INVESTIGATION OF THE VENUS ATMOSPHERIC DYNAMICS
FROM VMC AND VIRTIS INSTRUMENTS ON VENUS EXPRESS

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1. INTRODUCTION

This is the Year 1 Progress Report on NASA Grant NNX09AE85G (Venus Atmospheric Dynamics from VMC and VIRTIS Instruments on Venus Express). The Venus Monitoring Camera (VMC) continues to function well and is collecting images of Venus in all filters. The Visible InfraRed Imaging Spectrometer (VIRTIS) has suffered a cooler failure and is not currently acquiring mapping data in the near infrared.

Processed VMC images have been retrieved from the VMC Team. The flat-fielding of the images requires that the on-orbit flats be acquired using Venus cloud cover as the target when at close approach when the image contrast is negligible due to the very high spatial resolution. Processing of these “flats” takes a few days when the final processed Level 2 version (.01) is available. DLR also provides mapped products (Level 3) although these are not used in the data analysis done at University of Wisconsin.

2. PROGRESS MADE DURING YEAR 1

Progress was made on all areas of investigation proposed and is described below with some highlights.

2.1 HIGHLIGHTS

Two papers were published in refereed journals during this period. The first one described the work begun previously on the structures seen in the polar regions of Venus in ultraviolet and near infrared data.


This paper on the dynamical instability in the polar region of Venus as determined by a model simulation based on the cloud tracking data was published in Geophysical Research and the print issue highlighted the paper on the cover with a composite picture of the Venus vortex and Hurricane Frances (Figure 1).

- Moissl et al. (2012). The second paper describes the cloud motions using the visual tracking results from the VMC images (Moissl et al.). The tracking was done at University of Wisconsin by R. Moissl as part of his Ph.D. research. He also successfully completed the research and earned his degree from Branschweig University in Germany. I served as one of the mentors for him.

2.2 VMC OBSERVING SEQUENCE PLANNING

VMC has been acquiring images on most orbits since the operational phase began in late May 2006. Coverage has been obtained at all four wavelengths. In the initial orbits the exposures were varied to arrive at optimum signal level and contrast in the data. Global scale images were obtained from apoapsis portion and small-scale images at much higher resolution (~ 200 m) were taken on some orbits near the periapsis passage, along with the some images of the planetary limb.

One aspect of when and how the VMC images are acquired during the Venus Express orbit that has had an adverse effect on the cloud tracking has been that bulk of the images are acquired in the post-apoapsis portion of the orbit. This results in the images with a pixel size > 35 km/pixel which has an adverse effect on the cloud tracking in that the time required needs to be longer than one hour for sufficient accuracy in the zonal component (it is not adequate for meridional component at all). To ameliorate this, I suggested that VMC acquire a few images when the spacecraft is closer to the planet by using the pointing ability of the spacecraft to take multiple images at different pointing of the spacecraft when the planet is larger than the file-of-view of the VMC. Figure 2 illustrates the strategy that was recommended to the Venus Express Science Operations Center (VSOC) at the December 2008 VMC Team meeting in Katlenberg-Lindau. Orbits 1108-1110 were the first ones when this imaging strategy was adopted and the results of cloud tracking show that this strategy was very useful and productive. Sample results of the cloud tracking are shown in Figure 3 (below).

**Figure 2.** Three mosaics to be acquired by pointing the spacecraft when closer to the planet, later than the normal imaging mode. Such images were acquired in May 2009.

This mode has been recommended for implementation in future planning of observations to be acquired by VMC.
2.3 Digital Tracking of Images

Tracking of cloud features in processed VMC images from recent orbits is continuing with small updates to the tracking procedure. Figure 3 shows an example of the mosaic frames obtained at somewhat higher spatial resolution through controlled pointing of the Venus Express spacecraft about the nadir direction (nominal mode).

![Figure 3. Zonal component of cloud motions obtained from image triplets with one hour spacing from the targeted mosaic sequence on orbits 1108 and 1109.](image)

2.4 Global Structure of the Atmospheric Circulation

Since VMC images Venus in reflected sunlight, only the sun-lit hemisphere can be imaged. To provide some idea of a global view of the planet, the measured motions can be used to create a time-lapse composite view in a polar projection by rotating selected images through an angle determined by a representative rotation rate (~3.6 deg/hour) and the time interval between successive images. Figure 4 shows an example of such a space-time composite generated from images acquired over three consecutive orbits (orbits 443-446).

![Figure 4. A draft image of a space-time composite view of the southern hemisphere of Venus generated by compositing selected VMC images from three successive orbits.](image)
The images were remapped into a polar stereographic projection and the normalized using the Minnaert law to remove the effect of varying illumination and viewing geometry. The idea is to generate a composite by sliding over the images orbit by orbit to make a long animation using most of the VMC images acquired by the VMC to depict the temporal changes in the evolution of the vortex organization over a long time.

3. TEAM/SCIENTIFIC MEETINGS AND CONFERENCE PRESENTATIONS

I participated in several scientific conferences as well as VMC and Venus Express Team meetings either in person or by telephone and made presentations on my work. The table below lists the presentations made.

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<td>September 21-22, 2009</td>
<td>VMC Team Meeting, Berlin, Germany</td>
<td>Observation Planning, Data Analysis Status</td>
<td>By Telephone</td>
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<td>14-18 September 2009</td>
<td>Europlanets Conference, Potsdam, Germany</td>
<td>Observations of Small-scale wave-like features in VMC images</td>
<td>R. Moissl , J. Borchert W.J. Markiewicz, D.V. Titov, S. J. Limaye and the VMC Team</td>
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<tr>
<td>September 21-22, 2009</td>
<td>VMC Team Meeting</td>
<td>Venus Atmospheric Circulation: An update</td>
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<td>April 2009</td>
<td>European Geophysical Union Meeting, Vienna, Austria</td>
<td>Status of Venus Atmospheric Circulation from Venus Express – VMC Results</td>
<td>S.S. Limaye</td>
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<td>November 11-13, 2009</td>
<td>Venus Express SWT # 23</td>
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<td>S.S. Limaye</td>
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4. EDUCATION AND PUBLIC OUTREACH EFFORTS

I participated in several activities for Venus Express and supported the Venus (see table below) Express/NASA URL for Education and Public Outreach Program (venus.wisc.edu) led by Ms. Rosalyn Pertzborn. The activities are listed below:

1) 7 Jul 2009, Astrobiology Learning Institute for Instructors (ALI’I), University of Hawaii, Honolulu, Hawaii USA

   Presented the Venus cloud tracking curriculum and a presentation on habitable worlds and conducted Venus Cloud tracking Curriculum training for teachers.
   Dr. Sanjay Limaye


3) 28 February 2009, Science City, Ahmedabad, Gujarat India

   Presented a “Exploration of Venus with Venus Express”

4) 6 April 2009, Seminar at Massachusetts Institute of Technology Dept. of Atmospheric Science (Cambridge, MA USA)

   Venus Atmospheric Circulation

5) 24 Feb 2009

   IYA 2009 Public Lecture followed by sky gazing, Nehru Planetarium, New Delhi, India
   Unveiling Venus
   Dr. Sanjay Limaye

6) 5 Feb 2009, Visiting Scientist and Classroom Activity (in 6 classes), McKinley Middle School Honolulu, HI, USA

7) Lecture / Venus Images Hands-On Cloud Tracking Activity

   Dr. Sanjay Limaye and Hsuan-Yun Pi

8) 2 Feb 2009, Visiting Scientist and Classroom Activity (in 5 classes, grade 9-12),

   Kamehameha High School, Kea’au, Hawaii USA

   Hands-On Tracking Clouds on Venus and presentation on Venus Express Mission

   Dr. Sanjay Limaye and Hsuan-Yun Pi

9) 30 Jan 2009, , Lihue, Hawaii USA:

   Astronomy and Astrobiology Workshop and IYA 2009 Activities and Lectures:
   Unveiling Venus
   Why Study the Planet Venus
   Tracking Clouds on Venus

   Dr. Sanjay Limaye

10) Provided input for a web story, “Weather on Venus” (venus.wisc.edu) following the discovery of a bright spot on Venus in amateur images of Venus taken on 16th July 2009, the same day a comet impact occurred on Jupiter. A screen image of the web story is shown in Figure 5.
5. PUBLICATIONS AND CONFERENCE PRESENTATIONS


