Modeling of Saharan dust events within SAMUM: On the description of the Saharan dust cycle using LM-MUSCAT (Project #3)

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Introduction

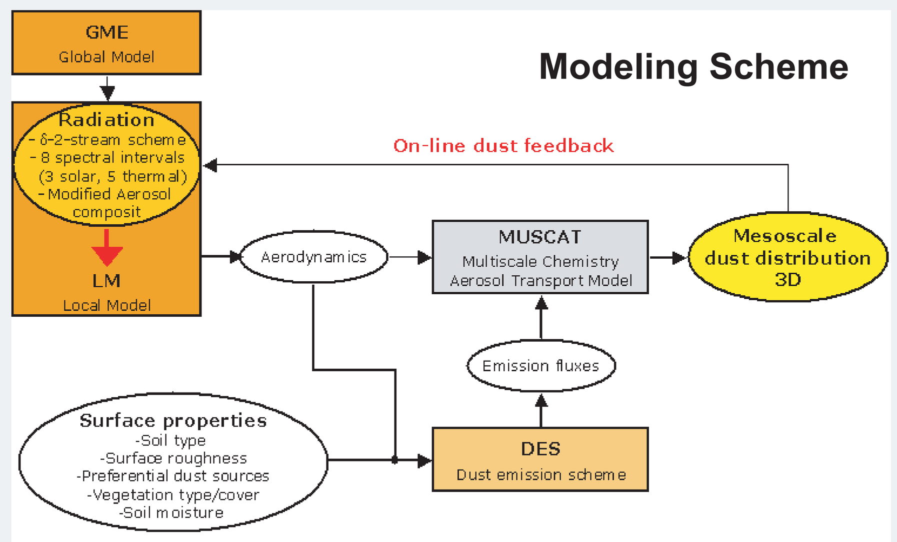
The project SAharan Mineral dUst experiMent (SAMUM) aims at investigating the properties of Saharan dust by means of a field campaign in Morocco in spring 2006. Within this framework a new regional model system was developed for simulations of emission, transport, deposition and radiative effects of Saharan desert aerosol.

The model performance is tested in a near-source study for a dust event in the Bodélé depression (Chad) in March 2005 during a field experiment carried out by UK scientists ('Bodele Dust Experiment', BoDEx; Giles, 2005) and in two far-field case studies for a major Saharan dust outbreak directed to Europe in August and October 2001. The modeled dust load is evaluated by comparisons with satellite observations, lidar profiles from the European Aerosol Research Lidar Network (EARLINET) and sunphotometer measurements at Aerosol Robotic Network (AERONET) stations.
To examine the solar and thermal radiative forcing and feedbacks by Saharan dust, the modeled dust interacts online with the radiation scheme of the model.

Model description

LM-MUSCAT

'Lokal Modell' (LM), operational non-hydrostatic meteorological model of DWD (Doms and Schättler, 1999), online coupled with the Multi-Scale Chemistry Transport Model MUSCAT (Wolke et al., 2004)



MUSCAT-Features

- Spatial discretization by finite-volume techniques on a staggered grid, multiblock grid structure
- Advection terms: 3rd order upwind method with additional limiting (Hundsdorfer, 1995)
- Time integration by 2nd order Runge-Kutta method for the horizontal advection, rest implicitly solved
- Coupling: Time-averaged (wind) and time-interpolated (other) meteorological fields
- Deposition adapted to dust

Dust Radiative Feedback

- LM radiation routine: Use of the dust distribution from MUSCAT and its dust optical properties instead of the aerosol type 'desert', originally fixed in time and space
- Calculation of radiation fluxes from the continuously up-dated dust load
- Modification of atmospheric dynamics due to the feedback of radiative flux changes into the LM

DES

Dust emission scheme, developed by Tegen et al. (2002) following Marticorena and Bergametti (1995), taking paleo- and temporal lake beds as preferential sources into account.

Model setup

Model domains

- **Near-source case:** 300×200/40 grid points/layers, 7 km horizontal resolution, lower left corner 12.0°N/11.0°E (Fig. 1, red)
- **Far field case:** 473×377/40 grid points/layers, 14 km horizontal resolution, lower left corner: 8.68°N/8.36°W (Fig. 1, yellow/grey)

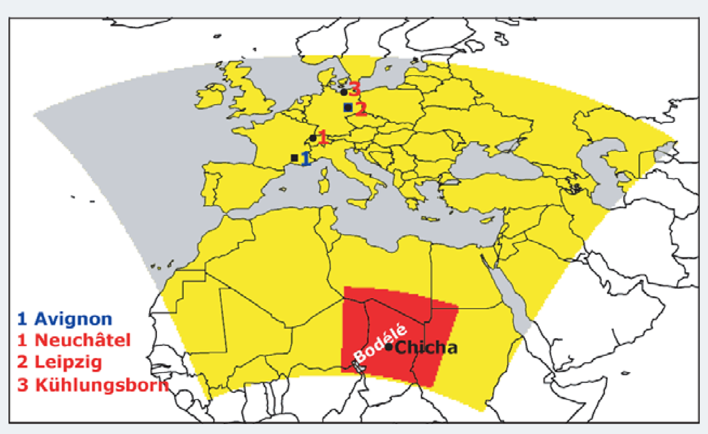


Fig. 1. Model domains and observation sites for model evaluation; red numbers: EARLINET lidar sites, blue numbers: AERONET sunphotometer stations. At Leipzig both data are available. Location of the BoDEx field site 'Chicha'.

Desert aerosol

- Transportation of the modeled dust as dynamic tracer in 5 independent size classes (0.1 µm - 24 µm)
- Removal of dust from the atmosphere by dry and wet deposition
  Near-source case: Adaptation of the model system to the Bodélé aerosol and dust production by 'self-abrasion' (Tegen et al., submitted)
  - Specific density of the particles = 2 g cm^{-3} (bulk density of ca. 1 g cm^{-3})
  - 20-fold reduction of the binding energy of soil particles (compared to the value for clay aggregates from Alfaro et al., 1997)
  - Lognormally distributed saltating particles, mode radius of 100 µm / 2 modes of disaggregated dust particles, mode radii of 1 µm (30%) and 10 µm (70%)

Optical properties

- **Near-source case:** Todd et al. (in review; remote sensing) at visible and Volz (1973) at infrared wavelengths
- **Far field case:** Internal mixture of 2% hematite and 98% kaolinite, Sokolik et al. (1999; laboratory meas.)

Modelled periods

- **Near-source case:** March 1 - 13, 2005
- **Far-field case:** July 27 - August 3 / October 8 - 16, 2001

Each run with (RAD) and without (CTR) dust radiative feedback

Near-source study: Bodélé

A considerable layer of diatomite sediment formed in the former lake Mega-Chad (ca. 6000 years B.P.) covers the surface of the Bodélé depression (Chad) and represents the most active dust source in the world (Giles, 2005). Optical properties and emission processes of Bodélé aerosol were studied in the 'Bodélé Dust Experiment' (BoDEx) during February and March 2005. The results of BoDEx (Washington et al., 2006; Todd et al., in review) are used as input to simulate the dust event.

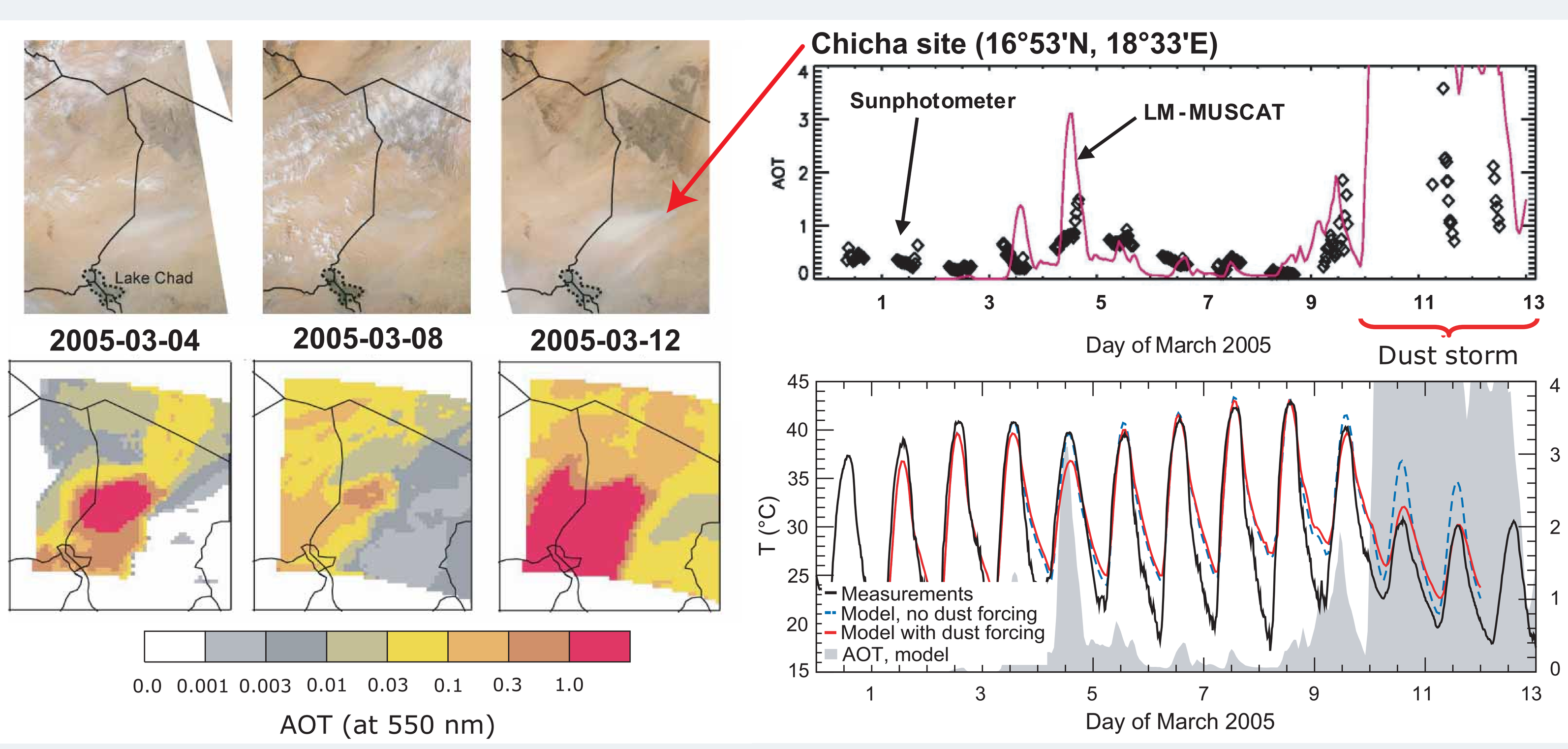


Fig. 2. Left: Dust distribution on March 4, 8 and 12, 2005 as seen by MODIS (top) and the regional dust model (bottom).

Right, top: Dust optical thickness from LM-MUSCAT (violet line) compared to sunphotometer measurements at Chicha site (black symbols). Bottom: 2m Temperature difference of model results including dust forcing (RAD, red line) and results without dust (CTR, blue dotted line) compared to measured 2m temperatures (black line). Radiatively active dust accounts for a decrease in maximum daytime temperatures by about 5 °C at the beginning of the dust storm, which is about half of the measured temperature decrease (Tegen at al., submitted).

Far-field study: August 2001

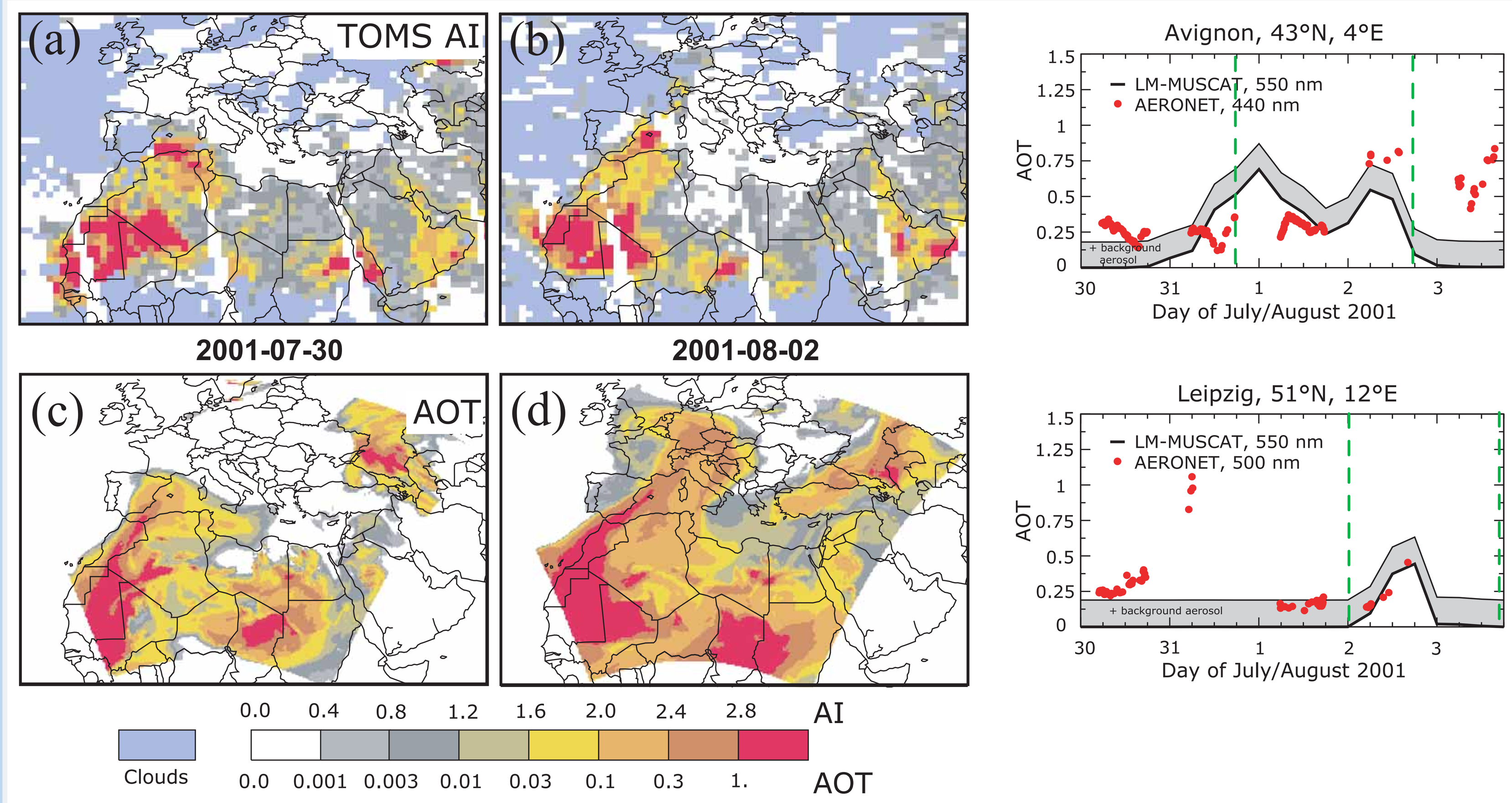


Fig. 3. Top left: Comparison of the horizontal distribution of Saharan dust on July 30 and August 2, 2001. Map of TOMS AI (a,b) and model-derived dust aerosol optical thickness at 550 nm (c,d). Note that the color bar describes different units.

Top right: Model-derived dust optical thickness and optical thickness provided by AERONET at Avignon and Leipzig on July 29 - August 3, 2001. The gray-colored area marks the background aerosol optical thickness added to the model results. Between the green dashed lines the Ångström exponent is lower than 1, indicating the presence of desert aerosol.

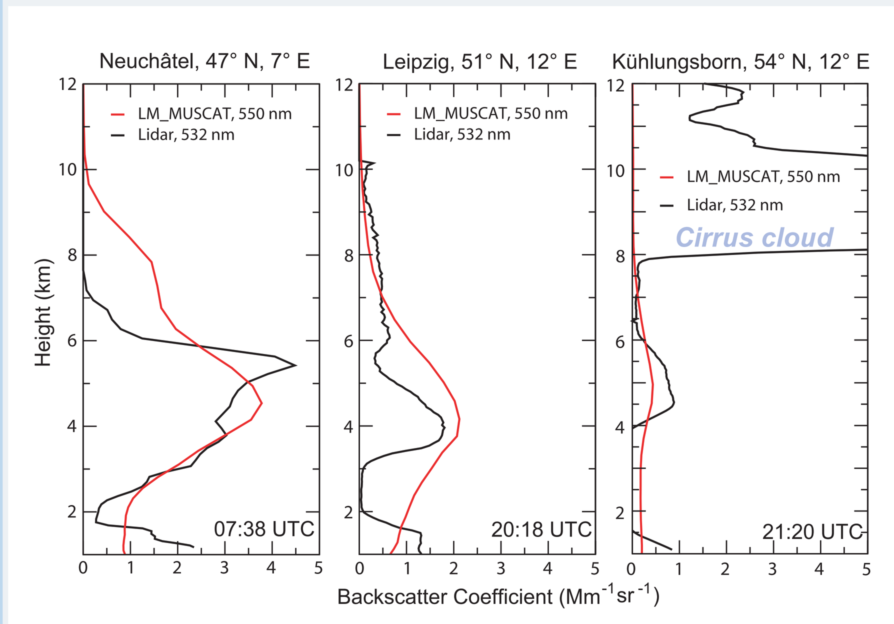


Fig. 4. Vertical distribution of Saharan dust backscatter coefficient above 1 km asl above the EARLINET sites Neuchâtel, Leipzig and Kühlungsborn on August 2, 2001. Comparison of modeled profiles (red line) with lidar data (black line).

Dust radiative feedback

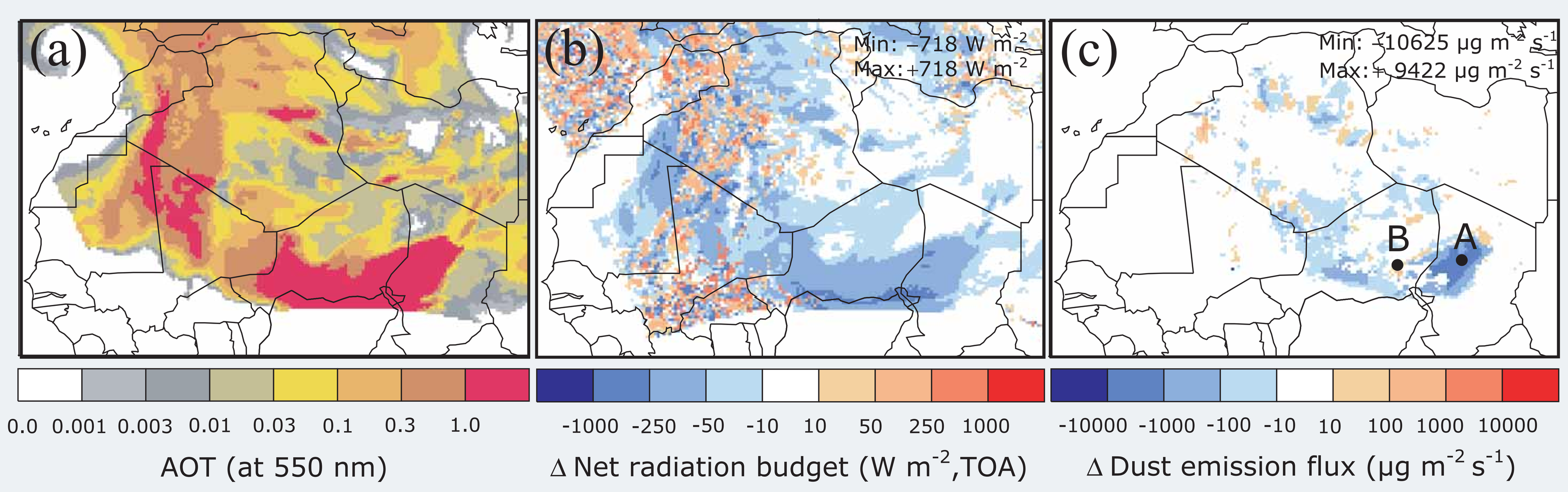


Fig. 5. October 11, 2001; 12:00 UTC: Horizontal distribution of modeled dust in terms of the aerosol optical thickness (AOT) (a), net radiative effect of Saharan dust at top of the atmosphere (TOA) (b) and dust emission (c) between the experiment including dust radiative forcing and results when the dust feedback is not included (RAD-CTR). Dust has a distinct negative effect on the net radiative budget at TOA (Fig. 7b), and the dust production is reduced by up to 50% at the location of strongest dust emission in Chad (Bodélé depression; Fig. 7c) as consequence of reduced wind speeds.

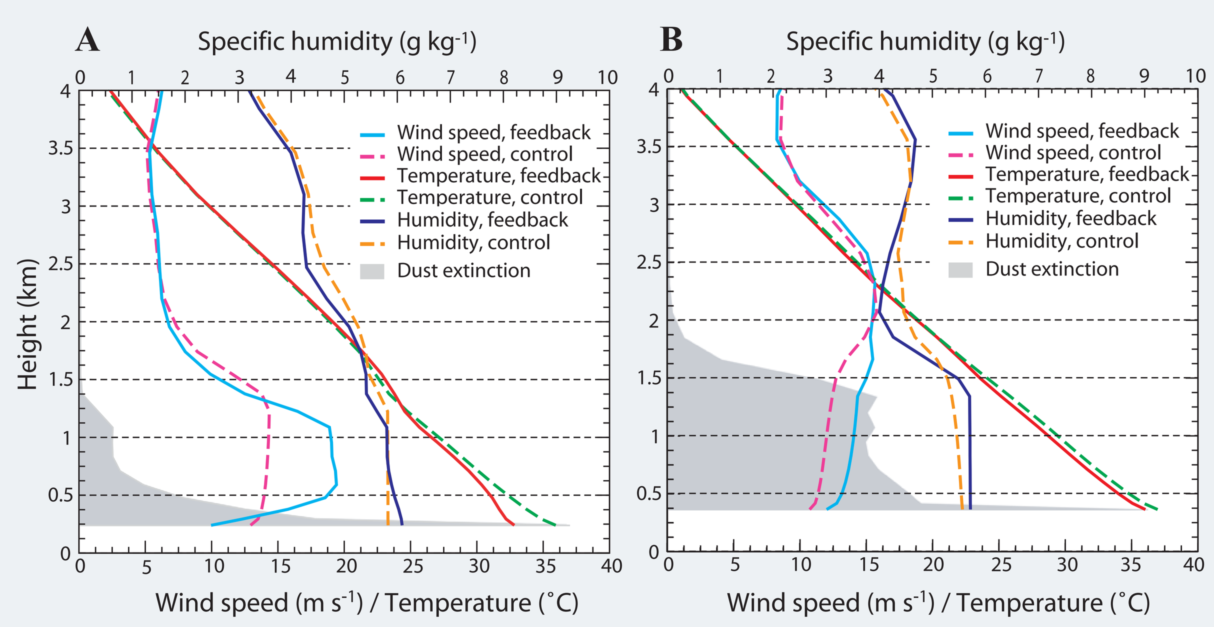


Fig. 6. Vertical profiles of wind speed, temperature, humidity and dust extinction coefficients (gray-colored area, arbitrary units) at a grid point centered in the Bodélé (A 16.8°N; 18.0°E, asl) and a grid point in Niger (B 15.8°N; 12.4°E, asl) on October 11, 2001; 12:00 UTC. Model results including the dust radiative feedback (RAD) are indicated by solid lines (feedback). Results without this feedback (CTR) are marked by dashed lines (control).

Summary and outlook

The new regional model system LM-MUSCAT-DES was developed to simulate the Saharan dust cycle in the mesoscale. It consists of the regional model LM, a dust emission scheme (DES) and the transport model MUSCAT. The capability of the model is shown in several case studies.

- **Near-source study**: LM-MUSCAT-DES was adapted to Bodélé aerosol. The dust event in March 2005 is well captured by the model. Dust aerosol interacts with the LM radiation scheme; the dust effect accounts for about half of the observed temperature decrease (about 5 K) on March 8 - 10.
- **Far-field study:** The model is capable of reproducing the Saharan dust outbreak directed to Europe in August 2001.The Model results agree well with the observations with respect to activated dust sources, transport patterns, magnitude/variability of dust optical thickness and the vertical distribution of Saharan dust.

  Dust radiative effects are examined for a Saharan dust episode in October 2001. The radiatively active dust has a negative effect on the net radiative budget at TOA and stabilizes the atmosphere. The dust production is lowered by up to 50% due to the reduced surface wind speeds when dust radiative forcing is included.

The model system will be used to accompany the analysis of the results from the SAMUM field campaign. In turn, the observations will serve to improve the dust parameterization and to specify dust optical properties. Sensitivity studies with several horizontal and vertical model resolutions and a formulation from Panofsky et al. (1977) that accounts for the subgridscale variability of wind speeds and the atmospheric stability are planned.

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