TOWARDS AN INTERMEDIATE COMPLEXITY MARTIAN CLIMATE SIMULATOR.

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1 Abstract

The Portable University Model of the Atmosphere (PUMA) is currently being adapted from terrestrial to martian setup. The dynamical core of the model is similar to that of the AOPP model, but the code benefits from a modular structure and is suitable for use on parallel architectures. Relatively simple modules for radiation, land surface processes and clouds and precipitation are provided with the dynamical core. Additionally, the model can be forced with prescribed ground temperatures (either from observations or to perform case studies).

The current state of the project is as follows: The physical parameters of the model have been adapted to Mars, and a MOLA-based topography is now built in. The temperature forced model gives wind fields that resemble the observed patterns and velocities reasonably well. Realistic radiative forcing at the outer boundary of Mars including the daily and seasonal cycle has been introduced. The radiative code that governs the temperature tendencies inside the atmosphere, however, needs further attention. The presentation of results is therefore restricted to temperature forced runs. An interesting point of discussion here will be how the topographic forcing of the atmospheric circulation can be described best.

2 Introduction

As part of the current priority programme 'Mars and the terrestrial planets' by the Deutsche Forschungsgemeinschaft, an initiative has been started to set up a model for martian climate studies. While considerable effort has already been put into martian atmospheric modelling by other groups (see, e.g. Pollack et al. 1990, Read et al. 1997, Forget et al. 1999, Richardson and Wilson 2002), Germany has not been active in this field up to now. Despite a longstanding history of research in planetary physics and also Mars in particular, no studies using General Circulation Models (GCMs) were performed.

The current Max-Planck-Institute of Aeronomie in Katlenburg Lindau, however, is in the phase of being transformed into the Max-Planck-Institute for the exploration of solar systems. As part of the current transformation and the revised working programme, a modelling project that aims at simulating the martian climate at a variety of time scales ranging from present to paleoclimate has recently been started. The recent successful missions to Mars, Mars Global Surveyor and Mars Odyssee, provided a strong motivation for entering into the field of martian climate modelling. While the initial goal is a successful simulation of the present climate, the choice of the model also reflects the intended use for studies of the martian climate history that will require long model runs. Also at a later stage, the assimilation of observations from current and upcomming missions to Mars, like Mars Express in 2003, is planned.

3 The model

The modelling basis for the project is the PUMA atmospheric GCM (Portable University Model of the Atmosphere, Fraedrich et al. 1998) with added components for the land surface, radiation, precipitation, clouds, and, if desired, an active ocean (documentation in preparation). PUMA is based on the Reading multi-level spectral model SGCM (Simple Global Circulation Model) described in Hoskins and Simmons (1975). Originally developed as a numerical prediction model, it was changed to perform as a general circulation model. PUMA was developed at the University of Hamburg with the following aims in mind: compatibility with the ECHAM (European Centre HAMburg) GCM, portability between different computing platforms, and training of junior scientists.

The code is rewritten in portable Fortran-90 without using any external libraries. It has been tested on platforms ranging from Pentium-PCs to vector/parallel super computers. The truncation scheme is changed from jagged triangular truncation to standard triangular truncation that is compatible to other T-models like ECHAM. The model output is such that it can be processed with the ECHAM afterburner, which allows the use of the ECHAM diagnostic software packages for interpretation of the PUMA output.

The initial PUMA code was basically the dynamical core of a GCM forced by Newtonian cooling and Rayleigh friction. It formed the basis for various applications: The code has been utilized to build and test new numerical algorithms like semi-Lagrangian techniques, to perform idealized experiments to analyse nonlinear processes arising from internal dynamics of the atmosphere, and for data assimilation purposes to interpret results from GCM simulations or observations.

The model solves the primitive equations formulated in terms of the vertical component of absolute vorticity ζ and the horizontal divergence D to compute the three dimensional temperature distribution, and velocity fields from spectral vorticity and divergence. Based on the dynamical kernel, the model has been extended by modules that compute specific humidity, cloud cover and precipitation, radiative cooling and heating in the short and long wave range, soil temperature and wetness, snow temperature and depth, the albedo and the surface roughness.

The radiation scheme allows for two wave-length bands in the solar range, while the thermal radiation code does not distinguish between different wave lengths. An implicit scheme is employed in the solar radiation code, that computes up and downward fluxes and corresponding heating rates from the incomming radiation. The code computes transmissivity and reflectance from relative humidity, (water) cloud cover, and surface albedo. Surface albedo for land points is mainly a function of temperature, with special values for ice covered areas. The additional dependence on vegetation cover was removed for martian applications.

4 Adaptation to Mars

As a first step, all physical parameters, like the planets radius, rotation rate, gas constant, lapse rate etc. have been replaced by their martian counterparts. A new subroutine has been introduced to initialize the model with more balanced temperature fields that take into account the large range of martian topography by adjusting the bottom temperature using the average lapse rate (2.5 K km^{-1}). This proved necessary to keep the model numerically stable.

The number of model levels has been doubled for Mars to better resolve the steeper martian topography. The timestep has been reduced from 60 min to 40 min to allow for the smaller gridboxes on Mars. The martian setup now consists of a T21 horizontal resolution ($\approx 5.6\,^{\circ}$) and 10 unevenly distributed sigma levels plus a surface layer in the atmosphere, and 5 layers in the soil model.

A topography derived from the MOLA (Mars Orbiting Laser Altimeter) 1° x1° measurements has been introduced to the model. The remaining topographic range is slightly more than 10 km, still considerably more than for the terrestrial setup. As a first approach, the restoration temperature field is set to 224K with correction for height using the average lapse rate for the free atmosphere. Some experiments with reduced lapse rates, so as to include topographic forcing, were not successful up to now. One of the first scientific applications will be the simulation of the topographic forcing.

Additional care has to be taken for the land surface and radiation schemes as these make frequently use of Earth derived parameterizations, e.g. the albedo is a function of temperature above or below the melting point of water. Currently the efforts are directed toward the adaptation of the radiation scheme and the land surface model.

5 Initial results from forced runs

Experiments have been performed with prescribed three dimensional restoration temperatures. To derive the restoration temperature field, pole-to-equator as well as pole-to-pole gradients are superimposed over a mean temperature (224 K for zero height). Varying the pole-to-pole gradient allows the simulation of seasons. The distribution in the vertical is computed from the average lapse rate and the height of the tropopause (40 km) with a transition zone close to the tropopause. The highest model level is currently located at 60 km height. The restoration temperature field in the bottom layer for a northern summer simulation is shown in Fig. 1.

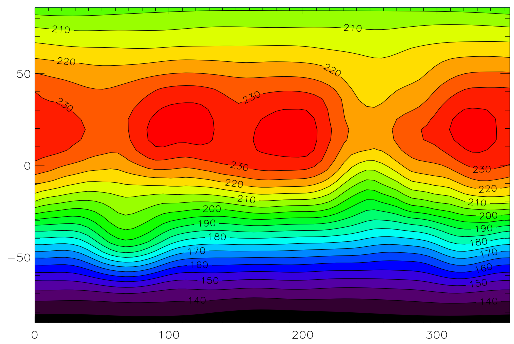

Figure 1: Surface restoration temperature field, resembling northern summer with a maximum temperature at 25° N. Deviations from a purely zonal structure are due to the martian topography.

From Fig. 2 the impact of two prominent features of the martian orography, the elevated Tharsis region at 120° W, 30° N to 60° S, and the large impact crater Hellas basin at 70° E, 45° S are fairly evident. Together with the north-south dichotomy, i.e., the gradient in elevation from southern highlands to northern lowlands, they determine the topographic steering of the large scale circulation. A free wavenumber 2 wave seems to be present at northern mid latitudes, however.

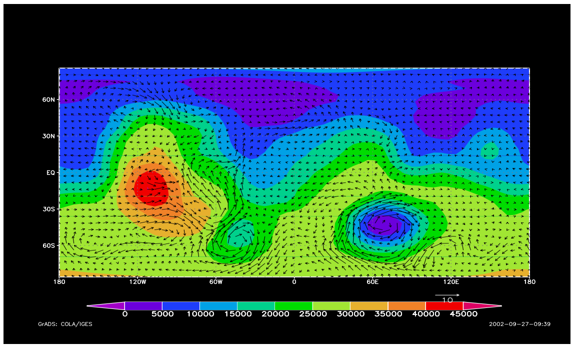

Figure 2: Surface geopotential [gpm] and wind vectors in the bottom layer. The model is driven by a pole to equator temperature difference of 60K and a pole to pole difference of 60K, corresponding to a northern summer situation (see Fig. 1). The restoration time scale is 15 days. Shown is the monthly mean for 6 month after the initialisation from rest. Maximum wind speeds are on the order of 20 m/s

Fig. 3 shows the meridional stream function also known as Hadley circulation. Note the dominant cell in the northern hemisphere that extends across the equator into the southern hemisphere. The smaller anticlockwise cell to the south of the equator partly results from neglection of topography in the computation of the stream function. This is currently under development.

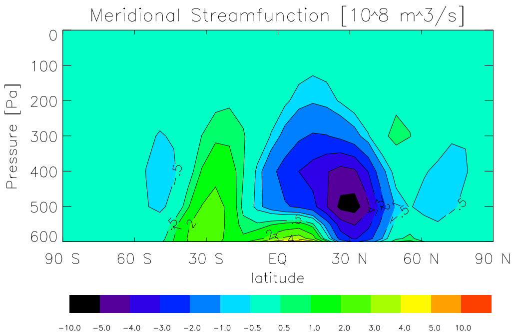

Figure 3: Meridional stream function for a northern summer situation. Blue corresponds to clockwise, green to anticlockwise circulation in the plane of the plot. Contour levels are given in the colourbar in $10^8 \mathrm{m}^3\mathrm{s}^{-1}$.

6 Summary and Outlook

After initial problems with numerical instabilities of the model that mainly resulted from the rugged martian topography, the dynamical core of the model now works satisfactory. The simulated wind speeds and patterns are similar to the results of other martian circulation studies. Major work still has to go into the parametrization of the radiation. The input of radiation at the upper limit of the atmosphere now includes the annual and diurnal cycles, but the radiative properties of dust and CO_2 still have to be modelled to obtain realistic cooling and heating rates. Also the transport of dust and CO_2 and their interaction with the martian surface (i.e., suspension and sedimentation of dust, and the condensation and sublimation of CO_2) need further effort. Furthermore it is planned to include the interactions of the atmosphere with the polar layered terrains, in particular the northern H_2O ice cap. Another possible developing area is the use of the land surface model to study the recently discovered subsurface water ice.

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