Venus Atmospheric Explorer New Frontiers Mission Concept

Kevin H. Baines, Jet Propulsion Laboratory/Caltech
818-354-0481; kevin.h.baines@jpl.nasa.gov

Sushil Atreya, University of Michigan
Tibor Balint, Jet Propulsion Laboratory/Caltech
Mark Bullock, Southwest Research Center
David Crisp, Jet Propulsion Laboratory/Caltech
David Grinspoon, Denver Museum of Nature and Science
Jeffery L. Hall, Jet Propulsion Laboratory/Caltech
Gary W. Hunter, NASA/Glenn Research Center
Sanjay Limaye, University of Wisconsin-Madison
Viktor Kerzhanovich, Jet Propulsion Laboratory/Caltech
Paul R. Mahaffy, NASA/Goddard Space Flight Center
Christopher T. Russell, University of California, Los Angeles
David Senske, Jet Propulsion Laboratory/Caltech
Stuart K. Stephens, Jet Propulsion Laboratory/Caltech
Chris R. Webster, Jet Propulsion Laboratory/Caltech

Science Objectives

Despite the proximity of Venus to Earth and their similarity in composition and size, our lack of knowledge of our sister planet is remarkable. As summarized in numerous studies in recent years, including the 2003 Decadal Study, reports by the Venus Exploration Analysis Group (VEXAG), book chapters from international conferences on Venus, and in several white papers being submitted to the current Decadal Study effort (e.g., Crisp et al., 2003; NRCDS, 2003; Luhmann et al., 2007; Baines et al., 2007; Smrekar et al., 2009; Limaye et al, 2009a; Limaye et al., 2009b), we understand very little about the planet's origin and evolution, its circulation, atmospheric chemistry, and meteorology. Yet, as amply demonstrated in the past – with, for example, fundamental revelations on the importance of the greenhouse effect and the terrestrial ozone hole – Venus has a lot to teach us about how planetary atmospheres, including the Earth, work and evolve.

A primary hindrance to understanding the world next door is its perpetual veil of clouds that greatly obscures views of the deep atmosphere except over a small range of near-infrared wavelengths. In-situ techniques are invaluable tools in filling this observational gap, allowing accurate measurements of salient atmospheric parameters such as pressure, temperature, winds, cloud properties, reactive gas distributions, and the abundances of noble gases and their isotopes. Such measurements address fundamental questions of "How Venus formed and evolved" and "How Venus works today", as well as directly address the forces of climate change on Earth.

Specific examples include (1) understanding the global super-rotating wind structure and (2) understanding the sulfur-based chemistry and its role in producing and maintaining clouds, radiative balance, and climate. The high-speed winds of Venus's middle atmosphere – which whip around the planet at speeds up to 60 times the planet's rotation rate – are an enigma. Mechanisms that can accelerate the atmosphere on a global scale to such high speeds are poorly understood. Momentum transport by solar thermal tides and eddy circulation has been suggested as a key process to explain the super-rotation. To determine both the tides and the eddy motions, we need to know the zonal and meridionally averaged winds and their spatial variability at a given level and latitude (Limaye, 2007). However, both have been impossible to measure to date with conventional cloud tracking techniques from orbit because (1) cloud tracking provides winds on day and night sides at different levels, and (2) the clouds themselves may vary in altitude longitudinally. By circumnavigating Venus at a known level and latitude, balloons can give the requisite data to determine the mean tidal effect and estimates of the local eddy components. Moreover, these data can be used to essentially calibrate more global cloud-tracking measurements, and thus extend the assessment of eddy components over large regions of the planet. As well, such a balloon can measure numerous other dynamical phenomena that may contribute to super-rotation as well as to the meridional circulation, including the characterization of planetary waves and Hadley cells.

The intense, reactive chemistry that results in Venus's ubiquitous cloud cover is poorly understood. In particular, the composition of the mysterious UV absorber (presumably an allotrope of sulfur), the production and loss mechanisms for this absorber as well as the H_2SO_4 clouds, and the roles of CO and OCS in helping to catalyze the formation and destruction of these clouds are not known. In-situ measurements of the numerous key species involved in this chemistry over all times-of-day and a variety of latitudes can help disentangle the roles of various photochemical and thermal reactions in controlling cloud formation/dissipation. As well, concurrent measurements of vertical dynamics, cloud particle size and density, and cloud-forming species will enlighten us on how Venus's current cloudy climate is maintained, and reveal how this climate may change with small variations in environmental factors.

Mission Architecture

The Venus Atmospheric Explorer would use both *in-situ* platforms and a planetary orbiter to explore Venus's atmosphere and surface, particularly the depths below the cloud tops. *In-situ* sampling of winds, temperatures, pressures, aerosols, and trace species over a large range of precisely-known altitudes, latitudes, longitudes, and times-of-day directly address the major question of How Venus Works, dynamically, chemically, meteorologically, and geologically. These data are supplemented by high-spatial measurements of chemicals and aerosols obtained remotely from orbit that extend the localized in-situ measurements globally and over time. Valuable surface science is also accomplished with surface imagery obtained from the orbiter and in-situ platforms, as well as by a topographic mapping RADAR onboard the orbiter. As well, the orbiter serves as a communications relay to transmit data from the balloon and track it when it flies on the backside of the planet, hidden from Earth.

The in-situ vehicles consist of a single balloon platform carrying an instrumented gondola and two drop sondes (a prototype balloon and drop sonde, developed at JPL, are pictured on the cover). The 7-meter-diameter super-pressure balloon vehicle floats at 55 km altitude at near room-temperature conditions (~30C, 0.5 bar), utilizing the ~ 65 m s^{-1} winds of Venus to circle the planet in ~ 6 days. Over a month, the balloon circumnavigates the planet ~ 5 times, drifting poleward from temperate to polar latitudes in the gentle (1-5 m/s) meridional winds of Venus (Sánchez-Lavega et al., 2008). A ~100 kg gondola hanging ~ 10 meters under the balloon carries the science payload, power, and communications systems. Science instrumentation measures (1) reactive trace gases as well as stable and noble gas isotopes via a Gas Chromatograph Mass Spectrometer or a combination Mass Spectrometer/Tunable Laser Spectrometer instrument, (2) aerosol size and column density via a 2-channel nephelometer, (3) pressures and temperatures with suitable sensors, and (4) the rate and strength of nearby lightning, via an electromagnetic lightning detector. In addition, Doppler/radio tracking of the vehicle by the orbiter as well as by an interferometric array of Earth-based radio telescopes yield the balloon's velocity in all three dimensions with high accuracy, providing invaluable data on atmospheric circulation.

The two drop sondes, each deployed over targeted surface features from their stowed position on the outside of the gondola, measure the vertical profiles of (1) five key trace gases via chemical microsensors (e.g., Hunter et al., 2006) and (2) the pressure/temperature structure. The drop sondes are tracked by both the orbiter and the balloon, to obtain deep-atmosphere wind measurements. In addition, a camera takes about a dozen single-filter images of the targeted surface feature as it descends through the last 5 km of altitude, acquiring detailed high-resolution (better than 1 meter) topo-graphic, surface albedo, and texture information.

The orbiter circles the planet in an inclined (~ 50 degree elliptical orbit with a ~ 60,000 km apoapse coinciding with the mean latitude of the balloon and positioned over the farside of the planet (as viewed from Earth). This ensures optimum conditions for communications with the balloon while it flies on the backside of Venus as seen from Earth. The orbiter carries a science package consisting of a near-infrared spectral-mapping camera, similar to Venus Express/VIRTIS and Cassini/VIMS, and a topographic RADAR. The near-infrared spectral-mapper (1) images cloud and airglow frequently enough to determine motions, (2) maps key trace gases globally (such as CO), and (3) maps the surface for high- and low-emissivity materials (building on the recent assessments of Mueller et al., 2008 and Hashimoto et al., 2009). The topographic RADAR maps the surface at 1-km/pixel spatial resolution near periapse, with a vertical resolution of about 1 meter. A ~1 year RADAR mapping mission ensures nearly complete, high-resolution coverage of the periapse-centered hemisphere. The high inclination orbit not only ensures high-resolution RADAR mapping over a large latitude range, but also provides a good vantage point near apoapse to monitor the evolution of the hemispheric vortex with the near-infrared spectral-mapper, thus enabling long-term observations of dynamic instabilities recently observed by VIRTIS on Venus Express (Limaye et al., 2009c). In the core of the vortex, at the pole, such instability features provide a probe of the deep circulation of Venus that can aid in understanding the planet's enigmatic super-rotation.

The Venus Atmospheric Explorer mission – the first long-duration in-situ exploration of Venus - requires minimal technology developments. The balloon operates in an Earth-like environment, and thus does not require high temperature components or pressure mitigation. Ongoing technology development efforts at JPL have already benefited the balloon design and the mitigation of sulfuric acid droplets in the clouds. While this mission concept requires further definition, it is expected to comfortably fit under New Frontiers cost cap. For even more extensive study of Venus, particularly of the harsher conditions of the deep atmosphere underneath the sulfuric acid cloud, additional developments are needed. The time is now to begin investments in such technology developments, to eventually lead to long-duration exploration of the deep atmosphere and surface.

References

Baines, K. H., Atreya, S. K., Carlson, R. W., Crisp, D., Grinspoon, D., Russell, C. T., Schubert, G. and Zahnle, K. (2007). Experiencing Venus: Clues to the origin, evolution, and chemistry of terrestrial planets via *in-situ* exploration of our sister world. In *Exploring Venus as a Terrestria l Planet* (L. W. Esposito, E. R. Stofan, and T. E. Cravens, Eds). Geophysical Monograph 176, American Geophysical Union, Washington, DC. pp. 171-189.

Crisp, D., Allen, M. A., Anicich, V. G., Arvidson, R. E., Atreya, S. K., Baines, K. H., Banerdt, W. B., Bjoraker, G. L., Bougher, S. W., Campbell, B. A. *et al.* (2002). Divergent evolution among Earth-like planets: The case for Venus exploration. In *The Future of Solar System Exploration, 2003-2013* (Mark Sykes, Ed). ASP Conference Series, Vol 272. pp. 4-34.

Hashimoto, G, Roos-Serote, M., Sugita, S., Gilmore, M. S., Kamp, L. W., Carlson, R. W., and Baines, K. H. (2009). Felsc highland crust on Venus suggested by Galileo Near Infrared Mapping Spectrometer (NIMS) data. *JGR-Planets*, 114 E00B24, doi:10.1029/2008JE003134

Hunter, G.W., Xu, J. C., Liu, C. C. and Makel, D. B. (2006). "Microfabricated Chemical Sensors for Aerospace Applications," in The MEMS Handbook Second Edition: Design and Fabrication, Chapter 11, edited by M. Gad-El-Hak, (CRC Press).

Limaye, S. S. (2007), Venus atmospheric circulation: Known and unknown, J. Geophys. Res.,112, E04S09, doi:10.1029/2006JE002814.

Limaye, S. S., Smrekar, S. and the VEXAG Executive Committee (2009a). VEXAG goals, objectives, investigations, and priorities: 2009. White Paper to the 2009-2010 Decadal Survey. http://www.lpi.usra.edu/vexag/reports.shtml

Limaye, S. S. and over 20 co-authors (2009b). Venus atmosphere: Major questions and required observations. White Paper to the 2009-2010 Decadal Survey. http://www.lpi.usra.edu/vexag/reports.shtml

Limaye, S. S., J. P. Kossin, C. Rozoff, G. Piccioni, D. V. Titov, and W. J. Markiewicz (2009). Vortex circulation on Venus: Dynamical similarities with terrestrial hurricanes, Geophys. Res. Lett., 36, L04204, doi:10.1029/2008GL036093.

Luhmann, J., Atreya, S., Mackwell, S., Baines, K., Cutts, J., Ocampo, A. (October, 2007). Venus exploration goals, objectives, investigations, and priorities: 2007. http://www.lpi.usra.edu/vexag/reports.shtml

Mueller et al., 2008, *J. Geophys. Res.*, 113, E00B17, doi:10.1029/2008JE003118

NRCDS: Solar System Exploration Survey, Space Studies Board, 2003. New Frontiers in the Solar System: An integrated exploration strategy. The National Academies Press, Washington, DC.

Sánchez-Lavega, A., Hueso, R., Piccioni, G., Drossart, P., Peralta, J., Pérez-Hoyos, S., Wilson, C. F. , Taylor, F. W., K. H. Baines, K. H., Luz, D., Erard S., and Lebonnois, S. (2008). Variable winds on Venus mapped in three dimensions. *Geophy. Res. Let.* **35**, L13204, doi:10.1029/2008GL033817.

Smrekar, S., Limaye, S. S. and the VEXAG Executive Committee (2009). Venus science goals, objective, and investigations and New Frontiers Concepts. Presentation to the Inner Planets Panel of the Decadal Study; http://www.lpi.usra.edu/decadal/vexag/InnerPlanetsPanel08272009_v3.pdf