Nature communications

Supporting Information for

The role of seasonal surface heating on the chaotic origins of ENSO spring predictability barrier

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Introduction

This support information provides additional information from the main article.

Text T1

The heat budget for SST tendency

A heat budget analysis of the SST tendency is used to quantify the contributions of different processes to the annual cycle of SST in the eastern tropical Pacific, which is calculated as (Wang et al., 2020; Meng et al., 2021):

$$\frac{\partial \bar{T}}{\partial t} = -\langle \bar{u}\frac{\partial \bar{T}}{\partial x}\rangle - \langle \bar{v}\frac{\partial \bar{T}}{\partial y}\rangle - \langle \bar{w}\frac{\partial \bar{T}}{\partial z}\rangle + Ent + D_{iff_v} + \frac{\bar{Q}}{\rho C_p h} + Re.$$

where $\langle\cdot\rangle = \frac{1}{h}\int_{-h}^{0}\cdot\, dz$ denotes the vertical mean within the mixed layer, h is the surface mixed layer depth (MLD) which is a function of both space and time. The overbar indicates the monthly climatology mean quantities. T is the sea surface temperature; u, v, and w represent the zonal, meridional, and vertical velocities of the ocean currents, respectively. $Ent = \frac{1}{h}\frac{\partial h}{\partial t}(\bar{T}|_{z=-h} - \langle\bar{T}\rangle)$ represents the entrainment process from the mixed layer. $Diff_v$ represents the vertical diffusion process. $\frac{\bar{Q}}{\rho C_p h}$ means the atmospheric heating absorbed by the sea water in the mixed layer, Q is the net surface heat flux, $\rho = 1025$ kg/m^3 is the sea water density and the $C_p = 4090$ J/(Kg·°C) is the heat capacity of the sea water. Re is the residual term, which includes the horizonal diffusion and subgrid processes.

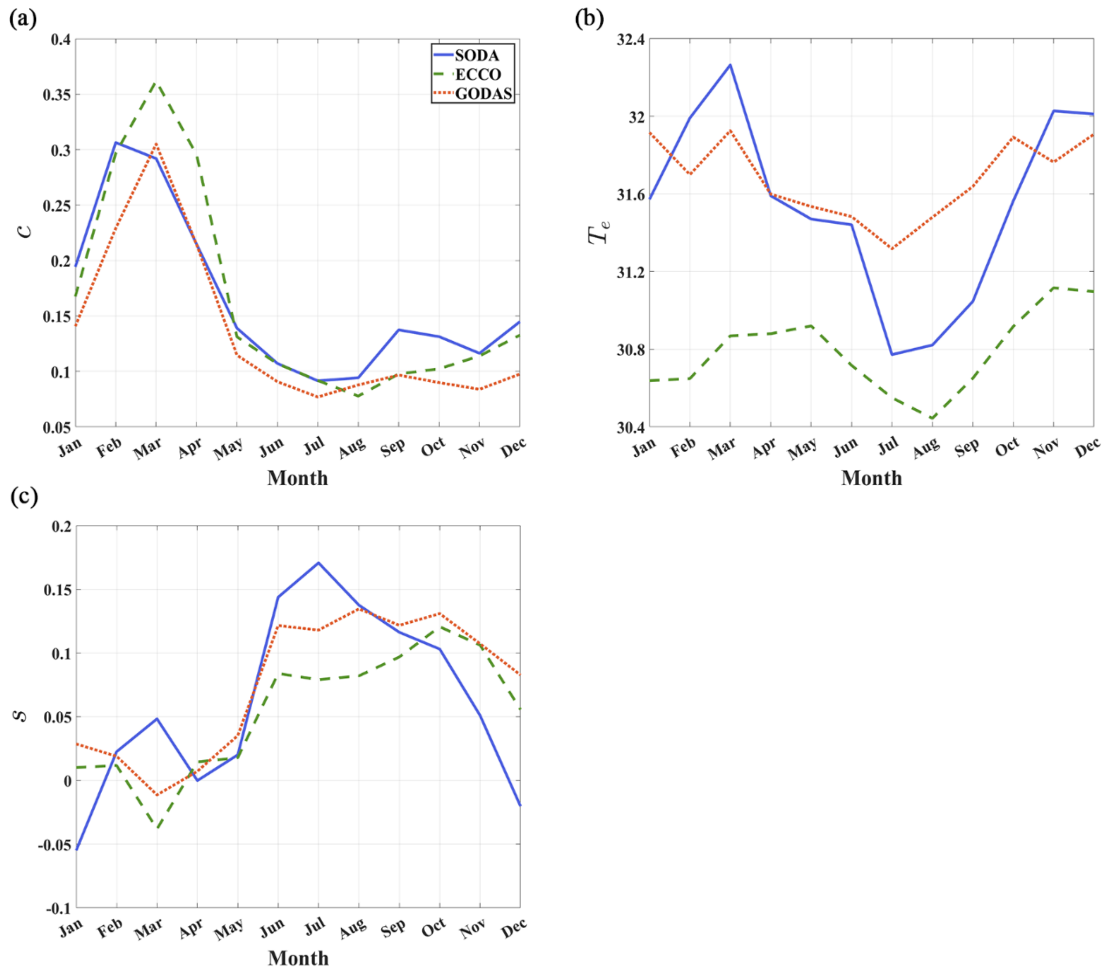

Figure S1. The monthly variations of three parameters based on three reanalysis datasets. (a) $\boldsymbol{c}$, the thermal damping rate of SSTA; (b) $\boldsymbol{T_e}$, the radiative–convective equilibrium temperature; (c) $\boldsymbol{q}$, the dynamic connection between the zonal SST gradient and the upwelling velocity. The blue solid line, red dash line, and yellow dot line represent the results of the SODA, ECCO, and GODAS reanalysis datasets, respectively.

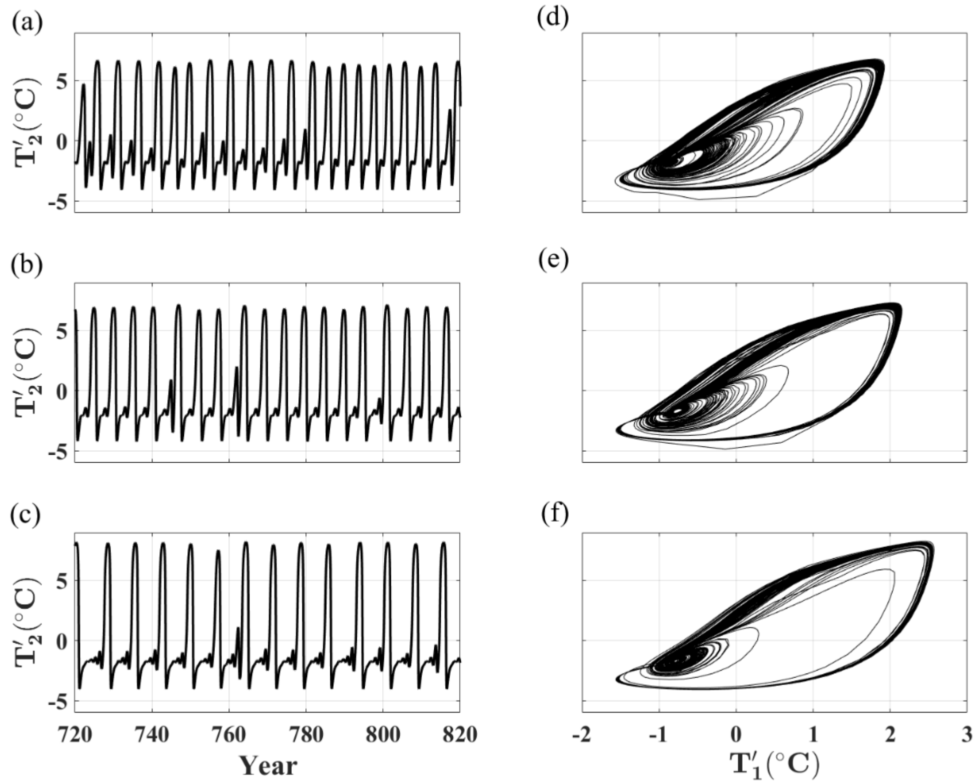

Figure S2. The ENSO dynamics simulated by the Box model with different T_e. (a), (b), (c) simulated time series of the eastern equatorial temperature anomaly T_2' (°C) and (d), (e), (f) phase space plots with western equatorial temperature T_1' (°C) and eastern equatorial temperature T_2' (°C) corresponding to different values of the radiative–convective equilibrium of the SST T_e of (a), (d) 30.7; (b), (e) 31.2; (c), (f) 32. Besides, other parameters are taken as $c = 0.22$, $q = 0.15$.

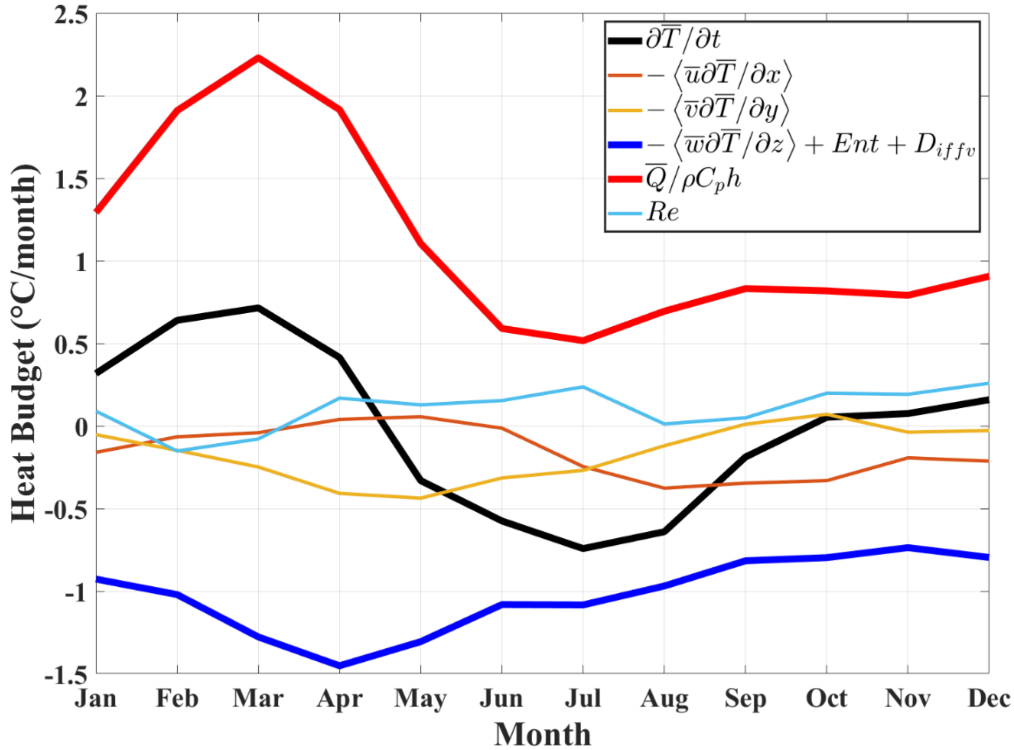

Figure S3. The monthly variations of different heat budget terms for the SST tendency in Niño 3 (5°N-5°S, 150°W-90°W) region. The black line (the SST tendency term $\partial\bar{T}/\partial t$), the blue line (the vertical cooling term $-\langle\bar{w}\partial\bar{T}/\partial z\rangle + Ent + D_{iff_v}$), and the red line (the atmospheric heating term $\bar{Q}/\rho C_p h$) are bold as they are significantly greater than other budget terms. The heat budget terms are calculated on the ECCO data set.