Supporting Information for

Fast Response of the Tropics to an Abrupt Loss of Arctic Sea Ice via Ocean Dynamics

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Text S1

We compute the heat budget for the upper 100m of the eastern equatorial Pacific region (10°S-10°N, 90°W-150°W) using the following equation:

$$\rho_o C_p \int_{-H}^{0} \frac{\partial T}{\partial t} dz = -\rho_o C_p \int_{-H}^{0} \nabla \cdot (\boldsymbol{U}T) dz - \rho_o C_p \int_{-H}^{0} \nabla \cdot \boldsymbol{K} dz + Q_{net} \quad (1)$$

where ρ_o is the reference density of seawater, C_p the specific heat of seawater, T is temperature, H=100m, $\boldsymbol{U}$ is the three-dimensional velocity, $\boldsymbol{K}$ is the diffusive temperature flux resulting from diapycnal diffusion and parameterized isopycnal diffusion, and Q_{net} is the net air-sea heat flux. The anomalous temperature tendency (TEND in Fig. 4a) is given by the sum of the advection term (first term on right hand side; ADV in Fig. 4a), the diffusion term (second term on right hand side; DIFF in Figs. 4a and 4b) and Q_{net}. The advection term can be divided into horizontal (ADV_h) and vertical (ADV_w) components as follows:

$$ADVh = -\rho_o C_p \int_{-H}^{0} \left(u' \frac{\partial \overline{T}}{\partial x} + \overline{u} \frac{\partial T'}{\partial x} + u' \frac{\partial T'}{\partial x} + v' \frac{\partial \overline{T}}{\partial y} + \overline{v} \frac{\partial T'}{\partial y} + v' \frac{\partial T'}{\partial y} \right) dz \qquad (2)$$

$$ADVw = -\rho_o C_p \int_{-H}^{0} \left(w' \frac{\partial \overline{T}}{\partial z} + \overline{w} \frac{\partial T'}{\partial z} + w' \frac{\partial T'}{\partial z} \right) dz \qquad (3)$$

where primed variables are anomalies and overbar variables are the climatology.

In Fig. 4c, the first, second and third terms on the right-hand side of Eqn. (3) are denoted $W'\overline{T}$, $\overline{W}T'$, and $W'T'$ for short, respectively.

With equation (2) and (3), equation (1) can be changed into

TEND-DIFF-Qnet = ADVh+ADVw (4)

Note that the right-hand side of Eqn. (4) includes the decomposition terms

$$\left(u'\frac{\partial \overline{T}}{\partial x} + \overline{u}\frac{\partial T'}{\partial x} + u'\frac{\partial T'}{\partial x} + v'\frac{\partial \overline{T}}{\partial y} + \overline{v}\frac{\partial T'}{\partial y} + v'\frac{\partial T'}{\partial y} + \quad w'\frac{\partial \overline{T}}{\partial z} + \overline{w}\frac{\partial T'}{\partial z} + w'\frac{\partial T'}{\partial z}\right).$$

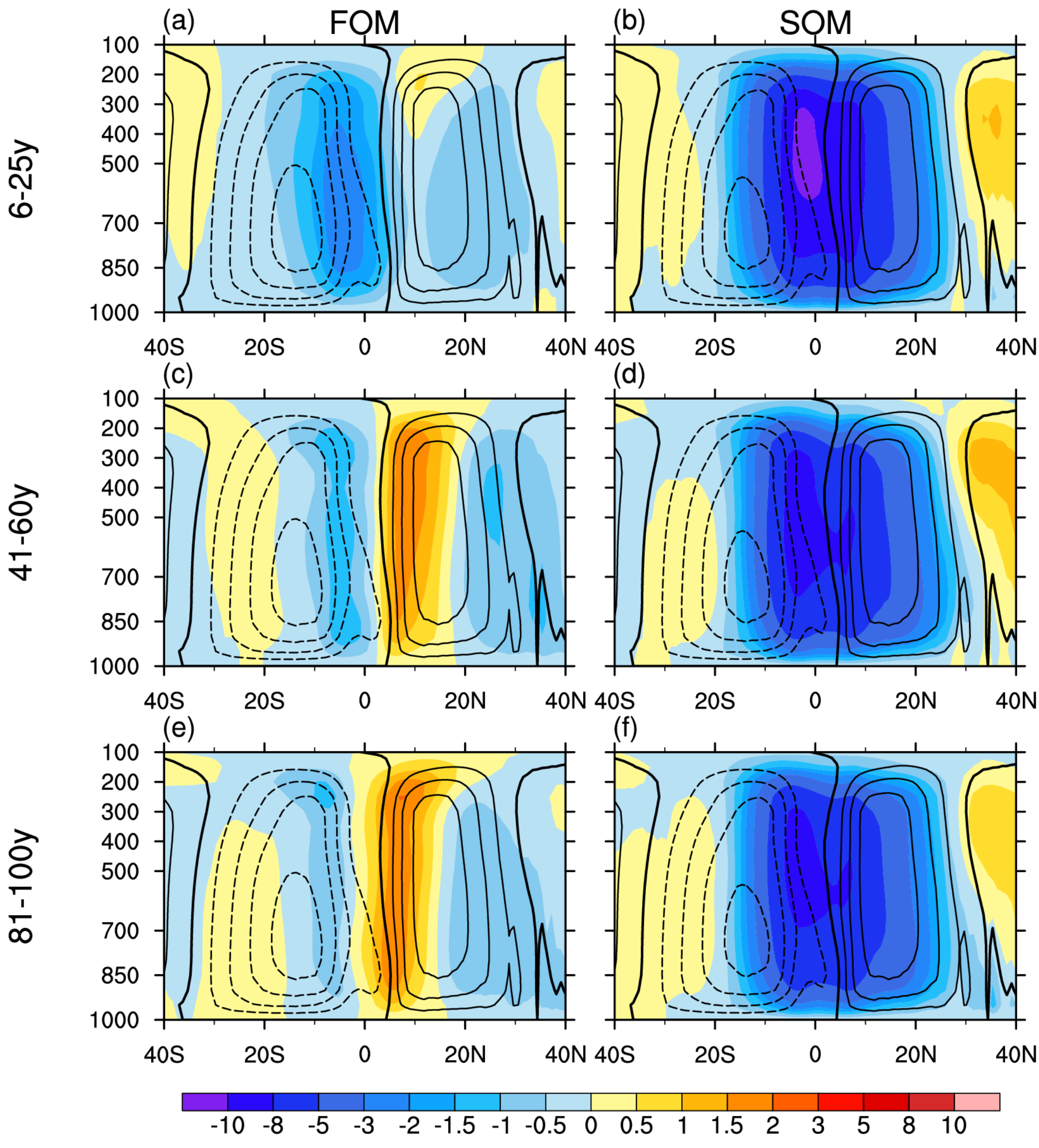

Figure S1. Meridional streamfunction response (color shading; 10^{-9} kg s^{-1}) to an abrupt loss of Arctic sea ice in FOM and SOM averaged over years (a, b) 6-25, (c, d) 41-60 and (e, f) 81-100. Contours show the late 20[th] century climatology (contour interval = 2 x 10^{-9} kg s^{-1}; zero contour is thickened).

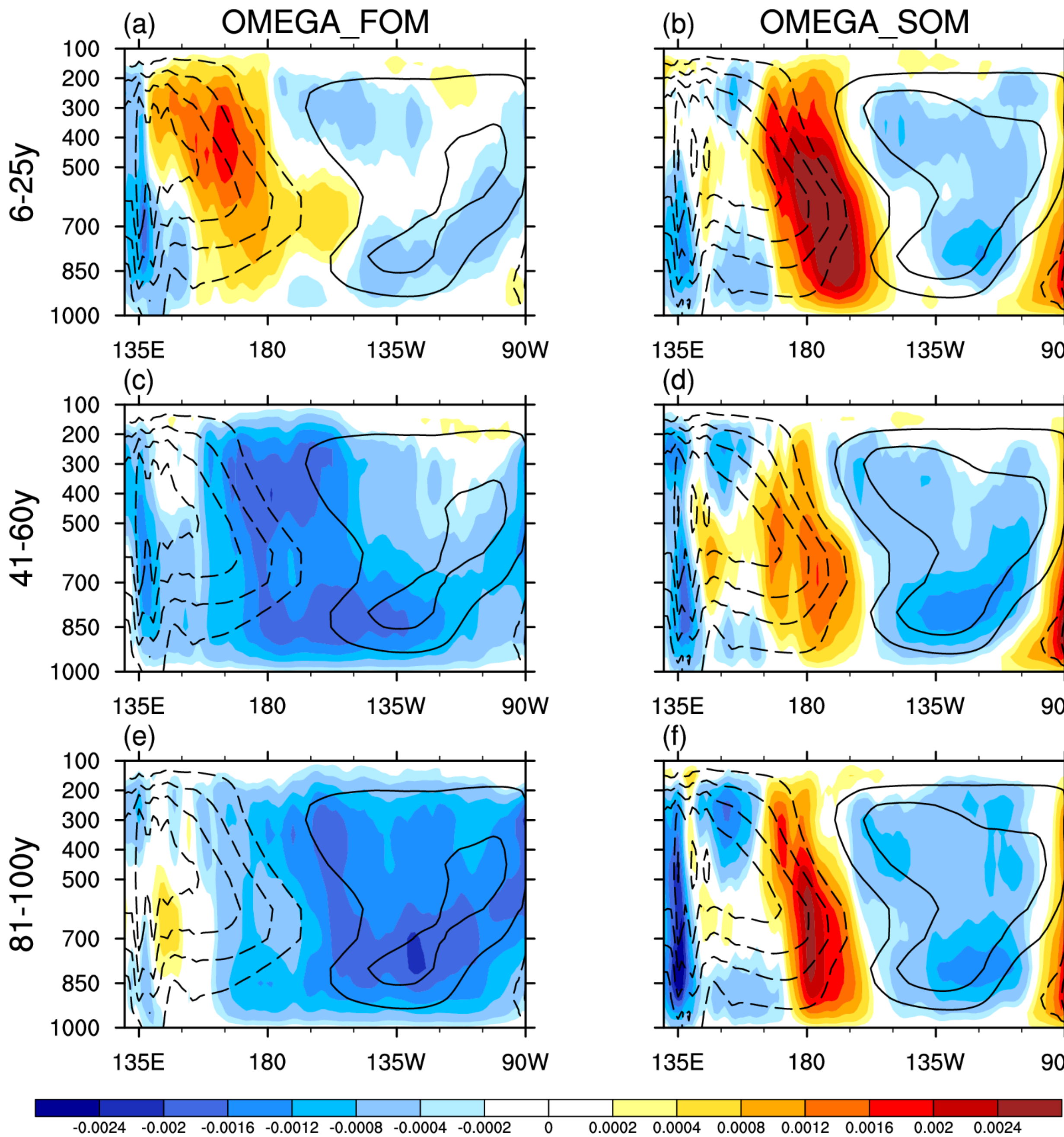

Figure S2. Pressure vertical velocity (omega; Pa s^{-1}) response across the Pacific averaged over 5°N-5°S (color shading) to an abrupt loss of Arctic sea ice in FOM and SOM averaged over years (a, b) 6-25, (c, d) 41-60 and (e, f) 81-100. Contours show the late 20th century climatology (contour interval = 0.01 Pa s^{-1}; negative values dashed). Positive (negative) values indicate downward (upward) motion.

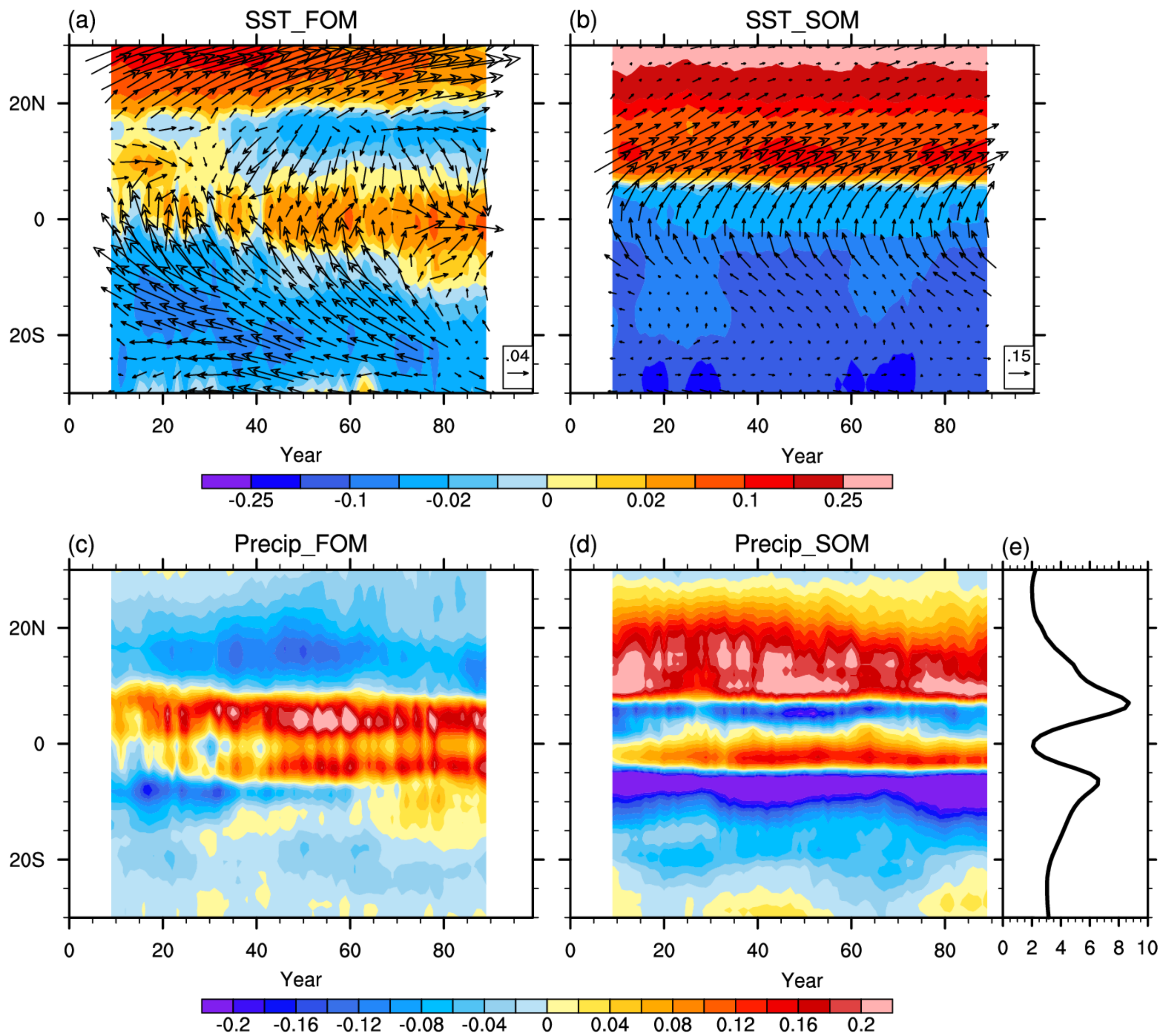

Figure S3. Evolution of Pacific zonal-mean (a, b) SST (°C) and surface wind (m s^{-1}) and (c, d) precipitation (mm d^{-1}) responses to an abrupt loss of Arctic sea ice in FOM and SOM. (e) Climatological Pacific zonal-mean precipitation (mm d^{-1}). Note the different wind vector scales in (a) and (b). The tropical (30N-30S) Pacific mean SST response at each time step has been removed for clarity in (a) and (b).

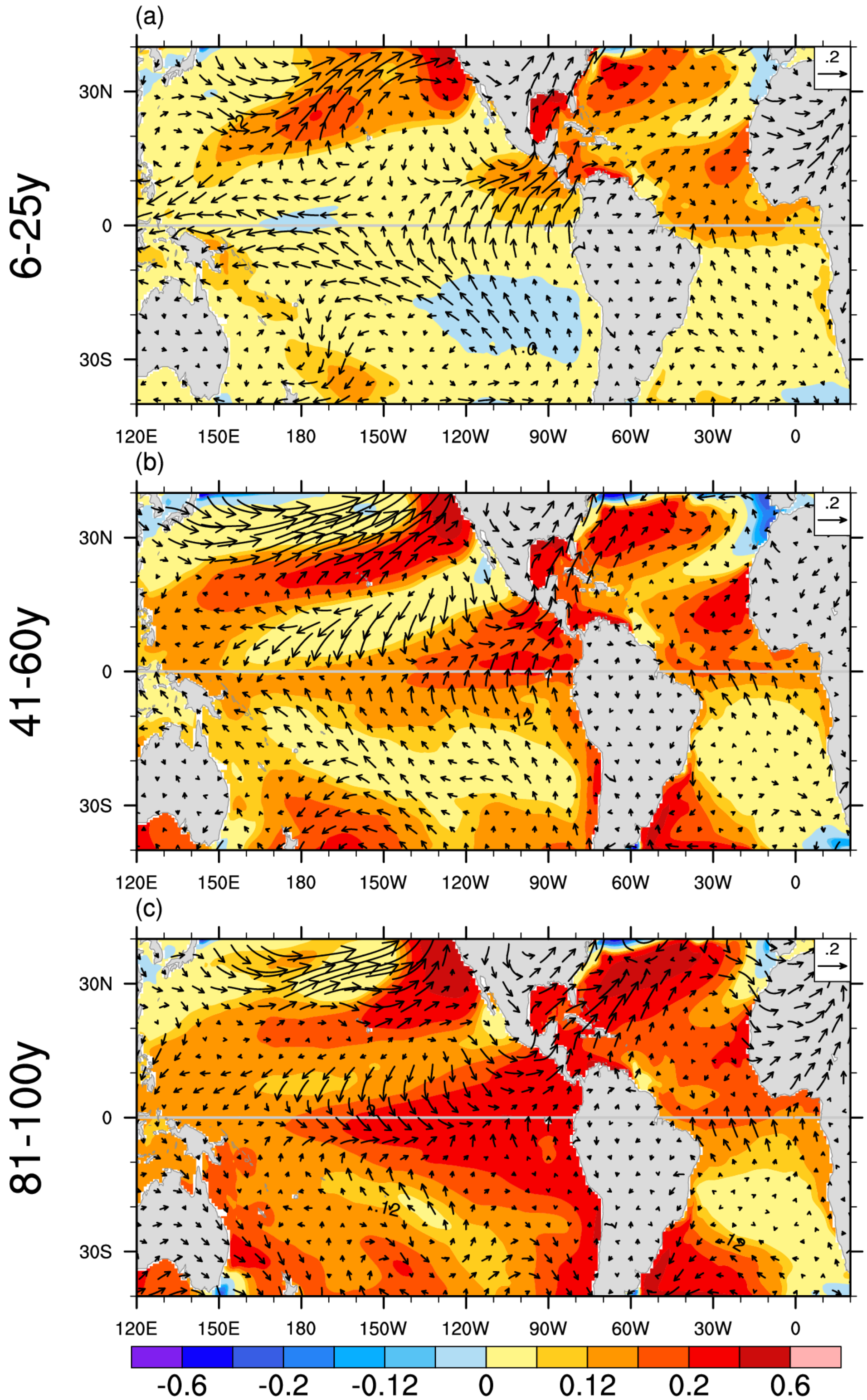

Figure S4. SST (°C) and surface wind (m s^{-1}) responses to an abrupt loss of Arctic sea ice in FOM averaged over years (a) 6-25, (b) 41-60 and (c) 81-100.

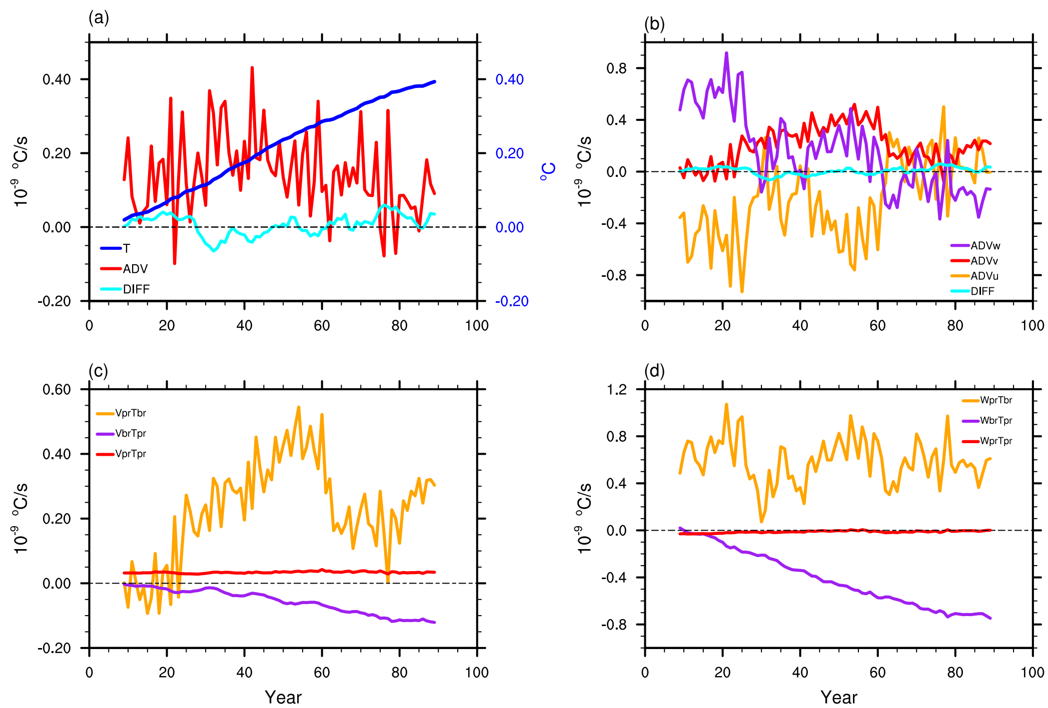

Figure S5. Heat budget decomposition for temperature averaged over the layer 200-400m (T; °C) in the region [10°S-10°N, 150°W-90°W] from FOM. The terms are defined as follows in units of °C s^{-1}: (a) ADV = total advection, DIFF = diffusion; (b) ADVw = vertical advection, ADVu = zonal advection, ADVv = meridional advection; (c) VprTbr = meridional advection due to the anomalous meridional current acting on the mean meridional temperature gradient, VbrTpr = meridional advection due to the mean meridional current acting on the anomalous meridional temperature gradient, VprTpr = meridional advection due to the anomalous meridional current acting on the anomalous meridional temperature gradient; (d) WprTbr = vertical advection due to the anomalous vertical motion acting on the mean vertical temperature gradient, WbrTpr = vertical advection due to the mean vertical motion acting on the anomalous vertical temperature gradient, WprTpr = vertical advection due to the anomalous vertical motion acting on the anomalous vertical temperature gradient.

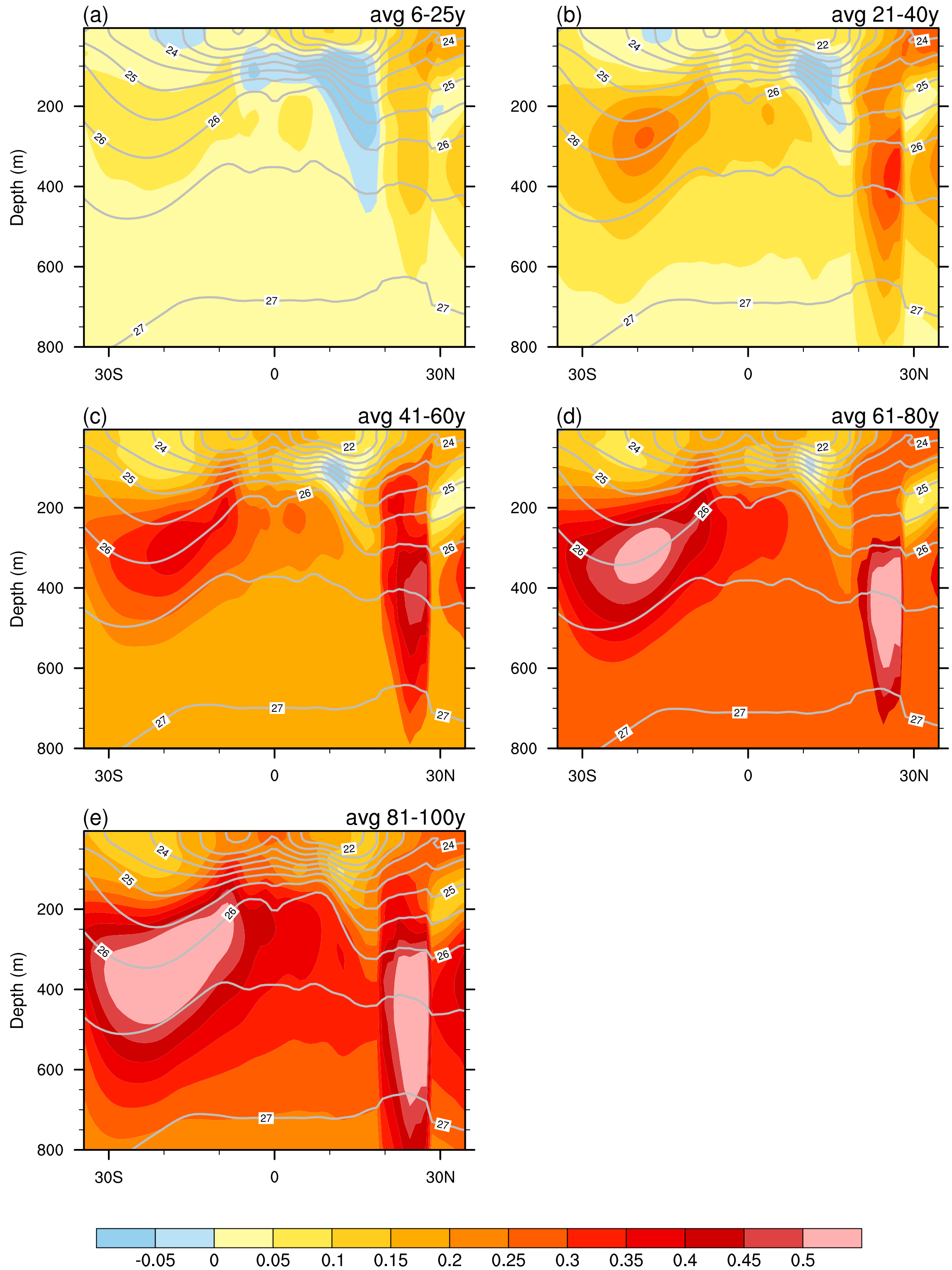

Figure S6. Depth-latitude sections of the temperature response (color shading; °C) superimposed upon climatological mean isopycnals (contours; kg m^{-3}) averaged over the longitude band (150°W-90°W) to an abrupt loss of Arctic sea ice in FOM, averaged over years: (a) 6-25, (b) 21-40, (c) 41-60, (d) 61-80 and (e) 81-100.

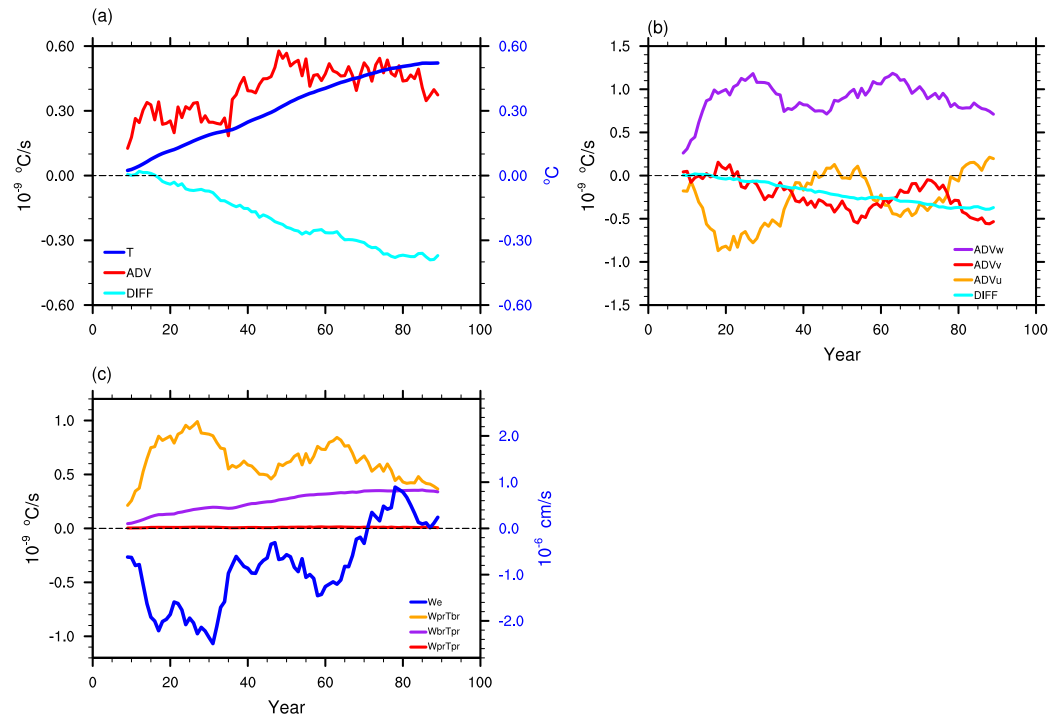

Figure S7. Heat budget decomposition for temperature averaged over the layer 200-400m (T; °C) in the region [30°S-10°S, 150°W-90°W] in FOM. The terms are defined as follows, in units of °C s^{-1}: (a) ADV = total advection, DIFF = diffusion; (b) ADVw = vertical advection, ADVu = zonal advection, ADVv = meridional advection; (c) WprTbr = vertical advection due to the anomalous vertical motion acting on the mean vertical temperature gradient, WbrTpr = vertical advection due to the mean vertical motion acting on the anomalous vertical temperature gradient, WprTpr = vertical advection due to the anomalous vertical motion acting on the anomalous vertical temperature gradient, We = Ekman pumping computed from the wind stress curl (10^{-6} cm s^{-1}).

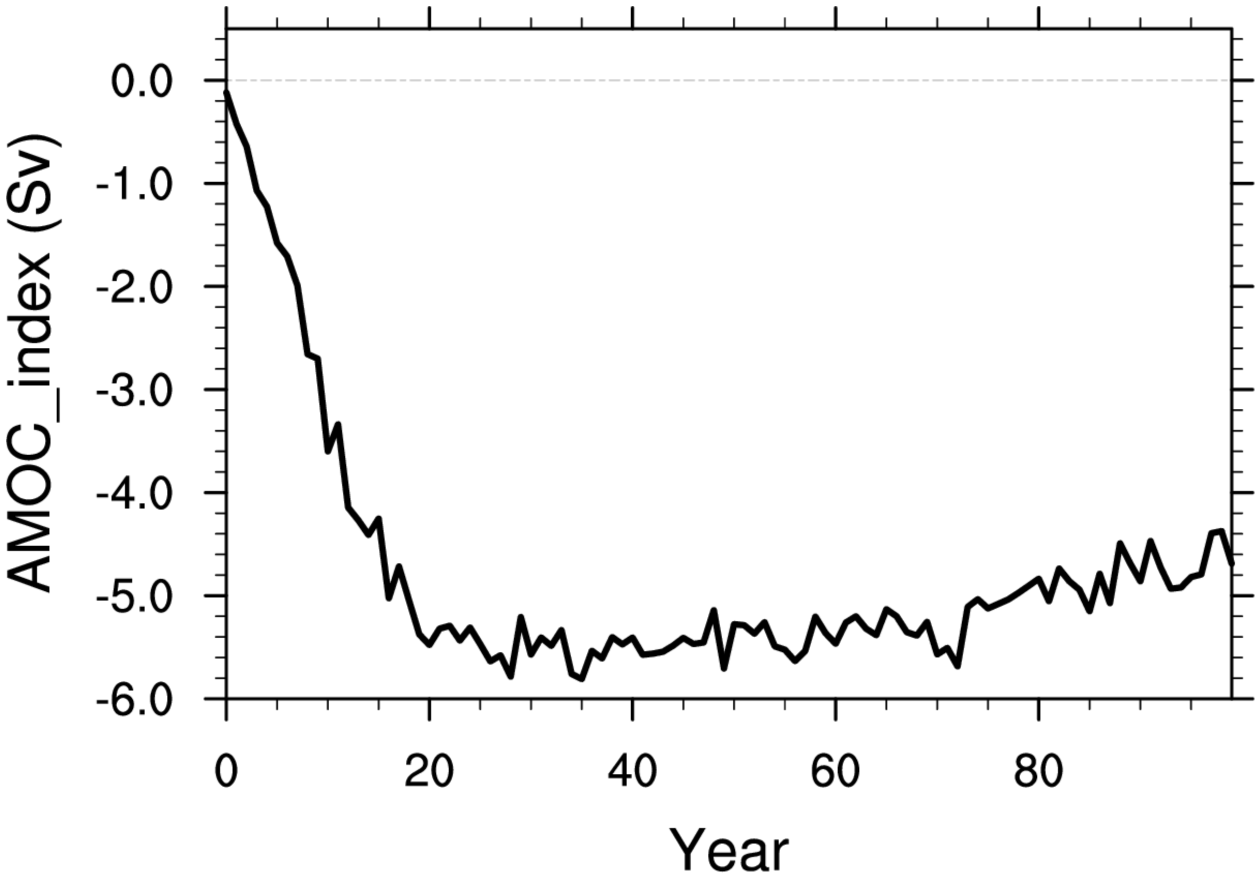

Figure S8. Evolution of the AMOC response (Sv) to an abrupt loss of Arctic sea ice in FOM. AMOC is defined as the maximum meridional overturning streamfunction in the Atlantic sector.

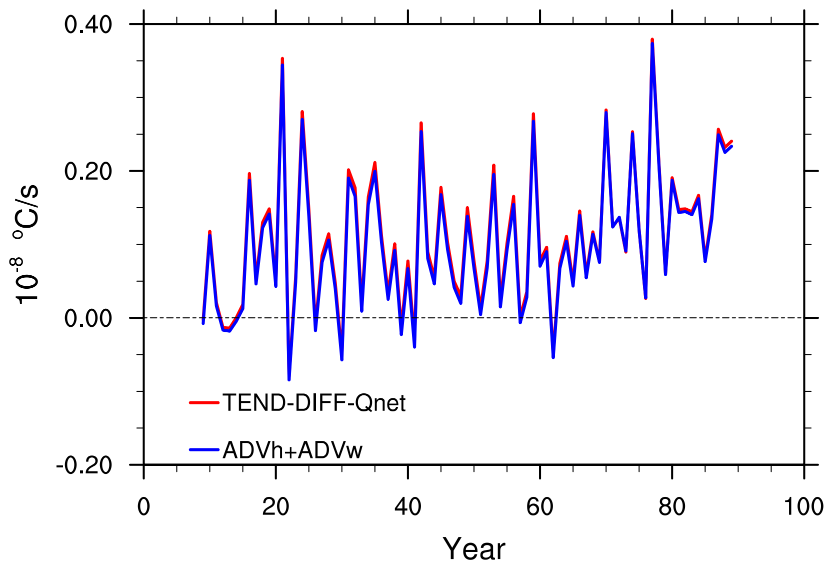

Figure S9. Demonstration that the heat budget decomposition for temperature averaged over the upper 100m in the region [10°S-10°S, 150°W-90°W] closes. Red curve shows the sum of the terms on the left-hand side of Eqn. (4) in Text S1 (TEND – DIFF - Qnet); blue curve shows the sum of the terms on the right-hand side of Eqn. (4) in Text S1 (ADVh + ADVw). The close match between the red and blue curves indicates that our heat budget decomposition closes to a high degree of accuracy.