PACIFIC CLIMATE IMPACTS CONSORTIUM, MARCH 2013

PCIC SCIENCE BRIEF 4: INCREASING DROUGHT DUE TO GLOBAL WARMING IN OBSERVATIONS AND MODELS

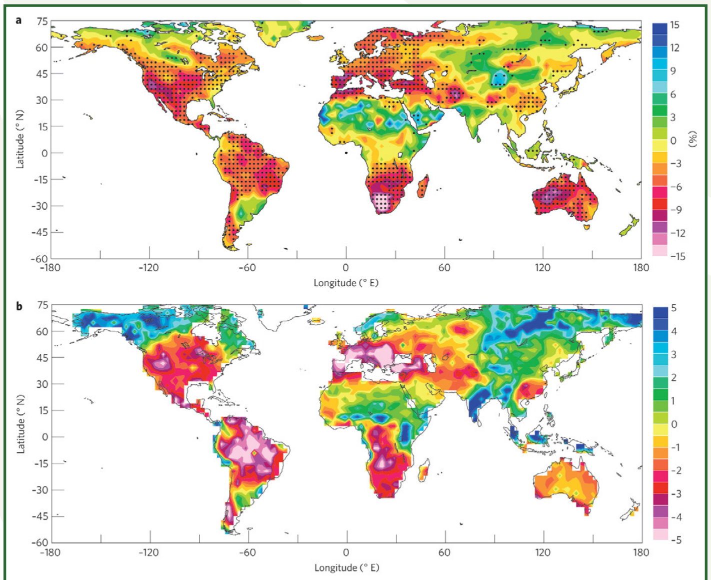
PCIC Science Briefs are short reports on recent climate science literature relevant to stakeholders in the Pacific and Yukon Region of Canada. Science Briefs contextualize and explain the results and implications of important scientific findings.

A recent paper by Aiguo Dai (2013) in *Nature Climate Change* concludes that observed decreases in precipitation and streamflow, as well as increases in drought in certain areas are consistent with model projections of severe[1] widespread droughts later in this century.

Conditions of decreased precipitation and streamflow are collectively known as aridity. Observational records show an increase in aridity over certain areas since 1950 and climate model projections suggest that this trend will continue into the twenty-first century, though certain areas that have experienced increased wet conditions will see increased aridity and vice-versa.

Aridity has increased over Southern Europe, southeast Asia, eastern Australia and most of Africa since the 1950s. Increased wet conditions over northern high-latitude areas, the central United States and Argentina have been observed over the same period.

Dai (2013) examined output from models used for the third and fifth phases of the Coupled Model Intercomparison Project[2] (CMIP3 and CMIP5, respectively), comparing them against observations over the historical period and examining their projections for the end of the 21st century. For the former, he considered a "medium" greenhouse gas emissions scenario that results in an atmospheric carbon dioxide concentration of 750 parts per million by the year 2100 (SRES[3] A1B). For the latter, an atmospheric carbon dioxide concentration of 550 parts per million by year 2100 was assumed (RCP[4] 4.5), which is roughly double that of the concentration in pre-industrial period (280 parts per million).



Future changes in soil moisture content and PDSI from Dai (2012). a) Projected changes in soil moisture content in percent for 2080-2099 compared to 1980-1999 for the upper 10 centimetre soil layer, from the ensemble mean of 11 CMIP5 models for the scenario that assumes an atmospheric greenhouse gas concentration of 550 parts per million (RCP 4.5) by 2100, as compared to the preindustrial period. **b)** The mean PDSI averaged over 2090-2099 using data from 14 CMIP5 models using the same scenario as a). A value of -3 or smaller indicates "severe to extreme" drought conditions in the current climate.

1. Drought severity refers here to the Palmer Drought Severity Index (PDSI). This index uses a scale of 5 to -5 to categorize precipitation and drought conditions, with -2 indicating moderate drought, -3 indicating severe drought and -4 and below indicating extreme drought, while 2, 3, 4 and above indicate moderate, very and extremely moist conditions, respectively. These are standardized to local climate and so differences in PDSI indicate a shift from the normal climate of the region(s) . http://www.ncdc.noaa.gov/oa/climate/research/prelim/drought/palmer.html
2. For more information on the Coupled Model Comparison Project, see here: http://cmip-pcmdi.llnl.gov/.
3. The Intergovernmental Panel on Climate Change published a set of emissions scenarios known as the Special Report on Emission Scenarios (SRES) in 2000, in order to provide input for evaluating the consequences of various trajectories of future greenhouse gas emissions. For more on the these emissions scenarios, see here: http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=23
4. (See other side.)

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The author first examined observational data, using statistical methods to examine how sea surface temperatures and aridity changed over time and to draw out similarities in the features of these changes. In examining the variability of sea surface temperatures and aridity, he found that the two varied together, to some extent, and that there were two dominant patterns in how they varied together. Further, Dai found that these two patterns corresponded to (1) changes in El Niño and (2) changes in the concentration of atmospheric greenhouse gases. These relationships were apparent both spatially and in the global mean.

Dai then examined climate model simulations of the 20th Century in order to see if these relationships were apparent in the models' output. He found that, if one looked at overall, global mean aridity, the relationship did hold for both El Niño and the greenhouse gas forcing. The spatial pattern associated with El Niño in models was similar to that in observations, but models display a different spatial pattern of change in association with greenhouse gas forcing than deduced from observations.

Finally, the author used model projections for the 21st Century in order to calculate potential changes to aridity. While there is heightened uncertainty owing to the lack of correspondence between the greenhouse gas forcing and spatial changes in the model simulations of the 20th Century, there is reason to have some confidence in these projections, because the models tend to agree on the trend and represent the global mean aridity trend over the 20th Century well.

Spatially, the models project increasing drought conditions over most of North and South America, Europe, Southern Africa, Southeast Asia and Australia (see figure on opposite page). For western North America, the model projections show an overall trend in decreasing soil moisture content. The spatial trend in projected aridity changes sign within BC, with southern BC potentially facing increased aridity while northern BC and Yukon will potentially be experiencing more moist conditions.

Methodology

Dai used model output consisting of one run each from 22 CMIP3 models and 14 CMIP5 models. For CMIP3, model runs were selected from the medium A1B scenario, which projects emissions for a world that undergoes rapid economic growth, population growth that peaks in the middle of the century and a rapid introduction of efficient technologies, with a balanced use of fossil-fuel and non-fossil-fuel energy sources. For CMIP5, Dai selected models from a scenario in which the atmospheric carbon dioxide rises to roughly double the preindustrial value by 2100. The data sets for the historical period used in the paper included the Hadley Centre Sea Ice and Sea Surface Temperature data set[5], for sea surface temperatures, as well as a number of sets[6] to compute aridity. Dai then calculated the values for the Palmer Drought Severity Index (which depends on precipitation, evaporation, runoff and the moisture in soil layers).

The author then used a statistical method called maximum covariance analysis to determine to what extent changes to sea surface temperature (such as those caused by El Niño) and changes in aridity varied together, spatially and in the global mean. Dai examined the patterns in how sea surface temperature and aridity varied together and compared them against changes to atmospheric greenhouse gas concentrations and El Niño. All of these analyses were conducted for both the historical and future period.

From this, Dai arrived at the conclusions above.

Dai, A., 2012: Increasing drought under global warming in observations and models. *Nature Climate Change*, **3**, 52–58.

4. CMIP5 (Taylor et al., 2012) developed four new trajectories of atmospheric greenhouse gas concentration, known as Representative Concentration Pathways (RCP) for it's Fifth Assessment report. The four trajectories are denoted by the change to radiative forcings that would result from the concentration, hence, RCP 4.5 would result in an increase of 4.5 Watts per square meter from the preindustrial period (taken to be the year 1750). For more information on RCP, see: Taylor, K.E., et al., 2012: An Overview of CMIP5 and the experiment design." *Bulletin of the American Meteorological Society*, **93**, 485-498, doi:10.1175/BAMS-D-11-00094.1.
5. For more information about the Hadley Centre Sea Ice and Sea Surface Temperature data set, see: Rayner N.A., et al. 2003: Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century. *Journal of Geophysical Research: Atmospheres*, **108**, D14, 4407. Online, here: http://onlinelibrary.wiley.com/doi/10.1029/2002JD002670/abstract
6. For a description of the methods and historical forcing data used to compute the aridity, see the following paper (specifically, the section where sc_PCDSI_pm is calculated): Dai, A., 2011: Characteristics and trends in various forms of the Palmer Drought Severity Index during 1900–2008. *Journal of Geophysical Research: Atmospheres*, **116**, D12115, doi:10.1029/2010JD015541.

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