PROPERTIES OF THE AURORAL ZONE IONOSPHERE INFERRED USING PLASMA CONTACTOR DATA FROM THE INTERNATIONAL SPACE STATION

Edgar A. Bering, III(1,2)**, Steven L. Koontz**(3)**, David S. Evans**(4)**, Ira Katz**(5)**, Barbara Gardner**(6)**, Robert M. Suggs**(7)**, Joseph I. Minow**(7)**, Penni J. Dalton**(8)**, Dale C. Ferguson**(8)**, G. Barry Hillard**(8)**, Jerry L. Counts**(9)**, Hagop Barsamian**(10)**, John Kern**(10)**, and Ronald Mikatarian**(10)

(1)University of Houston, Physics Department, 617 Science & Research 1, Houston, TX, 77204-5005, USA, e-mail: eabering@UH.edu

(2)ASPL/JSC / NASA,13000 Space Center Blvd., Houston, TX, 77059, USA, e-mail: edgar.a.bering1@jsc.nasa.gov

(3)JSC / NASA, Code ES2, 2101 NASA Rd 1, Houston, TX, 77058, USA, (4) NOAA,Space Environment Center, Boulder, CO, USA, (5)JPL / NASA, 4800 Oak Grove Dr., Pasadena, CA, 91109, USA, (6)SAIC,10260 Campus Pt. Dr. San Diego, CA, 92121, USA, (7) MSFC/ NASA, Code ED44, Marshall Space Flight Center, AL, 35812, USA, (8) GRC/ NASA, 2100 Brookpark Rd., Cleveland, OH, 44135, USA, (9)Boeing, Rocketdyne Propulsion and Power Division, Canoga Park, CA, USA, (10)Boeing, ISS, Houston, TX 77058, USA

ABSTRACT

The International Space Station (ISS) has two plasma contactors that emit the electron currents needed to balance electron collection by the lattice of bare rods on the solar array masts. During the first months of 2001, these currents exceeded 0.1 A in the auroral oval south of Australia. When subject to orbital **v**x**B•l** induced potentials, the mast rods collect substantial currents. The PCU current gave an estimate of plasma density that was often larger than model predictions.

INTRODUCTION

The International Space Station (ISS), is being constructed in a low earth orbit with an altitude of ~375 km and a relatively high inclination, 51.5º. Comparison of the auroral electron precipitation maps produced by the NOAA POES satellite constellation with the flight path of the ISS reveals that ISS regularly passes through the southern auroral oval south of Australia. The ISS orbit often passes through the austral auroral oval south of Australia, where the equatorward edge of the oval is at its most northerly location. Observation of the aurora by ISS crew has confirmed that the station passes directly through auroral forms at active times.

This paper will present measurements of the properties of the F region ionosphere that were measured on the ISS by the plasma diagnostic instrumentation onboard. This instrumentation is there because the ISS has a problem with the electrostatic potential that the ISS structure, which is the electrical ground for the station, can achieve relative to the ambient plasma and the associated shock hazard that this situation might represent for EVA personnel [1, 2]. The problem arises because it has not proven possible to build lightweight efficient photovoltaic solar power arrays (PVA's) that do not have exposed electrical connections. In the case of ISS, this exposure means that there are exposed points in the PVA's that are at 160 V positive potential with respect to the ground of the spacecraft. These points attract electrons and draw significant currents (up to ~400 ma at the present) from the surrounding plasma. What this current can do, if not controlled, is to drive the spacecraft ground far enough negative to collect enough ion current to balance the electron current. At present models have shown that, in the absence of any mitigation, that the ISS ground can be as low as –90 to –120 V with respect to plasma [3]. This occurs in full ram orientation, in sunlight, not during wake or eclipse period if not controlled. Most of the exterior surfaces of the ISS are anodized with a thin coating of dielectric, insulating material, which means that the outer surface of this dielectric can become one plate of a highly charged capacitor. Since the material is thin, this configuration has a relatively large capacity. The predicted potentials are far greater than those that could be stood off by the anodized aluminum surfaces on ISS, so that ISS would arc due to dielectric breakdown [4]. These arcs could have consequences ranging from a steady degradation of ISS surface thermal properties to possibly life threatening currents flowing through an astronaut's space suit. The result is a substantial electrostatic shock hazard for EVA personnel [5]. The control strategy that has been developed is the addition of two electron emitting plasma contactor units (PCUs), each containing an Hollow Cathode Assembly (HCA) for the discharge of the electrons. These PCUs are located near the ISS structure midpoint [6, 7, 8]. An instrument called the floating potential probe (FPP) provides short-term verification of the control strategy and PCU function [9, 10, 11, 12]. The FPP measures plasma potential relative to ISS ground. By emitting a highly conductive xenon plasma, these PCUs can efficiently emit electrons collected by the solar arrays, and thus keep the ISS structure at nearly the same potential as its surrounding plasma, so-called "plasma ground." The currents emitted by the PCU’s are measured in real-time and recorded continuously.

During the first few months of 2001, the station flew in an orientation such that the active side of the solar arrays were slightly into the wake, about 10º, and didn’t collect electron current from the ionosphere. However, during this period, the station’s plasma contactor emitted currents that, at times, exceeded 0.1 A. The largest currents frequently occurred as the station was passing through the southern auroral oval. In this paper we will discuss how ISS current measurements show that the ambient electron current density in the nighttime auroral ionosphere is frequently several times that predicted by the International Reference Ionosphere (IRI)-90 model. The IRI 2001 model appears to work better as a predictor of the data.

Two models were used; a simple approximate analytic model and a much more detailed computer code termed the Space Station Environment WorkBench (EWB). During certain periods, the electron current collected by the masts was much larger than predicted by EWB. Analysis of the results indicate that the IRI-90 model of the ionosphere used by EWB doesn’t account for plasma temperature and density enhancements due to auroral activity, and that the ISS plasma contactor emission current provides a good measure of the electron thermal current in the ambient ionosphere.

The reason that the IRI-90 (and therefore EWB) provides a relatively poor estimate of the plasma contactor emission current may be found in the physics of the aurora. The biggest anomalies are found in the Southern hemisphere south of Australia. Owing to the offset of the Earth’s magnetic dipole, the auroral oval gets closest to the geographic equator in this sector. The location and intensity of auroral precipitation may vary by 100’s of km and orders of magnitude respectively. At space station altitude, the geographic asymmetries of the Earth’s magnetic field require the use of a semi-empirical model that separately sorts data by geomagnetic conditions, geographic location, magnetic local time, and geomagnetic activity level. Thus, there is a continuing need for more observations of the plasma properties of the ionosphere. We will use the plasma contactor data to provide some insight into the station plasma environment. The observed plasma contactor emission current can be converted to an estimate of ionospheric plasma density if we know the local electron temperature. This parameter was not independently measured, so IRI-2001 is used to estimate it and thereby to infer plasma density, using the simple analytic current collection model. The central physics idea is that the tensioning rods on the space station solar array masts collect current from the ionosphere in the same way as a bare wire electrodynamic tether. On the space station, the solar array 40-meter long masts each have over 400 meters of stainless steel tensioning rods. When subject to orbital $\mathbf{v}\times\mathbf{B}\cdot\mathbf{l}$ induced potentials, the rods collect currents from the ionosphere. The station’s plasma contactor emits the net electron collection by the masts. During the period being analyzed, the station flew in a orientation such that the solar array masts were perpendicular to the orbital velocity vector, and horizontal, that is parallel to the earth’s surface. In the space station case, maximum $\mathbf{v}\times\mathbf{B}\cdot\mathbf{l}$ potentials are generated near the magnetic poles, when the vertical component of the earth’s magnetic field is greatest. The current drawn by the masts is linearly proportional to the local plasma density.

EXPERIMENTAL RESULTS

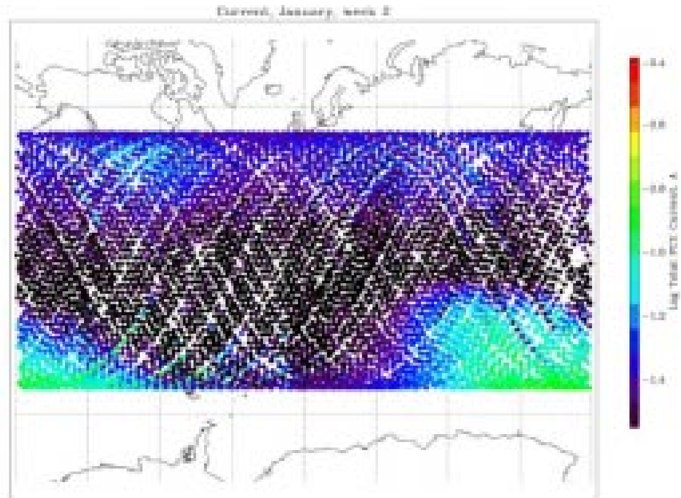

Figure 1. The total PCU current plotted in false color along the ISS orbit on a map of the Earth

The data were plotted using a false color mapping approach. Figure 1 shows one-minute averages of two weeks data, plotted in geographic coordinates using a false color scale to indicate the total of the two PCU currents. Generally, the data support the hypothesis that the current peaks are the result of increased tension wire current collection owing to an increased **vxB** potential on the outer ends of the PVA arrays. Furthermore, the location of most of the most intense current spikes is consistent with the interpretation that these events were the result of passage through auroral arcs. It is important to note that the strongest current event of the interval appears south of New Zealand in a likely location for an auroral arc.

We have developed an analytic approximation that can be used to infer electron density from the PCU emission current data. It approximates the ISS as one ion collecting plate and an array of rods the same size as the tensioning array. Instead of IRI-90, it uses IRI-2001 to predict the electron temperatures. Since we are solving for density, the model will have too many free parameters if the floating potential is also predicted, so we assume that V_{body} ~ -6V. It then solves for N_e that is required to predict the observed PCU current. Since the V_{body} is held fixed, the model fails at low current near the equator, where the low **vxB** potential reduces the electron current and allows the ISS potential to rise closer to ground. There are regions where the model doesn't work. As shown in Figure 2, these regions are the regions near the equator where very little current was collected by the PCU. The inversion infers very high densities at the edges of the low current regions. These are obvious artifacts of the model failing as the total current falls below useful levels. The region where the data are valid are the poleward strips of nearly solid color in Figure 2.

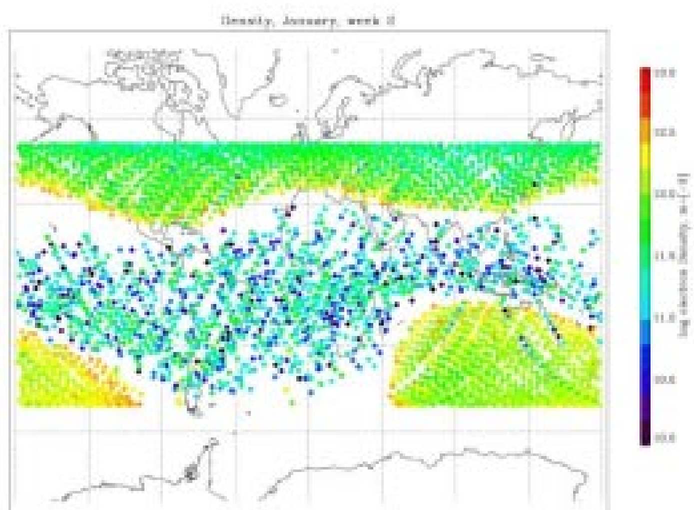

Figure 2. The density inferred from the data in Figure 1, plotted in a similar format.

For comparison, Figure 3 shows the predictions of IRI-2001 for the ISS orbit track during January 2001. In the region of validity the data were somewhat higher than the model prediction, particularly in the Southern hemisphere. In terms of the pattern of geographic variation, the agreement is quite good.

CONCLUSIONS

The basic physics of current collection by the ISS has been identified. Positive **v x B** potentials on the PVA tension wires collect electron currents at high latitude. Ionospheric electron density can be inferred from PCU data at high latitude. Auroral activity produces significant electron density enhancements above the values predicted by the statistical models. On the other hand, geomagnetic activity does **not** strongly organize the data. The ISS Environment has been shown to be clean enough to permit collection of useful ionospheric observations that show no obvious evidence of degradation owing to contamination or poor signal to noise ratio.

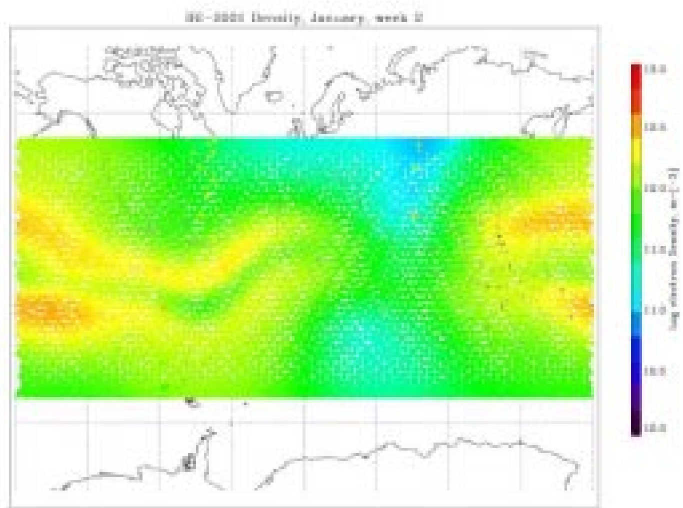

Figure 3. The plasma density predicted by IRI-2001 for the ISS orbit during the interval shown in Figure 1.

ACKNOWLEDGMENTS

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