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Supplement of

Midlatitude atmospheric circulation responses under 1.5 and 2.0°C warming and implications for regional impacts

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Supplement

S1 Model biases

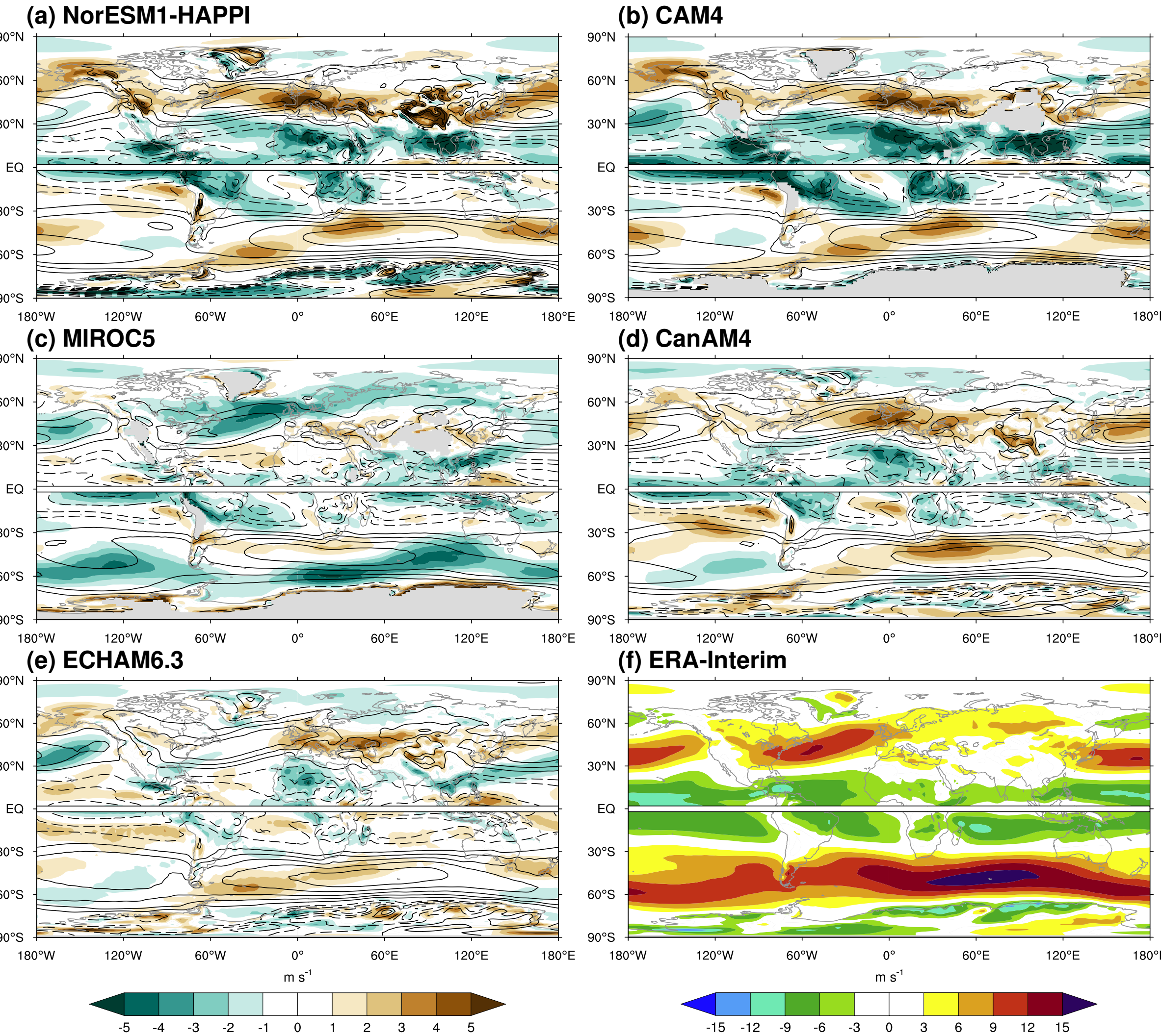

Figure S1. Model bias in winter (Northern Hemisphere DJF, Southern Hemisphere JJA) zonal wind at 850 hPa ($u850$) compared to ERA-Interim. (a)-(e) show the bias in individual models (shading; units m s^{-1}) along with the ERA-Interim climatology (contour interval 3 m s^{-1}). (f) shows the ERA-Interim climatology.

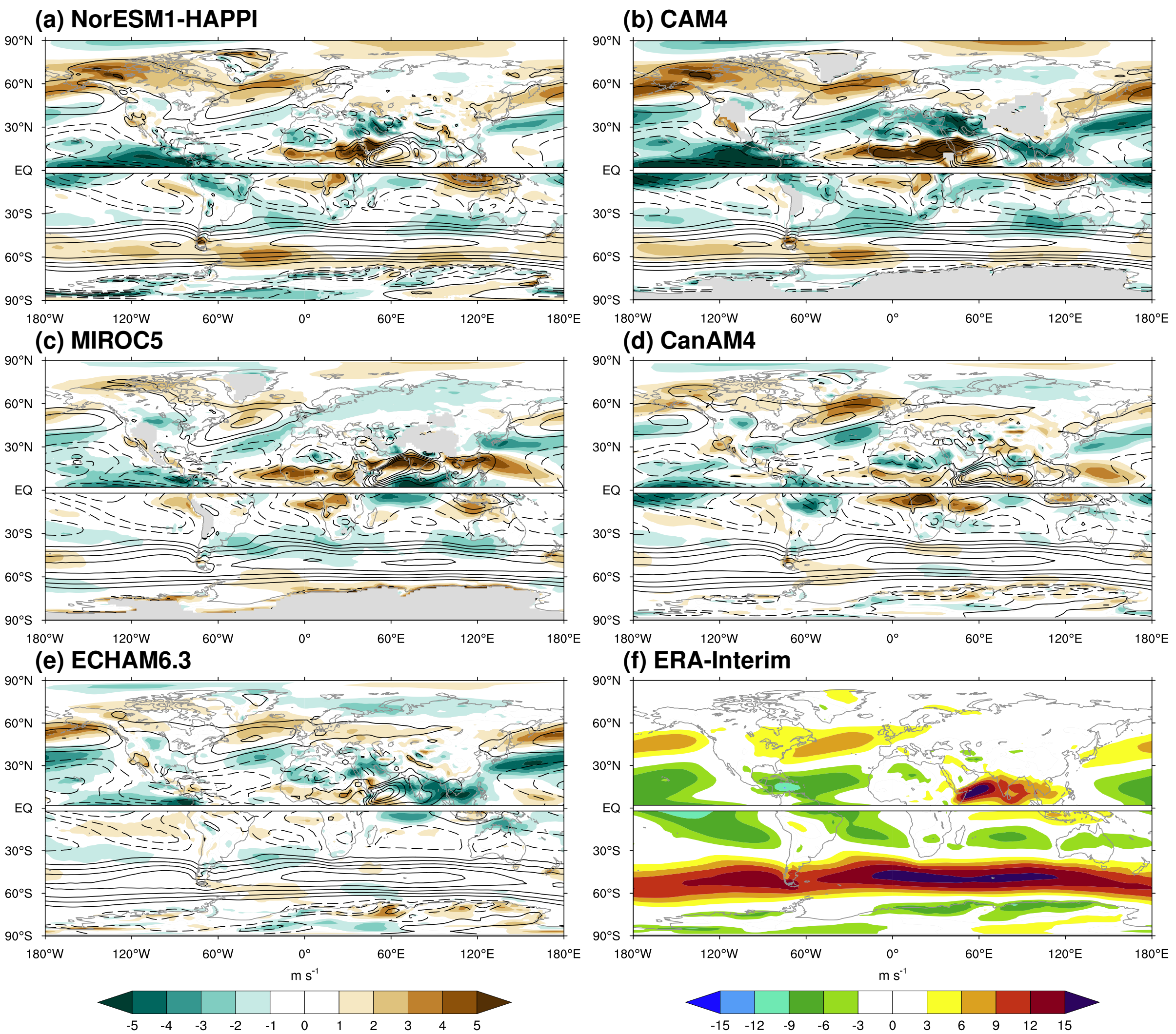

Figure S2. Model bias in summer (Northern Hemisphere JJA, Southern Hemisphere DJF) zonal wind at 850 hPa ($u850$) compared to ERA-Interim. (a)-(e) show the bias in individual models (shading; units m s^{-1}) along with the ERA-Interim climatology (contour interval 3 m s^{-1}). (f) shows the ERA-Interim climatology.

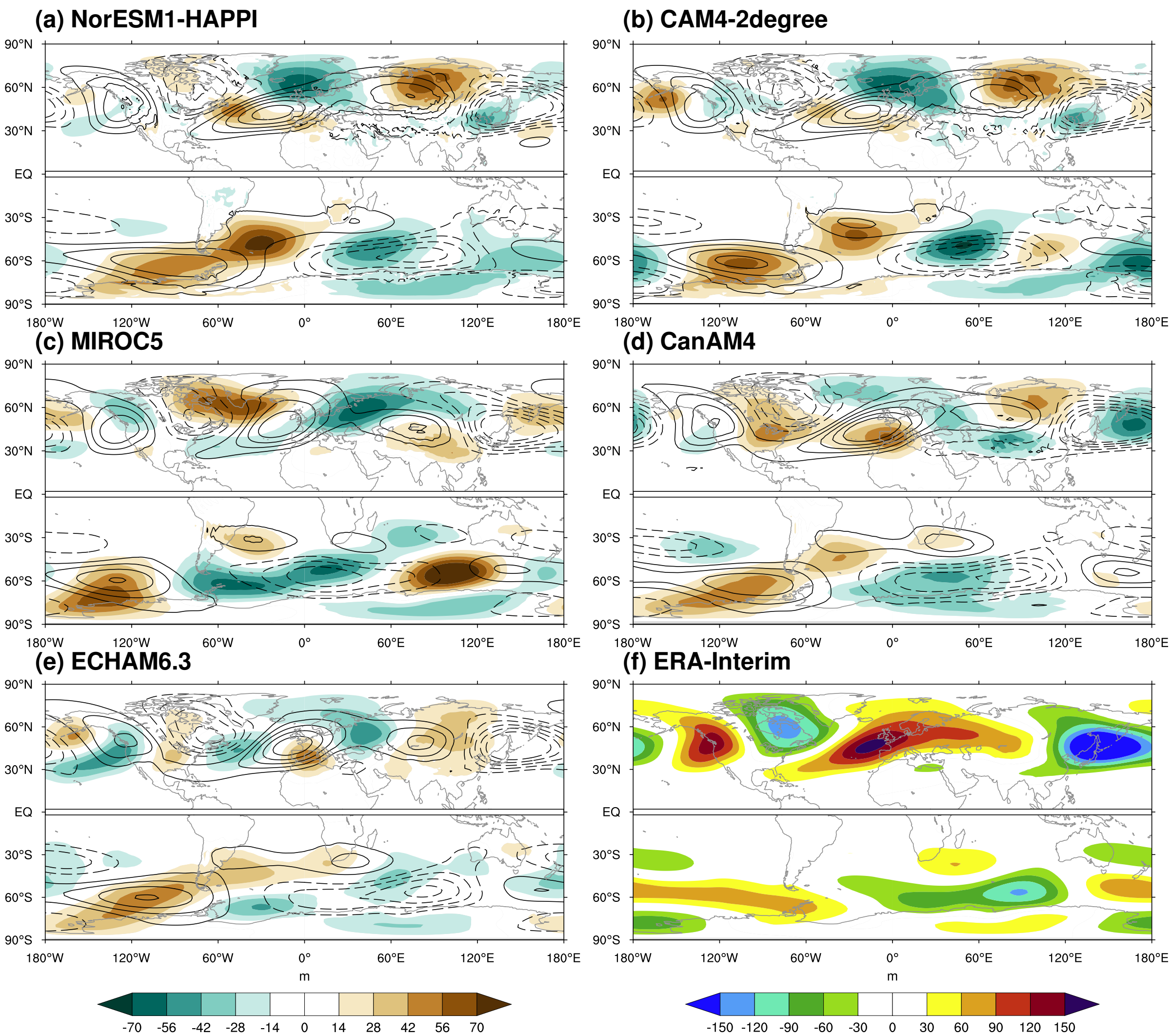

Figure S3. Model bias in winter (Northern Hemisphere DJF, Southern Hemisphere JJA) stationary waves at 500 hPa compared to ERA-Interim. (a)-(e) show the bias in individual models (shading; units m) along with the ERA-Interim climatology (contour interval 30 m). (f) shows the ERA-Interim climatology. Stationary waves are defined as departures from the zonal mean of geopotential height (Z^*) at 500 hPa.

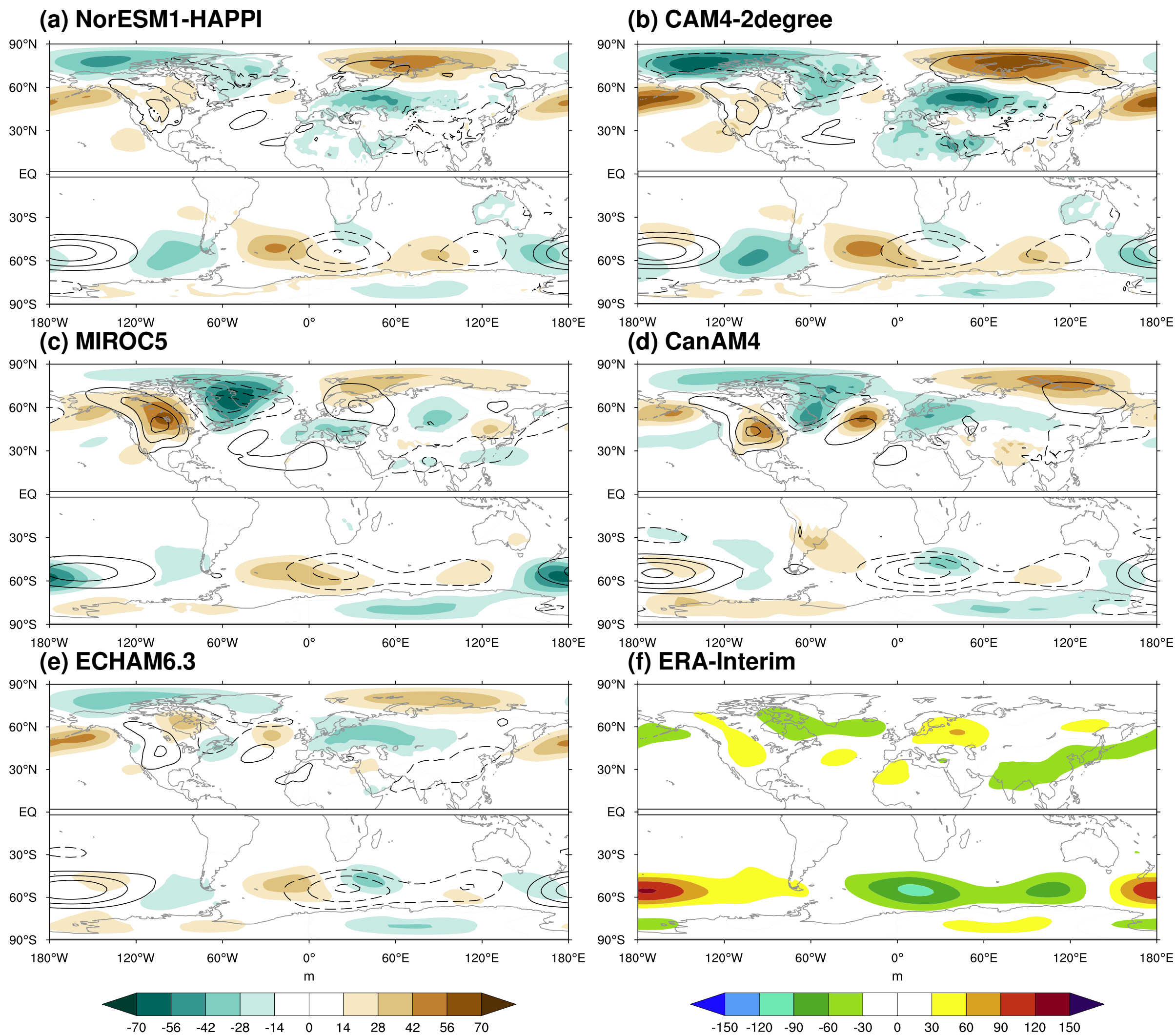

Figure S4. Model bias in summer (Northern Hemisphere JJA, Southern Hemisphere DJF) stationary waves at 500 hPa compared to ERA-Interim. (a)-(e) show the bias in individual models (shading; units m) along with the ERA-Interim climatology (contour interval 30 m). (f) shows the ERA-Interim climatology. Stationary waves are defined as departures from the zonal mean of geopotential height (Z^*) at 500 hPa.

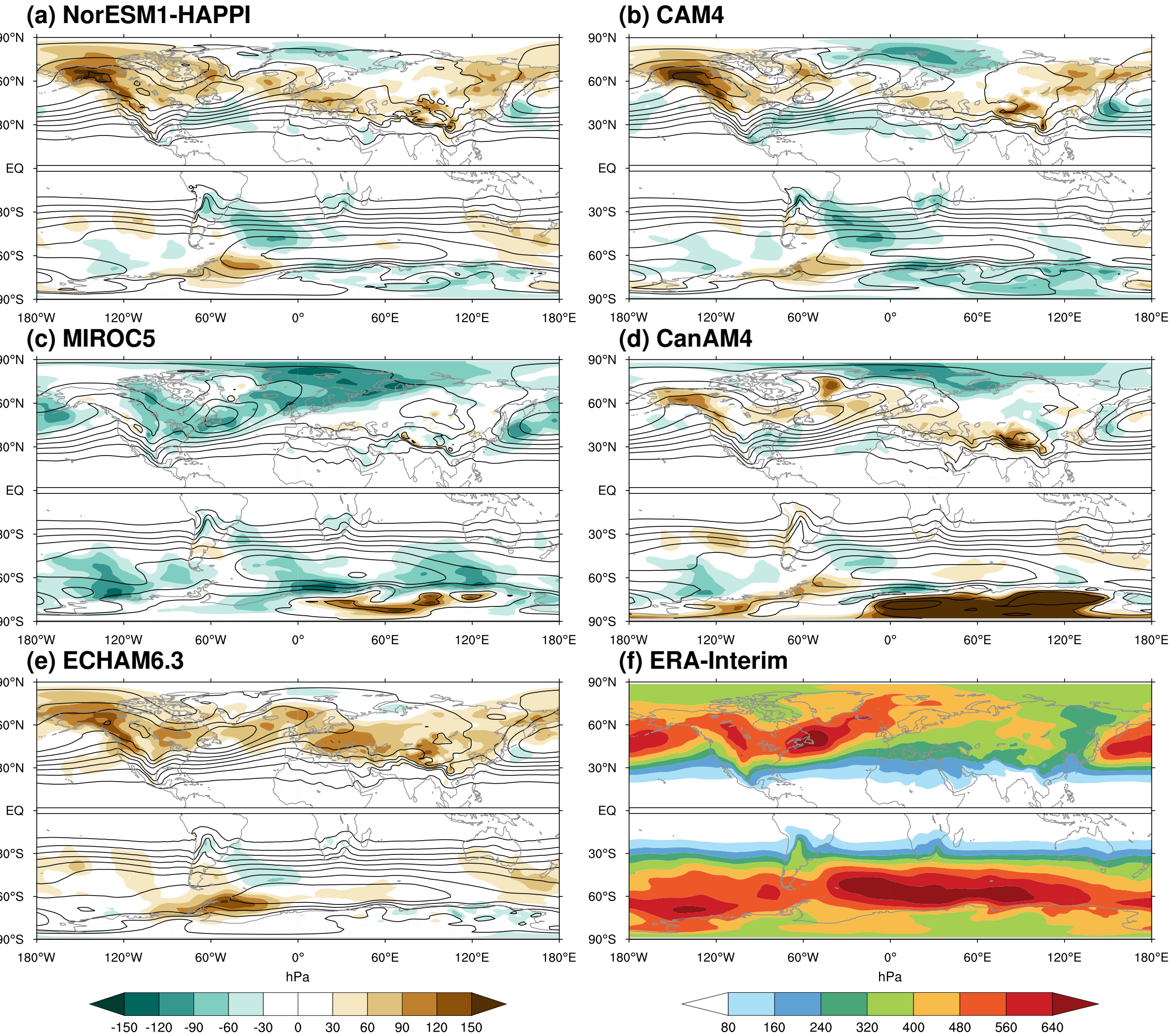

Figure S5. Model bias in winter (Northern Hemisphere DJF, Southern Hemisphere JJA) MSLP storm tracks compared to ERA-Interim. (a)-(e) show the bias in individual models (shading; units hPa) along with the ERA-Interim climatology (contour interval 80 hPa). (f) shows the ERA-Interim climatology. The storm tracks are defined as the standard deviation of bandpass filtered daily MSLP.

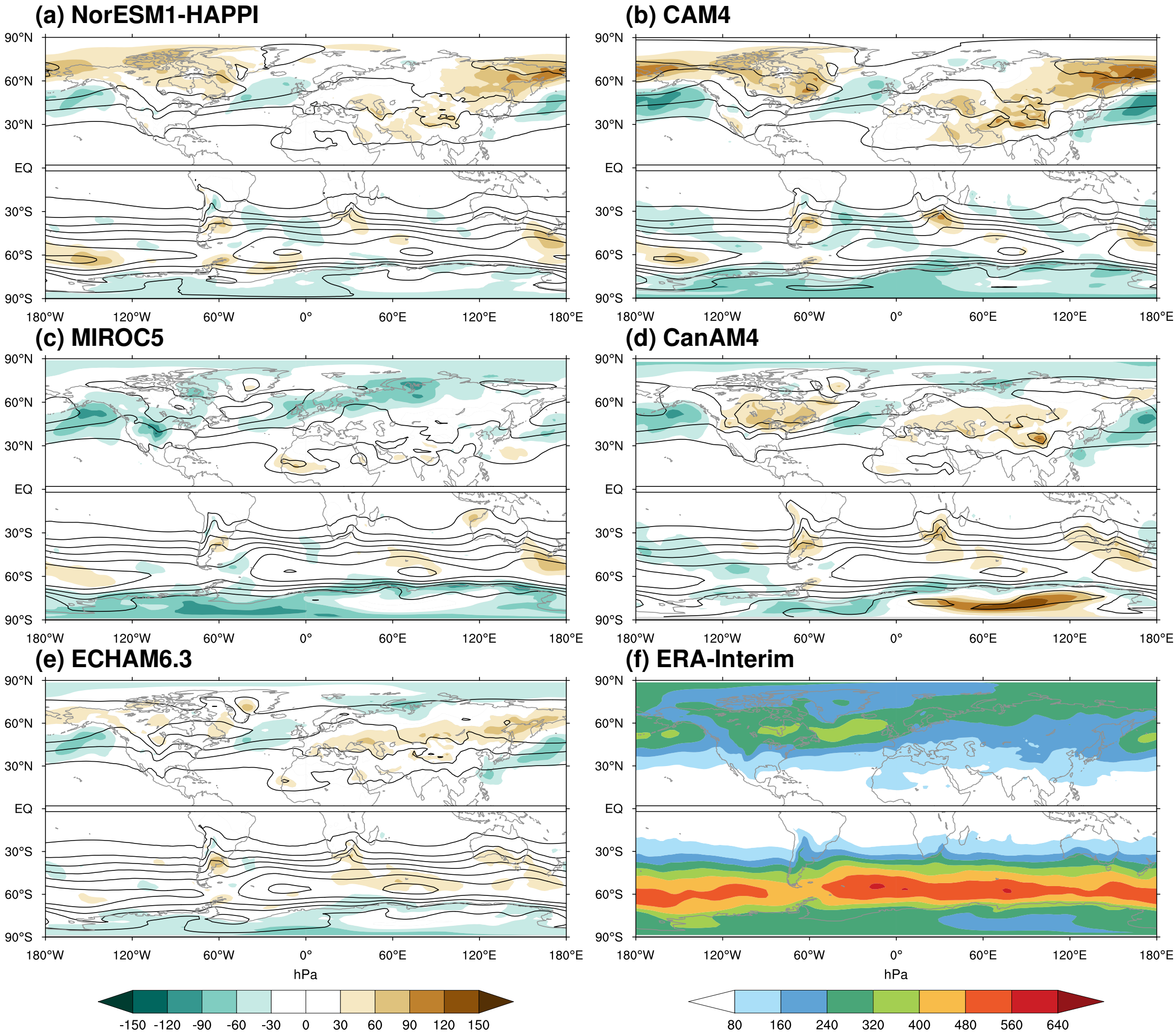

Figure S6. Model bias in summer (Northern Hemisphere JJA, Southern Hemisphere DJF) MSLP storm tracks compared to ERA-Interim. (a)-(e) show the bias in individual models (shading; units hPa) along with the ERA-Interim climatology (contour interval 80 hPa). (f) shows the ERA-Interim climatology. The storm tracks are defined as the standard deviation of bandpass filtered daily MSLP.

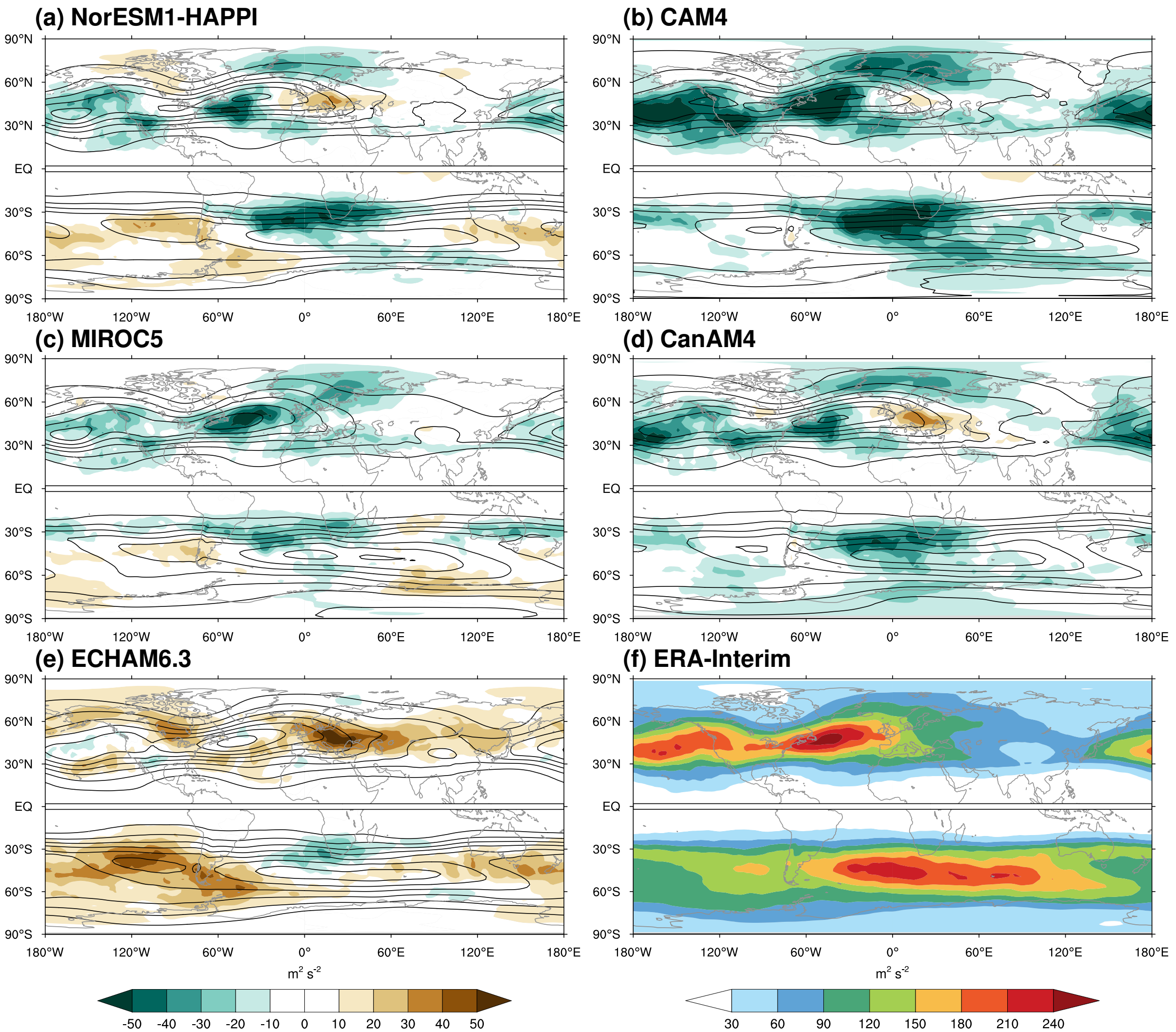

Figure S7. Model bias in winter (Northern Hemisphere DJF, Southern Hemisphere JJA) EKE storm tracks at 250 hPa ($EKE250$) compared to ERA-Interim. (a)-(e) show the bias in individual models (shading; units m^2 s^{-2}) along with the ERA-Interim climatology (contour interval 30 m^2 s^{-2}). (f) shows the ERA-Interim climatology (contour interval 30 m^2 s^{-1}). The storm tracks are defined as EKE calculated from bandpass filtered daily wind at 250 hPa.

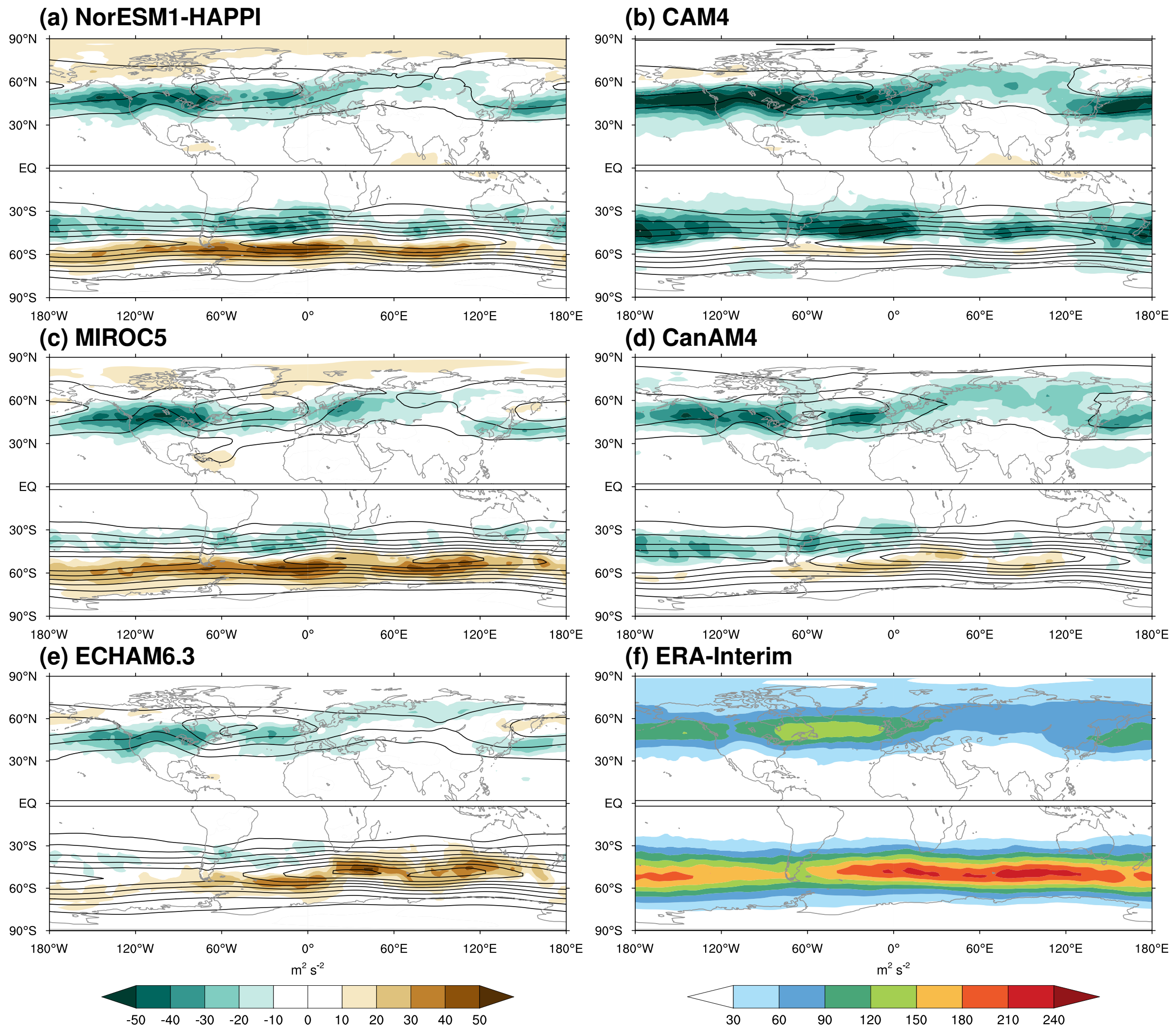

Figure S8. Model bias in summer (Northern Hemisphere JJA, Southern Hemisphere DJF) EKE storm tracks at 250 hPa ($EKE250$) compared to ERA-Interim. (a)-(e) show the bias in individual models (shading; units m^2 s^{-2}) along with the ERA-Interim climatology (contour interval 30 m^2 s^{-2}). (f) shows the ERA-Interim climatology (contour interval 30 m^2 s^{-1}). The storm tracks are defined as EKE calculated from bandpass filtered daily wind at 250 hPa.

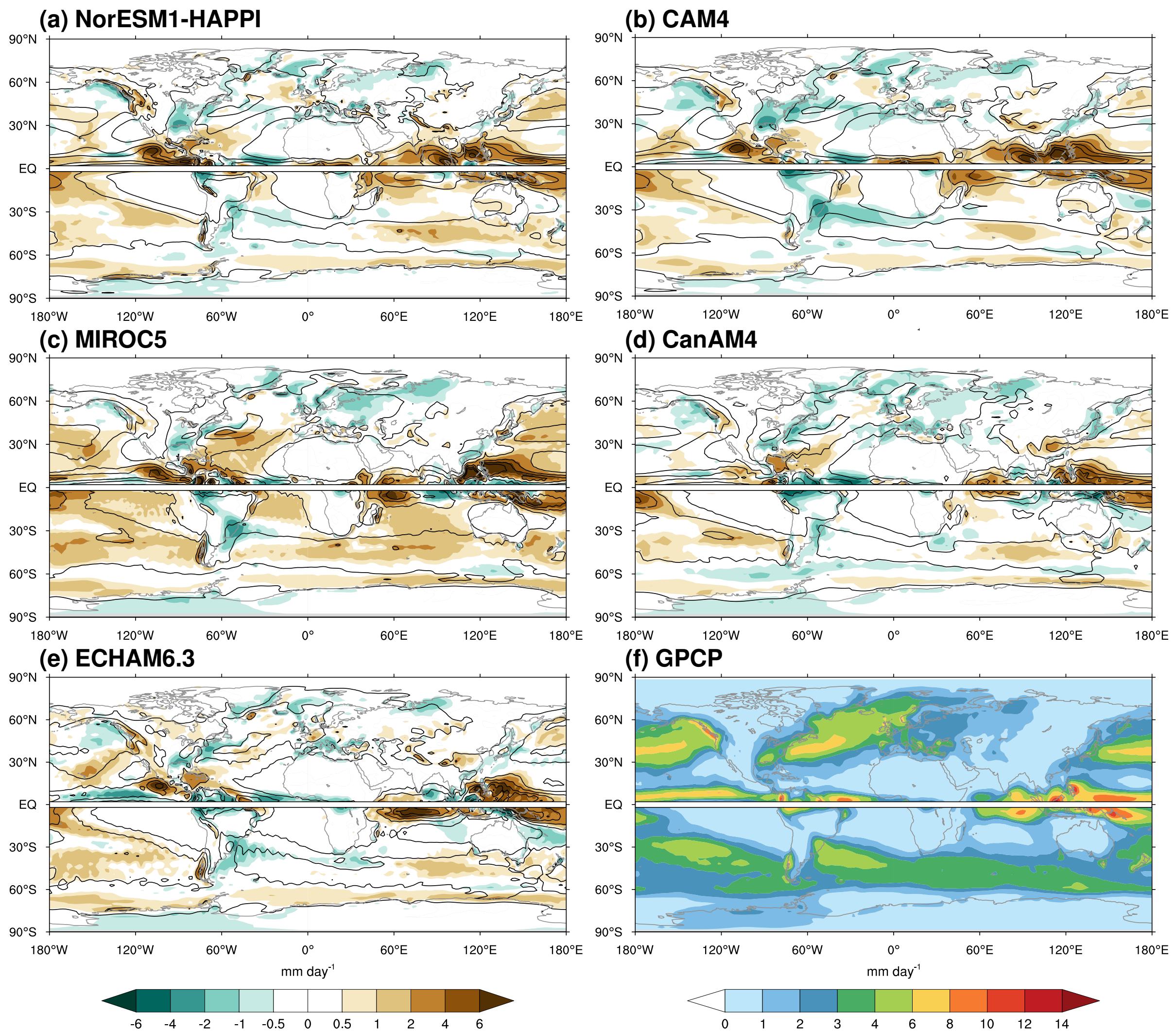

Figure S9. Model bias in winter (Northern Hemisphere DJF, Southern Hemisphere JJA) total precipitation compared to Global Precipitation Climatology Project (GPCP) Monthly Precipitation Analysis. (a)-(e) show the bias in individual models (shading; units mm day^{-1}) along with the GPCP climatology (contours 1, 3, 6, 9, and 12 mm day^{-1}). (f) shows the GPCP climatology (contours 1, 3, 6, 9, and 12 mm day^{-1}).

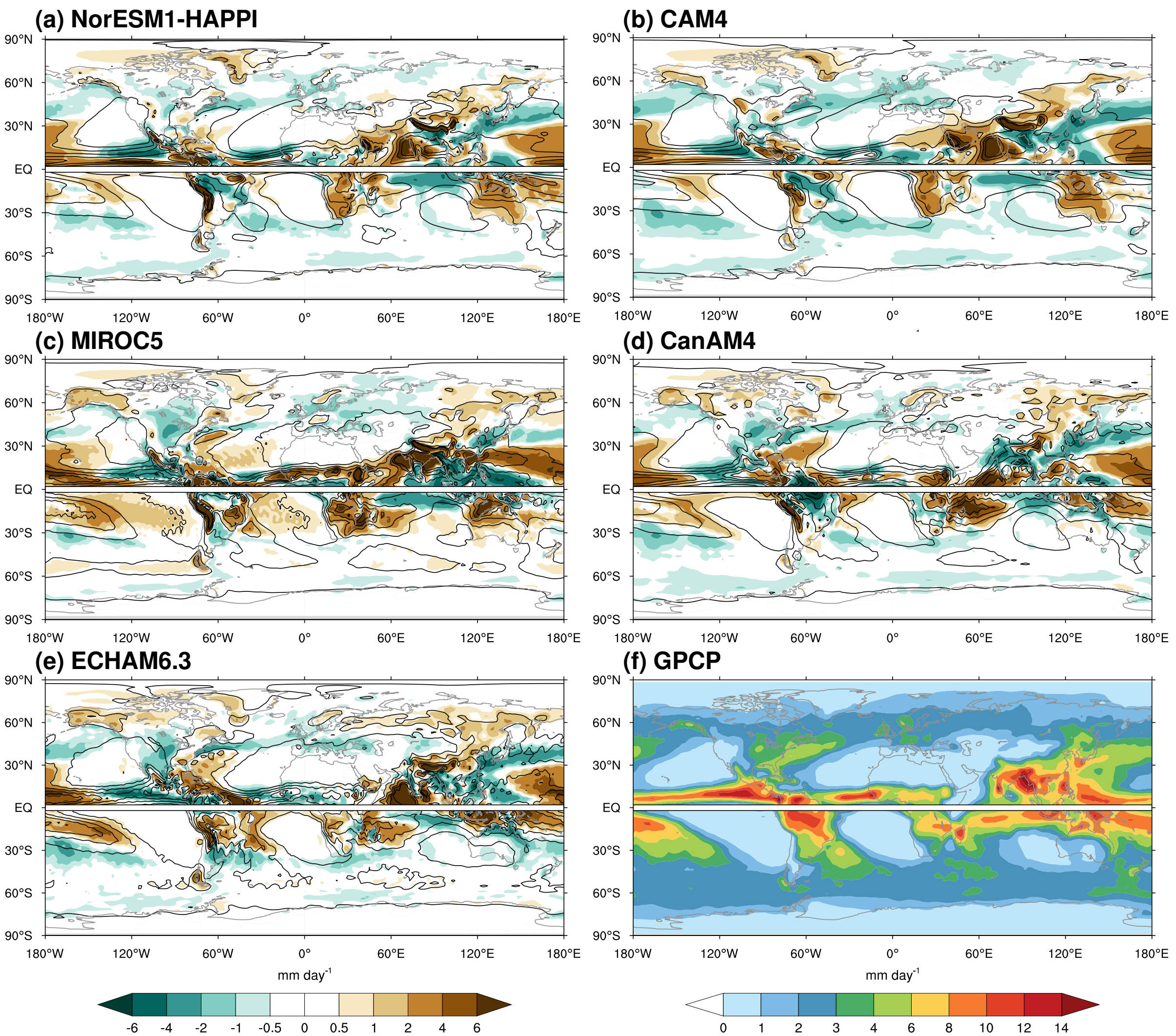

Figure S10. Model bias in summer (Northern Hemisphere JJA, Southern Hemisphere DJF) total precipitation compared to GPCP. (a)-(e) show the bias in individual models (shading; units mm day^{-1}) along with the GPCP climatology (contours 1, 3, 6, 9, and 12 mm day^{-1}). (f) shows the GPCP climatology (contours 1, 3, 6, 9, and 12 mm day^{-1}).

S2 Summer responses in circulation fields

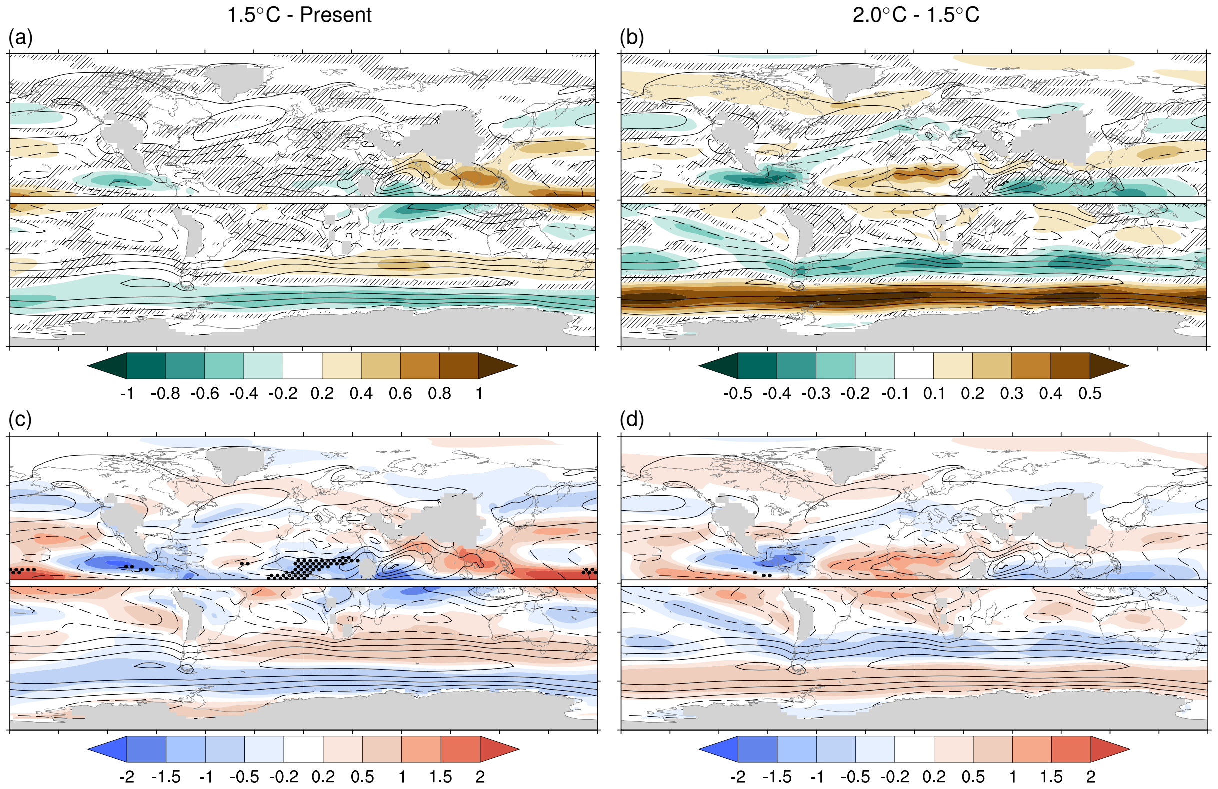

Figure S11. Response of summer (Northern Hemisphere JJA, Southern Hemisphere DJF) zonal wind at 850 hPa ($u850$) for 1.5°C−PD (left) and 2.0°C−1.5°C (right). Top panels show responses (shading; units m s^{-1}) along with the climatology (contour interval 4 m s^{-1}) for the (a) PD and (b) 1.5°C experiments. Bottom panels show signal-to-noise ratio β/σ, where the sign corresponds to the sign of the response, along with the climatology (contour interval as above) for the (c) 1.5°C and (d) 2.0°C experiments. In (a) and (b), hatching masks out regions where there is no model consensus (fewer than four out of five models agree) on the sign of the response. In (c) and (d), black dots (if present) mask out regions where the models do not agree on the magnitude of the response ($f^2 > 1$). Grey shading indicates regions of high topography intersecting the plotted variable.

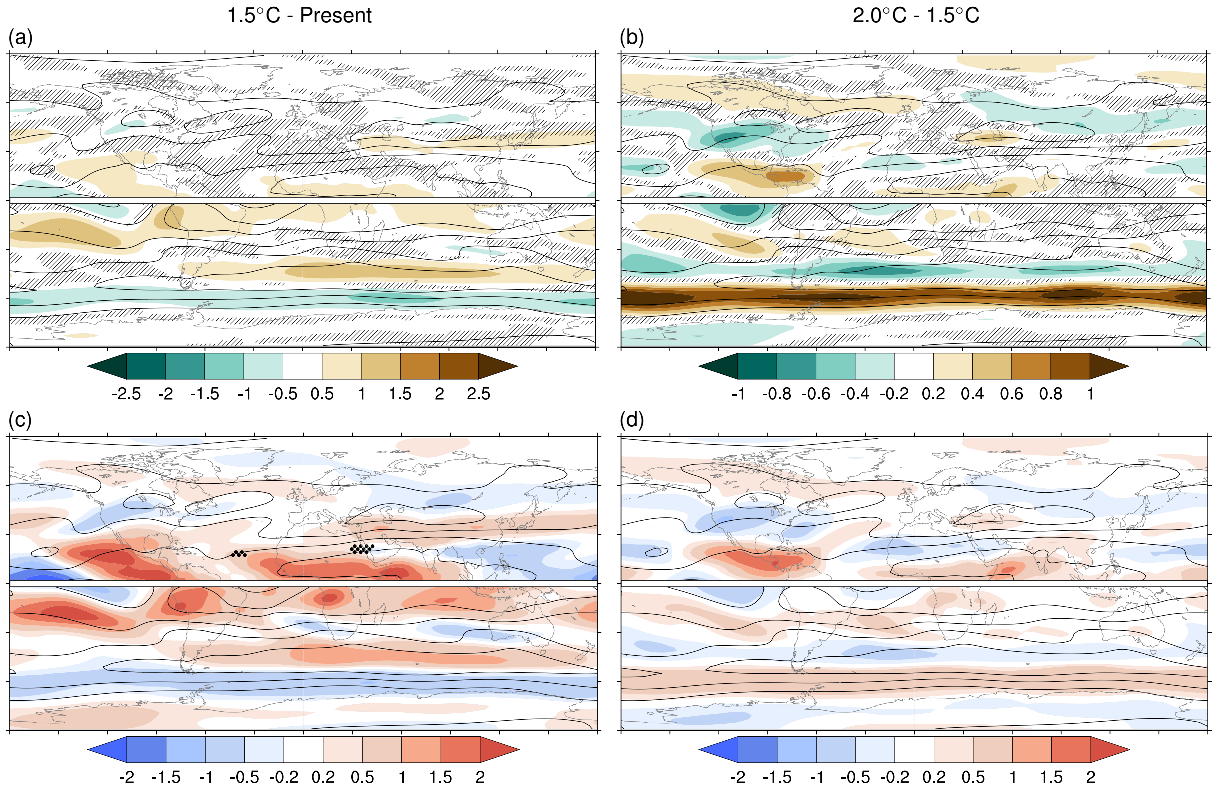

Figure S12. Response of summer (Northern Hemisphere JJA, Southern Hemisphere DJF) zonal wind at 250 hPa ($u250$) for 1.5°C−PD (left) and 2.0°C−1.5°C (right). Top panels show responses (shading; units m s^{-1}) along with the climatology (contour interval 10 m s^{-1}) for the (a) PD and (b) 1.5°C experiments. Bottom panels show signal-to-noise ratio β/σ, where the sign corresponds to the sign of the response, along with the climatology (contour interval as above) for the (c) 1.5°C and (d) 2.0°C experiments. In (a) and (b), hatching masks out regions where there is no model consensus (fewer than four out of five models agree) on the sign of the response. In (c) and (d), black dots (if present) mask out regions where the models do not agree on the magnitude of the response ($f^2 > 1$).

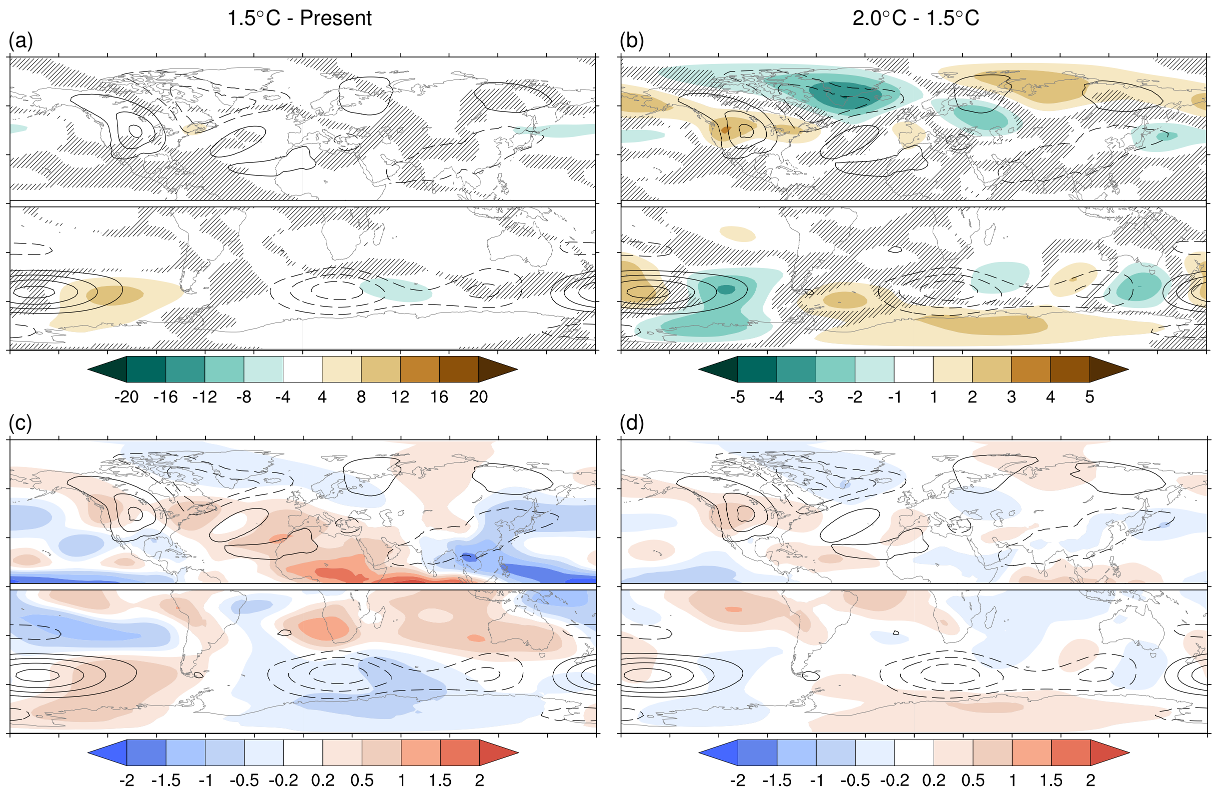

Figure S13. Response of summer (Northern Hemisphere JJA, Southern Hemisphere DJF) stationary waves at 500 hPa for 1.5°C−PD (left) and 2.0°C−1.5°C (right). Top panels show responses (shading; units m) along with the climatology (contour interval 25 m) for the (a) PD and (b) 1.5°C experiments. Bottom panels show signal-to-noise ratio β/σ, where the sign corresponds to the sign of the response, along with the climatology (contour interval as above) for the (c) 1.5°C and (d) 2.0°C experiments. In (a) and (b), hatching masks out regions where there is no model consensus (fewer than four out of five models agree) on the sign of the response. In (c) and (d), black dots (if present) mask out regions where the models do not agree on the magnitude of the response ($f^2 > 1$). Stationary waves are defined as the departures from the zonal mean of geopotential height (Z^*) at 500 hPa.

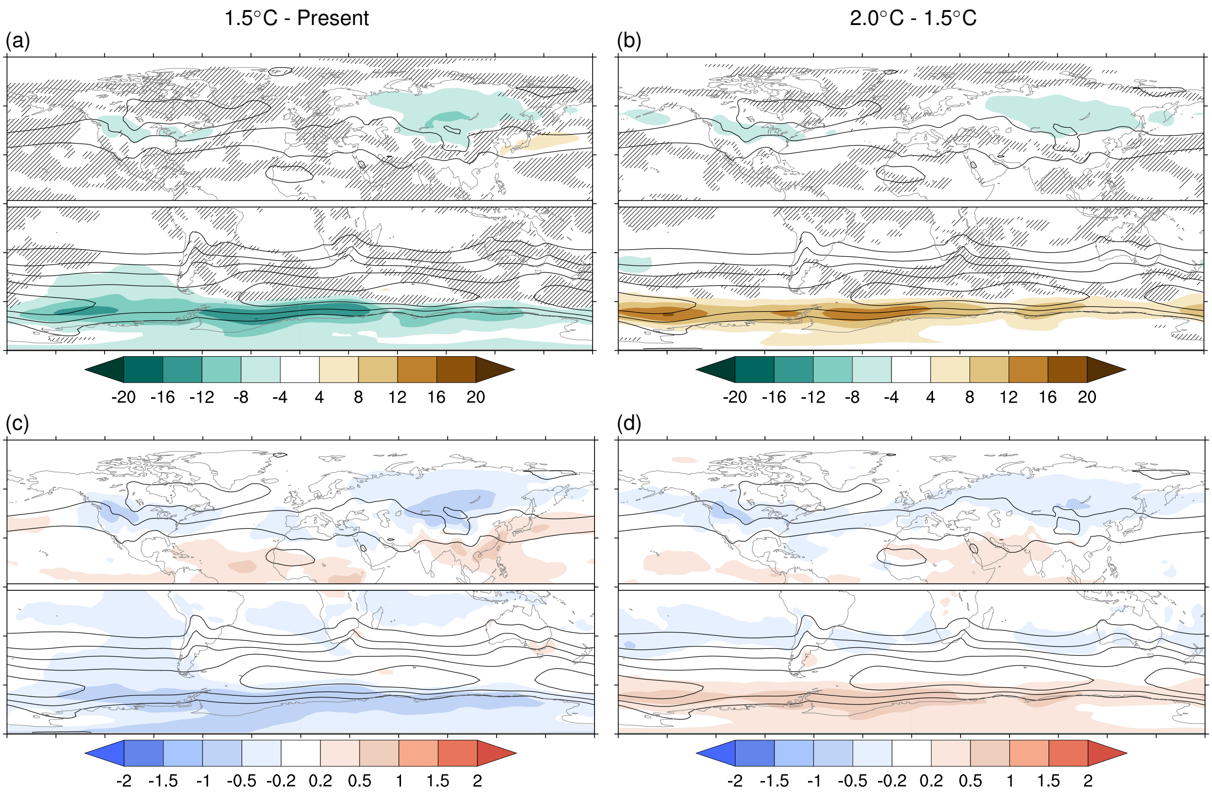

Figure S14. Response of summer (Northern Hemisphere JJA, Southern Hemisphere DJF) MSLP storm tracks for 1.5°C−PD (left) and 2.0°C−1.5°C (right). Top panels show responses (shading; units hPa) along with the climatology (contour interval 100 hPa) for the (a) PD and (b) 1.5°C experiments. Bottom panels show signal-to-noise ratio β/σ, where the sign corresponds to the sign of the response, along with the climatology (contour interval as above) for the (c) 1.5°C and (d) 2.0°C experiments. In (a) and (b), hatching masks out regions where there is no model consensus (fewer than four out of five models agree) on the sign of the response. In (c) and (d), black dots (if present) mask out regions where the models do not agree on the magnitude of the response ($f^2 > 1$). The storm tracks are defined as the standard deviation of bandpass filtered daily MSLP.

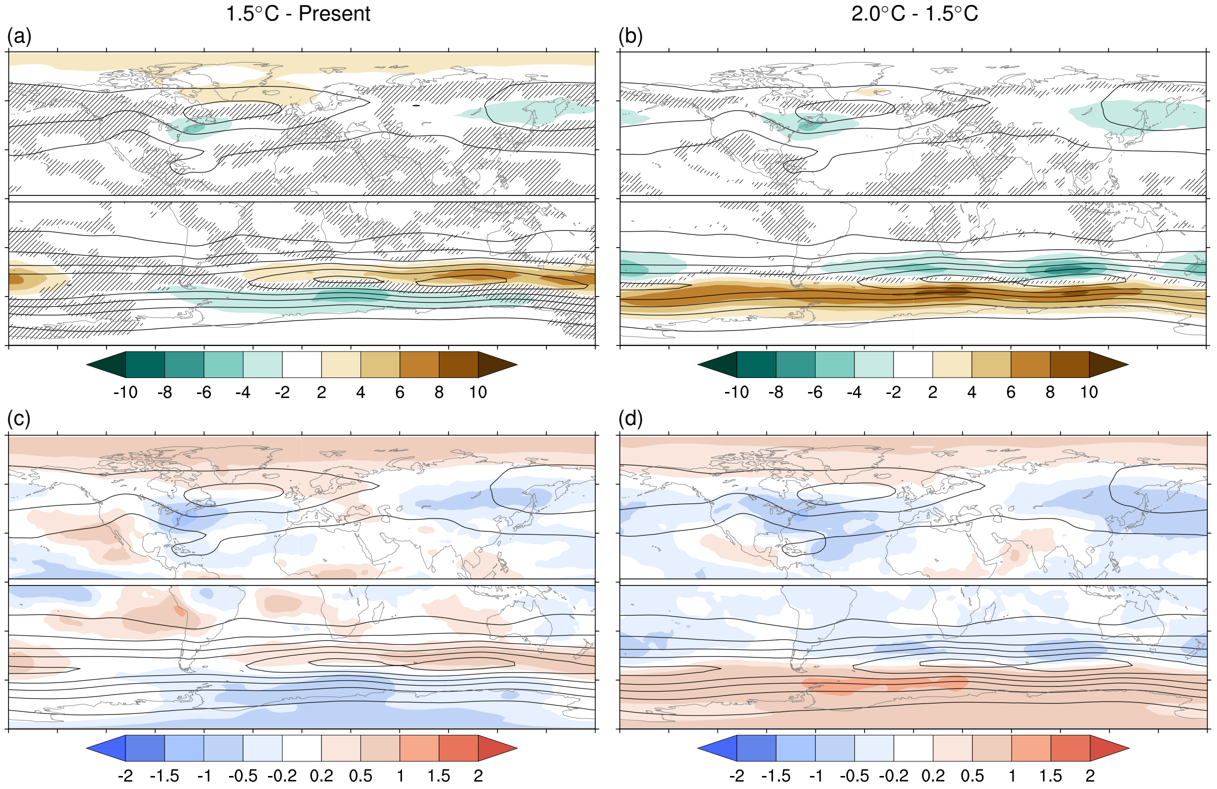

Figure S15. Response of summer (Northern Hemisphere JJA, Southern Hemisphere DJF) EKE storm tracks for 1.5°C−PD (left) and 2.0°C−1.5°C (right). Top panels show responses (shading; units hPa) along with the climatology (contour interval 100 hPa) for the (a) PD and (b) 1.5°C experiments. Bottom panels show signal-to-noise ratio β/σ, where the sign corresponds to the sign of the response, along with the climatology (contour interval as above) for the (c) 1.5°C and (d) 2.0°C experiments. In (a) and (b), hatching masks out regions where there is no model consensus (fewer than four out of five models agree) on the sign of the response. In (c) and (d), black dots (if present) mask out regions where the models do not agree on the magnitude of the response ($f^2 > 1$). The storm tracks are defined as EKE calculated from bandpass filtered daily wind at 250 hPa.

S3 2.0°C minus PD responses

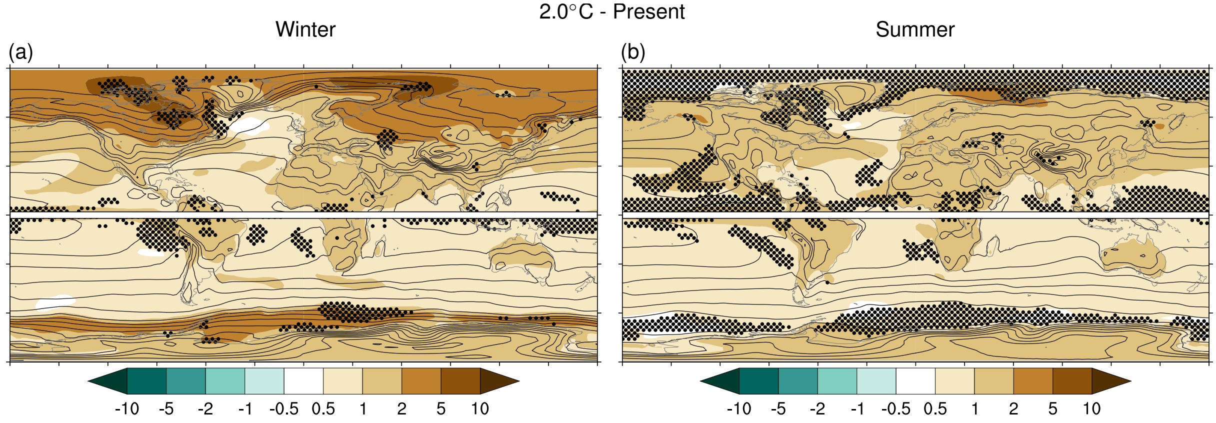

Figure S16. Response of winter (left) and summer (right) surface air temperature for 2.0°C−PD (shading; units K) along with the climatology (contour interval 5 K) for the PD experiment. Black dots mask out regions where the models do not agree on the magnitude of the response ($f^2 > 1$).

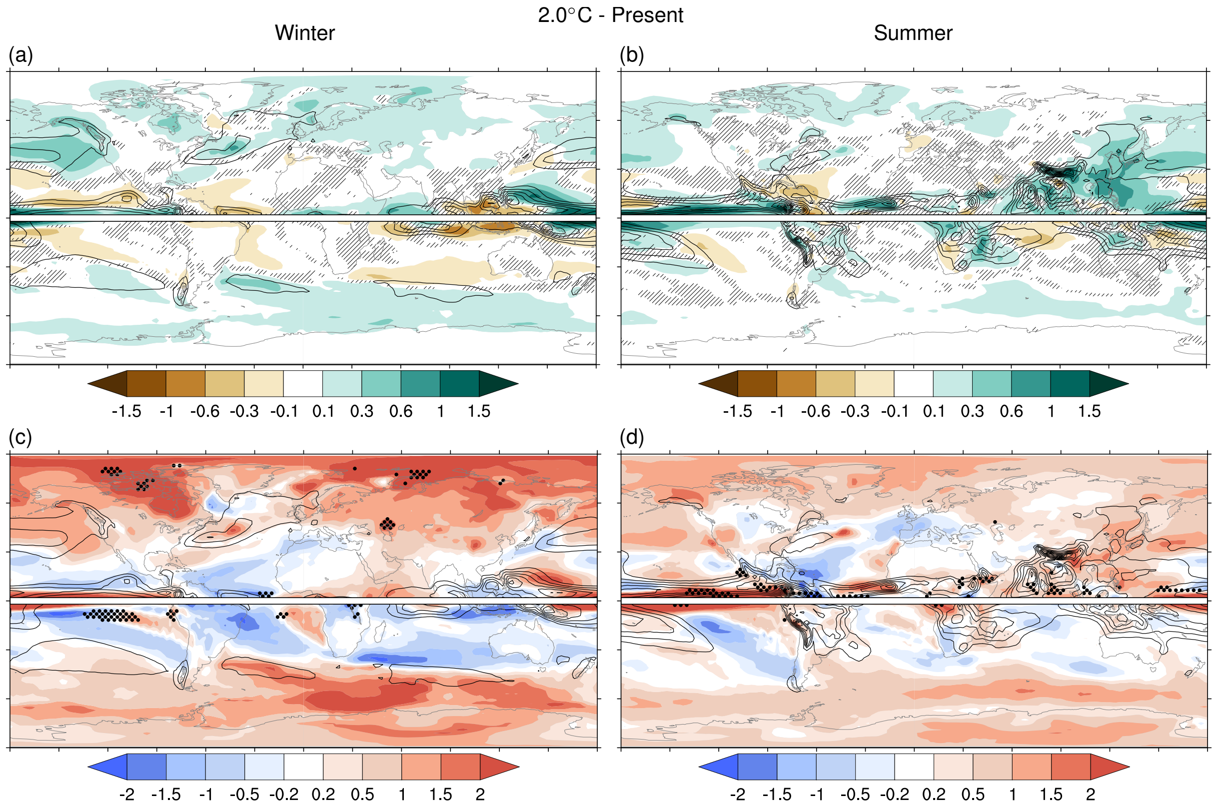

Figure S17. Response of winter (left) and summer (right) precipitation for 2.0°C$-$PD. Top panels show responses (shading; units mm d^{-1}) along with the climatology (contour interval 2 mm d^{-1} starting from 4 mm d^{-1}) for the PD experiment. Bottom panels show signal-to-noise ratio β/σ, where the sign corresponds to the sign of the response, along with the climatology (contour interval as above) for the (c) 1.5°C and (d) 2.0°C experiments. In (a) and (b), hatching masks out regions where there is no model consensus (fewer than four out of five models agree) on the sign of the response. In (c) and (d), black dots (if present) mask out regions where the models do not agree on the magnitude of the response ($f^2 > 1$).

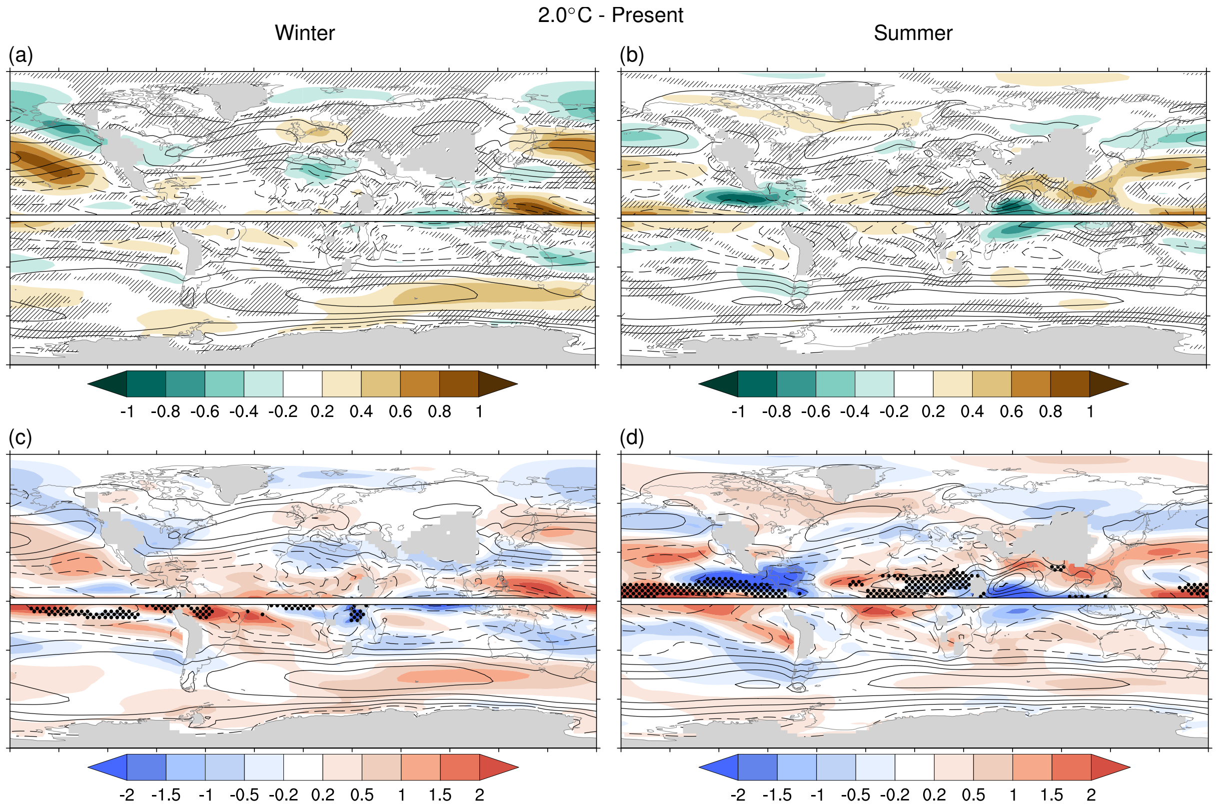

Figure S18. Response of winter (left) and summer (right) zonal wind at 850 hPa for 2.0°C−PD. Top panels show responses (shading; units m s^{-1}) along with the climatology (contour interval 4 m s^{-1}) for the PD experiment. Bottom panels show signal-to-noise ratio β/σ, where the sign corresponds to the sign of the response, along with the climatology (contour interval as above) for the (c) 1.5°C and (d) 2.0°C experiments. In (a) and (b), hatching masks out regions where there is no model consensus (fewer than four out of five models agree) on the sign of the response. In (c) and (d), black dots (if present) mask out regions where the models do not agree on the magnitude of the response ($f^2 > 1$). Grey shading indicates regions of high topography intersecting the plotted variable.

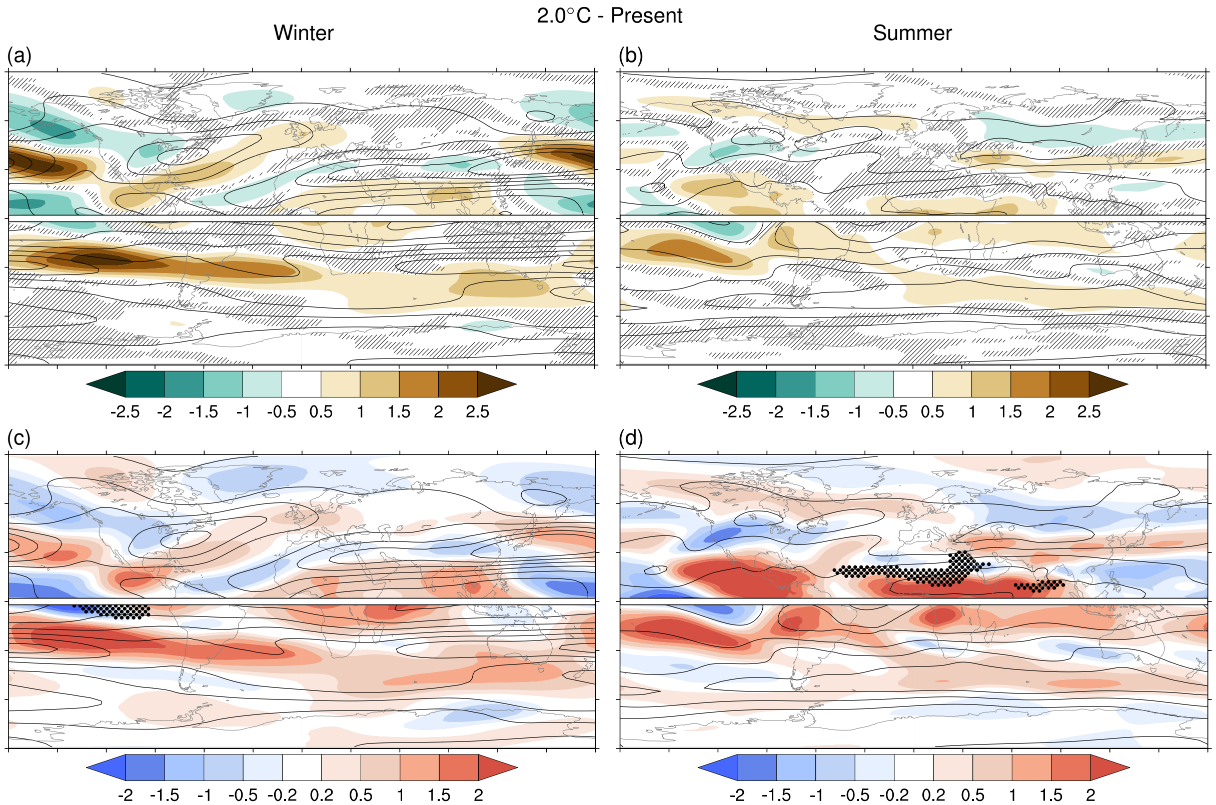

Figure S19. Response of winter (left) and summer (right) zonal wind at 250 hPa for 2.0°C−PD. Top panels show responses (shading; units m s^{-1}) along with the climatology (contour interval 10 m s^{-1}) for the PD experiment. Bottom panels show signal-to-noise ratio β/σ, where the sign corresponds to the sign of the response, along with the climatology (contour interval as above) for the (c) 1.5°C and (d) 2.0°C experiments. In (a) and (b), hatching masks out regions where there is no model consensus (fewer than four out of five models agree) on the sign of the response. In (c) and (d), black dots (if present) mask out regions where the models do not agree on the magnitude of the response ($f^2 > 1$).

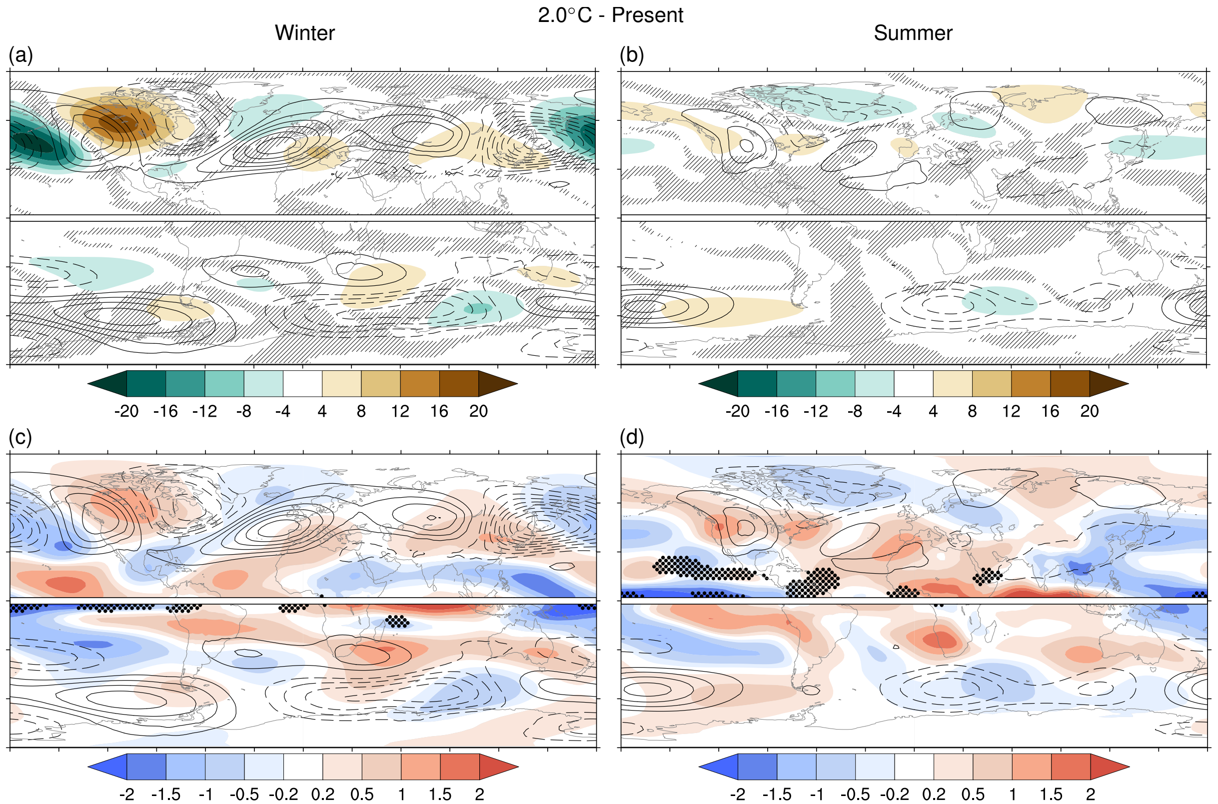

Figure S20. Response of winter (left) and summer (right) stationary waves at 500 hPa for 2.0°C−PD. Top panels show responses (shading; units m) along with the climatology (contour interval 25 m) for the PD experiment. Bottom panels show signal-to-noise ratio β/σ, where the sign corresponds to the sign of the response, along with the climatology (contour interval as above) for the (c) 1.5°C and (d) 2.0°C experiments. In (a) and (b), hatching masks out regions where there is no model consensus (fewer than four out of five models agree) on the sign of the response. In (c) and (d), black dots (if present) mask out regions where the models do not agree on the magnitude of the response ($f^2 > 1$). Stationary waves are defined as departures from the zonal mean of geopotential height (Z^*) at 500 hPa.

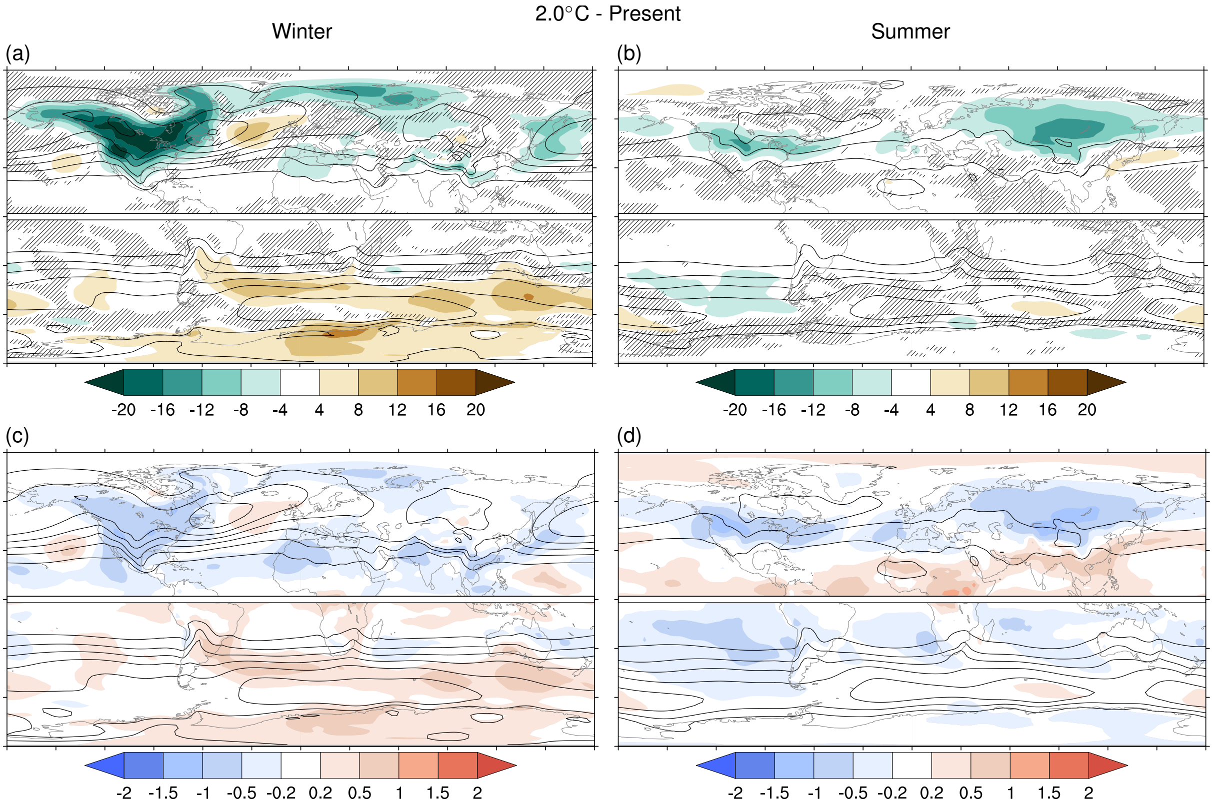

Figure S21. Response of winter (left) and summer (right) MSLP storm tracks for 2.0°C−PD. Top panels show responses (shading; units hPa) along with the climatology (contour interval 100 hPa) for the PD experiment. Bottom panels show signal-to-noise ratio β/σ, where the sign corresponds to the sign of the response, along with the climatology (contour interval as above) for the (c) 1.5°C and (d) 2.0°C experiments. In (a) and (b), hatching masks out regions where there is no model consensus (fewer than four out of five models agree) on the sign of the response. In (c) and (d), black dots (if present) mask out regions where the models do not agree on the magnitude of the response ($f^2 > 1$).

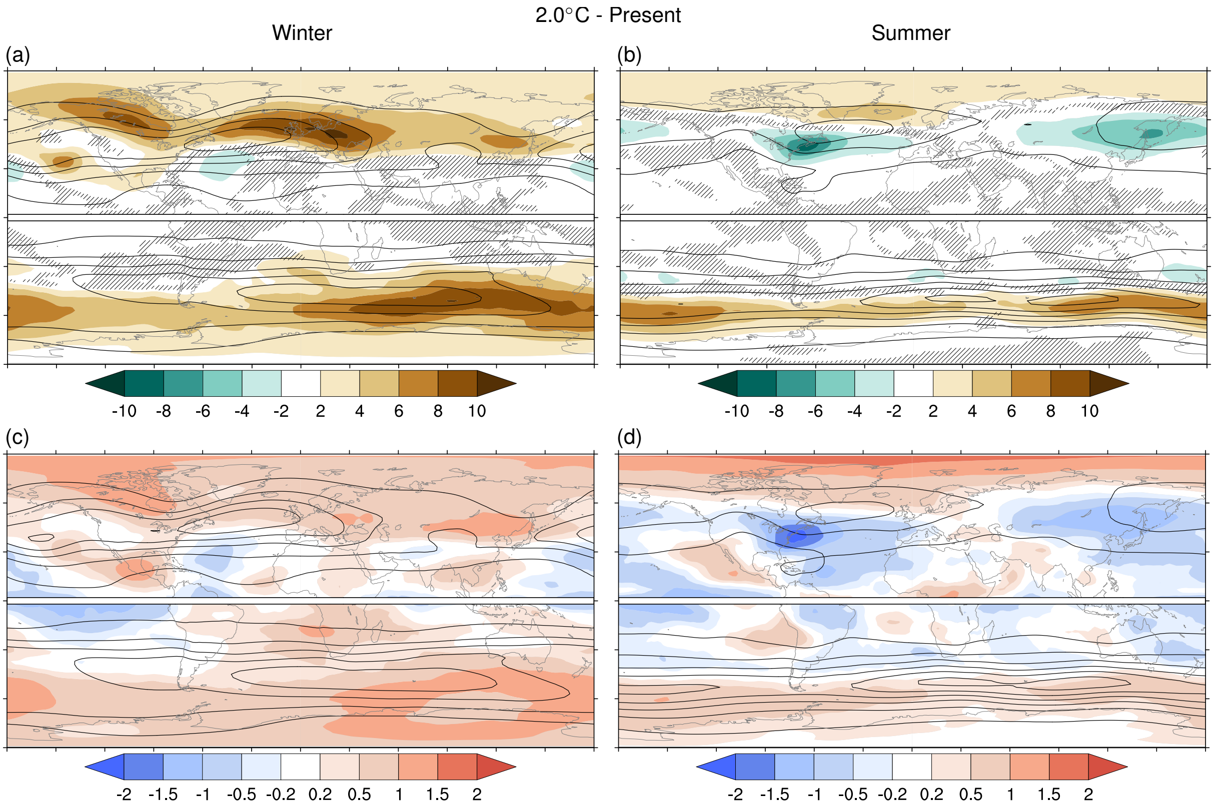

Figure S22. Response of winter (left) and summer (right) EKE storm tracks for 2.0°C−PD. Top panels show responses (shading; units m^2 s^{-2}) along with the climatology (contour interval 40 m^2 s^{-2}) for the PD experiment. Bottom panels show signal-to-noise ratio β/σ, where the sign corresponds to the sign of the response, along with the climatology (contour interval as above) for the (c) 1.5°C and (d) 2.0°C experiments. In (a) and (b), hatching masks out regions where there is no model consensus (fewer than four out of five models agree) on the sign of the response. In (c) and (d), black dots (if present) mask out regions where the models do not agree on the magnitude of the response ($f^2 > 1$). The storm tracks are defined as EKE calculated from bandpass filtered daily wind at 250 hPa.