PCIC SCIENCE BRIEF: TROPICAL PACIFIC IMPACTS ON COOLING NORTH AMERICAN WINTERS

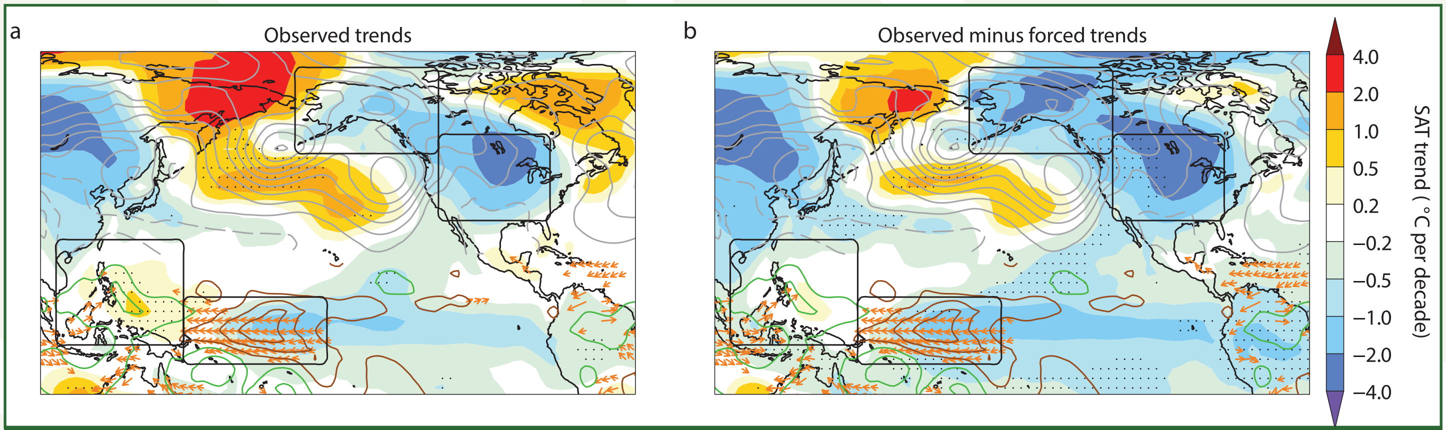

Figure 1: Observed winter trends in surface air temperature, wind stress, precipitation and sea level pressure, from SIgmond and Fyfe (2016).
These panels show trends in surface air temperature (coloured shading, dots indicate where the trends are significance at the 5% level), precipitation (brown contours represent decreased rain, green contours represent increased rain, contour intervals are 2 millimetres per day per decade), surface wind stress (orange arrows) and sea level pressure (solid grey contours indicate an increase, dashed contours represent a decrease and the contour interval is 0.8 hectopascals per decade). These are all winter trends from the 2001-2002 to 2013-2014 period. Panel a) shows observations (see the Methods section of Sigmond and Fyfe's paper) for each of these quantities. Panel b) shows the difference between the trends from observations and from Canadian Earth System Model (version 2) climate model output.

In a recent paper published in *Nature Climate Change*, Sigmond and Fyfe (2016) find that the causes of cooler winters over the early 2000s in North America vary by region. In the northwest, these winters were largely due to a pattern of western cooling and central warming in the tropical Pacific Ocean. In central North America, the cooler winters were primarily due to changes in the northerly winds driven by increased sea level pressure on the west coast of North America.

When scientists discuss recent climate change, they tend to mean changes in the Earth's climate system over periods of about 30 years or longer. Over such timescales variations in climate drivers such as volcanic eruptions, solar cycles and ocean circulation patterns tend to "average out." This makes it easier to distinguish long-term climate trends, such as the warming from anthropogenic greenhouse gas emissions, from short-term variability, such as a cool year following a volcanic eruption. However, as global climate models continue to improve, both in terms of their resolution and their representation of the physical processes that make up the Earth's climate system, we can use them to examine more localized patterns that ariseover shorter periods. Such efforts are currently taking two forms: developing decadal "climate" projections by setting the initial states of models to match observations and letting them run in order to make forecasts, and diagnosing the causes of patterns in the climate system over timescales on the order of a decade or so. The former may be used for planning purposes and the latter, such as the work discussed in this Science Brief, allows us to increase our understanding of the climate system and further refine our models. These are also related, because as our models improve and our knowledge of the Earth's climate system grows, this can improve our ability to perform forecasts.

Publishing in *Nature Climate Change*, researchers Michael Sigmond and John Fyfe from the Canadian Centre for Climate Modelling and Analysis seek to explain why winters in North America were cooler than expected for the 13 year period starting in 2001. We can see the overall temperature pattern in Figure 1, panel a, and panel b

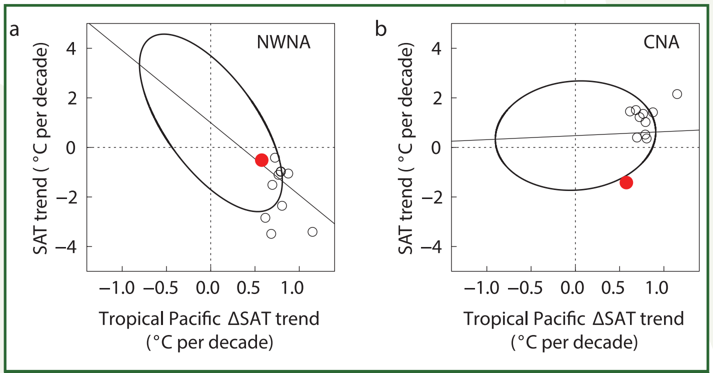

Figure 2: Surface air temperature trends in two regions of North America versus tropical Pacific Ocean surface air temperature trends, from Sigmond and Fyfe (2016). This figure shows the surface air temperatures for northwestern North America (panel a) and central North America (panel b) plotted against the gradient in surface air temperatures between the westernmost region of the tropical Pacific Ocean and the central western tropical Pacific (positive values indicate a warm western Pacific and cool west-central Pacific). The straight line shows the best fit between the surface air temperature trends in each region. The ovals represent the overall set of trends from climate model output. The red circle represents the observations over the 13 year period that Sigmond and Fyfe are examining. The unfilled circles represent the model simulations that were run with observed winds over the tropical Pacific Ocean.

shows the difference between the trends in the observations and the trends from climate model simulations. From this, we can see that the observations show colder winter trends than the model simulations, especially in central North America, where winters were substantially colder than output from global climate models would suggest. The authors focus their investigation on the tropical Pacific Ocean, which is known to directly influence climate in North America, Greenland and elsewhere. Specifically, they look at the surface air temperature pattern of warming over the far western Pacific and cooling over the central western Pacific that was present over this time period.

In order to see if the tropical Pacific might have played a role, the authors first had to test and confirm the ability of the models to reproduce the observed relationships between patterns of surface air temperature in the tropical Pacific Ocean and winter weather in North America. They do this and find that the model's output reproduces the known relationships and patterns quite well. They then examine what role patterns of surface air temperatures might have played in the thirteen unusually cold winters in the early 2000s. They find that the simulations show a similar relationships between cooler winters in northwestern North America and the specific pattern of air temperatures that were observed over the tropical Pacific in the early 2000s, with warming in the far west and cooling to the east of this area. These relationships can be seen in Figure 2 (panel a) in which the surface air temperature trend tends to decrease over northwestern North America in those simulations that show the pattern of warming in the westernmost tropical Pacific and cooling in the central western tropical Pacific. That this pattern appears both in the simulations and the observations is Sigmond and Fyfe's first line of evidence that the tropical Pacific was responsible for the cool winters. In addition, the authors drive one of the climate models with the winds that were observed over the tropical Pacific from 1979 onward and find that, again, the same pattern of surface air temperatures in the tropical Pacific occurs with cooler winters in northwestern North America. This is in line with the earlier findings of Kosaka and Xie (2013).

We may then ask what the underlying physical mechanism is. What causes this observed link between the pattern in Tropical Pacific surface air temperatures and winter temperatures in northwestern North America? In the tropics, the atmosphere's circulation is a direct result of the heating of land or ocean from the sun. In general, warm, moist air at the equator rises through deep convection in which towering thunderstorms convey warm air and water vapour to the top of the troposphere[1] and then spread northward and southward toward higher latitudes. This process also draws in surrounding, near-surface air from higher latitudes. As this air is drawn in, the rotation of the earth causes it to flow westward, forming the circulation pattern that we identify as the Trade Winds. The Earth's rotation causes northward and southward motion to rotate clockwise and counterclockwise respectively which

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1. The Earth's atmosphere can be thought of as divided into five layers. Ordered by closeness to the Earth's surface, these are: the troposphere, stratosphere, mesosphere, thermosphere and exosphere. The troposphere, which extends to just under 10 km over the Earth's surface at the poles and just over 17 km at the equator, contains most of the mass of the Earth's atmosphere and most weather occurs in it.
2. To describe the underlying dynamics of Rossby waves in the atmosphere would be beyond the scope of this Science Brief. In short, they arise because of the Earth's rotation, the effect of which is felt more strongly at some points on the Earth's surface than others, and the conservation of angular momentum in the atmosphere. They can be seen the in the large-scale meandering motions of the jet stream. The interested reader is directed to an undergraduate meteorology or climate dynamics textbook, such as Marshall and Plumb's *Atmosphere, Ocean and Climate Dynamics* or Holton's *An Introduction to Dynamic Meterology*.

causes the formation of high pressure systems on either side of the equator. These systems set up a steady pattern of alternating high and low pressure centres known as Rossby waves[2] that span northward from the tropics to the North Pacific and the North American continent. The steady pattern interacts with moving Rossby waves[2] which we experience as day-to-day weather. One of the steady pressure centres commonly overlies the Aleutian Low in the Gulf of Alaska. Changes in the wave pattern can have strong effects on the Aleutian Low, which directly impacts our weather. This low alters the path of the polar jet stream and when it is weak, allowing polar air to move southwestward over northwestern North America which causes cold winter conditions. When it is stronger, subtropical air moves northwestward over northwestern North America, causing warmer winter conditions. The pattern that Sigmond and Fyfe make note of is one in which the surface air temperatures over the tropical Pacific are warmer than usual in the west, near southeast Asia, and cooler to the east. This intensifies the trade winds, which moves the location of deep convection westward. This then weakens the Aleutian Low and thereby allows cooler than normal winter conditions to prevail in northwestern North America.

The authors use similar methods in order to examine the winter cooling trend in central North America over the same period and find that, in contrast the pattern of surface temperatures in the tropical Pacific cannot explain that trend. The relationship seen in the simulations actually suggests the opposite (Figure 2, panel b), that the tropical Pacific should have had a slight warming influence on central North American winters. In order to explain the cooler winters over these regions, Sigmond and Fyfe examine output from 100 climate model runs and find that three of them simulate a winter cooling trend in this region. The authors suggest that the cause, apparent both in the simulations and observations, is a persistent ridge of increased sea level pressure over western North America, which brought cold winds from the north into central North America.

This can be seen as a test of an earlier proposal made in the journal *Science* by Tim Palmer (2014). He suggested that the cold winters in central North America may have been due to a Rossby wave response to the enhanced warming of the tropical Pacific Ocean. While such a proposal is quite plausible in terms of physical principles and worth investigating, Sigmond and Fyfe's results stand as evidence against it.

We may then ask what this means for future winter weather here in the Pacific Northwest. To answer this, we can note that this paper is further evidence of a link between surface air temperature patterns in the western tropical Pacific and cold winters in northwestern North America. Such a link may help to shape seasonal forecasts for winters in the Pacific Northwest, though this would depend on our ability to forecast surface air temperatures over the tropical Pacific Ocean. Current seasonal forecasting skill for the tropical Pacific is generally higher for shorter lead times and decreases with increasing lead time, with the highest skill being in the 1-3 month forecast range. Taken together, this means that we can't say anything as of yet about how surface air temperature patterns there might affect this coming winter, but the links between the tropical Pacific and winter weather here in North America that are explored in Sigmond and Fyfe's work may be useful for forecasts in the future.

Holton, J.R., 2004: *An Introduction to Dynamic Meteorology*. Elsevier Academic Press, 533 pp.

Kosaka, Y. and S.-P. Xie, 2016: Recent global-warming hiatus tied to equatorial Pacific surface cooling. *Nature*, **501**, 403–407, doi:10.1038/nature12534.

Marshall, J. and A. Plumb, 2008: *Atmosphere, Ocean and Climate Dynamics, An Introductory Text*. Elsevier Academic Press, 340 pp.

Palmer, T., 2014: Record-breaking winters and global climate change. Science, 23, 344, 6186, 803-804, doi: 10.1126/science.1255147.

Sigmond, M. and J.C. Fyfe, 2016: Tropical Pacific impacts on cooling North American winters. *Nature Climate Change*, Advance Online Publication, doi:10.1038/nclimate3069.