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# Recent Geoeffective Space Weather Events and Technological System Impacts

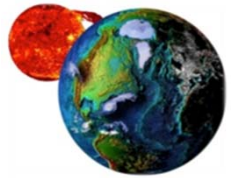
R. J. Redmon

W. F. Denig, T. M. Loto'aniu, H. J. Singer, D. C. Wilkinson, D. J. Knipp, L.

Kilcommons

NOAA / NCEI / CCOG / Solar Geophysics Branch

(Contact [Rob.Redmon@noaa.gov](mailto:Rob.Redmon@noaa.gov), +1 303 497 4331)



# Outline

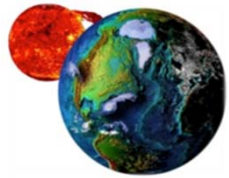
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February 27, 2014 Event Summary

St. Patrick's March 17, 2015 Event Summary

June 22, 2015 Event Summary

Overall Summary



# Event Summary Outline

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Subset of the available NOAA Sun to Earth information

Solar disk - **GOES**

Solar wind - **ACE** from NASA/OMNI for context

Magnetosphere

**GOES, POES** (measured)

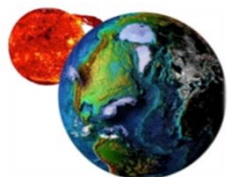
**Magnetopause** (modeled)

Ionosphere Response

POES / MetOp, **DMSP**, Ionosonde (measured)

**OVATION-Prime, DRAP, USTEC** (modeled)

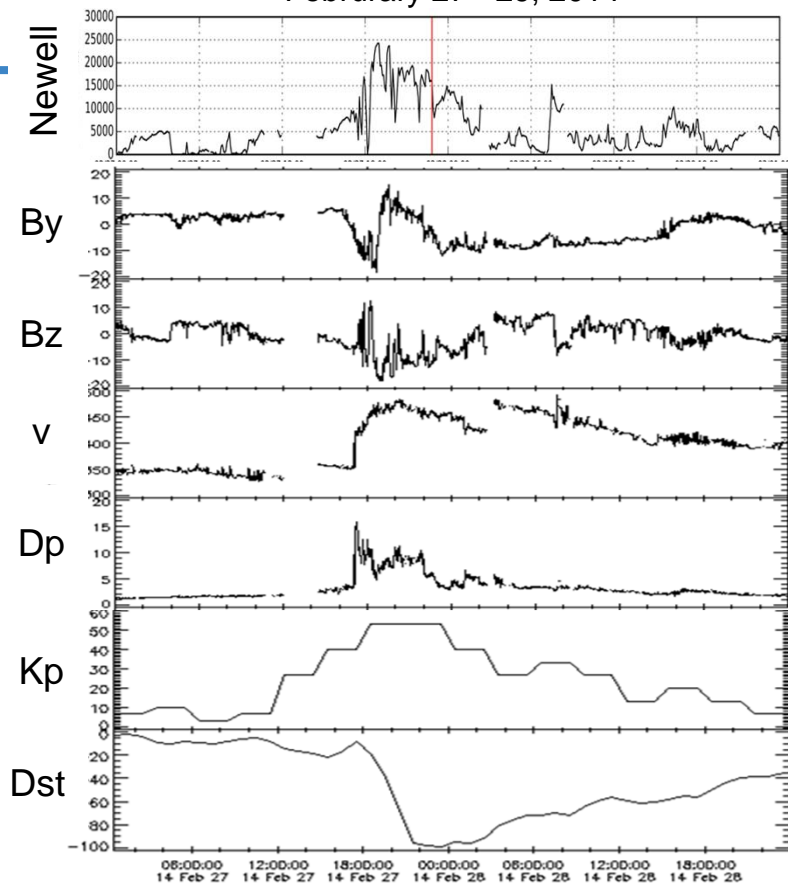
System Impacts - WAAS, Spacecraft Charging Hazards



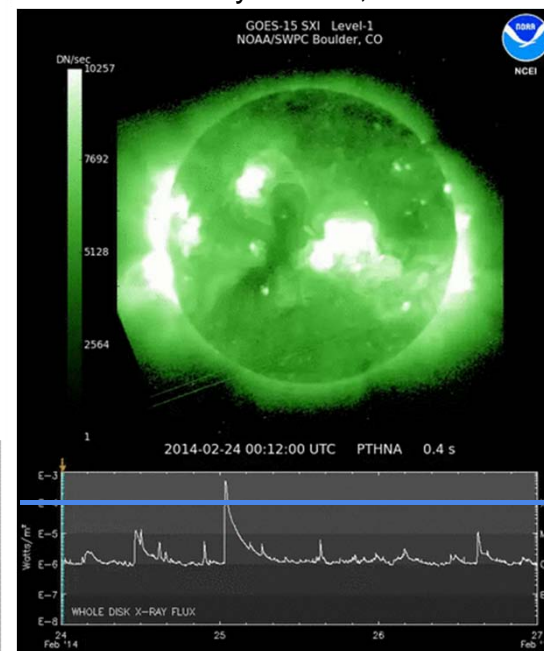
# E1: Feb-27 Solar Disk and Solar Wind

- X5-class flare
- SEP Feb-25
- CME glancing blow
- Geomag. moderate
  - $K_p < 6$ ,  $Dst_{min} \sim -100nT$
- Iono. significant
  - USTEC  $\sim 2xClimo$
- Systems:
  - Radio Impacts
  - S/C Charging: Surface  $\uparrow$  and SEU  $\uparrow$
  - FAA WAAS coverage degraded Feb 27-28

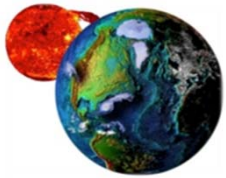
February 27 - 29, 2014



GOES SXI (top) and XRS (bottom)  
February 24 - 27, 2014

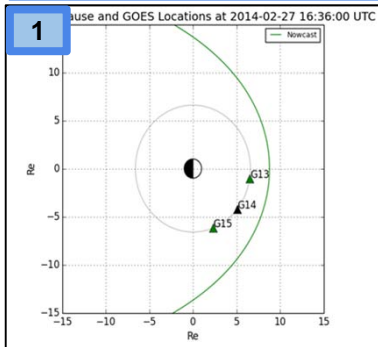


OMNI provided by J.H. King, N. Paptashvilli, ADNET, NASA GSFC, CDAWeb.

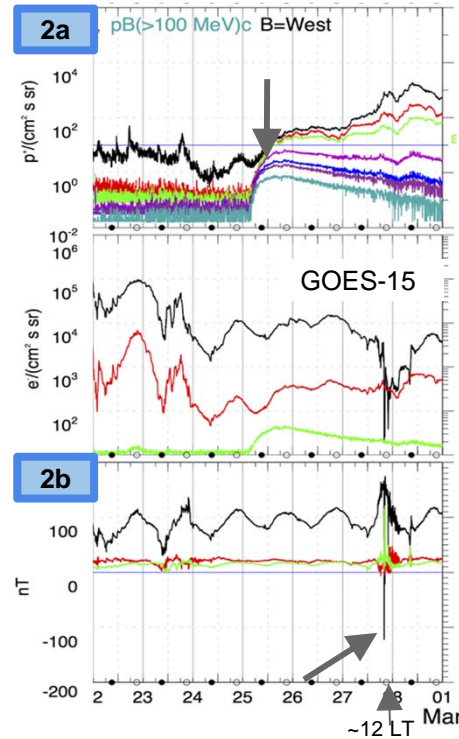


# E1: Radiation Belt Particles and Fields via GOES and POES/MetOp

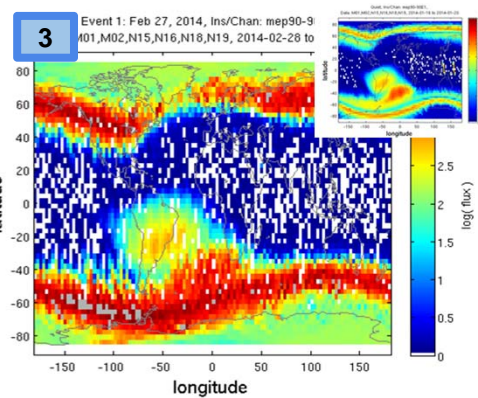
- 1 Magnetopause
- 2 GEO a) particles b) field
- 3 LEO Surface (>30keV)
- 4 LEO SEU (>35MeV)
- 5 LEO internal charge



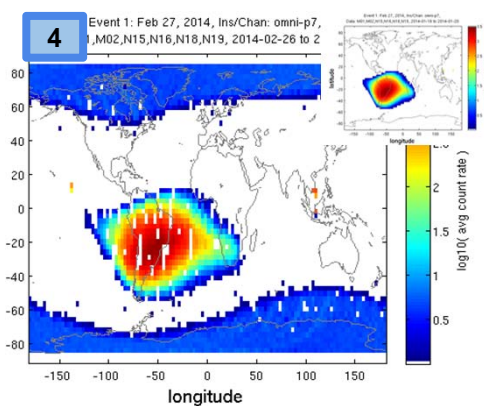
(1,2b) GEO noon magnetopause crossing (in  $B$  field) coincident with dramatic increase of SW flow pressure ~ Feb-27 at 18UT.



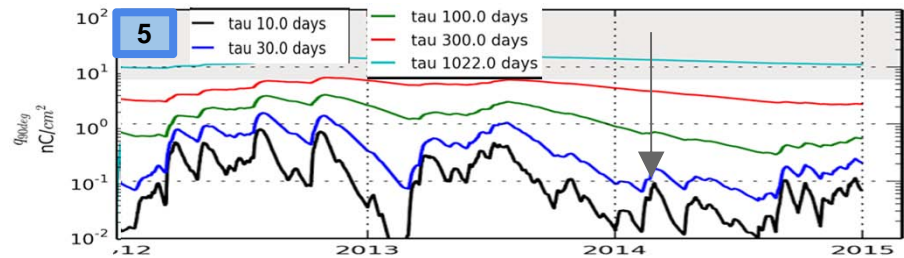
(2a) Solar proton event (SPE) began on Feb-25 at ~12UT.



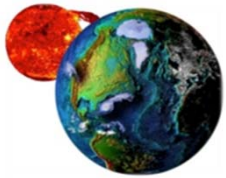
(3) Surface charging hazard (>30keV electrons) increased ~ 2x.



(4) SEU hazard (>35 MeV protons) increased ~ 1.5x.

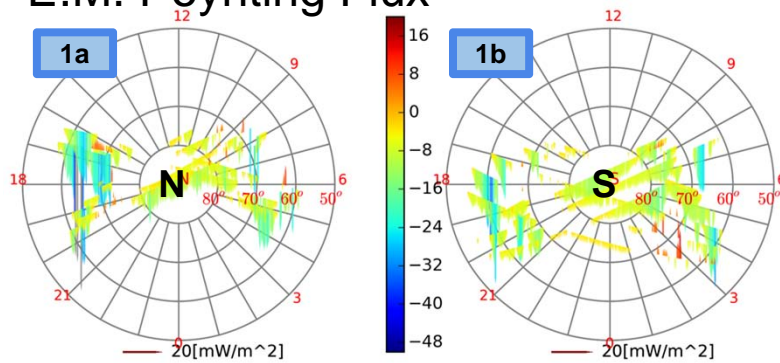


(5) Internal Charging hazard insignificant

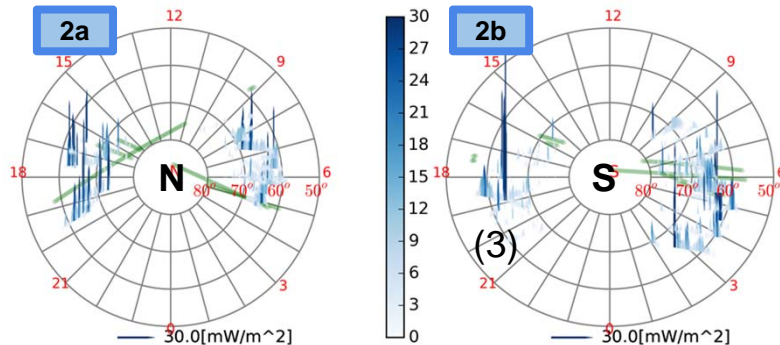


# E1: Ionosphere Measured DMSP over storm onset and main phase: Inputs and Vertical Response

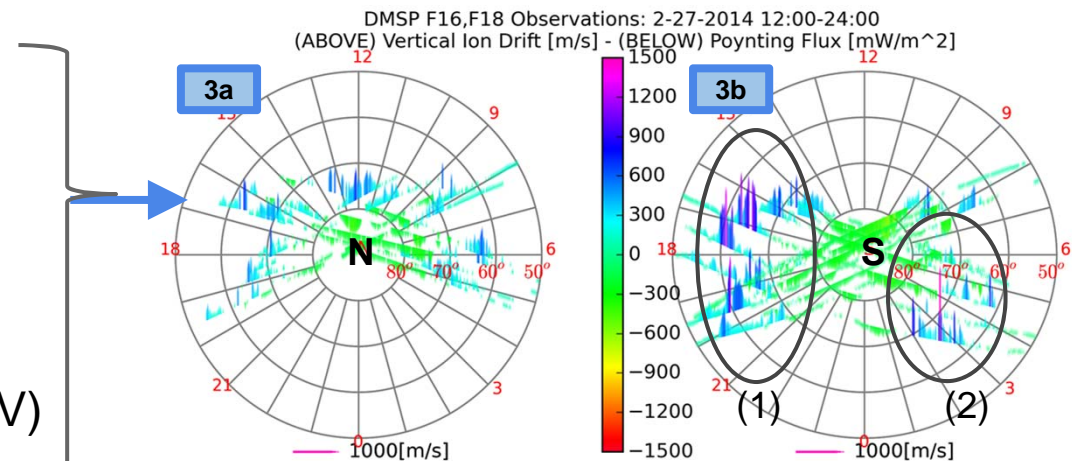
## E.M. Poynting Flux



## K.E. Particle Precipitation (30eV-30keV)

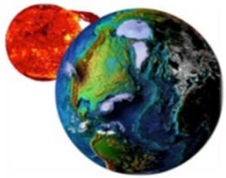


## Vertical O+



### Initial interpretation

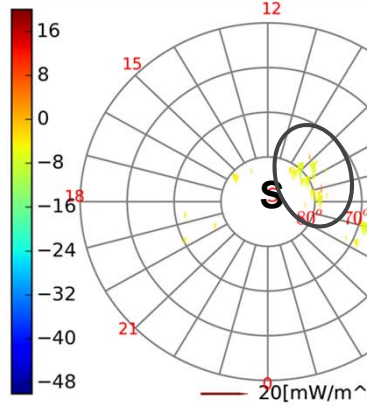
- (1) Dusk side: E.M. input into the s. polar cap [1b] appears more effective because there are more ions available to be heated at the altitude where S is converging due to greater N[O+] (s. summer).
- (2) Dawn side: Both E.M. and K.E. are coincident with upward O+.
- (3) Large K.E. [2b] on dusk side not coincident w/Vup on same orbit may be due to episodic nature and time lag.



# E1: Ionosphere Measured DMSP During storm recovery phase

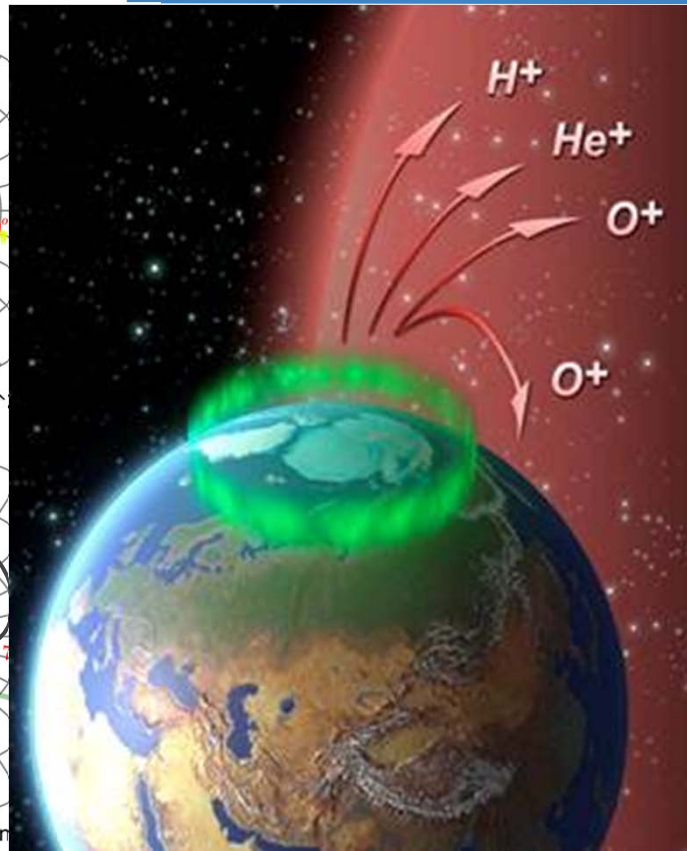
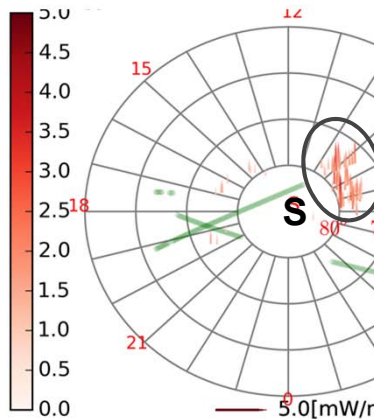
E.M.

1



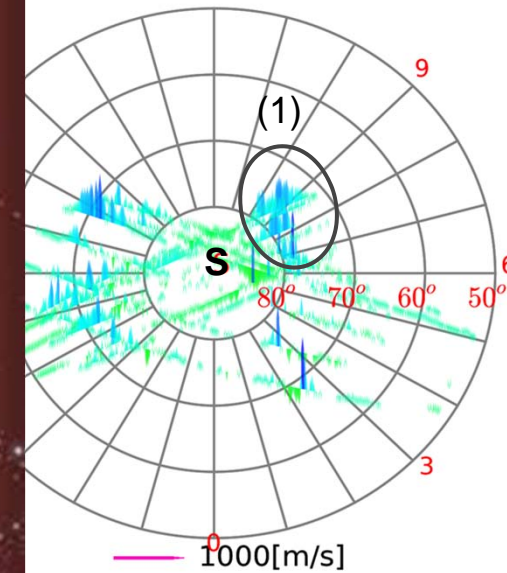
K.E.

2

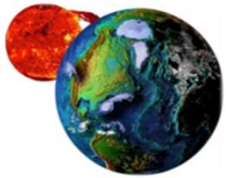


Vertical O+

DMSP F16, F18 Feb-28 12-24 UT



...nting flux) and K.E. (soft electron  
incident with upwelling 300-600 m/s O+.  
"health" note: Derived mostly from DMSP F18 and  
horizontal components of the Electric field vector.

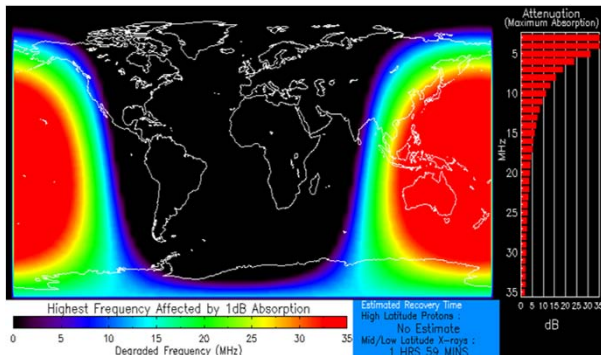


# E1: Ionosphere Modeled/Assimilated

- 1 D-Region absorption
- 2 Polar Cap input
- 3 CONUS TEC

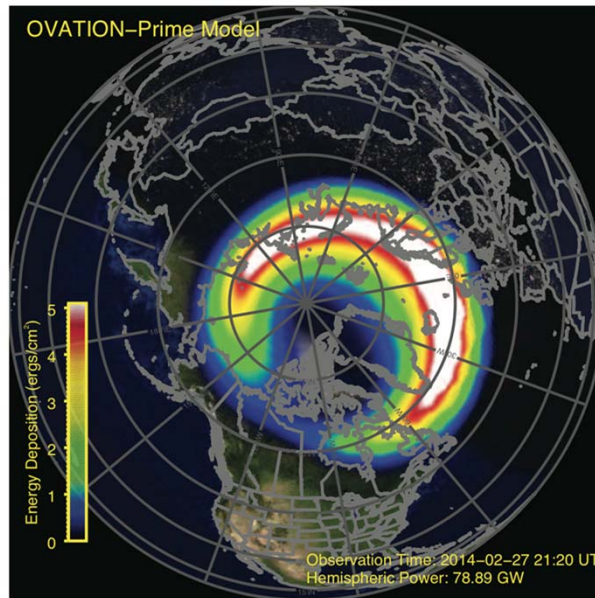
1

DRAP Feb-27 and Feb-28



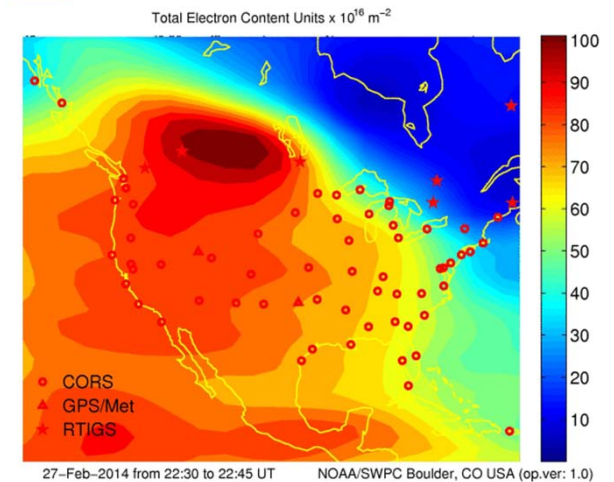
(1) D-region responds to X5 flare on Feb-25 ~ 00:50 (still image). Polar cap strongly ionized by SEP event particles several days (Feb-27 and Feb-28 movie shown).

2 OVATION Feb-27



(2) Hemispheric power of ~ 80GW predicted by OVATION Prime (2013) model at Feb-27 21:20UT. Adapted from Loto'aniu et al., 2015 (in review).

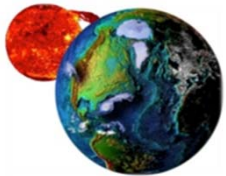
3 USTEC Feb-27 and Feb-28



(3) Large <TEC> up to 100 TEC units (~ 2\*Climo); highly structured maps with steep gradients and developing tongue of ionization (TOI) (Feb-27 22:30).

\*Note that TEC computed far from ground stations is not reliable (e.g. south-west features).





# E1: Wide Area Augmentation System Impacted (Adapted from Loto'aniu et al., 2015 (in review))

## FAA to SWPC on 2/27:

“An Ionospheric Storm began on 2/27/14. The Satellite Operations Specialists were alerted at the WAAS O&M by a Significant Event 757 at 2120 Zulu. So far, LPV and LPV200 service has not been available in Eastern Alaska and Northeastern CONUS. At times, North Central CONUS and all of Alaska have lost LPV and LPV200 Service.”

SED over N. America.

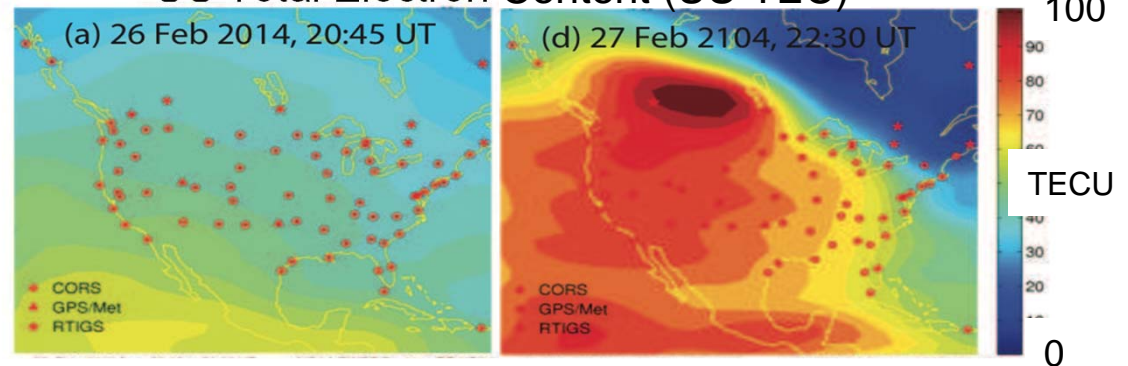
Geomag storm not as large as St. Patrick's.

Setup was ideal:

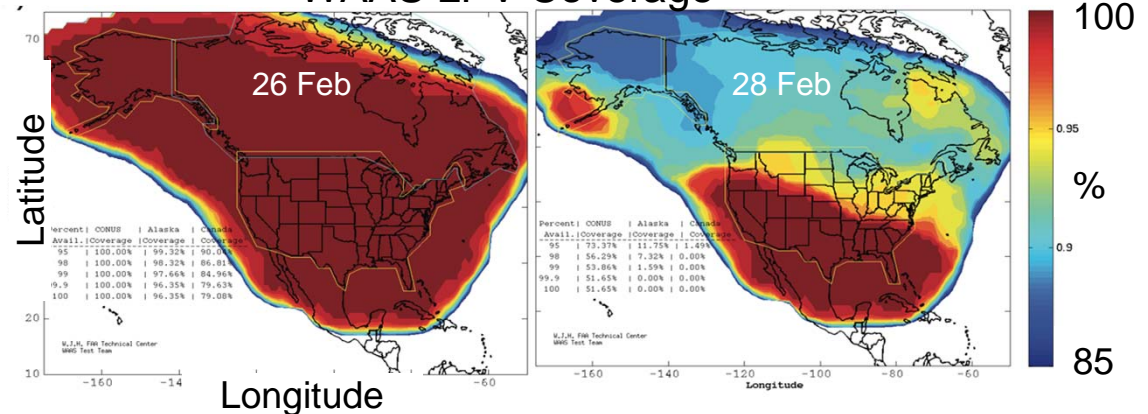
Magnetic field more inclined over CONUS.

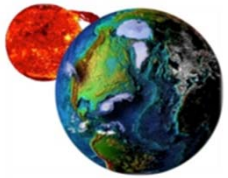
High lat convection E-field extending into mid-latitudes → large TEC increases (Sojka et al., 2005; Heelis et al., 2009).

## US Total Electron Content (US-TEC)



## WAAS LPV Coverage

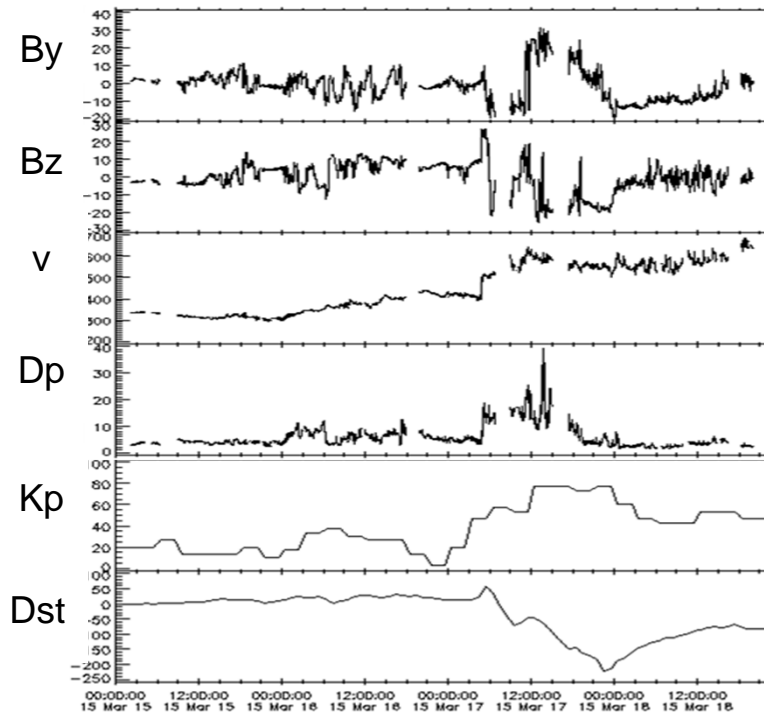




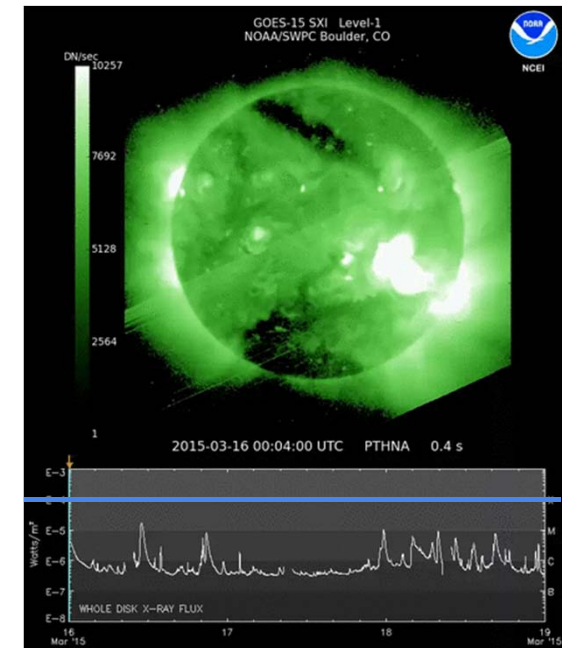
# E2: March-17: Solar Disk and Solar Wind

- M-class flare
- No SEP
- CME direct (1 or 2)\*
- Geomag. severe G4
  - Kp < 8, Dst<sub>min</sub> ~ -225nT
- Iono. significant
  - USTEC elevated
- Systems:
  - Radio Impacts
  - S/C Charging: Surface elevated
  - FAA WAAS coverage degraded Mar 17-18

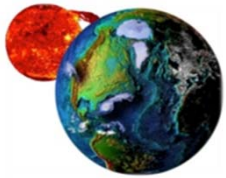
March 17-19, 2015



GOES SXI (top) and XRS (bottom)  
March 16 - 19, 2015

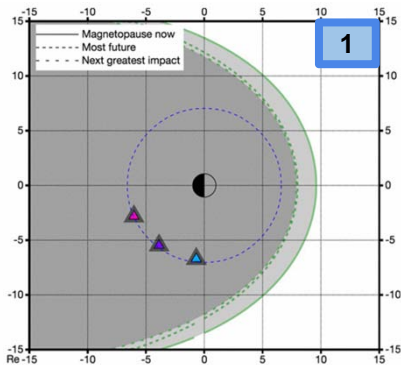


OMNI provided by J.H. King, N. Paptashvili, ADNET, NASA GSFC, CDAWeb.

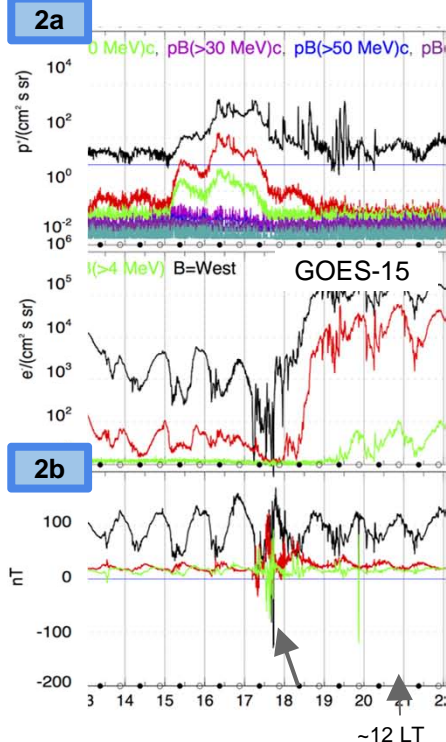


# E2: Radiation Belt Particles and Fields via GOES and POES/MetOp

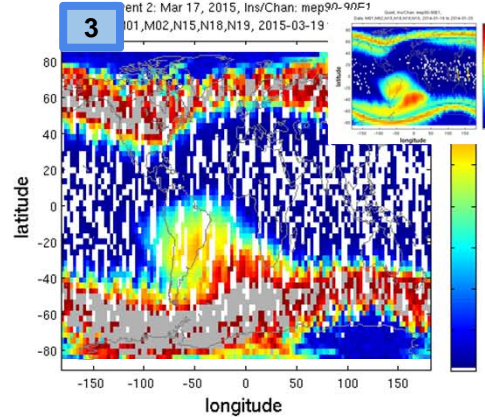
- 1 Magnetopause
- 2 GEO a) particles b) field
- 3 LEO Surface (>30keV)
- 4 LEO SEU (>35MeV)
- 5 LEO internal charge



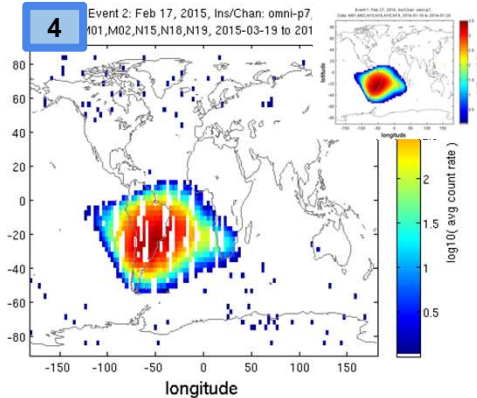
(1,2b) GEO noon magnetopause crossings (in  $B$  field) seen by G13 and G15 coincident with dramatic increase of SW flow pressure initiating on Mar-17 at 08:30 LT, 14UT.



(2a) No Solar proton event (SPE) (“>10MeV” protons < 10pfu).

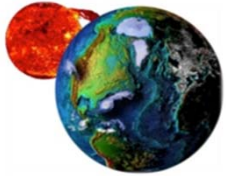


(3) Surface charging hazard (>30keV electrons) increased ~ 9x.



(4) SEU hazard (>35 MeV protons) no increase at high latitudes.

(5) Internal Charging hazard appears insignificant. Accumulated charge estimate not yet available.

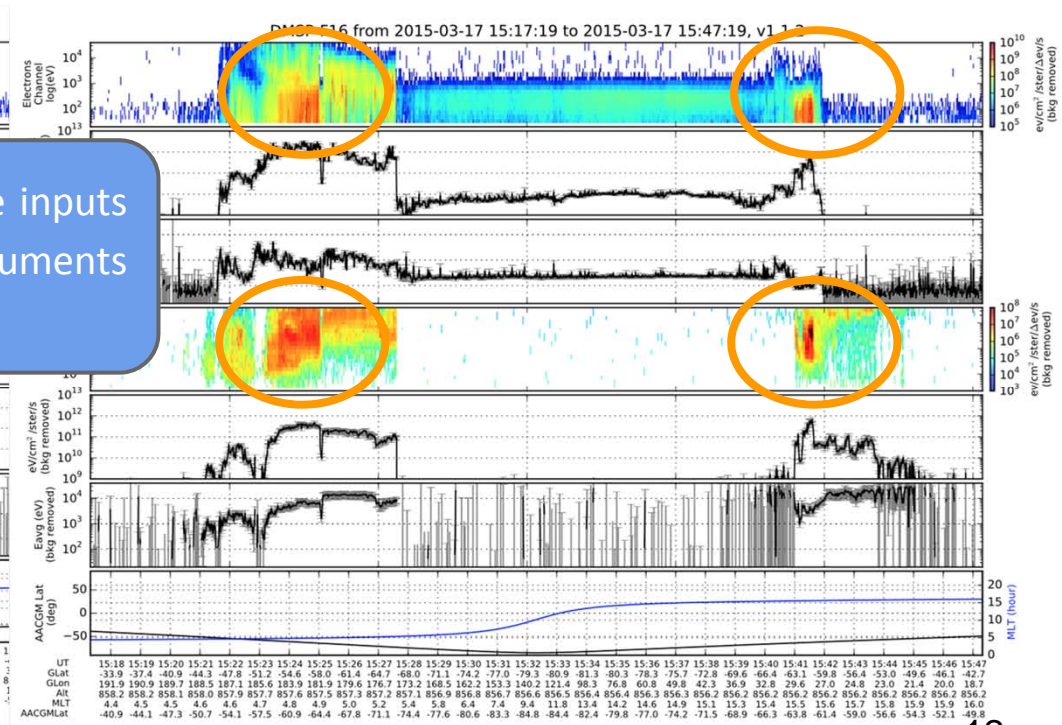
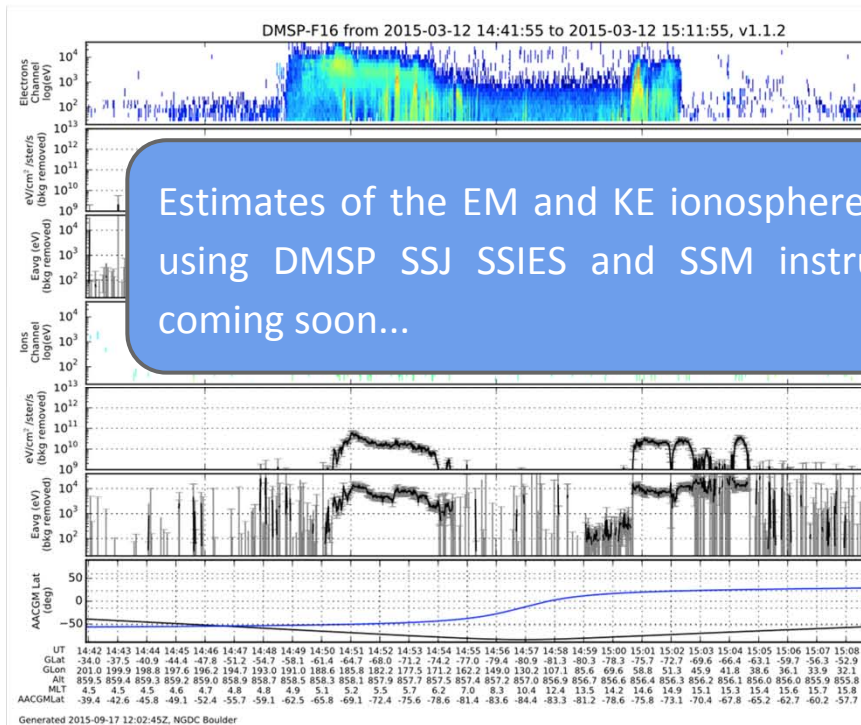


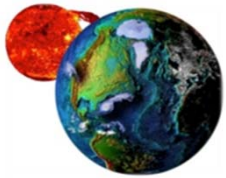
# E2: Ionosphere Measured: DMSP e-, i+ Precip. Morning - Afternoon Orbit (4-16 MLT)

Quiet Day (March-12)  
Kp ~ 2

Storm Main Phase (March-15)  
Kp ~ 8, Dst ~ -150 nT

Estimates of the EM and KE ionosphere inputs using DMSP SSJ SSIES and SSM instruments coming soon...



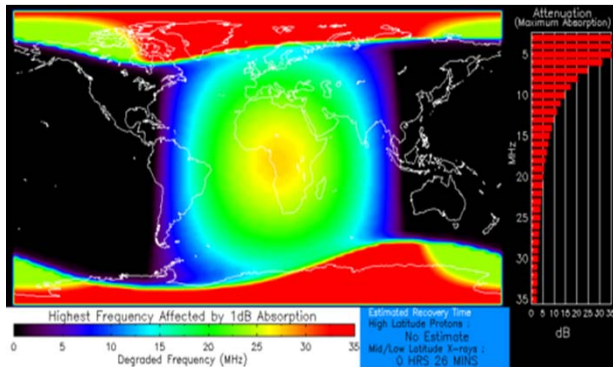


# E2: Ionosphere Modeled/Assimilated

- 1 D-Region absorption
- 2 Polar Cap input
- 3 CONUS TEC

1

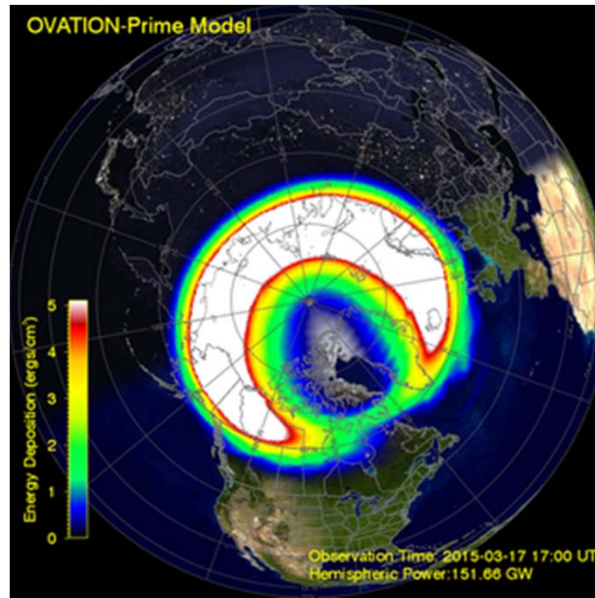
DRAP Mar-16 - Mar-18



Minor X-ray flux  
Product Valid At : 2015-03-16 11:00 UTC  
Normal Proton Background  
NOAA/SWPC Boulder, CO USA

(1) D-region responds to M flare on Mar-16 ~ 11:00.

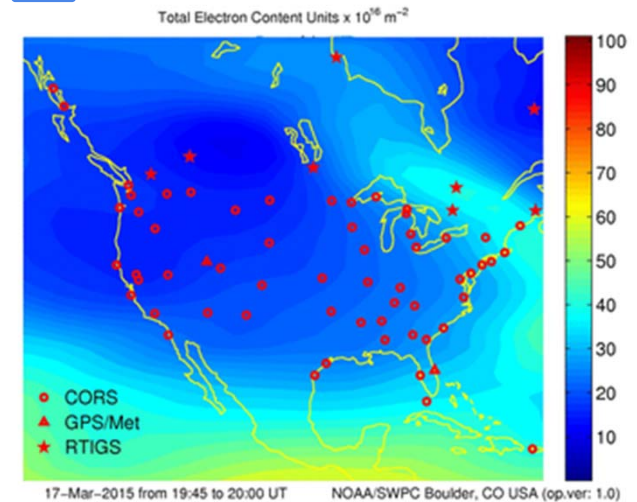
2 OVATION Mar-17



(2) Hemispheric power of ~ 80GW predicted by OVATION Prime (2013) model at Feb-27 21:20UT. Adapted from Loto'aniu et al., 2015 (in review).

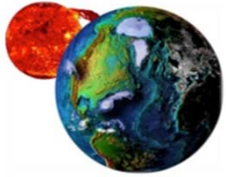
3

USTEC Mar-17



(3) Elevated <TEC> up to 70 TEC units (~ 1.5\*Climo); structured maps with steep gradients and possibly developing TOI (Mar-17 19:45 shown).

\*Note that TEC computed far from ground stations is not reliable (e.g. south-west features).

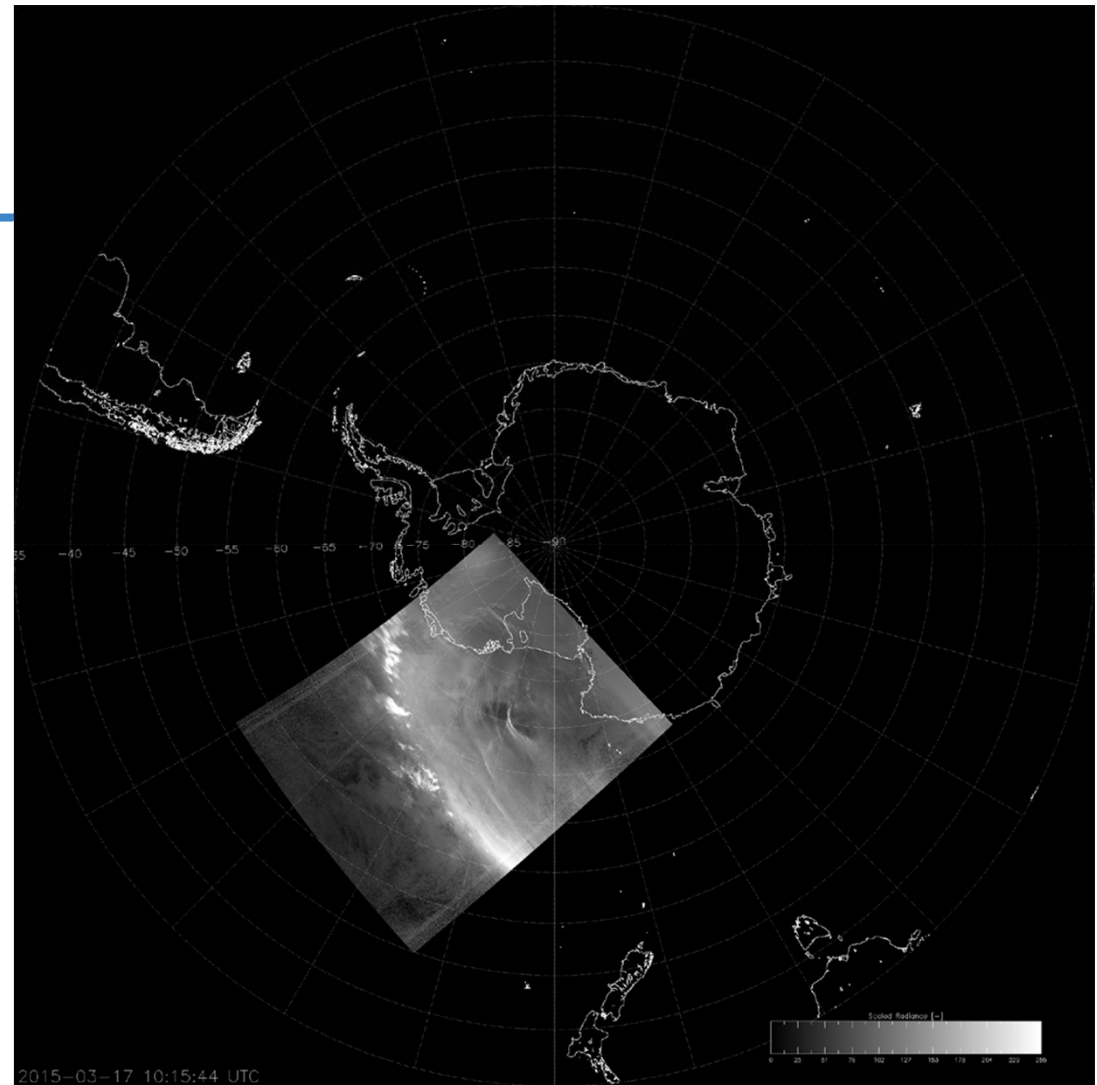


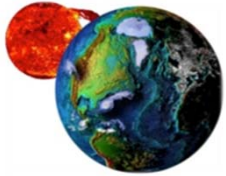
## E2: Ionosphere Measured: S-NPP

### *“The Aurora Seen Around the World”*

Animation of VIIRS DNB images of the aurora australis, 17-18 March 2015.

<http://rammb.cira.colostate.edu/projects/npp/blog/index.php/uncategorized/the-aurora-seen-around-the-world/>



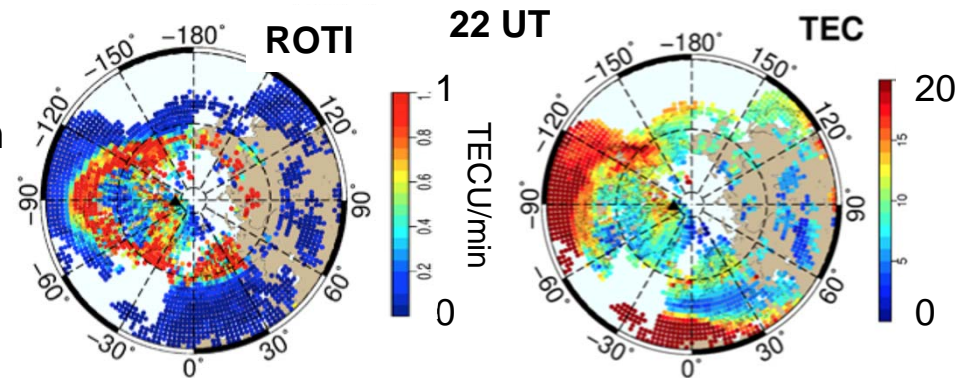


## E2: Wide Area Augmentation System Impacted

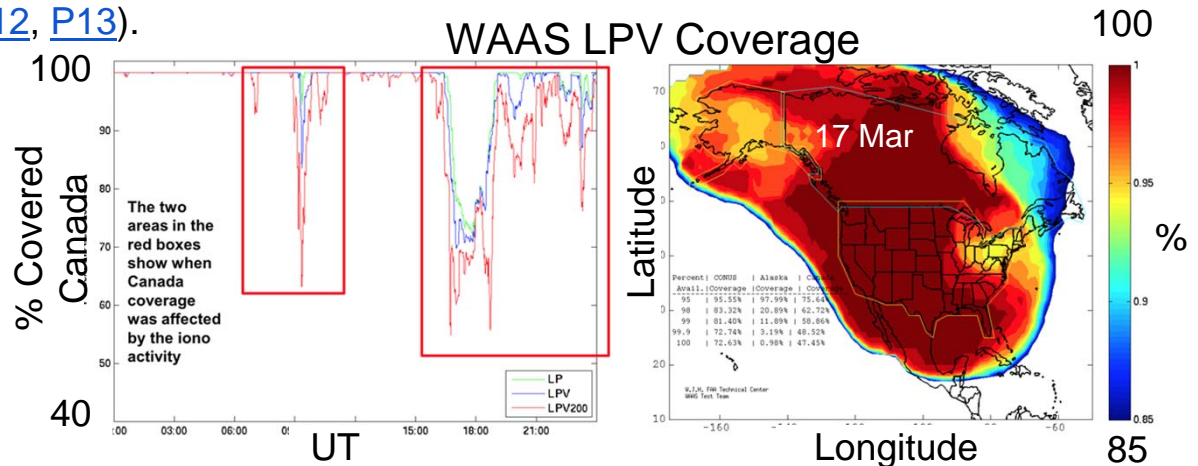
“Significant increases in the intensity of the irregularities within the polar cap region ... associated with the formation and evolution of the SED/TOI structures and polar patches.” -Cherniak et al., (2015).

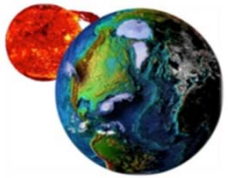
Polar maps of Rate of TEC Index (ROTI) and TEC shown at right.

See also Cherniak et al. ([2015](#), [P12](#), [P13](#)).



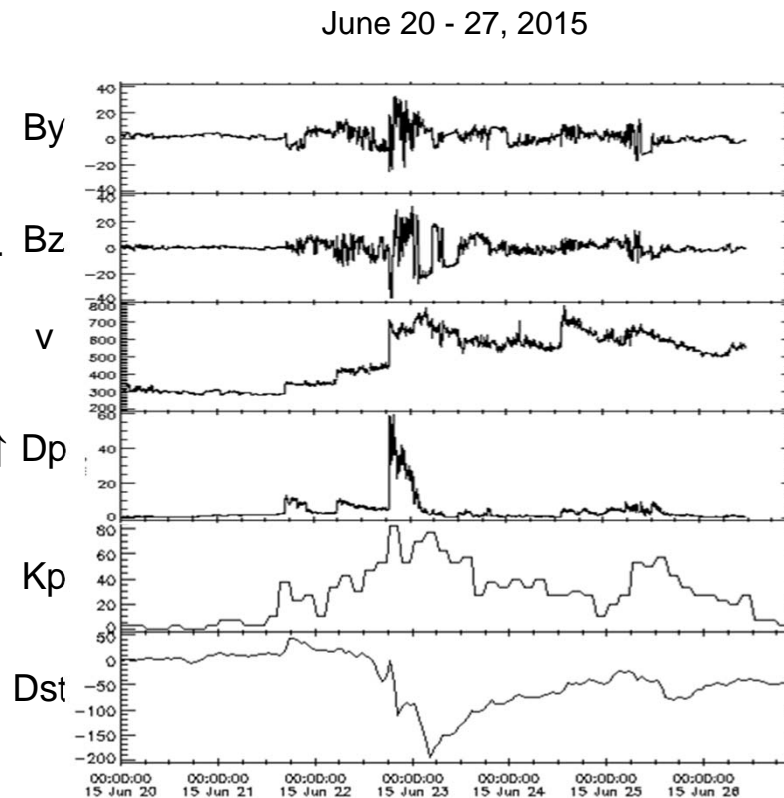
“Iono activity affected WAAS [LP, LPV, LPV-200] performance in Canada, Alaska, and CONUS on March 17 and March 18” - Wanner (2015) (FAA).



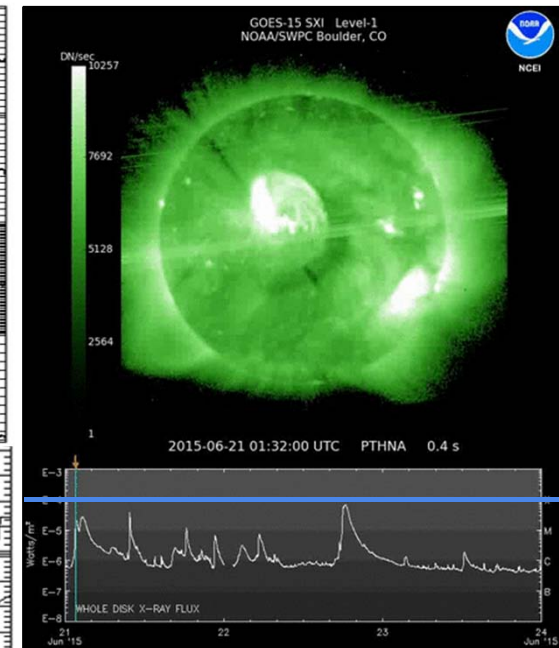


# E3: June-22: Solar Disk and Solar Wind

- M2,6-class flares
- SEP June 21 (~22UT)
- 4 (or 2) CMEs
- Geomag. severe G4
  - $K_p_{\max} \sim 8$ ,  $Dst_{\min} \sim 200\text{nT}$
- Systems:
  - Radio Impacts
  - S/C Charging: Surface  $\uparrow\uparrow$
  - FAA WAAS unaffected

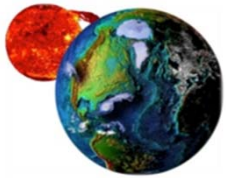


GOES SXI (top) and XRS (bottom)  
June 21 - 24, 2015



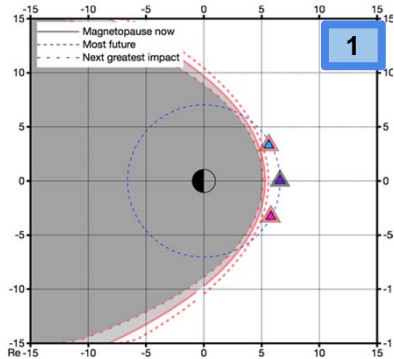
OMNI provided by J.H. King, N. Paptashvili, ADNET, NASA GSFC, CDAWeb.



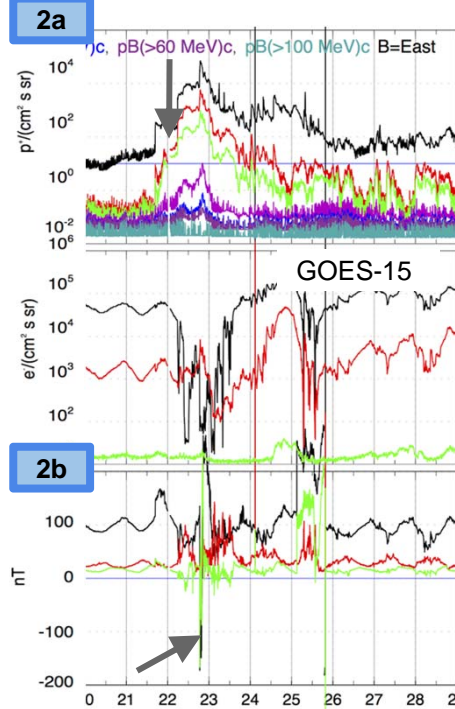


# E3: Radiation Belt Particles and Fields via GOES and POES/MetOp

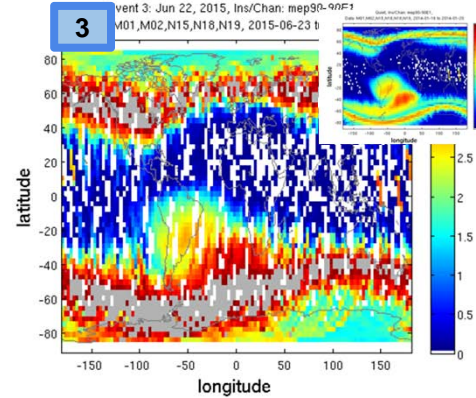
- 1 Magnetopause
- 2 GEO a) particles b) field
- 3 LEO Surface (>30keV)
- 4 LEO SEU (>35MeV)
- 5 LEO internal charge



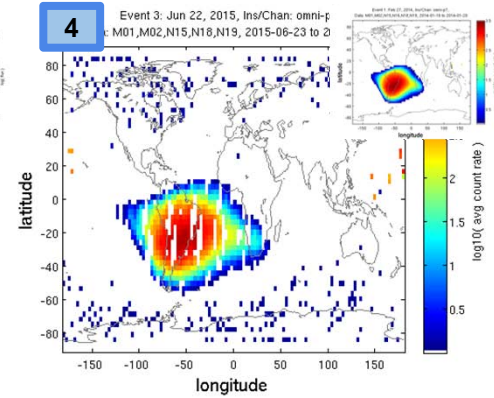
(1,2b) GEO noon magnetopause crossing (in  $B$  field) coincident with dramatic increase of SW flow pressure ~ Jun-22 at 10LT, 18:30UT.

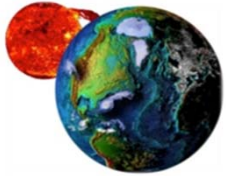


(2a) Solar proton event (SPE) began on Jun-21 at ~22UT.



(3) Surface charging hazard (>30keV electrons) increased ~ 9.4x.  
 (4) SEU hazard (>35 MeV protons) no increase at high latitudes.  
 (5) Internal Charging hazard appears insignificant. Accumulated charge estimate not yet available.

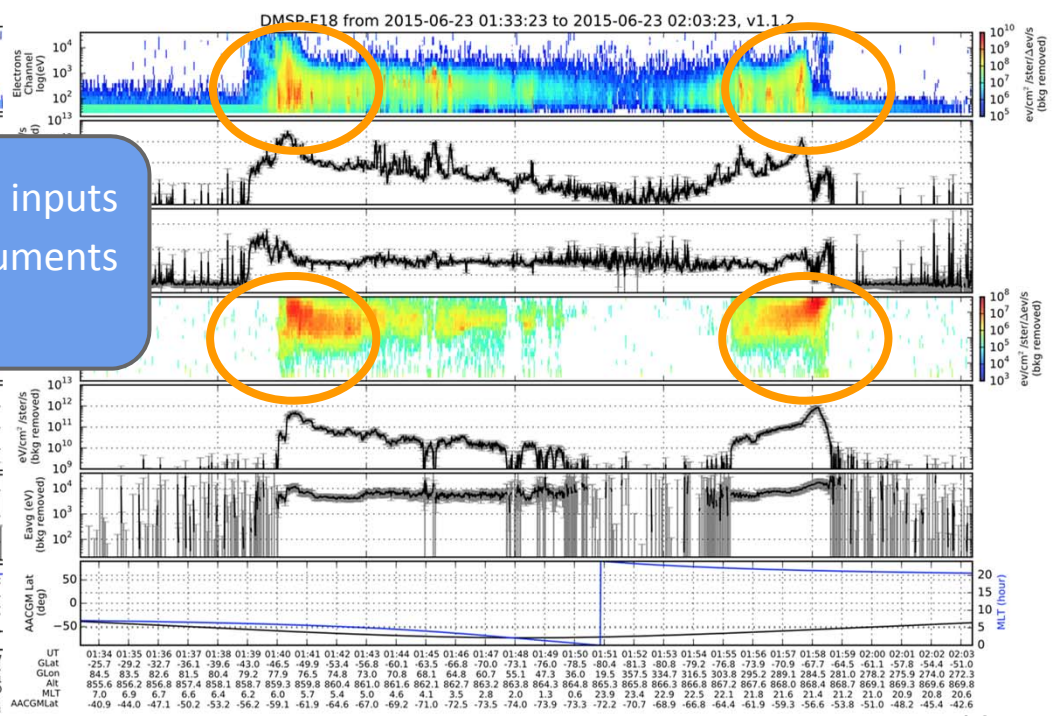
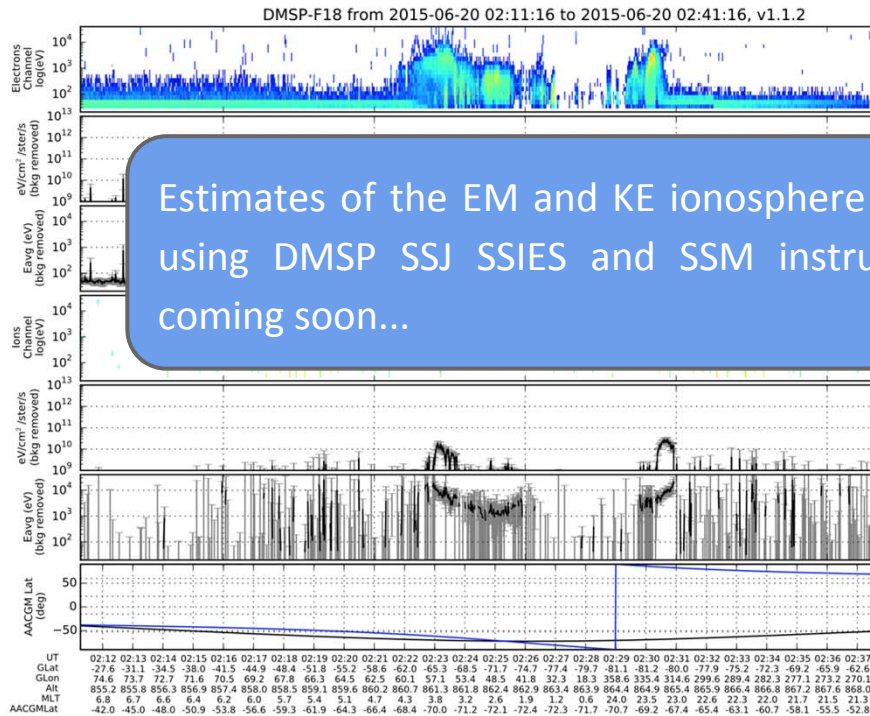




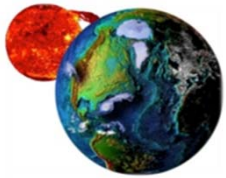
# E3: Ionosphere Measured: DMSP e-, i+ Precip. Morning - Pre-Noon-Pre-Midnight Orbit (7-20 MLT)

Quiet Day (June-20)  
Kp ~ 2

Storm Peak in Dst (June-23)  
Kp ~ 7+, Dst ~ -150 nT



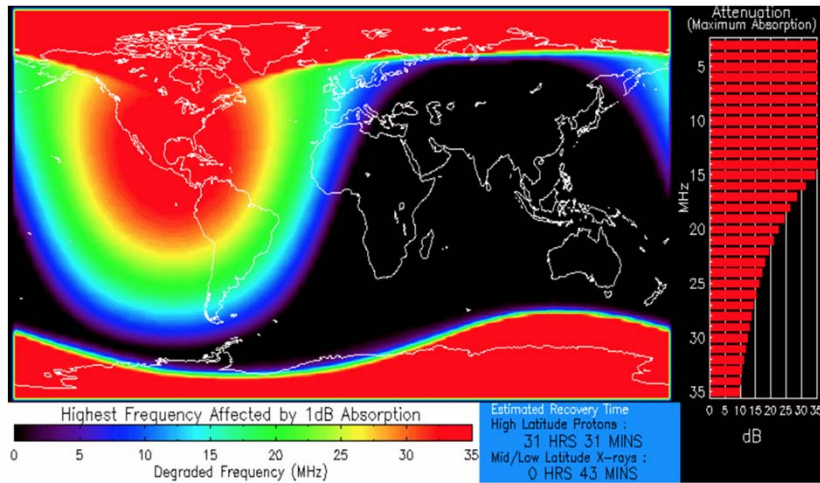
Estimates of the EM and KE ionosphere inputs using DMSP SSJ SSIES and SSM instruments coming soon...



# E3: Ionosphere Modeled/Assimilated

- 1 D-Region absorption
- 2 Polar Cap input
- 3 CONUS TEC *unavailable*

## 1 DRAP June 21

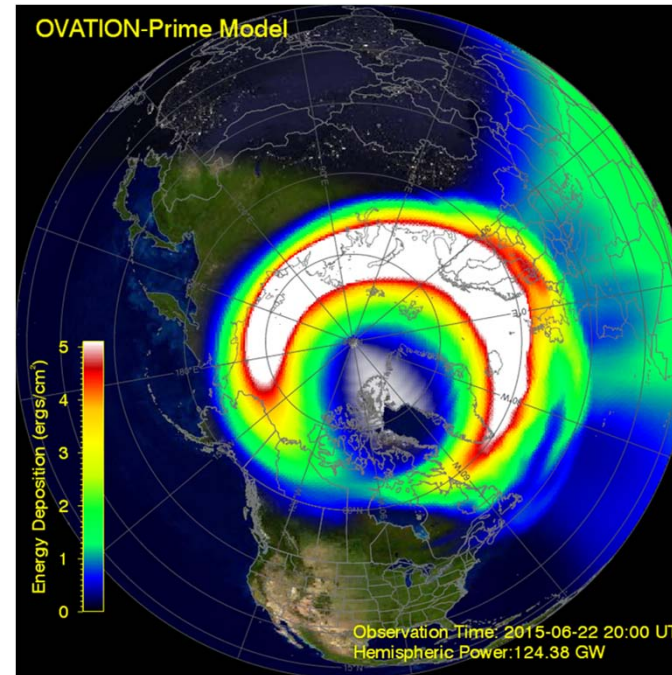


Moderate X-ray flux  
 Product Valid At : 2015-06-22 18:06 UTC

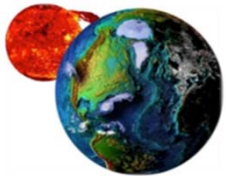
Moderate Proton Flux  
 NOAA/SWPC Boulder, CO USA

(1) D-region responds to M6.5 flare on June 22 at ~ 18UT.

## 2 OVATION Prime June 22

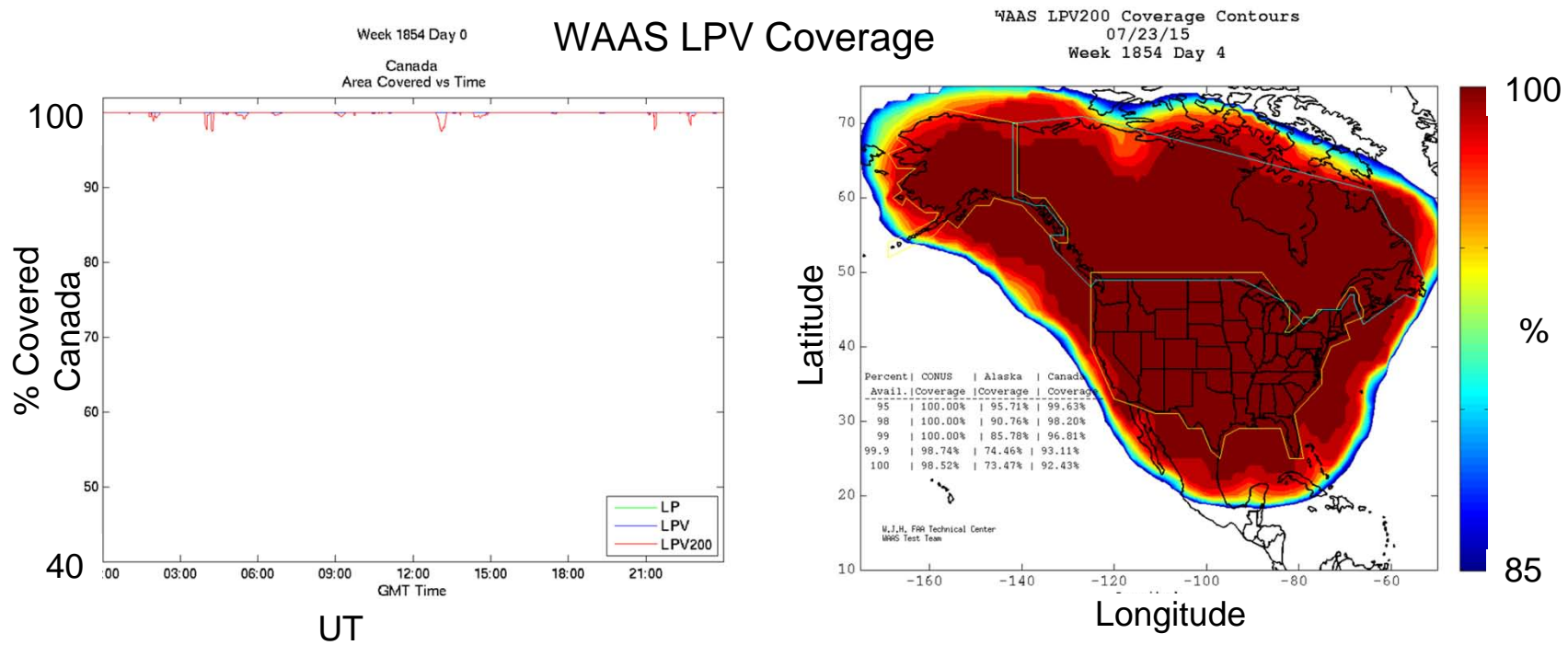


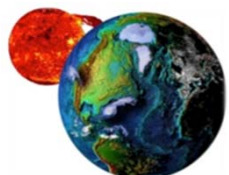
(2) Hemispheric power of ~ 124GW predicted by OVATION Prime (2013) model at Jun-22 20:00UT. Note greening in mid to low-lat is a plotting artifact. Credit: R. Viereck.



# E3: Wide Area Augmentation System Intact

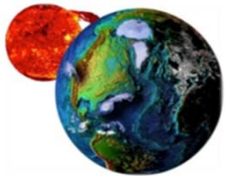
From, US WAAS system appears unaffected.





# Events Summarized

Event	Flares X	CMEs	SEP	GMC	Indices & Scales	Space Haz	System Impacts	Selected References
<b>“WAAS” Feb 2014</b>	X5	Glancing blow	Moderate	Yes	Kp 5+ Dst -100nT	SC ↑ SEU ↑	WAAS degraded; Mid-High latitude irreg.	Loto’aniu et al., (in review).
<b>St. Patrick’s March 2015</b>	No	Direct (1 or 2)	No	Yes	Kp ~ 8 Dst -225nT Severe G4	SC ↑↑	WAAS degraded; High latitude GPS irreg.	<a href="#">Cherniak et al., 2015</a> ; <a href="#">Wanner 2015</a> ; <a href="#">Kamide and Kusano 2015</a> ; <a href="#">Liu et al., 2015</a> ; <a href="#">Gopalswamy et al., 2015</a> .
<b>June 2015</b>	No M2,6	Direct (2 or 4)	Moderate	Yes	Kp 8 Dst -200nT Severe G4	SC ↑↑	Not WAAS	<a href="#">Liu et al., 2015</a>



# Acknowledgements & References

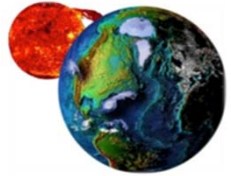
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## Data Access

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- POES Data Access: <http://ngdc.noaa.gov/stp/satellite/poes/>
- POES Radiation Belt Indices: [http://satdat.ngdc.noaa.gov/sem/poes/data/belt\\_indices/](http://satdat.ngdc.noaa.gov/sem/poes/data/belt_indices/)
- GOES Data Access: <http://ngdc.noaa.gov/stp/satellite/goes/>
- Magnetopause: [http://www.ngdc.noaa.gov/stp/mag\\_pause/](http://www.ngdc.noaa.gov/stp/mag_pause/)

# Questions?

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