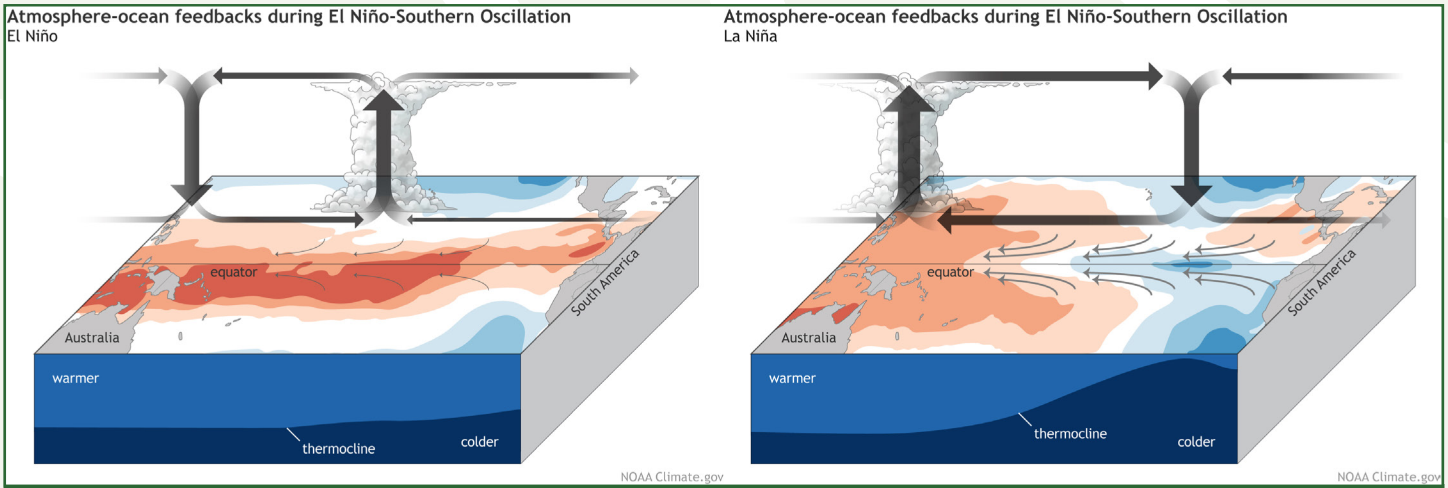
PCIC SCIENCE BRIEF: PROJECTED CHANGES IN SHORT-TERM CLIMATE VARIABILITY INDUCED BY HUMAN ACTIVITIES

Internal climate variability occurs due to interactions between the parts of the Earth's climate system and is an indelible feature of both observed and model-simulated climate . Anthropogenic climate change may alter the internal variability of the climate system which could, in turn, influence both the mean climate and extremes. Writing in the Journal of Climate, Coquereau and colleagues (2024) used global climate model simulations to examine how internal climate variability might change as the planet warms. In their article titled, *"Anthropogenic Changes in Interannual-to-Decadal Climate Variability in CMIP6 Multiensemble Simulations,"* the authors noted two regions in particular where changes in climate variability are manifested in future. The first is a decrease in temperature variability at higher latitudes, associated with the retreat of sea ice and the moderation of air temperature by the now exposed ocean surface. The second is an increase in the short-term variability of temperature and precipitation at low latitudes, which appears to reflect an increase in the frequency of the El Niño-Southern Oscillation. This Science Brief discusses these findings and what they might mean for the future climate in British Columbia.

Introduction

Conditions within the Earth's climate system are constantly evolving as energy is exchanged between its various components: primarily the oceans, atmosphere, land and ice. We can think about three aspects of the climate: 1) the *mean*, or stable background, climate; 2) internal climate *variability* (on the shortest time scale this is simply weather), and; 3) the effect of external forcings on both the mean climate and internal variability. Examples of external forcings are volcanism, changes in the composition of the atmosphere due to anthropogenic gas and aerosol emissions and changes in incoming radiation from the Sun. Internal climate variability is the focus of the paper of Coquereau et al. and this Science Brief.



Atmosphere-ocean feedbacks during El Niño-Southern Oscillation
El Niño

Atmosphere-ocean feedbacks during El Niño-Southern Oscillation
La Niña

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Figure 1: Conceptual Examples of ENSO states.
This figure shows two states of the El Niño-Southern Oscillation (ENSO), namely El Niño conditions (left panel) and La Niña (right panel). The third state (not shown) is the neutral phase between these two states. Credit: National Oceanic and Atmospheric Administration, Climate.gov.

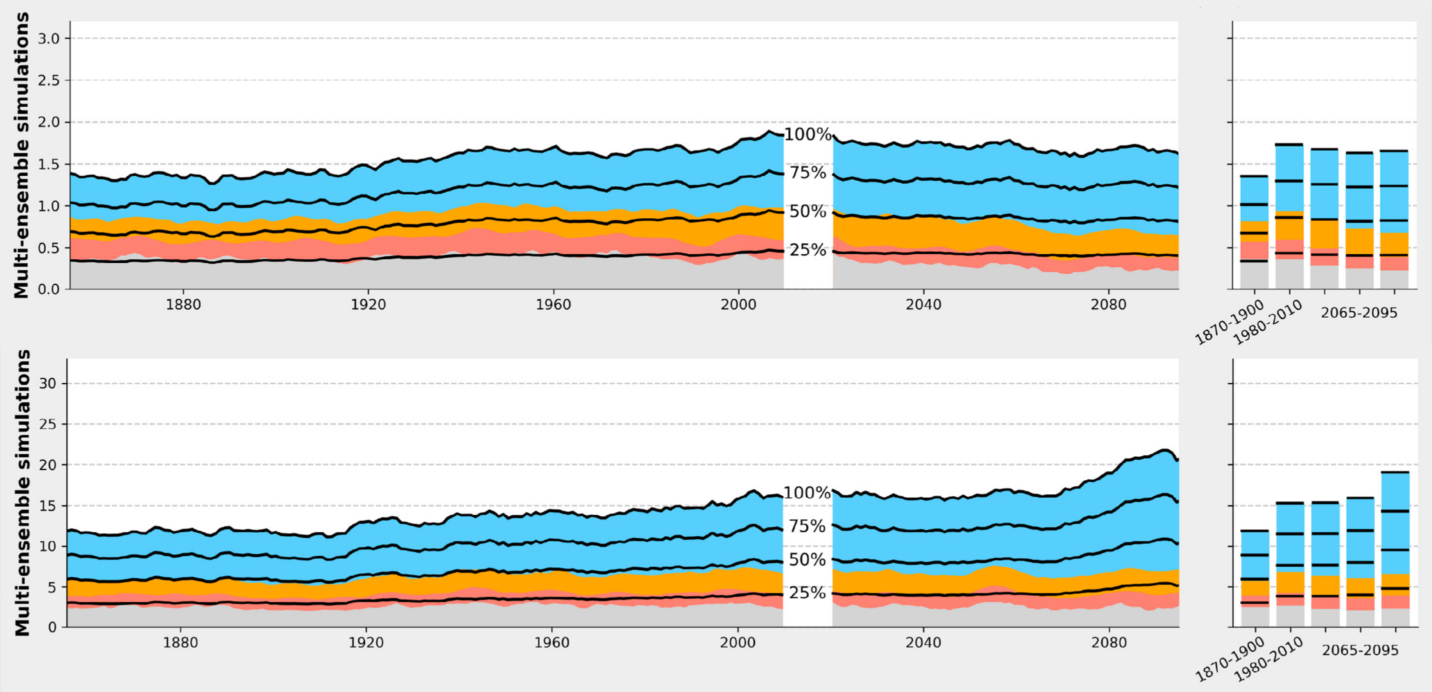

Figure 2: Ensemble Variance of Surface Air Temperature and Precipitation.
This figure, constructed from Figures 1 and 2 in Coqeureau et al. (2024), shows the ensemble variance of surface air temperature (top) and precipitation (bottom) over the 1850-2100 period. The different coloured bands show the contributions of variance at different timescales to the total variance: blue indicates timescales of 1-3 years, orange 3-5 years, red 5-11 years, and grey greater than 11 years. The left panels show the full time series, while the right panels show 30-year averages for different periods: 1870–1900, 1980–2010, with the three rightmost bars indicating the averages over 2065–2095 for three emissions scenarios. From left to right, these are: low (SSP1-2.6), middle-of-the-road (SSP2-4.5), and high emissions (SSP5-8.5).

The El Niño-Southern Oscillation (ENSO) is a prominent example of internal climate variability, and is distinct from weather in terms of both its timescale and mechanisms. Normally, trade winds blowing westward along the Earth's equatorial region maintain an east-west temperature gradient on the ocean. Under these "neutral" conditions, warm surface water is pushed toward the western Pacific. Meanwhile, in the eastern Pacific off the coast of South America, cool water from the deep ocean is drawn toward the surface in response. In the current climate, every three-to-seven years, these trade winds weaken and the warm surface water, no longer pushed strongly westward, spreads throughout the tropical Pacific Ocean, as illustrated in the left panel of Figure 1. This is the El Niño phase of ENSO. The opposite pattern, when the trade winds are stronger than average and the eastern tropical Pacific Ocean is cooler than normal, is known as a La Niña phase. Both states affect seasonal weather patterns, not just regionally but globally, through the large-scale atmospheric circulation.

In British Columbia, El Niño tends to bring warmer than usual conditions and a reduction in precipitation, while the opposite is true of La Niña. The effects of both of these phases on the province are most pronounced during the autumn and winter. In addition, a strong El Niño or La Niña can influence the intensity and frequency of climate extremes, such as drought and extreme precipitation.

Projected Changes to Climate Variability

Internal variability is also an important factor in near-term climate change projections, since it is the dominant mode of variability over timescales of years to decades. It is thus important to understand if and how internal climate variability might change in the future[1]. In their research, Coquereau and colleagues examined this question. Using simulations from four global climate models (GCMs) that

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1. In this Science Brief, we refer to both "periods" and "timescales," but the terms are distinct. The term "period" simply refers to a specific range of years, for example, 1980-2010 or 2065-2095. The term "timescale", by contrast, describes the interval over which a given real-world or modelled process operates in such a way as to produce noticeable changes in some part of the system. For example, the timescale for weather is seconds to days, but not months.

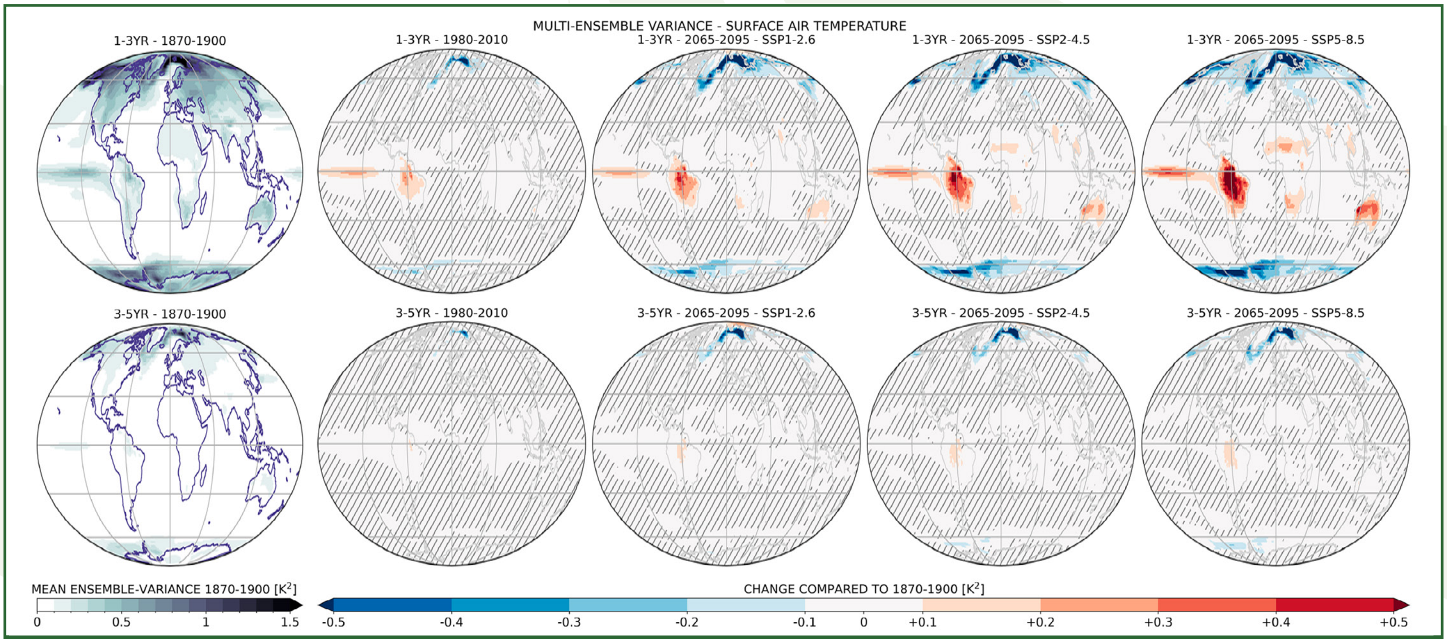

Figure 3: Ensemble Regional Variance of Surface Air Temperature.
This figure, constructed from Figure 3 in Coquereau et al. (2024), shows changes in the variance of surface air temperatures for the 1980-2010 and 2065-2095 periods and three emissions scenarios (low, SSP1-2.6, medium, SSP2-4.5 and high, SSP5-8.5, as indicated) compared to the preindustrial variance (left row), for different timescales (1-3 years in the top row, 3-5 years in the second row). Note the projected future decrease in variance for all timescales at northern latitudes, and the increase in short-term (1-3 year) variability in the low latitudes. The hatched areas indicate areas where the change in variance is not significant. The patterns (not shown) for timescales of 5-11 years and greater than 11 years are very similar to those for 3-5 years.

informed the sixth phase of the Coupled Model Intercomparison Project (CMIP6), they looked for evidence of changes to internal variability in future projections. They did this by choosing GCMs for which a large ensemble of simulations (numbering from 25 to 50 per model) had been conducted, with the only difference between runs being a slightly different initial state. Because the forcings are the same for all of the models and the overall effect of initial conditions passes within a few years in the simulations, the difference among the model runs represents variability internal to the climate system.. As there are more than 25 runs in each ensemble, these give a data sample sufficiently large to characterise and discern future changes in natural variability.

The authors used the variance within the ensembles (a measure of how much different climate variables vary from the ensemble means) as an indicator of internal variability for each climate variable. When they first examined total variance at the global scale over the duration of the climate simulations, 1850-2100, the authors found that while the variance in temperature increases toward the present period, then stabilizes in future, the total variance of precipitation increases throughout the simulations (Figure 2). However, when they refined their analysis to look at different *timescales* of variability separately, they noticed an increase in short-term (1 to 3 year) variability for both temperature and precipitation, (blue bands in Figure 2). Moreover, there is a weakening of variability in temperature at longer timescales, with little change in precipitation variability at those scales (orange, red, and grey bands in Figure 2). By examining the changes from 1870-1900 to 2065-2095, Coquereau et al. highlight the fact that the variance in temperature and precipitation at short timescales nearly doubles by the end of the century (blue bars in the far right panels of Figure 2), while the temperature variance at timescales longer than 3 years (orange, red and grey bars in Figure 2) decreases by different amounts (up to 40% at timescales greater than 11 years).

Spatial Pattern and Mechanisms of Changes in Variability

Coquereau and colleagues next turned their attention to where these changes are occurring. They found that the changes are primarily centred on two regions, as seen in

Figure 3. In the high latitude polar regions, there is a decrease in the internal variability of surface air temperatures at all timescales. By contrast, in the tropical latitudes, there is an increase in variance for both temperature and precipitation, almost entirely at the 1-3 year timescale.

The authors first investigated possible causes for the decrease in internal variability of surface air temperatures at high latitudes. By examining the variability of Arctic sea ice concentration over time, they found that it decreases in areas where temperature variability decreases, and increases at the highest latitudes where temperature variability also increases. When sea ice covers the region, it insulates the atmosphere from the ocean, preventing heat exchange between the two and allowing the atmosphere to cool to very low temperatures in winter. However, as the sea ice edge is displaced and retreats poleward, the warmer ocean moderates this seasonal cooling of the atmosphere, thus reducing temperature variability. The authors found a similar match between the air temperature and sea ice variability in the southern polar region, but of smaller magnitude.

The authors then examined the cause of the increase in variance for temperature and precipitation in the tropics. The increase in variance occurs almost entirely at the shortest timescale, 1-to-3 years, which is comparable to the 2-to-7 year period of ENSO, as it shifts between El Niño, neutral and La Niña conditions. By analyzing the pattern of the short-term variance increase, the authors showed that it strongly resembles that of ENSO, in addition to being located in the equatorial Pacific. The authors suggest that the increasing variability in the 1-to-3 year period in this region may portend a future increase in the frequency of ENSO. Further, they note that all four of the climate models used show agreement on this point, despite their differing resolutions and structure. The authors also note the consistency of their findings with other research showing an increasing frequency of ENSO in future climate projections (Fredriksen et al., 2020), and increases in the frequency of both extreme El Niño and La Niña events (Cai et al., 2014; 2015).

Summary and Outlook

In their model-based study, Coquereau and colleagues uncovered evidence of potentially significant changes in internal climate variability, driven by two distinct regional regimes. The first of these is a decrease in the variability of surface air temperature at high latitudes, at all timescales. The likely mechanism is progressive sea ice melt, which exposes more ocean surface in the future, allowing it to moderate regional temperatures. The second is an increase in interannual variability (1-3 year period) of both surface air temperature and precipitation at low latitudes. The authors propose that this likely reflects an increase in the frequency of ENSO. This is consistent with earlier research that PCIC scientists contributed to in 2023 (Sun et al., 2023) that found a modest increase in the number of projected future El Niño and La Niña events[2]. Given the influence that modes of internal climate variability, such as ENSO, can have on ecosystems and human societies, ranging from heatwaves, droughts and forest fires, to flooding, the work of Coquereau and co-authors suggests that changes in the frequency and intensity of these impacts may also be in store.

For Canada and BC, an increase in ENSO variability might pose challenges for climate adaptation. As mentioned earlier, El Niño and La Niña tend to enhance seasonal temperature and precipitation anomalies in opposite ways, particularly over western Canada. The future increase in ENSO variability suggested by the work of Coquereau et al. could make both seasonal climate and extreme temperature and precipitation events more difficult to predict in the region. As changes in the background, mean climate continue to occur under global warming, these additional changes in variability could make future planning and adaptation yet more challenging.

References:

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[2] Incidentally, Sun et al. (2023) also found that future warming leads to more intense extreme precipitation in all ENSO phases and that differences in precipitation extremes in different phases may also increase.