Direct Radiative Effect of Aerosols in a Mesoscale Model

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The Model

The model was run as a 2-D LES-type simulation using the following set of details:

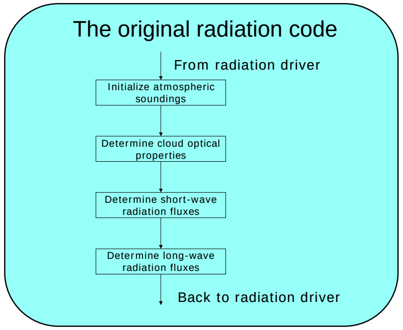
- 100 E-W horizontal gridpoints (Δx = 100m), with 138 vertical gridpoints (Δz = 50 upto 5km, stretched my a factor of 1.1 above)
- Timestep was 2 sec. --total run time, 78hrs
- Horizontal boundaries were cyclic, with no y-component horizontal velocity allowed.

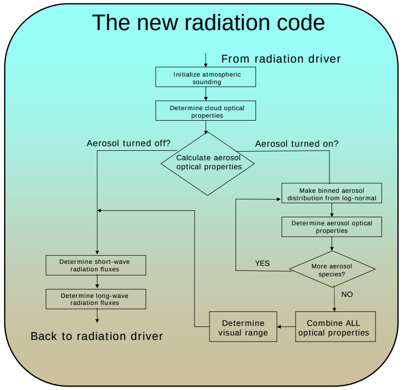
The new code to treat aerosols was designed as a new modular addition to the previous code. The following are highlights of how aerosols are now treated within the model:

- Aerosols are assumed to interact with radiation according to Mie Scattering Theory.
  - Therefore, refractive index is the only necessary input to determine the exact interaction of the aerosol particles with the incident radiation. Known refractive indices allow for exact values of the extinction coefficient (q_{ext}), the scattering coefficient (q_{scat}) and the asymmetry parameter (g_{asym}) to be calculated as a function of particle size, wavelength of incident radiation, and relative humidity for each aerosol species. These values are placed in look-up-tables for faster computing times.
- The overall values for optical depth, single scatter albedo and asymmetry parameter are updated to include aerosol effects.
  - This is where the radiation streams are modified, and the results are manifested. The model changes the upward and downward longwave and shortwave radiation streams to include the effect of aerosols. This in turn modifies the temperature profile within the model.
- A new output variable is present, visual range
  - The visual range is calculated by the Koschmeider equation:

$$x_v = 3.912/(b_{ext} * 1000)$$

Where x_v is the visual range in km, and b_{ext} is the optical depth in m^{-1} over the visible radiation band.





Aerosol Information

Initial testing of the model used three aerosol species:

- Ammonium sulfate, sea salt and mineral dust
- Modular approach allows for easy expansion for the future inclusion of more aerosols

Ammonium sulfate and sea salt concentrations were assumed:

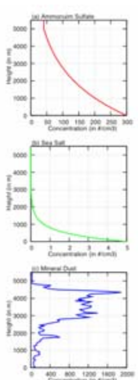
- Assumed surface concentrations with exponential decay in boundary layer to a background concentration at 5km height

Dust data were taken from SaHAran Dust Experiment (SHADE)

- Dust profiles were measured using a Passive Cavity Aerosol Spectromoter (PCASP)

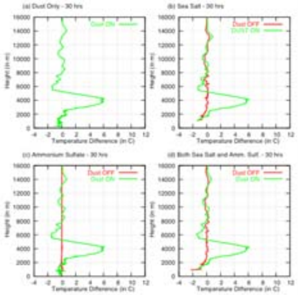
Since SHADE was designed to determine parameters necessary for the calculation of the direct radiative effect of Saharan Dust, a suite of instrumentation was available for verification:

- Upward and downward looking broadband radiometers
- Particle Soot Absorption Photometer (PSAP, particle absorption)
- Nephelometer (particle scattering)
- PCASP



Important Results

Temperature modification

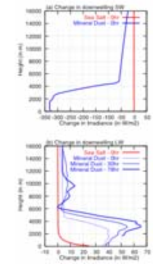


Results for after 30 hours of simulation time reveal a few things about the code:

1. Ammonium sulfate has only minor effects.
2. Sea salt also has minor effects, but does appear to cool the surface.
3. Mineral dust has strong heating in main core of dusty layer

The heating continues over each consecutive daytime heating period at a rate of approximately +3˚C/day. But since this set of model runs was completed in 2-dimensions, this heating would probably decrease in magnitude in 3-dimensional testing, when large-scale forcing is present.

Radiation modification

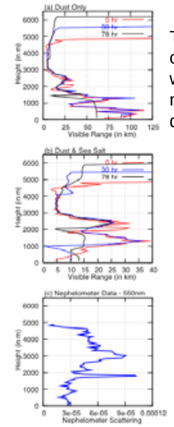


Radiation changes are symptomatic of the changes in the remainder of the model. The changes in the downwelling radiation streams due to the presence of aerosols are presented:

- Sea salt has negligible effect in the SW
- Strong low level effect in the longwave (due to mass of salt and growth due to the deliquescence of water)
- Mineral dust causes more downwelling longwave due to mass and heating

- Mineral dust causes massive decrease in downwelling shortwave. Much too high when compared with a maximum recorded value of -129W/m² during SHADE.

Prediction of visibility



The values for visibility from the model are comparable only to the nephelometer data, which measures scattering. No direct numeric comparisons can be made…just qualitative comparisons:

- The variable is acting as it should:
  - Maxima in the nephelometer field correspond to minima in the visibility field
- The dust layer has a visible range of 5km
- Clouds cause zero visibility
- Sea salt variations cause major changes in surface visibility
- Field is smoothed with time, showing general diffusion of the dust layer
- "Clear air" height increases with time caused by buoyant heating present only when mineral dust is present.

Sensitivity Testing

Model sensitivity to sea salt concentrations showed a very small effect on visibility. When sea salt was decreased by a factor of five, the surface visibility changes from 4km, to 20km.

The model is also sensitive to values of refractive index of mineral dust. Changes to the imaginary part of the refractive index as recommended by Haywood, et. al (2003) were implemented (MD15), with results shown in table below.

	Original	MD6	MD15
Max ΔT, 30hr	+6.1ÞC	+4.4ÞC	+3.6ÞC
Max ΔT, 78hr	+10.8ÞC	+7.8ÞC	+6.0ÞC
ΔLWUP	-24.8W/m²	-24.3W/m²	-24.8W/m²
ΔSWUP	-41.3W/m²	-36.5W/m²	-26.2W/m²
ΔTOTAL UP	-66.1W/m²	-60.8W/m²	-51.0W/m²
ΔLWDN	+35.2W/m²	+34.4W/m²	+35.2W/m²
ΔSWDN	**-328.3W/m²**	**-240.1W/m²**	**-99.1W/m²**
ΔTOTAL DN	-293.1W/m²	-205.7W/m²	-63.9W/m²

- Temperature reduced when ref. index reduced.
- Changes to SW down are now in line with maximum values observed for SHADE

- Visibility field not effected by changes in refractive index.

Conclusions and Implications

Temperature, radiation and visibility profiles are all working in the correct sense:

- Temperature changes are still too great:
  - This should be remedied by 3-dimensional testing with large scale forcing.
- Radiation streams seem to be acting well:
  - Independent verification of SHADE data would be helpful.
  - Certainty in refractive index needed to gain value of modifying the radiation streams.
- Visibility variable appears to be working:
  - Testing against actual visibility is recommended to verify results.
  - Three-dimensional testing would showcase the model's ability to predict small-scale visibility degradation episodes.

Care should be taken when using radiation subroutines for ammonium sulfate and sea salt:

- Using ammonium sulfate may be more costly (in terms of time) that it is worth (in terms of accuracy)
- Sea salt should be well known if the low-level visibility values are to be believed.

Mineral dust is acting as a greenhouse aerosol

Radiative effect of mineral dust could have implications for reduced precipitation:

- Temperature changes could reduce convective available potential energy (CAPE), causing less vigorous convection, and hence reduced surface rainfall. Testing needs to be completed to test this theory.