Analyzing the surface hydrology of North America under doubled CO_2

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Introduction

We present high-resolution simulations of the atmosphere and land surface under a doubling of atmospheric CO_2 using the RegCM3 regional climate model. Several techniques were used to evaluate model performance and to quantify potential changes in surface hydrology.

The Models

The A/OGCM is a combination of two general circulation models, v3.0 GENESIS and the v2.0 MOM ocean model, called GENMOM. This global model provides the boundary conditions for the regional model, RegCM3, which is run on a much finer grid. This study presents 40 model years of results from a 100-year run.

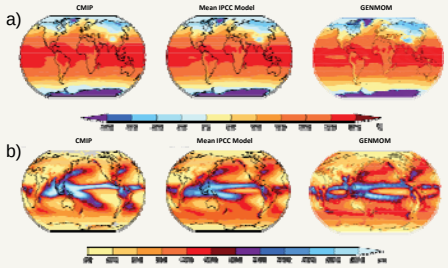


Figure 1. Comparison of mean annual a) temperature and b) precipitation for observations (left), the mean IPCC model results (middle), and GENMOM output (right). IPCC (2008).

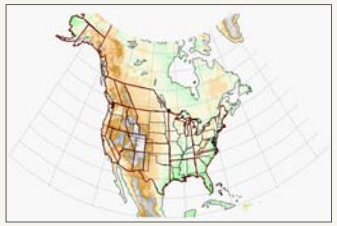
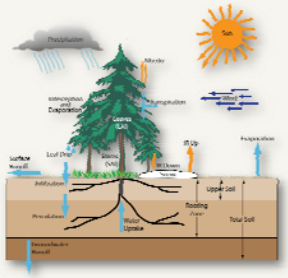


Figure 2. The domain and topography of the regional model. The horizontal grid is 50 km and the atmosphere is simulated with 23 vertical layers to resolve the boundary layer. Outlined in dark red are the subregions used for more detailed hydrological analyses.

Methods

The hydrological fields we present are obtained from the surface physics model Biosphere-Atmosphere Transfer Scheme (BATS), which is coupled with the atmospheric model to calculate the exchange of radiation, momentum, heat, and moisture components between the atmosphere and the Earth's surface.



Methods (cont.)

We evaluate the water balance in terms of standardized indices (SI) computed following the standardized precipitation index (SPI). Some of the advantages of the SI approach are 1) it places all variables on a standard scale of variability allowing direct comparisons, 2) unlike the PDSI it allows investigation of antecedent conditions over any desired time span (e.g., 48 months), and 3) it allows direct comparison of wet or dry conditions among regions of differing climates.

To compute the SI, a gamma distribution is built from the data time series using the probability density function (PDF):

$$f(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta}$$

where $x > 0$ is the data value (e.g. precipitation), and the distribution parameter $\alpha > 0$ and the shape parameter $\beta > 0$ are fitted from the data. The gamma function, Γ, is computed from:

$$\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1} e^{-y} dy$$

The parameters α and β are estimated using maximum likelihood functions and the SI for a given month and time span is computed from the cumulative distribution function (CDF):

$$G(x) = \frac{1}{\hat{\beta}^{\hat{\alpha}}\Gamma(\hat{\alpha})} \int_0^{x} x^{\hat{\alpha}-1} e^{-x/\hat{\beta}} dx$$

where the hats indicate parameter estimates. The CDF is transformed to the normal distribution with a mean of zero and standard deviation of one. Thus all variables are fitted, transformed, and placed on a common scale that measures departure from normal in standard deviations with a range of about ±3.

Results

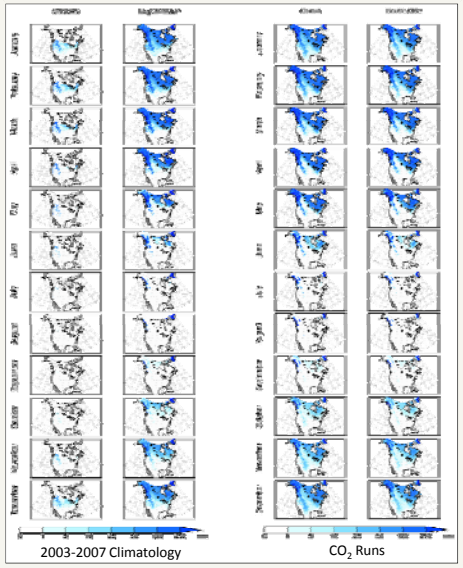


Figure 3. Left: Comparison of SNOw Data Assimilation System (SNODAS) snow climatology with snow simulated with the RegCM3 using NCEP boundary conditions. **Right:** Simulated 40-yr snow climatology for 1X and 2X CO_2. SNODAS is a modeling and data assimilation system developed by NOAA. It integrates snow data from satellite and airborne platforms and from ground stations with modeled estimates of snow .

Results (cont.)

We evaluate hydrologic conditions using monthly model output and 48-month standardized indices. A four-year span filters out high frequency variability and emphasizes lower frequency changes. The value at each point on the plots is the numerical departure of the immediate previous 48-month span with the composite mean of all other similar spans in the data set. To quantify change between the 1X and 2X CO_2 water balances, we fitted the SIs for the 1X simulations and applied the those distributions and their fitted parameters to the 2X CO_2 time series. This approach eliminates the need to interpret simple anomalies on different scales.

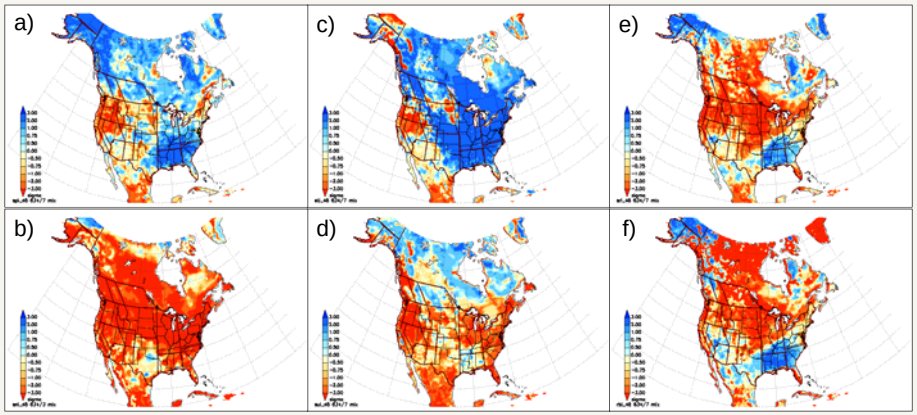


Figure 4. Spatial patterns of standardized indices for July of model year 634 for a) precipitation, b) snow (displays March instead of July), c) evapotranspiration, d) upper soil moisture, e) root zone soil moisture, and f) base flow. These are computed with 1X CO_2 fitted parameters and the 2X time data.

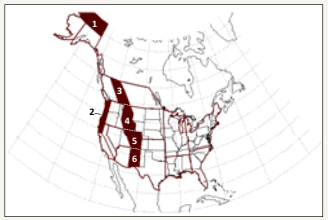


Figure 5. (Above) The North American domain is divided into 22 regions, which were used for surface hydrology analyses. These preliminary regions are based on climate zones, ecosystem distribution and topography. Highlighted here are 1) Northern Alaska, 2) Pacific Northwest Coast, 3) Canadian Rocky Mountains, 4) Northern Rocky Mountains, 5) Central Rocky Mountains, and 6) Southern Rocky Mountains. These regions display a range of changes in their water balances for both common and distinct climatic forcing and physiographic factors.

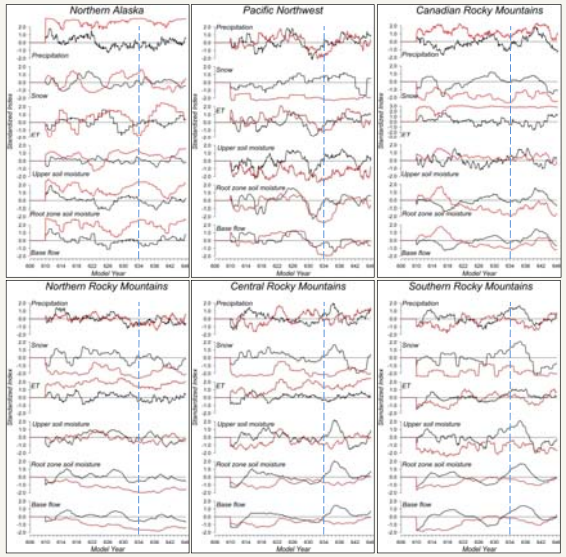


Figure 6. (Right) Time series of 48-month standardized indices of precipitation, snow water equivalent, evapotranspiration (ET), upper soil zone moisture, root zone soil moisture, and base flow for each focus region. The black lines are for the 1X CO_2 simulations and the red lines are computed with 1X CO_2 fitted parameters and the 2X time data. The vertical dashed blue line shows the year displayed on the maps above. Key examples of changes are: **1)** an increase in base flow in Northern Alaska due to warming-related increases precipitation and melting of permafrost; **2)** loss of snowpack in all other regions; **3)** general increase in ET; **4)** persistent and large reduction of base flow (stream flow) in the Northern Rocky Mountains; **5)** loss of root zone moisture; **6)** long periods of moderate to severe drought.