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Thermal Evolution of Saturn's Springtime Disturbance

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Abstract

Saturn's slow seasonal warming was spectacularly disrupted in December 2010 by the eruption of an enormous storm system in its springtime hemisphere. This storm, which is still evolving at the time of writing, is only the sixth known example of a planet-wide storm system on Saturn, and the first to occur at this latitude (near 40^{o}N) in over a century [1,2]. A combined analysis of thermal infrared imaging from ESO's Very Large Telescope VISIR instrument and 5-200 μm spectroscopy from instruments onboard Cassini revealed the substantial atmospheric perturbations related to the storm complex over a wide range of altitudes [1]. Since that time the storm complex has continued to evolve through the mature phase. In particular Saturn's newly-identified stratospheric beacons (a high-altitude response to mechanical forcing from the troposphere) have been observed to move in the stratospheric wind field, merge and strengthen to generate thermal differences considerably larger than those reported in our initial study (Fig. 1, from IRTF/MIRSI, May 22 2011).

1. Methods

Several different techniques were used to track the evolution of the thermal perturbations (and hence the changes in atmospheric temperatures, composition, wind speeds and cloud cover) since January 2011. Firstly, we make use of a number of Cassini Composite Infrared Spectrometer (CIRS) measurements (7-200 μm spectra, 0.5 cm^{-1} and 2.5 cm^{-1} spectral resolution) that stare at a particular latitude while Saturn rotates. These provide well-calibrated estimates of the perturbation amplitudes, although their spatial coverage is somewhat limited (e.g., Fig. 2). We therefore supplement these regional spectra with global filtered imaging from the VISIR instrument on ESO's Very Large Telescope in Chile and the MIRSI instrument on NASA's Infrared Telescope Facility on Hawaii (Fig. 1). These images provide a spatial resolution in the thermal-IR that can be directly compared to the near-continuous visible record from amateur observers. Finally, we utilize both night-side thermal emission and reflected sunlight observations from Cassini's Visual and Infrared Mapping Spectrometer (VIMS) to diagnose the vertical structure and possible composition of the storm clouds. All sources of data (ground-based and Cassini) were analysed in a consistent fashion using the suite of remote sensing and optimal estimation retrieval codes developed at the University of Oxford [3]. Retrievals of temperature, composition and cloud opacity are used to understand the vertical motions associated with the storm from the troposphere to the stratosphere.

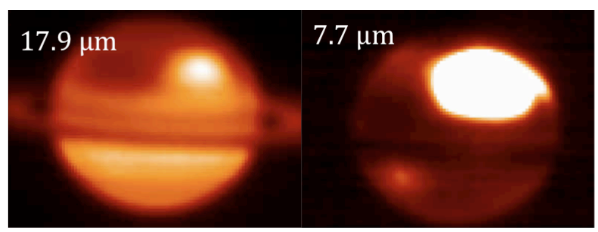

Figure 1 *IRTF/MIRSI images on May 22nd 2011 showing the beacon in the upper troposphere (left) and stratosphere (right). The beacon is deliberately over-exposed to show the rest of the planet at 7.7 μm.*

2. Results

Figure 3 shows the motions of the warm features in Saturn's stratosphere, thought to be regions of subsidence flanking the upwelling over the centre of the disturbance. These beacons are not formed by direct convection, but are thought to be a response to a mechanical forcing by the powerful convective storm in the troposphere. The Cassini and ground-based images showed that one such beacon, sitting over the storm head at a higher latitude, moved westward with a higher velocity (B1, 2.9±0.3°/day) than the second beacon which sat further to the south

(B2, 0.44±0.24°/day). B1 encountered B2 in late April 2011, when both a CIRS spectral map and imaging from IRTF/MIRSI confirmed an enormous stratospheric perturbation (Fig. 1, 2). The temperature rise (almost 60 K in brightness temperature) was sufficient that the resulting beacon completely outshone the rest of Saturn's disc when viewed at 7.7 and 12.3 μm (emission from stratospheric methane and ethane, respectively).

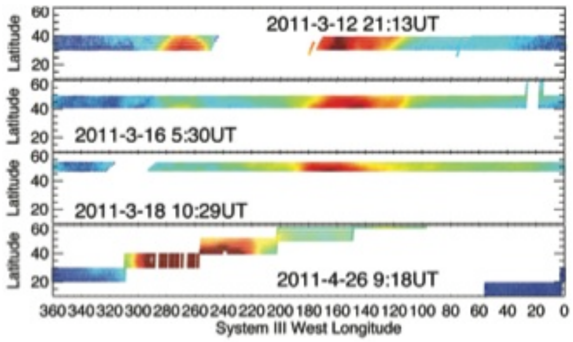

Figure 2 *Cassini CIRS observations of 7.7 μm emission from the stratospheric beacons in March-April 2011, showing the faster movement of B1 as it approached B2. The colour scale goes from 120 K (blue) to 170 K (red), showing the strengthening of the beacon.*

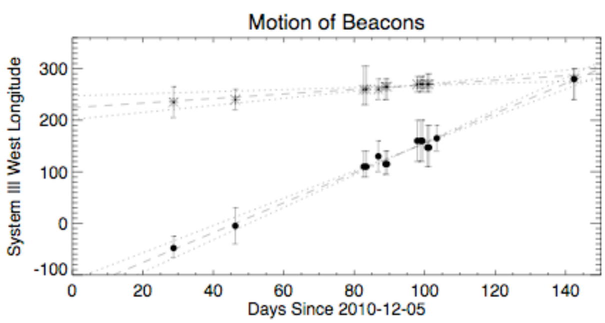

Figure 3 *Motions of the beacons B1 (circles) and B2 (crosses) determined from a combination of ground-based and Cassini measurements, showing their close passage in April 2011.*

Furthermore, both sets of data confirmed that the beacon was perturbing tropospheric temperatures, enhancing the emission from the H_2-He continuum in the 15-25 μm region and consistent with the downward propagation of warm airmasses flanking the central disturbance (Fig. 1), although to date no evidence for this warming has been observed in reflected sunlight. Vertical retrievals of the temperature structure and composition will be presented to reveal the nature of these features, and we hope that their evolution will be monitored with subsequent infrared observations between May and October 2011.

3. Discussion

We will assess the evolution of Saturn's thermal field (and hence the atmospheric motion in the upper troposphere and stratosphere) in response to the planet-wide disturbance of 2010, comparing the results to a seasonal climate model in the absence of strong convective dynamics [4]. Calculations of the vertical displacements and velocities will be used to determine the amplitude of the stratospheric response. The east-west velocities of B1 and B2 will be used to obtain crude estimates of stratospheric windspeeds and assess the applicability of the thermal windshear equations in this context. Finally, the longevity of the cold oval which formed within the disturbance in January-February 2011 will also be studied.

Acknowledgements

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