REGULARITY OF BAROCLINIC WAVES IN THE TERRESTRIAL AND MARTIAN ATMOSPHERES.

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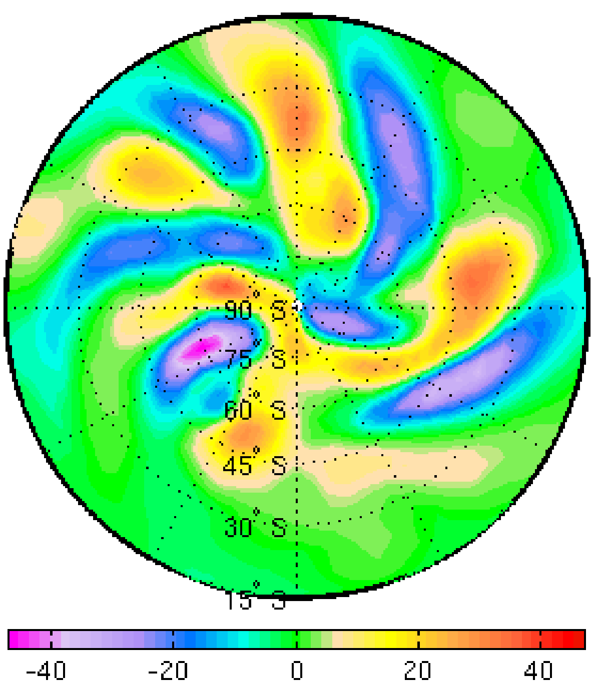
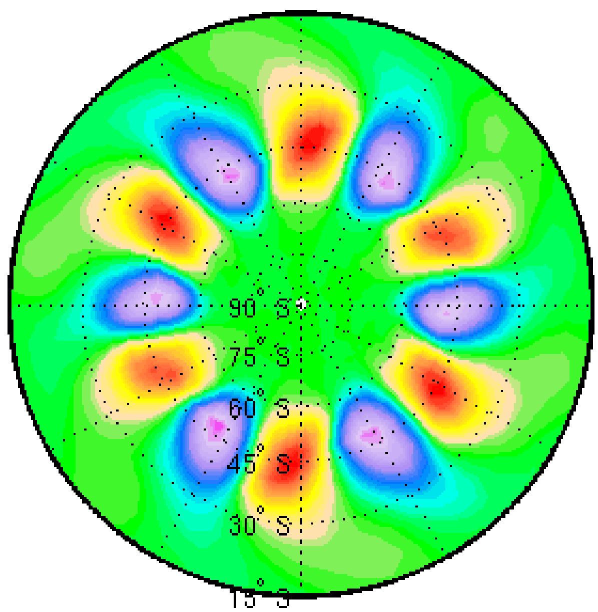
Introduction: The highly regular nature of baroclinic waves in the wintertime northern hemisphere of Mars was first suggested by meteorological observations made during the Viking program [1]. Despite subsequent observational studies (e.g., [2],[3]) that provide much more detail about the waves and a number of theoretical and modeling studies (e.g., [4],[5], [6]), understanding of the cause of the regularity of the waves remains incomplete. In this paper, we present the experimental design and some preliminary results from an investigation of this phenomenon with an idealized general circulation model.

Previous Theoretical Work: Based on the results of laboratory studies, Leovy [4] hypothesized that the high regularity of the Martian baroclinic waves compared to those of the Earth is a result of Mars having a significantly larger value of the ratio L_R/a than the Earth, where L_R is the Rossby deformation radius and a is the planetary radius. In physical terms, the greater regularity of the Martian baroclinic waves is hypothesized to result from the greater length scale of baroclinic instability relative to the domain scale available to the waves.

An alternative proposal was advanced by Barnes [5], who used an idealized numerical study of a baroclinic wave to illustrate the importance of the radiative damping timescale to its qualitative behavior. The use of shorter thermal damping timescales in the study's QG β-plane model tended to produce baroclinic waves that equilibrated at finite amplitude and propagated steadily, while longer thermal damping timescales resulted in waves not reaching such a state and instead varying in time. Additional evidence of the significance of the thermal damping time was produced by Collins and James [6], who conducted idealized GCM simulations with various values of the thermal and surface frictional damping times and found that the GCM could alternately produce a strong zonal wave 3 traveling baroclinic wave or a circulation without regular baroclinic waves.

Research Strategy: The hypothesis that the relatively short thermal damping time of the Martian atmosphere is the principal explanation for the regularity of its baroclinic waves has received more study than the earlier instability scale—domain scale hypothesis, but





Figures 1-2: Fig. 1 (above) and Fig. 2 (left) display instantaneous meridional winds in m s^{-1} at Ls = 180° for two different model configurations. In Fig. 1, the wind field is from a model level near 12 km and the model was run with p_s = 7.01 mb, τ_∞ = 1.15, and CO_2 condensation processes turned on. The simulation in Fig. 2 had p_s = 100 mb, τ_∞ = 8.20, and CO_2 condensation turned off and the wind field is from a model level at ~19 km. Both simulations had α = 0, terrestrial radius, and Mars-like seasonal cycles. The waves are much more regular in the p_s = 7.01 mb simulation.

we are unaware of any clear test to separate the two ideas. The present investigation aims to carry out such a test using an idealized GCM. In brief, the research strategy is to conduct simulations with different values of the thermal damping timescale and L_R/a and note how the modeled baroclinic waves respond. The possible role of other influences on baroclinic wave regularity, such as the structure of the surface temperature field, will also be investigated.

Idealized GCM: The model is a derivative of the GFDL Mars GCM (e.g., [7]) in which the realistic Mars radiative transfer scheme has been replaced by gray radiation as described in [8] or Newtonian relaxation to specified equilibrium temperatures.

The annual cycle of surface pressure associated with the oscillating sizes of the polar ice caps has been turned off, although some versions of the model still predict growth and decay of the ice caps and their effects on surface temperature. The atmospheric CO_2 condensation physics can optionally be turned off in the idealized GCM. Simulations have been carried out with both fixed seasons and Mars-like seasonal cycles. The topography is generally flat, but both Martian and terrestrial radii have been used.

Preliminary Numerical Experiments: The radiative properties of the atmosphere in gray radiation versions of the idealized GCM can be described by a total optical depth τ_∞, the surface pressure p_s, and a parameter characterizing the vertical distribution of infrared opacity α such that $\tau(p) = \tau_\infty\,[1 - (p/p_s)^{\alpha+1}]$. By adjusting the values of τ_∞ and p_s, we have succeeded in generating simulations with highly regular baroclinic waves perhaps analogous to those seen on Mars and simulations with more irregular waves that may be similar to the terrestrial circulation.

The difference between the two regimes is quite clear in movies of model output, and meridional wind fields illustrating the different wave regimes are shown in Figs. 1 and 2. However, the highly regular waves in Fig. 1 may be associated with a sharp polar cap edge temperature gradient near 45º S in the p_s = 7.01 mb simulation that is not present in the p_s = 100 mb simulation. The relevance of these simulated highly regular waves to regular waves on the real Mars remains an open question.

Quantifying Baroclinic Wave Regularity: Inspection of output from the idealized GCM allows one to form a subjective impression of the regularity of its baroclinic waves, but quantification of this property is essential for detailed analysis. An approach we have been using is to compute empirical orthogonal functions decompositions of one hemisphere of a model output field (such as surface pressure or meridional wind at a single level) and see how much of its variance can be explained as a function of the number of EOFs used. The larger the fraction of the total variance explained by a given number of EOFs, the more regular the variability of the field is.

This technique strikingly corroborates the impression created by Figs. 1 and 2. EOF decompositions of the meridional wind fields at the model levels plotted in Figs. 1 and 2 were calculated for a 52-day period centered on Ls = 180º, a time period in which the difference between the regular and irregular wave regimes is particularly prominent. It is found that the first pair of EOFs explains roughly 86% of the variance for the p_s = 7.01 mb simulation, but only about 26% of the variance for the p_s = 100 mb simulation.

Current Work and Future Plans: Although gray radiation versions of the idealized GCM exhibit diverse baroclinic wave phenomena, further simplification of the model is desirable to test hypotheses for the cause of the wave regularity. Because thermal relaxation times, deformation radii, and other potentially interesting quantities cannot be manipulated directly via the gray radiation scheme, we plan to attempt to reproduce the behaviors of interesting gray radiation simulations with appropriately forced Newtonian relaxation simulations. The Newtonian forcing fields can then be perturbed and the response of the model observed. It is hoped that this approach will supply information about the role of the perturbed quantity in creating the behavior of the original gray radiation simulation and ultimately the real Martian and terrestrial atmospheres.

To assess the relevance of the idealized modeling results to the real world, we also plan to compare them to observed baroclinic waves. Existing reanalysis datasets for Earth and Mars are expected to be suitable for this purpose (e.g., [9]).

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