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Observations and numerical modelling of the 2018 Jupiter's South Temperate Belt Disturbance.

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Abstract

Moist convective storms can trigger atmospheric activity of different scales in Jupiter's atmosphere: From localized storms to planetary-scale disturbances including "contained" activity over a given region. In February 2018 a convective storm erupted in Jupiter's South Temperate Belt. This occurred inside an elongated cyclonic region informally known as the STB Ghost, close to the large anticyclone BA. The initial storm lasted only a few days but it broke the elongated Ghost into two structures, one of them interacting with oval BA and the other being expelled to the West. After the rupture both features continued to evolve over time-scales of several months. Here we present a study of this perturbation based on the long-term analysis of amateur, JunoCam and HST observations and we perform numerical simulations aimed to reproduce the phenomenology observed. The simulations are run using the General Circulation Model EPIC and require a complex interplay between the Ghost, the convective eruption and oval BA. We constrain the strength of the convective storm to levels that are only compatible with water powered moist convection.

1 Introduction

Convective storms are an important mechanism for triggering changes in Jupiter. These storms usually develop at various latitudes and can have different intensities, going from small-scale storms, such as at the west of the Great Red Spot, to storms that trigger full planetary scale disturbances, such as the North Temperate Belt Disturbance (see [9] and [11]) or the South Equatorial Belt Disturbance (see [8] and [2]). Since October 2016 several phenomena have been observed in Jupiter related with a convective nature. In October 2016 four convective storms in Jupiter's North Temperate Belt (NTB) ended up developing a planetary scale disturbance that lasted several months [11]. In December 2016 a convective storm in the South Equatorial Belt (SEB) developed also a large-scale disturbance in this region with large-scale turbulence extending over several months. In October 2017 another disturbance was observed by several telescopes and the JunoCam instrument aboard Juno spacecraft, this time in the South Tropical Zone. This disturbance developed a South Tropical Zone Disturbance ([7]) with a recirculation of the zonal winds followed by its interaction with the Great Red Spot over 2018.

The so called South Temperate Belt (STB) Ghost is an elongated low-contrast cyclonic region located at the South Temperate Belt, at a planetocentric latitude around 27°S, that has been observed in every Jupiter apparition since 2011-2012. In February 2018 a series of convective storms erupted in a matter of 3 days inside the STB Ghost developing strong turbulence initially confined to this cyclonic region developing a South Temperate Belt Disturbance (STBD). This has been the first time in which a confined convective disturbance has been observed in all its phases and high-spatial resolution.

2 Evolution of the disturbance

In order to study this phenomenon we have used observations from several datasets: Amateur observations, our own observations made with the PlanetCam UPV/EHU instrument in the 2.2 m telescope at Calar Alto observatory on May and June 2018, publicly released Hubble Space Telescope observations at different dates over 2017 and February and April 2018 and JunoCam observations on December 2017. High quality amateur observations have been indispensable to study this event due to their capability of providing high temporal coverage and the quick evolving nature of this phenomenon. We have separated the evolution in three stages: Fist the situation before the convective activity, second the start of the convective activity and third the long-term evolution of the disturbance.

2.1 The STB Ghost prior to the convective eruption:

We studied the dynamical context of the STB Ghost before the beginning of the perturbation using HST and JunoCam data. We obtained wind measurements that characterize the STB Ghost circulation on HST images on February and April 2017. These images showed that the cyclone is an elongated feature with a size of $24,000 \times 4,500$ km with an external cyclonic circulation (clockwise) of 60 ± 10 m/s. The JunoCam images on December 2017 showed the structure of the Ghost but the small time separation between the images resulted in an estimation of the Ghost circulation of 80 ± 20 m/s. Over 2017 the Ghost has been slowly approaching to the long-lived anticyclone BA and it has been elongating until reaching a size of $28,000 \times 5,500$ km when the disturbance started. By the date of the convective eruption the Ghost was at a distance of 17° from the large anticyclone BA. The interaction of the East side of the Ghost with BA modified their longitudinal drift.

2.2 Characterization of the convective eruption:

The onset of the convective outbreak that triggered the disturbance was reported on amateur observations obtained on 4 February 2018. In those observations a bright spot of size

$1,800 \times 1,400$ km was observed inside the STB Ghost, with its convective nature demonstrated with observations in the strong methane absorption band. Two days later a second convective nucleus, with a size of $3,400 \times 1,700$ km, was observed to the west of the first one. The first convective outbreak was active during 5 days, while the second one was active only during 1 day. These storms triggered a local disturbance which was contained inside the STB Ghost.

On observations made by Hubble Space Telescope on 7 February 2018 (see Fig. 1) the first stage of the evolution of the disturbance can be seen. These images were taken 3 days after the onset of the convective outbreak and show how the storm acquires it's characteristic shape due to the shear of the tangential velocity within the cyclone and how it recirculates at the west border of the STB Ghost.

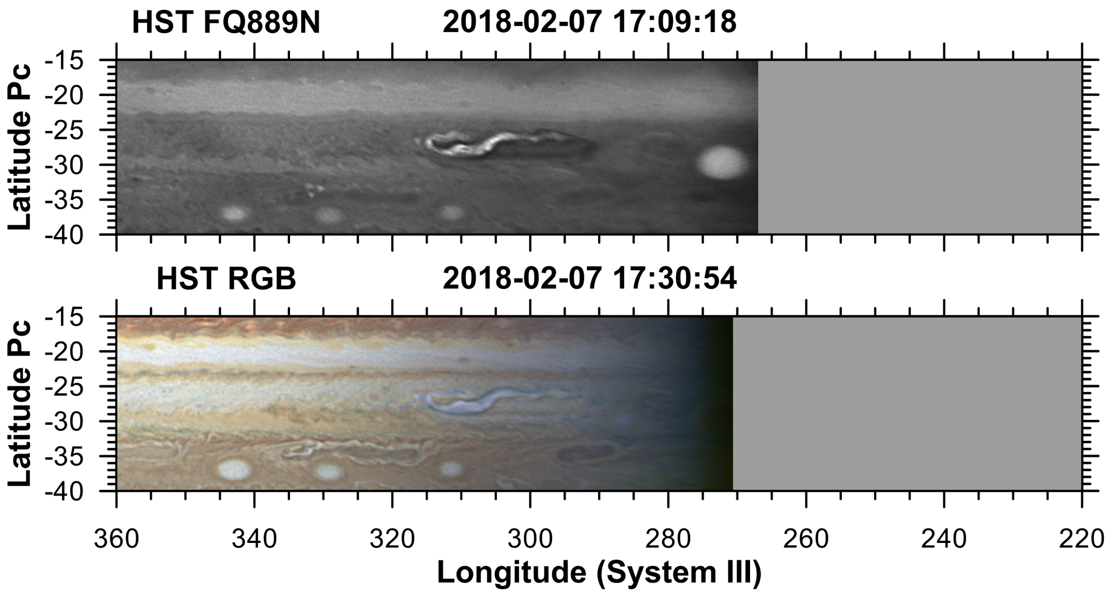

Figure 1: Observations of the South Temperate Belt Disturbance made with the HST the 7^{th} of February 2018. The upper image is an image in the strong methane absorption band at 889 nm and the bottom image is a RGB colour composition.

2.3 Evolution of the STB Disturbance after the eruption:

We studied the long-term evolution of the disturbance through frequent observations obtained by amateur observers and available in the PVOL database (see [5]) and ALPO-Japan. The convection left the whole region perturbed with bright and dark filaments circulating the Ghost. As a result of this activity the Ghost was fully perturbed generating strong turbulence confined to the Ghost area. During the evolution of the disturbance different ovals were formed and some of them merged. The merger of two of those ovals at the beginning stages of the disturbance generated an oval that has been present for months, since its formation on March until the last analysed observations on September. Also, many small anticyclones moving westward were expelled from the active region. As the disturbance evolved the Ghost expanded slowly and its East side strongly interacted with the cyclonic region to the west of oval BA. It was observed that the outer ring of BA changed in color. On 1 April 2018 the Ghost broke-up creating a large dark structure on its southwest. On this epoch also the East side of the Ghost merged with the small cyclonic region that had always been present to the west of the anticyclone BA. Over May 2018 it seemed that the visible features were evolving to a more stable configuration, being the southwest structure clearly separated from the Ghost and drifting Eastwards and expanding zonally. The remains of the Ghost were retained West of BA and seemed to interact with an anticyclone on its South side. Observations made on 22 May 2018 with the PlanetCam UPV/EHU instrument at Calar Alto Observatory in the methane absorption band showed how some bright structures were still inside the Ghost, implying that vertical motions might be present even at that late date. By the end of May 2018 a large structure separated from the southwest structure and on July other two structures more. Over July and August 2018 the southwest structure slowly elongated in longitude simply following the differential drift of the winds and finally on September 2018 a large section of the East side of the southwest structure tore apart creating some small dark features.

3 Numerical modelling

We have used the General Circulation Model EPIC (Explicit Planetary Isentropic-Coordinate, [1]) to simulate the complex phenomenology observed. We tried to simulate the complex interaction between these three main elements: the STB Ghost, the anticyclone BA and the convective outbreaks. The EPIC model introduces vortices (for example the cyclonic Ghost and the anticyclone BA) by perturbing a stable atmosphere. As an initial stable atmosphere we have used a standard reference atmosphere (see [6]) with the zonal winds that characterize the domain of the simulatuon based on measurements over HST images of Jupiter obtained in 2016 ([4]). The storms are simulated introducing heat pulses with Gaussian shape with prescribed onset and offset times as it has been done in previous studies of other convective events in Jupiter (see [3], [9] and [11]) and Saturn (see [10]). The different elements in the simulation are introduced one by one letting the atmosphere to stabilize before introducing new perturbations. This is done because the perturbations used to introduce the Ghost and the oval BA in the atmosphere are relatively strong producing unrealistic turbulent patterns for the first tens of days. We started introducing the STB Ghost, after that the anticyclone BA and finally the convective storms.

The STB Ghost is well reproduced by an elongated vortex at planetographic latitude $-30.6\,^\circ$ with a semi-major and minor axes size of $10.5\,^\circ$ x $2.3\,^\circ$, vertically placed on a pressure level of 680 mbar with an upper vertical size of 3 scale heights and lower vertical size of 2 scale heights, tangential velocity of 80 m/s and shape parameter of 2. It has been allowed to evolve freely during 68 days to let the atmosphere stabilize.

The anticyclone BA has been introduced at planetographic latitude $-33.3\,^\circ$ with a semi-major and minor axes size of $3.5\,^\circ$ x $3.5\,^\circ$, vertically placed on a pressure level of 680 mbar with an upper vertical size of 3 scale heights and lower vertical size of 3 scale heights, tangential velocity of 100 m/s and shape parameter of 2. It has been allowed to evolve freely during 22 days. After a few days both the simulated Ghost and oval BA are located at the same relative distance as the Ghost and oval BA at the time of the onset of the convective storm.

We then perform an exploration of the space of parameters that define the convective perturbation. The best results are produced by introducing two pulses:

- First storm: It is injected at planetographic latitude $-30.8\,^{\circ}$ with a semi-major and minor axes size of $0.8\,^{\circ}$ x $0.5\,^{\circ}$. The convective pulse is introduced drifting at a velocity of 10.3 m/s with a pulse amplitude of 0.55 W/kg. The pulse is active during 5 days.
- Second storm: It is injected 2.5 days later than the first storm at planetographic latitude $-30.1\,^{\circ}$ and $2.5\,^{\circ}$ more to the west than the injection point of the first storm. The semi-major and minor axes of this storm are $0.4\,^{\circ}$ x $0.25\,^{\circ}$, the drift velocity is -3.5 m/s and the pulse amplitude is 0.4 W/kg. The pulse is active during 1 day.

After the injection of the second pulse the system is left to evolve freely. The result of the best simulation can be seen on Fig. 2. From the comparison between Fig. 1 and the second frame of Fig. 2 we can see that the first stages of the phenomenon are well simulated in the model.

4 Conclusions

From the analysis of the simulations we have constrained the vertical structure of the STB Ghost to be 4-5 scale heights, 2 of them below the visible clouds. We have also constrained the intensity of the first storm in the range $0.45 - 0.8$ W/kg and the intensity of the second storm in the range $0.3 - 0.6$ W/kg. Scale analysis shows that this energy can only be supplied by water condensation. We have also noted that the observations are best fitted when using a wind profile derived from HST 2016 observations. Using wind profiles from previous years only slightly different to the 2016 wind profile did not result in good results. Observations show that the storm drifts differently to the initial circulation at the STB Ghost with "own motions" with an intensity of 10m/s for the first storm that could be representative of a deep root of the convective storm also favouring water as the source of energy.

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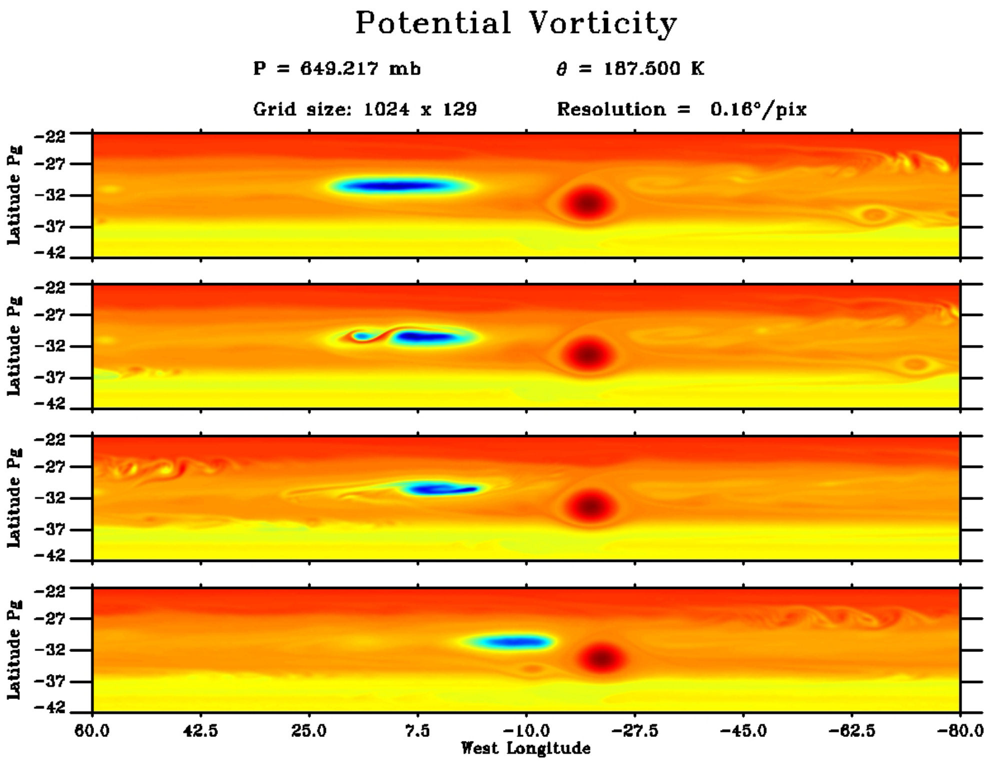

Figure 2: Some frames showing the potential vorticity of the best simulation obtained with the EPIC model. The days are corresponding to the simulation days 90.0, 93.54, 103.54, and 146.67 from the upper frame to the lower one.

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