Impacts of Space Weather on Department of Defense Operations and Systems

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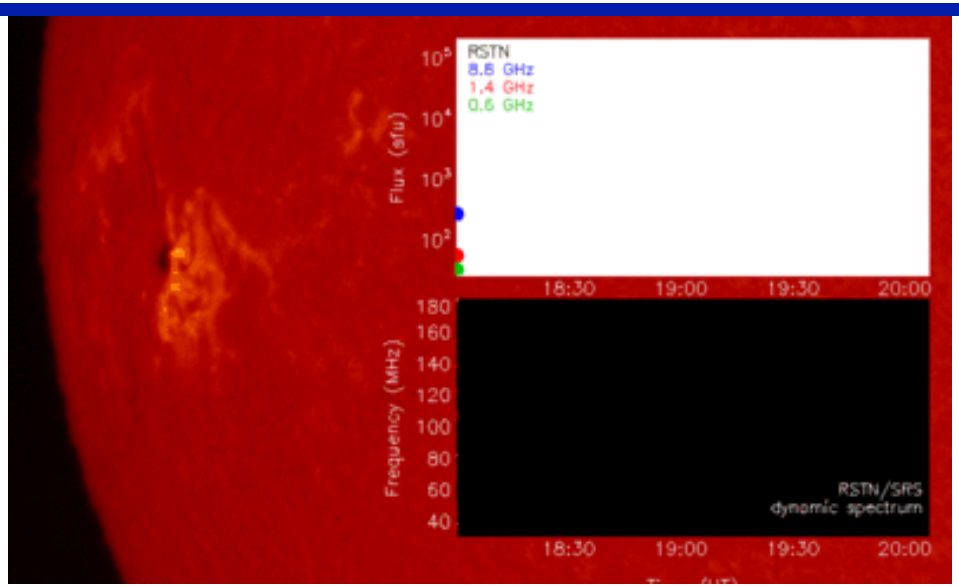
Space Weather - Flares and Radio Bursts

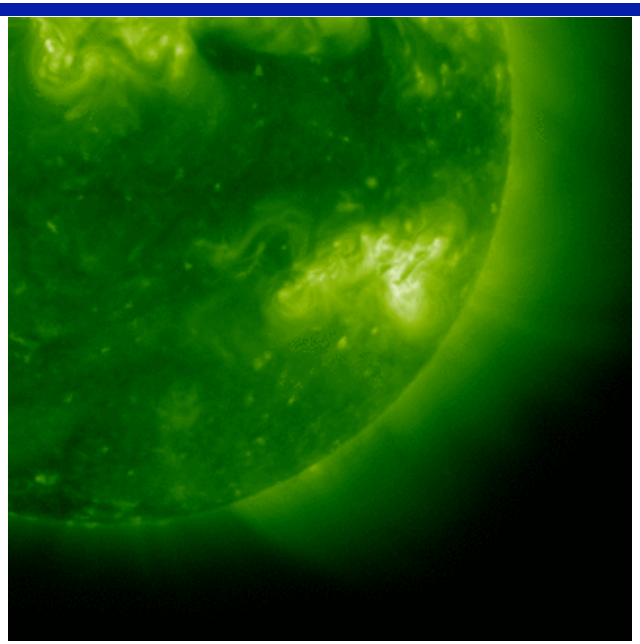
Stephen White, RVBXS



- Flares: immediate impact on HF radio comms due to ionization in D layer by X-rays
- Long-term impact by UV-EUV heating of the upper atmosphere, increases drag on satellites: measured by F10.7
- Radio bursts: can knock out GPS, interfere with comms, radar
- Large event of 2006 Dec 06: knocked out GPS for 20 minutes, affected cell phone reception, occurred after impulsive phase of flare. An issue for increased use of UAVs, aircraft landing.
- Solar interference is important for systems with wide beams
- High microwave, mm frequencies also see large bursts
- Flare prediction is an active area, helped by new ability to sense far-side activity

Space Weather - Coronal Mass Ejections

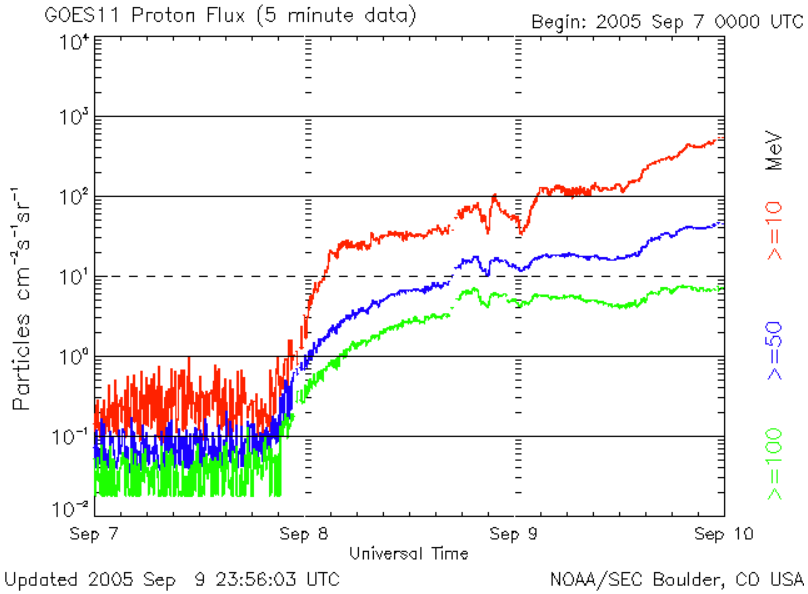
Stephen White, RVBXS



- Coronal mass ejections (CMEs): large eruptions of mass at 1000 km/s, generally associated with flares, take 1-3 days to arrive at Earth, generate magnetospheric storms.
- Need to know whether they will strike Earth, and what the magnetic field orientation is.
- Compression of magnetosphere can affect power systems, radiation belts, ionospheric communication conditions.
- May also be progenitors for solar energetic particles
- Solar wind: "corotating interacting regions" occur when there is a transition at the Earth's magnetosphere in the type of solar wind hitting it, can cause storms and "killer electrons"

Space Weather - Solar Energetic Particles

Stephen White, RVBXS

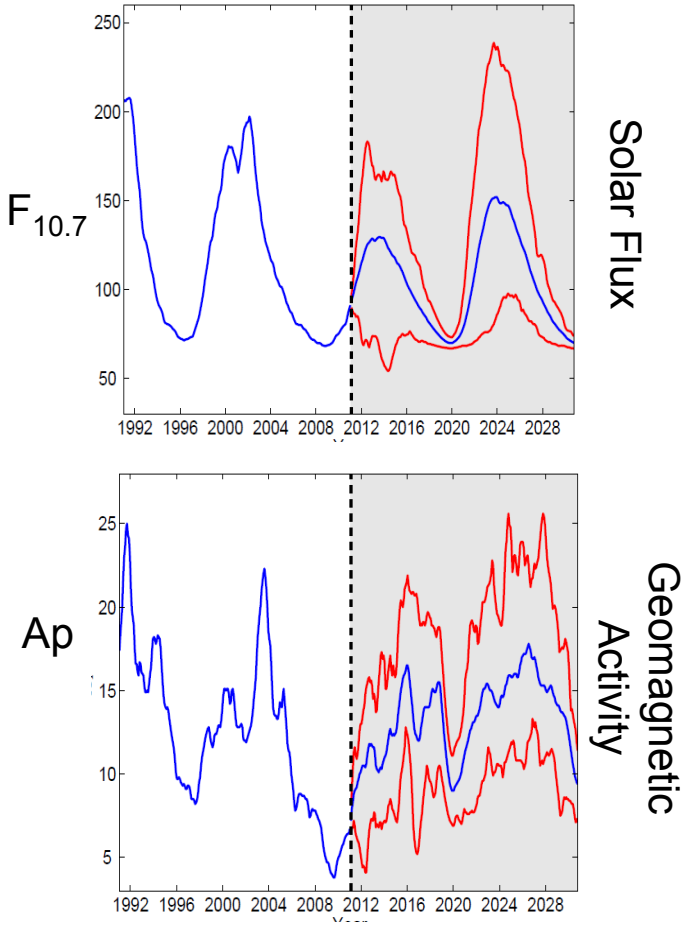


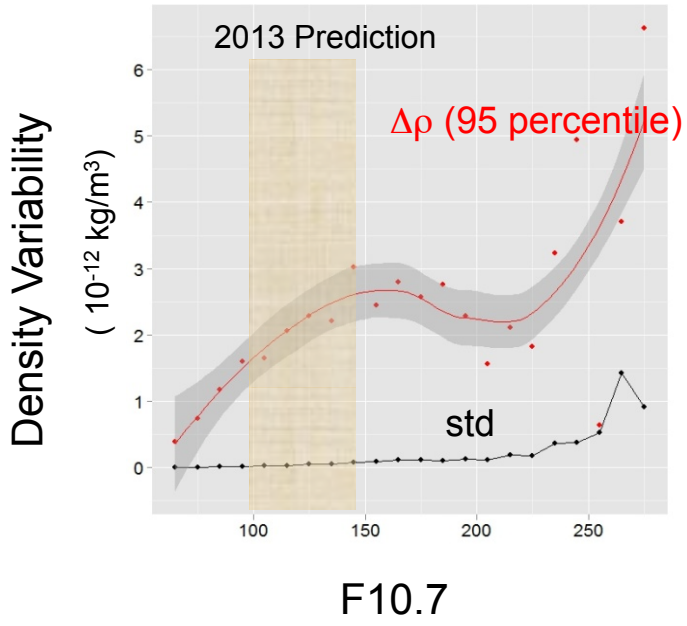
- Energetic particle events: protons with energies ~1 GeV, radiation hazard for astronauts and polar flights, affect satellite electronics, polar cap absorption in ionosphere
- Can come from flares or CMEs, can arrive within 10 minutes of a flare
- **v**×**B** forces in geomagnetic field control entry of SEPs: more important at poles than equator.
- Largest events (ground level enhancements, or "GLEs") are seen by neutron monitors: high-energy protons produce neutrons by nuclear interactions in the atmosphere, can reach detectors on the ground.
- Prediction: similar to flares, but not all large flares produce SEPs

Orbital Drag Predictions and Solar Activity

Chin Lin, RVBXI

Solar Activity Predictions



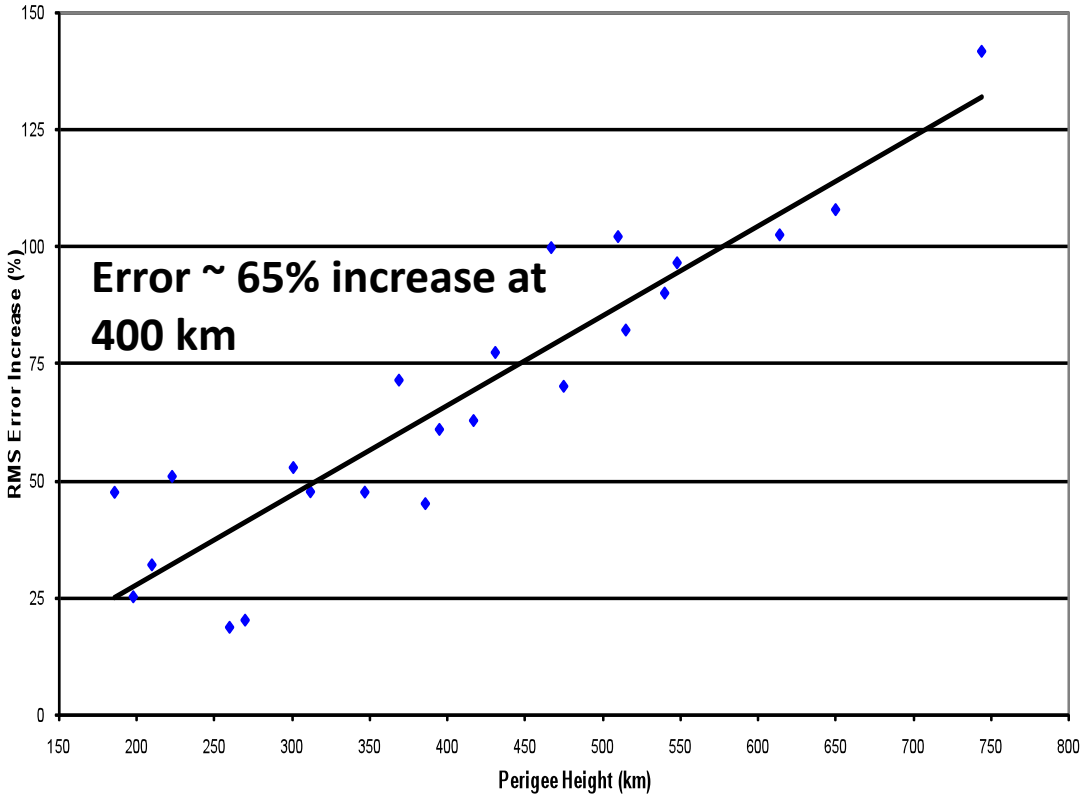


- Current model neutral density error ~15% during geomagnetic quiet times & > 50% during magnetic storms
- Data assimilative physical model will reduce orbit prediction error

AFSPC 72 Hour Prediction Errors Due to Geomagnetic Activity

Chin Lin, RVBXI

Compares orbit predictions for geomagnetically quiet vs disturbed periods in 2005

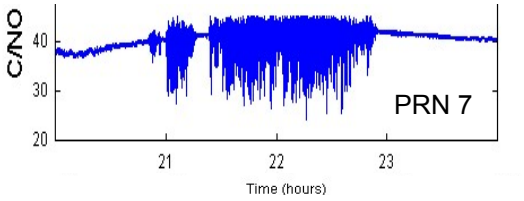


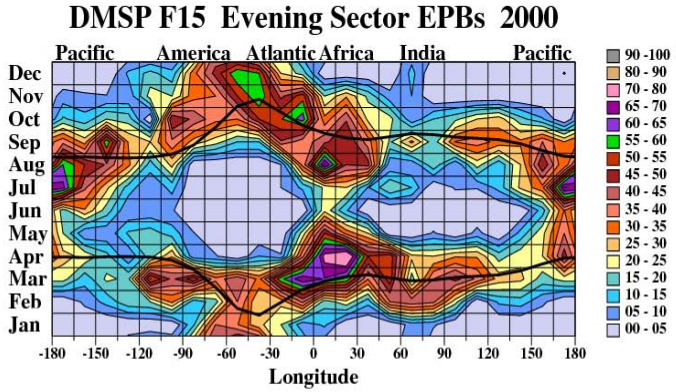
- **For HASDM:**
  - **Improve storm formulation and prediction capability**
- **Next-Generation Models**
  - **Realistic heating inputs**
  - **Physical Model development**
  - **New high resolution thermosphere data and data assimilation capability**

Ionospheric Space Weather Impacts

Odile de la Beaujardiere, RVBXP

- **Scintillation - Loss of communication**
  - During magnetic storms, scintillation can occur at all latitudes (during quiet times, scintillation will occur mostly at high and low latitudes)
  - Scintillation occurs during quiet and active times, intensity depends on F10.7
  - Impacts on systems
    - Scintillation can disrupt sat comm and cut HF options
    - Real-time targeting depends on "instant" communication
    - Higher bandwidth systems have increased vulnerability





- **Scintillation - Degraded navigation**
  - Ionosphere disturbances degrade GPS systems
  - Impacts on DoD systems
    - DoD relies on a multitude of GPS receivers
    - Collateral damage depends on accurate precision guided munitions

During solar max, in Spring, severe scintillation seen 75% of nights at longitudes that include Africa and Middle East

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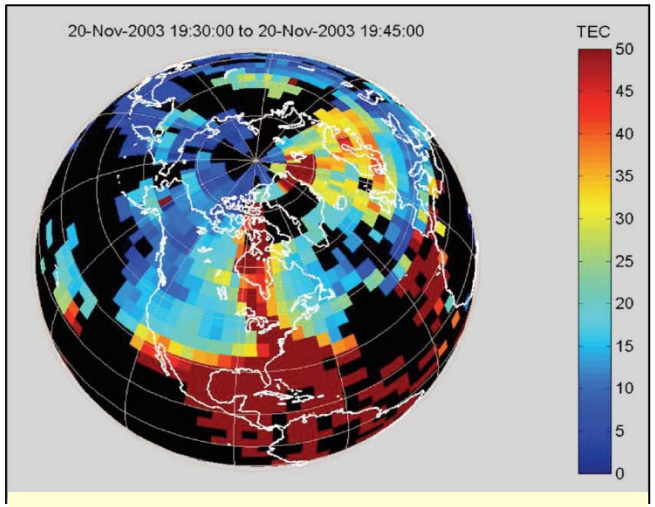
Ionospheric Space Weather Impacts

- **Degraded Geolocation, loss of accuracy in Electron Density Profiles (EDP) and Total Electron Content (TEC)**
  - Large gradients in electron density profiles cause geolocation errors
  - Surveillance & intel applications become difficult
- **Loss of Communications at high latitudes from polar cap absorption events**
- **Radio bursts directly interfere with GPS, Comm and radar systems**
  - False returns, false targeting, blinding surveillance radars and multiple HF systems
  - SATCOM also impacted due to signal interference and loss
  - GPS affected



Storm-enhanced density signature in TEC (Nov 20, 2003). Strong plasma density gradients are observed

Don Thompson, RVBXI

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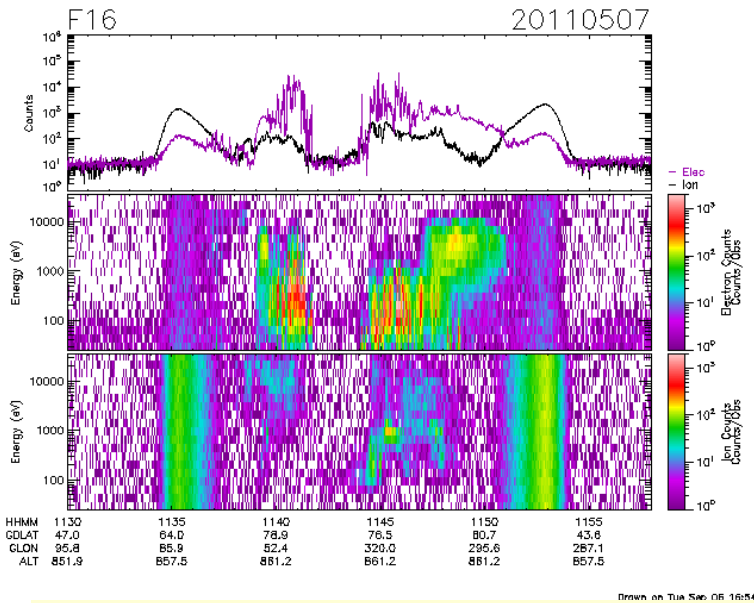
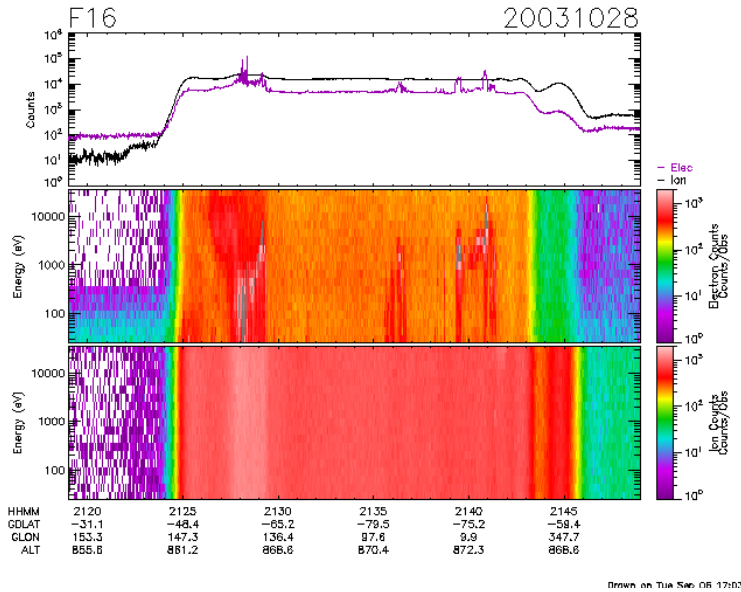
O. de La Beaujardiere, RVBXP and D. Thompson, RVBXI

Ionospheric Space Weather Impacts

- **Satellite sensors blinded by energetic particle events, then rapid degradation**
  - Micro channel plates (MCP) saturated by MeV and GEV particles that impact them directly
    - Example: DMSP particle detectors
  - MCP degrade rapidly from high fluxes – can be inoperable after the storm





During a normal pass, electron and ion spectra across a polar crossing, from SSJ5 instrument on DMSP

During energetic particle event, MCP counts high in both channels -- instrument blinded by high energy particles (~5 such events/solar cycle)

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Sources and Types of Satellite Anomalies

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- **Sources**
  - **Spacecraft Surface Charging**
    - May cause electrostatic discharges (ESDs) and arcing on solar arrays, power cables
    - Caused by electrons of 5-50 keV in GEO, 2-20 keV in PEO, or high voltage arrays in LEO
  - **Deep Dielectric Charging**
    - May cause arcing internally to spacecraft
    - Caused by total dose of electrons of 200 keV-3 MeV, protons of > 10 MeV, or prompt SEPs or X-rays
    - Single Event Upsets (SEUs) caused by ionization trail of single high energy particles in sensitive electronics
- **Types**
  - **Transient effects** (bit flips in electronics, EMI, causing spurious commands or software upsets)
  - **Permanent damage** (arcs, ESDs, and MCP saturation, may damage electronics, and/or cause power cabling or solar array failure)

A Few Anomalies and Their Probable Causes

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- **Tempo-2 and PAS-6 (1997) – sustained arcs from geomagnetic substorm ESDs**
- **ADEOS-2 (1994) – micrometeoroid strike during auroral charging event**
- **Galaxy 15 (2010) – ESD caused electronics problem coming out of eclipse during severe geomagnetic substorm**
- **DMSP-15 (2011) – computer upset after large total internal dose from X-class flare X-rays**
- **Echostar 129 (2011) – temporary pointing/positioning loss after huge peak in GOES > 2 MeV ("killer') electrons**

Space Situational Awareness

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- A key goal for DoD – 2010 National Space Policy
- DoD must determine whether anomalies are due to the Space Weather or to hostile actions
- Operations may be affected by efforts to prevent space weather-related outages
- DoD goals – real-time anomaly resolution, 72 hour predictive space weather capability

When DoD Satellites Fail due to Charging – Very Dangerous Periods

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- **Eclipse Seasons** (Spring and Fall equinoxes) – satellites charge more in eclipse (no photoemission)
- **Time of Day** – anomalies prefer the morning-side after eclipse (differential discharging from photoemission)
- **High and Extended Max Kp** – Days of Kp >~ 6 and Kp Sum > 35.0 are most dangerous
- **Minutes to hours after SEP events**
- **2-5 days following a CME** on the Sun

How to Design to Prevent Space Weather Charging-Related Anomalies

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- Harden all vital electronics and place in well-shielded Faraday cage
- Coat all surfaces with grounded conductors
- No ungrounded or unshielded wires (Galaxy 15 failure mechanism, NASA TP-2361)
- Design for more secondary electron emission and less photoemission (per Shu Lai, 2011, “Spacecraft Charging”)
- Design and test arrays to prevent ESDs and sustained arcs (Tempo-2 failure mechanism, NASA-STD-4005, NASA-HDBK-4006, ISO 11221)
- Design spacecraft to prevent deep dielectric discharges (NASA-HDBK-4002A)
- Fly charge monitors and charging mitigation systems

Operations to Mitigate Space Weather-Related Anomalies

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- Upload software that resets after Single Event Upsets (SEUs)
- Monitor space environments and charging predictions
- When severe Space Weather is predicted, turn off sensitive electronics (thrusters, focal-plane arrays, MCPs, etc.)
- Shunt arrays (or feather into the wake) when severe charging is likely and/or when coming out of eclipse