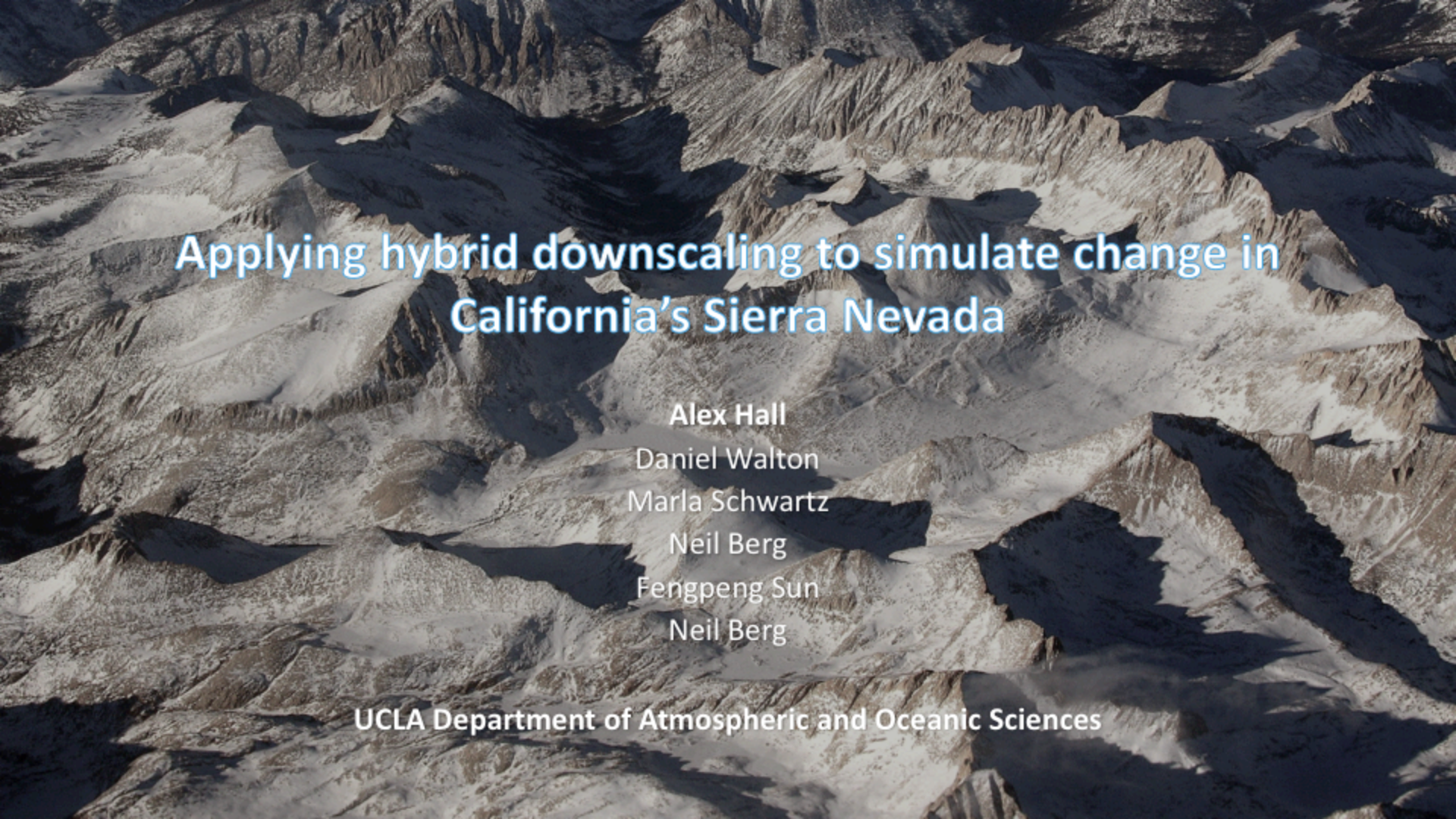

Applying hybrid downscaling to simulate change in California's Sierra Nevada

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Neil Berg
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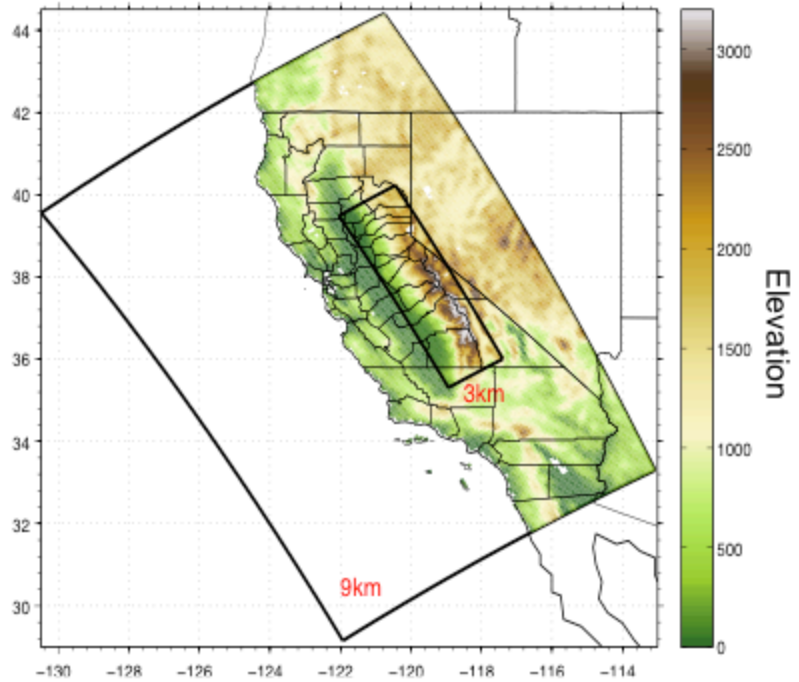
Hybrid downscaling – a brief overview

- The essence of hybrid downscaling is to do limited **dynamical** downscaling for a region, and then develop simple **statistical** models to mimic dynamical model behavior, i.e. do **hybrid** dynamical-statistical downscaling.
- The statistical models can then be used to produce regional data corresponding to any GCM, for any time slice or forcing scenario.
- Hybrid downscaling forces the researcher to diagnose climate change patterns produced by dynamical downscaling.
- It avoids the stationary assumption common to conventional statistical downscaling techniques.
- It allows for uncertainty characterization associated with GCM spread and forcing scenario.

Data Production



”Baseline” simulation of 1981–2015 climate. Weather Research and Forecasting (WRF) model forced by data from North American Regional Reanalysis (NARR).

5 future WRF simulations of Oct 2091–Sept 2101 climate, representing climate change signal from CNRM-CM5, GFDL-CM3, inmcm4, IPSL-CM5A-LR, MPI-ESM-LR GCMs under RCP8.5.

Hybrid downscaling projections of *mean changes* in temperature, snow cover, SWE, runoff, and 0-10 cm soil moisture at 2040–2060 and 2081–2100 under RCP8.5 and RCP4.5, representing full CMIP5 GCM ensemble.

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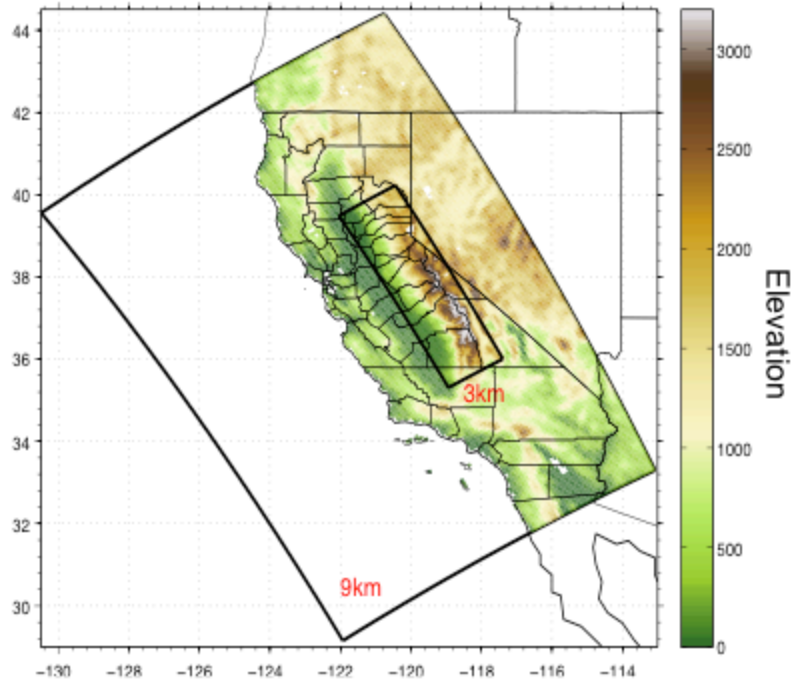

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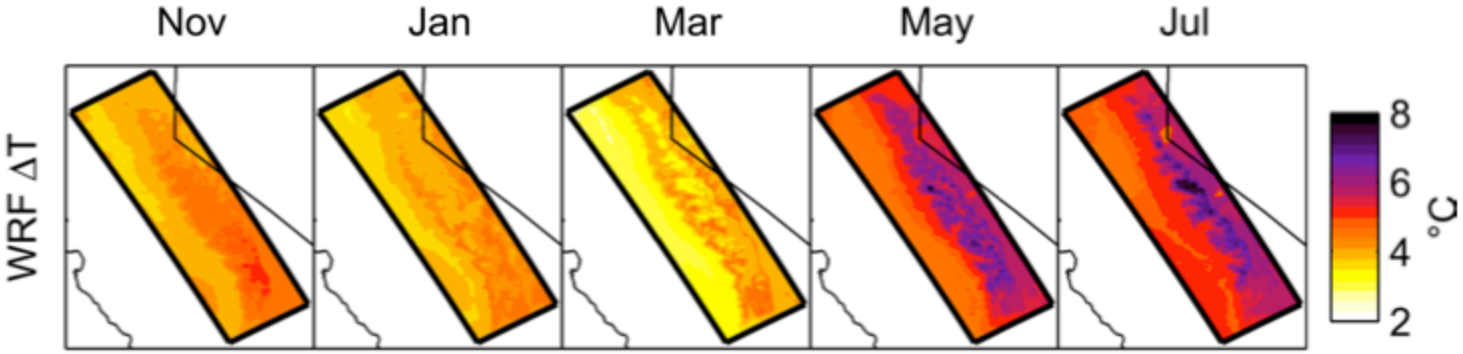
Dynamically downscaled warming



These are example warming patterns for 5 selected months, which span the most important phase of the annual cycle for Sierra water resources.

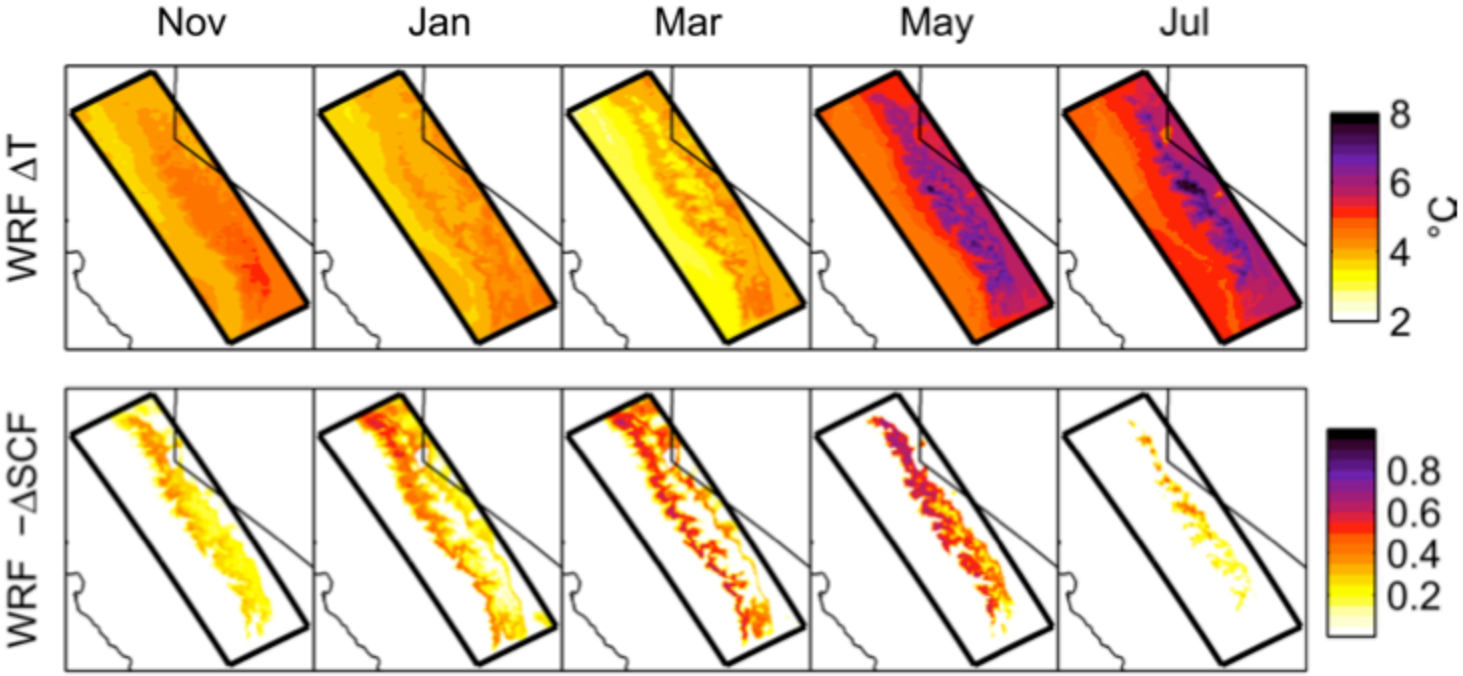
This is the average over all five dynamically downscaled futures. (Warming patterns are very similar for individual simulations, even if the magnitudes vary.)

Two features are evident:

1. Warming is greater on the continental side of the Sierra Nevada.
2. The imprint of snow albedo feedback is clear in every month.

Walton et al. 2017

Dynamically downscaled warming

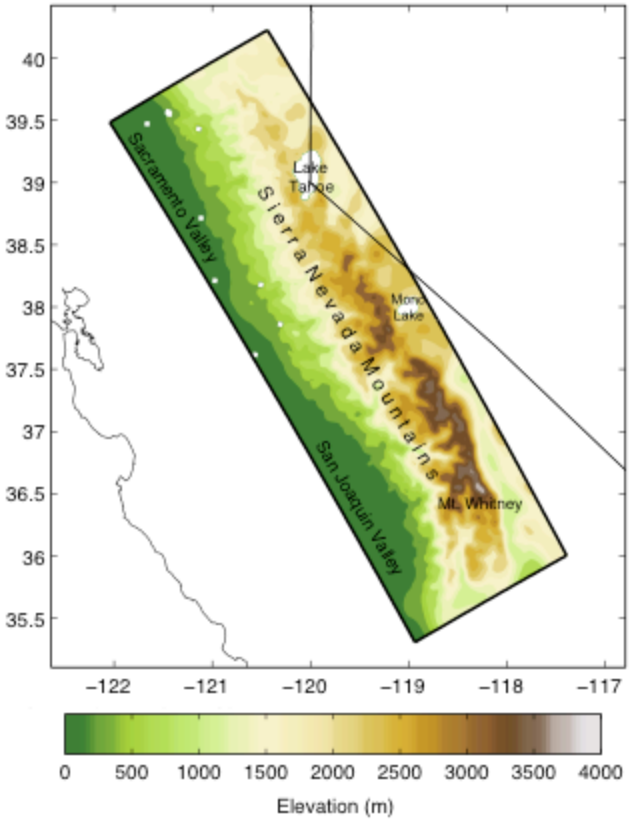


The impact of snow albedo feedback is especially evident if one compares the warming patterns to the change in fractional area covered by snow.

Walton et al. 2017

Development of Statistical Model

- Based on these results, we construct a simple mathematical model that takes as inputs the main drivers of regional warming.
- Through careful diagnostics, we have determined that those drivers are:
    1. Overall GCM warming in this region
    2. GCM warming contrast between N America and the adjacent Pacific Ocean
    3. Snow albedo feedback
- With these inputs, the statistical model then produces warming patterns that mimic those of WRF.



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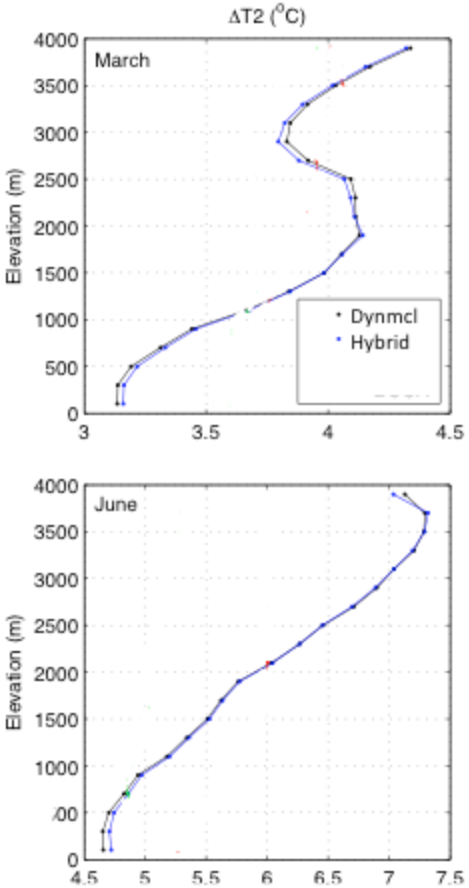
Test of Statistical Model



- This is the RCP8.5 end-century warming as a function of elevation, for March and June.
- Both the dynamical results from the 5-member ensemble and corresponding results from the statistical model are shown.
- The agreement is nearly perfect, indicating we can model WRF's warming patterns if we know:
  1) how much warming a GCM gives
  2) how much land-sea contrast that GCM has
  3) how much snow albedo feedback WRF produces

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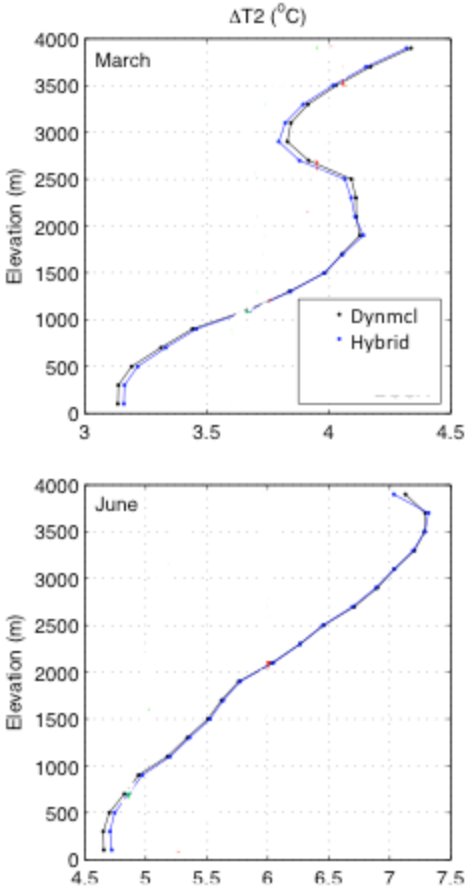
Other downscaling techniques



- How do these projections stack up against other downscaled data products?
- Here again is the warming produced by the hybrid approach as a function of elevation, for March and June.
- Let's now overlay the warming produced by two commonly used downscaling techniques.

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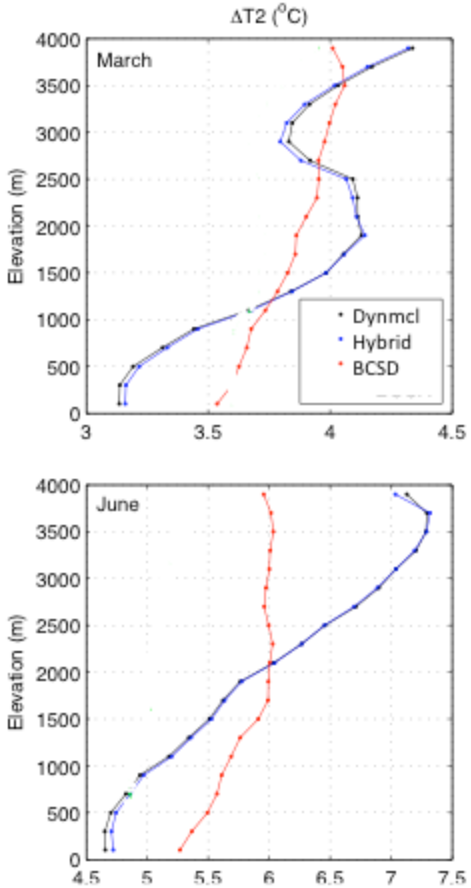
Other downscaling techniques



- Here's the warming given by BCSD, which may be one of the most commonly applied downscaling techniques.

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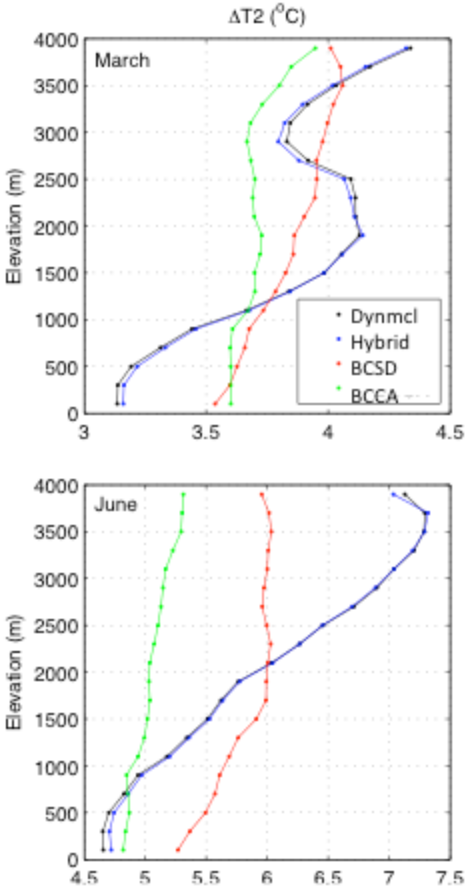
Other downscaling techniques



- And here's the warming given by BCCA, another common technique.
- Neither BCSD nor BCCA captures the large variations in warming with elevation.
- In fact, both BCSD and BCCA produce "flat" warming projections in the Sierra Nevada, with little spatial structure.

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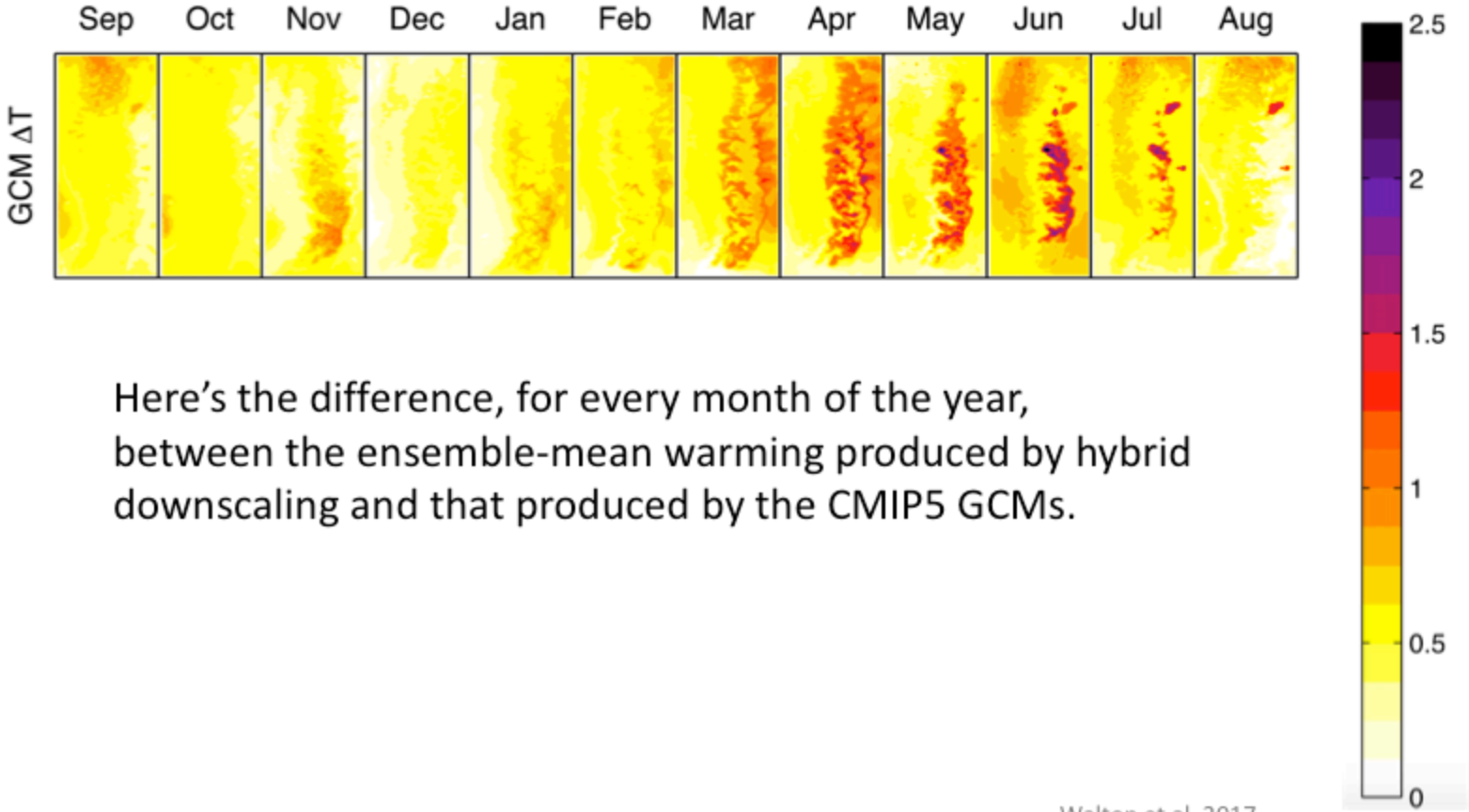
Differences in ensemble-mean warming patterns



Here's the difference, for every month of the year, between the ensemble-mean warming produced by hybrid downscaling and that produced by the CMIP5 GCMs.

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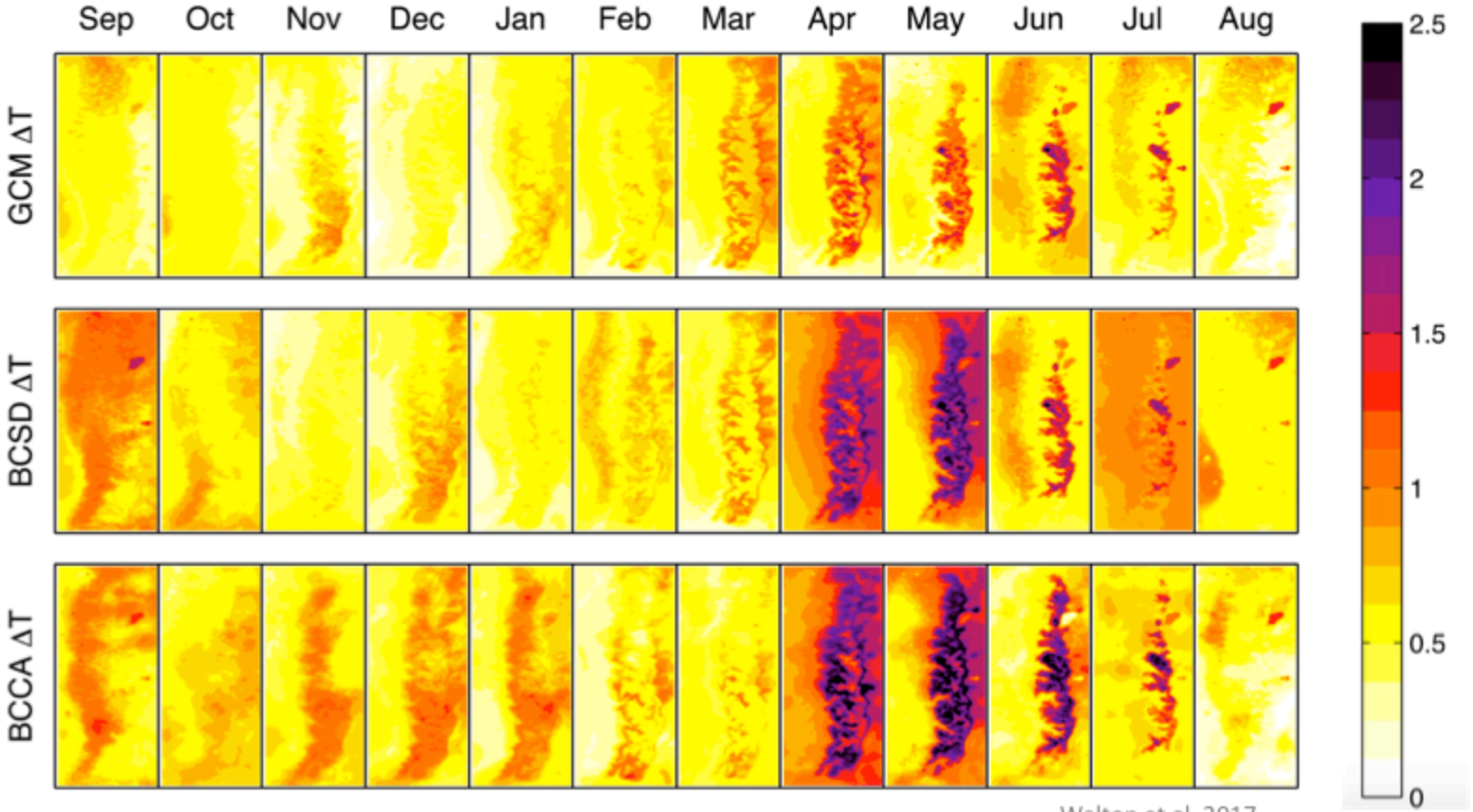
Differences in ensemble-mean warming patterns



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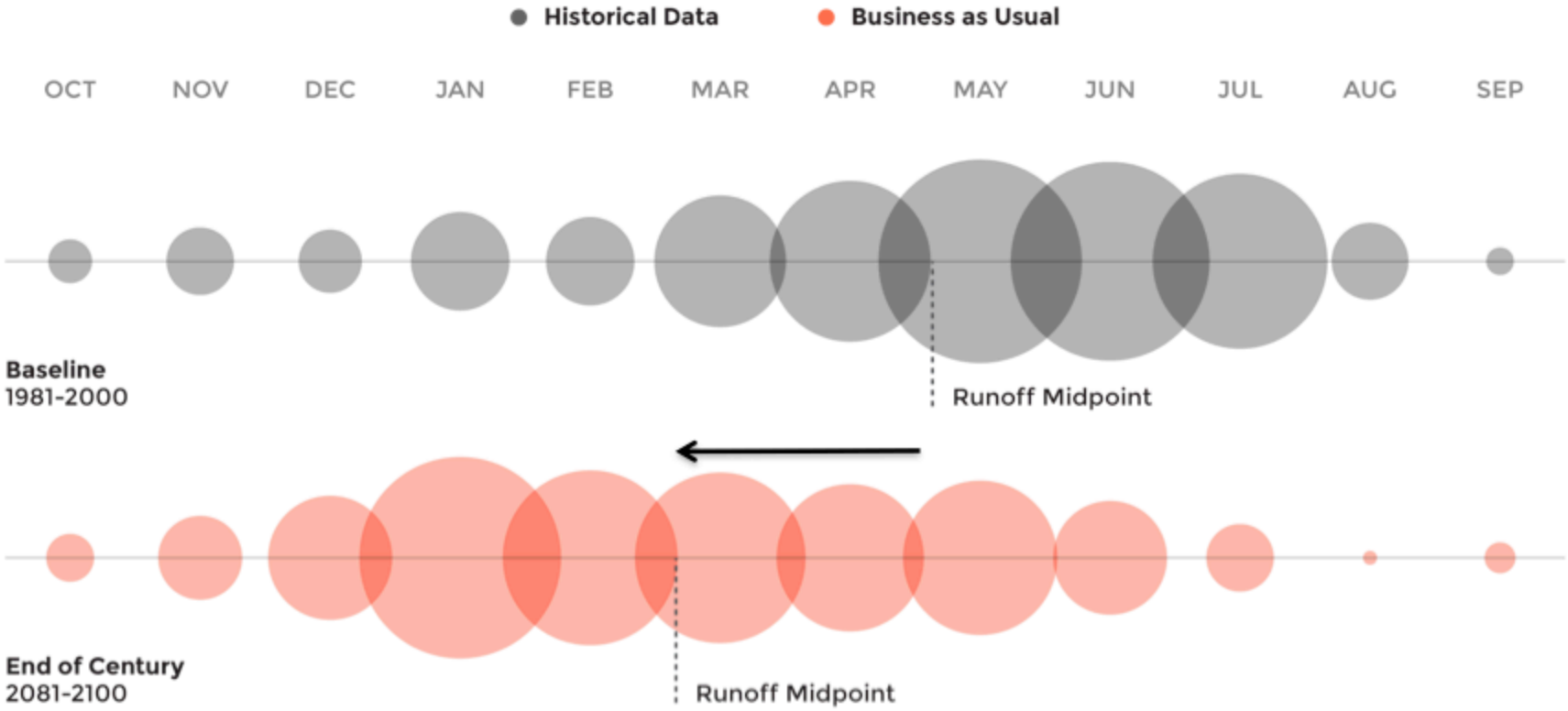
Earlier Shift in Runoff Timing

RCP 8.5, end-century, CMIP5 ensemble mean



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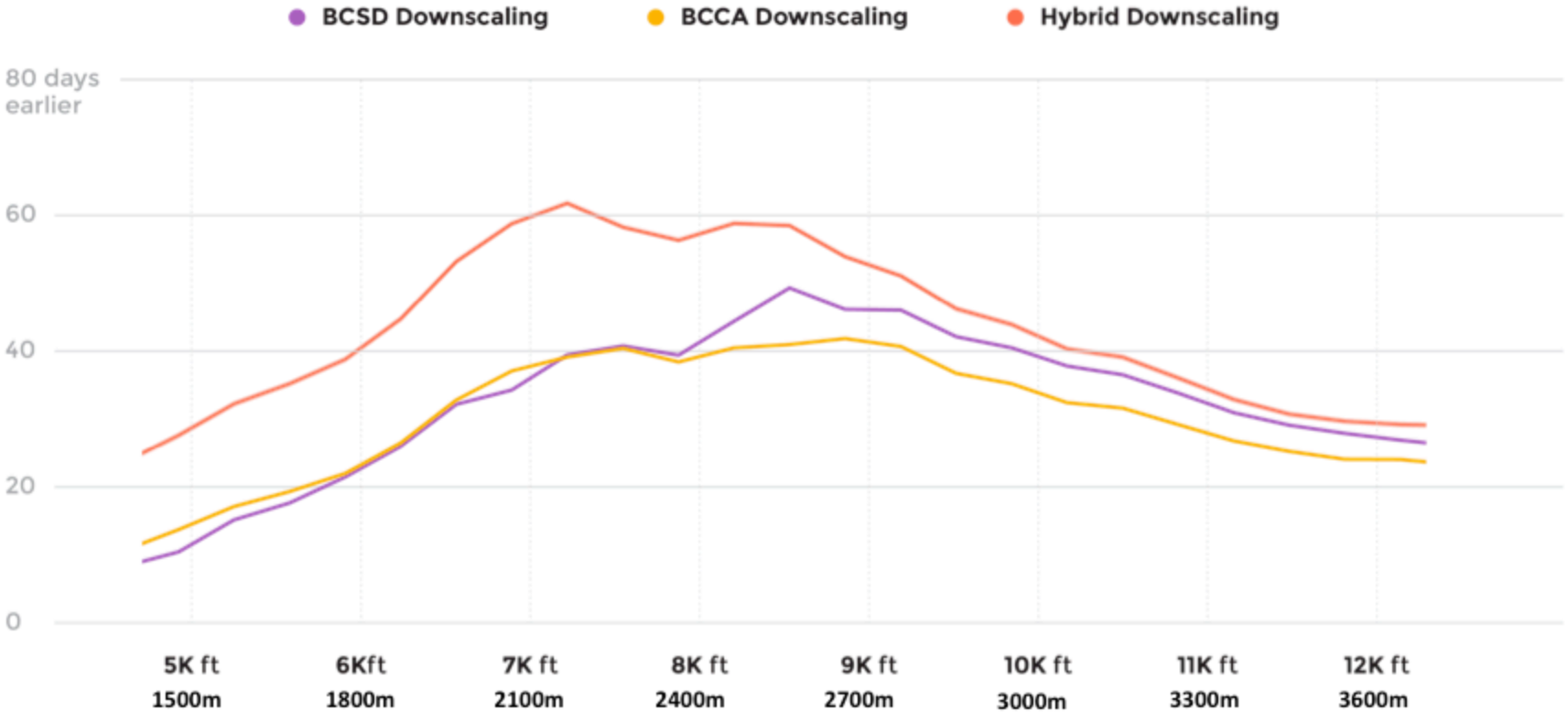
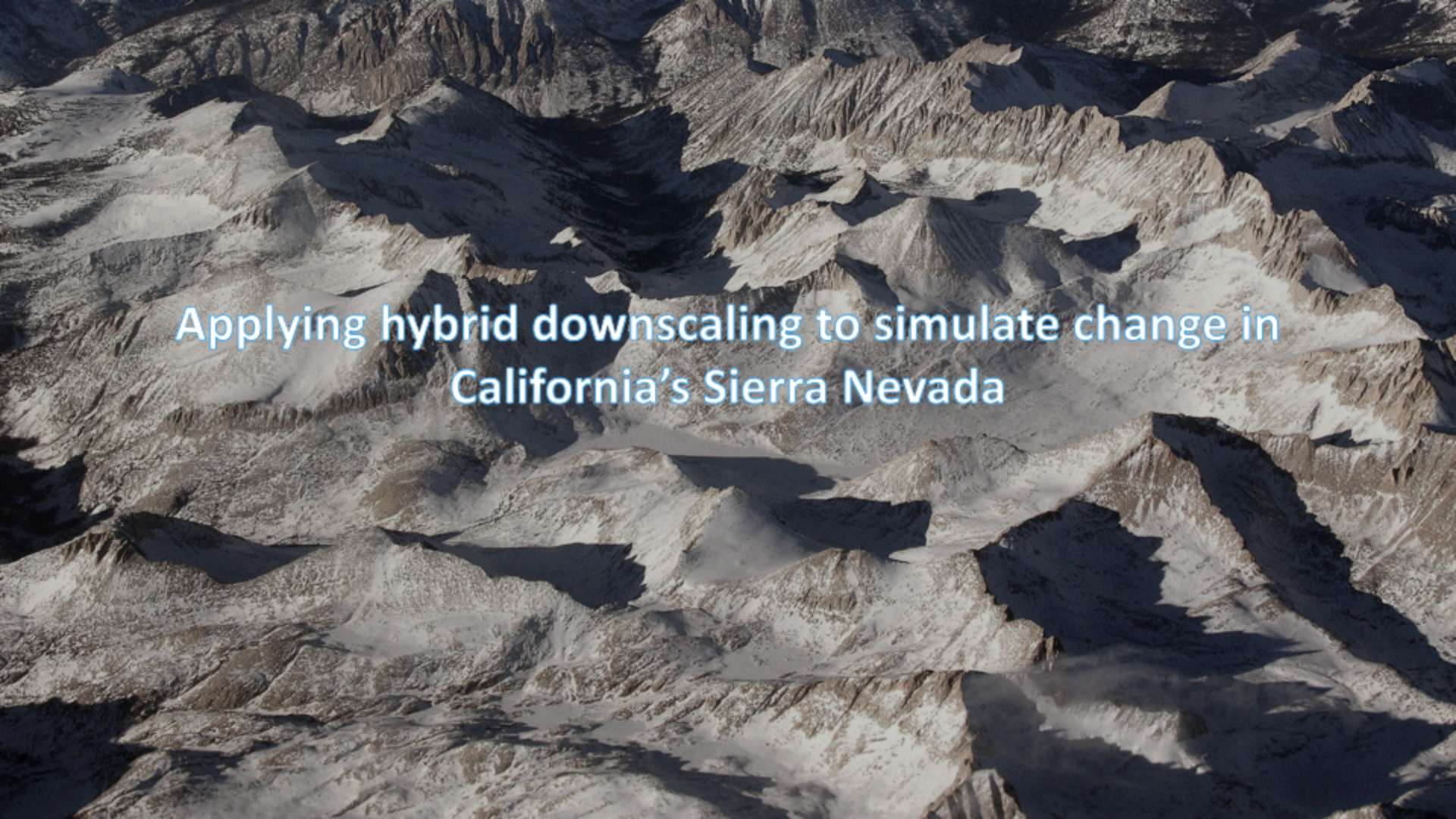
How Snow Albedo Feedback Affects Runoff Timing



Schwartz et al. 2017

Conclusions

- To have confidence in high-resolution climate projections used for decision making, it is critical to evaluate the physical mechanisms that underpin regional change patterns.
- If one formalizes this evaluation process through hybrid downscaling, one also has the benefit of a statistical model that can downscale an arbitrarily large GCM ensemble, providing ensemble-mean and uncertainty estimates associated with GCM spread.
- In the case of California's Sierra Nevada, snow albedo feedback adds critical spatial structure to the warming patterns, with important follow-on effects, e.g. runoff timing.
- Understanding key physical processes and ensuring their inclusion in downscaled climate projections can affect policy-relevant conclusions about regional climate change.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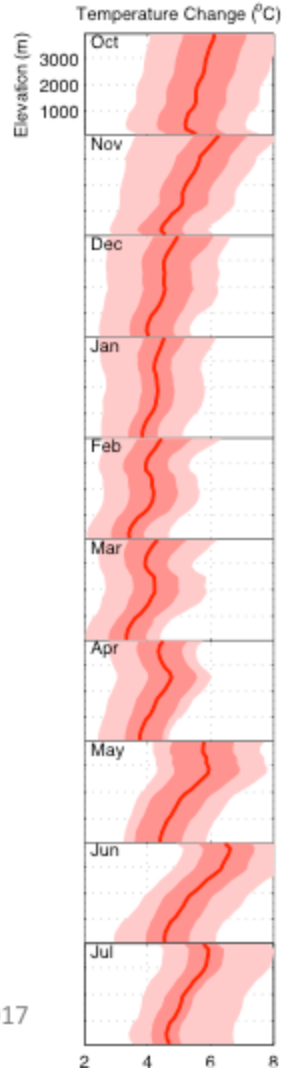
Extra Slides

Warming Outcomes

- The simple model can now be used to produce warming patterns that we would have produced *had we downscaled all available GCMs dynamically*.
- This is the RCP 8.5 end-century warming as a function of elevation, from October through July.
- The solid red line is the ensemble-mean, and the red shading is an indication of uncertainty associated with GCM spread.
- Note the “warming bulge” associated with snow albedo feedback. It moves to higher elevations with the seasonal retreat of the snowline.



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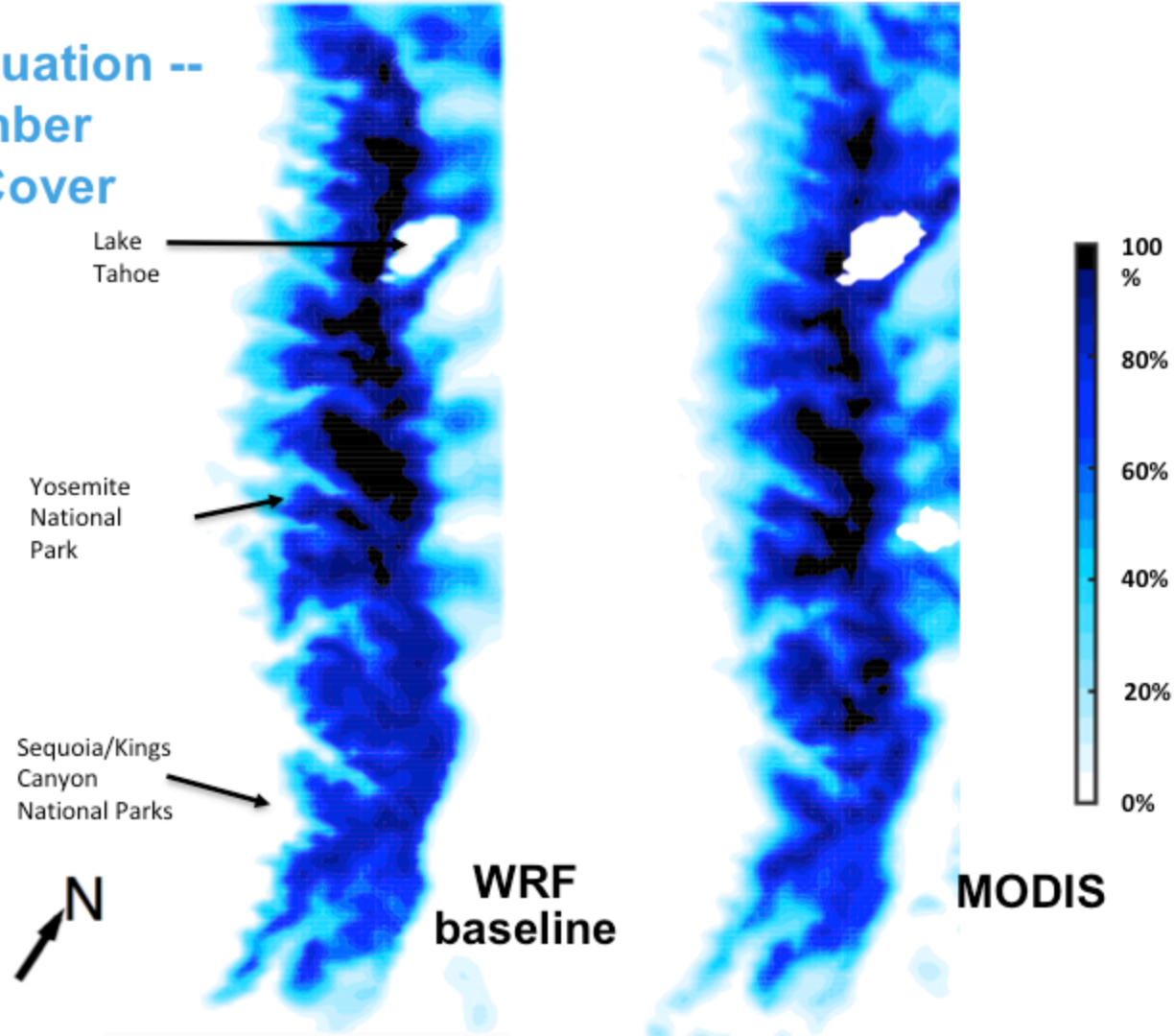
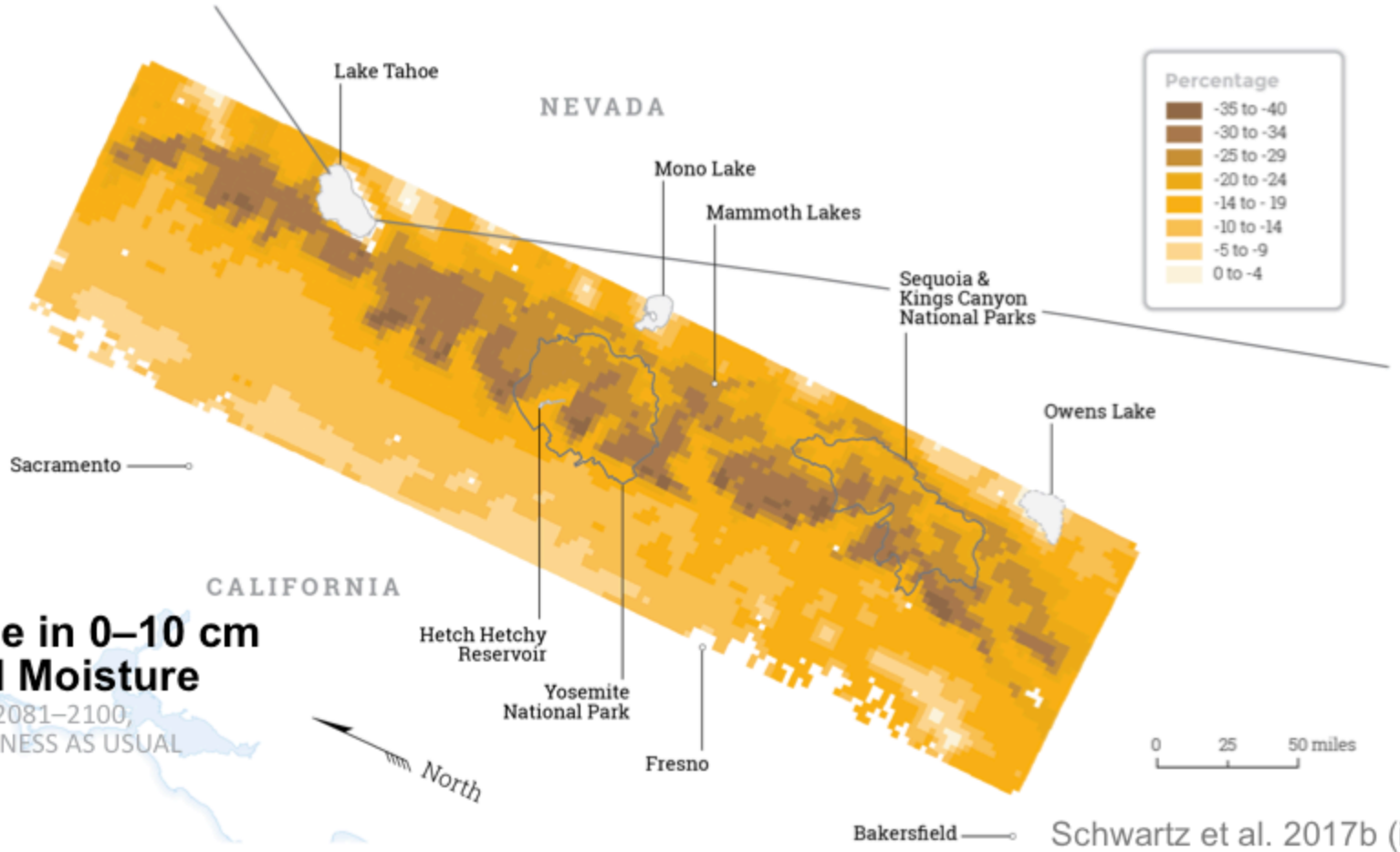
Model Evaluation -- December Snow Cover



Loss of Summertime Soil Moisture



Change in 0–10 cm Soil Moisture

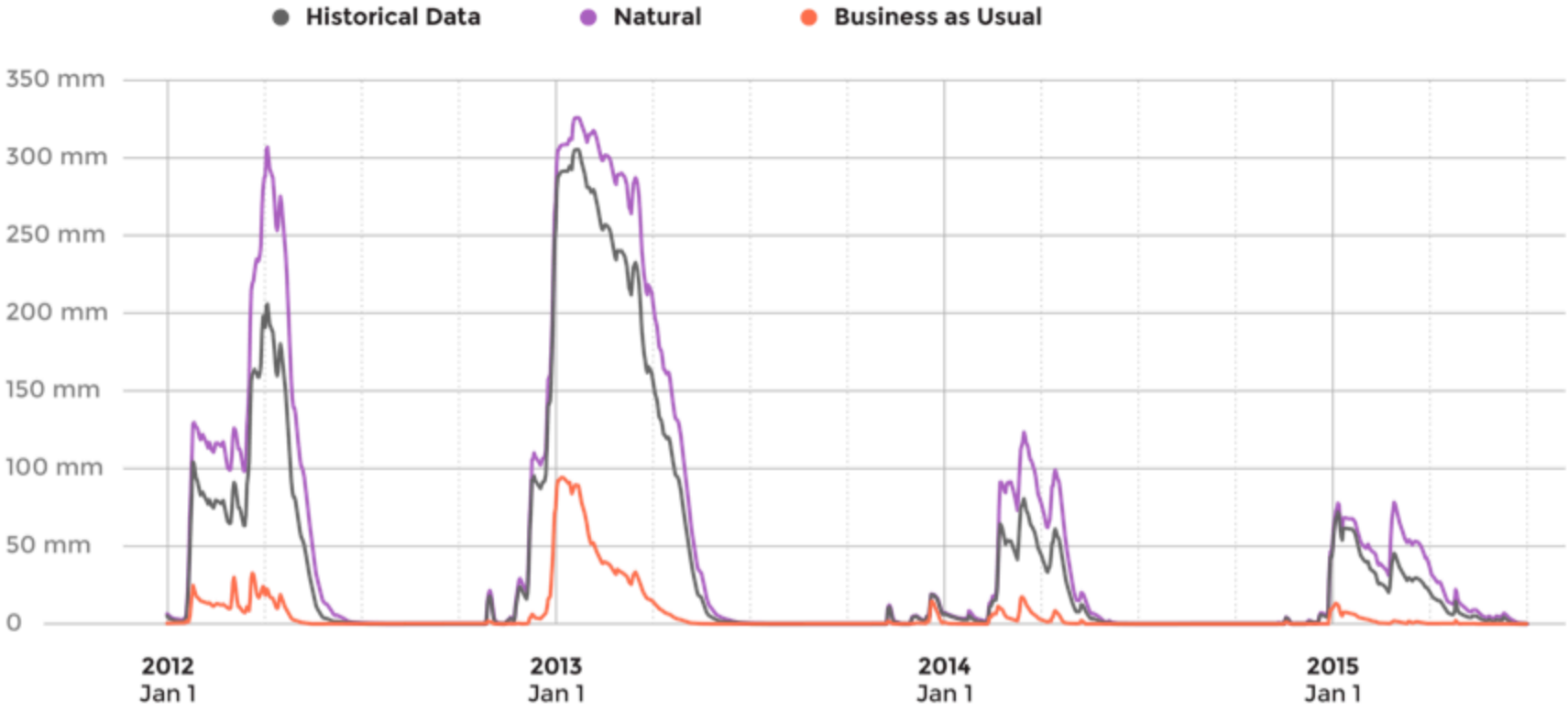
2081–2100,
BUSINESS AS USUAL

Schwartz et al. 2017b (in prep.)

Earlier Shift in Runoff Timing

Schwartz et al. 2017a (in rev.)

Snowpack Severely Impacted During Drought



Berg and Hall 2017