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Cloud-top temporal variation of Saturn's 2011-2012 stratospheric vortex by means of Cassini/VIMS-V data analysis

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Abstract

In this work, selected regions of the giant vortex observed at Saturn since January 2011, have been investigated by analyzing the observations from the visual channel of the *Visual and Infrared Mapping Spectrometer* (VIMS-V) on board the Cassini spacecraft. Previously, a forward radiative transfer model has been developed, based on the *LibRadtran* code [13], adapted to the atmosphere of Saturn. Then an inverse code, based on the optimal estimation technique [14], has been implemented to retrieve the microphysical and geometrical properties of the clouds. Best fits of the radiance spectra relative to the vortex are produced and then the cloud top pressures are estimated. Data retrieved on a time lapse of months allow to investigate the temporal variation of the vortex's cloud properties.

1. Introduction

Saturn's 2011-2012 vortex is a giant anticyclone that has formed in the planet's North hemisphere, following the huge storm that started on December 2010 [6,8,16]; though the storm has been weakening since July 2011 the vortex persisted, even if its shape and dimensions have been changing ever since [9].

Thanks to Cassini (the probe is orbiting Saturn since 2004), several data relative to the vortex in its different evolution stages have been recorded. In particular VIMS observed the vortex several times between January 2011 and January 2012.

VIMS is a multi-channel hyperspectral imaging spectrometer, consisting of an IR-channel ranging from 0.85 to 5.1 μm and a VIS-channel operating in the wavelength range 0.3 – 1.05 μm. The VIS-channel, whose data are being used in this analysis, has a nominal spectral resolution of 7.3 nm and a nominal angular resolution of 500 μrad [4].

The available data allow to track the evolution of the vortex over a one year time lapse, permitting to document temporal variations of the clouds vertical distribution above the anticyclone.

2. Analysis

The best fits for the spectra relative to the vortex are obtained by means of a least square analysis, that aims to minimize the differences between the observed VIMS-V spectra and the simulations. The forward model relies on the following assumptions: plane parallel atmosphere, multiple scattering discrete ordinate solver DISORT [17], Mie theory to compute single scattering properties of clouds and haze components, molecular scattering adapted to Saturn's atmosphere. In the visual range Saturn's atmospheric radiative transfer is influenced by H_2 [5], He [5], CH_4 [7,11] and H_2O [7,15]. The first two gases are responsible for the Collision Induced Absorption (CIA) by the H_2-H_2 [1] and H_2-He [2,3] interactions. Three cloud layers are assumed: the uppermost in the stratosphere and the middle one in the high troposphere, are made of a "grey" component with real part of the refractive index fixed at 1.4 (very similar to the one of ammonia ice) and the complex part having a value of 0.015 at 300 nm and scaled with a power law for the other wavelengths [10]. The third layer deeper in the troposphere is a thick NH_3 ice cloud [12].

This forward model is then inserted in the inverse code, that takes advantage of the Gauss Newton method to minimize the cost function, so that at each iteration step the solution is given by:

$$\mathbf{x_{i+1}} = \mathbf{x_i} + \left(\mathbf{K^T O^{-1} K} + \mathbf{B^{-1}}\right)^{-1}\{\mathbf{K^T O^{-1}}[\mathbf{y} - \mathbf{H}(\mathbf{x_i})] - \mathbf{B^{-1}}(\mathbf{x_i} - \mathbf{x_b})\} \quad (1)$$

where x_i is the state vector containing the solutions for the free parameters at iteration i; x_b is the state vector containing the background values for the free parameters; y is the observation vector; $H(x_i)$ is the simulated observation obtained with the forward model, initialized with the state vector at the iteration step i; B is the background error covariance matrix; O is the observation error covariance matrix; K is the Jacobian matrix, containing the derivatives of the simulated radiance with respect to the perturbation of

each free parameter. In this analysis the Jacobian has been computed numerically by finite differences.
The free parameters that are being inverted are: cloud effective radius r_e, number density profile scaling factor f, and cloud top pressure p_t. The effective sigma values σ_e of the assumed lognormal distributions for the dimensions of the particles, have been fixed at 0.2 μm [10]. By taking the best fit top pressures of the considered decks it is possible to map the structure of the vortex and track its evolution.

3. Discussion and work in progress

The inverse model here adopted has a very high potential. However, the Jacobian has to be calculated numerically, not being available an analytical solution. Thus particular care must be taken when using the finite difference method, either in the step used to perturb the parameters and in the choice of the coordinate in the parameter space at which the derivative is being calculated. The right choices can heavily cut down the required number of iterations to reach convergence and therefore, most of the work is done to study which coordinate and step have to be used. This is required when the Jacobian is calculated once, and then not updated at each iteration, to save computational time.
Another approach, actually under investigation, is to update the Jacobian at each iteration, to possibly remove the coordinate problem. Tests are in progress to check if this technique can improve the accuracy of the results and reduce the number of iterations.

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