NASA Robotic Missions:
Feedback and Future Needs - ISS

Joseph I Minow
EV44/Natural Environments Branch
NASA/Marshall Space Flight Center

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Space Environment Model, Data Needs

• MSFC’s Environments Branch is an applied science organization utilizing space environment data, models for NASA program support:
  – Characterizing space environments and effects for space system design
  – Launch vehicle space weather constraints
  – On-orbit vehicle operations, science payload support
  – Development of laboratory test protocols for qualifying materials for use in space environments
  – Anomaly investigations

• Today’s presentation gives examples of ISS space weather support activities
  – Introduction to data and model needs for NASA program support
  – ISS plasma instrumentation
  – Examples of data, model use for
    • EVA plasma hazard assessments (PVA charging)
    • ISS plasma interactions, payload science support
    • Anomaly investigations
  – Summary
Applied Space Environment Model, Data Needs

- Characterizing space environments for space system design
  - Historical data, environment models (empirical, physics based)
  - Effects models including surface and internal charging codes, radiation transport codes, single event upset rate calculations

- Launch vehicle space weather constraints
  - Requires data to verify current environment within launch constraint
  - Primarily used by NASA for solar proton launch constraints to protect launch vehicles
  - Evaluating options for establishing constraints for auroral, geostationary orbit charging environments (data? models?)

- On-orbit environments support for vehicle operations, science payloads
  - In-situ data preferred
  - Appropriate independent data (other satellites or ground based sensors) acceptable
  - Data constrained environment models
  - Unconstrained first principle physics models
  - Empirical models

- Anomaly investigations
  - In-situ measurements preferred
  - Measurements from independent spacecraft, ground based sensors acceptable if in-situ not available
  - Data constrained environment models
ISS Structure Potential, Charging Hazards

• ISS frame potential varies in low Earth orbit environment due to:

  **Current collection**
  – Current collection from ambient plasma  
  – 160 V US solar array  
  – Visiting vehicle (high voltage) solar arrays  
  – Operation of payloads that emit current sources  
  – Auroral electrons

  **Voltage Range (Observed to Date)**
  - 0.1 to -0.5 volts  
  -20 to -90 volts  
  -10 volts  
  +10 to +25 volts  
  -20 volts

**Inductive potentials**
– (vxB)\textbf{\cdot}L due to motion across geomagnetic field  
– E\textbf{\cdot}L due to ionospheric electric fields

+/-40 volts  
few volts

• Hazards to vehicle and crew

  – ISS-EVA-305: long term degradation of thin dielectric surface thermal control coatings due to arcing …EVA touch temp violations (eventually)
    ▪ Hazard marginalized by test and analysis - no controls needed

  – ISS-EVA-312: EVA electric shock
    ▪ Hazard 1 - Catastrophic at floating potentials more negative than -40V  
    ▪ Hazard 2 - Critical to catastrophic at positive floating potentials (> 0V)  
    ▪ Hazard 3 – critical to catastrophic ISS electrical power short through EVA crew to ground  
      – Plasma is a secondary cause – one circuit closure pathway

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ISS Program controls plasma hazards through a process of active potential control, operational mitigation strategies, environment monitoring and characterization, and probabilistic risk assessment.

- **Plasma Contactor Units (PCUs)**
  - Provides active ISS “ground” by dissipating excess charge to space
  - Two redundant PCU units provides single fault failure tolerance, two required for EVA

- **Operational control using ISS flight attitude, solar array wing angle, and solar array shunt state**
  - Manages solar array and magnetic induction charging
  - Provides two fault tolerance

- **Floating Potential Measurement Unit (FPMU)**
  - Provides validated measurements of ISS floating potential and ionospheric Ne, Te along ISS orbit
  - Predict EVA charging hazards based on measurements before EVA

- **Boeing/SAIC Plasma Interaction Model (PIM)**
  - ISS charging model validated with FPMU data
  - Predicts charging hazard severity and frequency of occurrence
Floating Potential Measurement Unit (FPMU)

**FPP:** Floating Potential Probe

**WLP:** Wide-sweep Langmuir Probe

**NLP:** Narrow-sweep Langmuir Probe

**PIP:** Plasma Impedance Probe

**Role:**
- Validation of PIM
- Assess PV array variability
- Interpreting IRI predictions
- Characterize ISS charging

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<th>Sensor</th>
<th>Measured Parameter</th>
<th>Rate (Hz)</th>
<th>Effective Range</th>
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[Wright et al., 2008; Barjatya et al., 2009]

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Characterizing ISS Environments, Charging

\[ (V_{\text{ISSxB}}) \cdot L \]

- Eclipse exit charging
- Equatorial charging

\[ \text{ISS/FMU 20080310 (2008/070)} \]

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Alternative Ne, Te Data and/or Model Sources

We have in-situ FPMU Ne, Te measurements along ISS orbit that we use for
- Assessing plasma hazards for charging before EVA’s
- Characterizing ISS plasma environment for payloads, other science collaborations

…but we are interested in identifying independent Ne, Te data sources from both measurements and models appropriate for ISS altitudes

- FPMU data unavailable during EVA, docking, and other operations with higher Ku band video downlink priority
- Ku band downlink is real time so we lose data during gaps in ISS to TDRS downlink
  - Real time data, models may be useful to provide coverage during these periods

- FPMU operated on campaign basis (~25 to 30% of year)
  - Well validated models or alternate data sources can provide environment characterization data between FPMU runs

- Contingency planning in case of FPMU failure
  - Default to current “worst case” analysis for EVA planning…but that impacts ISS power availability
  - Alternative data, validated models could provide operations relief to power constraint
FPMU Data Unavailable During EVA

RS EVA 25 (2010)
No FPMU data
CCMC Real-time Ionosphere Ne, Te for ISS

Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics (CTIPe) Model

- CCMC implemented real time CTIPe model in spring 2010 (CTIPe_RT) with output specific for ISS orbit
- ISS ephemeris from GSFC/SSCWeb
- New record every 10 minutes gives 90 minutes of data at 5 sec time steps

-70 min from file epoch to +20 min

---

CTIPe_at_ISS_20100909_192000.txt

# Data printout from CCMC-simulation: version 1.1
# Data type: CTIP ionosphere/thermosphere
# Run name: 2010-09 Missing data: -1.100E+12
# Coordinate System: GEO
# fixed dipole tilt angles used: SM-GSM: 0.0000 GSM-GSE: 0.0000
# Satellite Track: iss
# Output data: field with 1x1081-1081 elements

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CTIPe_RT output at CCMC:

Integrated Space Weather Analysis System (iSWA)
http://iswa.gsfc.nasa.gov/iswa/iSWA.html

Anonymous ftp
ftp://hanna.ccmc.gsfc.nasa.gov/

CTIPe Model Description:

MSFC is evaluating CTIPe_RT for possible ISS ops use:

• Periodically download text output files and process into daily data sets retaining the unique records

• Compare CTIPe_RT Ne, Te with measurements from FPMU

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Good CTIPe_RT/FPMU Comparison

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Characterizing High Latitude Charging Environment

• ISS environments teams are investigating variations in physics of eclipse exit charging
• CTIPe_RT model confirmed physical origin of the plasma depletions for charging events observed at high latitudes, allows us to predict periods for studying charging phenomenon

10-17 UT Eclipse Exit
Normal charging (NC) events observed at eclipse exit

17 – 24 UT Eclipse Exit
Rapid charging (RC) events observed when eclipse exit occurs in low density plasma troughs
Auroral Charging

ISS/FPMU 2008/03/26 (2008/086)

-38 V

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Auroral Charging

26 Mar 2008  07:30 – 08:00 UT

JHU/APL Ovation

Normalized B2I = 62  Flux = 726 MWs
Equivalent Kp = 3.0  Global E- E-Flux = 23.0 MW

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[Craven et al., 2009; Minow et al., 2011]
Solar Activity and CME Monitoring

X-ray flare, type II radio emission, halo CME alerts
- NOAA/SWPC, CCMC, SIDC

Models used to estimate shock arrival time
- NOAA/WSWPC, CCMC WSA-Enlil solar wind models
- CME transit time empirical models

ISS applications:
- Support FPMU campaigns to investigate auroral charging of vehicle
- Alert ISS crew (D. Pettit/Exp. 30) for auroral observation opportunities
- Space situational awareness for storm driven changes in solar array charging environments
  - EVA support
  - Anomaly investigations

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Gopalswamy et al. 2000; Wang et al. 2002; Zhang et al. 2003
Canary: USAF Academy (G. McHarg), JHU/APL
- Investigate ion interactions with ISS background plasma environment
- Target of opportunity to sample ram ions provided by ISS flight attitude when STS docked
- Correlate shifts in Canary energy spectrum, ion density with FPMU measured floating potential, ion density

Primary Arcing of Solar Cells at LEO (PASCAL): Lockheed Martin (J. Likar), Kyushu Inst Tech, JAXA
- Solar array arcing experiment
- Plasma diagnostics not included in package for evaluating current collection
- FPMU provides Ne, Te data for computing charging currents to solar cells biased to \( \leq 300 \) volts

Remote Atmosphere and Ionospheric Detection System (RAIDS): NRL (S. Budzien), Aerospace Corp., ONR
- UV/VIS remote sensing of airglow
- Compare RAIDS Ne(z) profiles retrieved from limb radiances with FPMU Ne(s) records at ISS altitude

FPMU data only available for limited campaign periods
- Alternative Ne, Te data source is desirable for full environment coverage for payload support when FPMU data not available

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ISS Anomaly Investigations

Investigations of charging, plasma environments

- Russian GNC computer failure (2007)
- Soyuz pyrobolt failure (2008)
- S-band transmission interruptions (2011)
- PVCU MDM card fault required system reset (2011)

Anomalous ISS 160 volt solar array charging

- FPMU measurements demonstrate floating potential within program requirements
- Boeing/SAIC ISS charging code demonstrates charging within acceptable levels
- Ne(s) along ISS orbit reconstructed from COSMIC Ne(z) profiles demonstrates environment within nominal levels for typical PVA charging

Anomalous plasma environment

- FPMU measured Ne, Te within nominal range
- Ne(s) reconstructed from COSMIC constellation Ne(z) profiles demonstrates environment within flight history
- NOAA SWPC, NGDC records demonstrate low geomagnetic activity

ISS would benefit from additional ionospheric data sources or data constrained models providing Ne, Te along ISS orbit (e.g., GAIM, CTIPe update?)
• ISS Program currently using FPMU Ne, Te in-situ measurements to support operations and anomaly investigations
  – Working to acquire alternative data sources if FPMU is not available

• Work is progressing on CCMC tools for low Earth orbit ionosphere characterization
  – Validation against FPMU data required before model output can be used for ISS operational support
  – Continue comparing CTIP output during FPMU campaigns
  – Results to date have been useful in identifying ionospheric origins of high latitude charging environments
  – WSA-Enlil model very useful for predicting arrival times of CME shocks

• Future needs:
  – Incorporate environment constraints (F107, HPI, etc) used in model in CTIPe_RT output files
  – Implement CTIPe_RT output for ISR, ionosonde sites
    • Provide additional data for validating CTIP output
    • Support validation of real time data to supplement FPMU output
  – Implement assimilative ionosphere models (e.g., GAIM)
    • Models constrained by Ne, Te data better for operations support, anomaly investigations
ISS Space Weather Needs

- Solar activity/thermosphere density prediction and satellite torque/drag predictions for:
  - Mission planning and controllability/real-time operations
  - MM/OD environment evolution

- Meteor storm severity predictions for potential impact to vehicle, operations

- Role of solar/geomagnetic activity/thermosphere in managing ISS crew ionizing radiation dose exposure

- Monitor for changes in the south Atlantic anomaly altitude structure and geographic extent for crew IR dose management

- Ionospheric Ne, Te values along ISS orbit for characterizing ISS charging hazards, payload science support, and anomaly investigations:
  - Near real time Ne, Te data
  - Well validated real time model Ne, Te output

- ISS interaction with auroral particle precipitation
  - characterize magnitude of charging
  - determine if auroral forecasting is required to support EVA