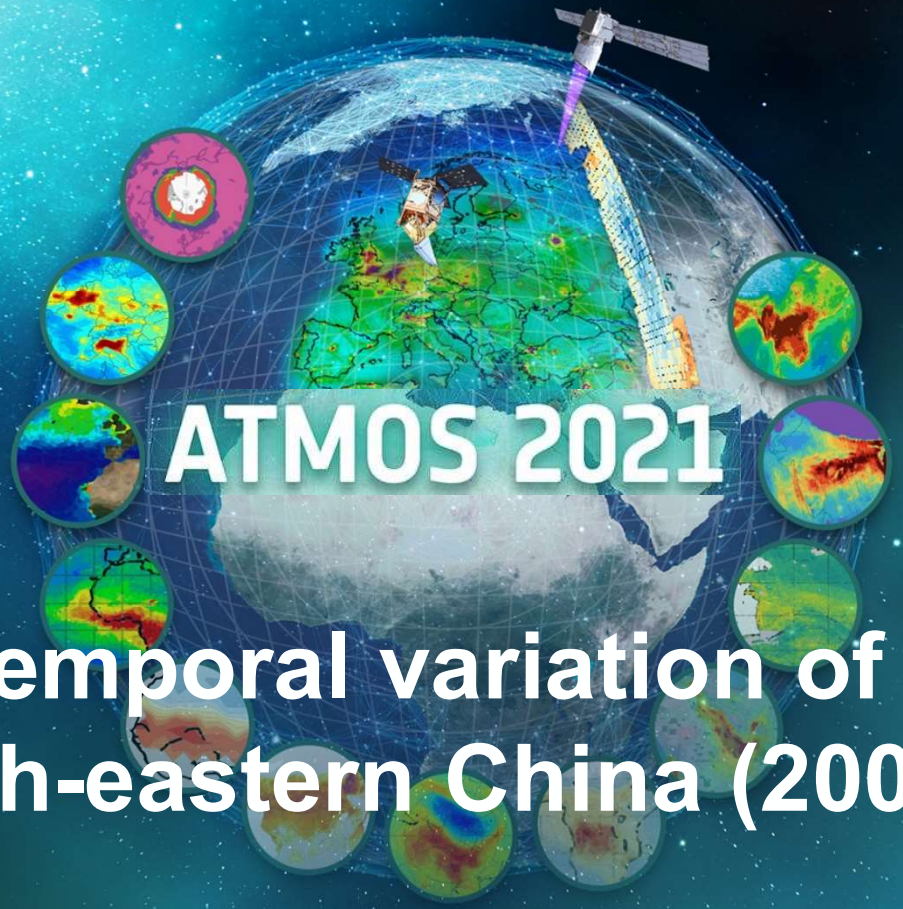

Spatio-temporal variation of the AOD over south-eastern China (2000 to 2021)

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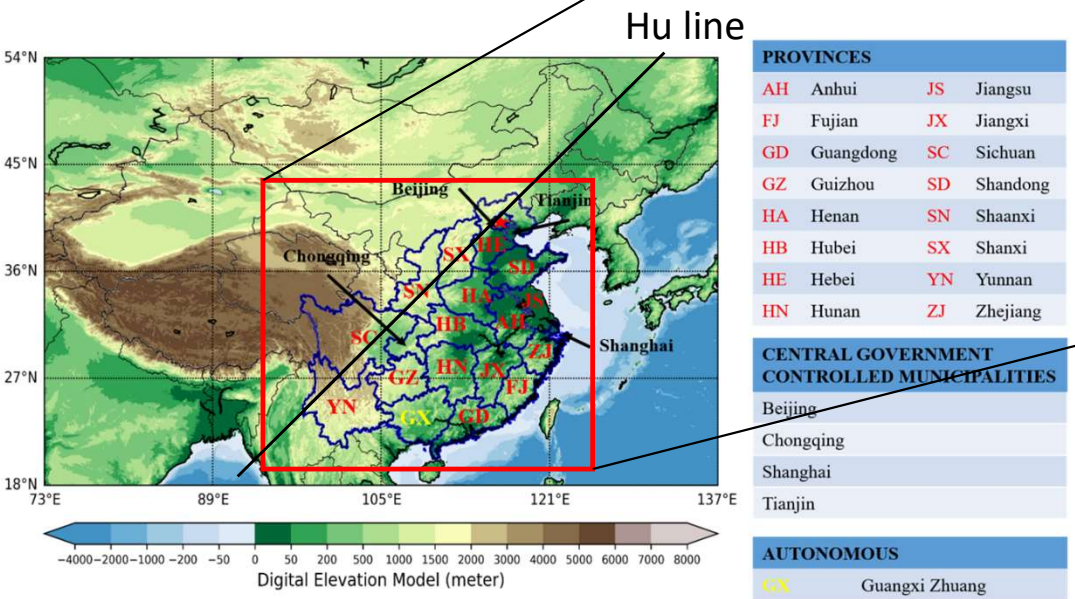
25/11/2021

Study area

The study area is south-eastern China, here defined as the land area including all provinces east of the Hu line:

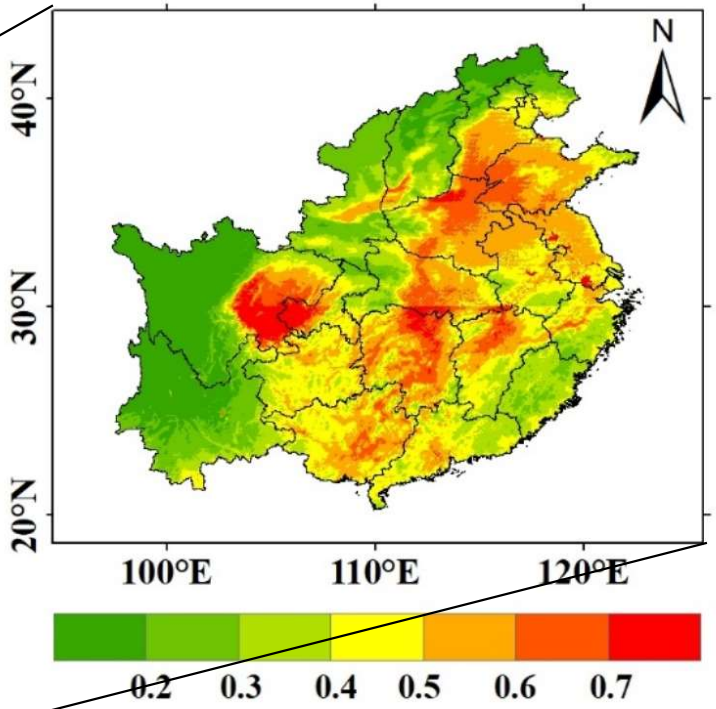
- Densely populated (94% of Chinese population)
- Highly industrialized, strong economic development
- Large variety of surface types, elevation
- Large variety of atmospheric composition
- Progressive emission regulation



PROVINCES			
AH	Anhui	JS	Jiangsu
FJ	Fujian	JX	Jiangxi
GD	Guangdong	SC	Sichuan
GZ	Guizhou	SD	Shandong
HA	Henan	SN	Shaanxi
HB	Hubei	SX	Shanxi
HE	Hebei	YN	Yunnan
HN	Hunan	ZJ	Zhejiang

CENTRAL GOVERNMENT CONTROLLED MUNICIPALITIES
Beijing
Chongqing
Shanghai
Tianjin

AUTONOMOUS	
GX	Guangxi Zhuang



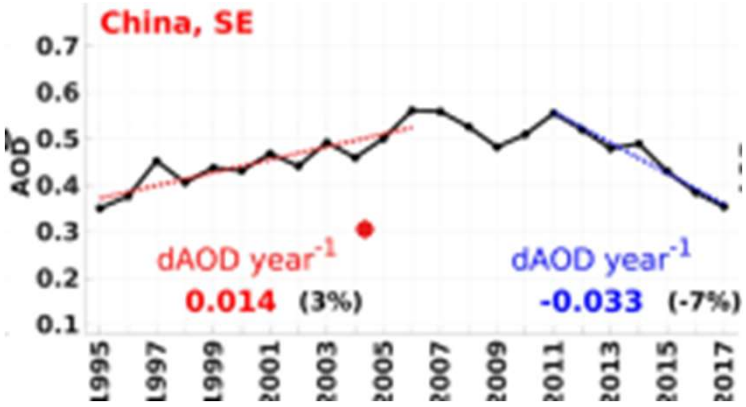
AOD over south-eastern China, using MODIS-MAIAC data (1 km spatial resolution), averaged over 21 years (2000-2020):

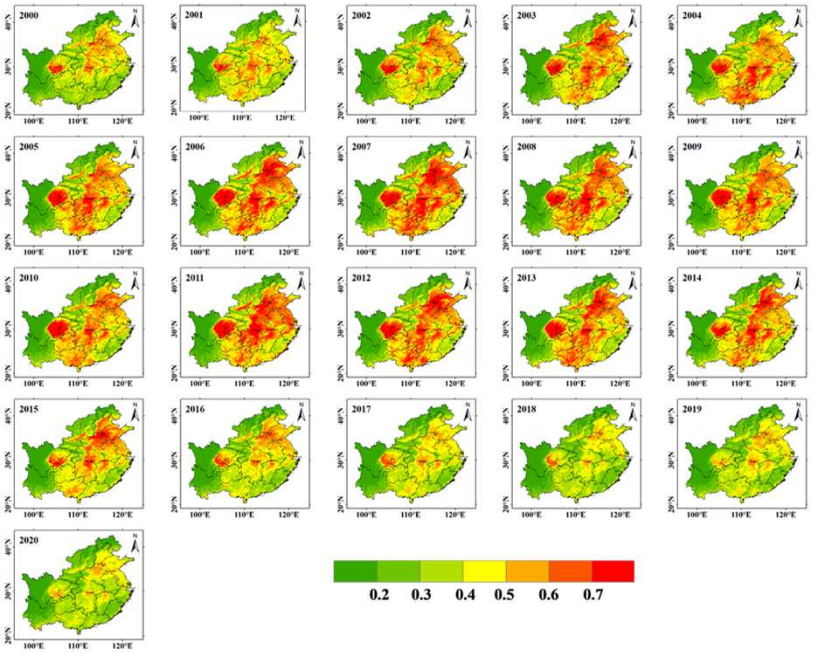
- Large spatial variety
- Areas with very high AOD

Spatio-temporal variation

- Maps of the annually averaged AOD show the evolution of the AOD across the study area, initially increasing until 2006/2007, varying until about 2014, then decreasing in response to emission regulation implemented as part of the clean air action plan (2013-2017). The evolution of the AOD during the period from 1995-2017 has been analyzed by many authors, e.g., Sogacheva et al. (ACP 2018) determined trends for 2 periods:

Similar analyses were published by other authors; time periods considered differ between authors

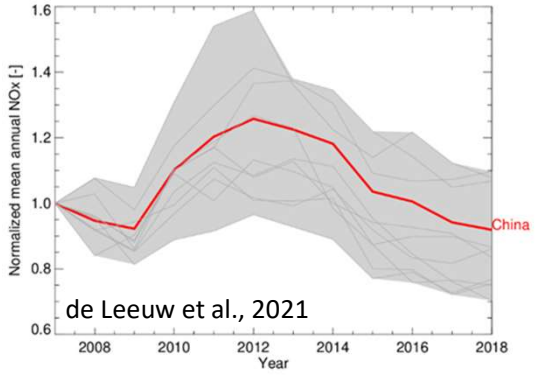




The **objective** of the current study is to extend earlier studies and evaluate the AOD variations on a provincial scale across south-eastern China.

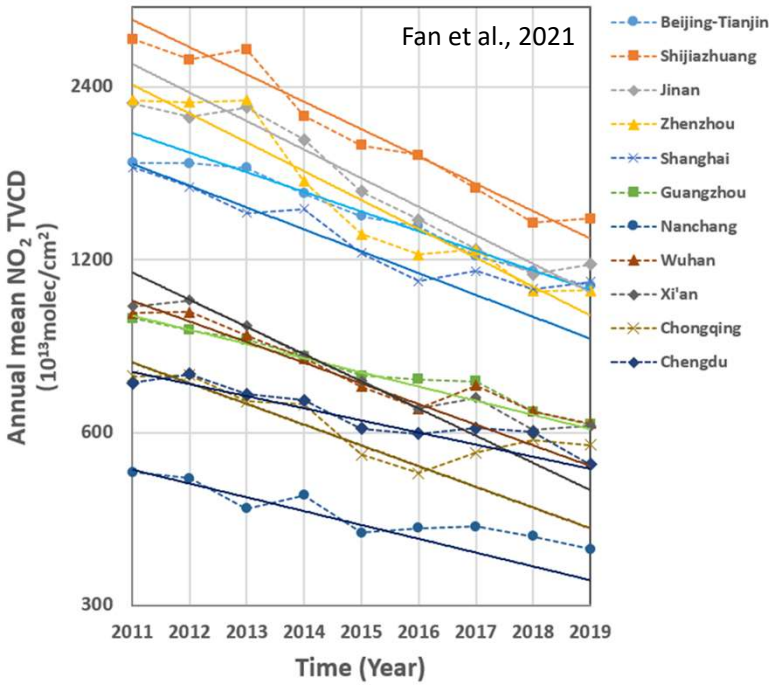
This study was initiated because of recent findings of flattening of the decrease of vertical column densities of tropospheric NO_2 (Fan et al., ACP 2021): with NO_2 a precursor gas for secondary aerosol formation, what is the effect on aerosols?

NO_2 trends



NO_2 emission trends, normalized to 2007, over provinces in north-eastern China, extended to 2018 as part of the DRAGON4 project. The red line is based on the average for East China (van der A et al., 2017; de Leeuw et al., 2021)

NO_2 tropospheric vertical column densities (OMI data, 2011-2019) and trendlines, for 11 areas in south-eastern China (Fan et al., 2021)



- Emissions and concentrations decrease from about 2012, with some difference between regions
- The concentrations seem to stabilize in more recent years, from about 2016 in the south and from about 2018 in the north
- Trend lines were calculated for different periods
- Clear difference between concentrations in the north and in the south

AOD time series

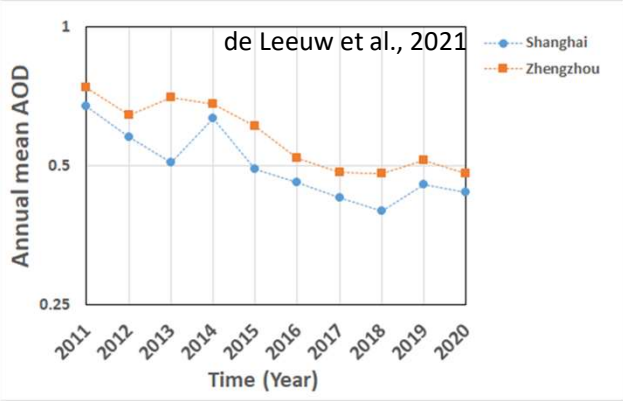
AOD time series over the same areas and period as for NO_2 also show flattening in recent years, as illustrated for Shanghai and Zhengzhou (de Leeuw et al., 2021).

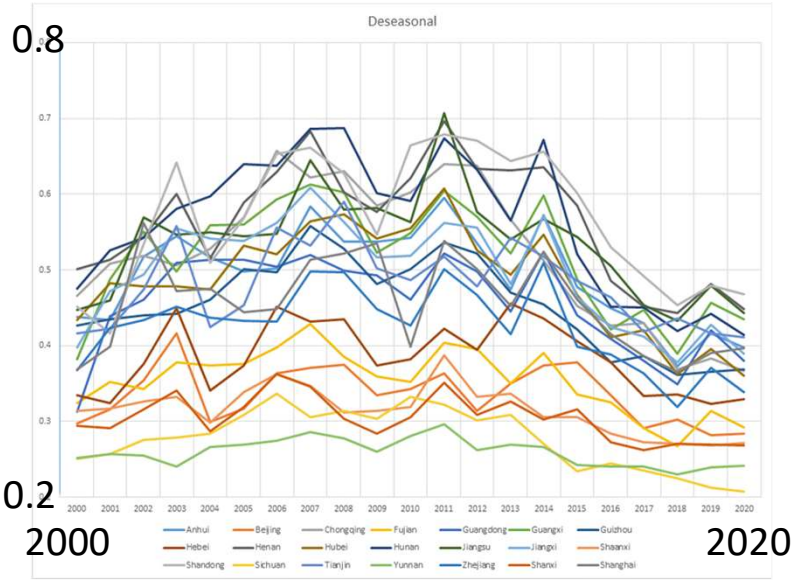
For the current study, AOD was averaged on provincial scales, rather than around major urban or industrial centers. Aerosol particles contributing to the AOD have much longer atmospheric lifetimes than NO_2 (days vs hours), allowing for averages over large areas. Furthermore, industrial development and urbanizations varies across the study area, while provinces may implement clean air actions at different times.

Clearly, strong fluctuations occur in the annually averaged AOD with differences between provinces or clusters of provinces.

Such differences may be due to variations in emissions of aerosols and precursor gases, while also climatological or meteorological effects influence the AOD

The time series used in this study cover the period starting in 2000 until July 2021.





Annually averaged AOD, over 21 provinces

Some events

2003: Siberian forest fires increase AOD in northern provinces in May/June

2007: AOD maximum, implementation of 11th 5-year plan reduces AOD; 2007 in many studies considered as pivot point when AOD starts to decrease

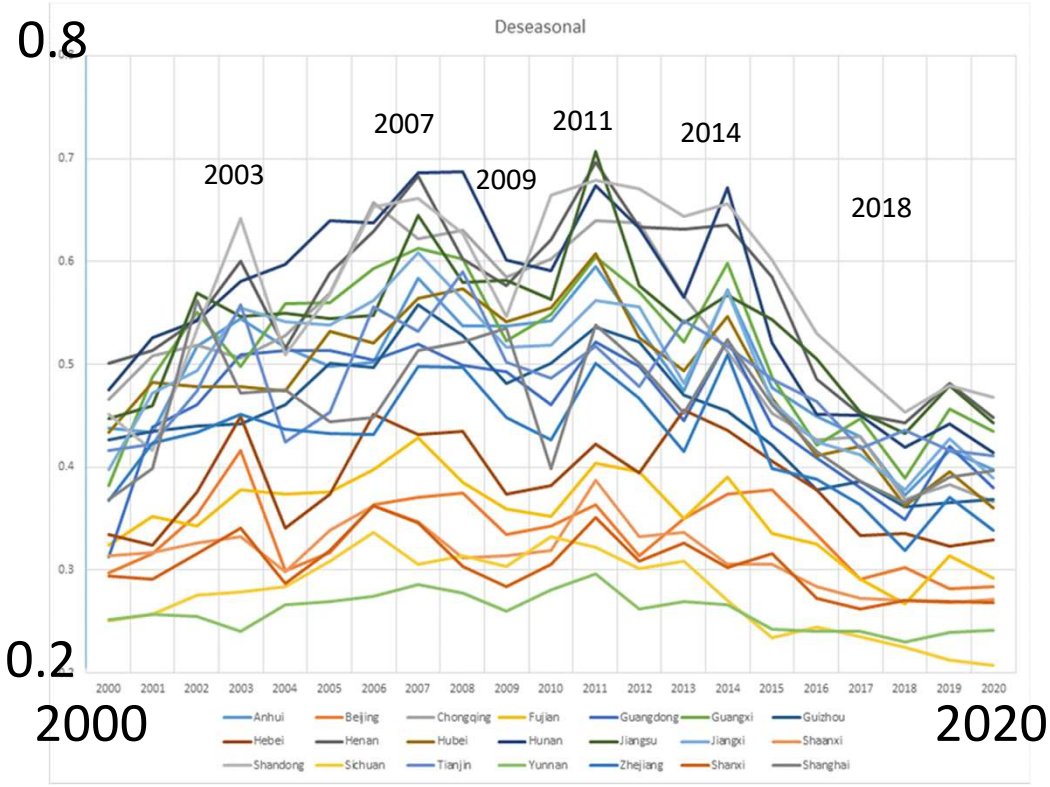
2009: world-wide financial crisis, reduced economic activity and transport results in AOD minimum in 2009/10

2011: start of 12th 5-year plan with key target to reduce energy consumption; climate anomaly (warm and dry); 2011 in some studies considered as pivot point when AOD starts to decrease further (after 2007 the AOD fluctuated)

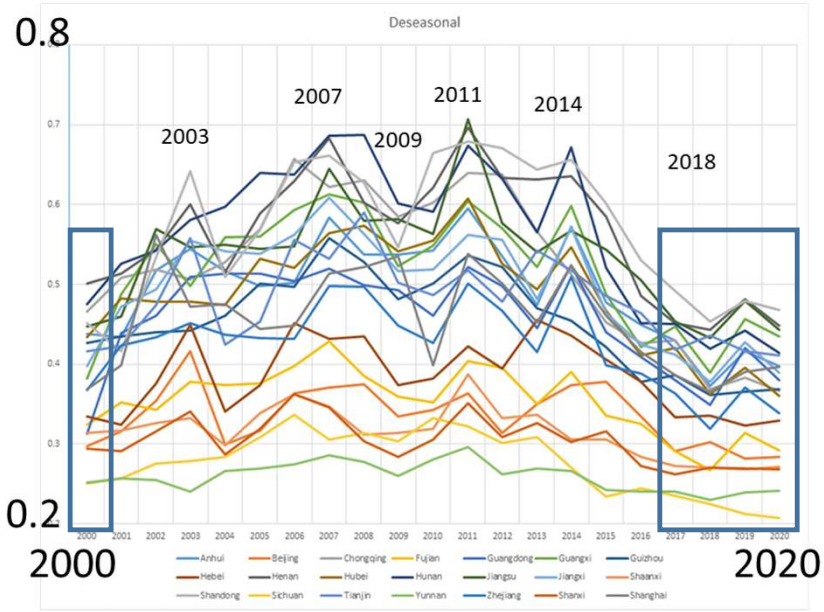
2013-2017: Clean Air Action Plan: strong reduction PM2.5 and AOD

2014: AOD peaks in central-south China; 2014 anomalous year (winter haze, summer drought, monsoon activity, …)

2018: AOD minimum over most provinces



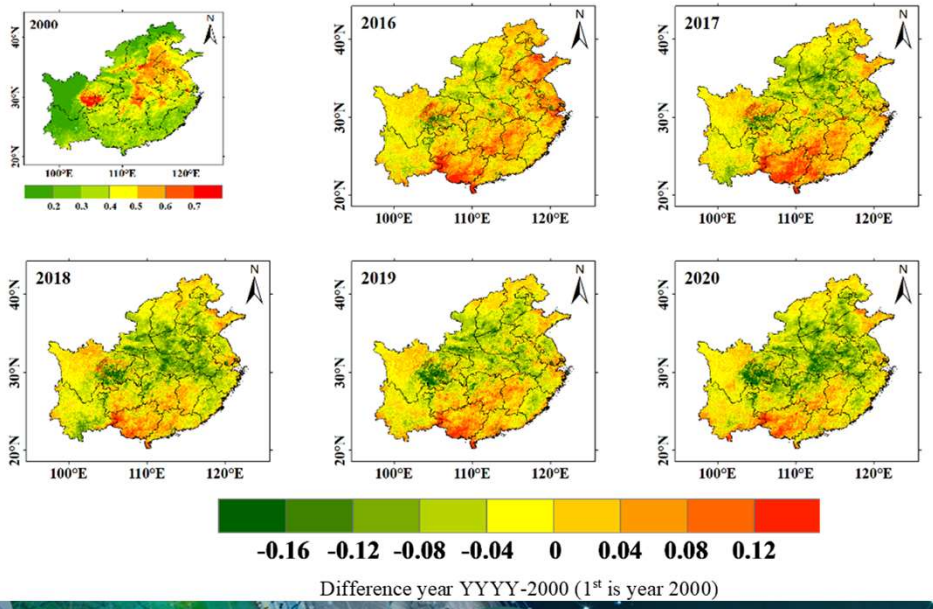
AOD stabilizes near that in 2000



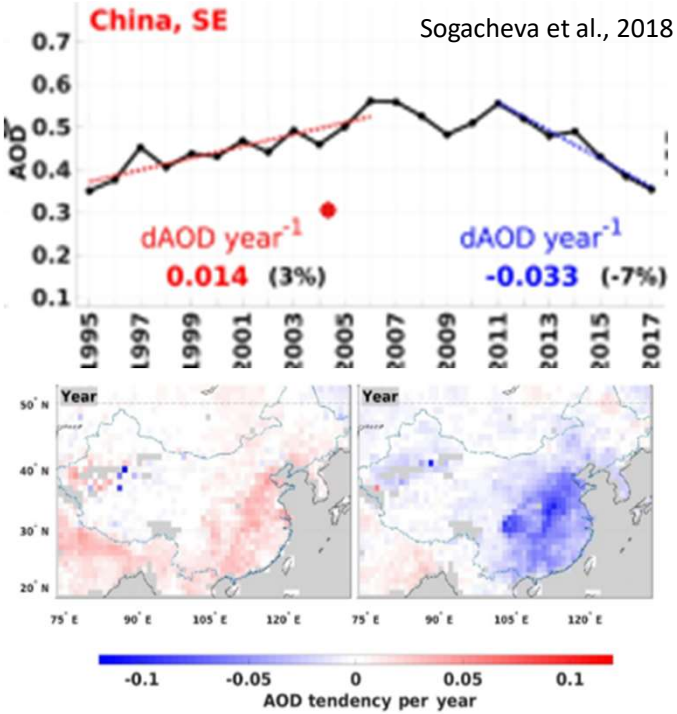
The AOD during recent years seems to have stabilized and fluctuates within 10% of the average during these years.

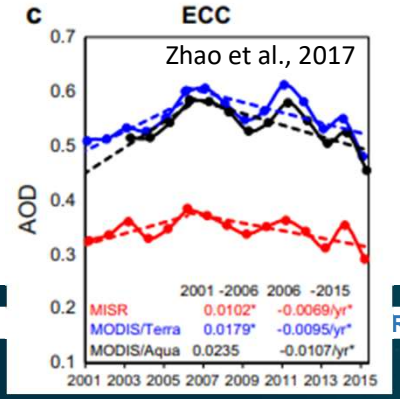
The AOD by the end of the study period is similar to, or even lower, than in 2000

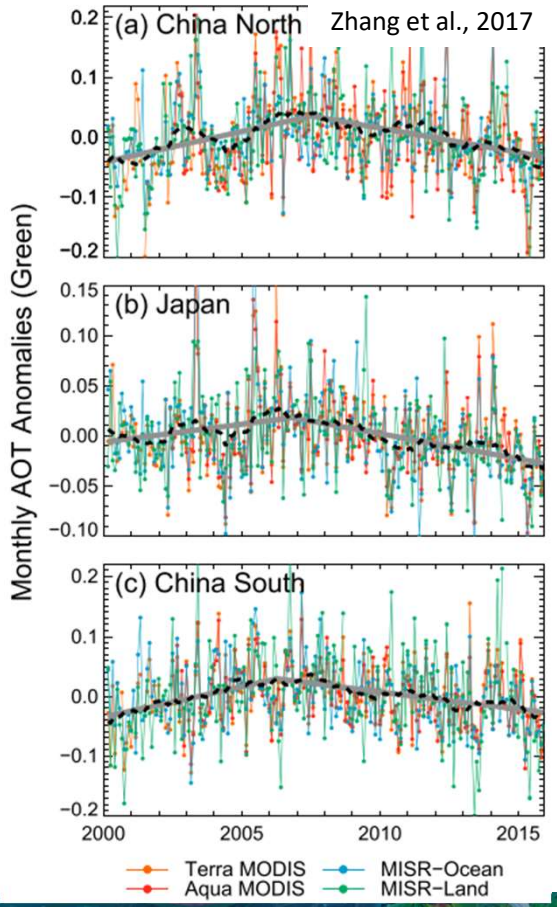
Comparison of the AOD in recent years with that in 2000, using AOD difference plots, confirms the similar/lower AOD over much of the study area, except in the southern provinces and part of Shandong. In 2017, AOD over these areas was a bit higher, in 2016 also over other parts



AOD trends





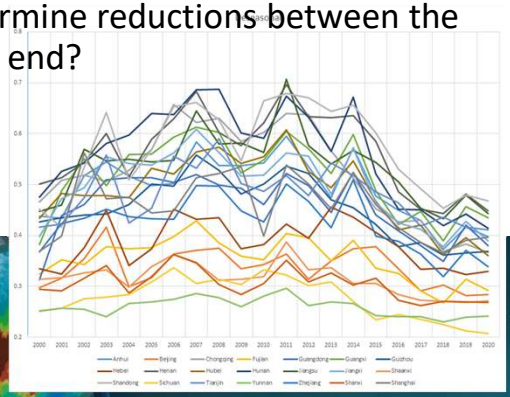


In view of:

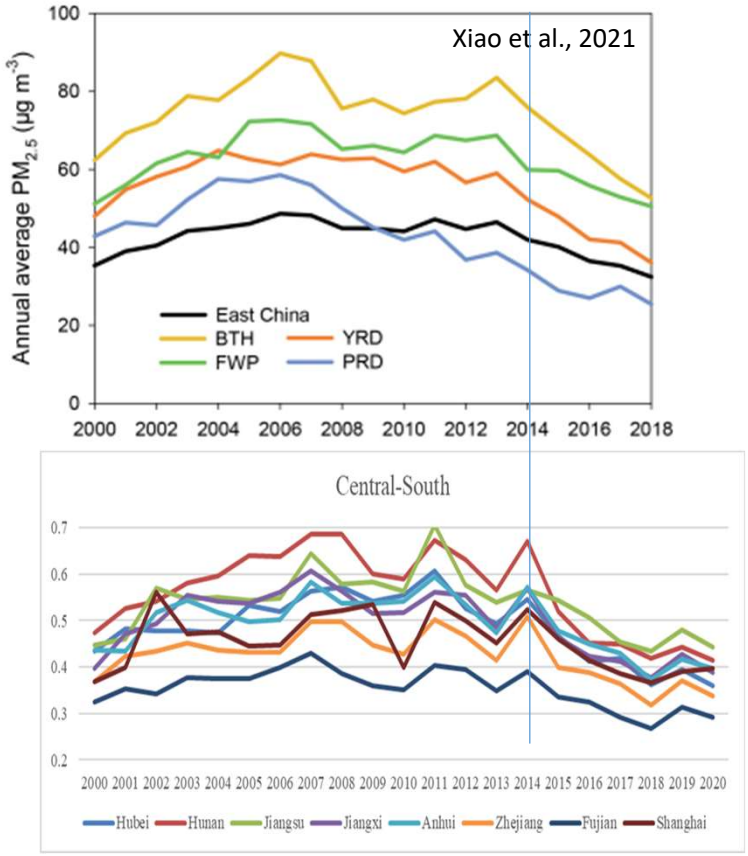
- the strong fluctuations on provincial scale, and the differences between these across China,
- The short times when a certain tendency occurs
- The flattening during recent years

The questions arise

- whether trends/tendencies can actually be derived over China
- Is it useful to derive such trends and what can be done with them?
- To evaluate the effects of policy measures on atmospheric composition, would it be more useful to just determine reductions between the beginning and the end?



Emission reduction vs meteorological effects



2014 was an anomalous year, with winterhaze, summer drought and monsoon effects. These factors caused an anomalously high AOD over central-south China (bottom). However, in the PM2.5 data derived from MODIS AOD using models, ground-based PM2.5 measurements and machine learning (Xiao et al., 2021), the anomaly in the AOD data seems to have been effectively removed, resulting in smooth PM2.5 time series. Other studies also do not show a PM2.5 peak in 2014.
The substantial increase in the AOD, which is not observed in PM2.5, indicates that factors affecting AOD, like the RH vertical profile, may have a much larger effect on AOD, and thus climate effects, than on PM2.5 which is important for health effects.

Model runs are underway to discriminate between natural and anthropogenic effects on the AOD (Kang et al., 2018).

Conclusions

- The AOD over south-eastern China has stabilized in recent years at a value similar to, and in part of the study area lower than, the AOD in 2000.
- The determination of AOD trends over south-eastern China may not be useful in view of large interannual fluctuations and the short periods during which consistent variations occur.
- Anomalous behavior of the AOD has been identified and to some extent explained.
- The implementation of the clean Air Action Plan (2013-2017) had a clear effect on the AOD over south-eastern China with a clear decline after many years when AOD fluctuated in response to anthropogenic and meteorological / climatological influences.
- Large spatio-temporal fluctuations are observed in the AOD over south-eastern China, with differences between provinces, north, and south and even within a cluster of provinces.

Thank you for your attention!

Any questions?

Feel free to contact me: gerrit.de.leeuw@knmi.nl

Acknowledgements: work presented contributes to the ESA / MOST cooperation project Dragon 4, Topic "Atmosphere – Air Quality" (EMPAC). MAIAC data on a 1-km grid (Lyapustin et al., 2018) were downloaded from the NASA's Land Processes Distributed Active Archive Center (https://lpdaac.usgs.gov/data/). Ground-based Sun-Sky radiometer data over China can be obtained via SONET (www.sonet.ac.cn).