IN11B-1531 Near Real Time Tools for ISS Plasma Science and Engineering Applications

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Abstract

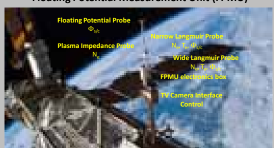
The International Space Station (ISS) program utilizes a plasma environment forecast for estimating electrical charging hazards for crews during extravehicular activity (EVA) [*Koontz et al.*, 2012]. The process uses ionospheric electron density (Ne) and temperature (Te) measurements from the ISS Floating Potential Measurement Unit (FPMU) instrument suite with the assumption that the plasma conditions will remain constant for one to fourteen days with a low probability for a space weather event which would significantly change the environment before an EVA. FPMU data is typically not available during EVA's, therefore, the most recent FPMU data available for characterizing the state of the ionosphere during EVA is typically a day or two before the start of an EVA or after the EVA has been completed.

Three near real time space weather tools under development for ISS applications are described here including:

(a) Ne from ground based ionosonde measurements of foF2
(b) Ne from near real time satellite radio occultation measurements of electron density profiles
(c) Ne, Te from a physics based ionosphere model

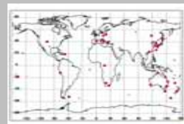
These applications are used to characterize the ISS space plasma environment during EVA periods when FPMU data is not available, monitor for large changes in ionosphere density that could render the ionosphere forecast and plasma hazard assessment invalid, and validate the "persistence of conditions" forecast assumption. In addition, the tools are useful for providing space environment input to science payloads on ISS and anomaly investigations during periods the FPMU is not operating.

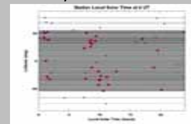
Floating Potential Measurement Unit (FPMU)



The ISS FPMU instrument suite includes two Langmuir probes, a plasma impedance probe, and a floating potential probe to provide redundant measurements of ionospheric Ne and Te and vehicle floating potential [*Wright et al.*, 2008; *Barjatya et al.*, 2009]. FPMU data is encoded in a video signal and downlinked through the ISS Ku band telemetry system. Signal acquisition and data processing is accomplished on the ground and a live signal from orbit is required to obtain the FPMU data.

Ionosonde Electron Density Tools

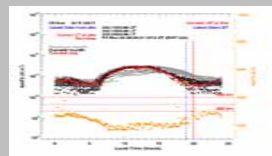




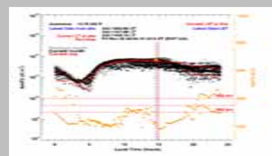
(a) Stations providing real time data (b) Local solar time and latitude coverage

NOAA Space Weather Prediction Center provides near real time ionosphere parameters from ionosonde stations distributed over a wide range of geographic locations. We use the F2-region foF2 and hmF2 parameters to update local solar time plots of NmF2 showing records from the current day, the current month, and the previous month to monitor for changes in the current F2-region peak electron density compared to recent history. Time resolution from different sites vary from 5 minutes to 60 minutes and the files are updated two times an hour.

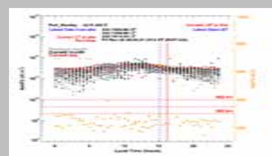
High northern latitude station



Equatorial station



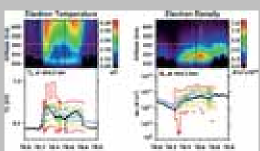
High southern latitude station



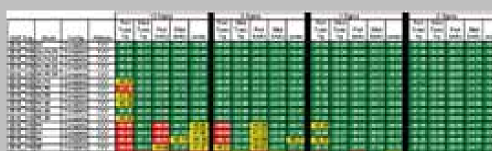
Plasma Hazard Evaluation for EVA Safety

Electric potentials on the ISS structure relative to the plasma background vary over an orbit due to the combined effects of inductive electric fields due to the motion of the vehicle across the geomagnetic field and current collection by the 160-volt solar array power system. Charge distributions due to these potentials represent a possible catastrophic hazard to crew safety during EVA. Hazards are mitigated operational by two Plasma Contactor Units UPCU) which dissipate the excess electrical charge. Two PCU's provide two redundant controls but a third control is required to meet NASA two-fault tolerant safety requirements to mitigate potentially catastrophic hazards in case one of the PCU's should fail. The third control has traditionally been provided by an emergency solar array shut down process of all eight ISS 160 V arrays which stops the contribution of solar array current collection to the charging process followed by reactivation of only two arrays allowing the EVA to proceed, albeit at reduced ISS power levels [*Koontz et al.*, 2012, 2013].

A modified version of the hazard control process is now used by the ISS program that allows more than two arrays to be used following a PCU failure when conditions in the ionosphere are such that reduced charging is expected from solar interaction with the ambient plasma. FPMU Ne and Te values are compared to output from an empirical ionosphere variability model [*Minow*, 2004] to determine if the current state of ionosphere relative to the IRI-2001 model is best represented as a +/-2σ, +/-1σ, or 0σ (nominal) environment. The statistical model output is then used as input to an ISS charging code to determine what solar array configurations will allow an EVA to continue without violating a -45.5 volt charging safety limit established for EVA [*Koontz et al.*, 2012]. The ISS Program is now considering options to eliminate use of the PCU's and extending the Ne, Te predictions to 14-days by using FPMU measurements two weeks in advance of an EVA and assuming the ionosphere does not change sufficiently to impact the charging based on a "persistence of conditions" forecast assumption. The space weather tools we show here are being developed for use in documenting the state of the plasma environments during EVA periods when FPMU data is not available and for monitoring for changes in the environment that would invalidate the plasma hazard forecasts.



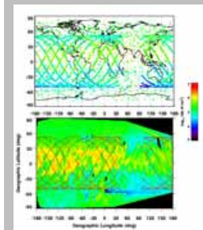
[*Minow*, 2004]

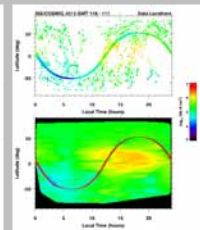


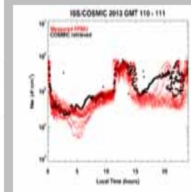
[*Koontz et al.*, 2012]

COSMIC Electron Density Tool

Between 500 and 1000 GPS radio occultation measurements are obtained every day from the COSMIC/FORMOSAT-3 constellation over a wide range of latitudes and longitudes. Ground based processing at the COSMIC Data Analysis and Archival Center (CDAAC) produces altitude profiles of electron density Ne(z) that are available to the ionospheric physics community both as near real time data products and as historical records. The COSMIC Electron Density Tool extracts the electron density at the mean ISS altitude Ne(z) from the profiles and uses them to generate an electron density "surface" from which the electron density along the ISS orbit Ne(s) is extracted.







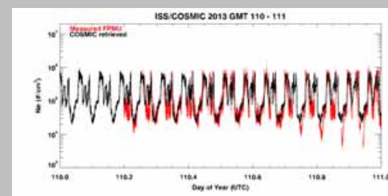
(a) Geographic latitude, longitude (b) Local solar time, geographic latitude (c) Measured, Retrieved Ne(s) for ISS Orbit

We first show an example of Ne(s) retrieval along the ISS orbit for GMT 2013/110 using the technique. Both COSMIC (1135 profiles) and FPMU data (52,015 records) are used to generate the Ne surface at the mean ISS altitude of 416 km. Distribution of data is first shown in (a) geographic coordinates and then in (b) local solar time (LST)-latitude along with a reconstructed Ne surface for each case. Ne(s) is extracted from the LST-latitude surface which best orders the Ne data relative to the ISS orbit. A comparison of (c) retrieved Ne values with FPMU Ne measurements show a good agreement with some discrepancies in the morning (3 hr < LST < 7 hr) and early night (16 hr < LST < 22 hr) sectors.

Retrieved Ne using both COSMIC and FPMU data compared to FPMU Ne measurements as a function of time to demonstrate the utility of the tool for filling periodic short gaps in FPMU data as well as extended periods of missing data.

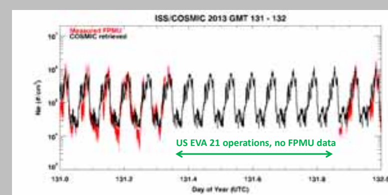
Data gaps occur in FPMU data as a result of incomplete coverage between ISS and the NASA TDRS satellites used for ISS orbit to ground communications.

FPMU data downlink will also be dropped when higher priority video operations require the same high data rate channel required by FPMU operations.

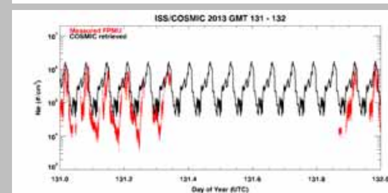


Next, two examples are presented comparing Ne(s) retrieval along the ISS orbit when FPMU data is not available due to EVA activity. US EVA 21 on GMT 2013/131 was a 5 hour, 30 minute EVA conducted on 11 May 2013 to repair components of a leaking ammonia cooling system. FPMU data is missing starting 08:16 UT until 20:52 UT because cameras supporting the EVA were tasked with higher priority than FPMU downlink. Retrieved Ne values are first shown using both COSMIC (774 profiles) and FPMU (29,341 records) data to generate the Ne surface at the mean ISS altitude of 420 km. Finally, only COSMIC data is used to generate the retrieved Ne values.

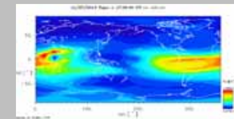
Ne retrieval using both COSMIC and FPMU data. The green bar indicates the period FPMU data is missing. EVA 21 was a subset of this period starting at 12:44 UT and ending 18:14 UT.

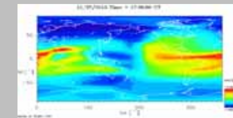


Ne retrieval using only COSMIC data. Reconstructed Ne is better when both COSMIC and FPMU data is used although COSMIC only results still bound Ne at the highest values. Discrepancies at low Ne values are more pronounced without the FPMU data to constrain the density along the orbit.



Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics (CTIPe) Model





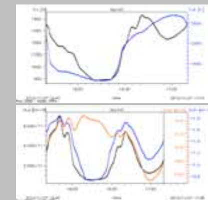
(a) N_e at 400 km (b) NmF2

GSFC's Community Coordinated Modeling Center (CCMC) runs a real time version of the CTIPe model (CTIPe-RT), providing updated ionospheric parameters of interest to spacecraft operators every ten minutes. The maps of (a) Ne and (b) NmF2 at 400 km altitude shown here are useful for comparing the differences between the HmF2 density reported by the ionosonde monitoring tool and the density near the actual ISS flight altitude (~415 km on 27 Nov 2013).

CTIP-e-RT for ISS

(c) T_e, T_i

(d) N_e, N_{O+}, N_{H+}

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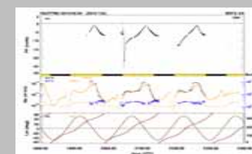
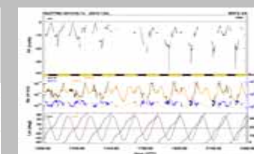
# Satellite TLE:
# ISS
# 1 25544U 98067A 13329.53345040 .00016717 00000-0 10270-3 0 9009
# 2 25544 51.6493 28.9529 0000902 89.4027 270.7227 15.50542373 19738
# Data printout from CCMC-simulation: version 1.2
# Data type: CTIP ionosphere/thermosphere # Run name: 2013-11 Missing data: NaN
# Satellite trajectory file: iss
# Coordinate System: GEO
# Satellite Track: iss
# Output data: field with 1x1081=1081 elements
# Year Month Day Hour Min Sec lon lat alt N_e N_O+ N_H+ T_i T_e
# [year] [month] [day] [h] [m] [s] [deg] [deg] [km] [m^-3] [m^-3] [m^-3] [K] [K]
2013 11 27 18 00  0.000 194.58 29.613 421.34 1.3819E+11 11.134 9.2006 1102.2 1753.4
2013 11 27 18 00  5.000 194.83 29.385 421.23 1.3959E+11 11.138 9.1987 1105.0 1762.1
2013 11 27 18 00 10.000 195.07 29.157 421.12 1.4098E+11 11.143 9.1970 1107.8 1770.8
2013 11 27 18 00 15.000 195.31 28.928 421.02 1.4238E+11 11.147 9.1952 1110.6 1779.5
2013 11 27 18 00 20.000 195.55 28.698 420.91 1.4379E+11 11.152 9.1936 1113.4 1788.2
2013 11 27 18 00 25.000 195.79 28.468 420.81 1.4520E+11 11.156 9.1919 1116.2 1796.9
2013 11 27 18 00 30.000 196.03 28.238 420.70 1.4661E+11 11.161 9.1904 1119.0 1805.6
2013 11 27 18 00 35.000 196.26 28.007 420.60 1.4803E+11 11.165 9.1889 1121.8 1814.3
2013 11 27 18 00 40.000 196.50 27.776 420.50 1.4953E+11 11.170 9.1873 1124.7 1822.8
2013 11 27 18 00 45.000 196.73 27.544 420.40 1.5101E+11 11.174 9.1858 1127.6 1831.2
         <---------------  (records deleted)  ----------------->
2013 11 27 19 29 45.000 161.15 37.537 425.42 1.1209E+11 11.037 9.4068 1021.2 1310.4
2013 11 27 19 29 50.000 161.44 37.334 425.30 1.1334E+11 11.042 9.4032 1026.4 1319.0
2013 11 27 19 29 55.000 161.74 37.130 425.19 1.1461E+11 11.047 9.3996 1031.8 1327.7
2013 11 27 19 30  0.000 162.03 36.926 425.08 1.1593E+11 11.052 9.3959 1037.1 1336.8
```


CTIPe output tailored to specific spacecraft orbits is also available from CCMC. The examples here include (c) electron and ion temperatures and (d) density of electrons, protons, and atomic oxygen along the ISS orbit. CTIPe-RT graphical products are generated from the output text files which are also archived and available to users. Text files are created once every 10 minutes, covering a 90-minute period with records at 5-second time intervals.

Records range from -70 minutes to +20 minutes from file epoch

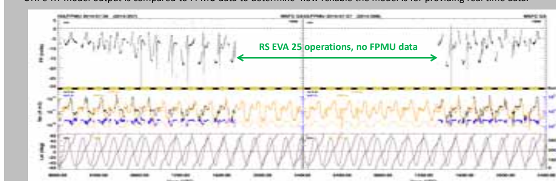
-70 min ← T+ 0 → +20 min
-70 min ← T+10 → +20 min
-70- min ← T+20 → +20 min





(a) GMT 2010/155 (b) GMT 2010/135

CTIPe-RT model output is compared to FPMU data to determine how reliable the model is for providing real time data.



CTIPe-RT model output can be used to fill gaps in FPMU data due to periodic loss of signal when live ISS downlink is not available or when FPMU downlink is dropped for higher video priority operations such as the extensive camera coverage required to support an EVA. This example from 2010 is the gap in FPMU data during a Russian EVA.

Acknowledgements

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