Impact of spring land-surface conditions over the Tibetan Plateau on the early summer Asian monsoon using an AGCM large ensemble

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Climate Dynamics (2024)

- **Influence of land-surface memory effects** over the Tibetan Plateau on the Asian summer monsoon has long been studied, but not quantified. This study examines the impact of spring land-surface conditions on the early stage of the Asian summer monsoon **using AGCM large-ensemble experiments**.
- The above-normal SAT over and around the Tibetan Plateau in May can enhance June monsoon circulation without the sea surface temperature (SST) forcing.
- **The spring SAT impacts on June monsoon circulations vary interannually**, indicating that the contribution of the land–atmosphere (L–A) coupling process to interannual monsoon variability differs from year to year.
- In May of the developing stage of monsoon circulation, the weak Walker circulation over the equatorial and northern Indian Ocean and undeveloped monsoon circulation are suitable for the L–A coupling to influence the development of the monsoon circulation effectively. However, the well-known oceanic events, such as El Nĩno, are found to be less connected with the interannual L–A coupling variations.

Land-surface Impacts on the Asian monsoon circulation

Introduction

- Land-surface conditions, like SAT & snow cover, over the TP controls the strength of the Asian monsoons.
    - (Hahn and Shukla 1976; Vernekar et al. 1995; Yasunari et al. 1991; Shaman and Tziperman 2005).
  - **ex. El Nino:** A weaker SAT gradient in the north-south direction weakens monsoon circulation, resulting in less monsoon precipitation.
    - (Goswami and Xavier 2005).
- **Because of significant SST impacts (e.g., El Nino), we have not isolated the land-surface impacts only.**
- This study isolates the impacts of land-surface conditions and tries to quantify them.
  - Using AGCM large-ensemble datasets (d4PDF; Mizuta et al. 2016, BAMS)

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Difficulty of isolating land impacts

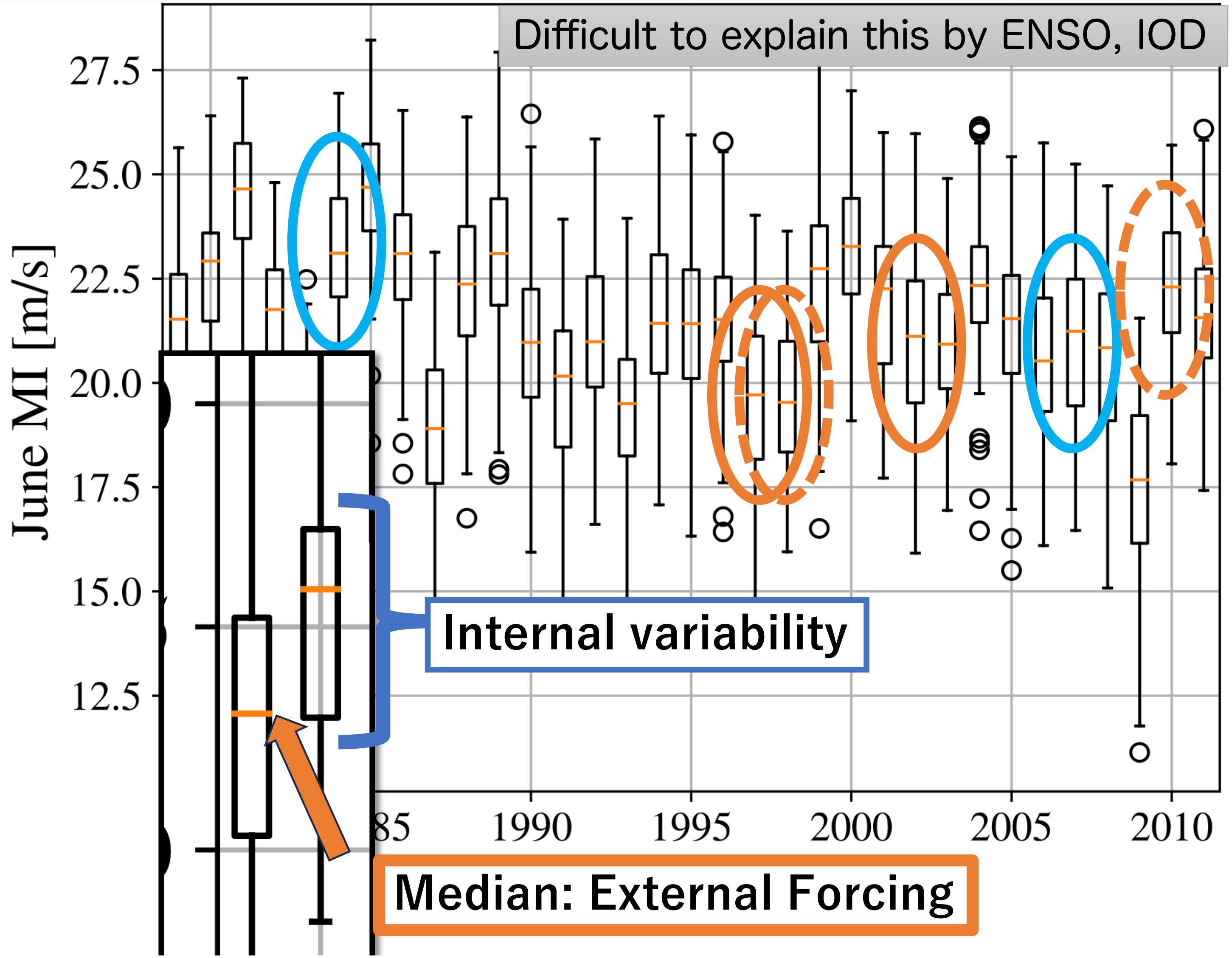
- Influence of land-surface memory effects over the Tibetan Plateau on the Asian summer monsoon **has long been studied, but not quantified** because of the difficulty of extracting only these effects from observational data.
    - Oceanic and ocean-atmosphere interaction impacts through SST anomalies (e.g., ENSO) are strong.
    - **To extract only land-surface effects with ignoring the oceanic influence, we need a large number of samples with similar SST conditions. Observational data have too few samples.**
    - Results of previous studies do not understand whether LAND+OCEAN or LAND influences. Also, can only LAND explain at least in part?
- To isolate only the LAND effect, we use the AGCM large ensemble.

Data and Analysis
(Detailed also see Takahashi et al. 2024)

- AGCM large-ensemble (100) data with prescribed observed SST
  - <u>100 random ATM+LAND samples with the similar SST</u> conditions
- Within the 100 samples (the same SST), we examine the **<u>internal climate relationship of the ATM-LAND system.</u>**
  - Influence of LAND **<u>(inter-ensemble regression/correlation)</u>**:
    - ex1. May SAT over TP is low => June MI is weak (El Nino like effects)
    - ex2. Jan. SAT is low => May SAT is also low (possible memory effects, but weak)

$$Corr_{inter-ens}(i,j) = \frac{\sum_{e=1}^{100}(MI_e - \overline{MI})(SAT_e(i,j) - \overline{SAT(i,j)})}{\sqrt{\sum_{e=1}^{100}(MI_e - \overline{MI})^2 \sum_{e=1}^{100}(SAT_e(i,j) - \overline{SAT(i,j)})^2}}$$

Boxplot of Interannual Monsoon Index variation



Oceanic forcing is large, but ENSO cannot always explain the interannual variation of MI. **Ext.**

- STD ~ 2 m/s

- Variability within land-atmosphere (boxplot) is not small.
  - Qn(0.75)-Qn(0.25) ~ 2 m/s **Internal**

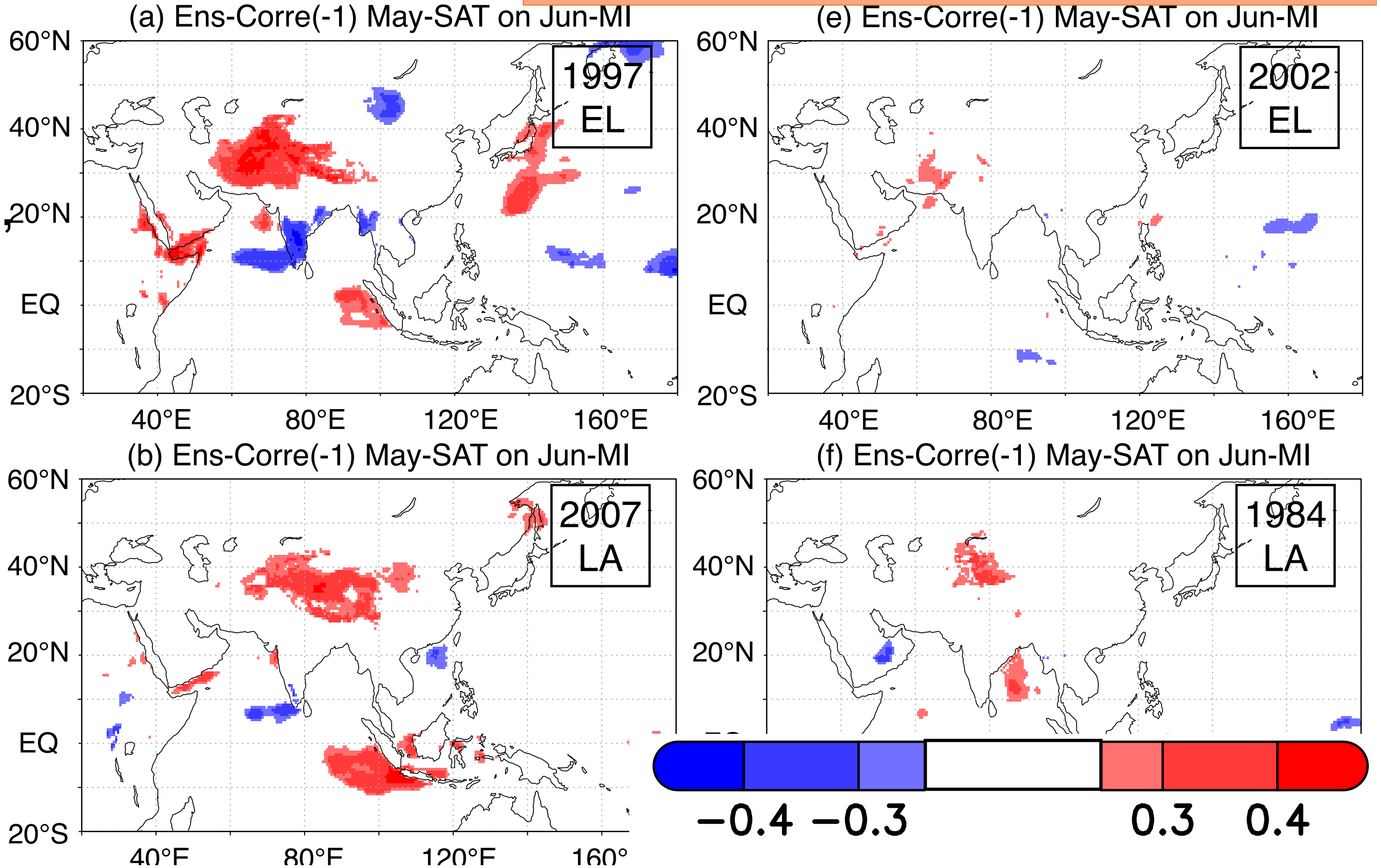
- For MI, the land influence cannot be ignored. They are comparable in AGCM.

Lag-correlations between SAT and monsoon circulation

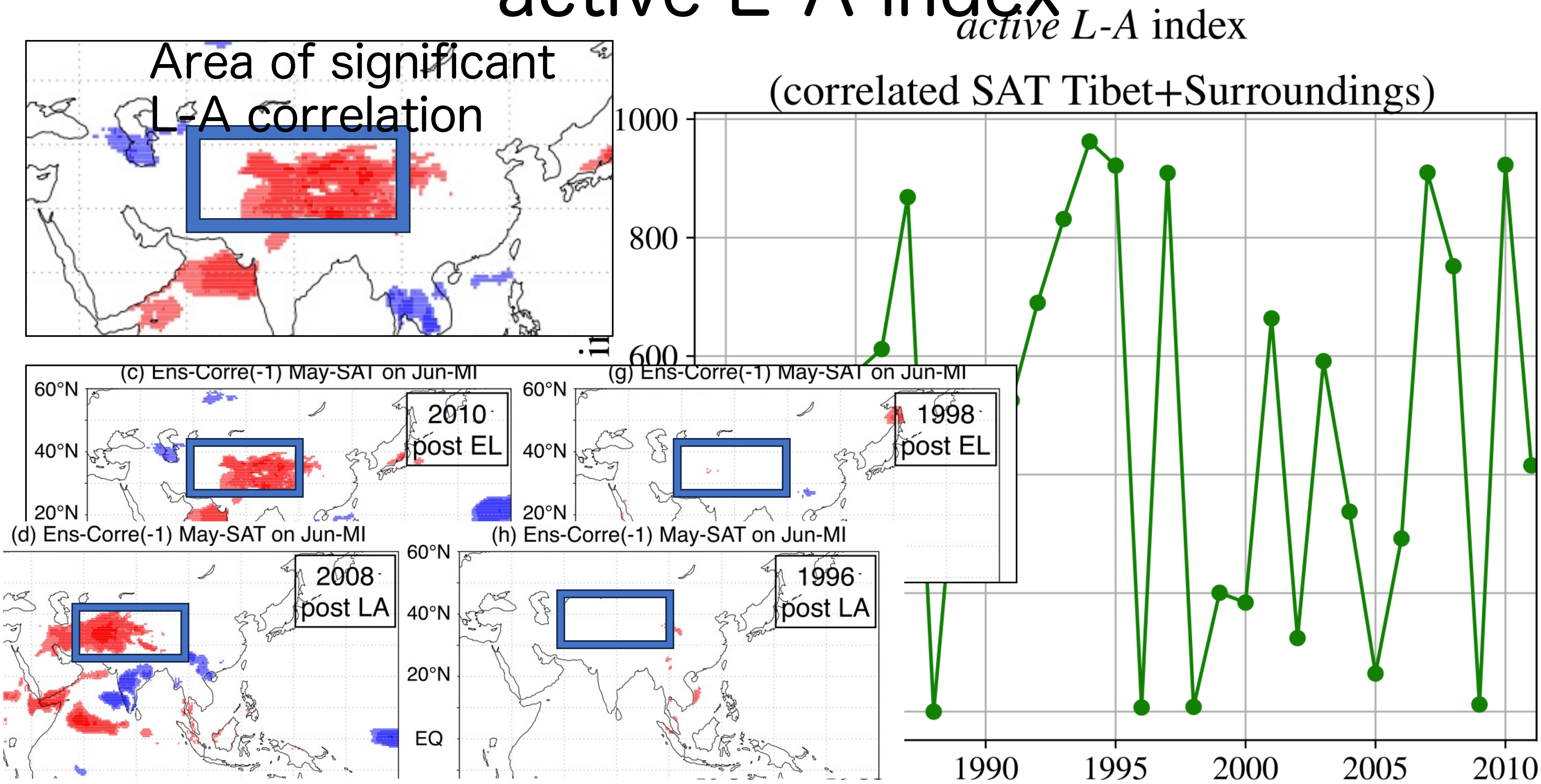
Red: May Warm SAT => June Strong Monsoon

Also, ColdSAT => Strong MI

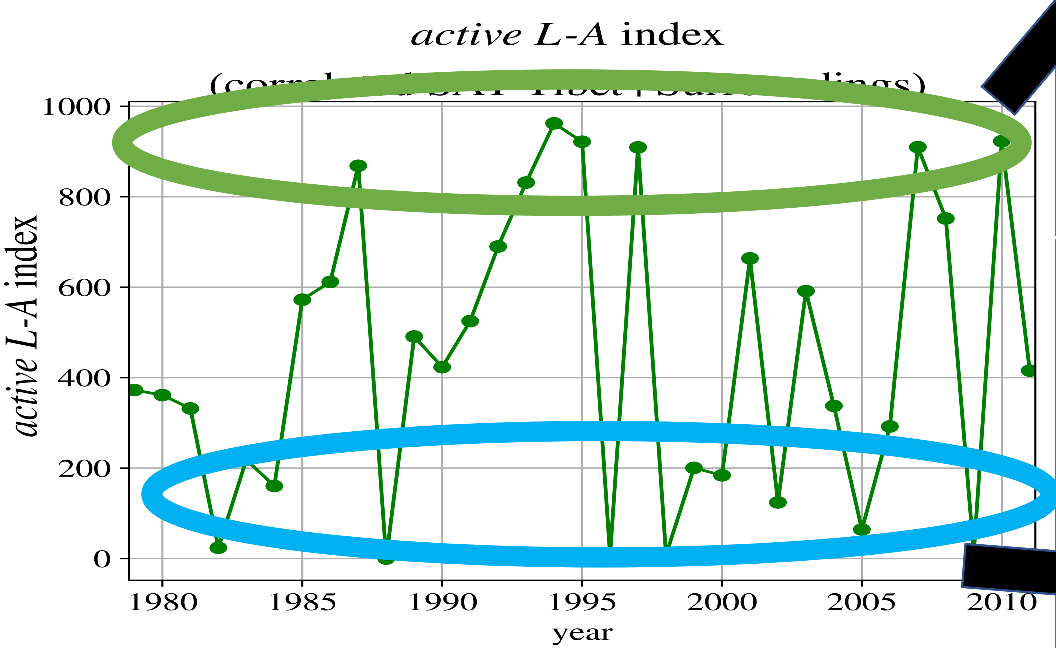
- TP surface conditions sometimes control monsoon circulation, but sometimes not.
- The TP surface effects vary interannually.
  - EL 1997 strong
  - EL 2002 weak
  - LA 2007 strong
  - LA 1984 weak

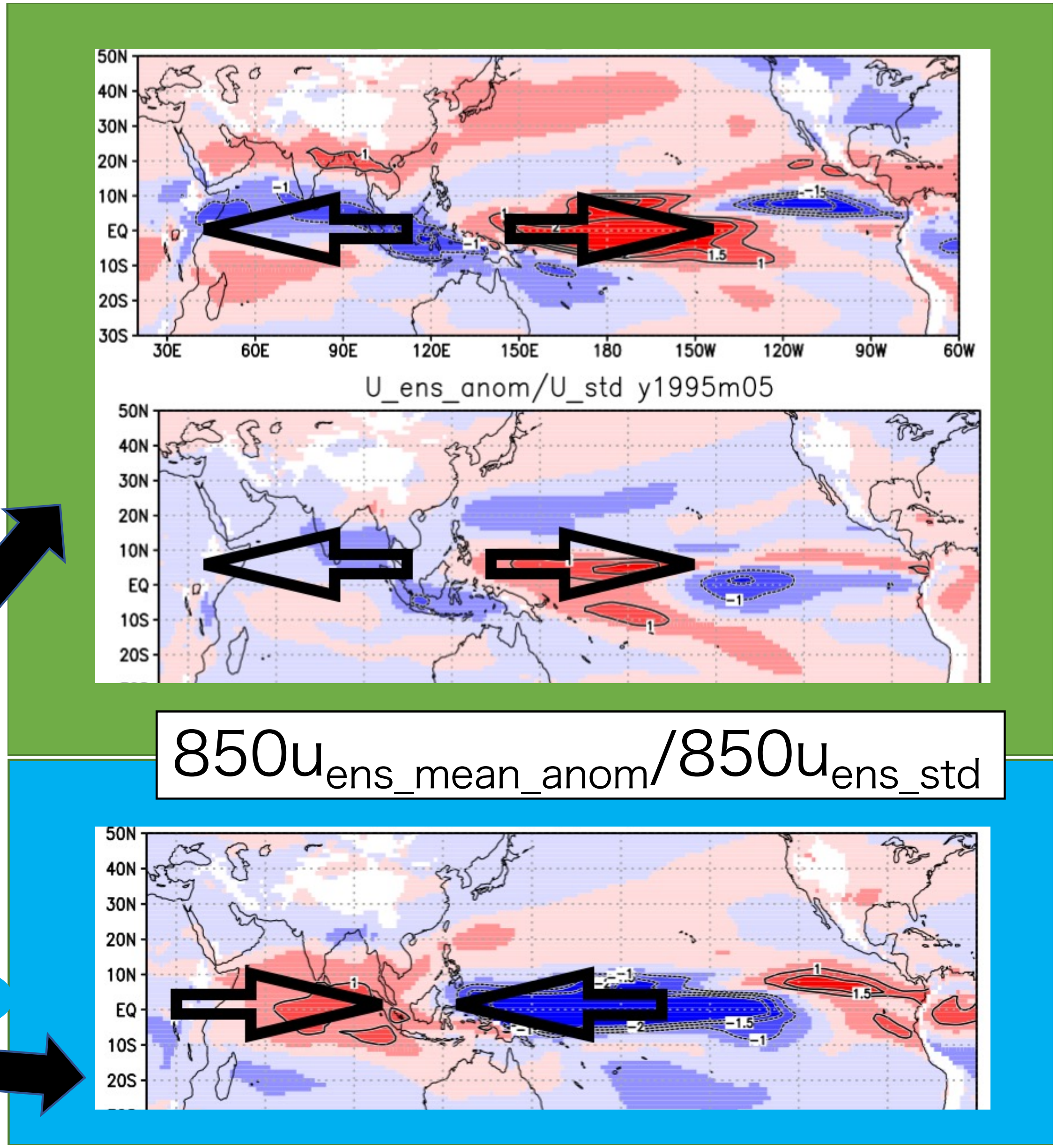


active L-A index



- Controlling by background conditions (Strong SST forcing may suppress L-A coupling.)
- Convective activity over Maritime Continent may suppress L-A coupling over the Asian monsoon region.



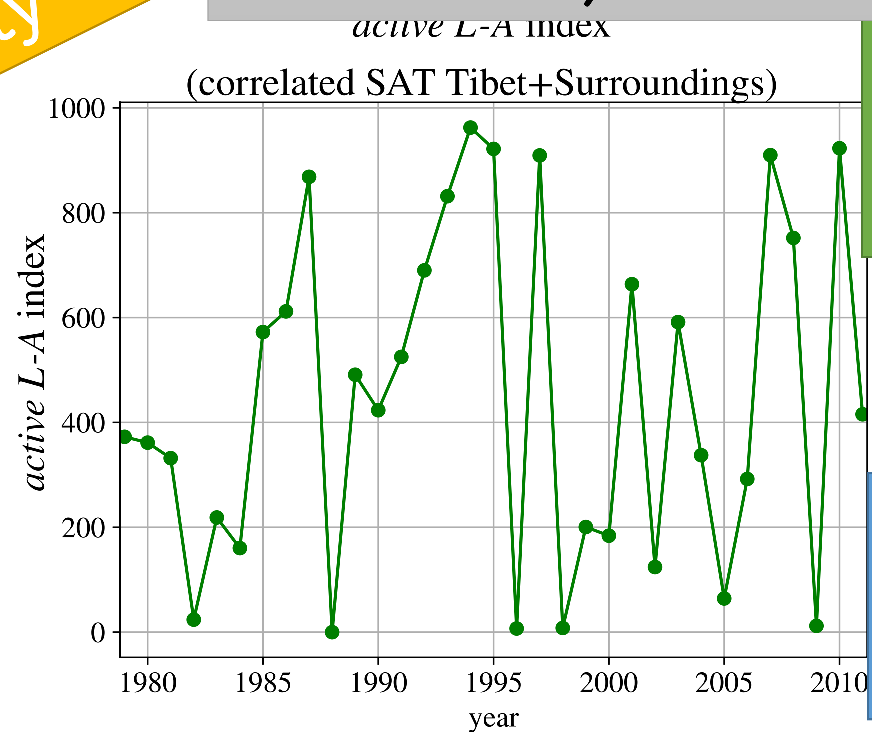


Impact of spring land-surface conditions over and around the Tibetan Plateau on the early summer Asian monsoon circulation using AGCM large-ensemble

Land-Atmosphere (L-A)

AGCM-LE: 100-AGCM exps. under the same SST conditions (100 times AMIP)

Land-Atmos-Ocean climate variability



active L-A year

Inactive L-A Year = strong SST forcing

Land-Atmosphere climate variability

Summary

- Influence of land-surface memory effects over the Tibetan Plateau on the Asian summer monsoon has long been studied, but not quantified. This study examines the impact of spring land-surface conditions on the early stage of the Asian summer monsoon using AGCM large-ensemble experiments.
- The above-normal SAT over and around the Tibetan Plateau in May can enhance June monsoon circulation without the sea surface temperature (SST) forcing.
- The spring SAT impacts on June monsoon circulations vary interannually, indicating that the contribution of the land–atmosphere (L–A) coupling process to interannual monsoon variability differs from year to year.
- In May of the developing stage of monsoon circulation, the weak Walker circulation over the equatorial and northern Indian Ocean and undeveloped monsoon circulation are suitable for the L–A coupling to influence the development of the monsoon circulation effectively. However, the well-known oceanic events, such as El Nĩno, are found to be less connected with the interannual L–A coupling variations.

Data

- d4PDF(monthly) AGCM Large-ensemble datasets
  - 100 members, 1951-2011 (We used 1979-2011)
- JRA-55 Reanalysis
- COBE-SST

- Monsoon Index(MI): (u850 – u200), averaged over EQ–20N, 40–110E
  - Webster and Yang (1992)
- SAT index of the Tibetan Plateau and its surrounding regions (28–40N, 60–100E)
  - Based on our analysis
- Inter-ensemble correlation

$$Corr_{inter-ens}(i,j) = \frac{\sum_{e=1}^{100}(MI_e - \overline{MI})(SAT_e(i,j) - \overline{SAT(i,j)})}{\sqrt{\sum_{e=1}^{100}(MI_e - \overline{MI})^2 \sum_{e=1}^{100}(SAT_e(i,j) - \overline{SAT(i,j)})^2}}$$

- where i and j are longitude and latitude grid numbers

Results: SST-forced variability

- SST-forcing can control the interannual variation
  - SAT (18% σ^2 controlled) also but weaker than MI (41%)
    - Calculated from $\sigma_{\text{median (forced variability)}} / \sigma_{\text{total (forced + internal)}}$
  - This is reasonable because Tibet is located inland + mid-latitudes.

Internal climate variability

- Internal climate variability is defined as deviation from the ensemble mean.

$$(MI_e - \overline{MI}) \qquad \underline{(SAT_e(i,j) - \overline{SAT(i,j)})}$$

-
- Using inter-ensemble correlation

  we investigate the relationship between June MI and land-surface conditions before June.

- We analyze the inter-ensemble relationship for each year (under almost the same SST).
- First, we analyze 1995, which has strong land-surface impact on MI.
  - We analyze other years later.

1995 (An example)

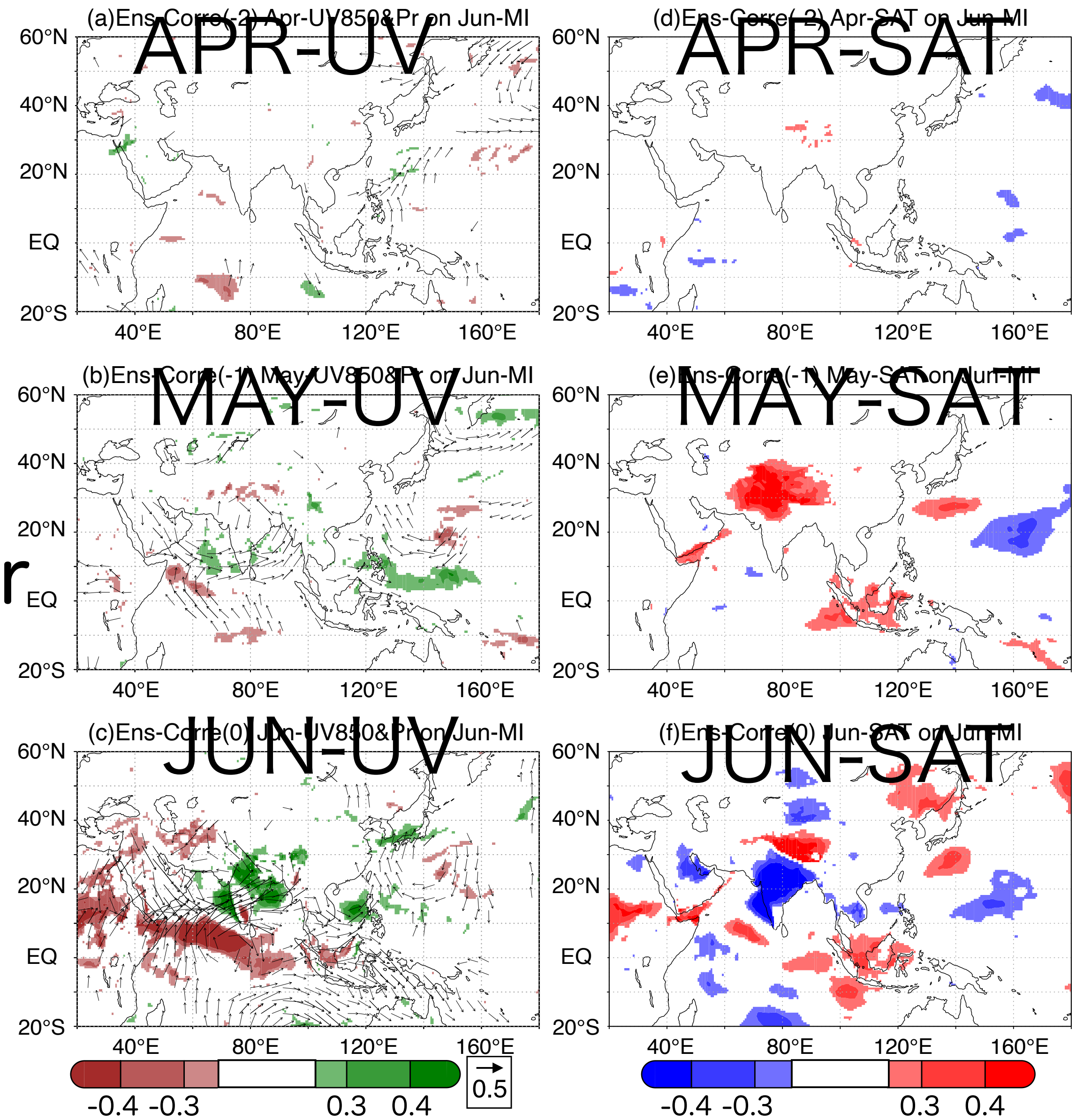
- In 1995, May SAT could explain June MI.
- *However, SAT (snow, Tsfc) signals were not notable before May. => One-month predictability*

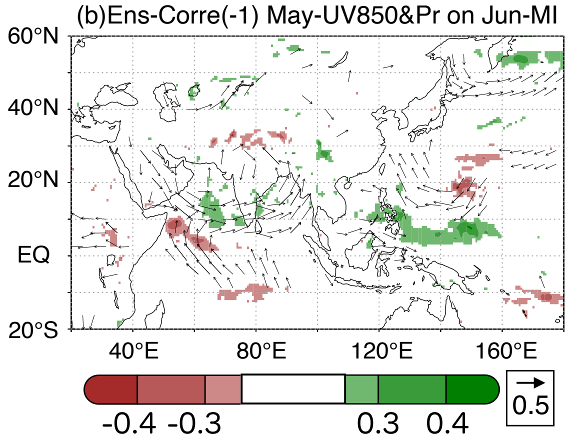
- 200-hPa wind signals could explain MI through SAT change.
- 850-ｈPa winds and precipitation might partly explain MI.

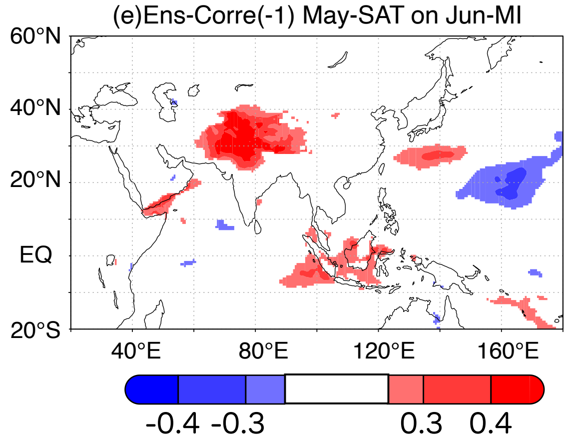
- ＝＞ We will check samples in other years.

Inter-ensemble correlation analysis

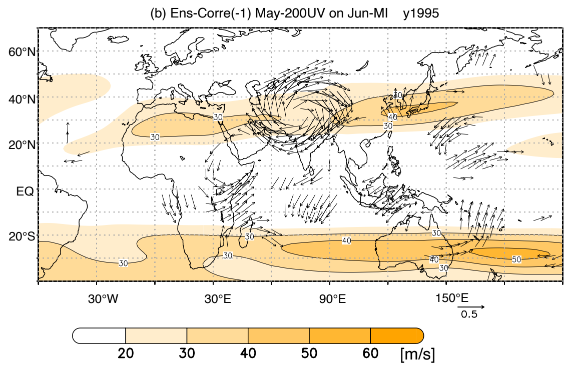
We expect that May SAT enhance or weaken June MI.

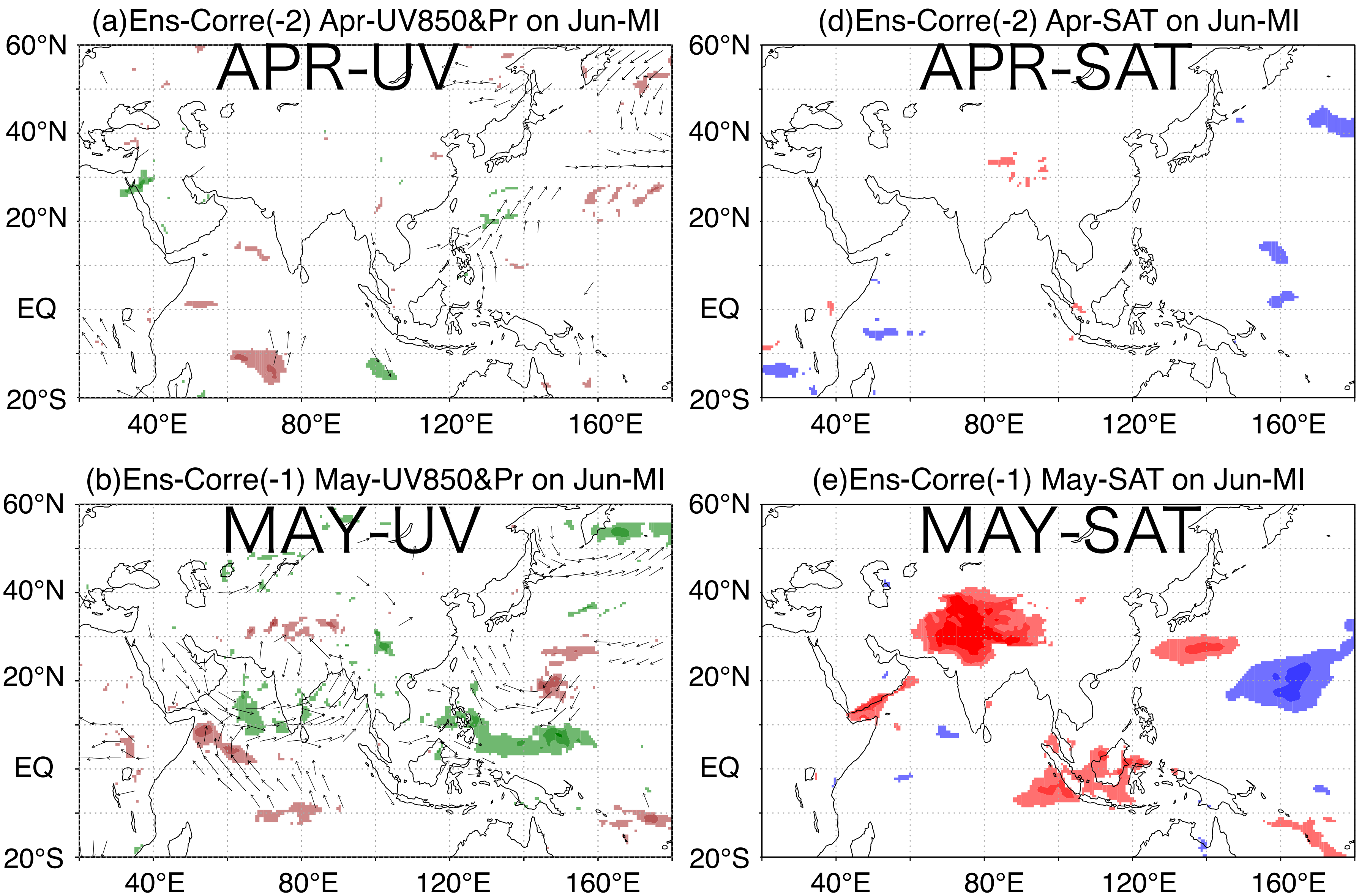




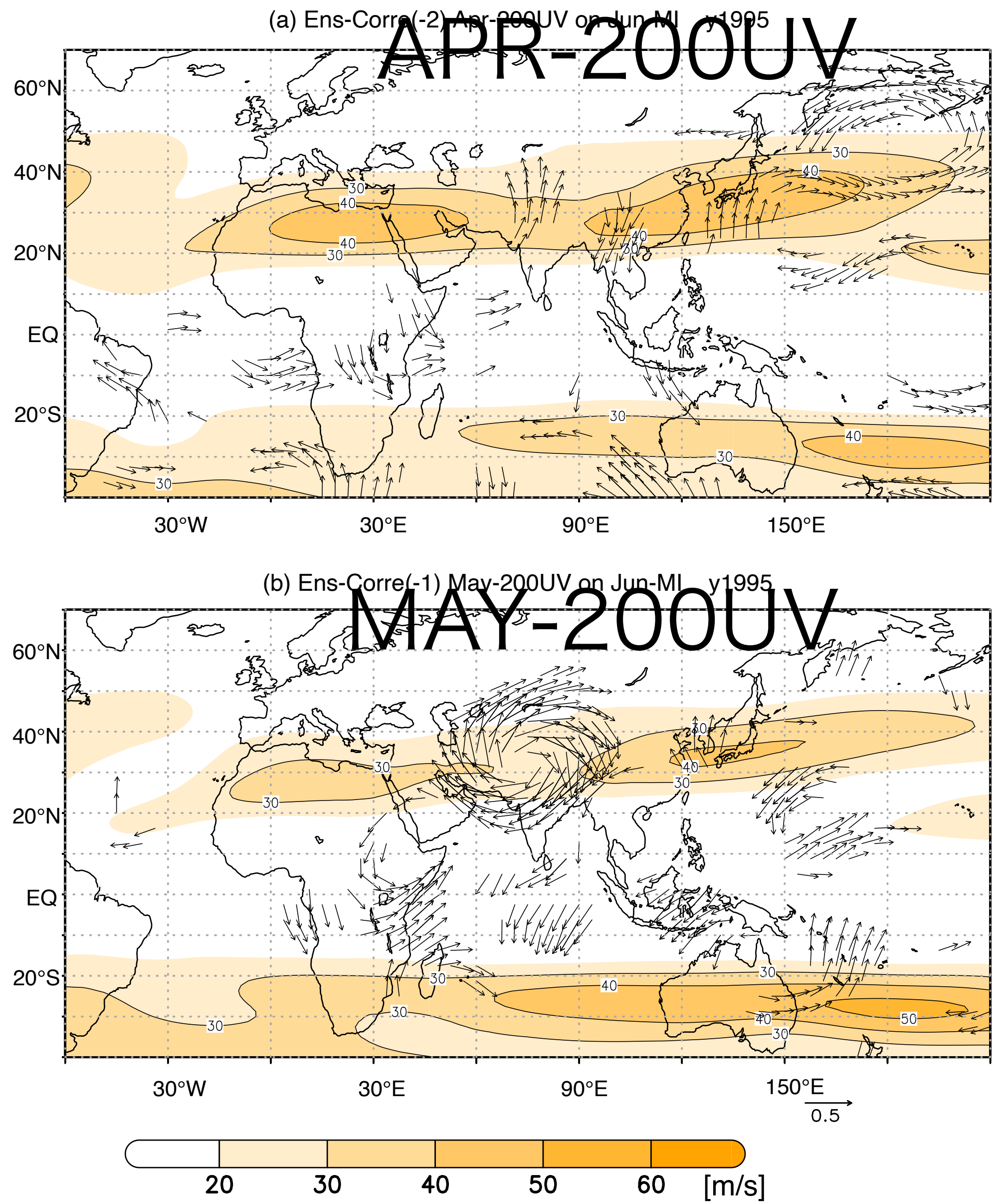


Inter-ensemble correlations (June MI & plotted values in May)





(a)Ens-Corre(-2) Apr-UV850&Pr on Jun-MI
APR-UV
(d)Ens-Corre(-2) Apr-SAT on Jun-MI
APR-SAT
(b)Ens-Corre(-1) May-UV850&Pr on Jun-MI
MAY-UV
(e)Ens-Corre(-1) May-SAT on Jun-MI
MAY-SAT
60°N
40°N
20°N
EQ
20°S
40°E
80°E
120°E
160°E



(a) Ens-Corre(-2) Apr-200UV on Jun-MI y1995
APR-200UV
60°N
40°N
20°N
EQ
20°S
30°W
30°E
90°E
150°E
(b) Ens-Corre(-1) May-200UV on Jun-MI y1995
MAY-200UV
60°N
40°N
20°N
EQ
20°S
30°W
30°E
90°E
150°E
0.5
20
30
40
50
60
[m/s]

1995 (An example)

- In 1995, high May SAT over Tibetan Plateu => strong June MI
- *However, SAT (snow, Tsfc) signals were not notable before May. => One-month predictability*

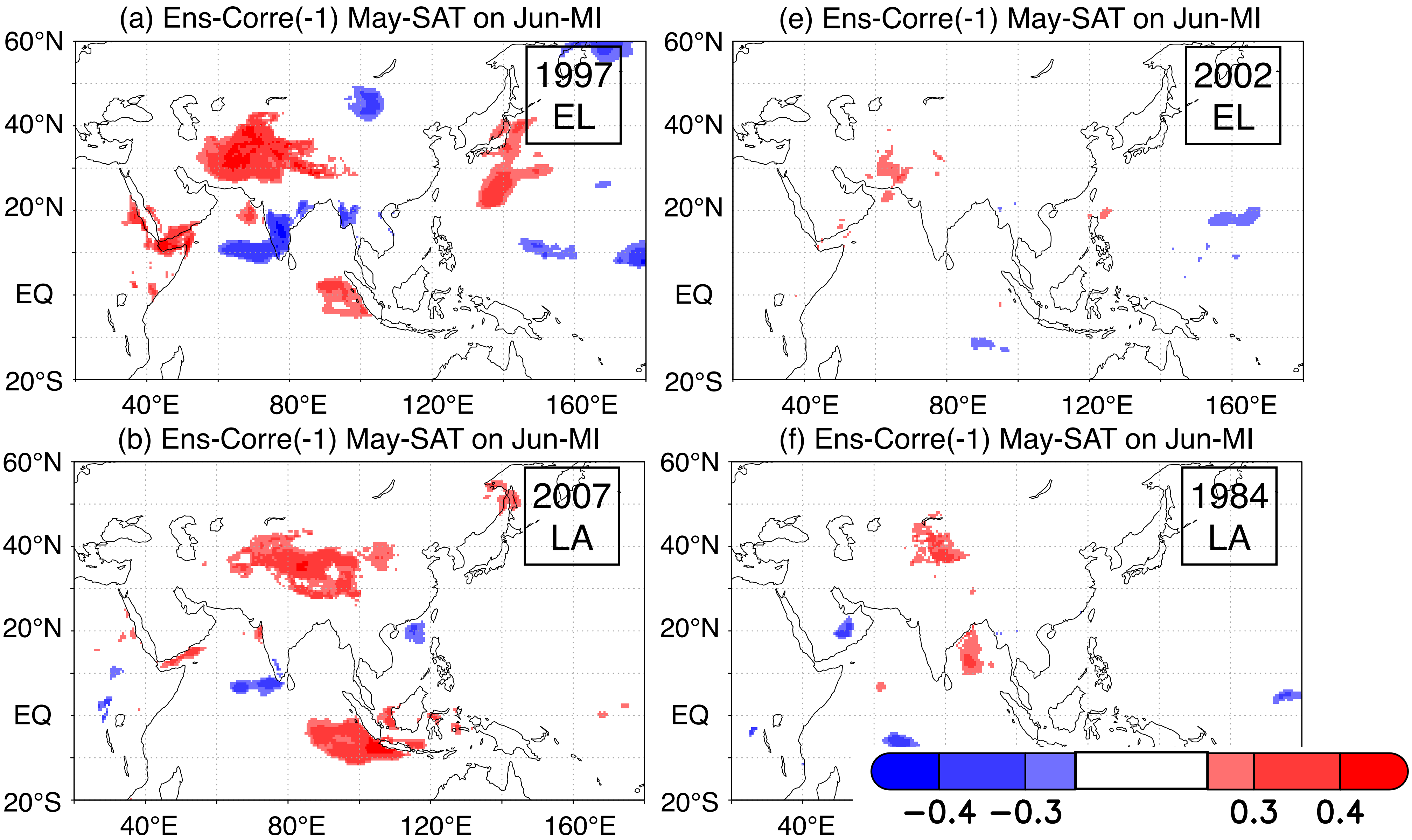
- ＝＞ We will check samples in other years.
- Because ENSO may be important, we subjectively selected ENSO related years.
  - However, in conclusion, ENSO could not explain the L-A strength.

ENSO may be important??

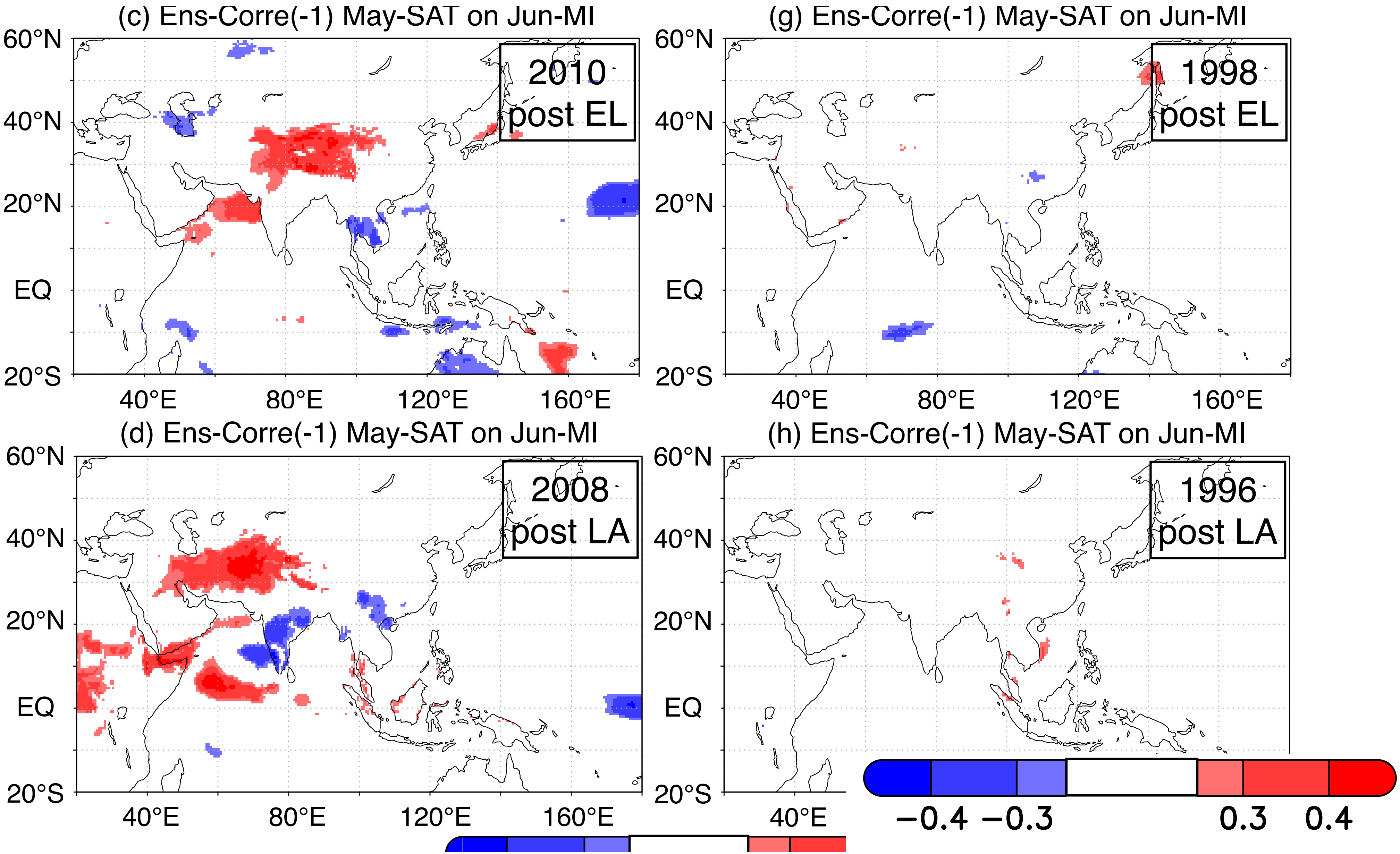
- Manually, we examined the inter-ensemble correlation between June MI and May SAT.
  - *We have active L-A years and inactive L-A years*

- It is expected that the relationship may be associated with the ENSO.

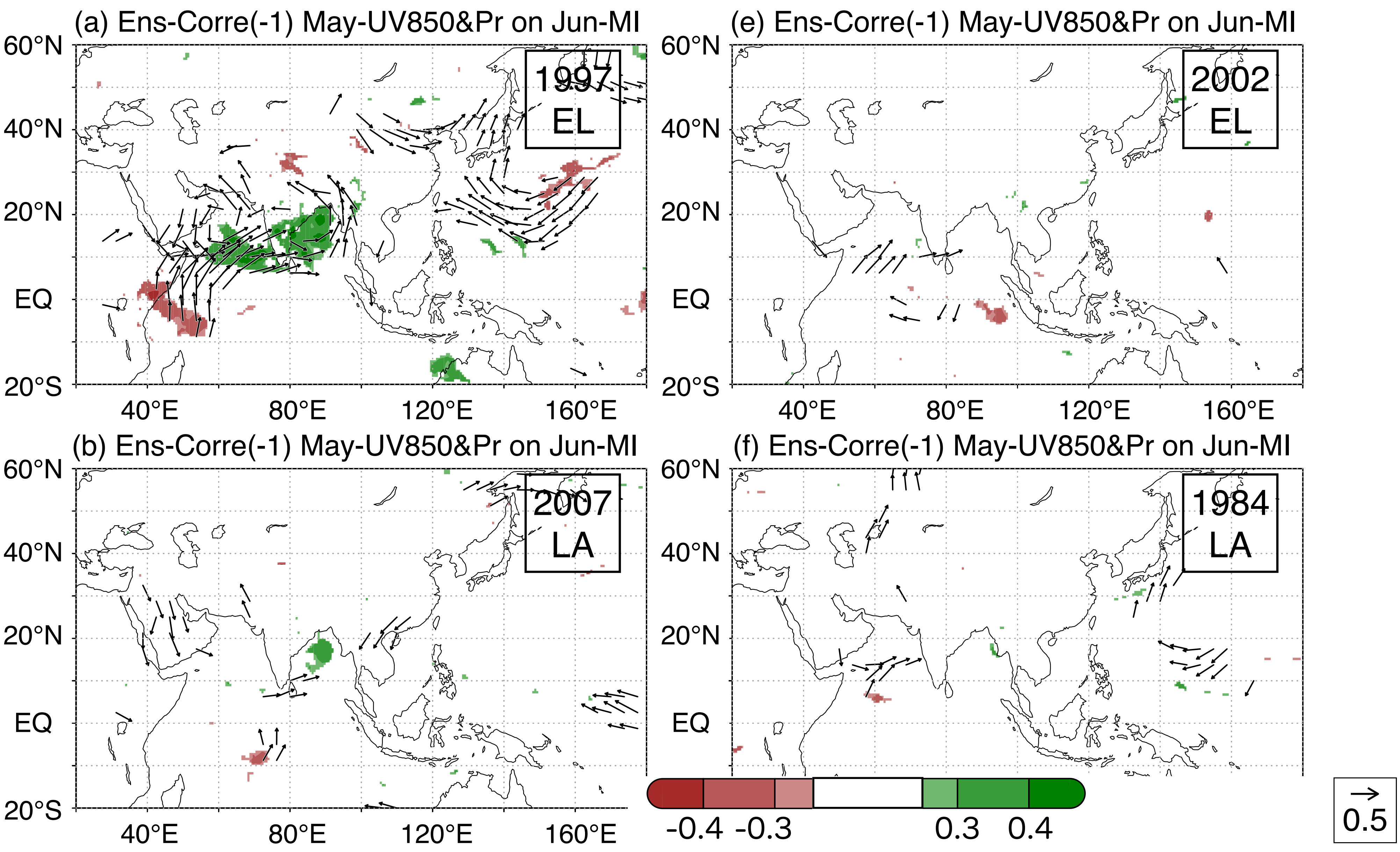
- We check the relationship for ENSO-related years.



(a) Ens-Corre(-1) May-SAT on Jun-MI
1997
EL
(e) Ens-Corre(-1) May-SAT on Jun-MI
2002
EL
(b) Ens-Corre(-1) May-SAT on Jun-MI
2007
LA
(f) Ens-Corre(-1) May-SAT on Jun-MI
1984
LA
60°N
40°N
20°N
EQ
20°S
40°E
80°E
120°E
160°E
−0.4 −0.3
0.3 0.4



(c) Ens-Corre(-1) May-SAT on Jun-MI
2010
post EL
(g) Ens-Corre(-1) May-SAT on Jun-MI
1998
post EL
(d) Ens-Corre(-1) May-SAT on Jun-MI
2008
post LA
(h) Ens-Corre(-1) May-SAT on Jun-MI
1996
post LA
60°N
40°N
20°N
EQ
20°S
40°E
80°E
120°E
160°E
−0.4 −0.3
0.3 0.4



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1997
EL
(e) Ens-Corre(-1) May-UV850&Pr on Jun-MI
2002
EL
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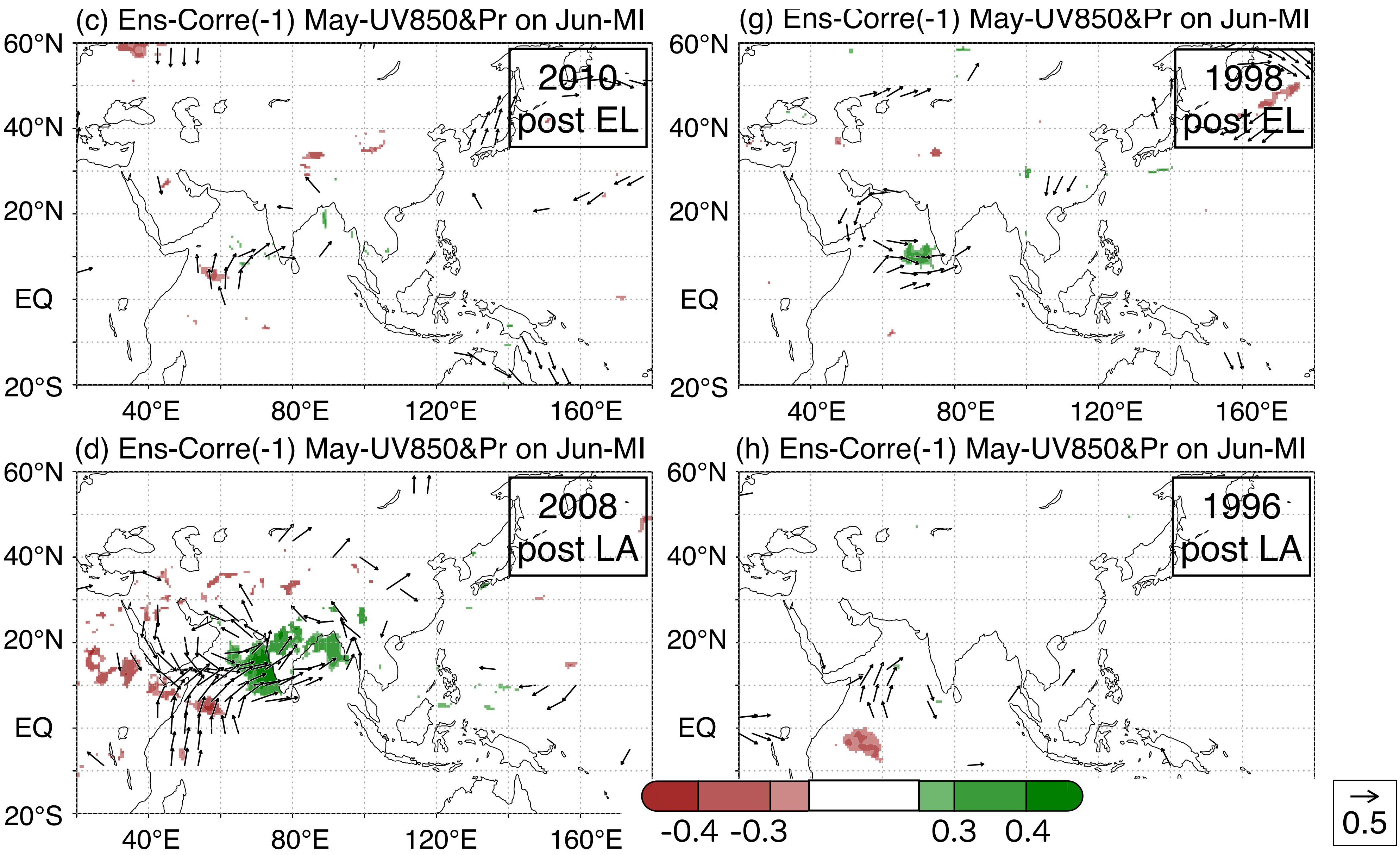
2007
LA
(f) Ens-Corre(-1) May-UV850&Pr on Jun-MI
1984
LA
60°N
40°N
20°N
EQ
20°S
40°E
80°E
120°E
160°E
-0.4 -0.3
0.3 0.4
0.5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2010
post EL
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1998
post EL
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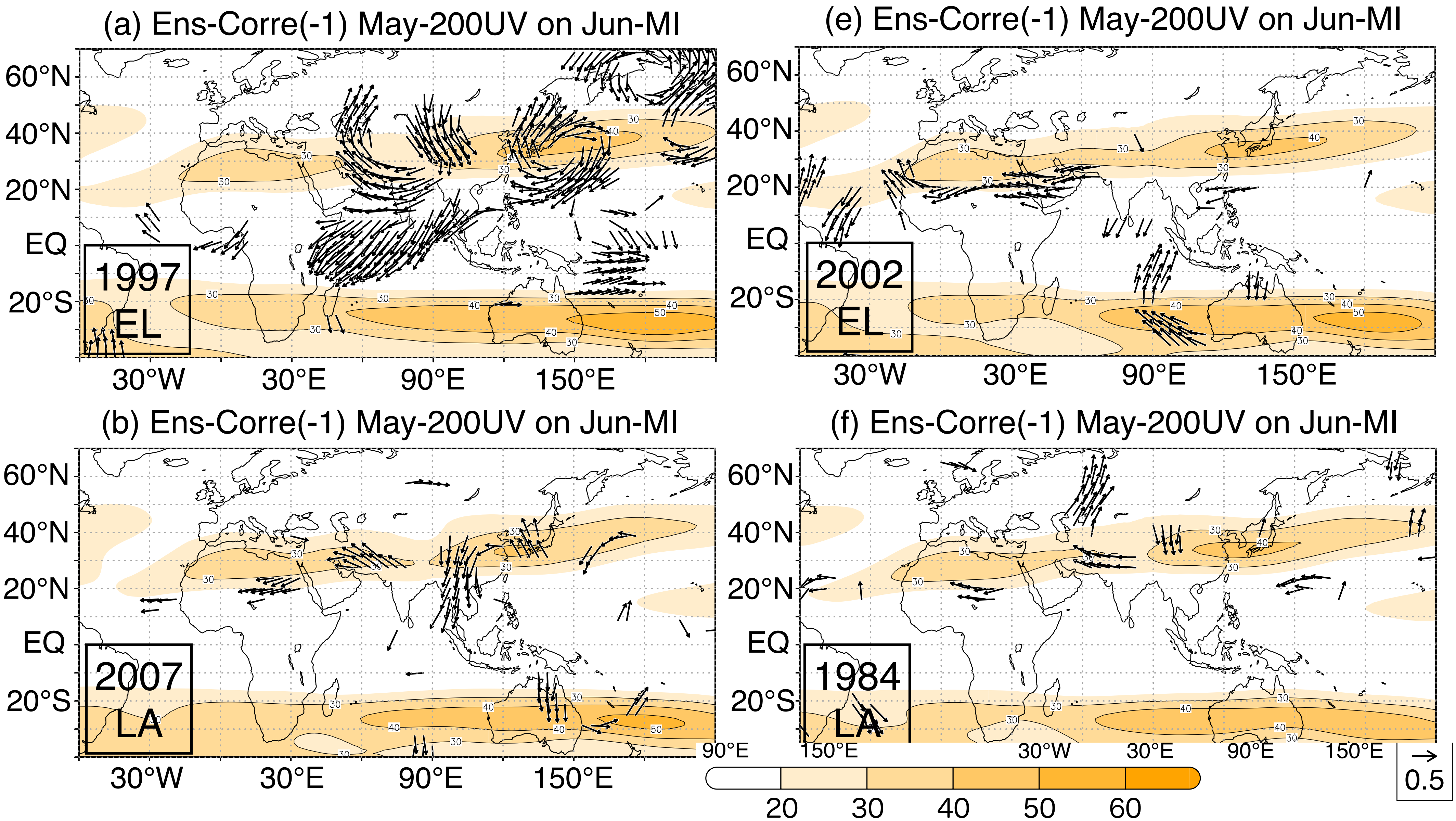
2008
post LA
(h) Ens-Corre(-1) May-UV850&Pr on Jun-MI
1996
post LA
60°N
40°N
20°N
EQ
20°S
40°E
80°E
120°E
160°E
-0.4 -0.3
0.3 0.4
0.5



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1997
EL
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2002
EL
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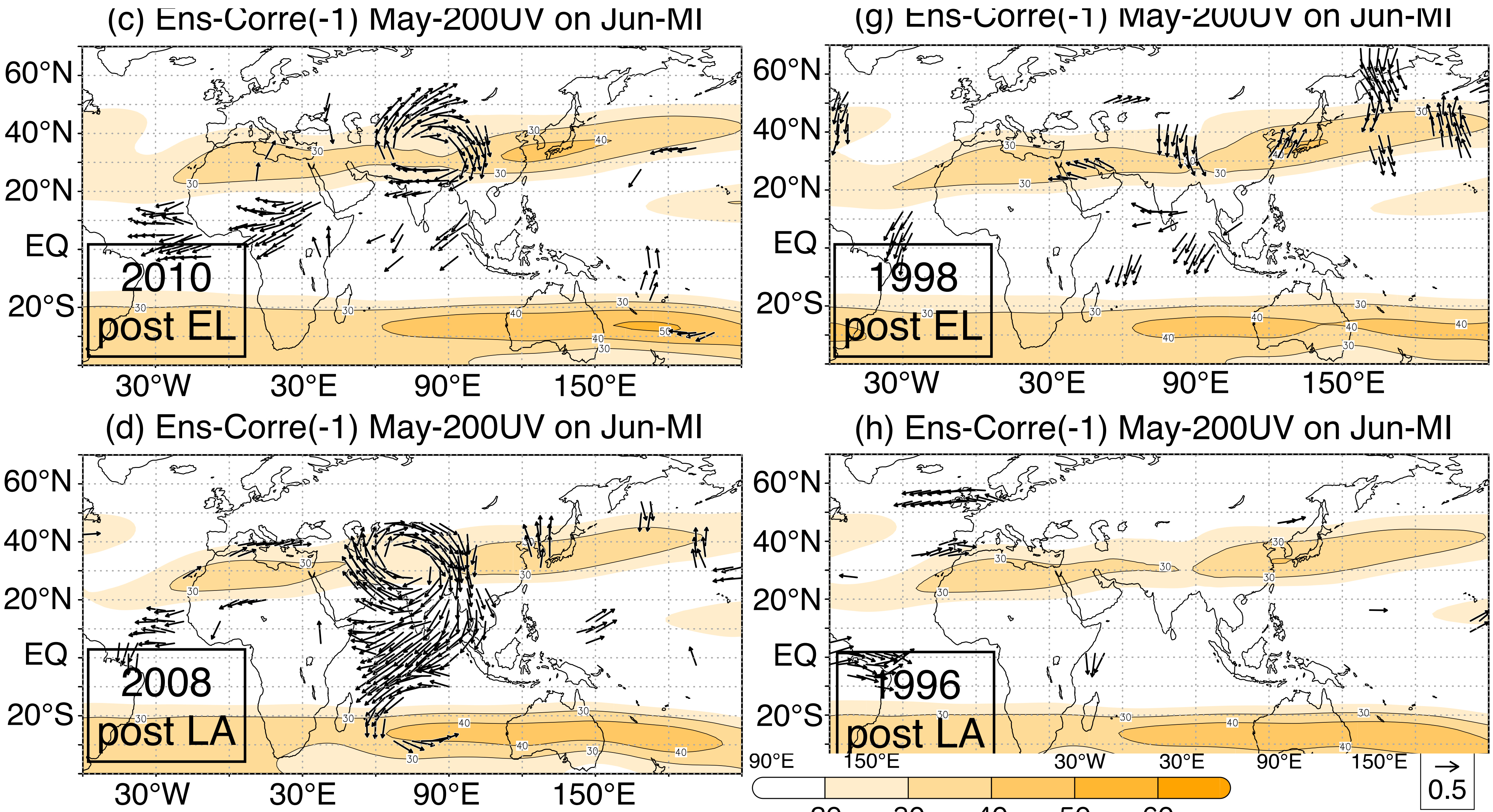
2007
LA
(f) Ens-Corre(-1) May-200UV on Jun-MI
1984
LA
60°N
40°N
20°N
EQ
20°S
30°W
30°E
90°E
150°E
20
30
40
50
60
0.5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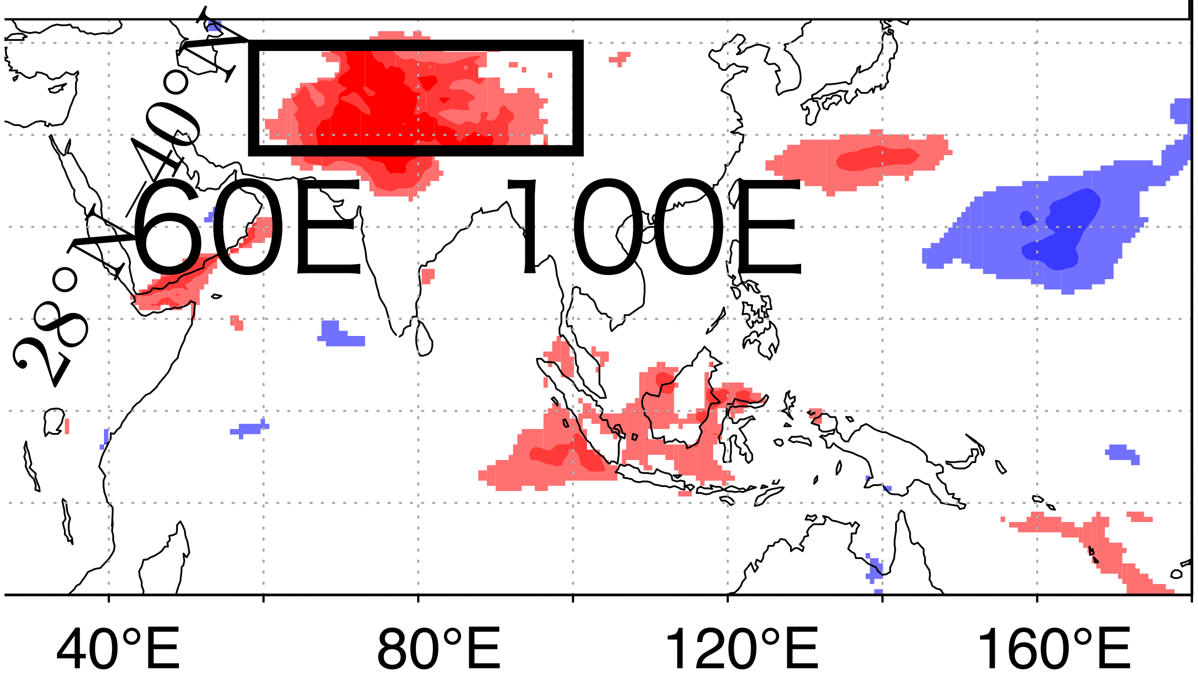
1996
post LA
60°N
40°N
20°N
EQ
20°S
30°W
30°E
90°E
150°E
20
30
40
50
60
0.5

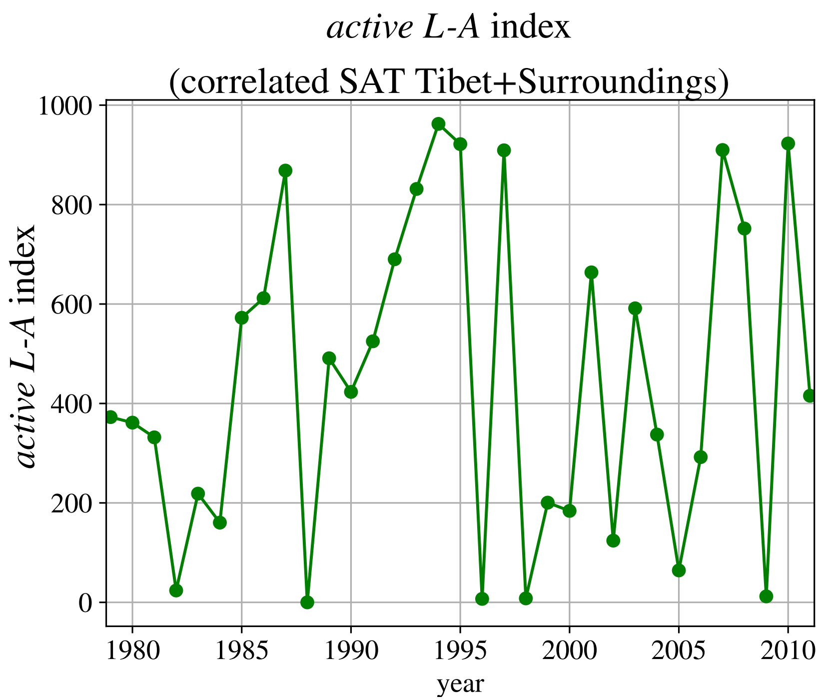
Results (all years)

- The results for other years were basically similar to results of 1995.
- *However, no signals were found in some years.*
- We quantify the coupling strength between June MI and May SAT (next).

To quantify the L-A coupling strength, we counted the number of grids of statistically significant inter-ensemble correlation between June MI and SAT over below rectangle region.

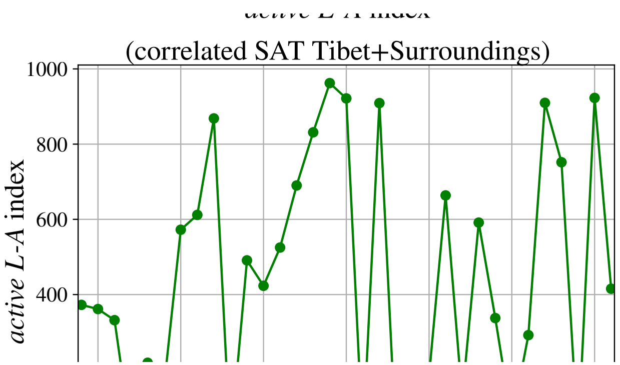
The area (# of grids) represent L-A coupling strength over the Asian monsoon region.
Warm (Cold) land => strong (weak) Monsoon

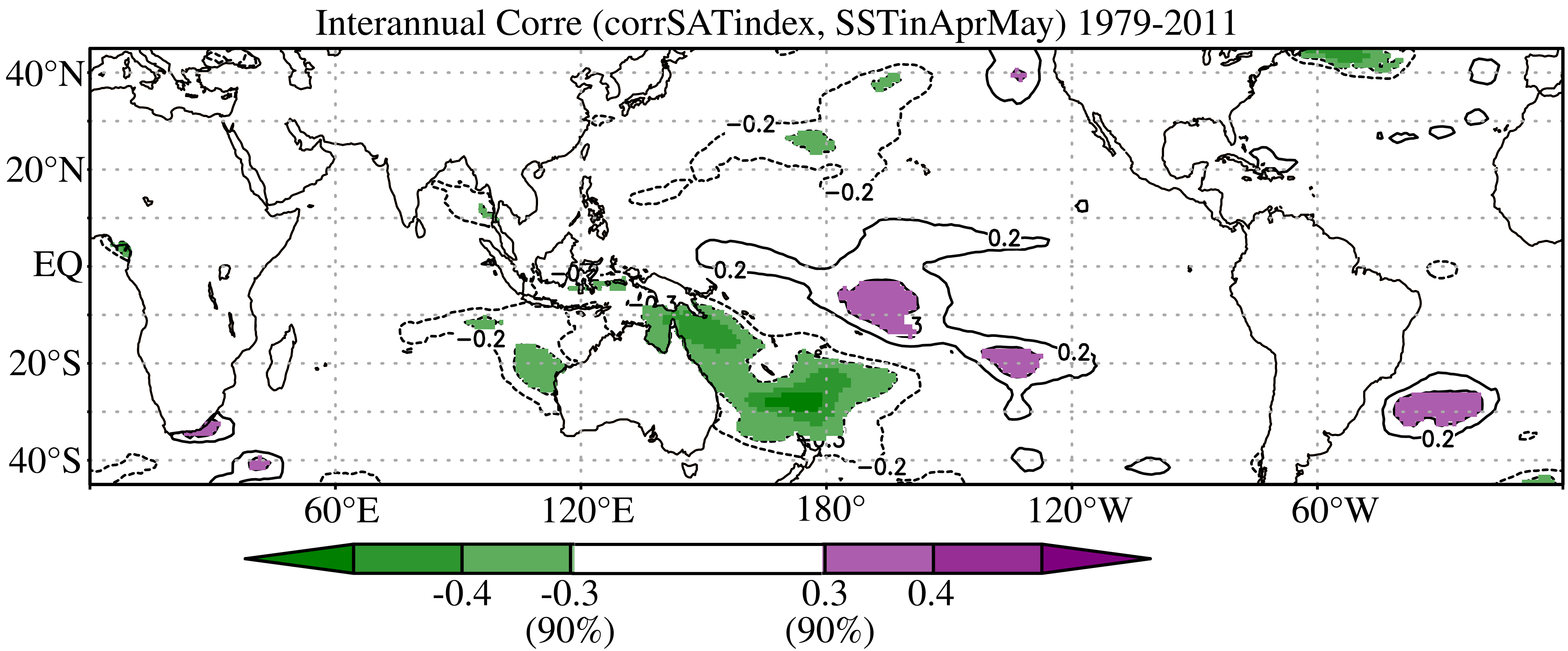




Discussion :What determine the interannual variability?

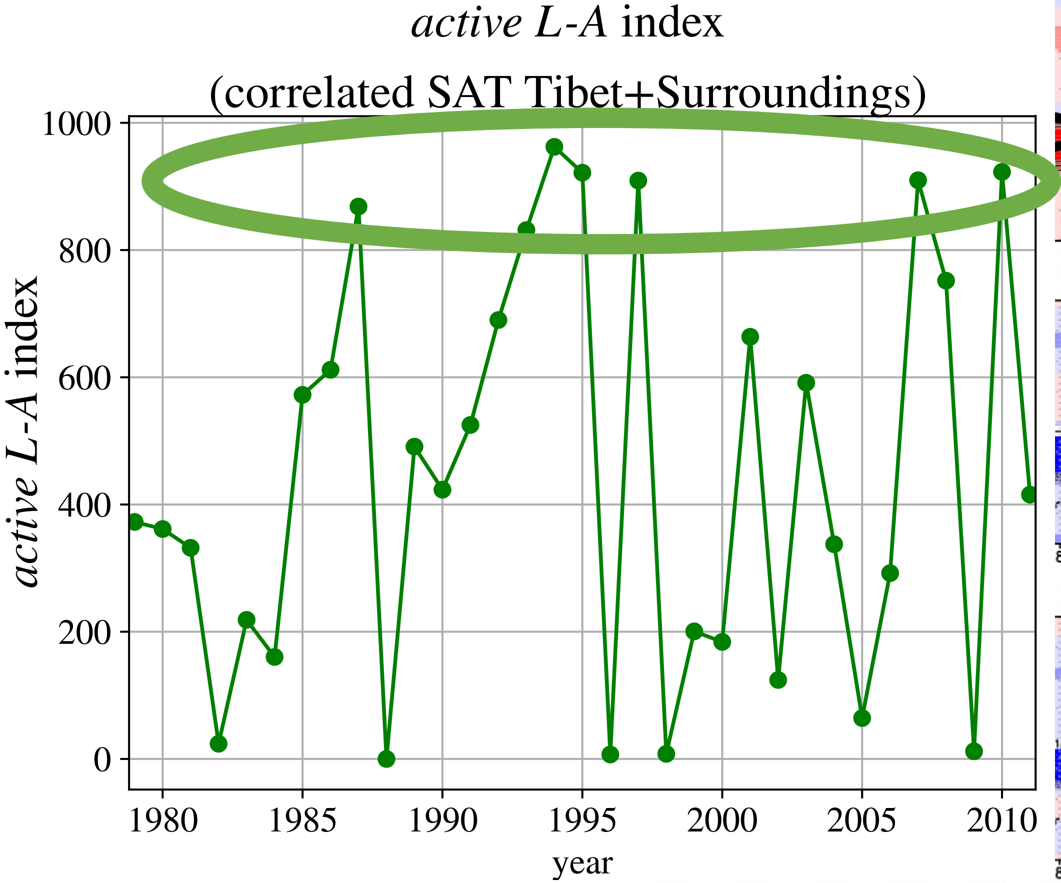
- The relationships between June MI and May SAT were changed interannually.
- One idea why the L-A coupling processes can only sometimes become obvious is that the SST forcing is generally stronger than the land-surface forcing.
- The notion that land-surface forcing may become apparent when the ocean-related stronger forcing takes a break.

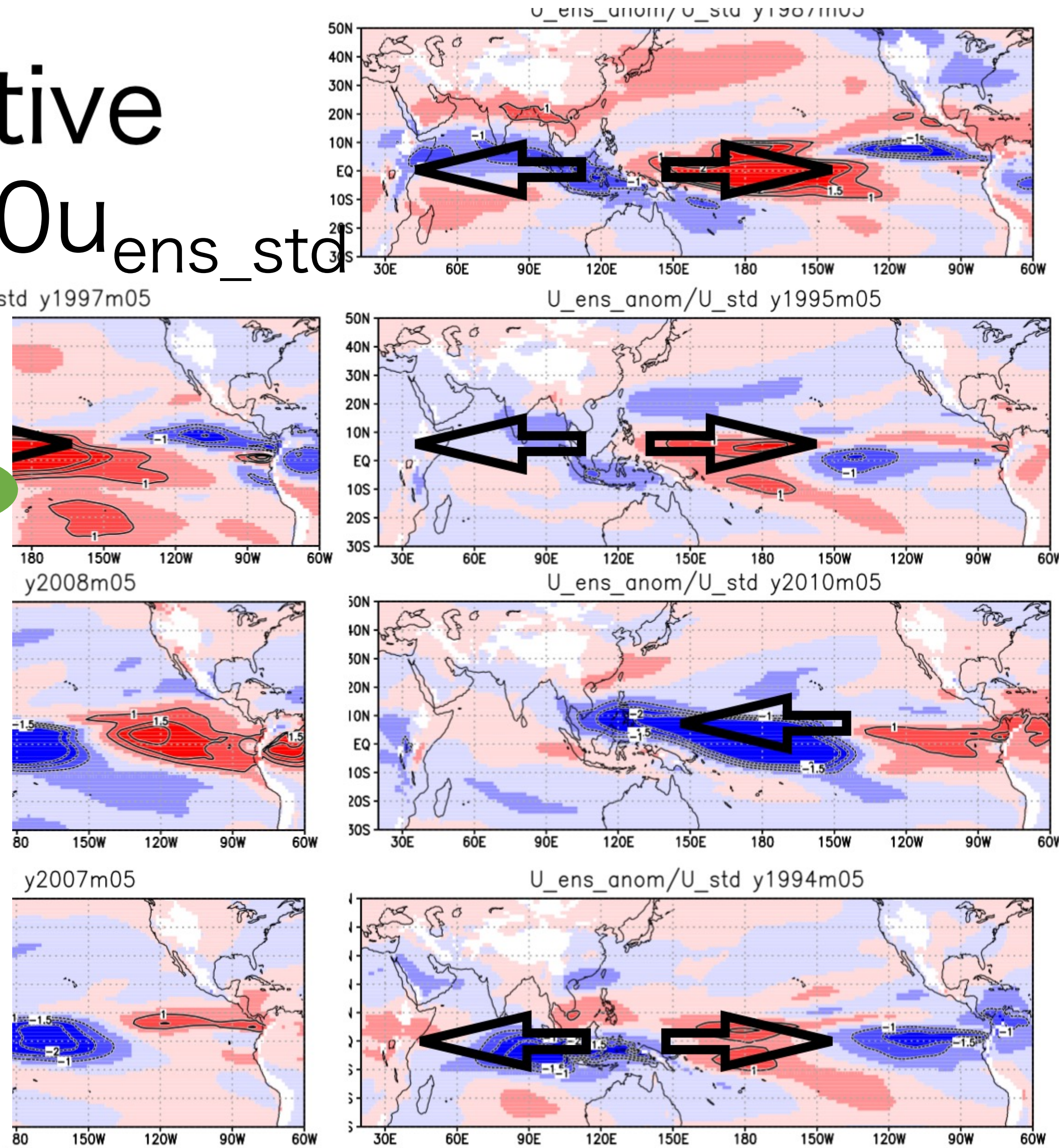

(correlated SAT Tibet+Surroundings)
1000
800
600
400
active L-A index


Interannual Corre (corrSATindex, SSTinAprMay) 1979-2011
40°N
20°N
EQ
20°S
40°S
60°E
120°E
180°
120°W
60°W
-0.2
0.2
-0.4
-0.3
(90%)
0.3
(90%)
0.4

L-A active

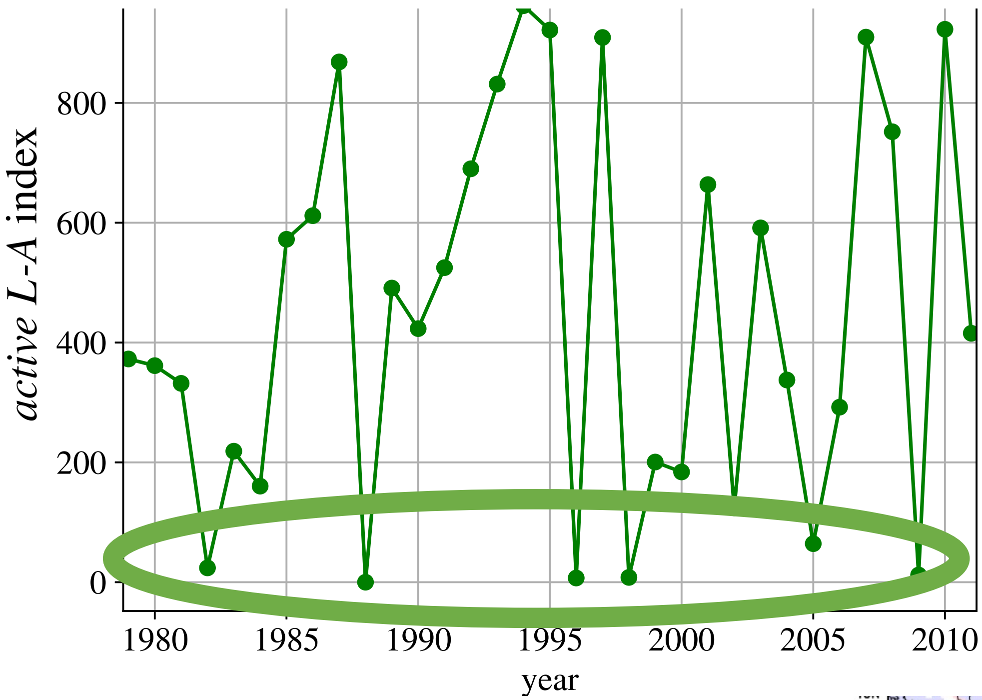
$850u_{ens\_mean\_anom}/850u_{ens\_std}$

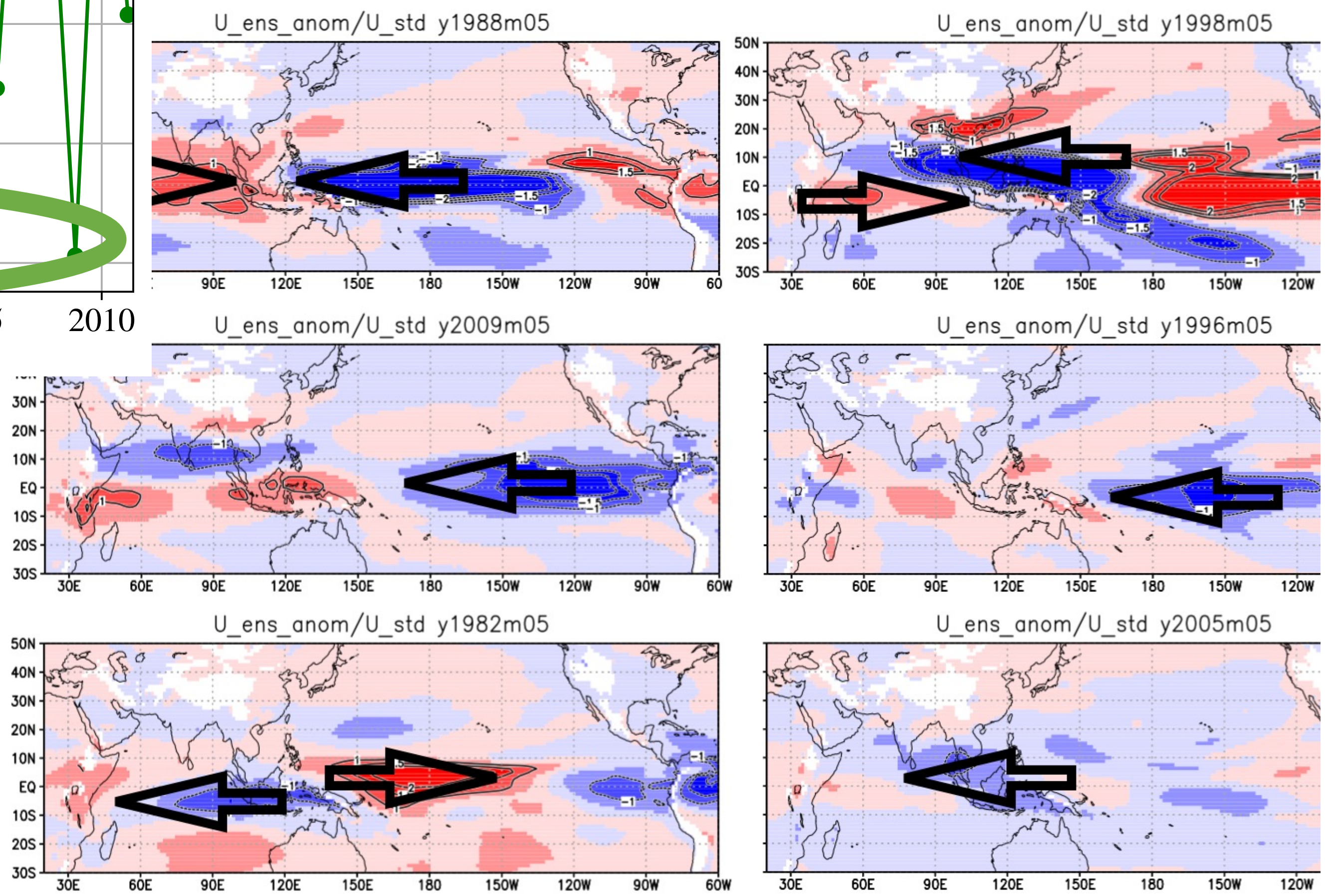




$50u_{ens\_mean\_anom}/850u_{ens\_s}$

A inactive





$$\sigma^2_{Land} = 1 - \sigma^2_{Atmos}/\sigma^2_{Tot}$$

$\sigma 2_{\text{atmos}}$:3月のSATがメジアンに近い50メンバーのみで、アンサンブル間分散を計算