Regional Hydrological Cycle effects

Black carbon - Clouds - Convection - Precipitation

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The World Is Warming

The rate and duration of warming of the 20th century has been much greater than in any of the previous nine centuries.

Similarly it is likely that the 1990s have been the warmest decade and 1998 the warmest year of the millennium.

At the halfway point, 2002 is the second warmest year on record.

Sources: IPCC Report: Summary for Policy Makers, Climate Change 2001: The Scientific Basis: NCDC Website
From CARB Website
Observed Global Surface Air Temperatures

- +1 °C (almost 2 °F) since 1880
- Melting of glaciers
- Sea level rose 4-8”
- +2 to 6 °F predicted by 2100

Source: CARB Website (Adapted from NASA GISS)
Magnitude of aerosol forcing

From Anderson et al. 2003
GCM - OBS low cloud changes for July

Convective cloud scheme
OLD
(Del Genio et al. 1996)

Convective cloud scheme
NEW
(Includes improved moist convective microphysics, etc. by Del Genio et al. 2004)
Convective cloud effects

From Graf, 2004
Convective cloud effects

Absolute anomaly of global precipitation for Jun-Jul-Aug

Calculate CDNC for convective clouds similar to that for stratiform clouds.

Modify convective precipitation as a function of CDNC and temperature.

Changes expected are in regions of high biomass burning during July: S. America, S African, NE Australia, Central and eastern Europe.

From Nober et al., 2003
Annual GCM cloud radiative forcing changes

Convective aerosol effects

No convective aerosol effects
Annual GCM (Net TOA Radiation - Direct effect)

Convective aerosol effects

No convective aerosol effects
Jun-Jul-Aug GCM precipitation changes

Convective aerosol effects
Trends qualitatively similar to those in Nober et al.

No convective aerosol effects
Precipitation changes (Aerosols+GHG)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Land</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precip</td>
<td>-.05</td>
<td>-.03</td>
</tr>
<tr>
<td>Sfc SR</td>
<td>-5.2</td>
<td>-3.8</td>
</tr>
<tr>
<td>Sfc Ts</td>
<td>0.6</td>
<td>0.5</td>
</tr>
<tr>
<td>Cld tau</td>
<td>.02</td>
<td>.02</td>
</tr>
<tr>
<td>Cld cover</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Hydrological cycle three times more sensitive to aerosol effects than greenhouse gases and
In a warmer climate aerosol source strength and atmospheric loading are determined by atmospheric changes and hydrological cycle.

(From Liepert et al. 2003; and Feichter et al. 2004)
Decrease in land surface radiative heating between 1960-1990.

Observed temperature increase of 0.4°C over land surfaces over the same period.

Imples \( \Rightarrow \Rightarrow \Rightarrow \text{Reduced surface cooling by turbulent fluxes -- evaporation}. \) (Wild et al. 2004).

Results in reduced precipitation -- Also implied by Observations?

Surface Radiation and Precipitation

Trends based on CRU Ts 2.0 data set of observed climate between 1901-2000 for land surfaces.

Courtesy of Mitchell, Tyndall Center for Climate Change Research.
Fossil fuel BC related changes

For 2XBCF (2BC), No BCF (NBC) and Normal BCF (Ctrl), change in CDNC is less than 5%.

Change in Net Rad at TOA

\[
\begin{align*}
\text{Ctrl} & = -1.45 \\
\text{NBC} & = -1.40 \\
2\text{BC} & = -1.46
\end{align*}
\]

Change in Net Rad at Zo

\[
\begin{align*}
\text{Ctrl} & = -1.90 \\
\text{NBC} & = -1.64 \\
2\text{BC} & = -2.34
\end{align*}
\]

Cloud cover (low), liquid water path and cloud optical thickness all increase with increasing BC.

Changes in surface radiative budgets and sensible/latent heat fluxes are larger compared to changes in TOA budgets.

Consequently precipitation changes become more negative with increasing BC.
Regional climate effects

Most significant effect of BC is shift in the regional pattern of precipitation - shift of centers along the ITCZ and SPCZ (Wang, 2003). Convection & precipitation enhanced north/south of ITCZ/SPCZ and vice versa. Change in snow depth for the NH.

Over eastern China for 1955-2000, ↓ trend in the frequency of low extremes and an ↑ trend for high extremes for daily mean summer temperatures (Gong et al. 2004). Largest ↓ in max temperatures for Yangtze river Valley that also shows ↑ in precipitation, (correlated to anomalies in the northwestern Pacific subtropical high + other factors ---circulation).

Similarly, precipitation trends, were stronger since the mid 1980s (Zhai and Pan, 2003). Other studies over China, (1951-2002), support the existence of ↑ precipitation trends over the Yangtze rive valley, with ↓ trends over the north and north-east China (Gemmer et al. 2004).

Seasonal variations in satellite retrieved cloud droplet effective sizes that are associated with precipitation changes over east Asia. (Kawamoto & Nakajima, 2003).
Regional precipitation trends (OLD and NEW work)

• We examine the recently observed mid-summer precipitation trends in China “North Drought-South Flooding” and its relation to aerosols. (Menon, Hansen, et al., Science, 2002)

• Changes in temperature gradients from aerosol forcing gives rise to the large scale precipitation changes.

• BC absorption ⇒ lower level heating, change in vertical motions, circulation, cloud cover and rainfall.
  – Aerosol vertical distribution is important and can affect the climate features we observe.

• Cloud cover decreases in the layer where heating occurs (semi-direct effect) except for aerosols below 550 hPa.

• For 470-180 hPa cloud cover (precipitation) decreases in northern China with overall increases in cloudiness at all levels for southern China. (Menon, Ann Environ. Res. 2004)
Jun-Jul-Aug Observed Precipitation Change

Anomalies for 1980-2000 relative to 1951-1979

JJA 1980–2000/1951–79 Anomaly Precip (mm/day)
GCM precipitation change - Indian Ocean region  (Jan-Apr)

Ramanathan et al.  
2001, JGR;  
Chung et al.  
2002, J. Clim
Convective schemes

Zonal mean differences and errors in precipitation over the tropics (30S to 30N) based on the NCMRWF (National Center for Medium Range Weather Forecasting) model for two different convective schemes:
Simplified Arakawa-Schubert scheme (SAS) and
Kuo cumulus scheme (Kuo)

From Chakraborty et al. 2004)
GCM precipitation change - Indian Ocean region (Apr)

Chakraborty et al. 2004

SAS convective scheme

Kuo convective scheme
**Simulation Setup**

**EXP BC:** Aerosols decrease with height.

**EXP L1 to L8:** All aerosols confined to a single model layer. From 1st level to 8th level

<table>
<thead>
<tr>
<th>Model Mid layer Pressure (hPa)</th>
<th>L1</th>
<th>L2</th>
<th>L3</th>
<th>L4</th>
<th>L5</th>
<th>L6</th>
<th>L7</th>
<th>L8</th>
</tr>
</thead>
<tbody>
<tr>
<td>984</td>
<td>959</td>
<td>894</td>
<td>817</td>
<td>635</td>
<td>470</td>
<td>338</td>
<td>248</td>
<td>180</td>
</tr>
</tbody>
</table>

**Sensitivity to aerosol vertical distribution**

- **Biomass burning**
- **Fossil fuel**
Jun-Jul-Aug GCM precipitation -- Vertical distr. sensitivity
## Absorbing aerosols: Semidirect and direct effects

<table>
<thead>
<tr>
<th></th>
<th>Semidirect</th>
<th>Direct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absorbing aerosol in BL</td>
<td>22.8</td>
<td>20.5</td>
</tr>
<tr>
<td>Absorbing aerosol in and above BL</td>
<td>10.2</td>
<td>15.4</td>
</tr>
<tr>
<td><strong>Absorbing aerosol above BL</strong></td>
<td><strong>-9.5</strong></td>
<td><strong>0.7</strong></td>
</tr>
<tr>
<td>Scattering aerosol above BL</td>
<td>-0.1</td>
<td>-7.4</td>
</tr>
</tbody>
</table>

⇒ (Based on results from an LES model by Johnson et al. 2004 for FIRE.)

⇒ Penner et al. (2003) also find **negative semidirect effect for biomass aerosols injected in the mid troposphere.**

<table>
<thead>
<tr>
<th></th>
<th>Semidirect</th>
<th>Direct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Std aerosol distribution</td>
<td>-5.39</td>
<td>5.82</td>
</tr>
<tr>
<td>All aerosols in 1st layer (0.42 km)</td>
<td>0.97</td>
<td>-0.06</td>
</tr>
<tr>
<td><strong>All aerosols in 4th layer (3.8 km)</strong></td>
<td><strong>-5.74</strong></td>
<td>8.37</td>
</tr>
<tr>
<td>All aerosols in 7th layer (10.5 km)</td>
<td>-19.8</td>
<td>15.3</td>
</tr>
</tbody>
</table>

⇒ (Based on results from the GISS GCM by Menon, 2004 for the China area (18-50N, 90-130E.))
Carbonaceous aerosols - Semidirect effect

Semidirect effect = Total forcing - direct effect
Summary - Future Outlook

Since Menon, Del Genio et al. (2002) our indirect effect estimates are decreasing….

- Importance of atmospheric nucleation in global models (Pirjola et al. 2004).
- Type of convective scheme used -- will affect precipitation space and response due to changes in heating profiles.
- Vertical aerosol distribution -- can change the sign of the semidirect effect.
- Adding aerosol effects on convective clouds as in Nober et al. (2003) -- Net Cloud radiative forcing is almost 0 W m\(^{-2}\) and Net Radiation is smaller by ~0.9 W m\(^{-2}\).
  - Overall greater reduction in cloud property changes and surface temperature response.
- However, aerosol-ice cloud effects and aerosol-mixed phase cloud effects need to be included.
- Heterogeneous chemistry effects to treat internally mixed aerosols.
- Transient runs for atmosphere-ocean coupled models to look at net climate forcing.