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Long-term variability of temperatures and clouds in Saturn from ground-based observations of thermal emission

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Abstract

We report the results of long-term studies of thermal emission from the atmosphere of Saturn using ground-based imaging covering 1990 to the present. Both seasonal and non-seasonal effects have been detected in its atmosphere. Seasonal effects are most pronounced and indicate a variance from radiative climate model results that is consistent with an additional source of stratospheric heating other than gaseous absorption of sunlight. Associated with the seasonal variations is the establishment of warm polar vortices in the stratosphere toward late spring and early summer, with the anticipation of such a vortex appearing imminently in Saturn's north polar region. Non-seasonal effects include a variation of low-latitude thermal waves, initially identified as consistent with a semi-annual oscillation, although recent observations indicate a variation from that behavior. Slowly moving zonal thermal waves have been detected irregularly; they have been most prominent in Saturn's southern mid-latitudes. Deep atmospheric cloud structure has shown consistent zonal-mean structure from 1995 to the present; however it has been marked by substantial discrete opaque ("cold") features. The great springtime storm of 2010-2011 produced substantial perturbations of both atmospheric temperatures and deep cloud structure.

1. Introduction

Measurements of Saturn's thermal emission at wavelengths between 5.1 and 24.5 µm have been recorded by imaging and spectroscopy from ground-based observations from the early 1990's to the present. A subset of these measurements is sensitive to temperatures in Saturn's upper troposphere and stratosphere and observations at 5.1 µm are sensitive to cloud opacity near the 2-3 bar pressure region. Our observations included mid-infrared thermal imaging and mapping spectroscopy of the CH_4 7.7-µm υ_4 band to sense stratospheric temperatures and H_2 collision-induced absorption in the 17-25 µm region to sense upper-tropospheric temperatures. Observations were made at the Infrared Telescope Facility (IRTF), the Subaru Telescope, the Keck I Telescope, the Gemini South Telescope and the Very Large Telescope.

1.1 Seasonal variability

Prominent seasonal variability is easily detected in the observations by comparing emission in opposite hemispheres at wavelengths sensitive to both tropospheric and stratospheric temperatures. The stratospheric temperature differences do not coincide with predictions of a time-dependent radiative model [1], but they can most probably be reconciled by the addition of a source of stratospheric heating in addition to the CH_4 gaseous absorption in the current model.

Warm polar vortices in Saturn are prominent near and after solstice. Orton and Yanamandra-Fisher [2] differentiated between a broad region of heating due to a combination of radiation and dynamics that covers a region within 30° of the pole and a more compact dynamically driven phenomenon. Figure 1 illustrates that both poles show this phenomenon. As of this writing, Saturn's north pole, heading toward solstice in 2017, has not yet displayed the distinct arctic warming that is prominent in the 1993 August 12 image corresponding to Saturn's early spring. Tracking of this warming in the next few years will constrain this radiative-dynamical phenomenon.

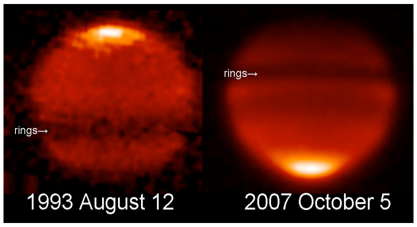

Figure 1. 7.8-µm images of Saturn, sensing ~20-mbar stratospheric temperatures, from Stewart Observatory (1993) and the IRTF (2007).

1.2 Semi-annual oscillation?

Orton et al. [3] detected a non-seasonal oscillation at low latitudes that appeared to have a period close to 14.7 years, nearly identical to half of Saturn's orbital period. However, recent observations indicate a variation from this behavior, which is consistent with independent observations made by the Cassini CIRS investigation [4].

1.3 Deep clouds

Imaging at 5.1 µm has revealed a detailed cloud structure representing variations of cloud opacity around Saturn's 2-3 bar pressure region that we have tracked since 1995 [5]. Since that time, the zonal-mean narrow, dark bands (Fig. 2) have remained constant and are correlated with variations of zonal jets. We have identified long-term variations in the cloud opacity that do not appear to be immediately correlated with seasonal changes.

1.4 Effects of the 2010-2011 storm

Substantial perturbations to the atmospheric temperature field in the northern hemisphere were documented earlier by Fletcher et al. [6]. We also note significant perturbations of the deep cloud field detected at 5.1 µm. The clouding over of the central storm track during early 2011 (Fig. 2, left) was followed by a central clearing and clouding over of regions to its north and south. This process made the storm latitude the clearest atmospheric region (i.e. the brightest at 5.1 µm) ever detected. It is gradually returning to its pre-storm state, but at a very slow rate and remains the clearest region on the planet (Fig. 2, right).

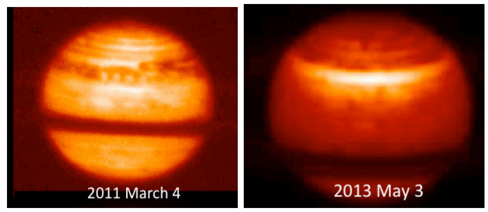

Figure 2. Perturbations to Saturn's deep cloud structure from the great storm, monitored by 5.1-µm imaging from the IRTF.

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