2019 CNES International Conjunction Assessment Workshop

Solar Cycle Effects on Earth Observing System (EOS) Operational Collision Avoidance Activities

June 26-28, 2019

Bill Guit

Aqua Mission Director – Code 584/428
Mission Validation and Operations Branch
Earth Science Mission Operations (ESMO) Project
Goddard Space Flight Center (GSFC)
National Aeronautics and Space Administration (NASA)

William.J.Guit@nasa.gov

301-614-5188

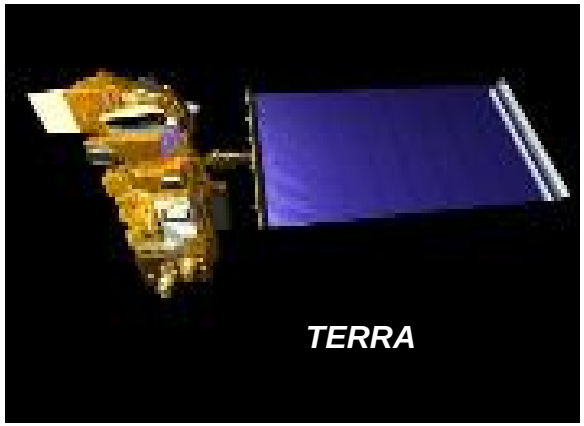
Cover Credit: the Yohkoh mission of ISAS (Japan) and NASA (US).

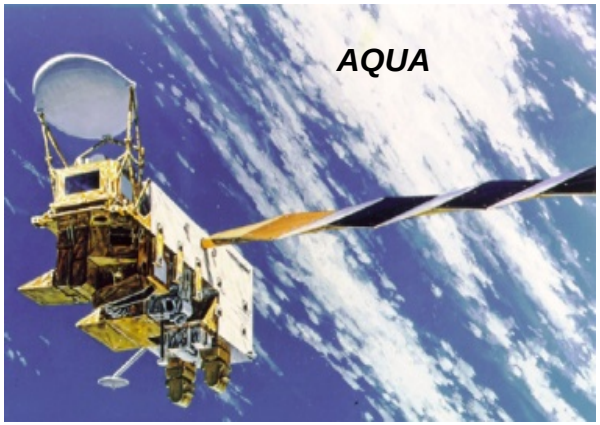
Topics

- Earth Observing System (EOS)
- International Earth Science Constellation (ESC)
- Solar Cycle Background, History and Predictions
- EOS Experience with High Interest Events (HIEs) during periods of Solar and Geomagnetic Activity
- EOS High-Interest Events (HIEs) Statistics
- Observations and Challenges
- Questions

EOS/ESC Background

NASA's Earth Observing System (EOS)





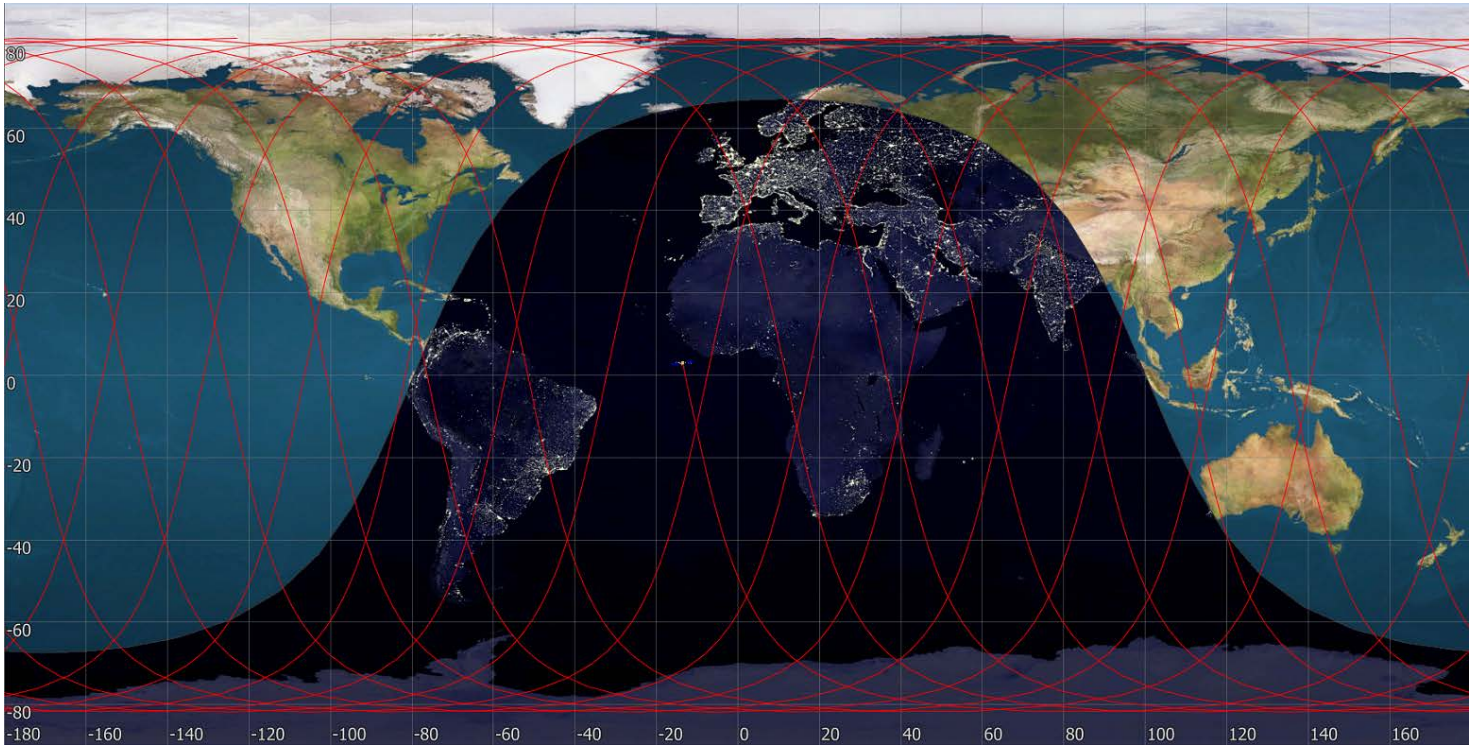
As of 6/26/2019	Terra	Aqua	Aura
Launch Date	12/18/1999	5/4/2002	7/15/2004
Current Orbit #	103,832	91,193	79,499
Duration	19y 6m 8d	17y 1m 23d	14y 11m 12d
HIEs	176	226	241
DAMs	16	11	10

Combined 51+ years of orbital debris collision-free safe operations

EOS Mission Orbit Constraints

(16-day, 233-orbit Repeat Cycle)

Source: EOS Flight Dynamics, 2016



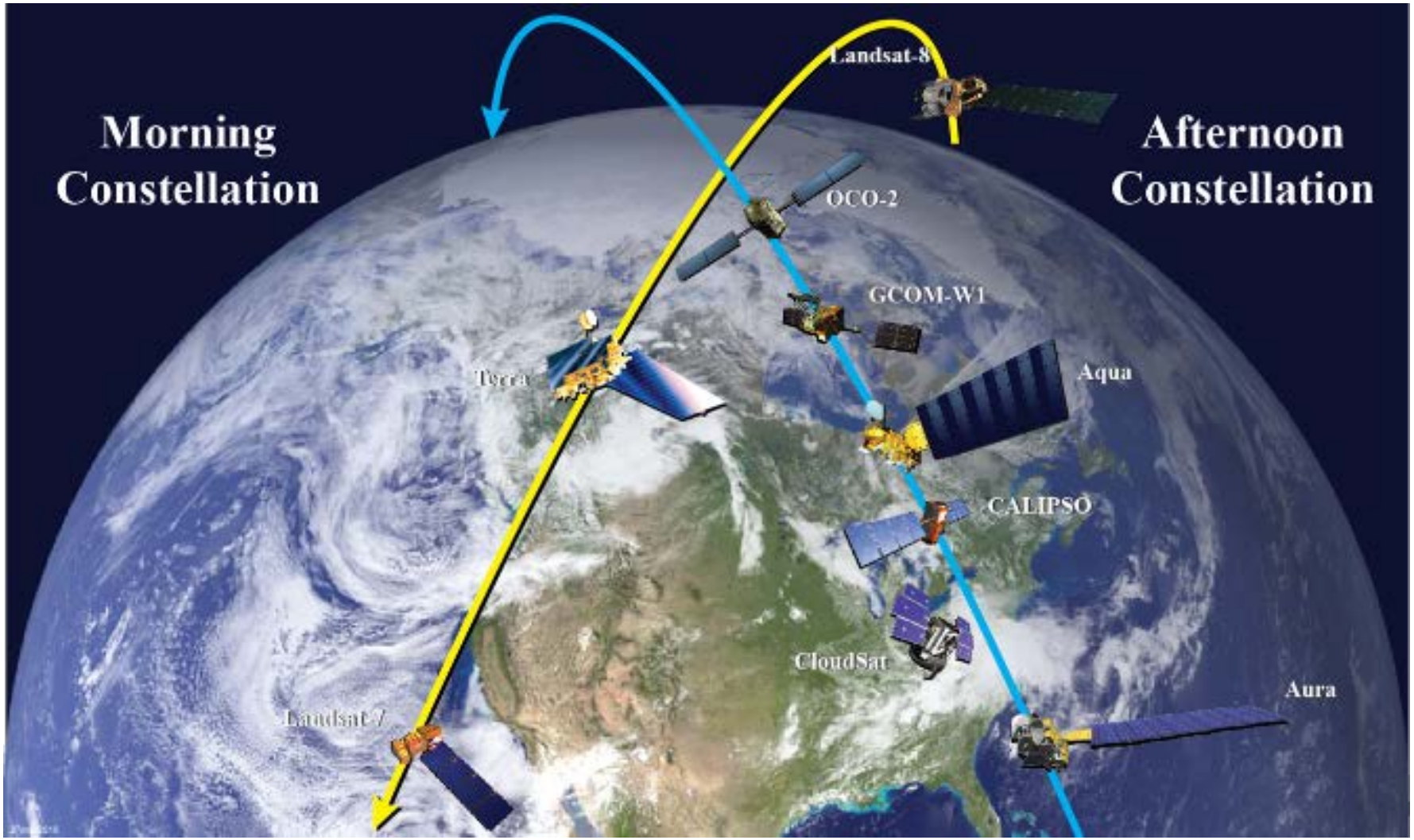
- Flying at 705km sun-synchronous orbit provides the benefit of repeating the same exact ground track every 16 days
- Both the **Altitude** and **Mean Local Time (MLT)/Inclination** have to be controlled to achieve this benefit

Spacecraft Design/Constraints

- **EOS Missions fly in repeat ground track orbits at 705km**
- **Spacecraft designed to perform Drag Make-Up (DMU) and Inclination Adjust Maneuvers (IAMs)**
  - **Retrograde capability not part of nominal maneuver set**
- **Drag Make-Up Maneuvers therefore used as Debris Avoidance Maneuver (DAM) to mitigate collision risk**
  - **Raise altitude (can only go up, one direction)**
- **Differences in DMU & DAM concepts are significant**

	DMU	DAM
Purpose	Maintain Orbit Altitude	Avoid Debris
Notification Time	Several Weeks	Few Days or Less
Ops Mentality	Routine, Methodical	Urgent, Quick Turnaround
Contingency Action	Reschedule	Health & Safety Concern
Burn Duration	Well Defined	Variable
Burn Options	One	Multiple
Execution Time	Day Shift Only, M-F	Anytime, Any Day

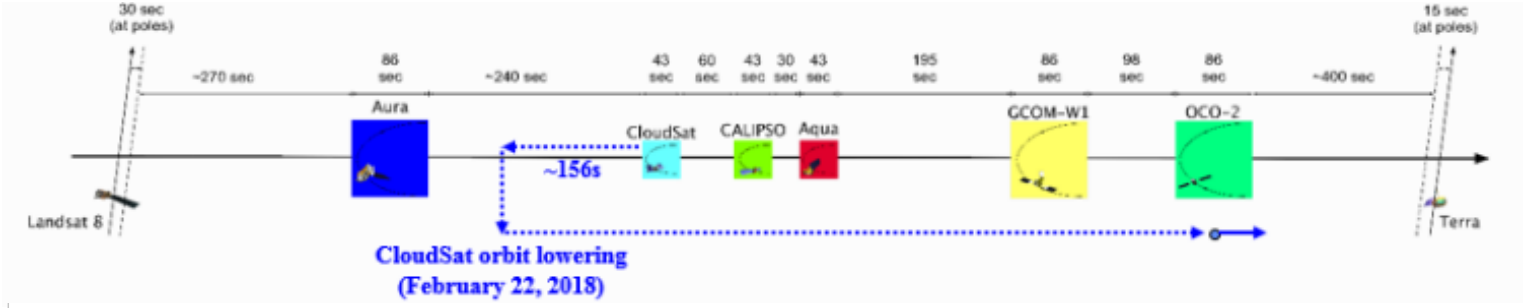
International Earth Science Constellations

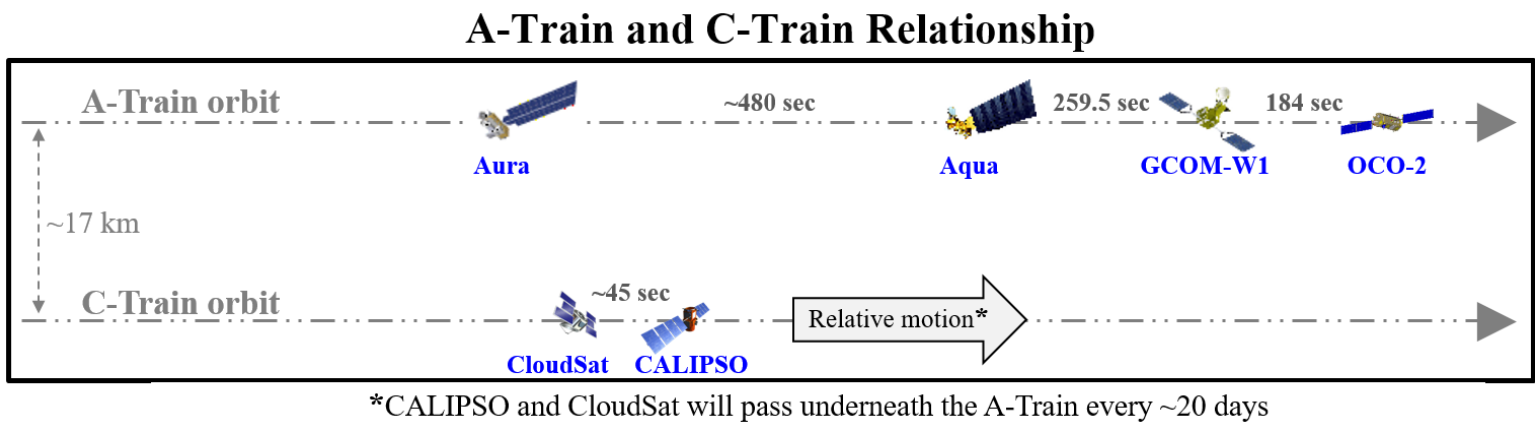


EOS Mission Orbit Constraints

(Afternoon Constellation (aka "A-Train") view)

- EOS Missions fly in 705 km, polar sun-synchronous orbits at 98.2º Inclination with 16-day, 233-revolutions repeat cycle
- Mission Science goals dictate orbital maintenance requirements including **ground track error** (GTE) and **mean local time** (MLT) of the node crossings
- EOS Missions fly in constellations, therefore must fly inside their **control box** (**orbital safety** & science)



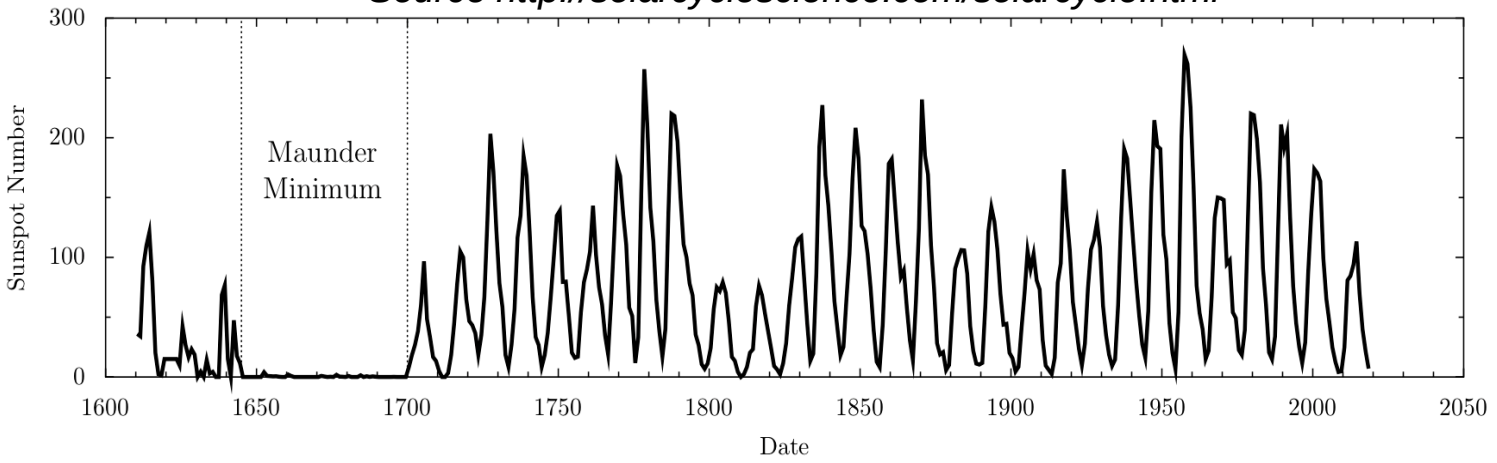


Solar Cycle Background and History

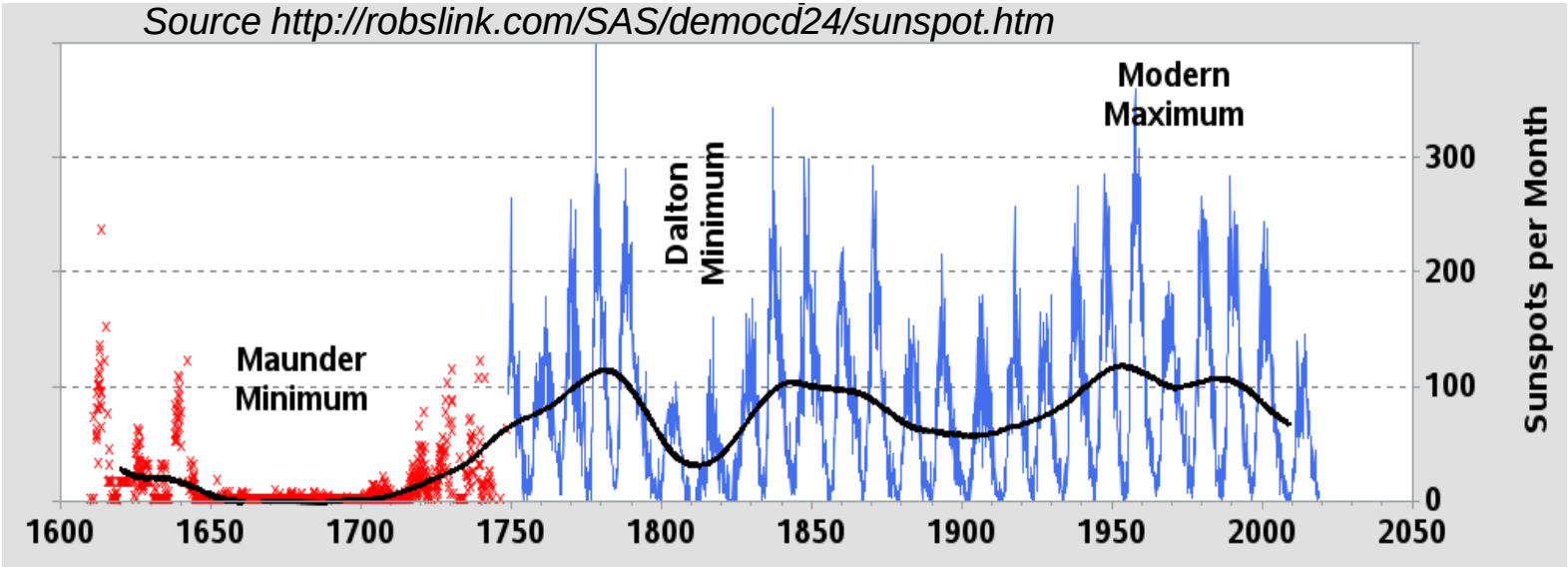
Solar Cycle

400 Years of Sunspot Observations

Source http://solarcyclescience.com/solarcycle.html

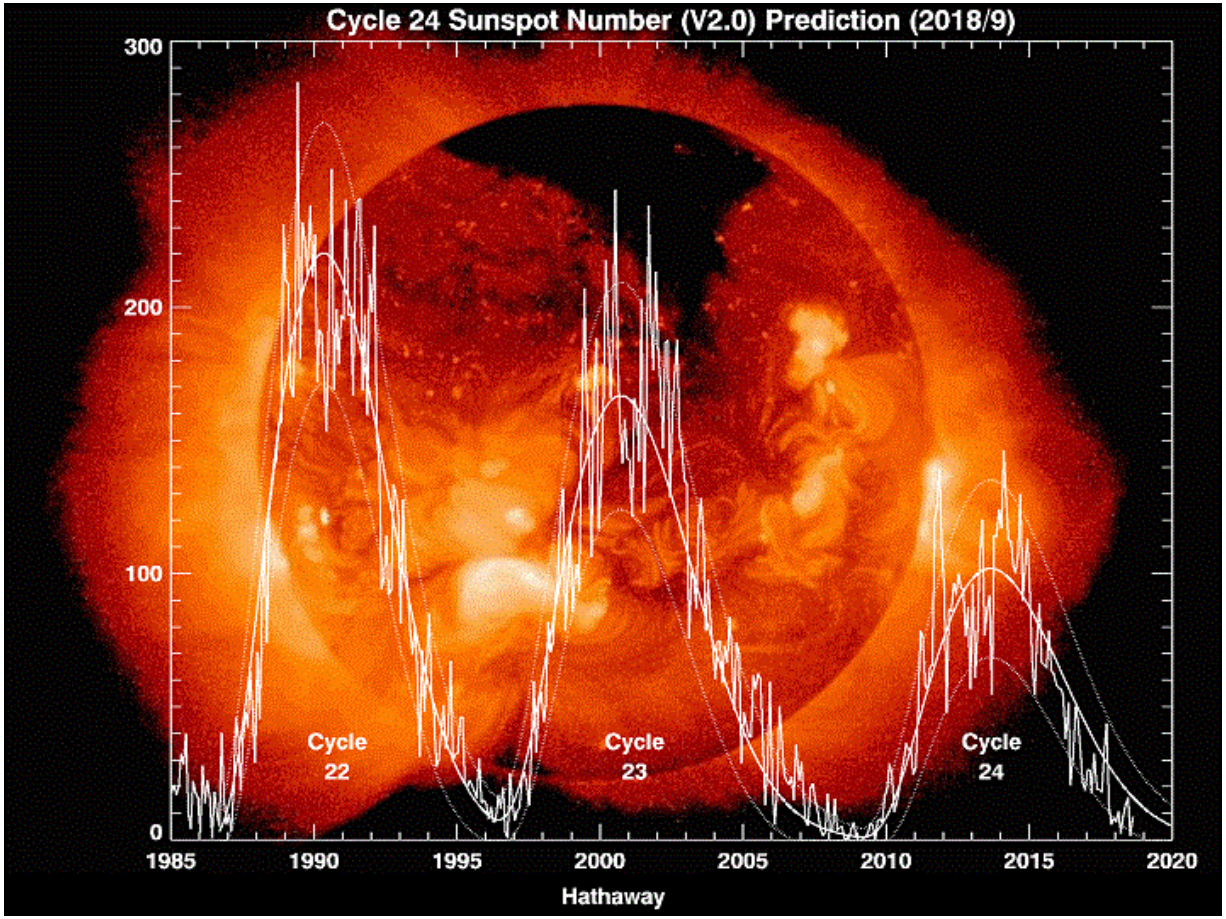


Source http://robslink.com/SAS/democd24/sunspot.htm



Solar Cycles 22-24 Sunspot Numbers (SSN)

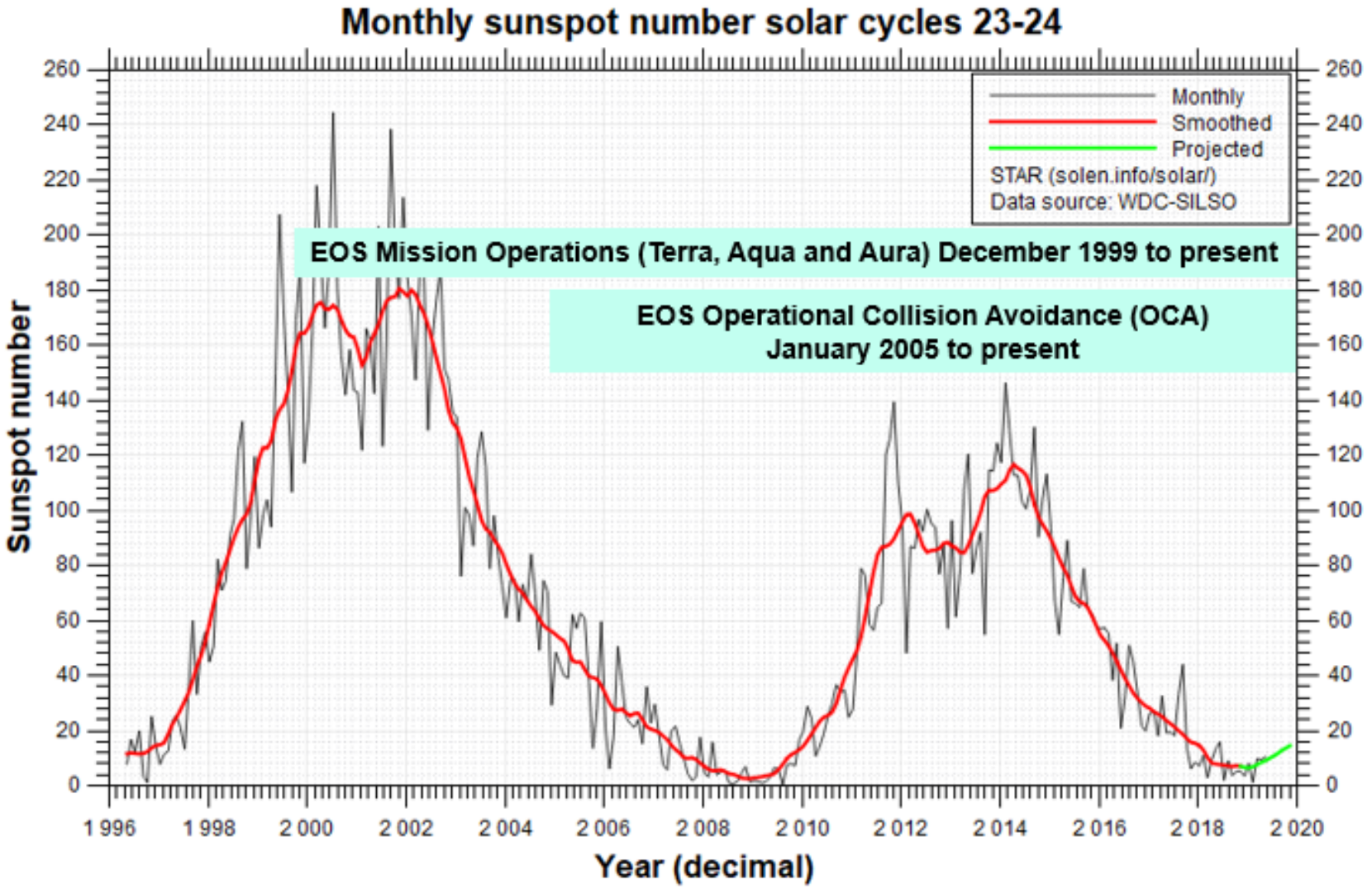
Source http://solarcyclescience.com/solarcycle.html



CREDIT: This website was developed and is maintained by two solar physicists: Dr. Lisa Upton and Dr. David Hathaway. Solar Image: Yohkoh/SXT 8 May 1992

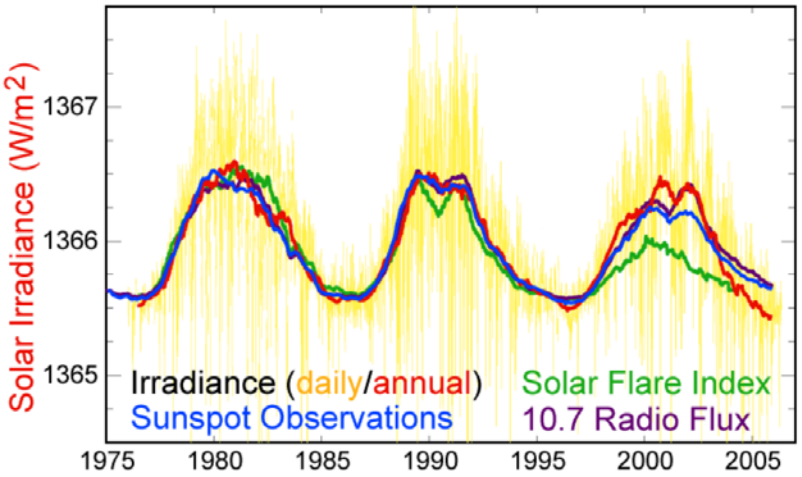
Solar Cycles 23-24
F10.7cm Radio Flux

Source http://www.solen.info/solar/images/cycles23_24.png

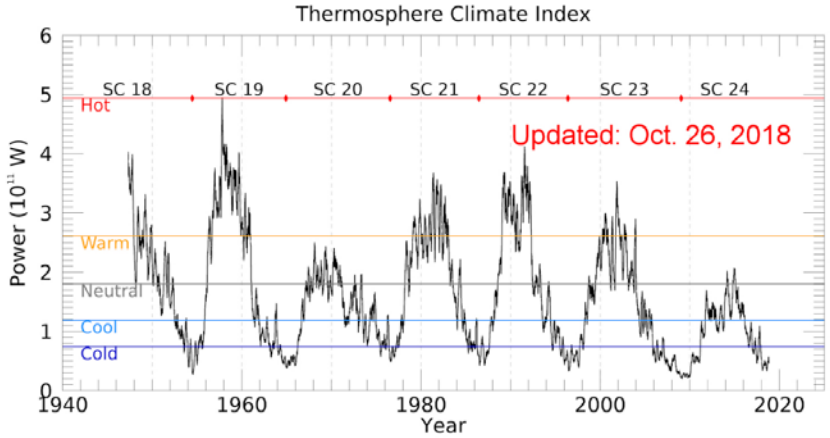


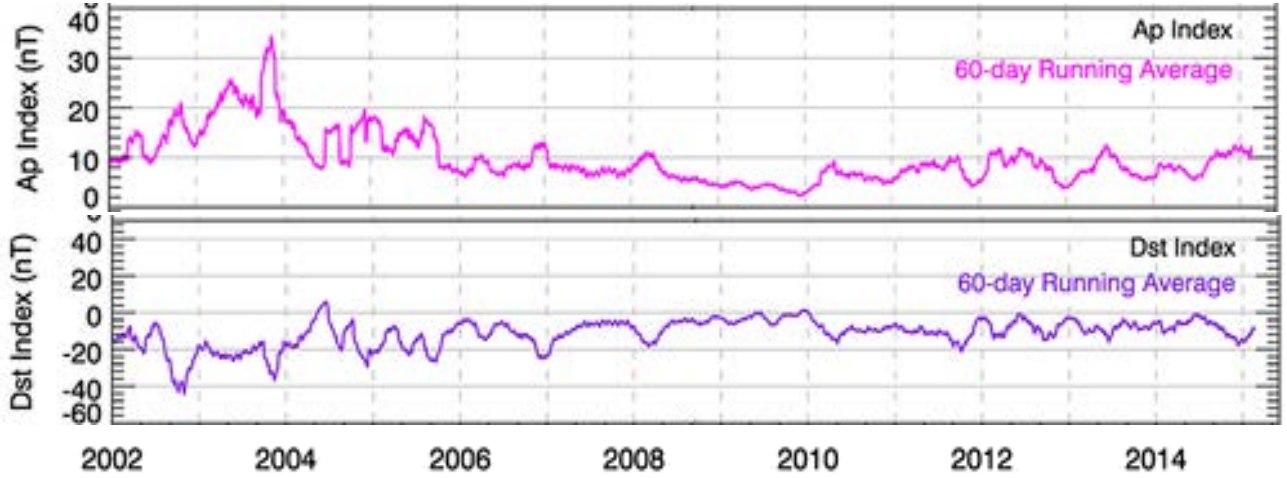
Some Other Solar Cycle Representations

Source https://en.wikipedia.org/wiki/Solar_cycle



Source http://spaceweather.com/images2018/26oct18/TCI_Daily_NO_Power_Percentiles_26oct18.jpg?PHPSESSID=gc33gjo9euvar464fvdtp4i5q0

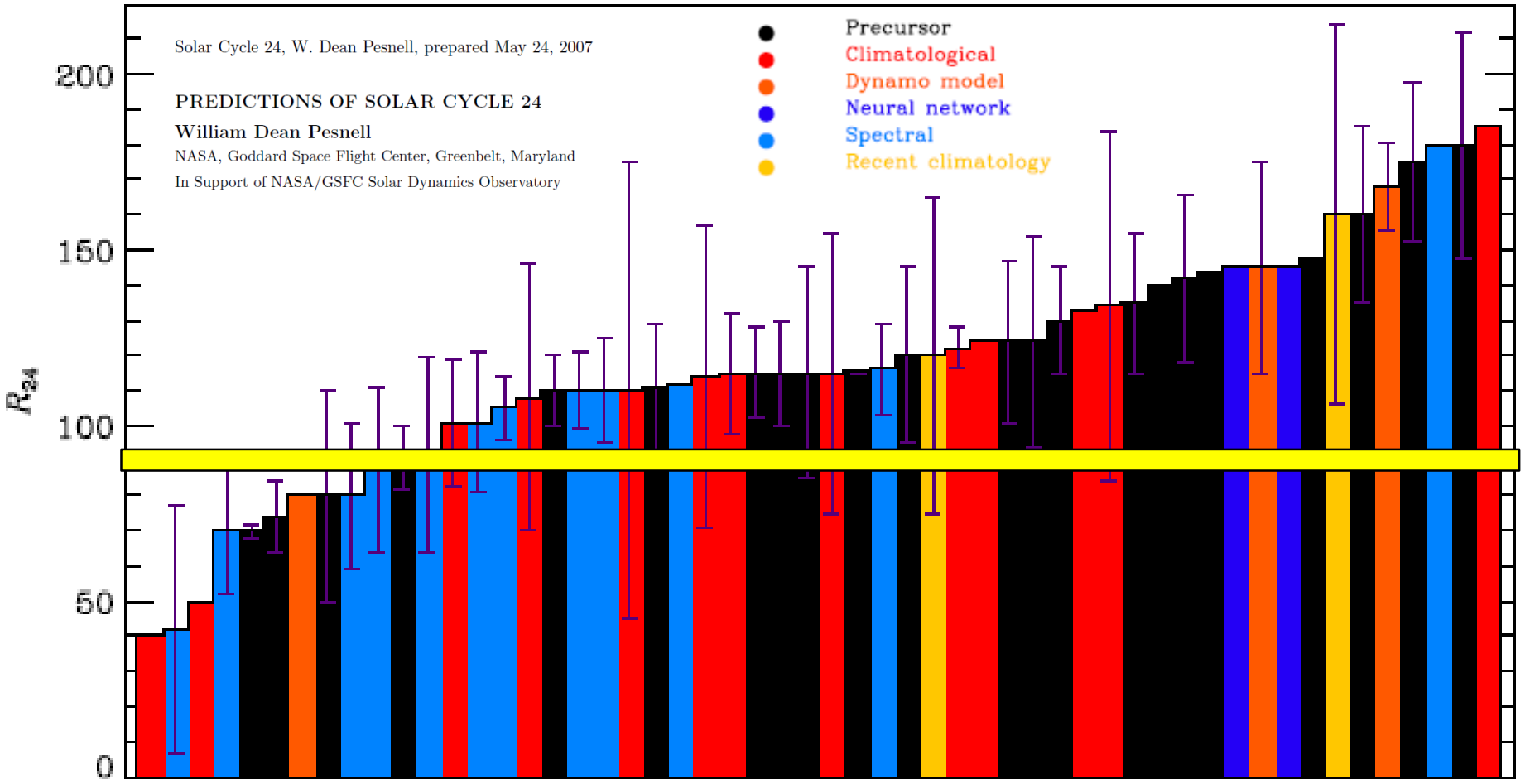




Source: A combined solar and geomagnetic index for thermospheric climate, Volume: 42, Issue: 10, Pages: 3677-3682, First published: 29 April 2015, DOI: (10.1002/2015GL064038)

Solar Cycle Predictions

Solar Cycle #24 (2009 – 2019)
Here's what was predicted in 2008

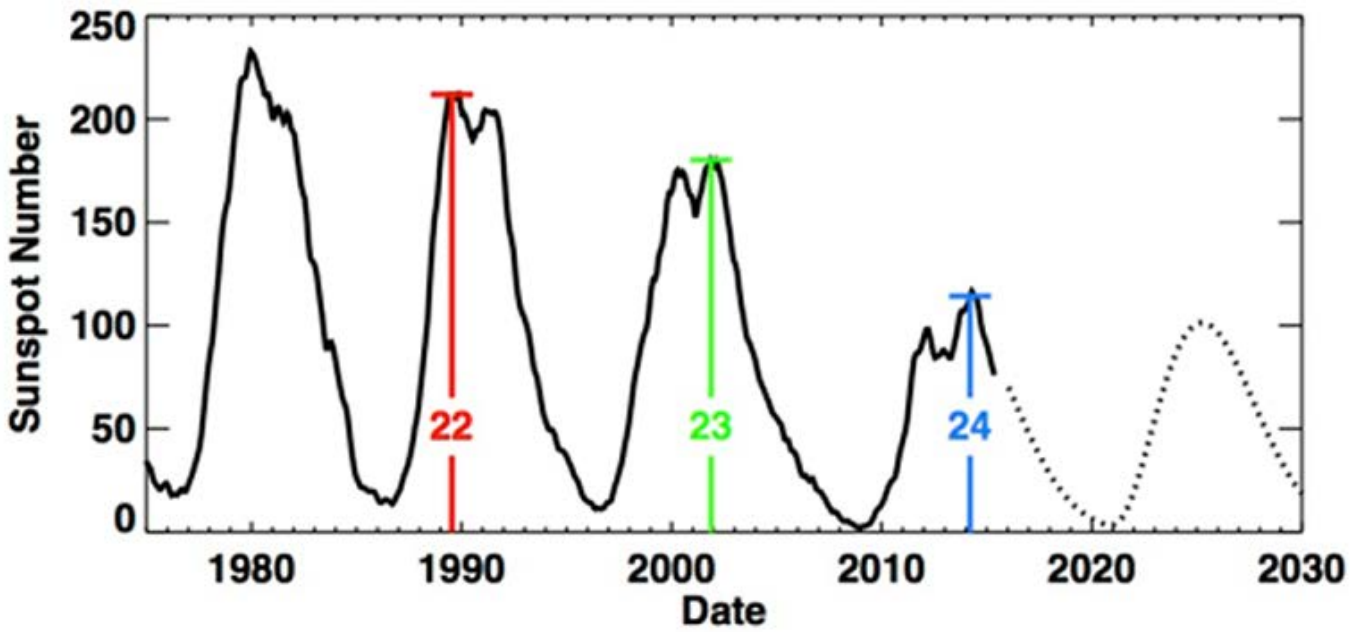


Source: NOAA/SWPC Space Weather Workshop 2014 Biesecker SolarCycle24

Solar Cycle #25 Prediction

(November 2016)

Source http://solarcyclescience.com/solarcycle.html

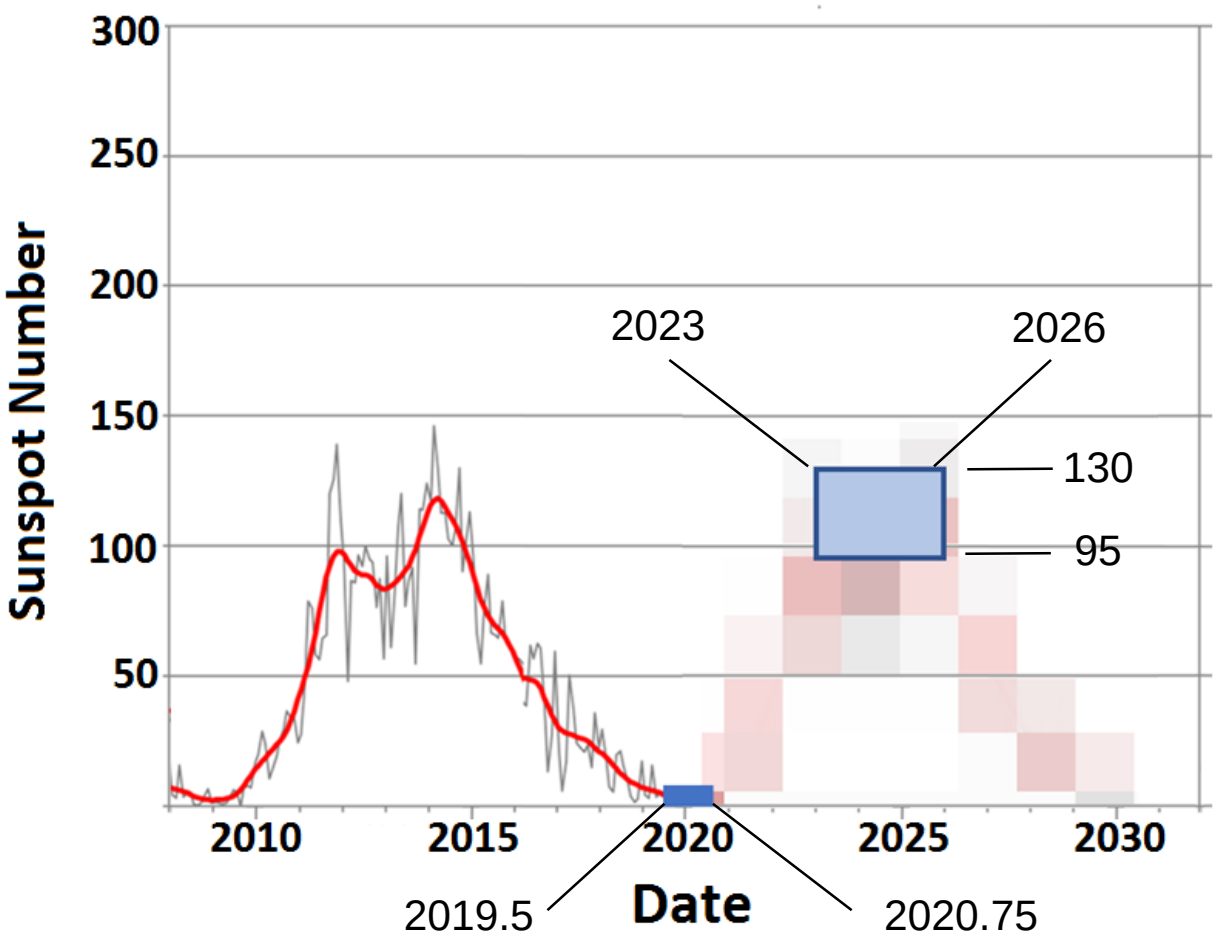


Cycle 25 will be similar or slightly smaller than Cycle 24.
Cycle 25 will start late with deep extended minima.
Extended minimum for the Cycle 24/25 with minimum in 2020.

Reference: David H. Hathaway and Lisa A. Upton
"Predicting the amplitude and hemispheric asymmetry of solar cycle 25 with surface flux transport"
Journal of Geophysical Research: Space Physics, Volume 121, Issue 11, pp. 10,744-10,753 "

NOAA
Space Weather Prediction Center

Solar Cycle #25 Prediction
(April 2019)



Reference: NOAA/SWPC Space Weather Workshop, April 1-5, 2019 Boulder, Colorado
Lisa Upton; Doug Biesecker and the Solar Cycle 25 Prediction Panel

ESMO Experience with Space Weather

ESMO/ESC Experience with Space Weather

- **2011: CloudSat High Interest Event (HIE) with radial miss distance changing signs on successive updates (space weather?/modeling?)**
  - ESMO Project raised concerns about managing HIEs during solar activity
- **2014: 6th GSFC Space Weather Workshop (Aura/35380 TCA: 2014-02-16)**
  - CME predicted to arrive about 30-hours prior to planned potential DAM, Planned DAM waived off Saturday, February 12th
- **2015: 7th GSFC Space Weather Workshop (Aura/89477 TCA: 2015-08-29)**
  - Short-notice (16-hours), high-risk HIE complicated by intense solar and geomagnetic activity prior to planned DAM – Planned DAM waived off shortly before TCA
- **2016: ESC/A-Train Mission Operations Working Group (MOWG) Meeting Presentation: CARA Short-Notice HIEs – Matt Hejduk**
  - **Aura vs. 89477**: Concluded JSpOC space weather predictions missed significant solar storm was the most-likely cause of changes in Pc
- **2016: 8th GSFC Space Weather Workshop Presentation:**
  - CARA Conjunction Assessment Late-Notice HIEs (Hejduk & Pachura)
- **2017: 9th GSFC Space Weather Workshop (Aura/39858 TCA: 2017-09-10)**
  - High-risk HIE complicated by intense solar and geomagnetic activity

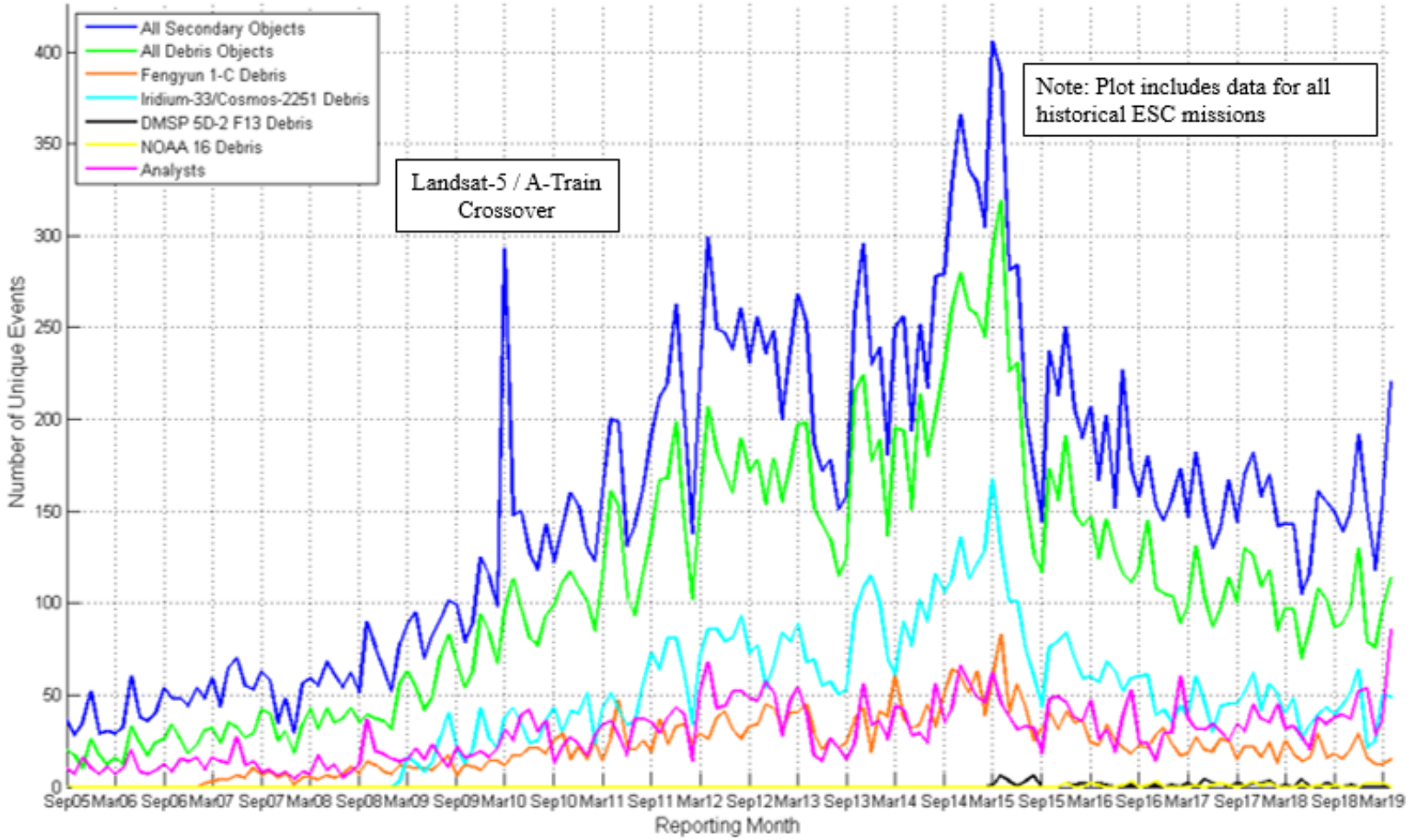
ESMO/ESC Experience with Space Weather

- **Presented at CNES CA WS 2017 (2 Aura Case Studies)**
  - Aura vs. 39858: 9/10/2017 – A significant Space Weather event (No DAM)
  - Aura vs. 89477: 8/29/2015 – JSpOC space weather predictions missed significant solar storm was the most-likely cause of changes in Pc (No DAM)
- **The Aura HIEs were similar to a number of other EOS short-notice HIEs some of which also included potential Space Weather effects.**
  - Aura vs. 37765: 9/03/2013 – SJ-11-02 HIE, CME on 8/28, DMUM on 9/2
  - Aura vs. 35380: 2/16/2014 – CME 30-hours prior to planned DAM
  - Aura vs. 34215: 1/19/2016 – A CME occurred on 1/18 – Aura DAM #6 (1/18/2016)
  - Aura vs. 34726: 3/16/2016 – Mild Geomagnetic Storm – Aura DAM #7 (3/15/2016)

What do we know about the effects of the solar cycle on conjunction assessment and collision avoidance?

ESC Conjunction Assessment Statistics

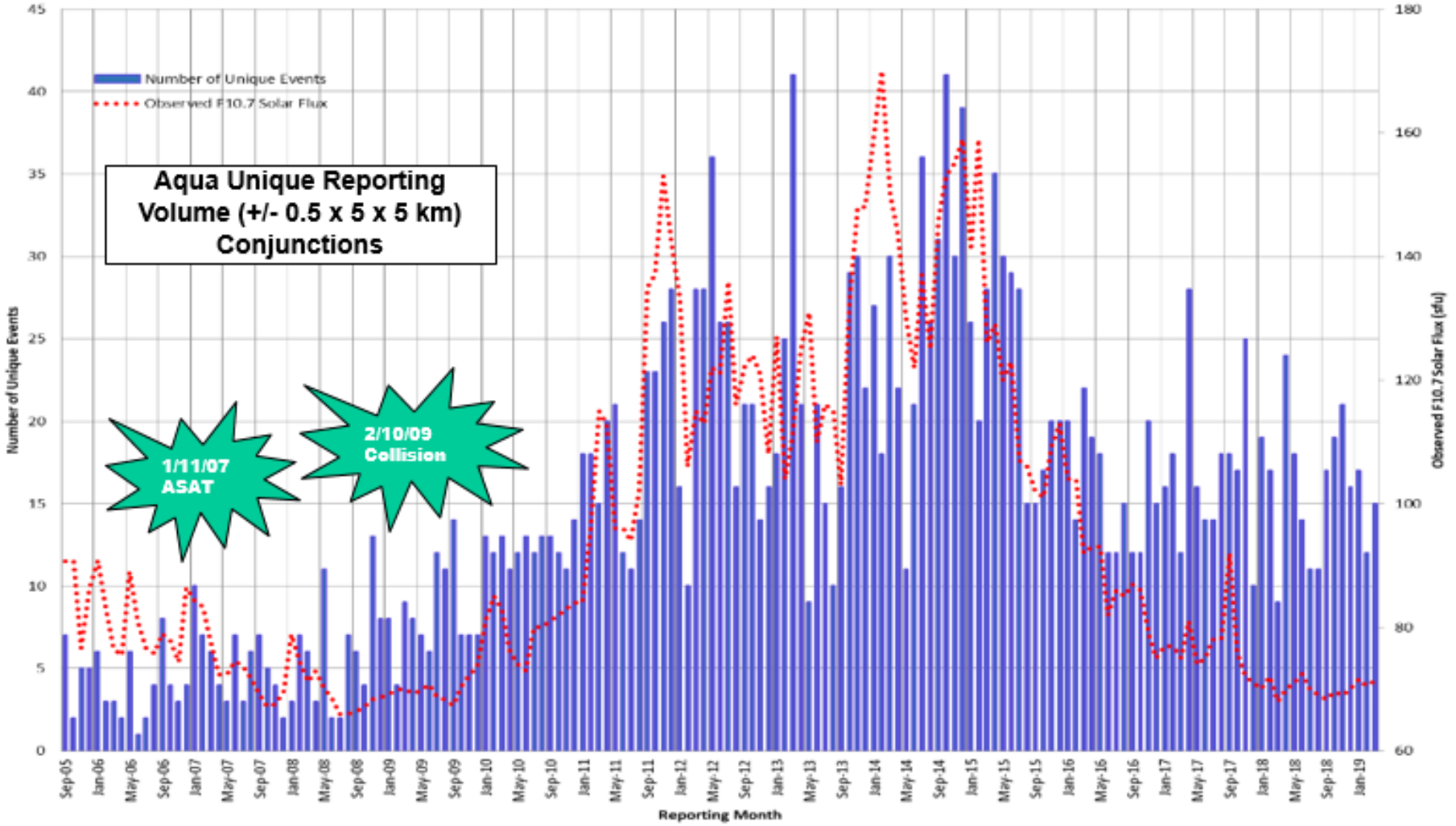
(Monthly Average – September 2005 thru March 2019)



CREDIT: Megan Johnson & Joseph Bryce/CARA Team

Aqua Conjunction Assessment Statistics vs. 10.7 cm Solar Flux

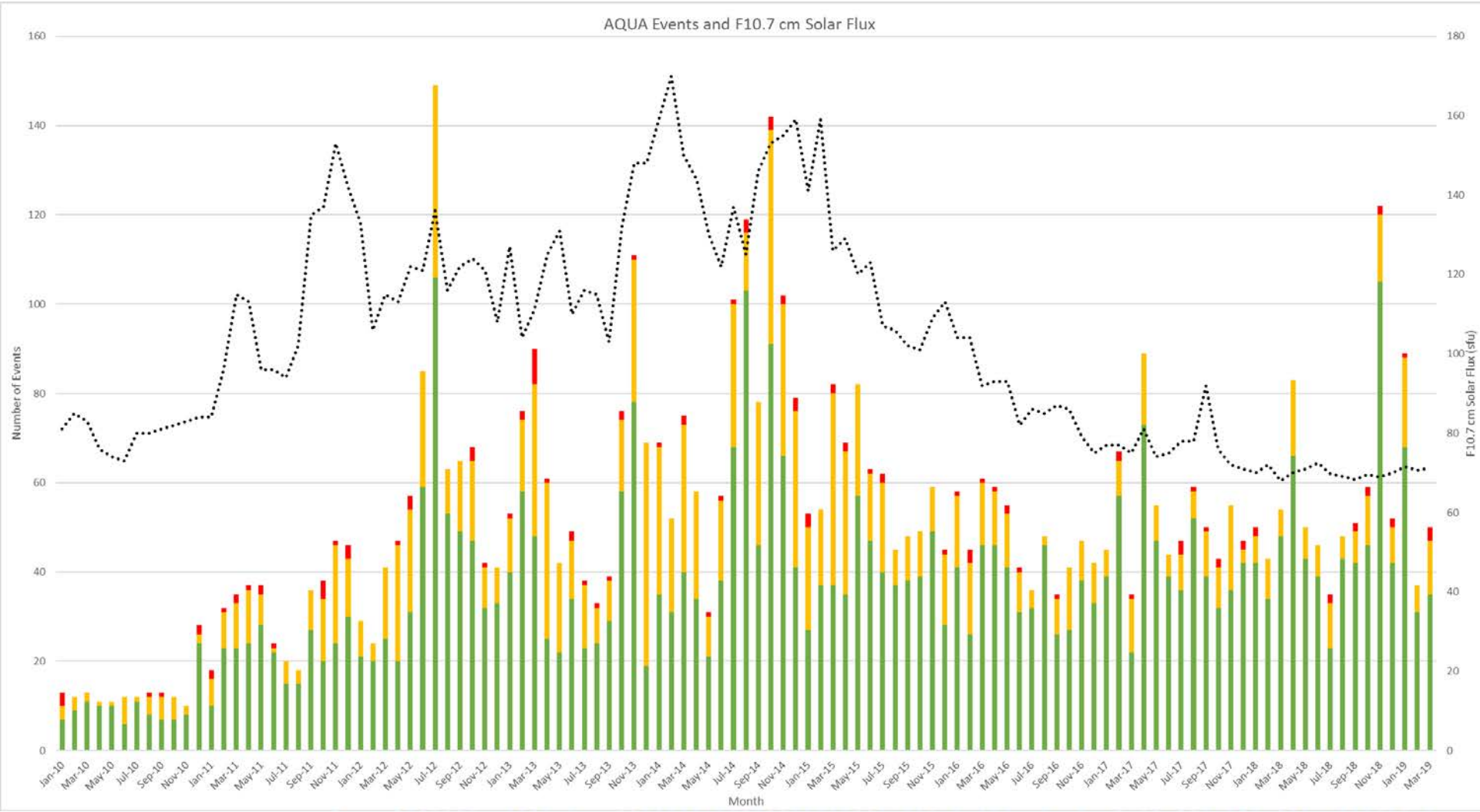
(Monthly Average – September 2005 thru March 2019)



CREDIT: Megan Johnson & Joseph Bryce/CARA Team

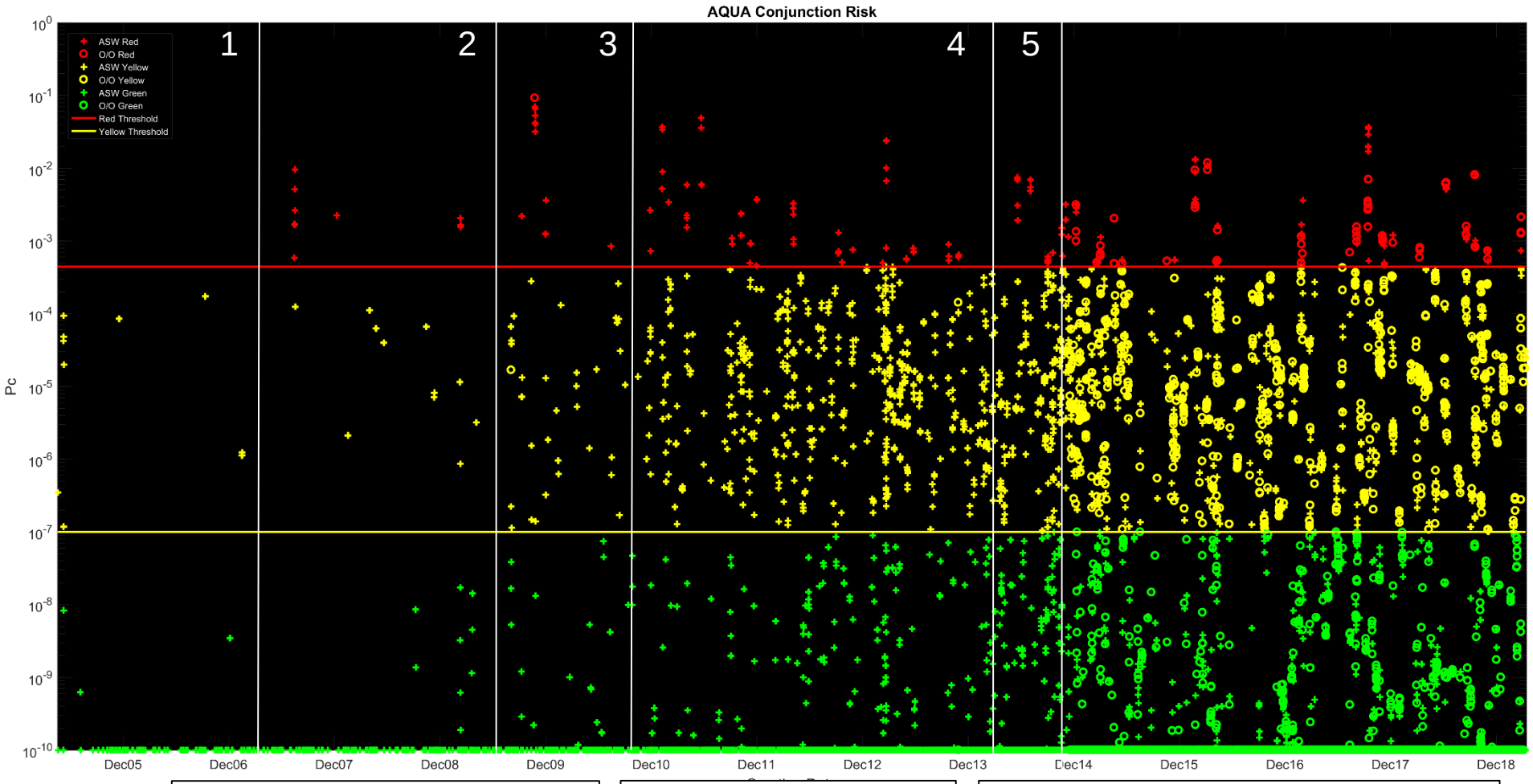
Aqua Conjunction Assessment Statistics vs. 10.7 cm Solar Flux

(Monthly Average – January 2010 thru March 2019)



CREDIT: Megan Johnson & Joseph Bryce/CARA Team

Aqua Historical Events by Risk Category



1. Fengyun 1-C event, 11 JAN 2007
2. Iridium-Cosmos event, 12 FEB 2009

3. Screening volume update, Fall 2010

4. Added second LEO screening, 1 MAR 2014
5. CONOPS, 1 NOV 2014*

CREDIT: Megan Johnson & Ben Moody/CARA Team

EOS High-Interest Event (HIE) Statistics

EOS Debris Avoidance Maneuvers

(2005 – 2019-05-31)

Year	Terra 25994	Aqua 27424	Aura 28376	Total DAMs	Waive-offs Re-plans
2005	1	0	0	1	0
2006	0 (1)	0	0	0	1
2007	1	0	0	1	0
2008	0	0	1 (2)	1	2
2009	0	1	0	1	0
2010	1	0	1	2	0
2011	0	4 (5)	0 (1)	4	6
2012	0 (1)	0 (1)	1 (1)	1	3
2013	3	4 (2)	1 (3)	8	5
2014	3 (3)	1 (2)	1 (2)	5	7
2015	2 (4)	0 (4)	0 (4)	2	12
2016	0	0	2 (3)	2	3
2017	1	0	1 (3)	2	3
2018	2	1 (2)	1	4	2
2019	2	0 (1)	1	3	1
TOTAL	16 (9)	11 (17)	10 (19)	37	45

Challenges

- **Space Fence:**
  - **Conservatively a 3-5 fold increase**
  - **Maybe larger? an Order-of-magnitude? Maybe more?**

- **Mega Constellations: The BIG Three**
  - **SpaceX Starlink: 4,425 – 11,943**
  - **Boeing: 1,396 – 2,956**
  - **OneWeb: 720 – 2,720**

Source http://www.parabolicarc.com/2017/03/03/spacex-launch-12000-satellites

- **Solar Maximum is coming**

Bottom Line: Nothing will happen until something happens


Thank you for your time and attention
Questions

Abbreviations/Acronyms List

A-Sat – Anti-Satellite
ASW – Astrodynamics Workstation
CA – Conjunction Assessment
CAE – FOT Collision Avoidance Engineer
CAM – Command Authorization Meeting
CARA – Conjunction Assessment Risk Analysis
CME – Coronal Mass Ejection
CMOC – Cheyenne Mountain Complex
CRMS – Collision Risk Management System
CSpOC – Combined Space Operations Center
DAM – Debris Avoidance Maneuver
DMUM – Drag Make-up Maneuver
EDT – Eastern Daylight Time
EDR – Energy Dissipation Rate
EOS – Earth Observing System
ESC – Earth Science Constellation
ESMO – Earth Science Mission Operations
FDS – Flight Dynamics System
FOT – Flight Operations Team
FST – Flight Support Team
GMT – Greenwich Mean Time
GSFC – Goddard Space Flight Center
GTE – Ground Track Error
HIE – High Interest Event
HIEB – High Interest Event Briefing
HQ – Headquarters
ISAS – Institute of Space and Astronautical Science
JAXA – Japan Aerospace Exploration Agency
km – kilometer
LUPI – Length of Update Interval
MD – Mission Director
MLT – Mean Local Time
MOWG – Mission Operations Working Group
MTS – Maneuver Trade Space
NASA – National Aeronautics & Space Administration
OD – Orbit Determination
OSA – Orbital Safety Analyst
Pc – Probability of Collision
RIC – Radial, In-track, Cross-Track
RMM – Risk Mitigation Maneuver
SP – Special Perturbations
SXT – Soft X-Ray Telescope
TBD – To Be Determined
TCA – Time of Closest Approach
TDRSS – Tracking and Data Relay Satellite System
USSTRATCOM – United States Strategic Command
UT – Universal Time
UTC – Coordinated Universal Time
WDC-SILSO – World Data Center - Sunspot Index and Long-term Solar Observations