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1. Introduction

The UCLA Joint Institute for Regional Earth System Science and Engineering (JIFRESSE) is a collaboration between UCLA and the Jet Propulsion Laboratory (JPL) to improve understanding and to develop projections of the impact of global climate change on regional climates and environments. The Institute combines UCLA's strength in climate modeling and JPL's strength in remote sensing and data collection from satellites. JIFRESSE is well poised to contribute to the challenge facing California in assessing, adapting to, and mitigating the impact of global climate change on our society and ecosystems due to the anthropogenic increase in atmospheric greenhouse gases (GHGs).

At present, the evidence strongly suggests that significant *global* climate change will occur in this century. This being said, the amplitude and consequences of the changes to the global climate are still far from certain, particularly on regional and local scales. To illustrate, the left panel of **Figure 1.1** shows projections of the annual mean surface air temperature (SAT) change for southern/central California from 18 different global climate models (GCMs) that have contributed to the 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Noteworthy is the fact that every model predicts increases in SAT for this region, albeit with an uncertainty factor of 3 at the end of the 21st century. More problematic for determining the consequences to society, agriculture, ecosystem viability, etc. are the associated projections for precipitation change that are shown in the right panel of **Figure 1.1**. In this case, the models are not even in agreement whether this large area of California will become wetter or drier with the uncertainty ranging up to +/- 20% of the annual mean rainfall.

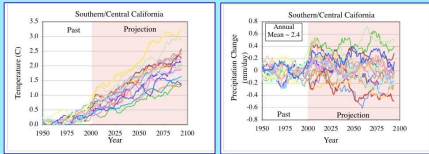


Figure 1.1 Global climate model (GCM) simulations of the changes in annual mean surface air temperature (left) and precipitation (right) for Southern California relative to a climatology calculated for the period 1900-1999. Each line represents a different GCM contribution (N=17) for the IPCC's 4th Assessment Report (2007). The period up to 2000 is based on simulations using "known" 20th century GHG forcing conditions, while the period after is based on "projected" (i.e. SRESA18 scenario) GHG forcing conditions.

A considerable part of the uncertainty and disagreement in **Figure 1.1** lies in the fact that the global models poorly, or do not, resolve important physical processes that are fundamental for obtaining a realistic simulation for regional and smaller scales. To illustrate, the left panel of **Figure 1.2** shows a global SAT map for Jan 1999 from one of the GCMs in **Figure 1.1** and the middle panel shows how well such a GCM typically resolves the southwest US (Dx ~ 150km). The right panel of **Figure 1.2** shows MODIS-derived surface temperature and false-color images for an embedded sub-domain. Evident is the extremely rich environmental structure that includes variability in atmospheric (e.g. clouds), oceanic (e.g., temperature and chl), and land surface (e.g., topography, vegetation types, snow cover) processes at very fine spatial scales (Dx ~ 1km). This structure is simply not represented by the GCMs discussed above, which not only prevents a realistic depiction of regional climate and its change, it also contributes to the uncertainty of the global-scale prediction since these finer-scale processes and interactions are known to rectify onto larger scales features.

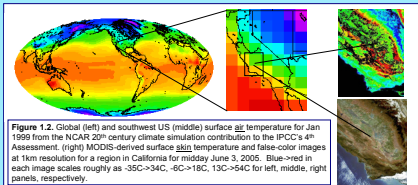


Figure 1.2 Global (left) and southwest US (middle) surface air temperature for Jan 1999 from the NCAR 20th century climate simulation contribution to the IPCC's 4th Assessment. (right) MODIS-derived surface temperature and false-color images at 1km resolution for a region in California for midday June 3, 2005. Blue-to-red in each image scales roughly as -35C to +34C, -6C to +18C, 13C to +54C for left, middle, right panels, respectively.

To address the above needs, JIFRESSE has developed a comprehensive Regional Earth System Model (RESM) that contains advanced treatments of meteorology, oceanography, air-quality and land-surface processes available (**Figure 1.3**). The development and application of the JIFRESSE RESM will be used to address environmental and climate change questions relevant to California as well as facilitate spaceborne mission development and instrument design.

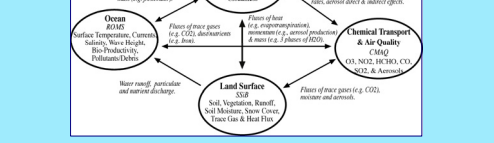


Figure 1.3 Schematic representation of the coupled regional Earth System model configuration, including advanced modeling components for the Atmosphere (WRF), Land Surface (SSS), Chemical Transport and Air Quality (CMAQ) and the Ocean (ROMS).

2. Air Quality: Evaluation of a Month-long AQ modeling for July 2005

Anthropogenic emissions are the leading cause of air pollution. They also affect regional climate by altering atmospheric composition and the local radiation budget. Hence, assessments of the impact of anthropogenic emissions on regional air quality, atmospheric composition, and climate have become an important subject in climate research. The impact of anthropogenic emissions on air quality and climate are determined by the amount of local emission, transports of air pollutants, chemical reactions, and meteorology. Transport of air pollutants and chemical reaction strongly depend on atmospheric conditions. In order to assess these impacts of anthropogenic emissions, the JIFRESSE RESM includes (one-way) coupling to the most recent version of the Community Multi-scale Air Quality (CMAQ) model. In our present work, we evaluate the WRF-CMAQ framework in simulating long-term air pollutants in southern California using the experimental framework shown in **Figure 2.1**. The simulation was performed for Southern California domain (**Figure 2.2**) for the one summer month July 2005.

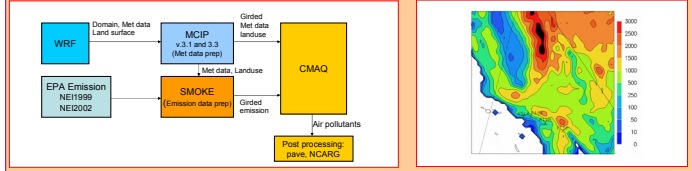


Figure 2.1 Schematic description of experimental setup and the associated information flow for the air quality simulation evaluation study.

Figure 2.2 The southern California domain and the model terrain (m) at a 12km horizontal resolution.

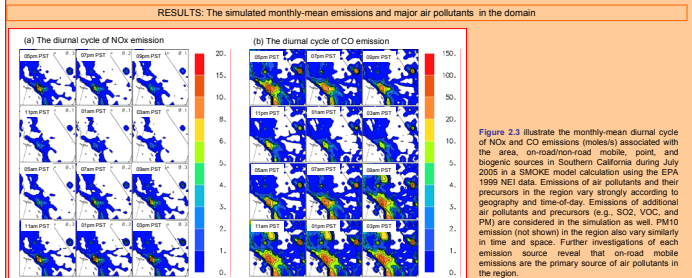


Figure 2.3 Illustrate the monthly-mean diurnal cycle of NOx and CO emissions (moles) associated with the area, on-road/non-road mobile, point, and biogenic sources in Southern California during July 2005 in a SMOKE model calculation using the EPA 1999 NEI data. Emissions of air pollutants and their precursors in the region vary strongly according to geography and time-of-day. Emissions of additional air pollutants and precursors (e.g., SO₂, VOC, and PM) are considered in the simulation as well. PM10 emission (not shown) in the region also vary similarly in time and space. Further investigations of each emission source reveal that on-road mobile emissions are the primary source of air pollutants in the region.

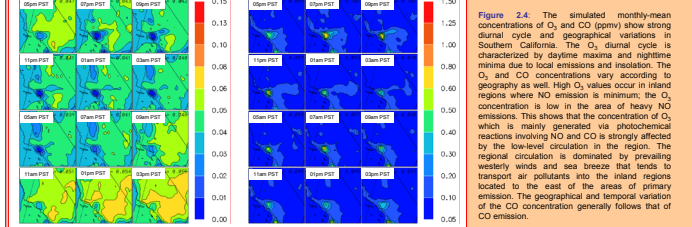


Figure 2.4 The simulated monthly-mean concentrations of O₃ and CO (ppmv) show strong diurnal cycle and geographical variations in Southern California. The O₃ diurnal cycle is characterized by daytime maxima and nighttime minima due to local emissions and insolation. The O₃ and CO concentrations vary according to geography as well. High O₃ values occur in inland regions where NO emission is minimum; the O₃ concentration is low in the area of heavy NO emissions. This shows that the concentration of O₃ which is mainly generated via photochemical reactions involves NO and CO is strongly affected by the low-level circulation in the region. The regional circulation is dominated by prevailing westerly winds and sea breeze that tends to transport air pollutants into the inland regions located to the east of the area of primary emission. The geographical and temporal variation of the CO concentration generally follows that of CO emission.



Figure 2.5 The simulated (black) daily timeseries of the daytime 8-hour (1100-1800 PST) mean O₃ concentration agrees well with observations (red) at the four stations. This 8-hour period represents the period in which daily maximum O₃ values occur (e.g., Figure 5). Noticeable discrepancies between the simulated and observed values occur only at the Riverside station, especially in the latter half of the month when the model systematically underestimated O₃ concentration. Results shown in Figures 5 and 6 suggest that the RESM possesses useful skill in simulating O₃ concentration in Southern California for extended periods, an important capability for assessing the impact of climate change on the regional air quality.

Conclusions
An air quality simulation in the Los Angeles basin during July 2005 using the WRF-CMAQ part of the JIFRESSE RESM has been evaluated. This study was performed as a part of preparation for a study in which the impact of global climate change on the air quality in Southern California will be investigated. Using the large-scale forcing from North American Regional Reanalysis (NARR), the WRF-ARW model was able to generate the low-level wind and temperature fields as well as their diurnal variations with reasonable accuracy. Emissions in Southern California are characterized by a strong diurnal cycle with daytime maximum and nocturnal minimum. On-road mobile emissions are the largest source of CO and NOx in the region. The monthly-mean diurnal cycle of the simulated ozone concentration agrees well with observations during the daytime when the peak concentration occurs. The nocturnal O₃ concentration shows positive biases at most of the verification sites, suggesting O₃ titration is too weak in CMAQ. The negative bias in O₃ concentration at the coastal West Los Angeles station during nighttime is partially related with the errors in low-level sea breeze in the coastal region is underestimated by WRF. The simulated time series of daily 8-hour maximum O₃ concentration also agrees well with observations. The evaluation study suggests that the coupled WRF-CMAQ part of the RESM possesses useful skill in simulating long-term characteristics of O₃ concentration in Southern California.

3. A Projection of the Impact of Climate Change on the Hydroclimate in California

Change to California's surface hydroclimate is a particularly far-reaching issue, as it stands to strongly influence the future landscape of California's agriculture, tourism, environment and even day-to-day water availability. In order to assess the impact of the climate change induced by the increase in greenhouse gases (GHGs), we performed a regional climate change study for the cold season using the dynamical downscaling method in which the Weather Research and Forecast (WRF) model is nested within the global climate scenario from the NCAR CCSM3 on the basis of the IPCC SRES-A1B emission profile. The cold season covers the 6-mo period October-March and includes two seasons; fall (OND) and Winter (JFM). The control climate which represents the late 20th century is calculated for the 20-yr period 1961-1980 and the future climate which represents the mid-21st century is calculated for the 20-yr period 2035-2054. The climate change signals are calculated as the differences between the future and control climatology.

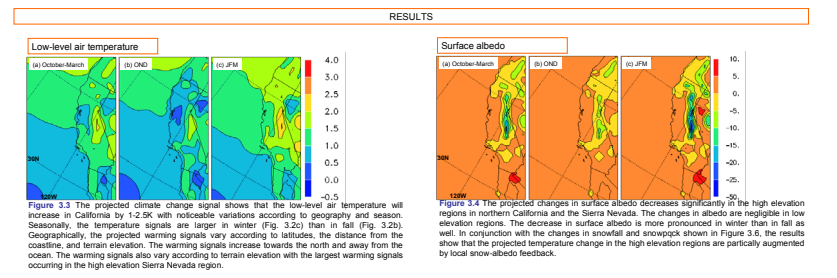
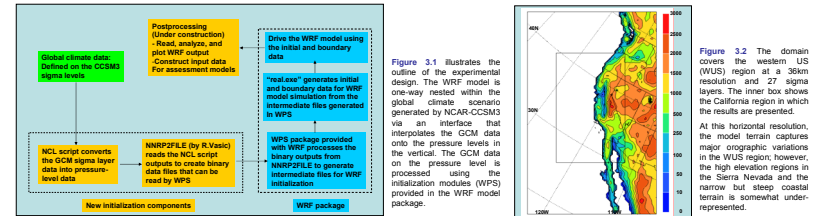


Figure 3.1 Illustrates the outline of the experimental design. The WRF model is nested within the global climate scenario from the NCAR CCSM3 via an interface that interpolates the GCM data onto the pressure levels in the vertical. The GCM data on the pressure level is processed using the initialization module (WPS) provided in the WRF model package.

Figure 3.2 The domain covers the western US (WUS) region at a 36km resolution and 27 sigma levels. The inner box shows the California region in which the results are presented. At this horizontal resolution, the model terrain captures major orographic variations in the WUS region; however, the high elevation regions in the Sierra Nevada and the narrow but steep coastal terrain is somewhat under-represented.

Figure 3.3 The projected climate change signal shows that the low-level air temperature will increase in California by 1-2.5K with noticeable variations according to geography and season. Seasonally, the temperature signals are larger in winter (Fig. 3.2c) than in fall (Fig. 3.2b). Geographically, the projected warming signals vary according to latitudes, the distance from the coastline, and terrain elevation. The warming signals also vary according to terrain elevation with the largest warming signals occurring in the high elevation Sierra Nevada region.

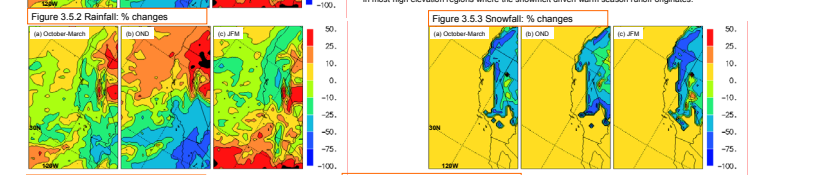


Figure 3.5.1 Precipitation: % changes. The precipitation change signals also vary according to geography and season. In the early part of the cold season (i.e., fall), positive precipitation changes in northern California are contrasted by negative precipitation in southern California. This north-south pattern is reversed in winter. For the entire cold season, precipitation decreases in the entire California region.

Figure 3.5.2 The spatial variations in the seasonal precipitation changes are associated chiefly with the rainfall changes. One exception is in the northern Sierra Nevada region where rainfall increases in both seasons. The increase in rainfall in this region is one of the most important consequences of the low level warming, converting snowfall in colder climate into rainfall in warmer climate.

Figure 3.5.3 Snowfall decreases everywhere in California except in a small region in the Sierra Nevada where the model terrain exceeds 2500m during winter. In this very high elevation region, the winter snowfall change signals range between 10 and 25% of the control climate. This result is consistent with the previous study by Kim (2001) whose study also projects the increase in snowfall in parts of the Sierra Nevada where the model terrain exceeds 2500m. This area of high elevation region is very small and the projected snowfall decreases substantially in most high elevation regions where the snowmelt driven warm season runoff originates.

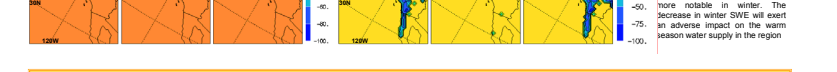


Figure 3.6 Corresponding to the changes in the precipitation characteristics (Figure 3.5), the seasonal mean snow water equivalence (SWE) and runoff in high elevation regions decreases substantially. The decreases are more notable in winter. The decrease in winter SWE will exert an adverse impact on the warm season water supply in the region.

Conclusions
A projection of the cold season climate change during the mid-21st century period has been performed using the dynamical downscaling method in which the WRF model is nested within the global climate change scenario generated by NCAR CCSM3 on the basis of the IPCC SRES-A1B emission profile. The projected temperature signals are positive and range from 1K to 2.5K in the California region with larger increases in northern latitudes, inland regions, and high elevation regions. The temperature changes in high elevation regions are partially augmented by the decrease in the high elevation snowfall and the associated decreases in surface albedo. Precipitation decreases over the entire cold season. The geographical distribution of the projected precipitation change signals varies according to season; the fall changes are characterized by increases (decreases) in the northern (southern) California region. This fall pattern in the precipitation change is reversed in winter. The seasonal variations in the spatial pattern of the precipitation change signals are closely associated with the seasonal variations in the rainfall changes. Rainfall in the northern Sierra Nevada region increases for both fall and winter due to the conversion of snowfall into rainfall in the warmer climate. The changes in precipitation characteristics and the low-level warming result in significant reduction in high elevation snowpack and runoff. **Acknowledgement**
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