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Thermospheric Circulation and Pole-to-Pole Temperatures from Cassini Grand Finale Occultations

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Abstract

We analyze Cassini UVIS EUV stellar occultations of Saturn's thermosphere from the Grand Finale suite of observations taken between June 24th and August 4th, 2017. Previously published stellar occultations have been observed at primarily low and middle latitudes, with only a few observations collected poleward of 60°. The Grand Finale suite of occultations concentrates in this underexplored region, while also providing coverage of lower latitudes (Fig. 1). Taken together with previously unpublished stellar occultations from 2016 and earlier in 2017, we produce a dataset of thermospheric density and temperature covering 33 points from 86 S to 86 N. With the broad latitudinal coverage and relatively close latitudinal spacing of this dataset taken within a two-year period, we derive a 2D map of Saturn's thermospheric temperature with latitude and depth. We determine the radii and latitudes of constant pressure surfaces, from which we estimate zonal and meridional winds under the assumption of modified geostrophy adapted from Larsen and Waltersheid [5]. Finally, we present findings from our retrieval of methane profiles with UVIS FUV channel occultation data.

1. Introduction

The high thermospheric temperatures of the outer giant planets of the solar system cannot currently be accounted for. In all four cases, observed temperatures exceed, by several hundred Kelvin, those predicted by solar heating alone. This indicates that additional processes are heating the thermosphere, an outstanding problem in planetary science dubbed the "energy crisis." Several mechanisms have been proposed to account for the additional thermospheric energy, including the dissipation of upwardly propagating gravity waves (e.g. Matcheva and Strobel [8]), the deposition and redistribution of auroral energy (e.g. Cowley et al. [2], Müller-Wodarg et al. [7]) and low-latitude electrodynamics (e.g., Shemansky et al. [9]). For example, enough auroral energy is deposited around the poles to account for temperatures observed at all latitudes, but modeling by Smith et al. [10] show that equatorward distribution is prevented by Saturn's strong Coriolis forces and polar ion drag. Because each of the proposed mechanisms relies intimately on atmospheric dynamics, new constraints on circulation will be useful in addressing the energy balance of the thermosphere.

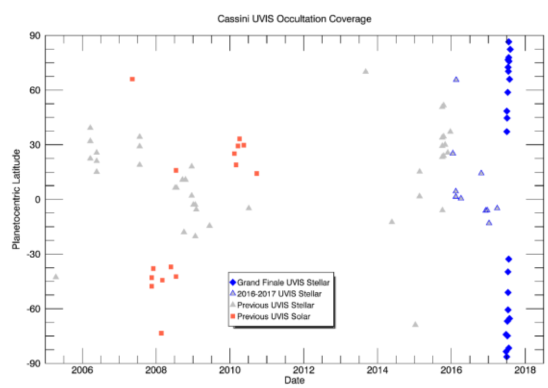

Figure 1. Coverage Map of Cassini UVIS occultations. We report on Grand Finale observations (blue diamonds) and observations made in 2016 and 2017 (blue triangles).

2. Methods

We retrieve H_2 density profiles from transmission in the Lyman and Werner electronic bands from UVIS EUV channel occultation data and invert density profiles to retrieve temperature using methods adapted from Koskinen et al. [3]. Because the cross section of H_2 in these bands is highly sensitive to temperature, we use an iterative process to fit forward model column densities to the observed line of sight transmission profiles. To retrieve CH_4 density profiles, we use FUV channel data in the continuum. Because the continuum cross sections are not significantly dependent on temperature, CH_4 does not require iterative retrieval.

To estimate horizontal winds from H_2 density profiles, we interpolate pressures determined from retrieved number densities for each observation to three pressure levels (10 nanobar, 1 nanobar, 0.1 nanobar) and determine gravitational potentials using the Anderson and Schubert [1] reference geoid. We then fit a six-degree polynomial to the kronopotentials and estimate zonal geostrophic winds from the potential gradient. We estimate horizontal winds based on equations 16 and 17 in Larsen and Waltersheid [5], which assume a balance between ion drag, pressure gradient, and Coriolis forces, and which we have modified to apply to both hemispheres and to reflect the difference in magnetic field direction at Saturn.

3. Results

We describe features of the thermospheric temperature distribution, including a surprising trend in the polar temperatures. Based on previously published data, results from the Saturn Thermosphere-Ionosphere general circulation model (STIM) published in 2012 [6] predicted Saturn's high altitude thermospheric temperatures would increase slightly poleward of 60° and plateau nearing the poles. Instead, we find that high altitude temperatures fall by over 100 K between middle latitudes and the poles in both hemispheres, suggesting that polar regions are subject to cooling that is so far not included in the model. Here we also compare our retrieved temperatures to the latest 2019 STIM results [7].

In addition, we present the results of our horizontal wind estimates, which show evidence for broad mid- to high latitude zonal jets at the pressure levels sampled. As with temperature, we compare our estimated winds to the latest STIM model predictions [7]. Finally, we report on results of our retrieved methane density profiles and comment on future work.

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