GEOLOGICAL FORCING OF SURFACE TEMPERATURES ON VENUS.

M. A. Bullock and D. H. Grinspoon, Laboratory for Atmospheric and Space Physics, CB 392, University of Colorado, Boulder, CO 80309-0392. bullock@sunra.colorado.edu

Introduction. Epochs of widespread plains emplacement on Venus would have significantly perturbed atmospheric inventories of water and sulfur gases. These gases are potent infrared absorbers that act preferentially to block outgoing thermal radiation within carbon dioxide spectral windows. Small changes in their abundances can significantly alter the efficiency of the Venus atmospheric greenhouse and hence globally-averaged surface temperatures [1]. However, they are also the primary reactants in producing Venus' global cloud cover and hence high planetary albedo.

Atmospheric water and sulfur dioxide together influence Venus' surface temperature in two competing ways -- by producing clouds which reduce solar forcing, and by amplifying the Venus greenhouse effect.

In addition to possible rapid changes in the concentrations of these gases due to volcanic outgassing, other planetary-scale processes involving the transport, escape and crustal sequestering of volatiles affect abundances over time, driving changes in climate.

Climate Modeling. We have developed detailed numerical models of the recent climate evolution of Venus. Atmospheric temperatures are calculated using a one-dimensional two-stream radiative-convective model that treats the transport of thermal infrared radiation in the atmosphere and clouds. These radiative transfer calculations are the first to utilize high temperature, high resolution spectral databases for the calculation of infrared absorption and scattering in Venus' atmosphere and clouds.

We use a chemical/microphysical model of Venus' clouds to calculate changes in cloud structure that result from variations in atmospheric water and sulfur dioxide. The cloud/microphysical model is coupled in a self-consistent way with the atmospheric radiative-convective calculations. Atmospheric abundances of water and sulfur dioxide change under the influence of the exospheric escape of hydrogen, outgassing from the interior, and heterogeneous reactions with surface minerals.

Radar images from the Magellan mission show that the surface of Venus has been geologically active on a global scale, yet its sparse impact cratering record is almost pristine. This geological record on Venus is consistent with one or more epochs of rapid plains emplacement 600-1100 million years ago [2]. Making assumptions regarding the water [3] and sulfur abundances of erupting lavas, (50 and 2000 ppm, respectively) a rapid, global volcanic event sufficient to cover the planet in a layer 10 km deep would increase atmospheric abundances of these species by factors of 10-100.

Using a reaction-diffusion model of the heterogeneous reaction of sulfur dioxide with calcite [1] and employing laboratory-derived kinetic data [4], we find that atmospheric sulfur dioxide can be lost to available surface minerals on timescales of 20-50 million years. The exospheric escape of hydrogen is modeled as a diffusion-limited process, with a residence time for water in the Venus atmosphere of 160 million years [3].

Results. The evolution of atmospheric mixing ratios of sulfur dioxide and water as a result of rapid outgassing associated with global plains emplacement for one scenario are shown in Figure 1.

The initial conditions are for a Venus atmosphere that is in chemical equilibrium with the surface at approximately current temperatures. We model this event as a single pulse of outgassing followed by an exponential decrease with a time constant of 100 million years. Atmospheric sulfur dioxide is lost more quickly than water due to its rapid uptake by surface minerals.

With these assumptions, our models show that intense volcanic outgassing of sulfur dioxide and water would have resulted in the formation of massive sulfur dioxide/water clouds (Figure 2) and the cooling of the surface for about 300 million years (Figure 3). The thick clouds would have subsequently given way to high, thin, water-rich clouds as atmospheric sulfur dioxide was lost to reactions with the surface. The atmospheric water/sulfur ratio in this scenario begins to increase after about 200 million years (Figure 1). When this ratio gets high enough (about 20), a runaway loss of clouds is observed as the atmosphere becomes too hot to support massive sulfuric acid/water clouds. Surface temperatures approaching 900 K would have been reached about 500 million years after the onset of widespread, intense volcanism. Evolution to current conditions would have proceeded due to loss of atmospheric water from exospheric escape of hydrogen, and the reappearance of sulfuric acid/water clouds.

Currently, the Venus atmosphere contains approximately 100 times more sulfur dioxide than there would be if it were in chemical equilibrium with surface calcite. Given that sulfur dioxide reactions proceed rapidly with the surface, this implies that volcanism on Venus has been active in the past 20-50 million years. In addition, the globally-encircling cloud layers, which endow Venus with its brilliance, are actively supported by recent geological activity.

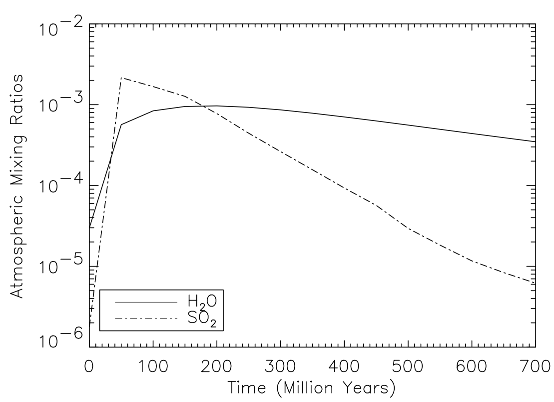

Figure 1. The evolution of atmospheric mixing ratios of sulfur dioxide (dot-dashed line) and water (solid line) as a result of rapid outgassing associated with global plains emplacement on Venus. Sulfur dioxide is subsequently lost by reactions with surface minerals, while water abundances decline due to the exospheric escape of hydrogen.

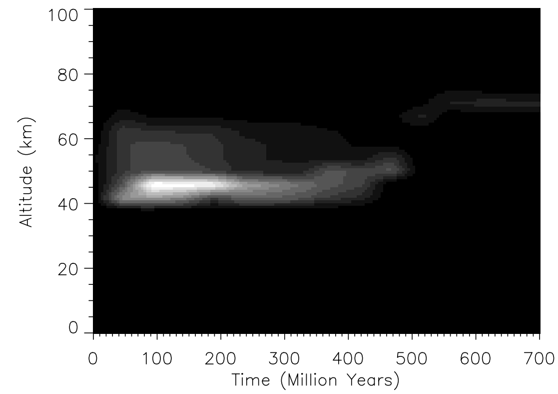

Figure 2. The evolution of Venus cloud visual optical depth as a result of rapid outgassing associated with global plains emplacement. The figure shows how a vertical cross section of the clouds evolves over time, driven by the changes in abundance plotted in the first figure.

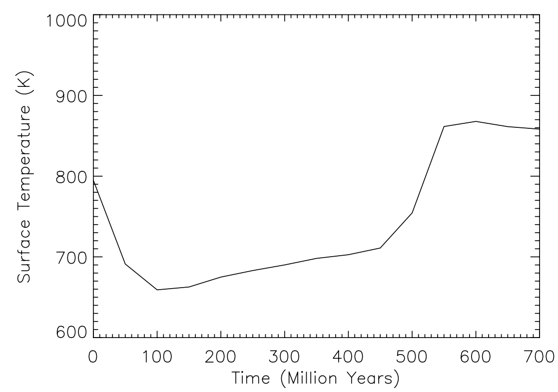

Figure 3. The evolution of Venus surface temperature as a result of rapid outgassing associated with global plains emplacement. Surface temperature evolves under the competing influence of cloud albedo and greenhouse effect, driven by the atmospheric abundance plotted in Figure 1.

References: [1] Bullock, M.A., and D.H. Grinspoon, *J. Geophys. Res.* **101** 7521-7529, 1996. [2] McKinnon, W.B. *et al.*, *Venus II*, 969-1014, 1997. [3] Grinspoon, D.H., *Nature* **363**, 428-431, 1993. [4] Fegley, B., and A.H. Treiman, *Venus and Mars: Atmospheres, Ionospheres and Solar Wind Interactions*, 7-71, 1992.