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Doppler wind measurements of Venus upper atmosphere: Comparisons with updated GCM experiments

Hideo Sagawa (1,*), Gabriella Gilli (2), Masahiro Takagi (1) and Hiroki Ando (1)
(1) Kyoto Sangyo University, Kyoto, Japan, (2) Instituto de Astrofisica e Ciências do Espaço (IA), Lisbon, Portugal
*email: sagawa@cc.kyoto-su.ac.jp

Abstract

We compared the Doppler-wind maps, obtained from observations of CO in the Venus mesosphere around 95–110 km, with updated numerical experiments of a ground-to-thermosphere Venus General Circulation Model (GCM). We simulated a Doppler-wind map from the GCM temperature, pressure, CO abundance, and wind profiles. Such atmospheric state above 90 km is very sensitive to the parameterization of non-orographic gravity waves (GW) implemented into the GCM. The most favorable GW parameters to explain the past observations are investigated.

1. Introduction

Atmospheric dynamics of Venus' middle/upper atmosphere (~70–120 km in altitude) still remains as a puzzle. It is considered as a transition region between the super-rotating tropospheric circulation and the day-to-night (or, subsolar-to-antisolar) diurnal wind system in the thermosphere. Several observations have challenged to understand the dynamics of this mesospheric altitude. The most widely employed approach is the heterodyne spectroscopy of Doppler-shift in carbon monoxide (CO) absorption lines at millimeter and sub-millimeter wavelengths. The derived Doppler-shift tells us wind velocity projected along the observational line-of-sight, a.k.a. "Doppler-wind" at ~95–110 km. The results of past observations can be found in [e.g., 1–3]. The earlier attempt to interpret those observations was to consider a global circulation as a linear combination of two wind regimes: a super-rotating retrograde zonal flow (hereafter, RZ) and a subsolar-to-antisolar flow (SSAS). However, not a few results of the observed Doppler-wind, particularly those of spatially-resolved maps from interferometer observations, cannot be satisfactory explained by such a simple combination of RZ and SSAS [e.g., 4], and the role of specific processes (e.g., GW propagation, thermal tides, large scale planetary waves) in the observed Doppler-wind variation is still under investigation.

A new interpretation was proposed by [5, 6] after the development of a new Venus upper atmospheric general circulation model (GCM). One of the key achievements of their GCM is the inclusion of vertical propagation of GWs. The line-of-sight wind obtained by their GCM showed a qualitative representation of the observed result of [4]. Recently, [7] included a non-orographicg GW parameterization in an improved and vertical extended version (0–150 km) of the Venus GCM developed at the Laboratoire de Meteorologie Dynamique (LMD). They succeeded in obtaining an overall agreement with the thermospheric temperature profiles measured by Venus Express and some ground-based instruments.

In this study, we revisit previous observations of the Doppler-wind maps covering several local times of Venus, and compare them with numerical experiments from recently developed GCMs.

2. Observations and GCM data

Table 1 summarizes the observational data used in this study. The note "m" and "e" after the dayside illuminated fraction represents whether the morning or evening terminator was visible from the Earth. The spatial resolution means the major and minor axis of an elliptic synthesis beam of the interferometer.

Table 1: Doppler-wind maps revisited in this study.

	Apparent diameter [″]	Dayside fraction	Spatial resolution [″]	Observatory*
#1	22.0	0.53 m	4.1 × 4.1	(1)
#2	18.7	0.62 m	5.5 × 5.2	(2)
#3	21.9	0.53 e	5.0 × 4.4	(2)
#4	24.2	0.50 e	4.9 × 4.5	(2)
#5	29.2	0.42 e	5.4 × 2.3	(2)
#6	40.3	0.27 e	5.3 × 3.0	(2)
#7	54.8	0.07 e	5.5 × 4.1	(3)

*(1) Plateau de Bure Interferometer (PdBI), (2) Nobeyama Millimeter Array (NMA), (3) Combined Array for Research in Millimeter-wave Astronomy (CARMA)

The Doppler-wind maps listed above are all derived from the CO (1–0) observation which sounds around 95 km altitude — however, one must keep in mind that this number is just a rough estimate. In practice, the derived Doppler-wind map does not correspond to a certain single altitude, but information from a finite vertical range (for example, ~10 km width around 95 km altitude) is convolved into the result. And also, the vertical range of the sensitivity can vary with the actual temperature and CO abundance profiles.

Outputs from the numerical experiment are prepared with a GCM described in [7]. Detail description for the GCM settings is omitted here due to the page limitation, but the key tunable parameters in those simulations are basic wave characteristics (e.g. horizontal wavelength, phase speed) used in the GCM non-orographic GW parameterization. The source of GW is chosen uniform and fixed at roughly 55 km, near the top of the convective layer. In this study we selected three test runs with different conditions in terms of horizontal wavelength and phase speed of GW (Table 2).

Table 2: Parameters for the GW in the GCM.

	Horizontal wavelength [km]	Phase speed [m/s]
#1	300 – 6000	1 – 111
#2	50 – 1000	1 – 61
#3	50 – 600	1 – 61

3. Comparison

For comparison, we adopt an "*observation simulation and simulating data analysis*" concept instead of deriving contribution factors of RZ and SSAS from the observed Doppler-wind map. Using the temperature, pressure, CO abundance, and horizontal wind velocity profiles from the GCM data as input, we simulate CO interferometric observations with a radiative transfer model considering an appropriate observation geometry (latitude, longitude, local times of each location inside the apparent Venus disk) and instrumental response functions. The simulated (GCM-based) CO spectra are analyzed with the same procedure applied to the real measurements data analysis. Then we get a GCM-based Doppler-wind map, and compare it with the one derived from the real measurement. This approach provides a robust comparison between the observations and GCMs without introducing any assumption regarding to the sensitive altitude range. Figure 1 shows an example about the effectiveness of this approach.

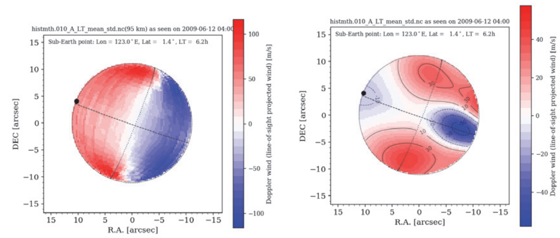

Figure 1: Example of GCM-based Doppler-wind map. Left figure shows the GCM-based Doppler-wind map using the horizontal wind velocity at a single altitude level, 95 km. Right figure is the same GCM-based Doppler-wind map but an output of our comparison procedure i.e. observation simulation. The appearance of the two maps is significantly different.

An example of the comparison is shown in Figure 2. This case shows a good agreement between the observation and GCM. The complete results of the comparisons will be reported in the presentation, and we will discuss the favorable GW parameters to generally explain the observation dataset.

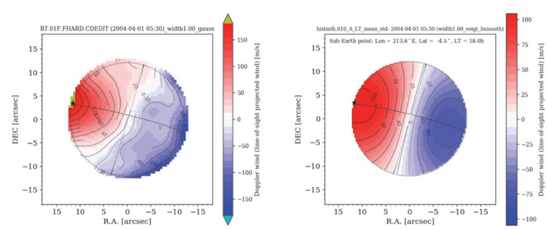

Figure 2: Comparison of the Doppler-wind maps from the actual observation (left) and the GCM-based simulation (right). Observation #4 and GCM data #1 are used.

References

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