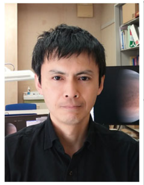
【Grant-in-Aid for Scientific Research (S)】

Circulation of Venus atmosphere from the surface to the upper atmosphere driven by waves and convection



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Purpose and Background of the Research

●Outline of the Research

Research in Venus meteorology has made significant progress in recent years. Particularly, understanding of planetary-scale waves and the high-speed zonal winds has advanced. However, the structure of material transport from the surface to the homopause determining climate remains poorly understood. In this study, we leverage new observational information obtained through our research to advance the refinement of numerical models including radiation and material transport. Building upon these advancements, we introduce new methodologies for the data assimilation of the Venusian atmosphere, enabling various new research initiatives. Consequently, we scrutinize dynamical processes such as atmospheric waves and convection driving meridional circulation, elucidating the structure of meridional circulation from the surface to the homopause. The aim is to unravel chemical material transport governing sulfuric acid clouds, upward transport leading to the homopause involved in water loss, and the long-term variations in Venusian climate the material/energy transport might induce. The numerical data generated in this study enhance Akatsuki's Venus meteorological dataset, serving as a foundation for planetary meteorology.

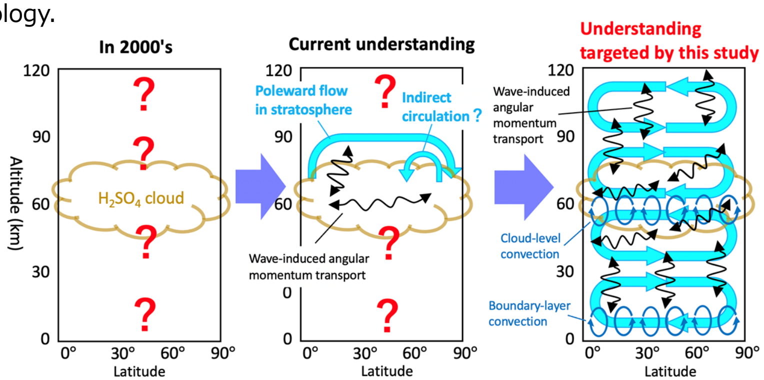

Figure 1. Conceptual diagram for the improvement of our understanding on the meridional circulation of the Venusian atmosphere.

●Fundamental Scientific Questions

We raise the following three questions that should be solved with new methodologies:

(1) What structure does the meridional circulation on Venus have, and how is it driven?
(2) How does the vertical material transport occur on Venus, and how is it involved in climate formation?
(3) How do long-term variations in the Venusian atmosphere arise, and how do they affect material circulation?

●Uniqueness of Research Methodology

A variety of observational data and novel data assimilation techniques are combined. The new observational data includes continuous observations spanning 10 Venusian years. This dataset encompasses global wind fields including the night side, information on mountain waves, spatiotemporal changes in chemical substances, and thermospheric dynamics and chemistry. As novel approaches in data assimilation, we will directly assimilate observable quantities, automatically update model parameters, and improve parameterization schemes.

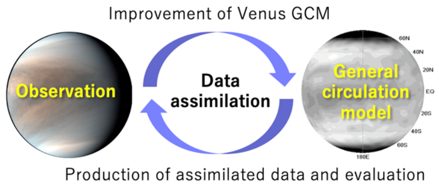

Figure 2. Recursive improvement of the numerical model and the assimilated data.

Expected Research Achievements

●Structure of Meridional Circulation and Driving Mechanism

Unraveling the structure of meridional circulation from the surface to the homopause and the transport of angular momentum and heat that drive the circulation. Especially, we aim to clarify the routes and velocities of vertical transport at various altitude levels. The altitude of the homopause, where the vertical transport process transitions from fluid motion to molecular diffusion, is determined. Wave disturbances driving these circulations are decomposed into spatial/temporal frequency components, and their excitation, propagation, and attenuation processes are inferred. Understanding how waves accelerate/decelerate the mean flow, maintaining super-rotation and meridional circulation simultaneously, constitutes a key aspect of this research.

●Material Transport and Climate Formation

The chemical reactions of trace gases are introduced into the assimilated 4-D dynamical field. By doing so, we aim to identify pathways through which key substances are transported from the lower atmosphere, across cloud layers, to the photochemical region, and to understand how their fluxes are regulated. Then, the temporal and spatial variations of SO_2 obtained from ultraviolet images are correlated with meridional circulation, convective transport, and contributions from large-scale waves. By examining changes in sulfate production rates corresponding to variations in the upward transport, we seek to elucidate how cloud amounts are controlled by atmospheric dynamics. Furthermore, the upward transport of water to the homopause is evaluated, considering both gaseous and liquid phases. By elucidating dehydration processes due to cloud formation and photochemistry, we aim to understand how the water vapor mixing ratio at the homopause, which determines the rate of water loss due to atmospheric escape, is determined. These findings will be compared with trace gas observations from the ground.

●Elucidation of Long-Term Variations and Climate Stability

We aim to understand the multi-year scale variations discovered through the long-term observations by Akatsuki. By examining the long-term changes in the angular momentum balance driven by meridional circulation and waves, the thermal energy balance determined by solar heating and infrared radiative cooling, and heat transport by circulation, we aim to estimate the forces driving changes in the mean state and validate the model diagnostics by comparing with observed variations.

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