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Trajectories towards the 1.5°C Paris target: modulation by the Interdecadal Pacific Oscillation

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Keywords: Global temperature, climate change, IPO, PDO, 1.5°C, 2.0°C, Paris agreement, Paris target

Key Points:

- Global average temperature is projected to exceed the 1.5°C Paris target before 2030, relative to observed 1850-1900 temperatures
- The Interdecadal Pacific Oscillation will be a determining factor of the rate at which global temperature approaches the 1.5°C level
- Modelled global temperature in the positive IPO phase exceeds 1.5°C in around 2026; in a negative IPO phase it exceeds 1.5°C in around 2031

Abstract

Global temperature is rapidly approaching the 1.5°C Paris target. In the absence of external cooling influences, such as volcanic eruptions, temperature projections are centred on a breaching of the 1.5°C target, relative to 1850-1900, before 2029. The phase of the Interdecadal Pacific Oscillation (IPO) will regulate the rate at which mean temperature approaches the 1.5°C level. A transition to the positive phase of the IPO would lead to a projected exceedance of the target centred around 2026. If the Pacific Ocean remains in its negative decadal phase, the target will be reached around 5 years later, in 2031. Given the temporary slowdown in global warming between 2000-2014, and recent initialised decadal predictions suggestive of a turnaround in the IPO, a sustained period of rapid temperature rise might be underway. In that case, the world will reach the 1.5°C level warming several years sooner than if the negative IPO phase persists.

1. Introduction

The Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC) in December 2015 agreed to '*pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognising that this would significantly reduce the risks and impacts of climate change*' (UNFCCC Conference of the Parties (COP) 2015). In response, the Intergovernmental Panel on Climate Change (IPCC) announced a special report on the 1.5°C target, due to be completed by September 2018. Currently there is a relative lack of scientific knowledge around the implications of 1.5°C warming (Mitchell et al. 2016; Hulme 2016; Schleussner et al. 2015; Schleussner et al. 2016), resulting in uncertainties for policymaking. One aspect of this uncertainty is how soon the world will reach the 1.5°C warming mark, and how the timing of the approach and overshoot is influenced by internal modes of climate variability.

Over the last century, we have observed decadal to multidecadal variability in global mean surface temperature (GMST), along with a persistent long-term rise (Hartmann et al. 2013, Figure 1a). Periods of around 1-2 decades of acceleration and slowdown in the rate of global warming are associated with, and partially caused by, the Interdecadal Pacific Oscillation (IPO; Figure 1b, Meehl et al. 2013; England et al. 2014; Dai et al. 2015; Kosaka & Xie 2016; Fyfe et al. 2016). The positive (negative) phase of the IPO is associated with anomalously warm (cool) sea surface temperatures (SSTs) in the tropical Pacific Ocean and anomalously cool (warm) SSTs in the subtropical North and South Pacific Oceans. Although closely associated with the El Niño-Southern Oscillation (ENSO), the IPO has a stronger extratropical signature than ENSO (Henley et al. 2015). The closely related Pacific Decadal Oscillation (PDO) is thought to be due to the combined effects of ENSO and several extratropical atmospheric and oceanic processes (Newman et al. 2016).

The IPO has memory on decadal-to-multidecadal timescales, as opposed to the 2-7 year oscillation timeframe of ENSO (Power et al. 1999; Henley et al. 2015). Several studies have attributed at least part of the temporary slowdown in temperature increase since around 1998 to the IPO (Meehl et al. 2013; England et al. 2014; Dai et al. 2015; Kosaka & Xie 2016; Fyfe et al. 2016). Other analyses have found potential influences from Atlantic (Dai et al. 2015; McGregor et al. 2014) and Indian (Nieves et al. 2015) Ocean heat update, anthropogenic aerosols (Schmidt et al. 2014), a minor influence of the prolonged solar minimum (Meehl 2015), as well as observational uncertainty (Karl et al. 2015) and instrumental data biases (Hausfather et al. 2017) on the slowdown. However, agreement is emerging that the dominant influence on at least the recent slowdown was the Pacific decadal variability related to the IPO (Dai et al. 2015; Fyfe et al. 2016; Meehl et al. 2016).

In this study, we examine model projections of global temperature towards 1.5°C. We then isolate and explore the influence of the IPO on future global temperature trajectories. Specifically, we investigate how the next phase of the IPO will affect the rate and timing of global warming reaching 1.5°C.

2. Data and Methodology

Data

We use observed global land and ocean mean annual (calendar year) surface temperature data (1880-2016) from NOAA (NOAA 2017), the HadCRUT4 data (1850-2016) from the UK Met Office (Morice et al. 2012) and GISTEMP (1880-2016) from NASA (Hansen et al. 2010). The tripole index (TPI) (Henley et al. 2015) is used to represent the IPO and is calculated using the ERSSTv4 dataset (Huang et al. 2015). GMST and TPI are calculated from monthly gridded surface air temperature data in 70 century-long simulations from 32 climate models under

RCP8.5 (high emissions scenario) in the fifth phase of the Climate Model Intercomparison Project (CMIP5, Taylor et al. 2012) archive (Supp Table 1) stored at the Australian National Computing Infrastructure (NCI) repository. Although underestimating the duration of decadal phases, the models adequately capture broad characteristics of the IPO (Henley et al. 2017) and our results are not overstated due to this likely bias. The models adequately capture global temperature variability (King et al. 2016).

Baseline

We use the 1850-1900 period as our quasi-pre-industrial baseline, as it is the earliest possible 51-year baseline using instrumental data, and is deemed sufficiently long to dampen the influence of decadal variability. This baseline was used by the IPCC to compare global mean temperature under RCP scenarios (Table 12.3 in Collins et al. 2013, IPCC 2013) . We firstly use the period 1961-1990 to align our three observed datasets. Since the HadCRUT4 dataset extends back to 1850, we use this dataset to compute the difference between 1850-1900 and 1961-1990. We then apply this baseline shift to all three datasets to compute the anomaly from 1850-1900. We note that there is no ideal preindustrial baseline (Hawkins et al. 2017) and that our results should be interpreted in the context of the selected baseline.

Analysis

We compute global temperature sequences from the CMIP5 ensemble and plot their future trajectories. For each sequence, we firstly express the global temperature as an anomaly from the commencing year. We estimate that the 2015-2016 El Niño induced short-term anomalous warmth of approximately 0.1°C (see *Supporting Information*). We then add each sequence to the observed temperature series, commencing our sequences 0.1°C cooler than the 2016 value. We then compute the tripole index (TPI, Henley et al. 2015) of the IPO and the annual (January-December) GMST in each model simulation for the period 2006-2100 (Table S1). We apply a correction to the GMST sequences to account for the higher warming rates in the latter part of the century (see *Supporting Information*). We then isolate the annual sequence of global mean surface temperatures within IPO positive and negative phases, commencing the sequences five years prior to the start of each IPO phase, and ending them five years after the end of the IPO phase (Figure S1 in the *Supporting Information* shows this definition schematically). IPO phases are defined as the TPI years above (IPO positive) or below (IPO negative) a threshold of +/– one standard deviation away from the long term TPI mean, after detrending using a power fit ($y=ax^b+c$). We conduct sensitivity tests on these analysis settings in the *Supporting Information*. Our method produces ensembles of future temperature trajectories in IPO positive and negative phases.

3. IPO Modulation of Global Temperature Trajectories

Here we examine our future global temperature simulations from CMIP5. The mean of our sequence of global temperatures reaches the 1.5°C warming level in around 2029, with an interquartile range (IQR) of 2026-2032 (Figure 2a). For the NASA and Hadley Centre observed datasets we see small differences in the timing of up to three years (*Supplementary material*).

We also compare composites of global mean surface temperature sequences in each of the two phases of the IPO. We find a statistically significant difference ($p<0.05$) between the ensemble mean of the GMST sequences in IPO positive and negative phases (Figure 2b). In IPO positive phases, global temperatures rise substantially faster than for IPO negative. For 14 consecutive years, from 2019, we find that in the IPO positive phase, global temperatures are statistically significantly higher than in IPO negative phases. This means that the rate that global temperatures approach the 1.5°C level is likely to be significantly quicker, or slower, depending on the IPO.

The projected timing of global warming reaching 1.5°C above the pre-industrial level can be expressed in a number of ways. These include, but are not limited to: a) the year in which an ensemble mean of temperature simulations reaches 1.5°C; b) the year in which the global mean first reaches 1.5°C; c) the year in which a longer-term (e.g. 5-year) mean first reaches 1.5°C; or d) the year in which the global mean reaches and does not return below 1.5°C, referred to as an '*expulsion from history*' (Power 2014).

Considering a), that is, the ensemble mean of our GMST sequences in each IPO phase (Figure 2b), if the world experiences a transition to an IPO positive phase we expect global temperatures to reach the 1.5°C level by around 2027 (IQR: 2024-2029). If, however, the Pacific Ocean remains in an IPO negative phase, there would likely be a delay in reaching 1.5°C for 4-5 years, until around 2031 (IQR:2026-2033). When the IPO positive GMST ensemble mean reaches the 1.5°C level, the mean temperature for the IPO negative scenario is around 1.3°C. The mean trajectories have a peak difference in global mean temperature of around 0.2°C (Figure 2b).

If we consider b), the year in which the global mean first reaches 1.5°C, the distributions are shifted a little earlier, with a mean of 2025 for IPO positive and 2029 for IPO negative (Figure 3a). For the 5-year mean projections, method c), the mean is around 2025-2026 for IPO positive and 2030-2031 for IPO negative. For method d), the '*expulsion from history*', we found too few long IPO sequences in our temperature sequences meeting this criterion to form a statistically powerful ensemble. As the expulsion above 1.5°C is further into the future, it is not yet possible to assess the IPO influence on the timing of that expulsion.

Figure 3c shows the distribution of trend rates of warming in each IPO phase in our ensemble. The global warming slowdown period (2000-2014), with a trend of 0.23°C/decade is located near the mode of the distribution of IPO negative phase temperature trends. The previous IPO positive phase (1976-1998) is associated with a higher rate of warming of 0.34°C/decade. This is consistent with the IPO positive trend distribution in our model ensemble. We note that the ensemble uses future temperature sequences, so we would expect the modelled distributions to have slightly higher warming trends than past IPO phases.

The models vary in their characterisation of decadal climate variability and tend to underestimate the duration and magnitude of the IPO variability (Henley et al. 2017; Power et al. 2016). However, this means our results are most likely to be conservative estimates of the *duration* of the IPO's impact on global temperatures. Meehl et al. 2016 quantified the contribution of the IPO to multidecadal GMST trends. Importantly, here we find that the observed rate of GMST rise in both IPO negative and positive (slowdown and acceleration) periods in the twentieth century is within, and consistent with, the distribution of the CMIP5 modelled trends (Figure 3c).

We note also that our multi-year multi-model mean trajectories, by design, dampen interannual and multi-annual variability, and the actual trajectory of any one sequence in our ensemble has higher year-to-year variability. Our projections do not include the potential influence of unpredictable external cooling influences such as volcanic eruptions. However, the difference in global temperature trajectories between IPO phases is consistent across the ensembles of projections and robust to methodological choices (*see supplementary data*).

4. Discussion and Conclusions

In the first decade of the 21st century the global climate was under the influence of a negative IPO phase. This may have provided a temporary buffer for the radiative forcing effect of continually rising atmospheric greenhouse gas concentrations on global temperatures. It is therefore possible that a negative phase of the IPO since the turn of the century has cushioned the impacts of global warming on extreme events, such as heatwaves. A global temperature record was set in 2015 and a strengthening El Niño followed in 2016, with associated widespread coral bleaching (Cressey 2016) and high temperatures leading to another global temperature record. Initialised decadal predictions are suggestive of a turnaround in the IPO to its positive phase (Meehl, Hu & Teng 2016), triggered by upper ocean heat content on decadal-timescales in the off-equatorial western tropical Pacific.

A turnaround of the IPO to its positive phase could initiate a period of accelerated warming over the next one to two decades. This would likely lead to the Paris target of 1.5°C being surpassed within the next decade. Our analysis provides an illustration that decadal climate variability is likely to be a significant determinant on global temperature trajectories over the next ten years. As a consequence, decadal variability will also influence when the global warming target of 1.5°C over a preindustrial climate is breached. Disregarding the influence of the IPO, it is likely that global mean temperatures will pass the 1.5°C warming mark within the next 10-15 years, with our ensemble mean projecting this will occur prior to 2030. Equilibrating the Earth's climate at 1.5°C above the pre-industrial level will likely involve overshooting the target and then reducing atmospheric greenhouse gas concentrations and global temperatures on a net negative carbon emissions pathway.

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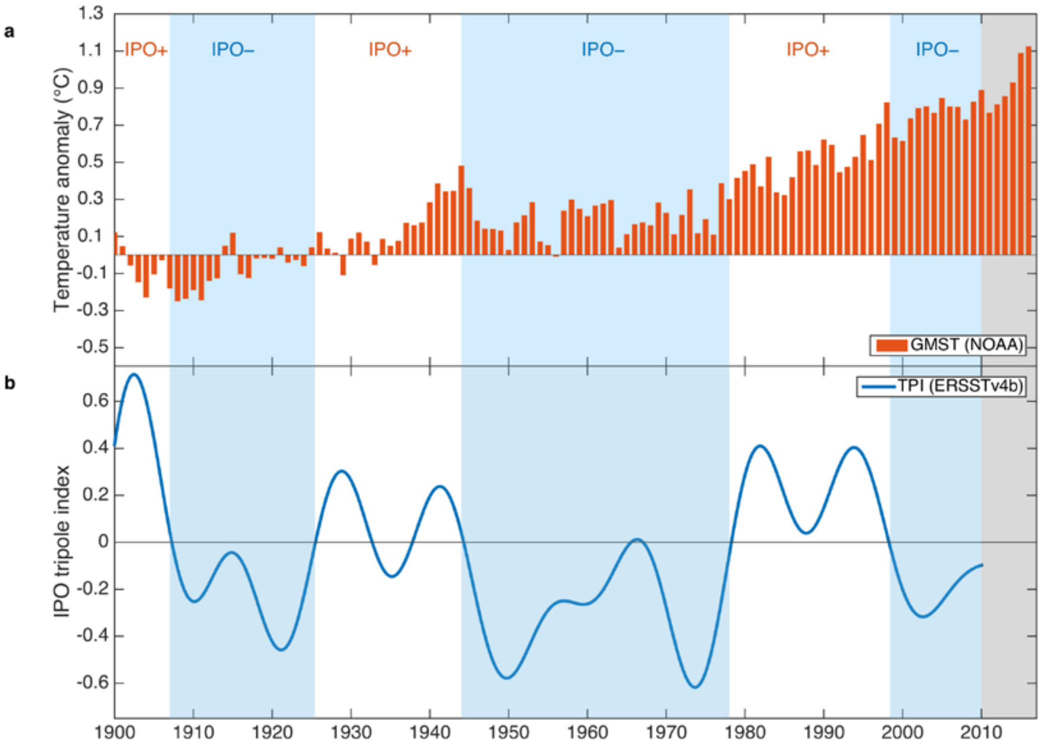


Figure 1. Global surface temperature anomalies and the IPO. a) Observed annual global mean surface temperature anomaly for 1900-2016 (NOAA, 1850-1900 baseline). b) IPO timeseries, low-pass filtered tripole index (Henley et al. 2015) (ERSSTv4). Observed IPO negative phases shaded in light blue, similar to England et al. (2014).

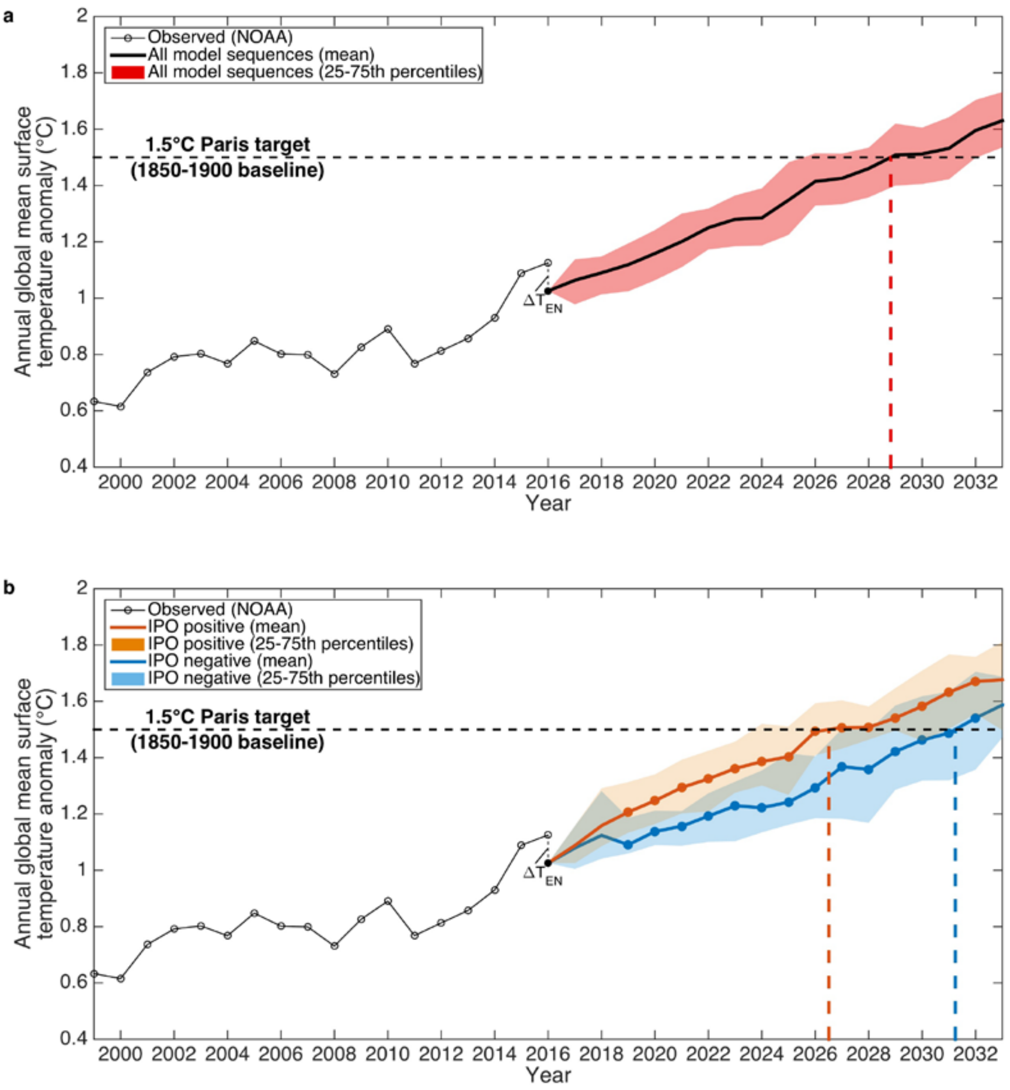


Figure 2. Observed and projected global temperature trajectories towards the 1.5°C Paris target. a) (black) Observed global annual mean surface temperature anomaly (NOAA, 2000-2015, 1850-1900 baseline), Modelled plume of future temperature anomalies accounting for a temporary 0.1°C influence of the 2015-16 El Niño, 1.5°C Paris Target and timing of ensemble mean breaching this level shown in dotted black and red lines; b) similarly for a, but for modelled temperature sequences of GMST in IPO positive (red) and IPO negative (blue) phases, including the preceding 5 years (CMIP5, RCP8.5); filled dots indicate

statistically significant differences between the mean in each phase (t-test, 5% significance level); dotted vertical lines indicate the expected timing of breaching the 1.5°C Paris target in each IPO phase.

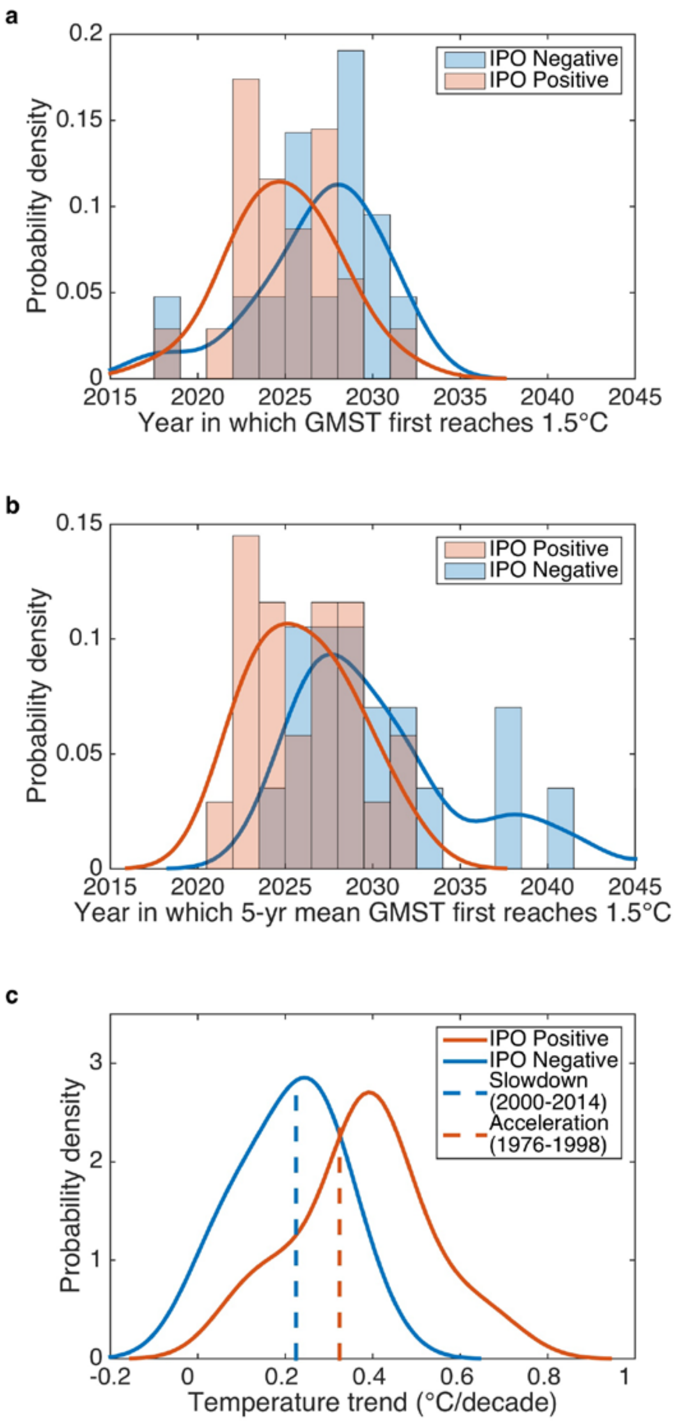
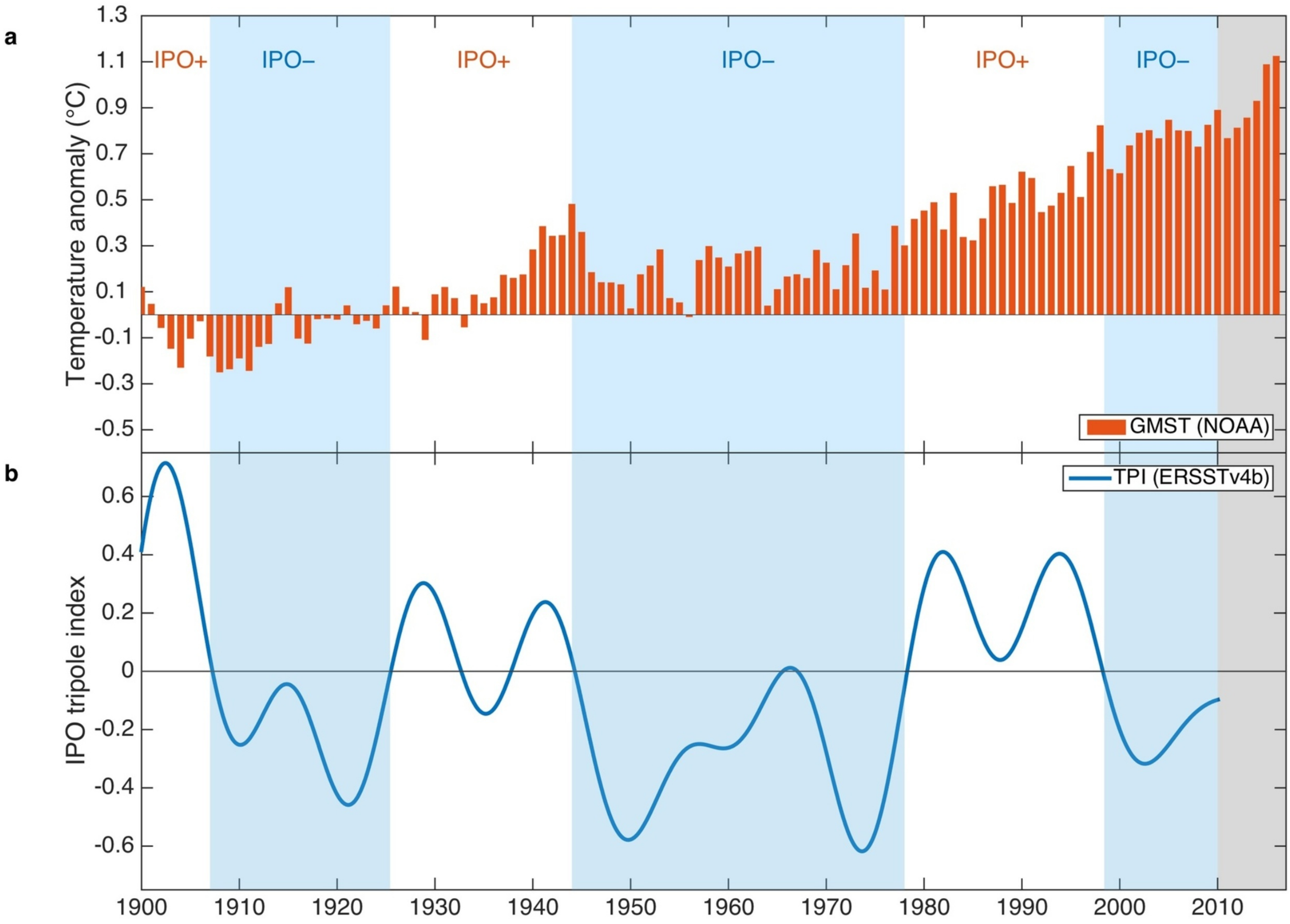


Figure 3. Probability distributions of global temperature and decadal trends. a) Distribution of years in which GMST first reaches the 1.5°C level in IPO positive

and negative phases; b) Similarly for a, but for 5-year mean GMST (dated in central year); c) Distribution of decadal trends in GMST in CMIP5 modelled IPO phases; Observed decadal trends in slowdown (2000-2014) and acceleration (1976-1998) periods shown with dotted lines.



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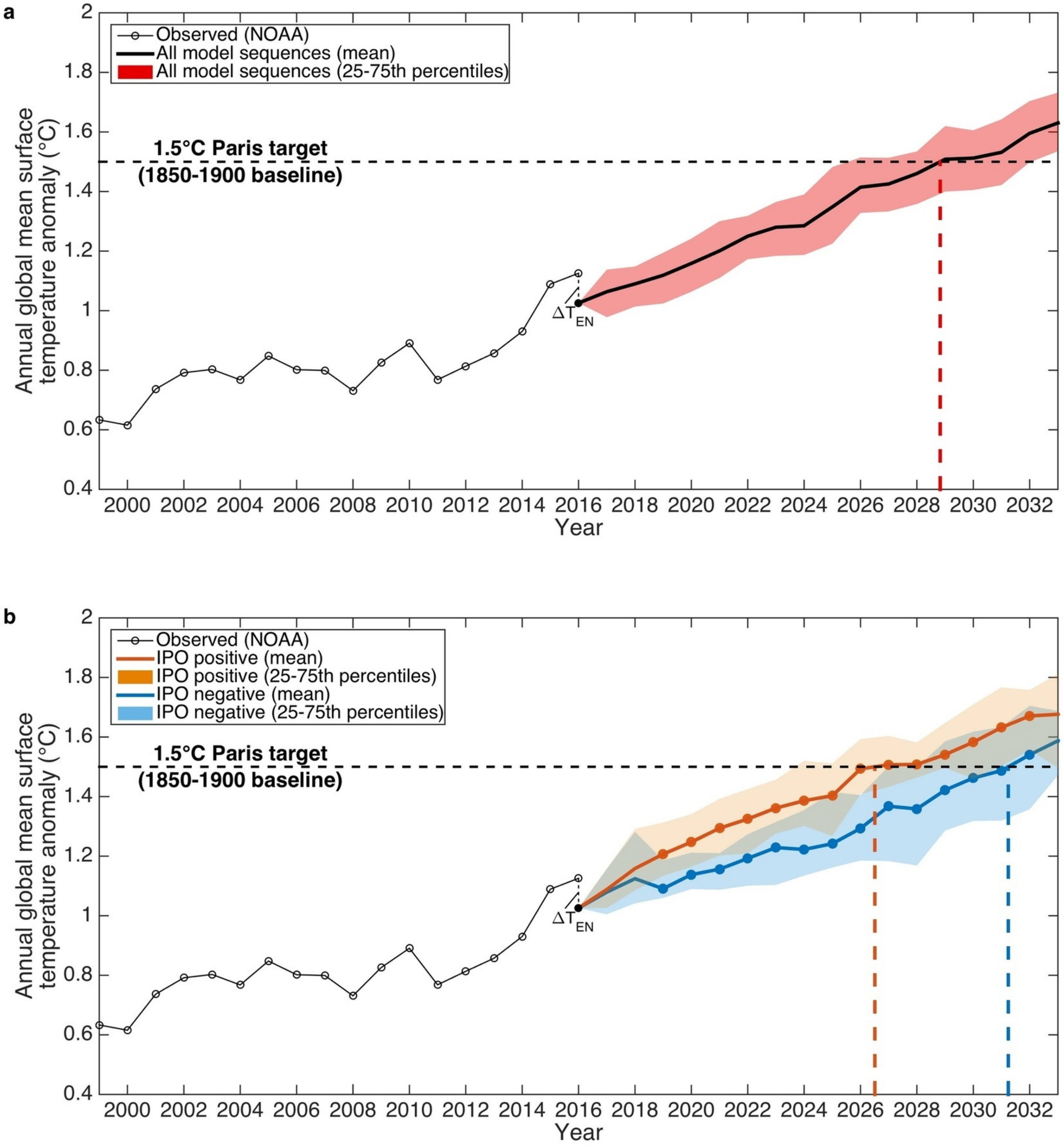

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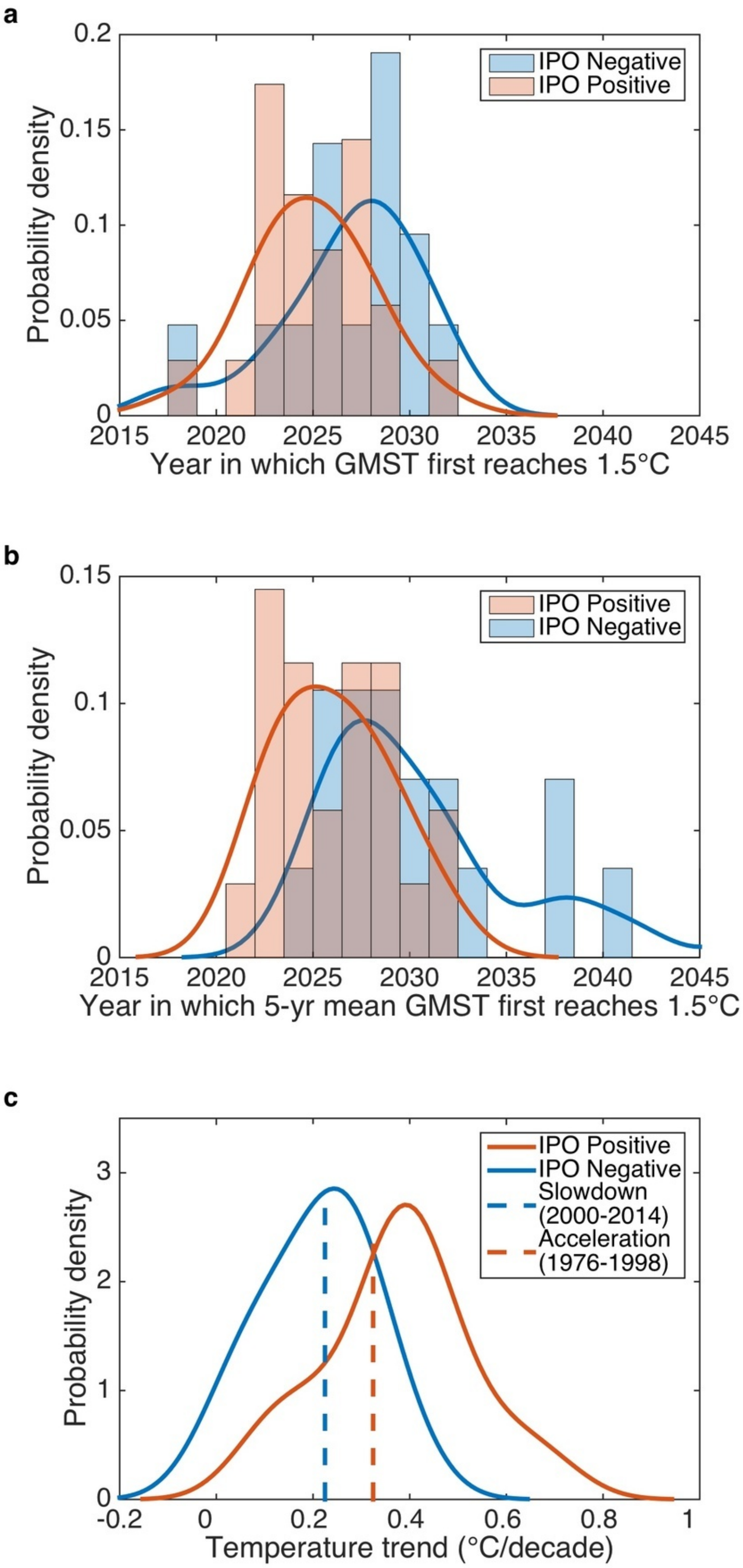

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