The role of the 2019-2020 Australian bushfire smoke in the current multi-year La Niña and the Interdecadal Pacific Oscillation (IPO)

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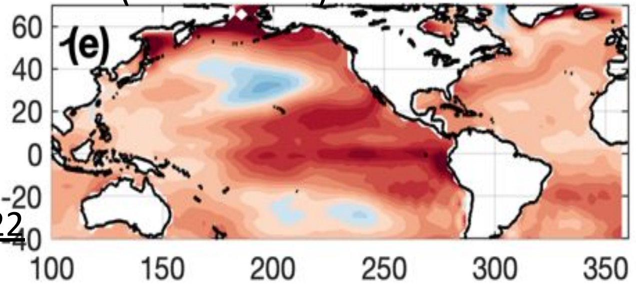
Regional and Global Model Analysis

Prediction of transition from negative to positive IPO around 2015-2016

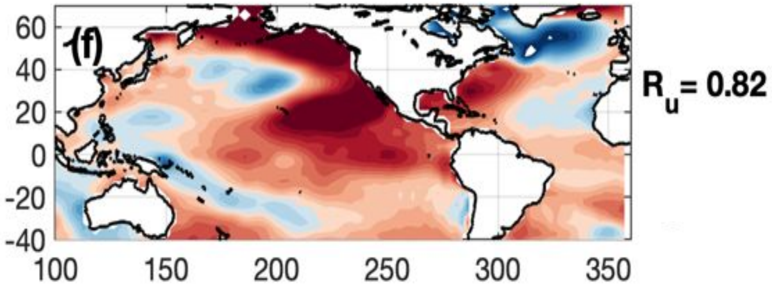
From DPLE with CESM1, initialized in 2013 for years 3-7 (2015-2019) shows transition to positive phase of the IPO different from persistence; global warming trend increased

(Meehl, G.A., H. Teng, D. Smith, S. Yeager, W. Merryfield, F. Doblas-Reyes, and A.A. Glanville, 2022, *Climate Dynamics*, https://doi.org/10.1007/s00382-022-06272-7)

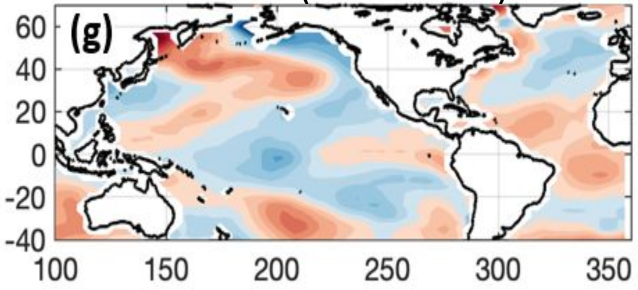
DPLE prediction initialized 2013 for lead years 3-7 (2015-2019)

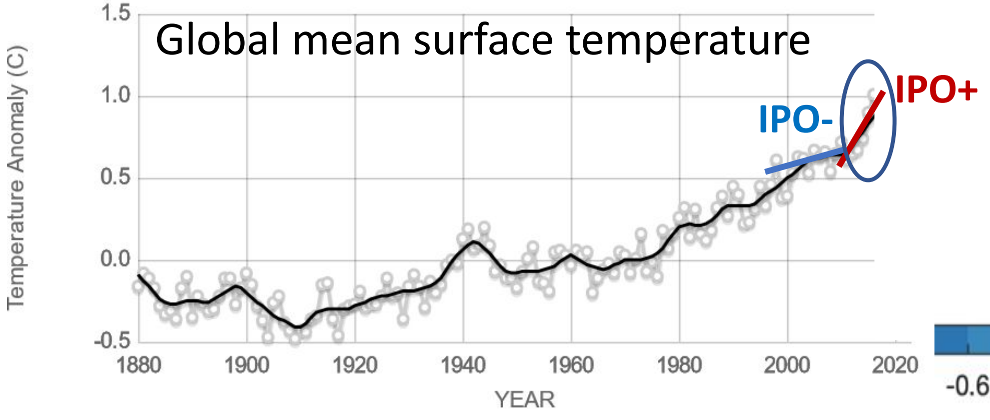


Observations (2015-2019)



Persistence (2015-2019)



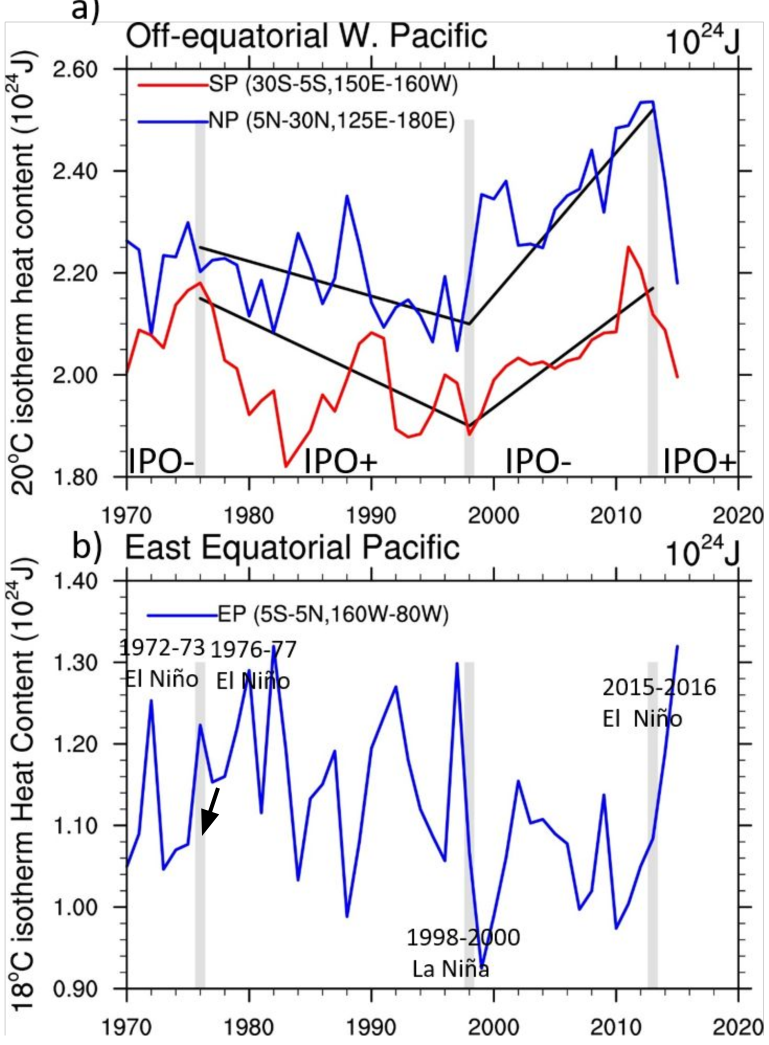


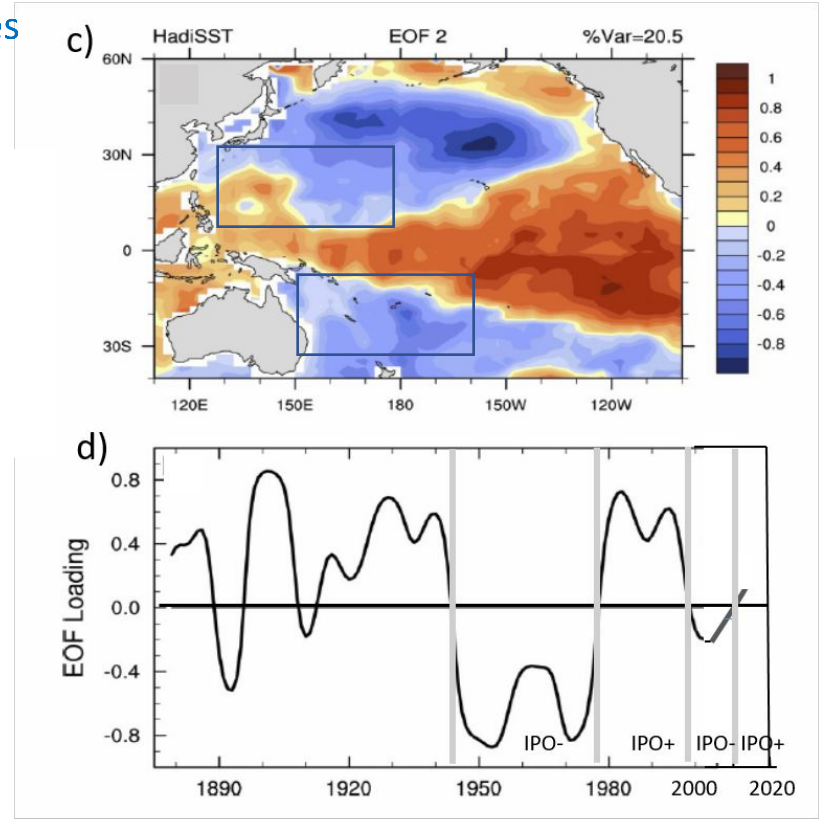
Source: climate.nasa.gov

Other studies documented an apparent IPO transition from negative to positive around 2015

(Hu and Fedorov, 2017, *GRL*; Su et al., 2017, *Sci. Reports*)

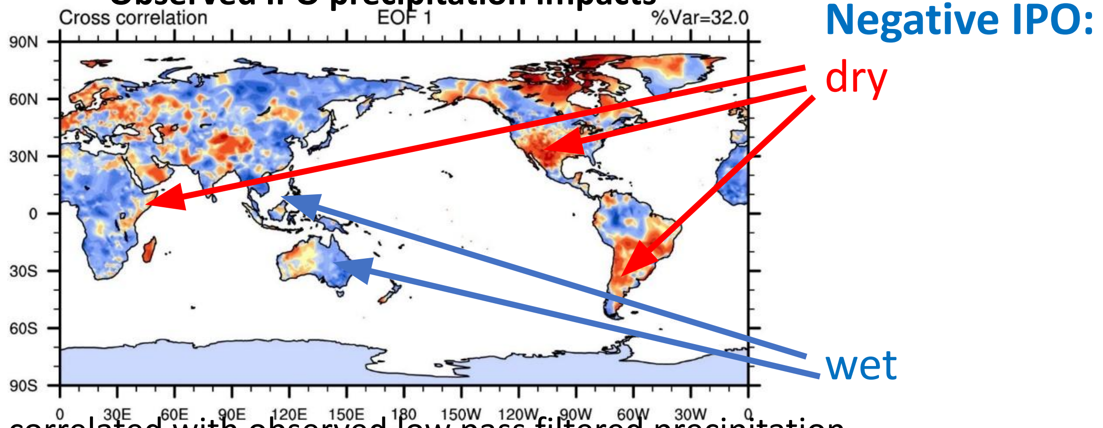
Decadal Prediction Large Ensemble (DPLE) Forced Ocean and Sea Ice (FOSI) ocean initial states





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

Observed IPO precipitation impacts



IPO correlated with observed low pass filtered precipitation

(1901-2000; Meehl and Hu, 2006, J. Clim.)

Off-equatorial ocean heat content in the tropical western Pacific appears to provide the conditions for ENSO events to trigger an IPO transition

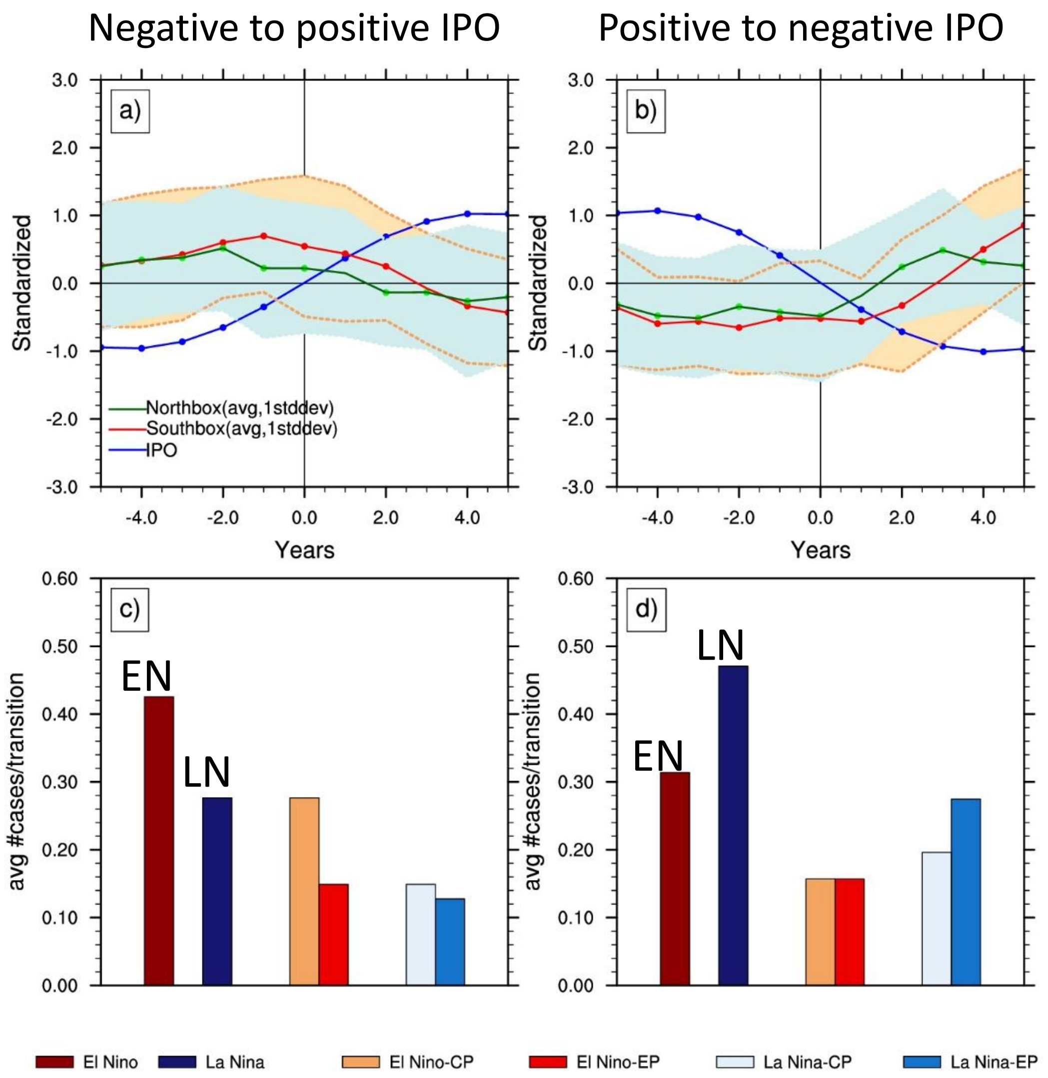
(Meehl, Hu, Teng, 2016, *Nature Communications*)

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)

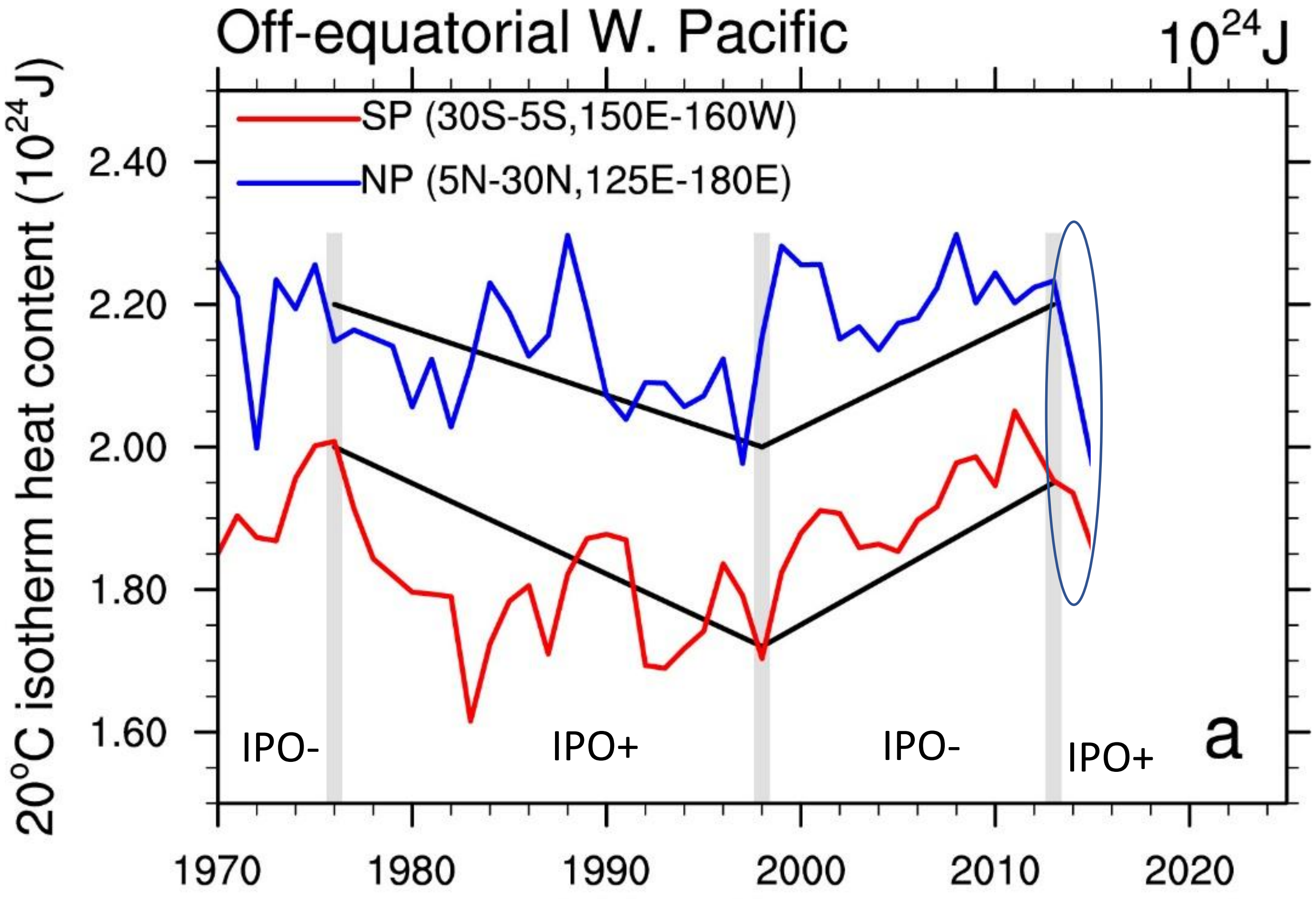


(El Niño: April-March Niño3.4 > +0.5°C for 5 consecutive overlapping 3 month seasons)

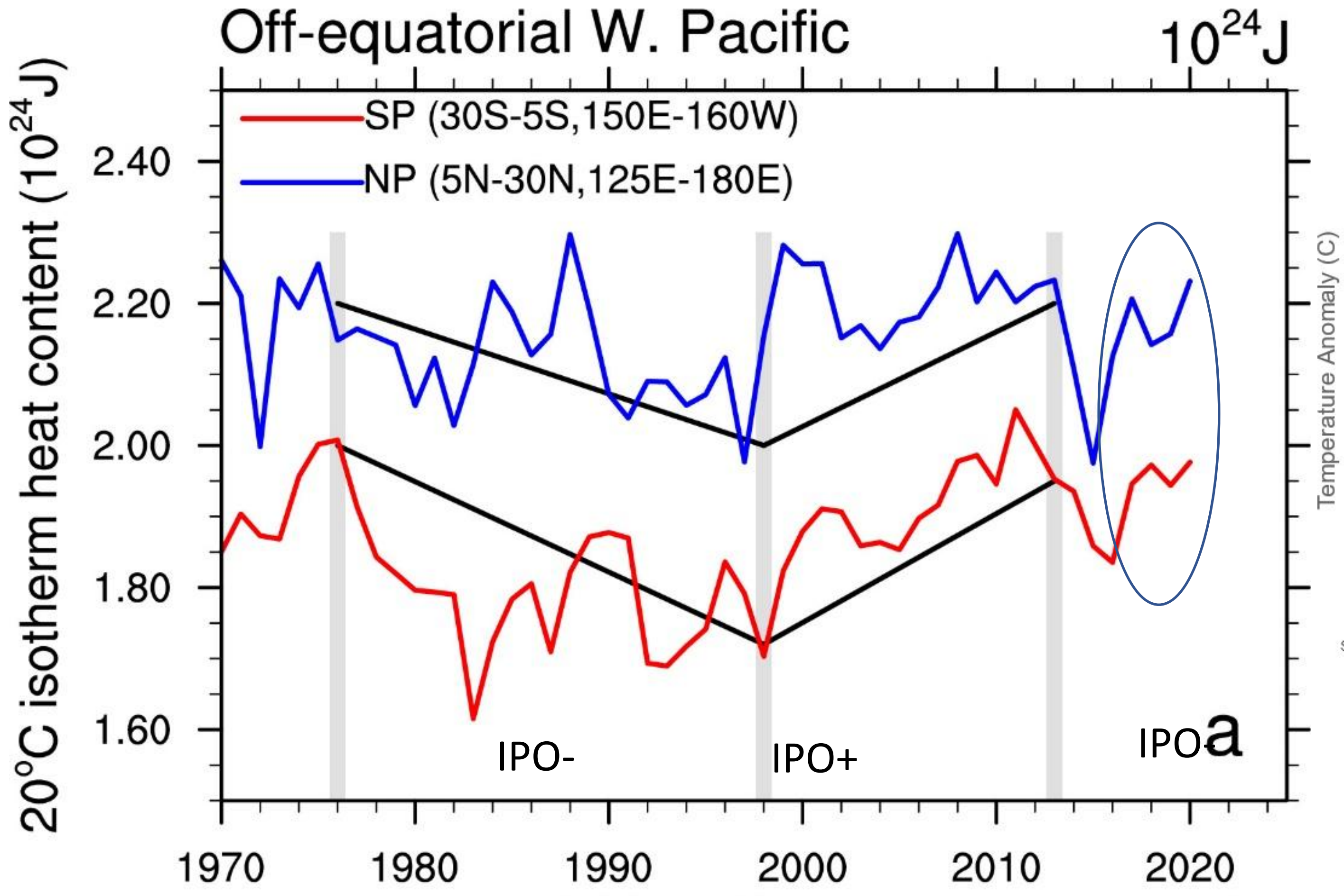
(events per IPO transition)

(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)

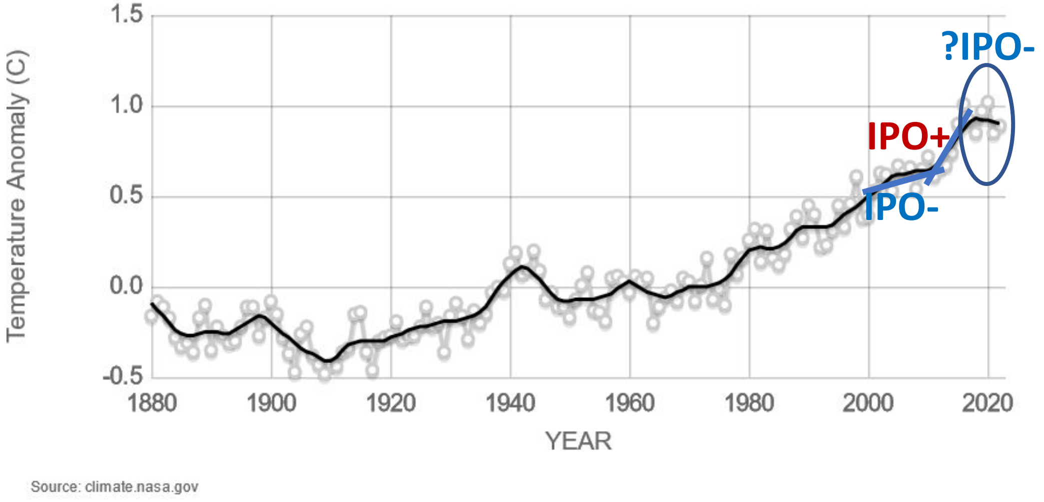
With the 2015-2016 El Nino, there appeared to be a sufficient trigger to transition from negative to positive IPO, and off-equatorial western Pacific ocean heat content declined as expected for such a transition…



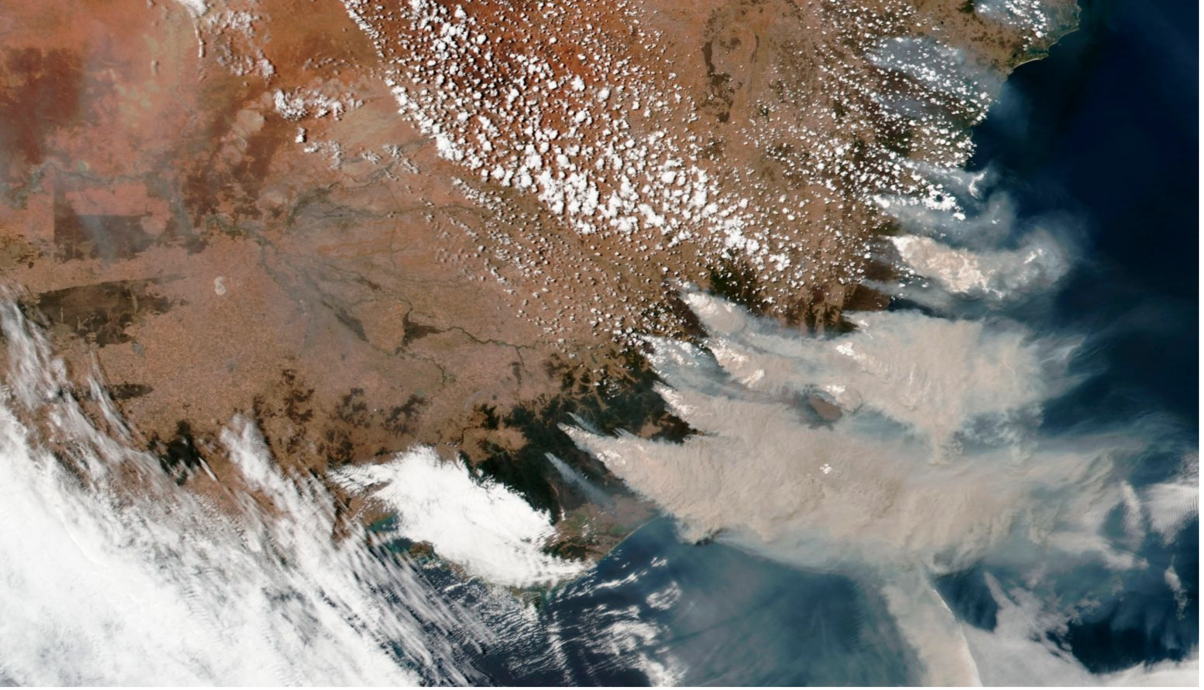
…but then something happened around 2019-2020 and turned around the declines of off-equatorial Western Pacific ocean heat content, and rate of global warming decreased, all signs of a return to negative IPO



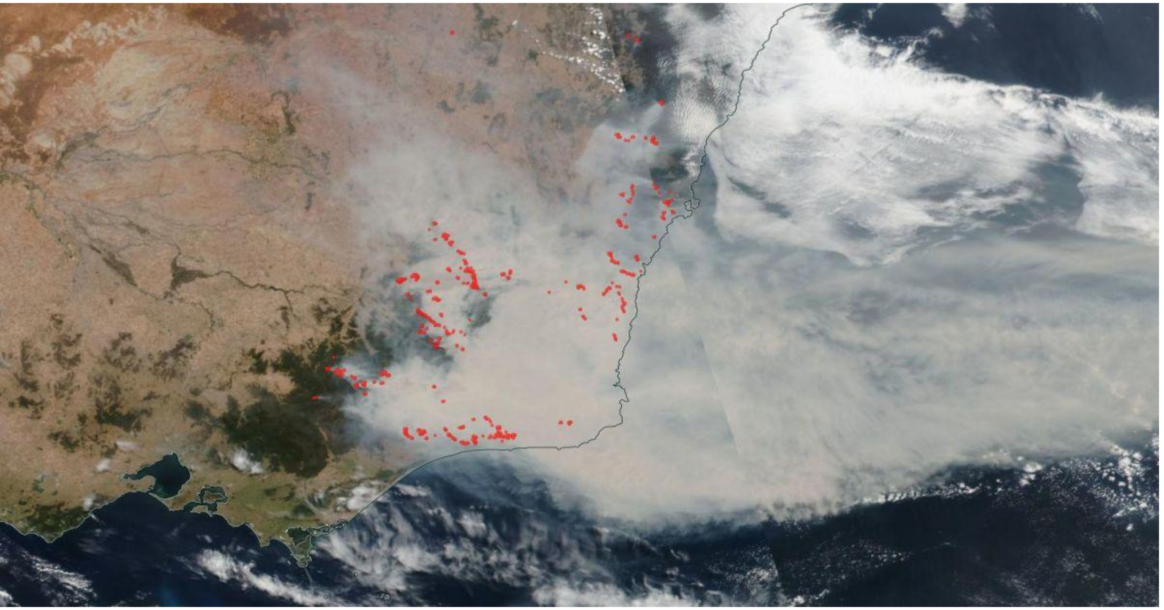
IPO?



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

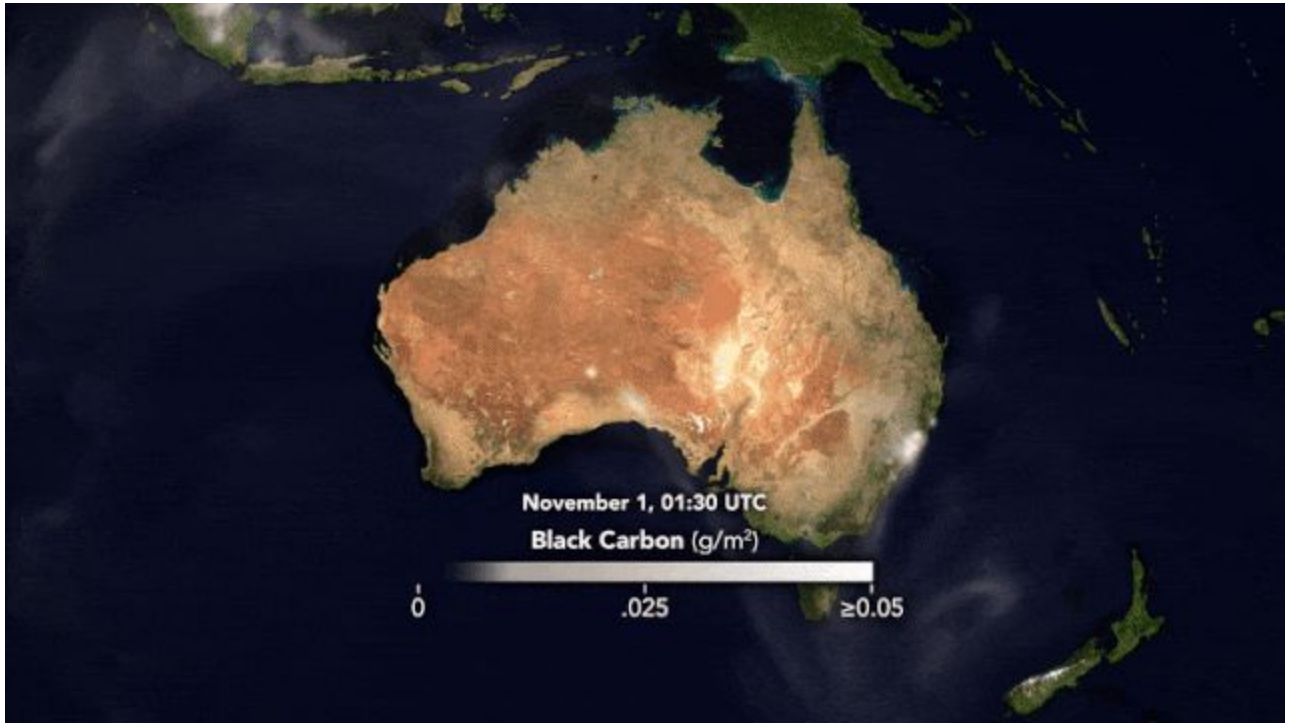


https://www.technologyreview.com/2020/01/06/131012/this-nasa-satellite-image-shows-the-extent-of-australias-devastating-wildfires/



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

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



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

Did the smoke from the Australian bushfires in 2019-2020 disrupt the IPO transition from negative to positive that appeared to have occurred around 2015, and externally force a three year La Niña and return the IPO to a negative phase?

Perform two sets of initialized hindcasts with CESM2

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, computed as differences "smoke minus no-smoke" to see what affects the smoke had on the prediction); the model includes an aerosol scheme whereby CCN and cloud albedo can be affected by smoke aerosols

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

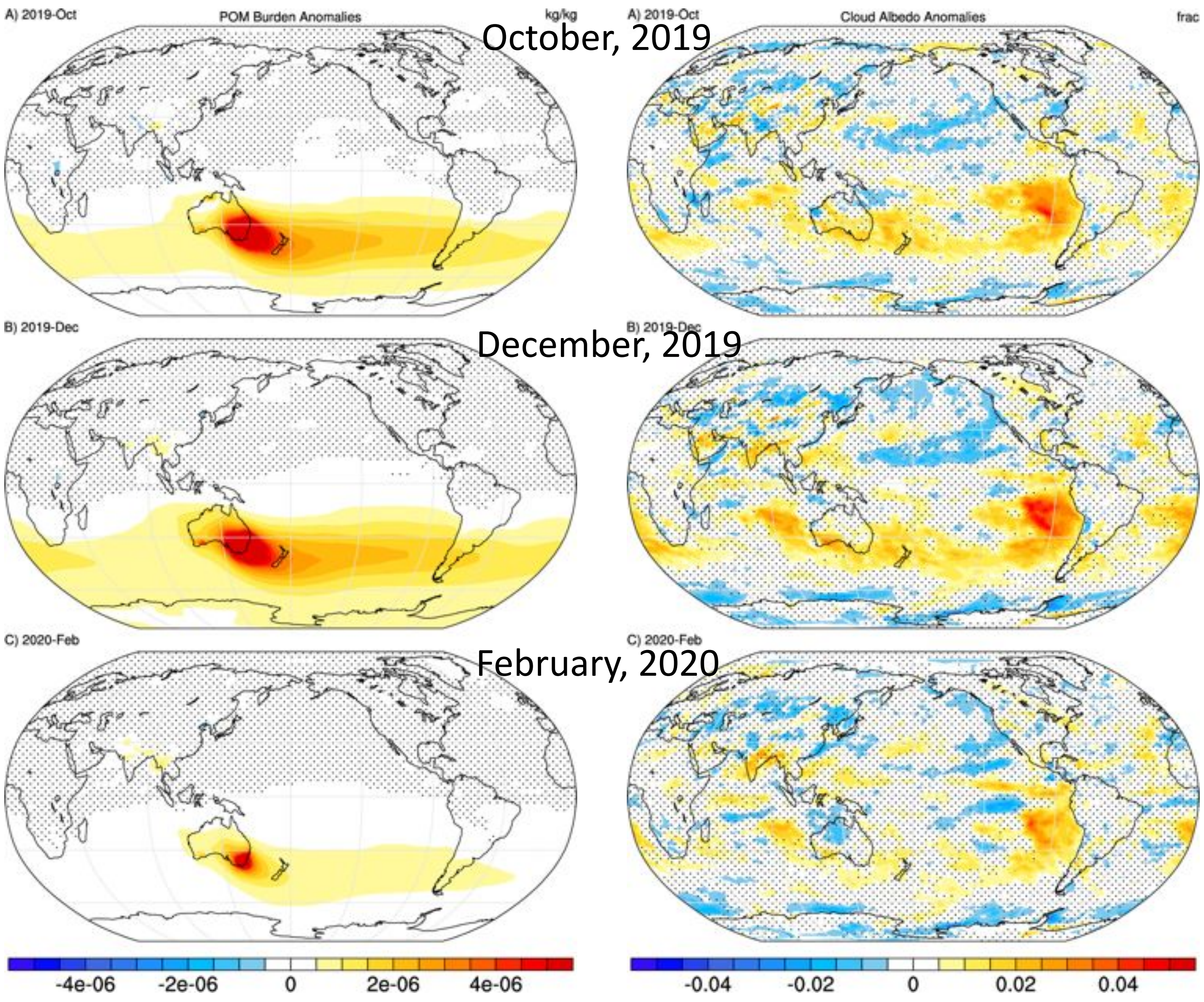
--One is run with the observed Australian bushfire smoke emissions from GFED ("AUFIRE" or "smoke", otherwise the same as the standard SMYLE experiment)

Smoke minus no-smoke: aerosols   cloud albedo

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.



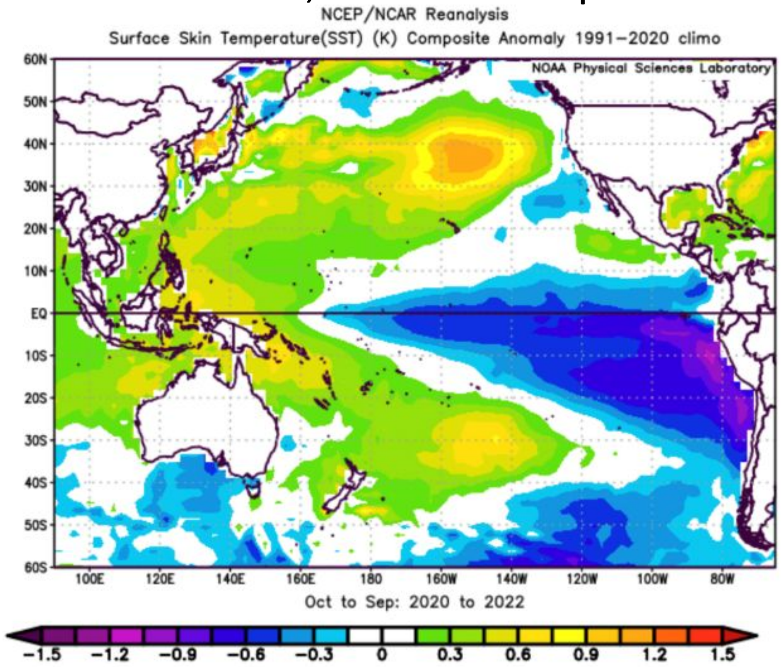
Aerosols are transported across the southern ocean;

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

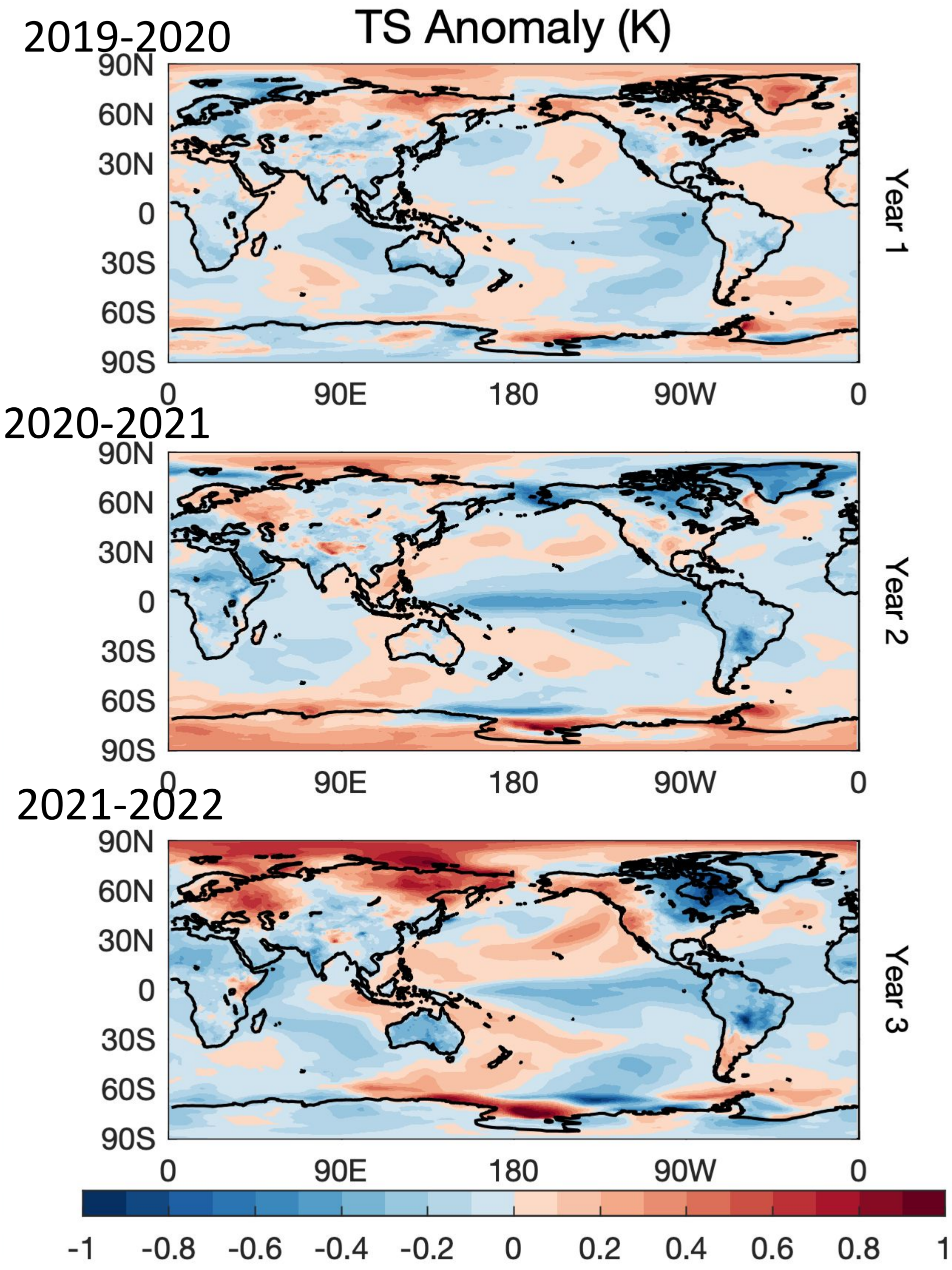
(Fasullo et al., 2021; 2022)

These SST anomalies persist for three years in the smoke minus no-smoke model differences, and resemble some aspects of the observations, particularly the connection to the Southern Hemisphere subtropics and midlatitudes

Observations, Oct. 2020-Sept 2022



Smoke minus no-smoke (Aug-July)



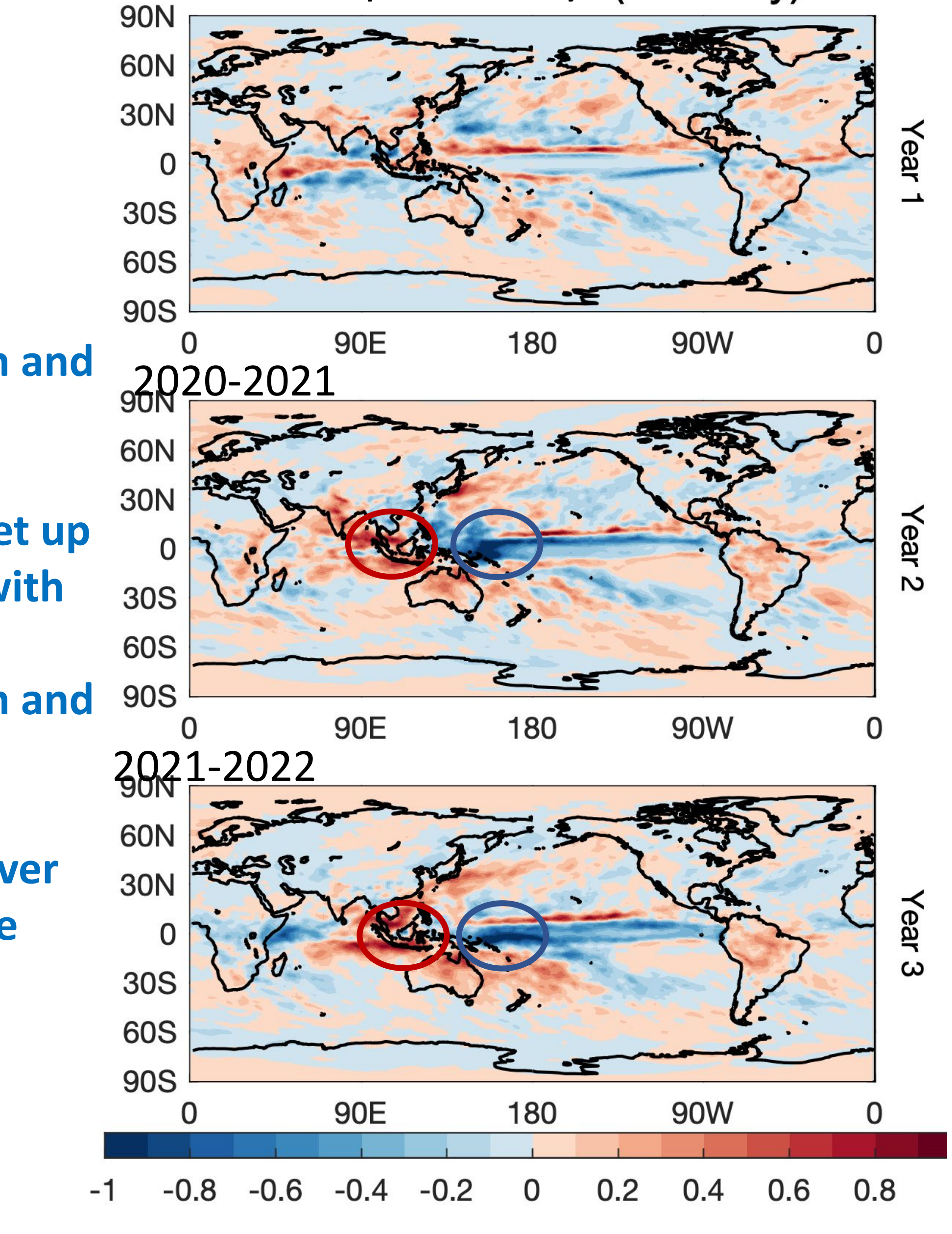
If the Australian wildfire smoke contributed to the initial La Niña-like response, and the smoke dissipated by March, 2020…

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

Negative precipitation and convective heating anomalies set up near 165E, with positive precipitation and convective heating anomalies over the Maritime Continent

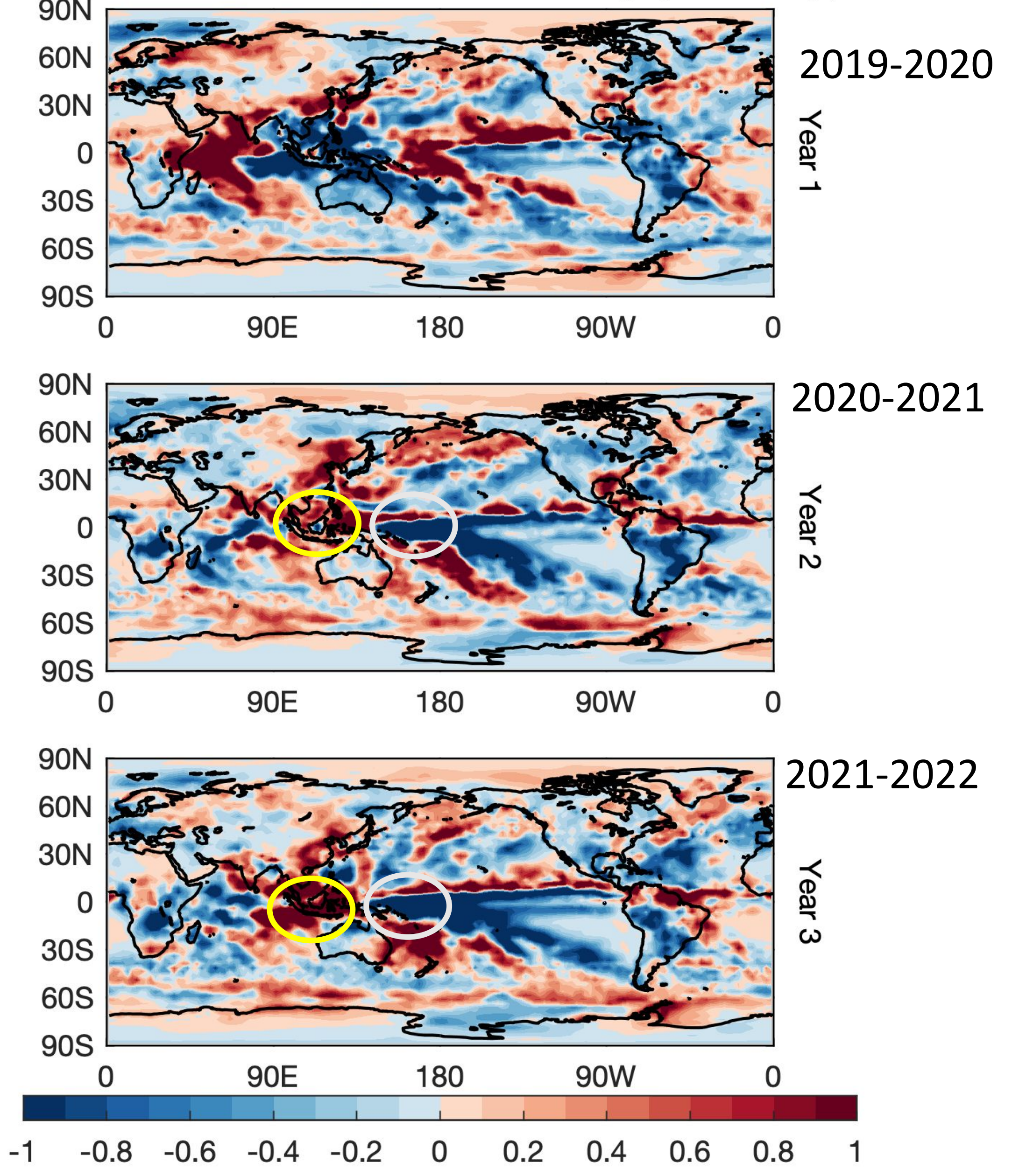
Smoke minus no-smoke (Aug-July)

2019-2020 Precip anomaly (mm/day)



observations (Aug-July)

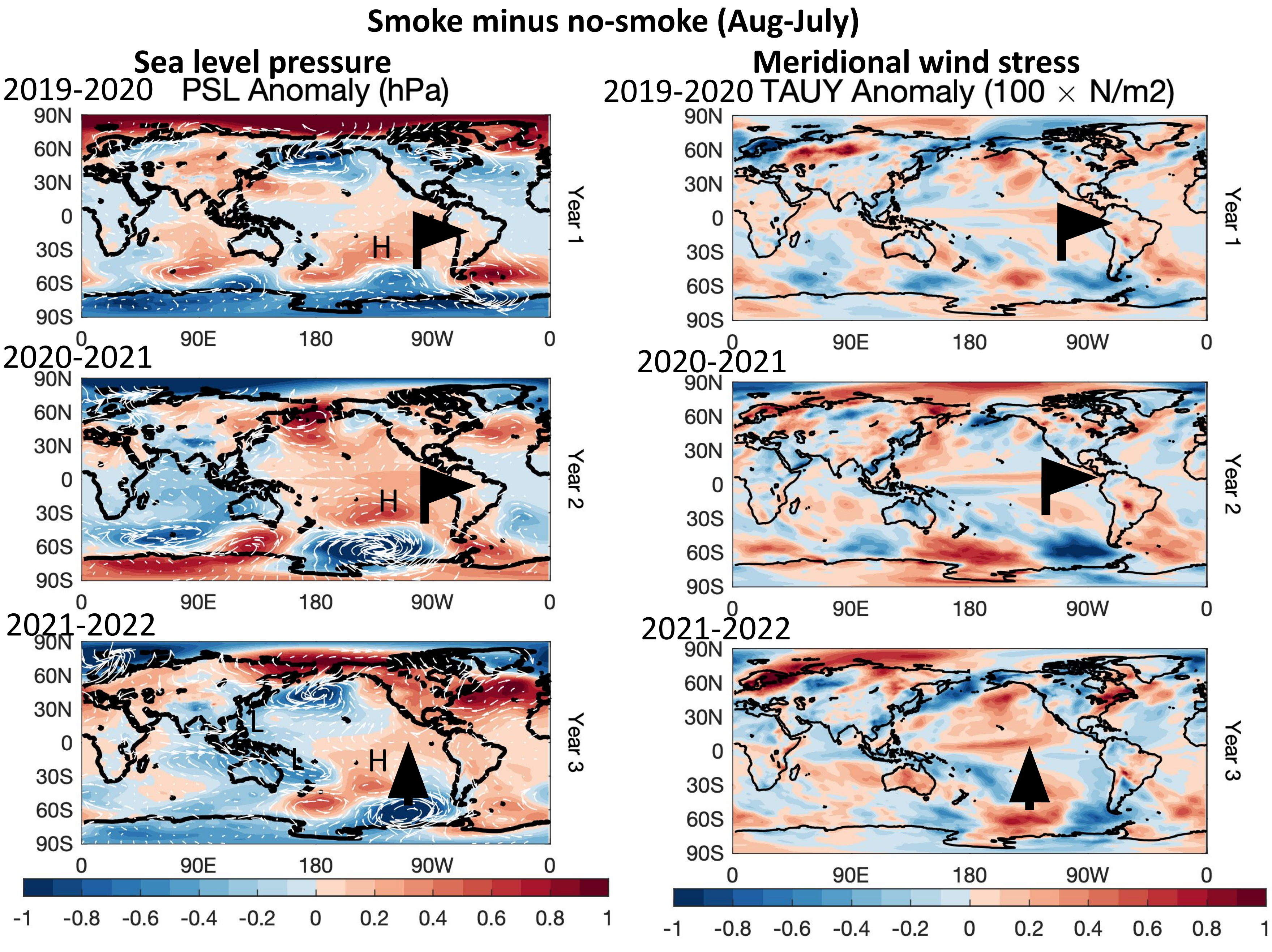
Observations Precip anomaly (mm/day) (GPCP)



The Walker Circulation intensifies with the strong convection over the Maritime Continent

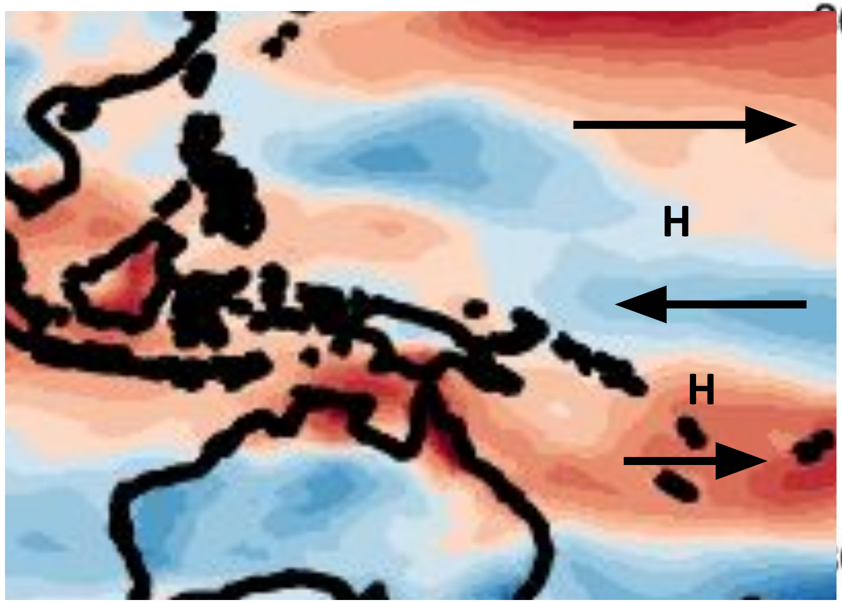
The South Pacific subtropical high strengthens, producing stronger northward wind stress and cold water advection into equatorial tropics

(e.g. Zheng et al., 2015, *Adv. Atmos. Sci.*; Song et al., 2022, *J. Mar. Sci. Eng.*; Fang et al., 2023, *Adv. Atmos. Sci.*)

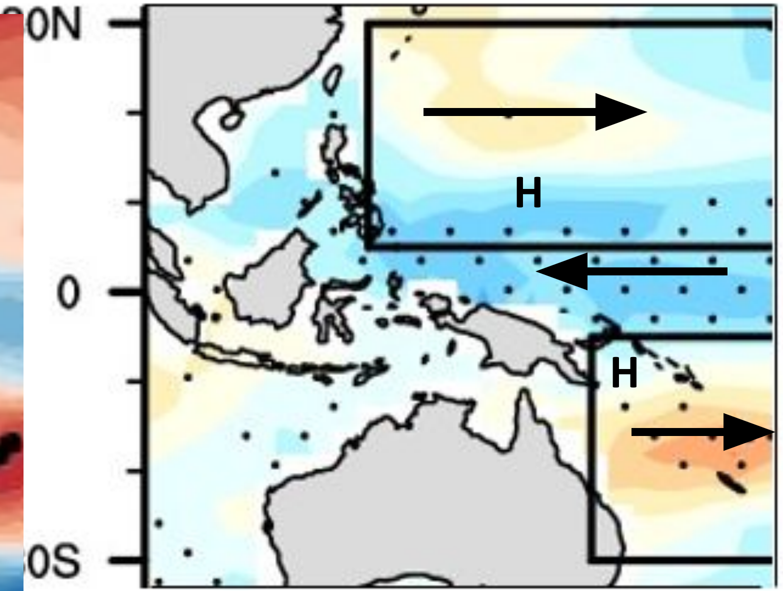


Negative convective heating anomaly near 165E produces u-component wind stress anomalies in off-equatorial western Pacific to sustain ocean heat content anomalies

Smoke minus no-smoke: u-component wind stress

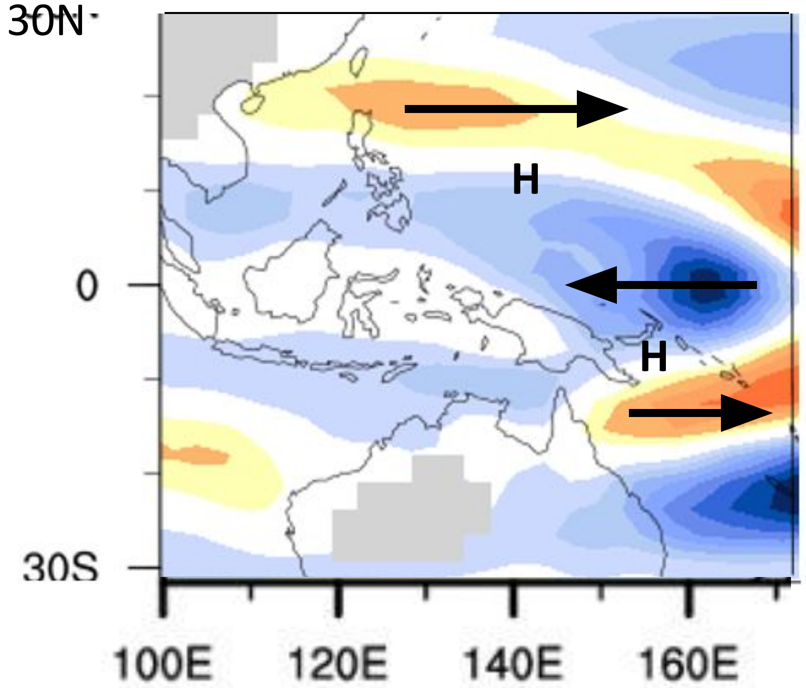


2021-2022



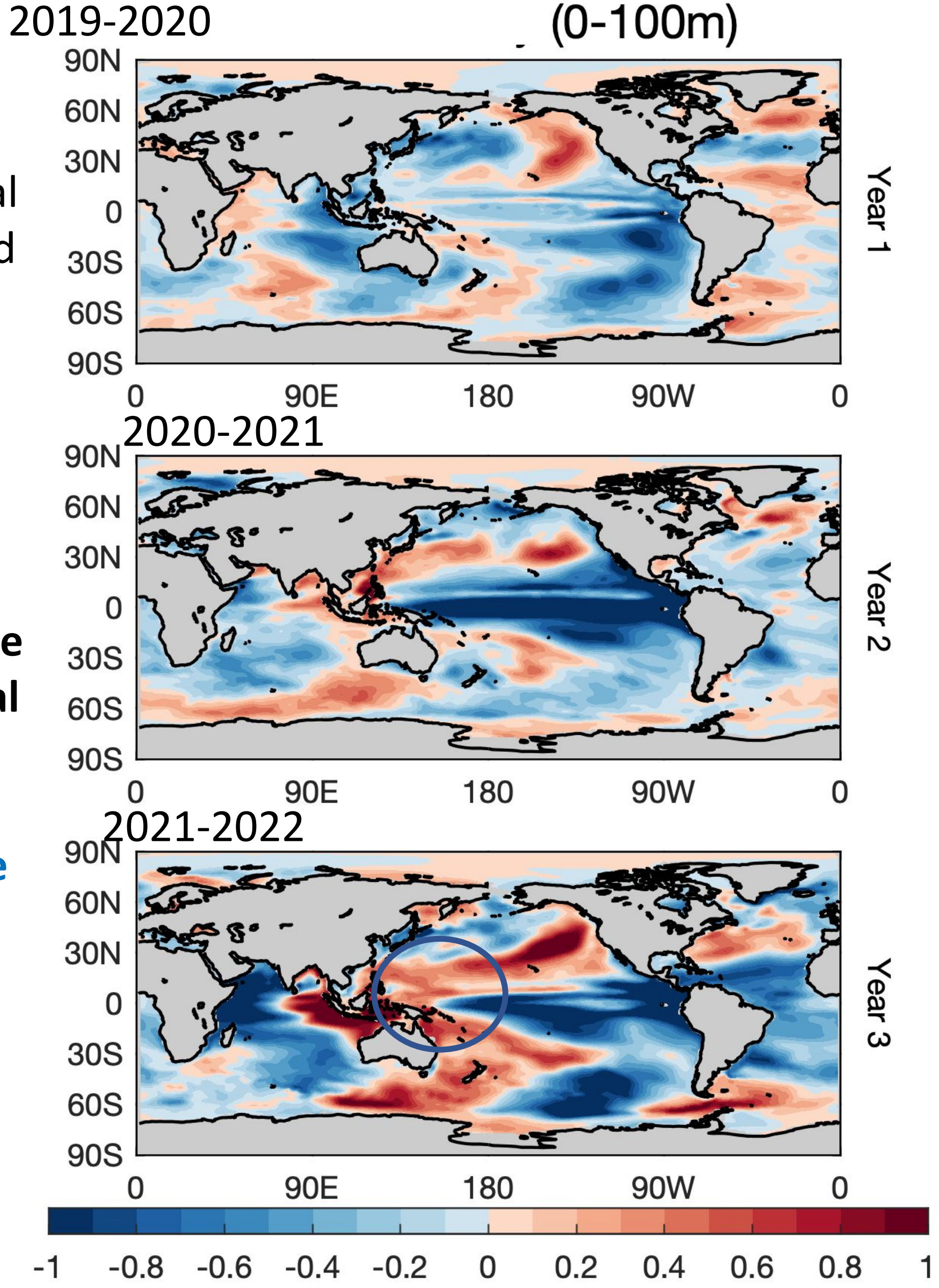
Model control run composite u-component wind stress, negative IPO

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



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

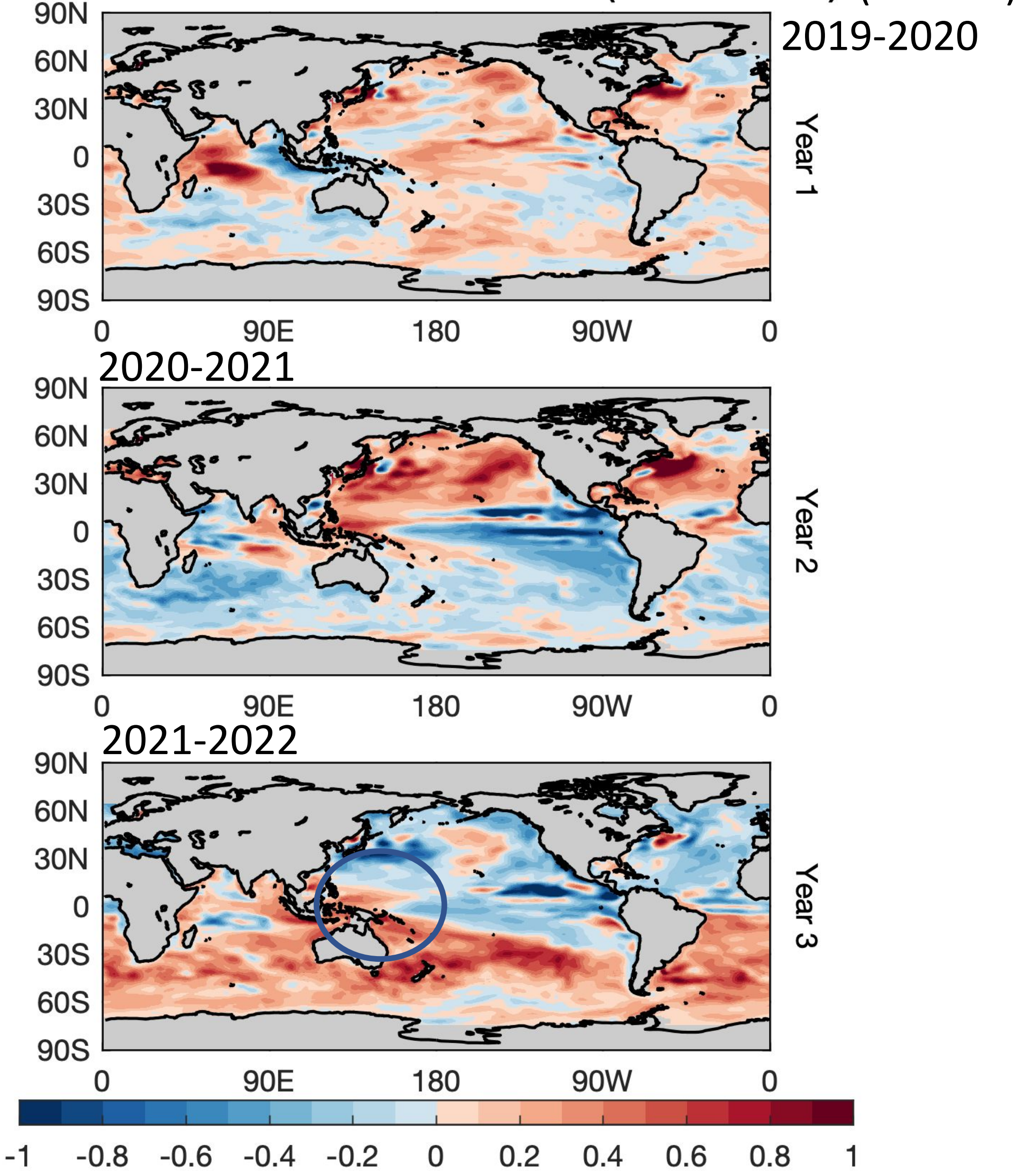
Ocean heat content Smoke minus no-smoke (0-100m)



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

Ocean heat content

Observations (10^9 Joules) (GODAS)



Summary

The IPO appeared to transition from negative to positive around 2015, triggered by the 2015-2016 El Niño event, with a decrease in off-equatorial western Pacific ocean heat content as in previous transitions

But around 2019, coincident with the Australian bushfires, there was the start of a three year La Niña, and the IPO seemed to transition back to negative

The processes:

smoke advected across the Pacific → clouds brighten off the South American coast → reduced incoming solar at the surface → SSTs cool → South Pacific High strengthens → trade winds strengthen → cooler water advected into the equatorial eastern Pacific → Bjerknes feedbacks spread the cooler water across the Pacific → reduced SSTs and precipitation in the western equatorial Pacific → SSTs and precipitation increase over the Maritime Continent → Walker circulation strengthens

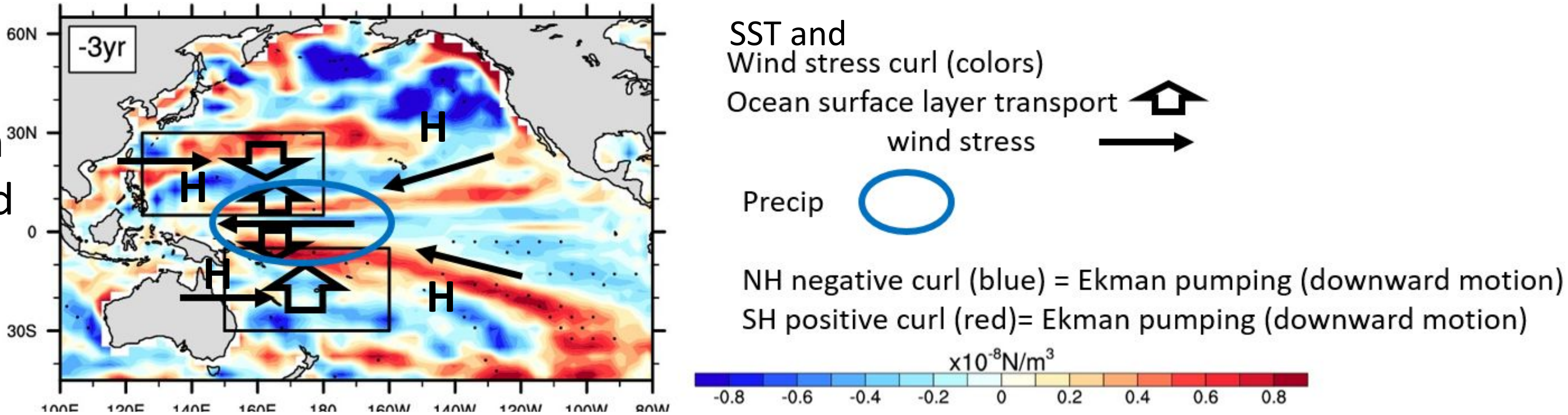
The feedbacks:

1. Walker Circulation strengthens → South Pacific High becomes stronger → northward surface wind stress in southeast Pacific increases → even more cool water advected into the equatorial Pacific, and so on

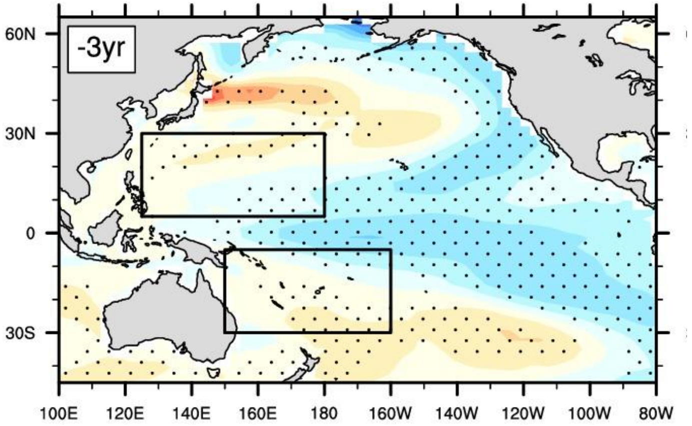
2. negative convective heating anomalies in the western equatorial Pacific produce a Gill-type response → produce off-equatorial westerly wind stress anomalies → Ekman pumping near 15N and 15S → increased off-equatorial western Pacific ocean heat content → sustained negative IPO → reduced rate of global warming

In past negative IPO events, they end with a strong El Niño event triggering a transition back to positive IPO…

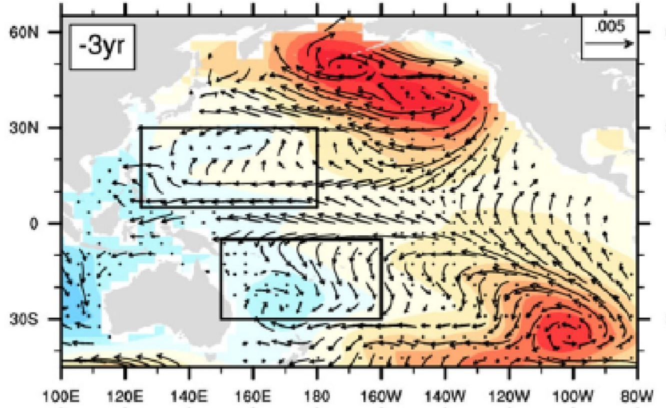
Curl of u component wind stress (colors); thin arrows denote wind stress anomalies; thick arrows show wind driven ocean transport



SST



SLP and wind stress



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

negative IPO:

persistent easterly anomaly equatorial surface winds and negative SST precipitation and convective heating anomalies in the western eq. Pacific

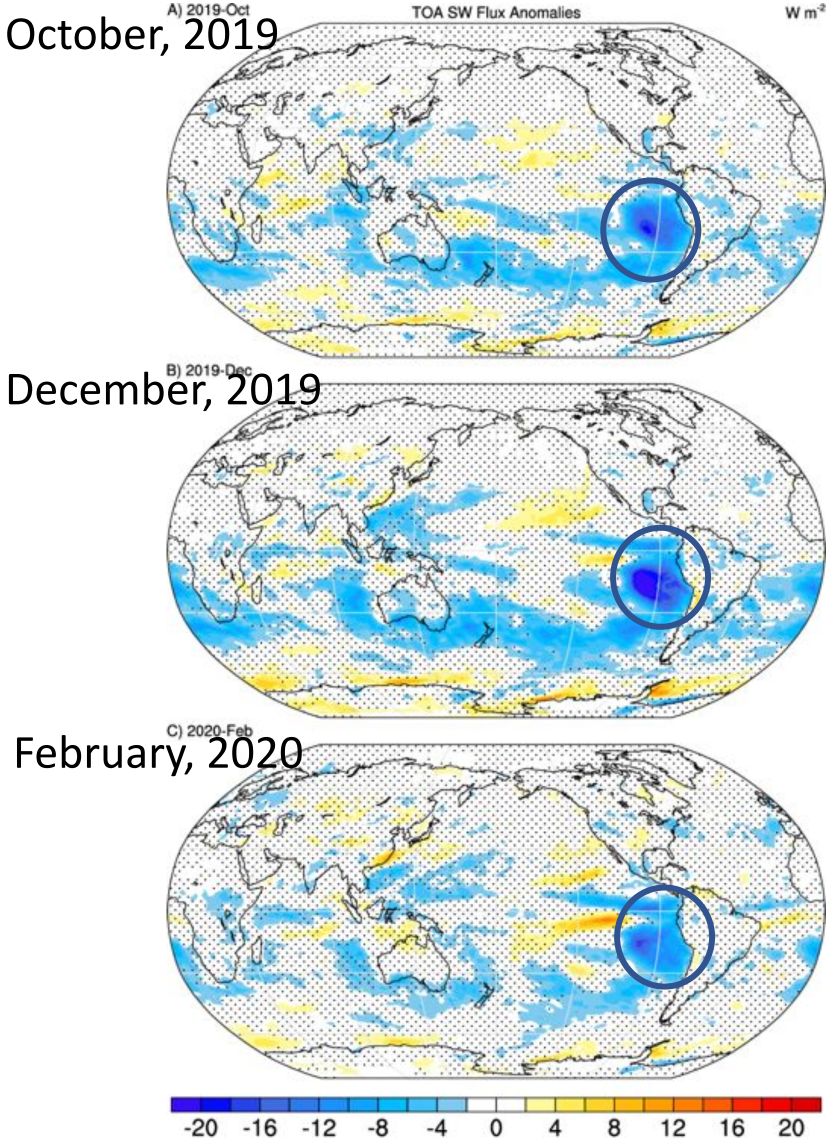
--Gill-type response to the northwest and southwest with easterly wind stress anomalies near 20°N and 15°S

-- wind stress curl anomalies (negative near 15°N, positive near 10° S) and consequent negative vertical motions in the upper ocean produce accumulation of heat content and convergence of warmer water into the off-equatorial western Pacific.

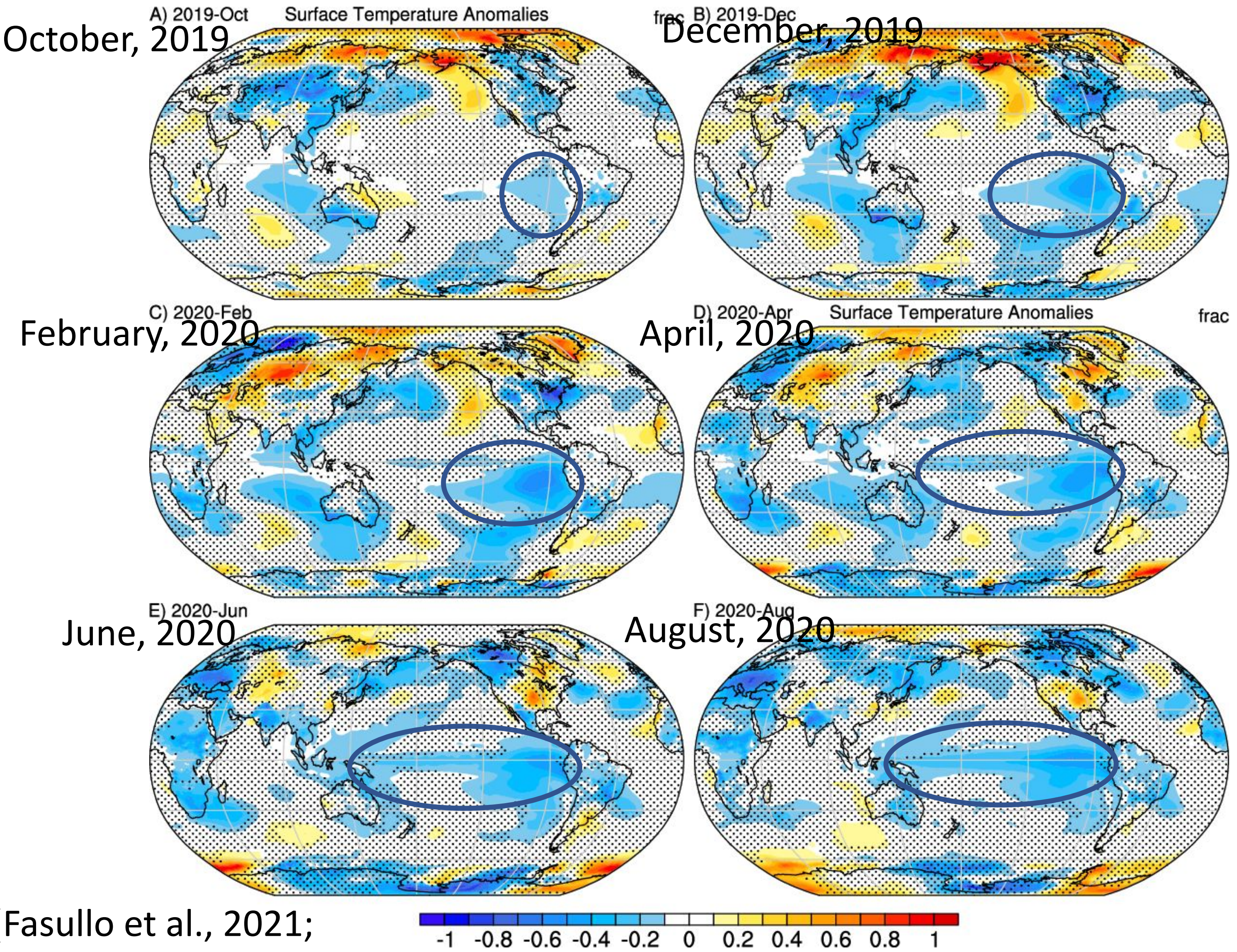
--stronger Trades in eastern tropical Pacific from anomalous high pressure in North and South Pacific from negative convective heating anomalies in equatorial central Pacific produce ocean Rossby waves that propagate slowly to the west, and NPMM and SPMM-type SST patterns

As clouds brighten in the southeastern Pacific, net solar at the surface is reduced, and cooler SSTs are advected into the equatorial eastern Pacific, and then all the way across the equatorial Pacific from 2019-2020, an externally forced La Niña?

Smoke minus no-smoke: net solar



Smoke minus no-smoke: surface temperature



(Fasullo et al., 2021; 2022)

There are a number of ways to deal with bias and drift when computing anomalies to evaluate skill of initialized multi-year hindcasts:

1. **Forecast year differences from a model climatology (e.g. Doblas-Reyes, et al 2013: Boer et al., 2016 for DCPP)**

(trends in bias and drift introduce enhanced skill estimates for earlier and later in the hindcast period)

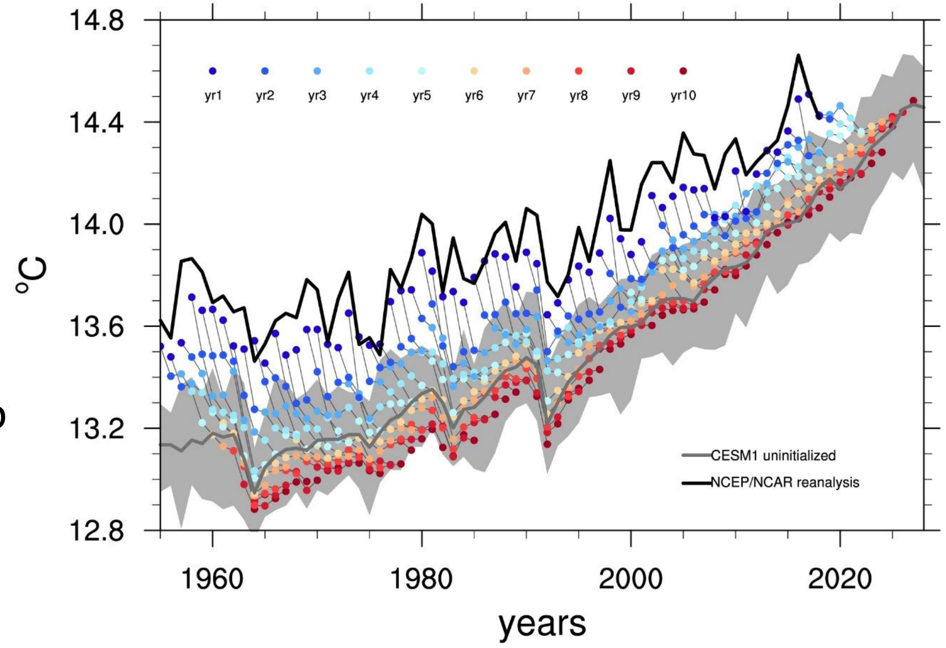
2. **Bias-adjusted lead year differences from the previous 15 year average from observations (e.g. Meehl et al., 2016)** (unrealistic skill can be introduced when lo frequency variability in the observations is large compared to the hindcasts on timescales greater than 15 years)

3. **Forecast year differences from the previous 15 year average of model initial states (Meehl et al., 2021)**

(somewhat lower skill compared to each of the previous methods, but less difficulties with long term trends in the model climatology, and no unrealistic situational skill from using observations as a reference)

4. **Form anomalies from a sensitivity hindcast experiment for the same time period as a reference hindcast**

(unambiguously removes bias and drift, but can only be used in a sensitivity experiment context)



(Meehl, Teng, Smith, Yeager, Merryfield, Doblas-Reyes, and Glanville, 2021, *Cli. Dyn.*)