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The Sun's role in decadal climate predictability in the North Atlantic

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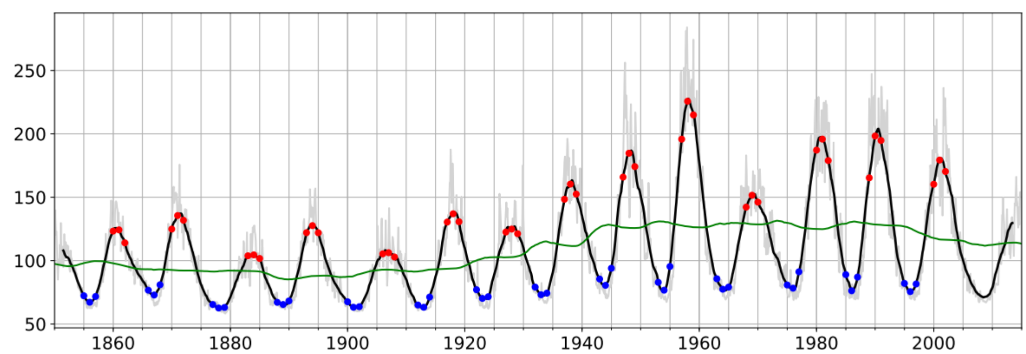

Fig. S1. Solar cycle-based composite definition. Monthly (thin grey line) and 3-year running mean of the solar radio flux at 10.7 cm in solar flux units (1 sfu = 10^{-22}Wm^{-2} Hz^{-1}) for the FULL experiment (black line) and LOWFREQ (green line). Red (blue) dots indicate the solar maximum (minimum) indices used for solar cycle-based composites.

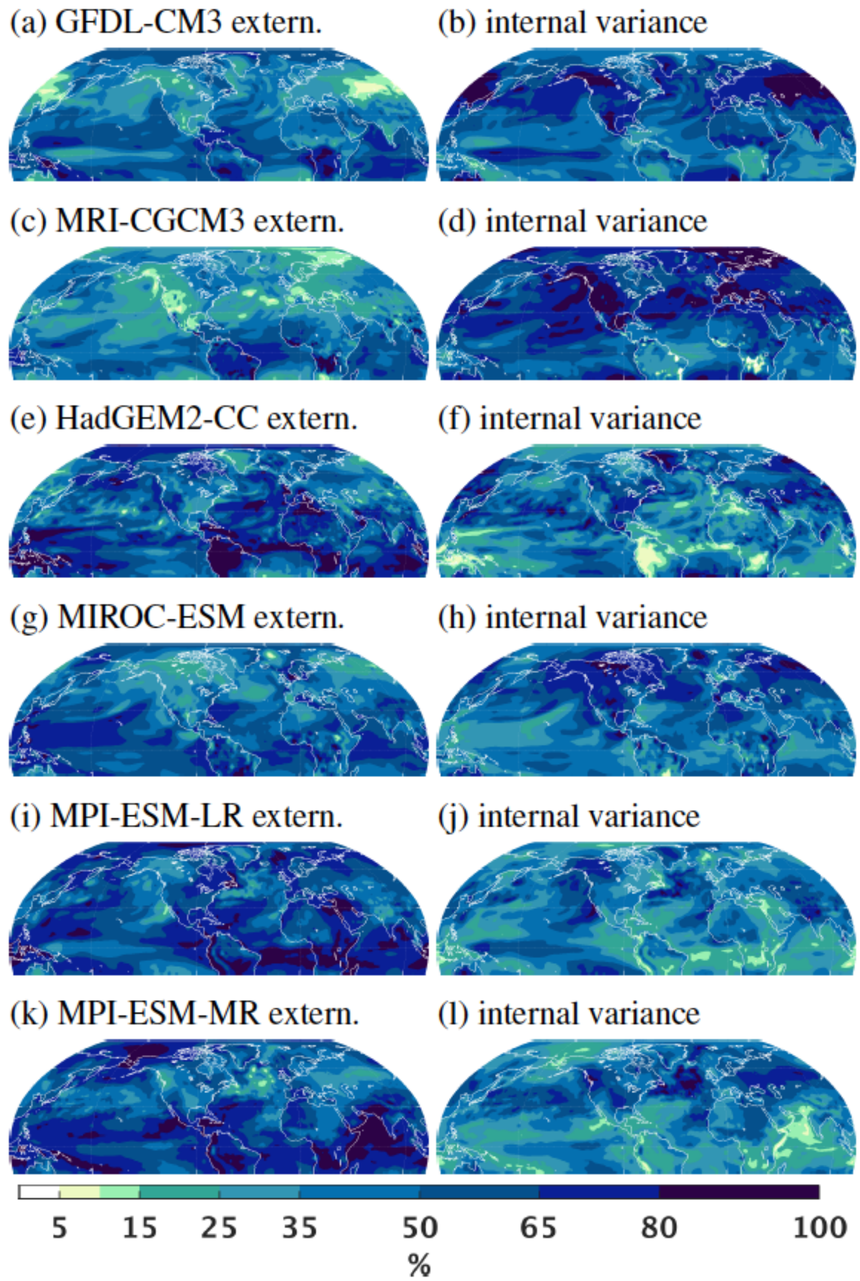

Fig. S2. Decadal potential predictability due to the external forcings and internal climate variability. Potential predictability variance fraction (explained variance) with respect to DJF averaged surface air temperature and associated with all external forcings (including full solar forcing) (left column), and remaining variance fraction due to internal climate variability (right column) in the 6 CMIP5 high-top models below during the strong epoch (common period 1932-2004, except the HadGEM2-CC which covers 1960-2004).

Model	Institute	Time period	Number of ensemble members
GFDL-CM3	NOAA GFDL (USA)	1860-2005	5
HadGEM2-CC	MOHC (UK)	1860-2005 (r1) 1960-2005 (r2-r3)	3
MIROC-ESM	MIROC (Japan)	1850-2005	3
MPI-ESM-LR	MPI-M (Germany)	1850-2005	3
MPI-ESM-MR	MPI-M (Germany)	1850-2005	3
MRI-CGCM3	MRI (Japan)	1850-2005	5

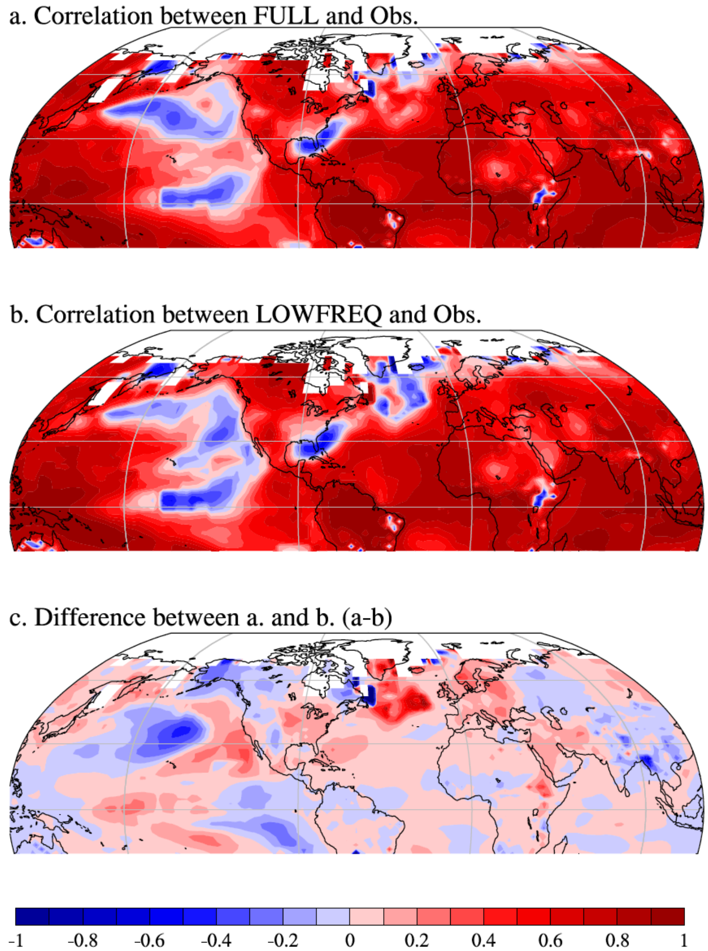

Fig. S3. Quantification of the forecast skill of climate predictions. a. Correlation coefficients of DJF averaged surface air temperatures between observations (NOAAGlobeTemp) and the FULL ensemble mean during the strong epoch. b. Same as a., but for observations and LOWFREQ ensemble mean. c. Correlation differences between a. and b. Note that there are large differences, shown in c, of the correlations between observations and FULL (a) compared to the correlation of observations and LOWFREQ (b) in the North Atlantic. This typical deterministic measure indicates a gain in skill when the solar cycle is added to the model. DJF surface air temperatures are smoothed with an 8-year running mean.

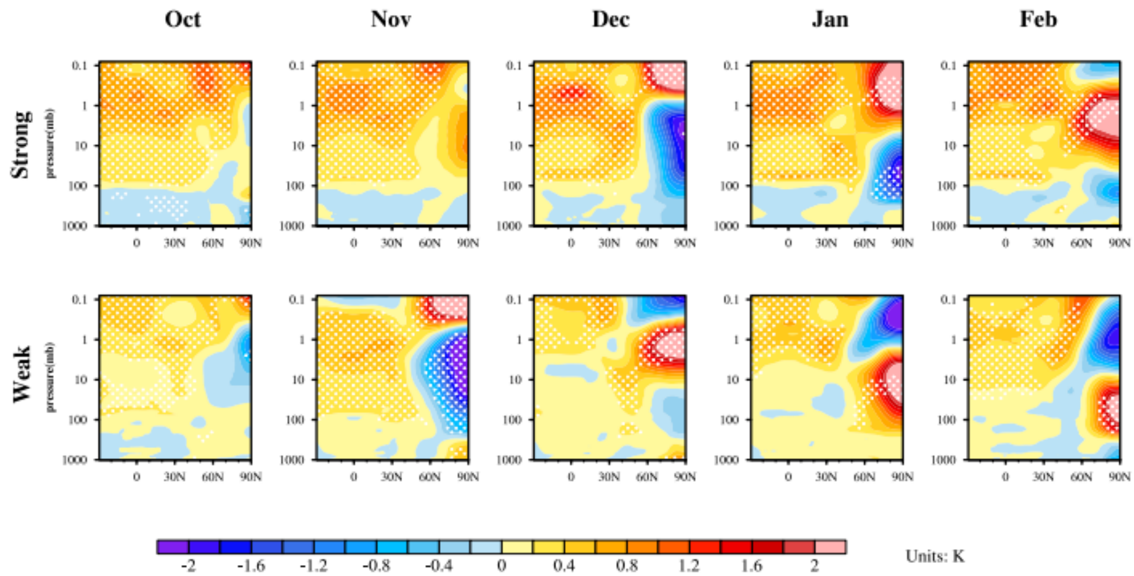

Fig. S4. Solar cycle response in zonal mean temperatures during the strong (top) and weak (bottom) epoch. Latitude-height cross sections from 30°S to 90°N and 1000 hPa to 0.1 hPa of solar-cycle based composite differences (in K) at lag 0. Significance levels are indicated by white dots (90%) based on a 1000-fold bootstrapping test. See "Methods" section for more details.

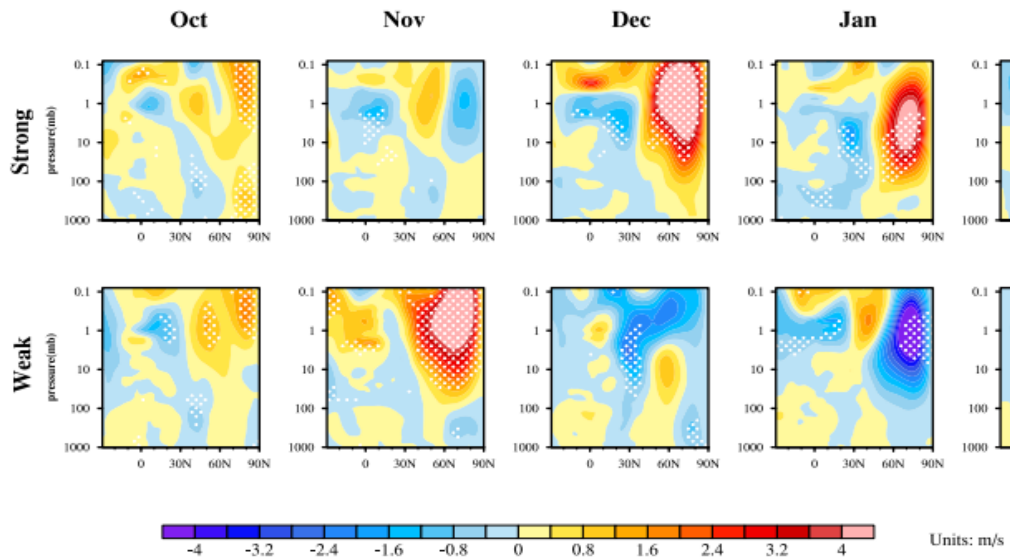

Fig. S5. Solar cycle response in zonal mean zonal winds during the strong (top) and weak (bottom) epoch. Latitude-height cross sections from 30°S to 90°N and 1000 hPa to 0.1 hPa of solar-cycle based composite differences (in m/s) at lag 0. Significance levels are indicated by white dots (90%) based on 1000-fold bootstrapping test. See "Methods" section for more details.

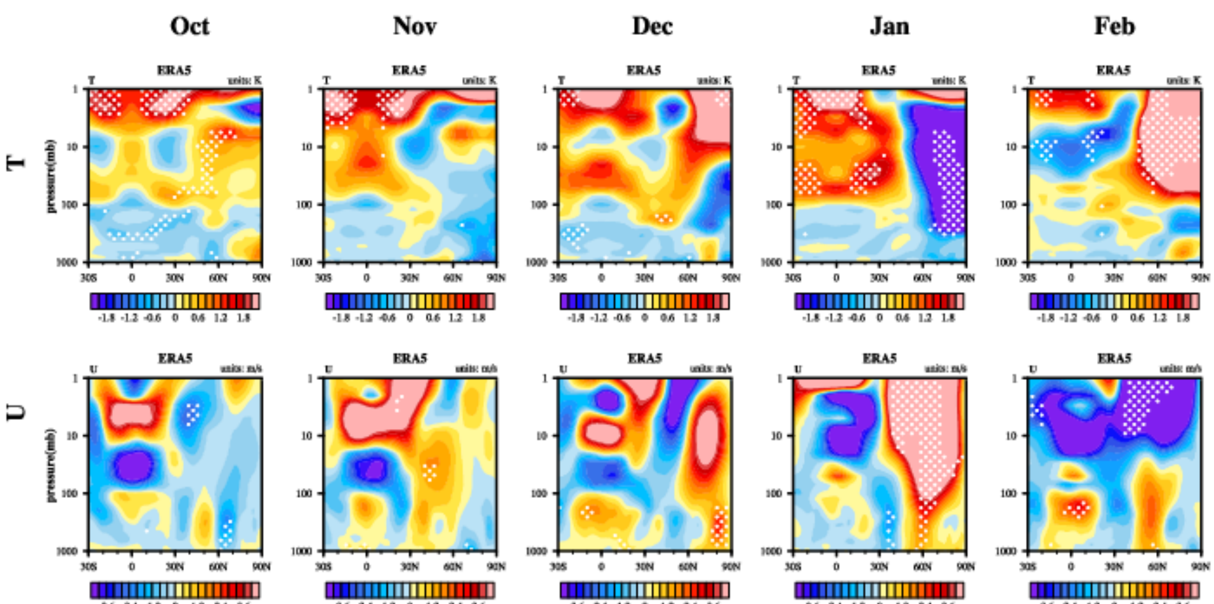

Fig. S6. Same as Fig. S4 and S5 (strong epoch row), but for monthly ERA5 from Oct to Feb (1979-2015).

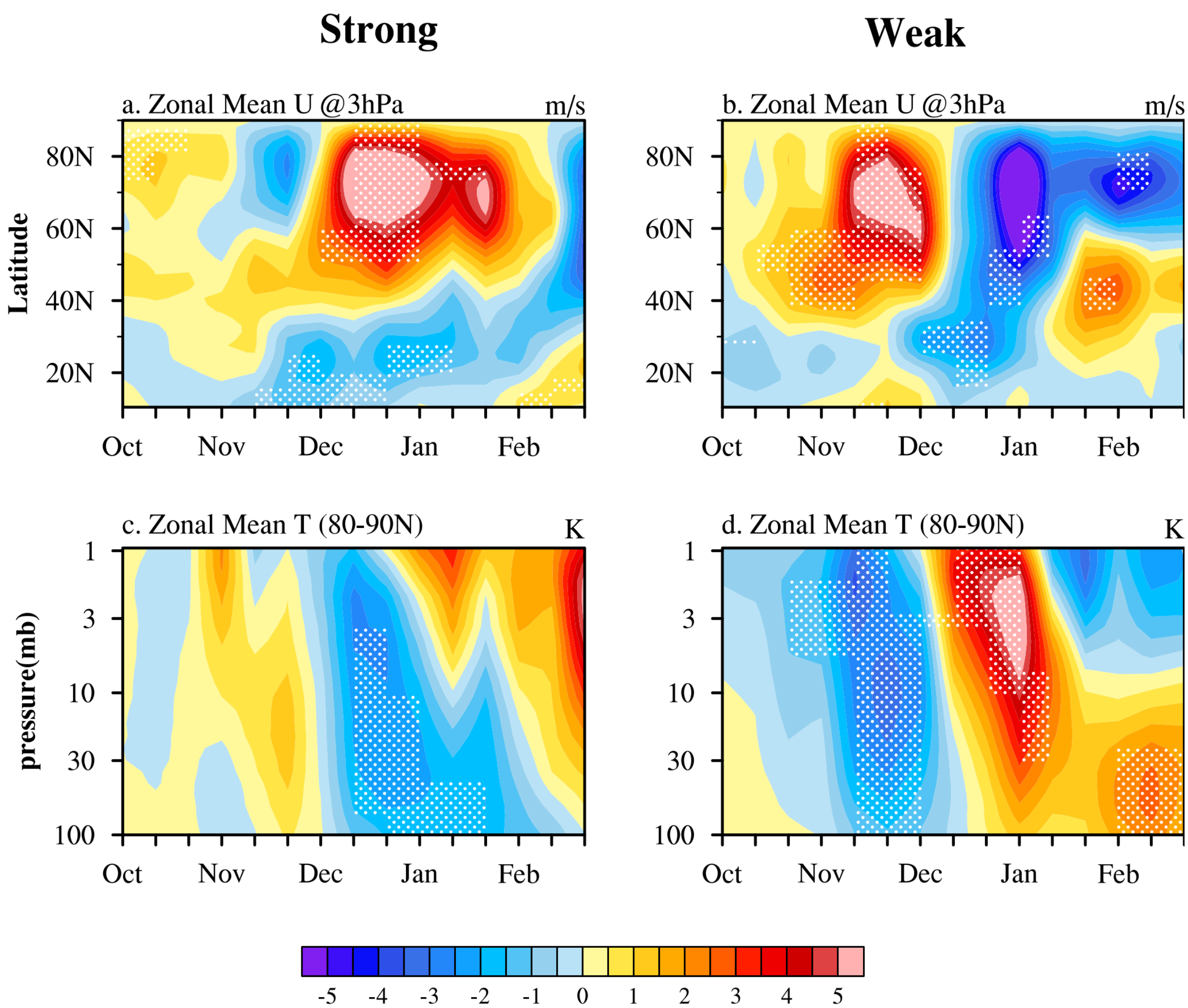

Fig. S7. Seasonal march of the solar signal in zonal mean zonal winds and zonal mean temperature during the strong (left) and weak (right) epoch. (a-b) Time-latitude cross sections of solar-cycle based composite differences of 10-day means in zonal mean zonal wind (in m/s) around 3hPa at lag 0; (c-d) Time-height cross sections from October through February and 100 hPa to 1 hPa of solar-cycle based composite differences of 10-day means in zonal temperature averaged over the polar cap(80-90N) (in K) at lag 0. Significance levels are indicated by white dots (90%) based on a 1000-fold bootstrapping test. See "Methods" section for more details.

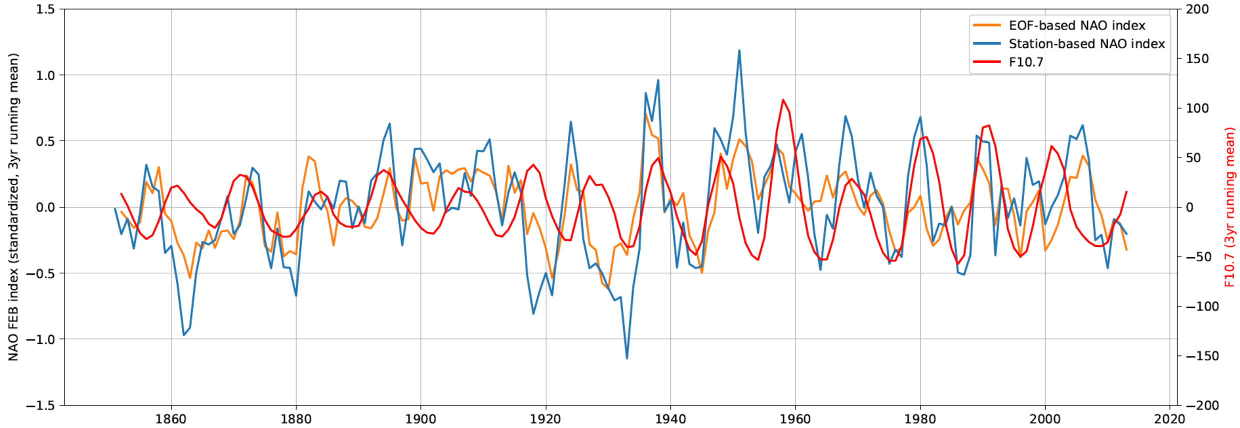

Fig. S8. Time series of the 11-year solar cycle and two different February NAO indices from the model simulations. The F10.7 (red), ensemble mean of EOF-based NAO index (orange) and the station-based NAO-like index (blue), all time series have been smoothed with a 3-year running mean.

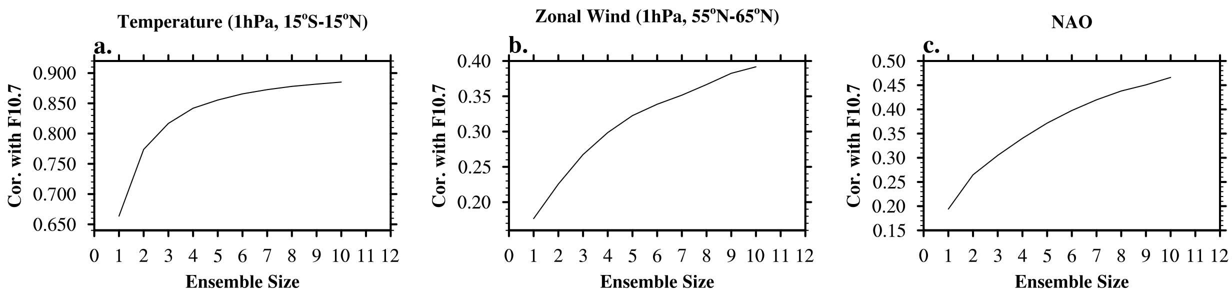

Fig. S9. Dependence of "detectability" of isolated solar signals on the number of ensemble members. Correlation with F10.7 as a function of ensemble size for a. December tropical stratopause temperature (1hPa, 15°S-15°N); b. December zonal mean zonal wind (1hPa, 55°N-65°N); and c. NAO index. For these figures, we randomly sampled subsets of the simulations from the 10 members and calculated the correlation of the solar signal in these subsets with the solar index 100 times.

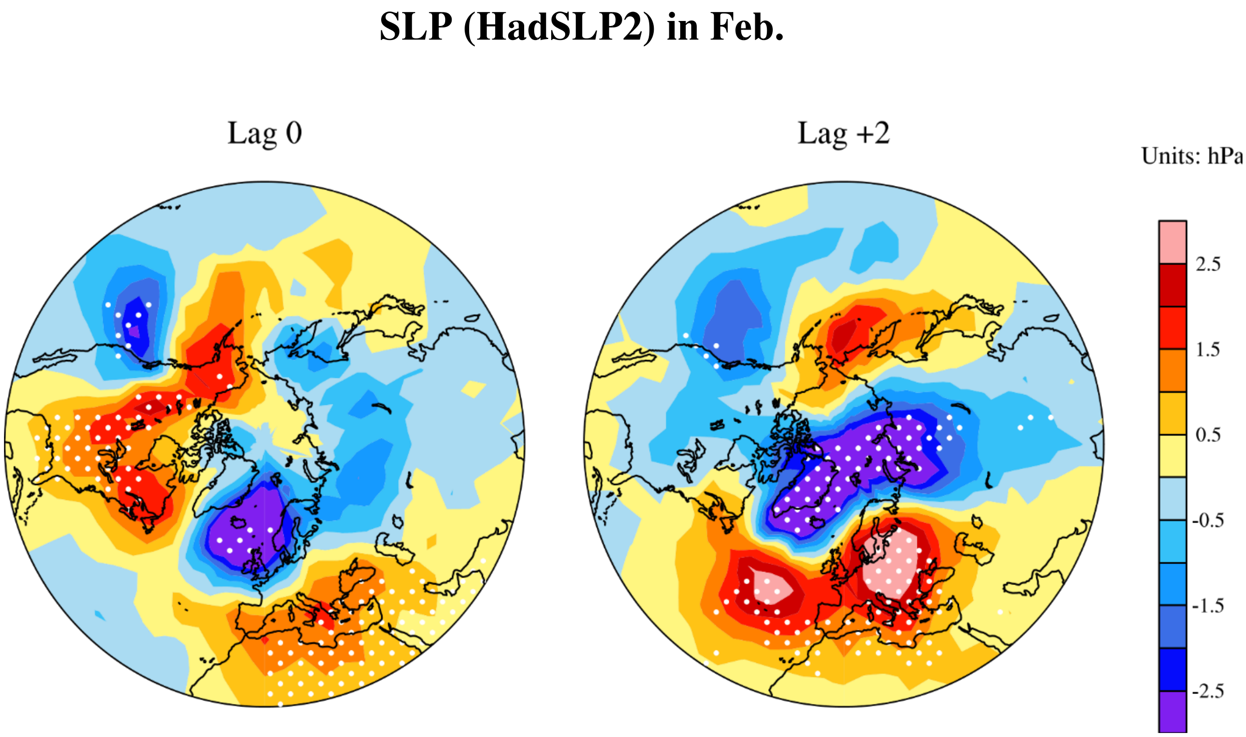

Fig. S10. Comparison of solar-induced SLP anomalies in observations. Lagged composite differences of solar maximum minus minimum for observed SLP (HadSLP2) anomalies in February during the strong epoch at lag 0 (left) and lag +2 (right) years. Note that the observed signal includes the full solar signal (i.e. the solar cycle as well as the low-frequency part of the solar signal) and internal variability. White dots indicate the 90% statistical significance level based on 1000-fold bootstrapping test.

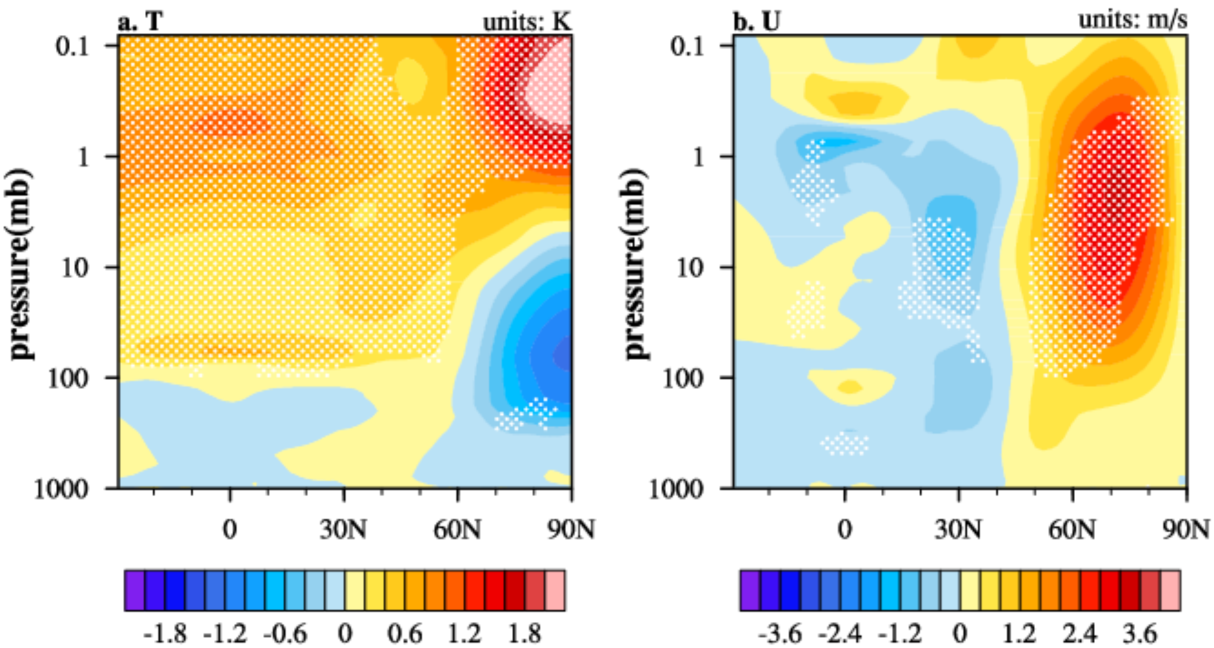

Fig. S11. Composite differences between the solar maximum and minimum for (a) zonal mean temperatures (K) and (b) zonal mean zonal winds (m/s) in DJF mean during the strong epoch. Significance levels are indicated by white dots (95%) based on 1000-fold bootstrapping test.

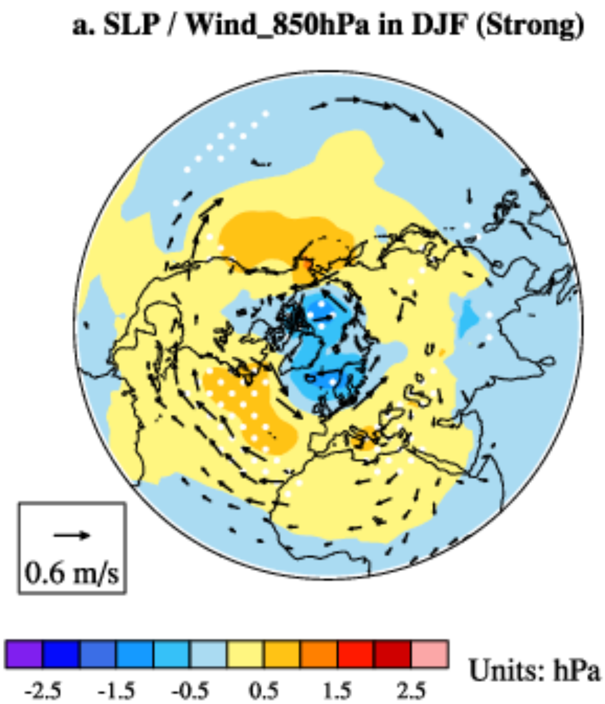

Fig. S12. Composite differences between the solar maximum and minimum for SLP (contours) and wind at 850hPa (vectors) in DJF mean. Only those vectors where the zonal wind component is significant at the 90% level are shown. White dots indicate 90% statistically significant level based on 1000-fold bootstrapping test for SLP.

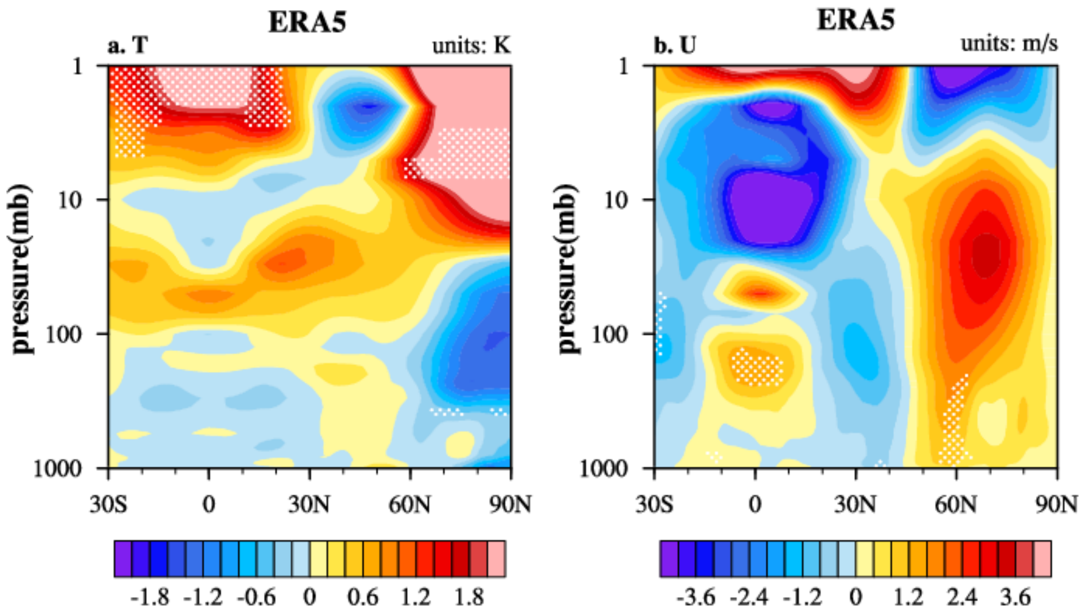

Fig. S13. Same as Fig. S11, but for observational DJF mean ERA5 (1979-2015).

Table S1.

Amplitudes of solar cycles in the weak and strong epochs, indicated by F10.7cm

Weak Epoch	Solar cycle	10	11	12	13	14	15	16
	Amplitude (Max-Min)	53.9	53.6	45.6	57.4	41.4	72.4	55.2
	Standard deviation	18.3	23.8	16.7	22.9	19.4	26.8	25.0
Strong Epoch	Solar cycle	17	18	19	20	21	22	23
	Amplitude (Max-Min)	89.8	99.2	161.7	81.5	124.8	137.8	111.6
	Standard deviation	31.7	37.4	60.4	32.5	48.1	54.1	38.8

Table S2.
All correlation coefficients for DJF mean and December zonal mean zonal wind and temperature.
"Var." is the variance fraction of the solar-induced changes compared to the magnitude of internal variability. "R" is the correlation coefficient with the solar forcing index.

	Weak epoch	**Strong epoch**		**Weak epoch**	**Strong epoch**
T_DJF	Var. = 31%	Var. = 69%	**U_DJF**	Var. = 22%	Var. = 23%
	R = 0.55	R = 0.72		R = -0.12	R = 0.36
T_Dec	Var. = 31%	Var. = 37%	**U_Dec**	Var. = 18%	Var. = 24%
	R = 0.21	R = 0.58		R = -0.14	R = 0.33