Venus Emissivity Mapper – Investigating the Atmospheric Structure and Dynamics of Venus' Polar Region

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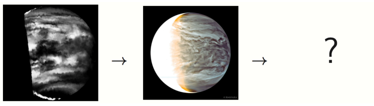
Foreword.

VEM is proposed for NASA's Venus Origins Explorer (VOX) and the ESA M5/EnVision mission proposals in combination with a high-resolution radar mapper. The primary mission of VEM is twofold: (1) measuring surface emissivity with 6 narrow bands between 860 and 1110 nm ; (2) constraining H_2O mixing ratio near the surface with 2 bands near 1150 and 960 nm. Proof of concept study with VIRTIS-M on board VEx has shown that proper correction of cloud-induced contrasts require at least 2 dedicated bands (current design has 3). Thanks to the circular polar orbit geometry of VOX and the ESA M5/EnVision, VEM has the unique capability to (1) better constrain the unknown microphysics of the polar lower clouds in three spectral bands at 1.195, 1.310 and 1.510 µm at a spatial resolution of ~10 km, and (2) investigate short-timescale cloud dynamics and local wind speeds by tracking cloud features in both polar regions, as well as wave-generating dynamical instabilities.

Cloud morphology

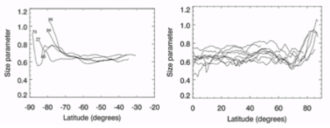
The intensity of the night side NIR window is primarily modulated by the optically thick lower cloud deck. Various space-borne instruments, such as NIMS/Galileo, VIRTIS/VEx or IR2/Akatsuki have already mapped it and studied the morphology of these lower clouds, sometimes matching VEM ~ 10 km spatial resolution. Yet VEM circular orbit will be the first to acquire a consistent climatology of these lower clouds, owing to its balanced and extensive coverage in latitude, planetocentric longitude and local solar time.



Galileo/NIMS Akatsuki/IR2

Cloud microphysics

VEM will provide images of the clouds at three different wavelengths (1195, 1310 and 1510 nm). Spatial variations in these band ratios will help in constraining variability in various lower cloud microphysical parameters: refractive index (related to the H_2SO_4/H_2O ratio in the particles), altitude, size distribution (e.g. mode 2:mode 3 ratio). Although already performed with VEx and Akatuski, VEM will bring (1) spatial and temporal sampling, (2) high SNR and wavelength stability as well as (3) unprecedented access to smaller scales between 200 and 20 km.

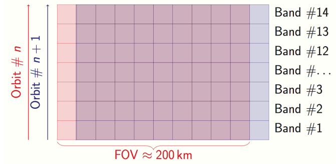


Left : Zonally averaged size parameter (y-axis) with latitude (x-axis) for South hemisphere data. Numbers on the graph show the orbit numbers. *Right* : Variation of the size parameter (y-axis) with latitude (x-axis) for North hemisphere data. Figures from Wilson et al. (2008).

Analysis of near-infrared emissions on the nightside of Venus observed by the Visible and Infrared Thermal Imaging Spectrometer (VIRTIS) instrument on board Venus Express revealed anomalous cloud particles found within the centers of polar vortices –either larger or different in composition from those elsewhere in the planet, possibly reflecting different cloud formation processes at latitudes greater than 60°.

Observation strategy

Either NF-4/VOX or M5/EnVision's orbits will be circular, quasi-polar at an altitude of about 200 km. It will slowly precess in longitude with each passing orbit. VEM will make use of this by using a pushbroom strategy, using the orbital motion to sweep the observed area onto each spectral band. This strategy also enables multiple views of the same targeted ground area during several successive orbits (about 90 min apart).

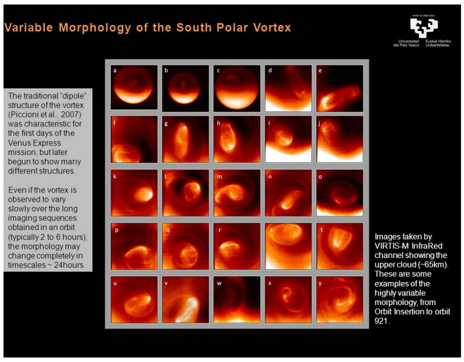


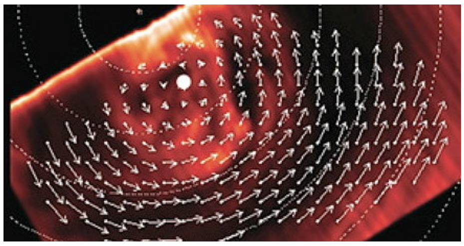
In order to meet the very high SNR requirements, data will be binned over a spatial extent of at least 10 km, slightly oversampling the atmospheric blurring limit due to multiple scattering of the lower atmosphere thermal emission by the optically thick clouds.

Vortices dynamics

Venus displays the best-known case of polar vortices evolving in a fast-rotating atmosphere. Few wind measurements exist in the polar region due to unfavorable viewing geometry of currently available observations. Cloud-tracking data indicate circumpolar circulation close to solid-body rotation. E-W winds decrease to zero velocity close to the poles. N-S circulation is marginal, with extremely variable morphology and complex vorticity patterns. Circular polar orbit geometry will provide an unprecedented study of both polar regions within the same mission. VEM's pushbroom method will allow short-timescale cloud dynamics to be assessed, as well as local wind speeds, using repeated imagery at 90 minute intervals.

Tracking lower cloud motions as proxies for wind measurements at high spatial resolutions will greatly benefit modeling of the vortices' physics. Convective modeling demonstrates that there will be cloud-level convection at high latitudes, so repeated imagery at 90 minute intervals will help constrain the time evolution of cloud-level convection as well as wave-generating dynamical instabilities. This will also allow a direct comparison of the N-S wind regimes and their temporal evolution at several time scales during a 4-yr mission.



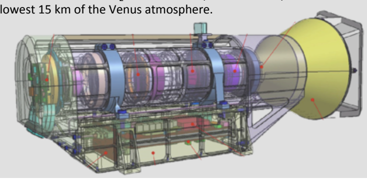


Cloud tracking of the southern polar vortex near 1.74 µm from Garate-Lopez et al. (2013). VEM will provide a consistent model for both polar vortices on Venus and the role they play in the general atmospheric circulation and Venus' superrotation. Tracking lower cloud motions as proxies for wind measurements is a VISE science goal.

Due to the 90 min orbit and fast zonal superrotation of the lower cloud deck, there will be no possibility of cloud tracking between two consecutive orbits at lower latitudes. But for latitudes higher than 80°, the smaller zonal shift between orbits and the transition from super-rotation into polar vortex dynamical regime will enable cloud-tracking in this ever-changing region. Also, even though the lower cloud optical thickness is usually much higher near the poles, VEM design nonetheless warrants a very high SNR.

The Venus Emissivity Mapper Instrument design

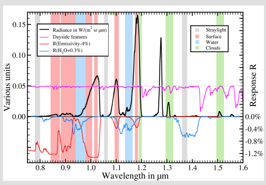
The Venus Emissivity Mapper (VEM) is focused mainly on observing the surface from a low circular polar orbit, mapping in all near-IR atmospheric windows using filters with spectral characteristics optimized for the wavelengths and widths of those windows. It also observes bands necessary for correcting atmospheric effects. These bands also provide valuable scientific data on cloud thickness, cloud opacity variations, particle size distribution and H_2O abundance spatial and temporal variations over a ~4 year mission timescale, in the lowest 15 km of the Venus atmosphere.



VEM is a pushbroom multispectral imaging system with a dispersive filter array and an InGaAs detector operated at +10°C. Telecentric optics image the scene onto the filter array. A 45° FOV yields a swath width of 207 km at an altitude of 250 km, providing a thorough sampling of surface emissivity and orbit-orbit repeat coverage to account for local atmospheric water vapor variations and cloud removal.

VEM uses a multilayered, dielectric-coating, ultra-narrow-band, filter array to split the light into 14 bands. The filter array is located at an intermediary focus of the optical path. Each band is imaged by a two lens relay optic onto 33×640-pixel rows on the FPA. Surface mineralogy bands are spatially interleaved between cloud bands. The Focal Plane Array (VEMFPA) is a TEC-stabilized, 640×512 pixel Xenics XSW-640 InGaAs detector. The FOV is 46.4°×37.8°. Each 20-µm-pitch pixel sees a 0.07°×0.07° FOV.

#	CWL (nm)	FWHM (nm)	Main Use
1	1310	30	Clouds
2	1060	15	Stray light
3	1150	30	Water
4	860	40	Mineralogy
5	1370	20	Stray light
6	960	40	Water
7	990	30	Mineralogy
8	1020	15	Mineralogy
9	790	20	Stray light
10	1180	12	Mineralogy
11	910	60	Mineralogy
12	1110	20	Mineralogy
13	1510	30	Clouds
14	1195	12	Clouds



The atmospheric radiative transfer model fit spectra measured by Venus Express/VIRTIS, enabling the retrieval of surface emissivity (solid black lines) over VEM spectral windows, while relative response R of spectrum to changes in input parameters, shows the sensitivity to atmospheric and surface parameters in the VEM bands (colored lines). Water vapor and cloud opacity are the most important atmospheric variables. Application of this analysis to only two cloud bands at 1195 nm and 1310 bands shows that the impact on retrieved emissivity is limited and can be reduced to less than 4% when averaged over multiple images.

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