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Supporting Information for
**Challenges in understanding atmospheric responses to SSTs—An illustrative
case of 2023/2024 winter**

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Text S1, Table S1 and Figures S1 to S5

Introduction

This supplement supports the submitted manuscript.

21 **Text S1**

22 Text S1 provides a description of the methodology for examining the effects of observed SST
23 trends on the atmospheric response. This procedure involves removing the linear trend in Sea
24 Surface Temperature (SST) for the period 1991–2020 from monthly SST data for 2010–2024. The
25 period 1991–2020 is selected because it is currently the climatological base period for seasonal
26 outlooks at the Climate Prediction Center. The following three-step procedure is used for carrying
27 out the sensitivity experiments in which the observed SST trend is removed.

28 **(1) Calculate the SST Trend:**

29 The linear trend in SST at each grid point, denoted as $SSTtrend(iy-1)$, is derived as the slope of
30 annual SST changes over the 1991–2020 period ($slope2d$). The formula for the trend is:

31
$$SSTtrend(iy-1) = slope2d \times [(iy-1) - 1990 - prdhalf]$$

32 Here: iy represents the year of the data (e.g., 2010, 2011, ..., 2024). $prdhalf$ is the midpoint of
33 the 1991–2020 period and is calculated as $(nyr+1)/2$, where $nyr=30$. For the given period,
34 $prdhalf = 15.5$.

35 **(2) Remove the Trend:**

36 At each grid point, the detrended SST for a given year iy is computed as:

37
$$SST_detrend(iy) = SST(iy) - SSTtrend(iy-1)$$

38 This ensures that any long-term linear trend is removed from the SST data before using it in
39 sensitivity simulations.

40 **(3) Application for Sensitivity Runs:**

41 For example, to force a sensitivity run for 2024, at each grid point, the SST trend for 2023
42 ($SSTtrend(2023)$) is subtracted from the SST data for 2024. This procedure creates a dataset
43 reflecting a scenario without the SST trend.

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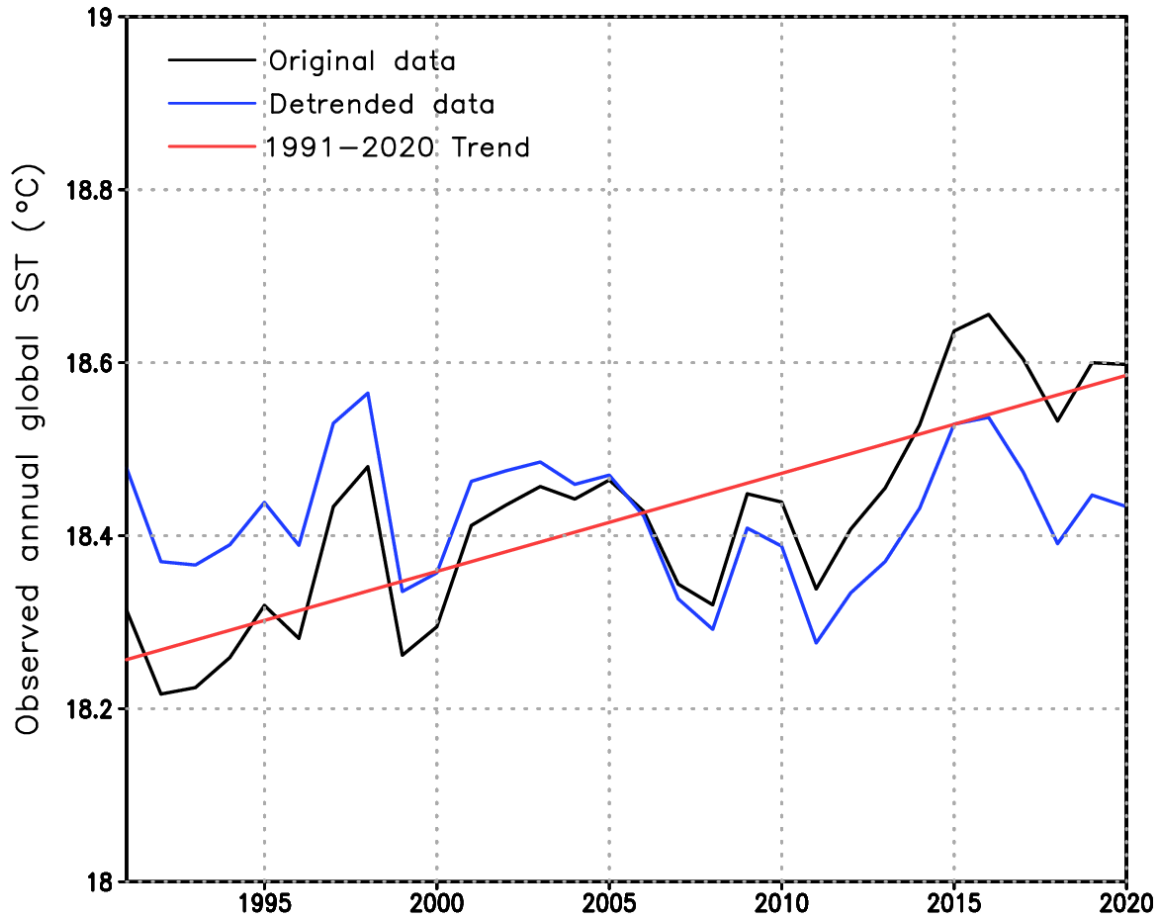
45 Table S1. List of model experiments based on FV3GFS. A brief description of the SST forcing
 46 used and the inferred impacts is included.

47

Experiments	SST forcing	Impacts
AMIP	Global full SST	Impacts of observed global SST anomalies
AMIP_DSST	Global detrended SST	Impacts of observed global SST anomalies without SST trends
AMIP - AMIP_DSST	Difference between AMIP and AMIP_DSST	Impacts of observed SST trends
Clim_ATL	Climatological SSTs over Atlantic region (30°S-40°N), Outside the Atlantic, SST anomalies remain the same as AMIP	Impacts of observed SST anomalies outside the Atlantic
AMIP - Clim_ATL	Difference between AMIP and Clim_ATL	Indirect estimate of impacts of observed SST anomalies over the Atlantic
Clim_NonATL	AMIP SST anomalies over Atlantic region (30°S-40°N), Outside the Atlantic, Climatological SSTs are used.	Impacts of observed SST anomalies over the Atlantic
AMIP - Clim_NonATL	Difference between AMIP and Clim_NonATL	Indirect estimate of impacts of observed SST anomalies outside the Atlantic

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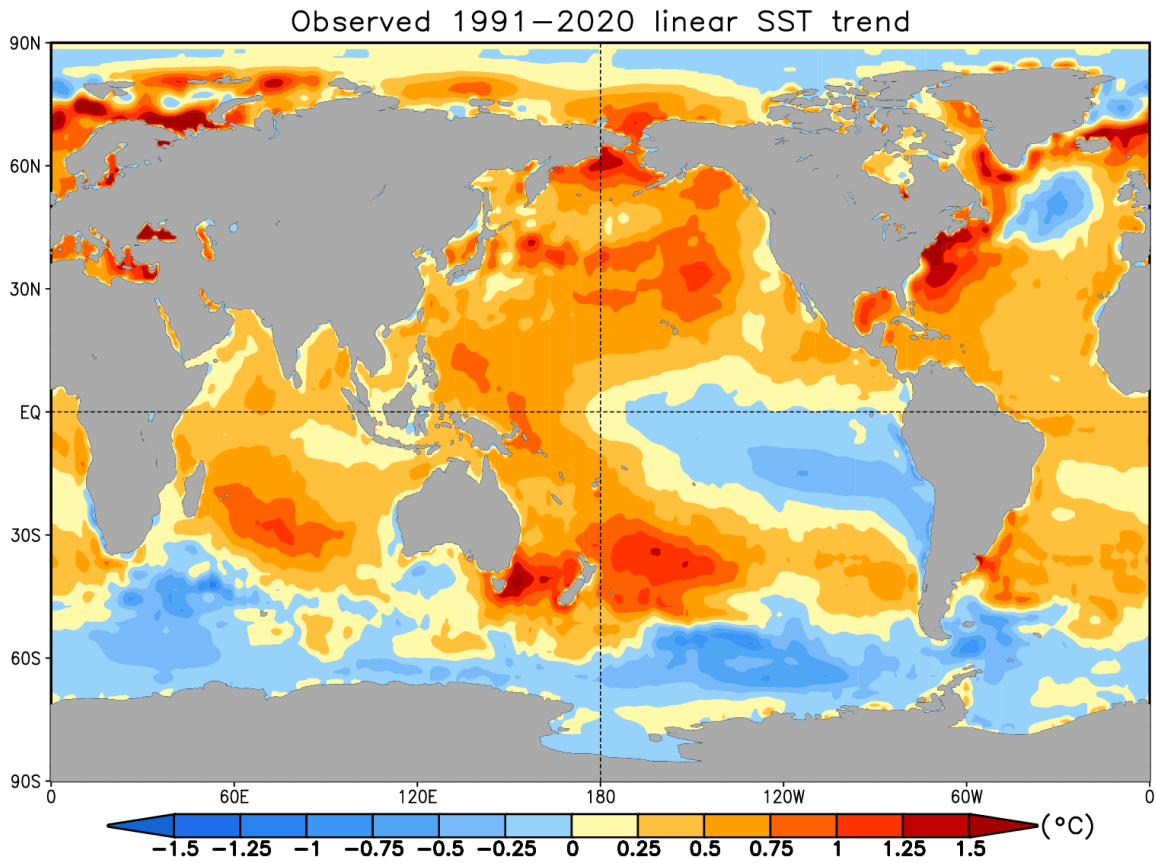
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52 Figure S1. Time series of observed globally averaged annual SST (black curve) and its detrended
53 data (blue curve). The 1991-2020 linear trend is shown as the red line.

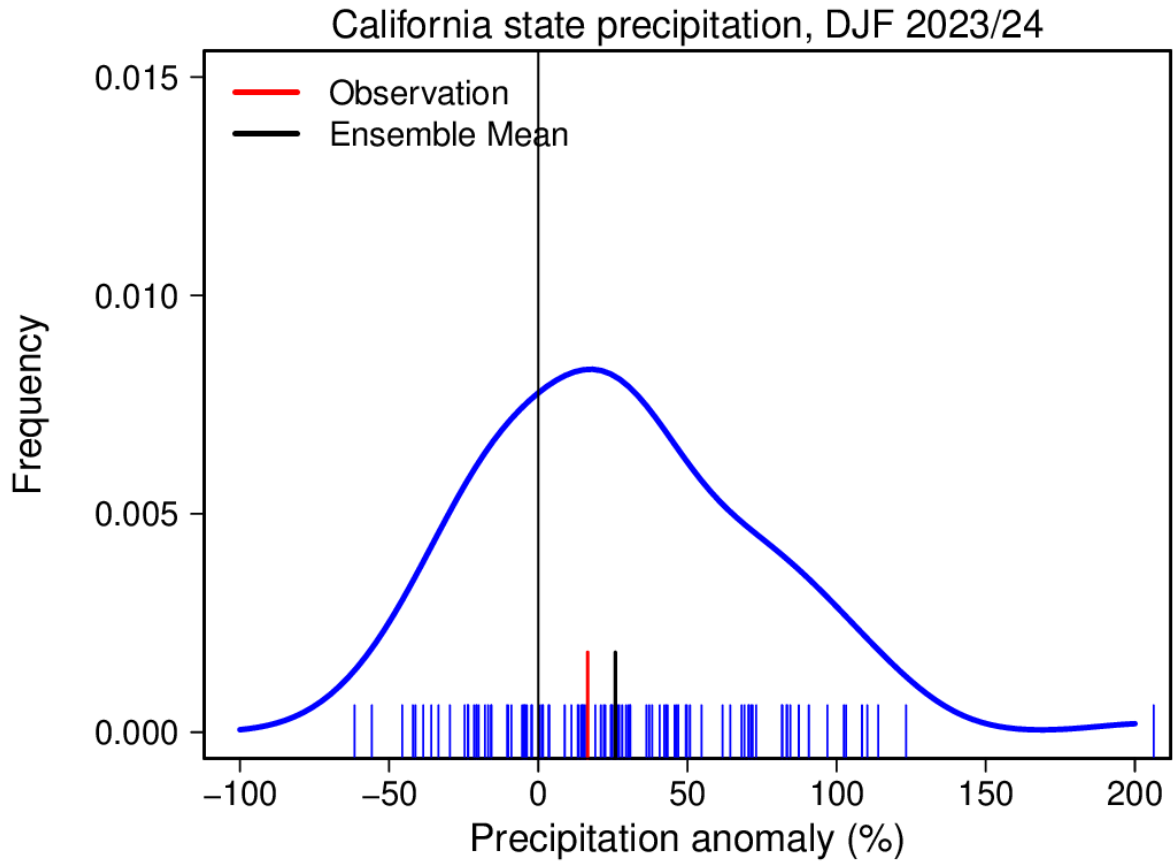
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Figure S2. The spatial pattern of observed 1991-2020 linear SST trend computed at each grid point and shown as the total change ($^{\circ}\text{C}$) for these 30 years.

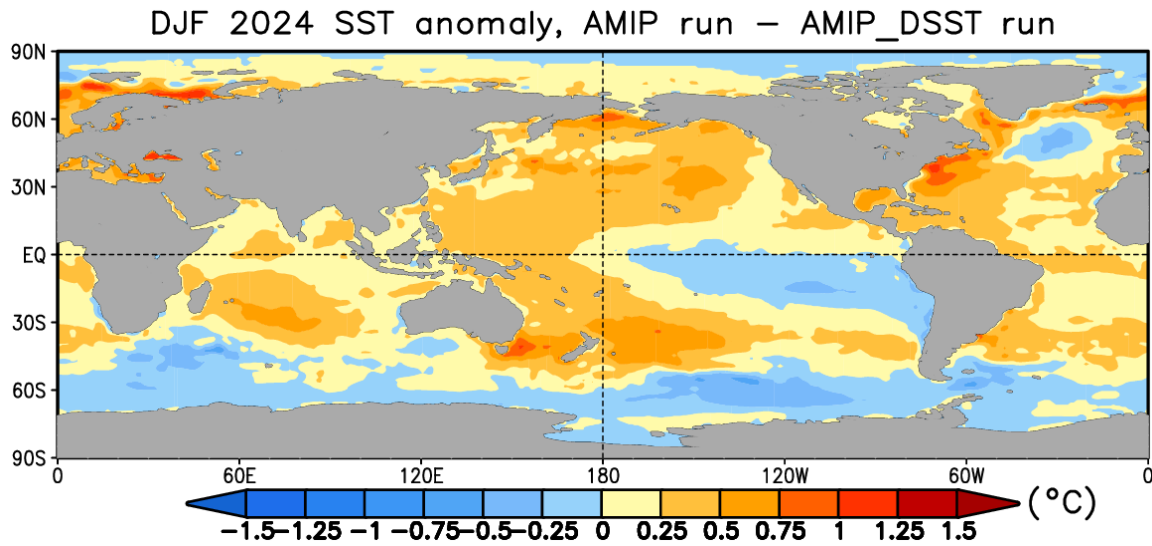
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Figure S3. Probability density function (PDF) of California state precipitation anomalies (percent departure) for 2023/24 DJF (blue curve). Results are based on 100-member AMIP simulations (short blue tick marks). Long tick marks at the bottom show corresponding observed values (red) and AMIP ensemble mean results (black).

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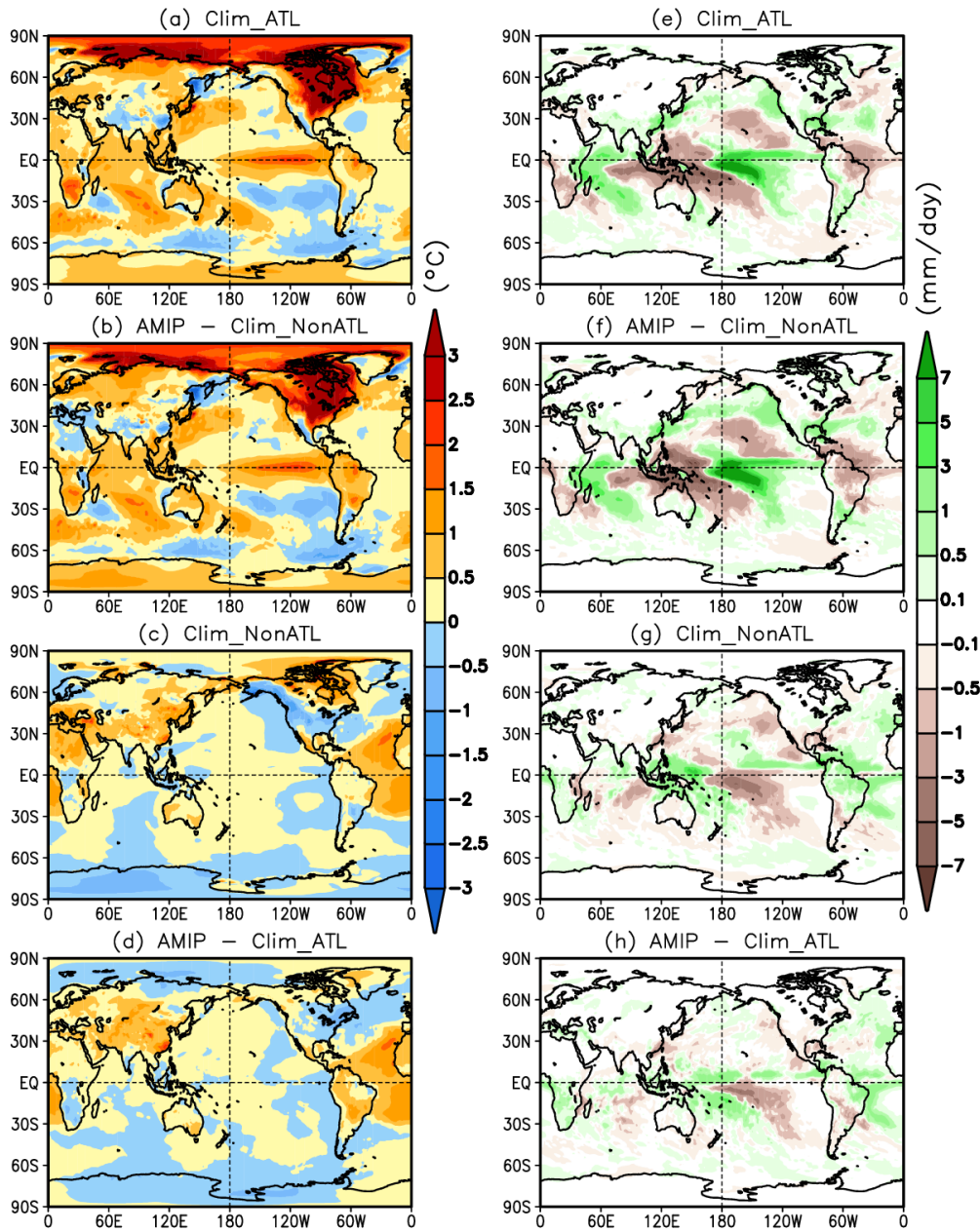
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74 Figure S4. The difference in DJF 2023/24 SST anomaly ($^{\circ}\text{C}$) used in model experiments between
75 AMIP simulations and AMIP_DSST simulations in which the SST trend is removed. The former
76 is forced by the observed full SST and the latter is forced by the detrended SST. The design of
77 these two sets of experiments is described in section 2.

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Simulated responses of DJF 2024 T2m and precipitation

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82 Figure S5. FV3GFS simulated responses of DJF 2023/24 (left) surface air temperature and (right)
 83 precipitation anomalies over the globe for (top row; a, e) Atlantic climatology SST simulations
 84 (Clim_ATL), (second row; b, f) the difference between AMIP simulations and Non-Atlantic
 85 climatology SST simulations (Clim_NonATL), (third row; c, g) Clim_NonATL simulations, and
 86 (bottom row; d, h) the difference between AMIP simulations and Clim_ATL simulations. The
 87 various experiments are summarized in Table S1.