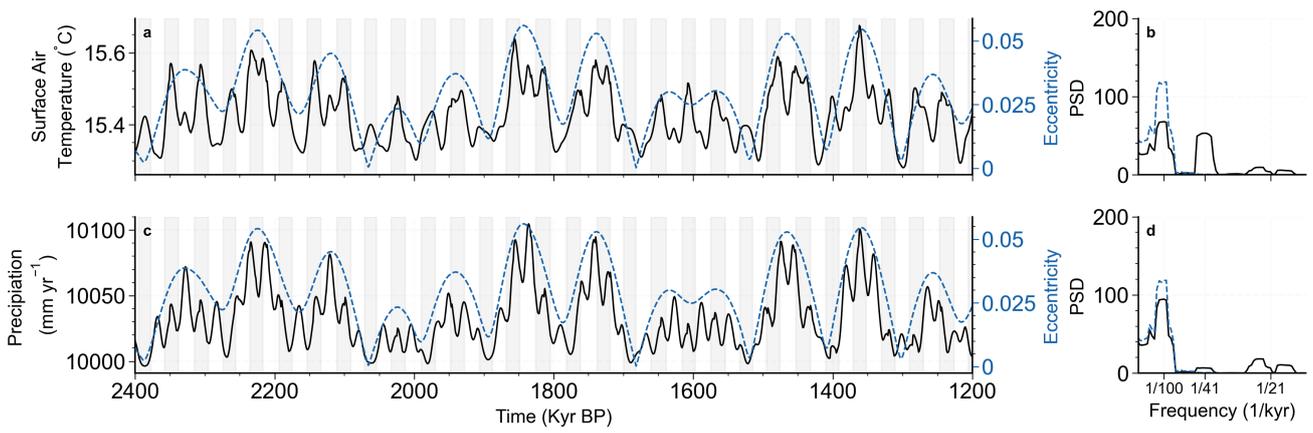
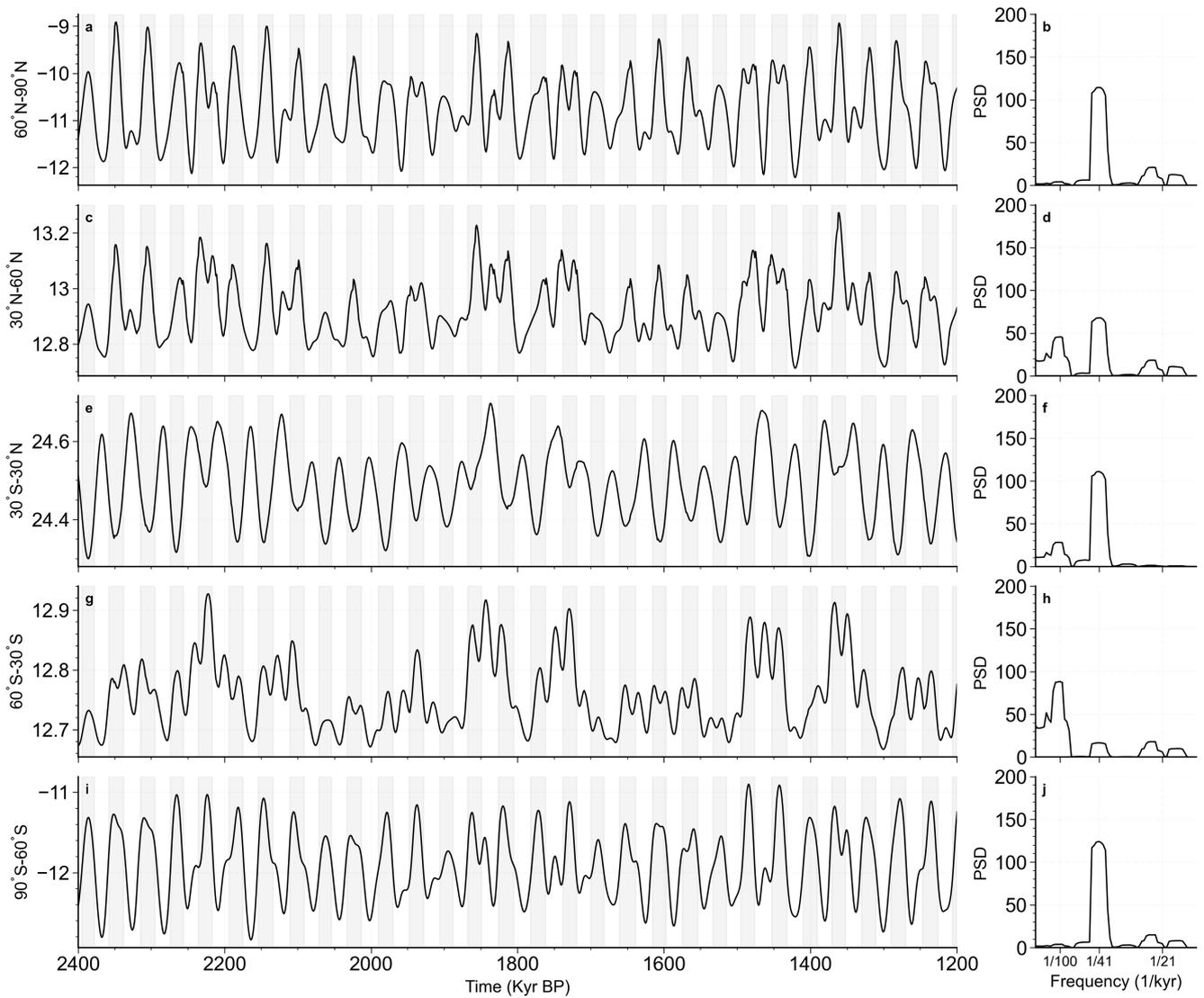


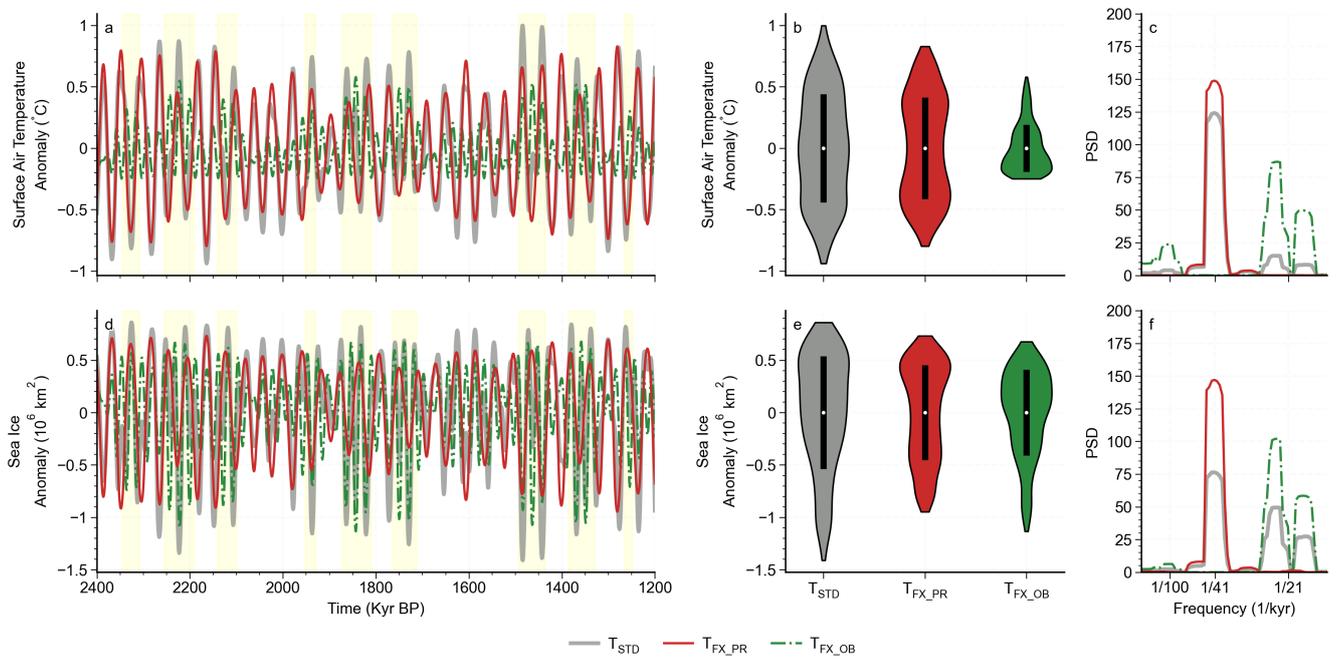
**Figure S1.** For the baseline orbital experiment ( $T_{BE}$ ), where all orbital parameters are varying, changes in the following variables are shown: surface air, land, and ocean temperatures (a-b); sea ice and snow cover area (c-d); and precipitation and snowfall (e-f), all averaged between  $60^\circ$  to  $90^\circ$ S. Additionally, the equator-to-pole gradient in moist static energy (MSE), with the equator averaged from  $0^\circ$ - $30^\circ$ S and the pole from  $60^\circ$ - $90^\circ$ S (g-h). Changes in the northward flux of atmospheric (AHT), oceanic (OHT), and total heat transport (MHT) at  $60^\circ$ S is also illustrated (g-h).



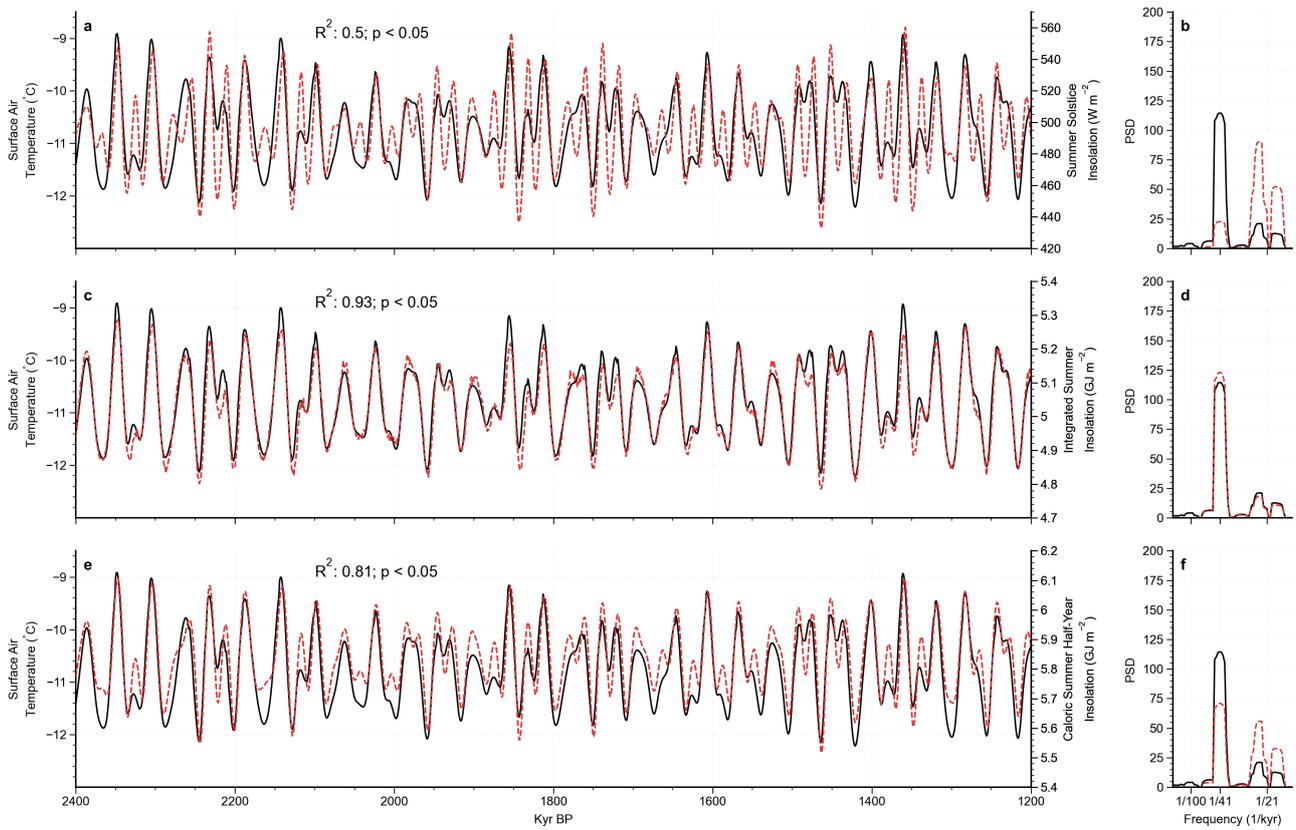
**Figure S2.** Globally averaged changes in surface air temperature and precipitation for the baseline orbital experiment ( $T_{BE}$ ).



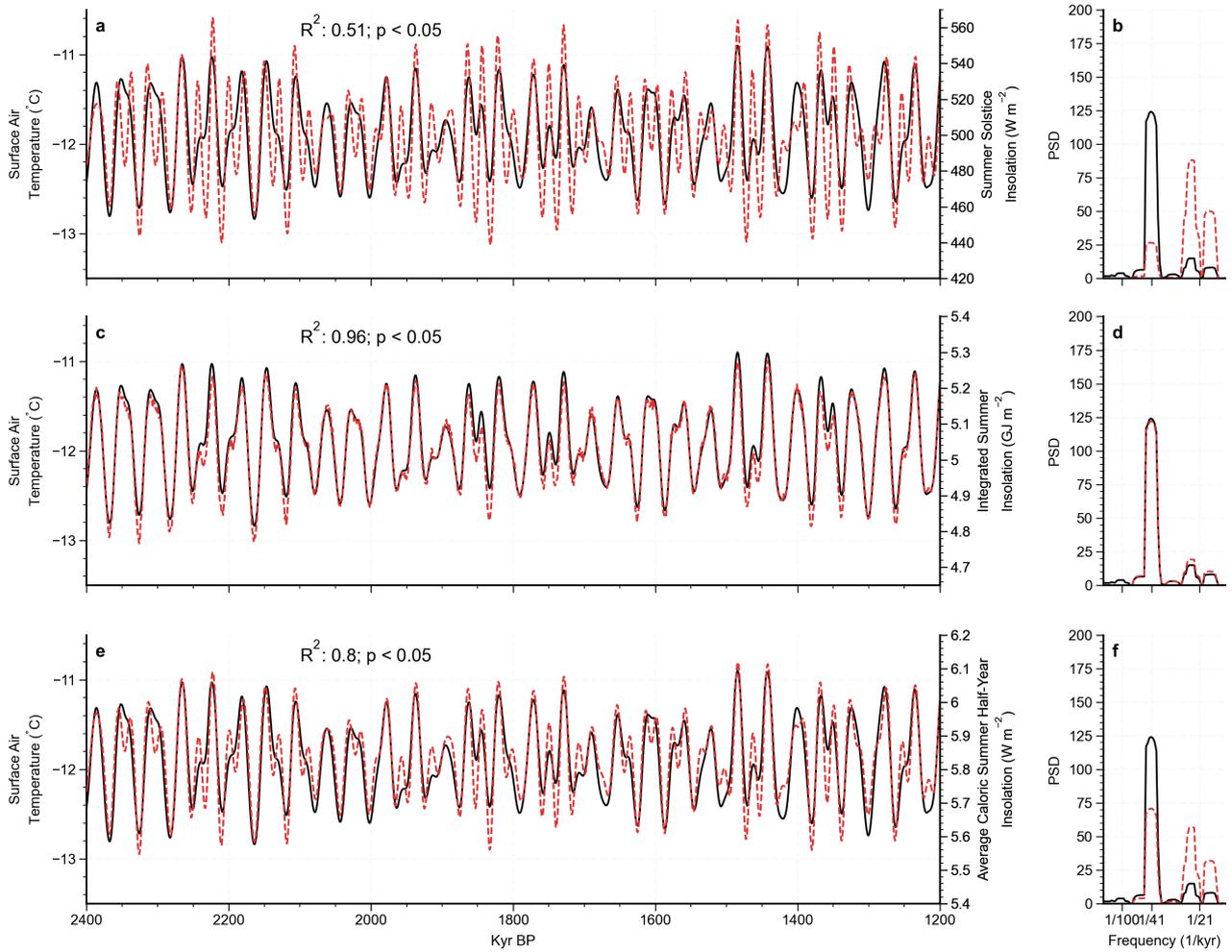
**Figure S3.** Changes of surface air temperature for different regions in the baseline orbital experiment ( $T_{BE}$ ), including from  $60^{\circ}\text{N}$ - $90^{\circ}\text{N}$  (a-b),  $30^{\circ}\text{N}$ - $60^{\circ}\text{N}$  (c-d),  $30^{\circ}\text{S}$ - $30^{\circ}\text{N}$  (e-f),  $60^{\circ}\text{S}$ - $30^{\circ}\text{S}$  (g-h) and  $90^{\circ}\text{S}$ - $60^{\circ}\text{S}$  (i-j). On the left hand side (a,c,e,g,i) is the time series and the right hand side (b,d,f,h,j) is the power spectral density of the time-series.



**Figure S4.** For the standard  $T_{BE}$  (in grey), the fixed precession  $T_{FX\_PR}$  (in red), and the fixed obliquity  $T_{FX\_OBL}$  (in green) experiments, the top row shows changes in surface air temperature (a-c), the middle row shows sea ice variations (e-f), and the bottom row shows changes in snow cover (g-i), for the SH polar regions ( $60^{\circ}$ - $90^{\circ}$ S). The figure include the time series (a,d,g), violin plots illustrating the distributions (b,e,h), and the power spectral density (c,f,i) corresponding to each variable. Shaded yellow regions in (a,d,g) represents periods when eccentricity is above 0.035.



**Figure S5.** Changes in surface air temperature at the NH polar latitudes ( $60^{\circ}$ - $90^{\circ}$ N) versus changes in summer solstice insolation on June 21st (a-b), integrated summer insolation above a threshold of  $275 \text{ W m}^{-2}$  (c-d) and caloric summer half-year insolation (e-f) at  $65^{\circ}$ N. On the left hand side (a,c,e) is the time-series and the right hand side (b,d,f) is the power spectral density of the time-series.



**Figure S6.** Same as Figure S5 but for the SH polar latitudes (60°-90°S) and insolation metrics at 65°S.