Simulating jovian moist convection

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Abstract

Jovian moist convection has been the study of both observational and modelling attempts for several decades. In the Pioneer and Voyager era, plumes of volatiles were observed to erupt from the deep atmosphere regularly, prompting the question of the strength of the internal heat flux within Jupiter's atmosphere. Later, Galileo observed towering convective storms coinciding with the presence of lightning. Analysis of cloud formation on Jupiter considering the abundances of various condensible species revealed that the most likely source of these convective events was the deep water cloud which contains both the high density of volatiles and necessary convective potential to breach the upper cloud deck.

In this study, we use the Explicit Planetary Isentropic Coordinate (EPIC) atmospheric 3-dimensional general circulation model (GCM) to study the formation of Jovian moist convective events, using an active cloud microphysics scheme. We focus on the region centered on the 24° N jet where plume formation has been observed several times. We initiate cloud formation assuming different initial deep abundance values of both water and ammonia to test the sensitivity on the strength of plume formation and the buildup of convective potential energy (CAPE). We find that convective activity is affected by the thermal properties of the environment – the jet and the North Equatorial Belt are conducive of convection while the North North Tropical Zone is not.

Background

The *Pioneer* and *Voyager* missions to Jupiter first observed convective activity on Jupiter. They saw upwelling of white cloud material from deep below the atmosphere (Fig 1). Observations of the eastward atmospheric jet stream at 24° N latitude has seen similar periodic disturbances (Sánchez-Lavega *et al.*, 2008, 2017) which has significantly affected the structure of the jet. These disturbances are from storms containing water, which form 150km below the visible clouds. The heat released from water condensation fuels these storms, like large thunderstorm complexes on Earth.

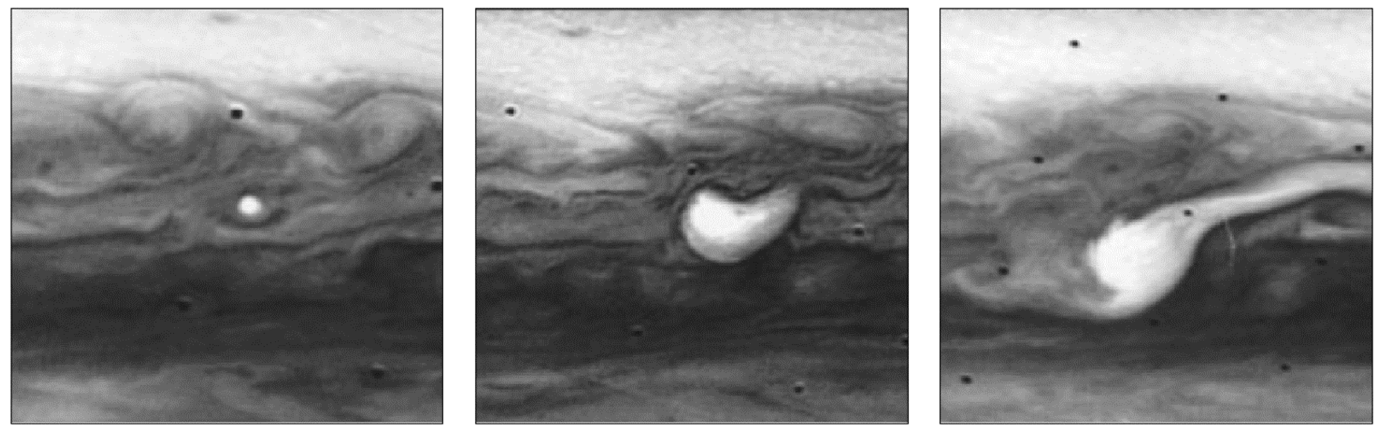

Figure 1: Convective upwelling near the North Equatorial Belt from *Voyager* approach movie. Adapted from Hueso and Sánchez-Lavega (2001)

Model parameters

These storms are generally formed by perturbations in the water cloud layer. Condensation of water releases latent heat, heating the atmosphere and driving the upwelling. To study the formation of these storms we model the region from the North Equatorial Belt (NEB) to the North Tropical Belt (NTB). We introduce three atmospheric profiles with a solar water mole fraction. After spinning up the model atmosphere, we introduce random perturbations similar to heat pulses and turn on the cloud formation processes.

Convective potential

The buoyant force experienced by the upwelling plume opposes the downward force of gravity. Convection can be quantified using the potential energy gained by latent heating effects by integrating the net force experienced by a parcel of moist air from its initial pressure to the top of the cloud. This is defined as the convective available potential energy (CAPE). We calculate the CAPE of a parcel starting 6 bars (i.e. just below the water cloud level).

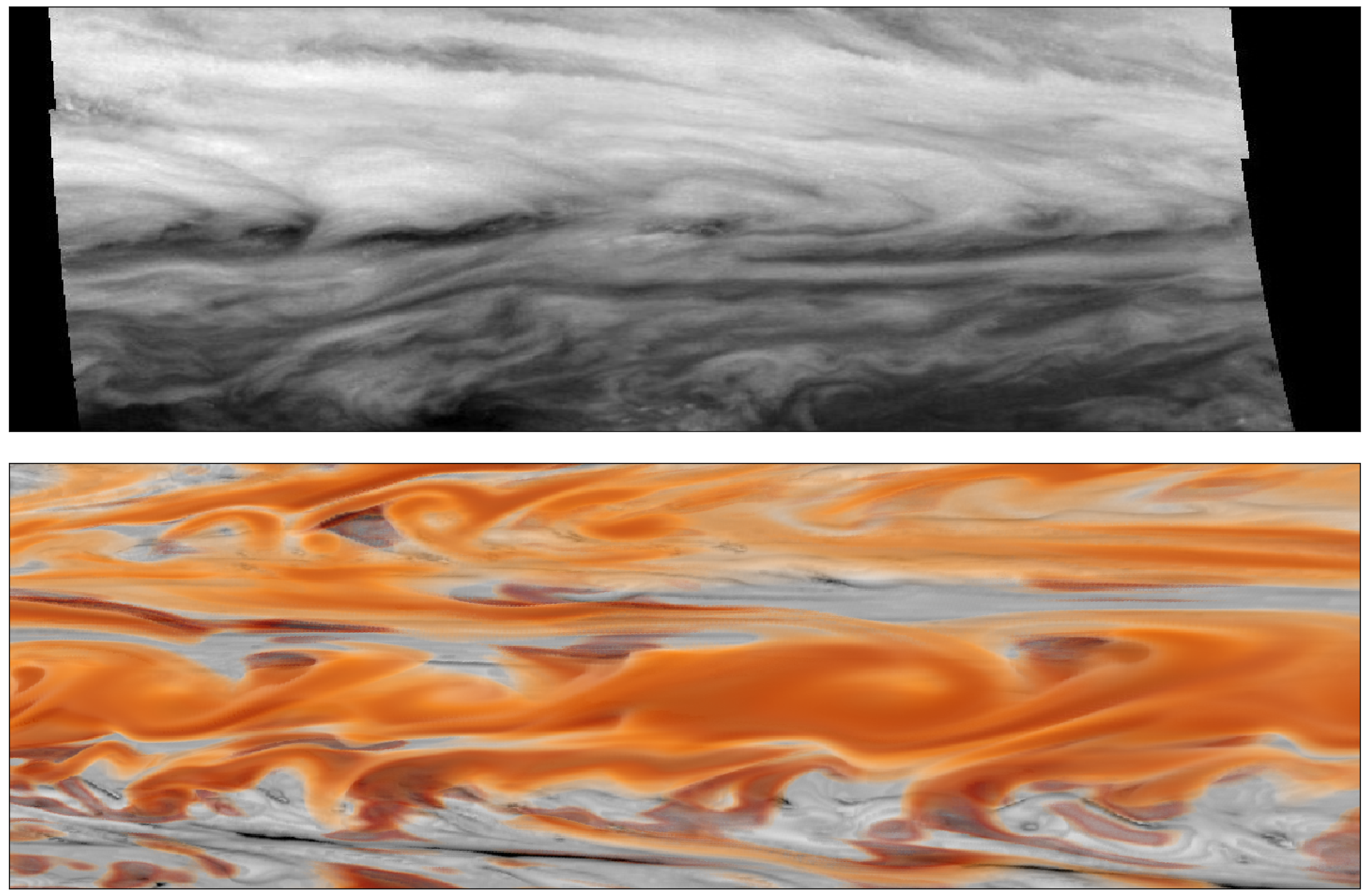

Figure 2: *Voyager* image of the North Tropical Belt region (top) and model output of the same region (bottom)

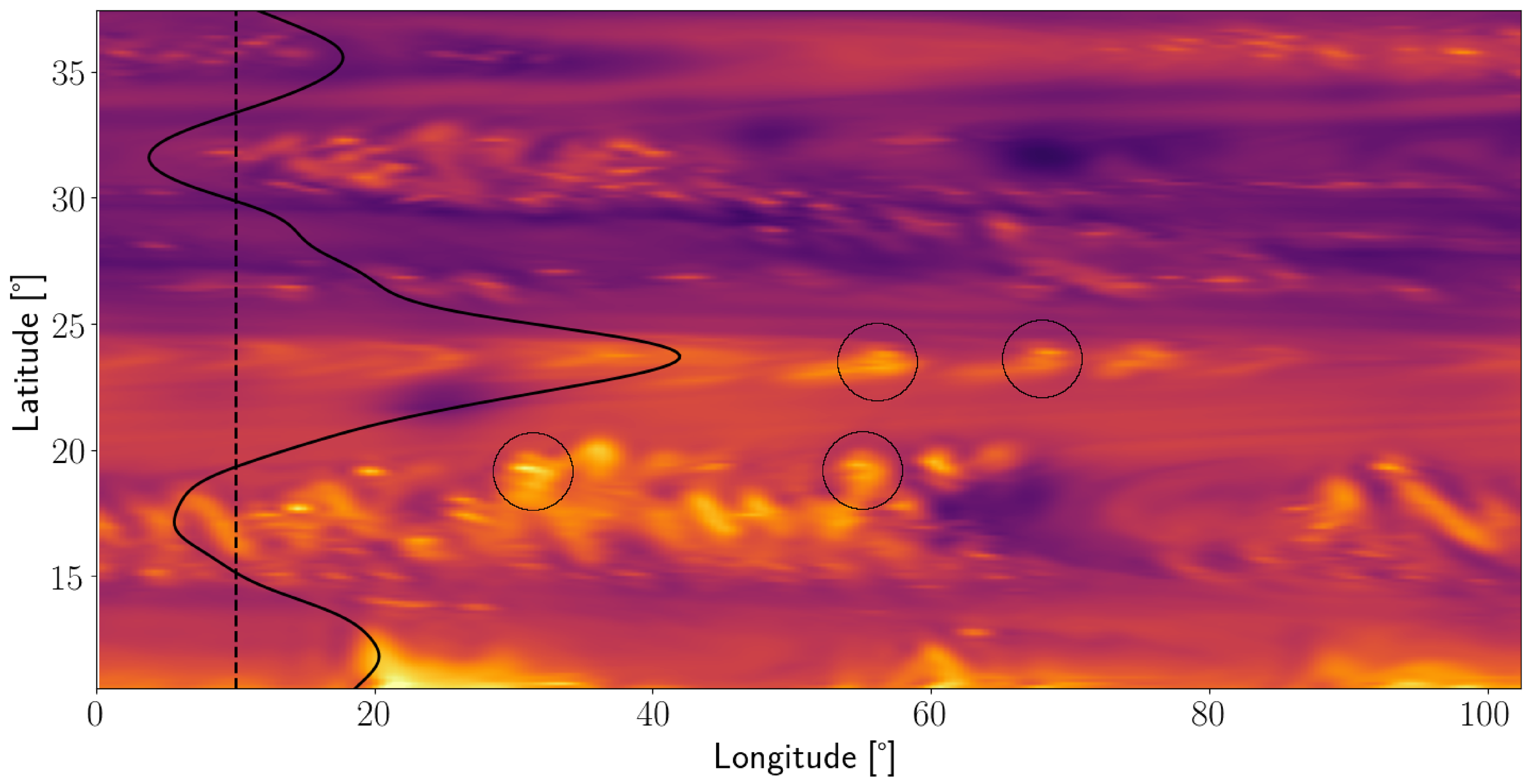

Figure 3: CAPE calculated from model output. The circles show possible locations of plume formation

Condensation from the water cloud level at ~ 5 bars releases latent heat allowing large thunderstorms to form and rise 150 km from its base. This affects the structure of the eastward jet at 24° N latitude. The jet structure may itself be maintained by convective cells between the North Tropical Zone and North Tropical Belt.

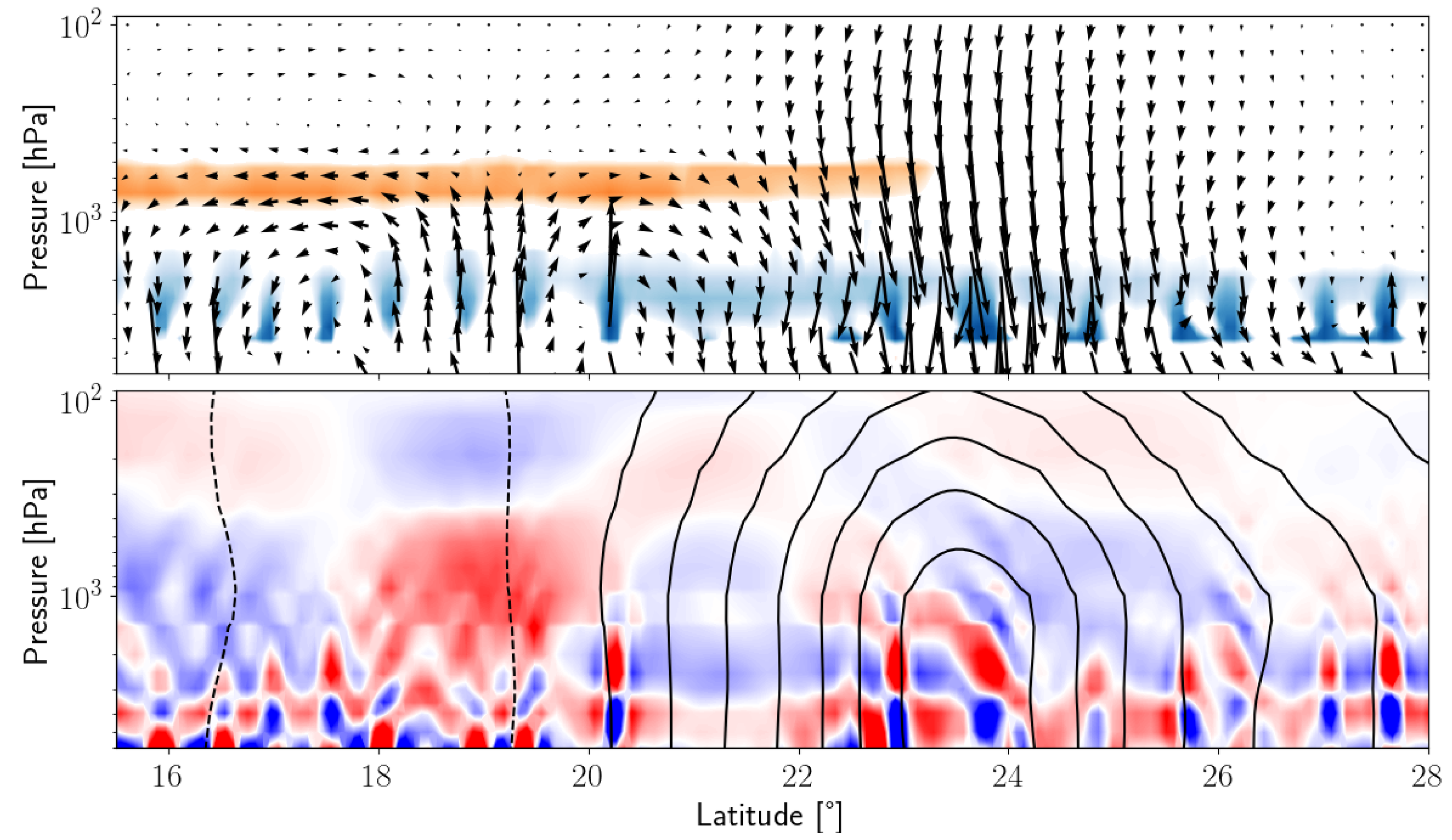

Figure 4: Zonally averaged winds as a function of latitude. Blue contour corresponds to water ice cloud and orange corresponds to ammonia ice (top). The bottom panel shows the horizontal wind divergence with positive being red and negative being blue.

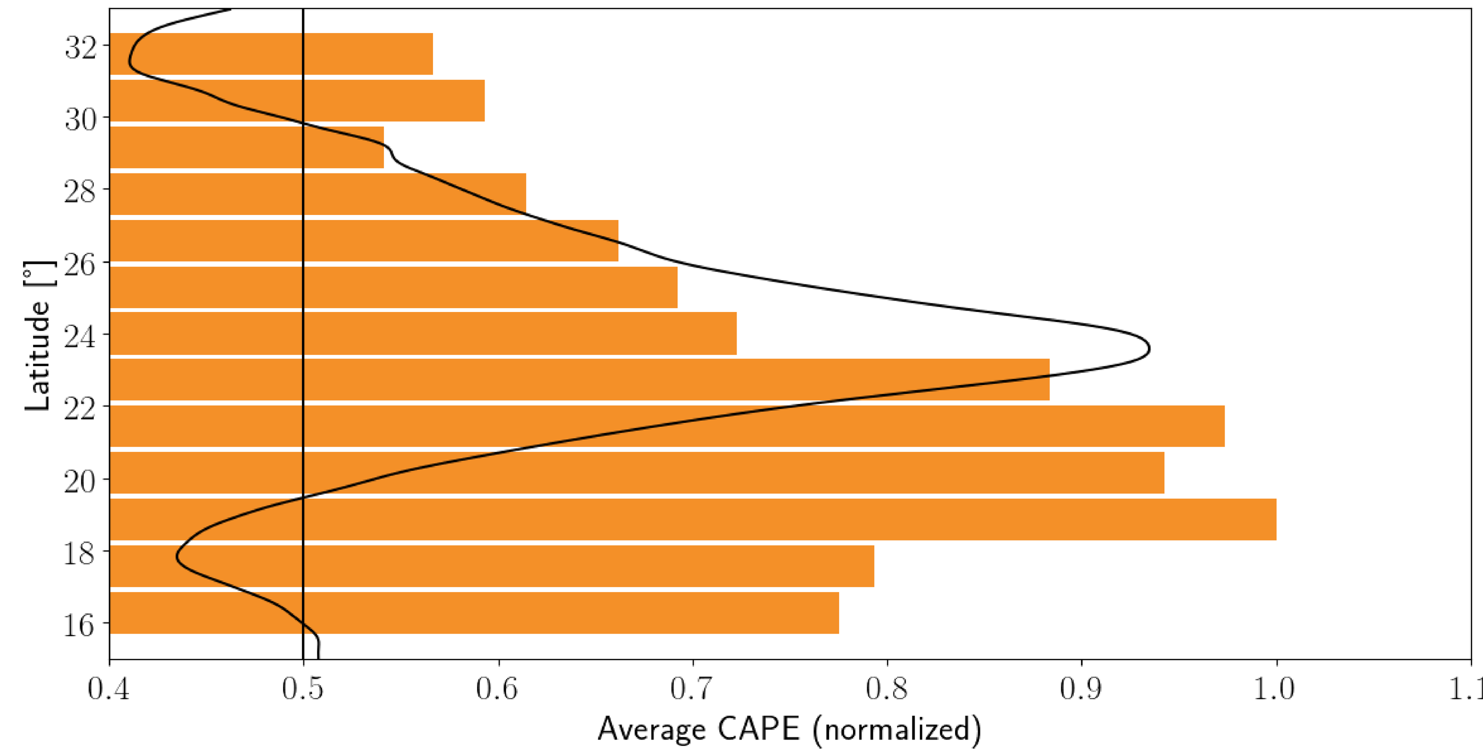

Figure 5: Average normalized CAPE as a function of the latitude. Zonal wind profile is shown with the black line.

Discussion & Future Work

The convective potential forms a gradient from south to north, with higher potential being south of the jet and lower to the north. This is due to the northern regions being colder aloft than the south as a result of thermal wind balance. The cool, dense air lowers the level of neutral ouyancy for a moist convective parcel. The convection appears to be triggered by convergence deep below the water cloud (Fig 4, which is stronger in the NEB.

Further simulations are required with different parameters to test these observations. We will change the deep abundance and initial relative humidity of water to test its effect on the strength of these perturbations. EPIC is a hydrostatic model, and thus, the vertical velocities are diagnosed from mass conservation. The model will be updated with a sub-grid scale moist convective parameterization using the Microphysics of Clouds with the Relaxed Arakawa-Schubert (McRAS) scheme (Sud and Walker, 2003) which will allow us to calculate the vertical upwelling prognostically. This would also enable this model to be used for extrasolar gas giant atmosphere, where convective upwelling is much stronger due to internal heating.

Acknowledgements

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