**Spatial-temporal hysteresis distribution and decomposition of solar activities and climatic oscillation**

**Purpose:**

In the "sun-climate-water resource" system, meteorological elements have different lag periods for influence factors such as solar activity (SA), climate oscillation (CO) and geographical factors (GF) at different spatiotemporal scales. However, this phenomenon has been insufficiently investigated. It is unclear whether the strong interaction/lag behaviors of meteorological elements responses to SA/CO that were calculated, statistically true and realistically possible. There is also insufficient information regarding the reasons and their weights for lag variation in different regions. Moreover, the transmission mechanism of the lag is also unclear. To overcome this knowledge gap, we studied temperature (T) and precipitation (P) data collected over 121 years from 3,836 grid stations across China. The spatial distribution of T and P, strong interaction periodic distribution responses to SA and CO, and hysteresis distribution were studied under six periodic scales (0–5, 5–10, 10–30, 30–60, 60–90, and 90–120 a). The weight distribution of lag influencing factors was plotted using false color RGB to represent SA, GF, and CO; a multivariate hysteresis decomposition model was proposed to simulate and quantitatively decompose the periodic lag considering the factors of the earth’s revolution.

All generated methods used in this study can be downloaded from https://github.com/myli1993/T-P-response-to-SA-CO. And generated data can be downloaded from https://pan.baidu.com/s/101t-wgtWa31Pf85J-VXO3A and the extract code is TPSA.

**Reference**:

**Programming instructions:**

[temp2,prec2]=fix\_t\_p(temp1,prec1,A): Fix the NaN value in the initial data.

[hangle]=sunshade\_china(year,month,day,time,latitude): Enter time and latitude to calculate solar altitude angle.

[ar\_t,ar\_p]=annual\_regulation\_fft(temp1,prec1,p): Fast Fourier transform is used to calculate the periodic regularity of temperature and precipitation in the input period.

[ar\_t\_plot,ar\_p\_plot]=annual\_regu\_plot(ar\_t,ar\_p,A,A\_num,do,p): Periodic patterns in the input period are mapped.

annual\_china\_draw(ar\_t\_plot,ar\_p\_plot,p,A,art\_lat,arp\_lat,art\_lon,arp\_lon): Output the periodic pattern results in the input period as TIFF (do=1) or mapped (do=2).

[x\_t1,x\_p1,x\_t2,x\_p2,x\_t3,x\_p3,a\_t1,a\_p1,a\_t2,a\_p2,a\_t3,a\_p3]=wtc\_nonmoon(SN,SOI,SST,temp\_d,prec\_d,p,t): Calculate the hysteresis period of temperature and precipitation with SA and CO.

[wtc\_t1\_plot,wtc\_p1\_plot,wtc\_t2\_plot,wtc\_p2\_plot,wtc\_t3\_plot,wtc\_p3\_plot]=wtc\_china\_draw(x\_t1,x\_p1,x\_t2,x\_p2,x\_t3,x\_p3,a\_t1,a\_p1,a\_t2,a\_p2,a\_t3,a\_p3,p,A,A\_num,do): Output the wtc results in the input period as TIFF (do=1) or mapped (do=2).

[x\_t1,x\_p1,x\_t2,x\_p2,x\_t3,x\_p3]=xwt\_china(SN,SOI,SST,temp\_d,prec\_d,p,t): Calculate the strong interaction period of temperature and precipitation with SA and CO.

[xwt\_t1\_plot,xwt\_p1\_plot,xwt\_t2\_plot,xwt\_p2\_plot,xwt\_t3\_plot,xwt\_p3\_plot]=xwt\_china\_draw(x\_p1,x\_p2,x\_p3,x\_t1,x\_t2,x\_t3,A,A\_num,p,do): Output the xwt results in the input period as TIFF (do=1) or mapped (do=2).

decom\_non.py: Seasonal-trend decomposition.

[temp\_d,prec\_d]=python\_nan\_remove(temp\_d,prec\_d,SN): Break up the Seasonal-trend decomposition result.

[reg\_t,reg\_p]=reg\_china\_pre(xwt\_t1\_plot,xwt\_p1\_plot,xwt\_t2\_plot,xwt\_p2\_plot,xwt\_t3\_plot,xwt\_p3\_plot,wtc\_t1\_plot,wtc\_p1\_plot,wtc\_t2\_plot,wtc\_p2\_plot,wtc\_t3\_plot,wtc\_p3\_plot,p,A,A\_num): Prepare for the MHD model input data.

[dis\_t5,dis\_p5]=reg\_china\_distingush(reg\_t,reg\_p,p,A\_num,A): Calculate the entropy weight of influencing factors (max=255).

[total\_t,total\_p]=reg\_china\_clu(reg\_t,reg\_p,p,A\_num,A,max\_lagt,max\_lagp,group,hangle,dis\_t5,dis\_p5,do): Group and reorganize the MHD model input data.

output=reg\_china\_cal1(total\_t,total\_p,group,period): Calculate the MHD model.

[Rt\_plot,Rp\_plot,Et\_plot,Ep\_plot]=reg\_china\_pred(total\_t,total\_p,output,A\_num,A,group,period,p,do): Output the MHD results in the input period as TIFF (do=1) or mapped (do=2).

[xwt\_t1,xwt\_p1,xwt\_t2,xwt\_p2,xwt\_t3,xwt\_p3,wtc\_t1,wtc\_p1,wtc\_t2,wtc\_p2,wtc\_t3,wtc\_p3]=Seven\_region(xwt\_t1\_plot,xwt\_p1\_plot,xwt\_t2\_plot,xwt\_p2\_plot,xwt\_t3\_plot,xwt\_p3\_plot,wtc\_t1\_plot,wtc\_p1\_plot,wtc\_t2\_plot,wtc\_p2\_plot,wtc\_t3\_plot,wtc\_p3\_plot,p): Strong interaction period and lag period in seven regions of China.

**Data:**

In the TPSACO\_data.mat, we provide the input data and output data. We're going to talk about what all the variables mean, and we're going to break it down into three parts, the input set, and the procedure set and the output set. You can download the TPSACO\_data.mat from.

**Input set:**

A: Scope of study area, 1 for study area, 0 for non-study area.

A\_num: A nonzero subset of the A data set.

temp: Temperature data of the study area.

temp\_d: Variable temp by Seasonal-trend decomposition is transformed into raster data in the study area.

prec: Precipitation data of the study area.

prec\_d: Variable prec by Seasonal-trend decomposition is transformed into raster data in the study area.

SN: Sunspot number data.

SOI: Southern Oscillation Index data.

SST: Sea surface temperature data.

group: period number.

hangle: solar altitude angle, which can be calculated by local time, local latitude, and the sun declination, and is expressed by equation 4.

p: the border of the period (please use 0 to start).

period: the number of the hysteresis period.

t: Time series.

total\_t/total\_p: the input of the MHD model.

**Procedure set:**

a\_ti/a\_pi (i=1 to 6): the ar1 coefficients of the series under six periodic scales.

p\_ti/p\_pi (i=1 to 6): the vector of "Fourier" periods (in time units) that corresponds to the SCALEs. SCALE: the vector of scale indices, given by S0\*2^(j\*DJ), j=0...J1, where J1+1 is the total # of scales.

a\_ti\_draw/a\_pi\_draw (i=1 to 6): Variables a\_ti/a\_pi are transformed into raster data in the study area.

p\_ti\_draw/p\_pi\_draw (i=1 to 6): Variables p\_ti/p\_pi are transformed into raster data in the study area.

ah\_ti\_draw/ah\_pi\_draw (i=1 to 3): When i=1, it means the angle of the hysteresis cycle in the cross wavelet between SA and T or P. When i=2, it means the angle of the hysteresis cycle in the cross wavelet between SOI and T or P. When i=3, it means the angle of the hysteresis cycle in the cross wavelet between SST and T or P.

dis\_t\_plot/dis\_p\_plot: entropy weight of influencing factors (max=255).

funt/funp: the function of the MHD model with T or P.

p1/p2/t1/t2: The amount of process to collate the MHD model input set.

temp\_d/prec\_d: Consolidate the temp/prec data into a grid form for each study area.

reg\_t/reg\_p: Each grid has a significant lag period of six lag cycles.

t\_decom/p\_decom: Consolidate the t\_dec/p\_dec into six periods.

x\_t/x\_p: The strong interaction period of each grid under six hysteresis periods.

x\_ti/x\_pi (i=1 to 3): The strong interaction period of each grid under six hysteresis periods. we split the variable x\_t/x\_p. when i=1, it means the strong interaction period between SA and t or p. when i=2, it means the strong interaction period between SOI and t or p. when i=3, it means the strong interaction period between SST and t or p.

x\_ti\_draw/x\_pi\_draw (i=1 to 3): Convert variable form to drawing.

**output set:**

output: the results and parameters of MHD model.

t\_RGB/p\_RGB: the RGB result to draw entropy weight of SA, CO, and regional GF to the periodic hysteresis of T and P.

t\_dec/p\_dec: the result of seasonal-trend decomposition.

par\_t/par\_p: the parameters of MHD model.

w\_t/w\_p: the entropy of SA, SOI, SST, longitude, latitude, and elevation.

wtc\_ti\_plot/wtc\_pi\_plot (i=1 to 3): when i=1, it means the wtc result (hysteresis period) between SA and T or P. when i=2, it means the wtc result (hysteresis period) between SOI and T or P. when i=3, it means the wtc result (hysteresis period) between SST and T or P.

xwt\_ti\_plot/xwt\_pi\_plot (i=1 to 3): when i=1, it means the xwt result (strong interaction period) between SA and T or P. when i=2, it means the xwt result (strong interaction period) between SOI and T or P. when i=3, it means the xwt result (strong interaction period) between SST and T or P.

**Statement:**

Wavelet toolbox refers to http://www.glaciology.net/wavelet-coherence. You can get more from the reference followed:

Grinsted, A., J. C. Moore, S. Jevrejeva (2004), Application of the cross wavelet transform and wavelet coherence to geophysical time series, Nonlin. Process. Geophys., 11, 561566 [link](http://www.glaciology.net/Home/PDFs/Announcements/Application-of-the-cross-wavelet-transform-and-wavelet-coherence-to-geophysical-time-series-).