VENUS' ROBOTIC EXPLORATION AT UPPER CLOUD LEVEL : A US-EUROPEAN PERSPECTIVE: T. Widemann[1], V. Wilquet[2], K. McGouldrick[3], A. Määttänen[4], J. Cutts[5], C. Wilson[6], K. L. Jessup[7], S. Limaye[8], R. Polidan[9], K. Griffin[9], the EuroVenus consortium[10], [1]LESIA – Observatoire de Paris, CNRS, 5 place Jules-Janssen, 92190 Meudon, France – thomas.widemann@obspm.fr, [2]IASB-BIRA-BISA - av Circulaire 3, 1180 Brussels, Belgium - [3]LASP - University of Colorado Boulder, CO, [4]LATMOS - Université Versailles St Quentin, CNRS, Guyancourt, France, [5]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, [6]Dept. of Physics, Oxford University, UK, [7]SouthWest Research Institute, Boulder, CO, [8]University of Wisconsin, Madison, WI, [9]Northrop Grumman Aerospace Systems, Redondo Beach, CA, [10]Seventh Framework project by the European Commission, 2013-2016.

Session: This topic is intended for the session "Within the Atmosphere". The focus is on exploration targets in the altitude range 57 km to 70 km.

In the context of the VEXAG Goals, Objectives, Investigations [1], the primary emphasis is on Goal I-C Cloud and Haze Chemistry and Dynamics.

Target: cloud top layer, 57-70 km – Target Region 1 (TR1) typical of a long-lived, semi-buoyant maneuverable platform [2].

Science Goal(s): I-C Cloud and Haze Chemistry and Dynamics.

General context: Venus is Earth's closest sibling, but it has ended up with a radically different climate. How did the environments of Venus and Earth become so divergent ? The answer to this question relies upon an understanding of Venus' origins, the nature of its present atmosphere, and the role that the clouds have played in evolution and current state of Venus.

This is increasingly important in an era in which we are trying to understand the divergent evolutionary outcomes for terrestrial planets, whether we are considering the future of our Earth or the habitability in other solar systems.

Coupling of winds and chemistry - The upper cloud layer (~57 – ~70 km) show great spatial and temporal variability. The upper haze on Venus lies above the cloud layer surrounding the planet, ranging from the top of the cloud (~ 70 km) up to as high as 90 km. In the~2 scale heights immediately above the cloud tops between ~70 km and ~80 km, superrotating zonal winds generally decrease with height while thermospheric, sub-solar to anti-solar winds increase.

The European mission has significantly improved our knowledge of both regions by providing global long-term remote sensing observations with complete coverage in latitude and local solar time. However major questions remain about key minor species, the physical properties of H_2SO_4:H_2O mixtures composing the hazes and clouds, and how they vary throughout the major atmospheric regimes in the upper atmosphere, near the cloud tops where photolysis and condensation processes occur.

Since most of the solar energy is absorbed at cloud level, the clouds play a key role in the maintenance of the super-rotation. General circulation models of the atmosphere also support the likelihood of this link. Numerical studies suggest that both the Gierasch-Rossow-Williams and thermal tide mechanisms operate simultaneously to maintain atmospheric superrotation on Venus [3], but more data are needed, and with better spatial resolution, to understand which waves carry momentum and how that transport is made. In situ measurements of the wind speeds within the clouds are limited to a handful of previous descent probes and two super-pressure balloons; and remote measurements of the wind speeds are susceptible to confusion by microphysical variations in the clouds themselves [4, 5].

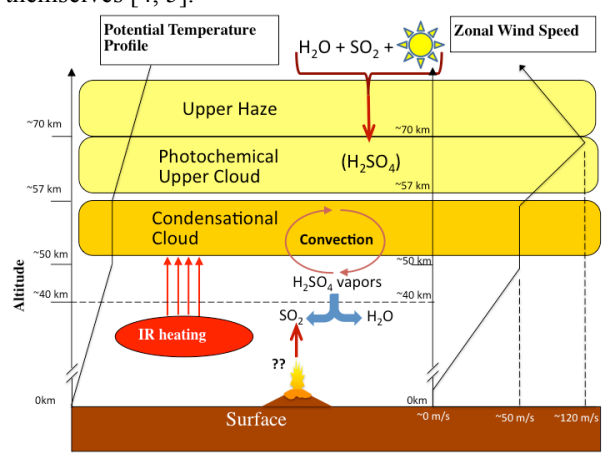

Figure 1: A schematic of the Venus clouds, showing the photochemically produced upper clouds and hazes, and the condensationally supported middle and lower clouds. A typical vertical profile of potential temperature is shown on the left side of the figure, where a constant potential temperature with altitude indicates a susceptibility to convective overturning. Also shown at the right side is a typical vertical profile for the zonal winds, based on previous in situ probes and cloud tracking. There is much variability seen in the existing measurements of the zonal winds, but a steady increase in wind speed after the first few kilometers above the surface, followed by an almost constant wind speed of about 50m/s through the convective region, and then peaking with a speed of around 120m/s near the tops of the upper clouds, is typical.

Cloud and haze microphysics, winds and heterogeneous chemistry - The clouds of Venus are ubiquitous, play a significant role in the radiative balance of the planet, are used as tracers to probe the atmospheric circulation, and are a key part of a global sulfurohydrological cycle that redistributes key greenhouse gasses such as SO_2 and H_2O. Thus understanding the clouds of Venus holds the key to understanding how Venus itself came to be the world of extremes that it is today.

Aerosols have been studied extensively because their optical properties impact the radiative balance through absorption and scattering of solar radiation. Data on the climatology of the upper haze of Venus were rather sparse but since its arrival at Venus in 2006, both VIRTIS-M IR on the nightside [6] and SPICAV/SOIR at the terminators [7] were able to target the upper haze above the cloud layers. Observations made it possible to postulate that the upper haze on Venus includes, in some instances, a bimodal population, one type of particles with a radius comprised between ~0.1 and 0.3 µm as inferred by the UV channel and the second type, detected in the IR, with a radius varying between ~0.4 and 1 µm depending on the altitude were indeed observed [7].

Formation of H_2SO_4 clouds - Measurements by an in-situ airborne mission can scrutinize upper cloud evolution in unprecedented detail. In particular, in-situ measurements of cloud particle sizes, acquired simultaneously with measurements of the concentration of H_2O, SO_2, and other species involved in the formation of H_2SO_4 clouds, can be correlated as well with the measured vertical velocities, local radiative balance and temperature variations.

Establishing a long-term chemical laboratory in the cloud layer which would measure the detailed composition of both gas and liquid phases, and their latitudinal, diurnal and vertical variability using a combination of mass spectrometry, gas chromatography, tunable laser transmission spectrometry, and polar nephelometry would significantly address all of these objectives. It would allow the determination of the size distribution, shape, and real and imaginary refractive indices of the cloud particles, and the measurement of intensity and polarization phase functions.

Our target species would include those known to be associated with cloud formation (e.g. H_2SO_4, SO_3, SO_2, H_2O), as well as species important in stratospheric chemistry (e.g. CO, ClCOx, Ox, HCl, HF) and surface-atmosphere buffering (e.g. CO, OCS, SOx, Ox, H_2S).

VAMP platform – For exploring Target Region 57-70 km, we recently considered the Lifting Entry / Atmospheric Flight (LEAF^{TM}) innovative class of combination entry-and-flight vehicles in development at Northrop Grummman Aerospace Systems and L'Garde, Inc [2]. VAMP is a semi-buoyant, self-propelled aerial vehicle.

This vehicle can survive for months to years in the Venus atmosphere, with the lifetime limited only by the gradual loss of buoyant gas through the envelope and/or corrosive effects of the atmosphere. It is maneuverable in latitude, longitude, and altitude via uploaded commands from the Science Operations Center on Earth.

The exact altitude range is a tunable parameter in the vehicle design; a point design targeting the cloud deck and the region immediately above the clouds is designed to maneuver at will between 56 and 70 km.

During propelled flight, the combination of lift and buoyancy provides altitude mobility; in passive flight during the Venusian night, the vehicle floats at its 100% buoyancy altitude of 56 km.

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