EPSC Abstracts
Vol. 11, EPSC2017-121, 2017
European Planetary Science Congress 2017

Data assimilation system for the Venusian atmosphere

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Abstract

A data assimilation system based on the local ensemble transform Kalman filter (LETKF) for a Venusian general circulation model (VAFES) has been developed. Two sets of data are assimilated separately to VAFES forecasts forced with the solar heating excluding the diurnal component (Qz); one is created from a VAFES run forced with the solar heating including the diurnal component (Qt) and the other is based on the observations of Venus Monitoring Camera (VMC) onboard Venus Express. Our system reduces errors between analysis and forecast quickly, and successfully reproduces the thermal tide excited by the diurnal component of the solar heating.

1. Introduction

The data assimilation is an effective tool widely used in the planetary atmospheric science. Since observation data are irregularly sampled in space and time, global and continuous analysis fields produced by general circulation models (GCMs) with the data assimilation, which are dynamically and thermodynamically consistent, are quite useful to study atmospheric dynamics.

For the Venusian atmosphere, however, the data assimilation has not been attempted so far. Recently, we developed a Venusian Atmospheric GCM named VAFES on the basis of Atmospheric GCM For the Earth Simulator (AFES) [1], which enables us to reproduce the realistic structure of the Venusian atmosphere. Using VAFES, we have succeeded in investigating barotropic/baroclinic instability waves [2, 3] and elucidating a puzzling temperature structure called “cold collar” [4]. In the present study, we develop a new data assimilation system for the Venus atmosphere based on VAFES and the local ensemble transform Kalman filter (LETKF) [5, 6], which is one of the most powerful schemes, and test it with idealized and observational data.

2. VAFES-LETKF system

VAFES is a full nonlinear Venus GCM with simplified physical processes [2-4]. The resolution is set to T42L60 (128 times 64 horizontal grids and 60 vertical levels). The vertical domain extends from the flat ground to ~120 km. In the upper atmosphere above 80 km, a sponge layer is assumed only for eddy components. The model includes vertical and horizontal eddy diffusion. Convective adjustment is applied to eliminate static instability. The infrared radiative process is simplified by a Newtonian cooling and the temperature is relaxed to a prescribed horizontally uniform temperature based on VIRA.

Vertical and horizontal distributions of the solar heating are based on previous observations and decomposed into a zonal mean component and a deviation from the zonal mean (diurnal component), which excite the mean meridional (Hadley) circulation and the thermal tide, respectively. Two cases of run are prepared as follows: Case Qt includes both components, whereas Case Qz the zonal mean component only. Other details of the model settings are described in our previous works [2-4].

The initial state is assumed to be an idealized superrotating flow in solid-body rotation. The zonal wind increases linearly with height from the ground to 70 km. The temperature distribution is in gradient wind balance with the zonal wind. Using this initial state, we perform nonlinear numerical simulations for more than 4 Earth years both for Cases Qt and Qz. The model atmospheres reached quasi-steady states within approximately an Earth year. Quasi-equilibrium data sampled at 1-hour intervals in Case Qt are used for the idealized observations, and those at 8-hour intervals in Case Qz are for initial conditions of each member of the ensemble.

In data assimilation schemes, an improved estimate (called analysis) is derived by combining observations and short time forecasts. The LETKF [5, 6] seeks the analysis solution with minimum error variance. Using an ensemble of VAFES runs, uncertainty of the model forecast is characterized. In the present VAFES-LETKF data assimilation system, 31-member ensemble and 10% multiplicative spread inflation are employed. The localization parameters are chosen to be 400 km in horizontal and lnP = 0.4 in vertical where P is pressure. Observation errors for horizontal winds are fixed to be 4.0 m s^{-1}. A minimal interval of the data assimilation cycle is 6 hours.

We prepare several idealized observations of horizontal winds at 70 km (the cloud top level) with different intervals from Case Qt of the VAFES run. The other observation data is based on the UV images taken by the VMC (Case Vmc) [7], which includes the horizontal winds at ~70 km in a narrow dayside region. Time-intervals of the VMC horizontal wind data are approximately an Earth day. All the observations capture the thermal tide component, although the VAFES forecasts to be assimilated do not. Therefore, if the VAFES-LETKF system works, it is expected that the thermal tide is reproduced in the data assimilation with both the two observation sets.

3. Results

The VAFES-LETKF data assimilation system quickly reduces the analysis and subsequent forecast root-mean-square error. Furthermore, though the observation data are given at 70 km only, the three-dimensional structure associated with the thermal tide appears clearly even in Case Vmc, suggesting its upward propagation above 70 km (Fig.1).

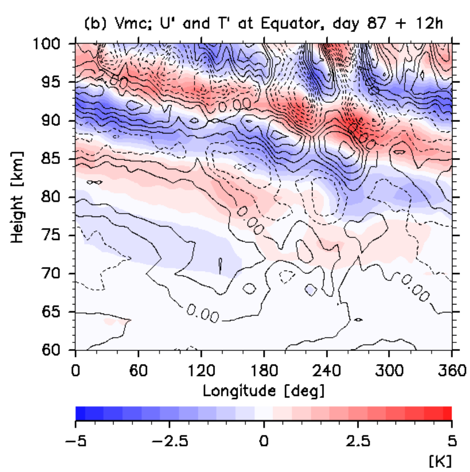

Figure 1: Vertical distributions of temperature deviation from zonally averaged temperature (color shades) for Case Vmc. Slowly varying components (thermal tide) are extracted by a low-pass filter with a cut-off period longer than 4 Earth days.

4. Summary and Conclusions

In the present work, we developed the VAFES-LETKF data assimilation system applicable to the Venus atmosphere and confirmed it works. In the presentation, we will show the impact of the data assimilation associated with the thermal tide on the general circulation. It is strongly expected that the Akatsuki data with the VAFES-LETKF data assimilation system enable us to reproduce more reliable structures of the Venus atmosphere.

Acknowledgements

This study was conducted under the joint research project of the Earth Simulator Center entitled ‘Simulations of Atmospheric General Circulations of Earth-like Planets by AFES.’ VAFES-LETKF data assimilation system integrations were performed on the Earth Simulator with the support of JAMSTEC.

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