nature COMMUNICATIONS

ARTICLE

DOI: 10.1038/s41467-017-01907-4 OPEN

Future loss of Arctic sea-ice cover could drive a substantial decrease in California's rainfall

Ivana Cvijanovic[1], Benjamin D. Santer[1], Céline Bonfils[1], Donald D. Lucas[1], John C.H. Chiang[2] & Susan Zimmerman[3]

From 2012 to 2016, California experienced one of the worst droughts since the start of observational records. As in previous dry periods, precipitation-inducing winter storms were steered away from California by a persistent atmospheric ridging system in the North Pacific. Here we identify a new link between Arctic sea-ice loss and the North Pacific geopotential ridge development. In a two-step teleconnection, sea-ice changes lead to reorganization of tropical convection that in turn triggers an anticyclonic response over the North Pacific, resulting in significant drying over California. These findings suggest that the ability of climate models to accurately estimate future precipitation changes over California is also linked to the fidelity with which future sea-ice changes are simulated. We conclude that sea-ice loss of the magnitude expected in the next decades could substantially impact California's precipitation, thus highlighting another mechanism by which human-caused climate change could exacerbate future California droughts.

[1] Climate Modeling and Analysis, Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, CA 94550-9698, USA. [2] Department of Geography and Berkeley Atmospheric Sciences Center, University of California, 547 McCone Hall, Berkeley, CA 94720-4740, USA. [3] Center for Accelerator Mass Spectrometry, Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, CA 94550-9698, USA. Correspondence and requests for materials should be addressed to I.C. (email: cvijanovic1@llnl.gov)

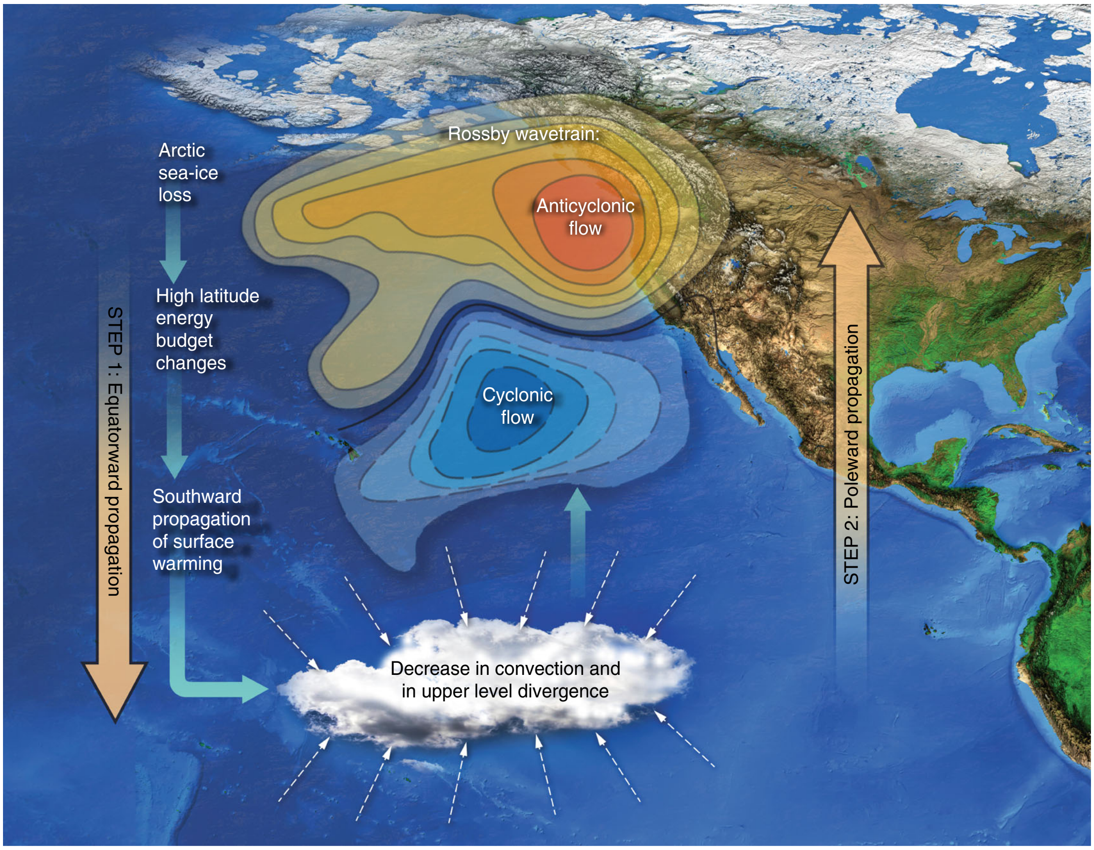


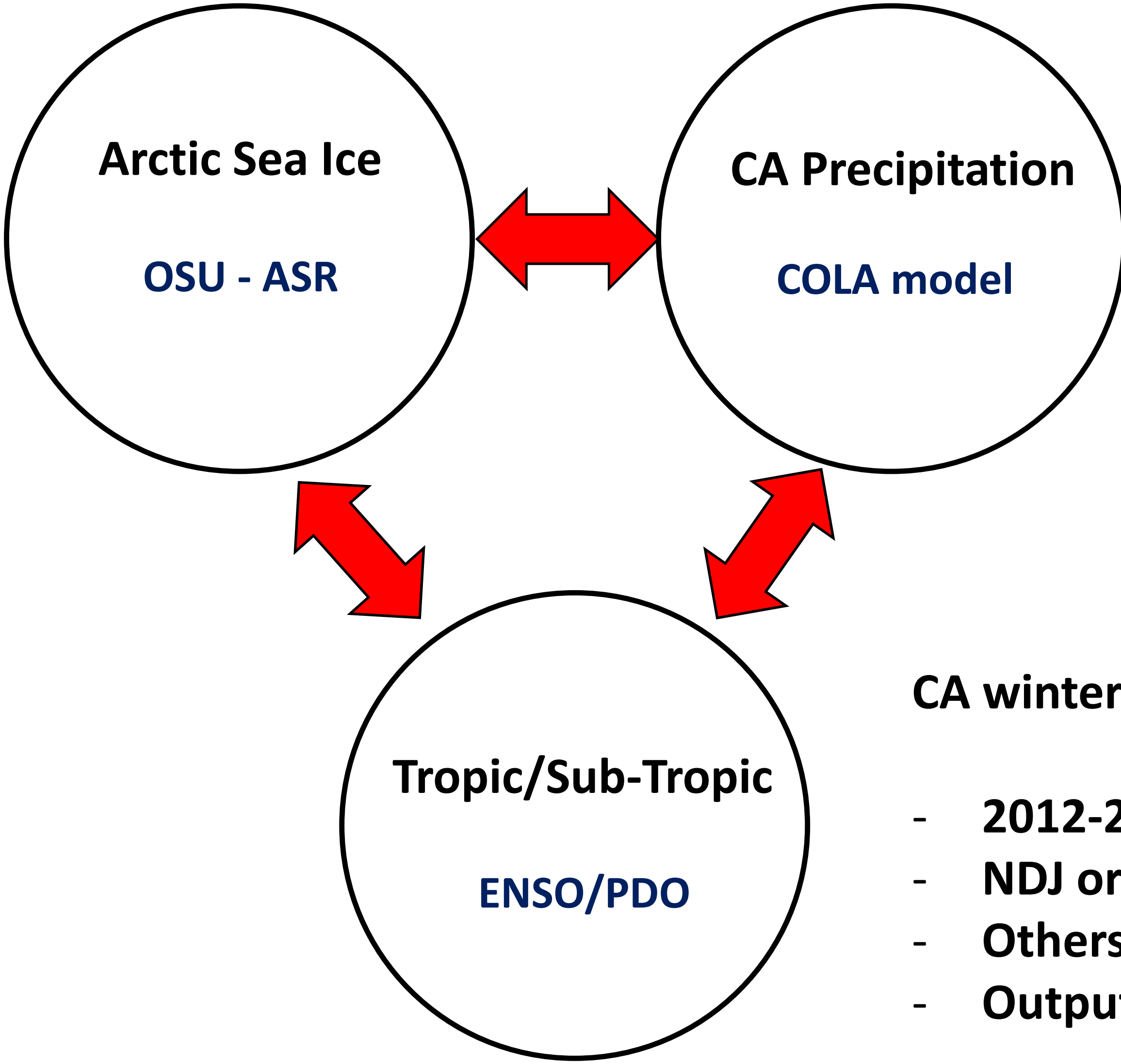
Fig. 4 Schematics of the two-step teleconnection. In step 1 (equatorward propagation), Arctic sea-ice loss induced high-latitude changes propagate into tropics, triggering tropical circulation and convection response. Decreased convection and decreased upper-level divergence in the tropical Pacific in turn drive a northward-propagating Rossby wavetrain with anticyclonic flow forming in the North Pacific. This ridge is responsible for steering the wet tropical air masses away from California

Discussion

Many aspects of the observed mean state of the atmosphere during the recent 2012–2016 California drought are qualitatively consistent with our simulated response to Arctic sea-ice changes. ERA-Interim estimates of the precipitation, geopotential, and OLR anomalies between 2012 and 2015 (relative to the period 1979–2010) are shown in Supplementary Fig. 7. Similar to our simulations, ERA-Interim exhibits a geopotential ridge in the North Pacific and a precipitation decrease over California (Supplementary Fig. 7a, b). In the tropics, precipitation decreases across the central and eastern tropical Pacific and increases northward of this region and in the west tropical Pacific (Supplementary Fig. 7a). Another commonality is the behavior of OLR changes across the central tropical Pacific and over California (see Supplementary Fig. 7c). The magnitudes of the observed 3-year mean anomalies during the recent California drought (Supplementary Fig. 7a) are much larger than the magnitudes of the 20-year mean response to sea-ice changes shown in Fig. 2a. This is expected given that the longer 20-year period contains both dry and wet years. As seen from Supplementary Fig. 8a, low Arctic sea-ice increases the likelihood of drier California, but does not result in drier conditions over California every single year. On average, when considering the 20-year mean, there is a 10–15% decrease in California's rainfall (Fig. 2c). Comparison with the driest 3-year interval within this 20-year period (Supplementary Fig. 8b) indicates that the magnitude of the simulated precipitation response is comparable to the magnitude of changes in ERA-Interim during the most recent drought.

This consistency does not, however, constitute compelling evidence that the 2012–2016 California drought is attributable to Arctic sea-ice changes. Rather, it illustrates that some of the atmospheric features of the droughts driven by Arctic sea-ice loss may resemble those of the most recent California drought. The intensification of dry conditions over California since late 2012 may have also been affected by several other factors not discussed in this study, such as the appearance of a large warm SST anomaly off the west coast of North America—though this appears to be a consequence rather than a cause of the altered atmospheric circulations causing the drought[41]. Another important factor may be the 2014 phase shift of the Pacific Decadal Oscillation from negative to positive. However, this shift would be expected to alleviate drought conditions over California—not intensify them[42]. Finally, we note that other hemispherically asymmetric forcings may also trigger—via the same physical pathways described here—tropical convection changes and teleconnections affecting California's precipitation. Possible examples include asymmetric forcing by anthropogenic aerosols, volcanic eruptions, and solar irradiance variations. All of these forcings can alter the inter-hemispheric temperature gradient[43], thereby causing shifts in the location of tropical convection and initiating "far-field" precipitation changes over California.

It is of interest to consider whether paleoclimatic evidence provides support for our model-inferred two-step teleconnection (Fig. 4). We focus on past periods with pronounced excursions in Arctic temperatures and sea-ice cover. The first part of the two-step teleconnection is well documented in both paleoclimate simulations and paleoclimate records of the last glacial period[44]. Abrupt high-latitude temperature increase during the last interglacial (the Dansgaard–Oeschger and Bølling–Allerød warmings) are manifest in the tropics through a northward shift in



CA winter drought case study:

- **2012-2016 or 2013-2014?**
- **NDJ or DJF?**
- **Others?**
- **Output/Presentation formats?**