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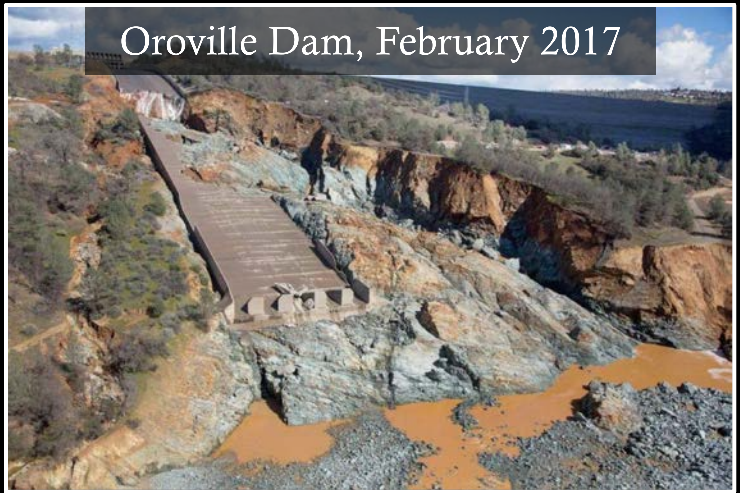
Regional downscaling of large ensemble simulations as a tool for understanding changing hydroclimatic extremes in a warming climate



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UCLA, NCAR, The Nature Conservancy

CLIVAR Large Ensembles Workshop

July 25, 2019

UCLA IoES

NCAR

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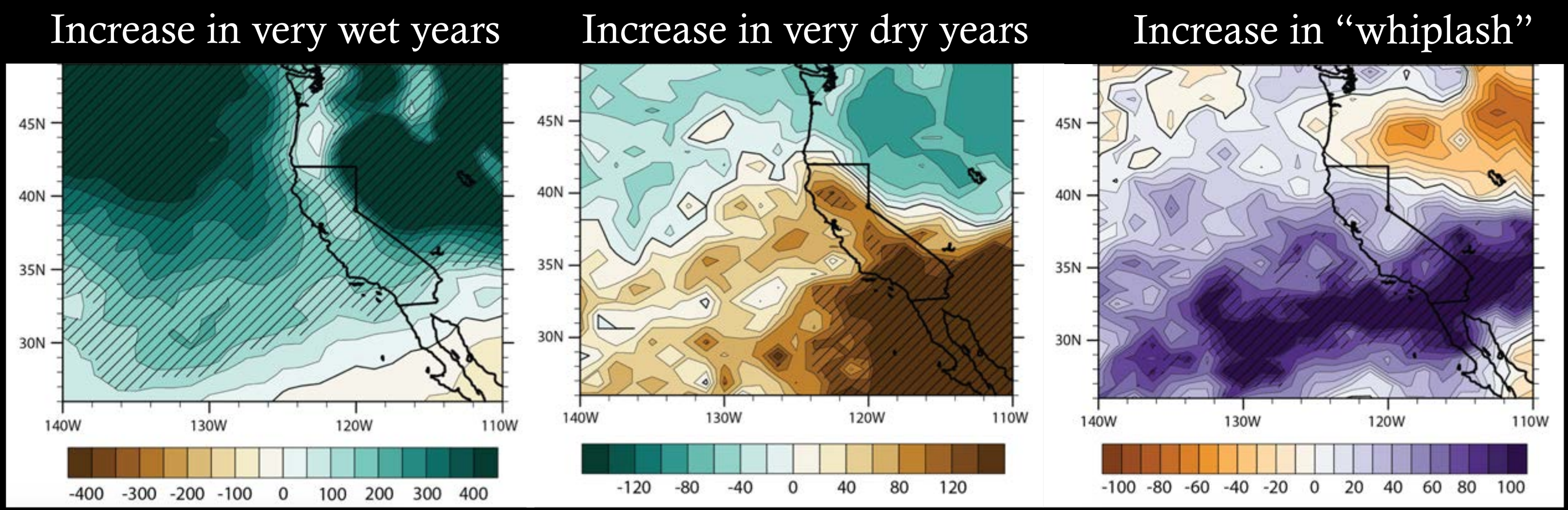
Goal: to understand changing characteristics of extreme hydroclimate events in warming world



Relative (%) change in CESM-LENS, RCP8.5 vs. HIST (Swain et al. 2018)

- Existing consensus that global warming will/has already increase(d) frequency & magnitude of heavy precipitation events globally
- Considerable uncertainty remains at regional scale; some changes in extremes not directly inferable from change in mean
- Wide regional variation in meteorological event types associated with precip extremes: tropical cyclones; mesoscale convective systems; atmospheric rivers, etc.

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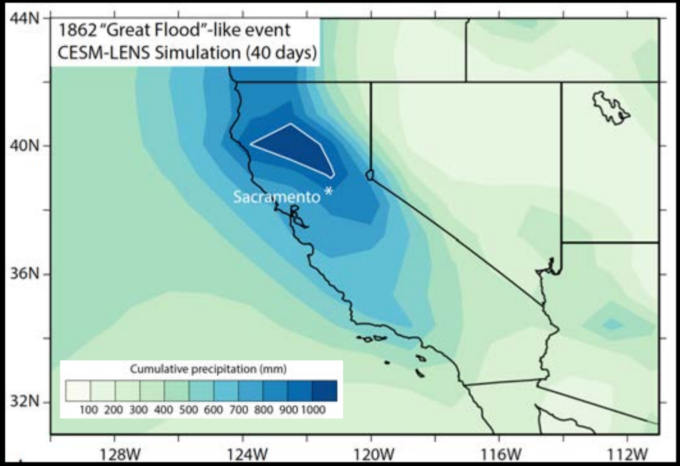
Challenge: extreme events are rare (by definition!)

Downtown Sacramento, Jan 1862

San Francisco Chronicle

Precipitation during “1862-like” event, CESM-LENS



Swain 2019

- Extreme events occur infrequently in obs & model simulations
- Example: California’s Great Flood of 1862. n = 0 in modern record!
- We can try to extrapolate beyond observed range of values, or use stats techniques (i.e., extreme value theory) to work with small n
- Alternate approach: generate much larger “synthetic” sample size using process-based physical models

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Hypothetical future solution: Global, non-hydrostatic large ensembles

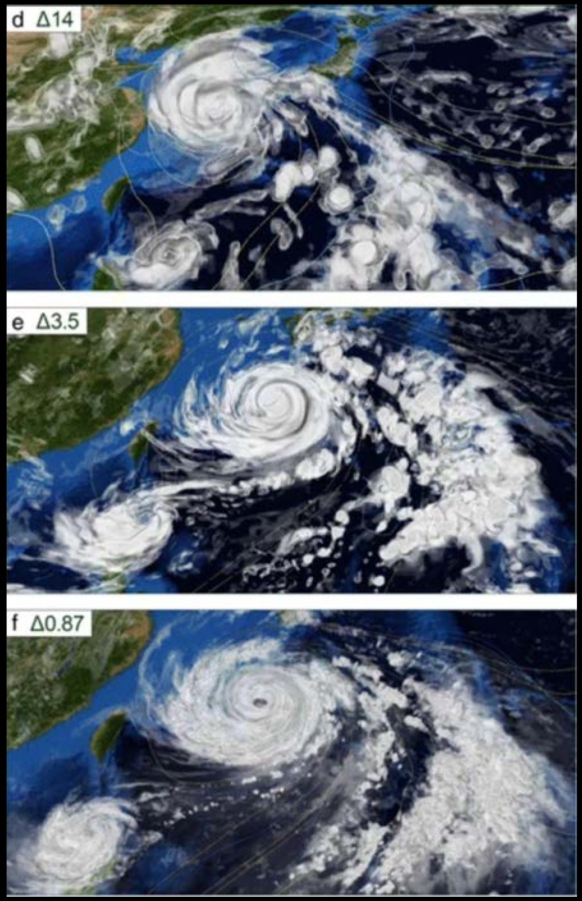
- Early examples of global non-hydrostatic climate model simulations exist, but are very limited in duration & # of members

- Computational constraints remain major impediment, and will likely remain so for next 1-2+ decades.

- Ideally, we would simulate entire global atmosphere using multiple iterations of a single kilometer-scale model

- But…we won't be there for a while. How to proceed in the interim?

Typhoon in global ~1km simulation



Satoh et al. 2017

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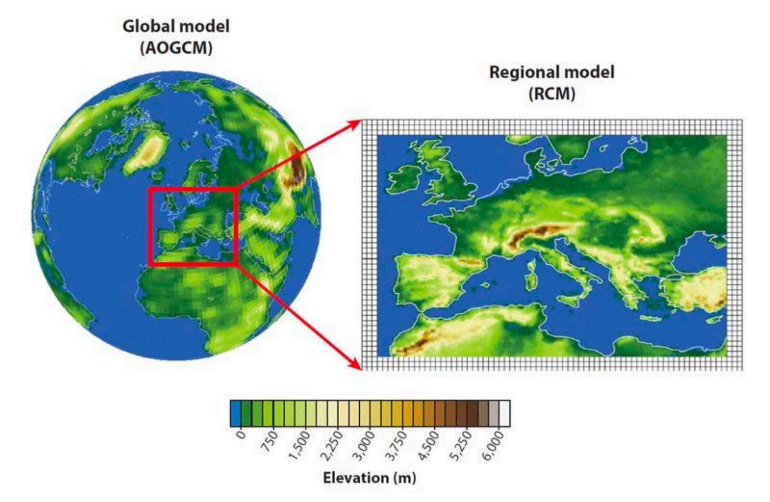
Present-day solution: Targeted dynamical downscaling within large ensemble



Giorgi et al. 2015

- Leverage the large model-year sample size of large ensemble (for each forcing period, often >1000 model-years)
- When parent GCM generates large-scale atmospheric patterns conducive to fine-scale extremes, initial/boundary conditions can be extracted to simulate discrete events in high-res, limited area model
- In essence, we aim to generate numerous high-impact weather "snapshots" under different levels of external climate forcing

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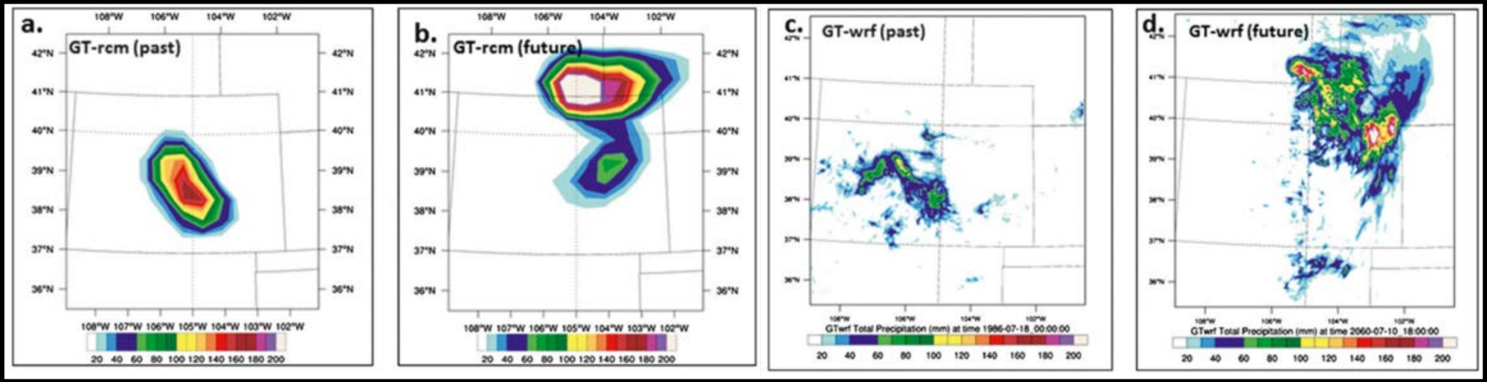
Existing work on dynamical downscaling of GCM-class models

Simulated precip extremes, coarse RCM vs. hi-res WRF



Mahoney et al. 2013

- Several organized dynamical downscaling campaigns have been conducted (NARCCAP, CORDEX, etc.)
- Many efforts involve "pseudo-global warming" (PGW) experiments, w/boundary conditions adjusted by mean forced signal
- "High resolution" for large campaigns often refers to horizontal grid spacing of 20-50km, though some smaller studies <5km
- A great example: Mahoney et al. 2013, who further downscale extreme Front Range precip events within NARCCAP using WRF

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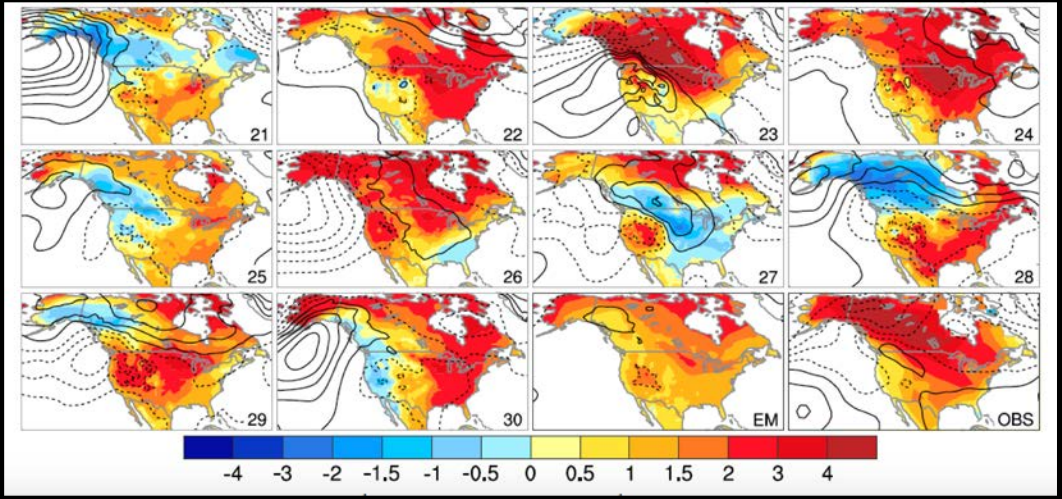
Strengths of GCM-class large ensembles

Different 20th century realizations, CESM Large Ensemble



Deser et al. 2015

- Improved quantification of internal variability in climate system
- Are observed regional/decadal consistent w/forced response?
- Increased sample size: we can re-run same periods/forcing regimes repeatedly, yielding a wide range of "plausible pasts/futures"
  - In CESM-LENS, 40 iterations of the historical period between 1920-2005 (85 years) yield effective sample size of 3,400 model-years! (0 vs. 17 "Great Floods")
- Key weakness: model representation of fine-scale extremes

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Strengths of high-resolution dynamical downscaling

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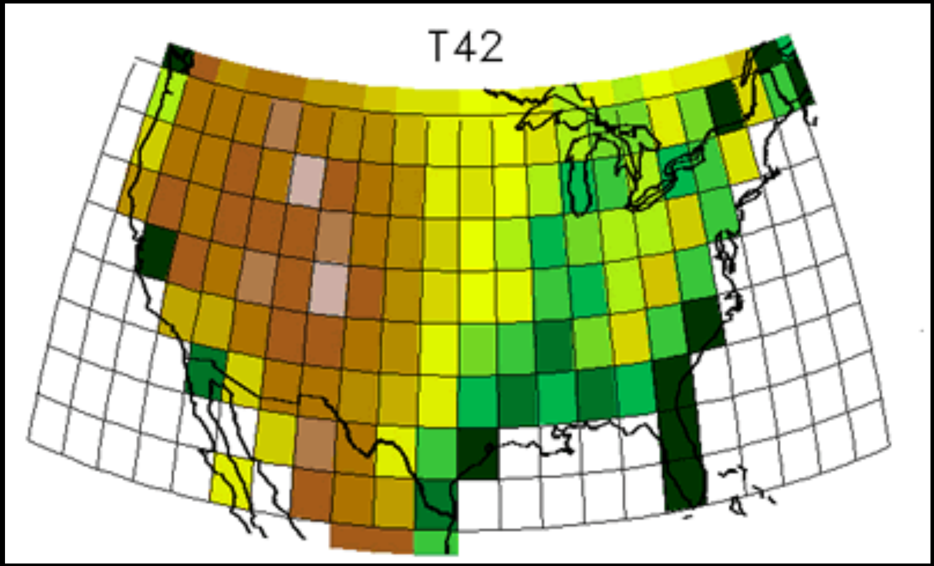

UCAR MetEd

- Improved representation of fine-scale physical processes vs. GCMs
- At sufficiently high resolution, non-hydrostatic model core & explicitly resolved convection (under ~4km grid spacing)
- Better resolution of topography, land/sea boundaries, land cover
- Key weakness: large-scale atmosphere/variability dictated by forcing dataset; any biases are inherited

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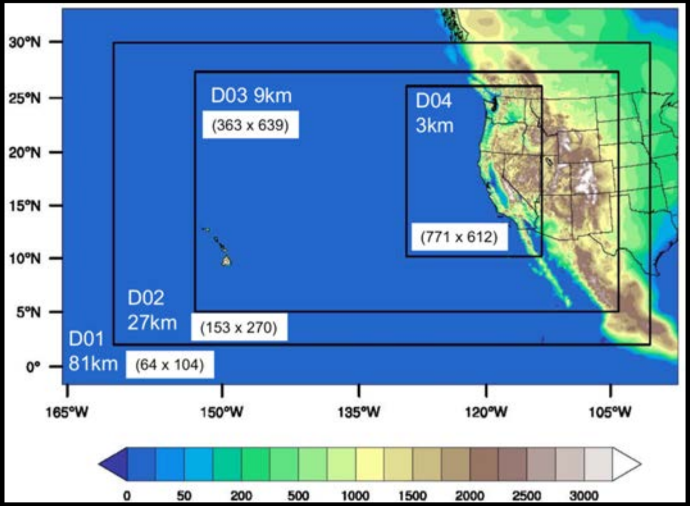
Our approach: storm-scale simulations using 3km WRF nested within CESM-LENS

CESM LENS-WRF nest



Xingying Huang, 2019

- Xingying Huang (UCLA/UCSB) leading simulations (see poster!)
- Extract most intense landfalling atmospheric river events from CESM-LENS simulations, then run ~15 day long WRF simulations
- Inner 3km WRF nest is non-hydrostatic; parameterizations informed by historical extreme event validation (Huang et al. 2019a, in review)
- Initial/boundary conditions from CESM-LENS; run on NCAR's Cheyenne supercomputer (using NSF/CISL large allocation)

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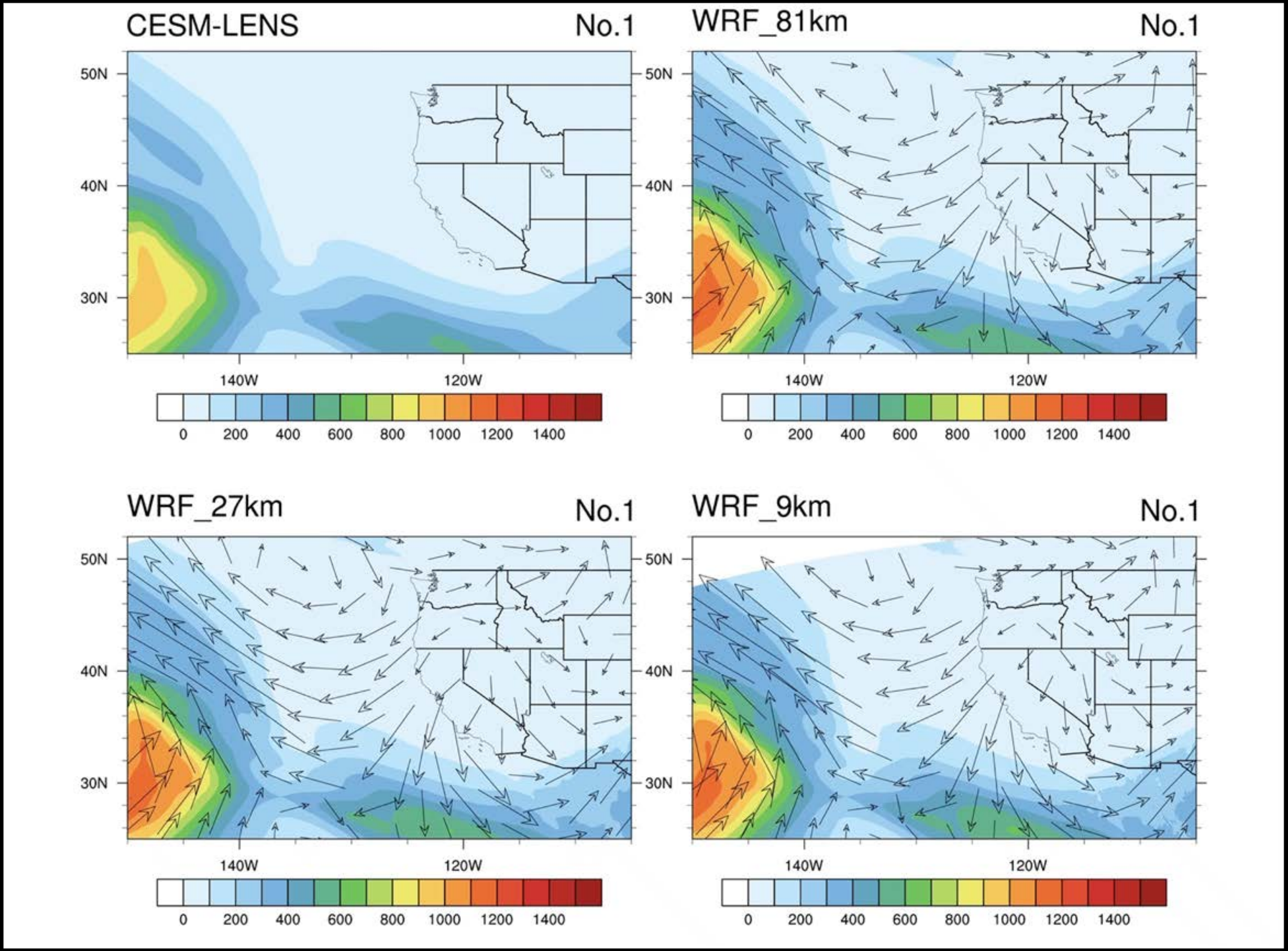
Some early results: CESM vs WRF

Integrated vapor transport (kg $m^{-1}s^{-1}$), assorted historical events



Xingying Huang, 2019

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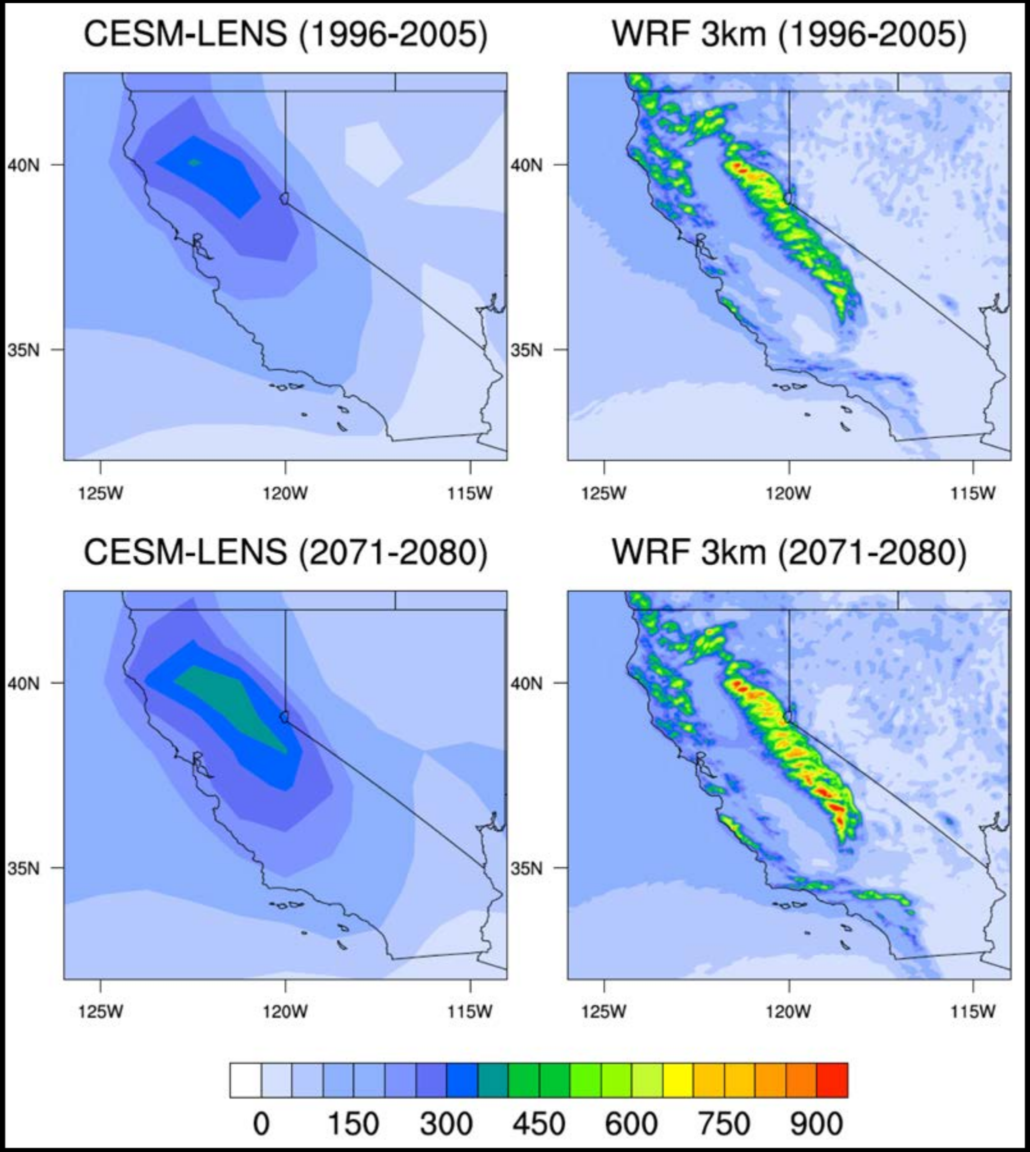
More early results: CESM vs WRF

Accumulated precipitation (mm/event), HIST vs. RCP8.5, top 40 events



Xingying Huang, 2019

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Closing thoughts

- Highly-targeted high resolution downscaling can be a bridge between coarse GCM-class ensembles and "weather prediction"-grade regional models.
- Leverages appealing attributes from each existing modeling tool
- Particularly well-suited to investigation of meteorological extremes not well represented by GCMs (extreme precip, tropical cyclones)
- May be especially useful in scenario development/climate adaptation
  - Physically-plausible worst-case scenarios? Better way to define PMF?
  - Working with USGS/Los Angeles County to revamp "ArkStorm" scenario for great flood in California

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