RECENT VARIATIONS IN THE VENUS ATMOSPHERIC TEMPERATURE DETECTED BY METEOROLOGICAL SATELLITES.

G. Nishiyama[1,2,3], Y. Suzuki[4], S. Uno[5], S. Aoki[2], T. Iwanaka[2], T. Imamura[2], Y. Fujii[3], T. G. Müller[6], M. Taguchi[7], T. Kouyama[8], O. Barraud[1], M. D'Amore[1], J. Helbert[1], [1]Institute for Planetary Research, DLR, Germany, (gaku.nishiyama@dlr.de), [2]The University of Tokyo, [3]National Astronomical Observatory of Japan, [4]Japan Aerospace Exploration Agency (JAXA), [5]RIKEN Center for Advanced Photonics, [6]Max-Planck-Institut für extraterrestrische Physik, [7]Rikkyo University, [8]National Institute of Advanced Industrial Science and Technology

Introduction: For understanding the Venusian atmosphere, thermal tides and planetary-scale waves have been considered important phenomena as sources of momentum transport [e.g., 1, 2]. Spatial and altitudinal patterns of both phenomena have been expected to be highly sensitive to various factors like static stability [e.g., 3]. Therefore, monitoring cloud-top temperature at various mid-infrared wavelengths of Venus provides hints to elucidate its atmospheric dynamics.

In the last decade, only two planetary missions, Akatsuki and BepiColombo, have conducted spaceborne observations of Venus's cloud-top temperature [4, 5]. However, Akatsuki has a single-band camera at the mid-infrared wavelengths and cannot retrieve temperature at various altitudes. In addition, BepiColombo observed Venus only at its flyby, and the observed area is limited because of its close distance to Venus. Therefore, multiband observation of Venus at mid-infrared wavelengths is still missing.

Meteorological satellites might be able to complement such a lack of mid-infrared Venus data. When the meteorological satellite observes the whole Earth, its observation extends to space adjacent to the Earth's rim, where several solar-system bodies, such as the Moon and Venus, are sometimes captured simultaneously (Figure 1) [6]. Some meteorological satellites are equipped with multiband infrared cameras. For example, Japanese meteorological satellites Himawari 8 and 9 have nine bands within 6 – 14 µm. Therefore, their Venus images are potentially able to provide a new spaceborne dataset to study its atmospheric dynamics.

In this study, Venus observations by the Himawari series are first archived as a new dataset for Venus science. Then, utilizing the archived multiband data, we demonstrate the temporal variations in thermal tide and Rossby-wave structures observed over the last decade.

Data: To archive the Venus temperature data, we analyze the Himawari Standard Data (HSD), which has been published by the Japan Meteorological Agency since 2015. The infrared HSD has been calibrated at the beginning of every observation with an internal calibrator. From all the HSDs taken by the end of 2024, we identified 420 occurrences in which Himawari satellites captured images of Venus. Because the Venus diameter in the image ranges from 0.85 to 5.1 pixels, the disk-integrated radiance was calculated after subtracting the background level. These observations are composed of 24 periods, in each of which Venus was captured with intervals of one day or more. Because Himawari can conduct imagery as long as the sun is behind the Earth, our data archive covers phase angles between 3 and 174 degrees. The observation error is less than 2 K and decreases with increasing apparent size of Venus. When Venus is larger than 3 pixels, the error becomes as low as 0.5 K and enables tracking 1-K variation in the Venus temperature field.

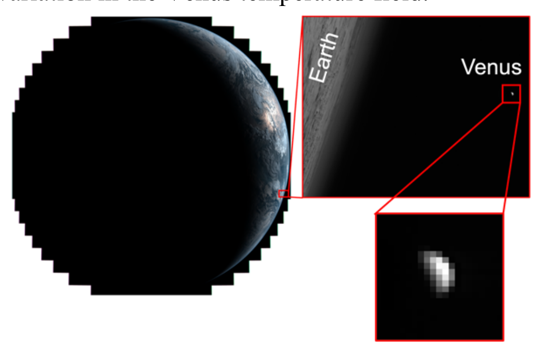

Figure 1. An example of Venus observation by Himawari 8 (2018/08/11 18:00 in UTC)

Results: Figure 2 shows all the observations by the Himawari series. Year-scale variations were observed at every band. Within each period, day-scale variation has also been captured. These variations are larger than the observation error and contain variations in thermal tide and Rossby-wave structures.

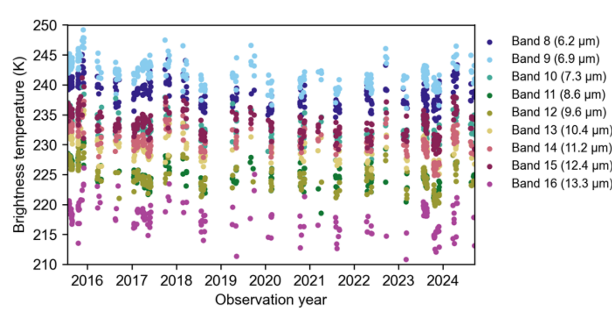

Figure 2. All the Himawari observations of Venus brightness temperature at each mid-infrared band.

Variation in thermal tide structure. The year-scale variation seen in Figure 2 is mainly composed of diurnal and semi-diurnal structures of thermal tide. Figure 3 shows the dependency of the observed brightness temperature on the local time. The cloud-top temperature shows a pattern similar to the previous Akatsuki observations [e.g., 7]. For example, the local maximum and minimum exist at local times of 16 and 21 h, respectively.

Temporal variation at the same local time is also present in Figure 3. For instance, observation in 2015 shows a local maximum at 6 h in local time, although data in 2024 rather exhibits a local minimum. The difference between these two epochs cannot be attributed to the observation error. This variation is perhaps attributable to a decrease in the amplitude of diurnal tide because the diurnal tide has the lowest temperature in the morning side [7]. Similar changes in the temperature pattern are observed at all the mid-infrared bands that are sensitive to altitudes between 64 to 71 km.

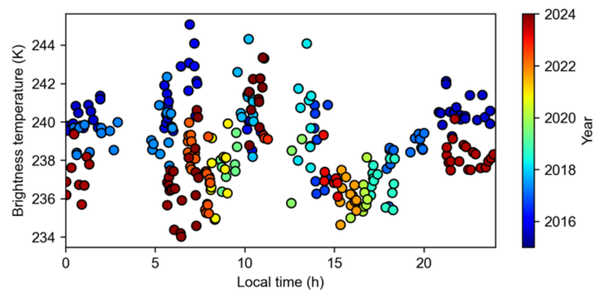

Figure 3. Observed brightness temperature at band 8 as a function of the local time and observation year.

Altitudinal dependence of Rossby waves. Particularly in two periods (2023/07/23–08/22 and 2015/07/21–08/29), the apparent Venus size is large enough to track day-scale temperature variations. For instance, each band shows a 1-K scale variation at each period (Figure 4-a). The observed variations show positive correlations among mid-infrared bands except for bands 11, 12, and 16. These bands are sensitive to altitudes higher than 68 km while sensing altitudes of the other bands range from 64 to 67 km.

To unravel the periodicity, we applied the Lomb-Scargle periodogram to the two measurement periods (Figure 4-b). The application result clearly shows existence of a 5-day period wave, corresponding to the planetary-scale Rossby wave. In addition, the amplitude of the 5-day period wave decreases with altitude and is not dominant at bands 11, 12, and 16. This tendency was found for both the two periods; however, the amplitude of the 5-day wave is smaller at 2015/07/21–08/29 than 2023/07/23–08/22.

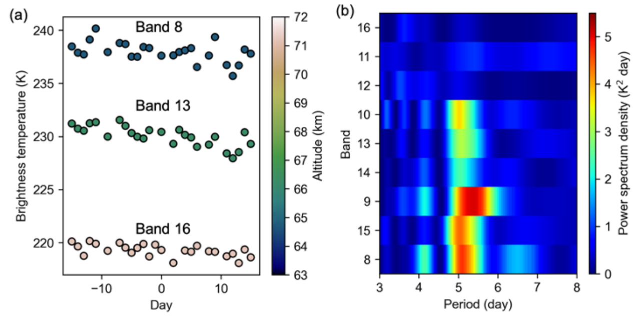

Figure 4. Rossby-wave observation result during 2023/07/23–08/22. (a) The original observation data. (b) Lomb-Scargle periodogram applied to (a). The band number in the y-axis is ordered by sensing altitude.

Discussion: The observed temporal variation in thermal tide and Rossby-wave structure may be attributed to various factors. Within the archived timeframe, the Akatsuki mission has observed albedo and wind speed variations[e.g., 8, 9], both of which could cause changes in thermal tide and planetary-scale waves. The Himawari observations also suggest a change in stability structure between 2015 and 2024. For example, the midnight temperature in 2024 is lower than that in 2015 (Figure 3); however, an opposite variation was detected at band 16, which contains the highest altitude information among the Himawari bands. Because the Himawari series will be operated until 2029, there still exist chances to track both year- and day-scale temperature variations. Future observations would provide more data to help understand these atmospheric dynamics, particularly in terms of thermal tides and planetary-scale waves.

Acknowledgments: This work was supported by JSPS KAKENHI Grant Number JP22K21344 and JSPS Overseas Research Fellowship.

References: [1] Fels S. B. and Lindzen R. S. (1974) Geophysical and Astrophysical Fluid Dynamics, 6, 149-191. [2] Del Genio A. D. and Rossow W. B. (1990) Journal of the Atmospheric Sciences, 47, 1, 293–318. [3] Suzuki A. et al. (2022) JGR: Planets, 127, e2022JE007243. [4] Nakamura M. et al. (2016) Earth, Planets and Space, 68, 75. [5] Helbert J. et al. (2023) Nature Communications, 14, 1, 8225. [6] Nishiyama G. et al. (2022) Earth, Planets and Space, 74, 105. [7] Kouyama T. et al. (2019) Geophysical Research Letters, 46, 16, 9457-9465. [8] Lee Y. et al. (2019) The Astronomical Journal, 158, 3, 126. [9] Horinouchi T. et al. (2018) Earth, Planets and Space, 70, 10.