Multi-decadal variations of atmospheric aerosols: Sources, transport, and effects on surface radiation

– MAP project

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Project:

- We propose a hindcast investigation on multi-decadal changes (1980–2010) of atmospheric aerosols and their effects on surface radiation, using the GOCART model and long-term observations from satellite and ground-based sites.
Global dimming and brightening

- Long-term observations of surface solar radiation reaching the surface, $S_{sfc}$, in the past few decades have shown a widespread general decreasing trend from 1950s until about 1990 – dimming.

- Measurements after 1990 have shown a transition from “dimming” to “brightening” (or less dimming) since about 1990.

- What is the role of aerosols?
Anthropogenic emission trends, 1980-2006

U.S.

- BC*30
- OC*10
- SO2

OECD Europe

- BC*30
- OC*10
- SO2

East Asia

- BC*30
- OC*10
- SO2

South Asia

- BC*30
- OC*10
- SO2
Global and regional aerosol trends

AVHRR global average AOD over ocean, 1981-2006

AOD over ocean, 2000-2006

Figure from G.

Figure from Mishchenko et al.,
Objectives

- Analyzing long-term global and regional aerosol trends and their relationship to the changes of aerosol and precursor emissions

- Assessing the role aerosols play in the multi-decadal change of solar radiation reaching the surface (known as “dimming” or “brightening”) at different regions of the world

- Investigating the intercontinental source-receptor relationships controlled by emission, transport pathway, and climate variability
Approach – Using model and data

- **Model:**
  - GOCART model using MERRA products
  - Parallel runs with off-line (CTM) and on-line (replay) version
  - Spatial resolution at 1.25° longitude x 1° latitude
  - Using prescribed oxidant fields from Retro and GMI for sulfur chemistry
  - Time-varying emissions of aerosols and their precursors
Emissions, 1980-2010

- Anthropogenic emissions of SO2, BC, and OC:
  - Streets et al., 2006, 2009; Bond et al., 2004
  - IPCC AR5 hindcast emissions

- Biomass burning emissions of SO2, BC, and OC:
  - Combination of Duncan (1980-2000) and GFED (1997-present) with Duncan emission adjusted based on the Duncan/GFED overlap time (1997-2000)

- Volcanic emissions of SO2:
  - Estimating from Global Volcanism Program (GVP) database of eruption date, duration, VEI
  - Replacing the estimated amount with TOMS and OMI SO2
Volcanic and biomass burning emissions

SO\textsubscript{2} emission from volcanoes, Tg/yr

OC emission from fire, Tg/yr

(Figure from Thomas Diehl)
Dust emissions

- Currently, dust emission in the GOCART model is calculated as:

\[ E_p = C S f_p u_{10}^2 (u_{10} - u_t) \]

- The source function \( S \) is the probability of dust uplifting (0-1) based on the Ginoux scheme (topography scheme, bare surface, topographically depressed area).

- \( p \): bin of particle size
- \( C \): dimensionless factor
- \( S \): source function
- \( f_p \): fraction of particle size \( p \)
- \( u_{10} \): horizontal wind at 10 m
- \( u_t \): threshold wind velocity (wind speed, soil moisture)
Development of a dynamic dust source function

1. Using 8-km resolution AVHRR NDVI data to create global 1°x1° percentage bareness map:
   - Choosing threshold NDVI = 0.15
   - % bareness = no. of 8-km NDVI<0.15 / total no. of 8-km data within the 1°x1° gridbox

2. Screening out the bare surfaces which are not dust source – using FAO soil depth map

3. Masking with ground temperature – if the ground is frozen then the possibility of dust mobilization is 0

4. Combining with topographic features
Example: January 2001

1. Percentage bareness

2 & 3. Masked with soil depth and T\textsubscript{g}

4. Masked with topographic feature

Global dust source S
Seasonal cycle over Australia 2005 – 2006

The dynamic dust source captures the dust minimum much better during the growing season.

Figures from: David Zheng Huisheng Bian
## Table 2. Planned model experiments for this study.

<table>
<thead>
<tr>
<th>Exp.</th>
<th>Period</th>
<th>Model Setup</th>
<th>Relevant Results</th>
<th>Purpose</th>
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<tbody>
<tr>
<td>ST</td>
<td>1980 – 2010</td>
<td>Model run with time-varying emissions from all sources</td>
<td>Long-term variations of aerosol composition, concentration, AOT, SSA, and downward $S_{sfc}$</td>
<td>Analyzing trends of concentration, AOT, SSA, and aerosol effects on $S_{sfc}$</td>
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<tr>
<td>NA</td>
<td>1980 – 2010</td>
<td>Model run with time-varying natural emissions from dust, sea-salt, volcanic, biogenic terrestrial and oceanic sources</td>
<td>Same as above but with natural and anthropogenic aerosols separated (Anthrop = ST – NA)</td>
<td>Assessing changes of aerosol levels and effects from natural and anthropogenic (including biomass burning) sources</td>
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<td>CL</td>
<td>1980 – 2010</td>
<td>Model run with repeating 1995 emissions but time-varying meteorological fields</td>
<td>The change of aerosols induced by meteorology</td>
<td>Understanding the controlling factors of climate variability and emissions on aerosols levels in regional and global scales</td>
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<tr>
<td>SR</td>
<td>1980 – 2010 in 5-yr intervals</td>
<td>Model run with tagged pollution sources from North America, Europe, Asia, and biomass burning sources from boreal and non-boreal regions</td>
<td>Aerosols from different pollution source regions and biomass burning areas</td>
<td>Elucidating the variability of source-receptor relationships at various stages of regional development</td>
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</tbody>
</table>
Climate variability

Ocean Nino Index

NAO Index

Source: NOAA CPC website
Data

- Long-term surface radiation data:
  - GEBA (Global Energy Balance Archive)
  - BSRN (Baseline Solar Radiation Network)
  - NOAA GMD
  - SRB (Surface Radiation Budget, satellite-based)

- Long-term aerosol data:
  - AVHRR, TOMS (longest record since 1980, less accurate)
  - MODIS, MISR, OMI (starting 2000s, more accurate)
  - AERONET
  - IMPROVE, AQS, EMEP, U. Miami concentration data

- Aircraft data
# 4-year schedule (with 1.3 FTE)

<table>
<thead>
<tr>
<th>Activity</th>
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<th>Year 3</th>
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<td>Estimating anthropogenic and volcanic emissions, emission data compilation</td>
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<td>Standard simulation (ST)</td>
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<td>Natural &amp; anthropogenic simulation (NA)</td>
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<td>Climate variability simulation (CL)</td>
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<td>Source-receptor simulation (SR)</td>
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<td>Model evaluation with satellite, ground-based, and aircraft data</td>
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<td>Analyzing aerosol and surface radiation trends</td>
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<td>Analyzing emission, AOT, and $S_{sfc}$ relationships</td>
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<tr>
<td>Analyzing source-receptor relationships</td>
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<tr>
<td>Analyzing climate variability and transport</td>
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