Climate and Environmental Changes in China: Are They Connected?

Zhanqing Li

Contributions

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Outline of My Talk

1. Economic growth & environment changes in China
2. Climate changes in China
3. Major observation campaigns
4. Optical properties and direct effects of aerosols
5. Indirect effects of aerosols and social-economic implications
6. Potential impact on monsoon circulation
GDP (and percentage contribution from industry for China during 1978-2004 (source: [China CBS, 2005])
Reported total SO$_2$ emissions, industrial SO$_2$ emissions, and industrial output value of China during 1995-2005 (source: [China CBS, 2005])
Observed PM10, AOD and VIS are very well correlated spatially with pollutants (e.g. sulfur) emissions, implying anthropogenic emission is the major source of atmospheric aerosols in China (Qian et al., 2009).

- **(a)** PM10 (2001-2006)
- **(b)** visibility
- **(c)** MODIS AOD
- **(d)** Sulfur emission
Variations of Gaseous Pollutants Observed during the Beijing Olympic Games in 2008

![Graph showing variations of gaseous pollutants](image-url)
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Temperature Trend
1956-2002

Rainfall Trend
1956-2002

1960-1990

A
Temperature trend (degree C/decade)

B
Precipitation trend (mm/decade)

Figure 8. (a) Trend (°C/decade) of summer (JJA) daily maximum air temperature indicating the cooling in south-central China (mid Yellow River Basin to the mid-lower Yangtze River Basin) from 1969 to 2007.
Global Solar Radiation Change from 1960-2000 under cloud-free days

Qian et al. (2007)
Annual Mean Total Cloud Cover Trend for 1954-2001

TCC: -0.88%; LCC: -0.33%

88% of 537 stations decreased 1-3%

Frequency of Cloud-free Sky have increased for 1954-2001 (Qian et al., 2006)
Figure 2. Urban stations including the top 30 largest cities in China and the “nonurban” stations totaling 275 first-class weather stations.

Ming Xu et al (2006)
Time-series of anomalous summer monsoon indices for WYI estimated by using NCEP Reanalysis dataset (a); and DHI estimated by using NCEP Reanalysis dataset (b). WYI=U850-U200. DHI=U850-U150. Bold straight lines denote the linear regression trend. The non-smoothed curves are obtained with the 6-order polynomial fitting. Unit: m/s
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East Asian Study of Tropospheric Aerosols: An International Regional Experiment (EAST-AIRE)

Observation: 2004-2006
JGR Special Issue 2007 (20 articles)
East Asian Study of Tropospheric Aerosols and Impact on Regional Climate (EAST-AIRC)

Observation: 2006-2010
JGR Special Issue 2010 (33 Articles)
Anchored by the AMF in Shouxian, additional instrumented sites to the east and north provided a comprehensive atmospheric data set for studying aerosol effects in the region.
Cloudy, with a chance of science

When American and Chinese scientists agreed to measure pollution and dust over China, nobody foresaw how difficult it would be. Jane Qiu reports.

T
e new partnership between U.S. and Chinese scientists has been hampered by everything from lack of funds to swarms of mosquitoes and dust storms.

The two countries have a long history of collaboration in science, and their leaders have expressed interest in partnering on projects to reduce pollution and improve air quality. But the partnership has faced challenges, including financial difficulties, logistical problems, and concerns about data sharing.

The project, known as the U.S.-China Cooperative Airborne Research Experiment (CARE), was launched in 2009 with the goal of gathering data on pollution and dust over China. The idea was to use aircraft and satellites to track pollution and dust, and to share the data with Chinese scientists.

However, the partnership has been hit by a series of setbacks. For example, the U.S. government has been slow to provide funding for the project, and Chinese scientists say they have been left out of key decision-making processes.

In addition, the partnership has faced logistical challenges. For example, it has been difficult to coordinate flights over China due to weather conditions, and the data collected has been prone to errors.

Despite these challenges, the partnership has made some progress. For example, Chinese scientists have begun to use the data collected by the CARE project to improve air quality models.

The partnership is also trying to address some of its problems. For example, the U.S. government is increasing its funding for the project, and Chinese scientists are working to improve their data quality.

The partnership is an important step in improving air quality in China, and it has the potential to lead to significant improvements in the country's air quality. However, it will require continued effort and commitment from both sides to succeed.
ARM Mobile Facility Deployment in Shouxian

Shouxian, Anhui
ARM Mobile Facility Typical Deployment

AMF Van Cluster

- O-Van
- AOS-Van
- M-Van
- D-Van
- AERI-Van
- BBSS Launcher
- RWP

AMF Instrument Field

- ECO
- SKYRAD Stand
- TSI Stand
- SMET Tower
- GNDRAD Tower

WACR

MWR, MWRP, Ceilometer, BBSS Antenna

MFRSR, TSI

PIR, PEP, B/W, IRT

PIR, PEP, IRT
Taihu near Shanghai
Taihu near Shanghai
Zhangy, Gansu
Tethered-Balloon Measurements
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6. Monsoon mechanisms and linking with aerosol
AOD records during 2008

Xianghe
\[ \tau_{\text{cimel}} = 0.55 \pm 0.69 \]
\[ \tau_{\text{MFRSR}} = 0.69 \pm 0.58 \]

Black: Cimel
Red: MFRSR

Shouxian
\[ \tau_{\text{cimel}} = 0.68 \pm 0.46 \]
\[ \tau_{\text{MFRSR}} = 0.66 \pm 0.40 \]

Taihu
\[ \tau_{\text{cimel}} = 0.71 \pm 0.42 \]
\[ \tau_{\text{MFRSR}} = 0.81 \pm 0.52 \]

Lee et al. (2010, JGR)
Monthly Aerosol and Cloud Radiative Forcing

- Aerosol (-24.15)
- Cloud (-41.02)
- Total (-53.91)

Radiative Forcing (W/m²)

Li et al. (JGR, 2007c)
National Mean of Aerosol Radiative Forcing at the TOA, Surface and inside the Atmosphere

Li et al. (2010, JGR)
Mean MODIS AOT

MODIS AOT Trend

Temperature Trend

Temperature trend
(degree C/decade)
Atmospheric adiabatic heating rate

Water Vapor Mixing Ratio (g/kg)

Temperature (K)

Heating Rate (K/day)

Height [Km]

Extinction Coefficient [Km\(^{-1}\)]

May 3, 2005

\(\tau = 1.06\)

\(\omega_0 = 0.86\)
SGP Aerosol CN Concentration and Duration of Inversions in 2008

\[ y = 360.42x + 2750.5 \]

\[ R^2 = 0.7778 \]
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Various Mechanisms At Work

Responses of Rainfall frequency to increasing CN

- **Background Diffuser**
  - Increase rainfall
  - Suppress rainfall

- **Meteorological Effects**
  - Depend on weather Cloud system

- **Invigoration Effects**
  - Depend critically on cloud base

- **Microphysical Effect**
  - Depend critically on available water
DER-AOD relationship
Discovery of Anti-Twomey Effect

Yuan et al. (2008, JGR)
### Global Analysis

<table>
<thead>
<tr>
<th>Region</th>
<th>Latitude range</th>
<th>Longitude range</th>
<th>Dominant Aerosol/Cloud Types</th>
<th>Period</th>
<th>AIE efficiency</th>
<th>Sample size</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Atlantic</td>
<td>5-20S</td>
<td>5E-20W</td>
<td>Smoke, Stratocumulus</td>
<td>June-August,2002</td>
<td>Negative</td>
<td>100,377</td>
</tr>
<tr>
<td>Southern Pacific</td>
<td>5-25S</td>
<td>75-105W</td>
<td>Sea salt, sulfate and pollution, Stratocumulus</td>
<td>August-October,2002</td>
<td>Negative</td>
<td>74,216</td>
</tr>
<tr>
<td>Indian Ocean</td>
<td>12-20N</td>
<td>60-70E</td>
<td>Dust with pollution, Trade cumulus</td>
<td>June-August, 2002</td>
<td>Negative</td>
<td>94,023</td>
</tr>
<tr>
<td>India</td>
<td>13-24N</td>
<td>70-85E</td>
<td>Mixture of sulfate, dust, sea salt and smoke, cumulus</td>
<td>June-August,2002</td>
<td>Neutral</td>
<td>53,888</td>
</tr>
<tr>
<td>Amazonia</td>
<td>8S-12N</td>
<td>44-76W</td>
<td>Mainly smoke</td>
<td>August-October, 2002</td>
<td>Negative</td>
<td>672,421</td>
</tr>
<tr>
<td>Southeastern China</td>
<td>23-43N</td>
<td>100-120E</td>
<td>Mixture, cumulus</td>
<td>June-August,2002</td>
<td>Positive</td>
<td>179,533</td>
</tr>
</tbody>
</table>

Student-t test indicates except India the difference among different loading of aerosols are statistically significant at least at the 95% level.
My study of possibly ‘yet another’ and more…
Cloud Thickness v.s. Aerosol Concentration for different Cloudbase Heights

- CBH:<1km \( R^2 = 0.9718 \)
- CBH:1km-2km \( R^2 = 0.9159 \)
- CBH:2km-4km \( R^2 = 0.1055 \)
WACR Cloud Radar (Oct 15 – Dec 15)

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>WACR 95GHz</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
95 GHz Cloud Radar from Oct 15 to Dec 15, 2008
Comparison of cloud distributions determined by the radiosonde and reflectivity measured by the WACR.
Rainfall Frequency for clouds with different liquid water path

- LWP: >0.8mm $R^2 = 0.9088$
- LWP: 0.4-0.8mm $R^2 = 0.037$
- LWP: 0.0-0.4mm $R^2 = 0.7803$

CN Number Concentration (1/cm^3)
Linear trends of frequency of rainy days (left) and precipitation amount (right) for different rain intensity over East China for 1956-2005

(top: JJA; bottom: Jan-Dec)

(a) Frequency of rainy days, Jun.–Aug.

(b) Precipitation amount, Jun.–Aug.

(c) Frequency of rainy days, Jan.–Dec.

(d) Precipitation amount, Jan.–Dec.
Time series of number of days for light rain (<10mm/day) for 1956-2005
(left: JJA; right: Jan-Dec)

(a) $0 \leq p \leq 10\text{mm/day}$, Jun-Aug

North, Trend $= -2.3\text{day/s}/10^\circ\text{r}, \alpha = 0.01$

South, Trend $= -1.2\text{day/s}/10^\circ\text{r}, \alpha = 0.01$

North+South, Trend $= -1.8\text{day/s}/10^\circ\text{r}, \alpha = 0.01$

(b) $0 \leq p \leq 10\text{mm/day}$, Jan-Dec

North, Trend $= -6.9\text{day/s}/10^\circ\text{r}, \alpha = 0.01$

South, Trend $= -8.1\text{day/s}/10^\circ\text{r}, \alpha = 0.01$

North+South, Trend $= -7.4\text{day/s}/10^\circ\text{r}, \alpha = 0.01$

Qian et al. (2009)
2. There is a general increasing trend in aerosol loading in China

Of the total 46 stations, the yearly averaged AOD variation curve can be briefly divided into two periods. One period is from 1961 to 1975, when AOD is smaller than the 30 year mean value; the other period is from 1976 to 1990, when AOD is higher than the mean value. Except for the peak in 1982 and 1983, which may be attributed to the eruptions of El Chichon, the curve shows a significant increasing trend from 1961 to 1990. The monthly averaged AODs of the total 46 stations also obviously increased.

Luo et al. (2001)
Dirty environment leads to stream weather by suppressing light rain and enhancing storms!
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6. Summary
Winter Sea Level and Wind (NOAA/NCAR Reanalysis)

(a) Mean Values  (b) Changes

Niu et al (JGR, 2010)
Observed and Modeled Changes in Sea Level Pressure and Wind Vector

(a) Modeled changes

(b) Observed changes

Niu et al (JGR, 2010)
Summary

1. Both climate and atmospheric environment have changed drastically in China, rendering an ideal test bed for studying their links.

2. Aerosols loading is heavy and absorbing, virtually no effect at TOA, huge impact at surface and in the atmosphere, tremendous impact on thermodynamics

3. Aerosol direct effect can explain the trends in temperature and radiation budget

4. Aerosol indirect effects is likely to have significant effects to help explain changes in cloud, precipitation and dynamics.

5. Plausible connection with the weakening of the East Asian Monsoon circulation
For More Details, refer to Our JGR Special Section Issues

• Volume 1, 2007: East Asian Study of Tropospheric Aerosols: An International Regional Experiment (EAST-AIRE) (20 articles)

http://www.agu.org/journals/jd/special_sections.shtml?collectionCode=EASTAIRE1

• Volume 2, 2010: East Asian Study of Tropospheric Aerosols and Impact on Regional Climate (EAST-AIRc) (~33 articles)

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Thanks!