THE MAOAM PROJECT: REVIEW OF THE RECENT WORK

P. Hartogh, C. Jarchow, T. Kuroda, A.S. Medvedev, R. Saito, G.R. Sonnemann, *Max-Planck-Institute for Solar System Research, Katlenburg-Lindau, Germany, (Hartogh@mps.mpg.de)*, **U. Berger, M. Grygalashvyly**, *Leibnitz-Institute of Atmospheric Physics, Kühlungsborn, Germany,* **A.G. Feofilov, A.A. Kutepov,** *Institute for Astronomy and Astrophysics, University of Munich, Germany,* **H. Elbern,** *Institute for Inverse Modeling of Atmospheric Chemical Composition, University of Cologne, Germany.*

Introduction:

MAOAM (The Martian Atmosphere: Observation and Modeling) is part of the German Science Foundation (Deutsche Forschungsgemeinschaft, DFG) research priority program SP 1115 "Mars and the Terrestrial Planets". The project started in 2001 and is approved until 2008. The basic idea of the project is to create a tool describing the dynamics and chemistry of the Martian atmosphere that helps to interpret data to be provided by future experiments sounding the atmosphere from ground up to the thermosphere. Especially submm instruments have the capability to highly resolve the Martian Atmosphere in this entire altitude range. A short status and progress report of recent instrumental developments/studies and future prospectives will be given below, followed by a review of the "tool" genesis. The tool is a general circulation model with coupled chemistry transport module which recently was labeled by the project name MAOAM.

Submm instruments: future promises

There are several classes of submm sounders:

1) Ground-based single dish telescopes. Recently the Atacama Pathfinder Experiment (APEX) started its first operation. Compared to former submm telescopes (e.g. SMT, CSO) APEX is able to observe lines at frequencies above 1 THz quite well. The main reason for this capability is the extreme good transmission of the troposphere in the Atacama Desert at above 5000 m altitude. This means on the one hand an improved maximum spatial resolution of < 5 arc seconds (the size of the Martian disc varies between about 4 and 25 arc sec) and on the other hand the access to new submm bands containing "new" or at least much stronger molecular transitions than available in the lower bands. For instance temperature and wind sounding will be possible to above 80 km using higher rotational transition of CO. The detection of new trace gas molecules is likely in the near future. The Atacama Large MM Array (ALMA) will follow in 2005. ALMA is an interferometer consisting of 64 telescopes similar equipped than APEX. For the longest baselines the theoretical resolution is as high as 10 milli arc sec. Since the number of photons detectable for ALMA from the 10 milli arc sec fringes is rather small, for Martian atmospheric observations the practical resolution limit will be more likely in the order of about 0.1 arc seconds – still more than enough to constrain general circulation models.

2) Near Earth astronomical satellites. Examples are the Submm Astronomy Satellite (SWAS) and Odin. Among others both satellites constrained globally averaged the vertical profile of water vapor. From 2008 on the Heterodyne instrument for the Far Infrared (HIFI) on the Herschel Space Observatory will follow. Due to the larger telescope dish, the more sensitive receivers and the much wider submm range coverage HIFI will be more than 3 orders of magnitude more sensitive, predestinated to provide data that helps to constrain Martian atmosphere chemistry models. HIFI will provide highly accurate vertical profile of trace gas molecules up to 80 - 90 km. Unfortunately HIFI will not be able to resolve the Martian disk.

3) The Stratospheric Observatory for Infrared Astronomy (SOFIA) will carry 2 submm instruments (Caltech Submillimetre Interstellar Medium Investigation Receiver, CASIMIR and German REceiver for Astronomy at THz frequencies, GREAT) with an even larger submm band coverage than HIFI. These instruments will observe from 12 – 14 km altitude - very suitable for Mars atmospheric science and address similar science objectives than HIFI. First flights of SOFIA were planned in 2005, however funding problem cased a delay of 1 to 2 years.

4) Mars orbiting submm instruments: there have been a number of proposals and studies since mid of the nineties. Orbiting instrument provide the best horizontal and vertical coverage and resolution of all submm instruments. Temperatures, Doppler winds and molecular species can be observed to altitudes far above 100 km. The first submm instrument MIME (Microwave Investigation for Mars Express) has been proposed 1998 and is technically almost identical with the Microwave Instrument for the Rosetta Orbiter (MIRO, launched in 2004). Since then, a number of follow up proposals have been submitted to the funding agencies. The latest study (Submm Wave Instrument, SWI), performed in 2004 with respect to the ExoMars orbite, was based on the MIME proposal, but took advantage of newest technical developments. Progress compared to MIME: larger telescope, higher receiver sensitivity, tunable receivers, two submm bands rather than one, better spectrometer technology, etc. Follow up studies are going on, trying to merge MIRO and HIFI technology. Unfortunately no instrument of class 4) has been funded thus far.

Figure 1 shows errors and vertical resolution of wind and temperature provide by submm radiative transfer and retrieval simulations.

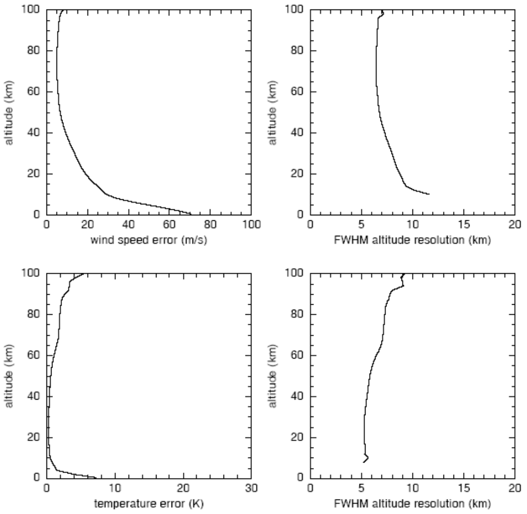

Figure 1: SWI temperature and Doppler wind retrieval simulations: Errors and vertical resolution

Progress in the model development: A detailed description of the Martian GCM status can be found in [Hartogh et al, 2005]. Compared to the 2003 version called Mart-ACC, which has been presented during the last Workshop on Mars atmosphere modeling and observation in Granada 2003 (see abstract), a number to changes have been performed. A brief listing of the changes follows:

- The numerical stability has been improved in a number of steps including optimization of the time integration scheme, the introduction of a staggered vertical grid, a vertically varying horizontal diffusion and an update of the convective adjustment scheme.
- The smoothed topography used in Mart-ACC has been replaced by the MOLA topography. Currently, our model works with the full topography at all resolutions.
- The surface physics has been improved by a new parameterization which is based on the calculations of the energy balance on the surface. It uses the available measurements (TES) of the surface thermal inertia and the albedo map.
-The radiation scheme has been changed using a new non-LTE heating/cooling rate scheme representing an optimized version of the ALI-ARMS code [Kutepov, 1998]. This optimized version will be presented during this workshop by [Feofilov et al, 2006].
- Simultaneous with the model refurbishment a dust radiation scheme was built, or better adapted from [Kuroda et al, 2005]. See also the presentation of [Kuroda et al, 2006]. The presentation illustrates an application of MAOAM helping to interpret the temperature inversion detected by the SWAS satellite during the 2001 dust storm on Mars [Gurwell, et al, 2005].
- The Mart-ACC gravity wave parameterization has been replaced by a scheme of [Medvedev and Klaassen, 2000], coupled for the first time with orographic sources of gravity waves.
- A new MAOAM chemistry-transport-module (CTM) has been developed and tested. For more details see the presentation of [Sonnemann et al., 2006].
- The model code consists of parts written in Fortran and C. The structure of the code has been completely redesigned to a user friendlier version. At the same time multi-processor capability has been implemented and tested on a 4 – processor Opteron Cluster. As the next step we plan to run MAOAM on a dedicated 48-processor Opteron Cluster, once it is delivered (end of 2005).
- The model name has been changed from Mart-ACC to MAOAM.

One of the first results was that MAOAM finds a stronger winter polar warming than other models. The interpretation of this performance is supported by a sensitivity study presented by [Medvedev et al., 2006a].

More details about the present status of the model and the comparison of model simulations with data will be presented by [Medvedev et al., 2006b].

Future work: Future work will address the following topics:
- Dust radiation: increase of number of spectral bands on new computer
- Chemistry: interactive coupling with dynamical part of MAOAM. Dependence of chemistry to dust distribution. Relation to Doppler-Sonnemann effect. Mars atmosphere stability problem: 3-D investigations, test of new catalytic cycles.
- Formation of water ice clouds: adoption of Comma-IAP ice cloud model. Model runs under different environmental conditions.
- CO_2 sublimation and condensation
- Intercomparison with other models and validation
- Implementation of a data assimilation scheme.
- Collecting of data for data assimilation and model validation.

References

Feofilov, A.G., A.A. Kutepov, A.S. Medvedev and P. Hartogh:, New technique for calculating non-LTE infra-red radiative cooling/heating rates in the Martian GCM, Granada Mars Workshop 2006.

Gurwell M. A. et al., *Icarus 175*, 23-31, 2005;

Hartogh, P., A. S. Medvedev, T. Kuroda, R. Saito, G. Villanueva, A. G. Feofilov, A. A. Kutepov, and U. Berger, Description and climatology of a new general circulation model of the Martian atmosphere, *J. Geophys. Res.*, 110, E11008, doi:10.1029/2005JE002498, 2005.

T. Kuroda, N. Hashimoto, D. Sakai, and M. Takahashi, Simulation of the Martian atmosphere using a CCSR/NIES AGCM, *J. Meteorol. Soc. Jpn.*, **83**, 1–19, doi:10.2151/jmsj.83.1, 2005.

T. Kuroda, A. S. Medvedev, P. Hartogh: the Martian atmosphere during the 2001 global dust storm: observations with SWAS and simulations with a general circulation model, Granada Mars Workshop 2006.

Kutepov, A.A., O.A. Gusev, and V.P. Ogibalov (1998), Solution of the non LTE problem for molecular gas in planetary atmospheres: Superiority of accelerated lambda iteration, *J. Quant. Spectrosc. Radiat. Transf.*, *60*, 199.220.

Medvedev, A.S. and G.P. Klaasen, Parameterization of gravity wave momentum deposition based on a nonlinear theory of wave spectra, J. Atmos. Solar-Terr. Phys., 62, 1015-1033, 2000.

Medvedev, A.S. P. Hartogh and T. Kuroda, Winter polar warmings and the meridional transport on Mars simulated with a GCM, Granada Mars Workshop 2006.

Medvedev, A.S., P. Hartogh, T. Kuroda, R. Saito, A.G. Feofilov and A.A. Kutepov, a new general circulation model of the Martian atmosphere: description and first results, Granada Mars Workshop 2006.

Sonnemann, G.R., P. Hartogh, A. Medvedev, U. Berger and M. Grygalashvyly: a new 3D-model of the dynamics and chemistry of the Martian atmosphere and some problems of the chemical model, Granada Mars Workshop 2006.