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Seasonality in Anthropogenic Aerosol Effects on East Asian Climate

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Outline

- Motivation
- Model and experiments
- Results
- Conclusions

East Asia has been the most polluted region of the world

Observed aerosol optical depth (AOD)

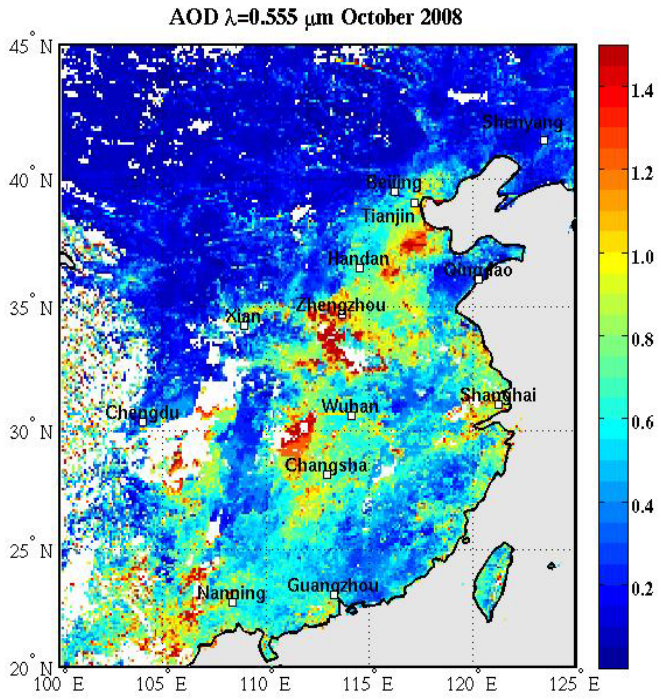


Photo from space

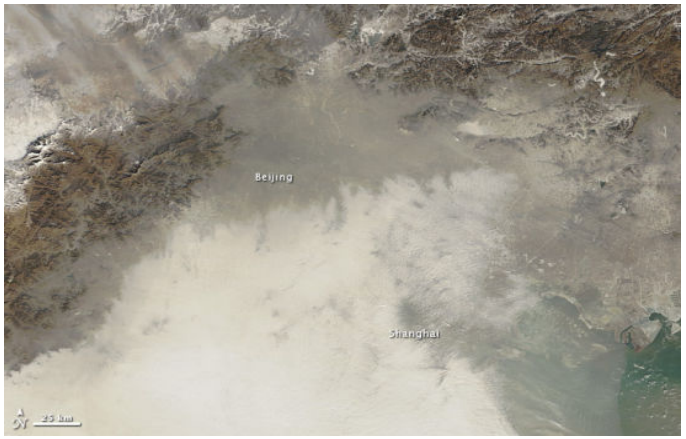


Photo at surface

Why the seasonality of aerosol effects on East Asian climate need our attention?

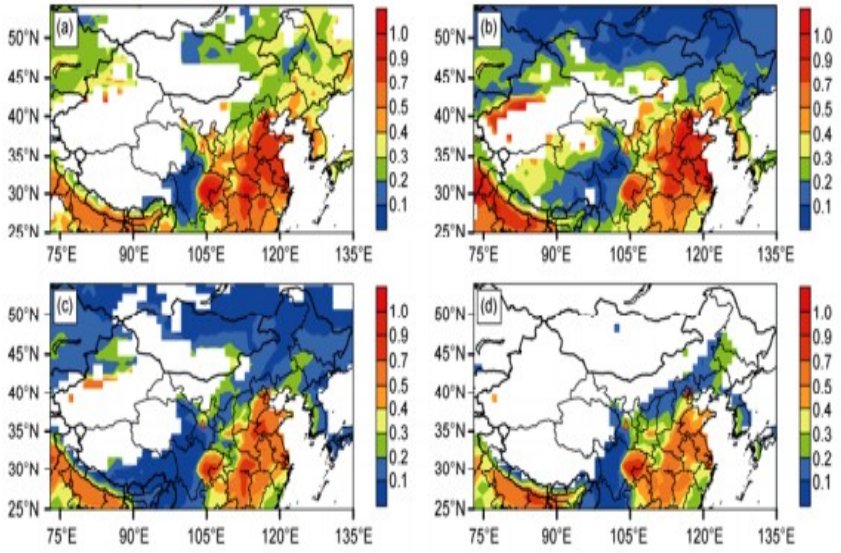
- Seasonality in the climate background (East Asian monsoon climate; Wang 2006)

- Seasonality in AOD distribution in observation (Wang et al. 2011; Kim et al. 2004; Kim et al. 2007b; Li et al. 2007b).

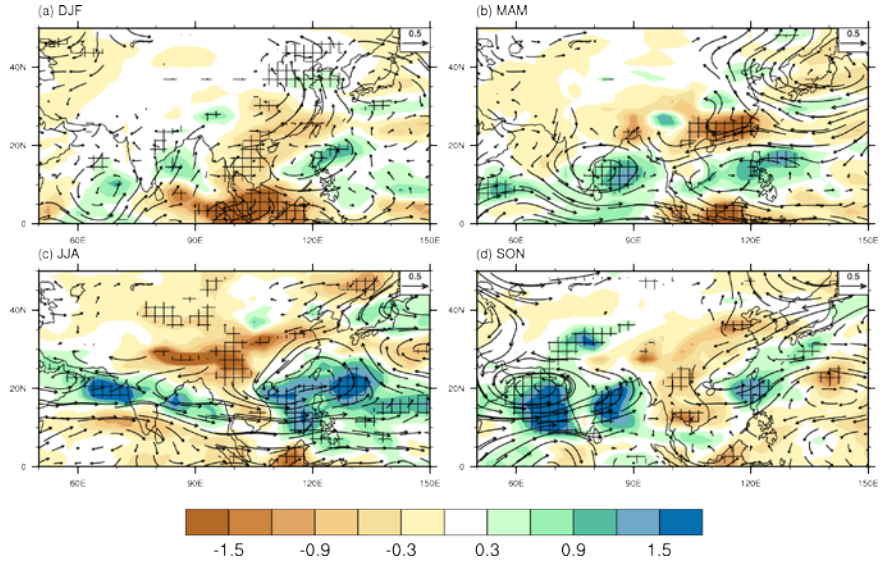
- The climate response to anthropogenic aerosols of different seasons exhibits strong diversities.

(*Gu et al.* 2006; *Kim et al.* 2007; *Hu and Liu* 2013; *Deng et al.* 2014*; Jiang et al.* 2013)

AOD



UV850 & Precipitation anomaly



Observed climate trend associated with the air pollution exhibits strong seasonality

- A decreasing trend of **horizontal visibility** (−2.1 km (10 yr)$^{-1}$) since the 1990s (Che et al. 2007), the maximal decreasing trend is during summer.
- **late spring drought** in **south of the Yangtze River valley** during since 1980s (Yu et al. 2004)
- **Summer drought** in Yellow River valley since 1980s and weakening of summer monsoon circulation (Ding et al. 2008)
- **Low-level cloud amount** has an **increasing** trend in China from 1954 to 2005 especially after the mid-1990s, while the total cloud amount has a decreasing trend (Xia 2010).
- The **atmospheric stability** is increased in recent 17 years over the central East China (Zhao 2006).

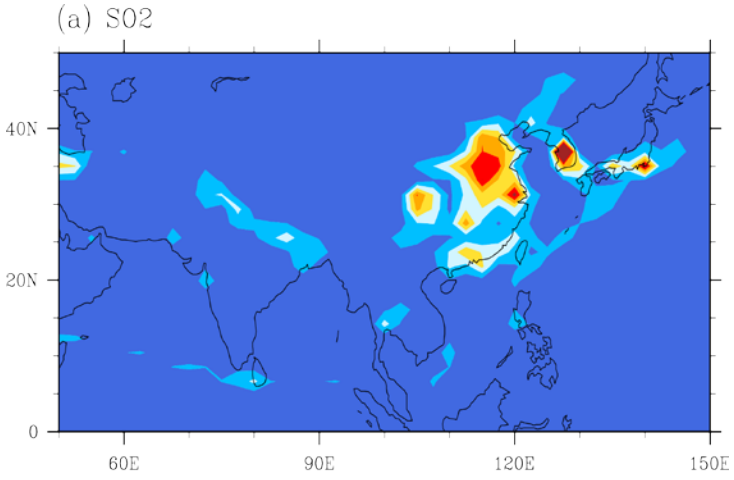
Question

How the seasonality of the East Asian climate background, anthropogenic AOD distribution, radiative forcing and climate effects correlated with each other?

Model and experiments

- Model：CAM5.0
- AMIP type simulations (fixed SST)
- 11 years for each experiments , first year to spin up
- Horizontal resolution: 1.9x2.5° , 31 vertical levels
- IPCC AR5 emissions (Lamarque et al. 2010)
- Five simulations, differ only in emissions

Experiment	Sulfur	BC	POM
PD	2000	2000	2000
PI	1850	1850	1850
PIso4	1850	2000	2000
PIbc	2000	1850	2000
PIpom	2000	2000	1850



PD - PI = All anthropogenic aerosols
PD - PIbc = Anthropogenic BC
PD - PIso4 = Anthropogenic sulfate
PD - PIpom = Anthropogenic POM

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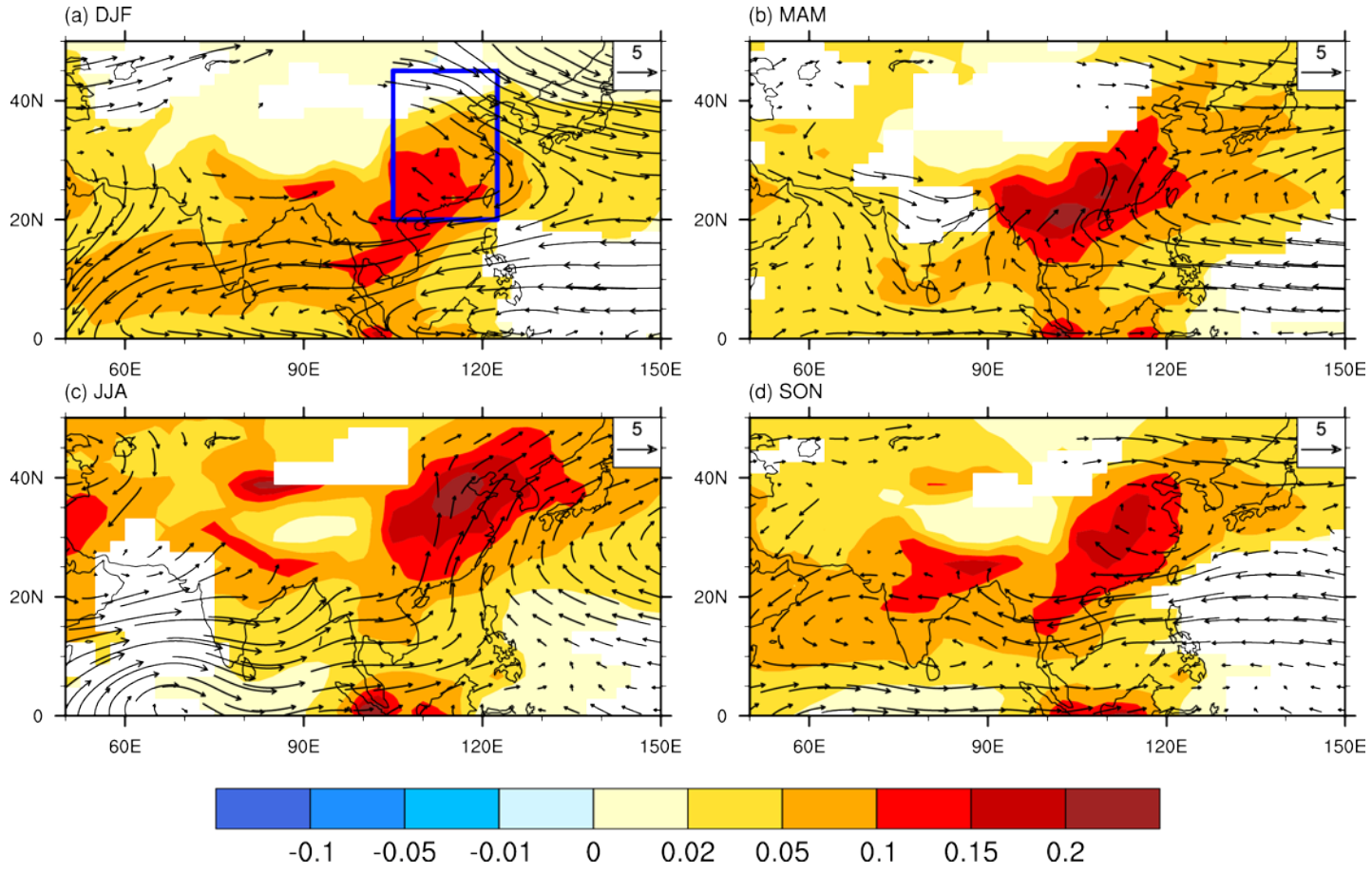
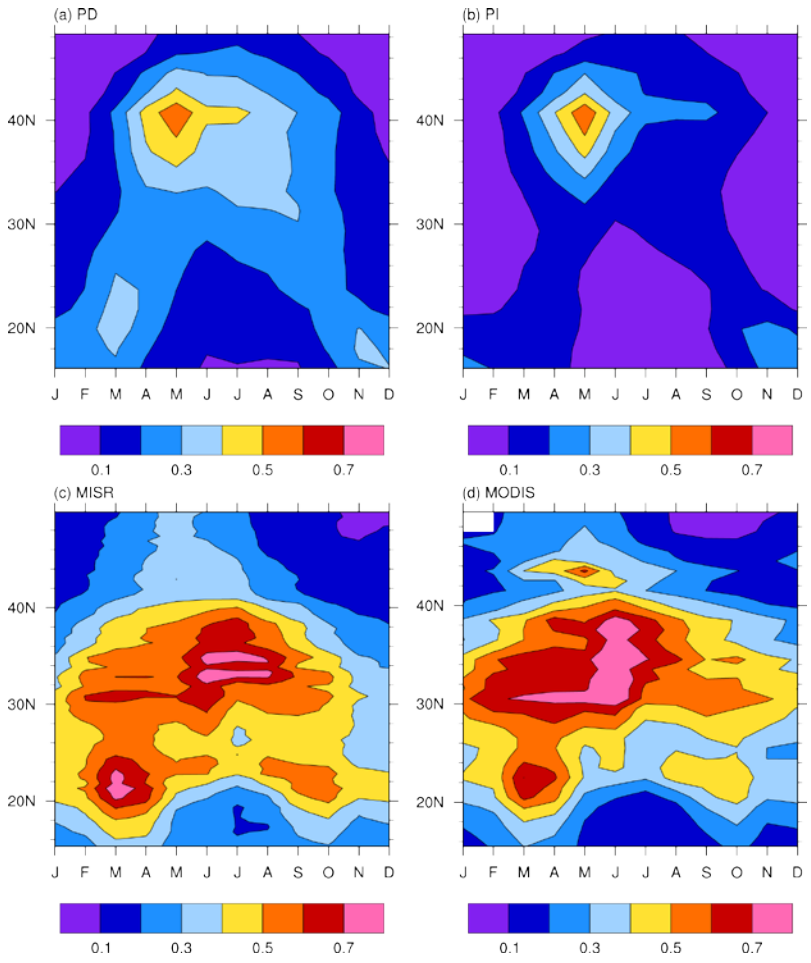
Seasonal variation of anthropogenic aerosol optical depth



“Inverted V” pattern in the AOD distribution

PD

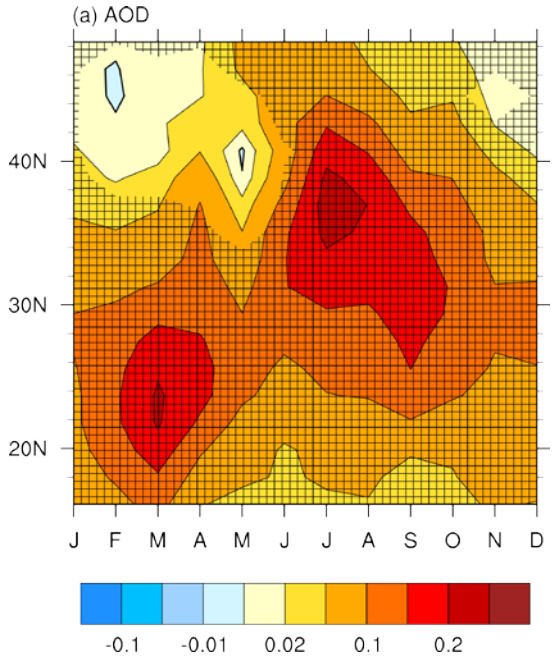
PI



MISR

MODIS

Anthropogenic AOD (PD-PI)



- An “inverted-V” like pattern in a latitude-month diagram is found for the monthly mean AOD change over East China by all anthropogenic aerosols.
- The AOD change has a maximum center in North China during summer, and a secondary center in South China during spring

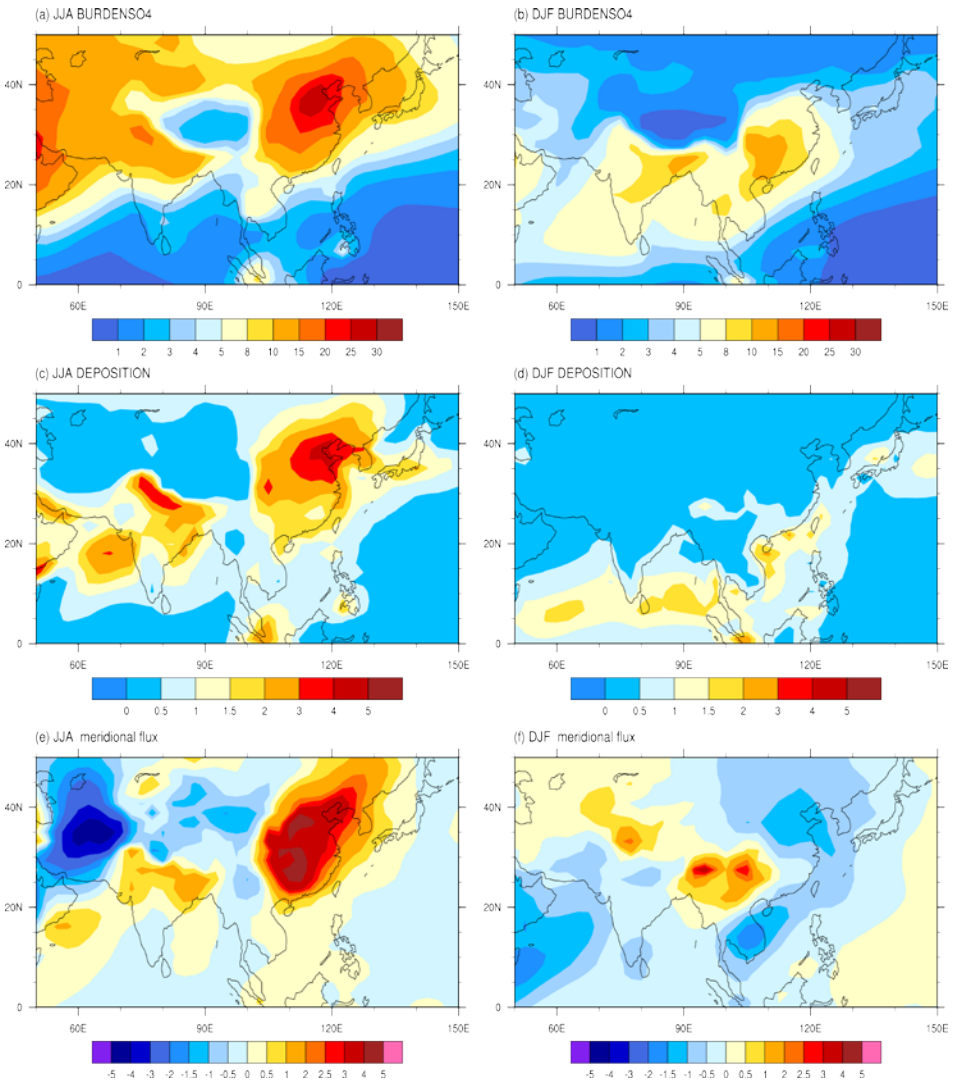
Why the AOD distribution exhibits “Inverted V like” pattern?

JJA DJF

SO4 burden

SO4 deposition

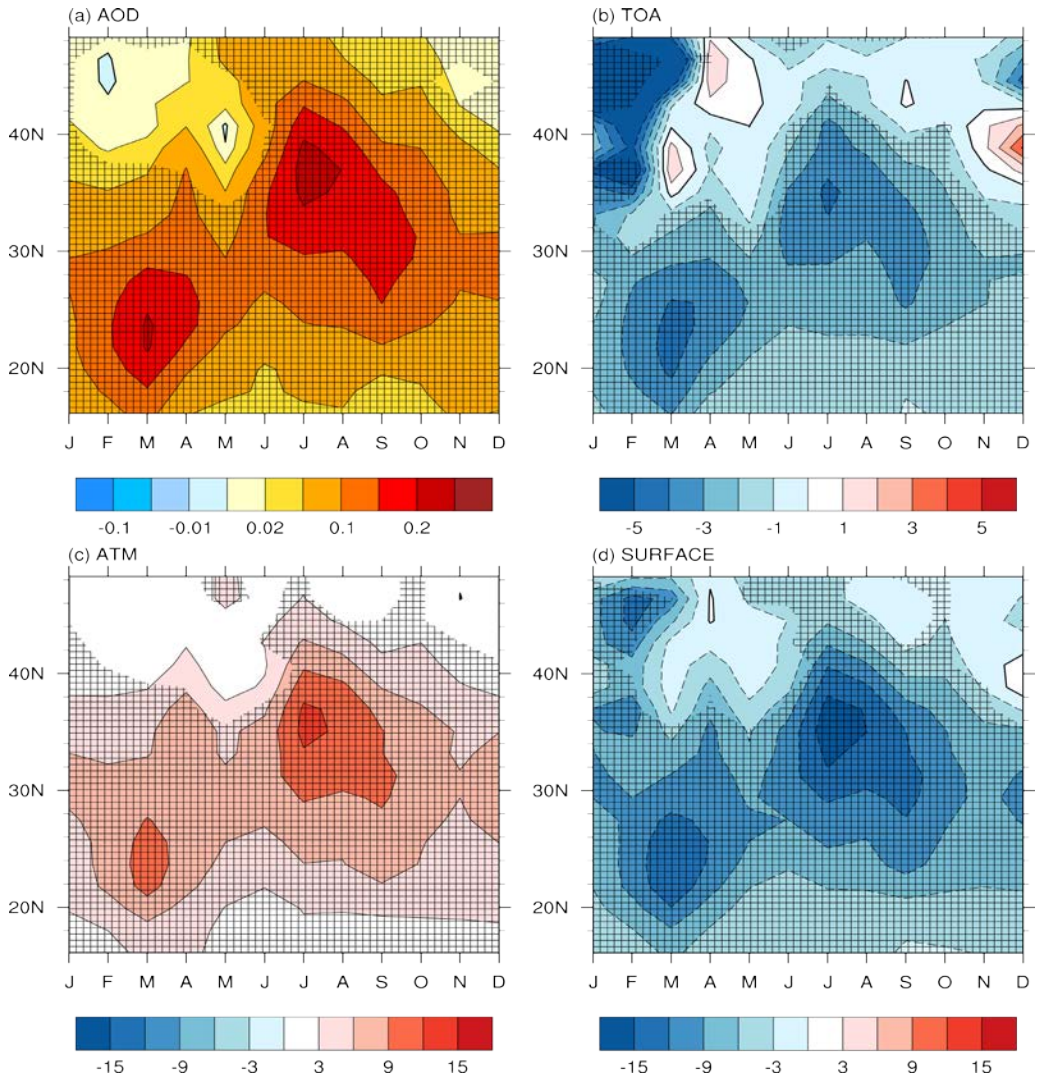
SO4 meridional Transportation



The distribution can not explained by the deposition.

The monsoon transportation is the primary reason.

Seasonality in anthropogenic aerosol direct effects (DE)



- The direct effect （DE） is measured by the solar flux change in the clear sky condition
- The pattern of direct radiative effect is consistent with that the AOD change.
- The shortwave flux change at TOA (-1 to -5 W m^{-2}) over East Asia is much weaker than the change in the atmosphere (3 to 12 W m^{-2}) and at surface (-4 to -15 W m^{-2}).

-2 W m^{-2}

TOA

8W m^{-2}

atmosphere

surface

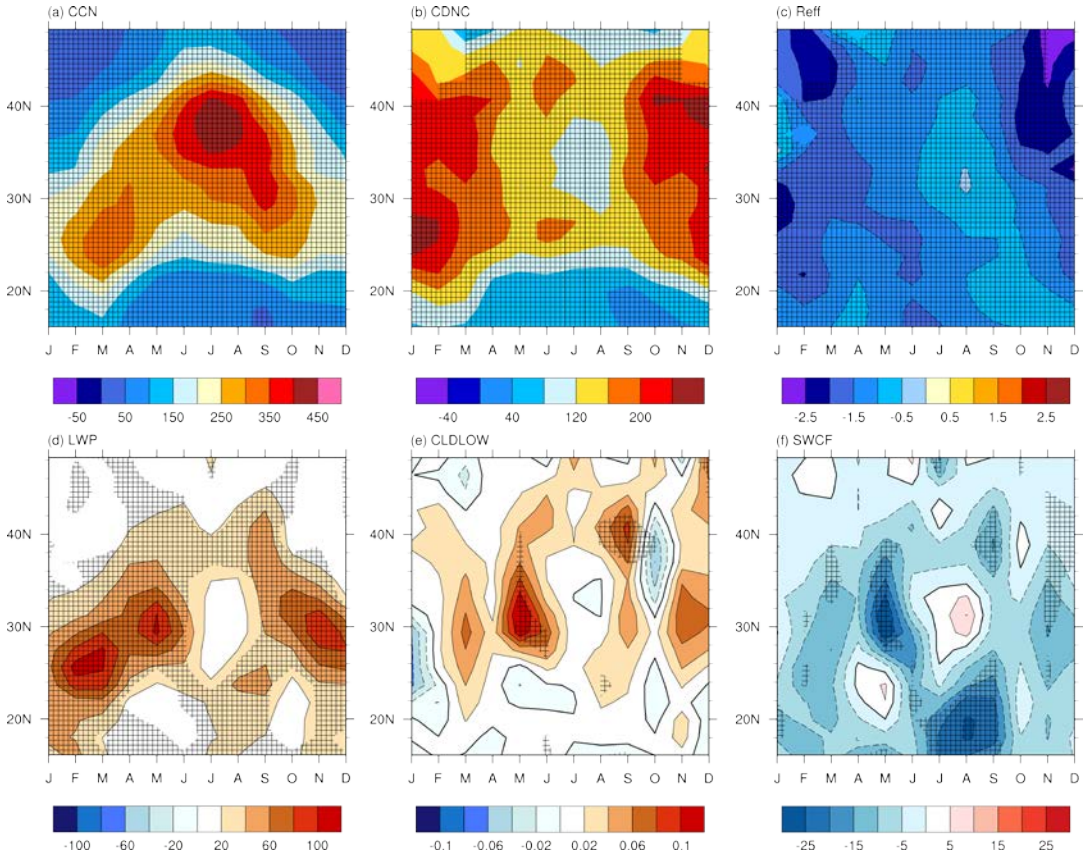
-10 W m^{-2}

Seasonality in anthropogenic aerosol indirect effects (IE)

CCN

CDNC

R_{eff}



LWP

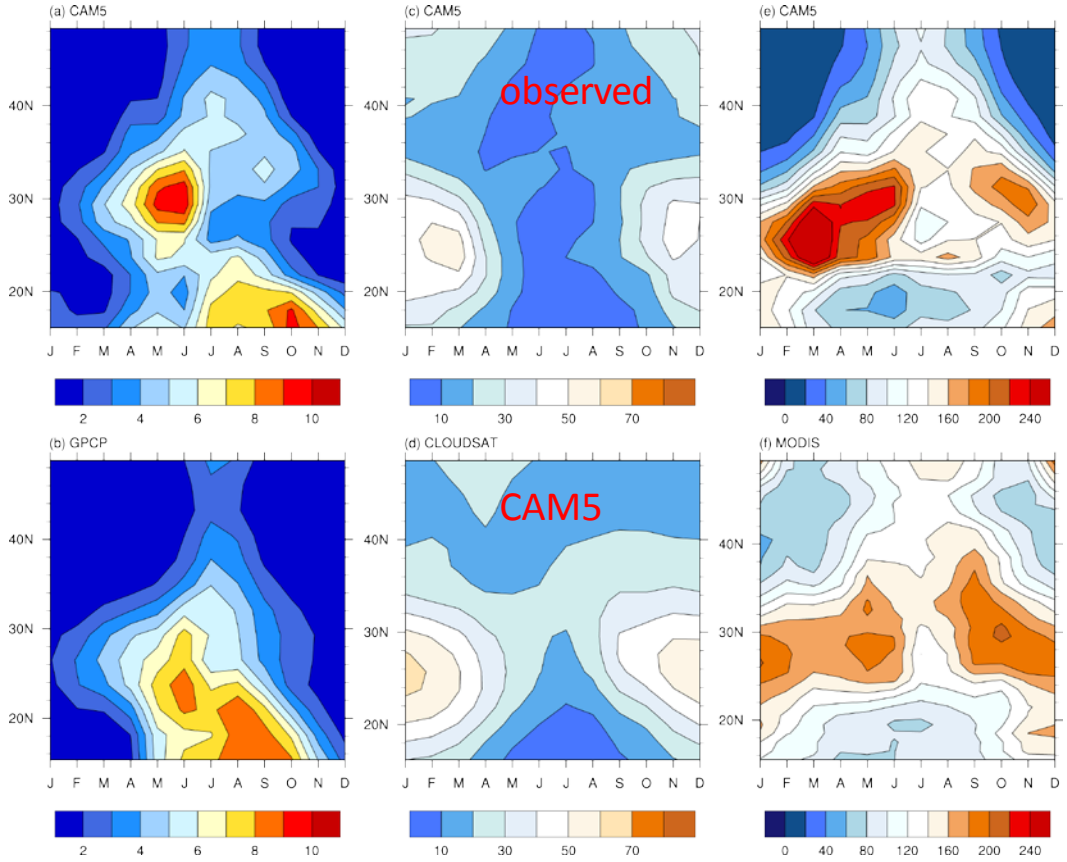
Low cloud

SWCF

- The CCN change is largest during summer in north China, which is consistent with the AOD change
- The LWP, CDNC, Reff, LWP CLDLOW and SWCF changes, however, are the weakest in North China during summer.

Why indirect effect is weakest in summer?

Precipitation **middle-low cloud** **LWP**

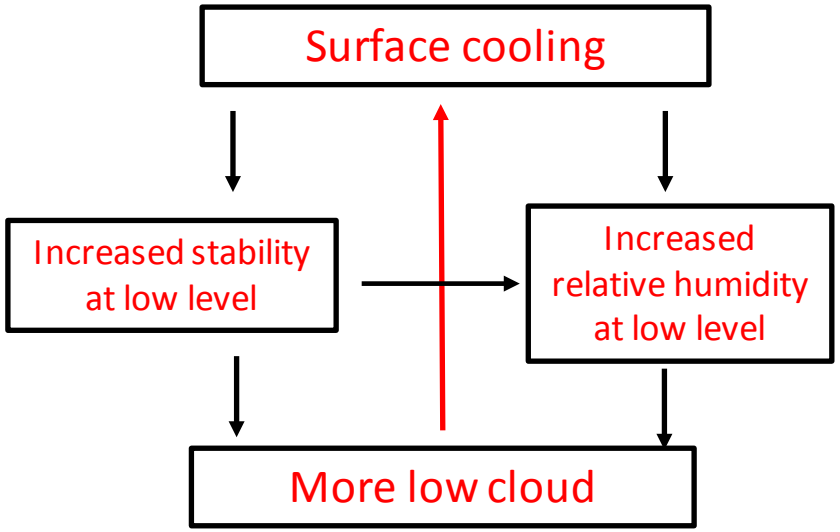


- Both the LWP and large scale precipitation are weaker in summer than in cold seasons and do not favor the aerosol effects on autoconversion.
- In summer, the convective precipitation is dominant and the autoconversion of cloud water to rain is quicker, which not favors the cloud life time effects.

Why indirect effect is largest during spring?

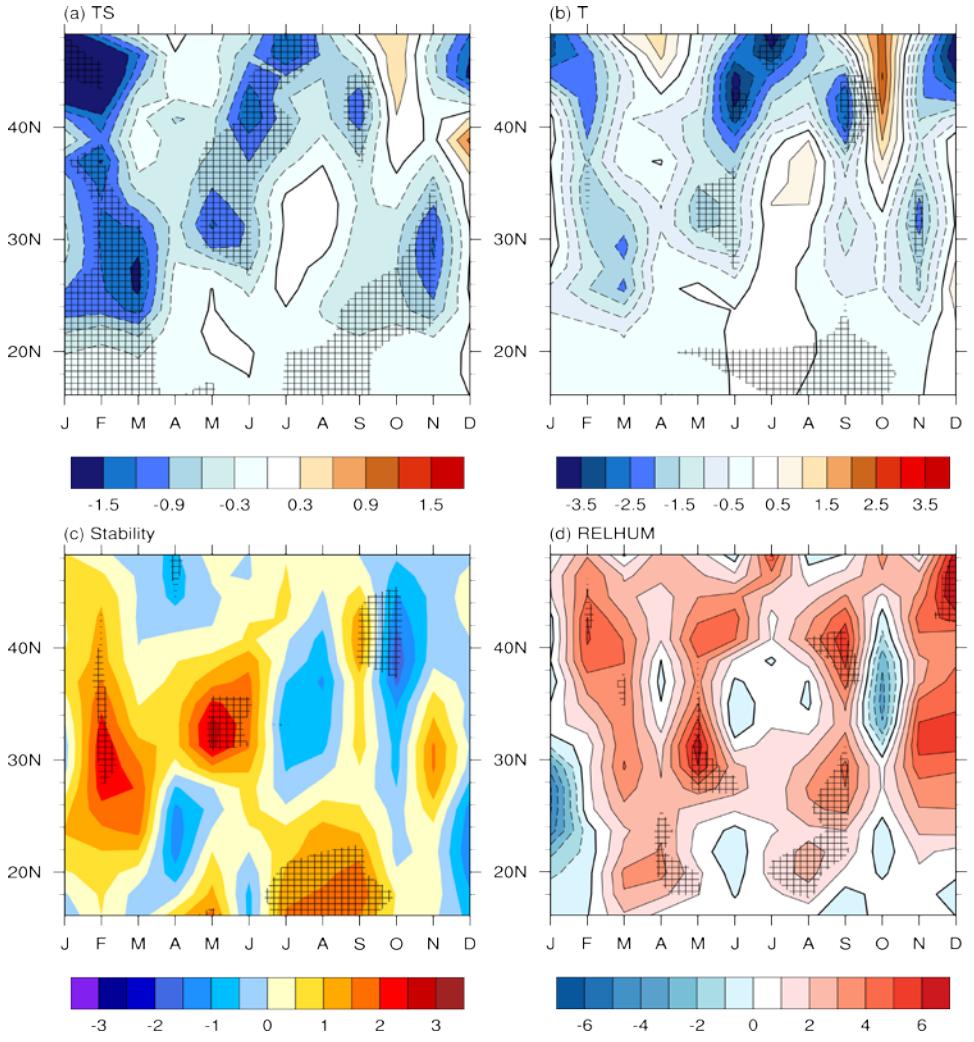
- The maximum AOD in spring is located in South China
- The LWP and low-level cloud is largest during spring
- A positive feedback between aerosol induced surface cooling and low-level cloud.

Yu et al. 2004



TS

T850



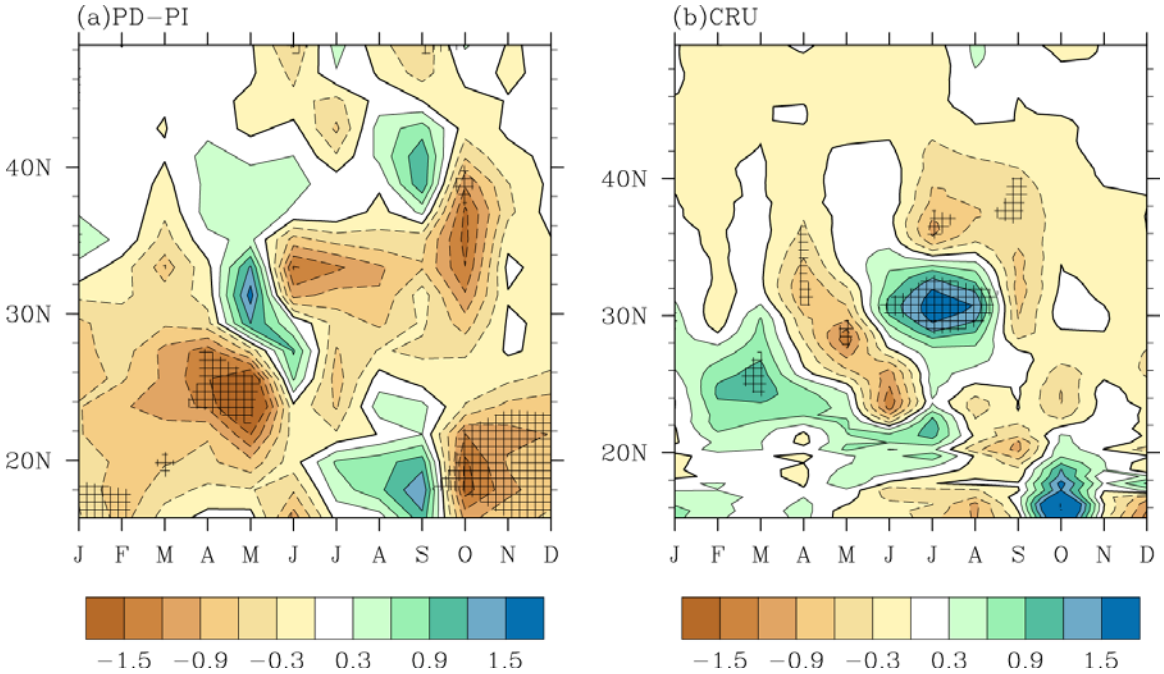
stability

relative humidity

Why “summer drought in North China” and “late spring drought in South China” happens?

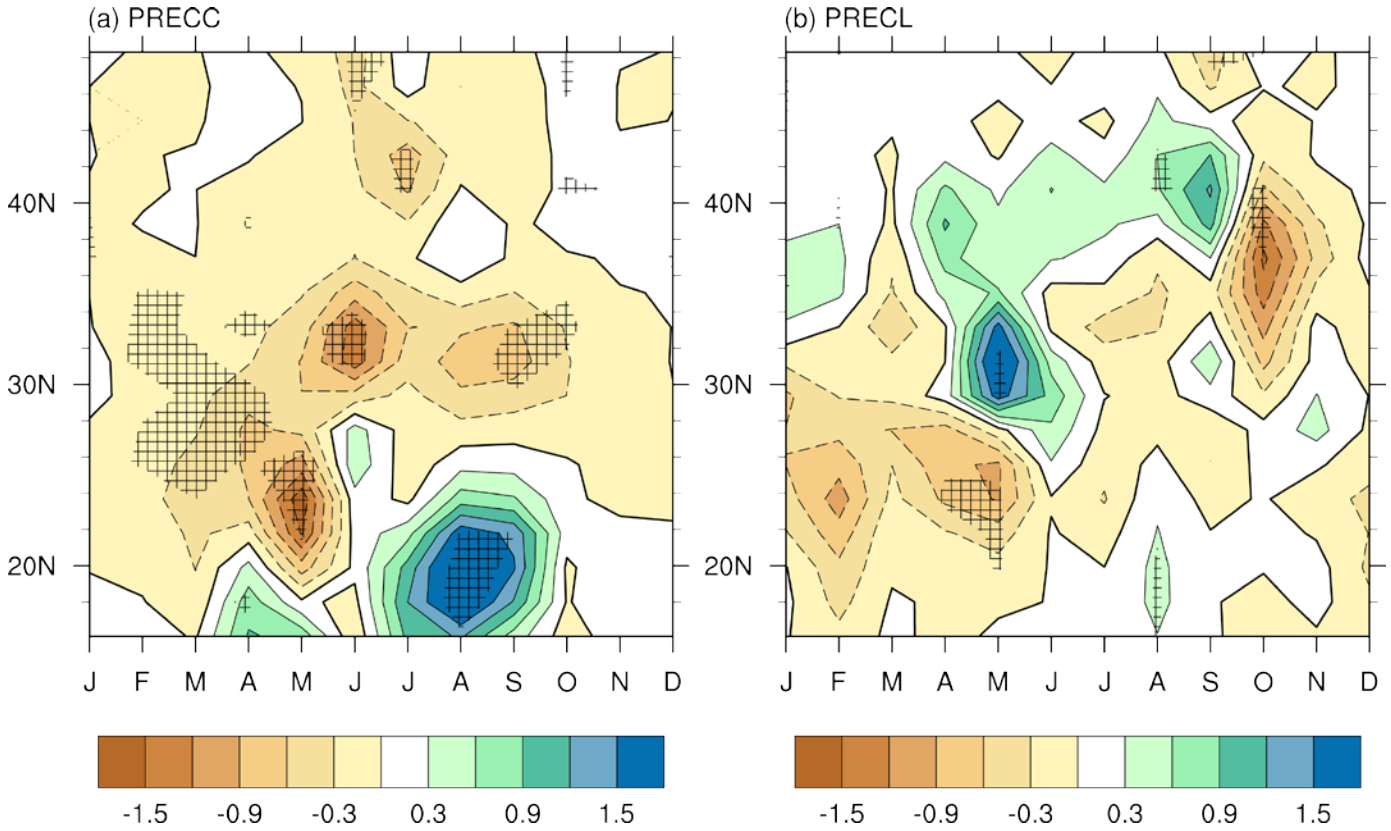
PD - PI

(1980–2001 minus 1958–1979）



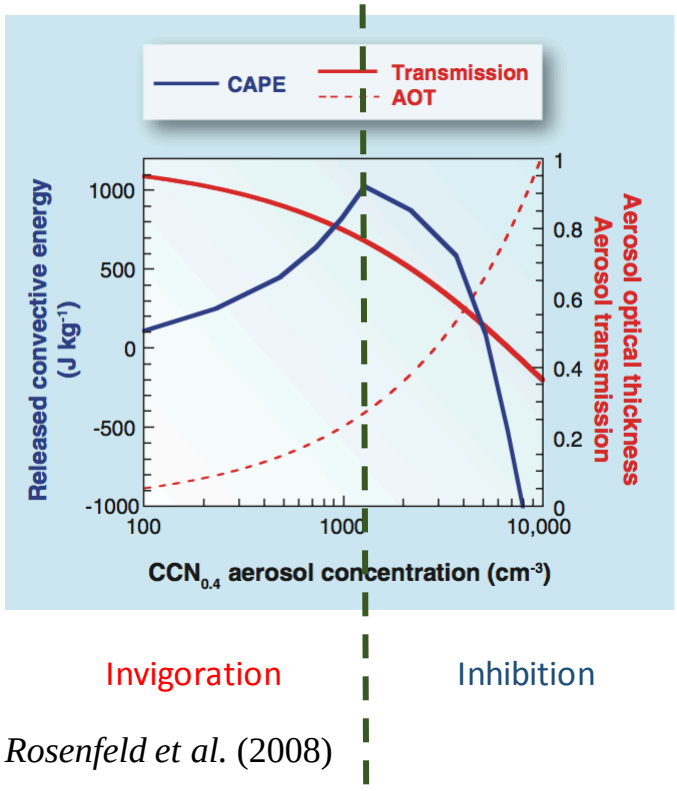
- The summer drought in North China is primarily due to aerosol direct effects.
- The spring drought in South China is due to both aerosol direct and indirect effects.

Change of convective and large scale precipitation

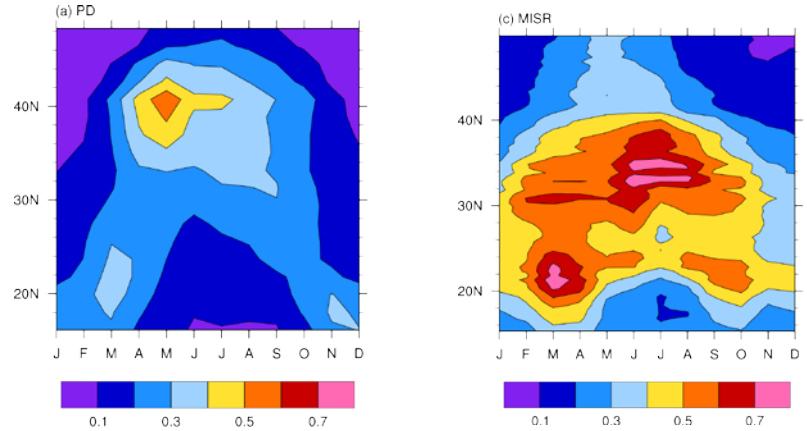


- Summer drought is most duet to convective precipitation
- Spring drought is from both convective and large scale precipitation

The Missing of indirect effects on convective clouds

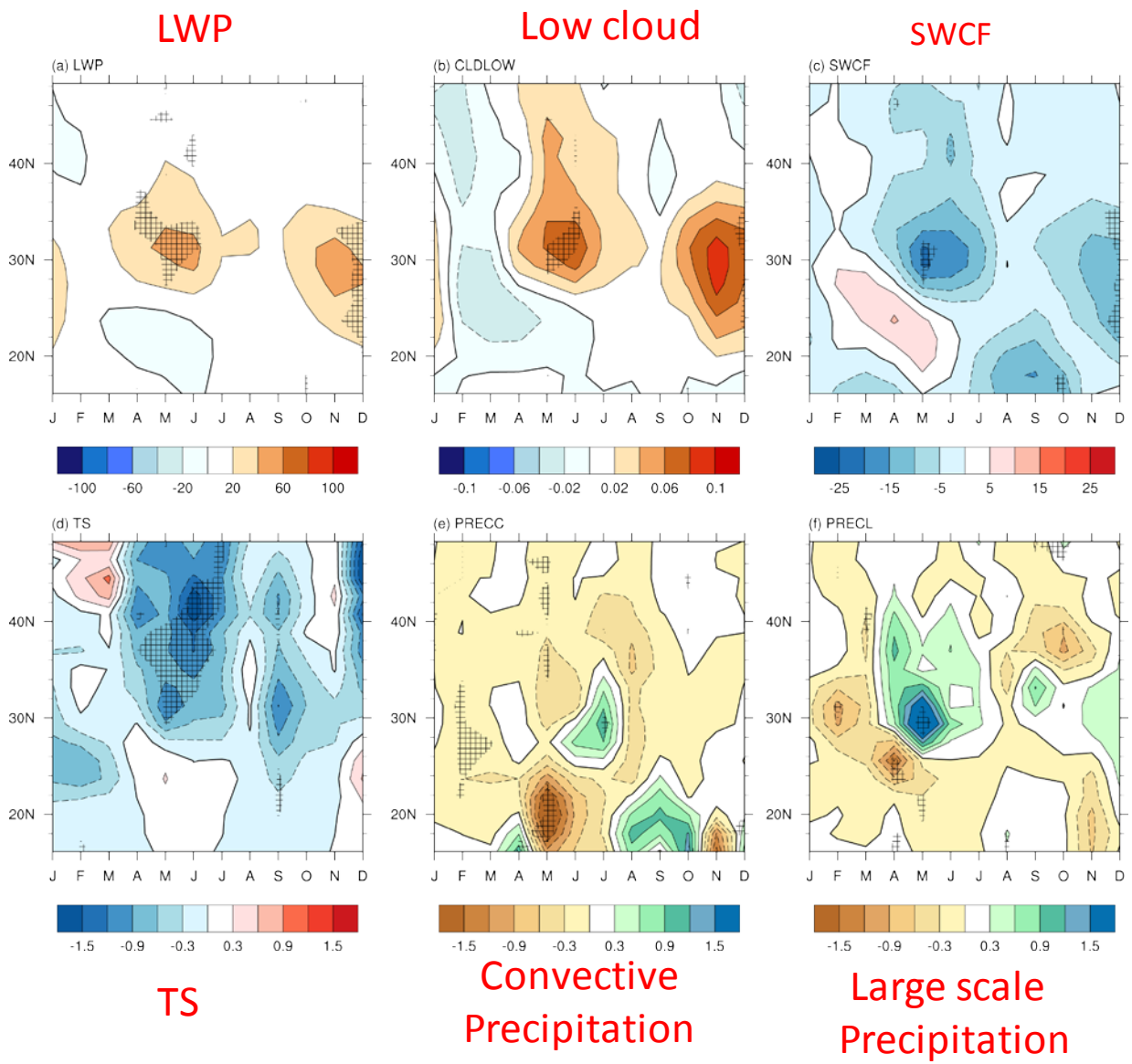


Rosenfeld et al. (2008)



- The influence could be the largest during summer when the convection is the most active.
- When the AOD is larger than 0.25, both microphysical and radiative effects lead to suppress the convection accompany with the increase of the AOD.
- Both observed and simulated AOD in North China is larger than 0.25 and the inhibition effects of convection should be dominant

The relative contribution of anthropogenic sulfate



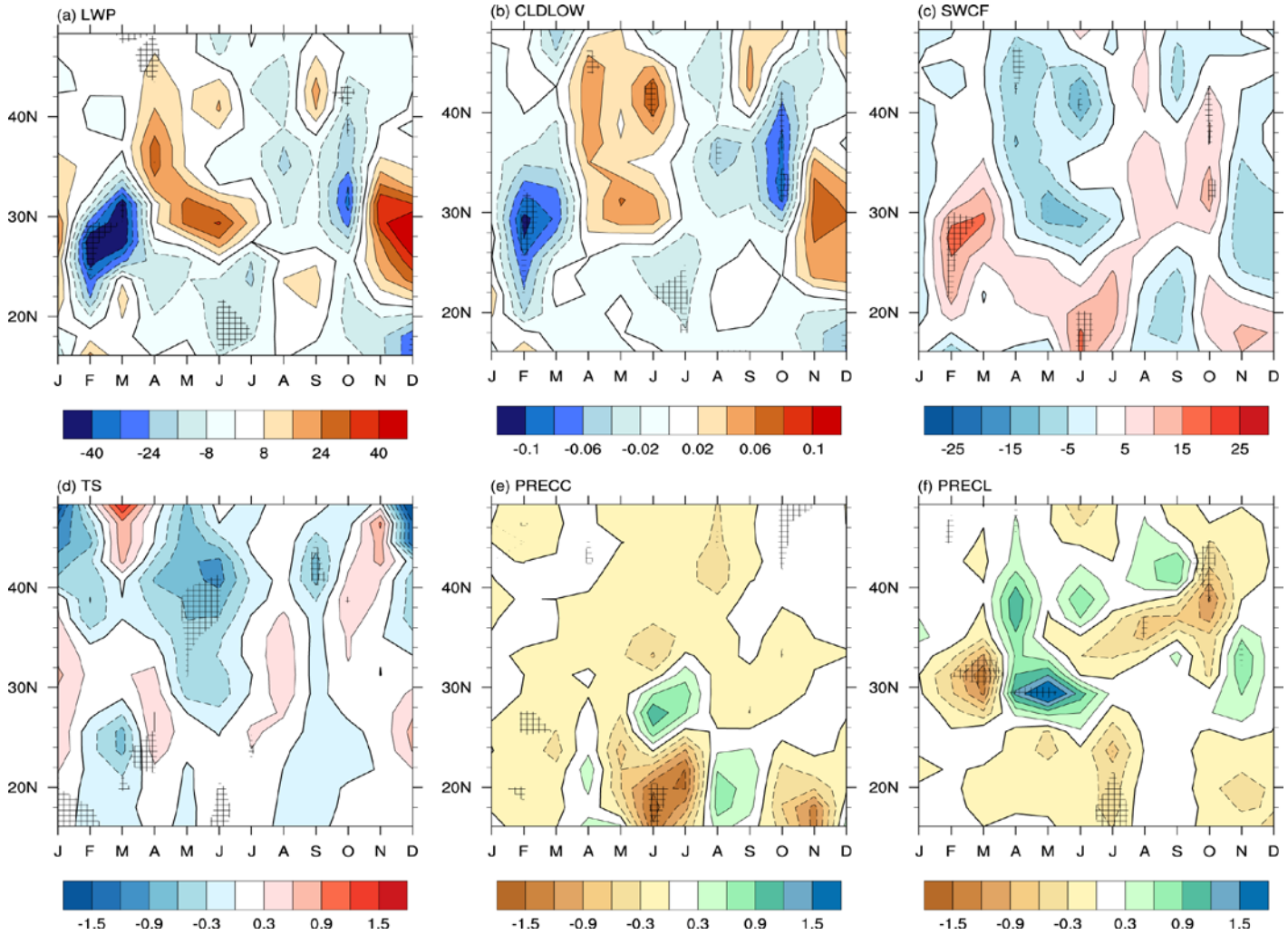
- Anthropogenic sulfate may explain most of the seasonal variation characteristics in cloud, precipitation and temperature changes.

Anthropogenic BC's effect is opposite and weak

LWP

Low cloud

SWCF



TS

Convective Precipitation

Large scale Precipitation

Summary and conclusions

- The differences between experiments with and without anthropogenic emissions exhibit a northward shift of the maximal AOD change in East Asia from March to July and then a southward withdrawal from September to November.
- Associated with the shift, the direct and semi-direct effects of the anthropogenic aerosols are the most pronounced in spring and summer, with a maximum center in North China during summer and a secondary center in South China during spring.
- The cloud liquid water path and shortwave cloud forcing changes, however, are the weakest in North China during summer.
- The indirect effect is found to be the strongest in South China during spring, which is related to the large amount of mid-low level clouds in cold seasons in East China.
- A positive feedback between aerosol induced surface cooling and low-level cloud increase is identified in East China, which acts to enforce the aerosol indirect effect in spring
- Accordingly, the climate response to the anthropogenic aerosols is also characterized by a northward shift of the surface cooling and the precipitation reduction from spring to summer, which is relevant to the observed trend since the 1980s in East China.
- The spring drought in South China is attributed to both direct and indirect effects of the anthropogenic aerosols while the summer drought in North China is primarily determined by the aerosol direct effect.

Jiang, Y., X.-Q. Yang, and X. Liu (2015), Seasonality in anthropogenic aerosol effects on East Asian climate simulated with CAM5, J. Geophys. Res. Atmos., 120, 10,837–10,861, doi:10.1002/2015JD023451.