

CLIMATE CHANGE ON VENUS AND FUTURE SPACECRAFT MISSION PRIORITIES

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Weathering of surface minerals in the sulfur-rich lower atmosphere of Venus may well have played a significant role in the recent evolution of the planet's climate. SO₂ in the atmosphere is interesting because it is the primary precursor of Venus' bright H₂SO₄/H₂O clouds, it is a greenhouse gas, it is most likely outgassed by volcanoes [Prinn, 1985], it probably reacts with the surface, and it is apparently much higher in abundance than would be expected from thermochemical equilibrium with the surface [Fegley and Treiman, 1992] (although interpretations of Vega 1 and 2 UV spectrometer data challenge the latter, see Bertaux *et al.*, [1996]). Changes in the atmospheric abundance of SO₂ would be accompanied by alterations in the optical properties of the clouds and in the greenhouse effect, thereby affecting surface temperatures [Bullock and Grinspoon, 2001].

Fegley and Prinn, [1989] demonstrated experimentally that the reaction $\text{CaCO}_3 + \text{SO}_2 \rightleftharpoons \text{CaSO}_4 + \text{CO}$ proceeds rapidly under Venus-like conditions, and concluded that SO₂ and hence the H₂SO₄/H₂O clouds would disappear in 1.9 My unless SO₂ in the atmosphere were continually replenished by volcanic outgassing. Using a coupled chemical kinetic reaction-diffusion and climate model, [Bullock and Grinspoon, 2001] calculated that volcanism must supply SO₂ to the atmosphere on approximately 30 My timescales in order to maintain clouds with their current optical properties. Clues to the nature of the recent Venus climate may be obtained by elucidating the sensitivity of cloud properties to changes in atmospheric SO₂ and H₂O and by investigations into the styles and depths of chemical weathering at the surface.

Future robotic spacecraft missions have the potential to provide significant insights into recent climate change on Venus and on the role that sulfur may have played. Among the most important and scientifically valuable investigations are:

1. High spectral, spatial, and temporal resolution near-IR imaging spectrometry from Venus orbit in order to retrieve accurate SO₂, H₂O and CO abundances and variability beneath the clouds. Coupling gas abundance and variability to cloud morphology, cloud optical properties, and to atmospheric dynamics would enable a far better understanding of how clouds and climate respond to changing atmospheric chemistry.
2. Visible to near-IR high resolution images of the surface from 15-20 km in order to complement the global synthetic aperture radar imagery of the Magellan mission (e.g. [Moroz, 2002]). Remaining scientific issues about Venus' geologic history, which is vigorously debated, may well be resolved by obtaining near-visual wavelength datasets of selected areas on Venus. These can be used to calibrate the global radar dataset in terms of surface properties and geomorphology.
3. Elemental and mineralogical analyses of the surface and subsurface, in order to establish both fundamental mineralogy and weathering products as a function of depth. Visual images of the surface by the Venera landers clearly show broken slabs a few cm in thickness [Surkov *et al.*, 1984]. This provides hints as to the nature and extent of weathering of the surface. A detailed mineralogy of the top 10 cm of the surface would provide highly valuable information on the nature and rates of surface-atmosphere interactions and their possible role in alterations of atmospheric chemistry and climate.

Although Venus is a difficult planet to study because of its shroud of sulfuric acid clouds and its otherwise harsh environment, it is the only planet that shares the similarity with Earth of having a climate that is actively modified by its geology. As the study of Earth's climate becomes of greater and greater significance to society, so too does the necessity of thinking of planetary climate 'outside the box'. The continued exploration of Venus is one of the most promising avenues to accomplish this.

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