Australian bushfire smoke, multi-year La Niña, and implications for the Interdecadal Pacific Oscillation (IPO)

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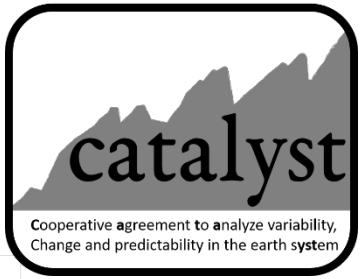
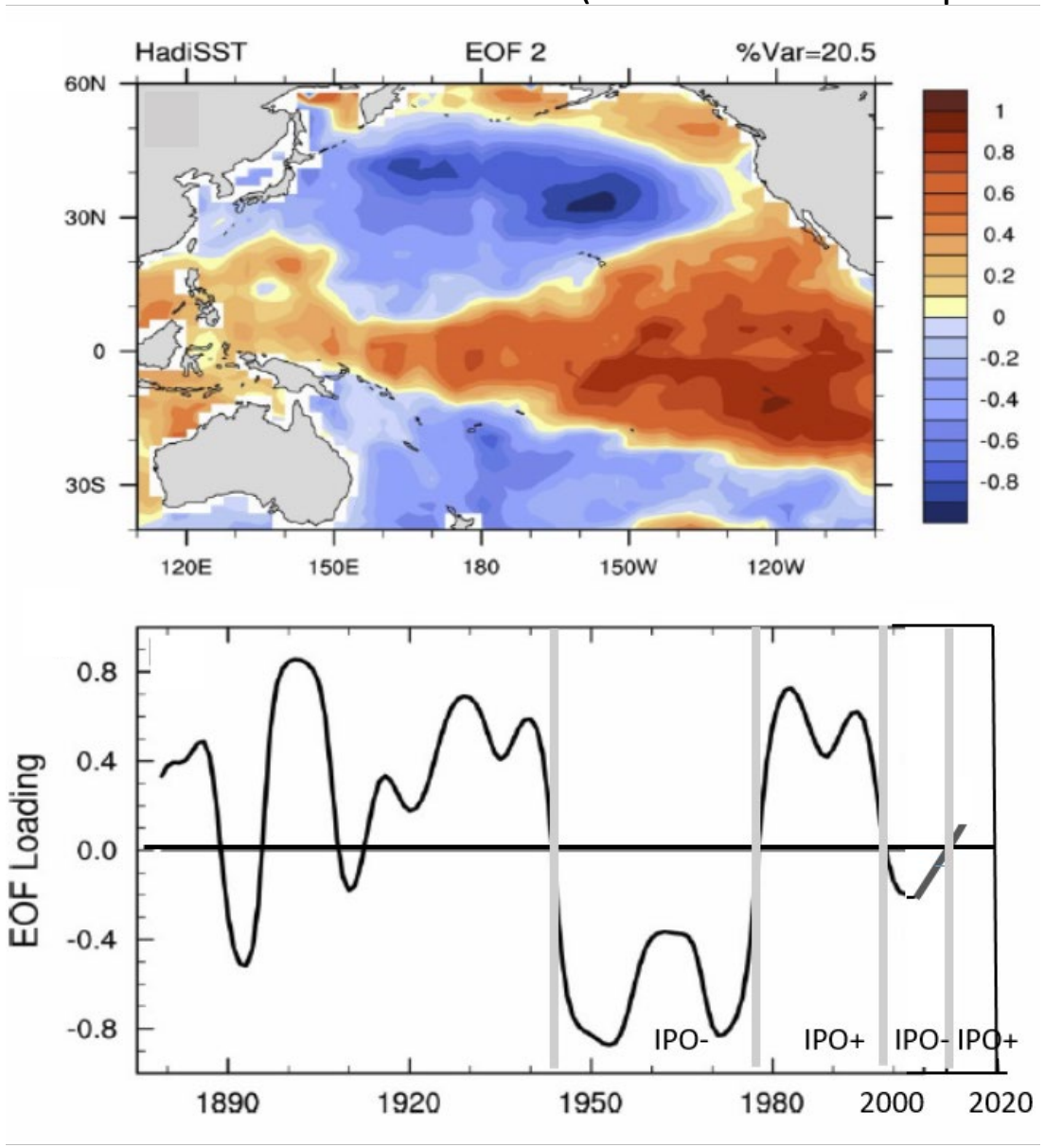


The Interdecadal Pacific Oscillation (IPO, e.g. Power et al, 1999) is the largest observed source of decadal variability in the Pacific Ocean with widespread teleconnections

The observed IPO (second EOF of low pass filtered observed SSTs)



(e.g. Meehl and Arblaster, 2011, J. Clim.)

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Context for yesterday's discussion: randomly generated observed internal decadal variability must sync nearly exactly with randomly generated decadal variability in model simulations to get the negative tropical Pacific SST trend from 1970s to 2010s: only 10 CMIP5 ensemble members out of 262 were able to simulate, by chance, negative IPO in the 2000s at the same time as observed
(Meehl et al., 2014, Nat. Clim. Chg.)

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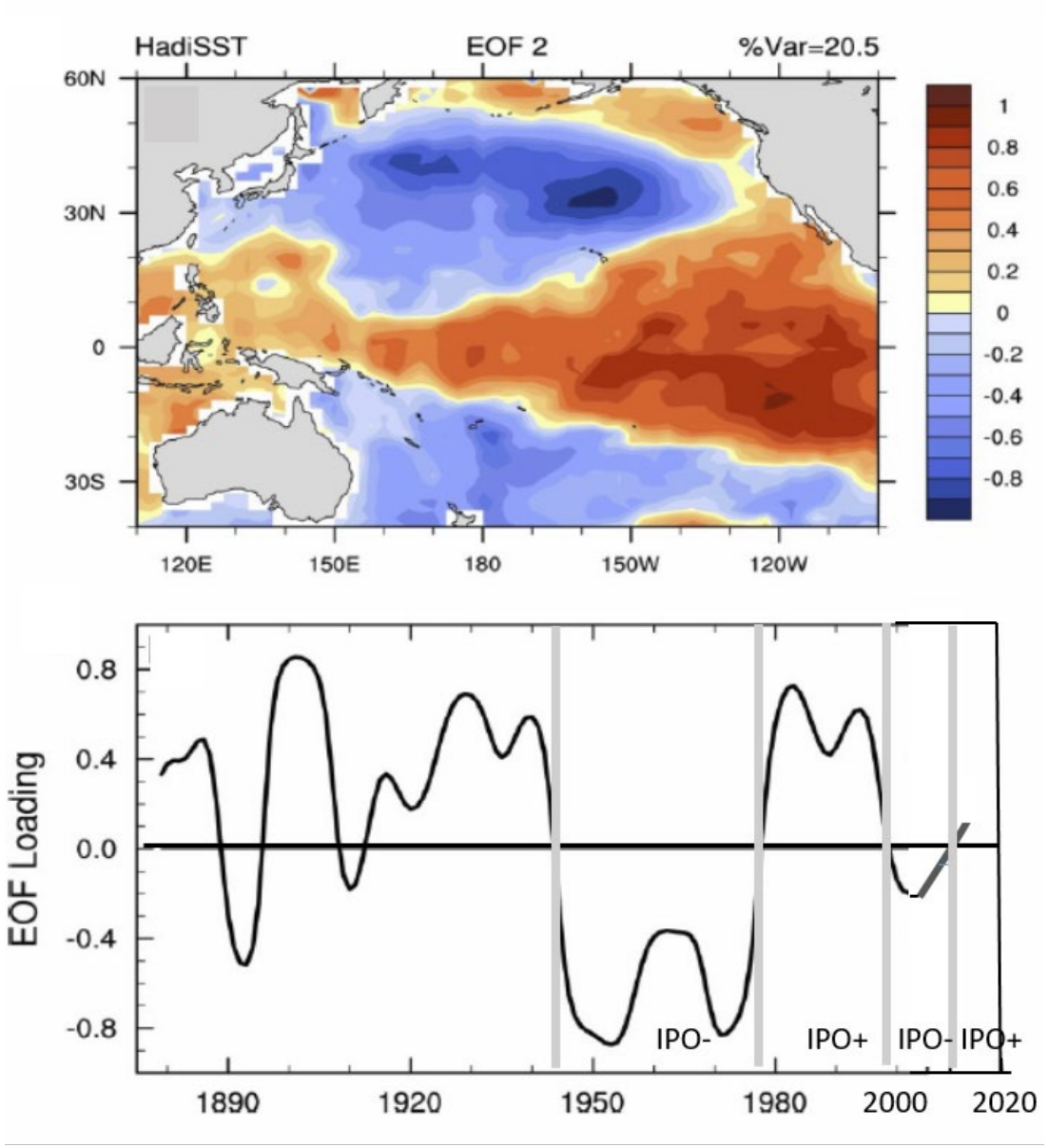

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But is the IPO a physical phenomenon or a manifestation of ENSO modulation?

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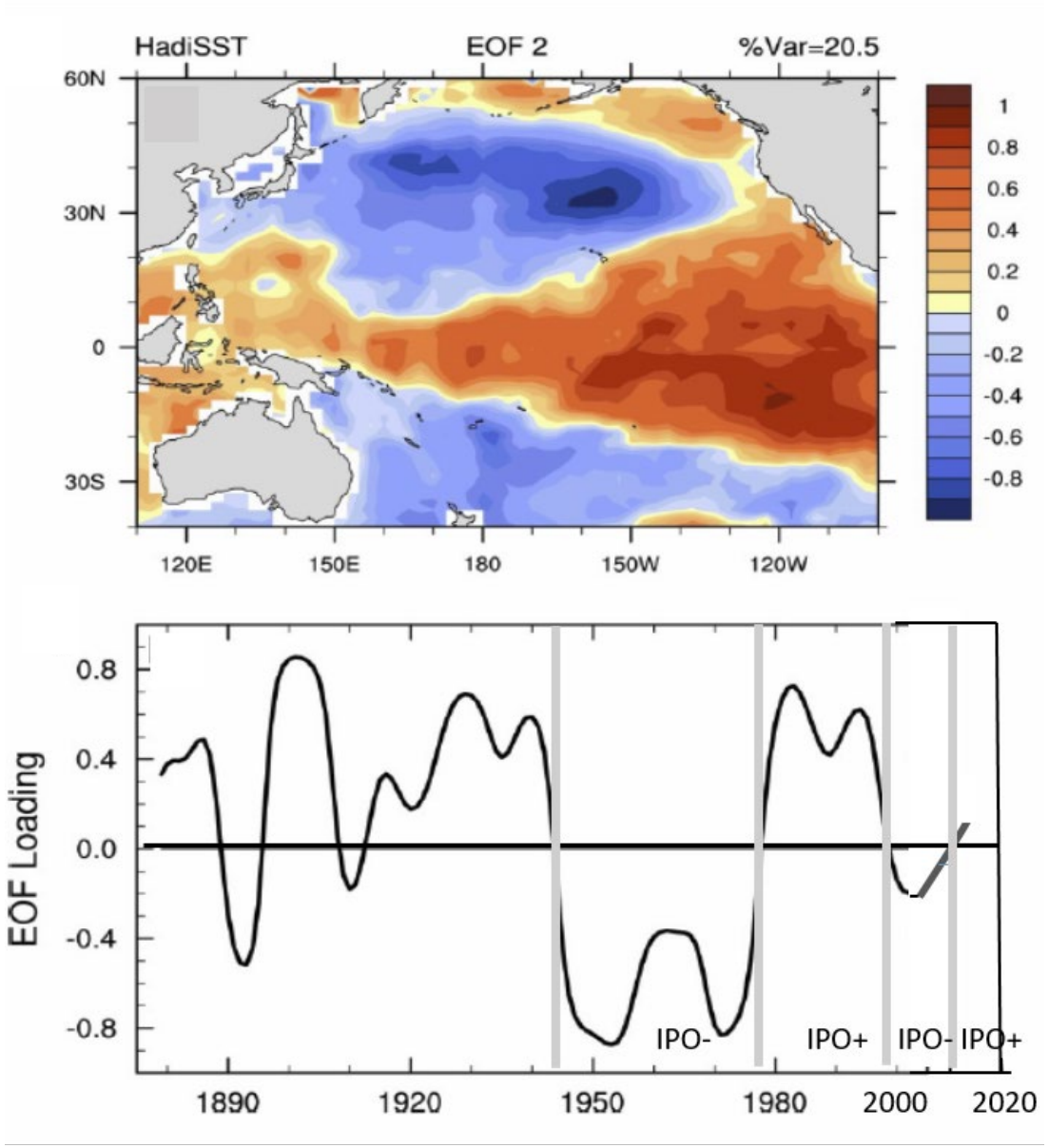

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But is the IPO a physical phenomenon or a manifestation of ENSO modulation?

Evidence from long model control runs suggest the former:
--key role of off-equatorial western Pacific Ocean heat content
--ENSO events provide a trigger for transitions in IPO sign

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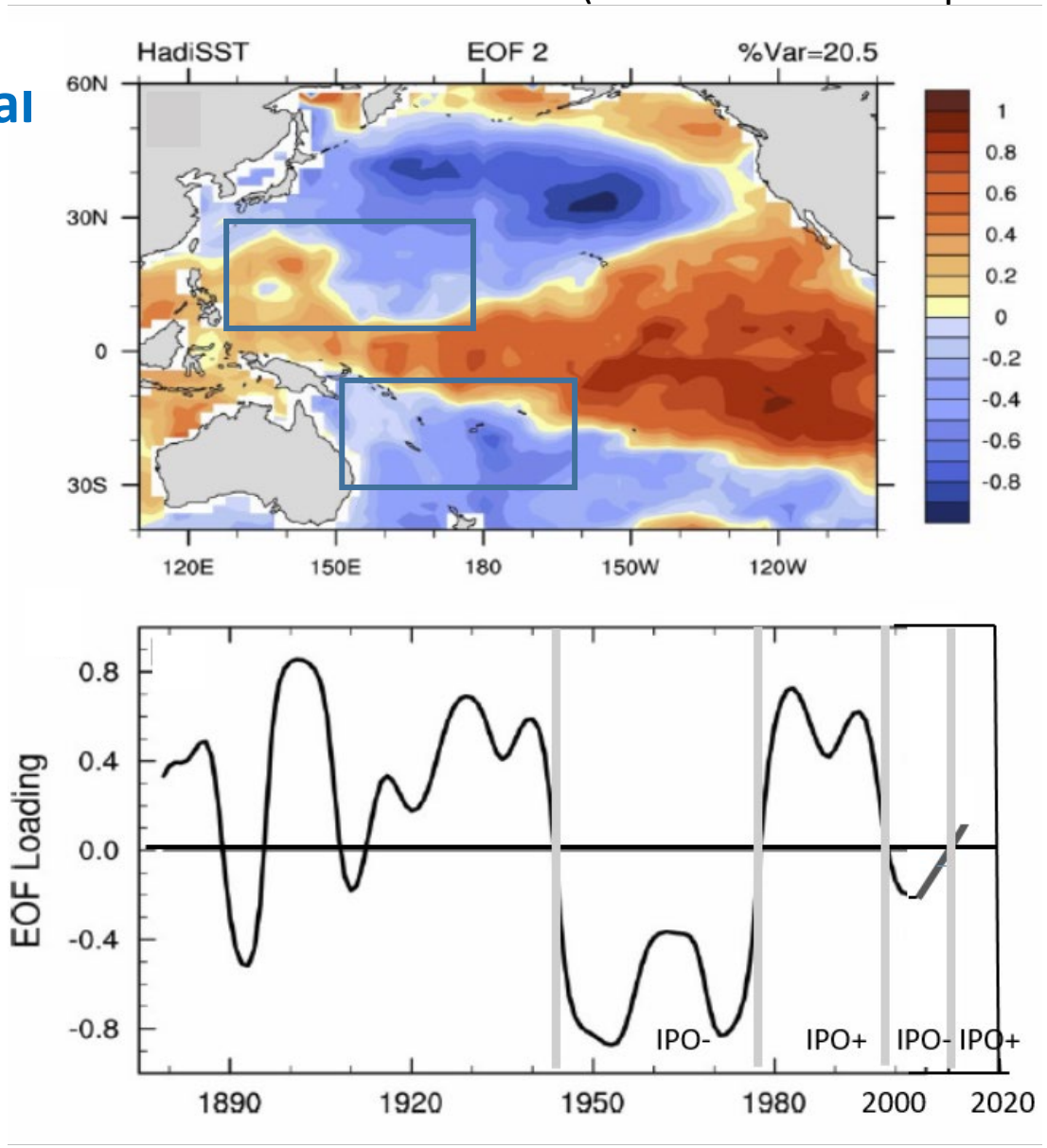

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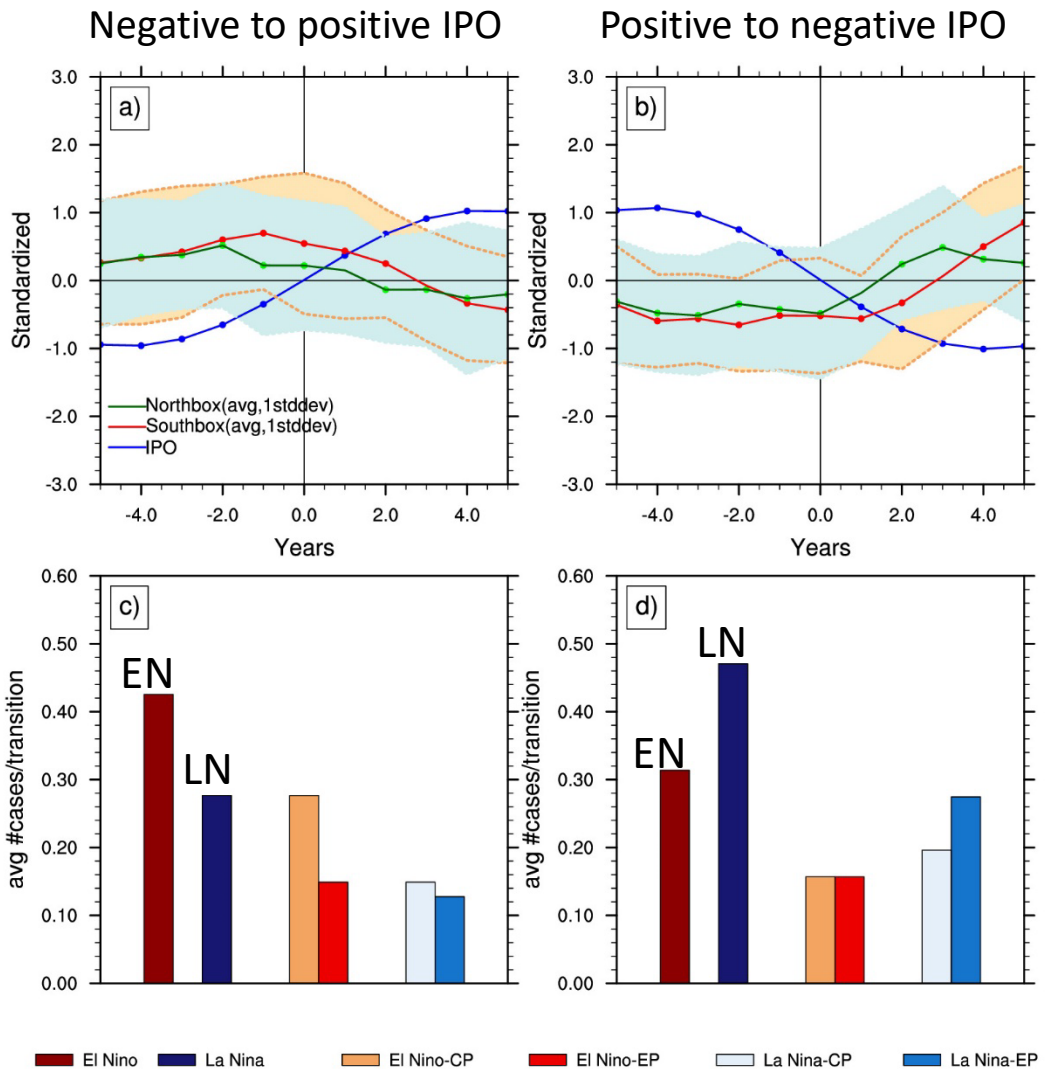
Composite IPO transitions from CESM1, 1800 year control run (47 cases of IPO negative to positive transition; 51 cases of IPO positive to negative transition)

Off-equatorial ocean heat content appears to reach a necessary (but not sufficient) threshold (~0.5 standard deviations) prior to an ENSO event that provides the sufficient condition for a transition

In the year of an IPO transition from negative to positive, there is a better chance of an El Niño event

(and better chance of a La Niña event from positive to negative IPO)

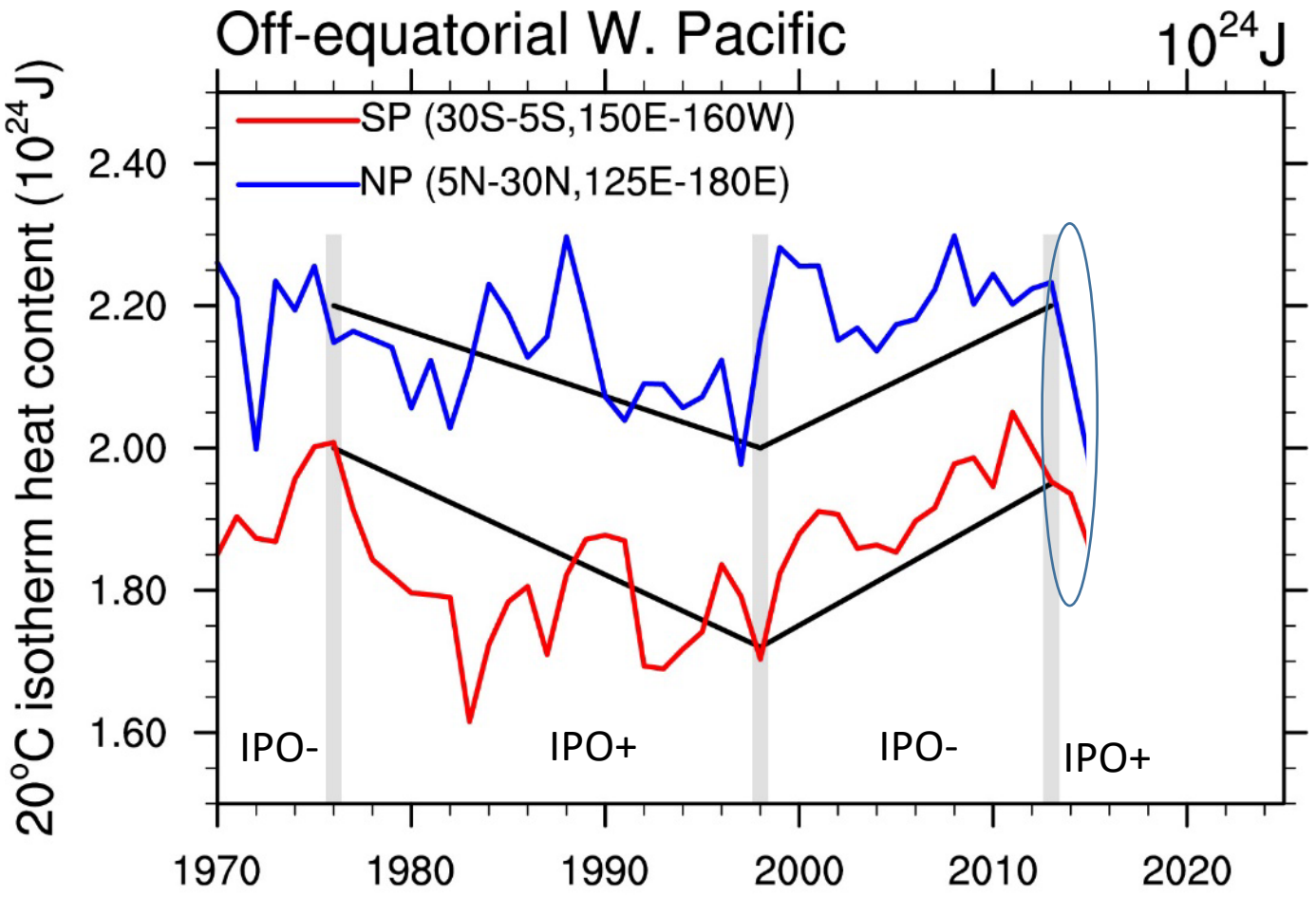


(El Niño: April-March Niño3.4 > +0.5°C for 5 consecutive overlapping 3 month seasons)

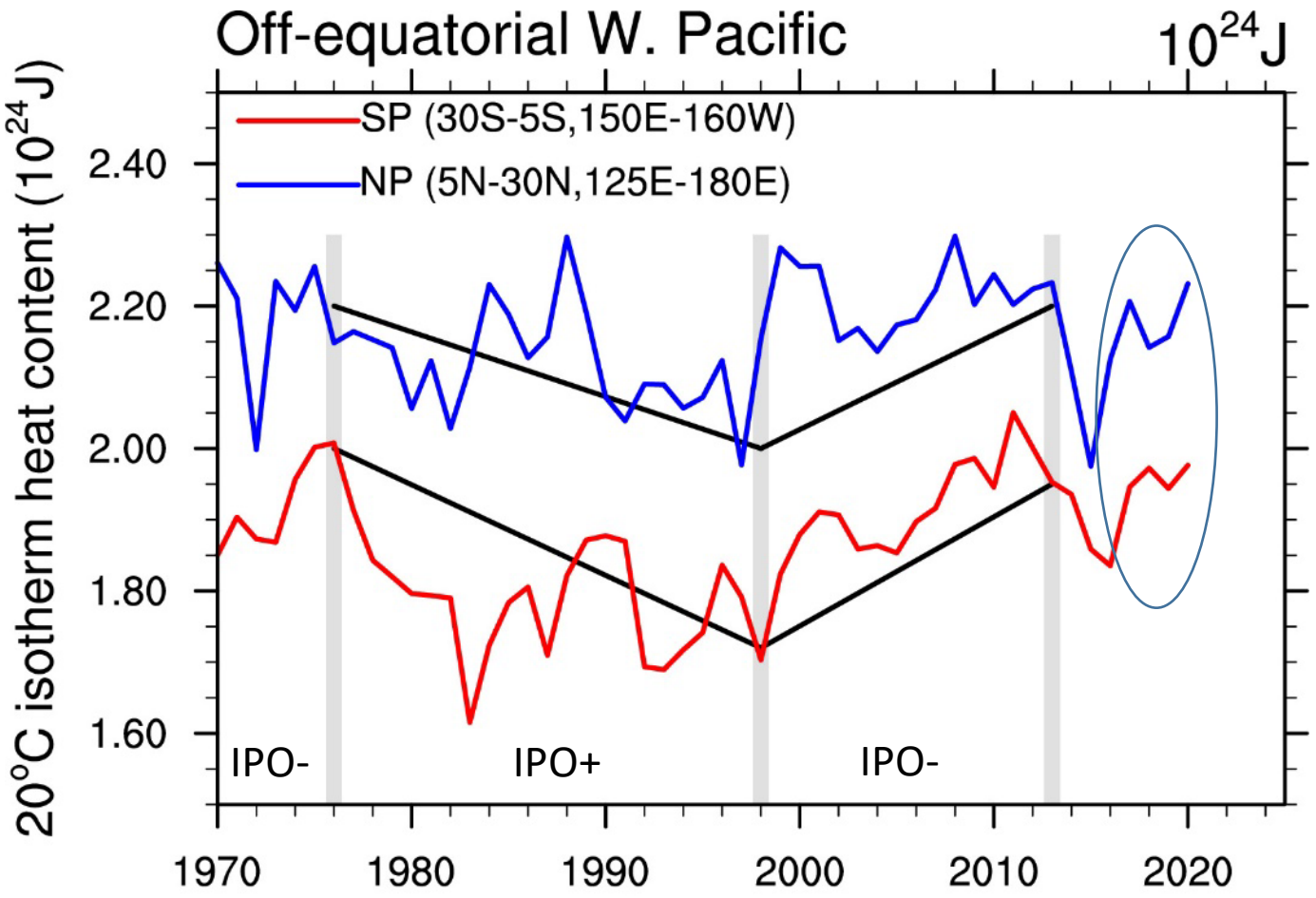
(events per IPO transition)

(Meehl, G.A., H. Teng, A. Capotondi, and A. Hu, 2021: The role of interannual ENSO events in decadal timescale transitions of the Interdecadal Pacific Oscillation, *Climate Dynamics*, doi: 10.1007/s00382-021-05784-y)

With the 2015-2016 El Niño, there appeared to be a sufficient trigger to transition from negative to positive IPO, and off-equatorial western Pacific ocean heat content declined as expected for such a transition…



…but then something happened around 2019-2020 and turned around the declines of off-equatorial Western Pacific ocean heat content, and rate of global warming decreased, all signs of a negative IPO



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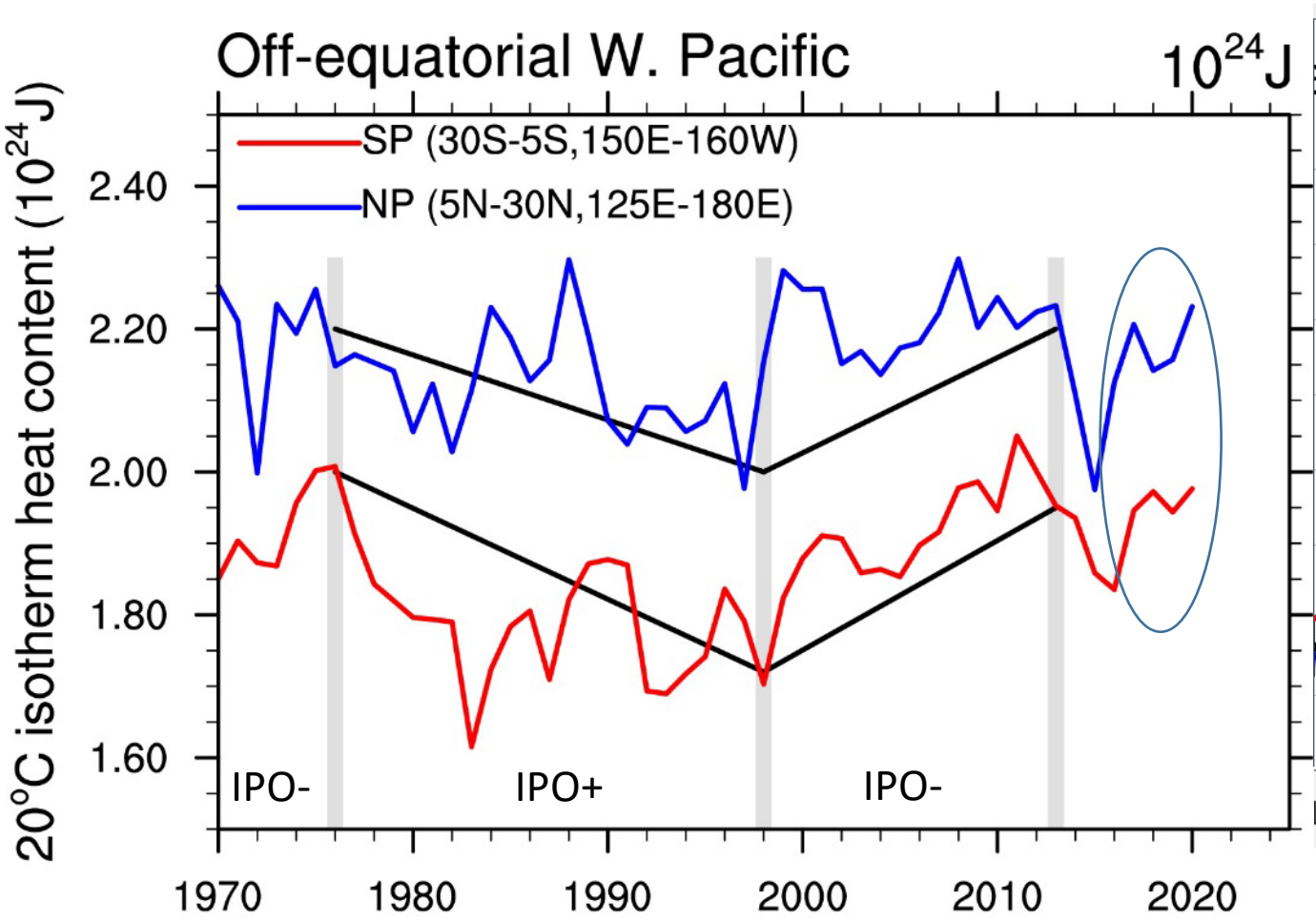
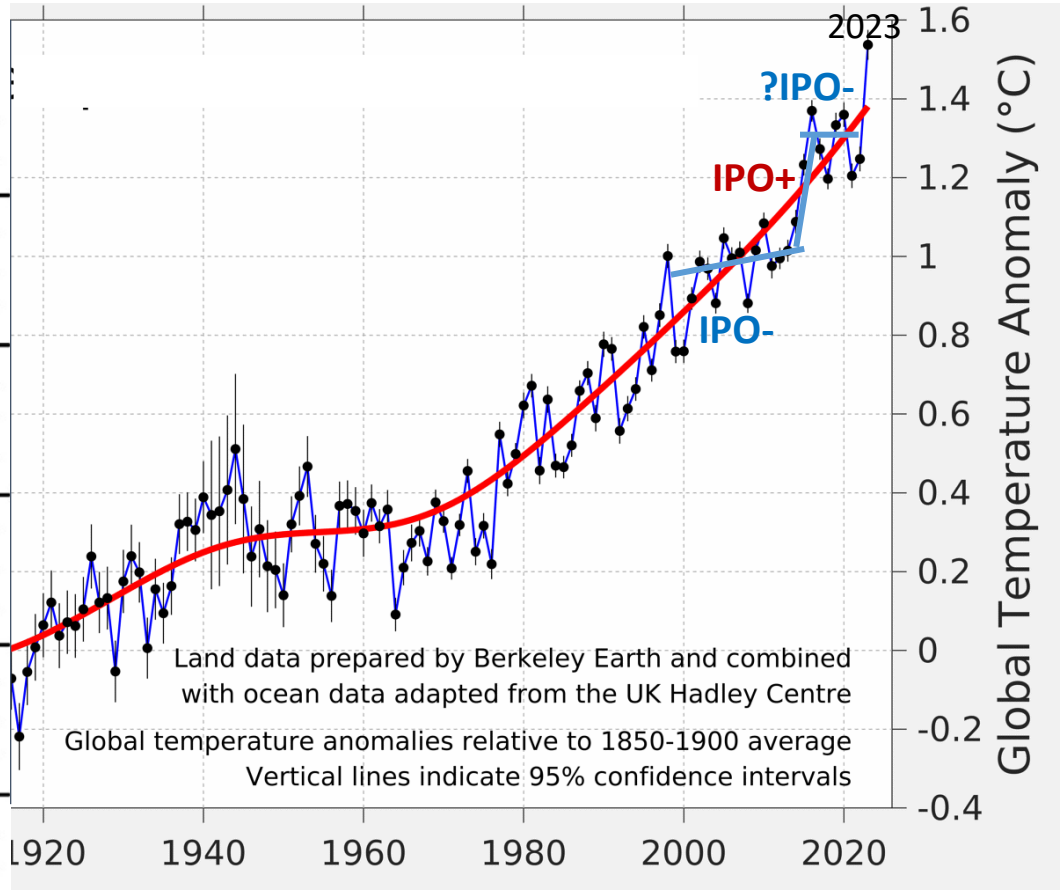
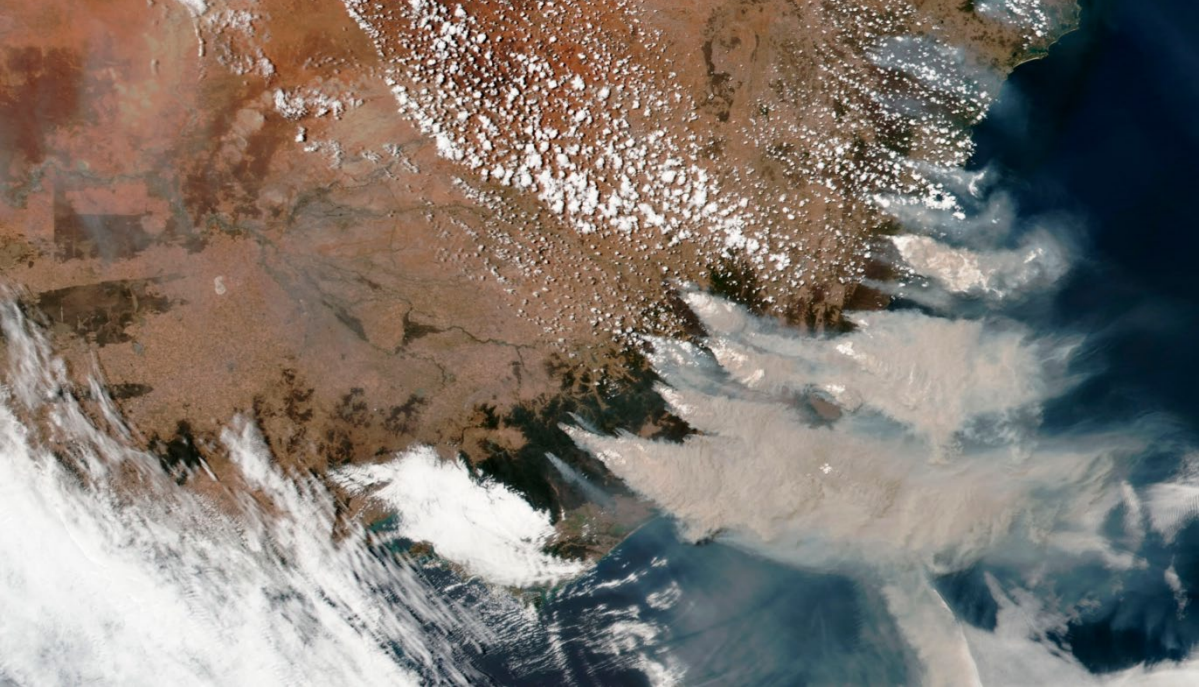
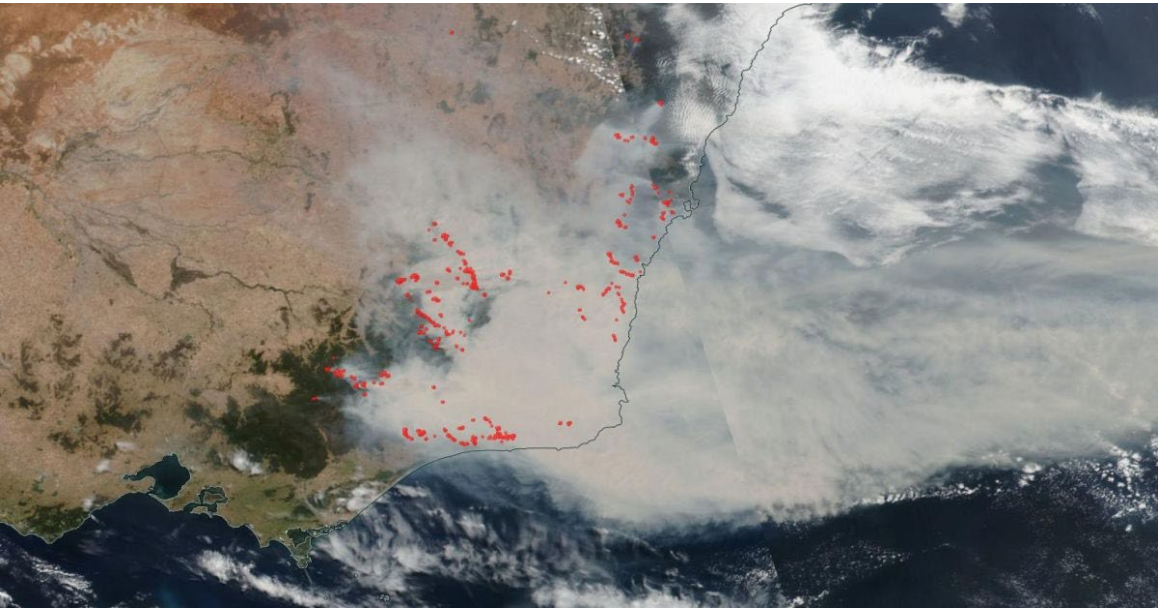




https://berkeleyearth.org/global-temperature-report-for-2023/



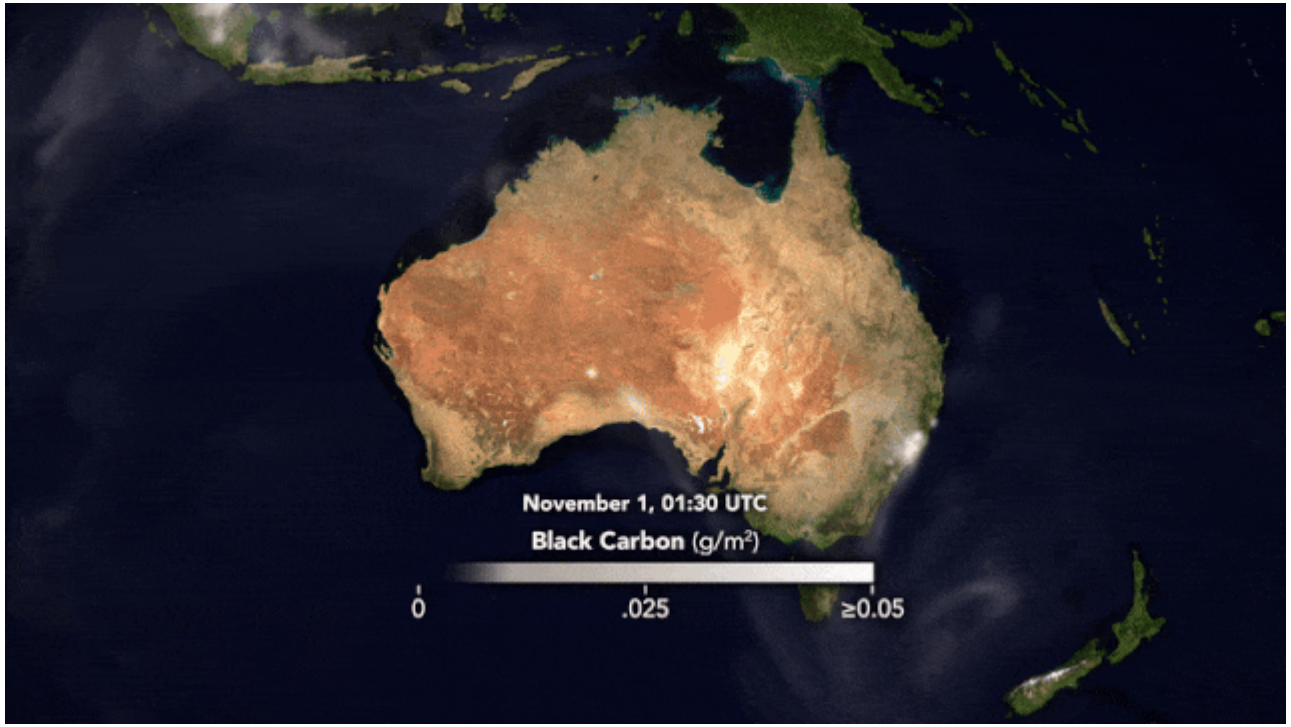
https://www.technologyreview.com/2020/01/06/131012/this-nasa-satellite-image-shows-the-extent-of-australias-devastating-wildfires/



https://www.space.com/australia-wildfires-nasa-satellite-images.html

Disastrous bushfires in Australia in late 2019-early 2020 produced tremendous amounts of smoke, and that smoke was advected across the Pacific

Animation of black carbon transport from Nov. 1 to Nov. 18, 2019



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Did the smoke from the Australian bushfires in 2019-2020 contribute to an externally forced La Niña (Fasullo et al 2023) and a return to negative IPO conditions (this work)?

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Perform two sets of initialized hindcasts with CESM2 and E3SM2

Both initialized in August 2019, and run for three years to July, 2022;
Each has 30 ensemble members (results here shown for annual averages, August to July);
the models include an aerosol scheme whereby CCN and cloud albedo can be affected by smoke aerosols

--One set is run without Australian bushfire smoke emissions (standard “SMYLE”, or “no-smoke” simulation with CESM2);

--One set is run with the observed Australian bushfire smoke emissions from GFED (“smoke”, otherwise the same as the standard SMYLE experiment)

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--Differences between these two initialized Earth system prediction experiments (“smoke minus no smoke”) show only the effects of the wildfire smoke

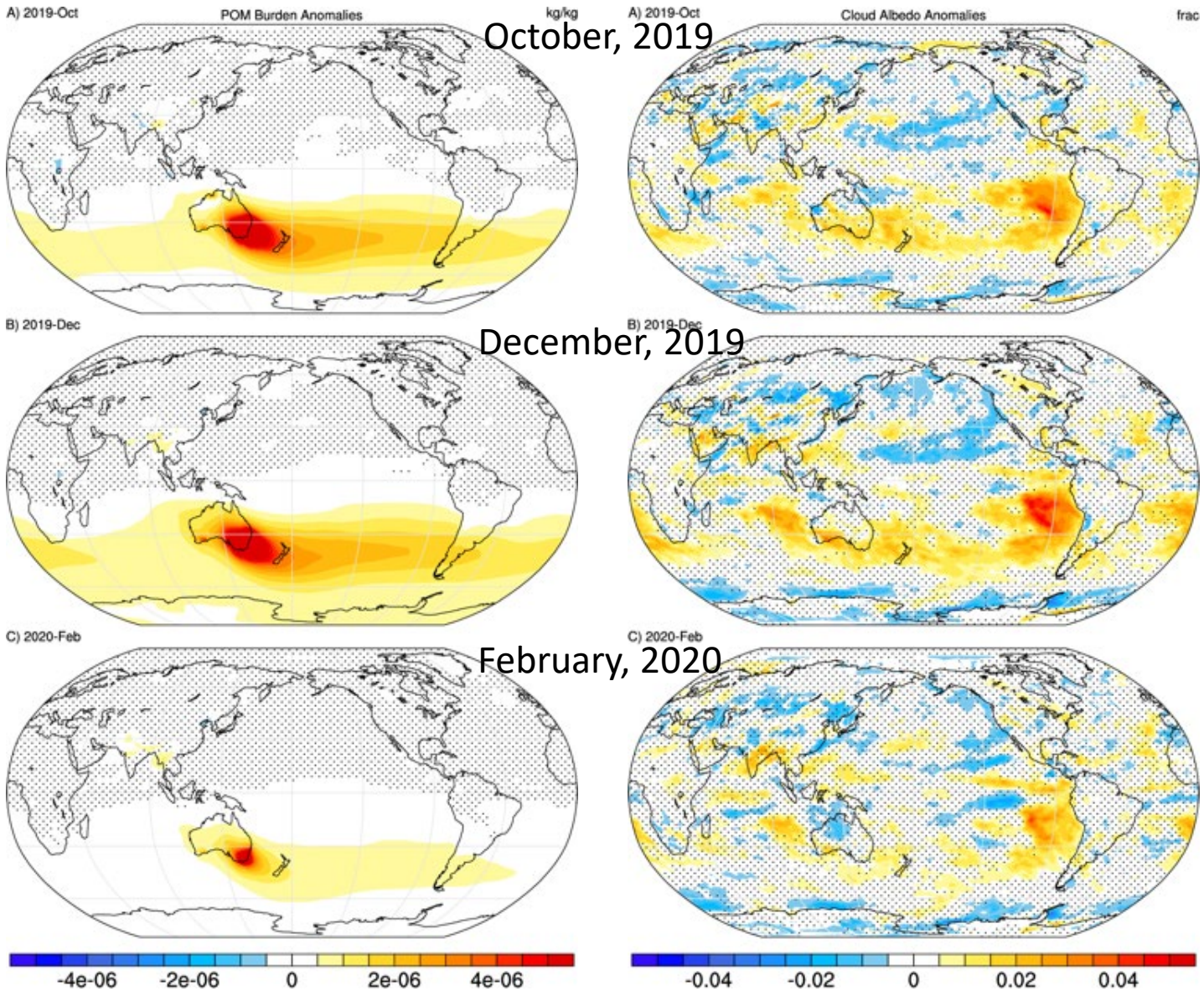
--By performing differences of parallel initialized experiments, model drift is identically removed

The Australian wildfires provided a pulse of CCN to the pristine southern ocean atmospheric environment.

Close agreement in timing and magnitude of the observed AOD max from MODIS (Loeb et al. 2021)

The smoke dissipates by March 2020.

Smoke minus no-smoke: aerosols **cloud albedo**



Aerosols are transported across the southern ocean;

Clouds brighten and last longer in response to the CCN in agreement with observations from CERES, and net solar at the surface decreases

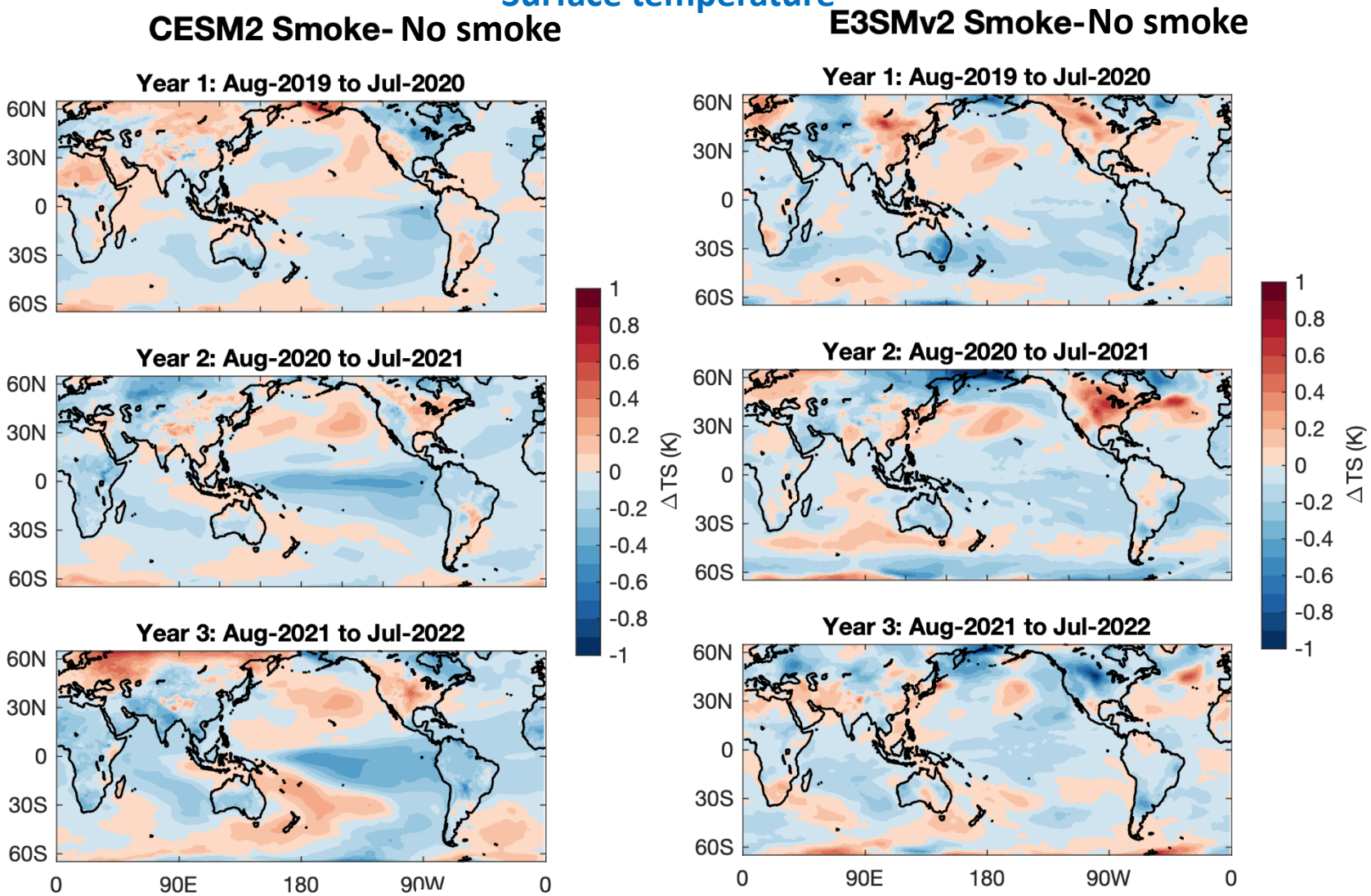
(Fasullo et al., 2021; 2023)

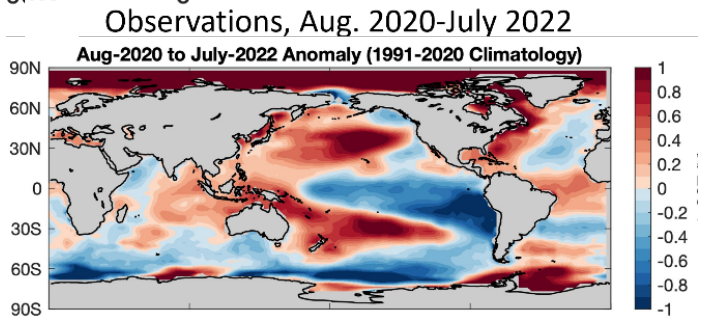
Surface temperature

The La Niña-like SST anomalies persist for three years in the smoke minus no-smoke model differences

If the Australian wildfire smoke contributed to the initial La Niña-like response, and the smoke dissipated by March, 2020…

Then what made the La Niña-like anomalies persist and grow into year 3?

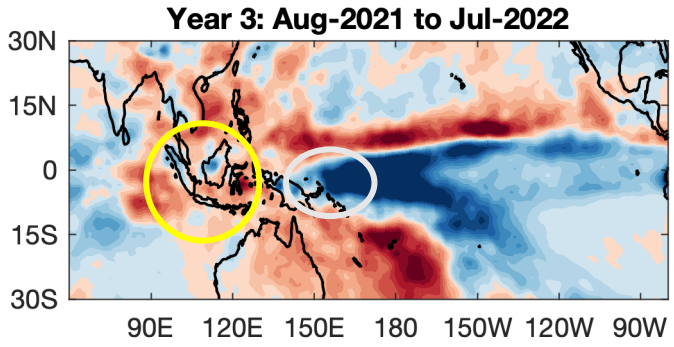


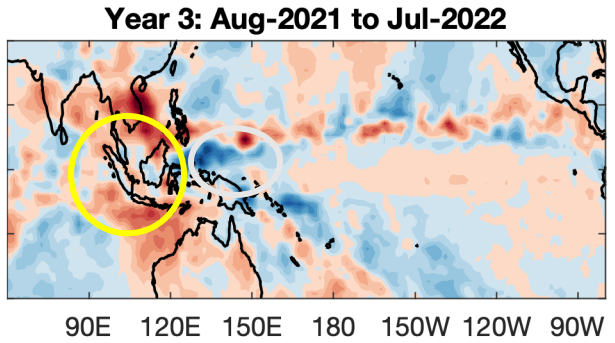


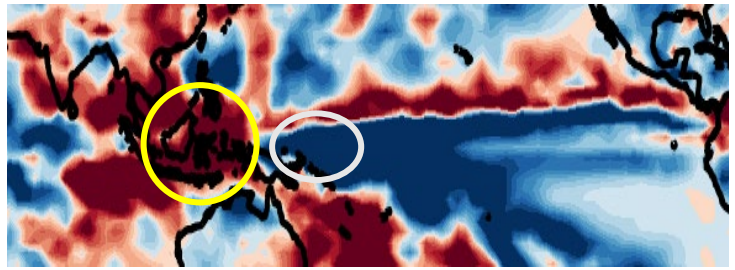
Smoke minus no-smoke: **CESM2** **E3SM2** **Observed**

Year 3

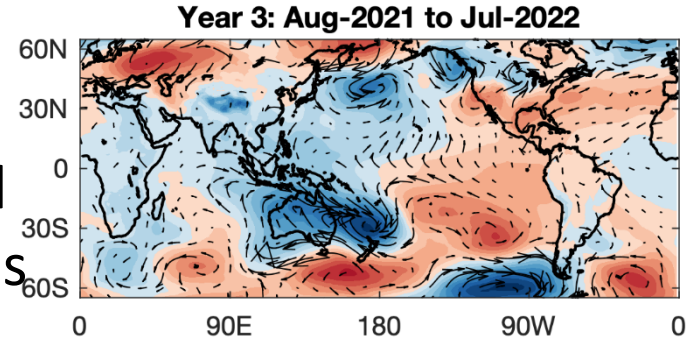
Precipitation

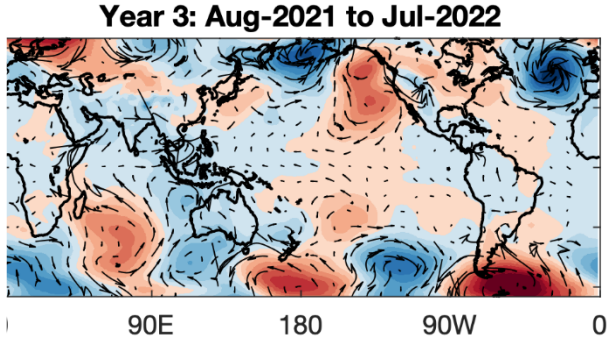




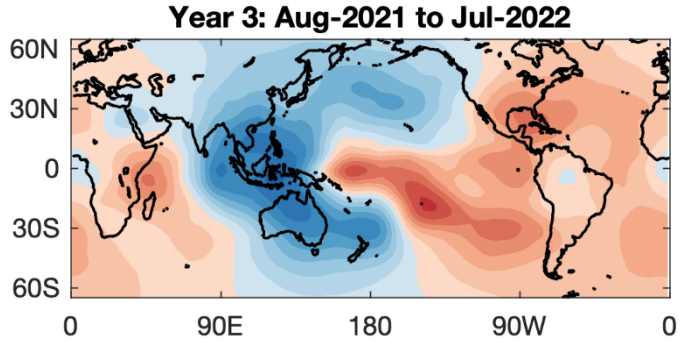


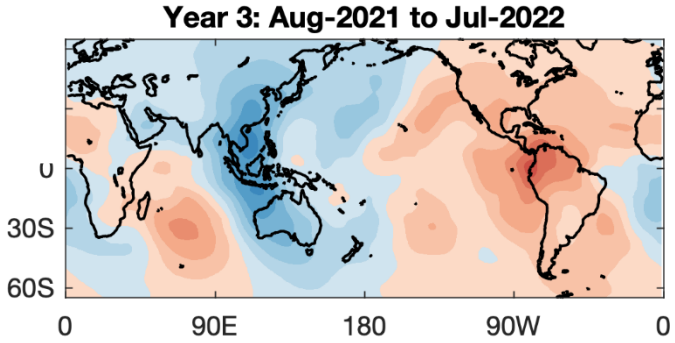
Sea level pressure and surface winds





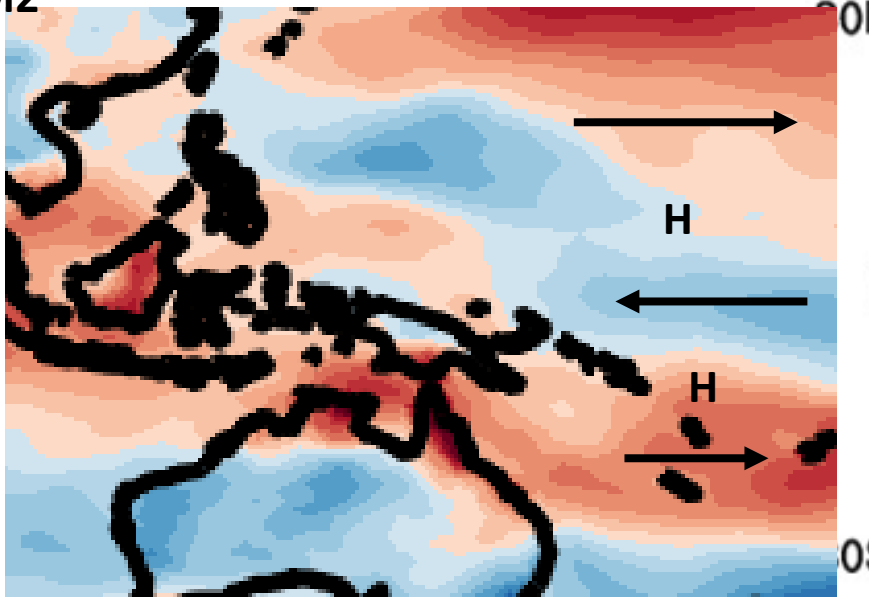
200 hPa velocity potential

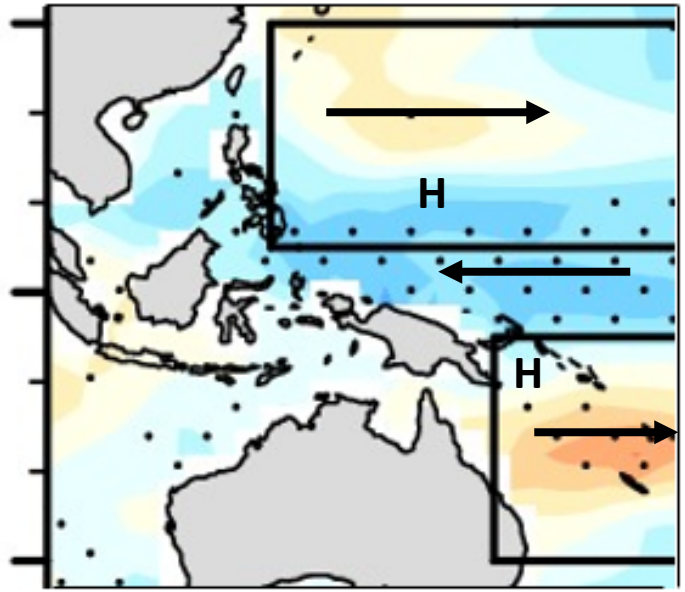




Year 3: Smoke minus no-smoke u-component wind stress

CESM2



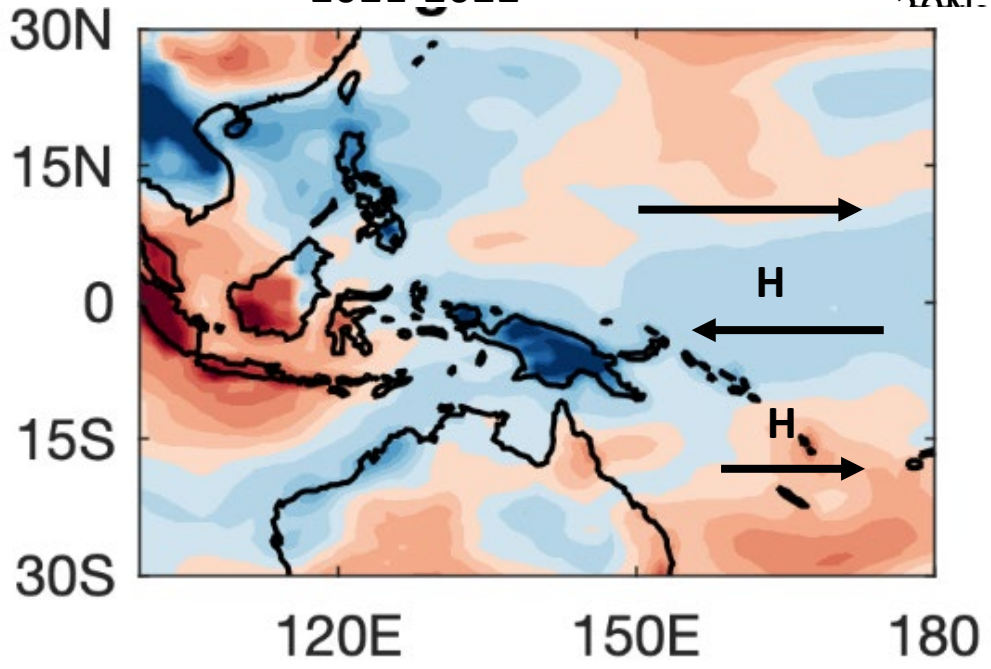


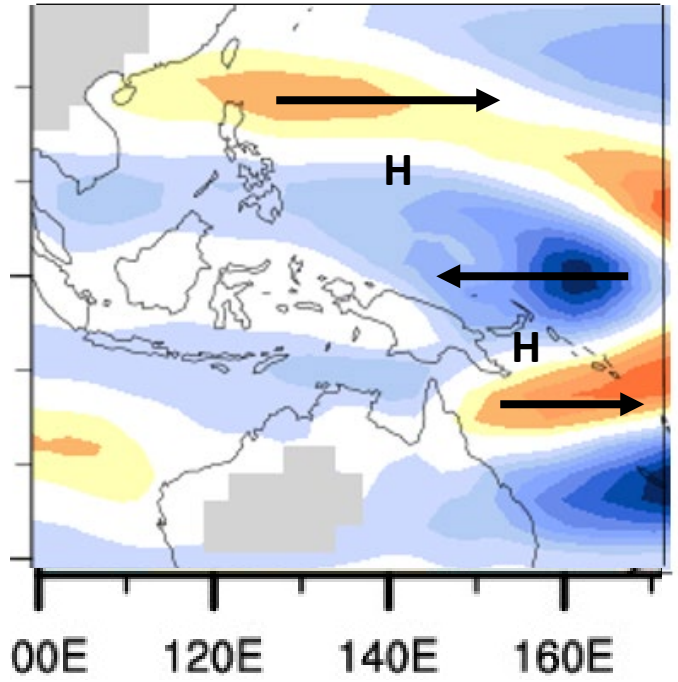
Model control run composite u-component wind stress, negative IPO

(Meehl et al., 2021, Clim.Dyn.)

Negative convective heating anomaly near 165E produces u-component wind stress anomalies in off-equatorial western Pacific to sustain ocean heat content anomalies

E3SM2 2021-2022



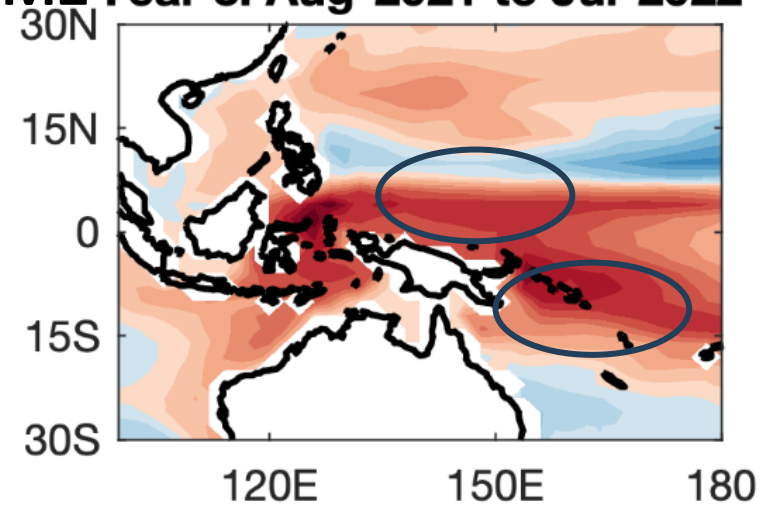


Specified negative convective heating anomaly experiment (representing negative SST and precipitation anomalies) at equator, 165E

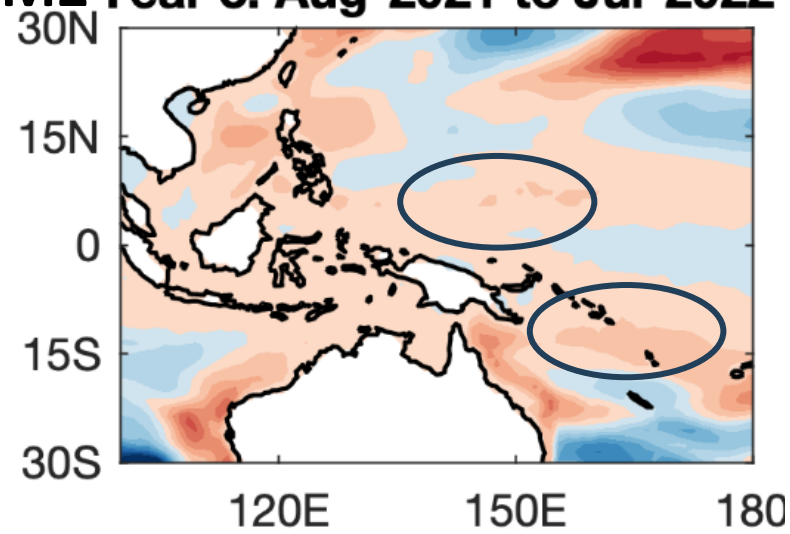
Ocean heat content

Smoke minus no-smoke

CESM2 Year 3: Aug-2021 to Jul-2022

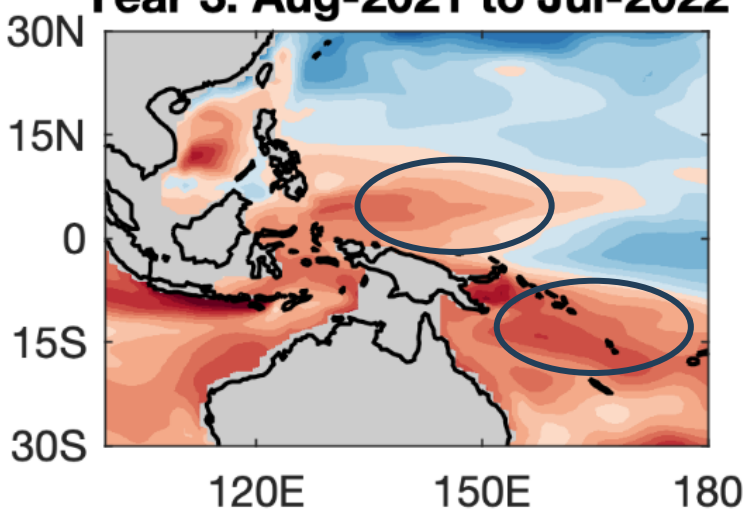


E3SM2 Year 3: Aug-2021 to Jul-2022



Observed (GODAS)

Year 3: Aug-2021 to Jul-2022

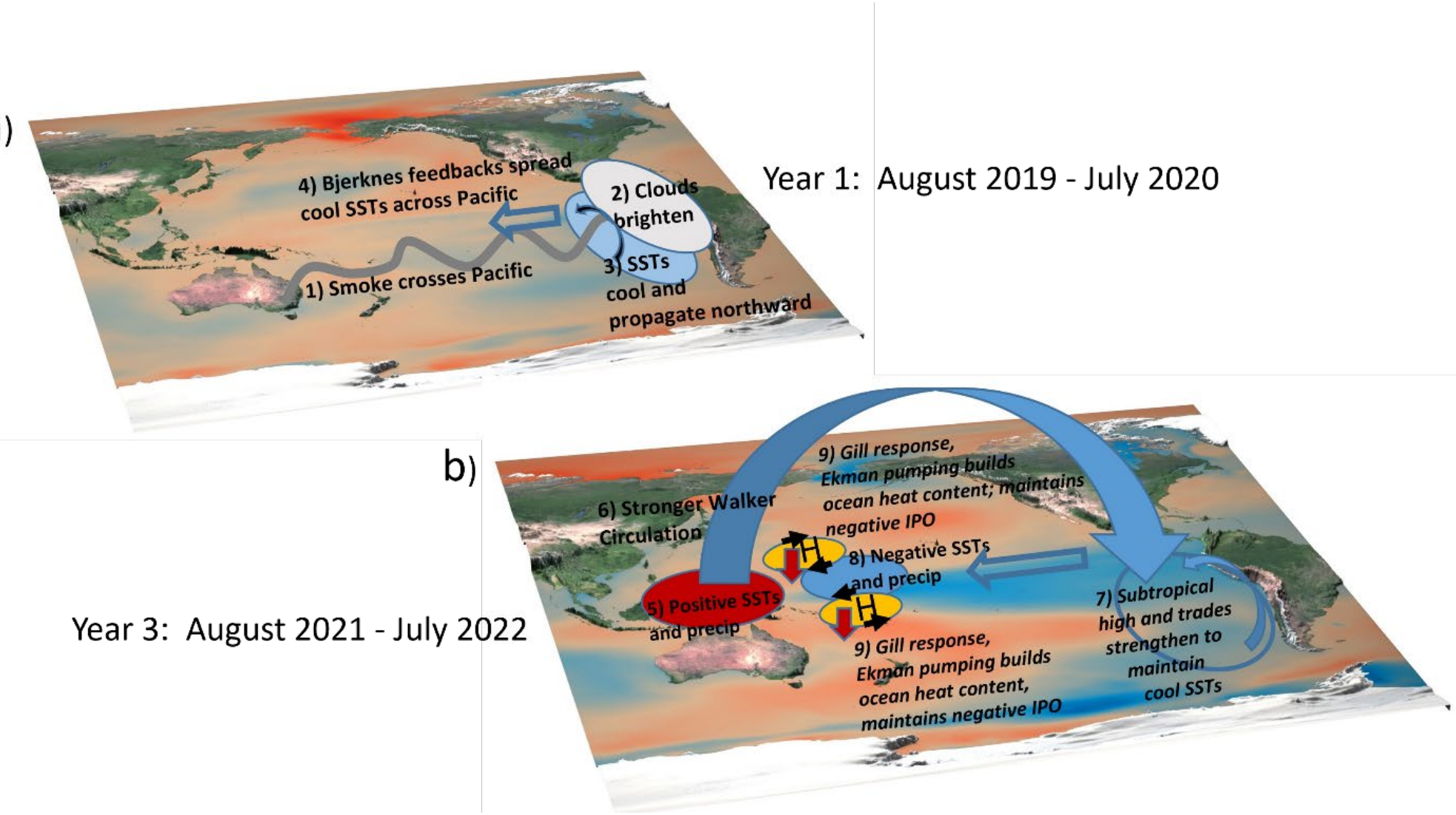


Off-equatorial westerly wind stress anomalies:

Ekman pumping builds up ocean heat content in the off-equatorial western Pacific:

the signature of negative IPO

Using initialized S2D Earth system predictions to elucidate multi-year La Niña/IPO-like processes and mechanisms triggered by the Australian wildfire smoke



Summary

Off-equatorial western Pacific ocean heat content build-up is a necessary but not sufficient condition for setting the stage for a transition to negative IPO

In early 2020, coincident with the Australian bushfires, there was the start of a three year La Niña with a negative IPO signature in year 3

The smoke triggered a set of coupled processes and two feedbacks that maintained the La Niña two years beyond the end of the smoke forcing

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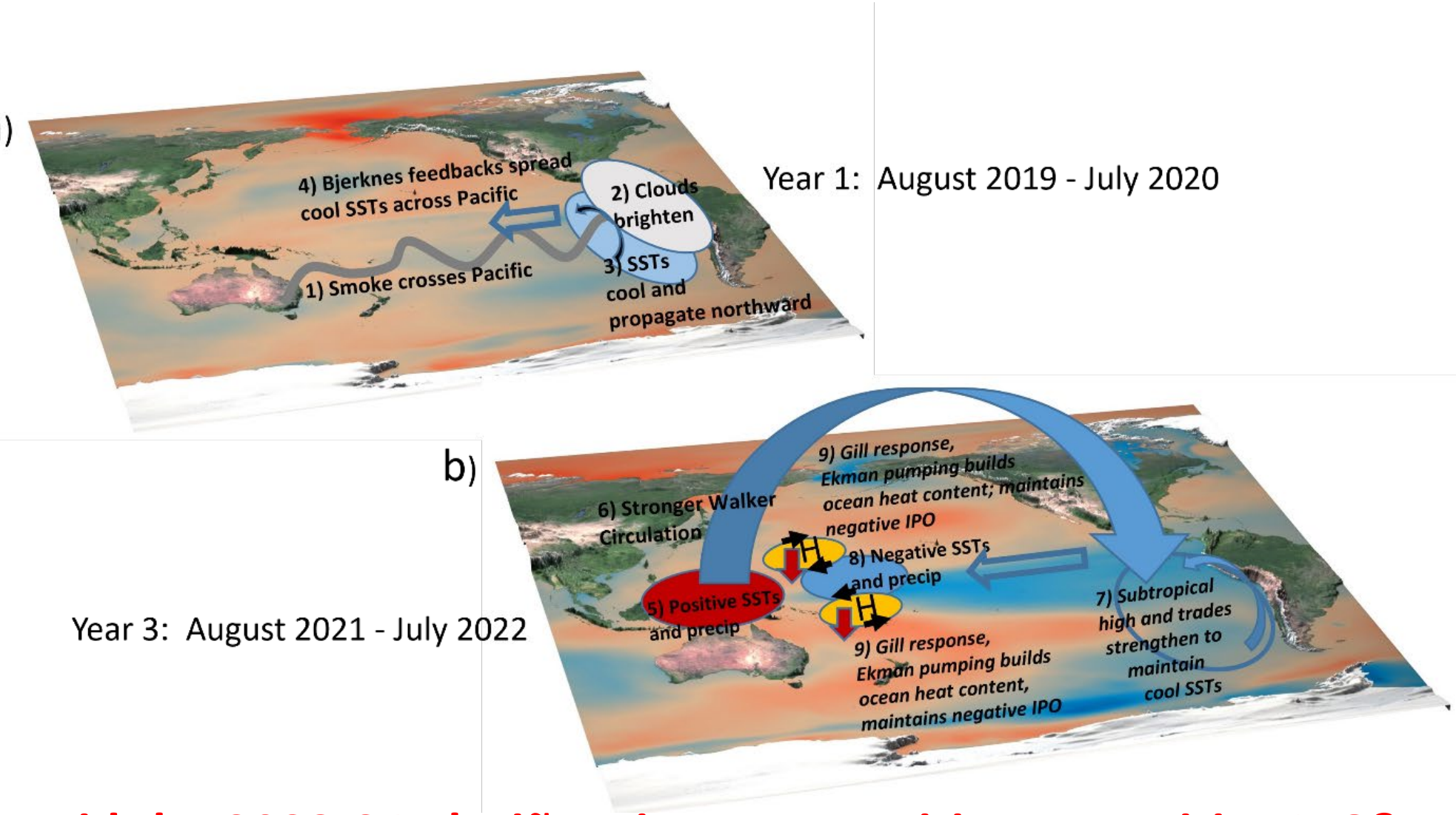

Did the 2023-24 El Niño trigger a transition to positive IPO?

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Ocean heat content Smoke minus no-smoke

(GODAS)

Off-equatorial westerly wind stress anomalies: **Ekman pumping builds up ocean heat content in the off-equatorial western Pacific** **the signature of negative IPO**