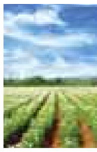
# CHAPTER 7

# Example Applications of Climate Model Results

In this chapter we present several cases where climate model simulation results were used for studies involving actual and potential end-user applications. With the increased availability of climate model simulation output through the CMIP3 multimodel archive, impacts and applications users are rapidly applying the model results for their needs. Just as quickly, the breadth and diversity of applications will continue to grow in the future as climate statistics are no longer considered stationary. The examples discussed in this chapter are meant for illustration and do not constitute a complete accounting of all published instances of applications from model results. The influence of climate, and therefore climate change, on different natural and societal systems is quite varied. Some impacts of climate change result primarily from changes in mean conditions. Other impacts are sensitive to climate variability—the sequence, frequency, and intensity of specific weather events. Note that the climate simulations described below are not offering predictions of 21st Century climate but simply projections of possible climate scenarios. Prediction requires knowing in advance how climatic forcings, including those produced by humans, would change in the future. SAP 3.2 examines climate projections by CMIP3 models in greater detail.

## 7.1 APPLYING MODEL RESULTS TO IMPACTS

As shown in previous chapters, climate models give approximate renditions of real climate. Consequently, applications of climate model results to impact studies require consideration of several limitations that characterize model output. In principle, using the direct output of climate models is desirable because these results represent a physically consistent picture of future climate, including changes in climate variability and the occurrence of such various weather phenomena as extreme events. In practice, this is rarely done for applications like those presented below because of simulation biases and the coarse spatial resolution of typical global simulations. Although the use of climate projections for impacts is beyond the scope of this report, aspects of the methodology for using the projections are based on the models' abilities to simulate observed climate. Employing coarse-resolution global model output for regional and local impact studies requires two additional steps—downscaling, as discussed in Chapter 3, and bias removal, or the adjustment of future projections for known systematic model errors, described in Chapters 2 and 5.



### 7.1.1 Downscaling

Downscaling is required because of the limitations of coarse spatial resolution in the global models. In mountainous terrain, a set of model values for a single grid box will represent conditions at the mean elevation level of that grid box. In reality, however, conditions at mountaintop and valley locations will be much different. Such processes as local snowpack accumulation and melting cannot be studied accurately with direct model output. Resolution also limits the accuracy of representation of small-scale processes. A prominent example is precipitation. The occurrence of heavy downpours is an important climate feature for certain impacts, but these events are often localized on a scale smaller than a grid box. In many actual situations, an area the size of a grid box may experience flooding rains at some points while others receive no rain at all. As a result, grid-box precipitation tends to be more frequent, and the largest values typically are smaller than those observed at the local scale. Chapter 3 covered both dynamical downscaling with nested regional models and statistical downscaling methods that include diverse techniques such as weather generators, transfer functions, and weather typing.

### 7.1.2 Bias Removal

A simple approach developed for bias removal during the early days of climate change assessments and still widely used today is sometimes dubbed the “delta” method. Climate model output is used to determine future change in climate with respect to the model’s present-day climate, typically a difference for temperature and a percentage change for precipitation. Then, these changes are applied to observed historical climate data for input to an impacts model. The delta method assumes that future model biases for both mean and variability will be the same as those in present-day simulations. One highly questionable consequence of this assumption is that the future frequency and magnitude of extreme weather events are the same relative to the mean climate of the future as they are in present-day climate. Other bias-removal methods have been developed, but none are nearly so widespread, or they are versions of the delta method.

## 7.2 CALIFORNIA CLIMATE CHANGE ASSESSMENTS

One of the most comprehensive uses of climate model simulation output for applications is overseen by the California Climate Change Center. The center was established by a state agency, the California Energy Commission (CEC), through its Public Interest Energy Research program (CEC 2006). The center wanted to determine possible impacts of climate change on California and utilized the CMIP3 model simulation database as its starting point for climate change projections.

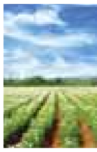
To generate future California scenarios, researchers selected three climate models from the CMIP3 multimodel archive: the National Center for Atmospheric Research–U.S. Department of Energy PCM, the NOAA GFDL CM2.1, and the Hadley Centre HadCM3 (Hayhoe et al. 2004; Cayan et al. 2006). The models were chosen in large part because of their ability to simulate both large-scale global climate features and California’s multiple climatic regions when simulations of the 20th Century were compared with high-resolution observations. Of particular importance was the correct simulation of the state’s precipitation climatology, with a pronounced wet season from November to March, during which nearly all annual precipitation falls. Further, these three models offered a range of sensitivities, with transient climate responses of 1.3 K for PCM, 1.5 K for CM2.1, and 2.0 K for HadCM3. Following model selection, projections from three scenarios with low, medium, and high future greenhouse gas emissions were chosen to span the range of possible future California climate states in the 21st Century. The California scenarios employed a statistical downscaling technique that, used observationally, derived probability density functions for surface temperature and precipitation to produce corrected model-simulated distribution functions (Cayan et al. 2006). Corrections were then applied to future scenario simulation results. Once the scenarios were generated, they were used to quantify possible climate change impacts on public health, water resources, agriculture, forests, and coastal regions (CEC 2006).

## 7.3 DRYLAND CROP YIELDS

The effects of weather and climate on crops are complex. Despite the fact that many details of weather interactions with plant physiology are poorly understood, numerous realistic crop-growth simulation models have been developed. Current-generation crop models typically step through the growth process with daily frequency and use a number of meteorological variables as input, typically maximum and minimum temperature, precipitation, solar radiation, and potential evapotranspiration. A key characteristic of these models is that they have been developed for application at a single location and have been validated based on point data, including meteorological inputs. Thus, their use in assessing climate change impacts on crop yields confronts a mismatch between the spatially averaged climate model grid-box data and the point data expected by crop models. Also, biases in climate model data can have unknown effects on crop model results because the dependence of crop yields on meteorological variables is highly nonlinear. The typical application study circumvents these difficulties by avoiding the direct use of climate model output.

The delta method continues to be a common approach in contemporary crop studies. In the U.S. National Assessment of the Consequences of Climate Variability and Change, monthly changes (model future – model control) were applied to observed data, and a weather generator was used to produce daily weather data for input to impacts models. For example, Winkler et al. (2002) found a longer growing season and greater seasonal heat accumulation in fruit-growing regions of the Great Lakes but uncertainty about future susceptibility to freezes. Olesen et al. (2007) investigated the potential impacts of climate change on several European crops. Crop models were driven by direct output of regional climate models and also baseline (present-day) observed daily climate data adjusted by GCM changes using the delta method. Thomson et al. (2005) adjusted current daily climate data with monthly change values derived from GCM projections (Smith et al. 2005) and then used them as input to models to study future yields of dryland crops in the United States. National yield changes were found to be up to ± 25%, depending on the climate scenario. These applications of the delta method produce daily climate unchanged in many respects from present-day observed data. The number of precipitation days and the time between them remains the same. Also, relative changes in intensity are the same for light and heavy days. Likewise, the length of extended periods of extreme heat and cold and the intensity of such extremes with respect to the new climate mean do not change.

In a recent study, Zhang (2005) used statistical downscaling to estimate Oklahoma wheat yields for a future simulation from HadCM3. In this study, mean monthly changes of the means and variances of temperature and precipitation between the HadCM3 control and future simulations were used to adjust the parameters of a weather generator model. Weather generator parameters include mean precipitation, precipitation variance, the probability of a wet day following a wet day, the probability of a dry day following a wet day, mean temperature, and temperature variance. The observed data were used to determine a relationship between the wet-wet and wet-dry day probabilities and total monthly precipitation. This relationship was used to assign future values of those probabilities based on the GCM-simulated precipitation changes. With the new set of parameters, the weather generator simulated multiple years of daily weather variables for input to the yield model. This approach is logical and consistent and produces different variability characteristics depending on whether future climate is wetter or drier than the present, unlike the simple delta method applied to daily climate data. However, these changes are assumed to be similar to what occurs in the present-day climate between wet and dry periods. Thus, more subtle climate model–simulated changes that might affect yields (e.g., a change to longer wet and dry spells without a change in total precipitation) are not transmitted.



## 7.4 SMALL WATERSHED FLOODING

This application faces many of the same issues as applying model output to estimate changes in dryland crop yields. For example, models used for simulating runoff in small watersheds have been validated using point station data. In addition, runoff is a highly nonlinear function of precipitation, and flooding occurrence is particularly sensitive to the exact frequency and amount of precipitation for the most extreme events. As noted in the *"Extreme Events"* section of Chapter 5, climate models often underestimate the magnitude of extremes. Again, the delta method is frequently applied to estimate the changes in flooding that may result from global climate change. Recently, Cameron (2006) determined percentage changes in precipitation from climate model simulations and applied them to a stochastic rainfall model to produce precipitation time series for input to a hydrologic model. Flood magnitudes were estimated for return periods of 10 to 200 years and for several climate changes scenarios. In most cases, flood flows increased, but one scenario produced a decrease.

Dibike and Coulibaly (2005) applied two statistical downscaling techniques to an analysis of flow on a small watershed in northern Quebec. One technique used the model of Wilby, Dawson, and Barrow (2002) to identify a set of large-scale variables (i.e., pressure, flow, temperature, and humidity) related to surface temperature and precipitation in the watershed. The resulting statistical relationships were applied to the output of a Canadian GCM climate change simulation to generate future surface temperature and precipitation time series. The second technique used a weather generator requiring various statistical parameters, estimated by comparing surface temperature and precipitation data between GCM control and future scenario simulations. The fundamental difference between these two statistical downscaling techniques is that the Wilby, Dawson, and Barrow (2002) model uses a more complete set of atmospheric data from the GCM output data while the weather generator uses only surface temperature and precipitation. The resulting time series from both methods provided input for a hydrologic model. In both cases, peak flows are higher in the spring and lower in the early summer in future warmer climates, reflecting changes in snowmelt timing. A major difference is that the Wilby, Dawson, and Barrow (2002) model produces a trend of increasing daily precipitation not seen in the weather generator data, resulting in larger spring increases in peak flow.

## 7.5 URBAN HEAT WAVES

This estimation of changes in heat-wave frequency and intensity can be accomplished using only near-surface temperature. Because heat waves are large-scale phenomena and near-surface temperature is rather highly correlated over the scales of GCM grid-boxes, downscaling is not usually required for their analysis. Biases, while remaining an issue, can be accounted for by using percentile-based definitions of heat waves. Meehl and Tebaldi (2004) used output from the PCM for 2080 to 2099 to calculate percentile-based measures of extreme heat; they found that heat waves will increase in intensity, frequency, and duration. If mortality estimates are desired, then biases are an issue because existing models (Kalkstein and Greene 1997) used location-specific absolute magnitudes of temperature to estimate mortality.

## 7.6 WATER RESOURCES IN THE WESTERN UNITED STATES

The possibility that climate change may adversely affect limited water resources in the mostly arid and semiarid western United States poses a threat to the prosperity of that region. A group of university and government scientists, under the auspices of the U.S Department of Energy–sponsored Accelerated Climate Prediction Initiative Pilot Project, conducted a coordinated set of studies that represented an end-to-end assessment of this issue (Barnett et al. 2004). This project is noteworthy because of close coordination between production of GCM simulations and the needs of impacts modeling. It also is a good example of more-sophisticated downscaling approaches.

A suite of carefully selected PCM climate simulations was executed (Dai et al. 2004; Pierce 2004) and then used to drive a regional climate model to provide higher-resolution data (Leung et al. 2004), both for direct assessment of effects on water resources and for use in impacts models. A careful statistical downscaling approach (Wood et al. 2004) also was used to produce an alternate dataset for input to impacts models. Using the observationally based 1/8° latitude-by-longitude resolution gridded dataset developed by Maurer et al. (2002), an empirical mapping function was developed to relate quantiles of the simulated monthly temperature and precipitation frequency distributions from control runs to the observed climatological monthly distributions at the GCM grid scale. This empirical mapping was then applied to simulated future monthly temperature and precipitation data and spatially disaggregated to the 1/8° resolution grid through a procedure that added small-scale structure. Daily time series of future climate on the 1/8° grid subsequently were produced by randomly sampling from historical data and adding in the changes resulting from the empirical mapping and disaggregation.

The daily time series were used in a set of studies to assess water resource impacts (Stewart, Cayan, and Dettinger 2004; Payne et al. 2004; VanRheenen et al. 2004; Christensen et al. 2004). The studies, which assumed the IPCC business-as-usual emissions scenario for the climate change GCM simulation, indicate that warmer temperatures will melt the snowpack about a month earlier throughout western North America by the end of the 21st Century. The shift in snowmelt will decrease flows and increase competition for water during the summer in the Columbia River Basin (Payne et al. 2004). In the Sacramento River and San Joaquin River basins, the average April 1 snowpack is projected to decrease by half. In the Colorado River basin, a decrease in total precipitation would mean that total system demand would exceed river inflows.