Investigation of African and Asian dust events using NOAA global forecasts

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Outline

- Introduction
- Analyses of dust events
  - African (Saharan) dust event
  - Asian dust event
- Dynamic boundary conditions for regional AQ forecast
- Summary
Introduction

- For the continual U.S., the predominant long-range transport dusts were mainly from African and Asian region
- Since NOAA global forecasts (NGAC) provides routine global forecast of dust, the long-range transport of dust can be investigated
- The NGAC output can provide more realistic (dynamic) boundary conditions for regional air quality forecasts of aerosols, especially for the dust event prevailing season

Objective

- Understand the African and Asian dusts and their long-range transport
- Evaluate the influence of African and Asian dust events on the U.S.
## Data sources

<table>
<thead>
<tr>
<th>Data type</th>
<th>Data pool</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-situ observation</td>
<td><strong>AERONET</strong> Level 1.5 from NASA GSFC</td>
</tr>
<tr>
<td>Satellite data</td>
<td><strong>VIIRS</strong> from NOAA STAR (0.25°x0.25° gridded)</td>
</tr>
<tr>
<td></td>
<td><strong>MODIS</strong> Aqua from GES DISC (Giovanni) (1°x1° gridded)</td>
</tr>
<tr>
<td>Modeling data (1°x1°)</td>
<td><strong>NGAC</strong> from NCEP (prod v1 and upcoming v2)</td>
</tr>
<tr>
<td></td>
<td><strong>ICAP-MME</strong> ensemble from US NRL</td>
</tr>
<tr>
<td></td>
<td>(based on four comprehensive aerosol models, ECMWF MACC, JMA MASINGAR,</td>
</tr>
<tr>
<td></td>
<td>NASA GSFC/GMAO GEOS-5, FNMOC/NRL NAAPS, and three dust-only models,</td>
</tr>
<tr>
<td></td>
<td>NOAA NGAC, Barcelona Supercomputing Centre NMMB/BSC-CTM and UKMO</td>
</tr>
<tr>
<td></td>
<td>unified model)</td>
</tr>
<tr>
<td></td>
<td><strong>GEOS-5</strong> from NASA GSFC</td>
</tr>
</tbody>
</table>

- The NGAC-simulated dust events will be evaluated with AOD observations from in-situ (AERONET) and satellite (VIIRS/MODIS) measurements, as well as AOD analysis from other centers (ICAP-MME, GEOS-5)
- Dust events are reported by forecast/observatory/AQ websites

**OMPS**: Ozone Mapping & Profile Suite  
**BDFC**: Barcelona dust forecast center 
**EO**: Earth Observatory  
**UMBC**: UMBC smog blog  
**EUMS**: European organization for the exploitation of Meteorological Satellites
The Saharan dust is seen stretching across the Caribbean Sea, northwestward into the Gulf of Mexico and over southern Florida.

The Saharan dust appears to also be mixing with a large area of smoke in the western Gulf of Mexico.

AOD retrievals over the Gulf and the southeastern U.S. shows AOD values ranging from 0.2-0.6 (top fig.)

Over the last few days (May 10-12) a nice example of Saharan dust moving out to the Atlantic (bottom fig.)
• The AERONET AOD were compared with NGAC, ICAP-MME and GEOS5 dust AOD near source region and the downwind region
Daily total and dust AOD on May 1-15 2015 (dust event: May 10-14)

- The VIIRS and MODIS AOD were compared with NGAC, ICAP-MME and GEOS5 dust AOD across the Atlantic
The Saharan dust is distributed from the surface to the aloft dust layer.

Dust extends back to surface on the U.S. east coast, affecting air quality.
Asian dust – Apr 1, 2015

Earth Observatory | Ozone Mapping & Profile Suite | Apr 1, 2015
- Dust scattered between Taklamakan Desert and the east coast of China (left).
- A large and intense dust cloud can be seen just over and to the east of Beijing.
- Sometimes dust from these storms reaches North America and are detected all the way to the east coast.

UMBC Smog Blog | Apr 6, 2015
The MODIS Terra image (right) notes elevated AOD over northern Wyoming, crossing over into southern Canada over Quebec, Ontario, and Manitoba. The HMS Fire and Smoke text believes this to be an episode of elevated Asian dust.
The AERONET AOD were compared with NGAC, ICAP-MME and GEOS5 dust AOD near source region and the downwind region.
• The Asian dust events are associated with more complicated composition of aerosol properties.
In Asian dust events, there is very little dust from aloft reaches surface layer, so impact on air quality is minimal.

(NGAC total aerosol cross section on Mar 20-Apr 7 2015 (dust event: Apr 1))
The elevated daily PM$_{2.5}$ concentrations (> 35 μg/m$^3$) and AOD indicated the dust intrusion event associated with long-range Saharan dust transport.
NAM-CMAQ PM$_{2.5}$ run

- NAM-CMAQ operation runs with static LBCs/22-layer (prod) and dynamic LBCs from NGAC/35-layer (para1)
- The CMAQ para1 shows better agreement with the observed PM$_{2.5}$ values
Summary

- In megacities, both local emissions and long-range transport pollutions affect local air quality

- For Saharan dust event:
  - At source region, NGAC dust AOD are comparable with OBS total AOD
  - Dust is distributed from the surface to the aloft dust layer. There is dust near the ground when the event reaches the east coast, affecting air quality

- For Asian dust event:
  - The Asian dust events are associated with more complicated composition of aerosol properties (i.e., air pollution)
  - There is very little dust below the dust layer when reaching west coast of U.S. and, thus, poses minimal impact on air quality

- Improvement of regional AQ forecasts with dynamic boundary conditions from NGAC can be demonstrated
Thanks.

Questions and Comments?
Backup slides
# Highlight dust events in 2015

Only the dust events affecting U.S. are selected

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
<th>Source/Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feb 28, 2015</td>
<td>West Africa dust</td>
<td>EO</td>
</tr>
<tr>
<td>April 11, 2015</td>
<td>Mid Africa (Sahel) dust</td>
<td>EUMETSAT</td>
</tr>
<tr>
<td>April 20, 2015</td>
<td>Saharan dust (+smoke)</td>
<td>OMPS</td>
</tr>
<tr>
<td>May 10-14, 2015</td>
<td>West Africa dust (+smoke)</td>
<td>UMBC, OMPS</td>
</tr>
<tr>
<td>Jun 17, 2015</td>
<td>Saharan dust</td>
<td>UMBC, OMPS</td>
</tr>
<tr>
<td>Jun 21-26, 2015</td>
<td>Saharan dust</td>
<td>UMBC</td>
</tr>
<tr>
<td>Jul 1-2, 2015</td>
<td>Saharan dust</td>
<td>UMBC</td>
</tr>
<tr>
<td>Jul 7-10, 2015</td>
<td>Saharan dust</td>
<td>UMBC</td>
</tr>
<tr>
<td>Jul 13-14, 2015</td>
<td>Saharan dust</td>
<td>UMBC</td>
</tr>
<tr>
<td>Jul 20-23, 2015</td>
<td>Saharan dust</td>
<td>UMBC</td>
</tr>
<tr>
<td>Apr 1-6, 2015</td>
<td>Asian dust</td>
<td>EO, EUMETSAT, OMPS, UMBC</td>
</tr>
<tr>
<td>Apr 27, 2015</td>
<td>Asian dust</td>
<td>EUMETSAT</td>
</tr>
</tbody>
</table>

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**EO**: Earth Observatory  
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NGAC evaluation and verification

NGAC vs. AERONET (2013-2014)

<table>
<thead>
<tr>
<th>Site</th>
<th># of monthly mean compared</th>
<th>Correlation coefficient</th>
<th>Bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEDE_BOKER</td>
<td>24</td>
<td>0.78</td>
<td>-0.04</td>
</tr>
<tr>
<td>Solar_Village</td>
<td>15</td>
<td>0.83</td>
<td>-0.11</td>
</tr>
<tr>
<td>Banizoumbou</td>
<td>24</td>
<td>0.64</td>
<td>-0.00</td>
</tr>
<tr>
<td>Ilorin</td>
<td>16</td>
<td>0.56</td>
<td>-0.31</td>
</tr>
<tr>
<td>Capo_Verde</td>
<td>24</td>
<td>0.92</td>
<td>0.03</td>
</tr>
<tr>
<td>Dakar</td>
<td>24</td>
<td>0.91</td>
<td>0.02</td>
</tr>
<tr>
<td>La_Parguera</td>
<td>24</td>
<td>0.80</td>
<td>-0.08</td>
</tr>
</tbody>
</table>
The AERONET AOD were compared with NGAC, ICAP-MME and GEOS5 dust AOD near source region and the downwind region.
Dynamic boundary conditions for regional AQ forecast

NGAC dust AOD

024-hr AOD fcst; Initialized from 00Z 2015-05-07

NGAC surface dust concentration

024-hr SMASS fcst (µg/m^3); Initialized from 00Z 2015-05-07

- 24, 48, 72-hr forecast of NGAC AOD and surface concentration (initialize from May 7)
- The NGAC results showed clear long-range dust transport reaching the continental US
Daily total ADO on Mar 20-Apr 7 2015 (dust event: Apr 1)

AOD550nm daily MOD vs. OBS on 2015MAR20

• The VIIRS and MODIS AOD were compared with NGAC, ICAP-MME and GEOS5 dust AOD across the Pacific
## NGACv1 and NGACv2 (Q4FY15)

<table>
<thead>
<tr>
<th></th>
<th>NGACv1</th>
<th>NGACv2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust and Emission</td>
<td>GOCART emission (Paul Ginux)</td>
<td>SS emission update (GOCART emission)</td>
</tr>
<tr>
<td></td>
<td>Annual global biomass emission (2010)</td>
<td>real-time biomass emission (GBBPEx)</td>
</tr>
<tr>
<td>GFS-physics</td>
<td>Eulerian</td>
<td>semi-Lagrangian</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(trace not conserve)</td>
</tr>
<tr>
<td>convection</td>
<td>SAS (Simplified Arakawa-Schubert)</td>
<td>RAS (Relaxed Arakawa-Schubert scheme)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aerosol</td>
<td>DU</td>
<td>full aerosol (DU, SS, SU, BC, OC)</td>
</tr>
<tr>
<td>Chem module</td>
<td>GOCART</td>
<td>updated GOCART</td>
</tr>
</tbody>
</table>
Q1FY16 upgrade: Multi-species forecast using near-real-time smoke emissions from satellites

Temporal and spatial variation in smoke emissions from GBBEPx

GBBEPx: Global Biomass Burning Emissions Product-eXtended, blended from Geo (NESDIS’s smoke products) and Polar (GSFC’s smoke products)
FY17 Upgrade: Improving NCEP global aerosol forecasts using JPSS S-NPP VIIRS aerosol products

**The Scope of the Project**

**NOAA Model**
- NEMS GFS Aerosol Component (NGAC)

**Satellite Observations**
- Aerosol observations from S-NPP VIIRS

**NOAA DA System**
- First guess
- The hybrid EnKF-GSI system
- New capability to assimilate aerosol optical depth (AOD) observations

**NOAA Products**
- New product: Aerosol analysis for multi-species

**Aerosol Data Assimilation**
- Values and benefits
  - Provide initialization for aerosol forecasts and thus improve aerosol forecast skills
  - Support NCEP’s efforts to develop an unified global coupled data assimilation and modeling suite
- Observations: VIIRS AOD initially; extended to use multi-sensor/multi-platform aerosol observations
Prognostic aerosols (GOCART) in candidate dynamic core

- Implementation and Testing of Regional and Global Dust Forecasting (Ginoux, GFDL)
- Using Advanced Photochemical and Aerosol Modules to Verify the Applicability of GOCART Aerosol Modules within Global Weather Prediction Models (Grell, ESRL)

Aerosols and weather/precipitation

- Investigation of Aerosol Effects on Weather Forecast using NCEP Global Forecast System (Lu, SUNYA)
- Evaluating the Impact of Cloud-Aerosol-Precipitation Interaction (CAPI) Schemes on Rainfall Forecast in the NGGPS (Li, U Md)

Upgraded to modal aerosol model

- Improving Cloud Microphysics and Their Interactions with Aerosols in the NCEP Global Models (Lu, SUNYA)
Improving Cloud Microphysics and Their Interactions with Aerosols in the NCEP Global Models

- Objective: Improve the representation of aerosol processes, cloud microphysics, and aerosol-cloud-radiation interaction in NCEP global models
- SUNYA-NCEP-GSFC collaborative efforts to upgrade NEMS physics suite by adapting GSFC’s physically-based aerosol and cloud microphysics package (which in turn is based on NCAR CAM5)
- While this project is funded by MAPP-Climate Test Bed (CTB), the development work is closely aligned with the NGGPS’s efforts to advance physical parameterization suite in NEMS
Improving cloud microphysics and their interactions with aerosols in the NCEP global models (cont’d)

**Primary outcome: NEMS physics suite improvement**
Adapting physically-based aerosol and cloud microphysics package to improve aerosol-cloud-radiation interaction in NEMS physics

**Secondary outcome: infrastructure upgrade**
Introducing a generic chemistry component (containing GOCART and MAM) which can be easily extended to include GEOS-5 tropospheric and stratospheric chemistry

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Integrated into GSM physics

**Coupling of macrophysics and microphysics**

**Cloud droplet activation & Ice nucleation**

**Two-moment MG cloud microphysics**

**Two-moment Modal Aerosol Module**

Adopting GEOS-5 aerosol-cloud package

**Atmos Component**
- Atm Dyn
- Atm Phys
- Aerosols
  - GOCART

**Chem Component**
- Bulk model
- Modal model
  - MAM-7

ESMF Coupler linking Phys and GOCART

ESMF Coupler linking Phys and Chem

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7th International Workshop on Air Quality Forecasting Research, College Park, MD, Sep 2th 2015
In-line chemistry advantage

- **Consistency**: no spatial-temporal interpolation and same physics parameterization
- **Efficiency**: lower overall CPU costs and easier data management
- **Interaction**: Allows for feedback to meteorology

**GOCART diagram provided by Peter Colarco (GSFC)**
The Modal Aerosol Module (MAM)

- A Modal Aerosol Module (MAM, Liu et al., 2012) has been developed for the Community Atmosphere Model version 5 (CAM5), the atmospheric component of the Community Earth System Model version 1 (CESM1).
- MAM is capable of simulating the aerosol size distribution and both internal and external mixing between aerosol components, treating numerous complicated aerosol processes and aerosol physical, chemical and optical properties in a physically-based manner.

Aerosol components
- Sulfate
- Black carbon (BC)
- Dust
- Sea salt
- Ammonium
- Primary organic
- Secondary organic

Aerosol modes
1. Aitken
2. Accumulation
3. Primary carbon
4. Fine sea-salt
5. Fine dust
6. Coarse sea salt
7. Coarse dust

Aerosol microphysics
- Nucleation (H$_2$SO$_4$-NH$_3$-H$_2$O and BL nucleation)
- Coagulation (intra- and intermodal of AIT, ACC, PCM)
- Condensation(H$_2$SO$_4$, NH$_3$ and SOA(g))
- Gas-aerosol exchange
Configuration of MAM7

**Aitken**
- number
- sulfate
- ammonium
- secondary OM
- sea salt

**Accumulation**
- number
- sulfate
- ammonium
- secondary OM
- primary OM
- BC
- sea salt

**Fine Dust**
- number
- dust
- sulfate
- ammonium

**Fine Sea Salt**
- number
- sea salt
- sulfate
- ammonium

**Primary Carbon**
- number
- primary OM
- BC

**Coarse Dust**
- number
- dust
- sulfate
- ammonium

**Coarse Sea Salt**
- number
- sea salt
- sulfate
- ammonium

Two attachment states:
- **a) interstitial** - suspended in air
- **b) cloud-borne** - attached to / contained within cloud droplets (AP in convective cloud droplet are not treated explicitly)

Coagulation condensation ($H_2SO_4$, $NH_3$, SOA)

*(Liu et al., 2012)*
Investigation of Aerosol Effects on Weather Forecast using NCEP Global Forecast System

- Objective: Investigate how much complexity is needed to accurately represent the aerosol processes and effectively account for aerosol effects
- SUNYA-NCEP-STAR collaborative efforts, funded by NGGPS R2O, to explore the optimal (accurate and yet affordable) aerosol configuration in GFS parallel scripts (NCEP’s full suite of scripts for the pre-implementation parallel runs)
- Tactical approach:
  - Producing an improved estimates of the temporal and spatial distributions of atmospheric aerosols
  - Using aerosol fields in conjunction with the forecast model (GSM), the analysis system (EnKF-GSI hybrid), and SST analysis (RTG_SST) to assess the atmospheric response to aerosols
  - Enhancing the parallel scripts through incorporation of flexible aerosol configuration
Proposed: Two-way loose coupling

Aerosol fields from low-resolution NGAC run are fed to high-resolution GFS run. This allows aerosol radiative effects in GSM, physical retrievals in RTG_SST, and aerosol attenuation in EnKF-GSI hybrid to be determined from low-resolution NGAC simulations. Use NGAC as the forward model in GDAS, which effectively fold the dual resolution system into a single fully-integrated system (tight coupling).