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Models and Observations of Moist Convection in the atmospheres of Jupiter and Saturn

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Abstract

The Atmospheres of the giant planets Jupiter and Saturn have deep internal heat sources and three gases able to condense forming clouds at different altitudes in their tropospheres. Together they form a complex “weather layer” which is prompt to the development of moist convective storms powered by latent heat release that play an important role in the large-scale dynamics of these atmospheres. Large [1, 2] and mid-scale storms have been observed in both planets with lightning discharges [3-5] and intense releases of energy [6] that point to a deep source in the unobserved water cloud layer. The scale size (1,000-10,000 km), long temporal evolution of the storms (from a few days to several months), and the lack of information from the lower water cloud have limited the development of numerical models able to reproduce the observations. As such we do not know the reasons underneath key observed characteristics of moist convective storms such as their spatial distribution in certain latitudes and their apparent periodicities. Here we review the characteristics of several numerical models developed for the giant planets and propose further steps for future research.

1. Types of moist convective models

Numerical models can be divided in different types:

a) Models that attempt to reproduce the cumulus formation process. They range in complexity from one-dimensional models [7] to two-dimensional (axysimmetric) [8, 9] and three-dimensional models [10, 11]. These models simulate a small portion of the atmosphere for a few hours and they predict the maximum height of the clouds depending on the thermodynamical state of the atmosphere at the lower levels, updraft velocities and divergence of cloud material at the cloud tops. They can also be used to explore charge separation mechanisms and to make prediction of the source of lightning [9, 12]. Except for the height of the cloud material the rest of the predictions are difficult to obtain even from spacecraft observations. The height of the clouds produced which is linked to the energy released points towards water as responsible of the largest scale storms.

b) Models aimed to reproduce the thermodynamical structure of the troposphere as determined from moist convection. These models require very long simulations in which several episodes of moist convection are produced in a two-dimensional zonally symmetrical framework [13]. They can answer some of the questions above and generally produce less intense convection since the models are always trying to equilibrate an atmosphere which is strongly radiatively forced. One of the main results of these models is that the weather layer might be partially decoupled from the lower atmosphere by strong static stability at the water condensation level [13].

c) Models that attempt to reproduce the observed morphology of convective storms. Models in this range vary from extremely simple to quite sophisticated. A purely advective model with a divergence source is able to reproduce the morphology of several convective disturbances in Jupiter [1, 14]. The same model works reasonable well in reproducing the shapes of small convective storms in the storm alley in Saturn. However larger-scale storms strongly modify their environment and can not be simulated without adding considerably more physics in the model. One possibility is to introduce a perturbation in a General Circulation Model representative of convection. Sánchez-Lavega et al. used the EPIC model [15] to successfully reproduce the morphology of large-scale storms in Jupiter and Saturn [1, 2] and planetary size disturbances produced by the storms.

d) Moist convection parameterizations in General Circulation Models. This kind of models allows to study the global impact of moist convection in the meteorology of Jupiter or Saturn. A nice approach has been recently developed at the University of Oxford in their OPUS model [16].

e) Models aimed to study moist convection as the source of zonal jets in Jupiter and Saturn. In a sense these models are very similar to the ones above but differ in model initialization and objectives of the simulation. Moist convection is introduced in a General Circulation Model and let to interact producing an inverse cascade-energy able to form zonal jets. Convective storms are introduced randomly [17] at the beginning of the simulation or continuously and randomly in space [18].

2. Pending Questions

Despite much modeling efforts and several spacecraft observations there are fundamental questions still unanswered. Some of them are here summarized: What is the amount of water in the inner tropospheres of the planets? What settles the periodicities of convective phenomena? How is it possible that seasonal effects propagate downwards to the water cloud level? What settles the latitudes where moist convections occur? What is the overall moist convective activity on any of the two giants over a full year?

3. A new look to old models

In this work we will give a new view to results from previous models [10, 11, 14] comparing model results with some of the recently observed convective storms in Jupiter and Saturn.

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