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Ensemble Forecast Sensitivity to Observations (EFSO) of the Venus data assimilation system

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Abstract

Last year, we developed the data assimilation system based on the local ensemble transform Kalman filter (LETKF) for a Venusian general circulation model (VAFES) [1]. This system reduces errors between analysis and forecast quickly, and successfully reproduced the thermal tide excited by the diurnal component of the solar heating. Recently, Ensemble Forecast Sensitivity to Observations (EFSO) technique has been implemented to quantify impact of each observation. The system would be useful for datasets from the Venus Climate Orbiter 'Akatsuki'.

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 are quite useful to study atmospheric dynamics because the produced data are dynamically consistent.

However, the data assimilation has not been attempted for the Venusian atmosphere so far. In recent years, we have developed a Venusian Atmospheric GCM [2] named AFES-Venus (VAFES) on the basis of Atmospheric GCM For the Earth Simulator (AFES) [3]. Using VAFES, we have succeeded in reproducing the realistic structure of the Venusian atmosphere, such as planetary scale waves [4], cold collar [5], polar vortex [6], and thermal tide [7]. Comparison between the VAFES simulations and Akatsuki observations suggests that VAFES could be used for the data assimilation at this moment. Therefore, we developed a new data assimilation system for the Venusian atmosphere, named VALEDAS (Venus AFES LETKF Data Assimilation System) [1], based on AFES-Venus and the local ensemble transform Kalman filter (LETKF) [8] which is one of the most powerful and efficient schemes for the data assimilation. In the present study, we have implemented Ensemble Forecast Sensitivity to Observations (EFSO) technique to quantify how much each observation would improve the VAFES forecasts, and conducted several test cases using idealized and real observation data.

2. VAFES-LETKF system

VAFES is a full nonlinear Venus GCM with simplified physical processes [2]. 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. The infrared radiative process is simplified by a Newtonian cooling scheme and the temperature is relaxed to a prescribed horizontally uniform temperature field 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. 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. We perform numerical time integrations for more than 4 Earth years. The model atmospheres reached quasi-steady states within approximately an Earth year. Quasi-equilibrium data sampled at 1-hour intervals are used for the *idealized observations*, and those at 8-hour intervals 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 [8] seeks the analysis solution with minimum error variance. Using an ensemble of VAFES runs, uncertainty of the model forecast is characterized. Details of the VALEDAS are described in [1].

EFSO can estimate impacts of assimilated observations using the 12-hour forecasts with the ensemble-based method [9]. Such estimations are usually made by data-denial experiments or Observing System Experiments (OSEs), but these experiments with various observation datasets are computationally very expensive. EFSO is simpler, more computationally efficient, and gives similarly accurate results without using the adjoint model. Here, several idealized observations at the cloud top level with different intervals of the VAFES run are used to test EFSO.

3. Results

The VALEDAS quickly reduces the analysis and subsequent forecast root-mean-square (RMS) error. Furthermore, though the observation data are given at 70 km only, the three-dimensional structure associated with the thermal tide appears clearly.

Figure 1 shows time series of EFSO value and total energy (TE) that has been improved by all observations. A correlation coefficient of ~86.9% clearly indicates that the EFSO value successfully estimates impact of observations.

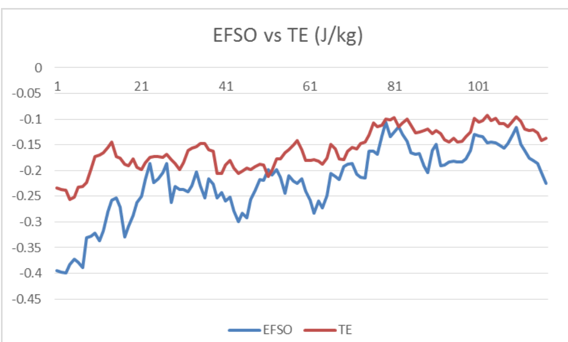

Figure 1: Time series of EFSO value and total energy (TE) that has been improved by all observations.

4. Summary and Conclusions

The VAFES-LETKF data assimilation system (VALEDAS) applicable to the Venus atmosphere has been developed and Ensemble Forecast Sensitivity to Observations (EFSO) technique was newly implemented to quantify impact of each observation. The VALEDAS with EFSO would enable us to reproduce more reliable structures of the Venus atmosphere by using Akatsuki observations.

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