Evaluating the Impact of Aerosols on Numerical Weather Prediction

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with input from Saulo Freitas, Angela Benedetti and many participants
Goals of Exercise
Proposed case studies
Participating Centers & modeling systems
Webpage and analysis tool
Preliminary results
  - Case 1: Dust Storm over Egypt
  - Case 2: Extreme Pollution Event in China
  - Case 3: Biomass Burning
Concluding Remarks
Aerosol Direct effect

Mostly Scattering Aerosol

- Solar Radiation Scattered to Space

- Less Solar Radiation Reaches Surface

- Surface Radiative Cooling

(e.g. sulfate, sea salt aerosols)

Mostly Absorbing Aerosol

- Solar Radiation Absorbed by Aerosol Layer

- Atmospheric Radiative Warming

- Less Solar Radiation Reaches Surface

- Surface Radiative Cooling

(e.g. black carbon, dust aerosols)

Animation by C. A. Randles
Aerosol INDIRECT effect

Larger cloud droplets, less reflective cloud. **Less Aerosols**
Larger cloud droplets, droplets rain out easier, clouds dissipate quicker.

Twomey Effect

Smaller cloud droplets, more reflective cloud. **More Aerosols**
Smaller cloud droplets, droplets rain out less, longer-lived clouds.

Albrecht Effect

Animation by C. A. Randles
Widespread absorbing aerosol layers can impact large-scale circulation and precipitation patterns like the Indian Monsoon (e.g. Ramanathan and Carmichael, *Nature*, 2008).
1. How important are aerosols for predicting the physical system (NWP, seasonal, climate) as distinct from predicting the aerosols themselves?
2. How important is atmospheric model quality for air quality forecasting?
3. What are the current capabilities of NWP models to simulate aerosol impacts on weather prediction?

* WGNE is a Joint Working Group of the Commission for Atmospheric Sciences and the World Climate Research Programme.
Select strong or persistent events of aerosol pollution worldwide that could be fairly represented in the current NWP model allowing the evaluation of aerosol impacts on weather prediction.

- Perform model runs both including and not the feedback from the aerosol interaction with radiation and clouds.

- Evaluate aerosol simulation
  - AOD or related parameter
  - Verification: AERONET, MODIS, MISR

- Evaluate aerosol impact on meteorology:
  - 2-meter temperature, dew point temperature, 10-meter wind
  - rainfall, surface energy budget, etc.
### Protocol: Variables

- **Variables to compare:**

<table>
<thead>
<tr>
<th>Variable name on 3 hours interval</th>
<th>Dimensionality</th>
<th>units</th>
<th>obs</th>
</tr>
</thead>
<tbody>
<tr>
<td>2m-Temperature</td>
<td>x,y</td>
<td>K</td>
<td></td>
</tr>
<tr>
<td>10m-wind direction and magnitude</td>
<td>x,y</td>
<td>Degree m/s</td>
<td></td>
</tr>
<tr>
<td>Aerosol optical depth at 550 nm</td>
<td>x,y</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>total aerosol mass column integrated</td>
<td>x,y</td>
<td>Kg/m²</td>
<td></td>
</tr>
<tr>
<td>Precipitation (from convective parameterization)</td>
<td>x,y</td>
<td>mm</td>
<td></td>
</tr>
<tr>
<td>Precipitation (from cloud microphysics at grid scale)</td>
<td>x,y</td>
<td>mm</td>
<td></td>
</tr>
<tr>
<td>shortwave and longwave downwelling radiative flux at the surface.</td>
<td>x,y</td>
<td>W/m²</td>
<td></td>
</tr>
<tr>
<td>temperature tendency associated to the total radiative flux divergence.</td>
<td>x,y,z</td>
<td>K/s (or dy)</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>x,y,z</td>
<td>K</td>
<td></td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>x,y,z</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Cloud drop number concentration</td>
<td>x,y,z</td>
<td>cm⁻³</td>
<td></td>
</tr>
</tbody>
</table>

- Output should be using a lat-lon rectangular grid. The preferred format is NETCDF.
# Protocol: Experiments

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Direct Effect</th>
<th>Indirect Effect</th>
<th>No aerosol Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Participants</td>
<td>Case 1</td>
<td>Case 2</td>
<td>Case 3</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>CPTEC</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>JMA</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>ECMWF</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Météo-France/Met. Serv. Algeria</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESRL/NOAA</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>NASA/Goddard</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>NCEP</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barcelona Super. Ctr.</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\( \text{X} = \text{data not yet available for processing or analyzed} \)
<table>
<thead>
<tr>
<th>Institution Model</th>
<th>Domain Resolution</th>
<th>Aerosol Species</th>
<th>A &amp; BB Emissions</th>
<th>Aerosol Physics</th>
<th>Cloud Physics</th>
<th>Aerosol Assimilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPTEC BRAMS LAM+CCAT</td>
<td>Regional 10 km</td>
<td>BC, Sea-Salt, OC, SO4</td>
<td>EDGAR 4.3BEM</td>
<td>bulk</td>
<td>2-mom</td>
<td>no</td>
</tr>
<tr>
<td>JMA MASINGAR</td>
<td>Global TL319L40</td>
<td>Dust, Sea-Salt, BC, OC, SO4</td>
<td>MACCity GFAS 1.0</td>
<td>2-mom</td>
<td>2-mom</td>
<td>no</td>
</tr>
<tr>
<td>ECMWF Global</td>
<td>Global T511L60</td>
<td></td>
<td>Bulk</td>
<td>Bulk</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td>Météo-France ALADIN + ORILAM</td>
<td>Regional 7.5 km</td>
<td>Dust</td>
<td>DEAD model</td>
<td>3-mom log-normal</td>
<td>Bulk</td>
<td>no</td>
</tr>
<tr>
<td>ESRL/NOAA WRF</td>
<td>Regional cloud res.</td>
<td>(many)</td>
<td>EDGAR 4.3BEM</td>
<td>Bulk and Modal</td>
<td>2-mom</td>
<td>no</td>
</tr>
<tr>
<td>NASA/GSFC GEOS-5+GOCART</td>
<td>Global 25 km</td>
<td>Dust, Sea-Salt, BC, OC, SO4</td>
<td>EDGAR 4.1 QFED 2.4</td>
<td>Bulk modal</td>
<td>Bulk or 2-mom MG</td>
<td>yes</td>
</tr>
<tr>
<td>NCEP NGAC+GOCART</td>
<td>Global T126</td>
<td>Dust, Sea-Salt, BC, OC, SO4</td>
<td>Climatological Aerosols</td>
<td>Bulk</td>
<td>Bulk</td>
<td>no</td>
</tr>
<tr>
<td>Barcelona SC</td>
<td>regional</td>
<td>dust</td>
<td>BSC-dust model</td>
<td>8 dust size bins</td>
<td>Same as in WRF</td>
<td>no</td>
</tr>
</tbody>
</table>
1) Dust over Egypt: 4/2012
2) Pollution in China: 1/2013
3) Smoke in Brazil: 9/2012
Website
http://meioambiente.cptec.inpe.br/wgne-aerosols/

Webpage hosted by CPTEC for data analysis and visualization

Developed by M. Zarzur
Case 1
Dust Plume over Egypt

- 18 April 2012
- Forecasts
  - April 13-23 2012
  - From 0 or 12 UTC
  - 10 day forecasts
- Center of domain
  - 30E, 25N
- Model configuration
  - Same as for NWP
- Direct effects only
Case 1: Dust
JMA & NASA AOD Forecast

(A) JMA – AOD @ 550nm

(B) NASA – AOD @ 550nm – 00Z16APR2012
AOD Forecast (JMA)
valid at 09UTC 18 April 2012

Aerosol Optical Depth at 550nm
JMA (with interactive aerosols)
Forecast: 09Z18apr2012
Started: 00Z16APR2012

57 hour forecast

Aerosol Optical Depth at 550nm
JMA (with interactive aerosols)
Forecast: 09Z18apr2012
Started: 00Z17APR2012

33 hour forecast

Aerosol Optical Depth at 550nm
JMA (with interactive aerosols)
Forecast: 09Z18apr2012
Started: 00Z18APR2012

9 hour forecast
AOD Forecast (ECMWF) valid at 09UTC 18 April 2012

Aerosol Optical Depth at 550nm
ECMWF (direct effect only)
Forecast: 09Z18APR2012
Started: 00Z16APR2012

57 hour forecast

Aerosol Optical Depth at 550nm
ECMWF (direct effect only)
Forecast: 09Z18APR2012
Started: 00Z17APR2012

33 hour forecast

Aerosol Optical Depth at 550nm
ECMWF (direct effect only)
Forecast: 09Z18APR2012
Started: 00Z18APR2012

9 hour forecast
AOD Forecast (NASA) valid at 09 UTC 18 April 2012

Aerosol Optical Depth at 550nm NASA (with interactive aerosols)
Forecast: 09Z18Apr2012
Started: 00Z16APR2012

Aerosol Optical Depth at 550nm NASA (with interactive aerosols)
Forecast: 09Z18APR2012
Started: 00Z17APR2012

Aerosol Optical Depth at 550nm NASA (with interactive aerosols)
Forecast: 09Z18Apr2012
Started: 00Z18APR2012
AOD Forecast (Barcelona) valid at 09 UTC 18 April 2012

Aerosol Optical Depth at 550 nm
BSC (with interactive aerosols)
Forecast: 09Z18APR2012
Started: 00Z16APR2012

57 hour forecast

Aerosol Optical Depth at 550 nm
BSC (with interactive aerosols)
Forecast: 09Z18APR2012
Started: 00Z17APR2012

33 hour forecast

Aerosol Optical Depth at 550 nm
BSC (with interactive aerosols)
Forecast: 09Z18APR2012
Started: 00Z16APR2012

9 hour forecast
AOD Forecast (MeteoFrance) valid at 09UTC 18 April 2012

Aerosol Optical Depth at 550nm
Meteo France (with interactive aerosols)

Forecast: 09Z18Apr2012
Started: 00Z17Apr2012

33 hour forecast

9 hour forecast

20E 22E 24E 26E 28E 30E 32E 34E 36E 38E 40E
20N 22N 24N 26N 28N 30N 32N 34N 36N 38N

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1 1.2 1.3 1.4 1.5 2
AOD 550nm Intercomparison

\[ \tau_{\text{MF}} > \tau_{\text{JMA}} \sim \tau_{\text{ECMWF}} \sim \tau_{\text{NASA}} \sim \tau_{\text{Barcelona}} \]
LW Rad @ Sfc Impact (Aero-NoAero)

- 0 UTC (night time)
- JMA misses LW signal
- ECMWF: stronger

48 hour forecast
T\textsubscript{2m} Impact
Aero-NoAero

- 0 UTC (night time)
- ECMWF shows stronger impact

48 hour forecast
- 9 UTC (morning)
- ECMWF and BSC indicate an increase in SW around the plume
T$_{2m}$ Impact Aero-NoAero

- 12 UTC (day time)
- ECMWF net warming may be a residual effect from the night

36 hour forecast
U_{10m} Impact Aero-NoAero

- o UTC (night time)

48 hour forecast
AOD Impact Aero-NoAero

- 0 UTC (night time)

48 hour forecast
Case 2
Extreme Pollution in Beijing

- January 2013
- Forecasts
  - January 7-21 2013
  - From 0 or 12 UTC
  - 10 day forecasts
- Center of domain
  - 116E, 40N
- Model configuration
  - Same as for NWP
- **Direct & Indirect effects**

So far, only JMA has submitted Indirect Effect experiments.
Case 2
Extreme Pollution in Beijing
Case 2: Pollution in China
JMA & NASA Forecasts

(A) JMA – AOD @ 550nm

(B) NASA – AOD @ 550nm – 00Z12JAN2013
AOD 550nm Intercomparison 3 UTC 14 Jan 2013 (51h)

- NCEP Climatology does not capture this event (as expected)
- ECMWF event relatively weak compared to NASA/JMA
3 UTC (day time)

Except for ECMWF, aerosol impact is to reduce SW in astern Asia

The role BC/OC vs SO4 needs to be examined (but no speciation data provided)
3 UTC (day time)

Relatively modest surface cooling, except for NASA
LW Radiation @ Surface Impact (Aero-NoAero) 15 UTC 14 Jan 2013 (72h)

- 15 UTC (night time)
- Very little aerosol impact on surface LW along the plume.
- Predominance of non-absorbing aerosols in these models?
- 15 UTC (night time)
- Consistently, not much of a surface temperature impact
So far, only JMA has submitted these cases
AOD 550 nm (JMA) 3 UTC 14 Jan 2013

DIRECT ONLY

Aerosol Optical Depth at 550nm
JMA (direct effect only)
Forecast: 03Z14JAN2013
Started: 00Z12JAN2013

DIRECT+INDIRECT

Aerosol Optical Depth at 550nm
JMA (with interactive aerosols)
Forecast: 03Z14JAN2013
Started: 00Z12JAN2013
Precipitation (Cloud Microphysics)
3 UTC 14 Jan 2013

Direct only – no aerosol

DIRECT+INDIRECT – NO AERO
Direct only – no aerosol

Direct + Indirect – NO AERO
Direct only – no aerosol

Direct+Indirect – NO AERO
Direct only – no aerosol

DIRECT+INDIRECT – NO AERO

Temperature at 2m
JMA (DE – XA)
Forecast: 15214JAN2013
Started: 00212JAN2013

Temperature at 2m
JMA (IA – XA)
Forecast: 15214JAN2013
Started: 00212JAN2013
Case 3
Persistent Smoke in Brazil

- September 2012
- Forecasts
  - September 5-15, 2012
  - From 0 or 12 UTC
  - 10 day forecasts
- Center of domain
  - 116E, 40N
- Model configuration
  - Same as for NWP
- Direct & Indirect effects

Fire Counts
September

62 099 hot spots
Concluding Remarks

- WGNE Exercise on Aerosol Impact on NWP is under way
  - Mostly direct effect cases have been submitted
  - Analysis of results progressing
    - Goal: Report by end of 2014, journal article by Q1/Q2 2014
  - There is still time for new participants!
- From these early results
  - Models show some skill in capturing aerosol events
  - Aerosol Direct Radiative forcing not consistent among all models
  - Likewise, near surface wind/temperature response vary
- Further analysis required, e.g.,
  - Validation by independent aerosol and meteorological data
  - Limited assessment of forecast skills
- Leading to refinement of the protocol for phase II.