JGR Atmospheres

On the Effect of Historical SST Patterns on Radiative Feedback

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https://doi.org/10.1029/2022JD036675 - 2022

The "pattern effect"

CFMIP July 2023

What is a pattern effect?

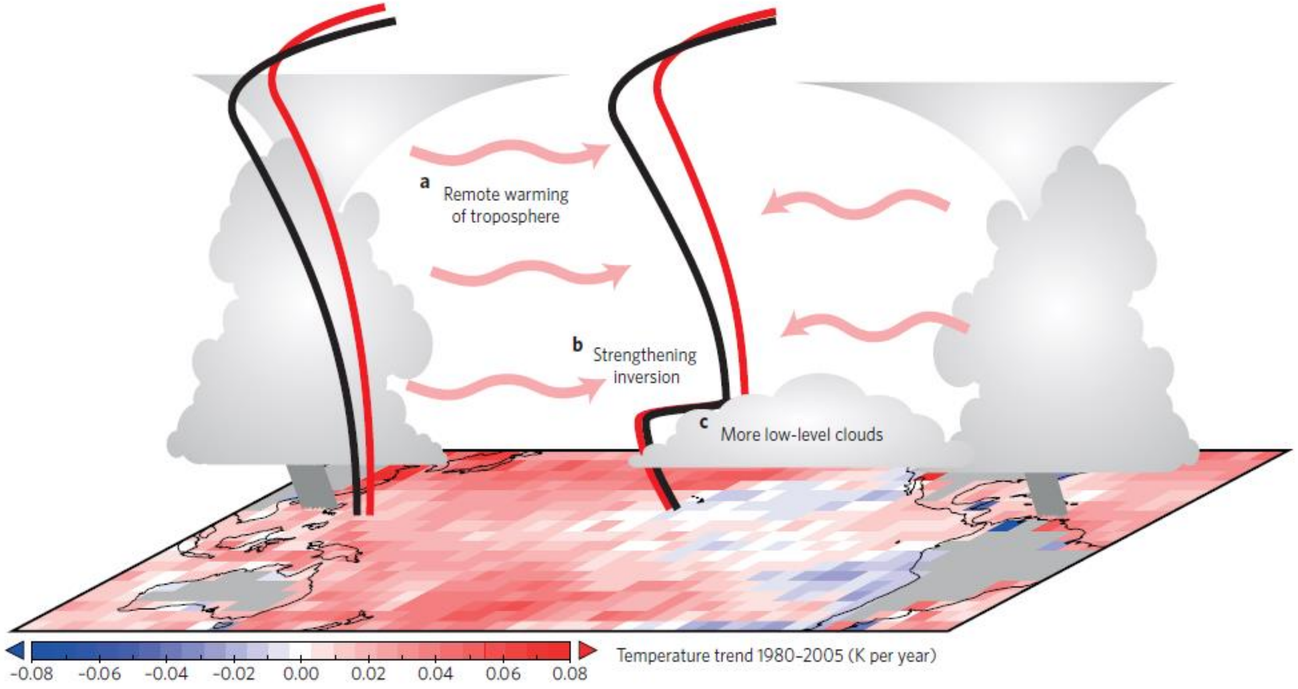
Climate feedbacks (especially cloud & lapse-rate) vary with the pattern of surface warming on various timescales.

- Warming in the west pacific warm pool – a region of deep ascent and convection – efficiently warms the free troposphere, leading to an increased negative lapse-rate feedback and stability increases widely across the tropics, leading to increased low level cloudiness (negative feedback).

When the planet warms with (relatively) strong western Pacific warming it has a low ECS.

- Warming in the eastern pacific – characterised by descending air and marine low cloud decks trapped under an inversion which form over the relatively cool upwelled SSTs – is 'trapped' in the boundary layer, resulting in reduced stability and cloudiness (strong positive cloud feedback) and no accompanying lapse-rate feedback.

When the planet warms with (relatively) strong eastern Pacific warming it has a high ECS.



Mauritsen (2016)

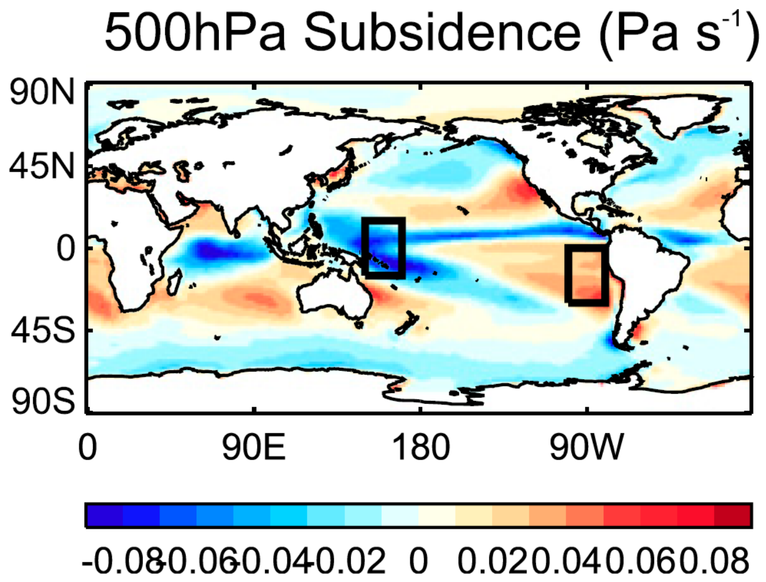
We see these processes and mechanisms in observations (e.g. Ceppi and Gregory, 2017; Fueglistaler and Silvers, 2021).

Key point: Historical record (at least recently) looks like top, while AOGCMs, paleo and some theory look like bottom.

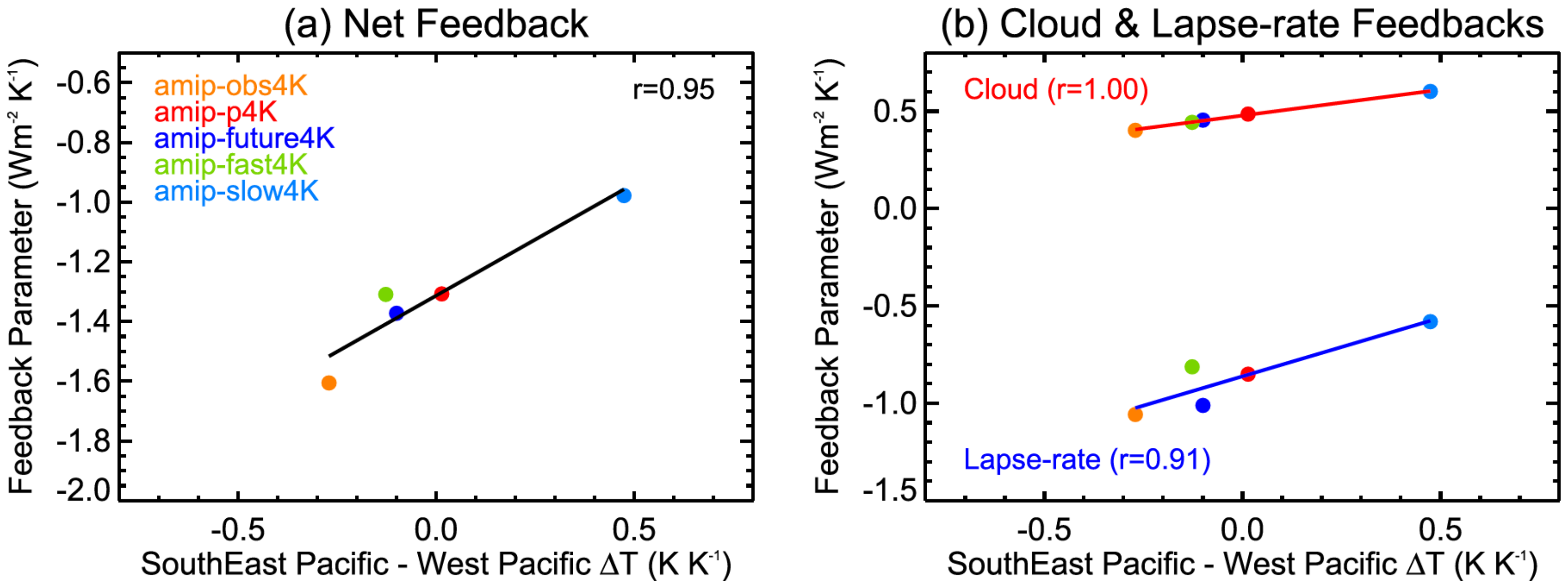
(See Zhou et al. 2016; Andrews and Webb, 2018; Ceppi and Gregory, 2017; Dong et al. 2019)

Various metrics of tropical pacific dSST pattern help explain feedback variations

- SEP – WP (Andrews and Webb, 2018).
- Omega500 (Ascending – descending) (Zhou et al., 2016).
- SST# (Fueglistaler and Silvers, 2021).
- EIS (Ceppi and Gregory, 2017).



Andrews and Webb (2018)



What's new? We now have a dataset of 14 AGCM simulations forced with real world SST & sea-ice variations, like AMIP, but with forcing agents constant (*amip-piForcing – proposed at CFMIP 2015*)

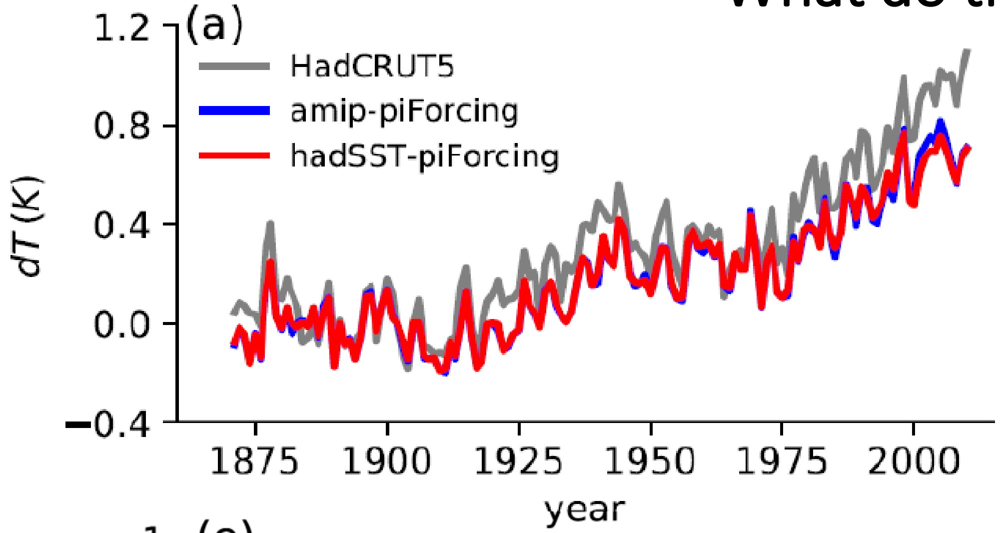
Table 1
Summary of the Atmospheric General Circulation Model Simulations Used in This Study

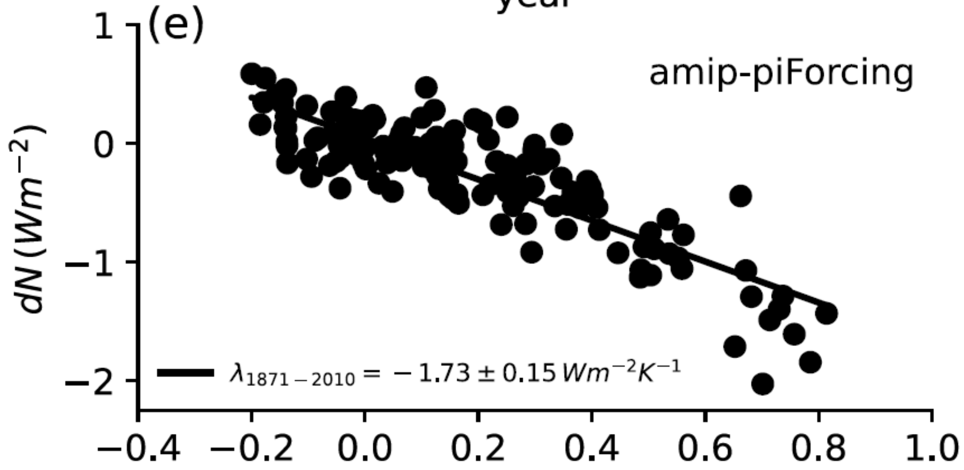
			amip-piForcing			*hadSST-piForcing*	
AGCM	Corresponding AOGCM name	Model description	CMIP6? (y/n)	Ensemble size	Time-period covered	Ensemble size	Time-period covered
CAM4	CCSM4	Neale et al. (2013)	n	3	1870–2014	3	1870–2014
CESM2	Unchanged	Danabasoglu et al. (2020)	y	1	1870–2014	1	1870–2015
CNRM-CM6-1	Unchanged	Voldoire et al. (2019)	y	1	1870–2014	–	–
CanESM5	Unchanged	Swart et al. (2019)	y	3	1870–2014	–	–
ECHAM6.3	MPI-ESM1.1	Mauritsen et al. (2019)	n	5	1871–2010	5	1871–2015
GFDL-AM3	GFDL-CM3	Donner et al. (2011)	n	1	1870–2014	1	1870–2014
GFDL-AM4	GFDL-CM4	Held et al. (2019)	n	1	1870–2016	1	1870–2016
HadAM3	HadCM3	Pope et al. (2000)	n	4	1871–2012	4	1871–2012
HadGEM2	HadGEM2-ES	Martin et al. (2011)	n	4	1871–2012	1	1871–2012
HadGEM3-GC31-LL	Unchanged	Williams et al. (2017)	y	1	1870–2014	1	1871–2016
IPSL-CM6A-LR	Unchanged	Boucher et al. (2020)	y	1	1870–2014	–	–
MIROC6	Unchanged	Tatebe et al. (2019)	y	1	1870–2014	–	–
MRI-ESM2-0	Unchanged	Yukimoto et al. (2019) and Kawai et al. (2019)	y	1	1870–2014	–	–
MPI-ESM1-2-LR	Unchanged	Mauritsen et al. (2019)	n	3	1871–2017	3	1871–2017

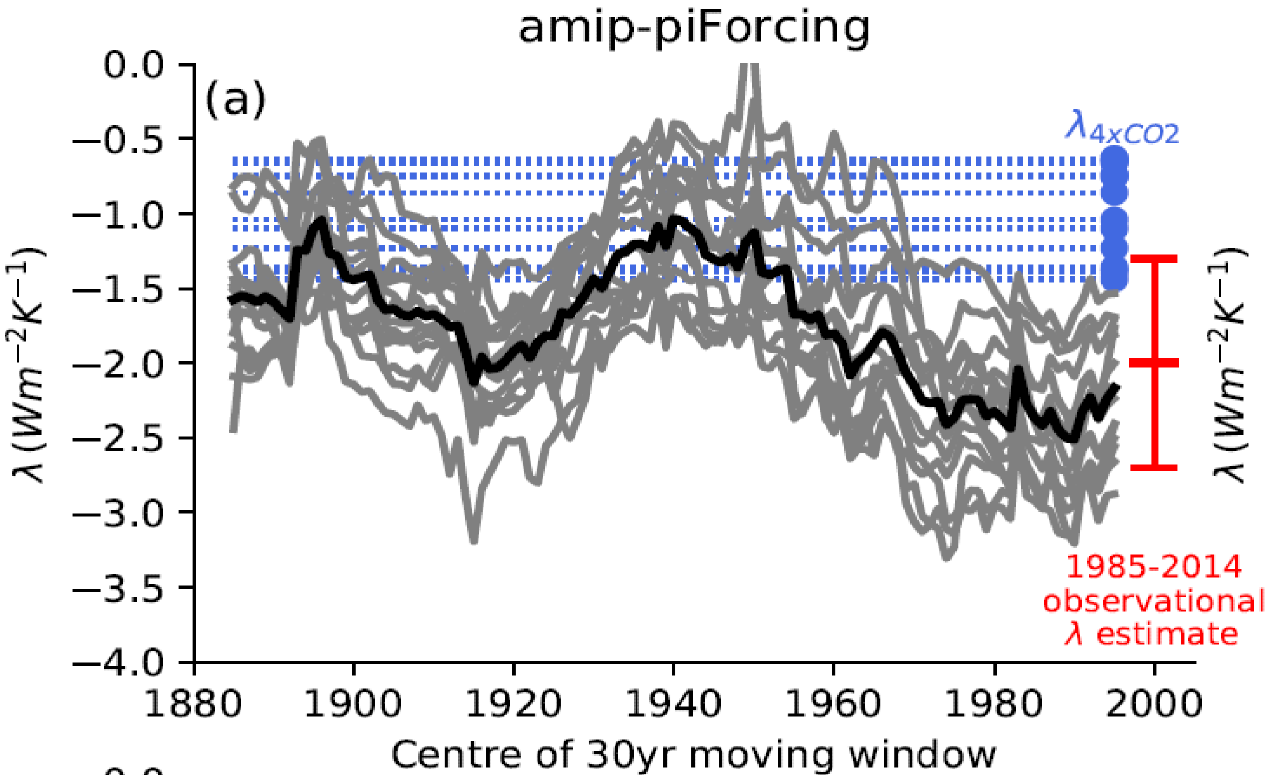
Note. amip-piForcing refers to an AGCM simulation forced with time-varying observed monthly SSTs and sea-ice using the AMIP II boundary condition SST and sea-ice data set, forcing agents such as greenhouse gases, aerosol emission etc. are kept at preindustrial levels. *hadSST-piForcing* is identical in all aspects except SSTs are taken from the HadISST1 database (sea-ice remains the same as *amip-piForcing*). The ensemble size and time-periods covered for each experiment and AGCM is indicated. *amip-piForcing* simulations included in the CFMIP3 (Webb et al., 2017) contribution to CMIP6 are indicated by a y/n. The corresponding name of each AGCMs parent AOGCM is indicated. Global-annual-ensemble-mean dT and dN time series data are available for all *amip-piForcing* and *hadSST-piForcing* AGCM simulations (see Data Availability Statement Statement).

NetCDF files for all global-annual-mean dT and dN available at https://github.com/timothyandrews/amip-hadSST-piForcing

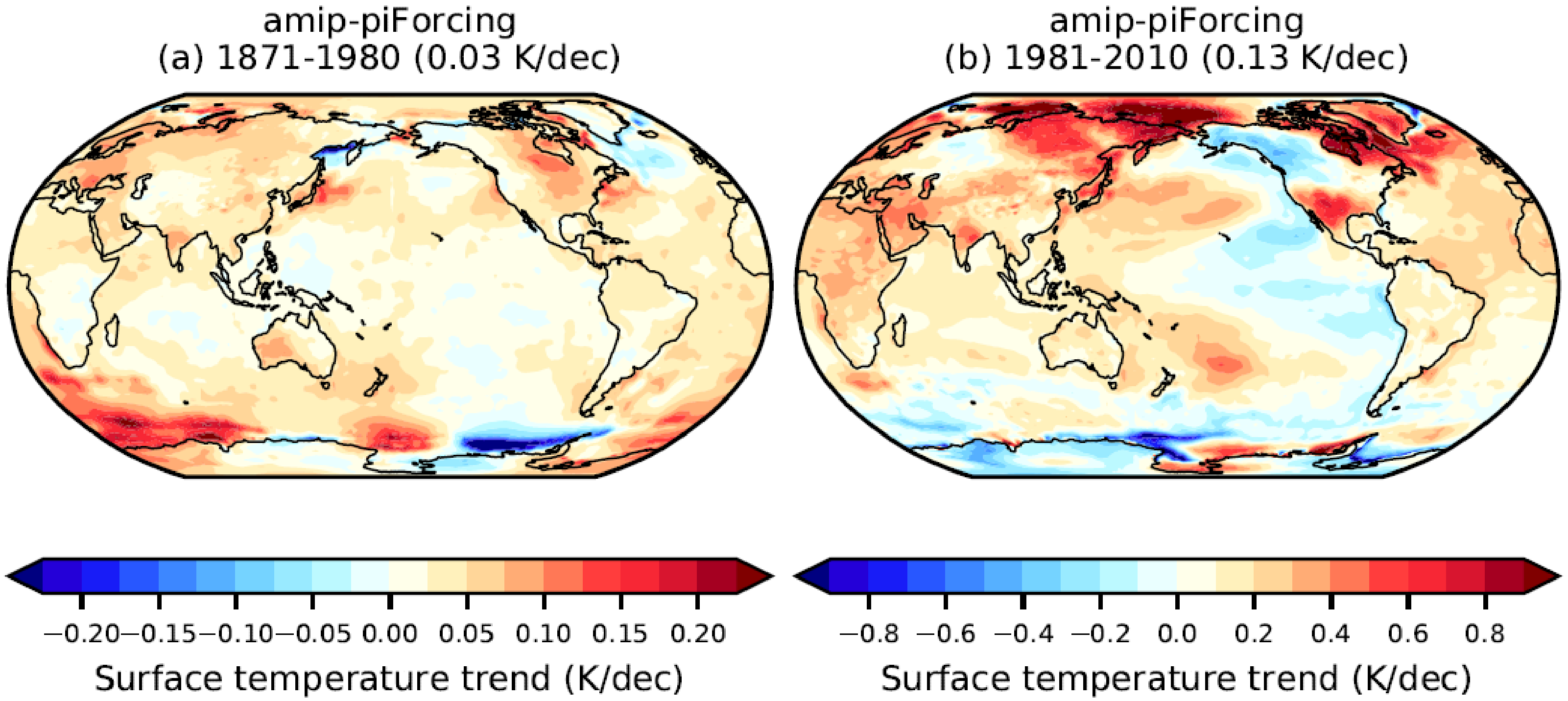
What do these simulations look like

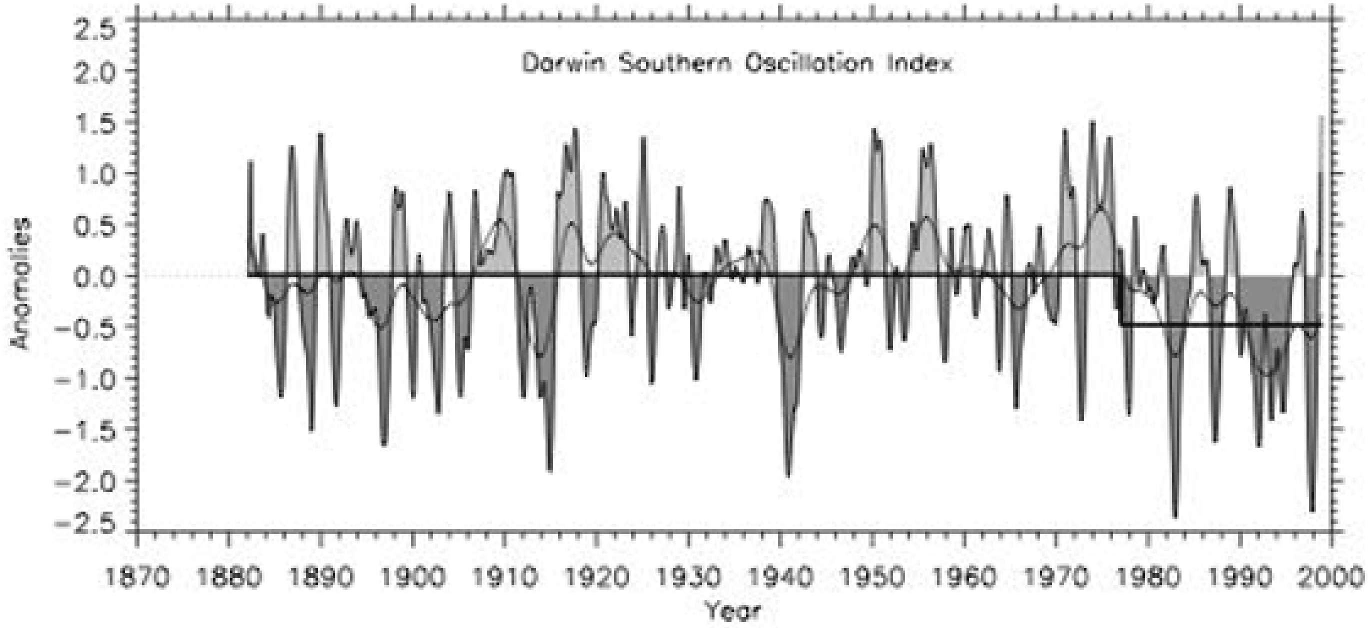






- **Simulations have the same global and regional SST pattern as the observed over the historical record**, with no change in forcing agents, so feedbacks can be trivially diagnosed from the radiation budget (e.g. lambda=d*N*/d*T*).
- Moving 30yr window of feedbacks, shows it becomes strongly negative (pattern effect largest, i.e. difference to $4xCO_2$) over the most recent decades that cover satellite records. Motivates us to separate the historical record here…

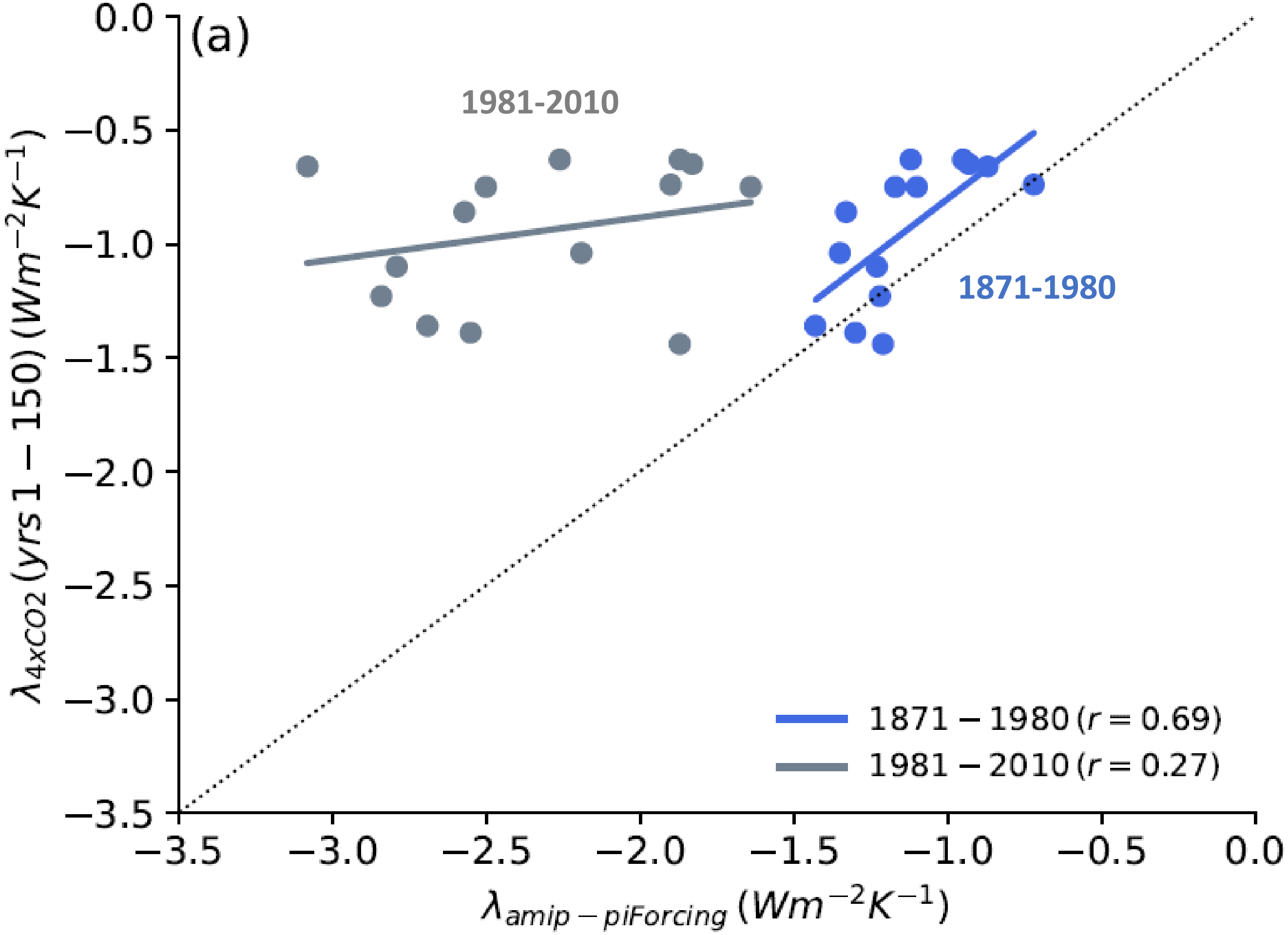




Now let's separate the historical record at ~1980, principal reasons:

1. Post 1980 is sometimes argued to be the best time period for constraining ECS:
   - Contains a well observed large global *T* response attributable to increasing GHGs.
   - Avoids the aerosol forcing uncertainty issue.
   - Is extremely well observed.
2. On the other hand, post 1980 the Earth warmed with an 'unusual' pattern (regions of deep convection warmed ~50% more than the tropical mean (Fueglistaler and Silvers, 2021)) that has driven a large negative cloud and lapse-rate feedbacks (very large pattern effect).
3. The 'great climate shift' from 1976 in the Pacific (e.g. Meehl et al., 2009).

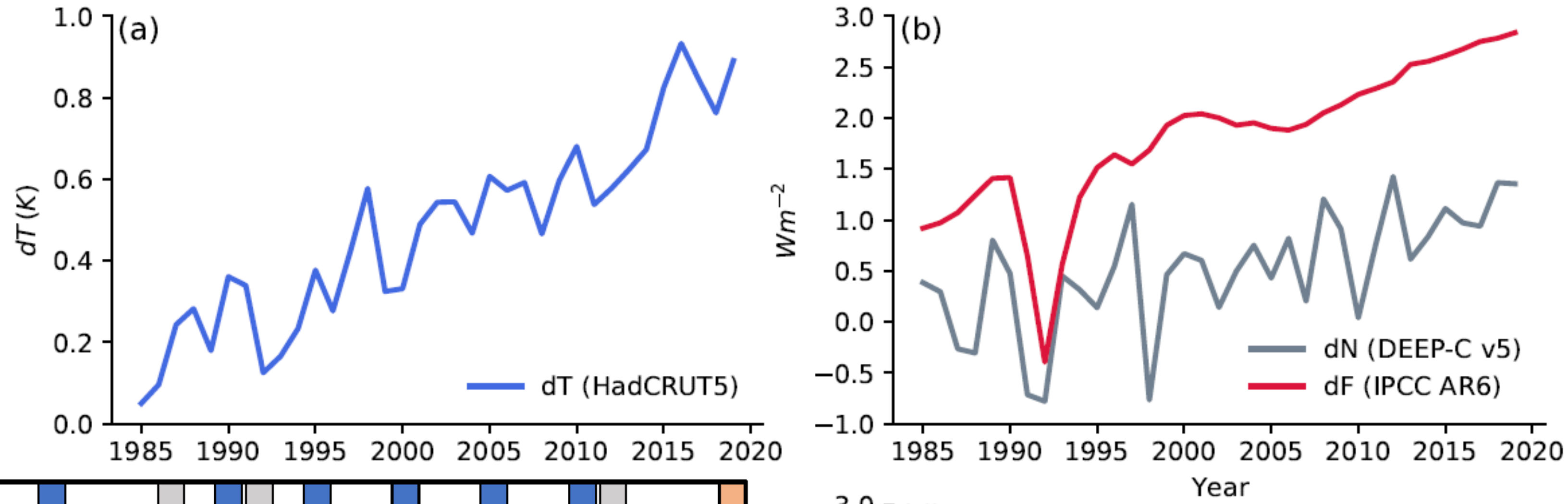
Feedbacks over 1871-1980 and post 1980. An unfortunate situation…

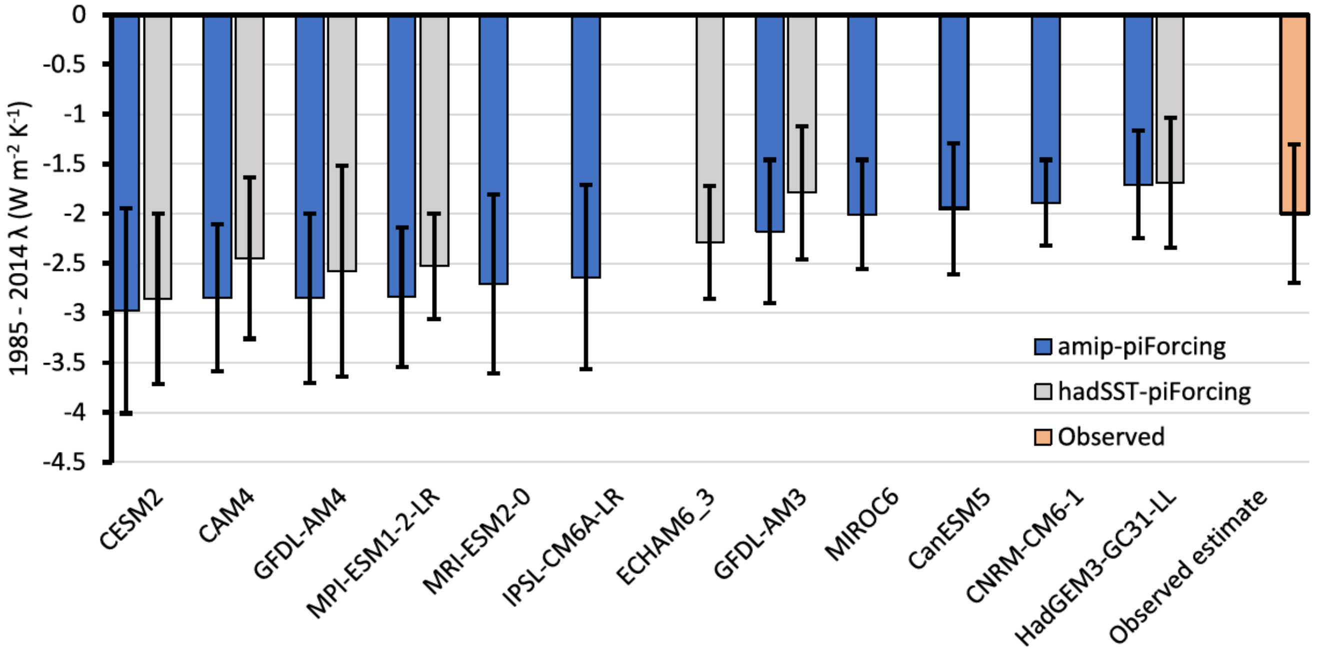


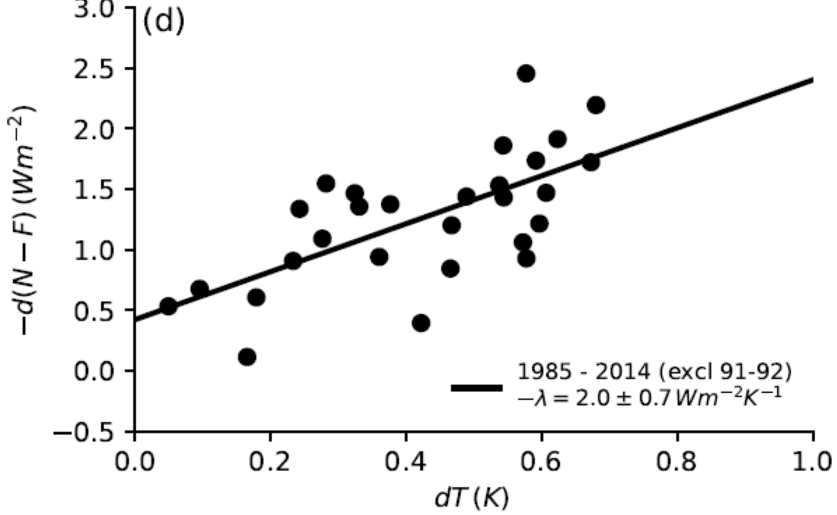
- Feedbacks post 1980 (grey dots) are unrepresentative of long term CO_2 driven feedbacks (large pattern effect, away from 1:1 line), but also largely uncorrelated with them (r=0.27).
- This is surprising. It might have been the best time period for constraining ECS. Yet, it is the opposite; it is the worst period.
- This is also unfortunate, we have been observing the Earth at the worst possible time for constraining long term sensitivity.
- Ironically, feedbacks acting earlier in the record (1871-1980) are more representative of the long-term response (smaller pattern effect, on 1:1 line) & do correlate with λ_{4xCO2} across models (r=0.69). Yet this period has a smaller climate change signal and is not as well observed. The usefulness of this time-period in constraining λ_{hist} is limited.

Are observations of recent (1985 – 2014) decadal climate change in agreement with the models? Yes.

dT = HadCRUT5
dF = IPCC AR6 ERF
dN = DEEP-C v5 (satellite based reconstruction of TOA fluxes from 1985 by merging ERBE and CERES, Allan et al. 2014)

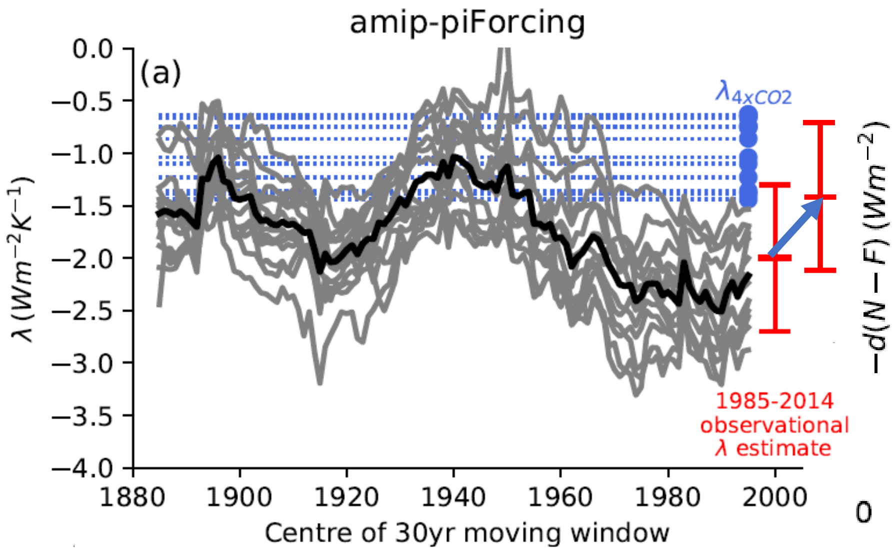


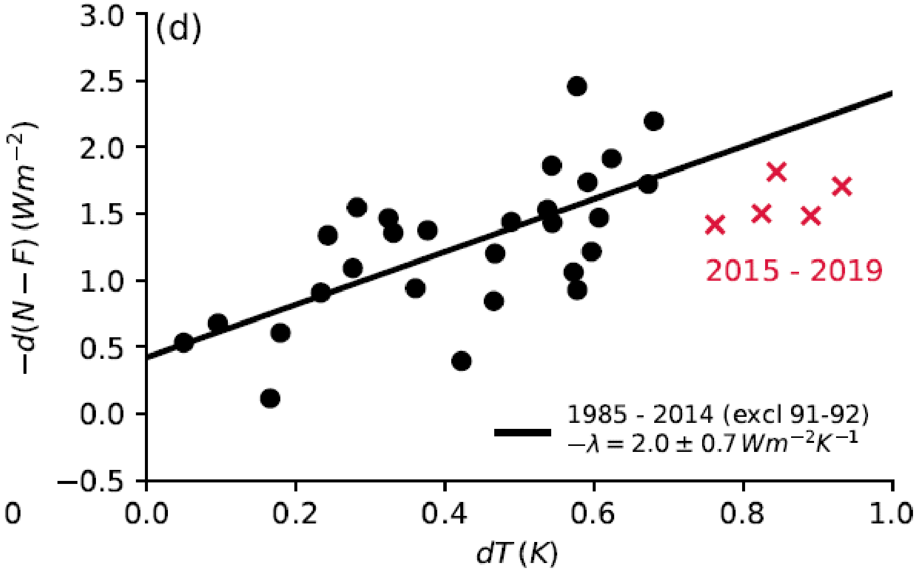


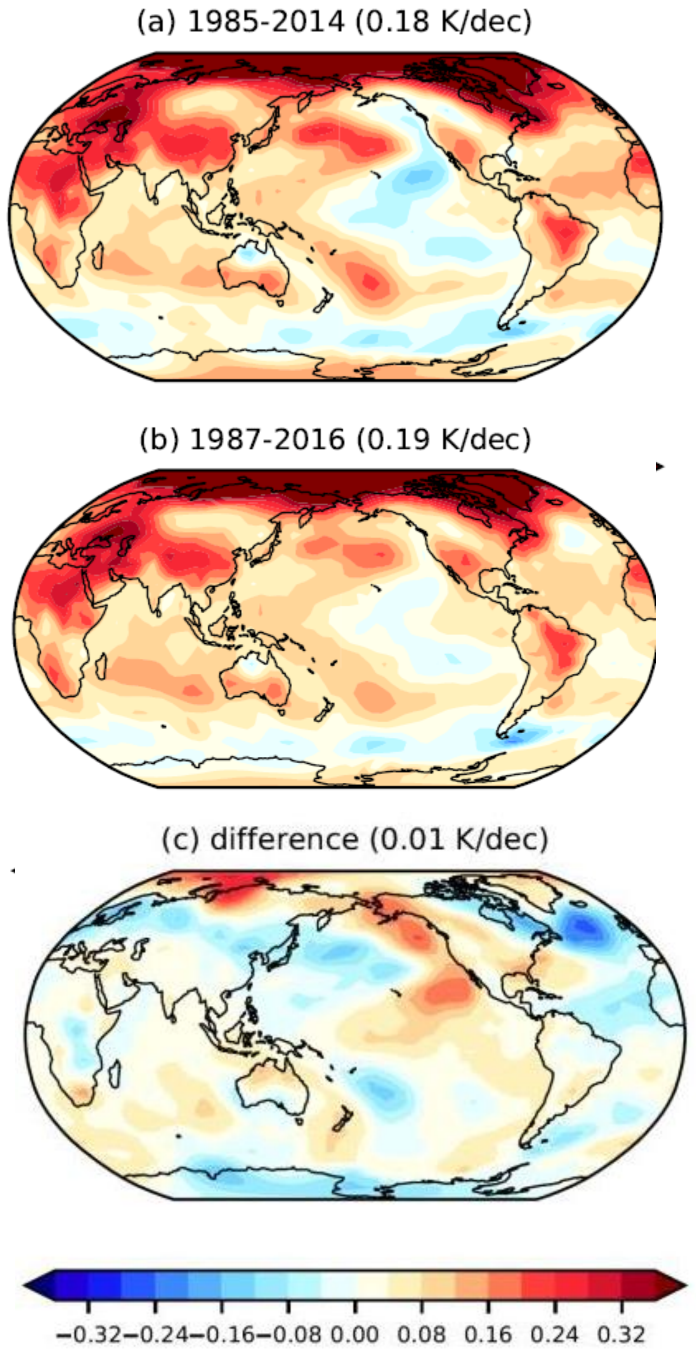


Obs in agreement with AGCMs for strongly stabilizing feedbacks over recent decades (~ $-2Wm^{-2}\,K^{-1}$, or EffCS ~ 2.0K).

Are we at a turning point?

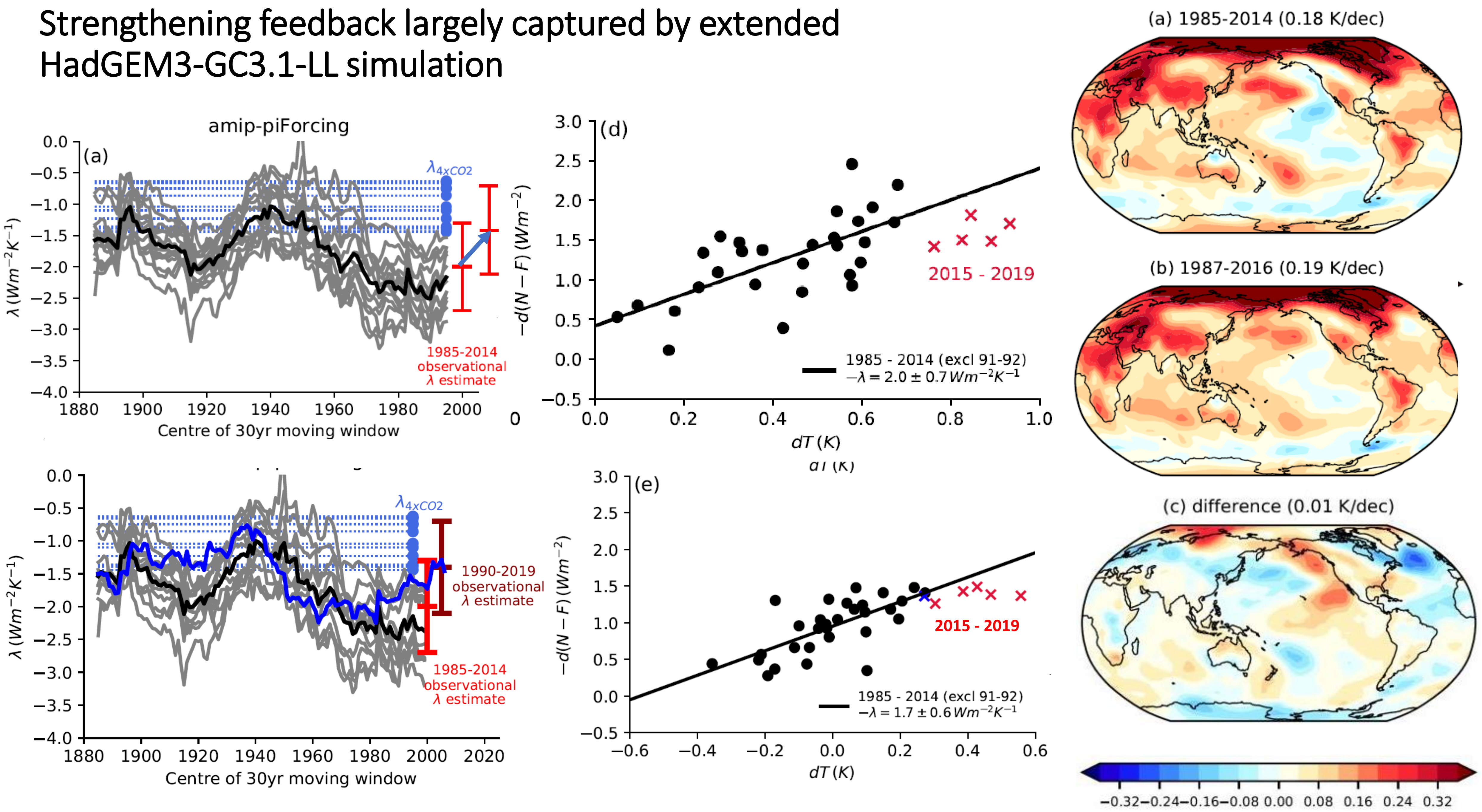




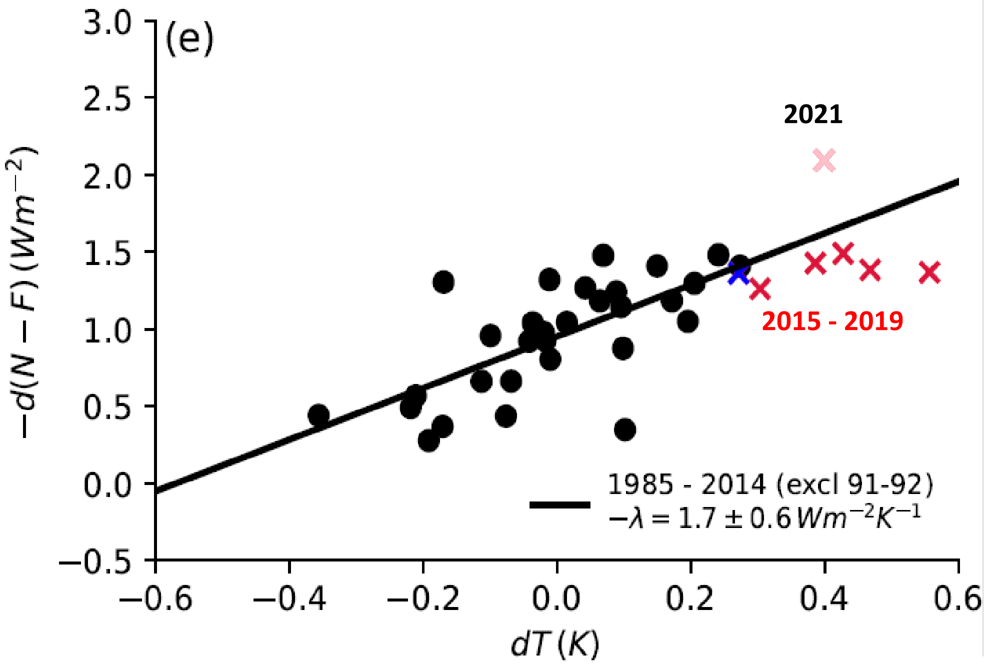


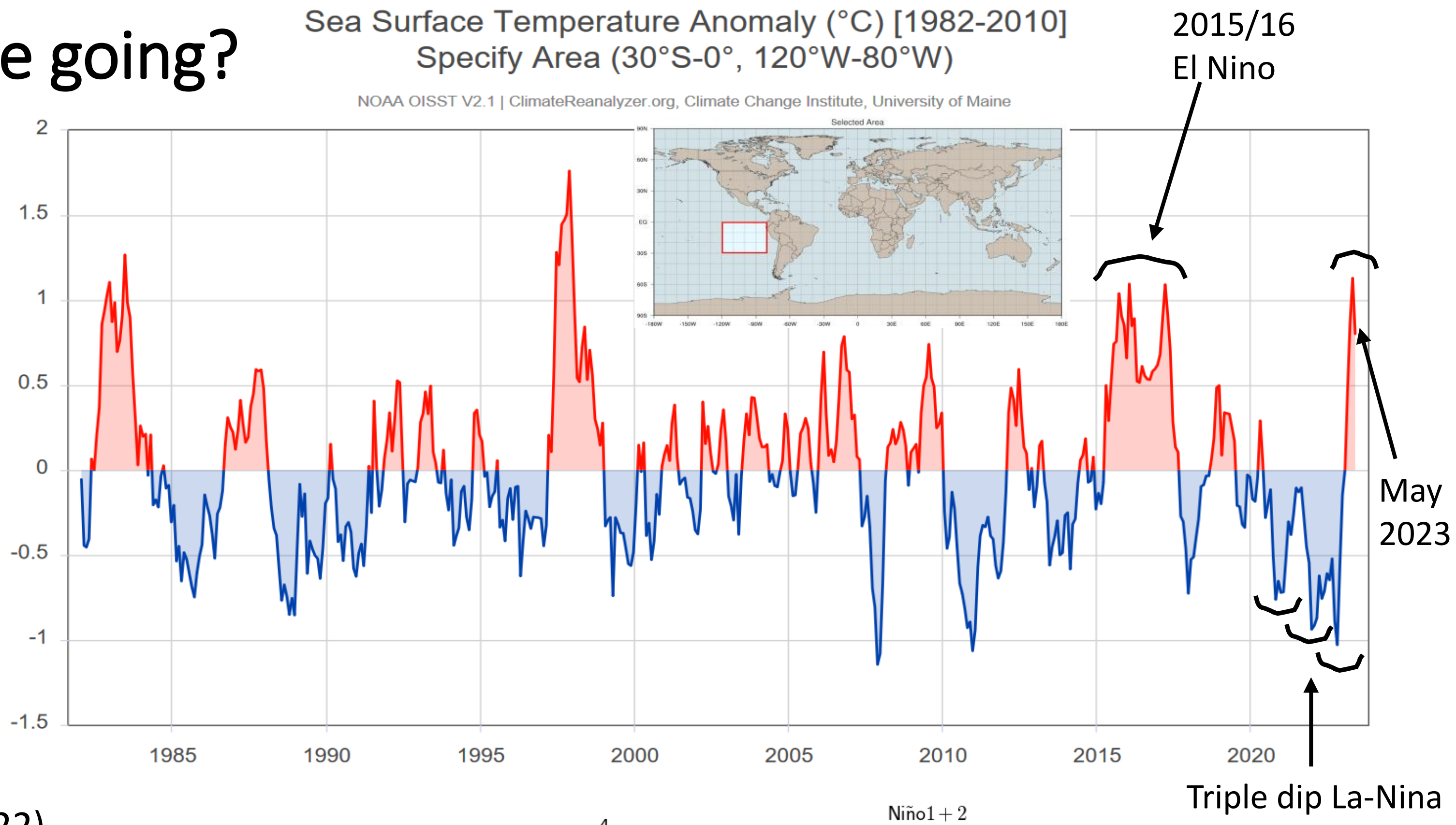
- While our model simulations largely stopped at 2014 with the CMIP protocol, the observations do not…
- The major El-Nino event of 2015/16 associated with eastern Pacific warming (see right) caused a marked detectable change in the Earth's radiation budget (Loeb et al., 2020; 2021).
- This reduces the observed λ from ~2.0 to 1.5 $Wm^{-2}\,K^{-1}$ when calculated over 1990-2019 (25% reduction in magnitude compared to 1985-2014) and would suggest a much diminished pattern effect over the most recent data.

Strengthening feedback largely captured by extended HadGEM3-GC3.1-LL simulation



Where are we now? Where are we going?

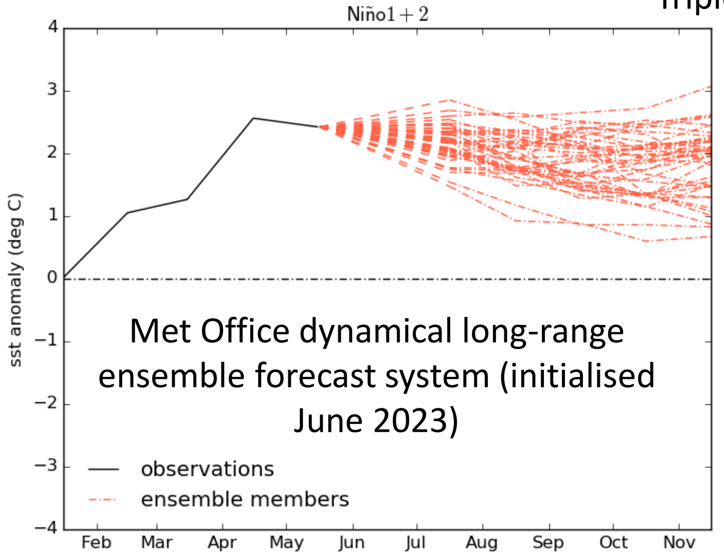




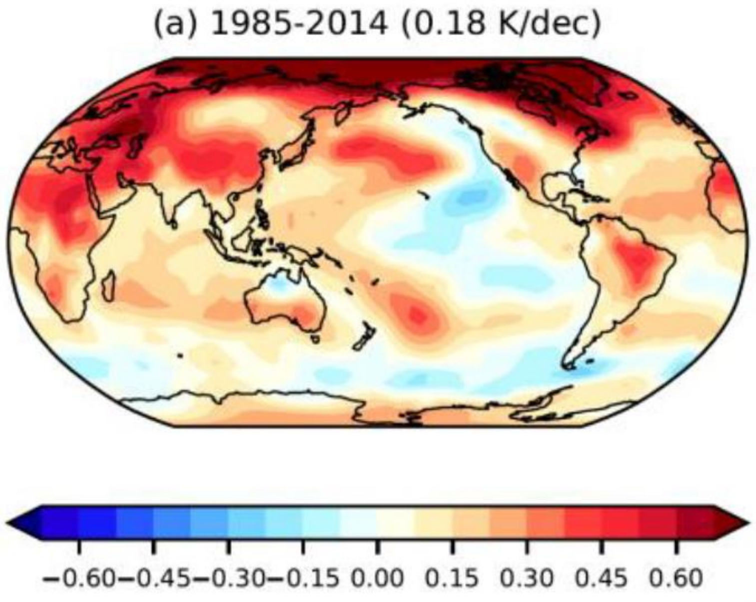
- 2015/16 El Nino followed by triple dip La-Nina (2020-22)
- Extended HadGEM3-GC3.1-LL simulation to Dec 2021 shows triple dip La-Nina impact. 2021 back above the line, i.e. less positive feedback which buffers the effect of the 2015/15 El Nino on feedbacks diagnosis.

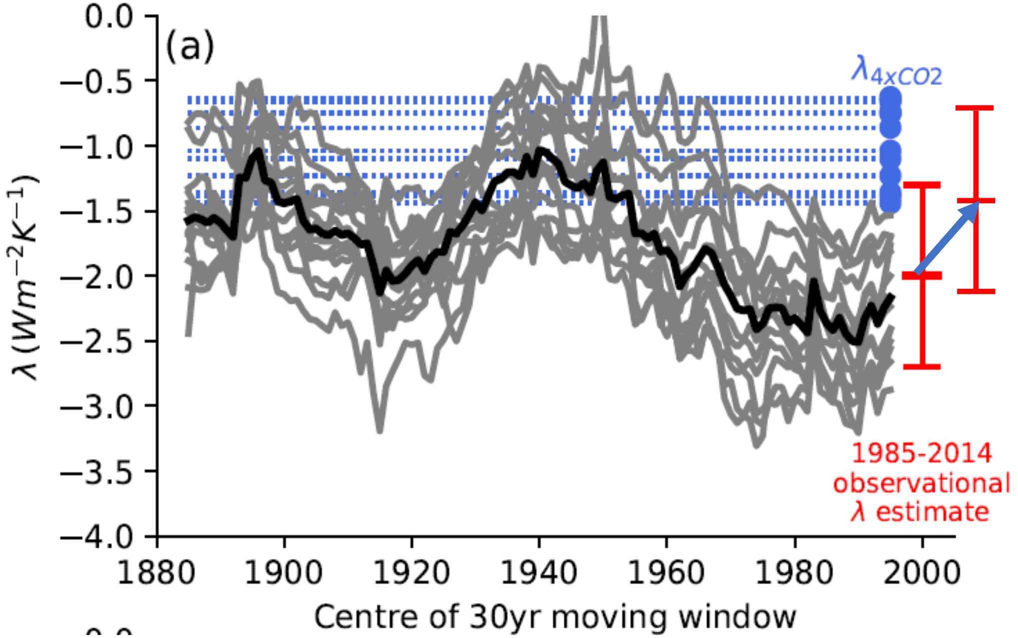
However, NOAA Climate Prediction Centre, Jun 2023:

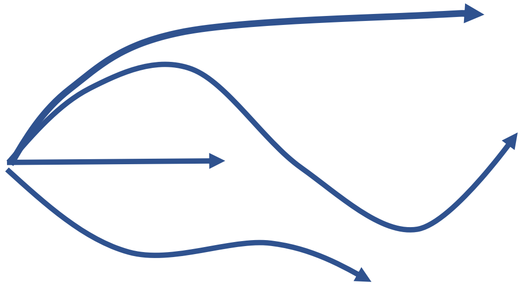
- El Niño conditions are observed.
- Equatorial SSTs are above average across the east-central & eastern Pacific Ocean.
- **El Niño conditions are expected to gradually strengthen into the NH winter 2023-24 -> Expect to return to strongly positive feedbacks & diminishing pattern effect.**

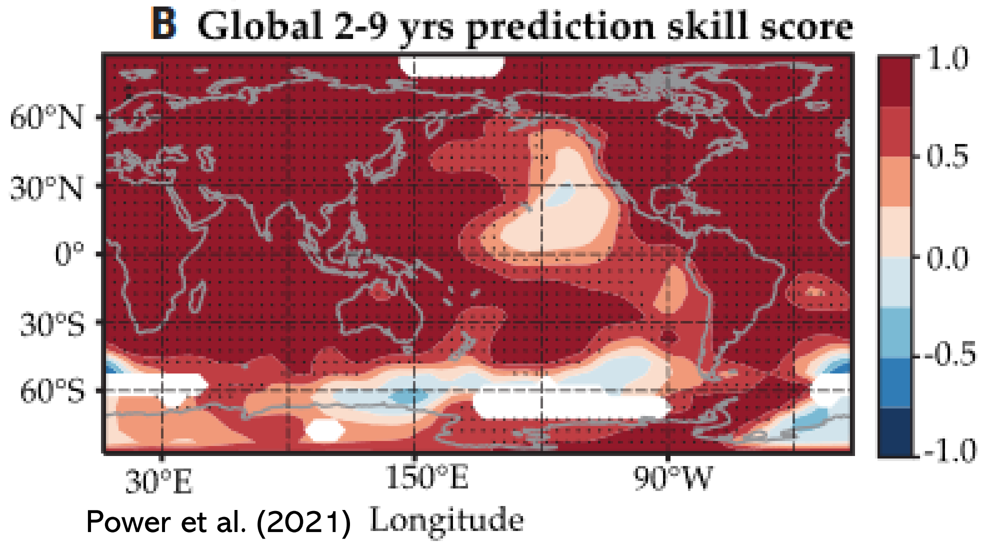


Where are we going over the coming decade or so?









Power et al. (2021)

- Unfortunately initialized decadal prediction have very poor skill score on 2-9yr time frames in the eastern Pacific (Power et al. 2021). Maybe some hope in the western Pacific?

- Need to understand what caused the recent pattern (variability, aerosols, volcanism, ozone hole, Southern Ocean / ice melt, thermostat), as each predicts are different near term behaviour (e.g. PDO might suggest decadal change, Southern ocean impacts hundreds of years). Requires theory, obs and modelling.

Summary

- We find that over 1871-1980, the Earth warmed with feedbacks largely consistent and strongly correlated with long-term climate sensitivity feedbacks (diagnosed from corresponding atmosphere-ocean GCM abrupt-4xCO2 simulations).
- Post 1980 however, the Earth warmed with unusual trends in tropical Pacific SSTs (enhanced warming in the west, cooling in the east) that drove climate feedback to be uncorrelated with – and indicating much lower climate sensitivity than – that expected for long-term CO_2 increase.
- These conclusions are not strongly dependent on the AMIP II SST dataset used to force the AGCMs, though the magnitude of feedback post 1980 is generally smaller in eight AGCMs forced with alternative HadISST1 SST boundary conditions (see paper).
- Satellite observations of changes in top-of-atmosphere radiative fluxes since 1985 suggest that the pattern effect was particularly strong over recent decades, in agreement with the amip-piForcing simulations.
- Changes in the tropical Pacific post 2014 suggest the pattern effect maybe waning due to a warming of the eastern Pacific. This was buffered somewhat by the triple dip La Nina, but current strong warming of the Eastern Pacific that is forecast to strength through 2023-24 suggests feedbacks will stay strong and pattern effect continue to dimmish.
- Might we expect a period of accelerating warming if feedbacks become more positive? Perhaps, unless buffered by ocean heat uptake efficiency changes on decadal timescales (see paper).

Prediction: given strong warming in the eastern Pacific since 2015 and forecast for it to continue through 23-24 (albeit buffered a little by the triple dip La-Nina), observed estimates of ECS from the historical record will increase as positive feedbacks strengthen and the pattern effect wanes…