The effects of mineral aerosols on the summertime climate of Southwest Asia

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Improving the modeling of mineral aerosols over semi-arid regions

Enhancements made to the dust emission scheme of RegCM3

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Outline

1. Motivation

2. Implementation of sub-grid surface variability
   - Wind gustiness
   - Land cover/roughness length

3. The role of dust concentration boundary conditions

4. Future work
Motivation - Impacts of Dust Emissions

• Dry seasons bring dust storms that dramatically alter landscape and habitability

• Mineral aerosols have profound effects on climate (Miller & Tegen 1998, Sokolik 2001)

• Significant biases in surface temperatures and shortwave incident radiation
Motivation - Area of Interest

- SW Asia - strong seasonality in precipitation and therefore dust emissions (April - September)
- RegCM3 simulations - 5 year, 30 km resolution, NNRP2, OISST, Modified Kuo (Marcella & Eltahir, 2008)
Motivation - Surface Biases

ALB – CRU JJA Avg. Temp. [°C]

SRB JJA Sfc. SW Incident (W/m²)

CONT JJA Shortwave Incident [W/m²]
Motivation - AOD Bias

MODIS Annual Monthly AOD

MISR Annual Monthly AOD

DUST Annual Monthly AOD
Quantifying wind variability

• Assume a normal distribution of wind speed in a given grid-cell with model resolved mean value (Cakmur, et al 2004)

• Assume variance in grid-cell can be described by model meteorology: the dry convective scale---kinematic heat flux
  
  • dry convective eddies by strong surface heating in the vertical are proxies for horizontal fluctuations of wind within the PBL (Wyngaard, 1985)

• Binned values for wind distribution within the dust model are run through entire emissions equations & integrated based on probability of wind (bin) value

Marcella and Eltahir, JGR, 2010
What wind variability looks like

- Assume a normal distribution for surface wind using RegCM3/BATS surface mean winds for gridcell, and dry convective scale (kinematic heat flux) as standard deviation
  - create 10 wind bins (user chooses, covers 99% CL) with corresponding probability, passed to aerosol model to compute emissions

\[
 w_d = \left( \frac{Q_{\text{sh}} g H}{\rho C_p T} \right)^{\frac{1}{3}} = \sigma
\]

\[
 \mu = |U|, \quad \sigma = w_d
\]

Aerosol grid

\[
 FDP = \sum_{b=1}^{10} p(w_b) * f(w_b)
\]

\[
 w_b, \quad p_b | b = 1,10
\]

RegCM3-BATS grid

Marcella and Eltahir, JGR, 2010
Roughness Length Variability

• Use GLCC land cover (4km dataset) to fit empirical distribution of roughness length over a given model (i.e. 30km) grid-cell

• Bin for each land cover the possible emissions given its roughness length value (new values for wind threshold and friction velocity)

• Integrate over the percentage of each grid-cell covered with the respective land cover to get total emissions

Marcella and Eltahir, *JGR*, 2010
What Roughness Variability Looks Like
Effects of sub-grid variability on AOD

DUST JJA AOD

ROU JJA AOD

WIND JJA AOD

WIND–DUST JJA AOD
Impact of Dust on Surface Climate
Conclusions from Dust & Sub-grid Variability

- Average daily surface cooling from dust ranges from 0.5°-1°C across the Arabian Peninsula.

- Incident shortwave attenuation of nearly 30 W/m² occurs throughout the region with most reduction occurring in the sensible heat flux.

- Model shows strong response to including sub-grid variability for wind but not roughness length—modeled AOD values closer to observations particularly MISR estimates.
Still a bias in AOD…
Dust at the boundaries

• Currently RegCM3 aerosol and dust model operates over interior of model, setting the boundaries to zero and allowing only transport of dust from the interior to the boundary slices.

• Use dust output from larger RegCM3 output to fix the boundaries (in bdyval.f) in x-z and y-z slices to average dust concentrations for each tracer bin.
Boundary conditions schematic
Impact of boundary conditions on AOD

CONT JJA AOD

DBC s JJA AOD

DBC s–CONT JJA AOD

BC s–CONT JJA AOD Percent Difference
Effects on dust seasonality

- Increase in seasonality with summer months 20-30% larger dust loading with boundary conditions implemented.
Tracer size dependent

- At the boundaries, smaller tracers (e.g. tracer 1) are transported further into the domain, and therefore are more important as boundary conditions.
Impact of boundary conditions

BCs–CONT JJA 2m Shortwave Incident [W/m²]

CLIMA BCs–CONT JJA 2m Temperature [°C]
Boundary condition conclusions

• Including boundary conditions has a significant impact on the mean (magnitude and spatial) summertime dust loading over SW Asia (20-30% increase) as well as seasonal variation.

• The eastern border experiences increase in dust loading due to advection into the domain while the southern boundary sees increases due to diffusion.

• At the boundaries, lighter or small dust particles are more important as boundary conditions than larger particles.
Future work

• Sub-grid representation for variability in soil moisture

• Still underestimating dust loading (missing sources in N. Iraq, fall out too quickly)

• Use of a climatology dataset for dust concentration boundary conditions (from GCM-tracer model output, observations, etc.)

• Investigate changes in extremes and daily maximum temperatures caused by dust emissions