MRAMS TODAY – ONE EXAMPLE OF CURRENT MARS MESOSCALE MODELING CAPABILITIES.
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Introduction: Currently there exist a number of Mars mesoscale atmospheric models (e.g., [1], [2], [3]), with many more in development and/or testing around the world. In light of this burgeoning worldwide use of such models, it may be useful to describe some of the capabilities that a current Mars mesoscale model may possess. This will be accomplished here by reviewing notable changes and additions to the nonhydrostatic Mars Regional Atmospheric Modeling System (MRAMS) since its introduction in 2001 [1].

Numerical Techniques: The basis of any numerical model, the "numerics" may also contain subtle instabilities and questionable assumptions.

Fully compressible dynamics. In 2001, MRAMS used a quasi-Boussinesq approximation (inherited from the terrestrial RAMS model [4] on which MRAMS was originally based) that allowed for some aspects of fluid compressibility, but not all. In particular, a change in potential temperature would not directly affect the air pressure. For many terrestrial applications this approximation has only relatively minor consequences, although it has been recognized as a limitation in some cases (e.g., [5]).

For the atmosphere of Mars, however, the use of this approximation resulted in significant mass loss (on the order of 0.1 hPa/sol) from the model domain. The drastic difference between the model's behavior on Earth versus Mars is thought to be primarily due to the significantly larger atmospheric heating/cooling rates (chiefly due to radiative transfer) on Mars, particularly those near the surface. The model's use of an altitude-based vertical coordinate (vs. a pressure-based one) may also have played a role. To remedy this issue, MRAMS was modified to treat the atmosphere as being fully compressible, following [5].

Improved Cartesian horizontal gradients. Many atmospheric diffusion schemes require the calculation and/or interpolation/extrapolation of Cartesian horizontal gradients of temperature and other fields. Particularly in regions of complex topography overlain by thermally-stratified air, simpler mathematical treatments to determine these gradients from the model state variables (which are on the native terrain-following coordinate system) often produce significant errors. Such errors typically manifest most strikingly in thermal fields, with temperatures in valleys far too cold (e.g., 50K), and temperatures above ridges far too warm (e.g., 400K). A new method to carefully calculate/interpolate/extrapolate these gradients with much smaller errors was developed, and is now used in MRAMS whenever the model topography is non-zero (i.e., when the surface is not perfectly flat).

Radiative Transfer: For astronomical bodies with a "shallow" atmosphere, radiative transfer is a primary mechanism for the exchange of energy to/from the atmosphere, the surface, and the external environment. As such, some approximation of radiative transfer must necessarily be included in any realistic atmospheric model (particularly those that are run for more than one diurnal period).

Two-stream radiative transfer (RT) algorithm. MRAMS originally used a two-band (1 shortwave and 1 longwave) RT code from the NASA Ames Mars general circulation model (MGCM; e.g., [6]) that utilized lookup tables from a prior offline calculation. Unfortunately, this meant that many parameters were fixed in space and time, such as the composition of the martian air, and the optical properties of airborne dust and other aerosols.

To remove these restrictions from MRAMS, a new two-stream RT code, based on [7], was developed and is now routinely used (currently with 7 shortwave and 5 longwave spectral bands). It uses a correlated-*k* technique to render the gas opacity calculations more manageable – currently a variable mixture of carbon dioxide and water vapor (data provided by the NASA Ames MGCM group) is used. The RT contributions of aerosols are also treated, using relatively large lookup tables of optical properties (generated offline; more on this topic below) to support any size/mass distribution of dust, water ice, and/or carbon dioxide ice particles. Also, no assumption of any "shortwave to infrared" factor is required for the aerosol radiative transfer, as it is calculated explicitly for every grid cell.

"Known" aerosol optical properties. In order to allow the calculation of aerosol optical properties that are a function of radiation wavelength and particle radius and composition, some assumptions must necessarily be made due to computational limitations. The aerosols currently treated are dust, water ice, and carbon dioxide ice particles. The complex refractive indices for all aerosols across a large spectral range (~200 nm to ~100000 nm) were pieced together from numerous published sources. Dust is assumed to be Hawaiian palagonite (an often-mentioned Mars dust analog). All particles are assumed to be spherical and homogeneous in composition in order to use a straightforward Mie scattering code to obtain the final aerosol

optical properties estimates.

The overarching philosophy in generating the aerosol optical properties in this fashion is that at least nearly all of the assumptions are *known*, even if they may not be overly realistic. Assuming that the dust is roughly spherical may not be too much of an extrapolation. Of course, water and carbon dioxide ice crystals forming in Mars conditions are unlikely to be well-approximated by spheres – however, the true habits (crystal shapes) of these ice aerosols on Mars is poorly constrained. One might try assuming the ice particles to be oblate spheroids or cylinders instead, but it is unclear whether those shapes would yield a better estimate of the true electromagnetic radiation interaction than if they were spheres, given the relatively unknown true shapes.

Topographic slope, aspect, and shadowing. The complex and extreme terrain on Mars (particularly at the mesoscale), coupled with the relatively short radiative relaxation timescale for the atmosphere, indicate that variations in surface insolation due to topographic slope, aspect (azimuth), and shadowing effects may be significant. While the effects of the slope and aspect of the local surface on the surface insolation are relatively simple to calculate, including shadowing is somewhat more involved. Shadowing is implemented in MRAMS using a type of offline (but is redone for every new grid configuration; uses the processed model topography fields) "ray-tracing" technique that generates lookup tables for use later. This technique also allows the shadowed portions of the atmosphere (not just the surface) to be accounted for.

MRAMS currently includes all three effects in its radiative transfer calculations. Atmospheric circulations associated with the large volcanoes, canyons, and relatively large craters all appear to be significantly affected by the inclusion of these effects.

Lower Boundary Specification and Interaction: A numerical model generally has a lower boundary of some kind – for astronomical bodies with a "shallow" atmosphere, the lower boundary is the body's surface. Many significant interactions take place at the surface-atmosphere interface, such as particle lifting, aerosol precipitation, volatile exchange, and energy exchange.

Dust/aerosol lifting and surface particle reservoir. The surface source of dust (and potentially other types of particles) injected into the atmosphere is parameterized as described in [8]. Briefly, the scheme employs a mass flux expression based on surface friction velocity. The mass flux of entrainable particles is weighted by a Weibull probability distribution function (PDF), and then integrated over all possible wind speeds to obtain the actual mass flux that MRAMS utilizes. The Weibull PDF is used to account for the unresolved (subgrid-scale) wind speed variance, which in some applications, may be large. The "width" of the Weibull PDF used varies as a function of the near-surface bulk Richardson number (*Ri*; a measure of atmospheric stability), ranging from large widths for unstable conditions to narrow widths for stable cases. The particle distribution acted upon by this scheme is discretized across a number of size/mass bins (e.g., typically 8 for dust).

A surface reservoir for aerosol particles has also been developed for MRAMS. Such a reservoir may serve as a finite source for particle injection into the atmosphere, as well as recording precipitation onto the surface. The surface reservoir particles use the same bin discretization as the airborne particles.

Volatile surface processes. MRAMS currently includes calculations for two volatile surface processes – carbon dioxide ice and water ice sublimation/deposition. The carbon dioxide ice scheme is the most developed of the two, and allows thermal conduction from the subsurface through the overlying ice, albedo to vary with the depth of the ice, and the ice heat capacity to vary as a function of temperature (requires an iterative solver). The water ice scheme is currently quite simple, and does allow any water vapor to diffuse in/out of the subsurface – it will be improved soon.

Cloud Microphysics: Since Mars has clouds composed of both water ice and carbon dioxide ice particles, a relatively detailed time-dependent cloud microphysical scheme (based on the CARMA model [9] and [10]) was integrated into MRAMS to simulate them (and their effects). See [11] for more information and a case study using this capability. All modeled aerosol particles are subject to the full range of atmospheric transport, including gravitational settling (precipitation) and turbulent mixing. Water ice and carbon dioxide ice are permitted to heterogeneously nucleate (and then deposit/sublimate) on the explicitly modeled airborne dust. All/any of the modeled aerosol species may be radiatively active, if desired. The coupling of this microphysical code with MRAMS permits the detailed investigation of cloud formation on Mars by explicitly modeling the evolution of the water ice, carbon dioxide ice, and dust particle size distributions.

Final thoughts: Mars mesoscale models have gained significant capabilities over the years, and the future holds much promise for them (or at least the parameterization schemes and techniques that were developed using them).

References:

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