Latitudinal cloud characteristics in the Venusian northern hemisphere evaluated from Venus Express/VIRTIS observations with GCM simulations

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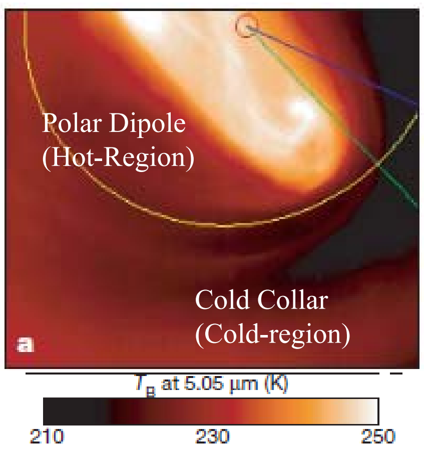
Contents of Master Thesis

Characteristics of Venusian polar vortex



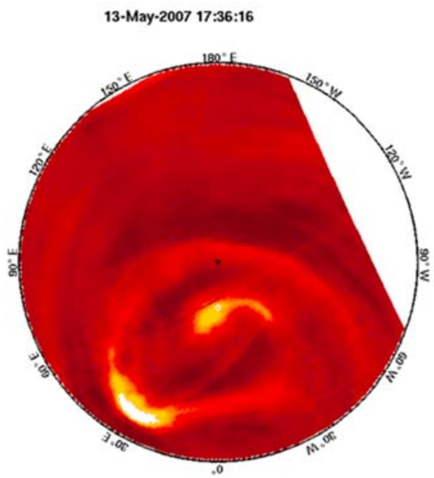
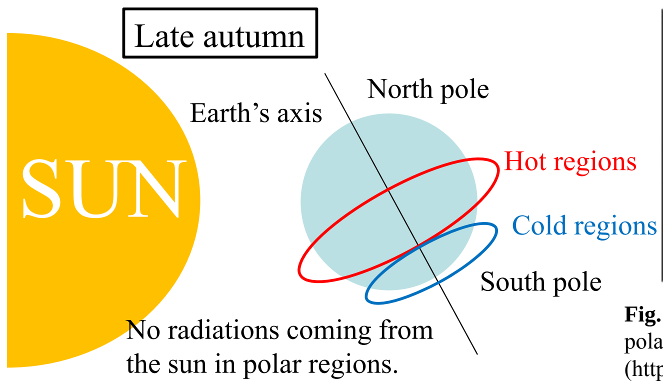


Fig (left). Venusian polar vortex in the southern hemisphere investigated from VEX/VIRTIS observations [Piccioni et al., 2007].
Fig (right). The motion of Venusian polar atmosphere. (http://sci.esa.int/scieence-e/www/object)

Characteristics of terrestrial polar vortex



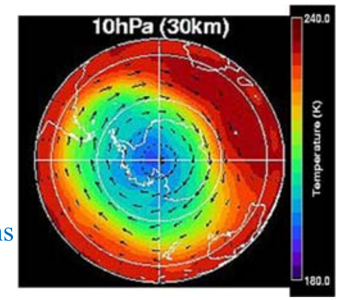
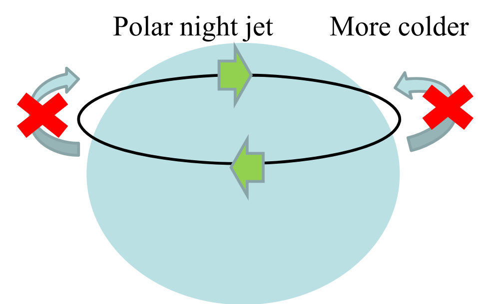


Fig. Temperature image around Antarctic polar vortex (http://www.ccpo.odu.edu/~lizsmith/SEES/ozone/class/Chap_11/index.htm).



1. Polar night jet doesn't exist on Venusian atmosphere due to little axial tilt.
2. Venusian polar vortex has a hot dipole feature surrounded by a cold collar.

Formation mechanism of Venusian polar vortex is different from that of terrestrial one.

Preceding studies by VEX

Recent long-term observations by Venus Express (ESA) have been investigating the southern polar vortex.

1. There is a hot dipole feature surrounded by a cold collar in the southern hemisphere.
2. The cloud top altitude is located at 74 ± 1 km in low and middle latitudes, and it decreases poleward and reaches 63-69 km in the polar region.
3. The abundance of carbon monoxide (CO) under the cloud layer increases toward the poles.
4. Since CO under the cloud is transported from the upper layer, its enhancement in the high-latitude can be interpreted the down-welling region of the Hadley-Circulation.

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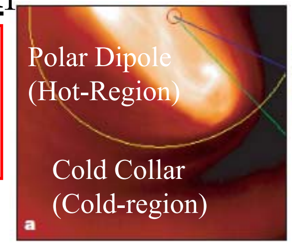

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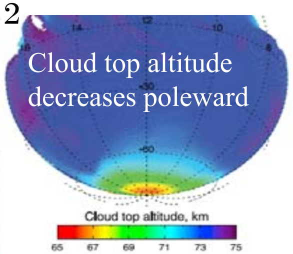

Fig (left). The Venus south-polar vortex [Piccioni et al., 2007].
Fig (right). Map of cloud top altitude [Ignatiev et al., 2009].

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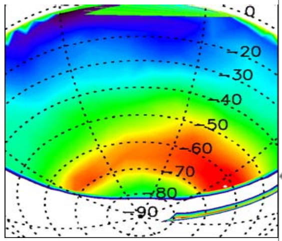

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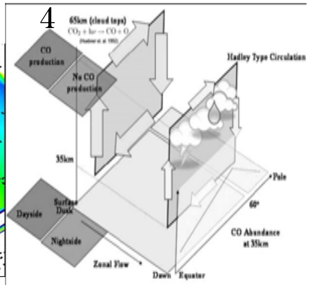


Fig (left). The retrieved CO abundance at 35 km from VEX/VIRTIS-M Data [Tsang et al., 2008].
Fig (right). A pictorial representation of the Hadley circulation [Tsang et al., 2008].

Our research

Purpose

Understanding of the fundamental question why Venusian polar vortex has a hot dipole feature surrounded by a cold collar.

Viewpoint

1. To investigate the latitudinal cloud characteristics (opacity, top temperature, and top altitude) in the northern hemisphere from VIRTIS data.
2. To interpret their characteristics with the possible atmospheric circulation by abundance of carbon monoxide (CO) under the cloud layer from VIRTIS data.
3. To calculate the movements of cloud particles and to derive the cloud top altitude and temperature using a Venusian General Circulation Model (VGCM).
4. To compare the latitudinal cloud characteristic between the observational results and VGCM results, and then, to try to evaluate the suggestion about the fundamental question.

VIRTIS (Venus Express)

Table. Parameters of Venus express

Launch	2005/11/09
Orbit	Polar-Orbit
Peri-Venus altitude (km)	165
Apo-Venus altitude (km)	66000

Fig. Local time and latitude coverage of selected VIRTIS observation data.

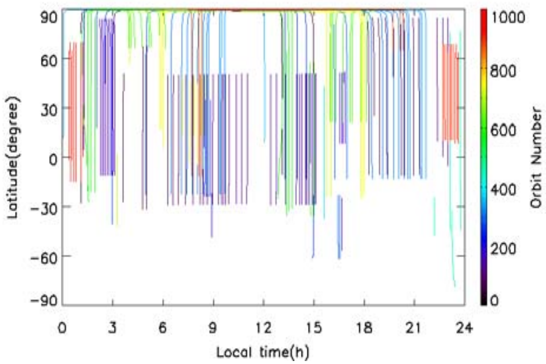
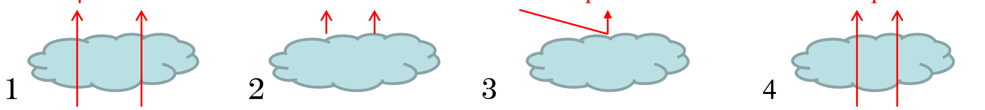


Table. Parameters of VIRTIS

	VIRTIS-M	VIRTIS-H
Wavelength (nm)	1050-5130	1840-4990
Resolution	100-500	1300-3000
Spectrometer	Offner Relay	Echelle spectrometer

- VIRTIS nadir observations can get information of northern hemisphere that has not been well reported in past VEX studies.
- We used only nadir data, so it is possible to ignore the zenith angle dependence of outgoing radiations by the scattering of cloud particles.

Analysis -cloud opacity and cloud top temperature-



1. Cloud opacity

Cloud optical depth can be evaluated form night side 2.29µm thermal radiations which are coming from under cloud layer. The brightness at 2.29 µm changed by mainly cloud-scattering, so the bright regions correspond to relatively cloud-free areas.

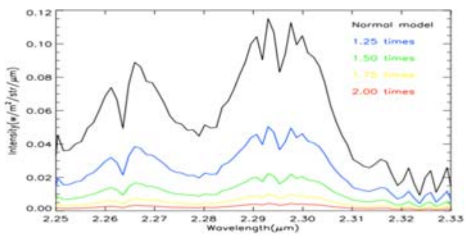


Fig. Synthetic spectra with cloud optical depth of 23.1 at 2.30 µm; (black) normal, (red) × 1.25, (blue) × 1.5, (green) × 1.75, and (purple) × 2.0.

2. Cloud top temperature

Night-side 4.98 µm thermal radiations are emitted from the cloud top range, so we investigated the brightness temperature of cloud-top by fitting the 4.98 µm spectrum to the Plank functions.

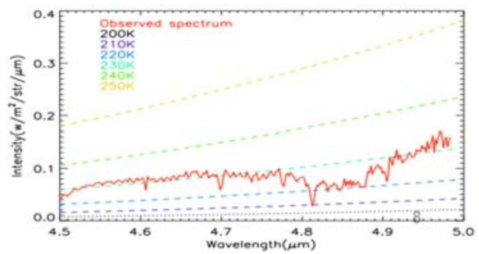


Fig. Plank function at temperature of 200, 210, 220, 230, 240 and 250 K around 5.0 µm and observed spectrum.

Analysis - cloud top altitude and carbon monoxide (CO) -

3. Cloud top altitude

Using the depths of CO_2 absorption bands, the cloud top altitude can be evaluated. In this analysis, we used 2.16 μm CO_2 absorption band and defined the ratio

α = Intensity (B) / Intensity (A)

where (A) is the continuum level and (B) is the bottom of the absorption .

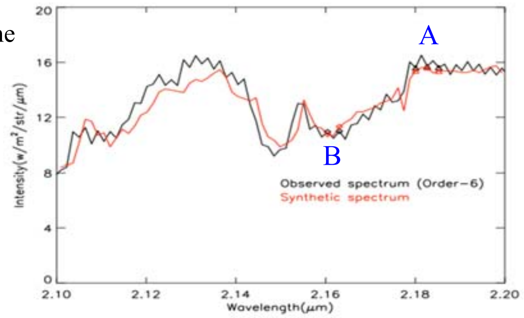


Fig. The observed and the synthetic spectrum around day-side 2.16μm range.

4. CO abundance

To retrieve the CO abundance under the cloud layer, we used the the intensity ratio of continuum level to the line bottom, I(2.29 μm) / I(2.32 μm) to calculate the abundance of CO mole function.

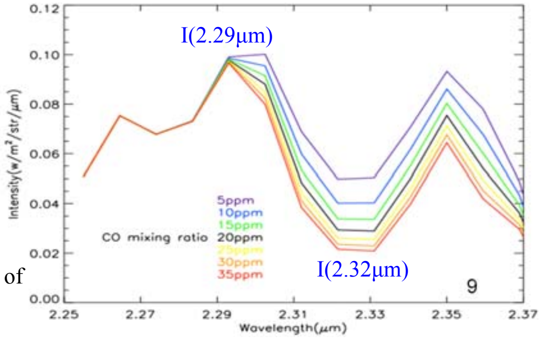


Fig. Synthetic spectrum with CO mole function of 5, 10, 15, 20, 25, 30 and 35 ppm.

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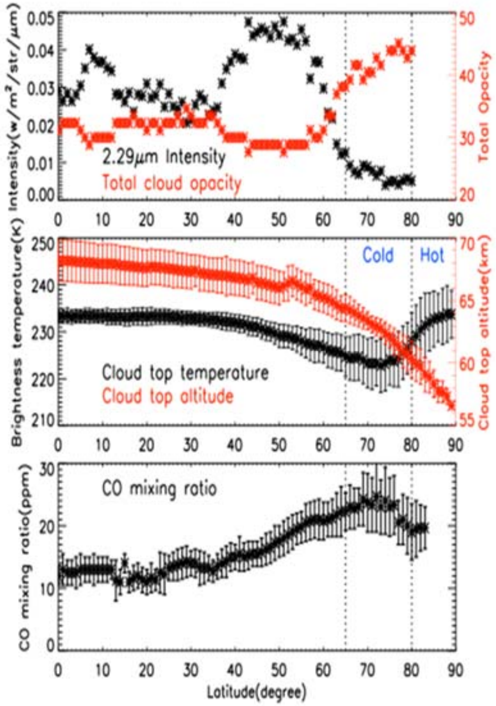
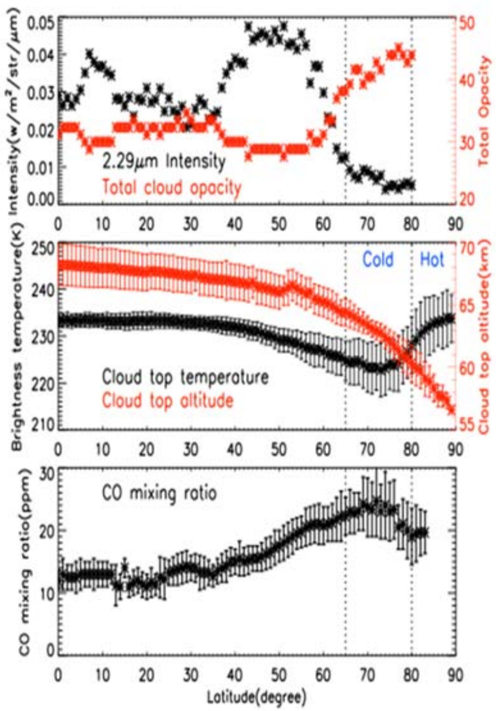
Result -Latitudinal variations of opacity, temperature, altitude and CO-



1. We could not find enough flux from lower altitude in the latitude more than 70degN.
2. Total optical thickness of cloud layer increases from 40degN (30.0) to 80degN (43.9) about 1.5 times.
3. The averaged cloud top temperature is almost constant from equator to 40degN (232±2K), and gradually decreases to 70degN (223±5K), and increases toward North Pole (233±6K) again.
4. The averaged cloud top altitude is monotonously decreases from equator (68.2±1.6km) to North Pole (58.3±1.0km).
5. The averaged CO mole function increases from 13±3 ppm at equator region to 24±5 ppm at 70 degN, and decreases to 19±5 ppm at 80 degN.

Fig. Latitudinal variations: (top) (black) 2.29 um radiations and (red) total cloud optical depth (middle) (black) cloud top altitude and (red) cloud top temperature. (bottom) CO mole function.

Discussion -Correlations between opacity, temperature, altitude and CO-



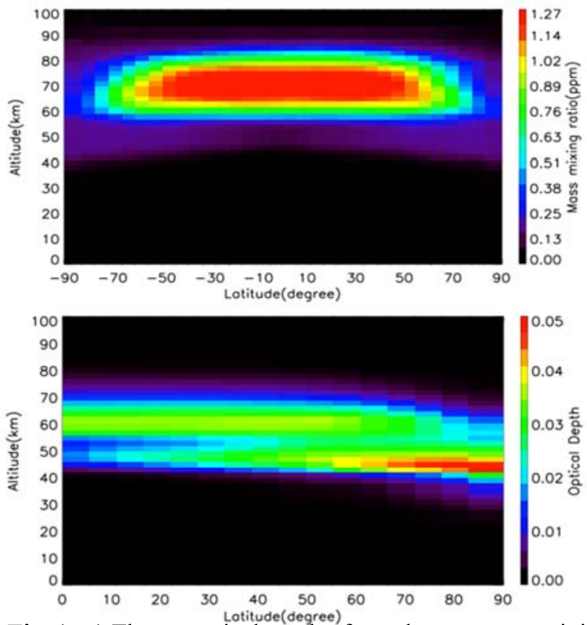
1. From the mid latitude region (~50degN) to the cold collar region (~70degN), the optically thickness of the cloud layer is gradually thicker, while the cloud-top temperature is decreased, i.e., the cold collar region can be interpreted as the optically thicker regions.

1. The cloud-top altitude is more sharply decreased beyond 70degN. It suggests that the structure of the Venusian polar vortex seen from thermal radiation is affected by the cloud top altitude.

1. There is a negative correlation between the cloud top temperature and CO abundance, and the peak of CO abundance is located in the cold collar regions. Since CO under the cloud is transported from the upper layer, the CO enhancement in the cold collar can be interpreted the down-welling region.

Fig. Latitudinal variations: (top) (black) 2.29 um radiations and (red) total cloud optical depth (middle) (black) cloud top altitude and (red) cloud top temperature. (bottom) CO mole function.

Result - Cloud particle tracking by GCM simulations -



In this study, we included the vertical profiles of cloud particles based on Haus et al. (2010), which is same model used in our VEX/VIRTIS studies, and calculated the movements of these cloud particles in the atmosphere.

From this calculation, we investigated the variability of the distributions of cloud top altitude and temperature and tried to compare the results with those evaluated from the data analysis.

As a result, the cloud particle falls down at high-latitude region. It indicates that the cloud top altitude decreases toward north pole.

Fig. (top) The numerical result of zonal-mean mass mixing ratio of the mode 2 cloud particles at one Venusian day after the initial distribution.
(bottom) Cloud extinction optical depth (/0.1 km) of each cloud layers at 2.16 μm.

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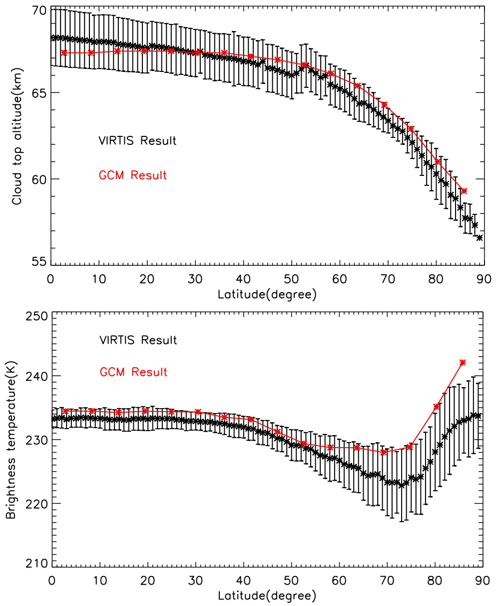
Result -Comparison between GCM results and VIRTIS results-



1. The cloud top altitude is monotonously decreases from equator (67.3 km) to polar region (59.3 km).
2. The cloud top temperature is constant from equator to 40 degN (234 K), and gradually decreases to 70 degN (228 K), and increases toward north pole (242 K) again.

The latitudinal characteristics of cloud top altitude and temperature calculated from GCM simulations are consistent with those investigated from our VIRTIS data analysis.

Fig. (top) Cloud top altitude and (bottom) Cloud top temperature:
(Black) investigated from VIRTIS-H observations and (Red) calculated from GCM simulations.

Discussion -Venusian polar vortex (hot dipole and cold collar)-

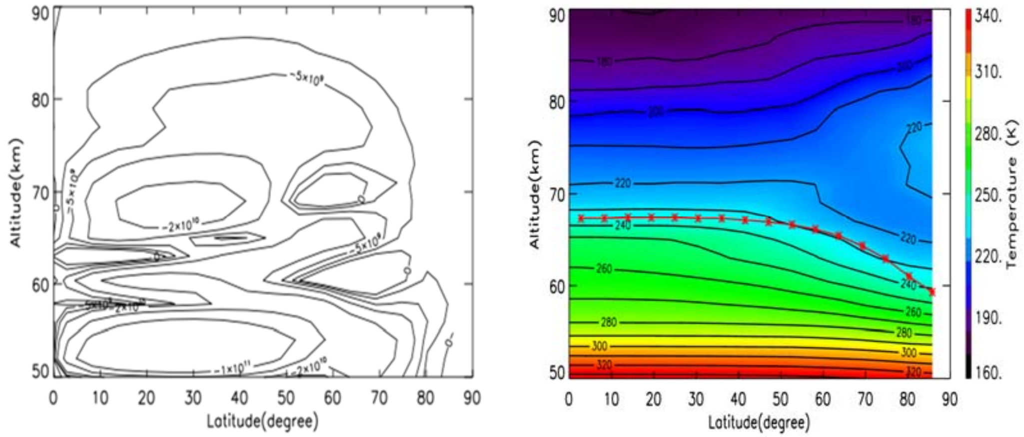


Fig. Results calculated from GCM simulations:
(left) Mass stream function (kg/s) around cloud top level.
(right) The latitude–altitude temperature profile and cloud top altitude (red line).

It suggests that the structure of Venusian polar vortex (hot dipole and cold collar) seen from thermal radiations are created from decreasing of cloud top around the polar region due to the Hadley - Circulation.

Summary

*We investigated the latitudinal characteristics of Venusian northern cloud, i.e, its opacity, top temperature and top altitude, and CO under the cloud, and then, thier relationships were estimated from VEX/VIRTIS observations.

1. Beyond the cold collar region can be interpreted as the optically thicker regions.
2. The structure of the Venusian polar vortex seen from thermal radiation is affected by the cloud top altitude
3. The CO enhancement in the cold collar can be interpreted the down-welling region of Hadley-Circulation

*We calculated the movements of the cloud particles in the atmosphere using VGCM and derived the latitudinal cloud top altitude and temperature. Then, we tried to compare the results with those evaluated fromVEX/VIRTIS observations.

The latitudinal characteristics of cloud top altitude and temperaturecalculated from GCM simulations are consistent with those investigated from our VIRTIS analysis.

*Why dose Venusian polar vortex have a hot dipole feature surrounded by a cold collar?

The structure of Venusian polar vortex (hot dipole and cold collar) are created from decreasing of cloud top around the polar region due to the Hadley - Circulation.

Future Suggestions

Data analysis

Venus Express → Akatsuki

1. Cloud opacity
   IR2 2.26μm night
2. Cloud top temperature
   LIR 10μm day & night
3. Cloud top altitude
   IR2 2.02μm day
4. Vertical temperature profile
   Radio Science
5. Carbon monoxide below cloud
   IR2 2.32μm night

Simulation

To add the production and decomposition process of H_2SO_4 cloud particles in our GCM.

Photochemical production

$3SO_2 + 2H_2O \rightarrow S + 2H_2SO_4$
or
$CO_2 + SO_2 + H_2O \rightarrow CO + H_2SO_4$

Thermal decomposition

$H_2SO_4 \rightarrow H_2O + SO_2 + O$

Ground-based observations

1. Mid-Infrared LAser Heterodyne Instrument (MIRAHI)
Night-side vertical temperature profiles (altitude from 65 to 100km) by observations of pressure broadened CO2 absorption features around 10μm + Detection of SO2 over the cloud top.

2. Near-Infrared high-resolution echelle spectrometer
Detection of Atmospheric minor components (CO and OCS) for understanding of Venusian atmospheric circulations + Investigation of local-time variability of cloud top altitude.