To: Delta Council ISB Deltacouncilisb@deltacouncil.ca.gov
Sent: Friday, May 19, 2023 1:45 PM
From: Deirdre Des Jardins ddj@cah2oresearch.com

Subject: Research basis for the importance of a drought scenario analysis – some notes

Dear Delta Independent Science Board members

I wanted to send some notes on some recent research on climate variability that I referred to in my remarks to the Delta ISB on Wednesday.

This research forms a growing line of evidence that anthropogenic forcing may have dominated climate variability since about 1950. It may explain why the current generation of climate models -- CMIP5 and CMIP6 -- aren't adequately capturing observed trends. If this line of research is correct, some of the observed trends since 2000 are likely to continue. It makes a drought scenario analysis potentially extremely important. (Drought scenarios were recommended by the 2015 report of the Climate Change Technical Advisory Group as a way to deal with climate model uncertainty.)

1. **Why ocean variability?**

Ocean variability dominates climate variability on annual to multidecadal timescales. The global ocean is the "memory" of the earth climate system.

Nice illustration of dominant processes on different timescales from Von Der Heydt et. al. Quantification and interpretation of the climate variability record - ScienceDirect (cc 4.0 license):
Blue is ocean variability

NAO - North Atlantic Oscillation
QBO -- Quasi Biennial Oscillation
ENSO -- El Nino / Southern Oscillation
PDO -- Pacific Decadal Oscillation
AMV -- Atlantic Multical Variability
SOCV -- Southern Ocean Centennial Variability

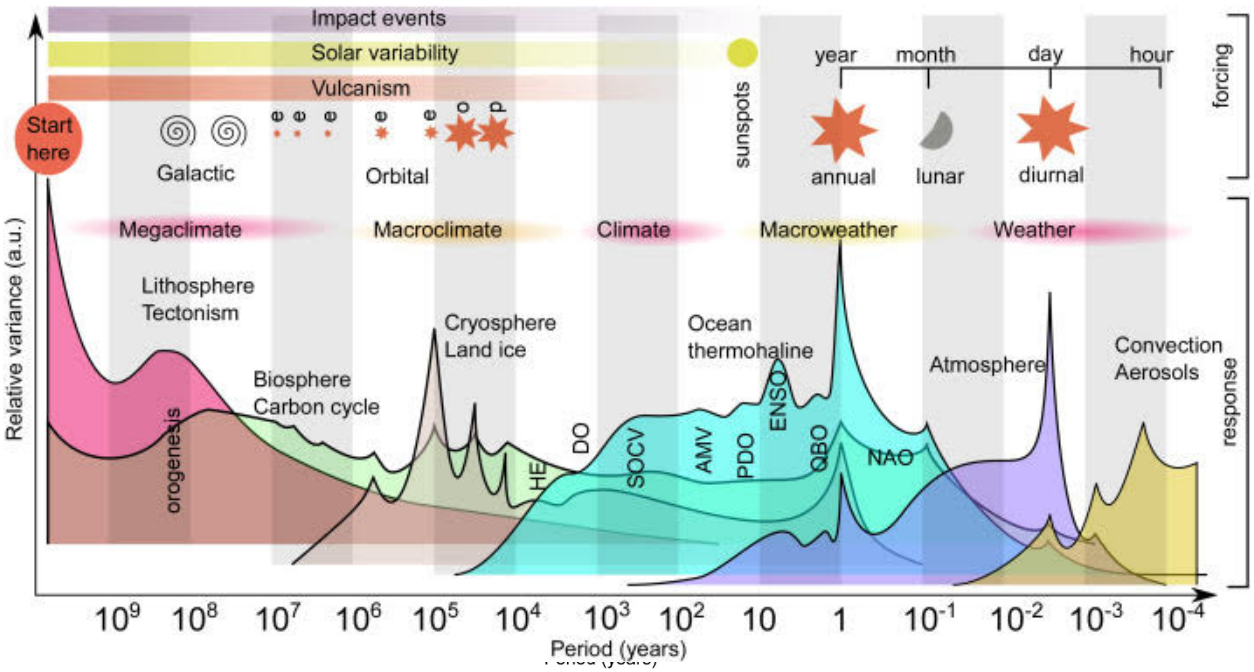


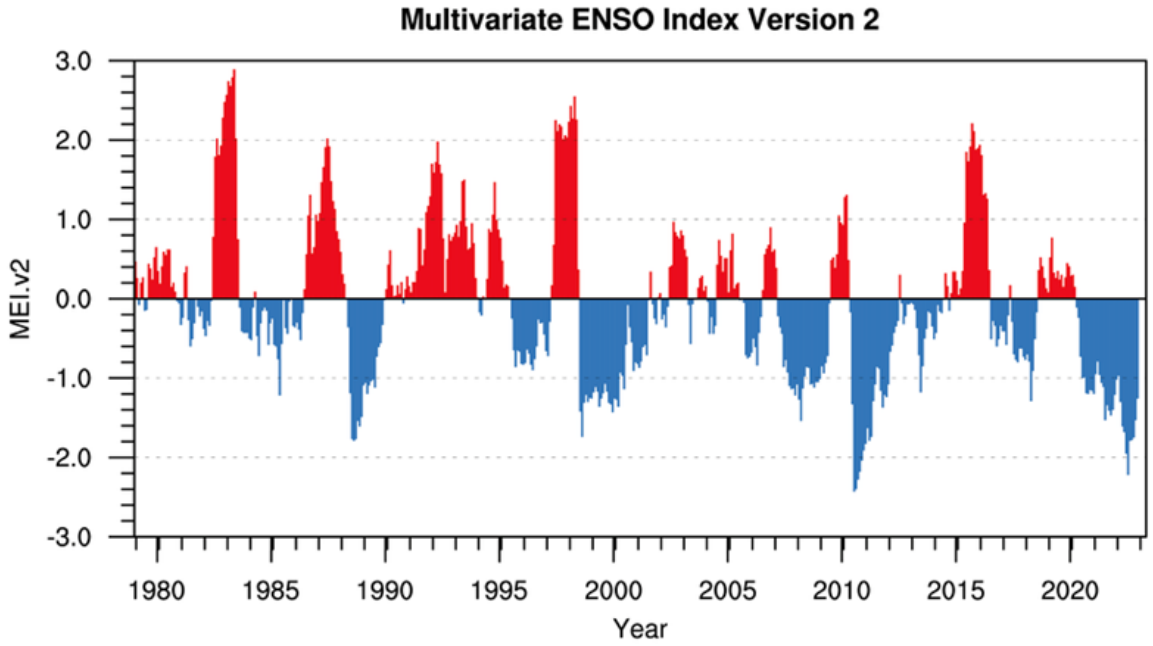
Fig. 2. A conceptual landscape of periodicities present in a typical climate signal from the atmosphere at the Earth's surface, updated after Mitchell (1976). The external forcing is shown in the upper part of the diagram, where approximate periodic forcing from solar system orbital behaviour. The landscape of responses and internal variability due to dynamics in various parts of the earth system are shown below, after removal of a background, where the stepped background indicates that short term variability is only known from recent records. Orbital variability due to eccentricity (e), obliquity (o) and precession (p) is shown, as well as timescales of galactic forcing. Impact events, solar variability and vulcanism events represent aperiodic forcing of highly variable amplitude. Known modes of variability with their approximate periodicities (broad peaks) are indicated with their acronyms (see Table 1) and explained in the text.

Ocean variability & research

a. **Annual -- ENSO -- El Nino / Southern Oscillation**

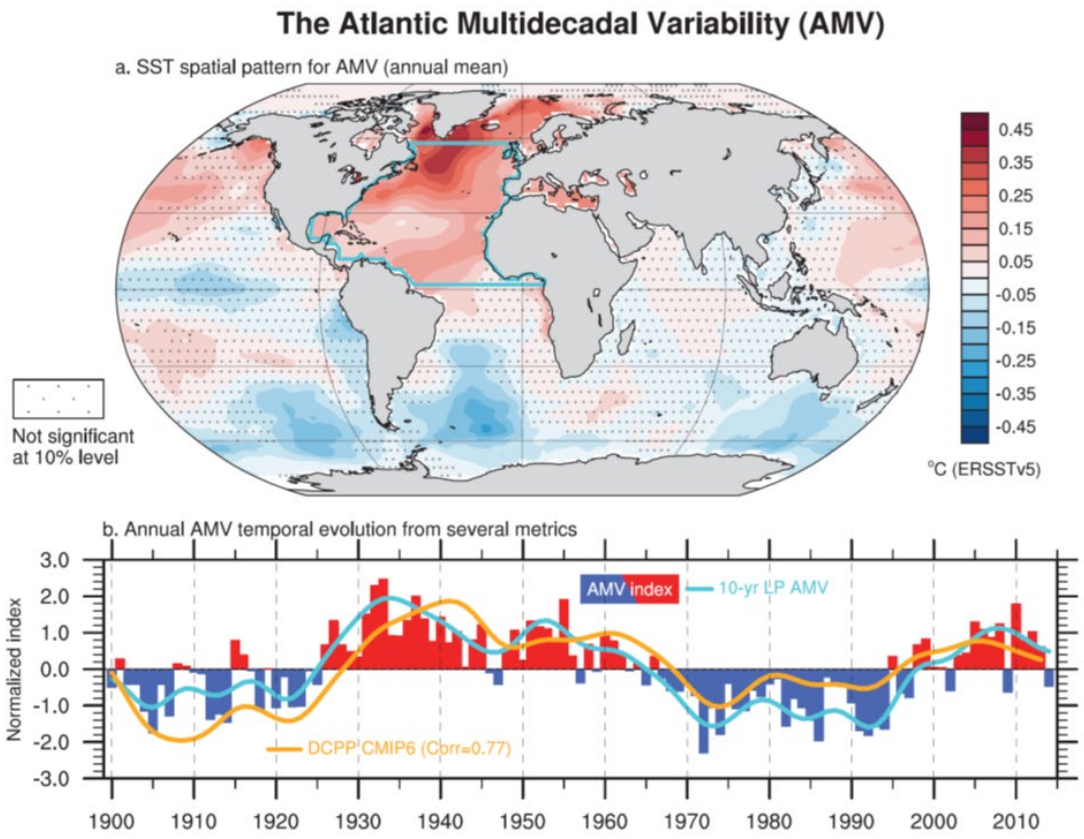
La-Nina like trends since the 1970s

See Bob Henson: [A mystery in the Pacific is complicating climate projections » Yale Climate Connections]



2. **AMV -- Atlantic Multidecadal Variability**

May be dominated by anthropogenic forcing since about 1950, first aerosols (cooling), and then GHGs (warming.) See the preprint by ChengFei He and Amy Clement et. al. here: [Microsoft Word - manuscript_AMV_impacts_020623.docx (researchsquare.com)]



3. **PDV -- Pacific Decadal Variability -- North Pacific / Marine Heat Waves**

Barkhordarian et. al. Recent marine heatwaves in the North Pacific warming pool can be attributed to rising atmospheric levels of greenhouse gases | Communications Earth & Environment (nature.com)

Ulla Heede Colder Eastern Equatorial Pacific and Stronger Walker Circulation in the Early 21st Century: Separating the Forced Response to Global Warming From Natural Variability - Heede - 2023 - Geophysical Research Letters - Wiley Online Library

Here's a summary of this research:

German researchers Armineh Barkhordarian, David Marcolino Nielsen, & Johanna Baehr, which found that Marine Heat Waves (MHWs) in the North Pacific increased 9-fold in duration, 4.5-fold in duration, and 3-fold in intensity in the 21st century. Barkhordarian et. al. showed this evolution of Marine Heat Waves during recent droughts (figures under cc 4.0 license)

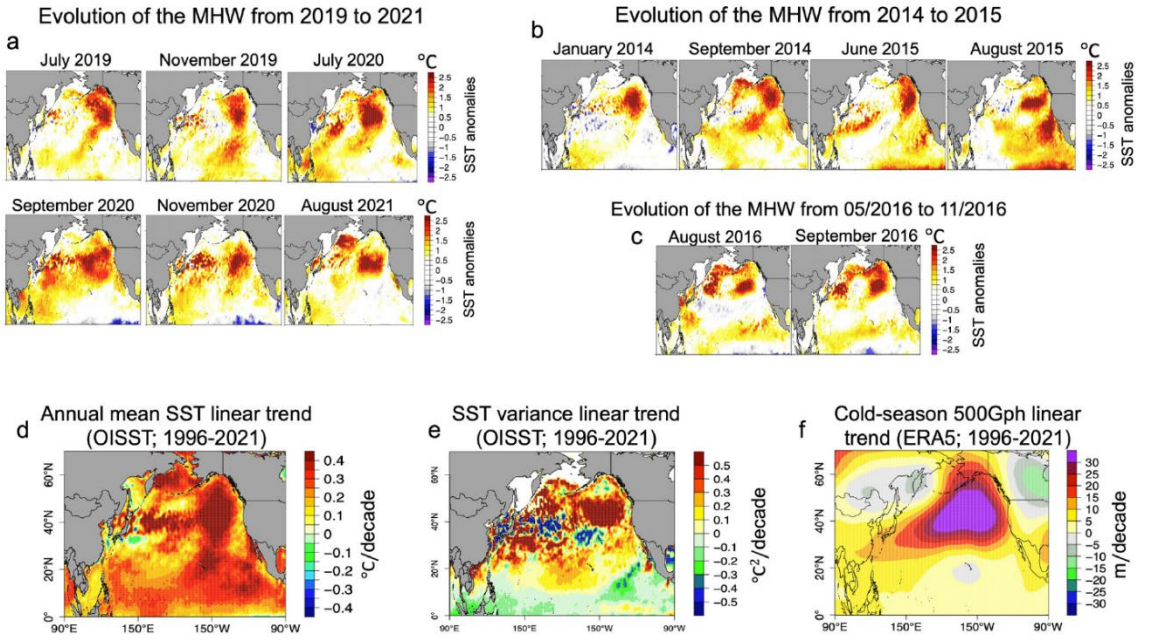


Fig. 2 Evolution of the MHWs, and the long-term trends of the background state. a SST anomaly patterns (above the 1983–2012 climatology) during the evolution of the MHW from 2019 to 2021, **b** the MHW from 2014 to 2015, and **c** the MHW from 05/2016 to 11/2016. Observed pattern of trends over 1996–2021 in (**d**) annual mean SST (OISST; Units: °C decade^{-1}), **e** SST annual variance (OISST; units: °C^2 decade^{-1}), **f** cold-season (November-to-February) geopotential height at 500-hPa (ERA5 reanalysis; units: m decade^{-1}).

The modeling by Barkhordarian et. al. found that since 1956, North Pacific SSTs were influenced first by anthropogenic aerosols causing cooling, and then by warming due to GHGs In recent years the GHG warming has dominated. This is consistent with results found by Chengfeng He and Amy Clement et. al. for Atlantic Multidecadal Variability.

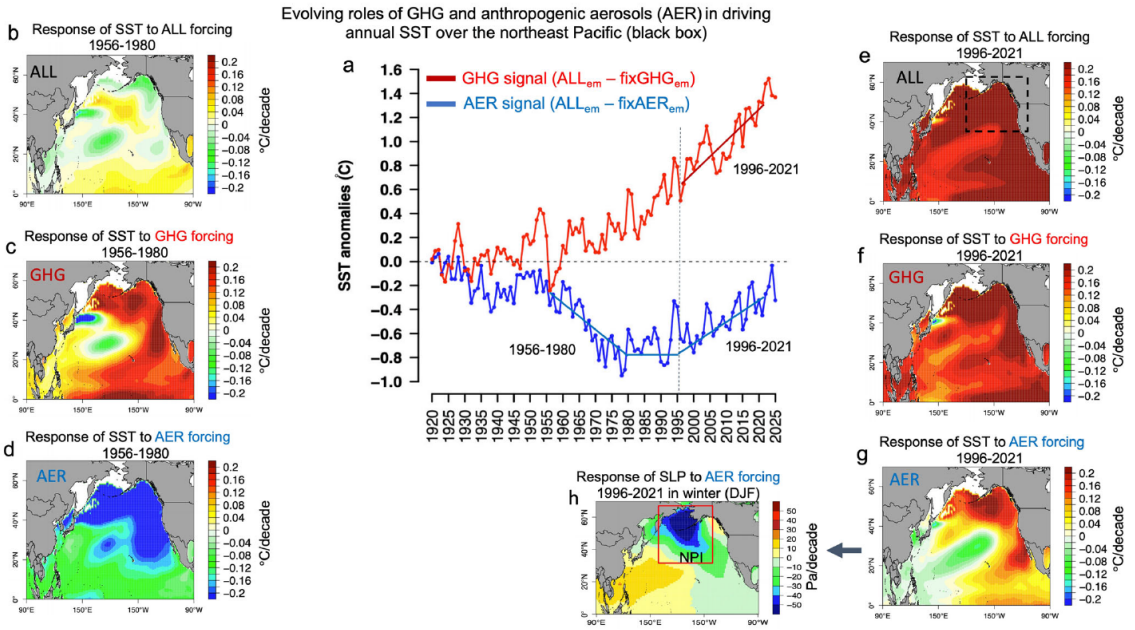
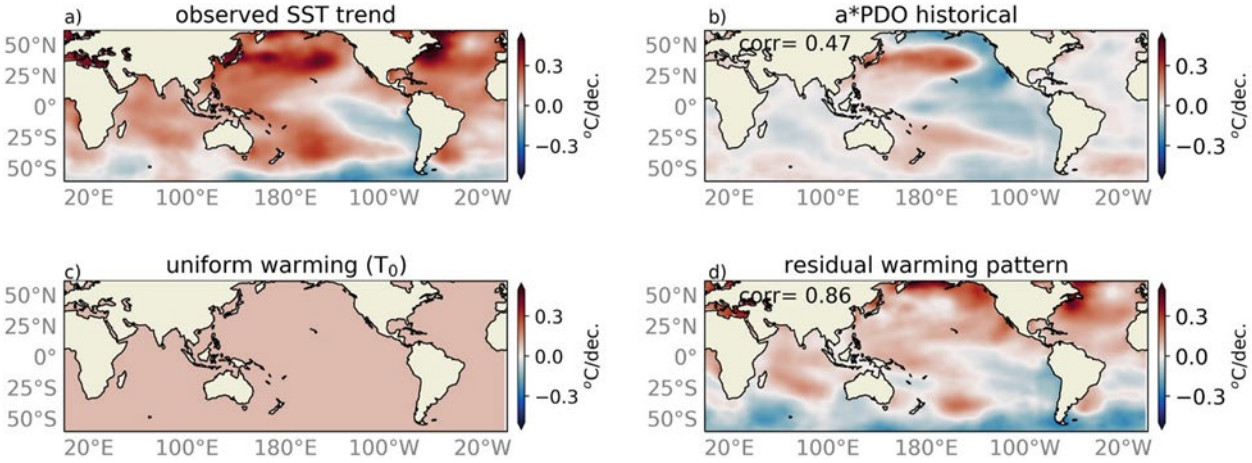


Fig. 5 Evolving roles of the greenhouse gases forcing and industrial aerosols in driving annual SST over the North Pacific. a Area mean annual SST anomalies over the Gulf of Alaska (black dotted box in **e**), derived from the ensemble mean of 20 realizations of CESM1-LE model, ALL_{em} minus $fixGHG_{em}$ in red, and ALL_{em} minus $fixAER_{em}$ in blue. Response of annual SST to the ALL forcing (anthropogenic + natural), greenhouse gases (GHG) forcing and industrial aerosols (AER) forcing (**b**–**d**) over 1956–1980, and (**e**–**g**) over 1996–2021. **h** Response of mean sea-level pressure (SLP) to AER-forcing in DJF (December–February). The Aleutian low region defined by 160–220°E, 30–65°N latitude-longitude is denoted by a red box in **h**.

This is similar to the warming trend found by Heede and Federov (2023) when they removed the historical Pacific Decadal Oscillation trend. Heede and Federov did model experiments which found the observed pattern closely resembles the transient pattern that the Ocean Thermostat subset of CMIP6 models generates in the first decades of the abrupt-4xCO2 experiments.



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Integrative scientific synthesis

"We aren't just failing to address the growing climate crisis to come; we're unprepared even for the impacts already here—in part because they keep surprising us with their intensity and in part because we can't seem to fathom our genuine vulnerability." – David Wallace Wells

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