Climate Change in the Southwest United States: An Integrated Approach to Understanding Ecological Change

Todd Ringler, Theoretical Division, LANL
Matthew McCabe, International, Space and Response, LANL
Nate McDowell, Earth and Environmental Science, LANL
Everett Springer, Earth and Environmental Science, LANL

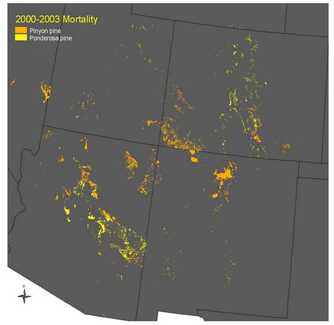
Introduction: A Problem of Scales

The radiative forcing of greenhouse gases is leading to changes in the large-scale circulation of the atmosphere (below). These changes have strong theoretical, numerical and, in some cases, observational support. Unfortunately, socioeconomic and eco- systems are arranged on spatial scales significantly smaller than the large scales that we can model directly.

The Southwest United States is particularly at risk for significant impact due to changes in the large-scale circulation. Examples of these risks include dramatic changes in amount and timing of water resources due to shifts in the storm track and changes to ecosystem function due to drought driven mortality events (see figure to right).

Our goal is to set up an integrated system to monitor, manipulate, and model ecosystem function in the Southwest United States in order to quantitatively assess climate-change driven impacts and how these impacts will feedback on the regional climate system.

Mortality resulting from recent drought



Changes in the Large-Scale General Circulation

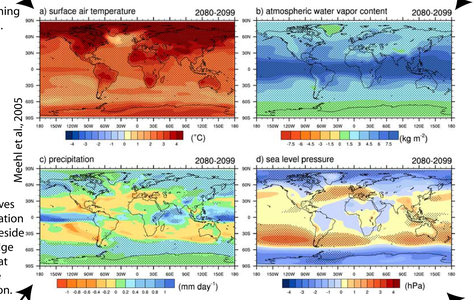
The below figure shows changes in the large-scale circulation in terms of differences between the predicted 2080-2099 climate and 1980-1999 climate. The results represent an ensemble mean of nine different climate models using the A1B scenario.

Warmer

All regions are expected to warm, with the most warming occurring over land.

More water in the atmosphere

A warmer atmosphere holds more water and leads to an intensification of the water cycle -- wet areas get wetter and dry areas get drier.



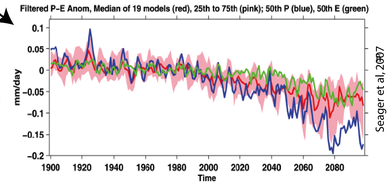
As the storm track moves poleward, the precipitation follows. Regions that reside at the equatorward edge of the storm track are at particular risk for large changes in precipitation.

A weakening of the pole-to-equator temperature gradient leads to a poleward shift in the storm track.

Less Precipitation in Semi-Arid Regions

Poleward Shift in Storm Tracks

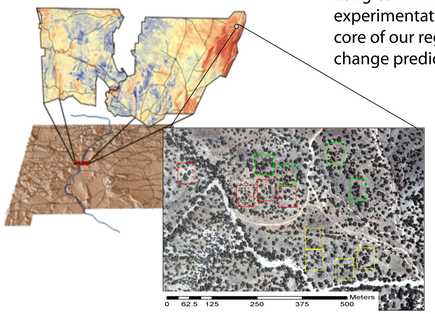
Steadily decreasing precipitation over the next century punctuated by ongoing episodic drought.



Ensemble-mean for Southwest precipitation

Field Observations and Experiment

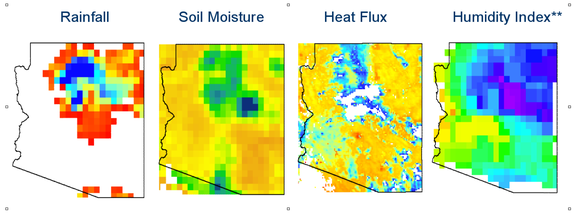
A core component of this work is the long-term observation of representative ecosystems of the Southwest. Shown below are field sites in pinon-juniper woodlands located within the Sevilleta Long Term Ecological Research area. Manipulative experiment include precipitation treatment to study physiological processes leading to plant mortality. Extensive instrumentation and isotopic analysis allows pathways of the water and carbon cycle through the soil-plant-atmosphere system to be quantified. This data is critical for the development of predictive tools associated with ecosystem-scale climate processes.



Long-term monitoring and experimentation form the core of our regional climate change prediction program.

Remote Sensing

Remote sensing from a wide array of satellite platforms provides three critical components of our regional climate prediction work. First, remote sensing complements the long-term monitoring of the field work by extending the "field-of-view" across the entire region. This allows the possibility to identify ecological analogs of our field sites throughout the Southwest. Second, similar to our field work, remote sensing can provide a systems levels understanding of the flows of water and energy across the land-atmosphere interface. And finally, given its wide spatial and temporal extent, along with increasing sensor resolution, remote sensing data is critical for the testing and validation of the modeling framework (described to the right).



By combining sensor data across numerous satellite platforms, we can start to build a coherent picture of soil-plant-atmosphere interactions. Some sensors measure at the scale of 10-100 meters which allows cross-validation with the field experiments described above.

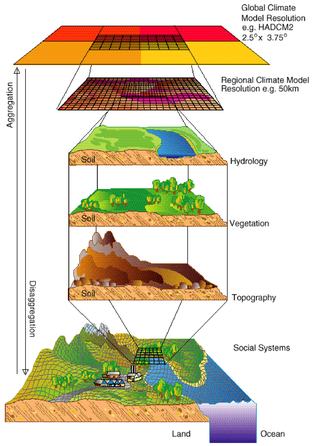
Tools for Prediction

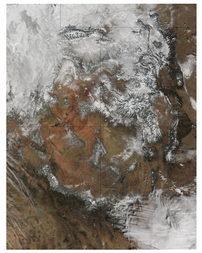
Numerical models have been, and will continue to be, the primary tools used to assess global climate change and its subsequent impacts. While far from perfect these numerical models encapsulate our understanding of the global climate system and how individual components of the system interact in space and time. Our lack of knowledge related to many aspects of the climate system (such a cloud processes and climate-ecosystem dynamics) combined with the wide range of temporal and spatial scales that must be captured makes climate modeling one of the grand challenges in science and computing today.

Global Climate System Modeling
resolution ~ 200 km

Global coupled climate system models will continue to serve as the primary tool to assess changes in the large-scale circulation. Basic research is still required to determine how best to use this large-scale forcing as boundary forcing for the regional atmospheric model detailed below.

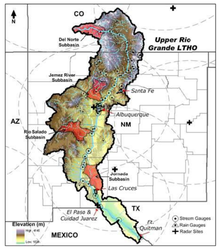
Integrated Modeling System





Regional Atmospheric Modeling
resolution ~10 km

Regional atmospheric models have traditionally been used for short-term, weather forecasting. Only recently have these models when reapplied to the long-term, nearly statistically steady-state problem of climate change. Significant challenges exist related to model bias and drift related to cloud process and surface energetics. Even at 10 km, these models do not capture the highly variable terrain of the Southwest. In addition, this scale is still fair too coarse for realistic prediction of hydrological processes detailed below.



Regional Hydrology
resolution ~ 100 m

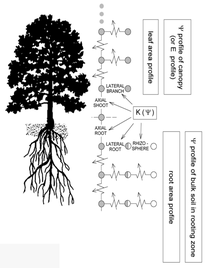
Detailed modeling of the entire Rio Grande Basin from headwaters through New Mexico is now being attempted. As with the modeling described above, this is a computationally intensive activity requiring thousands of computer processors to conduct a single simulation. For long lead times, characterization of surface hydrology processes requires not only knowledge of changes in atmospheric forcing, but also changes in ecosystem function and structure detailed below.

Ecosystem dynamics
resolution ~ 1 km

While at the core of assessing risks to bio-diversity, the current class of IPCC coupled climate models used for assessing global climate change do not include processes related to ecological change. Assessing ecological change under increasing green-house gases remains primarily a field and remote sensing activity. Coupled climate-ecosystem models sit on the horizon for IPCC-type climate simulations.

Plant Physiology
resolution ~ 1 m

Models of individual plant function provide the opportunity to directly model plant mortality. More importantly, these models allow direct comparison to field observations and experiments.



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