Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

U003-01 Room:304 Time:May 27 08:30-08:45

AKATSUKI return to Venus

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ISAS/JAXA launched the Japanese Venus Climate Orbiter AKATSUKI on 21st May, 2010 and it reached Venus on 7th December, 2010. The Venus Orbit Insertion (VOI) process, however, was unsuccessful due to the malfunction of one of the check valve upstream of the fuel line. Not enough He gas pressure was supplied to the fuel, and the oxidizer was too rich in the combustion chamber. Such condition caused some problem in the Orbit Maneuver Engine (OME) and the VOI was canceled 158sec after the OME was started. This caused AKATSUKI to be on the orbit around the sun again, not around Venus.

Even we were unsuccessful in the first VOI operation of AKATSUKI, AKATSUKI is flying in a very healthy condition. We will keep the spacecraft condition as best as we can, and are going to put it into the orbit around Venus in a several years. In this talk we will describe more detail of the orbit maneuver plan to Venus, and how to operate the spacecraft even having the malfunctioning check valve at the next VOI operation. Such operation is very critical, but ISAS will do its best to make AKATSUKI return to Venus. We never give up to achieve the scientific goal which we set when we proposed this mission in 2001.

Keywords: AKATSUKI, Venus, Exploration

Japan Geoscience Union Meeting 2011
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U003-02 Room:304 Time:May 27 08:45-09:00

Renewed science plan of Akatsuki

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The main goal of the Japanese Venus orbiter Akatsuki is to understand the Venusian atmospheric dynamics and cloud physics, with the explorations of the ground surface also being a theme. Onboard science instruments, five of which are imagers dedicated to meteorological studies and one of which is a reference radio source, sense multiple height levels of the atmosphere to model the three-dimensional structure and dynamics. The lower clouds, the lower atmosphere and the surface are imaged by utilizing near-infrared windows. The cloud top structure is mapped by using scattered ultraviolet radiation and thermal infrared radiation. Lightning discharge is searched for by high speed sampling of lightning flashes. Night airglow is observed at visible wavelengths. Radio occultation complements the imaging observations by determining the vertical structure of the atmosphere.

Although the arrival of Akatsuki at Venus was postponed for several years due to a malfunction of the propulsion system during the first Venus orbit insertion on December 7, 2010, the observation strategy mentioned above will be basically unchanged. The science instruments will be kept in conditions appropriate for long-term survival. Nevertheless, we are considering a further optimization of the observation plan based on the achievements made by ESA's Venus Express. Venus Express covers a broad range of sciences including atmospheric chemistry, atmospheric dynamics, surface processes and plasma environment. The spectroscopic information on clouds, the dynamical features of the polar region, and the mesoscale features seen in close-up images captured by Venus Express help us to improve Akatsuki's meteorological observation and data analysis.

Keywords: Venus, Akatsuki

Japan Geoscience Union Meeting 2011
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U003-03 Room:304 Time:May 27 09:00-09:15

Venusian cloud top temperature obtained by LIR onboard Akatsuki

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Venus orbit insertion of Akatsuki which has been launched on 21 May 2010 has been postponed until in six years. However, the Longwave Infrared Camera (LIR), which mounts an uncooled micro-bolometer array (UMBA), has succeeded in taking images of the Earth and the deep space immediately after the launch and during the cruise to Venus. Furthermore, It has succeeded in taking the image of Venus from six hundred thousand kilometers distance. LIR detects thermal emission from the top of the sulfur dioxide cloud of Venus in a wavelength region 8-12 um to map the cloud-top temperature which is typically as low as 230 K. The image of Venus which has been calibrated and verified using the earth or deep space images showed the obvious cold polar collars and zonal wave structures. These features have started to be compared with results of the ground observation. They also will be compared with images of the Ultraviolet Imager (UVI) onboard Akatsuki, or the Venus Monitoring Camera (VMC) onboard the Venus Express.

Keywords: Venus

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U003-04 Room:304 Time:May 27 09:15-09:30

Venus atmosphere observed by Akatsuki/UVI

Shigeto Watanabe[1*], Atsushi Yamazaki[2], Manabu Yamada[2], Naoki Take[1], Ko Hamamoto[1], Yukihiro Takahashi[1]

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Akatsuki/UVI has measured the Venus clouds at the wavelengths of 365nm and 283 nm for the first time. The albedo from Venus cloud at 283nm wavelength is due to SO_2, but the albedo at 365nm wavelength is not known still. From 2 data sets of the albedo at 365 nm and 283 nm wavelengths, we estimated the Venus cloud altitude distribution. We report the results of the initial analysis.

Keywords: Venus atmosphere, ultraviolet image, absorption by SO_2, Akatsuki spacecraft

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(May 22-27 2011 at Makuhari, Chiba, Japan)

U003-05 Room:304 Time:May 27 09:30-09:45

1 micro-m camera IR1 on board AKATSUKI: Current status and future view

Naomoto Iwagami[1*], Shoko Ohtsuki[2]

[1]University of Tokyo, [2]JAXA/ISAS

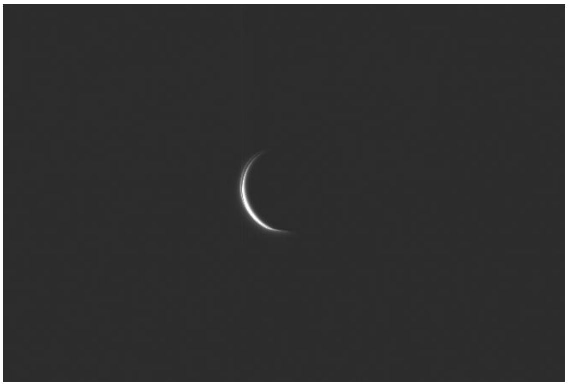
Venus crescent taken 2 days after the 1st fly-by
at 600 thousand km away

The results of the imaging tests carried out during the cruising phase between the Earth and the Venus and after the fly-by by the IR1 camera on AKATSUKI are described. The troubles and/or problems found by those tests and the views for future operations are also discussed.

The imaging tests taken are the followings.
(1) Earth imaging 10 hours after the launch on 21 May to check the normal performance of the camera
(2) Star imaging to check the optical alignment between AKATSUKI and the IR1 camera. The focus and the absolute sensitivity are also checked
(3) Venus imaging 2 days after the 1st fly-by at 600 thousand km away to check the normal operation of the camera for the right target.

The troubles and/or problems found so far are the followings.
(1) Black and white noise
(2) Missing line (?)
(3) Blooming-like structure
(4) Sensitivity decrease (?)
(5) Attitude stability

Although there are some unsolved problems noted above, the camera seems to be working normally as seen in the image taken after the fly-by.



Keywords: Venus, AKATSUKI, infrared, imaging

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

U003-06 Room:304 Time:May 27 09:45-10:00

Lightning and airglow observation in Venus with spacecraft and ground-based telescope

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Lightning is potentially a good proxy of atmospheric circulation in planets, including Venus and Jupiter, where very limited in-situ measurements can be made. Recently it is reported that the magnetometer on board Venus Express detected whistler mode waves whose source could be lightning discharge occurring well below the spacecraft. On the other hand, night airglow is expected to provide an essential information on the atmospheric circulation in the upper atmosphere of Venus. But the number of consecutive images of airglow is limited and even the detail variations of most enhanced location is still unknown.

In order to identify the discharge phenomena in the atmosphere of Venus without ambiguity and to know the daily variation of airglow distribution in night-side disk, we sent a optical sensor to Venus, the lightning and airglow camera, LAC onboard Akatsuki. Though, unfortunately, its arrival will be delayed by several years, before the spacecraft measurement we plan to make a ground-based observation using 1.6 m telescope installed at Nayoro, Hokkaido, by Hokkaido University. In this presentation the strategies for investigation both for lightning and airglow, both with ground-based telescope and spacecrafts.

Keywords: Venus, lightning, airglow, spacecraft, telescope

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(May 22-27 2011 at Makuhari, Chiba, Japan)

U003-07 Room:304 Time:May 27 10:00-10:15

Cloud tracking system for Akatsuki data and its tests using VEx/VMC images

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A zonal retrograde super-rotation of the entire atmosphere is the most curious atmospheric phenomenon. The wind velocity increases with height and reaches ~100 m/s near the cloud top. This is very mysterious because the solid planet rotates very slowly with a period of 243 Earth days corresponding to an equatorial rotation speed of 1.6 m/s. Various theories have been suggested so far to explain mechanisms which maintain the super-rotation. However, none of them has been able to fully explain the mechanisms because of insufficient observational information on the meridional circulations crucial for the zonal momentum transport. Wind speed distributions obtained by previous missions were based on cloud tracking on only dayside. Therefore, it has been uncertain weather zonal mean of them approximates the actual meridional circulation. Akatsuki, Venus Climate Orbiter (VCO) has the potential to solve this problem. Cameras onboard Akatsuki image cloud features of both dayside and nightside at more than one vertical levels. IR1 visualizes the distribution of clouds illuminated by sunlight at ~50 km above the surface. IR2 can visualize the global cloud height distributions at 50-55 km by utilizing the 2.02 um filter on dayside and the 1.735 um filter on nightside. In addition, LIR is able to take images of both dayside and nightside with equal quality and accuracy. Tracking of cloud features in images taken by these instruments enable us to obtain three dimensional global wind distributions, which lead to understanding of the meridional circulation and the super-rotation.

We prepare images in longitude-latitude coordinate by coordinate transformation. This is not straightforward because Venus in each image is not a circle but an ellipse when the space-craft is near Venus. We fit an ellipse to the Venusian limb on images using many parameters of the orbit and the attitude to achieve this transformation. We track cloud features found on the images in longitude-latitude coordinate to obtain the distributions of horizontal wind. In our presentation, we explain a pipeline process for getting a global wind distribution from an image and present results of some kinds of tests for the pipeline process using images obtained by Venus Monitoring Camera on board Venus Express.

Keywords: Venus, super-rotation, Akatsuki, data processing, cloud tracking

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

U003-08 Room:304 Time:May 27 10:15-10:30

Venus' atmospheric waves indicated by ground-based dayside infrared spectroscopic observation

Mayu Hosouchi[1*], Naomoto Iwagami[1], Shoko Ohtsuki[2], Masahiro Takagi[1]

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In the Venus' atmosphere, waves of various scales transport angular momentum and play an important role in the atmosphere. For example, the mechanism of the super rotation may be explained by the equatorial Kelvin wave [Yamamoto & Tanaka, 1997] or by the thermal tides [Takagi & Matsuda, 2007].

Most of studies have focused on the ultraviolet region to observe atmospheric waves at 70 km [Del Genio et al., 1982, 1990]. Several studies have focused on the infrared region and analyzed thermal emission from the nightside to observe atmospheric waves at 50 km [Belton et al., 1991]. In contrast, we observed the dayside to derive the clouds structure at 60 - 65 km by quantifying CO_2 absorption. We performed infrared spectroscopic measurements at the NASA Infrared Telescope Facility (IRTF) with CSHELL spectrometer in May and November 2007, June 2009 and August 2010.

We derive the clouds structure from CO_2 absorption equivalent width above the clouds. We can compare data of different terms because equivalent width is unaffected by observation conditions. From the clouds structure, we estimated that the atmosphere rotates at 60 km with a period of 5 days in May 2007 and 5.5 days in August 2010. These periods are different from a period of 4 days at 70 km. It is found that the representative height in August 2010 was 2 km lower than that in May 2007. The changes suggest that the Venus' clouds descend gradually year by year. We derive the clouds structure by rigid body rotations like the past studies. We also derive that by differential rotation, made with wind speeds taken from Venus Express data.

Keywords: Venus, Planetary atmosphere, atmospheric waves, super rotation

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(May 22-27 2011 at Makuhari, Chiba, Japan)

U003-09 Room:304 Time:May 27 10:45-11:00

Relationship between planetary-scale waves and the background wind field at the cloud top of Venus

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In this study, we reveal temporal variation of the super-rotation of Venus atmosphere and spatial structures of planetary scale atmospheric waves at the cloud top level by deriving wind speeds and their variations at the cloud top from UV (365 nm) images taken by Venus Monitoring Camera (VMC) onboard Venus Express of European Space Agency. Because VMC has taken many cloud images covering from low to high latitudes of the southern hemisphere, well suited for derivation off wind speeds and their variations. We applied a proven cloud tracking method (reported at the 2008 Meeting) to these images and found that the equatorial zonal wind speed changes quasi-periodically, alternating "fast season" (over 100 m s^{-1}) and "slow season" (below 90 m s^{-1}) every ~100 earth days

From Fourier analysis of the wind speed and the cloud brightness variations, planetary-scale 5 day period variations were identified in the zonal and meridional wind speeds and the cloud brightness in the fast season of background zonal wind speeds. The phase speed of the 5-day period variations is slower than the background wind speed. The phase relationship between the zonal and meridional winds implies that the 5-day variation is a manifestation of a Rossby wave. These results are consistent with previous studies from Pioneer Venus observations (Del Genio and Rossow, 1990; Rossow et al., 1990). On the other hand, planetary-scale 4 day period variations were identified in zonal wind speeds and cloud brightness in the slow season. The phase speed of the 4-day period variations is faster than the background wind speed. These features are similar to those of the Kelvin wave-like perturbations observed in the previous study (Del Genio and Rossow, 1990).

According to the numerical results of Yamamoto and Takahashi, 1997, the Kelvin wave originating from the lower atmosphere can propagate vertically into the cloud top level and transport angular momentum vertically. On the other hand, the Rossby waves , which can be excited by the baroclinic instability in Venus atmosphere, transport angular momentum from the latitude where these are excited to the higher latitude, and dissipate this instability. The time variation of the super-rotation could be affected by these waves. In this study, we will evaluate the angular momentum transport by these waves based on the derived parameters from our analysis.

Keywords: Venus, super-rotation, Venus Express, Venus Monitoring Camera, atmospheric waves

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

U003-10 Room:304 Time:May 27 11:00-11:15

Effects of gravity waves on the wind velocity in the Venusian mesosphere and thermosphere

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Momentum transport from the cloud layer (50-70km) toward the upper atmosphere by gravity waves is essential to understand the general circulation in the Venusian mesosphere (70-110km) and thermosphere (>110km) (e.g. Bougher et al. [2006]). Zhang et al. [1996] performed simulations with a gravity wave parameterization and showed that the momentum transport by gravity waves drove the retrograde zonal wind (RZW) as fast as 15 ? 30 m/s above about 140 km. They also showed the westward shift of the O2-1.27um nightglow emission region because of the RZW. However, parameterizations used in previous simulations could not consider the wave-wave interaction and the attenuation of gravity waves caused by molecular viscosity. In our simulations, we considered these physical processes by using the new gravity wave parameterization developed by Medvedev et al. [2000] (Medvedev scheme) in our GCM calculation and investigated effects of gravity waves on the Venusian mesosphere and thermosphere.

In the Medvedev scheme, the characteristic horizontal wavelength and the spectrum of the vertical wavelength at the lower boundary are the adjustable parameters. The information is referred from the recent gravity wave observations with Venus Express (VEX) [Peralta et al., 2008]. We performed the numerical simulations with two lower boundary conditions: the wind velocity at the lower boundary is (1) 0 m/s and (2) 80 m/s. In the calculation of case (1), we compared the wind velocity distribution between the results with Medvedev scheme and Rayleigh friction, which was the gravity wave parameterization used in previous studies. We discussed the influence of gravity waves on the RZW in the case (2).

Our result of case (1) shows the dominance of the subsolar-to-antisolar(SS-AS) flow with the maximum value of about 290 m/s in the thermosphere. The amplitude of the SS-AS flow is about 50 m/s bigger than that calculated with the Rayleigh friction. There is a possibility that wave drag of Medvedev scheme become smaller than that of Rayleigh friction above 140 km because of the gravity wave attenuation caused by the molecular viscosity. In the case (2), the gravity wave transports the westward momentum upward and drives the RZW with the amplitude of about 70 m/s above about 120 km. The amplitude of the RZW is almost 0 m/s at about 100 km and becomes bigger with altitude. The vertical gradient of the RZW amplitude is consistent with previous ground-based observations [Sandor et al., 2009]. Our result also shows that the RZW causes the shift of the nightglow emission region from 00:00 LT to 02:30 LT.

Keywords: Venus, mesosphere, thermosphere, gravity wave

Japan Geoscience Union Meeting 2011
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U003-11 Room:304 Time:May 27 11:15-11:30

General circulation of the Venus lower atmosphere simulated by a GCM with a new radiative transfer model

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The atmospheric superrotation is one of the most remarkable features of the Venus atmosphere. In recent years, several numerical experiments with general circulation models (GCMs) have been performed to investigate the generation mechanism of the Venus atmospheric superrotation (Yamamoto and Takahashi 2003; Takagi and Matsuda, 2007; Lee et al., 2007; Hollingsworth et al., 2007; Kido and Wakata, 2008). The results suggest that both the Gierasch mechanism (Gierasch, 1975; Matsuda, 1980) and the thermal tide mechanism (Fels and Lindzen, 1974; Plumb, 1975) may explain the atmospheric superrotation in dynamically consistent ways. However, in these studies, the radiative process is extremely simplified by Newtonian cooling. Since the Venus atmosphere is optically very thick in the infrared region, this simplification cannot be justified at all, especially in the Venus lower atmosphere. It has been also pointed out by Hollingsworth et al. (2007) that only extremely weak atmospheric superrotation is generated when realistic solar heating is adopted. In order to understand the real generation mechanism of the atmospheric superrotation, the radiative processes should be improved. Recently, Lebonnois et al. (2010) carried out numerical simulations by using a GCM combined with a radiative transfer model based on Eymet et al. (2009). Their results show that the atmospheric superrotation with about 70 m/s is obtained above about 40 km, while the mean zonal wind remains very weak below.

In the present study, a radiative transfer model applicable to the Venus atmosphere (Takagi et al., 2010) is incorporated into a three-dimensional general circulation model to investigate the generation mechanism of the atmospheric superrotation by focusing on the mean meridional circulation. A dynamical core of the GCM is the same as used by Takagi and Matsuda (2007). The model atmosphere extends from the ground to about 100 km, which is divided into 50 layers at a regular spacing of 2 km. The horizontal resolution is T10 (triangular truncation at wave number 10). Temperature dependence of the specific heat at constant pressure is taken into account (Staley, 1970). Horizontal eddy viscosity is represented by the second-order hyperviscosity with relaxation time of 1 Earth day for the maximum wave number component. Rayleigh friction is not used in the present model except at the lowest level, where the surface friction acts on horizontal winds. In addition, the dry convective adjustment scheme is used to restore the temperature lapse rate to the neutral one when an atmospheric layer becomes statically unstable. The solar heating is zonally averaged and prescribed in the present study. The vertical profile is based on the works of Tomasko et al. (1980) and Crisp (1986).

After numerical integration for 100 Earth years, it is found that the mean zonal flow with remarkable jets is generated in 30-70 km. Meridional temperature difference is only few K degrees near the cloud top level. This is consistent with the weak zonal flows obtained in this simulation in view of thermal wind balance. A weak local maximum (7-8 m/s) is observed in the equatorial region at 70 km. Weaker midlatitude jets are also found at about 40 km. Below 30 km, the mean zonal flow remains very weak. The temperature contrast between the equator and poles is less than 1 K at these levels. The mean meridional circulation splits into two cells which extend from 20 to 50 km and from 50 to 80 km. The maximum velocity of the mean meridional flow is about 12 m/s at about 67 km near 60 N/S. The mean meridional circulation simulated in the model splits into three parts. The upper two cells seem persistent. The present result implies that the atmospheric superrotation may be strongly affected by the mean meridional circulation in the lower atmosphere, and the Gierasch mechanism may not work in the Venus atmosphere.

Keywords: Venus, superrotation, meridional circulation, radiative transfer

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

U003-12 Room:304 Time:May 27 11:30-11:45

Microscale simulations of convective adjustment and mixing in the Venus atmosphere

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Heat, momentum and material transport processes caused by convective adjustment and mixing are important in subgrid-scale parameterization of the Venus general circulation model (VGCM). Recently, in order to investigate the thermal and material transport processes near the surface, Yamamoto (2011) conducted microscale atmospheric simulations near the Venusian surface by altering the astronomical and physical parameters in WRF (Weather Research and Forecasting model). When convective adjustment occurs, the heat and passive tracer are rapidly mixed into the upper stable layer with convective penetration. The convective adjustment and mixing produce high eddy diffusion coefficients of heat and passive tracer, which may explain the large eddy diffusion coefficients estimated in radiative-convective equilibrium models (Matsuda and Matsuno 1978; Takagi et al. 2010). In the case that values of surface heat flux Qs is larger than a threshold, the convectively mixed layer with high eddy diffusion coefficients grows with time. In contrast, the mixed layer decays with time in the case of Qs smaller than the threshold. The thermal structure near the surface is controlled not only by radiative processes with extremely long time scales (10,000 Earth days), but also by microscale dynamical processes with short time scales (a few hours). A mixed layer with high eddy diffusion coefficients may be maintained or grow with time in the regions where the surface heat flux is high (e.g., the volcanic hotspot and adjacent areas).

In the present study, I applied the abovementioned microscale atmospheric model of Yamamoto (2011) to dynamical processes in the unstable/neutral layer of the Venusian cloud (50-55 km), and examined the eddy mixing and its effective eddy diffusivity. Maximum magnitudes of eddy fluxes of momentum, heat and passive tracer become larger with increasing the vertical negative gradient of the initial potential temperature (Gamma) and the heat flux at the bottom of the lower cloud (Qb). In the unstable/neutral cloud layer, the eddy diffusion coefficients of 10ˆ3 m2 s-1 are estimated for momentum, heat and passive tracer. In the cases that the vertical shear of the initial zonal wind is changed, although the flux magnitudes are somewhat different from those in the cases of the zero initial shear, the sensitivities to Gamma and Qb are qualitatively similar to those in the cases of the zero initial shear. Such microscale simulations are expected to contribute to physical interpretations of the balloon and radio science experiment data and improvements of the eddy diffusion coefficients in VGCM and chemical and aerosol transport models.

Keywords: Venus, Convective adjustment, Convective mixing, Microscale atmospheric model, Eddy diffusion coefficient

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

U003-13 Room:304 Time:May 27 11:45-12:00

Ground-based observations of atmospheric waves in Venus O2 night airglow

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Venus 1.27-micron O_2 night airglow is the indicator of the general circulation at about 95 km in Venus. Recent observations reported that the airglow emission showed the temporal variations with a period of a few hours and days [e.g. Ohtsuki et al., 2008; Gerard et al., 2008]. The temporal variations are thought to be caused by the upward momentum transport and fluctuations by atmospheric waves. In recent years, the importance of planetary-scale waves on the general circulation of the Venus atmosphere has been recognized. Forbes and Konopliv [2007] suggested the propagation of planetary-scale waves originated in the cloud deck into the upper atmosphere. However, effects of planetary-scale waves on the Venus upper atmosphere has not been investigated yet. Now, GCM simulations considering the planetary-scale waves which are prominent at the cloud top (thermal tides, Kelvin wave and Rossby wave) is performing in order to understand effects of planetary-scale waves on the temporal night airglow variations and the general circulation in the Venus upper atmosphere. Our results show the Kelvin wave is the dominant wave in the planetary-scale waves. The Kelvin wave causes the shift the night airglow emission region between 00:00LT and 00:40LT and the large temporal intensity fluctuation of 0.7 to 1.0 MR (paper by Hoshino is in preparation).

In September 2010, we try to detect the atmospheric waves in the nightside upper atmosphere of Venus by 6-days monitoring the Venus 1.27-micron O_2 airglow and its rotational temperature. The cryogenic echelle spectrograph (CSHELL) of NASA's Infrared Telescope Facility is used for acquiring high-resolution spatially resolved spectra. Its resolution is high enough to show each emission line. The spatial resolution will achieve down to about 300km at the center of the Venus disk and be comparable with the planetary-scale waves (thermal tides, Kelvin wave and Rossby wave). These observations will provide us new information on the dynamics of the upper atmosphere.

In this presentation, we will report primary results of these observations.

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

U003-14 Room:304 Time:May 27 12:00-12:15

Venus superrotation simulated by an AGCM with a new radiative transfer model

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A maintenance mechanism of the superrotation in the Venus atmosphere is investigated by using an atmospheric general circulation model (AGCM). We have constructed a new radiative transfer model for the Venus AGCM. This radiation model can treat absorption, scattering, and emission processes due to the gases and the atmospheric particles from short-wave to long-wave region. The surface temperature and temperature distribution close to observations can be reproduced in the radiative-convective equilibrium calculation; convection layer extends from the surface to about 40 km altitude. The role of various radiatively active gases is investigated by computing the radiative-convective equilibrium without each absorber. The results imply that the effect of each gas depends on treatments of line profile of gas absorption and the CO_2 continuum opacity.

The new radiation model has been incorporated into the CCSR/NIES/FRCGC AGCM. Zonal flow of about 50 m s^{-1} is reproduced at the equatorial cloud top. Momentum transport associated with thermal tides play an important role in maintenance of the mean zonal flow in the cloud layer. The sensitivity to uncertainties in the distribution of the unknown UV absorber near the cloud top is examined. This test indicates that the superrotation in the middle atmosphere is affected by the distribution of the UV absorber. Although superrotational flow is maintained in the middle atmosphere, the zonal wind is much weaker than observations under the cloud layer. Although the mean meridional circulation contributes to the momentum balance of the superrotaion in the middle atmosphere, it does not efficiently transport the angular momentum necessary to maintain the superrotation. It is suggested that the meridional circulation driven by this radiation model does not have sufficient strength to maintain the superrotation.

A simulation which includes momentum transport by small-scale gravity waves is performed to examine the maintenance mechanism of the superrotation below the cloud. Although greater energy flux of eastward gravity waves is required to assume, the superrotation in the lower atmosphere is maintained by critical level absorptions of gravity waves in this simulation.

Keywords: Venus, superrotation, AGCM

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U003-15 Room:304 Time:May 27 12:15-12:30

Latitudinal variation of UV reflectivity of Venus: VEX/VMC data anaylses

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We examined a latitudinal variability of ultraviolet reflectivity of Venus using images obtained by the Venus Monitoring Camera (VMC) on board the Venus Express spacecraft. The Venus Express is orbiting around Venus, and the VMC observed a reflection of sunlight at 365 nm wavelength. To analyze the VMC images, we calculated a solar incidence angle and emission angle for each pixel of the image. Since the intensity of reflected light depends on the solar incidence angle and emission angle, we selected pixels which were observed in the same conditions. Our analysis indicated that the uv reflectivity increases with latitude on the Venus' southern hemisphere.

Keywords: Venus, atmosphere

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U003-16 Room:304 Time:May 27 12:30-12:45

Vertical wavenumber spectra of gravity waves in the Venus atmosphere from Venus Express radio occultation

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We obtained five profiles of the temperature from 35 to 95 km altitude by the radio occultation in Venus Express mission using the UDSC antenna. Vertical wavenumber spectra of small-vertical scale perturbations in these profiles were obtained for the regions above and below the cloud layer and were examined based on the assumption that the temperature perturbations are associated with internal gravity waves. The spectra above clouds tend to show power law indices of around -3 for large wavenumbers, being indicative of saturated gravity waves. The spectra below clouds show less power and less spectral slopes, suggesting that the waves are not saturated in this region.

Keywords: Radio occultation, Venus Express, Internal gravity wave, Vertical wavenumber spectra

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U003-17 Room:304 Time:May 27 14:15-14:30

The Venus Express mission

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The ESA mission Venus Express was launched from Baikonur, Kazakhstan, on 9 November 2005. After a 5 months cruise phase, the spacecraft was inserted in a Venus orbit on 11 April 2006. The main objective of the mission is to carry out a detailed study of the atmosphere and the plasma environment and a number of properties of the surface of Venus, both on a global level and on a small scale level. The nominal duration of the mission was two Venus sidereal days (486 earth days) but the mission has been extending three times and is now funded until end of 2014, enabling data to be collected during a significant part of a full solar cycle.

The orbit is a highly elliptical polar orbit with 24 hours period and a percicentre located close to the North Pole. It is optimised for remote observations of the southern hemisphere at a global scale from high altitude, and for detailed studies of the northern hemisphere from low altitude, both at varying solar aspect angles. It also allows for in-situ plasma measurements covering a large range of distances from the planet. The payload is dedicated to studies of the physics and chemistry of the atmosphere and the clouds and the related processes. The interaction of the upper atmosphere with the solar wind will be investigated by dedicated instruments. With a time from the mission approval to the launch of just above three years this mission by far is the fastest scientific mission undertaken by ESA until now.

This talk will describe the main features of the mission and summarise the most important results from the different investigations as an introduction to the subsequent talks on the individual investigations.

Keywords: Venus, planetary atmosphere, planetary mission, spacecraft

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

U003-18 Room:304 Time:May 27 14:30-14:45

Venus Express science operations and co-ordinated observation planning.

Colin Wilson[1*], Hakan Svedhem[2], Dima Titov[2], Raymond Hoofs[2], Thomas Widemann[3]

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Venus Express has been in orbit around Venus since April 2006. Its orbit is highly elliptical, with altitude varying from 160-250 km at pericentre to 66,000 km at apocentre, and polar, with a pericentre near the North pole. The orbital period is 24 hours.

Science operations planning is undertaken to satisfy the many different goals and observation modes of the spacecraft - including nadir and limb imaging and spectroscopy, radio occultation, and solar and stellar occultation - as well as geometrical, thermal and other constraints.

In addition to science goals of the Venus Express science teams, the science operations planning also responds to requests for co-ordinated observations from ground-based or other spacecraft observations.

In this talk we will present an overview of the Venus Express Science operations planning process and constraints, and discuss opportunities for co-ordinated observations.

Keywords: Venus Express, Science operations

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U003-19 Room:304 Time:May 27 14:45-15:00

An overview of SPICAV results on the atmosphere of Venus fromVenus Express mission.

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SPICAV is a suite of three spectrometers in the UV and IR range flying on ESA Venus Express orbiter, dedicated to the study of the atmosphere of Venus : UV (110-320 nm), Vis-Nir (0.65-1.65 micron), and mid IR (2.3-4.4 micron), from ground level to the outermost hydrogen corona at more than 40,000 km.

The UV spectrometer is working in the stellar and solar occultation mode, and nadir or limb viewing, day and night. It has mapped on the night side the gamma and delta bands of NO produced by recombination of O and N atoms coming from the dayside thermosphere. They indicate a maximum at 115 km altitude and around 02:00 LT (influence of super-rotation), while the O2 emission mapped simultaneously by Virtis peaking at 95 km altitude (~10 km below NO emission) is centered at midnight, a puzzle for general circulation models. Vertical profiles of CO2, temperature, SO2, clouds and aerosols are obtained with star occultations and ozone was detected for the first time. Haze extends up to 104 km, where a layer of SO2 and SO is detected in solar occultation. Day side observations allows to monitor the distribution of SO2 at cloud top.

The SPICAV VIS-IR sensor (0.7-1.7 micron, resolution 0.5-1.2 nm) employs a pioneering technology: acousto-optical tunable filter (AOTF). Day side observations indicate a variable latitude distribution of cloud top altitude (decreasing toward the pole) and water vapor mixing ratio. Night side observations of the thermal ground emission allows to retrieve low altitude H2O.

The mid IR (2.3-4.4 micron) spectrometer SOIR works in solar occultation. It achieves the highest spectral resolution R>20,000 ever flown in a planetary mission. Vertical profiles of CO, HDO, H2O, HCl, SO2, CO2 isotopes and temperature are regularly retrieved, as well as aerosols.

Keywords: Venus, atmosphere, Venus Express, SO2, occultation

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U003-20 Room:304 Time:May 27 15:00-15:15

SPICAV-SOIR on board Venus Express: an instrument to probe the neutral atmosphere of Venus

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The SOIR instrument performs solar occultation measurements in the IR region (2.2 - 4.3 um) at a resolution of 0.12 cm-1, the highest on board Venus Express. It combines an echelle spectrometer and an AOTF (Acousto-Optical Tunable Filter) for the order selection.

The wavelength range probed by SOIR allows a detailed chemical inventory of the Venus atmosphere at the terminators in the upper mesosphere and lower thermosphere (80 to 180 km) with an emphasis on vertical distribution of gases, such as CO2, H2O, HCl, HF, CO, as well as their isotopologues, including HDO.

In particular, measurements of CO2 density and rotational temperature vertical profiles have been routinely performed allowing a better description of the mesosphere and lower thermosphere. This moreover improves the understanding of the processes ? chemical and dynamical ? that occur at the terminators.

We will present the instrument and describe its capabilities in terms of measurements possibilities and accuracy. We will illustrate it with retrieval examples of various gases and show the high variability of the Venus atmosphere.

Keywords: Venus, mesosphere, thermosphere, atmospheric composition, temperature profile

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U003-21 Room:304 Time:May 27 15:15-15:30

Results from VIRTIS on board Venus Express after five years in orbit

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After five years since the orbit insertion, VIRTIS aboard the Venus Express spacecraft has addressed a significant amount of the planned scientific objectives and also other unexpected results, from the surface up to the upper atmosphere, in terms of mapping, composition, structure and dynamics.

The VIRTIS instrument consists of two channels: VIRTIS-M, an imaging spectrometer with moderate spectral resolution in the range from 0.25 to 5.2 microns and VIRTIS-H, a high spectral resolution spectrometer in the range from 2 to 5 microns coaligned with the field of view of VIRTIS-M. The resolution of VIRTIS-M is 2 nm from 0.25 to 1 microns, and 10 nm from 1 to 5.2 microns. The resolution of VIRTIS-H is about 2 nm.

The atmosphere above the clouds is regularly observed both on day and night sides, in solar reflection and thermal emission in nadir geometry. Limb observations provide O2, OH, NO, CO2 and CO emissions, through nightglow and fluorescence observations. Spectroscopy of the 4-5 micron range gives access to the cloud structure in the 60-95 km altitude levels.

The deeper atmospheric windows, limited by CO2 and H2O bands are accessible only in thermal emission on the night side. The sounded levels at 1.7 and 2.3 microns are limited respectively to 30-20 km altitude, while at shorter wavelengths (1.18, 1.10, 1.01, 0.9 and 0.85 microns), the hot surface of Venus is seen through the scattering clouds.

Multiwavelength clouds tracking and thermal fields allow to study the wind fields and the global dynamics. Automatic wind tracking procedures permit to study in detail the polar vortex dynamics.

A brief description of the instrument and some selected results achieved by VIRTIS on Venus Express are reported in this talk.

Keywords: Venus, Spectroscopy, Atmosphere, Surface

Japan Geoscience Union Meeting 2011
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U003-22 Room:304 Time:May 27 15:30-15:45

1600 Earth days around Venus imaging with Venus Monitoring Camera on Venus Express

Wojciech Markiewicz[1*], Dimitri Titov[4], Elena Petrova[2], Nikolay Ignatiev[2], Igor Khatuntsev[2], Sanjay S. Limaye[3], Oksana Shalygina[1], Miguel Almeida[4]

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The Venus Monitoring Camera (VMC) on Venus Express (VEX) spacecraft has been observing the upper cloud layer of Venus since April 2006. To date nearly two hundred thousand images have been acquired. VEX has a highly elliptical orbit allowing for global as well as close up views with resolution down to 200 meter per pixel. In this talk we will show examples of obtained images emphasizing spatial and temporal variability as well as some quantitative results that were derived from them.

Keywords: Venus, Atmospheres, Clouds

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U003-23 Room:304 Time:May 27 15:45-16:00

Cloud morphology and atmospheric dynamics from the Venus Express observations

Dima Titov[1*], Nikolay Ignatiev[2], Arianna Piccialli[1], Igor Khatuntsev[2], Yeon Joo Lee[3], Silvia Tellmann[4], Sanjay Limaye[5], Wojciech Markiewicz[3], Giuseppe Piccioni[6], Pierre Drossart[7], Martin Paetzold[4], Bernd Haeusler[8]

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Since its orbit insertion in April 2006 the ESA Venus Express spacecraft has been performing a global survey of the Venus atmosphere. The powerful suite of remote sensing instruments that includes cameras, spectrometers and radio occultation experiment provided the largest and the longest set of atmospheric data collected so far. Coordinated use of various observation techniques enables investigation of different aspects of the Venus atmospheric physics. This paper focuses on the study of the cloud morphology and dynamics of the Venus atmosphere by synergistic use of the data from the Venus Monitoring Camera (VMC), Visible and Infrared Thermal Imaging Spectrometer (VIRTIS), and radio science (VeRa) experiments.

The VMC camera investigates the cloud top morphology by imaging at 365 nm - characteristic wavelength of the unknown UV absorber. Low latitudes (< 40 deg) are dominated by relatively dark clouds that have mottled and fragmented appearance clearly indicating the presence of turbulence in the sub-solar region. At ˜50 degrees latitude this pattern gives a way to streaky clouds suggesting that horizontal flow prevails here. Poleward from ˜60 degrees the planet is covered by almost featureless bright hood crossed by dark thin (˜300 km) spiral or circular structures. The features of the global UV pattern are qualitatively explained by changes in the temperature structure and atmospheric stability with latitude. Simultaneous imaging in the UV and thermal-IR ranges showed that the cloud patterns on the day and night sides are correlated.

Joint analysis of the VIRTIS spectro-imaging data and the VeRa temperature sounding revealed remarkable changes in the vertical structure of the Venus cloud tops. The cloud top altitude changes from 74+/-1 km in the low and middle latitudes to about 64 km in the polar region marking vast polar depression. The descent of the cloud top correlates with drastic changes in aerosol scale height from 3.8+/-1.6 km to 1.7+/-2.4 km. The altitude of the sharp cloud top inside and poleward from the cold collar region coincide with position of strong temperature inversion, thus indicating its radiative origin.

Tracking of cloud features in the VMC UV images allowed characterization of the mean state of the atmospheric circulation at the cloud tops as well as its variability. An almost constant zonal wind speed of 90+/-10 m/s at low and middle latitudes gives way to the wind that quickly vanishes with latitude. The meridional poleward wind ranges from 0 m/s to about 20 m/s. Thermal wind field derived from the VIRTIS and VeRa temperature sounding using cyclostrophic approximation is in good agreement with the cloud tracked wind pattern indicating validity of the cyclostrophic balance.

Keywords: Venus Express, Clouds, Atmospheric dynamics

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U003-24 Room:304 Time:May 27 16:00-16:15

The Venus Neutral Atmosphere and Ionosphere as seen by the Radio Science Experiment VeRa on Venus Express

Silvia Tellmann[1*], Bernd Haeusler[2], Martin Paetzold[1], Michael K. Bird[3], Takeshi Imamura[4], Hiroki Ando[5], G. Leonard Tyler[6], Tom Andert[2], Stefan Remus[7]

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The Venus Express Radio Science Experiment VeRa performs routinely radio-sounding measurements of the Venus atmosphere and ionosphere as part of the ESA Venus Express (VEX) mission since 2006. An Ultrastable Oscillator (USO) provides a high quality onboard frequency reference source for the derivation of electron density profiles in the ionosphere and profiles of pressure, temperature and neutral number density of the neutral atmosphere. A total of more than 350 vertical scans of the Venus ionosphere and atmosphere were obtained in the first nine occultation seasons until the end of 2010.

The polar orbit of Venus Express provides the opportunity to study the troposphere and mesosphere between 40 ? 90 km at almost all planetocentric latitudes under varying illumination conditions.

The Venus mesosphere shows a high variability resulting from atmospheric waves and turbulence. Small scale temperature fluctuations originating from internal gravity waves with vertical wavelengths of only a few kilometers are detectable in the VeRa profiles. Standard wave theory can be used to analyze the observed wave structures with regard to their vertical and horizontal structure as a function of latitude and local time.

The ionosphere consists of a two layer structure between 115 km to 160 km. The main layer layer V2 is dominantly formed by solar EUV photoionisation, the lower V1 is formed by solar X-ray and dominant secondary ionization. The V1 and V2 peak altitudes and peak density show a Chapman-like behaviour through the range of solar zenith angle. The topside is highly variable and the ionopause is located at extremely low altitudes (250 ? 330 km) during the declining phase of the solar cycle (2007-2008) and at solar minimum (2009-2010).

Keywords: Venus Express, VeRa, Venus Atmosphere, Venus Ionosphere, Atmospheric Waves, Radio Science

Japan Geoscience Union Meeting 2011
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U003-25 Room:304 Time:May 27 16:30-16:45

Five Years of Venus Express Magnetic Field Observations

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Since the Venus Express insertion into a highly elliptical polar orbit with a period of 24 h around the planet Venus, the magnetometer has operated continuously for about 5 years and obtained a wealth of data in the solar minimum at rather low altitude, which was not reached by earlier missions. In this paper, we review the magnetic field observations by Venus Express emphasizing on the solar wind interaction with Venus.

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(May 22-27 2011 at Makuhari, Chiba, Japan)

U003-26 Room:304 Time:May 27 16:45-17:00

Review of results from the plasma package ASPERA-4 onboard Venus Express

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The plasma package ASPERA-4 (Analyzer of Space Plasmas and Energetic Neutral Atoms) is operational since the Venus orbit insertion in April 2006 and provides measurements of ions, electrons, and energetic neutral atoms in the range from a few eV to few tens keV. We provide basic introduction into the instrument design and review the main results of the experiment mainly in the field of electrodynamics of the ion population including the ion escape measurements.

Keywords: Venus Express, ASPERA-4, ion escape

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U003-27 Room:304 Time:May 27 17:00-17:15

Ground-based observations of the mesosphere and lower thermosphere : Coordinated campaigns with Venus Express

Thomas Widemann[1*], Yukihiro Takahashi[2], Shoko Ohtsuki[3], Manuela Sornig[4], Brad Sandor[5], Eliot Young[6], Constantine Tsang[6], Tom Slanger[7], Sanjay Limaye[8]

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Coordinated measurements with ground-based observations allow to (i) perform measurements not feasible by an orbiting spacecraft like Venus-Express or Akatsuki, (ii) obtain cross-validation and record different diagnostics of similar phenomena, (iii) obtain simultaneous measurements sampling a large range of altitudes and (iv) improve the temporal baseline on time-varying phenomena. The 2010 coordinated campaign was supported by several international teams from the ground : Ohtsuki et al. (IRTF/CSHELL, 1.27 um), Iwagami et al. (IRTF/CSHELL, 1.7-2.3 um), Young et al. (IRTF/SpeX, 2.26-2.52 um), Sornig et al. (Kitt Peak/THIS, ˜10 um), Livengood et al. (IRTF/HIPWAC, ˜10 um), Bailey et al. (AAT/IRIS2, APO/ARCES, 1.1-2.4 um), Sandor et al. (JCMT, 330-360 GHz CO, T(z), winds), Limaye et al. (2-m HCT/ HFOSC 2.3 um), Widemann et al. (CFHT/EsPADOnS, 0.35-1.05 um), Slanger et al. (10-m Keck I/HIRES, APO, nIR O2 and Vis. airglow), Jessup et al. (Hubble Space Telescope/STIS), Encrenaz et al. (IRTF/EXES, 7-8 um). We will discuss science results obtained through coordination with VEx, and mention future ground-based instrumentation esp. in Japanese facilities. We will briefly introduce new balloon experiments proposed to observe Venus continuously in the near-IR, as well as specific projects in coordination for the observation of next year's Venus solar transit.

Keywords: Planetary Science, Planetary Atmospheres, Venus Atmospheric Dynamics, High Resolution Spectroscopy, Visible, Infrared, Millimeter-wave, Venus Atmospheric Chemistry

Japan Geoscience Union Meeting 2011
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U003-28 Room:304 Time:May 27 17:15-17:30

Characterization of Venus' atmospheric dynamics with ground-based Doppler velocimetry

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We present an analysis of observations of Venus made with the Ultraviolet and Visual Echelle Spectrograph (UVES) instrument at ESO's Very Large Telescope. This instrument allows to perform Doppler velocimetry based on high-resolution spectra of solar Fraunhofer lines, probing an altitude close to cloud tops, where opacity in the visible reaches unity. Observations were made at a central wavelength of 580 nm.

The UVES instrument achieves both high spectral resolving power (R ˜ 100000) and high spatial resolution. The narrow slit width combined with the large angular size of the planet allows a direct determination of the latitudinal (slit perpendicular to equator) and longitudinal (slit parallel to equator) variation of the zonal winds in both hemispheres.

The circulation up to the cloud tops is characterized by a monotonically increasing zonal wind, reaching its maximum close to 70 km altitude. Cloud-top winds were measured from Doppler velocimetry, a technique which has been used previously to measure the winds of Titan from the Doppler shifts of the solar reflected spectrum (Luz et al. 2005, Icarus 179, 497; Luz et al., 2006, JGR 111, E08S90), and in Venus from Doppler shifts of solar Fraunhofer and CO_2 absorption lines (Widemann et al. 2007, PSS 55, 1741; 2008, PSS 56, 1320; Gaulme et al. 2008, PSS 56, 1335; Gabsi et al., 2008, PSS 56, 1454). The spatially-resolved velocity changes on the source are measured using the optimal weight of intensity variations along the spectra to perform absolute accelerometry, with respect to a reference spectrum.

The objective of this work is to measure zonal winds on Venus, in the context of the study of atmospheric super-rotation, in coordination with the effort under way with the European Space Agency's Venus Express mission (VEx). Major objectives are (1) to measure the latitudinal profile of the zonal winds in the cloud layer, mesosphere and in the thermosphere and to search for wave motions through ground-based spectroscopic observations, using Doppler velocimetry techniques; (2) to complement in-situ observations made by space missions (which use cloud tracking techniques or infer winds indirectly); (3) to improve our understanding of the nature of the processes governing super-rotation, in particular waves and wave-mean flow interactions, as well as the latitudinal extent of the cyclostrophic balance approximation at cloud top level.

The narrow slit width combined with the large angular size of the planet allows to characterize latitudinal and longitudinal variations of the wind. Relative Doppler shifts allow to retrieve relative variations in the latitudinal profile of the zonal wind and combined results of three nights of observation were used to deduce the variability of the circulation.

This technique allowed to create an approximate wind map in the case of observations obtained with the spectroscopic slit parallel to the equator and to estimate the hemispheric asymmetry of the zonal wind. We shall discuss these results in the light of previous spacecraft observations, in particular Venus Express observations by the VIRTIS and VMC instruments (Sanchez-Lavega et al. 2008, GRL 35, L13204; Moissl et al., 2009, JGR 114, E0031).

Keywords: Venus, Atmosphere dynamics, Ground based, Spectroscopy

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U003-29 Room:304 Time:May 27 17:30-17:45

Direct Wind and Temperature Measurements in Venus Upper Atmosphere by Ground-based Infrared Heterodyne Spectroscopy

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Dynamics of the Venusian atmospheric transition zone between the sub-solar to anti-solar (SS-AS) flow dominated region above 120km and the superrotation dominated region below 90km is not yet fully understood. Temperatures in the same region are not very well constrained. Measurements are essential to gain a global understanding of the atmosphere and to validate global circulation models. Space based observations can provide temperatures but do not offer direct wind measurements at these altitudes and ground-based results lack in time coverage and spatial resolution. Hence measurements on various time scales and on different locations with sufficient spatial resolution on the planet are important.

The Tunable Infrared Heterodyne Spectrometer (THIS) was developed at the University of Cologne, I. Physikalisches Institut. The ground-based receiver is transportable and can be used at various telescopes. Beside high spectral resolution ($R>107$) this technique also guarantees high spatial resolution on the planet. Temperatures and winds in planetary atmospheres can be retrieved from detection of narrow non-LTE emission lines of CO2 at 10 mum. These emission lines are induced by solar radiation. Non-LTE emission can only occur within a narrow pressure/altitude region around 110km. Resolving the molecular features allow to retrieve temperatures and wind velocities. Temperatures with a precision of 5K can be calculated from the Doppler-width of emission lines and wind velocities can be determined from Doppler-shifts of emission lines with an precision up to 10 m/s.

We observed Venus at several characteristic orbital positions using the McMath-Pierce-Solar Telescope on Kitt Peak, Arizona, USA. Observations at maximum elongation in May and November 2007 and June 2009 and observations close to inferior conjunction in March and in April 2009 have been accomplished. These observing geometries allow investigations of wind velocities of different combinations of the superrotational component and the SS-AS flow component including investigations of temporal behavior on different time scales.

Keywords: Venus, atmosphere, heterodyne spectroscopy, dynamics, temperatures

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U003-30 Room:304 Time:May 27 17:45-18:00

Ground based submillimeter observations of thermal structure, CO distribution, and wind in the Venus mesosphere

Hideo Sagawa[1]*

[1]NICT

Heterodyne spectroscopy at the millimeter/submillimeter domain is a powerful tool to study the thermal structure, chemical compositions, and dynamics in the Venus mesosphere. A large number of roto-vibrational transitions of many photochemically important species in the Venus atmosphere such as H_2O, HDO, CO, SO and SO_2 are found in this spectral region. The vertical profiles of the atmospheric state (e.g., temperature, chemical compositions) can be retrieved by using the pressure dependency of the spectral line shape of those rotational transitions. Furthermore, the high spectral resolving power of the submillimeter heterodyne technique achieves the detection of the Doppler shift of molecular lines, which provides the capability of direct measurements of the mesospheric wind as line-of-sight velocity. The spatial resolution of such observations can be improved by using the interferometer facilities.

This paper describes about the recent works on the ground-based submillimeter observations of Venus atmosphere using the Combined Array for Research in Millimeter-wave Astronomy, CARMA, and the Sub-Millimeter Array, SMA, in 2009. Disk-resolved wind field maps are obtained from these observations, and the results are suggesting that an intense spatial variability of the wind pattern in the Venus mesosphere.

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

U003-31 Room:304 Time:May 27 18:00-18:15

VEXAG and the Exploration of Venus in the next decade - the Decadal Survey Recommendations

Sanjay Limaye[1*], Sue Smrekar[2], Steve Mackwell[3], Ellen Stofan[4]

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Venus remains an important exploration target as it provides insight into not only the future climate of Earth, but also for the conditions on terrestrial planets around other stars. At present ESA's Venus Express mission is providing valuable monitoring of the planet and yielding important discoveries about Venus and its atmosphere. JAXA's Akatsuki mission may go into orbit into Venus in 2015 and provide valuable data on the super rotating circulation of the Venus atmosphere. However, there are many other questions about Venus that will remain unanswered after these missions.

"Vision and Voyages for Planetary Science in the Decade 2013-2022" presents the results and recommendations of the Planetary Science Decadal Survey conducted by the US National Academies during the past two years upon a request from NASA. The recommendations of this survey serve as a guideline for NASA's planetary exploration and supporting activities. Among the tasks performed by the Steering Committee were - (1) A broad survey of the current state of knowledge of the solar system, (3) An inventory of the top-level science questions that should guide flight programs and supporting research programs, (4) Recommendations on the optimum balance among small, medium, and large missions and supporting activities (5) A discussion of strategic technology development needs and opportunities, and (6) A prioritized list of major flight investigations in the New Frontiers and larger classes recommended for initiation over the decade 2013-2022.

The Decadal Survey recommendations include a Venus Climate Mission as well as New Frontiers missions and Discovery Missions to Venus. The survey recognizes the value of international partnerships such as those between ESA and NASA. These guidelines are thus significant for prospects of future US missions to Venus, and also important for international collaborative efforts to explore Venus in the current. budgetary climates.

The current New Frontiers Opportunity (NASA) is undergoing evaluation of three concept studies, one of which includes a mission to Venus, and the Discovery Missions Opportunity is evaluating many proposals for missions to Venus. The outcome of these competitions should become known in the next few months and selection of Venus missions will accomplish some of the goals identified by the Decadal Survey and guide future exploration activities.

NASA's Venus Exploration Analysis Group (VEXAG) serves as a forum to identify scientific priorities and exploration strategies for Venus. It will hold a workshop during August 30 – 1 September in the Washington, D.C. metropolitan area to which all scientists interested in Venus exploration are welcome.

Keywords: Venus, exploration

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U003-P01 Room:Convention Hall Time:May 26 16:15-18:45

Momentum transport and mean zonal flow induced by thermal tides in the Venus atmosphere

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In the Venus atmosphere, the zonal wind velocity increases with height and reaches 100m/s at 65km. This phenomena is called superrotation, which is one of the most important unsolved problems.

There are clouds of sulfuric acid between 45 to 70km, and solar heating excites thermal tides at the top of these clouds.

The momentum transport by thermal tides is thought to play an important role in the generation and maintenance of the superrotation.

Various parameters such as the wind velocity of basic state and the Brunt-Vaisala frequency determine the vertical structure of thermal tides and momentum flux.Changes of the altitude region where thermal tides are excited would also cause changes in the momentum transport and the resultant zonal wind acceleration.

In this study momentum transport is calculated for various atmospheric parameters using a two-dimensional (longitude and height) model.We will discuss the sensitivity of the momentum transport to these parameters.

Keywords: Venus, thermal tides, superrotation

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U003-P02 Room:Convention Hall Time:May 26 16:15-18:45

A plan to study the Venus cloud structure based on the several Venus observations

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Venus is our nearest neighbor, and has a size very similar to the Earth's. However, previous spacecraft missions discovered an extremely dense (92 bar) and CO_2 atmosphere with H_2SO_4 clouds floating at high altitudes. H_2SO_4 clouds covered whole planet. The CO_2 atmosphere brings about a high atmospheric temperature (740 K) near the surface via greenhouse effect. The atmospheric circulation is also much different from the Earth's. The mechanisms which sustain such conditions are unclear. To understand such Venus climate, radiative transfer calculation including both sunlight absorption and scattering by cloud particles and atmosphere is performed. 'Cloud model' is necessary for this calculation. The 'cloud model' is vertical distribution of optical thickness of each cloud particles (mode1, 2 and 3). The 'Pollack model' is famous and often used. However, I think Pollack model should be improved for several reasons. The purpose of my study is make new realistic cloud model. For this purpose, previous entry probe, ground-based spectroscopic observation and Venus Express observation will be used to make new cloud model.

Keywords: Venus, cloud

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U003-P03 Room:Convention Hall Time:May 26 16:15-18:45

Derivation of two-dimensional wind velocity distribution in south polar vortex of Venus from VEX/VMC

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Vortical structures called "polar vortices" exist on the poles of Venus. Polar vortices also exist on other planets in the solar system such as Earth, while the vortices of Earth are low-temperature regions, the temperature structures of the vortices of Venus observed in infrared region are characterized by high-temperature regions called "polar dipoles" on the poles, and low-temperature regions called "polar collars" or "cold collars" surround the dipoles.

The vortices on Venus are unique in their dipole- or oval-like shaped high-temperature regions and significant longitudinal non-uniformity. These dipoles rotate with periods of 2.5 to 3 days, which are extremely faster than rotation period of solid planet (243 days). It is known to blow a zonal wind called "super-rotation" at mid- and low-latitude areas with a period of 4 days at equator. Its period at latitude of 70 degrees is about 3 days, which is consistent with the period at the edges of the vortices [Markiewicz et al., 2007]. This suggests that the rotations of the dipoles and the super-rotation are successive. On the other hand, the collars do not rotate quickly as dipole and the lowest temperature region is at dawnside. This means that the structure of the dipoles is wavenumber 2 and the collar is 1, in addition, the dipoles vary considerably in shape, from single mode to mode 3, or even more complex shapes [Piccioni et al., 2010].

Pioneer Venus Orbiter (PVO) in 1978 and Galileo in 1990 observed the vortex, but they observed only north, and for short periods. Venus Express (VEX) which injected into Venus orbit in 2006 observed south vortex for the first time, and continues to obtain data until now. VEX mounts instruments named Venus Monitoring Camera (VMC) and Visible and Infrared Thermal Imaging Spectrometer (VIRTIS). VIRTIS observed wide range at near-infrared regions, at which we can observe the well-marked structures of dipoles and collars. This is thermal emission from the cloud top, which reflects the distribution of temperature. Meanwhile, UV channel of VMC is at 365nm, at which distinct features are observed, and believed to reflect the distribution of unknown UV absorbers at about up to 70km altitude which represent above the cloud layer. We can see features also on the pole at this channel, but the dipole and collar are unclear.

The study aims to derive two-dimensional wind velocity distribution in the south vortex by analyzing VMC data at 365nm by cloud tracking method. Markiewicz et al. [2007] and Moissl et al. [2009] derived the distribution by using VMC data, and Sanchez-Lavega et al. [2008] did it by using VIRTIS data. These researches, however, derive latitude distribution of zonal-mean wind velocities, and average the velocities latitudinally with some degrees width . Therefore, it is not suitable for studying the structure of the dipole which has notable longitude non-uniformity, and we cannot discuss about the fine latitudinal structures. We still do not know that longitude non-uniformity like dipoles and collars at infrared regions is also observed on the motion of the unknown UV absorber at the polar region. Thus, we require to derive two-dimensional wind velocities with higher resolution than previous studies to confirm the non-uniformity.

Furthermore, the cloud trackings on previous studies use the manual tracking method which identifies similar features by visual check, but this method has limitations of objectivity and throughput. We will apply the cross correlation method developed to derive the latitudinal wind velocity distribution at mid- and low-latitude [Kouyama et al., 2009] to high-latitude region, and consider the possibility of automatic wind velocities derivation with objective criteria. There are proper difficulties at high latitude that the clouds do not go straight but rotate, low contrast and streak features of clouds. Therefore, we need to resolve these problems to derive wind velocity distribution of the vortex.

Keywords: Polar vortex, Venus, wind velocity distribution, Venus Express, VMC, Venus Monitoring Camera

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

U003-P04 Room:Convention Hall Time:May 26 16:15-18:45

Superrotation Strength Estimated from Algebraic Equations

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We estimate the strength of equatorial superrotation of planetary atmospheres by solving a set of algebraic equations based on Gierasch's model. Gierasch (1975) explained that the equatorial superrotation of Venus is maintained by upward and equatorward angular momentum transport by means of meridional circulation and strong horizontal eddy diffusion, respectively. The parametric dependence of this model was explored by Matsuda (1980). However both Gierasch and Matsuda ignored the effect of meridional thermal advection. By taking account of the effect, we extend their studies.

We derive a set of algebraic equations from the primitive equations of the steady axisymmetric Boussinesq fluid, by substituting unknown scalar variables for unknown functions (i.e., zonal and meridional velocity, and temperature). Coefficients of the algebraic equations consist of the thermal Rossby number, the vertical and the horizontal Ekman numbers, and the relaxation time constant of Newtonian heating and cooling.

Solutions of the algebraic equations are compared with representative values of numerical solutions of the primitive equations for a parametric range of many orders of magnitude. The superrotation strength obtained from the full primitive equations (i.e., latitudinally averaged zonal velocity at the top divided by the planetary rotation velocity at the equator) can be estimated from the solutions of the algebraic equations; the accuracy of the estimates is better than 70% in most cases. The superrotation strength is proportional to the cubic root of the thermal Rossby number for the cases that the dominant balance is between the centrifugal acceleration and the pressure gradient that is weakened by the meridional thermal advection.

Keywords: superrotation, atmospheric general circulation, planetary atmospheres, atmospheric dynamics, geophysical fluid dynamics

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Energy transportation of Venusian atmospheric turbulence evaluated by VEX/VMC UV images

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In the Venusian atmosphere, there are waves with various scales and the waves compose turbulence.

In order to evaluate the energy transportation of the turbulence in the Venusian atmosphere, we derived the power spectra of the cloud brightness distribution at the cloud top (altitude ~65 km) using the UV images obtained by Venus Monitoring Camera (VMC) onboard Venus Express. VMC has provided the first uniform long-term data set of Venusian UV images, which covers over 4 years with high spatial resolution, ~25 - 45 km/px, that has been never performed before.

According to the classical turbulence theory, power spectral intensity at the wavenumber k is expressed by $P(k)=C_k k^{-n}$ where the index ?n corresponds to the slope of the spectrum in the logarithmic plot and characterizes the power spectrum. In this study, we analysed the 44 images of Venus full disc obtained from May 2006 to January 2010. We derived the long-term characteristics of the power spectra from 0.0001 /km to 0.01 /km in the latitude from 20S to 70S. This wide wavenumber coverage enables us the comparison with the similar characteritics found in the terrestrial atmosphere. We also evaluated the correspondence between the slopes of the obtained spectra and the theoretical values (-3 and -5/3).

The main results obtained from this study are as follows:

(1) The power spectra of the cloud brightness distribution mostly show the inflection. The slope at lower wavenumbers is generally steeper than that at higher wavenumbers. Such a feature agrees with the characteristics in the kinetic energy spectra on Earth (Nastrom et al., 1984; Nastrom and Gage, 1985).

(2) The obtained slopes at planetary wavenumbers $K < 50$ (~ 0.001 /km at the latitude of 20S) are intermediate value between the theoretical values (-3 and -5/3). It agrees well with the previous Venusian studies (Peralta et al., 2007) in which the slope at $K < 50$ was also in this range. Our results also confirmed that this feature is common over three years.

(3) Because of the high spatial resolution of VMC, the slope at higher wavenumbers (0.002 - 0.01 /km) can be derived. It sometimes shows close to zero, which is not seen in the terrestrial cases. Further checks and investigations are needed to fix the view.

(4) Here is the first attempt to identify the temporal/spatial changes of the slopes in short interval as several hours. This result also suggests that the PSD slope has a large variability in the individual latitude.

(5) The wavenumbers at the inflection point are 0.001 - 0.003(/km). The numerical study (Kitamura and Matsuda, 2006) suggests that the inflection point (wavelength ~330-1000km) is the border between 2D and 3D turbulence. Thus, our result indicates that the enstrophy forward cascade of 2D turbulence occurs at lower wavenumbers and the energy forward cascade of 3D turbulence occurs at higher wavenumbers.

Tung and Orlando (2003) suggested that the injection would occur at synoptic-scale. However, due to the limitation of the longitudinal coverage of our measurements, it is hard to investigate in the range of synoptic-scale. As a future work, full-disc observations are indispensable in order to investigate the source of injection. At present, baroclinic instability wave and thermal tides are considered for the possible driving mechanism of injection. Specifying the injection cause will provide us important information on the energy and enstrophy transportation. Therefore composite of the multiple images will enable us to expand the longitudinal coverage and derive the spectra which cover synoptic-scale.

Furthermore, recent results using the same instrument successfully performed cloud wind tracking, which shows the highly variability of the Venusian dynamics (Moissl et al., 2009). The comparison of the cloud brightness spectra with the kinetic energy spectra derived from wind velocity is expected to achieve more precise understanding of Venusian turbulence.

Keywords: Venus, UV, cloud top, spectral analysis

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Latitudial distribution of HDO above the Venus's clouds

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The abundance of HDO in the Venus' dayside atmosphere above the clouds was measured by ground-based 2.3 um spectroscopy for 4 days. The latitudinal distributions found show no significant structure. The latitudinal average of mixing ratio of 2.3 ppm at a presentative height of 62-67 km is consistent with previous measurements. According to previous measurements, the HDO/H2O ratio in the height region 30-40 km and higher than 80 km in Venus' atmosphere is 120 times and 250 times telluric ratio respectively. In this works, the ratio of HDO/H2O in the height region 62-67 km calculated with Pollack's model is 160 times that on Earth and the vertical distribution is found.

Keywords: Venus, HDO

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Constructing a new Venus cloud model using a multiple scattering method

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Venus clouds lie at an altitude from 45km to 90km in the Venus atmosphere and cover the whole planet. It is relevant that the Venus clouds consist of main cloud deck which composed of upper, middle, and lower regions and a tenuous haze above and below. Before now, several cloud models are constructed, but it is relevant that there are several problems in these cloud models. For example, when using a cloud model made by Pollack(1993), a big difference of cloud height is occurred along the lines of longitude which is not matched past observations.

To resolve these problems, I will make a new cloud model using CO2 spectroscopic data performed by using IRTF at Mauna Kea with CSHELL spectrometer.

Keywords: Venus, cloud model

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Characteristic features seen in a temperature distribution at nightside cloud top of Venus

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The Longwave Infrared Camera (LIR) onboard Akatsuki succeeded to obtain an infrared image of Venus nightside for the first time. LIR visualizes thermal infrared radiation emitted from the upper cloud layer of sulfuric acid, and a temperature distribution at the cloud top altitude is obtained by converting the infrared radiation to brightness temperature.

Characteristic features seen in the temperature distribution are summerised, and the obtained temperature is compared with the past observations. The remarkable features are low temperature regions in the polar regions and the polar collars, limb darkening due to difference in optical path length, zonal structures seen in the middle and low latitudes, and smaller scale structures. An altitude profile of optical depth will be derived from the limb darkening effect. The temperature distribution obtained by LIR will give constraint to theoretical studies of atmospheric dynamics and cloud chemistry in the cloud top altitude region.

Keywords: Akatsuki, venus, LIR

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Vertical distribution of UV absorber in the Venusian cloud layer inferred from cloud images

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Various UV features are observed on the Venus. The features are attributed to at least two UV absorbers; one is SO_2 and the other is unidentified.For studying the characteristics of the second absorber and its role in the atmospheric energy balance, the vertical distribution of the absorber needs to be determined.

The vertical distribution will be reflected in the brightness distribution on the sunlit disk. For example, limb darkening feature depends on the location of the absorbing layer relative to the cloud top. We will constrain the vertical distribution of the absorber by comparing Venus images taken by Venus Express VMC and radiative transfer calculations.