THE ROLE OF LARGE SCALE JOVIAN STORMS IN THE ENERGY BALANCE OF JUPITER

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Abstract Mid-scale to large-scale moist convective storms are relatively frequent on Jupiter. They extract their energy from latent heat release of condensing water at the clouds and they can represent an important output of the global energy transport from the deep interior levels to the upper troposphere. In this work we summarize results from 3D modelling of single cell storms and 2D models of multi-cell systems in Jupiter. We center our discussion on the energy transport of these events, global moist convective activity on the planet and the possible consequences for the global transport of the planetary deep energy source.

1. Introduction

Moist convection in Jupiter is a powerful phenomenon suspected to play a key-role in the planet's atmospheric dynamics (Ingersoll et al 2000). It forms storms with thick, high and fast evolving clouds. These storms seem to appear only at particular latitudes where the wind speed is almost null and its shear is cyclonic. Lightning is observed over these regions (Little et al 1999) and can be used to trace storm activity (Gierasch et al 2000). Radiative transfer analysis of the associated clouds shows they have a deep base at levels where only water can condense (Banfield et al 1998). The lightning has also characteristics of a deep origin close to the water clouds base (Dyudina et al 2000).

2. Models of storm formation

Powering moist convection in a H_2-He atmosphere is not easy. Humid air susceptible of condensing is heavier than the dry air and sinks impeding condensation and convection.Therefore, water moist convection in Jupiter needs a favorable environment with large values of relative humidity (>75%)and favorable microphysics able to produce precipitation removing the weight of the condensed particles.

Various models have been used to study the appearance of moist convection on Jupiter since the early work of Stoker (1986). Hueso and Sánchez-Lavega (2001) designed a 3D anelastic cloud model and explored it under a variety of atmospheric compositions and dynamical scenarios with different efficiencies of precipitation. Only water storms, and not ammonia storms, are able to reach the high tropospheric levels (between 150 and 450 mbar) where the cloud tops at the storms are observed. Updrafts in any single storm can be on the order of 40 to 150 m/s speed depending on environmental conditions and precipitation rates. Hueso et al (2002) presented a detailed analysis of one large-scale convective event (5,000 km diameter active convective core with cloud features extending 50,000 km). They used a 2D mass continuity model concluding that the kind of large-scale storms we observe in Jupiter are systems of clusters of convective cells with up to 200 different updrafts operating at the same time. Each of the updrafts would have typical ascending velocities on the order of 45 m/sec and radial expanding motions at the cloud level on the order of 30 m/sec.

3. Release of Energy by Moist Convection

Jupiter possess an important source of internal energy which is on the order of the energy absorbed from the Sun. This internal energy source is due to the release of primordial heat accumulated during the planet formation and leads to 5.7 W/m^2 or 3.5×10^{17} W over the whole planet. Moist convection is relatively frequent, definitively energetic and transports energy from the deep troposphere to the upper radiative layers. It is therefore a natural question to ask about the energy released by moist convection over the planet and what is the relation with the vertical transport of the internal heat.

Hueso et al (2002) calculated the energy contribution of small scale storm cells and systems of them able to explain the observed characteristics of large-scale storms in Jupiter. They obtained a power release at single updrafts on the order of $P \sim 10^{15}$ W and about $P \sim 10^{16}$ W for the large-scale systems of convective cells. The Voyager 2 observed nearly 12 of these large-scale storms arising on the South Equatorial

Table 1. Energy of different type of storms and global moist convective activity

Storm Type	w	V_r (m/sec)	L (km)	Power ($\times 10^{15}$ W)	Ref
Different	30	15	240	0.4	(1)
single cell	45	30 (†)	330	1.0	(1)
simulations	60	50	420	1.6	(1)
	150	100	600	4.7	(1)
SEB large-storms	(‡)	(‡)	5000	14.0	(1)
Mid-scale storms			3000	5.0	(2)

Convective activity	N_{storms}	Area	Global Heat	Notes	Ref
Lightning observations	40	0.07 %	3.3 W/m^2	(a)	(2,3)
Mid-Scale storms	8	0.12 %	0.9	(b)	(4)
Large-Scale storms	1-10	0.04-0.4 %	$0.2 - 2.0$	(c)	(1,4,5)

Symbols: w is the vertical velocity, V_r the expanding velocity of the clouds, L the typical size of the storms, N the number of storms that can be active at the same time assuming different ways of estimation, Area the % of the area of the planet covered by moist convection and Global Heat the amount of energy released by the storms averaged over the planet. **References:** (1) Hueso et al (2002), (2) Gierasch et al (2000), (3) Little et al (1999), (4) Sánchez-Lavega and Hueso (1998), (5) Banfield et al (1998). **Notes:** (†) Values fit the onset of storms on the SEB in Jupiter. (‡) Simulation of a cluster of 100-200 updrafts with the characteristics in (†) fitting the observations of a large convective event in the SEB. (a) Storm activity from Galileo Orbiter lightning observations. (b) Storm activity from normal SEB storm activity. (c) Large-scale storms giving rise to a general disturbance in the SEB and NTB belts. The SEB events took place on average every 1-3 years, and the NTB events every 10 years or more.

Belt (SEB) of Jupiter over a period of a month, contributing to about $P \sim 3 \times 10^{16}$ W and therefore representing an important fraction of the total amount of released internal energy. Ingersoll et al (2000) suggested in view of these activity that moist convection could be the key mechanism responsible of the transport to the upper layers of the internal planetary heat and that it could be the dominant source of energy dominating the meteorology of the planet.

We point out however that (see Table 1):

- Moist convection appears irregularly in time and only at defined latitudes, while the internal heat source is continuously and homogeneously distributed over the planet. Moreover, intense storm activity of the kind observed by the Voyagers is rare (Table 1, lower part).

- Small scale convection by single updrafts would be more efficient to transport the deep energy. About 2000 storms distributed around the planet with the characteristics of the SEB onset cell would efficiently transport the internal heat of the planet (Table 1, case (†)).

4. Conclusions

Large-scale storms are not responsible of a significant part of the vertical global transport of energy on the troposphere of Jupiter. They do not operate continuously and seem to represent the sudden release of stored energy over time. The storms are best explained by clusters of convective cells operating together. Small-scale storms of the single-cell type and less powerful are better candidates to transport the deep energy, since they could be continuously operating at different locations and still produce small enough clouds not to have been observed. The very localized sites where storms develop could either imply that moist convection effectively forces the atmosphere in an organized way or that moist convection is somehow a consequence of the same forcing mechanism that produce the jets in Jupiter. Since the storms are highly variable, where the jets are extremely stable over time, we favor this second interpretation.

The Cassini mission will arrive to the Saturnian system in the summer of 2004. Saturn posseses also its own convective storms and its own internal source of energy. The observations of Cassini will without doubt help us to understand the role of moist convection in the global energy budget of the giant planets.

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