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Supplementary Materials for

Arctic sea ice, Eurasia snow, and extreme winter haze in China

Yufei Zou, Yuhang Wang, Yuzhong Zhang, Ja-Ho Koo

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This PDF file includes:

Supplementary Materials

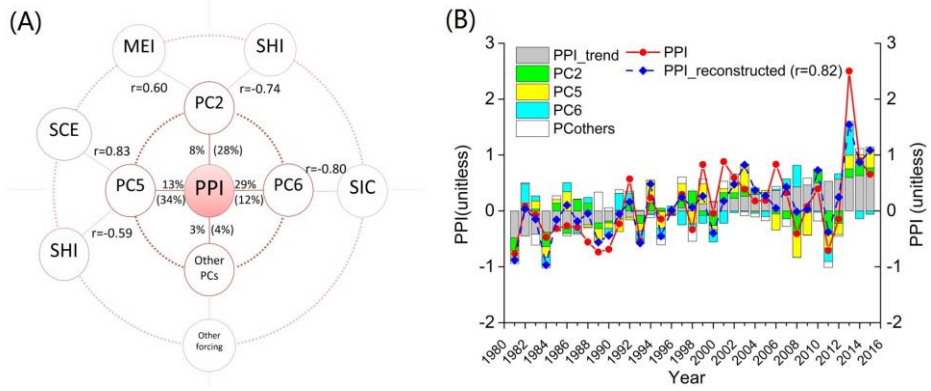

fig. S1. PCA decomposition and reconstruction of PPI. (**A**) attributions of detrended PPI to PCs; percentages in the inner ring are contributions to the extreme PPI in January 2013 (without parentheses) and the total variance (with parentheses) by each PC; the climate indices (table S2) most correlated with PC2, PC5, and PC6 are shown on the external ring; (**B**) comparison of original PPI and PCA reconstructed PPI; the PPI trend is added back to the reconstructed PPI. The correlation coefficient is shown in parenthesis.

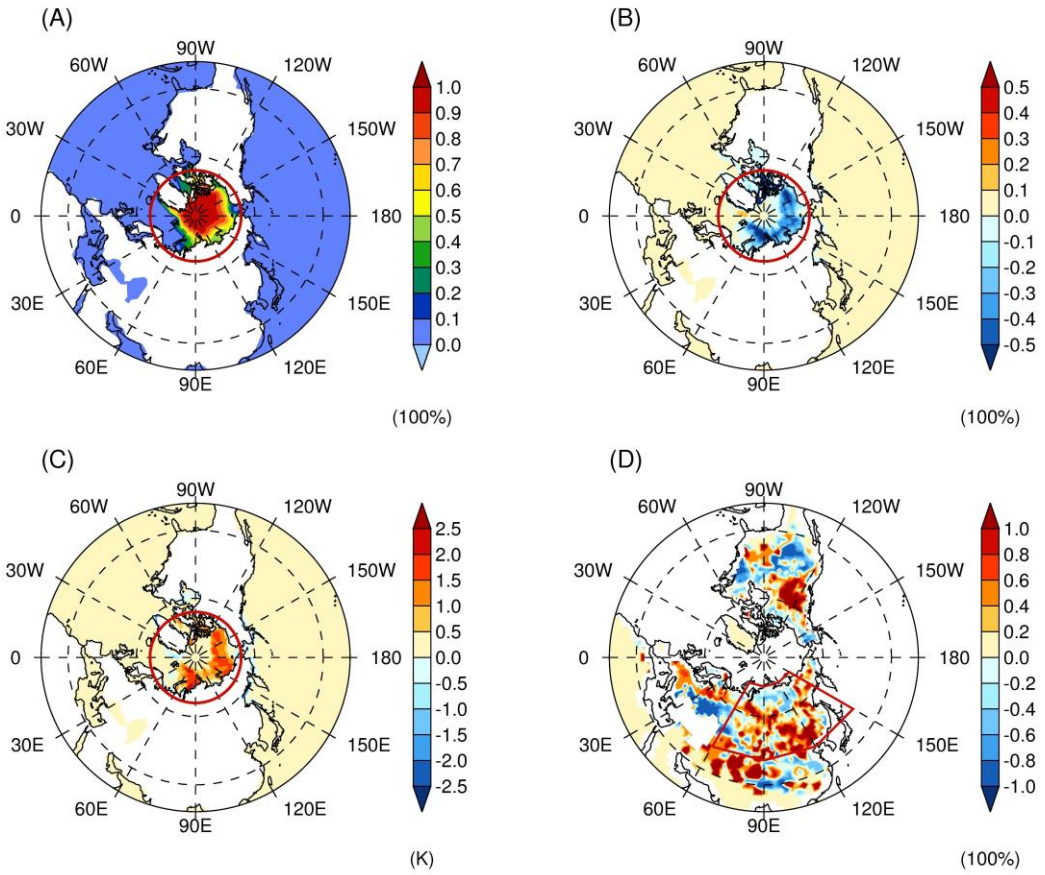

fig. S2. Cryosphere forcing specifications used in the CESM numerical experiments. (**A**) Arctic SIC climatology (1981–2010) averaged from August to November (ASON); (**B**) Arctic SIC anomalies in autumn and early winter of 2012 (ASON averaged); (**C**) SST anomalies corresponding to SIC anomalies in (B); The red circles in (A), (B), and (C) denote the prescribed sea ice forcing region within the Arctic Circle (66.6 ° N); (**D**) Boreal SWE fractional anomalies averaged from October to November of 2012; the red polygon in (D) denotes the prescribed snow forcing region at mid- to high-latitudes (60° E to 150° E, 40° N to 75° N) in SENS2/3; the regions are also shown in Fig. 1A.

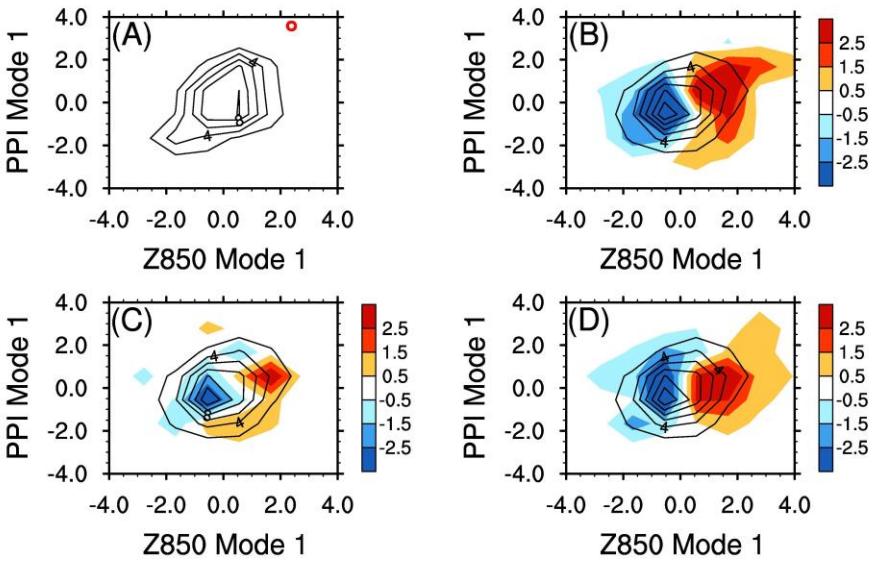

fig. S3. Sensitivity response of the first coupled PPI and Z850 modes to cryospheric forcing. (**A**) Density distribution of the first MCA modes of Z850 and PPI based on 35-year reanalysis data (contour lines from 2% to 10% at intervals of 2%; unit: %; the red circle is the data point for 2013); (**B**) density distribution of the first MCA modes in CTRL (contour lines from 2% to 12% at intervals of 2%; unit: %) and density distribution changes between SENS1 and CTRL (color shading; unit: %); (**C**)–(**D**) the same as (B) but for changes in SENS2 and in SENS3 from CTRL.

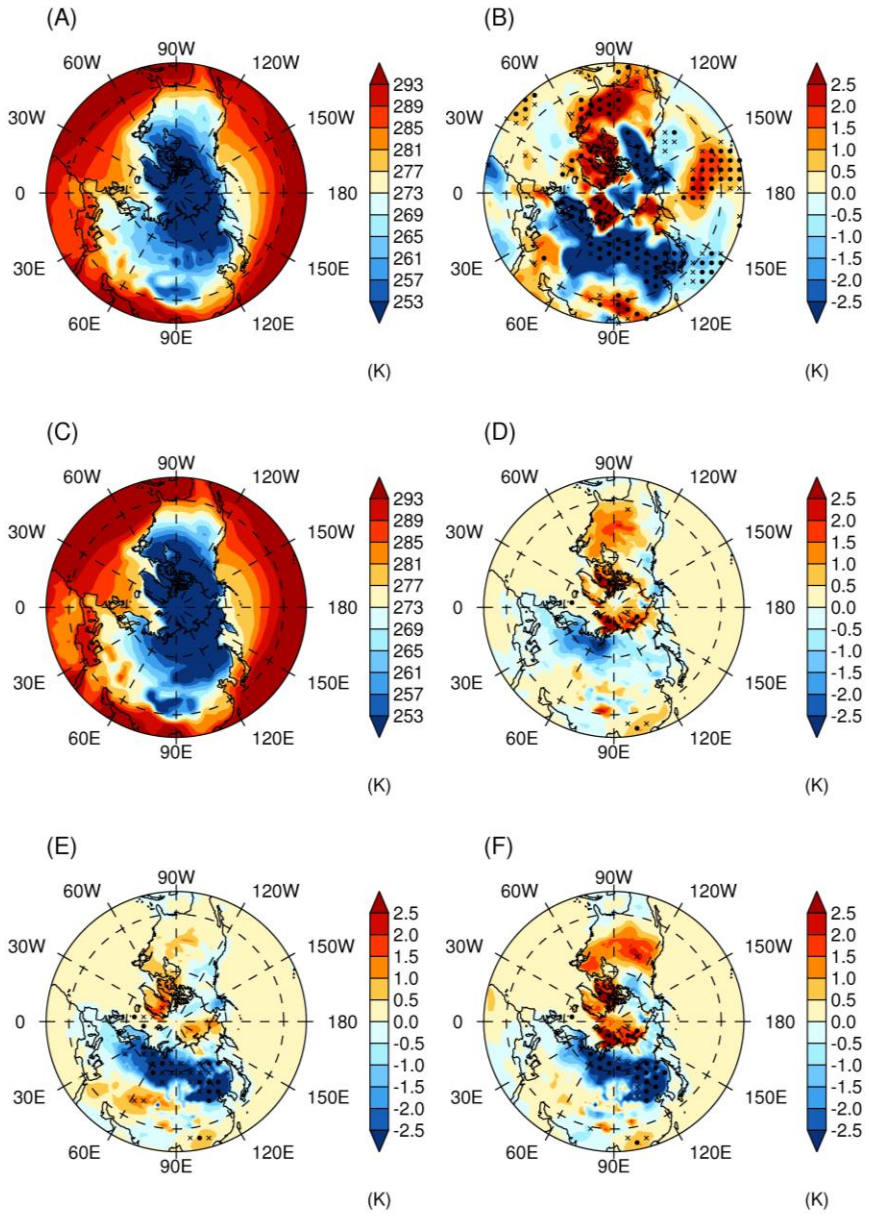

fig. S4. Comparison of surface air temperature in December between reanalysis data and numerical experiments. (**A**) SAT climatology (1981–2010) of reanalysis data; (**B**) SAT anomalies in December 2012 of reanalysis data; (**C**) ensemble averaged SAT climatology based on the CTRL simulation; (**D**) ensemble averaged SAT responses in SENS1 (SENS1-CTRL); (**E**) –(**F**) the same with (D) but for responses in SENS2 and in SENS3, respectively; In (B), (D), (E), and (F), black dots (cross) denote the 99% (95%) significance level based on the bootstrapping method.

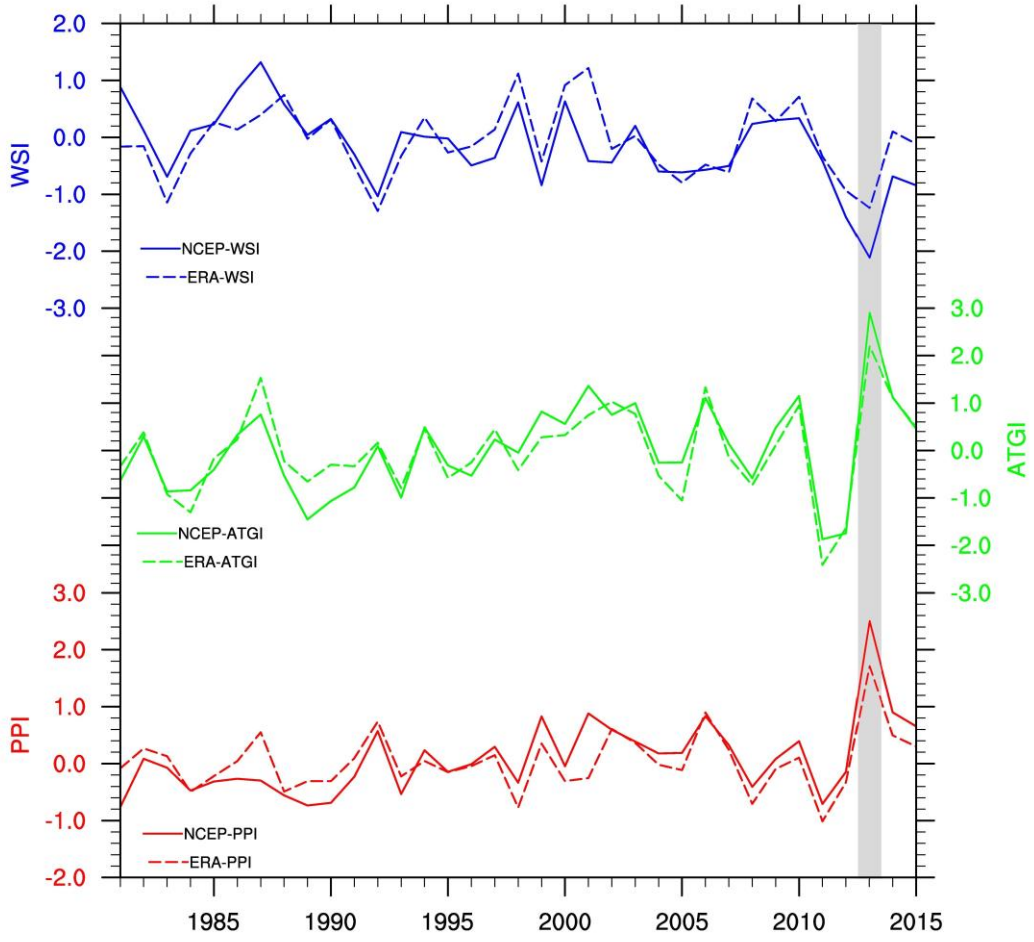

fig. S5. Time series of monthly WSI, ATGI, and PPI over the ECP region for January. The gray bar denotes 2013.

table S1. A list of acronyms used in this study.

Abbr.	Full Name
ECP	East China Plains
EAWM	East Asian Winter Monsoon
WSI	Wind Speed Index
ATGI	Potential Air Temperature Gradient Index
PPI	Pollution Potential Index
MCA	Maximum Covariance Analysis
PCA	Principal Components Analysis
CESM	Community Earth System Model
CMIP5	the 5^{th} phase of the Coupled Model Inter-comparison Project
PM	Particulate Matter
ViI	Visibility Inverse
AOD	Aerosol Optical Depth
AO	Arctic Oscillation
SIC	Sea Ice Concentration
SCE	Snow Cover Extent
ENSO	El Niño/Southern Oscillation
PC	Principal Component
CFI	Cryospheric Forcing Index
Z850	850-hPa geopotential height
CTRL	the control run of the sensitivity experiments
SENS1/2/3	the 1^{st}/2^{nd}/3^{rd} sensitivity simulation set
SST	Sea Surface Temperature
SWE	Snow Water Equivalent
CDF	Cumulative Distribution Function
CAM5	the Community Atmosphere Model version 5
CCSM4	the Community Climate System Model version 4
GSOD	the Global Surface Summary of the Day database
NCDC	the National Climatic Data Center
MODIS	the Moderate Resolution Imaging Spectroradiometer
NCEP	the National Centers for Environmental Prediction
NCAR	the National Center for Atmospheric Research
NOAA	the National Oceanic and Atmospheric Administration
HadISST	Hadley Centre Sea Ice and Sea Surface Temperature data set
PCR	Principal Components Regression
DJF	December-January-February
kde2d	the two-dimensional Kernel Density Estimation
RCP4.5	Representative Concentration Pathway 4.5

table S2. Correlations among ventilation indices, PM observations, and cryospheric forcing factors.

Index	Data	WSI (1981–2015)		ATGI (1981–2015)		PPI (1981–2015)	
	Availability	r	p-value	r	p-value	r	p-value
PM_{10}–ECP	2005–2015	–0.73	<1E-2	0.70	<1E-2	0.92	<1E-3
$PM_{2.5}$–BJ	2010–2015	–0.80	0.01	0.58	0.09	0.79	0.07
ViI	1981–2013*	–0.63	<1E-3	0.36	0.17	0.62	<1E-3
Terra AOD	2001–2015	–0.58	<1E-2	0.21	0.36	0.43	0.02
Aqua AOD	2003–2015	–0.64	<1E-3	0.28	0.25	0.50	<1E-2
Arctic SIC	1980–2014	0.45	0.01	–0.26	0.29	–0.43	0.04
Asian SCE	1980–2014	–0.42	0.01	0.55	<1E-3	0.64	<1E-3
Boreal CFI	1980–2014	–0.51	<1E-2	0.49	0.01	0.65	<1E-3

* The 2014 to 2015 visibility data are not included due to a change of meteorological observation system in China after January 1st 2014 (*44*).

table S3. Climate and synoptic weather indices in the PCA.

Component	Index	Description	Equation/Source
Atmosphere	SHI	Normalized regional mean of the sea level pressure (SLP) in the center of the Siberian High in January	$\overline{P_{slp}}$ (40°N to 60°N, 70°E to 120°E) (*11*)
	ALI	Normalized regional mean of the SLP in the center of the Aleutian Low in January	$\overline{P_{slp}}$ (40°N to 60°N, 160°E to 160°W) (*11*)
	V850	Normalized regional mean meridional wind speed at 850hPa in January	$\overline{V_{850\text{hPa}}}$ (30°N to 60°N, 105°E to 150°E) (*11*)
	AO	Arctic oscillation index in January	NOAA CPC (*17*)
Ocean	MEI	Multivariate ENSO Index (MEI) in previous November-December	NOAA CPC (*23*)
Cryosphere	SIC	Arctic Sea Ice Concentration (SIC) index in previous August-November	HadISST (*21*)
	SCE	Eurasian Snow Cover Extent (SCE) index in previous October-November	GSL at Rutgers Univ. (*22*)

table S4. Correlation statistics among PCs and climate indices.

r	PPI	SHI	ALI	V850	AO	SIC	SCE	MEI
PC1	0.10	–0.50*	0.71*	0.75*	0.84*	0.45*	–0.22	–0.03
PC2	0.53*	–0.74*	–0.41*	0.43*	–0.39*	0.30	0.26	0.60*
PC3	0.08	0.02	0.37*	0.42*	–0.35*	–0.19	0.15	–0.62*
PC4	0.15	–0.32	–0.35*	–0.18	0.05	–0.04	–0.45	–0.50*
PC5	0.58*	–0.59*	–0.22	0.07	–0.16	0.18	0.83*	0.20
PC6	0.34*	–0.07	0.08	–0.03	0.01	–0.80*	–0.04	0.07
PC7	0.02	0.09	–0.24	0.16	0.07	–0.18	0.11	–0.05

* denotes > the 95% significance level.

table S5. PCR coefficients of the detrended PPI onto PC.

PCR	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Reg. coef.	0.03	–0.23	–0.05	–0.10	0.21	–0.44	–0.03
p-value	0.42	<1E-3	0.51	0.24	0.05	0.01	0.88

table S6. The CMIP5 ensemble simulations used in this study.

Model Name	Modeling Center	Institute ID	Ensemble Members
CCSM4	National Center for Atmospheric Research	NCAR	r1i1p1, r2i1p1, r3i1p1, r4i1p1, r5i1p1, r6i1p1
CESM1(CAM5)	Community Earth System Model Contributors	NSF-DOE-NCAR	r1i1p1, r2i1p1, r3i1p1