Possible Impact of Solar Activity on the Convection Dipole over the Tropical Pacific Ocean

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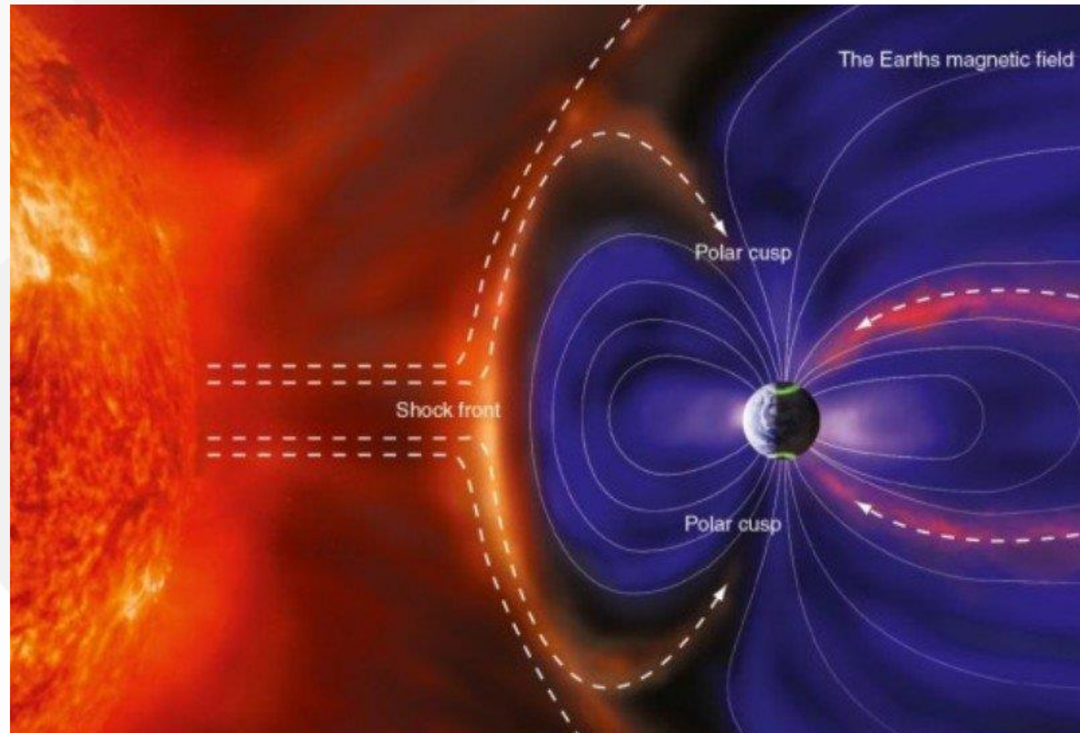
Introduction

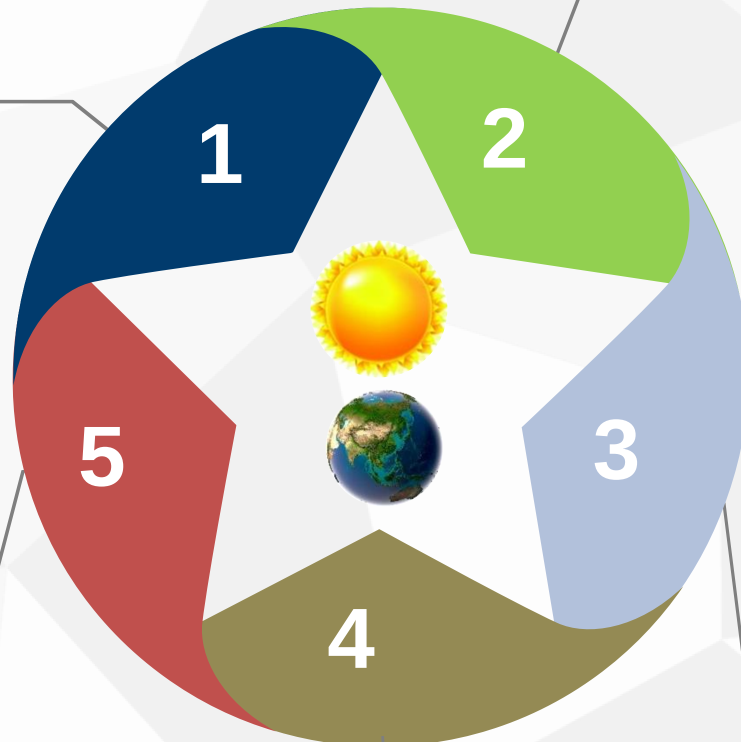
Introduction

- It is well known that changes in solar activity can influence the Earth's climate over long time spans.

- As pointed out in IPCC report , our understanding of the mechanisms by which solar activity influences climate is not very clear, and thus many uncertainties exist regarding possible sun-climate interactions.



Introduction



There are some significant responses of climate to solar variations in many regions of the Earth. [Bond et al., 2001; Wang et al., 2005; Van Loon et al., 2007; Bal et al., 2011; Xiao et al., 2013]

During solar maximum years, the ascending branch of the Walker circulation in the equatorial western Pacific and the descending branch of the Walker circulation in the eastern Pacific are enhanced. [Gleisner et al., 2003]

The ascending branch of the Hadley cell is enhanced near the equator in response to solar forcing during the boreal winter (December-January-February, DJF). The Walker circulation is strengthened in response to solar forcing in both the JJA (June-July-August) and DJF. [Lee et al., 2009]

In the western Pacific, an area showing deep convection shifts to the east in correspondence with the 11-year solar cycle. Misios et al. [2012]

Tropical low-latitude changes in cloud cover are closely associated with changes in solar activity, and that convection is the main cause of the changes in tropical cloud cover. [Svensmark and Friis-Christensen, 1997; Farrar, 2000; Carslaw et al., 2002; Harrison, 2008]

Data & Methodology

Data & Methodology

Dataset：

Outgoing Longwave Radiation (OLR)monthly data：1975-2013 [Liebmann and Smith, 1996]

NCEP/NCAR reanalysis monthly dataset: 1954-2013 [Kalnay et al., 1996]

10.7 cm solar radio flux (F10.7) monthly index: 1954-2013 [the National Research Council of Canada]

Hadley Center sea ice and sea surface temperature (HadISST) monthly dataset: 1954-2013 [Rayner, N.A., P.Brohan, D.E.Parker, C.K.Folland, J.J.Kennedy, M.Vanicek, T.Ansell and S.F.B.Tett, 2006]

Methodology：

Correlation analysis

Compositing analysis

Spectral analysis

Empirical orthogonal function (EOF) analysis

OLR: negative values indicate strong convection and positive values indicate weak convection.

Vertical velocity: negative values indicate ascending motions and positive values indicate descending motions.

Data & Methodology

The high solar (low solar) years are defined as years in which the standardized anomaly of the JJA mean F10.7 index (Fig. 2.1) is greater (less) than 1.0 (-1.0).

Table 2.1

HS, LS years, the first years following the HS and LS years (HS + 1, LS + 1), and the second years following the HS and LS years (HS + 2, LS + 2).

Solar	Year
HS	1956, 1957, 1958, 1959, 1979, 1980, 1981, 1989, 1990, 1991, 1999, 2000, 2002
HS + 1	1957, 1958, 1959, 1960, 1980, 1981, 1982, 1990, 1991, 1992, 2000, 2001, 2003
HS + 2	1958, 1959, 1960, 1961, 1981, 1982, 1983, 1991, 1992, 1993, 2001, 2002, 2004
LS	1953, 1954, 1964, 1976, 1986, 1995, 1996, 1997, 2007, 2008, 2009
LS + 1	1954, 1955, 1965, 1977, 1987, 1996, 1997, 1998, 2008, 2009, 2010
LS + 2	1955, 1956, 1966, 1978, 1988, 1997, 1998, 1999, 2009, 2010, 2011

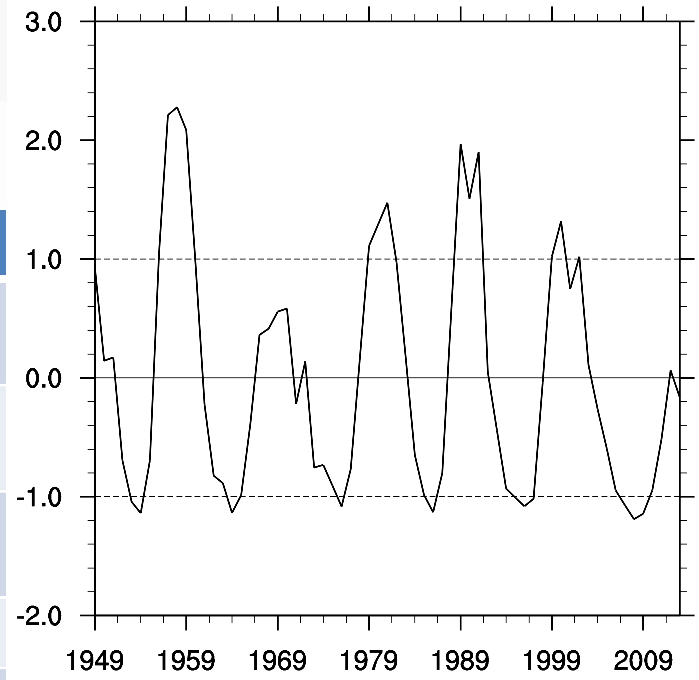


Fig. 2.1 Time series of the JJA mean standardized F10.7 index.

Data & Methodology

Composite analysis:

The average of high solar (HS) years minus the average of low solar (LS) years.
HSave – LSave
The average in the first year following HS years minus the average in the first year following LS years.
(HS+1)ave – (LS+1)ave
The average in the second year following HS years minus the average in the second year following LS years.
(HS+2)ave – (LS+2)ave

Season selection:
Boreal summer = June-Junly-August (JJA)

Data & Methodology

ENSO signal ?

Roy and Haigh [2010]

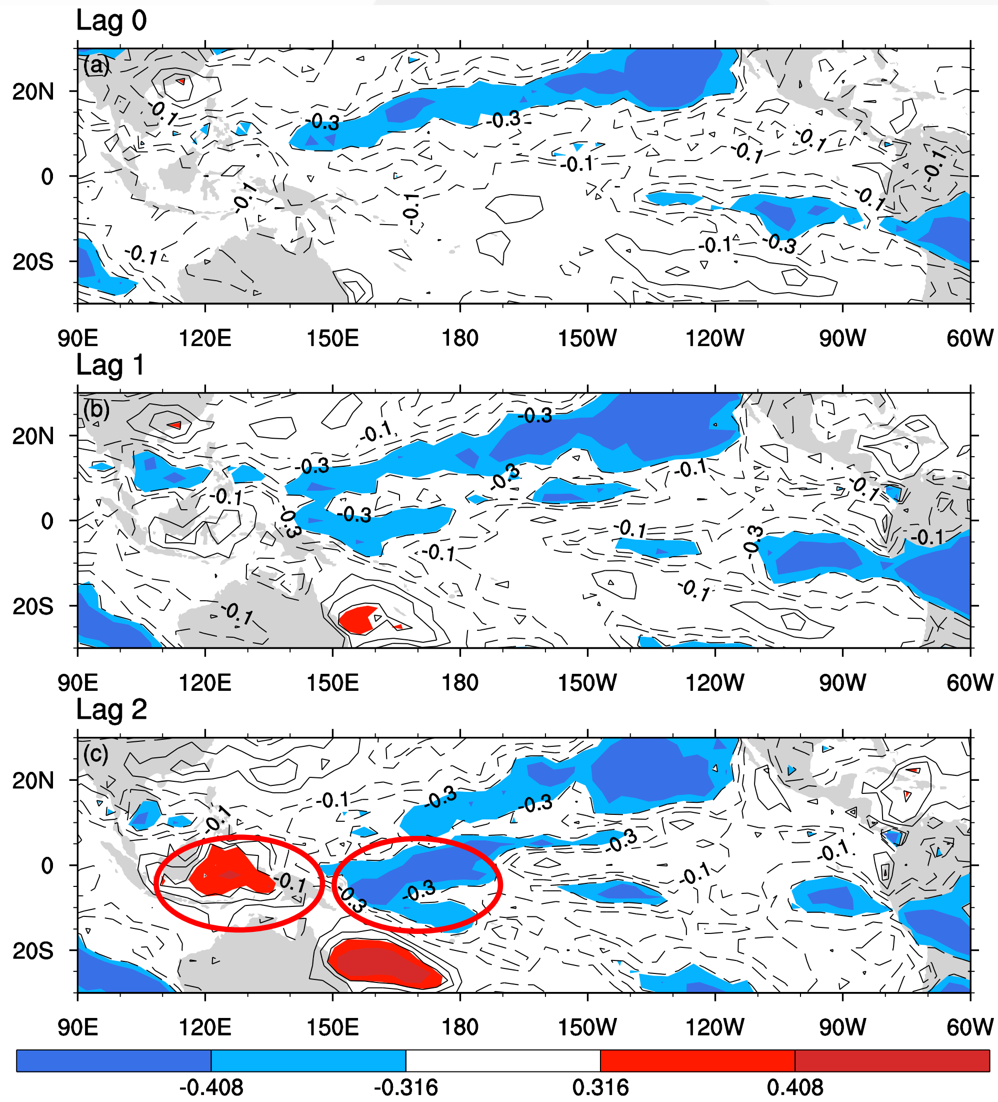
If ENSO is not taken into account with care, that a signal in sea surface temperature or sea surface pressure might be misinterpreted as a solar effect.

To remove the ENSO signal, we subtracted the data regressed by the Nino3 index (15° W-90° W, 5° N-5° S) from the original data.

Results

Results

Fig 3.1 After removing ENSO signal, correlation coefficients between the JJA mean F10.7 index and OLR. (a) Contemporaneous correlation coefficients; (b) OLR lagging the F10.7 index by one year; (c) OLR lagging the F10.7 index by two years. Light shading indicates regions where the correlation exceeds the 95% significance level. Dark shading indicates areas where the correlation exceeds the 99% significance level.



Results

Fig 3.2 (a) The first EOF pattern of the JJA mean OLR;
(b) time series of the first EOF pattern.

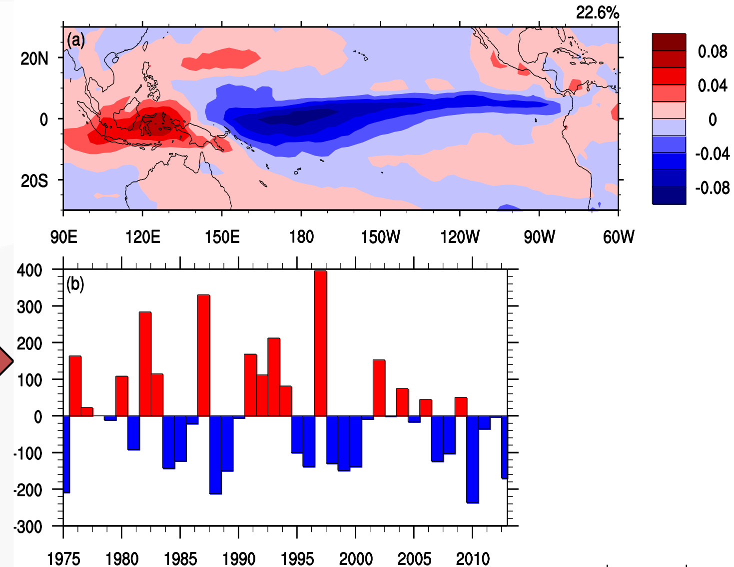
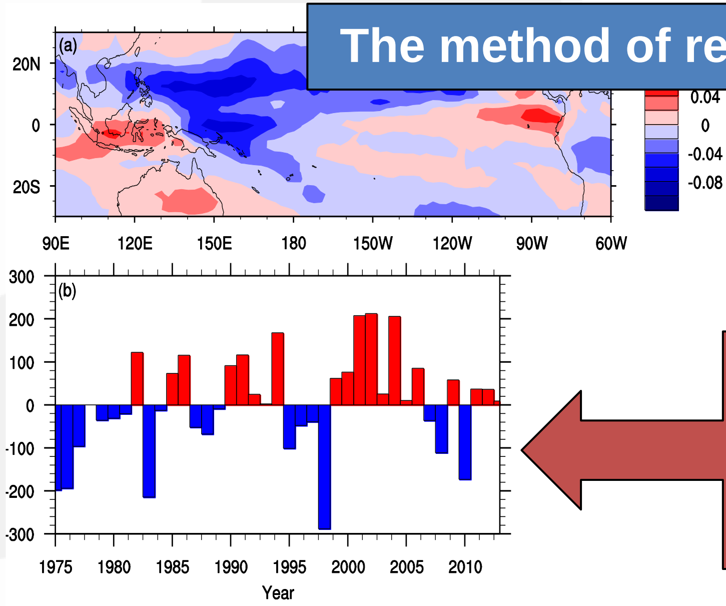


Fig 3.3 (a) The second EOF pattern of the JJA mean OLR;
(b) time series of the first EOF pattern.

The method of removing the ENSO signal is effective.



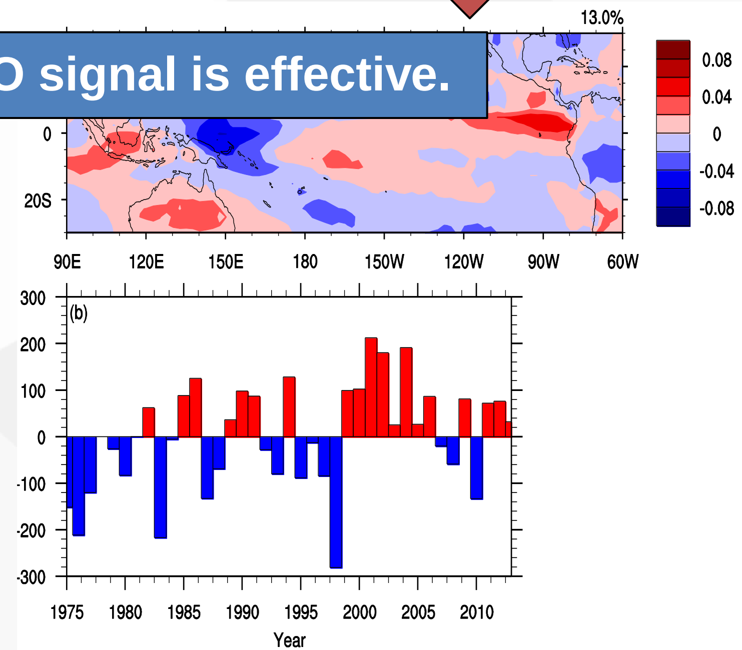


Fig 3.4 After removing ENSO signal,
(a) The first EOF pattern of the JJA mean OLR;
(b) time series of the first EOF pattern.

Results

Table 3.1

Contemporaneous lagged correlation coefficients between the time series data from the first EOF pattern with the ENSO signal removed and the JJA mean F10.7 index. A single asterisk (*) represents a correlation coefficient exceeding the 90% significance level. A double asterisk (**) represents a correlation coefficient exceeding the 95% significance level.

lag	0	1	2	3	4	5
r	0.30 *	0.40 **	0.39 **	0.30 *	0.01	-0.06

Results

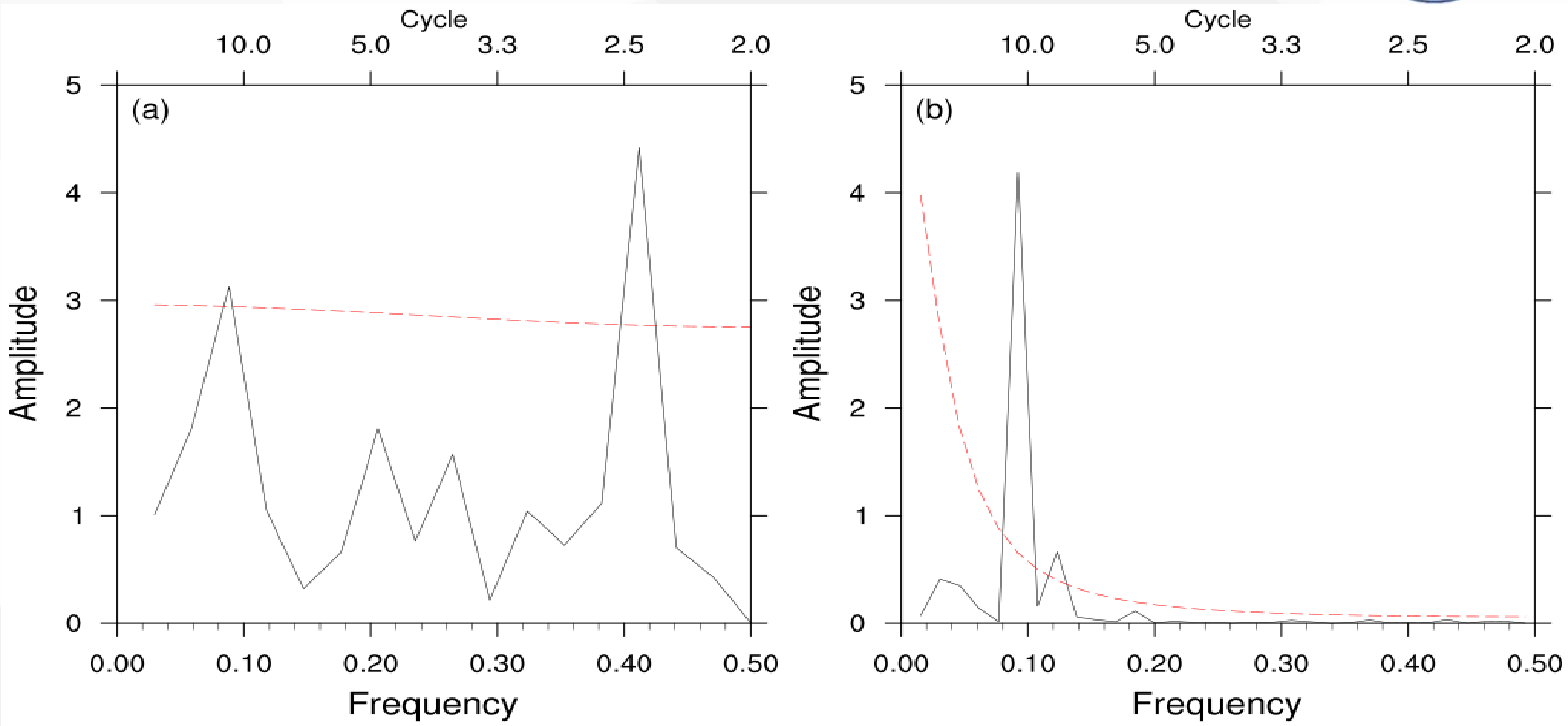


Fig 3.5 The spectral of (a) the time series data from the first EOF pattern of the JJA mean OLR with the ENSO signal removed, and (b) the JJA mean F10.7 index. The significance level (red curve) represents the 90 % against background noise.

Results

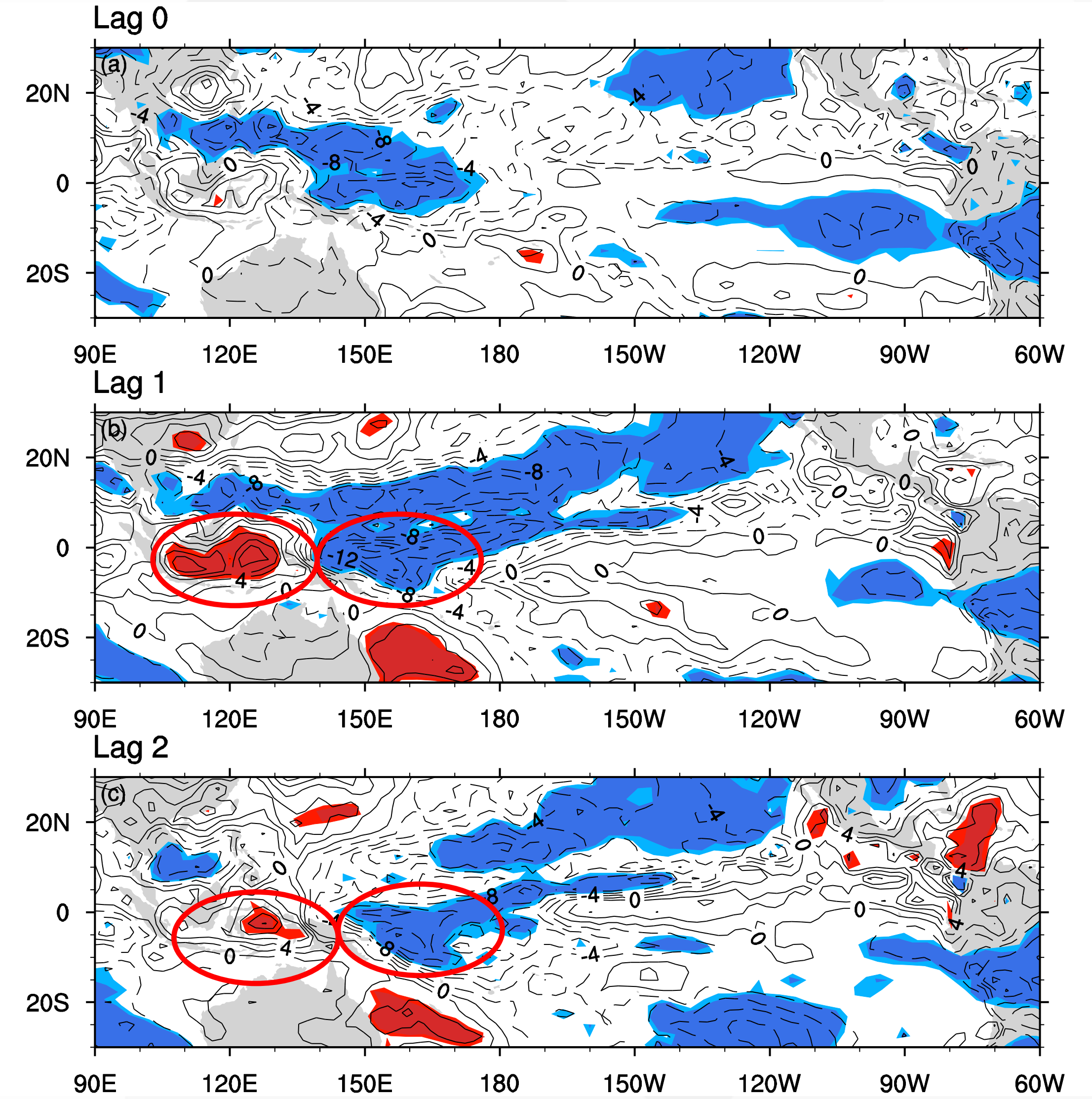


Fig 3.6 After removing ENSO signal,
(a) HSave-Lsave ;
(b) (HS+1)ave-(LS+1)ave ;
(c) (HS+2)ave-(LS+2)ave ;
Light shading indicates regions where the correlation exceeds the 90% significance level. Dark shading indicates areas where the correlation exceeds the 95% significance level.

Results

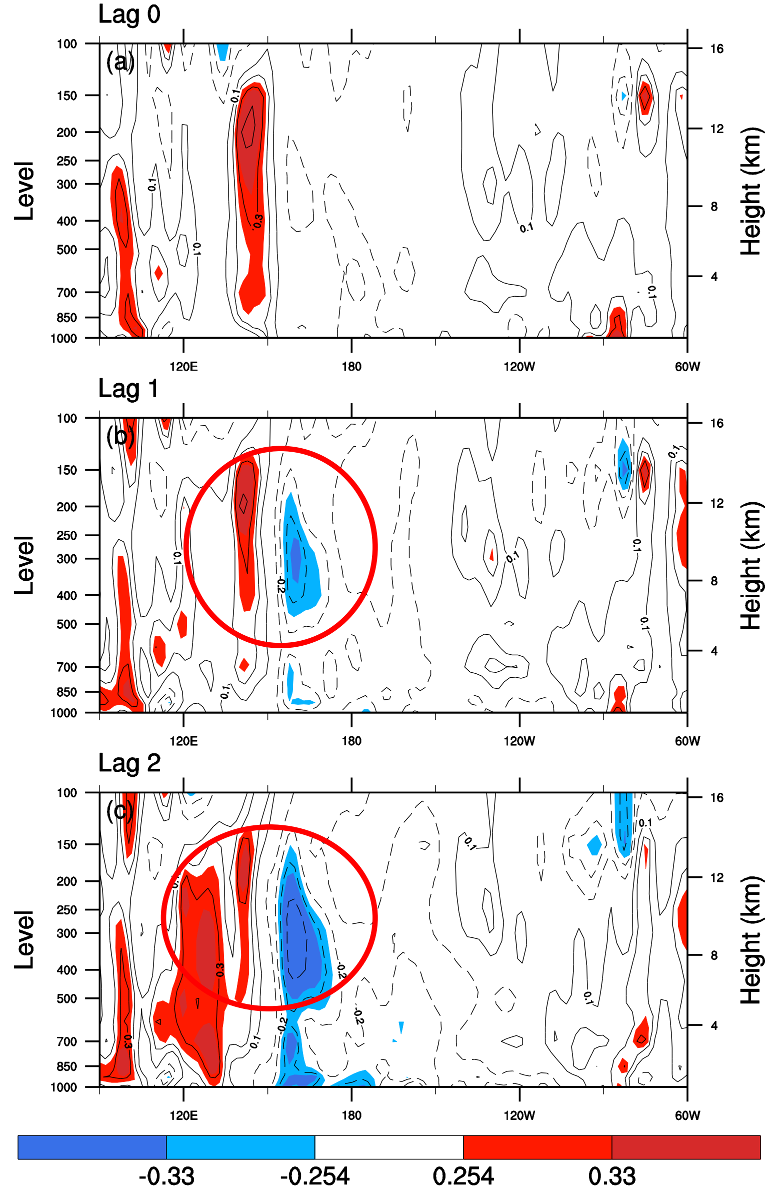
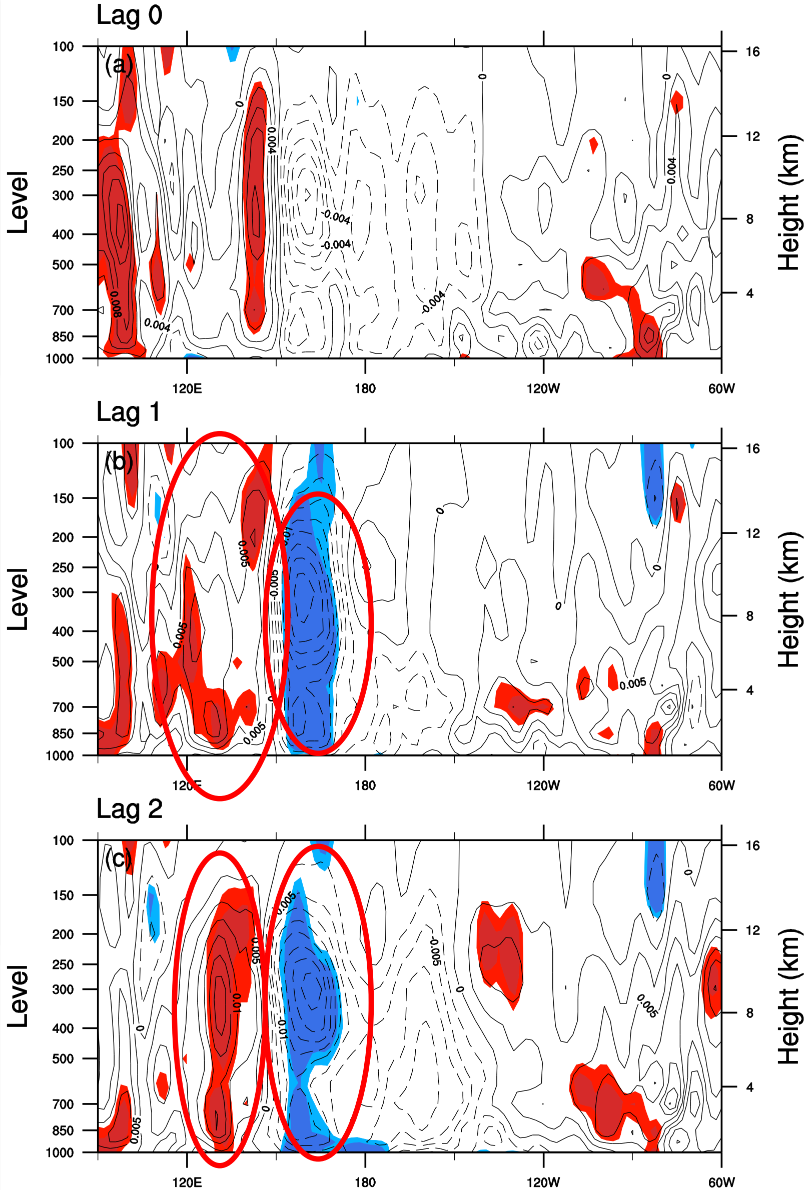


Fig 3.7 Correlation coefficients between the JJA mean F10.7 index and vertical velocity(5° S~5° N average) with the ENSO signal removed. (a) Contemporaneous correlation coefficients; (b) vertical velocity lagging the F10.7 index by 1 year; (c) vertical velocity lagging the F10.7 index by 2 years. Light shading indicates areas exceeding the 95% significance level. Dark shading indicates areas exceeding the 99% significance level.

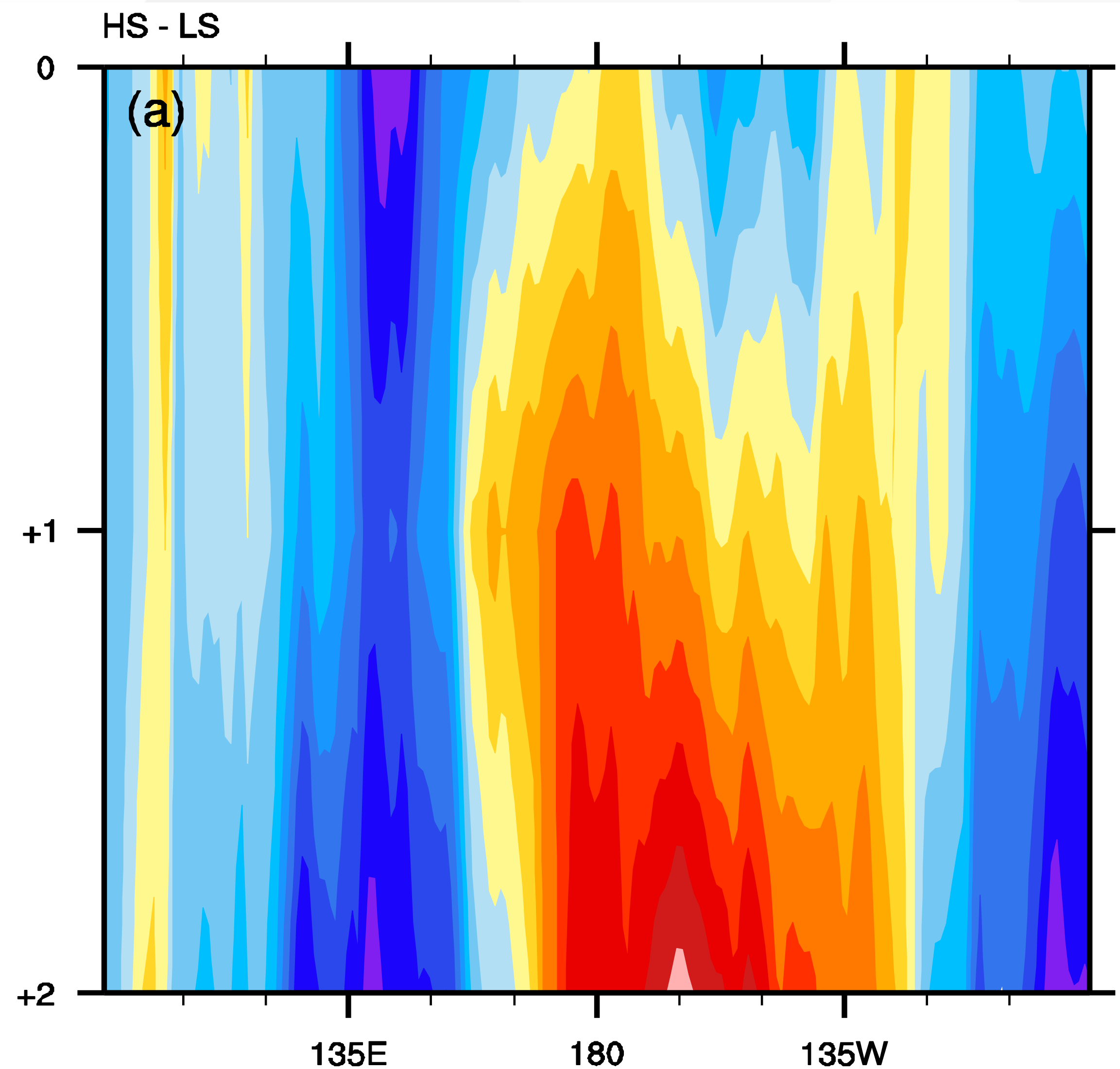
Results

Fig 3.8 After removing ENSO signal,
(a) HSave-Lsave ;
(b) (HS+1)ave-(LS+1)ave ;
(c) (HS+2)ave-(LS+2)ave ;
Light shading indicates regions where the correlation exceeds the 90% significance level. Dark shading indicates areas where the correlation exceeds the 95% significance level.



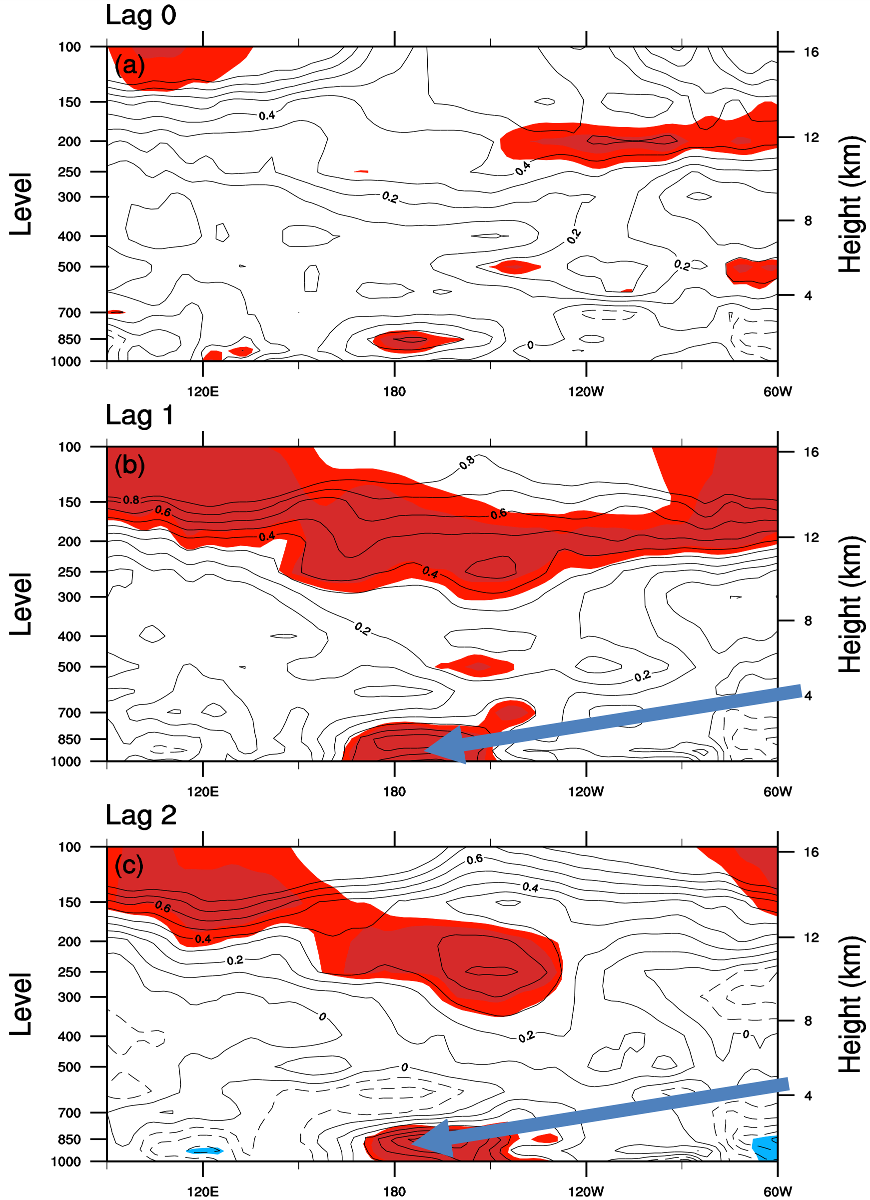
Results

Fig 3.9 After removing ENSO signal, JJA mean SST(5° S-5° N average) Hovmöller diagram, HSave-LSave (0) ; (HS+1)ave-(LS+1)ave (+1) ; (HS+2)ave-(LS+2)ave (+2) ;



Results

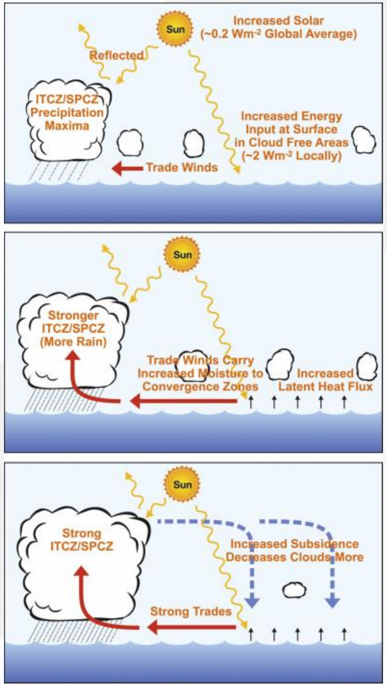
Fig 3.10 After removing ENSO signal, JJA mean air temperature (5° S-5° N average),
(a) HSave-AVE ;
(b) (HS+1)ave-AVE ;
(c) (HS+2)ave-AVE ;
Light shading indicates regions where the correlation exceeds the 90% significance level. Dark shading indicates areas where the correlation exceeds the 95% significance level.



Discussion

Discussion

- In the first and second years following HS years, as compared with the first and second years following LS years, the convection over the western tropical Pacific will stimulate an a zonal dipole pattern, which shows an eastward shift of deep convection and the ascending of Walker circulation over the western Pacific.



[Meehl and Arblaster, 2008]

Dynamic coupled processes initiated in response to solar forcing in the tropical Pacific produced wind-driven ocean Rossby waves in HS years. Rossby waves reflect off the western boundary, producing downwelling equatorial Kelvin waves, which deepen the thermocline, reduce upwelling of cool water, and result in a transition from negative to positive SST anomalies, with a lag time of 1-2 years.

[Meehl and Arblaster, 2009]

Modulating the tropical vertical air temperature →

Eastward shift of deep convection and the ascending of Walker circulation over the western Pacific

↓

Convection dipole over the western Pacific

Discussion

- Roy and Haigh [2012] discussed that such a SST lag response, which has been suggested by Meehl and Arblaster [2009], is only observed during latter half of 20th century. On account of constraints of the current data, the solar signal in tropical convection we want to show is mainly dominated by the later period of 20th century.
- Longer datasets are needed to further verify that the lagged convection dipole pattern is due to solar activity.
- More analyses, especially numerical modeling experiments, are needed to confirm the exact mechanism.

Thank you!