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Sent: Thursday, March 20, 2025 2:30 PM
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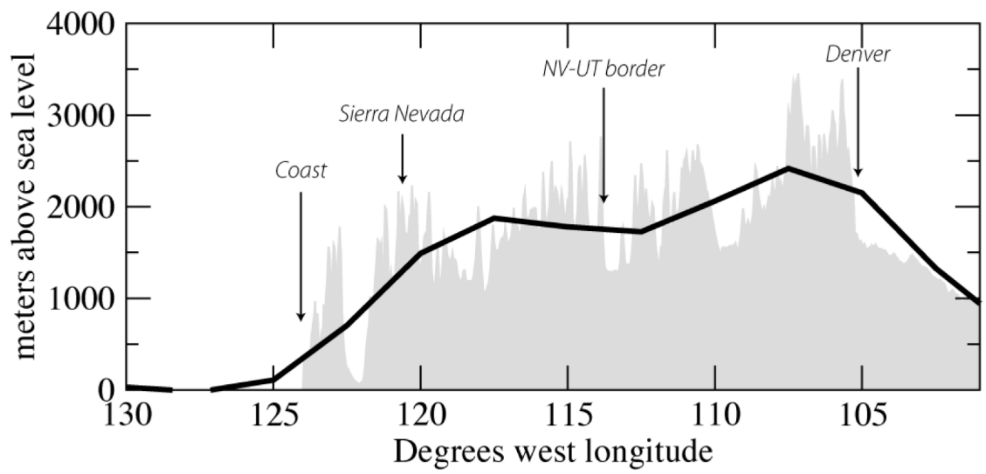
Subject: Downscaling

The 2015 Climate Change Technical Advisory Group report had a discussion of the poor resolution of California terrain in GCMs, and how they failed to resolve the coast range and higher peaks in the Sierra Nevada. The CCTAG urged DWR to use dynamically downscaled modeling data when it became available.

Figure 4-1 Average Elevations at Each 2.5º x 2.5º Grid Cell in the NCEP-NCAR Reanalysis Fields for Transect at 40 Degrees North Latitude



Notes:

NCEP = National Centers for Environmental Prediction, NCAR = National Center for Atmospheric Research. Average elevations are represented at each 2.5º x 2.5º grid cell in the NCEP-NCAR Reanalysis fields (black curve) and from a 25-meter (80-foot) digital elevation model (grey shading), along the latitude band centered on 40ºN, as an example of the topographic smoothing that occurs in global-model scale fields and outputs.

About the time the CCTAG stopped meeting, the World Climate Research Program started the global Coordinated Regional Downscaling Experiment (CORDEX) to provide dynamically downscaled data for regional climate adaptation planning. The North American CORDEX (NA-CORDEX) part of the effort was done at the National Center for Atmospheric Research NCAR in Boulder. NCAR used the same WRF model that Daniel Swain & the Scripps folks have used.

Researchers at NCAR and UC Boulder published a study on precipitation in 2022 using the NA-CORDEX data set. Here's some key bits.

Changes in extreme integrated water vapor transport on the U.S.west coast in NA-CORDEX, and relationship to mountain and inland precipitation

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While GCMs are necessary for projections of the global climate system, the complex terrain of the WUS is coarsely represented by the grid spacing of current-generation GCMs, leaving many of the processes that control precipitation in this region poorly resolved or absent entirely (Gutowski et al. 2020; Warner et al 2015; Hughes et al. 2014). These process limitations act both through direct and secondary processes.

For example, elevation gradients of GCM terrain are generally too small, thus convergence and its resultant precipitation across GCM terrain is reduced (e.g., Smith et al. 2015). This too-small orographic precipitation then can result in too much moisture penetrating beyond initial mountain barriers into interior areas (e.g. Hughes et al. 2014). Regional climate models (RCMs) driven with boundary conditions from GCMs have demonstrated ability in adding value for precipitation processes in areas of complex terrain (e.g., Torma et al. 2015) while maintaining the large-scale synoptic features of their driving GCMs (Prein et al. 2019). The North American Coordinated Regional Climate Downscaling Experiment (NA-CORDEX) downscales a subset of CMIP5 simulations (Table 1) to grid spacings of ~ 50 km and ~ 25 km. Current and future WUS NA-CORDEX precipitation have been evaluated (e.g., Gibson et al. 2019; Mahoney et al. 2021) and in general projections in NA-CORDEX were found to be consistent with previous CMIP5 results, but with terrain-controlled mesoscale details differing significantly in certain regions, for example the Sierra Nevada of California (Mahoney et al. 2021).

In general, the higher resolution in NA-CORDEX simulations results in a more realistic representation of precipitation over terrain than in the CMIP5 simulations (Figure S1 and Mahoney et al. 2021), and thus a natural question is, how does the projected precipitation change in NA-CORDEX compare with the change from its set of driving GCMs? The multi-model NA-CORDEX RCM cool-season precipitation changes (Fig. 1c) are similar to those seen in the NA-CORDEX CMIP5 subset (Fig. 1b) with a regional mean increase north of ~ 35 N, but with greater detail and some localized decreases over the complex terrain of the region. Unlike the GCM-subset precipitation changes, decreases in precipitation are larger across the highest terrain of the Cascades, Sierra Nevada, and Mogollon Rim of AZ, with smaller decreases along the coast near the CA/OR boundary…

We use a subset of NA-CORDEX simulations (Table 1; see the current simulation matrix) that were available during our analysis period. We analyze precipitation from 19 NA-CORDEX simulations (at both ~ 50 km and ~ 25 km grid spacing), generated by a combination of 6 RCMs (CRCM5, RCA4, RegCM4, WRF, CanRCM4, and HIRHAM5) driven at their lateral boundaries by 6 CMIP5 GCMs (HadGEM2- ES, CanESM2, MPI-ESM-LR, MPI-ESM-MR, ECEARTH, GFDL-ESM2M) as well as by ERA-Interim reanalysis (ERAi). Throughout the manuscript we use the naming convention of GCM.RCM for the NA-CORDEX simulations, abbreviating the GCM names as shown in Table 1; for example, the CanESM2-forced CRCM5 simulation is called Can.CRCM5. Due to the availability of model output, our IVT analysis focuses only on the 25 km WRF simulations, with some of the (qualitatively very similar) results for the 50 km WRF simulations shown in supplemental material.

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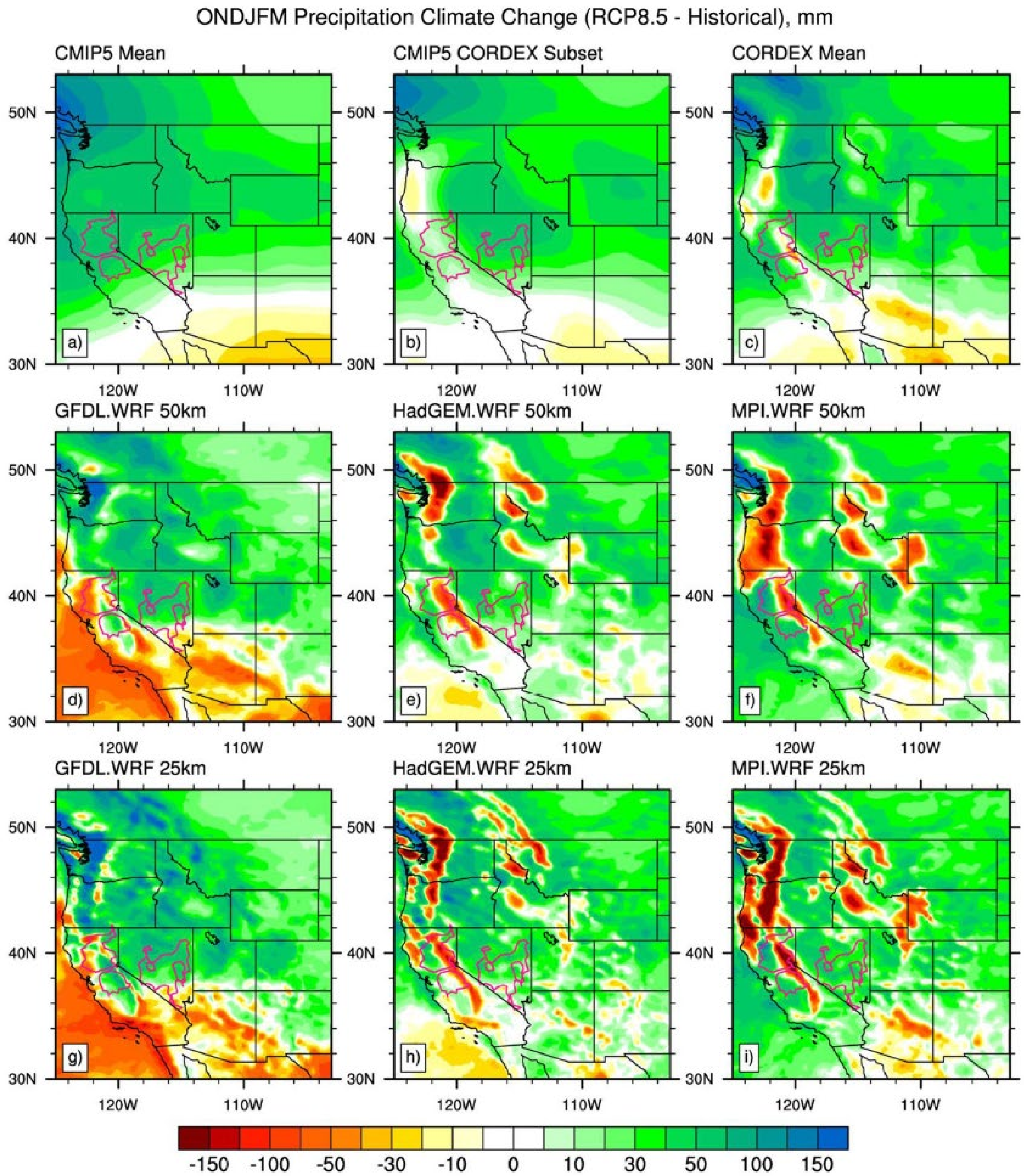

Fig.1 a Cool season total mean precipitation change in mm (RCP8.5-historical) for CMIP5 ensemble. B Same as a except for five of six CMIP5 models used as boundary conditions for NA-CORDEX simulations (i.e. HADGEM2-ES, Can-ESM2, MPI-ESM-LR, MPI-ESM-MR, and GFDL-ESM2M). c Same as a but for NA-CORDEX ensemble. d-f Cool season total precipitation change in mm (RCP8.5-historical) for 50km d GFDL. WRF, e HadGEM.WRF, and f MPI.WRF. g-i Cool season total precipitation change in mm (RCP8.5-historical) for

25km, g GFDL.WRF, H HadGEM.WRF, and i MPI.WRF. Magenta contours outlin three watersheds: Sacramento (top left), San Joaquin (bottom left), and Central Nevada River Basin (right).

The precipitation rate changes for the moderate IVT events are small compared to precipitation rate changes during extreme IVT-events. However, moderate IVT-events occur 6–8 times as often (Table 2), so to understand the relative impact on cool season precipitation we next compare the change in total precipitation (divided by 30 so that it has units of mm per-cool-season) from the two types of events (Fig. 10). Here a clear picture emerges across all three simulations: extreme IVT-events generally produce precipitation increases across most of the WUS, particularly across the Cascades and the northern Sierra Nevada. In contrast, moderate IVT-events have large decreases across much of the higher terrain of the WUS, with modest increases in a few locations… although the exact patterns vary across simulations, each simulation has localized decreases at higher elevations amidst increases across much of the rest of the WUS.

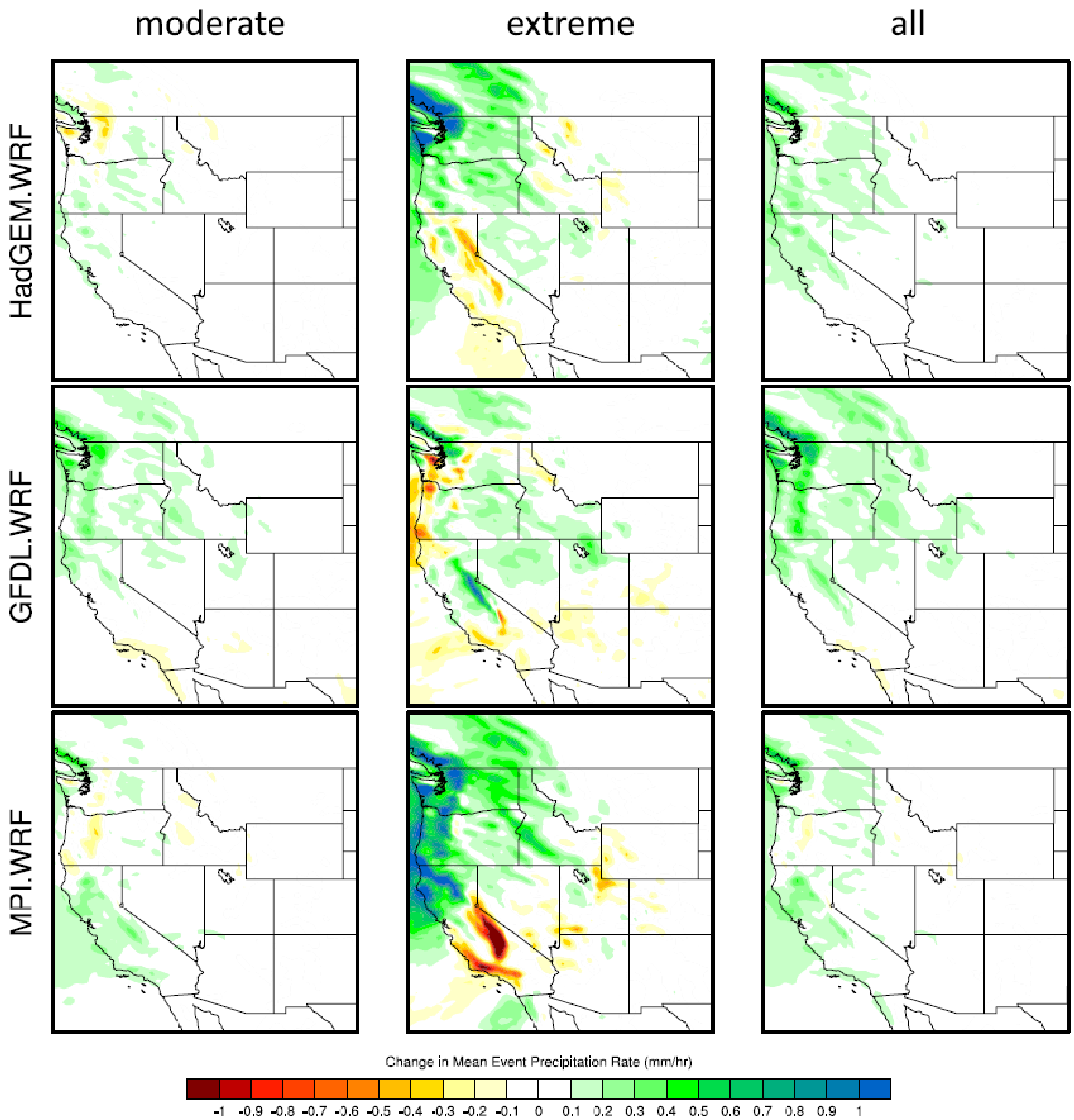

Fig. 9 Change (future – historical) in mean precipitation rates during (left) moderate IVT events, (center) extreme IVT events, and (right) all IVT events in (top) HadGEM.WRF, (middle) GFDL.WRF, and (bottom) MPI.WRF in 25 km WRF simulations.

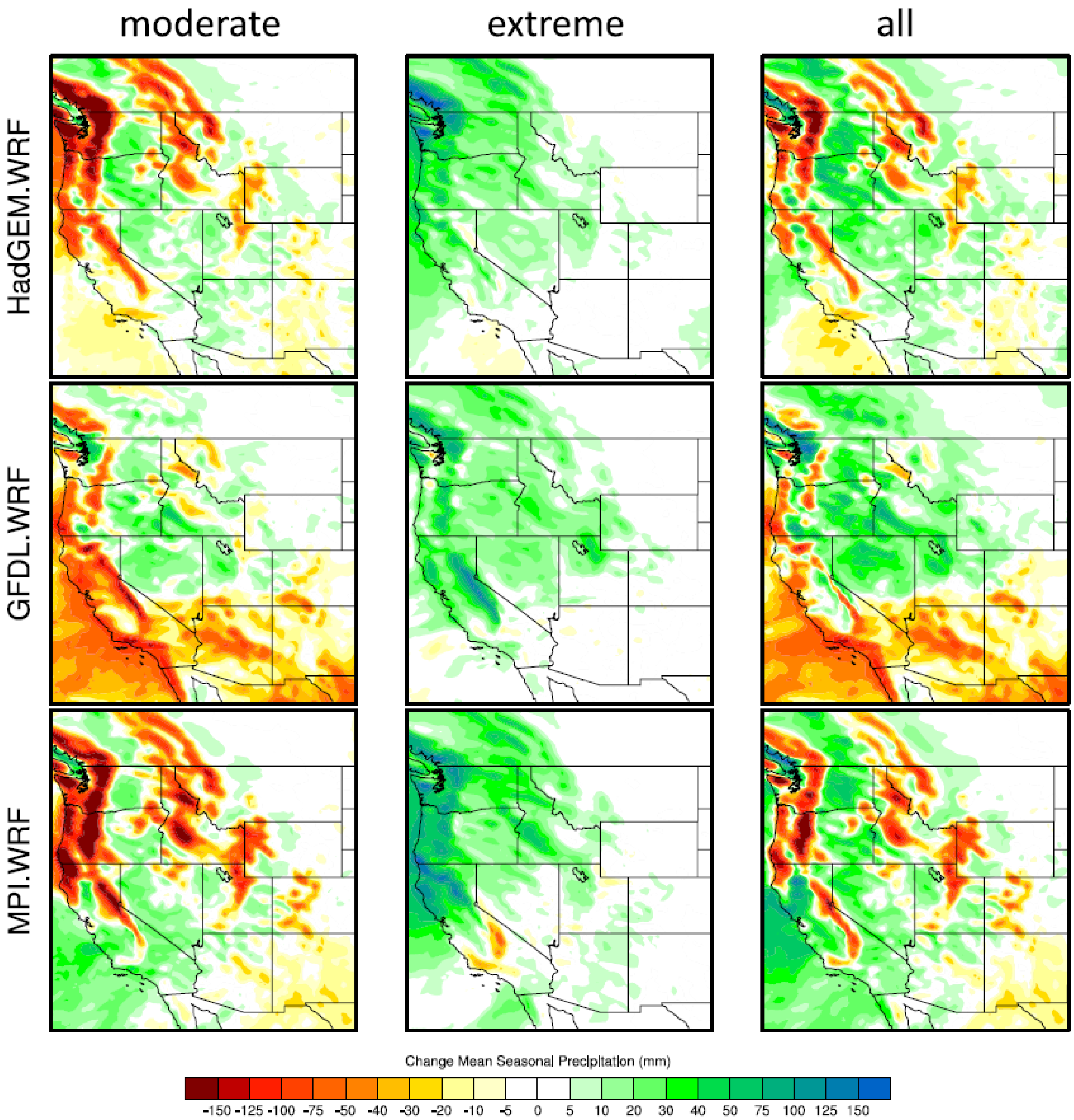

Fig 10 Change (future-historical) in mean seasonal precipitation from (left) moderate IVT events, (center) extreme IVT events, and (right) all IVT events in (top) HadGEM.WRF, (middle) GFDL.WRF, and (bottom) MPI.WRF in 25 km WRF simulations

This is from the 2015 CCTAG report, noting that dynamic downscaling would do a better job of representing atmosphere-land surface interactions, including changes to ET, snow accumulations and snowmelt, as well as better representing orographic changes to precipitation.

Shaaban et al. 2011; Kavvas et al. 2013), because statistical downscaling (to be discussed in the following section) cannot capture or track land-change influences. Such a coupled modeling approach is able to resolve the 2-way interaction between the atmosphere and the land surface through the atmospheric boundary layer that will evolve under the changing atmospheric and land-surface conditions through time during the 21st century. Consequently, the ultimate approach to the assessment of the impact of the simultaneous change in climate and land-surface conditions on the water resources of California would be a dynamical-downscaling approach that uses coupled atmospheric–land-surface–hydrologic–hydroclimate models.

Many climate variables, in addition to the commonly provided temperature and precipitation, are included among dynamical-downscaling outputs. Most notably for DWR, three-dimensional winds, radiation fluxes (solar and longwave) at the surface, and humidity variables can be outputs from dynamical downscaling. This fuller suite of outputs allows for more complete estimation of evaporation and evapotranspiration (ET) demands and rates. At present, most standard hydrologic models (and all used by DWR) estimate ET rates based on proxy relationships between temperatures and potential ET, relationships fitted to historical observations but that may not remain the same under the changing climate (Milly and Dunne 2011). Notably, these "other" variables, such as winds, humidity and even (to an extent) radiation, are determined by, and have an impact on, conditions in the turbulent layer of atmosphere in the first kilometer (0.6 mile) or so above the surface, the planetary boundary layer. Planetary boundary-layer processes are another facet of local climate (in addition to local land topography) and a natural part of dynamical downscaling that the models used are particularly well suited to address and track as the climate changes. Beyond ET, to model the full range of processes of snow accumulations and snowmelt that will determine the future of snowpack storage and the largest part of water resources in California, incident radiation at the snow surface is a very important input (e.g., for energy-balance snow models) (Ohara and Kavvas 2006). Temperatures play a role, but most of the energy in snowpacks and snowmelt comes from radiation fluxes on the snow surface. In most existing hydrologic models, and all of the models currently used by DWR, temperature fluctuations are also used as a proxy for estimating these radiation fluxes. The proxy relationships used are based (at best) on historical correlations between temperature and radiation that may not remain valid under future climate changes. In

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California Water Research

Integrative scientific synthesis

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"Science is a way of thinking much more than it is a body of knowledge" -- Carl Sagan

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