PCIC UPDATE MARCH 2015

ECONOMIC IMPACTS OF CLIMATE CHANGE ON BC AGRICULTURE IN FOUR REGIONS

Projected changes to British Columbia's climate, including changes to the frequency and magnitude of climate extremes, may have significant impacts on agriculture in the province. Economic analysis by PICS intern Kayleigh Donahue during her term as Climate Change Research Analyst for the Ministry of Agriculture's Innovation and Adaptation Services Branch, uses climate projections provided by PCIC to develop a set of illustrative scenarios that explore the effects that climate change may have in four regions of BC in the 2030s and how adaptation measures may reduce agricultural impacts and improve economic outcomes.

The author develops these scenarios using climate projections and collaborative discussions with industry experts, agrologists from all four regions and PCIC. The results of this process are used to estimate economic outcomes from various adaptation measures.

One scenario examined by Donahue is a combination of reduced winter snow and a summer drought in the Cowichan Valley, an area of mixed agriculture that includes field and horticulture crops, greenhouse vegetables and animal agriculture, on Vancouver Island. In this scenario, the impacts of reduced water availability, including lower yields and increased livestock feed costs, could be reduced by adaptations that include water planning and irrigation efficiency improvements. In this particular scenario, adaptation measures are found to have potential benefits in the drought year of between $5 million and $14 million.

Three other scenarios developed by the author examine the ability of adaptation measures to offset the impacts of climate change in BC's Cariboo, Peace River, and Okanagan regions. She finds that planning and adaptation measures can provide substantial economic benefits, compared to not adapting, in all four of the scenarios. These benefits vary with the scenario, but have a combined total range of $105 million to $270 million across a diverse set of agriculture, from ranching to forage crops, grains, oil seeds, fruits, grapes and wine.

The analysis shows the benefit of forward-looking planning and preparation similar to the programming that has been initiated by the BC Ministry of Agriculture. Read the report online at the Pacific Institute for Climate Solutions.

Donahue, K., 2014: *Climate Stressor Scenarios: Final Report – Regional Economic Impact of Climate Change in B.C. Examined Through Scenario Analysis*. British Columbia Ministry of Agriculture, 42 pp.

PCIC RESEARCHERS CO-AUTHORS ON NATURE CLIMATE CHANGE PAPER ATTRIBUTING ARCTIC CLIMATE CHANGE

Recent research published in Nature Climate Change by PCIC's Mohammad Reza Najafi and Francis Zwiers, and Nathan Gillett from the Canadian Centre for Climate Modelling and Analysis attributes the amount of change in surface air temperature in the arctic due to natural forcing agents, anthropogenic greenhouse gas emissions and other anthropogenic forcings (primarily aerosols). In their work, selected as a Nature Research Highlight, they find that anthropogenic greenhouse gases have been responsible for the observed Arctic warming over the past century. They also find that anthropogenic forcings other than greenhouse gases have offset about 60% of the warming that would have occurred if greenhouse gases had acted on their own. They estimate that without this offsetting effect, the arctic warming of 1.2 °C would have been about 3.0 °C. The study uses recently updated surface air temperature datasets assessed by the IPCC, and climate change simulations from models participating in the fifth phase of the Coupled Model Intercomparison Project (CMIP5). These models project a large, 8.3 °C warming by the end of the century under a business as usual scenario, further highlighting the need for reductions in greenhouse gas emissions.

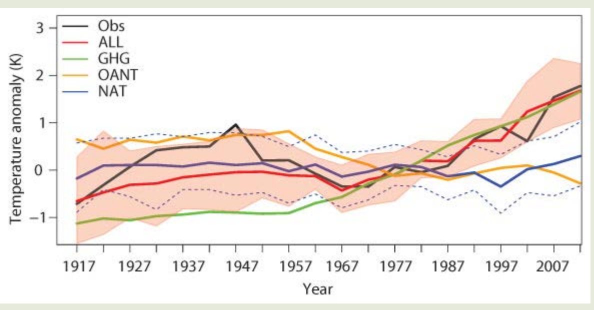

Figure 3: Observed and simulated Arctic temperature anomalies, from Najafi, Zwiers and Gillett, 2015. The black line represents five-year mean observed Arctic temperature anomalies, the coloured lines represent the simulated responses to all forcings (red), greenhouse gases alone (green), other anthropogenic forcings alone (mostly aerosols, orange) and natural forcings (blue). Red shading indicates the 5-95% uncertainty range for all forcings, and blue dashed lines indicate the 5-95% uncertainty range for natural forcings only.

Following a warming trend early in the 20th century and mid-century cooling, surface air temperatures in the Arctic have shown a strong increase over the last few decades, warming at about twice the global average. This polar amplification is thought to be due largely to changes in sea ice, with some contributions from changes in snow cover, atmospheric and ocean circulation, cloud cover and the presence of soot. Some of the projected impacts of climate change on the Arctic region include: damage to infrastructure from permafrost loss and changes in precipitation patterns, spatial shifts and changes to the productivity of marine organisms due to changes in ocean conditions and sea ice, reduced food security for some Arctic communities and impacts on Arctic and sub-Arctic marine mammals, especially those that depend on sea ice.

In order to better understand the causes of the Arctic's changing climate, the authors used observational data and nine CMIP5 global climate models to tease apart the effects of anthropogenic greenhouse gas emissions, natural forcings and other anthropogenic forcings (aerosols, ozone and land use changes). As can be seen in Figure 2, the observational data (in black) falls within the range of climate model simulations that are run using all forcings (shaded red), but lies outside the range of model simulations run using only natural forcings (dashed blue lines). Najafi and colleagues use statistical methods to quantify the contributions of each forcing on Arctic surface temperatures over the interdecadal scale. They repeat their analysis for each season and then with two other observational data sets. The authors find that the results from each of these analyses are consistent, showing that the effects of changes in greenhouse gases, aerosols and other anthropogenic forcings on the climate of the Arctic region can be detected. As detailed above, they conclude that greenhouse gases are responsible for the observed warming in this region and that their effect is being partly offset the effect of other anthropogenic influences, primarily aerosols.

Read the paper at Nature.com.

Najafi, M.R., **F.W. Zwiers** and N.P. Gillett, 2015: Attribution of Arctic temperature change to greenhouse-gas and aerosol influences. *Nature Climate Change*, Advance Online Publication, doi:10.1038/NCLIMATE2524.

PCIC RESEARCHER SHARES HIS EXPERIENCE AT THE AMERICAN GEOPHYSICAL UNION MEETING

Figure 2: A poster session at the 2014 Fall Meeting of the American Geophysical Union. Image credit: NASA Ames.

PCIC's Regional Climate Impacts Analyst, Stephen Sobie recently attended the Fall Meeting of the American Geophysical Union (AGU), the largest annual conference of its kind. He shares his experience, below.

I recently attended the AGU's Annual Fall Meeting in San Francisco, CA. This is the world's largest Earth science conference with over 23,000 scientists, managers, planners and vendors attending this year. The conference spans areas from Atmospheric Sciences to Volcanology with several other topics in between over the course of one week, resulting in many interesting sessions.

My focus at the conference was to attend sessions in the climate change and atmospheric science fields, and to present some of our research studying statistical downscaling in British Columbia. During the conference I attended a variety of interesting oral and poster presentations. The ongoing California drought was a extensively covered through observational and modelling studies examining the current and potential future impacts. The CalWater2 experiment studying Atmospheric Rivers is scheduled to begin this year. This should lead to a greater better understanding of the physical mechanisms of Atmospheric Rivers and improve their predictability, which is important for BC as several large floods in the province have been due to these events. This year there was also a growing emphasis on the health effects of climate change, with several talks and posters investigating heat waves and movement of pathogens in a warming climate.

In the exhibitor hall, several different organizations including Google, NOAA, and NASA held demonstrations on new visualization tools designed to work with larger datasets in more manageable ways. These types of tools could become more useful as PCIC's stored datasets grow larger and larger. In a session on extreme precipitation events, I presented a poster covering our work on the scale dependence of extreme precipitation when downscaling with global and regional climate models. I met with many interested researchers working in similar areas and had a number of great discussions on modelling, downscaling and extreme precipitation.

2014: RANKED WARMEST YEAR IN SEVERAL INSTRUMENTAL TEMPERATURE RECORDS

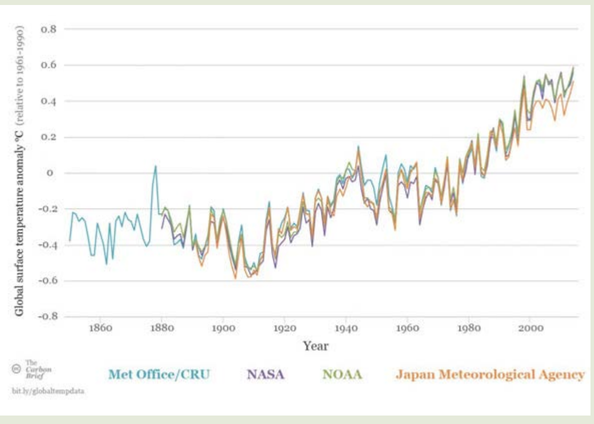

Figure 3: Global surface temperatures from the UK Met Office and the University of East Anglia's Climate Research Unit (HadCRUT4), NASA (Global Land-Ocean), NOAA (Merged Land Ocean Surface Temperature Analysis) and Japan Meteorological Agency. Image credit: Rosamund Pearce, Carbon Brief.

The United States National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA) have recently released results ranking 2014 as the year with the warmest surface temperatures in the instrumental record. This ranking matches with the similar surface temperature records maintained by Japan Meteorological Agency and Berkeley Earth. However, it differs slightly from two other records, that of the Met Office, in which 2014 is tied with 2010 for the top spot, and the reconstruction of Cowtan and Way that combines the Met Office record with satellite data for the Arctic region and finds 2010 to be the warmest on record, followed by 2014. Figure 3 shows how the surface temperature anomalies from four of these groups line up.

In interpreting the rankings above, we must keep in mind that all measured values of physical phenomena have associated uncertainties. This is true of measures of the Earth's surface temperature. Figure 4 illustrates this these uncertainties. In this figure, each red bar representing the annual average global temperature of a given year is accompanied by a grey bar that represents the amount of uncertainty in the form of a confidence interval (loosely speaking, there is a 95% probability that the actual value is within the grey bar). The grey bars are larger close to the beginning of the century, indicating greater uncertainty, and shrink toward the end of the century, as more stations are added to the record. Note that many of the uncertainties overlap. While the best estimate, in red, for one year might be higher or lower than another given year, so long as their uncertainties overlap there is a limit as to how confidently we can rank them.

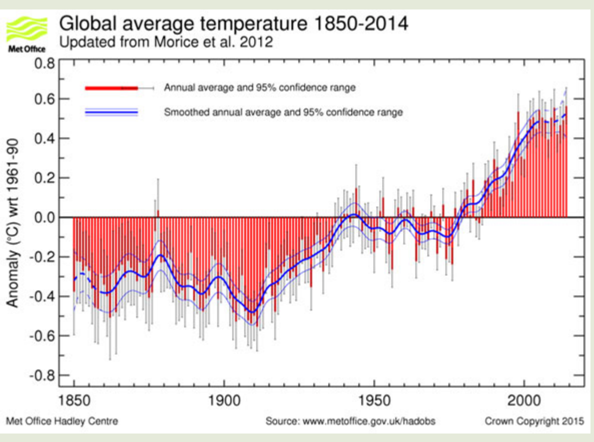

Figure 4: Global surface temperature anomalies from the Met Office and the University of East Anglia's Climate Research Unit (HadCRUT4) The red show the annual average temperature anomalies, the grey bars represent the 95% confidence intervals, the thick blue line shows the smoothed trend (using a 21 point binomial filter) and the thin blue lines represent the 95% confidence interval for the smoothed trend. Image credit: Met Office Hadley Centre.

So, what does this mean for the ranking of 2014 as the warmest year on record? The confidence intervals for several of the warmest years in each of the records overlap to some degree. So, while we can rank our best estimates of each year's temperature and examine the probabilities associated with these rankings, we are limited in how confident we can be of our assessment. To take an example, in the NOAA record, 2014 has roughly a 48% chance of being the warmest on record, followed by 2010, 2005, 2013 and 1998, with likelihoods of about 18%, 13%, 6% and 5%, respectively. This makes 2014 easily the most likely candidate for the warmest year in this record, with a likelihood that is slightly greater than those of the next four warmest years combined. However, with a likelihood of only 48%, we are still limited in how confident we can be that 2014 was the warmest year in NOAA's record.

We might ask what it is that causes differences between these different surface temperature records. The answer is that the methodologies and data sets used by each group differ slightly, and this leads to slight differences between the records. One reason for differences between the records has to do with how they handle areas with scant data, such as the Arctic (and some areas of Africa, South America and the Antarctic). So, for instance, whereas NOAA, the Japan Meteorology Agency and the Met Office omit areas in the Arctic Ocean without stations from their analysis, NASA estimates the temperature over these regions and includes it in their analysis. Another reason for differences between the records is the way that each handles corrections to sea surface temperature data. Usable sea surface temperature measurements have been recorded for more than 160 years, owing to an agreement on the standardization of ocean observations among several seafaring nations at the Brussels Maritime Conference of 1853. In the time since the conference, the methods used to collect and measure water temperatures have changed several times, from wooden buckets, to insulated canvas buckets, to thermometers in the engine intakes of ships and even automated floats and satellite measurements. The amount of data has also changed, increasing over time. Different temperature records correct for factors such as these in different ways. While there are benefits and drawbacks to each approach used, one of the end results is that the records differ slightly. Nonetheless, the surface temperature reconstructions are strongly consistent with each other, show an overall warming trend since the middle of the last century and they each place 2014 among the warmest years that have been recorded in the instrumental record.

NEWSWORTHY SCIENCE

PCIC has released a new science brief that covers two recent articles that serve to answer two questions about the climate system's response to carbon emissions. The first paper, by Goodwin et al. (2014) in Nature Geoscience, investigates why transient surface warming on the timescale of decades to centuries is nearly-linear. They find that this is the result of the competing effects of the ocean absorbing both heat and carbon. They also find that increasing emissions lead to increased surface warming and that this warming will last many centuries. The second article, by Ricke and Caldeira (2014) in Environmental Research Letters, examines how long it takes for maximum warming to occur due to a given carbon dioxide emission. They find that the median time between such an emission and the maximum warming due to that emission is 10.1 years.

Read this Science Brief.

RECENT PAPERS AUTHORED BY PCIC STAFF

Cannon, A.J., in press. Revisiting the nonlinear relationship between ENSO and winter extreme station precipitation in North America. *International Journal of Climatology*, doi:10.1002/joc.4263.

Cannon, A.J., 2015: An intercomparison of regional and at-site rainfall extreme value analyses in southern British Columbia, Canada. *Canadian Journal of Civil Engineering*, **42**, 2 doi:10.1139/cjce-2014-0361.

Najafi, M.R.., **F.W. Zwiers** and N.P. Gillett, 2015: Attribution of Arctic temperature change to greenhouse-gas and aerosol influences. *Nature Climate Change*, Advance Online Publication, doi:10.1038/NCLIMATE2524.

Neilsen, D., S. Smith, T. Van Der Gulik, B. Taylor and **A.J. Cannon**, 2015: Modeling regional water demand for current and future climate in the Okanagan basin, British Columbia, Canada. *Acta Horticulturae (ISHS)*, **1068**, 211-218.

Ribes, A., **N.P. Gillett** and **F.W. Zwiers**, in press: Designing Detection and Attribution simulations for CMIP6 to Optimize the Estimation of Greenhouse-gas Induced Warming. *Journal of Climate*, doi:10.1175/JCLI-D-14-00691.1.

Shrestha, R.R., **M.A. Schnorbus** and **A.J. Cannon**, in press: A Dynamical Climate Model-Driven Hydrologic Prediction System for the Fraser River, Canada. *Journal of Hydrometeorology*, doi:10.1175/JHM-D-14-0167.1.

Ullman, D.J. A.E. Carlson, A.N. LeGrande, **F.S. Anslow**, A.K. Moore, M. Caffee, K.M. Syverson and J.M. Licciardi, 2015: Southern Laurentide ice-sheet retreat synchronous with rising boreal summer insolation. *Geology*, **43**, 1, 23–26, doi:10.1130/G36179.1.

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