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Sulphuric acid clouds on Venus: an improved nucleation parameterization and a new microphysical model

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1. Introduction

Both the clouds of Venus and aerosols found in the Earth's stratosphere are mainly composed of sulphuric acid droplets. On the Earth, the sulphur in the stratosphere originates from surface emissions of long-lived sulphur species, transported to the stratosphere by the general circulation, and from volcanic eruptions that can inject material above the tropopause. On Venus, the source of sulphur is most likely volcanism, but the question is still open. The clouds on Venus are organised in three quite distinct layers with differing properties in terms of particle size distributions and possibly composition. Some early observations hint to species other than sulphuric acid present in the clouds, but recent missions have not been able to verify their existence. The clouds are optically very thick in the visible, inhibiting visual observation of the surface. The lowest cloud layers are very dynamic and the reason for the observed multimodal size distributions could be partly explained by mixing and distinct altitudes of nucleation. However, the possibility of mixed phase clouds and different chemical compositions of the droplets have not yet been excluded.

2. Nucleation parameterization

We are currently extending the two-component nucleation parameterization for sulphuric acid and water in stratospheric conditions [9] to very low relative humidities. Our motivation for this work was an application to the extremely dry atmosphere of Venus, where relative humidities can fall below the lowest limit of the previous parameterization [9], $RH=0,01\%$. We use the thermodynamically consistent version of the Classical Nucleation Theory [8]. The previous model was improved by deriving analytical formulae for the second derivatives of the

formation free energy, since the numerical derivatives were unstable at the one-component limit. Instead of the cluster distribution based on the dihydrate used previously, we have used the self-consistent distribution of [10], which behaves correctly at the one-component limit, and constrained it by scaling to recent quantum chemistry calculations [2]. We have studied analytically the differences between the kinetic parts of the one- and two-component models, and verified that the numerical models behave as predicted by the analytical studies. In developing the parameterization, for continuity and consistency, the two-component model is used also at the one-component limit. The data were calculated for the temperature range of 150-400 K, relative humidities ranging from $1e-6$ to 100%, and sulphuric acid concentrations of $10^4 - 10^{17} \text{ m}^{-3}$. The parameterization has been developed mainly for the needs of the Venus cloud model (described in the following section), but it can naturally be applied to other, for example stratospheric, conditions as well.

3. Model description

We use a model developed for the sulphuric acid aerosols and polar stratospheric clouds in the terrestrial stratosphere [1,4]. The model describes the important microphysical processes, including nucleation via a parameterization for two-component nucleation of water and sulphuric acid [9]. As we are working on an extension of the earlier parameterization [9] to lower relative humidities [6], in the current model version we still use the old parameterization [9]. In addition to formation of droplets via nucleation, the model includes their subsequent growth by condensation, evaporation of droplets, coagulation, and sedimentation. We have also included turbulent mixing, which should be very

important in the convective lowest and middle cloud layers. Since the model describes explicitly the size distribution with tens of size bins (50-500), it can handle multiple particle modes. In the future, we will explore simplifications of the fully size-resolved model in order to develop a moment method model for coupling with a global atmospheric model [5]. We are planning to include possible (in)soluble condensation nuclei in the model at a later stage.

4. Simulations and results

First tests of the model have been carried out with a standard temperature profile from the Venus International Reference Atmosphere VIRA [3] and a compilation of water vapour and sulphuric acid concentration profiles [7]. Further sensitivity tests with profiles from the LMD Venus GCM [5] have been performed. The temperature and pressure profiles do not evolve with time in the 1-D version, but the vapour profiles naturally evolve with the cloud. Sensitivity tests on the role of nucleation as the determining factor of the final particle size distribution and as the possible reason for the layered structure of the clouds will be performed. We will also investigate the effect of the turbulent diffusion coefficient and its magnitude on the cloud structure. The simulations are run for several hundreds of Earth days to obtain a stationary state and the results are taken from the last day of simulation. The preliminary results of the model will be evaluated against the classical view of Venus clouds built upon observations of missions such as Pioneer Venus and Venera, and also later on against the modern view emerging from Venus Express.

5. Summary and Conclusions

We will present the development of two tools for modelling the sulphuric acid clouds on Venus: an improved version of a nucleation parameterization and a microphysical model accounting for all the aerosol dynamics processes that govern the formation and evolution of a cloud.

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