A preliminary study of Magnetosphere-Ionosphere-Thermosphere coupling key parameters at Jupiter Based on Juno multi-instrument data and modelling tools

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Abstract: The dynamics of the Jovian magnetosphere is controlled by the interplay of the planet’s fast rotation, its solar-wind interaction and its main Io plasma source. Magnetosphere-ionosphere-Thermosphere (MIT) coupling processes controlling this interplay are significantly different from their Earth and Saturn counterparts. At the ionospheric level, they can be characterized by a set of key parameters (ionospheric conductances, electric currents and fields, exchanges of particles along field lines, Joule and particle energy deposition, etc.) from which one can determine (1) the closure of magnetospheric currents into the ionosphere, and (2) the net deposition/extraction of momentum and energy into/out of the upper atmosphere associated to MIT coupling.

We present a method combining Juno multi-instrument data (MAG, JADE, JEDI, UVS, JIRAM and Waves) and modelling tools to provide preliminary estimates of these key parameters along the Juno’s ionospheric magnetic footprints. We apply this method, as a first test, to the case of one particular main auroral oval crossing (PJ6-South) to present preliminary estimates of the ionospheric closure of magnetospheric field-aligned currents, of the resulting ionospheric conductances, currents and fields and of their control by electron precipitation. This synergistic use of data and models will be extended in the near future to a larger set of Juno orbits to progressively build a comprehensive view of MIT coupling at Jupiter and to provide a better determination of parameters not directly measured by Juno, such as the vertical structure of the Jovian upper atmosphere.

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The dynamics of Jovian plasma is controlled by MIT coupling processes involving exchanges of particles, fields, waves and electric currents between the three regions illustrated in Figures (I) and (II): magnetosphere, polar and auroral magnetic field lines, and ionosphere/thermosphere.

The physical quantities and objects involved in the coupling of these three regions (solid boxes) and some of the associated processes (dash-dotted boxes) are shown in (III).

This study focuses particularly on the relationship between measurements of magnetic field and particles with Juno and the parameters characterizing current flows and energy dissipation at ionospheric altitudes.
Main methodology elements:

- Use of in-situ and imaging **Juno data (I above)** as inputs to three basic models: atmosphere, ionosphere, electrodynamics (next slide).
- Combined use of models and **Juno data** to determine the key parameters of MIT coupling (II above).
- Derivation of **ionospheric currents and fields, field-aligned currents** at top of ionosphere conductor and ionospheric Joule heating under the simplifying assumption of “weak variations” along auroral oval (see III).
Monoenergetic beams

Precipitating particle ionization rate from continuous slow-down approximation (8,15); Conductances for a H$_3^+$ ionosphere (8,15);

Pedersen and Hall conductances have similar magnitudes;

Hall/Pedersen ratio increases with precipitating e- energy

Energy of precipitating e- modulates intensity and direction of ionospheric currents

Variations of all quantities along the auroral oval << variations across the oval.

\[ \frac{\partial}{\partial x} \ll \frac{\partial}{\partial y} \]

2. Relationship between $\delta B$ (Juno) and electric currents:

\[ \nabla \times \vec{B} = \mu_0 \vec{J} \]

\[ \nabla \cdot \vec{J} = 0 \]

3. Derivation of ionospheric currents, fields and Joule heating $Q_T$:

\[ J_y \]

From $\delta B$

\[ \Sigma \]

From JADE & JEDI

\[ E_s = 0 \]

\[ J_s = \frac{\sum \mu J}{\sum P} \]

\[ E_y = \frac{J_y}{\sum P} \]

\[ Q_j = \frac{J_s}{\sum P} \]
Results for a First Case: PJ06 South

The auroral Pedersen and Hall conductances are variable over large scales from ~1 mho to over 10 mhos during the traverse across the main oval, and are correlated with the electron precipitations (see Panels a and b).

Juno passes inside a radio emission source between 06:50:14 and 06:52:50 seen by Waves (panel (e)) and coincident with intense upward-going electrons (panel d). It may be associated to a weak downward FAC just before the strong upward current sheet crossing (blue shading), as suggested by panel c.

Electric field across the oval and Joule heating are low in the main two Field-Aligned-Current (FAC) sheet crossings, but reach their maxima in the region between them. This is the result of the closure of these two FACs in a region of very low ionospheric conductances.

A total electrostatic potential drop on the order of 2.2 MV at ionospheric altitudes between the upward and downward FACs can be estimated from the integration of the electric field. The main voltage drop occurs in the region of low precipitation and low conductance (or high resistivity) of the ionospheric conductor in-between the two FACs.

During the traverse of the radio emission region, bidirectional electron beams in the loss cone were observed with comparable total energy flux for upward/downward electrons.

Orders of magnitudes of the “key parameters” found during the main oval crossing for PJ06S:

- $\Sigma_P \sim 3$ mho, $\Sigma_H \sim 5$ mho
- $J_x = 1000$ mA/m, $J_y = -560$ mA/m; $J_{//} = 2$ uA/m²
- $E_y \sim [-300, 400]$ mV/m
- Potential drop between the two FAC sheets: 2.2 MV
- Joule heating: ~100 mW/m²
- Electron precipitation energy flux: ~100 mW/m²
We are very grateful to NASA and to the contributing institutions that have made the Juno mission possible, and to all institutions supporting the development, operation and data analysis of the Juno instrument suite used in this study: MAG, UVS, JIRAM, JADE, JEDI, Waves. The French authors wish to express their gratitude to CNES for its support to their participation in the Juno mission. All Juno data used in this study are archived and available in NASA’s Planetary Data System and, for particles-and-fields data, in the CDPP (CNES-CNRS).