Effects of Black Carbon on Temperature Lapse Rates

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Outline

- The historical record: Temperature measurements at the surface and in the mid-troposphere.

- Temperature trend in numerical simulations.

- BC’s role in temperature trend.
Long term surface temperature record shows long and short term variations
Observed Surface Temperature as Inferred by 3 groups
## Surface temperature trend

<table>
<thead>
<tr>
<th>Group</th>
<th>1890-1998 (K/decade)</th>
<th>1979-1998 (K/decade)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jones et al (1999)</td>
<td>0.059</td>
<td>0.19</td>
</tr>
<tr>
<td>Quayle et al (1999)</td>
<td>0.053</td>
<td>0.17</td>
</tr>
<tr>
<td>Hansen et al (1999)</td>
<td>0.053</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Mid troposphere temperature

- The Radiosonde balloon network
  - The radiosonde network operated since the late 1940s, and there are enough data to document global changes after 1960s.
  - The coverage is mainly over land, a few over ocean areas
  - Different trends can be inferred (little or no warming to 0.2K/decade since 1958) depending on the data source, but the purely statistical uncertainty of the signal in individual data sets is large enough to effectively encompass the spread among the data sets (Seidel et al., 2004)
Radiosonde network:
1958 - 1997 Temperature Trends: Radiosonde network

**Fig. 12.** Trends (K decade\(^{-1}\)) in global temperature for 1958–97 for three layers (top) 100–50, (middle) 300–100, (bottom) 850–300 hPa, in four regions, from radiosonde datasets. The confidence intervals shown are the ±1 standard error uncertainty estimates.
Troposphere temperature

- Radiometers on satellite
  - The temperature sounding microwave radiometer (MSU) on NOAA’s polar orbiting weather satellites, started in 1979;
  - MSU measures temperatures in broad atmospheric layers according to the weighting function from different channels.
  - Provides comprehensive global coverage, and consecutive temporal coverage.
MSU Channel 2 temperature

- **Difficulty:**
  
  Rather intricate processing to retrieve the brightness temperature from raw data and must correct for satellite drift and calibration

- **Three independent data sets from the same MSU Channel 2 raw data:**
  
  - Christy and Spencer (UAH), longest history, started from 1990s; Mears and Wentz (Wentz), 2002; Vinnikov and Grody (VG), 2003.
  
  - UAH and Wentz have released 2.5*2.5 gridded data. VG only have the global-averaged time series.
Comparison of UAH global trends and that from radiosonde locations
Comparison of UAH trends and radiosonde trends
MSU temperature trends by different groups:

Santer et al., 2003

Vinnikov and Grody: 0.22 to 0.26 C/decade (79-02)
Comparison of radiosonde and MSU2 trends-Seidel et al. 2004

1979-1997

1979-2001
Comparison of MSU trend and surface trend

msu2 and surface temperature

- Wentz = 0.10 +/- 0.11 °C/decade
- UAH = 0.02 +/- 0.11 °C/decade
- Jones = 0.18 +/- 0.11 °C/decade
Observed difference: surface – MSU

temperature difference(st-msu2)

- Jones-Wentz = 0.05 C/decade
- Jones-UAH = 0.14 C/decade
What do we expect from climate model simulations?

The radiative forcing of climate since 1750 by gases, particles, land use and solar variation.
Model calculated temperature change from external forcing

- Greenhouse gases warm the troposphere more than the surface.

- Stratosphere ozone cools the troposphere more than the surface.

- Sulfate aerosol gives nearly the same cooling at the surface and in the troposphere.

- Absorbing aerosol (black carbon) warms the troposphere more than the surface.
Importance of cooling in the mid-troposphere depends on the relative strength of warming vs cooling
Comparison between observations and simulations

- Averaging method: masked vs. unmasked
- Equivalent MSU2 temperature: weighting function vs. radiative transfer model
Comparison of MSU trend and surface trend

Reported trends have been masked according to availability of surface data
Equivalent MSU2 temperature

- The radiative transfer model (RTM)
  Consider the atmosphere profile change, such as the water vapor. But expensive

- The weighting function (WF)
  Cheap. On a global scale, this method agrees well with the result from RTM. But on a regional scale there may be differences...
Two transient simulations:

- Transient PCM runs include:
  - Greenhouse
  - Sulfate direct
  - Stratosphere + troposphere $O_3$
  - Solar
  - Volcanoes

- Transient CSIRO runs include:
  - Greenhouse
  - Sulfate direct + indirect
  - Stratospheric $O_3$
  - Solar
Spatial pattern for temperature trend at surface (°K/decade) (1979 - 1999)

The model data is masked according the availability of measured surface data
Trend in MSU2 (1979-1999)
The trend difference (surface – mid-troposphere)
What is the role of BC in changing these patterns?

Temperature change from ff carb (Q-flux run, PD-PI):

Cooling in heavy pollution region at surface.
Warming in mid-troposphere.
What is the role of BC in changing these patterns?

- The forcing from BC was not included in the PCM and CSIRO transient runs.
- The absorption of atmospheric aerosol may be stronger than the estimate from IPCC 2001 emissions.

Sato et al (2003): the amount of BC in current model should be increased by a factor of 2-4.

Aerosol absorption over ocean: 3.5-4.5 W/m^2 (Yu et al 2004), 2.5 (2.2-3.1) W/m^2 (Bellouin et al 2003).
Best estimate of aerosol absorption from Polder/Aeronet = 2.5 Wm$^{-2}$ (Range 2.2 – 3.1)

Bellouin et al., 2003
Aerosol absorption in model:
The IPCC emissions model may underestimate BC absorption.
BC emissions from fossil fuel:
Fraction of ff BC+OM temperature change pattern depends on time history of emissions:
ΔEmissions for 1979-1999 are much smaller than those for PD-PI.
Total Emissions and Trends derived using method from Novakov are significantly different than those from Bond.
Effect of forcing on pattern of temperature change is approximated

- Add PCM transient model run with volcanic forcing only to CSIRO transient run
- Add fraction of CSIRO fossil fuel BC+OM pattern to transient trends from PCM and CSIRO models
- Scaling factor: 0.05, 0.10, 0.20
CSIRO model:
Surface temperature trend and pattern
PCM model:
Surface temperature trend and pattern
CSIRO trend: Comparison to UAH MSU2 trend
CSIRO trend: Comparison to Wentz MSU2 trend
PCM trend: Comparison to Wentz MSU2 trend

Wentz
Mean 0.124

PCM VGSSuO+ffc
Mean 0.090

PCM VGSSuO+0.1ffc
Mean 0.095

PCM VGSSuO+0.2ffc
Mean 0.106
## Global average trend (°K/decade)

<table>
<thead>
<tr>
<th></th>
<th>Surface</th>
<th>Wentz MSU2 (UAH)</th>
<th>Surface – MSU2 (UAH)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Observed</strong></td>
<td>0.18</td>
<td>0.12 (0.04)</td>
<td>0.05 (0.14)</td>
</tr>
<tr>
<td>CSIRO GSuOS</td>
<td>0.16</td>
<td>0.14</td>
<td>0.02</td>
</tr>
<tr>
<td>CSIRO + PCM Volcano</td>
<td>0.14</td>
<td>0.11</td>
<td>0.03</td>
</tr>
<tr>
<td>CSIRO + PCM Volcano + 0.2 ffc</td>
<td>0.14</td>
<td>0.13</td>
<td>0.01</td>
</tr>
<tr>
<td>PCM VGSSuO</td>
<td>0.14</td>
<td>0.08</td>
<td>0.06</td>
</tr>
<tr>
<td>PCM + 0.2 ffc</td>
<td>0.15</td>
<td>0.11</td>
<td>0.04</td>
</tr>
</tbody>
</table>
Conclusions

- Current results are consistent with the magnitude and pattern of temperature change at the surface and MSU2 levels.

- There is better agreement between both the PCM model and the CSIRO model and the Wentz data for MSU2 than with that from UAH.

- Improvements should include the effect of BC absorption on ice and snow albedos and a transient simulation that includes the time history of BC emissions.