Report from the Venus climate working group

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1 Observational aspect

1.1. Present status of the Venus Express mission (Svedhem, Titov)

The Venus Express mission continues to provide detailed monitoring of atmospheric structure, cloud morphology and dynamical processes of the Venus atmosphere. Radio, solar and stellar occultation, together with thermal emission spectroscopy, of the atmospheric structure in the altitude range from 150 to 40 km with vertical resolution of few hundred meters, reveal strong temperature variations all over the planet driven by radiation and dynamical processes. Multi-spectral imaging is performed to investigate the cloud morphology at different levels and its latitudinal and temporal changes. It shows vigorous convection in the cloud layer at low latitudes that ceases towards the poles. Sequences of images are used to track motions of the cloud features and to derive wind speeds in the 50-70 km altitude range.

The polar orbit of Venus Express providing near-nadir viewing of middle and high latitudes in the southern hemisphere, enables the first detailed observations of the cloud morphology and dynamics, leading to the discovery and characterisation of the complex "eye" of the southern polar vortex. The imaging instruments also perform thermal mapping of the surface in the near IR spectral windows on the night side, searching for surface emissivity anomalies and signs of active volcanism.

The chemistry and dynamics of the mesopause region (~100 km altitude) is being studied by observing non-LTE emission from O2 and NO molecules in the UV and near-IR. Composition measurements over a wide range of altitudes are providing for the first time vertical profiles of CO, H2O, HDO, HCl, HF, and SO2 in the mesosphere (70-100 km), and global mapping of CO, COS, H2O, and SO2 in the lower atmosphere at heights around 35 km.

The Venus Express instruments measure the magnetic field and densities of neutral atoms, ions and electrons in-situ. These observations determine the structure and properties of the circumplanetary plasma and characterize escape processes at Venus. They cover the time of solar minimum, and thus complement Pioneer Venus investigations at solar maximum. Interestingly, the H/O ratio was found to be ~2 thus suggesting that these ions are escaping in the stoichiometric ratio of water. The magnetometer is detecting whistler signals in ~10% of the peri-centre passes. This is interpreted as evidence of lightning and the rate is estimated to be at least as frequent as on Earth.

The Venus Express observations contribute significantly to the field of comparative planetology and, in particular, to a more in depth understanding of the Earth climate and its evolution and to the dynamics of the planetary atmospheres in general.
The mission is funded until May 2009; a request has been submitted for an extension to 2012. Such an extension is important, as it will assure overlapping with the Japanese mission

1.2. Status report of the Japanese mission (Yamamoto)

The present status of the Japanese Venus mission was briefly reported based on information by the JAXA group (Dr. Imamura) (Nakamura et al. 2007). Japan's Venus Climate Orbiter (VCO/PLANET-C) with 6 instruments on board is scheduled for launch in 2010 and will observe the planet for 2 Earth years. The main target is the meteorology of Venus (super-rotation mechanism, meridional circulation, mesoscale process, cloud physics, and lightning). The horizontal distributions of meteorological elements (cloud-tracking wind vector and temperature), minor constituent concentrations (H2O, SO2, and CO) and the vertical distributions of temperature and sulphuric acid vapour can be observed by the on-board instruments (a long-wave IR camera, an ultraviolet imager, two IR cameras of 1 and 2 my wavelength, a lightning and airglow camera, and an ultra-stable oscillator for radio science). They plan to operate the sequential observation on the equatorially elongated orbit with the revolution period of about 30 hours.
When the satellite is far from Venus, global images of the atmosphere and the ground surface will be acquired continuously over 1 Earth day. When the satellite is located near Venus, close-up images will be acquired and lightning flashes and airglow will also be detected. Near the peri-center, limb images can be obtained. The flight model design and manufacture have been conducted. At the next step, the final test integration will be started in 2009 toward the 2010 launch.

US Activities (Limaye)

A report was given from the VEXAG meeting last May. A key objective in a future US mission will be comparative climatology but include an in-depth understanding of the polar vortex through a combined use of models and observations. A Venus Flagship mission has a budget envelope of the order 3-4G$. It will be extended over 4 years and include drifting balloons and two landers. Most likely time for a mission will be 2020-2025.

2. Modeling activities

2.1 Modeling work in the UK (Lewis)

A simplified Venus general circulation model (VGCM) has been in development in the UK since 2002, based on the UK Meteorological Office Unified Model (Earth atmospheric GCM). The model was originally developed at Oxford by Christopher Lee (as a postgraduate student) under the supervision of Stephen Lewis (now at the Open University) and Peter Read. The model employed an Arakawa B grid, typically with 5°x5° horizontal resolution and roughly 3km vertical resolution, covering the altitude range 0-90km. Results which have been published (Lee et al., 2005, Lee et al., 2007) mostly employed simple Newtonian cooling and Rayleigh friction, but options exist to represent topography, a diurnal cycle, a more sophisticated grey radiation scheme and a radiatively inactive cloud scheme (Lee et al., 2008).

The VGCM was successful in producing robust atmospheric super-rotation at about the correct altitude (near the cloud-tops on Venus), along with intriguing polar vortices and a variety of global waves, including Kelvin and mixed Rossby-gravity modes. Super-rotation was maintained by the horizontal transport of momentum towards the equator by the wave modes, counteracting the poleward transport of momentum at the cloud-top height by the meridional circulation. In its default configuration, the VGCM underestimated the zonal wind speeds and hence the super-rotation at the equator by a factor of about two. It was also found that the model winds were highly sensitive to parameters such as the horizontal diffusivity and, indeed, to the dynamical core used, a result confirmed by later work with the Caltech Planet WRF model.

A new phase of VGCM development is about to start in the UK, with graduate students recruited to work at Oxford (João Mendonça) with Peter Read and the Open University (Jon Dawson) with Stephen Lewis. A more realistic VGCM will be designed as a collaborative project, with Oxford taking the lead on radiative and cloud schemes and the OU developing surface-atmosphere interactions, the planetary boundary layer and gravity wave drag as well as implementing a flexible scheme to use different dynamical cores.

2.2. Modeling work in US (Covey)

Venus modelling work goes on a several places in the US adopting Earth weather prediction/climate models to Venus. This includes work by the Extra-terrestrial CAM consortium using the NCAR community atmospheric model. Relevant activities take place at Caltech (Chris Lee), UCLA (Helen Parish and Curt Covey and at University of Louisville (Tim Dowling). Work is also going on with conceptual models at NASA/Ames (Jeffrey Hollingsworth).

2.3. Modeling work in Japan (Yamamoto)

The present status of Japanese Venus atmospheric modeling based on CCSR/NIES (Center for Climate System Research/National Institute for Environmental Studies) GCM was reported. The research group has three-type Venus GCMs: Simplified Venus GCM (SVGCM), Venus Middle Atmosphere GCM (VMAGCM), and full-physics Venus GCM.

SVGCM with Newtonian cooling has been used to investigate Venus super-rotation. Sensitivity study shows that large lower-atmospheric heating is needed to reproduce the super-rotation found on Venus. If the additional lower-atmospheric heating is not included, it is very difficult to drive the super-rotation below the cloud layer. This implies that some additional driving forces (radiative forcing and/or eddy momentum source) in the lower atmosphere are needed in Venus modeling (Yamamoto and Takahashi 2008).

VMAGCM have been also developed as a research tool of Venus middle atmospheric dynamics, and now the preliminary experiments have been conducted.

They are developing full-physics Venus GCM including radiative process (Crisp 1986, Nakajima et al. 2000, Matsuda and Matsuno 1978) and sub-grid gravity-wave parameterization (Hou and Farrell 1987). Venus' thermal structure is reproduced by the radiative forcing in the GCM. The super-rotation can be driven in the cloud layer, but cannot be driven below the cloud. In the case that the gravity-wave parameterization is introduced as an additional driving force, the realistic zonal flow can be simulated (Ikeda et al. 2008). The radiative and sub-grid physical processes in the GCM will be further developed in order to elucidate the unknown driving force in the lower atmosphere.

2.4. Modeling work in France (Lebonnois)

Scientists at Laboratoire de Meteorology Dynamique, in Paris, have been developing a Venus GCM for several years now, based on the experience in planetary GCMs.
Despite some encouraging results last year, there have been many technical difficulties to get the simulations working, with results close to reality. However, the latest simulations are now good enough for good scientific work. The temperature structure is self-consistently computed, with an infrared radiative scheme specifically developed for this dense atmosphere. The GCM includes topography, and can test the role of diurnal cycle, of the Cp dependence in temperature, and may also be run with a simplified temperature forcing, for comparison with other models.

2.5. Modeling work in Germany (Titov, Schmidt)

Presently there is now Venus modeling work using comprehensive GCMs in Germany but discussions are underway between the Max Planck Institute for Solar System Research in Katlenburg-Lindau (Titov) in cooperation with the Max Planck Institute for Meteorology in Hamburg (Schmidt).

3. Discussion

Following the presentation a general discussion on the further work of the group took place. The general view was that several aspects of the modeling result were promising and the preliminary emphasis should be put on the dynamics. It was agreed that as a next step a protocol for an agreed format of numerical experiments should be established. In the mean time such a protocol has been set up by Sebastien Lebonnois and is being circulated among the participating Venus modeling groups.
The atmospheric chemistry of Venus is fundamentally important. The source of S and SO4 are not clear. Another important problem is the strange absorber in the wavelength domain 0.32-0.5 my in the upper cloud 58-65 km.
The question of the radiation balance in the atmosphere of Venus was raised and reference was made to the recent monograph by Titov et al (2007, Geophysical Monograph Series 176)

<u>Next meeting to take place at ISSI 27/28 April 2009 alt 18/19 May 2009</u>

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