Making an Operational Mission Happen

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Outline

- Requirements
  - Operational v Science
- Proving something will work
  - False alarms and misses are the enemy
- The satellite
  - Class A, B, C, D?
  - Lifetime requirement
- The ground system
  - Receiving stations and telemetry
  - A Lesson from STEREO
- L5 (or on the way there) is good
  - Another lesson from STEREO
- NOAA L5 Requirements
- My thoughts on Carrington

NOAA Requirements Process

- The good
  - Threshold requirements must be backed up by scientific literature
    - Goal requirements can be wishful thinking
      - You'll only get the goal if it's essentially free
  - Justifying requirements is difficult
- The bad
  - NOAA requirements documentation format is Earth science driven
  - Platform driven
    - A coronagraph at L1 and a coronagraph on ISS would need different requirements for FOV and cadence

All new programs get reviewed at the NOAA, Department of Commerce, and ultimately at the OMB level. If it makes it through all of these, it appears in the President's Budget, then Congress makes the final decision Thus, we need very strong justifications on the benefit and to demonstrate that this is the best and/or only solution.

Carrington should carry only things that have added value because of L5.

What NOAA needs to set/change a requirement

- Setting/changing a requirement is a stringent process
  - The need must be clear, strong, and documented
  - Documentation can be
    - Journal article, workshop report, program review document, technical memo…
  - We need document reference, page, paragraph, explanation, and rationale.
    - I'm looking for the one sentence that says:

    '…the instrument sensitivity is required to be 5% in order to get model performance that results in a 50% improvement in predicting…'

To justify an increase in funding for numerical model transition, at the NOAA/Commerce level, I had to show that WSA-Enlil improves prediction by factor of 2, from the literature. (Taktakishvili *et al.* 2009)

CME Requirements

What they are:

Observation Requirement	Solar Imagery: Corona, L1
Priority	1
Spatial Coverage	Heliocentric
Vertical Range	3-17 Rsun
Spatial/Angular Resolution	50 arcsec
Measurement Range	$1x10^{-11} – 1(5)x10^{-8}$ B/Bsun/pixel
Measurement Accuracy	10% (flux)
Sampling Frequency	15 minutes
Data Latency	15 minutes
	Additional Requirements
*Pointing Knowledge	25 arcsec
*Spectral Response	White-light w/option for polarization
*Flux resolution	$1x10^{-12} – 2x10^{-11}$ B/Bsun/pixel in the outer/inner FOV

What they should be:

- The purpose of NOAA CME imagery is to enable detection and characterization of CME's in the low corona.
- NOAA requires a minimum of two images of every potentially geo-effective CME be fit with a Cone Model to derive inputs for heliospheric propagation models.
- NOAA requires that plane of sky positions of the CME leading edge are measured in a minimum of three images.
- CME mass is to be computed for all images containing a CME.

Contingency Tables and Skill Scores

- Skill scores just boil the contingency table down to one number
- A forecaster basically thinks like a 2x2 contingency table
  - Hits and correct negatives are what you want (*e.g.* Heidke Skill Score)
  - Too many misses or false alarms and the forecaster won't even look at your model
- Too many scientists look only at hits
  - I can't convince NOAA if I can't justify all four quadrants

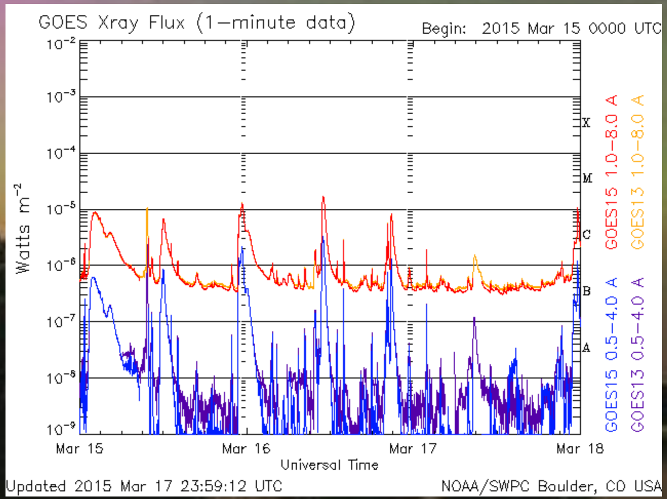
2x2 Contingency Table		**Event Observed**	
		YES	NO
Event Forecast	YES	Hit	False Alarm
	NO	Miss	Correct Negative

N = Hits+Misses+False Alarms+Correct Negatives

>10MeV Proton Events Balch 2007		**Event Observed**	
		YES	NO
Event Forecast	YES	72	55
	NO	89	3567

Science with an Operational Mission

- Mixing science and operations opens the door to requirements creep and cost growth
  - Greatly increases the odds of getting nothing
- 2006 - NOAA Drops GOES-R Sensor
  - Hyperspectral Environmental Suite (HES)
    - http://www.space.com/2904-noaa-drops-sensors.html
    - Successor to the Sounder that had flown for many years on many successive GOES missions
    - From 18 IR bands to 1500
    - 10x greater spatial resolution
- 2010 – NPOESS terminated
  - A key issue was requirements
    - Complexity of multi-agency requirements
- Don't many of you do research with NOAA's Operational GOES instruments?
  - X-rays, Protons, Electrons, Magnetometers…



What class do you want to be (NASA NPR 8705.4)?

GOES-R started as Class A but is now Class B

Characterization	CLASS A	CLASS B	CLASS C	CLASS D
Priority	High	High	Medium	Low
National Significance	Very high	High	Medium	Low to Medium
Complexity	Very high to high	High to medium	Medium to low	Medium to low
Baseline Mission Lifetime	>5 years	2-5 years	<2 years	<2 years
Cost	High	High to medium	Medium to low	Low
Re-flight opportunities	None	Few or none	Some or few	Many
Examples	HST, Cassini, JWST	MRO, MER	Explorer Payloads, MIDEX	SPARTAN, SMEX

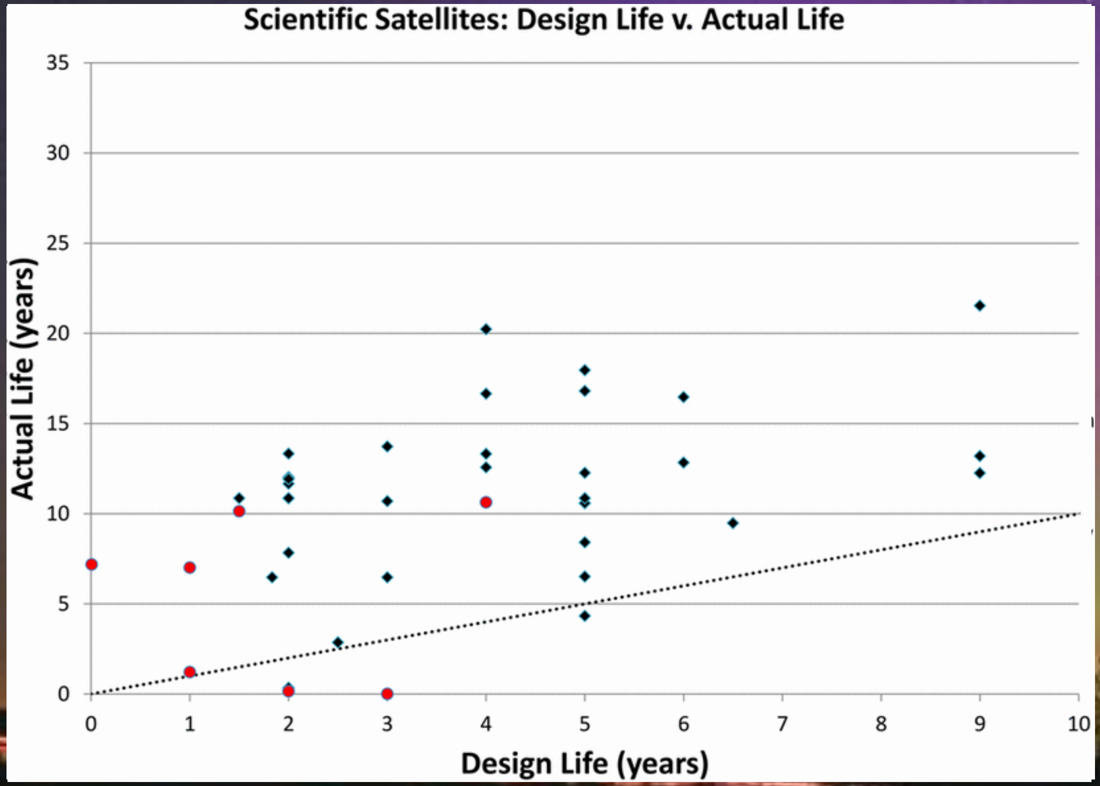
http://nodis3.gsfc.nasa.gov/npg_img/N_PR_8705_0004_/N_PR_8705_0004_.pdf

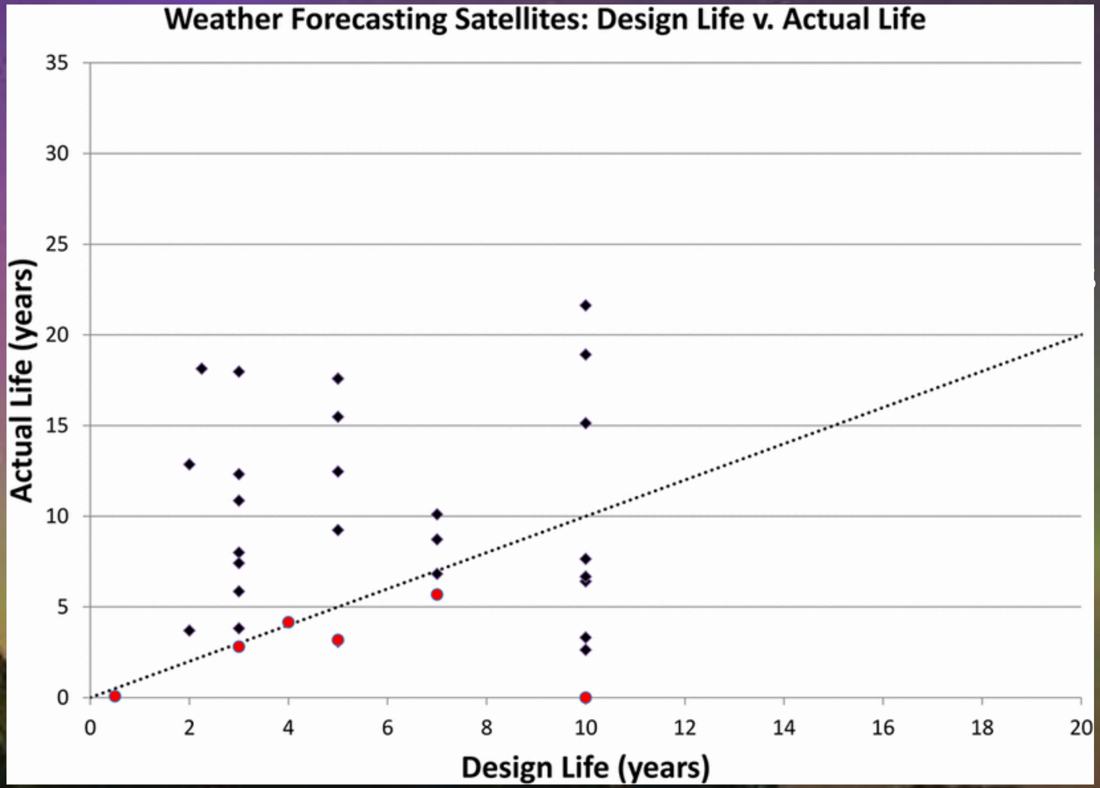
NASA Recommended Program Requirements by Class

	CLASS A	CLASS B	CLASS C	CLASS D
Single Point Failures (SPFs)	Critical SPF's not permitted without formal waiver	Critical SPFs may be permitted but are mitigated by use of high reliability parts and additional testing. Essential spacecraft functions and key instruments are typically fully redundant	Critical SPFs may be permitted but are mitigated by use of high reliability parts, additional testing. Single string and selective redundancy may be used	Same as Class C.
EEE Parts http://nepp.nasa.gov/npsl	NASA Parts Selection List (NPSL) Level 1	Class A requirements or NPSL Level 2	Class A, Class B or NPSL Level 3	Class A, Class B, or Class C
Reviews	Full formal review program at Center level. Formal inspections of software requirements, design, verification documents and code.	Same as Class A except peer reviews of code.	Same as Class A except peer reviews of design and code.	Reviews can be delegated to project level. Peer reviews of software requirements, design and code.
Materials	Verify heritage of previously used materials and qualify all new or changed materials. Use source controls on procured materials and acceptance test each lot.	Use previously tested/flown materials or qualify new materials. Acceptance test each lot.	Use previously tested/flown materials or characterize new materials. Acceptance test sample lots.	Requirements based on applicable safety standards. Materials should be assessed for application and life limits.

Are these so last century?

Design Life vs Actual Life



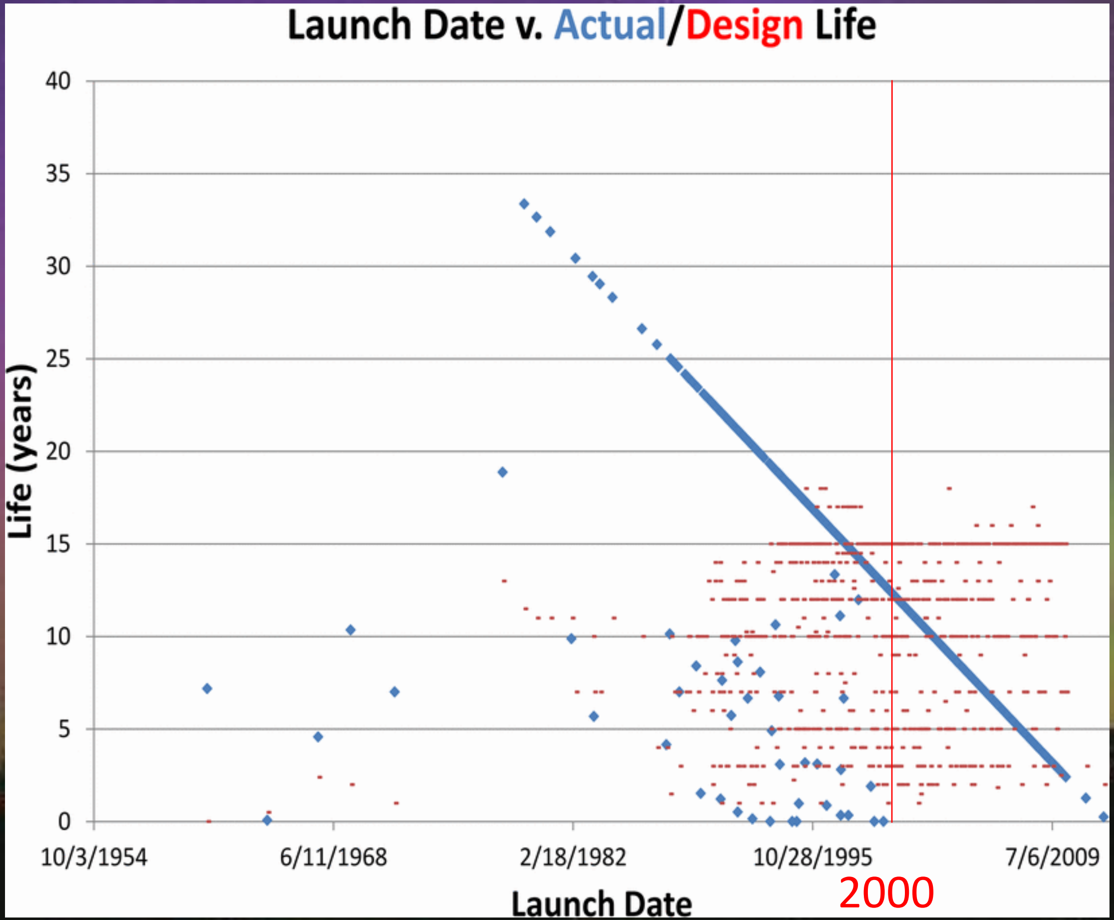


Fox et al, Aerospace Conference, 2013 IEEE, Issue Date 2-9 March 2013

Modern satellites keep on ticking – if they survive launch

Since 2000

All satellites have exceeded their design life



The Ground Segment

- Space Weather and L1 and L5 present the problem of requiring continuous tracking from stations spread across the globe
  - Did it with ACE (the Real-Time Solar Wind Network)
    - Well, we still need that for L1/DSCOVR/Space Weather Follow-on
  - Kind of did it with STEREO (633 bps)
    - Receiving stations in Asia and Europe
    - Receiving Turbo encoded telemetry at X-band
      - Pretty much hits the theoretical limit of link margins
    - Stations are typically not operational
      - Redundancy of multiple stations provides the necessary continuity
- Every reason to believe the STEREO Beacon Network will be available for an L5 mission

STEREO Tracking Sites (Turbo)

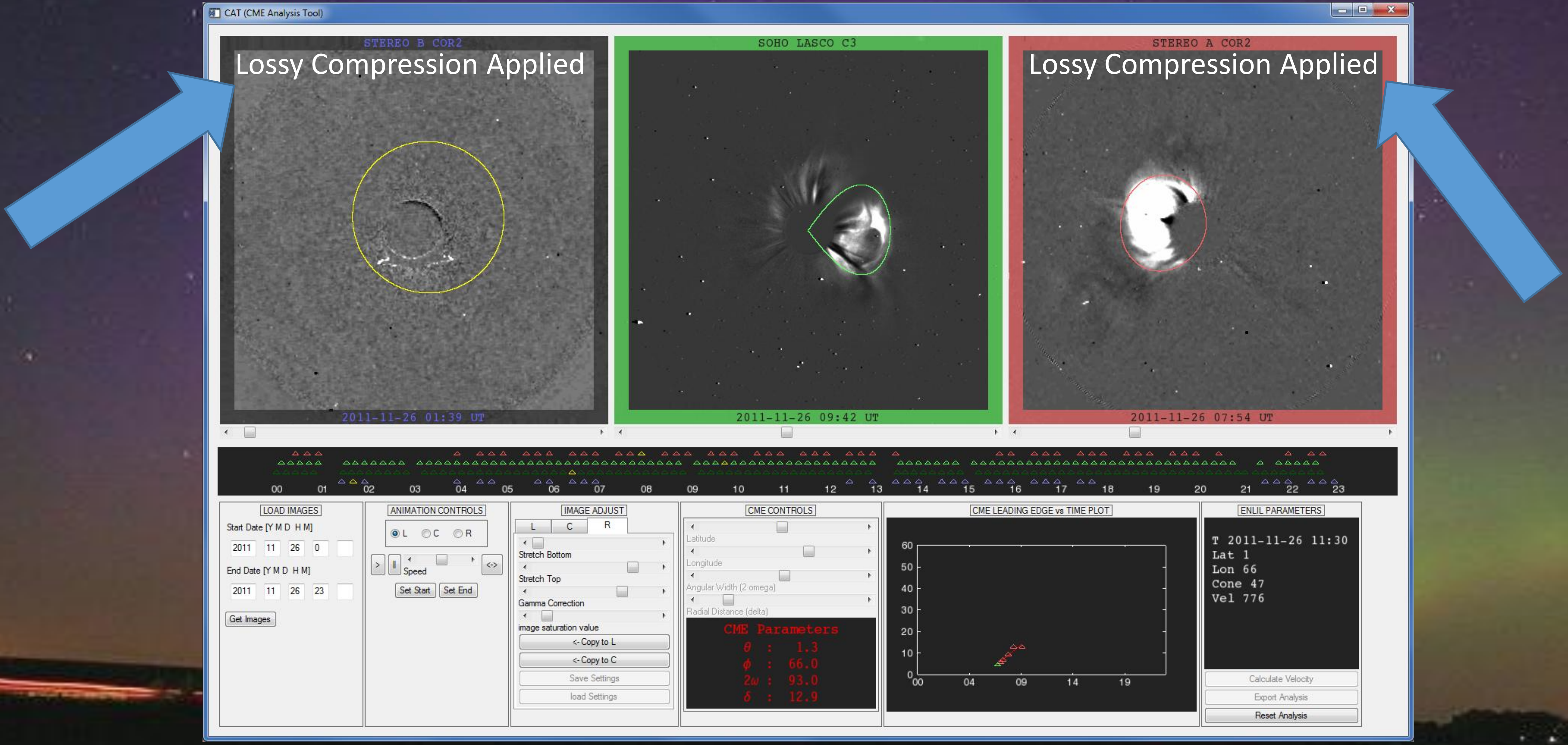
Dedicated station

As available

As Available Stations

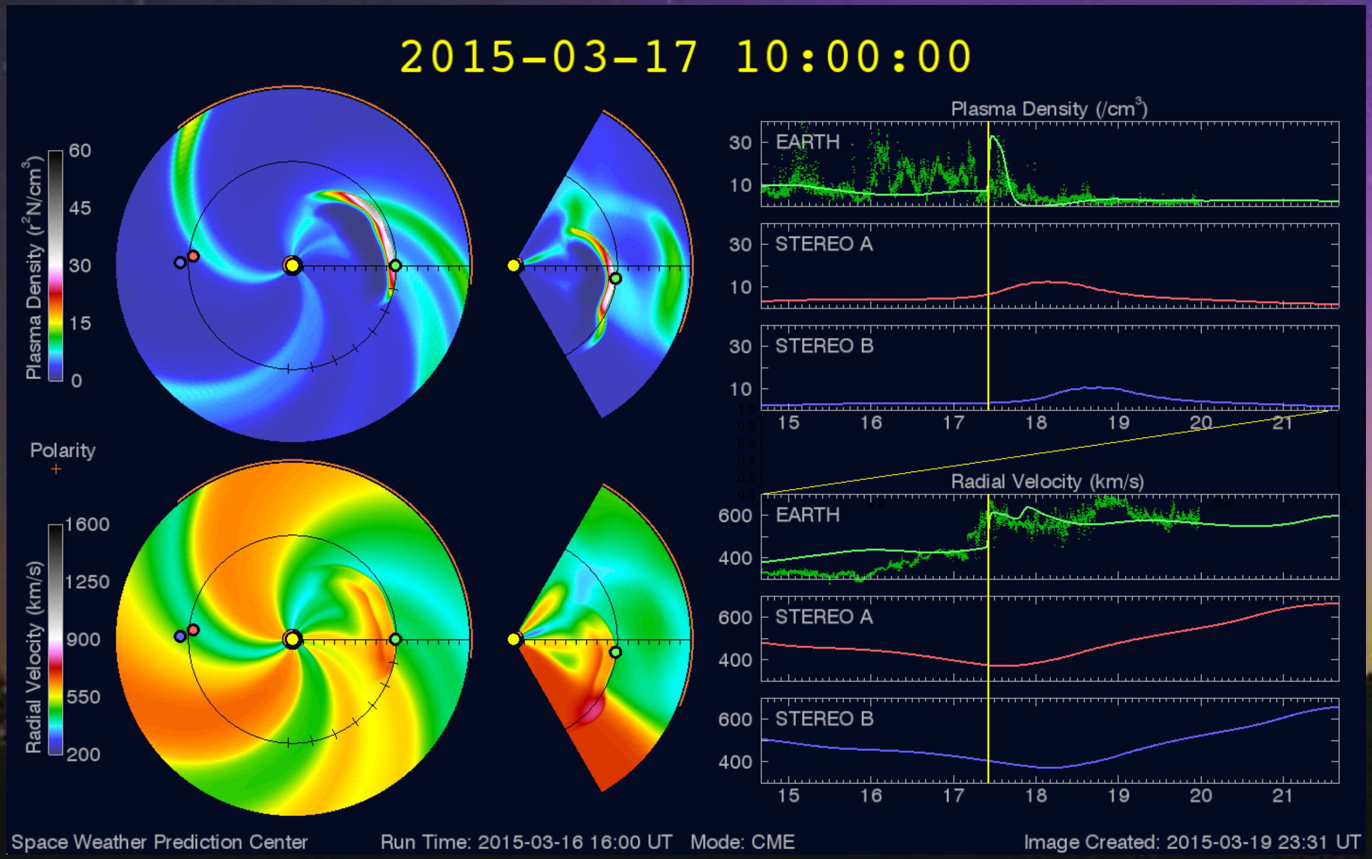
- JHU /APL currently primary for Van Allen Probes
- NICT generally available every day. Shared with an astronomy mission

SWPC CME Analysis Tool (SWPC CAT)



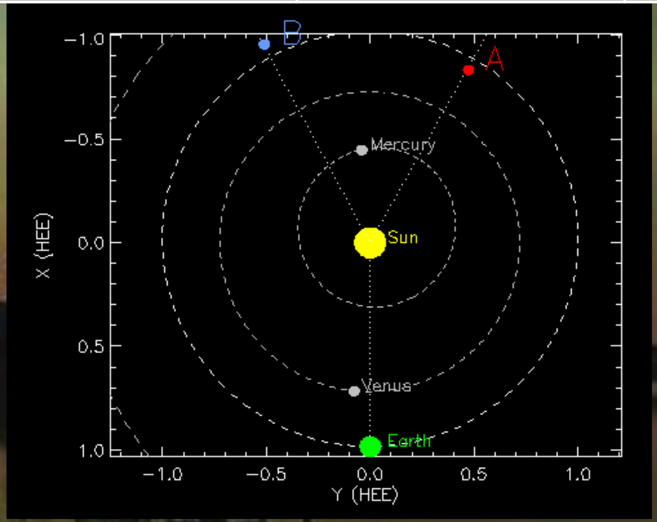
- 3D rendering of 'lemniscate' (tear drop) onto images from STEREO and LASCO
    - Assume circular symmetry

Pretty Much Any Location Works



CME/ICME Arrival Time Prediction Error

YEAR	AVERAGE	RMS	ST-Sun-`Earth' Angle
2011-2014	**6:39:22**	**8:28:38**	
2011	7:06:17	8:24:47	88°
2012	7:53:02	10:21:29	71°
2013	5:02:40	6:11:02	50°
2014	5:06:53	6:12:40	29°



STEREO HI was another story

- STEREO/SECCHI used a tunable compression scheme
  - Wavelet based
- Retuned HI-1 in Nov 2007
  - From 6kB to 23kB per image
- HI-2 was a problem
  - Binned and lossy compressed images were worthless
  - Retuned HI-2 in 2009
    - Masked to retain Sunward half only
    - 4x4 binned (*i.e.* 128x256)
    - Pixel values clipped at 2^{20}-1
    - 4 least significant bits removed
      - 32 bit precision reduced to 16 bit
    - Rice compressed

NOAA Requirements for L5

Prioritization is Doug Biesecker's. This is not an official SWPC or NOAA prioritization. However, all of those listed are on the official NOAA requirements list.

0) Coronal Imaging

1) Interplanetary Magnetic Field (0-100 (150 nT))

1) Plasma Velocity, Density, and Temperature (200-2000 (2500) km/s, …)

1.5) Heliosphere Imaging

2) Magnetograph

3) Energetic Protons

4) High Energy Electrons

5) EUV/X-Ray Imaging

Doug’s Comments on Carrington

- Agree that Magnetograph takes priority over EUV imagery
  - However, forecasting requires not only region complexity, but flare history.
  - Recommend the GOES-R XRS
    - low data rate and can give flare intensity and location
- Would recommend not going beyond SWPC requirements
- Compress the data as needed to allow existing ‘free’ networks to receive the data
  - On order of 13m dishes
- Consider co-launch with Space Weather Follow-on
- Provide data during cruise to L5

Thank you!

For anyone headed to HELCATS in Göttingen