

# Space Weather and Emerging Services for Aviation

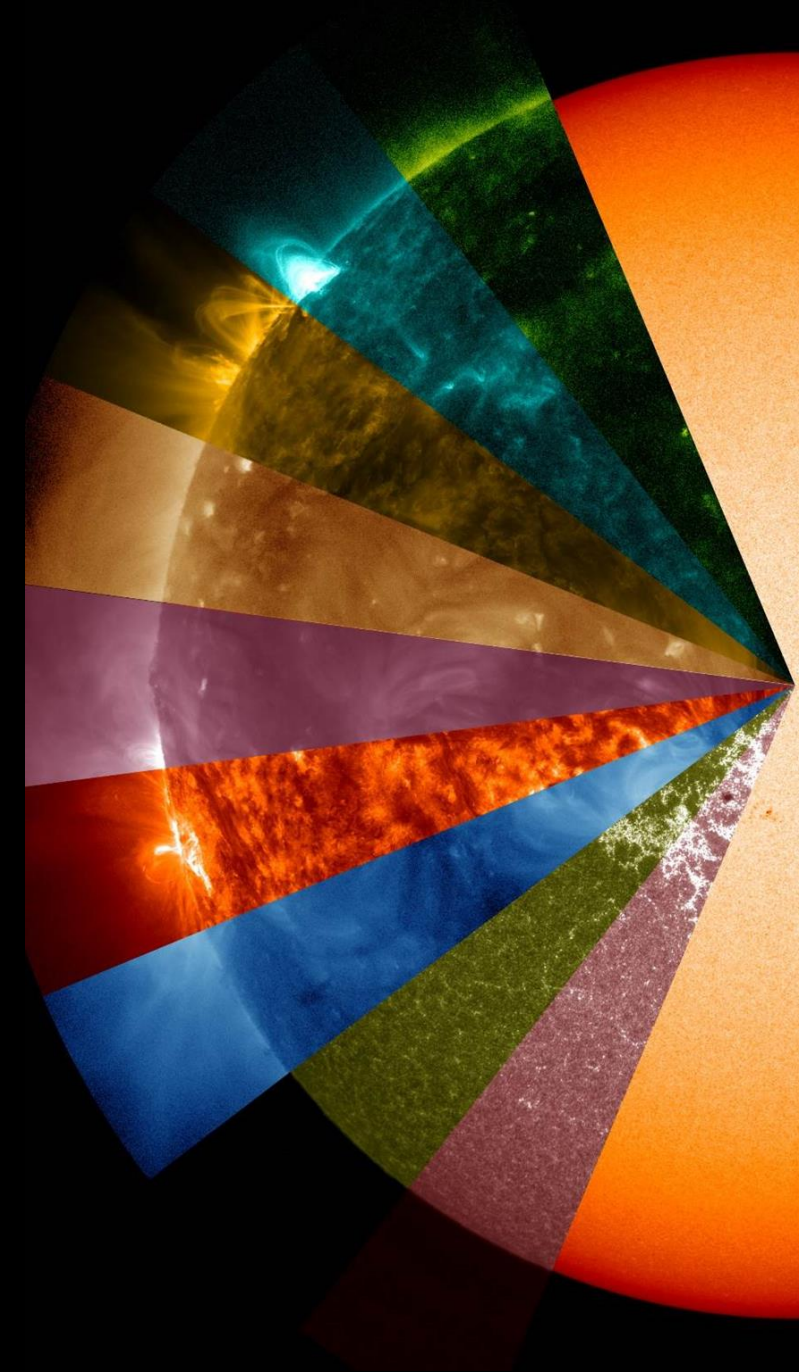
Bob Rutledge

NOAA Space Weather Prediction Center, Boulder, CO

Seconded Expert, WMO Aeronautical Meteorology Division

# Outline

- ✈ Space Weather Primer/Sequence of Events
- ✈ Services Within ICAO
- ✈ Challenges in Service Provision
- ✈ Evolution of Services and Needs



# Sunspots and the Solar Cycle

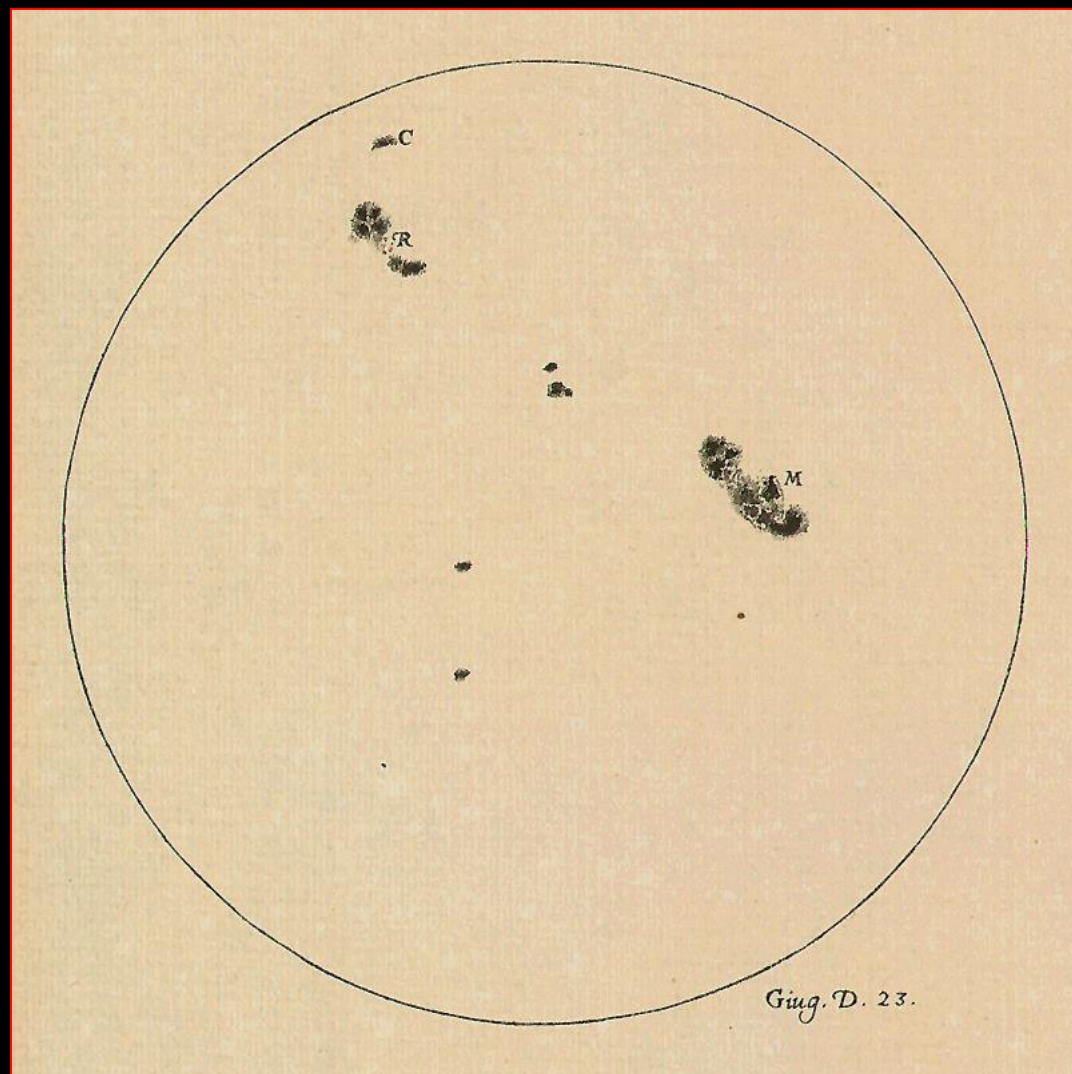


Image Credit – The Galileo Project

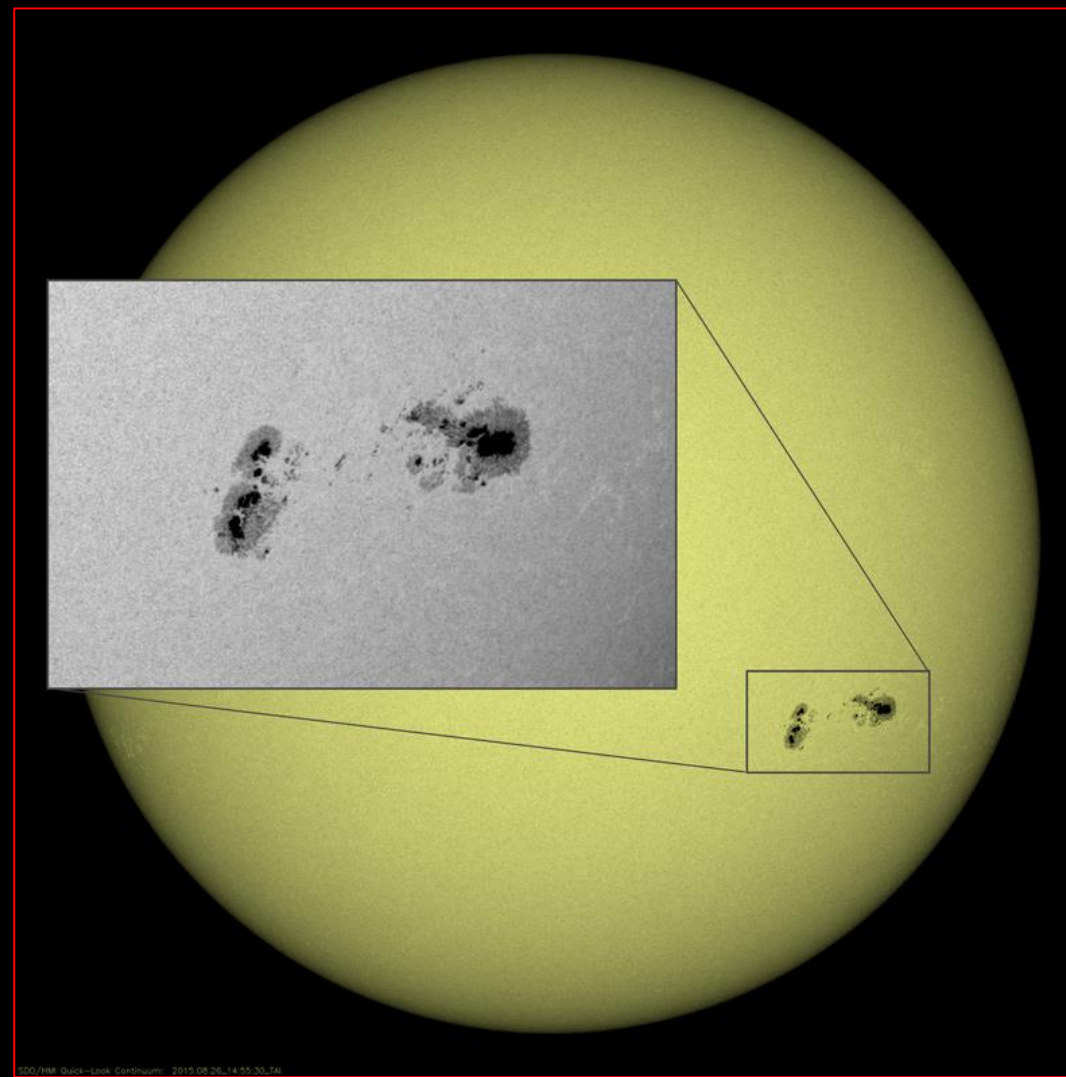


Image Credit – NASA AIA/HMI Consortium

# Sunspots and the Solar Cycle

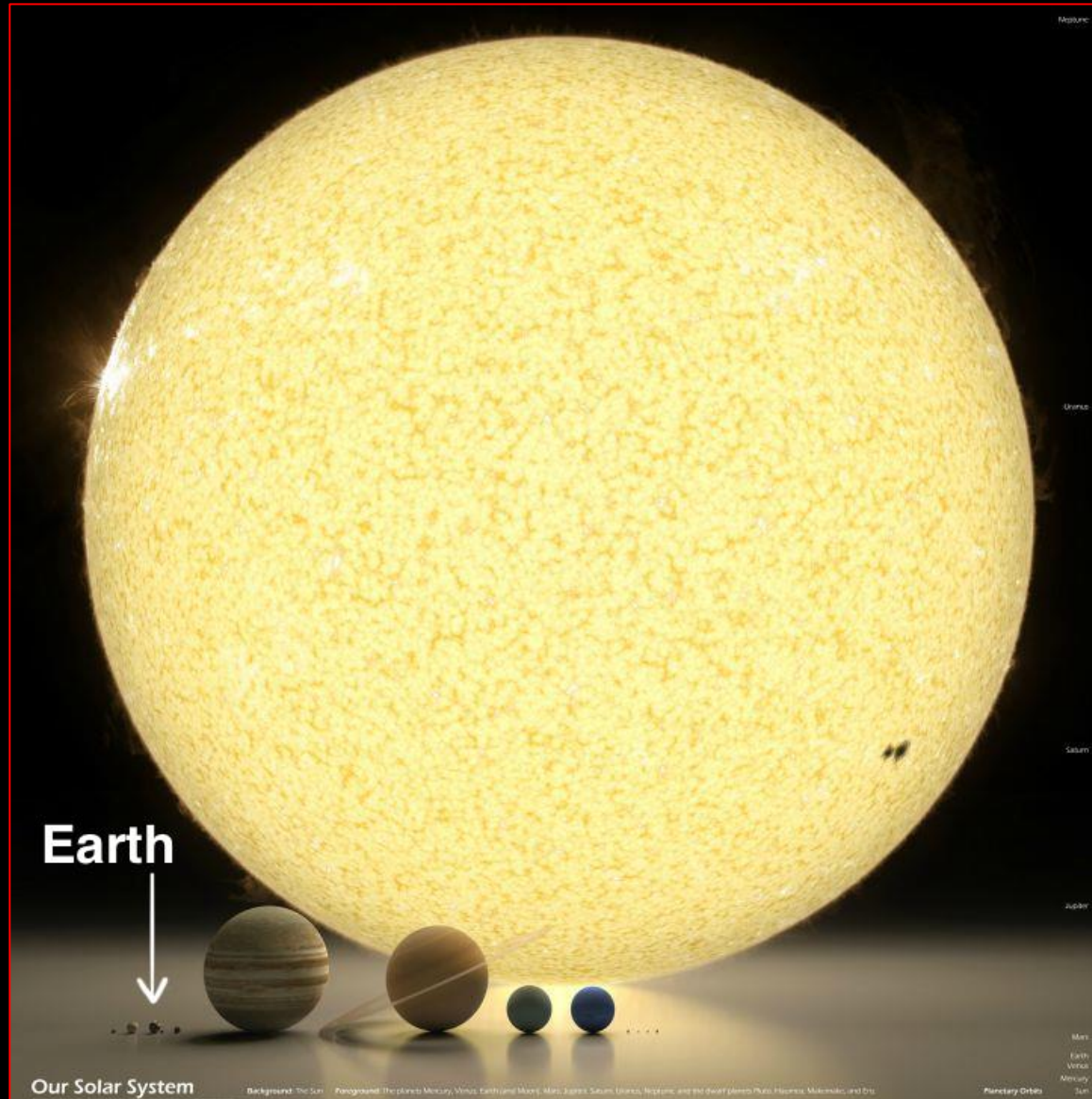
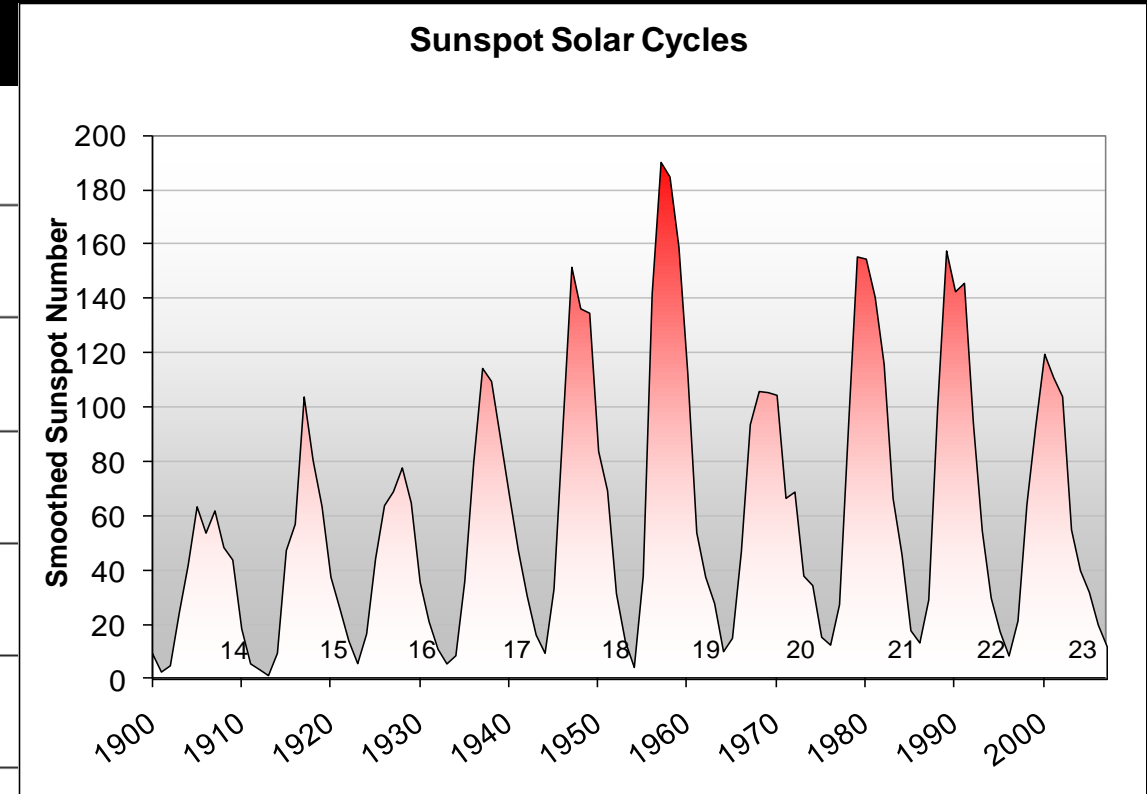
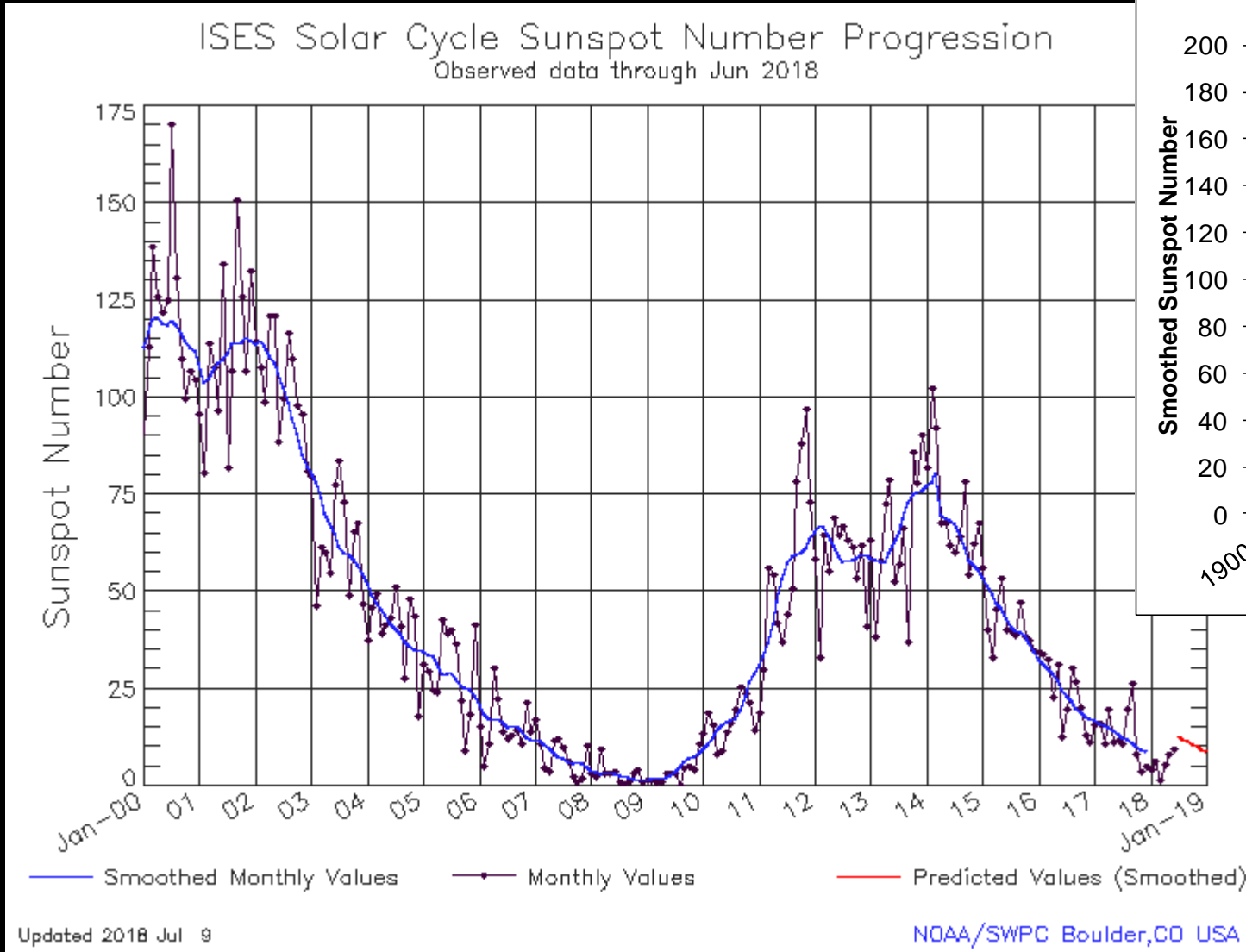


Image Credit – WaitButWhy.com

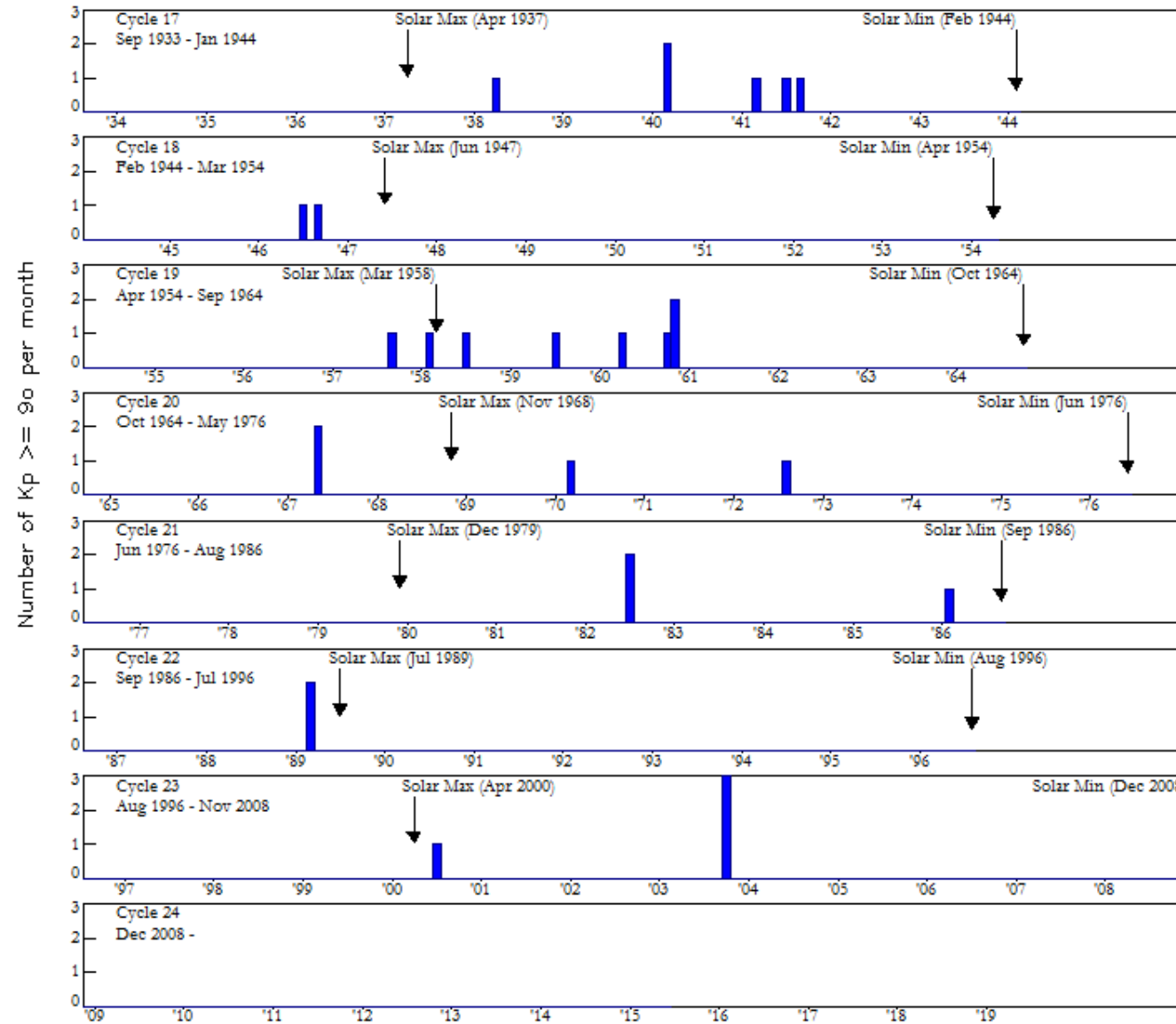
# Sunspots and the Solar Cycle



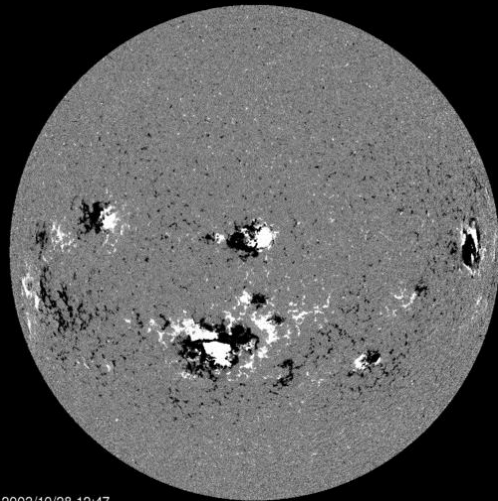
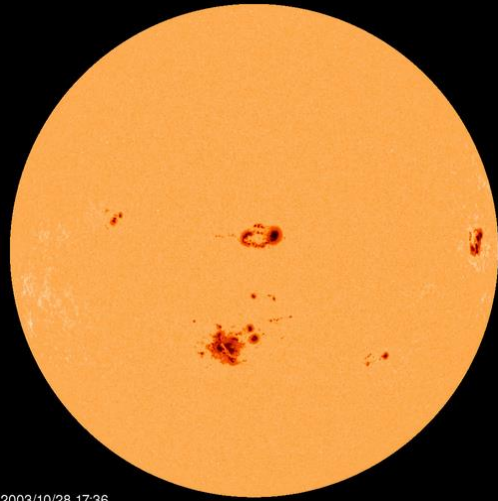
# Periods with Kp $\geq 9$

June 2015

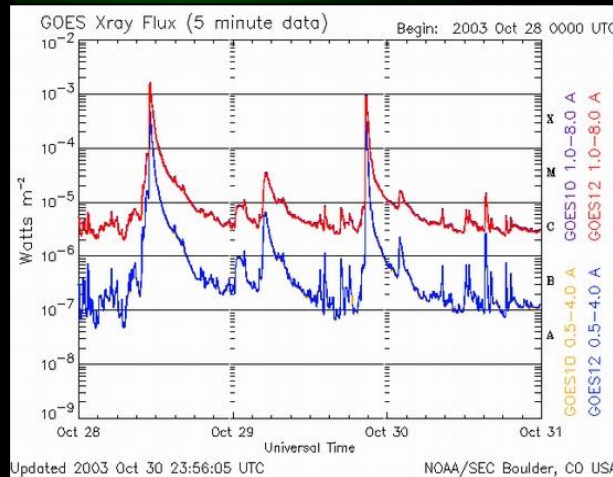
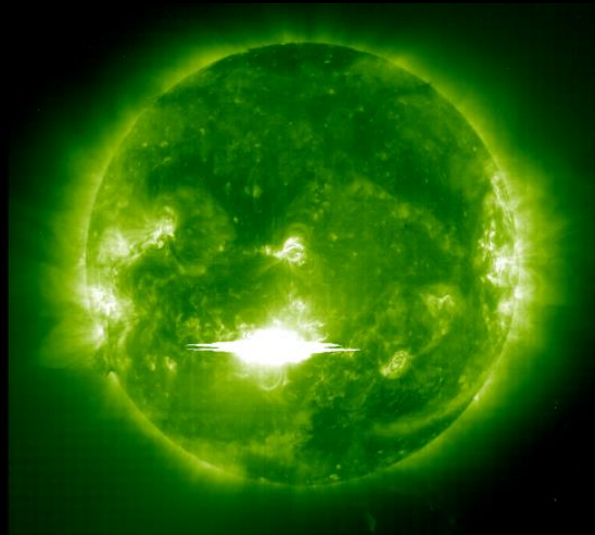
(Month 79)



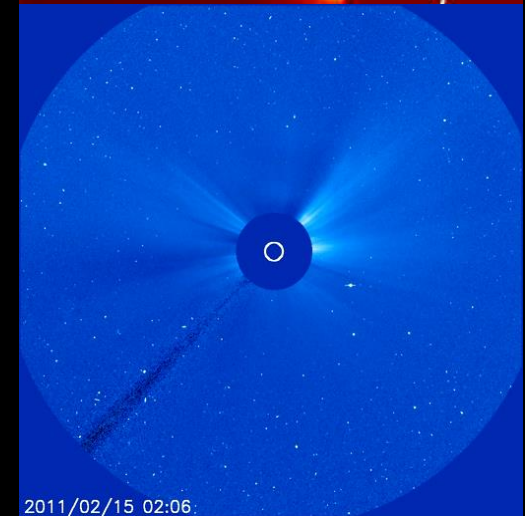
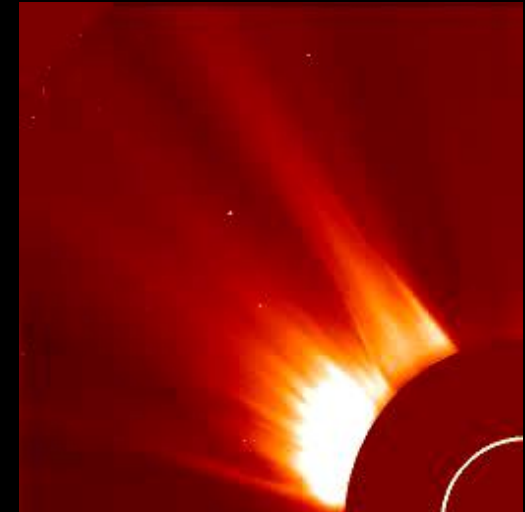
# Sequence of Events



Conditions are Favorable  
for Activity

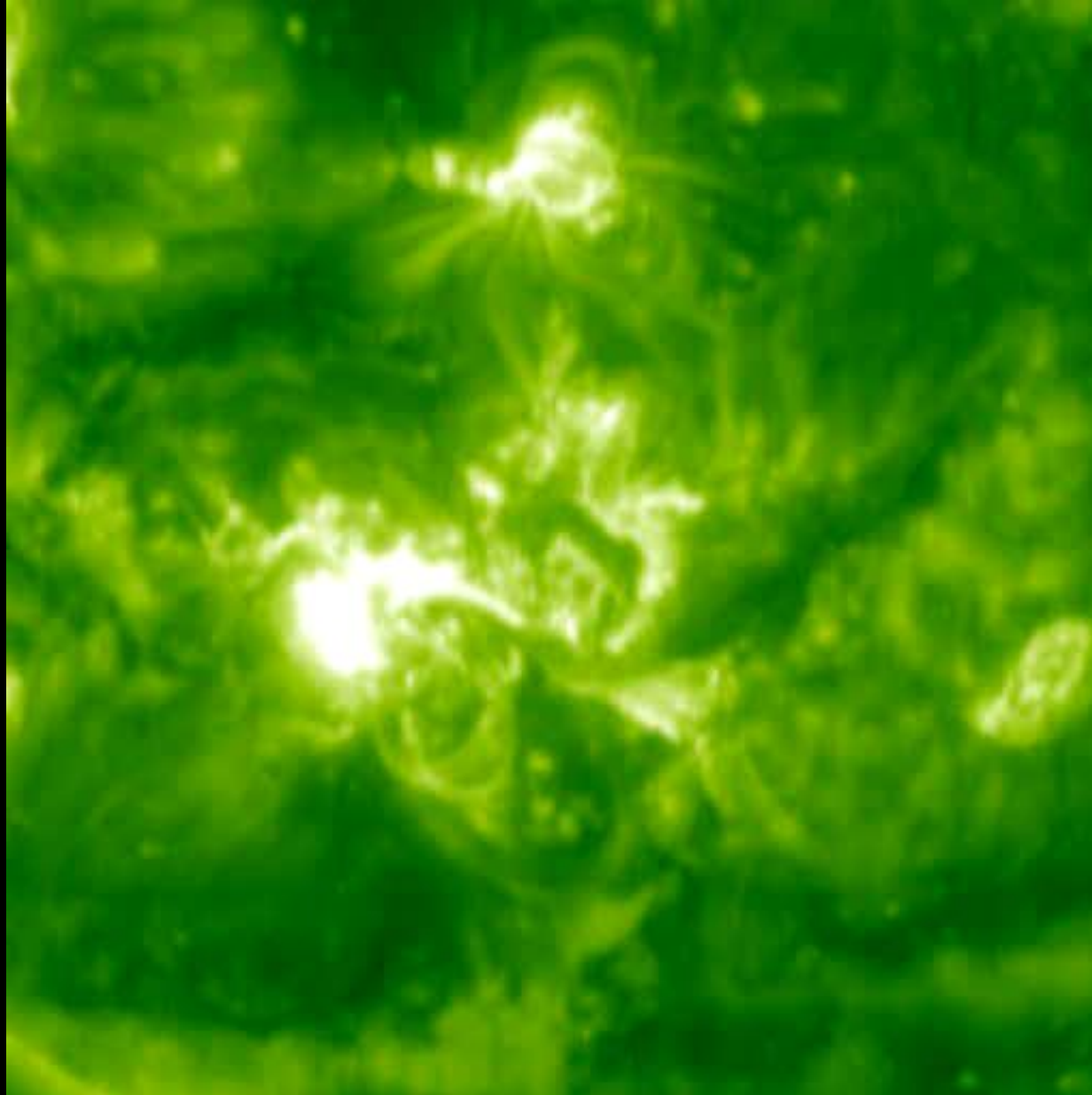


Event  
Occurs



Coronal  
Observations

# Sequence of Events



CAeM-16 Side Event - Exeter, UK



# Phenomena Reference/Impacts

## Solar Flare Radio Blackout (R Scale):

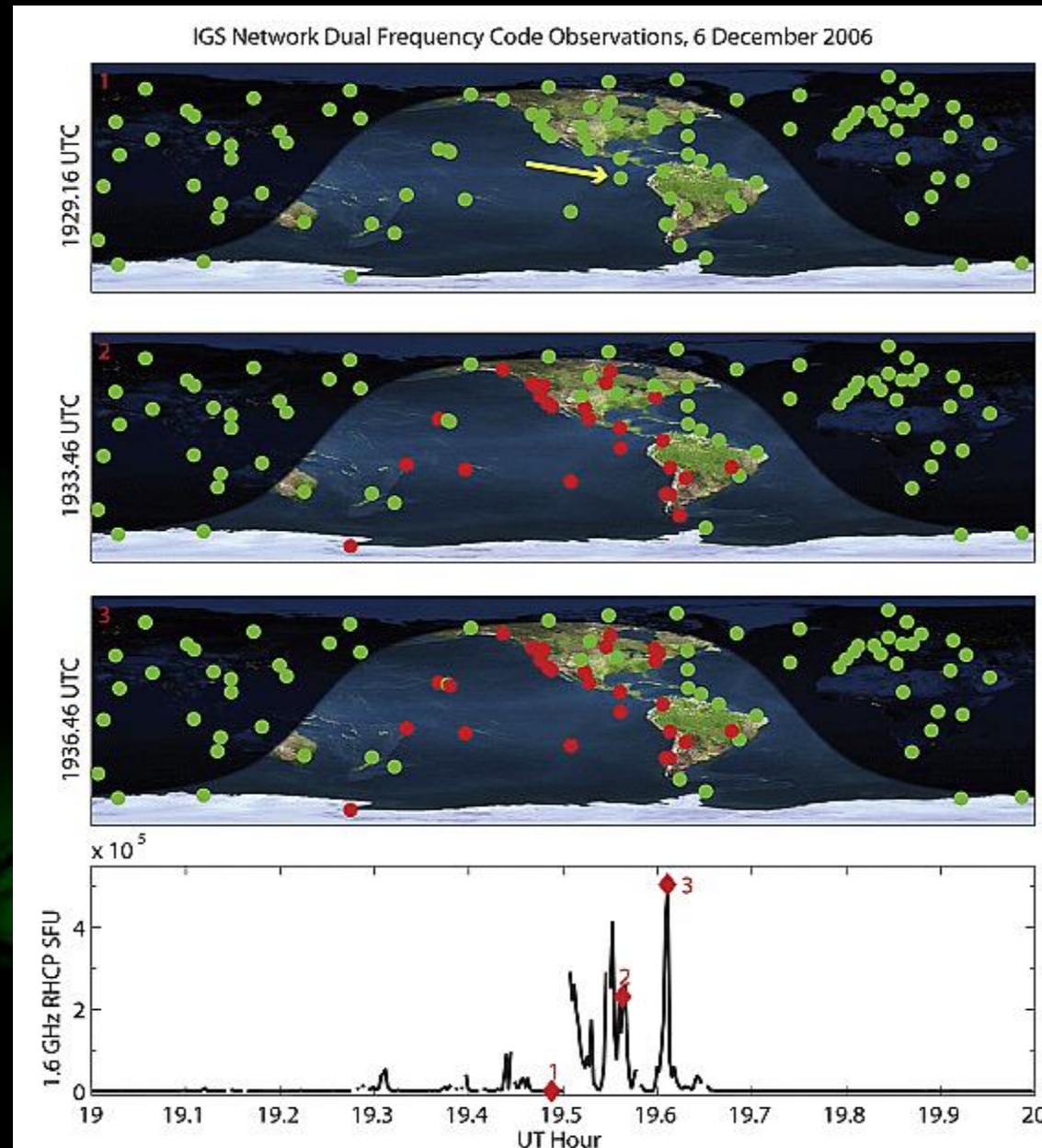
- No advance warning
- Effects lasts for 10's of minutes to several hours
- Impacts High Frequency (HF) communication on the sunlit side of the Earth
- First indication significant S and G scale activity may be possible

## Solar Radiation Storm (S Scale):

- Warnings possible on the minutes to hours time scale
- Elevated levels can persist for several days
- Impacts to the health and operation of satellites and International Space Station operations and crew
- Impacts High Frequency communication in the polar regions, affecting commercial airline operations
- On rare occasion, elevated radiation exposure for airline passengers and crew

## Geomagnetic Storm (G Scale):

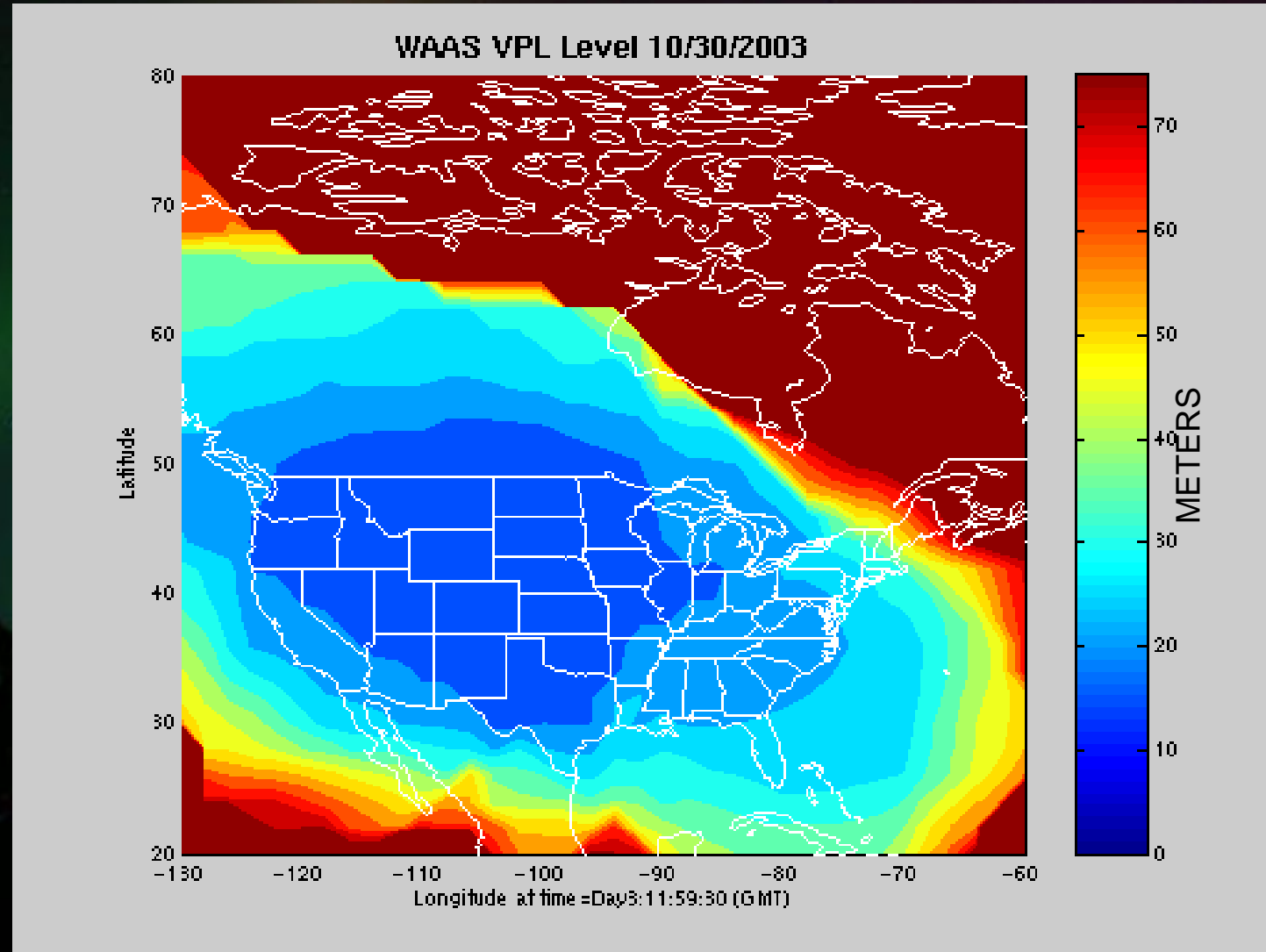
- Advance notice possible given coronal mass ejection (CME) transit times from Sun to Earth range from just under a day to several days (CMEs being the main driver of significant storms)
- In extreme storms, impacts to power grid operations and stability
- Impacts to Global Positioning System (GPS) accuracy and availability
- Driver of aurora; severe to extreme storms may cause aurora to be visible over most of the lower 48



Cerruti, A. P., P. M. Kintner Jr., D. E. Gary, A. J. Mannucci, R. F. Meyer, P. Doherty, and A. J. Coster (2008), Effect of intense December 2006 solar radio bursts on GPS receivers, *Space Weather*, 6, S10D07, doi:[10.1029/2007SW000375](https://doi.org/10.1029/2007SW000375).

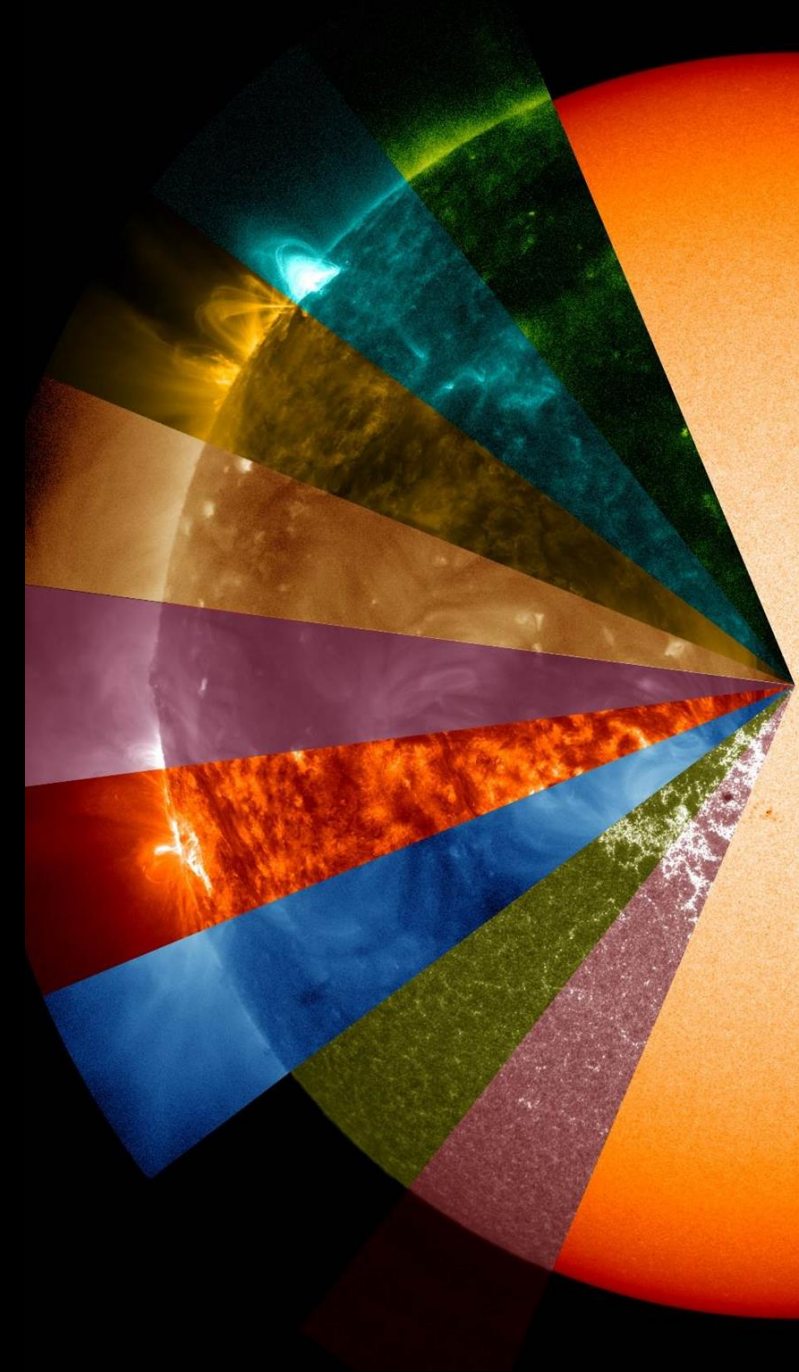
# **GPS IMPACT – U.S. Federal Aviation Administration (FAA) Wide Area Augmentation System (WAAS)**

- Intense geomagnetic and ionosphere storms occur on 29 and 30 Oct, 2003
- Acceptable vertical error limits were exceeded for 15 and 11-hour periods



# Services Within ICAO

- ✈ Services proposed for inclusion in Amendment 78 to Annex 3
  - ✈ HF Communications (propagation, absorption)
  - ✈ Communications via satellite (propagation, absorption)
  - ✈ GNSS-based navigation and surveillance (degradation)
  - ✈ Radiation at flight levels (increased exposure)
- ✈ Event-driven advisories for Moderate or Severe effects
- ✈ Applicability in November 2018
- ✈ Global/regional service model



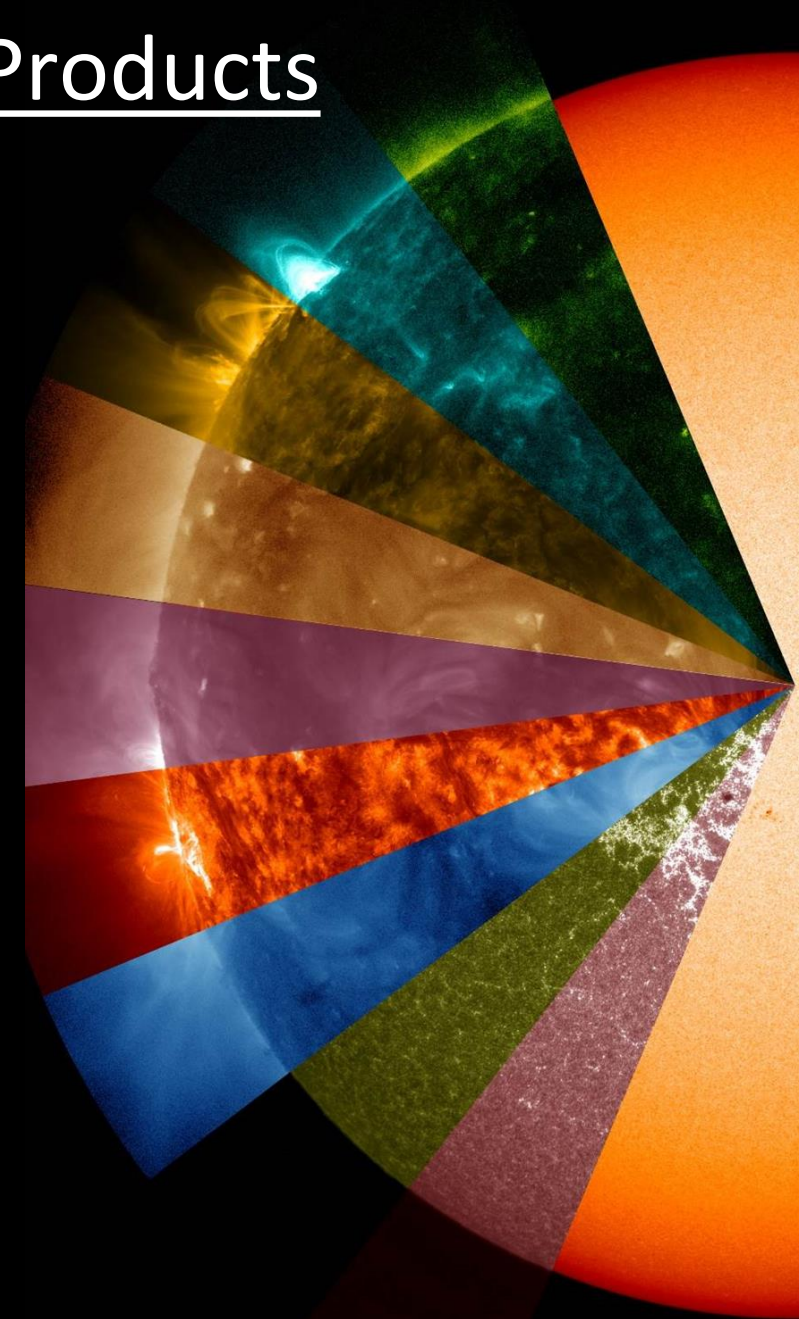
# Services Within ICAO – Example Products

Example A2-4: Space weather advisory message (RADIATION effects)

(communication header)	
SWX ADVISORY	
DTG:	20161108/0000Z
SWXC:	(to be determined)
SWX EFFECT:	RADIATION MOD
ADVISORY NR:	2016/2
FCST SWX:	20161108/0100Z HNH HSH E18000 – W18000 ABV FL350
FCST SWX +6 HR:	20121108/0700Z HNH HSH E18000 – W18000 ABV FL350
FCST SWX +12 HR:	20161108/1300Z HNH HSH E18000 – W18000 ABV FL350
FCST SWX +18 HR:	20161108/1900Z HNH HSH E18000 – W18000 ABV FL350
FCST SWX +24 HR:	20161109/0100Z NO SWX EXP
RMK:	RADIATION LEVELS HAVE EXCEEDED 100 PERCENT OF BACKGROUND LEVELS AT FL350 AND ABOVE. THE CURRENT EVENT HAS PEAKED AND LEVELS ARE SLOWLY RETURNING TO BACKGROUND LEVELS. SEE <a href="http://WWW.SPACEWEATHERPROVIDER.WEB">WWW.SPACEWEATHERPROVIDER.WEB</a>
NXT ADVISORY:	NO FURTHER ADVISORIES

Example A2-3: Space weather advisory message (GNSS and HF COM effects)

(communication header)	
SWX ADVISORY	
DTG:	20161108/0100Z
SWXC:	(to be determined)
SWX EFFECT:	GNSS MOD AND HF COM MOD
ADVISORY NR:	2016/1
OBS SWX:	20161108/0100Z HNH HSH E18000 – W18000
FCST SWX +6 HR:	20121108/0700Z HNH HSH E18000 – W18000
FCST SWX +12 HR:	20161108/1300Z HNH HSH E18000 – W18000
FCST SWX +18 HR:	20161108/1900Z HNH HSH E18000 – W18000
FCST SWX +24 HR:	20161109/0100Z NO SWX EXP
RMK:	LOW-LEVEL GEOMAGNETIC STORMING IS CAUSING INCREASED AURORAL ACTIVITY AND SUBSEQUENT MOD DEGRADATION OF GNSS AND HF COM AVAILABILITY IN THE AURORAL ZONE. THIS STORMING IS EXPECTED TO SUBSIDE



# Adding Value

## ✈️ **Radiation**

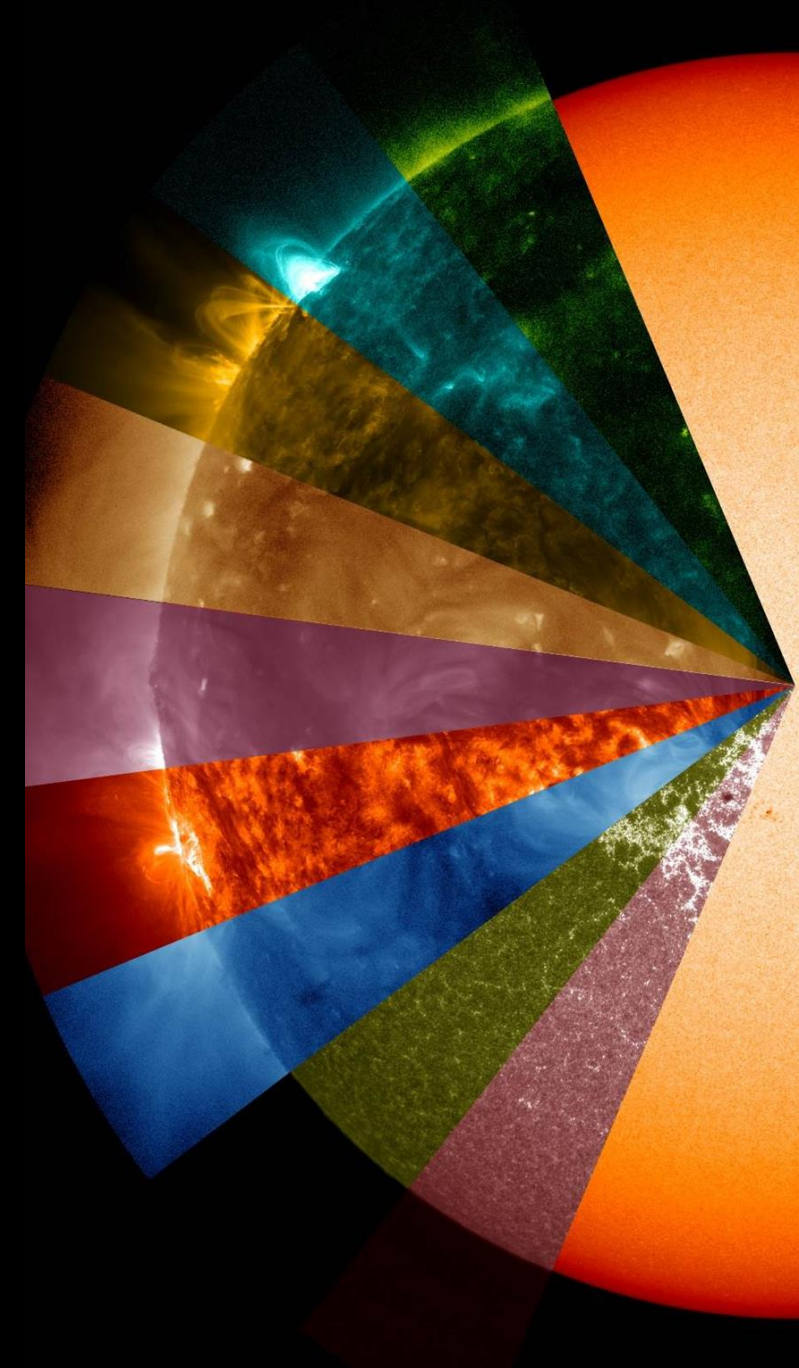
- ✈️ For the September GLE/radiation storm, operations were affected, but to what degree should they have been? Peak of the event on the order of the ICAO Moderate event threshold

## ✈️ **GNSS**

- ✈️ Augmentation systems generally monitor performance and shut down accordingly, but knowing that ahead of time may lead to different flight planning

## ✈️ **Communications**

- ✈️ For the same September event, French Civil Aviation authorities reported that HF radio contact was lost with one non-Controller Pilot Data Link Communications (CPDLC) equipped aircraft off the coasts of Brazil and French Guyana for approximately 90 minutes, triggering an alert phase until a position report was received by New York radio
- ✈️ ATC in Miami had issues with lost communications for aircraft flying oceanic routes around Hurricane Irma



# Interpreting Products – Exposure Example

A common substance example:

Median Lethal Dose ( $LD_{50}$ )

- 192 milligrams per kilogram in rats
- (Estimated) ~150-200 milligrams per kilogram in humans

*Holmgren, et al. 2004*

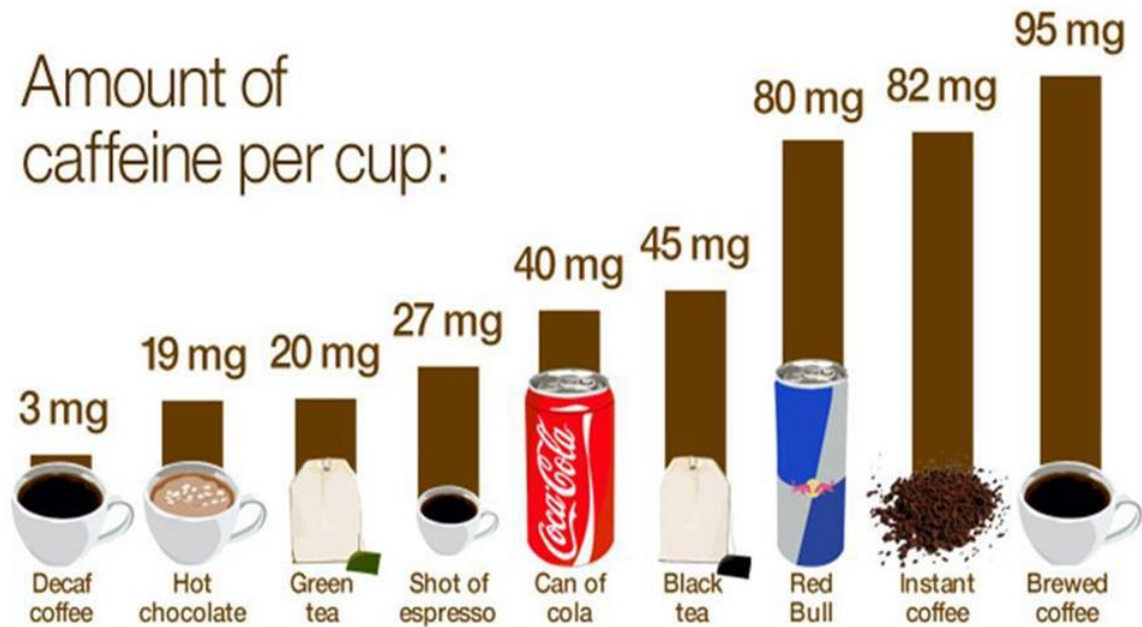
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<http://www.mountainstrongdenver.com/caffeine-and-sports-performance/>



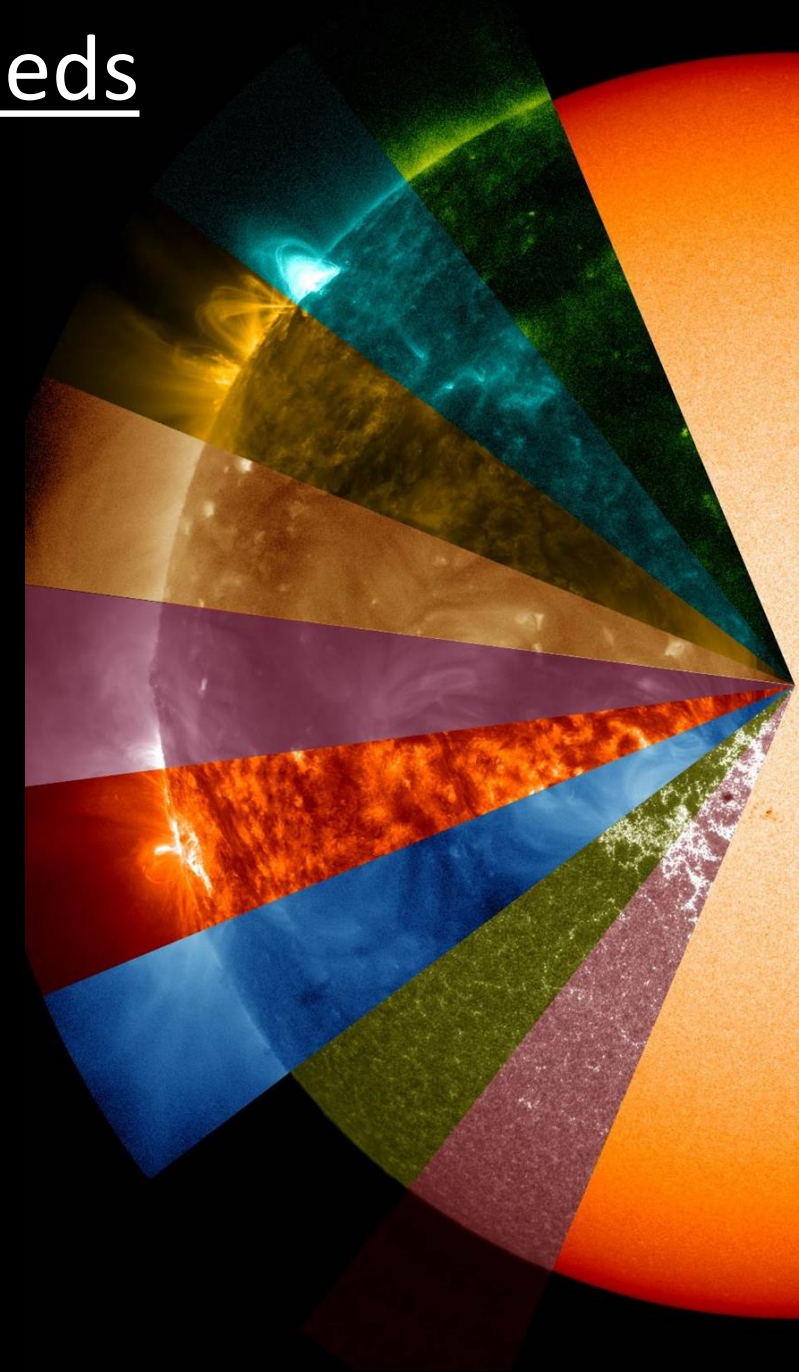
# Evolution of Services and Needs

## ✈️ **Radiation**

- ✈️ As aircraft fly farther and longer, exposures will increase
- ✈️ In situ observations will help with model validation, data assimilation, and operational decision making

## ✈️ **GNSS**

- ✈️ Additional GNSS frequency adoption can largely eliminate ionospheric-induced position errors
- ✈️ Engineers with time and money can engineer around some challenges, but some will remain
- ✈️ Scintillation will likely remain the primary issue



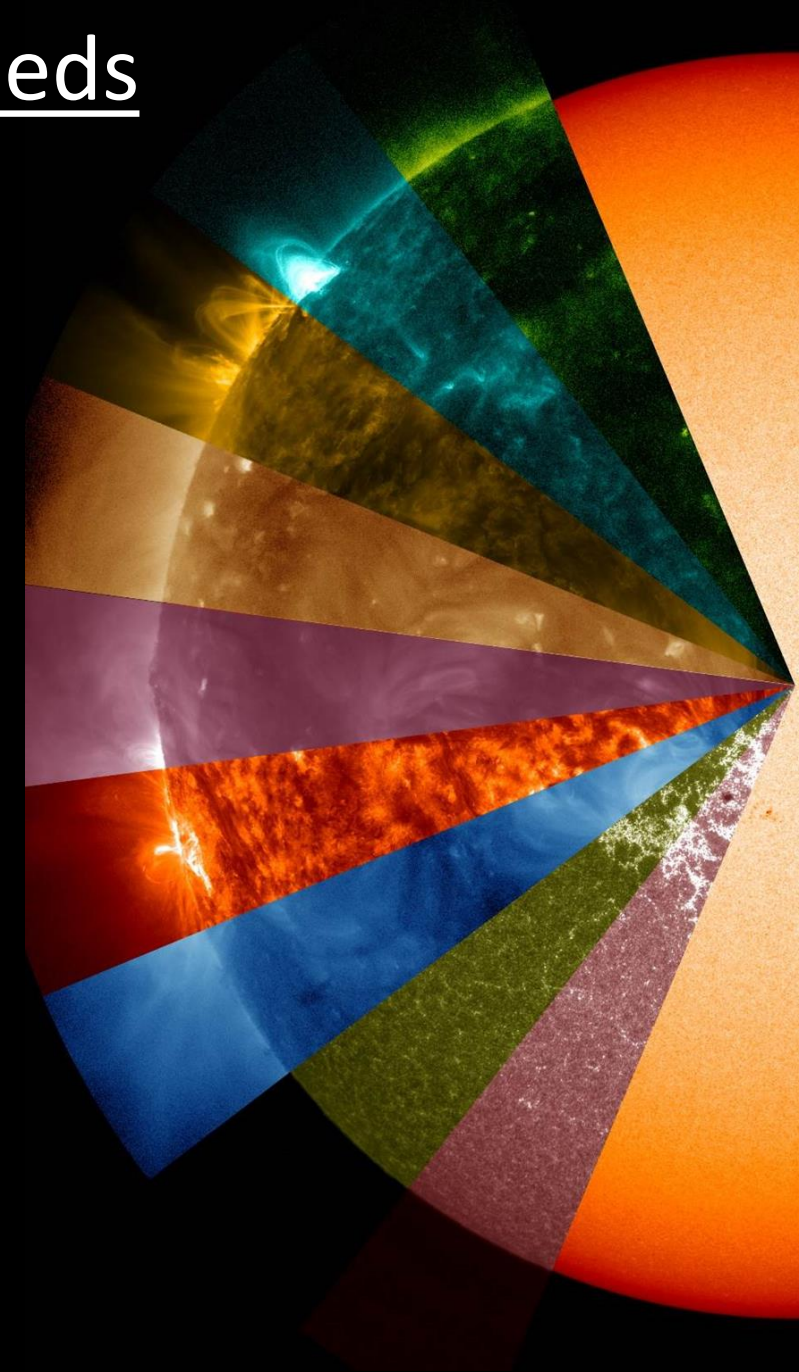
# Evolution of Services and Needs

## ✈ **Communications**

- ✈ Application of HF is changing. HF datalink use still prevalent
- ✈ Geosynchronous and LEO-based satellite communication increasing

## ✈ **Overall...**

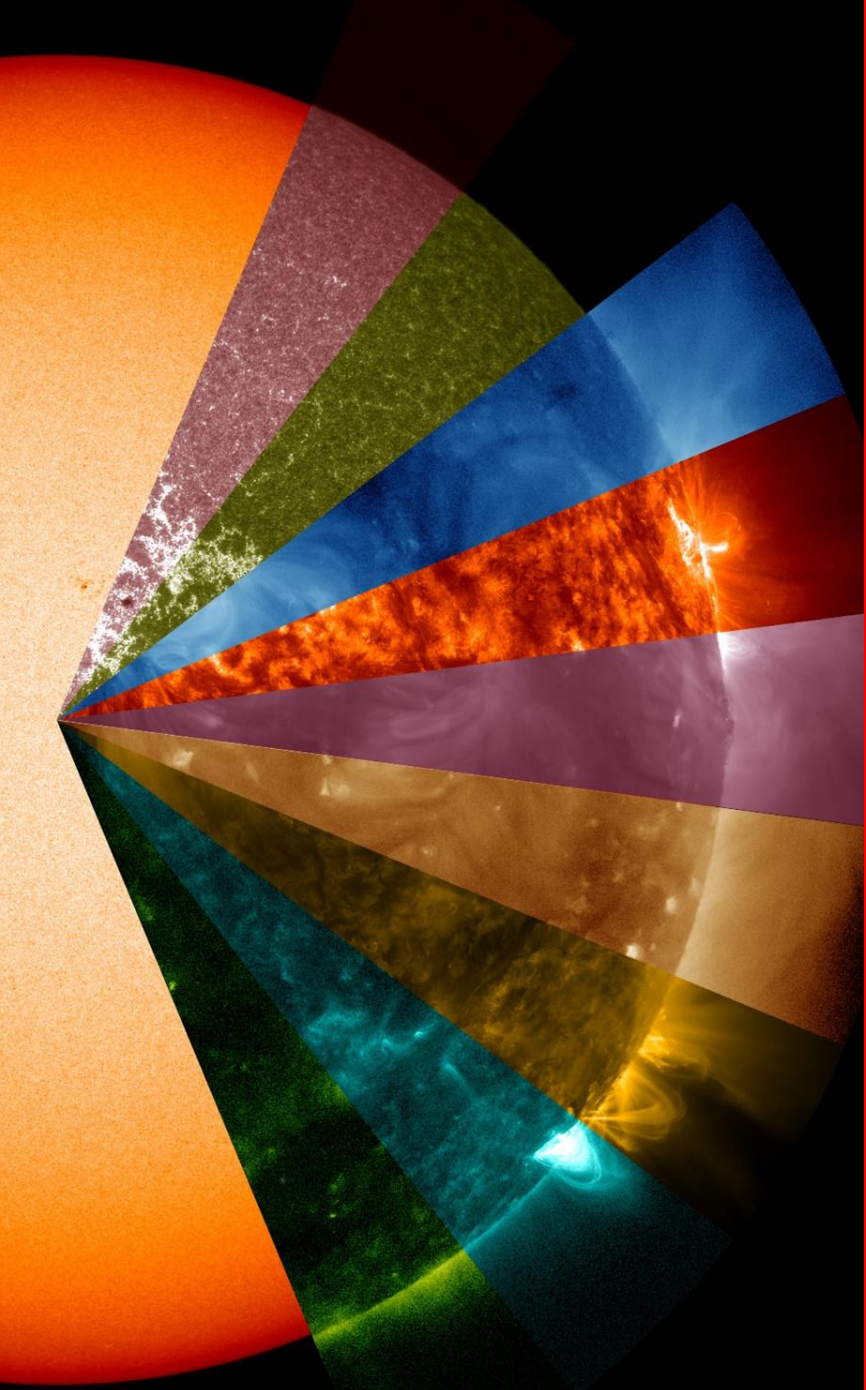
- ✈ Short-term forecasting gains are coming
- ✈ However, no paradigm shifts in multi-day forecasting are likely in the foreseeable future
- ✈ Given the chaotic, eruptive nature of the phenomena, space weather may never be like weather, but we can try...



# NOAA Space Weather Prediction Center Boulder, Colorado

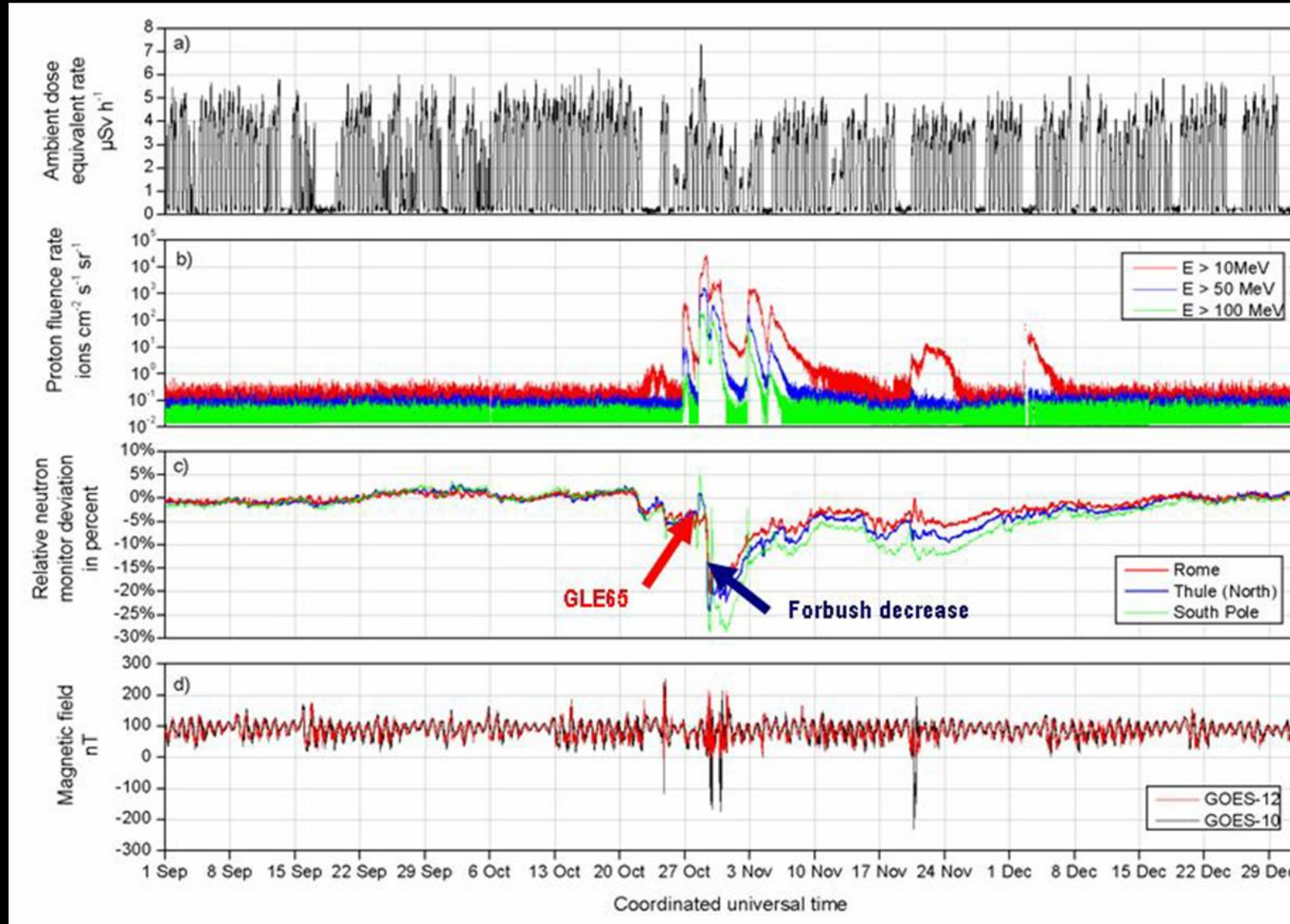


[www.spaceweather.gov](http://www.spaceweather.gov)



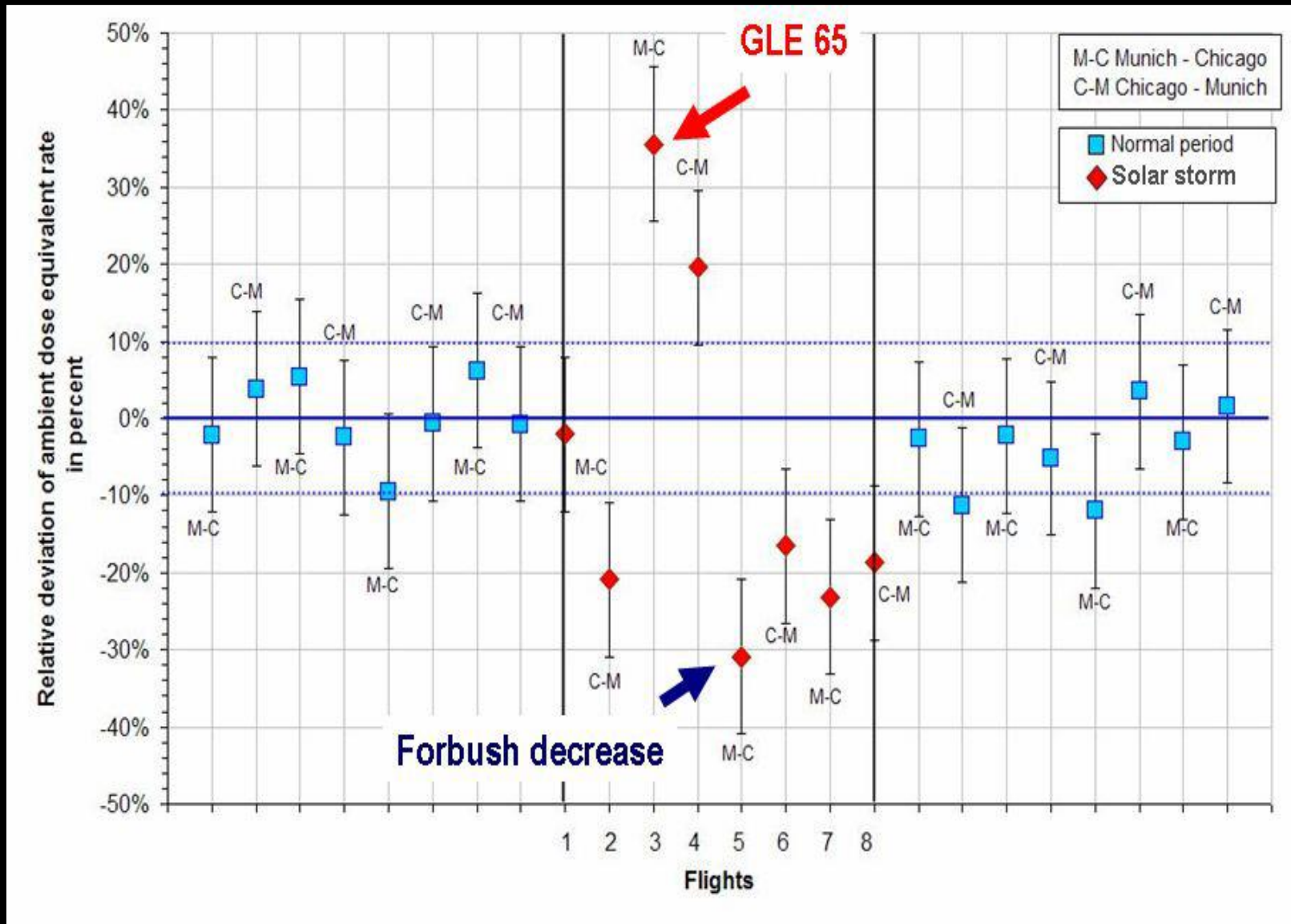
# Backup Material

# Halloween Event Radiation Storm



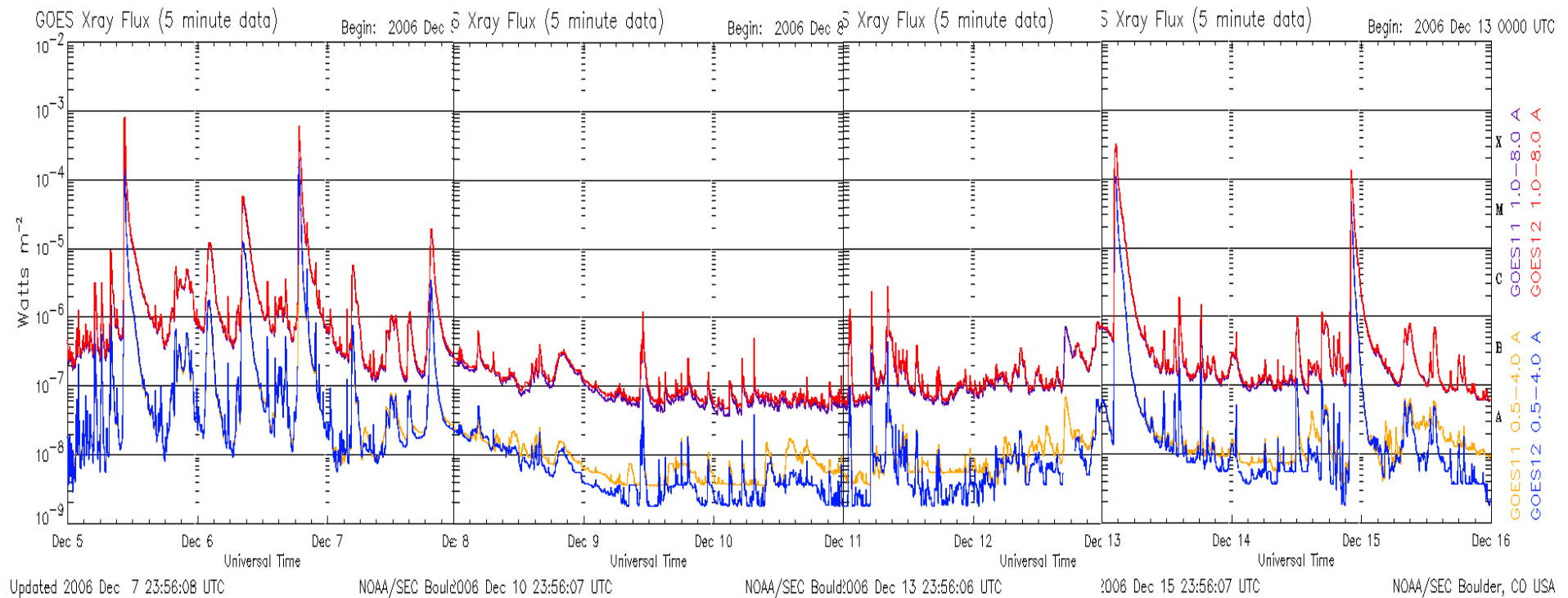
Peter Beck, et al. 2005

# Halloween Event Radiation Storm

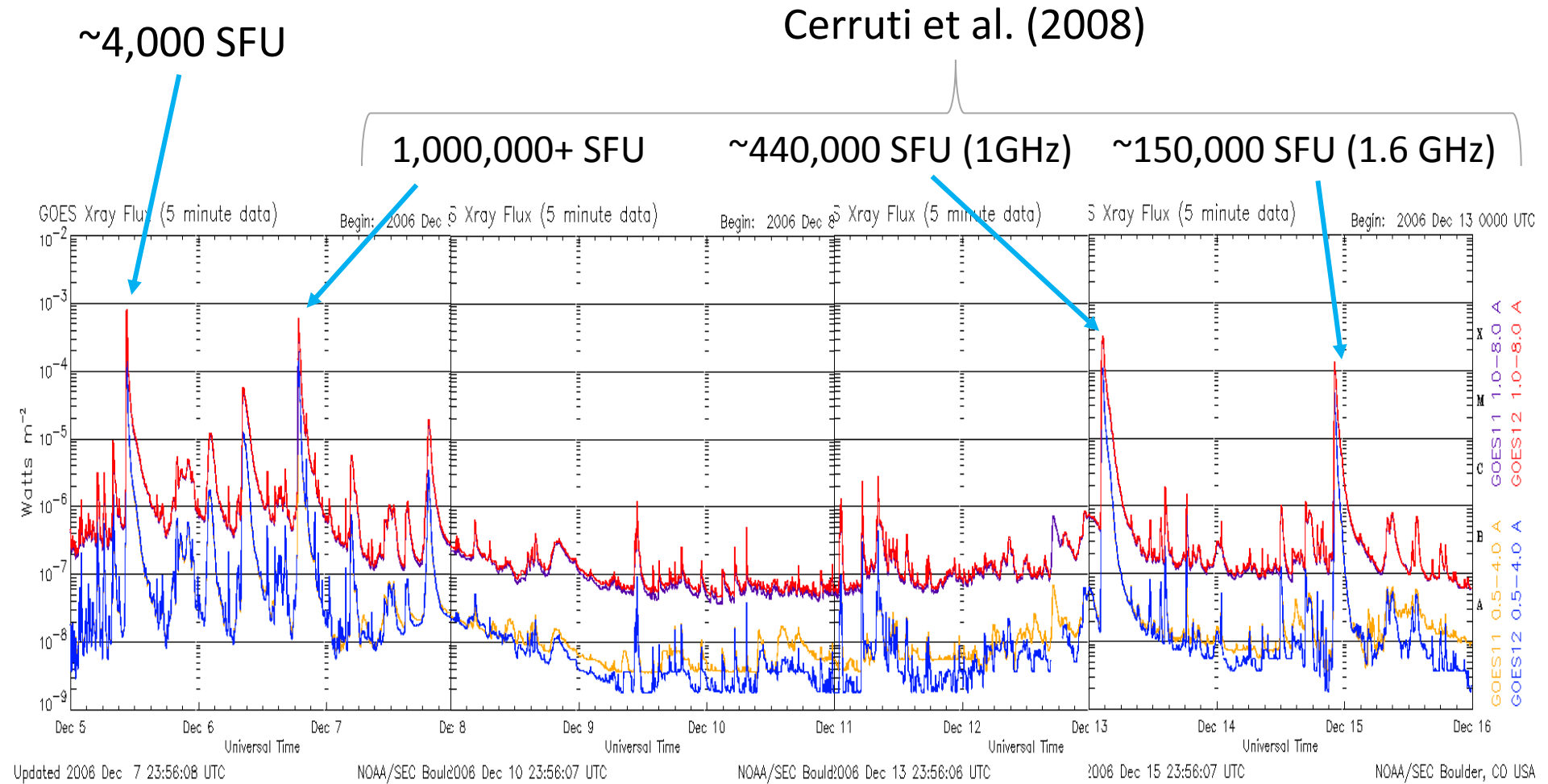


Peter Beck, et al. 2005

# December 2006 – 1415MHz Radio Bursts



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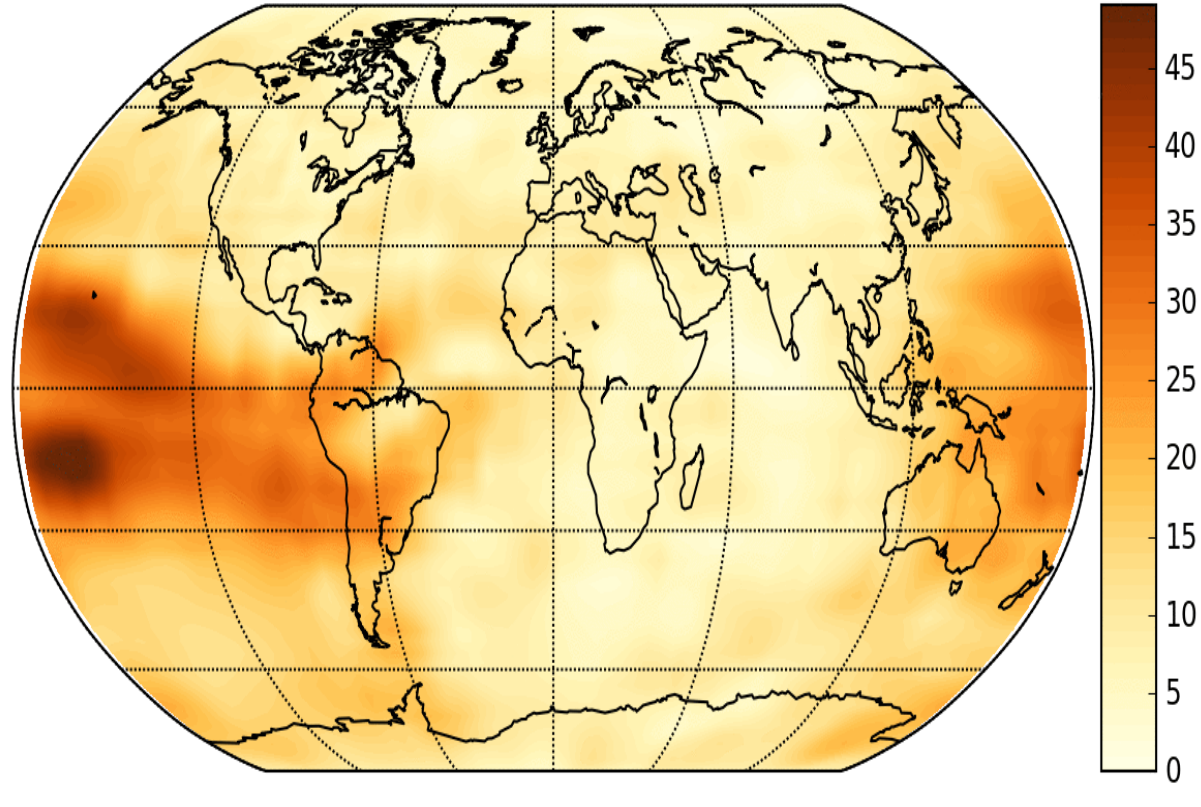




# The Ionospheric Response

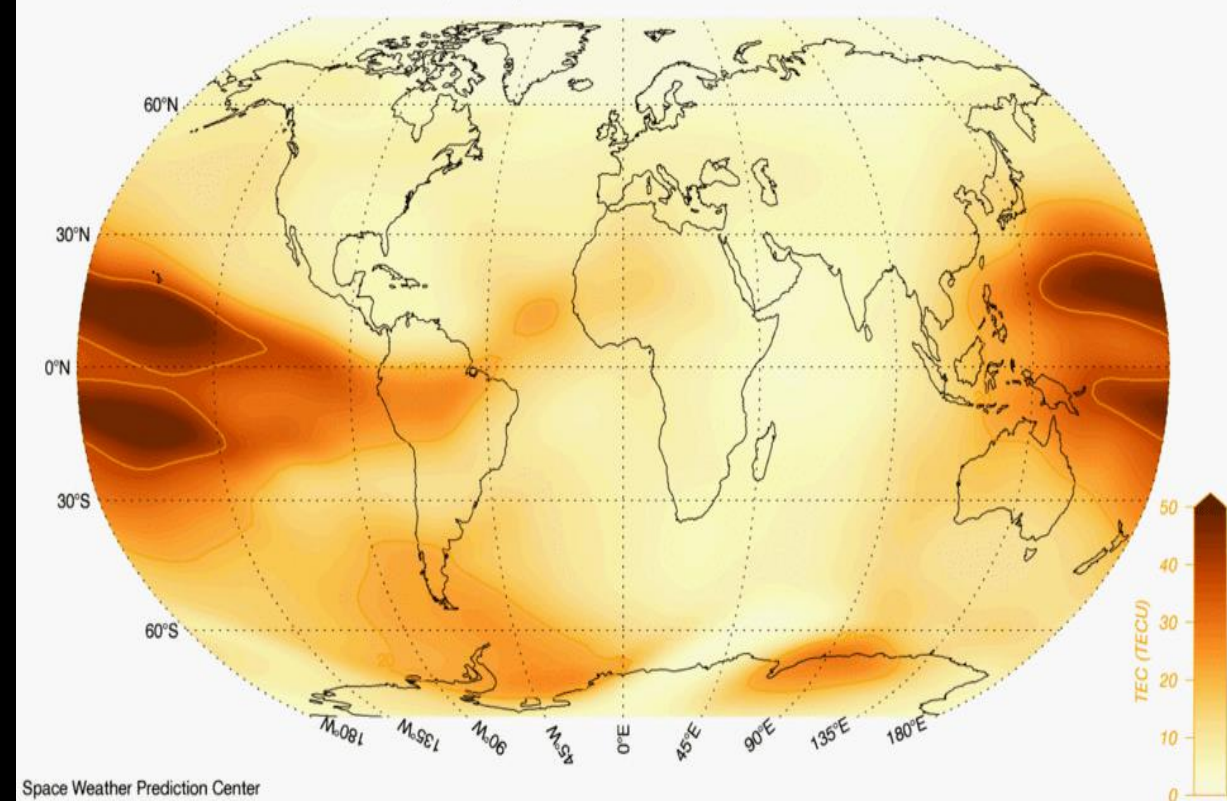
**GloTEC TEC: Data Driven Assimilative Model**

2017.11.021 00:05UT Max: 51.4 Min: 0.6



**WAM-IPE TEC Physics-based Model**

WAM-IPE, Ionospheric TEC : 2017-11-21 00:15 UTC



# The Ionospheric Response

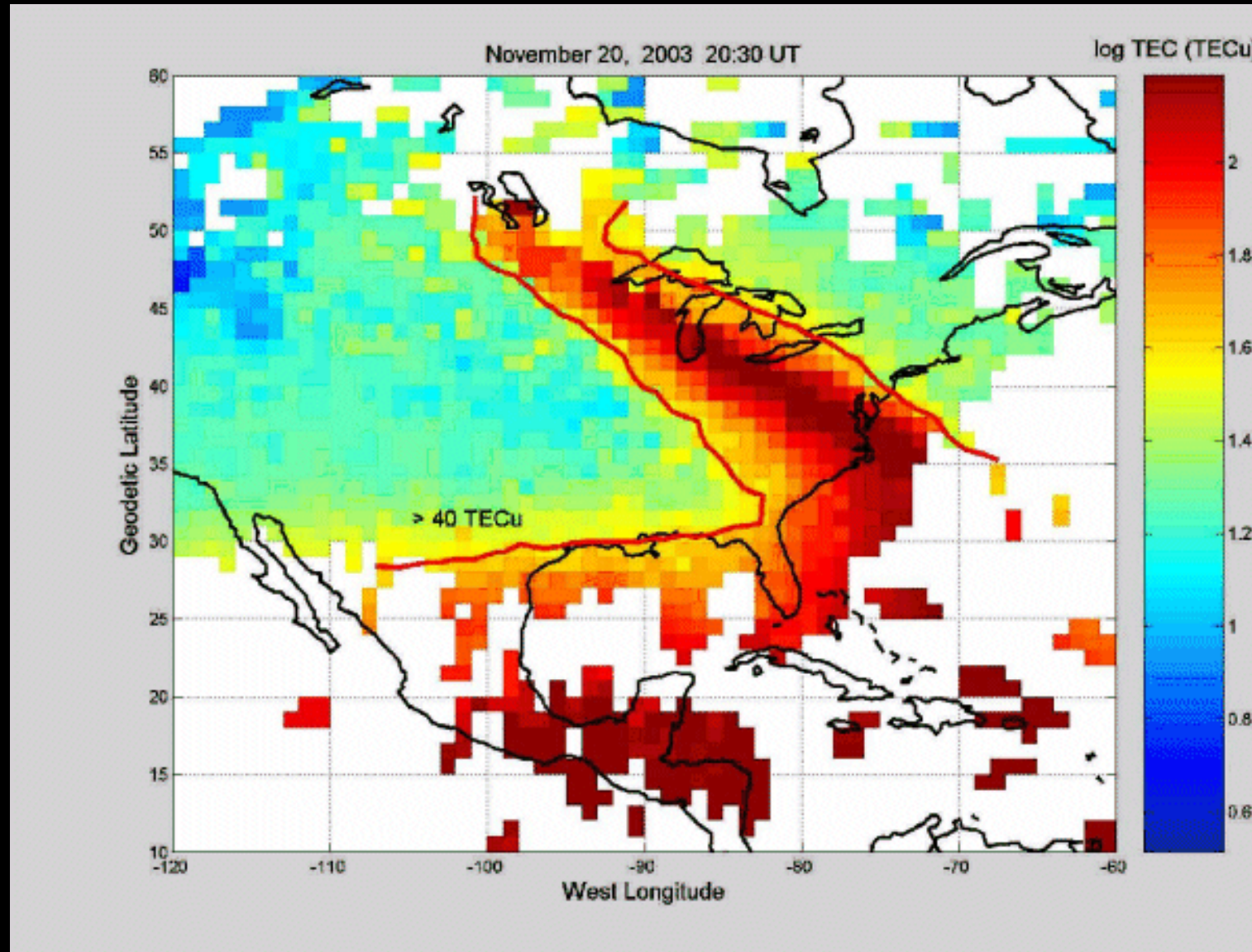


Image: Anthea Coster/John Foster/MIT

CAeM-16 Side Event - Exeter, UK