EPSC Abstracts
Vol. 13, EPSC-DPS2019-1019-1, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Results from an Improved Model of Electrodynamics in Saturn's Upper Atmosphere

Jess Vriesema (1), Tommi Koskinen (1), Roger Yelle (1) and Ingo Müller-Wodarg (2)
(1) Lunar and Planetary Laboratory, USA, (2) Imperial College London, United Kingdom (vriesema@lpl.arizona.edu)

Abstract

Recent observations of magnetic field perturbations in Saturn's upper atmosphere, obtained by the Cassini MAG instrument during the Grand Finale tour, strongly suggest the presence of equatorial electrodynamics [5], which is associated with in-situ resistive heating and ion drag. This indicates that low-latitude electrodynamics may play an important role in controlling the dynamics, energy balance and variability of the neutral gases, ions and electromagnetic fields. In order to explore the consequences of low-latitude electrodynamics in more detail, we couple the Saturn Thermosphere-Ionosphere Model (STIM, [7, 8]) to an axisymmetric model of a wind-driven dynamo [9], and present a more general calculation of electric currents. To the best of our knowledge, this is the first time such a coupled model has been used to simulate electrodynamics in solar system giant planet atmospheres. We use the model to simulate the global impact of both auroral and dynamo-driven electrodynamics on Saturn's upper atmosphere.

1. Introduction

The global role of electrodynamics of Saturn's ionosphere and thermosphere is largely unknown. Measurements of significant azimuthal magnetic field perturbations by the Cassini MAG instrument during the Cassini Grand Finale [3] provide evidence of ionospheric electrodynamics at low latitudes, possibly driven by an equatorial jet [5, 12].

Auroral heating is thought to be more than sufficient to explain the observed temperatures at low latitudes provided that it could be distributed globally [2, 6]. However, Smith et al. [11] and Müller-Wodarg et al. [7] concluded that the Coriolis force at high latitudes, enhanced by ion drag, should effectively prevent equatorward transport of auroral energy. More recently, Müller-Wodarg et al. [8] included zonal Rayleigh drag in STIM that allows for the auroral energy to be redistributed to match the observed temperatures as a function of latitude. Such drag can be attributed to atmospheric waves and/or a more detailed calculation of ion drag at low to middle latitudes. Resistive heating by the newly discovered equatorial current system can also contribute to heating low latitudes and alter circulation. Here, we study ion drag and resistive heating in more detail to better quantify their role in Saturn's upper atmosphere.

2. Methods

STIM is a general circulation model that numerically solves the coupled, nonlinear, three-dimensional Navier-Stokes equations of momentum, energy and continuity for the major species in Saturn's upper atmosphere (e.g. [7]). STIM's previous electrodynamics formulation was implemented by [7] to study the response of Saturn's ionosphere and thermosphere to steady-state polar forcing. This formulation, intended for high latitudes, calculated current density at each grid point via a layer conductivity approximation [10] that assumes zero vertical current and is singular at the magnetic equator. We have implemented a more general calculation of current density in STIM that does not have vertical currents to be zero and is valid at all latitudes.

In order to simulate electric currents generated by the wind dynamo, we calculate an axisymmetric polarization electric field according to Richmond [9] and Vriesema et al. [12], and couple it to STIM. This formulation calculates the perpendicular polarization electric field via the continuity equation for current density in the meridional plane. For the purposes of the dynamo model, we assume infinite parallel conductivity and Saturn's magnetic field to be a dipole shifted northward along the axis by 0.0466 Saturn radii [3]. The assumption of infinite parallel conductivity means that the product of a geometric scale factor and polarization electric field is constant along magnetic field lines.

Finally, if the MAG observations are to be explained by ionospheric electrodynamics, they imply the presence of an equatorial zonal jet, presumably propagating from below [5, 12]. We investigate electrodynamics in the presence of such an equatorial jet by imposing the zonal wind as a lower boundary condition in STIM according to the description in Friedson and Moses [4].

3. Results

In the absence of the wind dynamo, relaxing the layer conductivity approximation leads to relatively small changes in high-latitude temperature structure that nevertheless help to match the observed temperature structure better [1]. In addition to exploring the polar temperature structure, we will describe how including the wind dynamo in our model affects the circulation and temperature profile at other latitudes. Finally, we will present results that more closely match the MAG data and discuss their implications for Saturn's upper atmosphere.

Acknowledgements

Jess Vriesema was supported by the NASA Earth and Space Sciences Fellowship Program (Grant NNX16AP55H). Tommi Koskinen and Roger Yelle acknowledge support from the Cassini Data Analysis Program (Grant NNX15AN20G).

References

[1] Brown, Z., et al.: Thermospheric Circulation and Pole-to-Pole Temperatures from Cassini Grand Finale Occultations, submitted to *European Planetary Science Congress*, 2019.

[2] Cowley, S. W. H., Bunce, E. J., and O'Rourke, J. M.: A simple quantitative model of plasma flows and currents in Saturn's polar ionosphere, *Journal of Geophysical Research: Space Physics*, 2004.

[3] Dougherty, M. K., et al.: Saturn's magnetic field revealed by the Cassini Grand Finale, *Science*, Vol. 362(6410), 2018.

[4] Friedson, A. J., and Moses, J. I.: General circulation and transport in Saturn's upper troposphere and stratosphere, *Icarus*, Vol. 218(2), pp. 861–875, 2012.

[5] Khurana, K. K., et al.: Discovery of Atmospheric-Wind-Driven Electric Currents in Saturn's Magnetosphere in the Gap Between Saturn and its Rings, *Geophysical Research Letters*, pp. 1–7, 2018.

[6] Müller-Wodarg, I. C. F., et al.: A global circulation model of Saturn's thermosphere, *Icarus*, Vol. 180(1), pp.147–160, 2006.

[7] Müller-Wodarg, I. C. F., et al.: Magnetosphere-atmosphere coupling at Saturn: 1 - response of thermosphere and ionosphere to steady state polar forcing, *Icarus*, Vol. 221(2), pp. 481–494, 2012.

[8] Müller-Wodarg, I. C. F., et al.: Atmospheric Waves and Their Possible Effect on the Thermal Structure of Saturn's Thermosphere, *Geophysical Research Letters*, Vol. 46(5), pp. 2372–2380, 2019.

[9] Richmond, A.: Equatorial electrojet I. Development of a model including winds and instabilities, *Journal of Atmospheric and Terrestrial Physics*, Vol. 35(1967), pp. 1083–1103, 1973.

[10] Rishbeth, H., and Garriott, O. K.: *Introduction to Ionospheric Physics*, Vol. 14 of *International Geophysics*, Academic Press, 1969.

[11] Smith, A. D., et al.: An unexpected cooling effect in Saturn's upper atmosphere, *Nature*, Vol. 445(7126), pp. 399–401, 2007.

[12] Vriesema, J. W., Koskinen, T. T., and Yelle, R. V.: Electrodynamics in Saturn's Thermosphere at Low and Middle Latitudes, submitted to *Icarus*, 2019.