Evaluation of cloud-resolving modeling of haboobs using in-situ and remotely sensed observations

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Motivation

- Evaluate the **WRF-Chemistry** performance to simulate the mesoscale dust storms in the Arabian Peninsula. **Arabian Peninsula is one of the major dust generation regions that at present is severely under-sampled** (only single dust observational campaign in 2008)!
- Estimate the generation and physical properties of dust uplifted by gust front outflows in desert environment.
- Assess the mineral dust size distribution in **WRF-Chem** configured with **MOSAIC** aerosol scheme.

Aircraft measurements

- The key element of the study is the unique dataset of aircraft measurements performed during the “Kingdom of Saudi Arabia Assessment of Rainfall Augmentation”. Features the measurements of aerosol size distribution within the haboob “dust cloud”.

Model

- **Cloud-resolving WRF-Chemistry** – 2 nested domains (4.5 + 1.5 km)
- ECMWF 25 km operational analysis BC
- **MOSAIC** 8 bin aerosol scheme w. aerosol water stage and aqueous chemistry
Model setup & data

WRF-Chemistry setup

- 2 nested cloud-resolving domains (4.5 + 1.5 km) – convection parameterization has been turned off, 40 hybrid vertical layers
- ECMWF 25 km operational analysis BCs
- Spectral nudging in both domains towards driving BC
- EDGAR-HTAP anthropogenic emissions of gases and aerosols
- CBMZ chemistry + MOSAIC aerosols (chem_opt=10):
  - MOSAIC 8-bin aerosol scheme: 9 species: dust, BC, POM, sulfate, nitrate, chloride, ammonium, sodium, water (Zaveri et al., 2008)
  - GOCART dust emission + MODIS source function, fixed size distribution at emission is assumed (Kok et al., 2011)
  - aerosol dry deposition in PBL (Binkowski & Shankar, 1995)
  - aerosol wet deposition (in-cloud and below-cloud) (Easter et al., 2004 & Chapman et al., 2009) and aerosol-cloud interactions (indirect effects) (Gustafson et al., 2007 & Chapman et al., 2009), coupled with Lin et al. microphysics
  - direct effects (Zhao at al., 2013), coupled with RRTMG radiation in both SW and LW

Data

- NASA MERRA-2 50-km reanalysis (assimilates AERONET & MODIS)
- NASA MODIS Collection 6 combined Deep Blue/Dark target AOD
- Meteosat SEVIRI qualitative “pink dust” product (Lensky and Rosenfeld, 2008)
- Meteosat SEVIRI AOD product (Banks & Brindley, 2013)
- AERONET AOD & inversion products (column-integrated size distribution)
- Aircraft aerosol number size distribution measurements (Posfai et al., 2013)
- Meteorological radar measurements in Riyadh
- TRMM precipitation
- Weather station data for meteorological validation
Outline

1. Introduction
   • Motivation & tools
   • Model setup & data

2. Brief theory. What is a haboob?

3. Synoptic situation during the observational campaign

4. Model evaluation

5. Aircraft measurements
   • Aircraft equipment
   • Observational cases

6. Model results
   • Convection & haboobs in the model and observations
   • Aerosol size distribution

7. Conclusions
What is a haboob?

- Haboobs are a type of mesoscale dust storm produced by cold pool outflows from precipitating convective clouds (e.g. MCS).
- Cooling by precipitation produces a downdraft or downdrafts, a cold pool at the surface, and strong winds.
- The leading edge of the cold pool and strong winds is known as a gust front and, in areas where this leads to dust emissions from the surface, typically demarcates the leading edge of the haboob.

Phoenix, Arizona
22 August 2016

http://wasatchweatherweenies.blogspot.com/2016/08/what-is-haboob.html
Synoptic situation during the observational campaign
ECMWF operational analysis
Synoptic situation during the observational campaign

ECMWF operational analysis

GP @850 hPa (color) + Wind velocity @850 hPa (vectors)

7 April 2007, 12.00 UTC

9 April 2007, 12.00 UTC

10 April 2007, 12.00 UTC

11 April 2007, 12.00 UTC

12 April 2007, 12.00 UTC
Synoptic situation during the observational campaign
ECMWF operational analysis

Wind velocity @300 hPa (color) + GP @300 hPa (contour lines)
Model evaluation: bias & RMSE
5 - 14 April 2007 accumulated precipitation
Model evaluation: AOD temporal evolution @ Aeronet sites

Solar Village

- Aeronet
- SEVIRI
- MERRA-2
- WRF AOD big domain
- WRF AOD small domain

Abu Dhabi

- Aeronet
- SEVIRI
- MERRA-2
- WRF AOD big domain

Dhadnah

- Aeronet
- SEVIRI
- MERRA-2
- WRF AOD big domain

Hamim

- Aeronet
- SEVIRI
- MERRA-2
- WRF AOD big domain
Model evaluation: AOD patterns

2007-04-07 Total aerosol optical depth

WRF-Chem, 2007-04-07 10:00:00

MERRA-2, 2007-04-07 10:30:00

2007-04-10 Total aerosol optical depth

WRF-Chem, 2007-04-10 07:30:00

MERRA-2, 2007-04-10 07:30:00

SEVIRI, 2007-04-07 10:00:00

MODIS AQUA, 2007-04-07 09:55:00

2007-04-10 Total aerosol optical depth

SEVIRI, 2007-04-10 07:30:00

MODIS TERRA, 2007-04-10 07:20:00

AOD

0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9

0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
Model evaluation: AOD patterns
Aircraft measurements: details

• Given the small spatial extent of the aircraft trajectory (but high altitudes reached), we treat the measurements, we perform the vertical integration and treat them as column averages.

• Model vertically-integrated profiles are obtained by averaging within 1 x 1° around the flight area.

• Model results are presented separately for all aerosols and dust-only aerosols.

• The comparison against AERONET size distribution inverse product was also performed.
- Forward Scatter Spectrometer Probe (FSSP) – cloud droplets (3mm - 50mm)
- Passive Cavity Aerosol Spectrometer Probe (PCASP) – aerosols (0.1 to 3mm)
- King Liquid Water Content Probe (KLWC) – cloud liquid water content
- TAMU Differential Mobility Analyzer (DMA) – aerosols (0.01mm to 0.38mm)
- DMT Cloud Condensation Nucleus (CCN) counter
- Arizona State University (ASU) Microanalysis Particle Sampler (MPS)
- University of Wyoming CCN counter

**Aircraft equipment**

**Riyadh 2006 - 2008**

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<th></th>
<th>DMA</th>
<th>PCASP</th>
<th>CAS (Learjet)</th>
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<td>0.01</td>
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<td>D_p (µm)</td>
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Aircraft observational cases against the model

SEVIRI "pink dust" RGB product & aircraft trajectory

WRF-Chem AOD & vertically-integrated hydrometeor content

Aircraft elevation, m

AOD
Haboobs in the model

WRF-Chem surface wind & vertical velocity @ 1000 m

WRF-Chem 2-m temperature & dust generation
Aircraft observations: vertical profiles of aerosol volume concentrations
DMA and PCASP overlapping region
Conclusions

• The meteorological variables from WRF-Chemistry simulation compare reasonably well with station measurements. The model captures the main features of convection in the Central Arabian Peninsula, producing the precipitation pattern consistent with the driving ECMWF operational analysis. Both TRMM and MERRA-2 underestimate and miss precipitation during the period of interest.

• The simulated AODs in the AERONET site locations are in good agreement with observations. The model captures most of the dust outbreaks in the central Arabian Peninsula (Solar Village) near the source region, including those that are not present in the MERRA-2 reanalysis. The background AODs in the remote sites are also well reproduced.

• The model large-scale AOD patterns across Arabian Peninsula are consistent with the remotely sensed SEVIRI & MODIS AOD and MERRA-2 reanalysis. However, some of the mesoscale dust outbreaks in Southern Arabian Peninsula are missed.

• The aerosol size distribution in the model is generally in good agreement with the aircraft observations and the AERONET inversion product. Both WRF-Chem and AERONET underestimate the coarse mode especially during the strong dust events in comparison with the aircraft observations. However, model results are in a better agreement with observations.

• Overall, the modeled size distribution is relatively stable in our case-study as we sample it close to the dust source with a fixed emission size distribution.