6th Space Weather & NASA Robotic Mission Ops Workshop

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Earth Science Mission Operations

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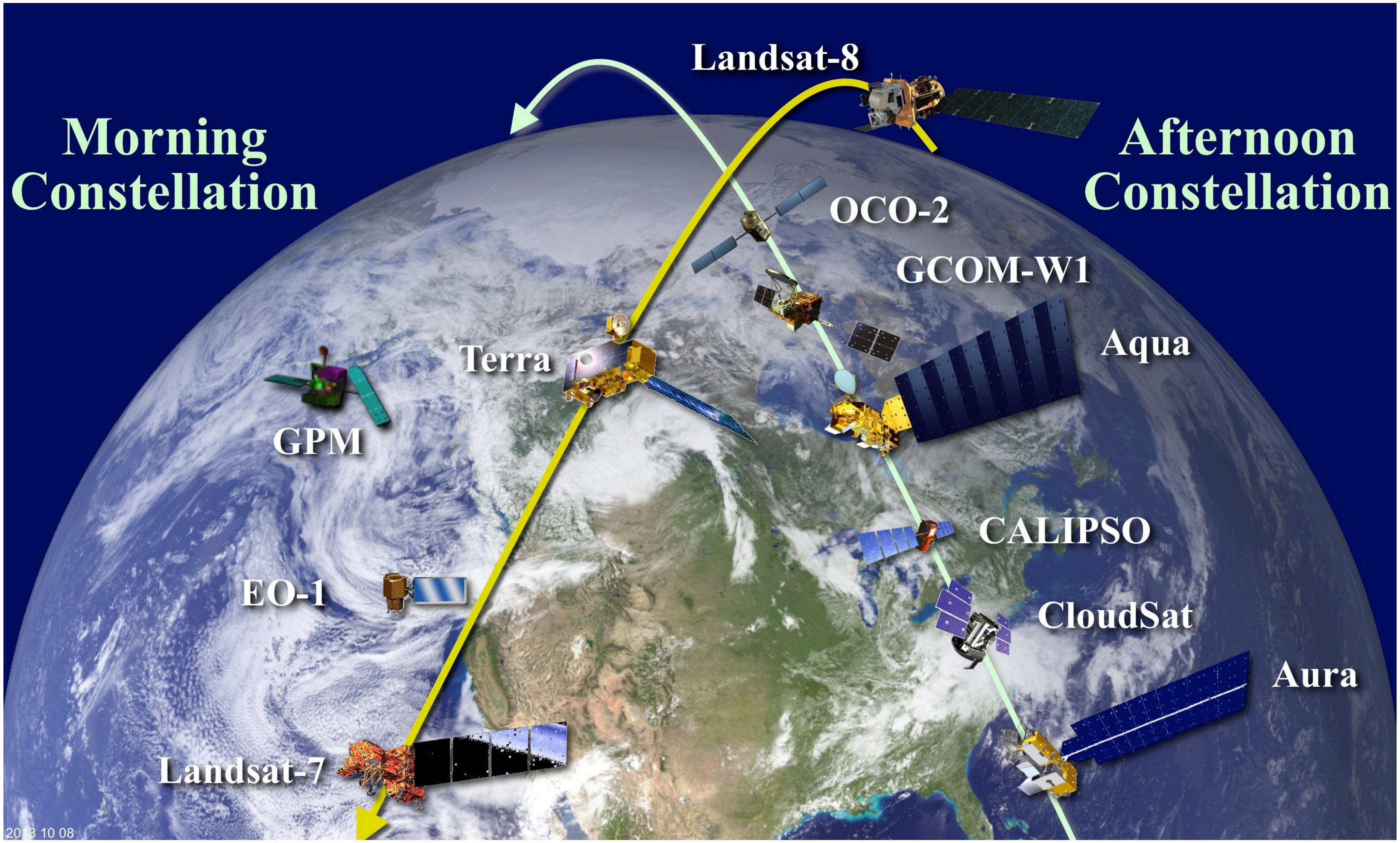
ESMO Missions

Mission Name	Orbit	Instrument(s)	Launch Date	Design Life
TRMM	402.5 km 35.0° Inclination	CERES - Radiometers LIS - Imaging PR - Radar TMI - Microwave VIRS - Infrared	27-Nov-97	3 years
Terra	705km polar, sun-synchronous, 98.2° inclination	MODIS - radiometer MISR - camera MOPITT - Radiometer CERES - Radiometers ASTER - Infrared	18-Dec-99	5 years Goal: 6 years
EO-1	689 km polar, 98.2° inclination	ALI - Multi-Spectral Hyperion - Spectrometer LAC - Spectral	21-Nov-00	18 Months
Aqua	705km polar, sun-synchronous, 98.2° inclination	MODIS - radiometer AIRS - spectrometer AMSU - microwave AMSR-E - microwave CERES - Radiometers HSB - Microwave	4-May-02	6 years
SORCE	630km 40° Inclination	SIM - Spectrometer SOLSTICE - Spectrometer TIM - Radiometer XPS - Spectrophotometers	25-Jan-03	5 years
Aura	705km polar, sun-synchronous, 98.2° inclination	HIRDLS - Infrared MLS - microwave OMI - spectroradiometer TES - infrared	15-Jul-04	6 years
GPM	407 km 65° inclination	GMI - Microwave DPR - Radar	Planned 27-Feb-14	3 years Goal: 5 years

705km Constellation



Satellites & Space Weather

- **Effects of space weather on spacecraft systems are well documented** (Ref: NOAA Space Weather Prediction Center)
  - Surface Charging/Electrostatic Discharge (ESD)
  - Deep dielectric or bulk charging
  - Single Event Upset (SEU)/Single Event Latch-up (SEL)
    - Solar proton events (SPEs)
    - Galactic cosmic rays (GCRs)
  - Spacecraft drag
  - Total dose effects
  - Solar radio frequency interference and telemetry scintillation
  - Debris
  - Spacecraft orientation
  - Photonics noise
  - Materials degradation
  - Meteorite impact

Thanks Bill Gult

Spacecraft Anomalies & Space Weather

Anomaly Investigation – How Space Events are Blamed

Many spacecraft anomalous events occur throughout a mission

- Hardware Failures – EOS Aura Solar Panel Connector
- Degradation – EOS Aqua and Aura Solar Array Degradation
- Debris and micrometeorite impact – EOS Terra Battery and Aura Solar Panel
- Single Event Upsets (SEUs) – Experienced by all 3 EOS missions
- Single Event Functional Interrupt (SEFI) – EOS Aura FMU/SSR
- Single Event Latch-up (SEL)
- Electrostatic Discharge (ESD)

Anomaly Investigations usually start with understanding the Space Environment and geographical location of spacecraft at the time of anomaly

Contributing Factors often considered during investigation:

- Solar Events
- Cosmic Rays? Is this information available and presented in a way that is useful?

EOS Aura & Space Weather

EOS Aura – Microwave Limb Sounder (MLS) internal mechanism electronics are subject to potentially destructive latch up by high energy protons and should be powered off during confirmed 10 MeV proton flux alerts of 100,000 pfu (S5 alert from the SWPC).

- NOAA Space Weather Prediction Center (SWPC) notifies EOS-Aura Operations team of Proton Flux greater than category S5.
- Instrument Team starts to evaluate at category S3 and monitors trend. Will request power off if think Proton Flux could reach S5.
- Alert is sent via email/text message to multiple locations
  - Flight Operations Team and MLS Instrument Operations Team
    - Pagers/Cell phones
    - Email
  - Email to system being monitored for proton flux alert message
    - Forwards message to Online Command & Telemetry System
    - Triggers Limit violation
    - Flight Operations Team executes response to power off Mechanisms

- Never performed MLS Power Off on orbit due to Proton Flux Concerns

SEUs and the SAA

Significantly greater likelihood of Single Event Upsets in the South Atlantic Anomaly (SAA), North and South Poles

Preventative Actions typically used by many Low Earth Orbiting Satellites

- Avoid performing special activities during significant Solar Flares
- Avoid issuing commands or uploading code while traversing SAA

Terra:

- High Gain Antenna Motor Drive Assembly – opticoupler susceptibility results in temporary loss of communications
- Science Data Format Equipment (SFE) – susceptibility results in temporary loss of science data formatting

Aqua:

- Various instrument anomalies have been attributed to SEUs

Aura:

- Various instrument anomalies have been attributed to SEUs

Degradation & Space Weather

Solar Array (SA) Degradation is expected: long-term exposure to low earth orbit causes gradual degradation of SA power generation. Causes include: Ionizing and ultraviolet emissions, contamination of protective glass by the products of destruction of the outer surface materials of spacecraft, thermal cycling, radiation electrization, and plasma thruster plumes

Terra:

- Solar Array degradation over time

Aqua:

- Solar Array degradation over time
- Solar flare of 5 November 2003, an X28 - the strongest ever recorded according to NOAA, caused greater than 1% degradation of the Aqua SA

Aura:

- Solar Array degradation over time

Conjunction Assessment & Collision Avoidance

Solar Events around Time of Closest Approach

- Typically Risk Mitigation Maneuvers (RMM) are performed ~24 hours prior to Time of Closest Approach (TCA) using the predicted Solar Events
  - Use latest tracking data
  - Keep burn durations small
  - Allow sufficient time for change in velocity to increase separation
- Joint Space Operations Command (JSpOC) uses High Accuracy Satellite Drag Model (HASDM) which accounts for some of the space weather changes
- Uncertainty due to Solar Effects still exist:
  - Arrival, Confidence and Magnitude of Solar Event effects projected Miss Distances

Event Issue Date: **2013-09-19 12:44:59.0 GMT**
CME Arrival Time: **2013-09-22 14:14:49.0 GMT**
Arrival Time Confidence Level: **± 6 hours**
Disturbance Duration: **24 hours**
Disturbance Duration Confidence Level: **± 8 hours**
Magnetopause Standoff Distance: **6.6 R_e**

  - Uncertainties on arrival time and magnitude of Solar Events prior to TCA complicate evaluation in determining if a RMM is warranted or could possibly make matters worse

Managing Spacecraft Close Approaches

- The number of close approaches between ESMO Spacecraft and Debris and other active spacecraft has increased over the last few years. Reasons for increase include
  - The evolving threat of conjunction was exacerbated by the Chinese anti-satellite missile test with Fengyun 1C on January 11, 2007 and the Iridium 33/COSMOS 2251 collision on February 10, 2009
  - Increases in solar drag and variability in drag due to solar events has resulted in added uncertainties in propagating out close approaches over multiple days thereby increasing number of conjunctions requiring risk mitigation actions
  - Many spacecraft operate in similar Orbits with Orbit paths intersecting frequently
  - International Space Station (ISS) is deploying a large number of CubeSats above TRMM and GPM
- Managing close approaches has become a daily activity that consumes resources to maintain awareness and prepare for each High Interest Event (HIE)
- Maneuver planning takes time so we usually start preparing 3 to 5 days out depending on the conjunction. After developing possible maneuver options, JSpOC screens the maneuvers, CARA analyzes the results and ESMO determines if need to re-plan since process is often iterative
  - Many maneuvers have post maneuver conjunctions so we have to plan multiple options and frequently have to postpone and re-plan maneuvers
  - Maintaining our ground track and constellation flying requirements while mitigating the close approach risks adds to the complexity and does not give us the option to perform large risk mitigation maneuvers therefore, we frequently need to re-plan as we get closer to Time of Closest Approach (TCA)
  - Each High Interest event is different. Rapid changes to solar drag, repeat conjunctions, space tracking, high drag and elliptical orbits of secondary objects etc. increase the complexity of many conjunctions
- The risk of most HIEs declines as the time to TCA gets closer but we frequently expend the majority of work to execute a Risk Mitigation Maneuver (RMM) prior to the risk dropping off to the point that we can stop planning.

High Interest Events

CARA developed a work tear criteria for HIEs.

Work Tier	Description
0	Event reported in routine Summary Report
1	Mission stakeholder manually notified of event
2	High Interest Event briefing conducted
3	Event resulted in maneuver (or equivalent mitigation) planning
4	Event resulted in maneuver (or equivalent mitigation) execution

Maneuver planning takes time so we usually start preparing 3 to 5 days out depending on the conjunction.

After developing solutions it takes up to one day for JSpOC to screen the maneuvers and we need time to re-plan in case risk not mitigated or if creates another post-maneuver conjunction of concern.

On many occasions predicted low risk events have significantly increased in risk due to changes in solar drag.

Therefore, ESMO has to do the majority of the work to be prepared.

Each High Interest event is different

- Rapid changes to solar drag, repeat conjunctions, space tracking, high drag and elliptical orbits of secondary objects etc. increase the complexity of many conjunctions

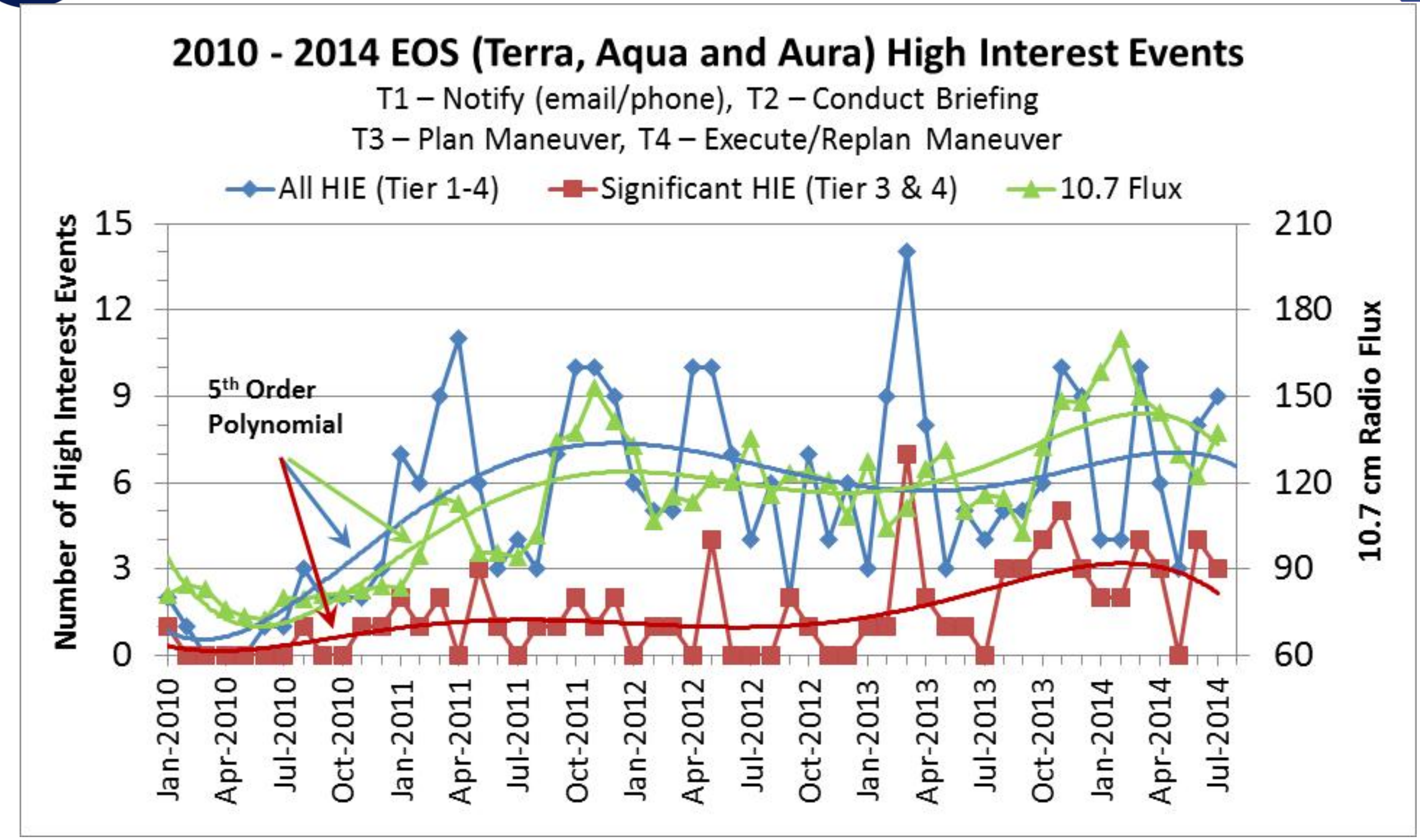
The risk of many HIEs declines closer to TCA however the majority of work to prepare for a RMM has been expended prior to the risk dropping off to the point that we can stop planning

Many Work Tier 3 events take almost as much work as a as a Work Tier 4 Event

- We do all the planning and then call off the maneuver

Note: There can be and often is overlapping HIEs for a single mission or even more frequently in the case of multi-mission operations centers (EOS)

Increase in High Interest Events (HIE)



Number of HIE appears to directly correspond to Solar Activity

Space Weather Wish

- Conjunction Assessment improvements regarding Space Weather
  - Ability to accurately predict space weather effects
    - Atmospheric density at various altitudes (Uncertainty not incorporated into propagation results)
    - Solar Event arrival time and magnitude
  - Uncertainty in atmospheric density not currently incorporated into Conjunction propagation results (What is the uncertainty in Probability of Collision?)
  - Incorporation of active atmospheric drag model with dynamic updates in generating/ screening maneuver ephemeris

- Understanding Spacecraft Anomaly likelihood due to Cosmic Rays(?)
  - Is Cosmic Ray information available and presented in a way that is useful?
  - Able to predict cosmic ray intensity?
  - Observed spacecraft anomalies during last Solar Minimum likely caused by cosmic rays

- Continued support by the GSFC Space Weather Group in evaluating space weather around anomalies and providing opportunities to provide space weather training classes.

Thanks for the support you provide to ESMO