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Climate change effects on southern California deserts

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ABSTRACT

Climate change has already affected southern California where regional increases in temperature and vegetation shifts have been observed. While all the CMIP5 temperature projections agree on a substantial level of warming throughout the year, there is fair bit of divergence in the magnitude and seasonality of projected changes in rainfall. While desert plants and animals are generally adapted to extreme conditions, some species may be approaching their physiological threshold. We calculated the climate velocity of both temperature and aridity (PPT/PET) in SE California to illustrate the spatial variability of climate projections and reported on the probable expansion of barren lands reducing current species survivorship. We used a vegetation model to illustrate both temporal and spatial shifts in land cover in response to changes in environmental conditions. Such information is useful to plan land use for renewable energy siting in the region.

1. Introduction

The Desert Renewable Energy Conservation Plan (DRECP), part of California's renewable energy planning efforts, is a collaborative effort between the California Energy Commission, California Department of Fish and Wildlife, the U.S. Bureau of Land Management, and the U.S. Fish and Wildlife Service. Its goal is to provide adequate protection and conservation to ~22.5 million acres of southeast California desert ecosystems, the state's largest and most intact natural landscape (Chornesky et al., 2015), while allowing for the development of renewable energy projects.

North American deserts are expected to become warmer at faster rates than other regions (Stahlschmidt et al., 2011). Climate projections from various sources agree that temperatures will increase in the southern California deserts by more than 2 °C by mid-century (Stralberg et al., 2009; Snyder and Sloan, 2005; Snyder et al., 2004; Bell et al., 2004) while observations are already showing a measurable warming that has occurred during the last 30 years (LaDochy et al., 2007). Desert plants and animals are generally adapted to extreme warm temperatures, but some species may be approaching their physiological threshold (e.g. Serra-Diaz et al., 2014). While some species may not experience increases in temperature-driven mortality, their survival may nonetheless be affected. For example, the sex determination of eggs laid by desert tortoise is affected by incubation temperature (Burke et al., 1996) and hatchling vigor can also be impacted by higher temperatures (Spotila et al., 1994).

Precipitation in North American deserts is low and varies temporally at both short (season) and longer (decade) time scales (Stahlschmidt et al., 2011). A review of recent publications focused on California (PRBO, 2011) illustrated the wide range of rainfall projections for both the Mojave and Sonoran Deserts for the 21st century: some GCMs project increases, some decreases in annual rainfall. Cayan et al. (2008) chose two climate futures that both simulated a summer monsoon, but the warmer GFDL projected an overall increase in precipitation while PCM projected a decrease under the A2 emission scenario. Furthermore, while climate projections from the 5th Coupled Model Intercomparison Project (CMIP5) generally agree with earlier projections from the 3rd CMIP in many areas of the world, projected winter precipitation by CMIP5 climate models generally increases over California. However projections for precipitation over southern California regions remain uncertain in the CMIP5 ensemble (Neelin et al., 2013). Given the degree of aridity in the region, even relatively modest changes are likely to have large ecological consequences and drought conditions are likely to get worse.

Recent studies have shown that climate change has already affected southern California where regional increases in temperature (LaDochy et al., 2007) and vegetation shifts (Guida, 2011;

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Kelly and Goulden, 2008) have been observed. Guida (2011) observed over the last 30 years (1979–2008) an increase of 1.5 °C in the average annual minimum temperature and a decrease of 3 cm in the average annual precipitation in the Newberry Mountains, on the southeastern corner of the Mojave Desert, near its transition to Sonoran conditions. Changes were more pronounced at high elevation and correlations between climate and species distributions suggested that species most reliant on higher precipitation were already migrating to higher elevations to adapt to on-going changes in climate (Guida, 2011). Similarly, Kelly and Goulden (2008) attributed to climate change the shifts in vegetation distribution they observed along the Deep Canyon Transect of Southern California's Santa Rosa Mountains between 1977 and 2007. While they associated mortality events to two extreme droughts, they also documented the upslope movement of the dominant species by approximately 60 m in 30 years and linked it to the increase in climate variability (particularly precipitation) and warming.

We report here on a series of climate analyses using the most recent IPCC projections for the region and describe the likely responses of the major vegetation types on the landscape. We used a velocity index to illustrates the rate and magnitude of change in the area, a barren index to describe the risk of soil erosion simply due to drought conditions, and results from a dynamic global vegetation model to illustrate overall potential vegetation dynamics in response to changes in temperature and precipitation regimes.

2. Methods

2.1. Study area

The DRECP region includes fractions of the Mojave and Sonoran deserts that occupy the lowest elevations on the eastern slopes of the southern Sierra Nevada and the mountains of southern California. Annual frost-free season ranges from 210 to 365 days in Mojave and Sonoran Deserts, respectively. Elevations range from below sea level in the Salton Sea Basin and Death Valley upward to 1,500 m along the Sierra Nevada. The Mojave Desert is an area of extreme temperatures with a mean July maximum of 47 °C (117 °F) in Death Valley but it is a high desert overall with elevations ranging between 600 and 1,200 m, consequently with lower minimum temperatures than the Sonoran desert. The Sonoran desert is the hottest North American desert in part because of its low elevation (<600 m).

Seasonal rainfall patterns vary substantially over the DRECP region. During winter, storms originating in the Pacific Ocean move inland and are pushed against the Coast Ranges or the Sierra Nevada mountains. This causes adiabatic cooling, condensation, and long-duration low-intensity rainfall over large areas. Despite the rain shadow from the Sierra Nevada, the Mojave Desert portion of the DRECP receives most of its rainfall from these winter storms. Summer weather is dominated by the North American monsoon where strong storm cells from the Gulf of Mexico move northwestward causing local cyclonic thunderstorms of short duration and high intensity (McMahon, 2000). The Peninsular Ranges create rain shadows for the Sonoran Desert, which displays a bimodal rainfall regime with 50% of its rainfall occurring during summer. Differences in seasonal rainfall, winter dominated in the Mojave and bimodal in the Sonoran, are sufficient to cause substantial differences in vegetation structure and floristic composition (McMahon, 2000) between the two deserts, with a transitional ecotone known for its species and genetic diversity (Wood et al., 2012).

2.2. Climate inputs

Historical climate data (1895–2010) were created and distributed by the PRISM group at Oregon State University (Daly et al., 2008). To match the scale of the future projections, they were upscaled to a 1/24° by taking the mean of the original 1/120° (~800 m) grid cells (Daly et al., 2008). Climate projections (2010–2100) from the 5th Coupled Model Intercomparison Project (CMIP5) had been downscaled to 1/24° (~4 km) using a method developed by Abatzoglou (2012) and provided through his web site (http://maca.northwestknowledge.net/). CMIP5 climate models include Earth System Models (ESMs) that represent the biosphere in more detail than most climate models (e.g. nitrogen cycle, dynamic vegetation, fire emissions). We looked at the 20 sets of downscaled climate projections and chose three that bracketed the full range of future precipitation for a similar level of warming over the DRECP region (Fig. A1).

The three models (MIROC5, CCSM4, and CanESM2) were ranked among the top 10 CMIP5 performers by Rupp et al. (2013) with respect to their ability to simulate historical climate for the west coast of the US and for their overall structural soundness. Each model projects a different precipitation future – one with approximately the same level of winter and summer precipitation as historical but somewhat drier overall (the 5th generation of the Model for Interdisciplinary Research on Climate, MIROC5), one with wetter winters than historical but similar annual moisture to historical (the Community Climate System Model, version 4.0, CCSM4), and an earth system model that projects both much wetter winters and summers than historical (the 2nd Generation Canadian Earth System Model, CanESM2). None of the top 10 CMIP5 future climates projected drier winters and wetter summers, so we did not consider such a scenario.

In the 5th Assessment Report for the Intergovernmental Panel for Climate Change (AR5), the storyline emission scenarios (Nakicenovic et al., 2000) were replaced by four Representative Concentration Pathways (RCPs) projecting the evolution of the concentration of atmospheric carbon dioxide over time. The RCPs (vanVuuren et al., 2011) were developed to simulate four levels of radiative forcing (2.6 W m^{-2}–8.5 W m^{-2} by 2100) resulting from different carbon dioxide concentration trajectories driven by diverse climate policies. We analyzed climate model results for the low RCP 4.5 and the more likely RCP 8.5.

2.3. Climate velocity

Based on the IPCC (2014) summary for policy makers, "*Climate velocity is defined as the rate of change in climate over time (*e.g., *°C/yr, if only temperature is considered) divided by the rate of change in climate over distance (*e.g., *°C/km, if only temperature is considered)* (Loarie et al., 2009; Dobrowski et al., 2013). *Climate velocity for temperature is low in mountainous areas because the change in temperature over short distances is large*." In low relief areas, climate velocity for temperature is generally high and can exceed 80 km/yr for the RCP 8.5 because the rate of change in temperature over distance is low.

Because it is expressed in units of distance over time, climate velocity provides a consistent and useful way to compare diverse measures of climate change. Previous analyses of climate change velocity have mostly focused on changes in temperature (e.g. Loarie