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Intense decadal variations of Venus' UV albedo, and its impact on solar heating rate and atmospheric dynamics

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Abstract

We report the first quantitative study on the variability of Venus' cloud albedo at 365 nm using data acquired by four independent space-based instruments. We show a factor of 2 albedo variation had been occurred in the past decade. This is sufficient amount to alter solar heating rate at the cloud top level, which consequently can affect atmospheric dynamics, i.e., zonal winds near the cloud top level.

1. Introduction

An unidentified absorber in the Venusian clouds creates broad absorption spectrum in the UV-to-visible wavelength range that peaks around 340–380 nm around the cloud top level, 70 km above the surface. This unknown absorber is known to absorb about half of the solar energy deposited in the atmosphere according to model calculations [1]. As a result, this absorber plays a critical role in the atmospheric energy balance. Therefore, monitoring its temporal variation is crucial to understand radiative energy balance of the planet.

2. 365-nm albedo observations

We analyse 365-nm images acquired by the Venus Monitoring Camera (VMC) on board Venus Express (2006–2014) and the UV imager (UVI) on board Akatsuki (2011 and December 2015–May 2017) [2], and UV spectral data by MASCS on board MESSENGER (June 2007) [3] and STIS on board Hubble Space Telescope (January 2011) [4]. These results show that

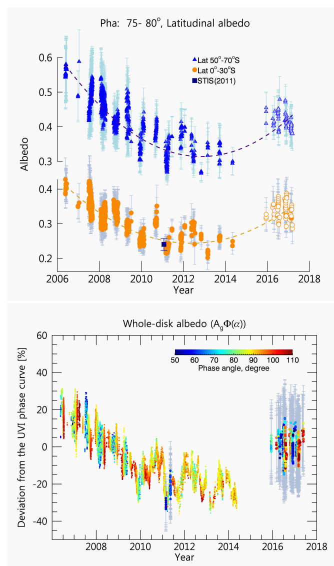

Figure 1: 365-nm albedo observations taken from VMC (2006–2014), UVI (2011 and 2015 Dec.–2017), and STIS (2011). MASCS' data is not shown. (Top) Mean values at low latitudes (0–30S) and high latitudes (50S–70S) at the 75–80° phase angle. Standard deviations are shown with errorbars. (Bottom) Relative variations of whole-disk albedo from VMC (2006–2014) and UVI (2011 and 2015–2017). The uncertainties of VMC's start calibration is omitted in the figure (82%), while that of UVI, 18%, is shown with errorbars.

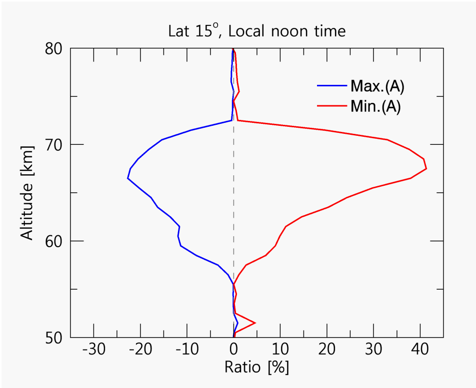

Figure 2: Estimated solar heating rate variations during the past decade at low latitudes (15°) compared to the mean albedo condition. This calculation assumes that the abundance variations of the unknown absorber in the cloud top level is responsible on the observed 365-nm albedo changes.

the 365-nm albedo has been varied by a factor of 2 from 2006 to 2017 at all of high and low latitudes (Fig. 1). The same trend is retrieved from the whole-disk (disk-integrated) albedo that includes UVI's 2011 data (Fig. 1).

3. Solar heating rate variations

We take into account this observed range of 365-nm albedo variations in our radiative transfer calculations, fitting the observed albedo by multiplying factors to the mode-1's assumed absorption coefficient for the unknown absorber in the spectral range of 310–780 nm [1]. The results show that the observed albedo variance can produce a $-25\sim40\%$ variance in solar heating rate at low latitude local noon time. This means that the cloud top level atmosphere should have experienced considerable solar heating variations over the decade.

4. Impacts on atmospheric dynamics

This variable solar heating rate would drive dynamical changes at the same altitudes. Simulations in a Venus global circulation model (IPSL-VGCM, [5]) shows that considerable zonal wind speed variations can be caused by the above calculated solar heating rate changes. The simulated wind speed range is comparable to the observed Venus' zonal wind variations from 2006 to 2017 [6, 7].

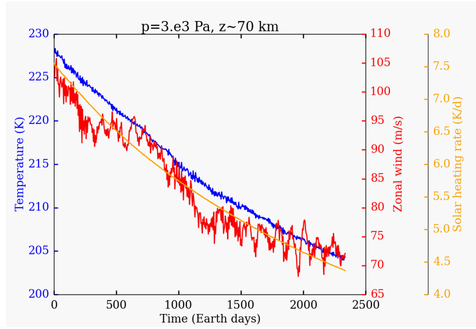

Figure 3: Relationships of solar heating rate, temperature, and zonal wind speed at low latitudes at the cloud top level from VGCM calculations. 40% of solar heating is slowly changed over ~6 Earth years, mimicking the scale of solar heating rate variations inferred from this study.

5. Summary and Conclusions

We find intense decadal variations in the 365-nm albedo of Venus between 2006 and 2017. This should involve significant solar heating rate variances, which can affect atmospheric dynamics. This provides the evidence of current climate change on Venus, and future observations are required to verify reasons of UV albedo changes.

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