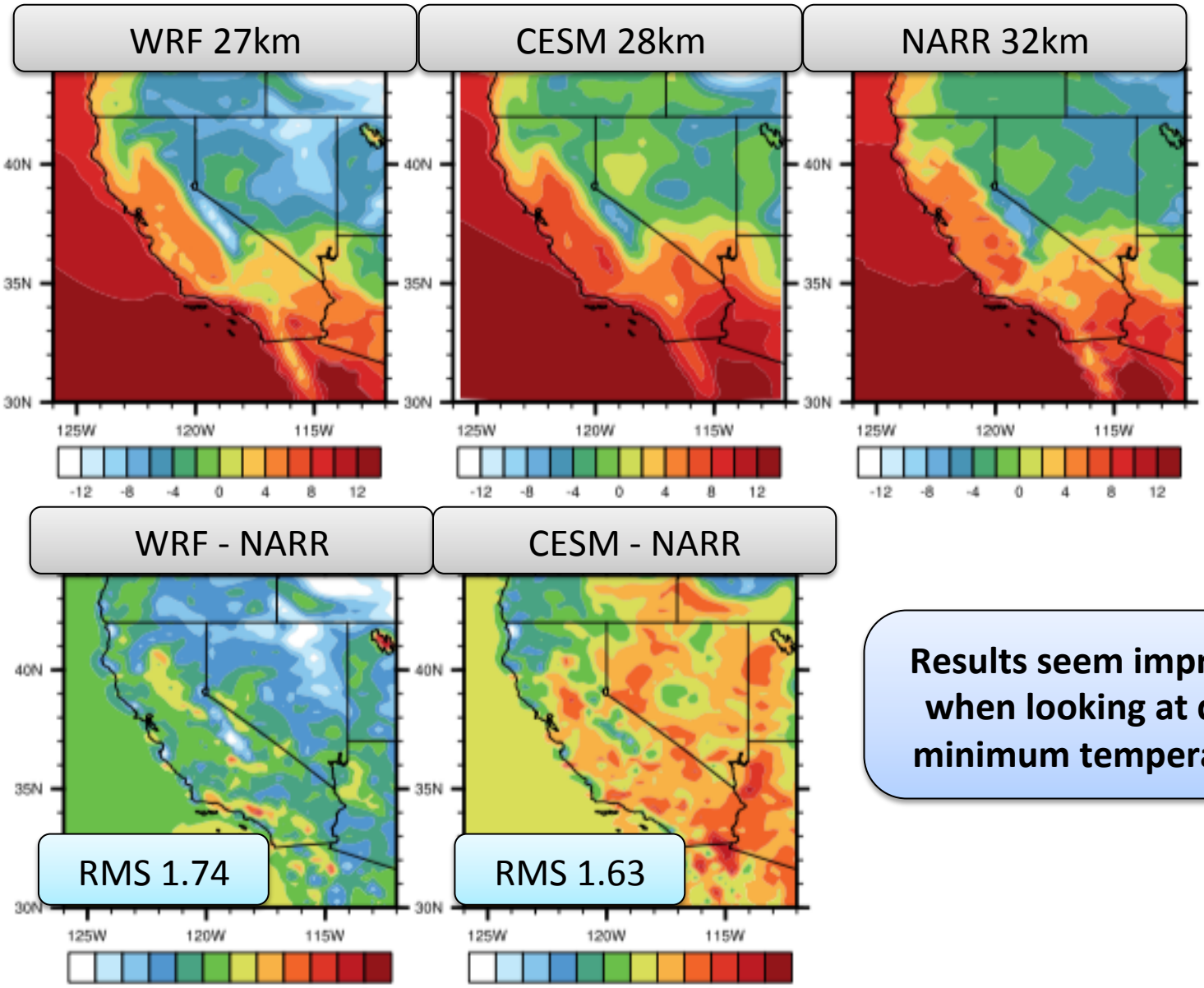
DJF Daily Maximum Temperature



CESM: Far too warm DJF relative to NARR

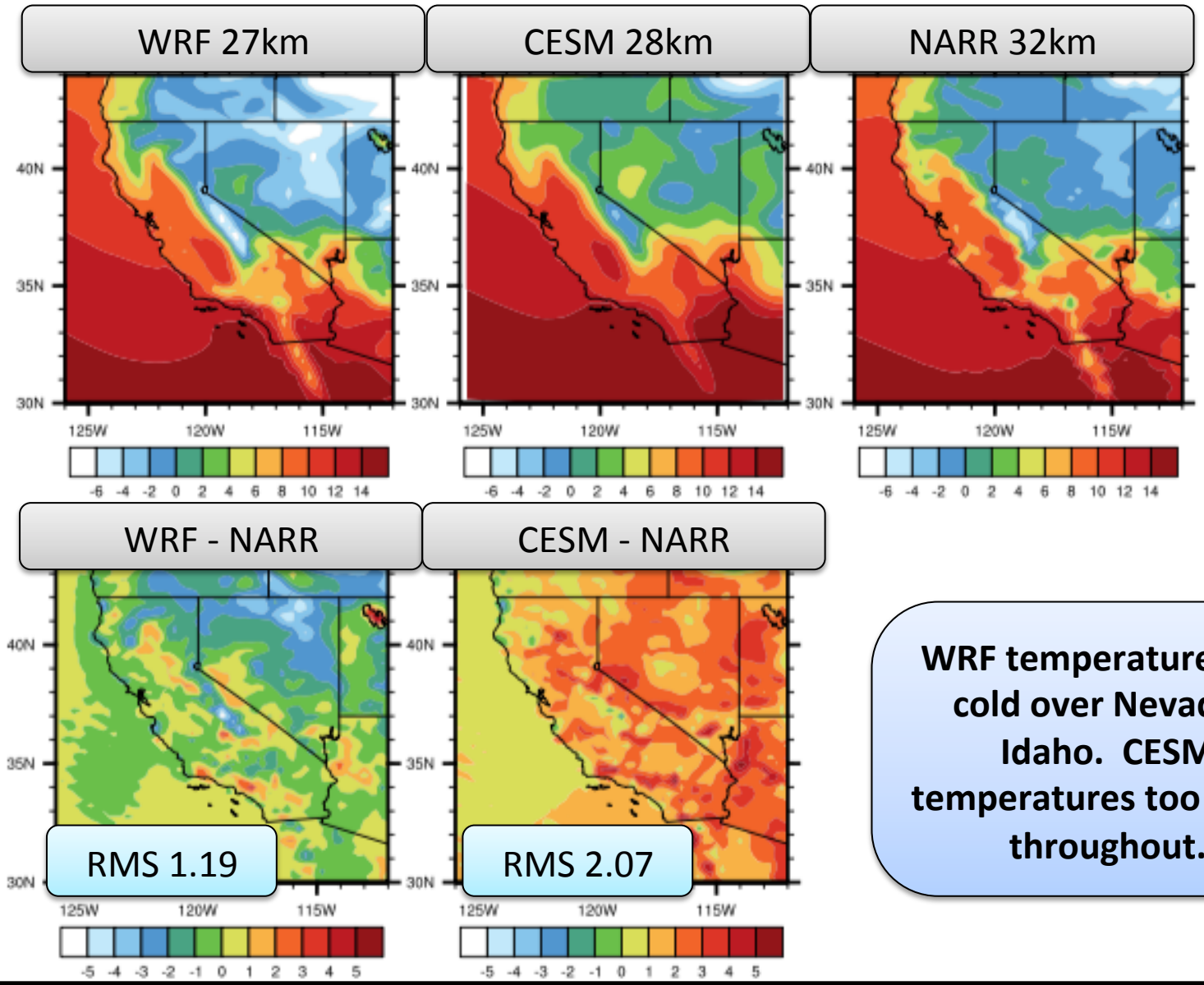
Due to excessively warm ocean temperatures?

DJF Daily Minimum Temperature



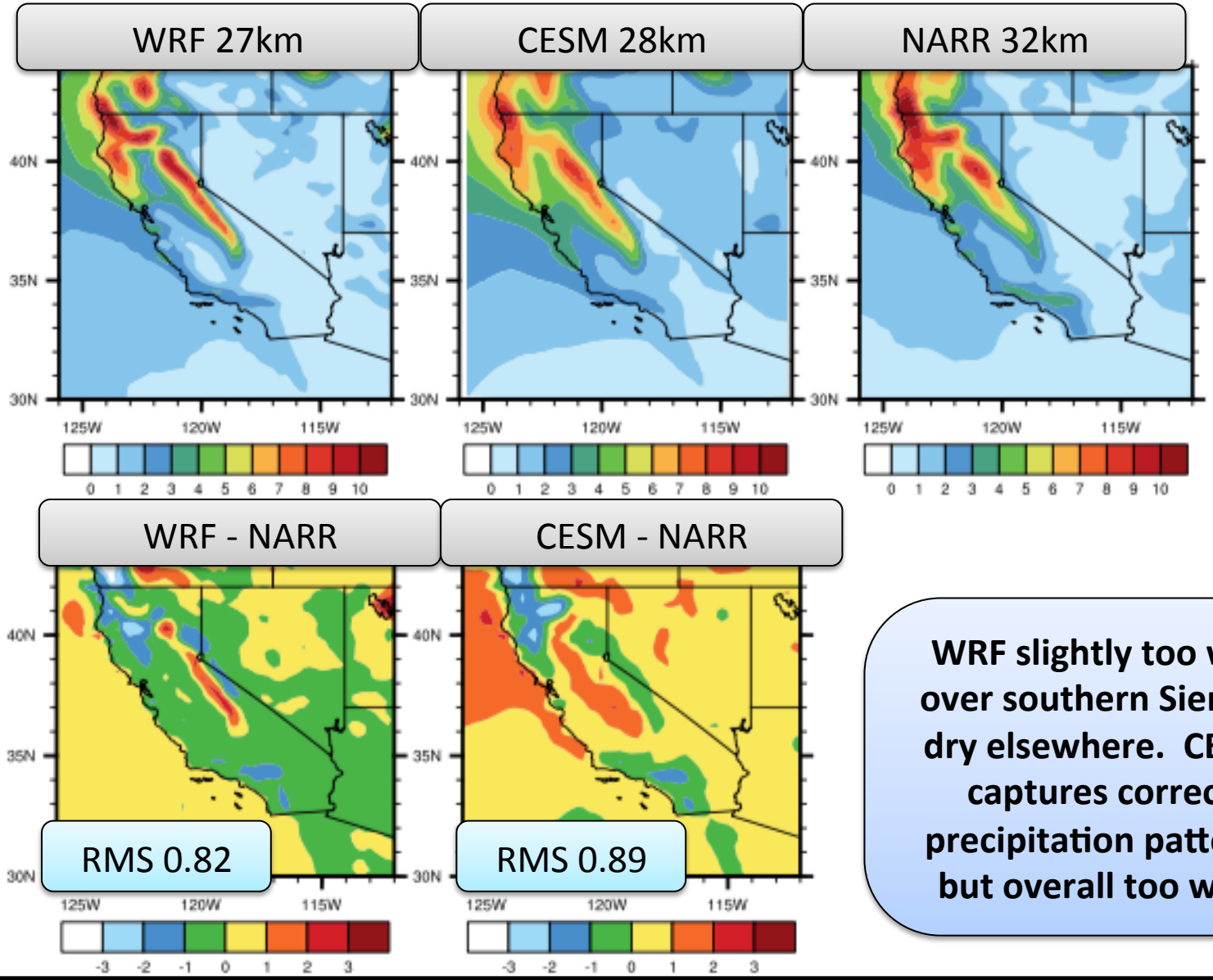
Results seem improved when looking at daily minimum temperature

DJF Daily Average Temperature



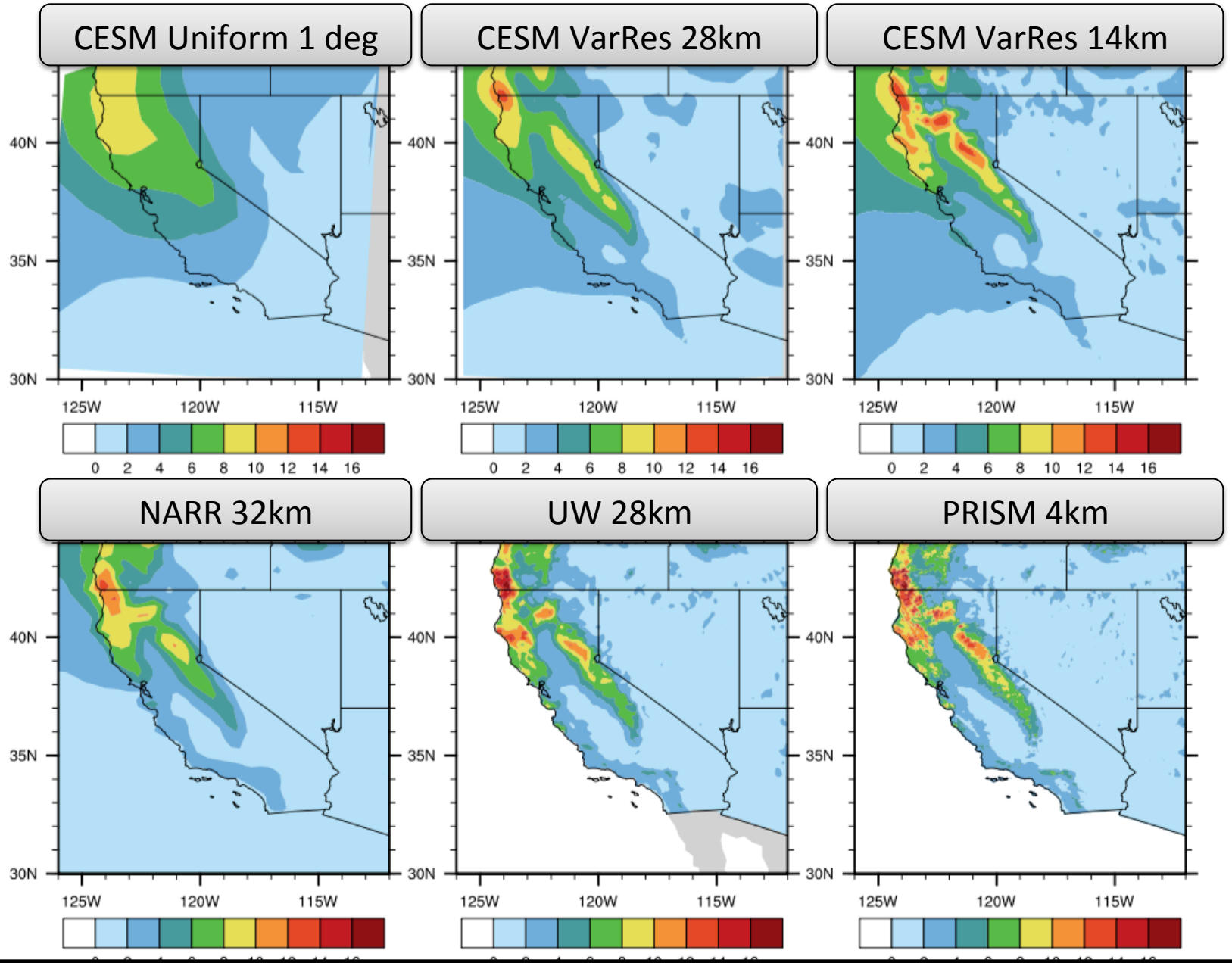
WRF temperatures too cold over Nevada / Idaho. CESM temperatures too warm throughout.

DJF Daily Average Precipitation

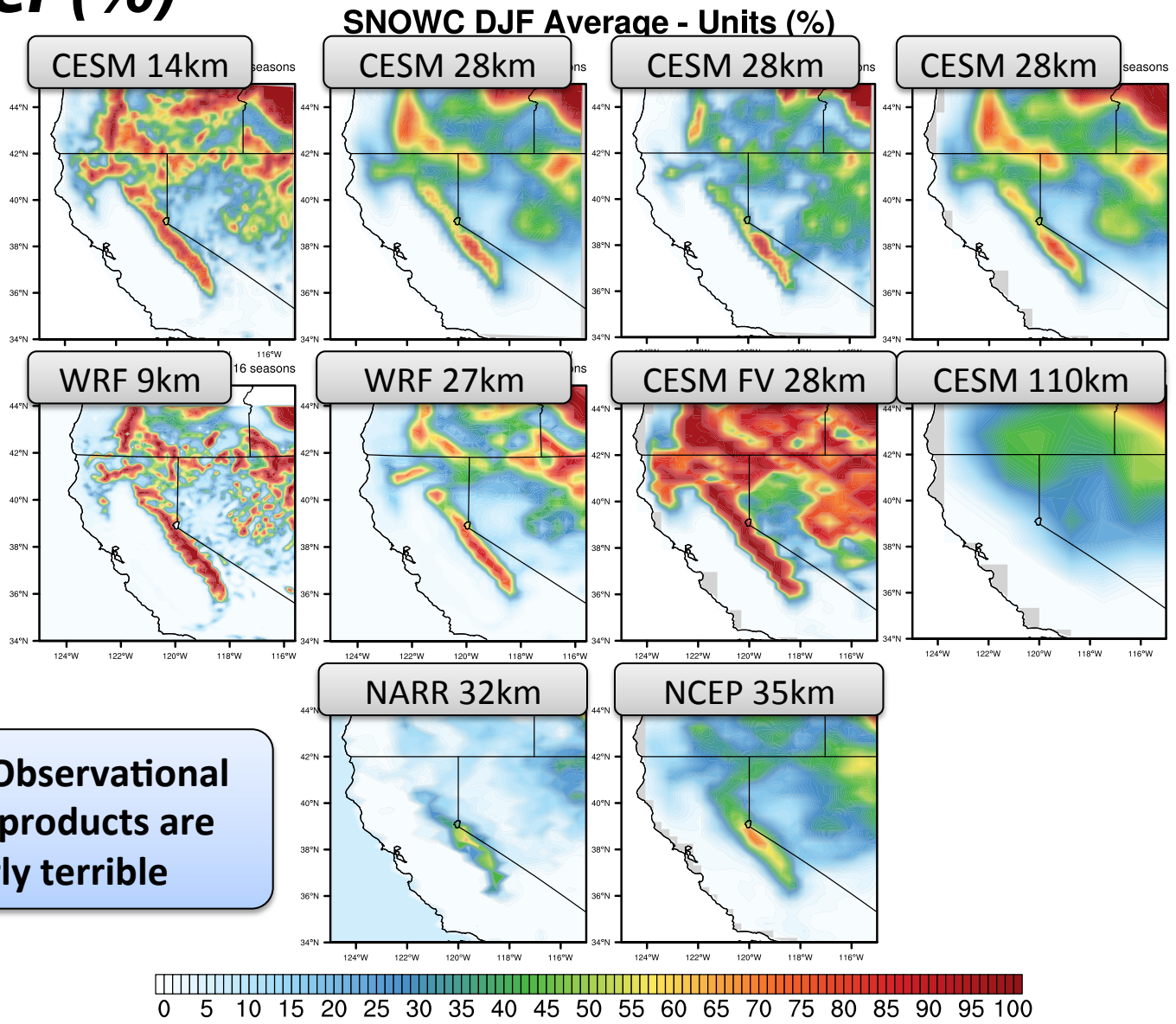


WRF slightly too wet over southern Sierras, dry elsewhere. CESM captures correct precipitation pattern, but overall too wet.

Average daily precipitation rate DJF 1980-1986 unit:mm/d



Snow Cover (%)

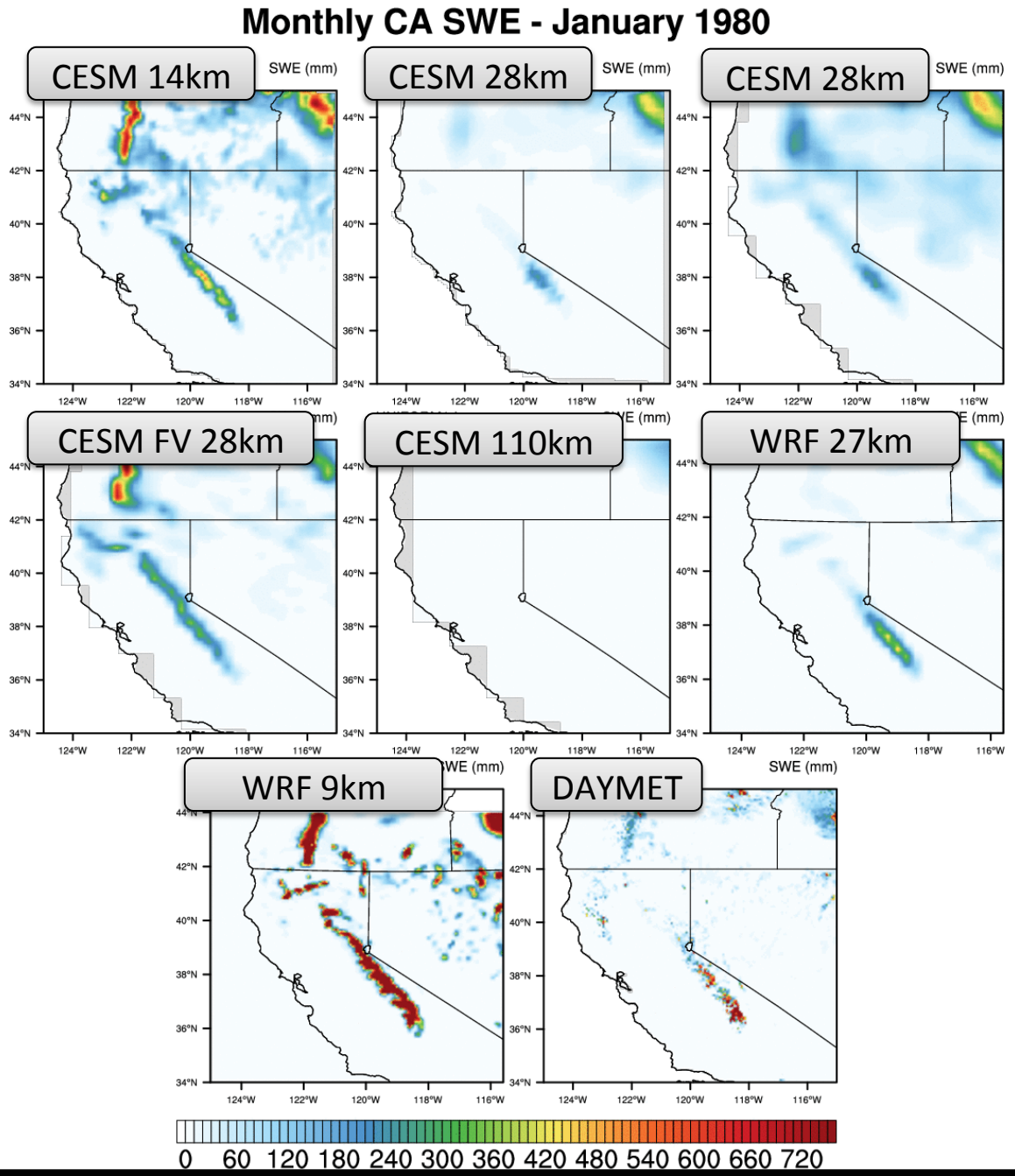


Note: Observational snow products are fairly terrible

Higher resolution greatly improves the resolution of Snow Water Equivalent (SWE).

However, WRF at 9km **greatly overpredicts** total mountain SWE.

All models **melt too early**, likely due to insufficient resolution over high topography.



Credits

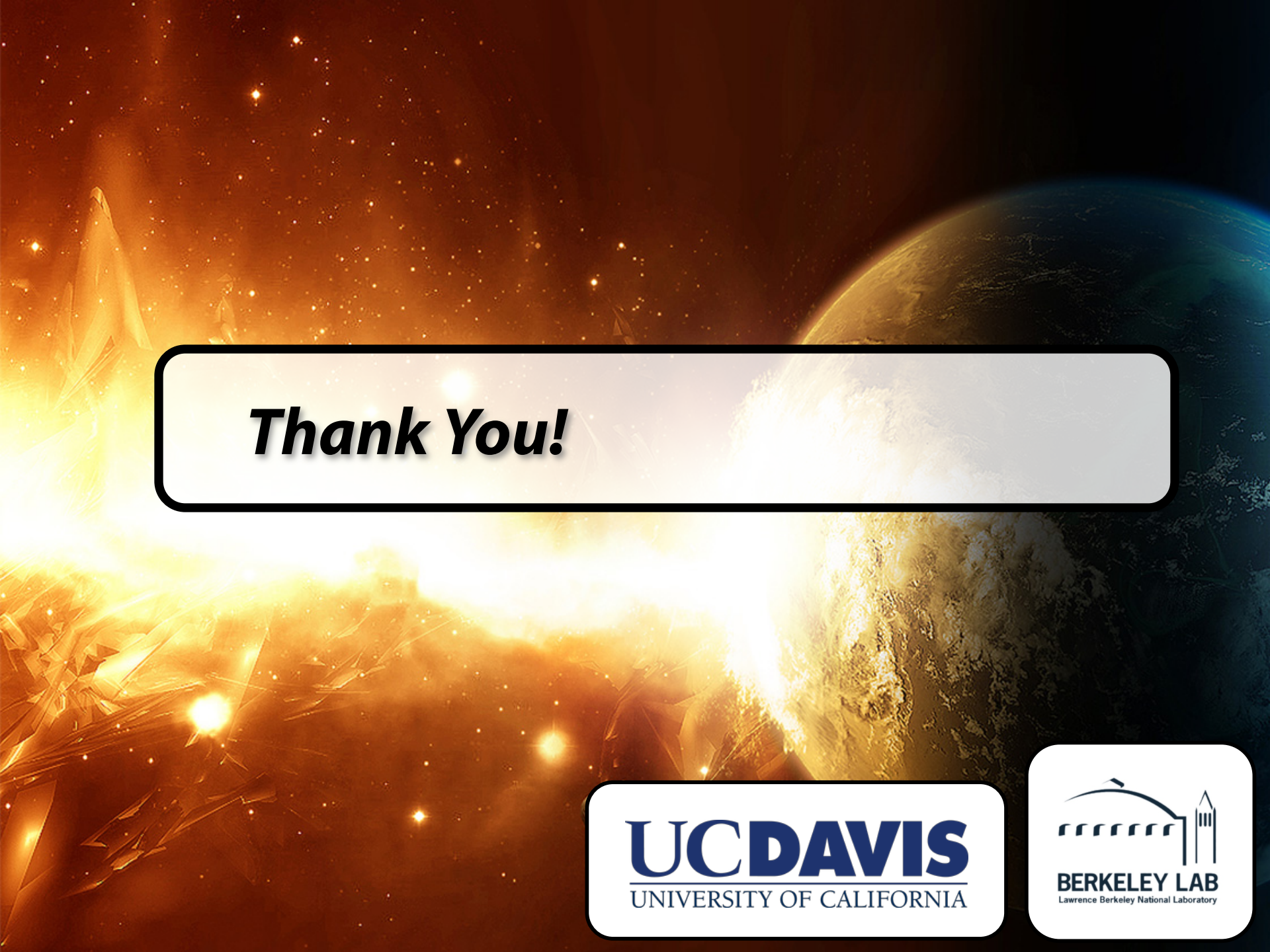
This work is supported in part of ongoing research on the Department of Energy project

Multiscale Methods for Accurate, Efficient, and Scale-Aware Models of the Earth System

BERKELEY LAB
Lawrence Berkeley National Laboratory

SciDAC
Scientific Discovery through Advanced Computing

Office of Science


Thank You!
UCDAVIS
UNIVERSITY OF CALIFORNIA
BERKELEY LAB
Lawrence Berkeley National Laboratory