The Model for STRatospheric Aerosols (MOSTRA): Some results

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Introduction

We present the current status development of a stratospheric aerosol model describing their spatio-temporal evolution under the effect of transport and various microphysical effects.

It is known that volcanic stratospheric aerosols play a major role in ozone depletion issues, due to their implication in the formation of polar stratospheric clouds. They can also be related to climate change issues, because they are able to greatly influence the radiative and dynamic properties of the stratosphere after large volcanic eruptions.

Further, the presence of soot aerosols has been recently suspected in the stratosphere, probably originating from human activities and biomass burning [4]. The study of such non volcanic aerosols is important because they may be a proxy for long-term trends related to anthropogenic influence on the climate.

The ambition of the present work is to develop an adequate tool able to investigate, to monitor and to predict all those issues related to stratospheric aerosols.

The MOSTRA model

The MOdel for STRatospheric Aerosols is a 4D transport/microphysical model describing the evolution in time and space of stratospheric aerosols. Various parameters are computed for describing this evolution, such as the size distribution (distribution per size bins, estimation of the corresponding lognormal size distribution) and related parameters (surface area density, volume density, effective radius), radiative parameters (extinction), and composition related parameters (refractive index, aerosol acidity, aerosol density).

The distribution per size bins is used as basic parameter for transport and microphysics. The initialization of the size bin distribution is made by extrapolation at the full model grid of data provided by the NRS climatology developed by Bingen et al. [1,2].

In order to have an efficient tool at disposal for analyzing simulation results, a possibility is given to archive a wide range of thermodynamical fields on regular time stamps (typically, each month), and the option is provided to store results and to calculate mean profiles by using 3 systems of vertical coordinates : altitude, pressure levels, and isentropics.

The model is written in FORTRAN 90. It is based on existing transport and microphysical modules, that are revised to improve the robustness and portability of the code, to make it closer to standard FORTRAN 90, and to make optimal use of the capabilities of parallel computer architecture. OpenMP is used as parallel programming interface.

Output files including the current state of the model at the end of each month, zonal mean profiles at given time steps and monthly zonal mean profiles, are archived using HDF format.

Main features of MOSTRA

Dynamics

Dynamical fields (wind fields, temperature, pressure) are forecast or analysed fields provided by ECMWF. Other thermodynamical fields (potential temperature, air density, mean free path of air particles, viscosity of air etc.) are computed by MOSTRA and can be archived on request. The ensemble combined with the set of computed aerosol parameters (see above) gives a very complete description of the thermodynamical status of the atmosphere and of the aerosol composition.

Transport

The transport module is basically the transport module used in the Belgian Assimilation System for Chemical Observation from Envisat (BASCOE) developed at our Institute. This module has been fully revised and improved to better match FORTRAN 90 standards.

The advection scheme is based on the flux-form semi-Lagrangian scheme developed by Lin and Rood [3]. This approach is based on the resolution of the flux form of the continuity equation, that insures the conservation of mass without a posteriori correction and prevents some kinds of numerical instabilities and the generation of artificial extrema. The advection scheme foresees the recomputation of the vertical wind velocity from the continuity equation, avoiding the production of dubious fluxes and the local violation of the conservation laws.

Microphysics

Microphysical modules are based on the PSCBOX tool developed by Larsen [2]. So far, microphysical processes considered in MOSTRA are the gravitational sedimentation and brownian coagulation. Other processes that are needed to have a full picture of microphysical processes (such as condensation/evaporation, nucleation, PSC formation), will be added in the future.

Species description

At this stage, aerosols consist of a mixture of sulphuric acid and water. So far, the aerosol acidity is considered as constant, but a recomputation of this parameter as a function of the thermodynamic condition will be added in the near future.

Some insight into the model

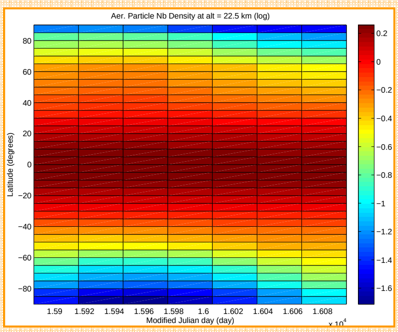
As already mentioned, MOSTRA provides on request a wide range of aerosol parameters and of thermodynamical fields giving a good insight into the status of the atmosphere at a given moment.

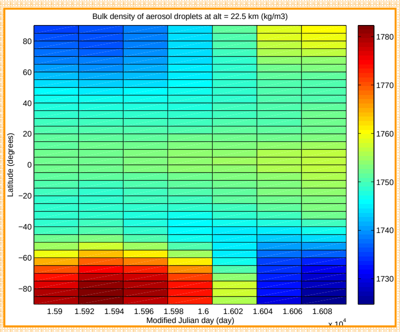
The present illustrations show examples of the evolution in time of such thermodynamical parameters, during a 9 months run spanning the period May 1993 - January 1994.

The first plot shows the time evolution at an altitude of 22.5 km of the aerosol particle number density (the color bar is coded using the $\log_{10}$ of this quantity, expressed in cm^{-3}), whereas the second plot shows the time evolution of the bulk density of aerosol droplets, expressed in kg/m^3.

Notice the annual dependence of these quantities, especially at high latitudes.

The model was initialized using the NRS climatology [Bingen et al., 2004] interpolated and extrapolated to the full model grid. The model resolution for this run is 5°x5°, and the simulation is carried on at 37 fixed pressure levels from 10 to 100,000 Pa (i.e., from about 60 km down to ground). Time step is 30 minutes.





Some results

The following plots illustrate some preliminary results obtained by a 9 month run of MOSTRA, from begin May 1993 until end January 1994.

Characteristics of the run : See "Some insight into the model"

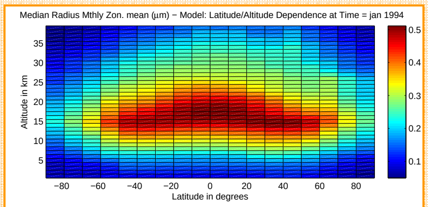
The first figure shows the zonal monthly mean of the median radius of aerosol particles obtained by MOSTRA for January 1994. For comparison the two latest figures represent the corresponding values of the NRS climatology, and a cost function defined as :

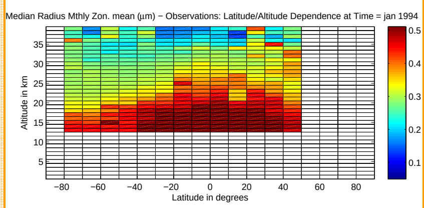
$$Cost = \frac{(Model - Observation)^2}{(Error\,on\,observation)^2}$$

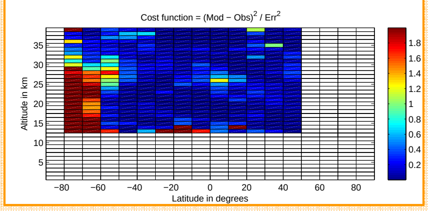
Notice that the cost function is equal to zero if the model gives results equal to the observation, and smaller than 1 if the model gives results that are within the error bar of the observation.

The agreement between the model and the observations described through the NRS climatology is very satisfying, except at high Southern latitudes. This might be due to the choice of extrapolation method used to obtain the initialization field at full grid from the NRS climatology. This point must be further investigated.

The mean radius obtained by MOSTRA is the mean radius of a lognormal size distribution fitted on the size bin distribution used by MOSTRA. This latest bin distribution consists of 20 bins from 0.02 to 1.5 µm.







Conclusions and perspectives

We are developing an aerosol transport/microphysical model called MOSTRA. So far, preliminary results are encouraging and show that MOSTRA is able to provide an extended data set of aerosol parameters and thermodynamical fields, giving a good insight of the state of the atmosphere at a given moment. Although more microphysical effects have to be added to have a good description of the real spatio-temporal evolution of aerosol droplets, MOSTRA is potentially a very powerful tool to analyse and to understand the evolution of stratospheric aerosols.

Beyond the refinement of the microphysical module, we foreseen to improve the model in the future by adding more aerosol species, and possibly the necessary chemical module to describe their evolution.

References

[1] Bingen C., D. Fussen and F. Vanhellemont, A global climatology of stratospheric aerosol size distribution parameters derived from SAGE II data over the period 1984-2000: 1. Methodology and climatological observations, *J. Geophys. Res.*, **109**, D06201, doi:10.1029/2003JD003518, 2004

[2] Larsen, N., Polar Stratospheric Clouds—Microphysical and optical properties, Scientific Report 00-06, Danish Meteorological Institute, Copenhage, 2000

[3] Lin, S.-J. and R.B. Rood, Multidimensional Flux-Form Semi-Lagrangian Transport Schemes, Monthly Weather Review, 124, 2046-2069, 1996

[4] Renard, J.-B. et al., Optical and physical properties of stratospheric aerosols from balloon measurements in the visible and near-infrared domains. II. Comparison of extinction, reflectance, polarization, qnd counting measurements, Appl. Opt., 41, 7540-7549, 2002.

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