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Space Weather Effects on the Wide Area Augmentation System

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ICG Experts Meeting: GNSS Systems/Services
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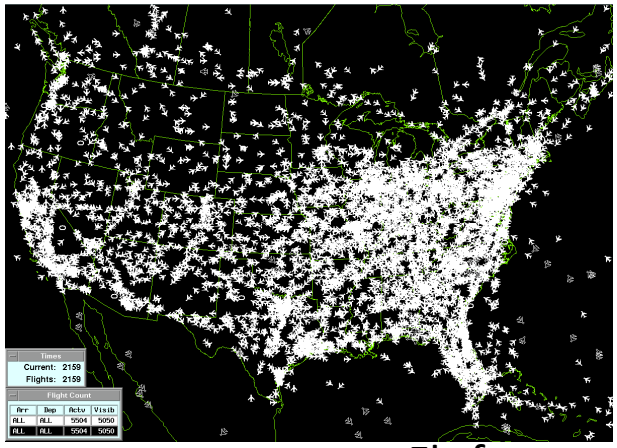
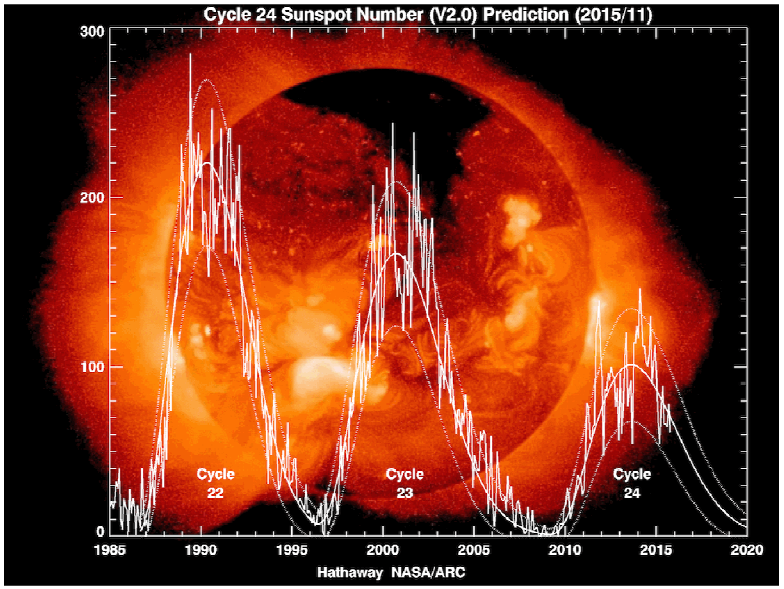
Outline

- Wide Area Augmentation System (WAAS)
  - Short Introduction
  - Measurements and Performance
    - Nominal Conditions
    - Disturbed Conditions
- Space Weather Events - WAAS
  - Solar Cycle 23
  - Solar Cycle 24
- U.S. National Space Weather Strategy

Peak Aircraft Traffic Over The US

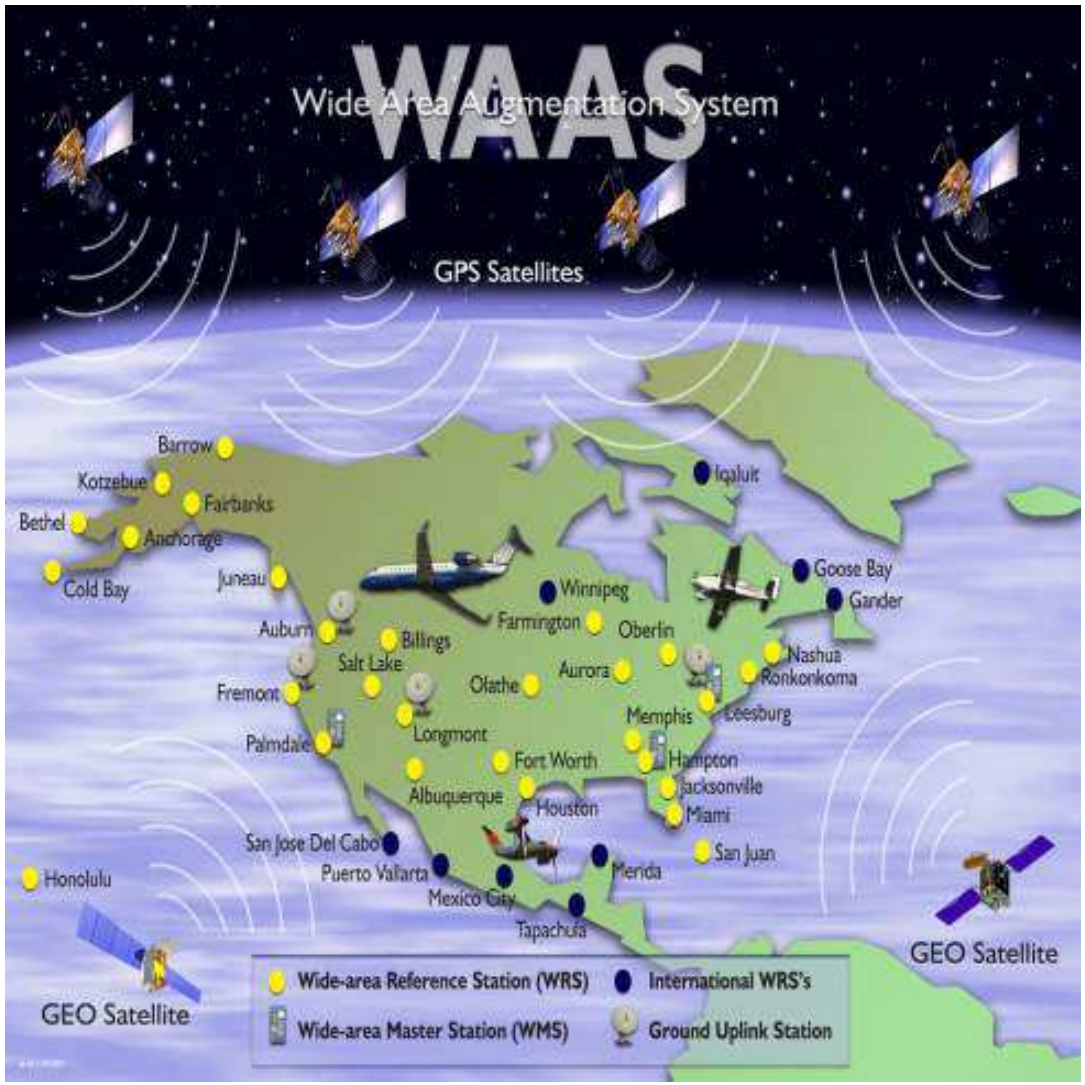


Fly.faa.gov



The Wide Area Augmentation System (WAAS)

Augments GPS to meet aviation requirements for accuracy, availability and integrity.



Courtesy of the FAA

- **Future primary means of civil air navigation**
- **For all aircraft in all phases of flight**
  - **Non-Precision Approach (NPA) – en-route**
  - **Vertically Guided Approach (LPV) – runway**
- **Many worldwide systems (EGNOS, GAGAN, MSAS, SDCM)**

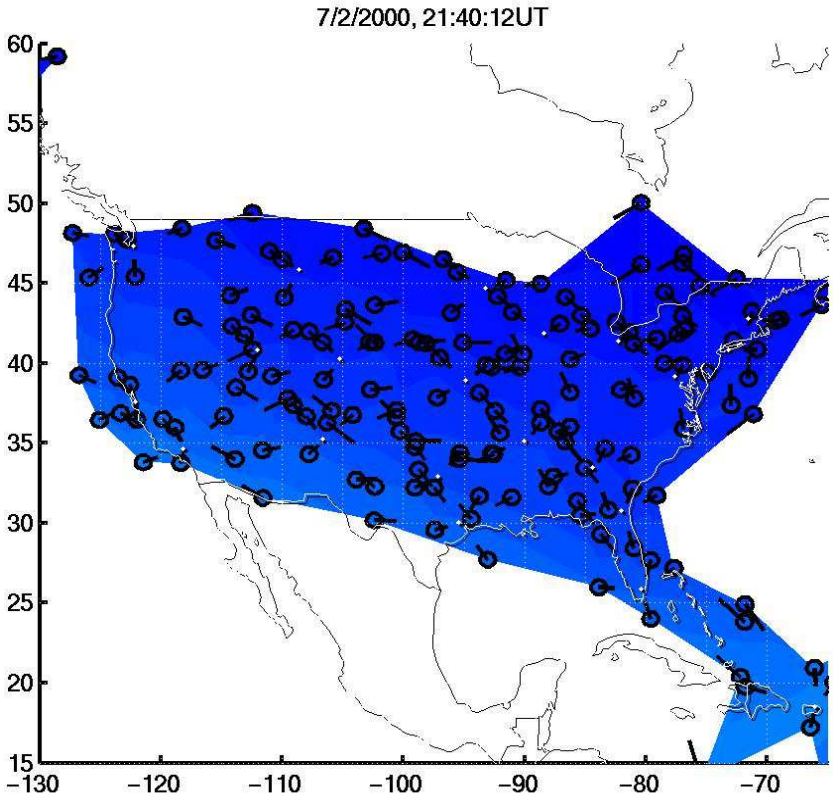
WAAS message provides:

- corrections for satellite orbits, time and the ionospheric
- estimates of the uncertainty of those corrections

WAAS Accuracy: ~1–3 m

Space Weather Effects on WAAS

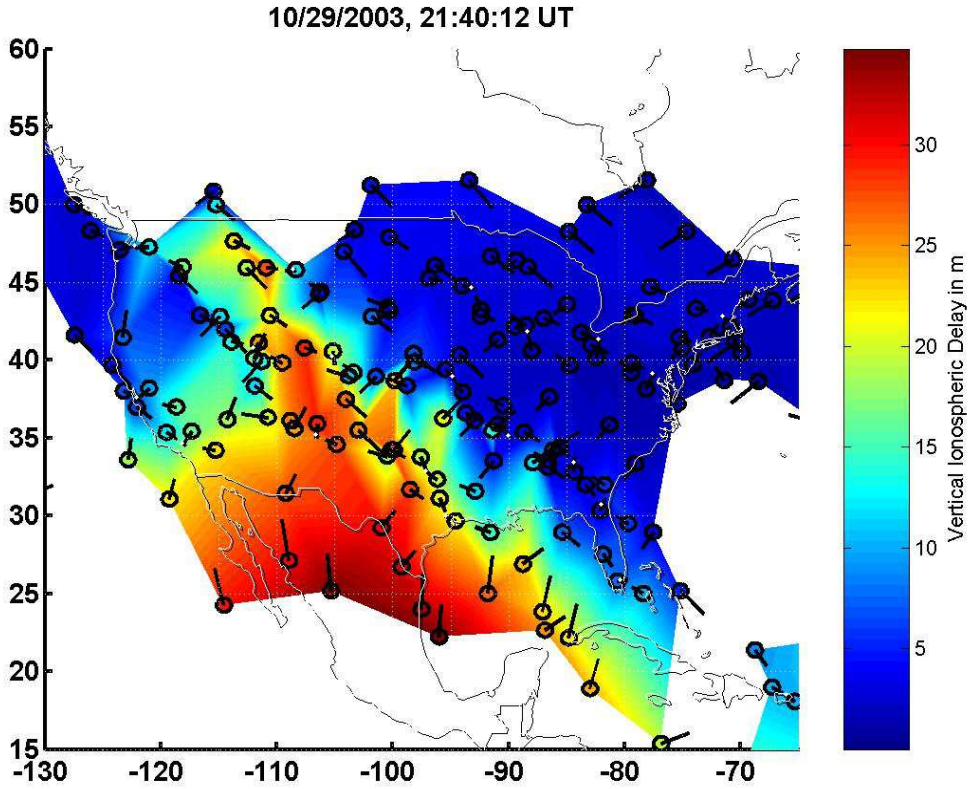
Quiet Ionosphere



CONUS RANGE ERRORS ARE BETWEEN 1 and 5M

Figure Courtesy of S.Datta-Barua

Disturbed Ionosphere

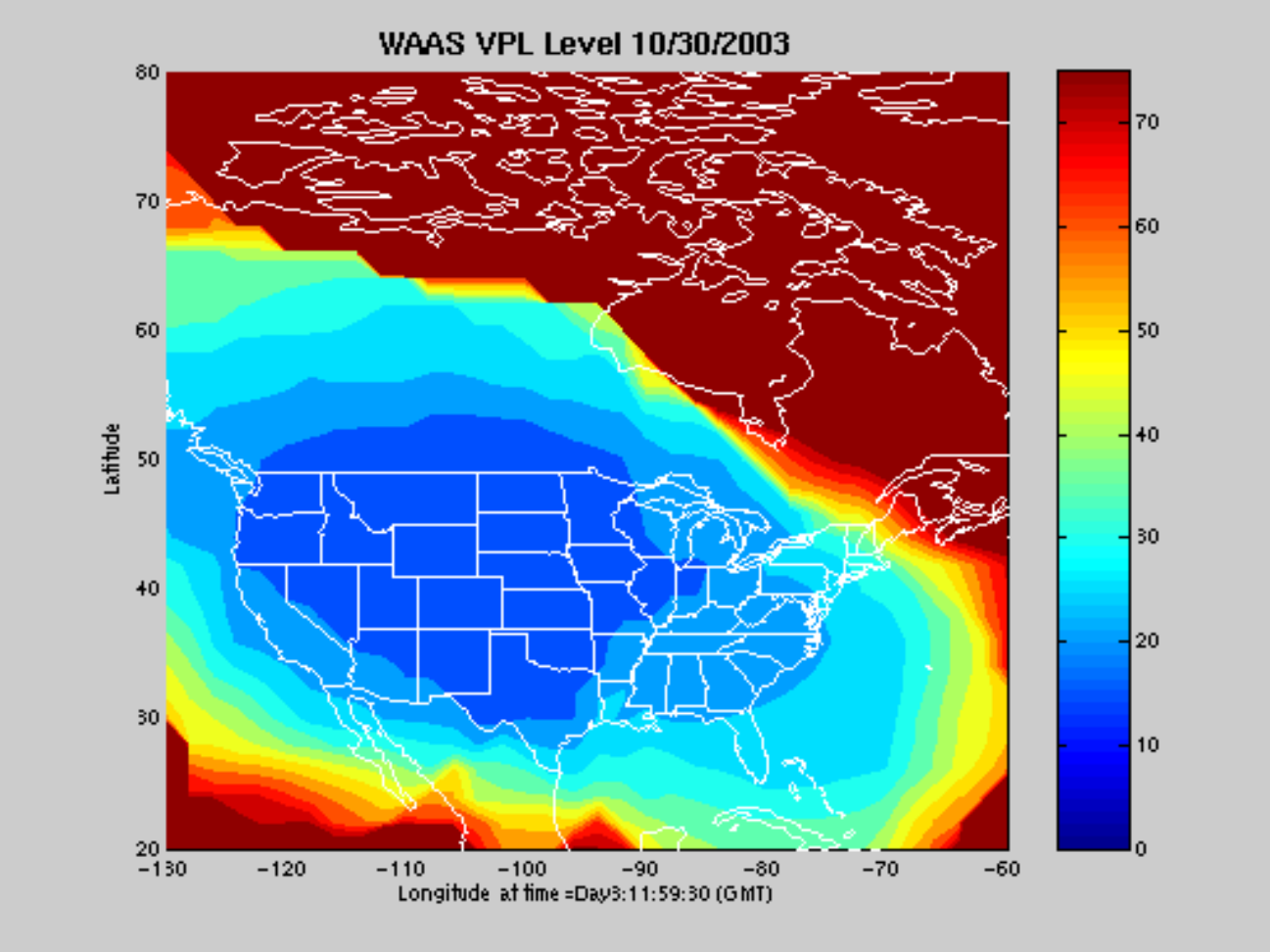


CONUS RANGE ERRORS ARE BETWEEN 1 and >35M

WAAS availability interrupted

Space Weather Effects of Solar Cycle 23

WAAS Service Availability Challenged -- October 30, 2003



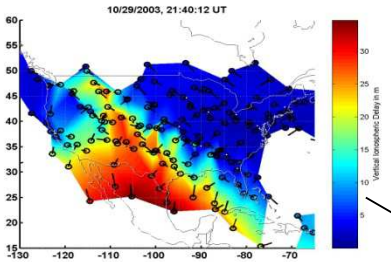
Vertical Navigation Capability

(Animation Courtesy of FAA NSTB)

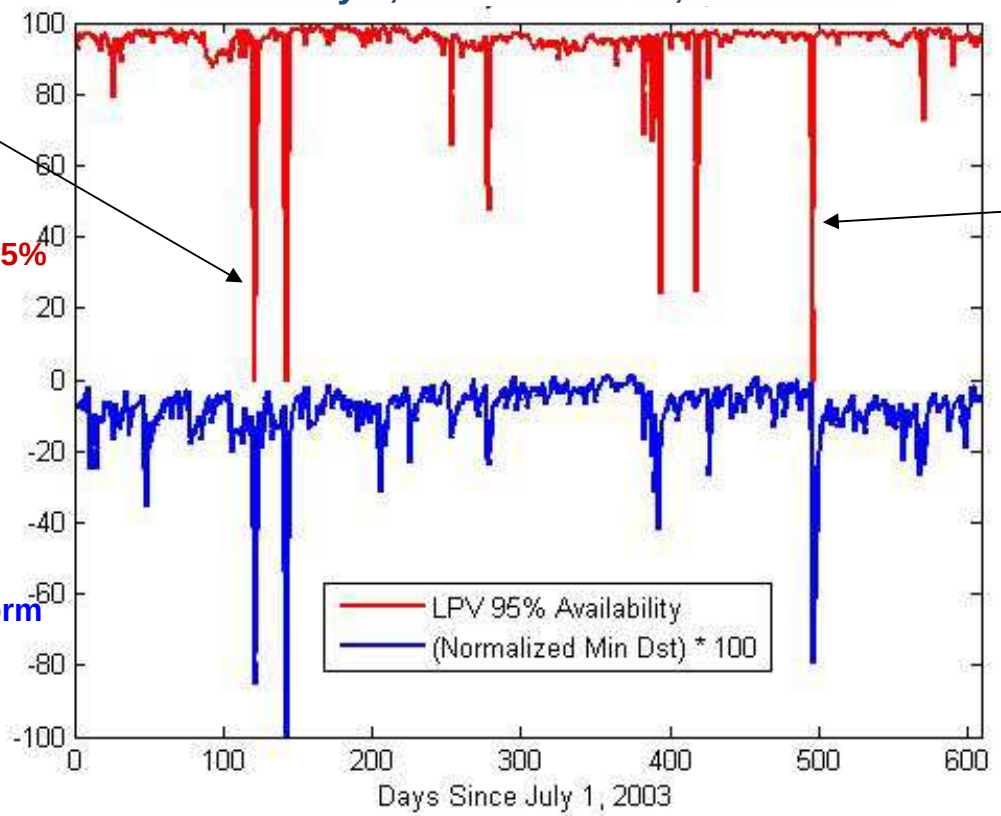
Space Weather Effects of Solar Cycle 23

(Oct 30, 2003)

(SC 23 produced several storms resulting in extended loss of availability for WAAS)



July 1, 2003 – March 1, 2005



% CONUS at 95% Availability

Magnetic Storm Index

(Nov 8, 2004)

Based on work by S.Datta-Barua

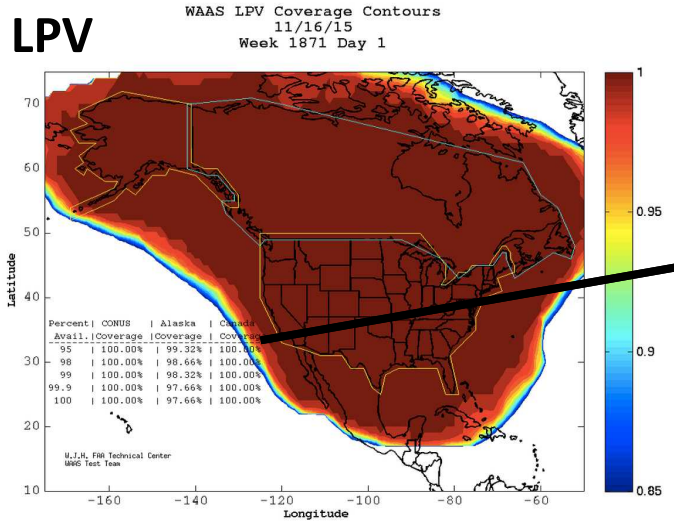
Solar Cycle 24 - WAAS – Coverage Contours vs % Availability

(WAAS – note extended coverage since SC23)

UNDISTURBED CONDITIONS 11/16/15

100% of the CONUS and CANADA with 100% availabilty

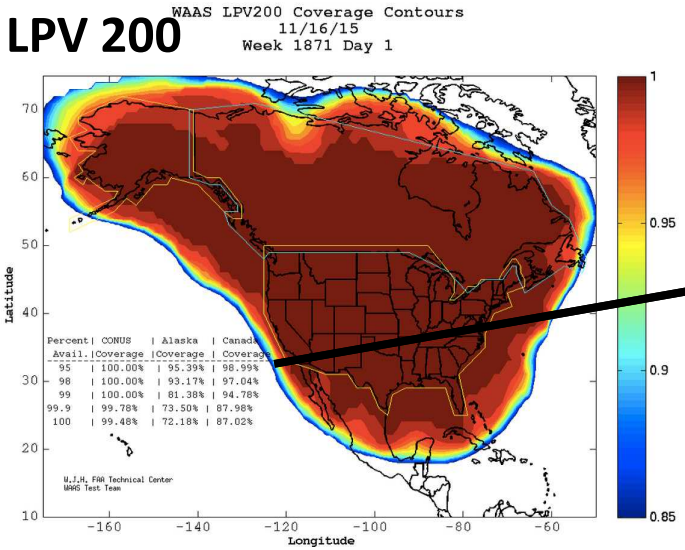
LPV



Percent Avail.	CONUS Coverage	Alaska Coverage	Canada Coverage
95	100.00%	99.32%	100.00%
98	100.00%	98.66%	100.00%
99	100.00%	98.32%	100.00%
99.9	100.00%	97.66%	100.00%
100	100.00%	97.66%	100.00%

100% of the CONUS; 81% of Alaska; 95% of Canada with 99% availability

LPV 200

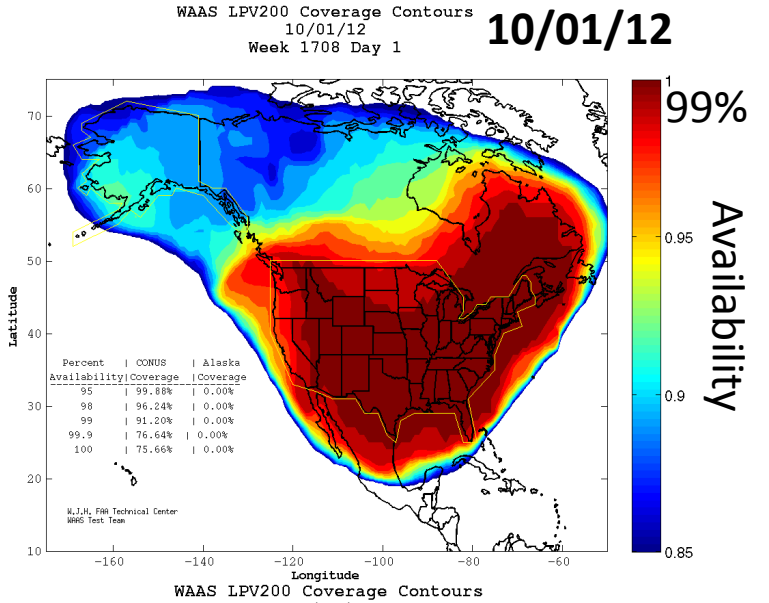


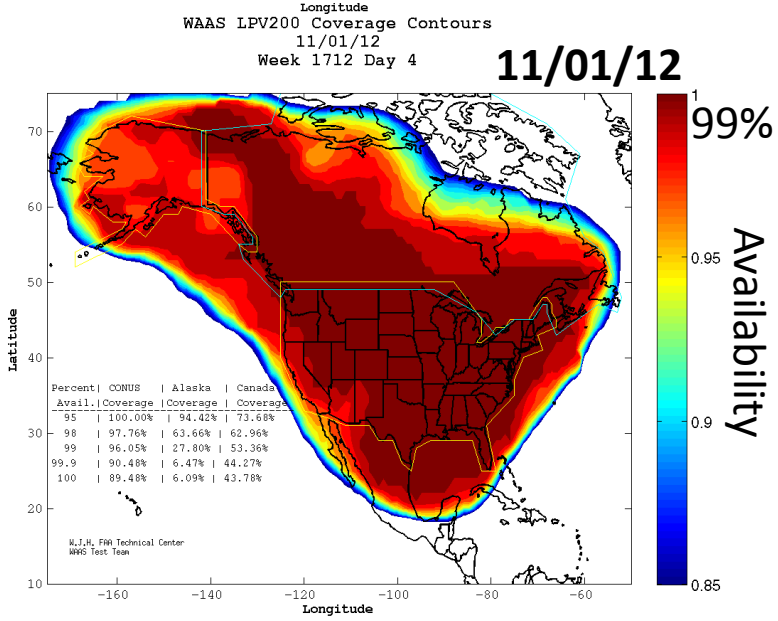
Percent Avail.	CONUS Coverage	Alaska Coverage	Canada Coverage
95	100.00%	95.39%	98.99%
98	100.00%	93.17%	97.04%
99	100.00%	81.38%	94.78%
99.9	99.78%	73.50%	87.98%
100	99.48%	72.18%	87.02%

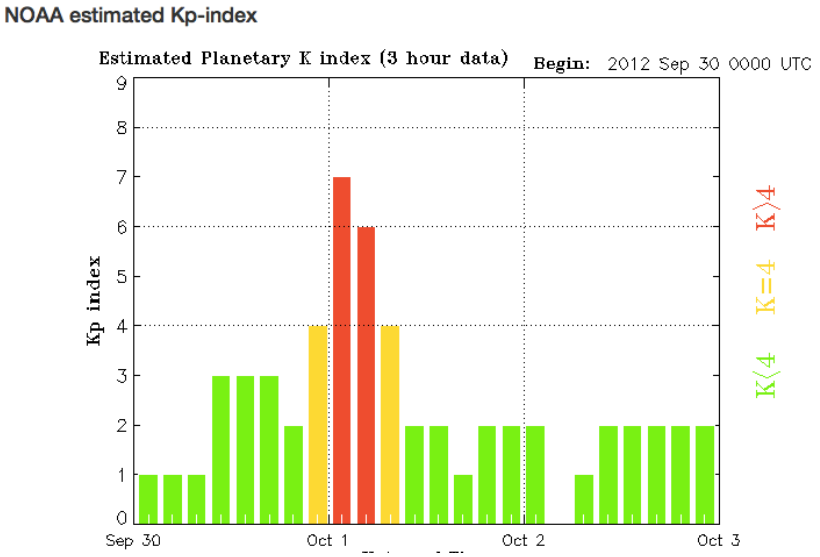
www.nstb.tc.faa.gov/24Hr_Waaslpv.htm
www.nstb.tc.faa.giv/24Hr_Waaslpv200.htm

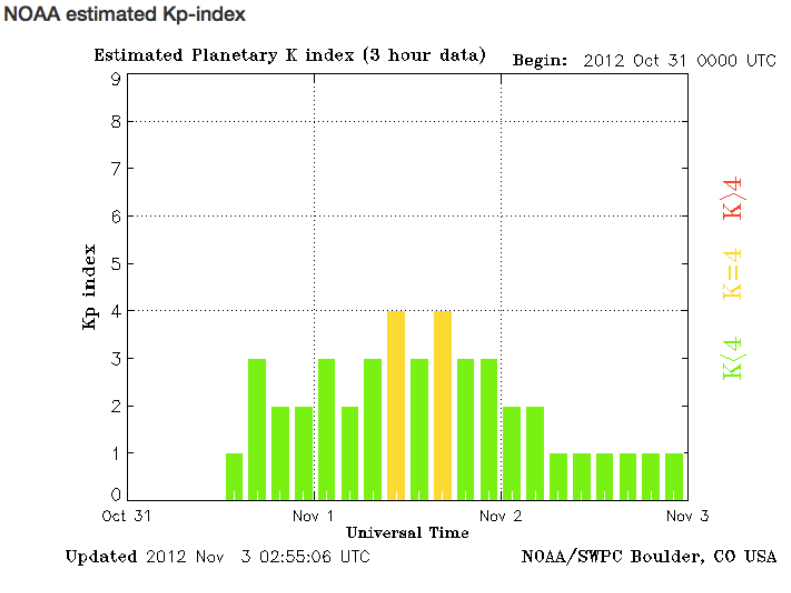
WAAS – Coverage Contours vs % Availability

Disturbed conditions of Solar Cycle 24)



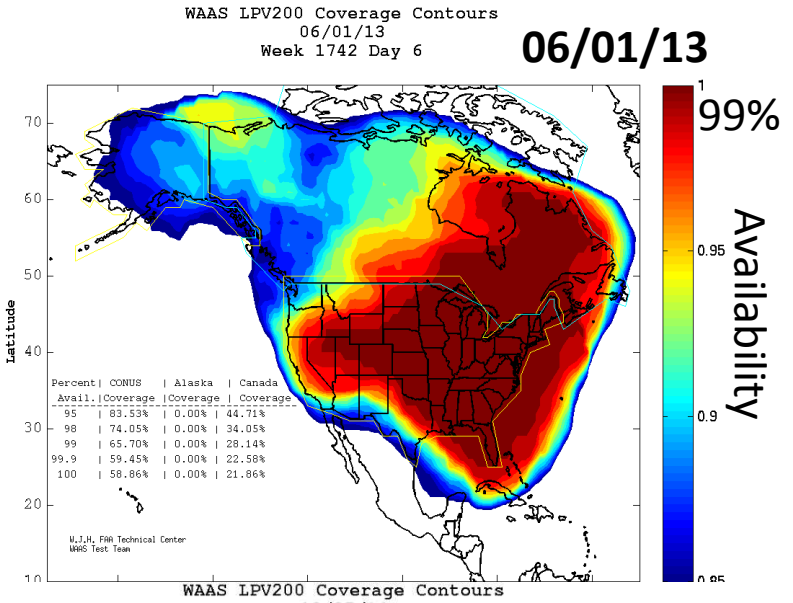


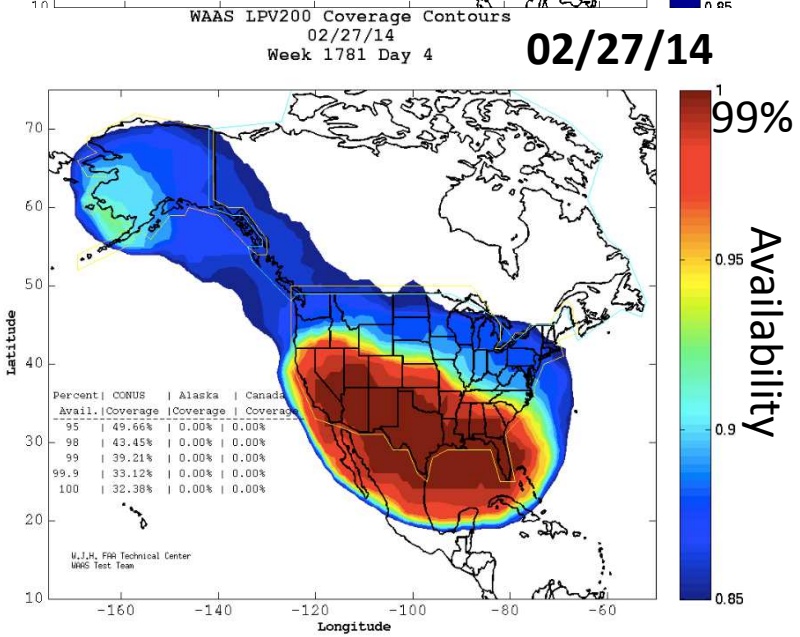


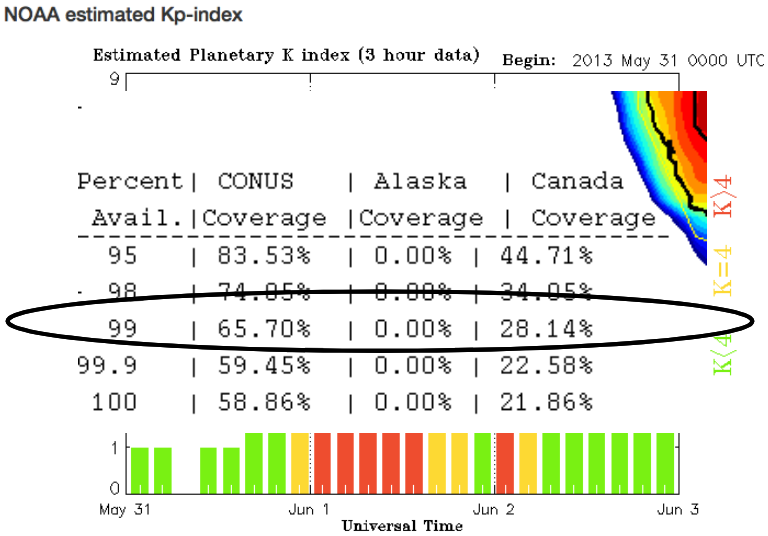


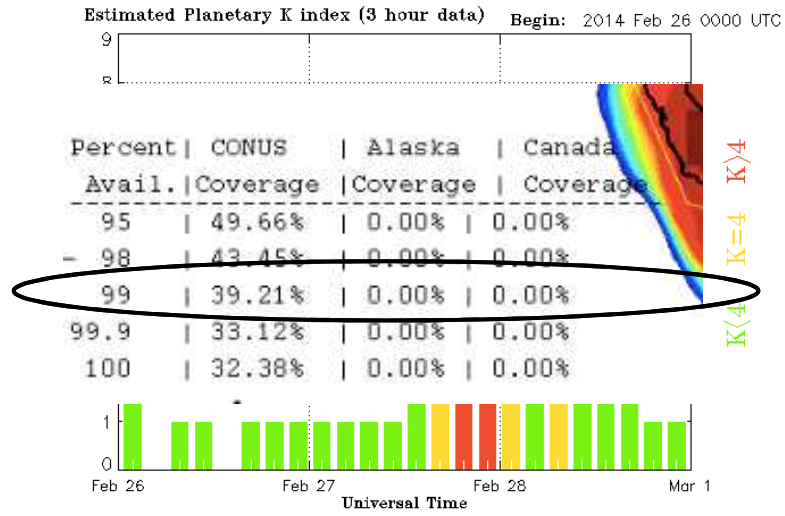
WAAS – Coverage Contours vs % Availability

Disturbed conditions of Solar Cycle 24)



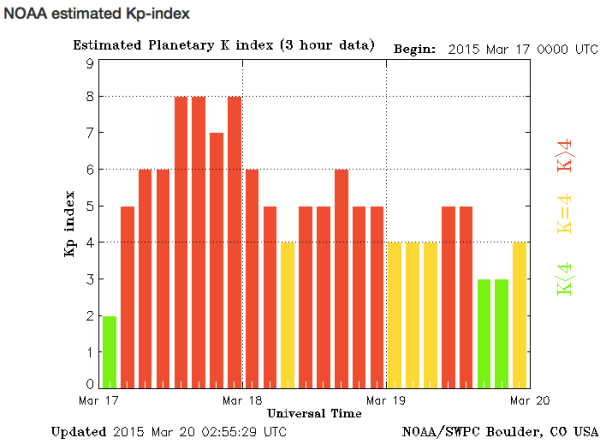


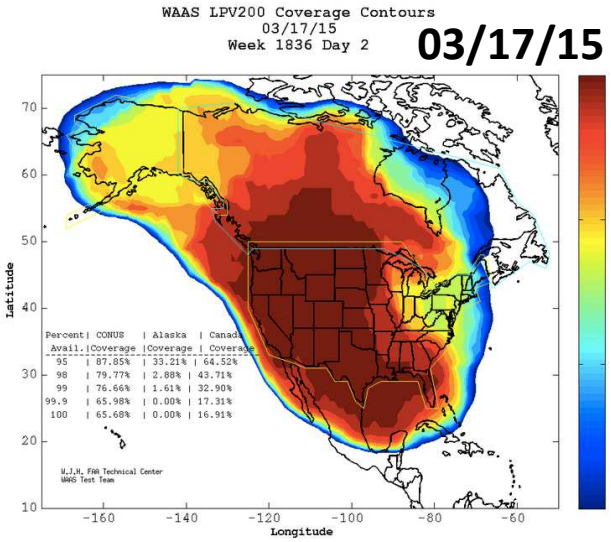


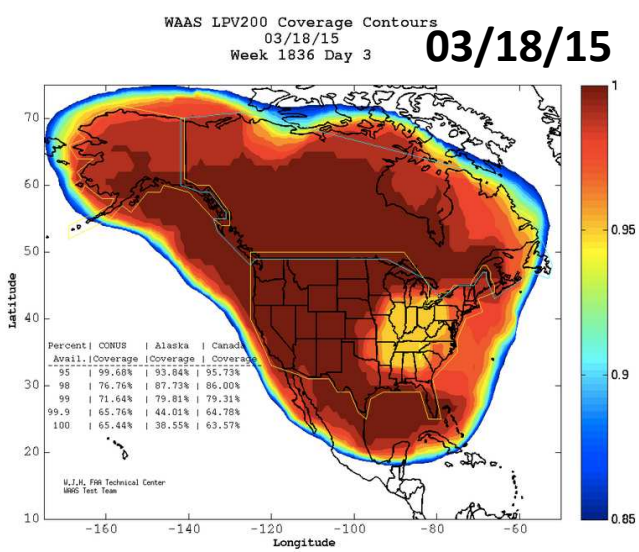


WAAS – Coverage Contours vs % Availability

Disturbed conditions of Solar Cycle 24)





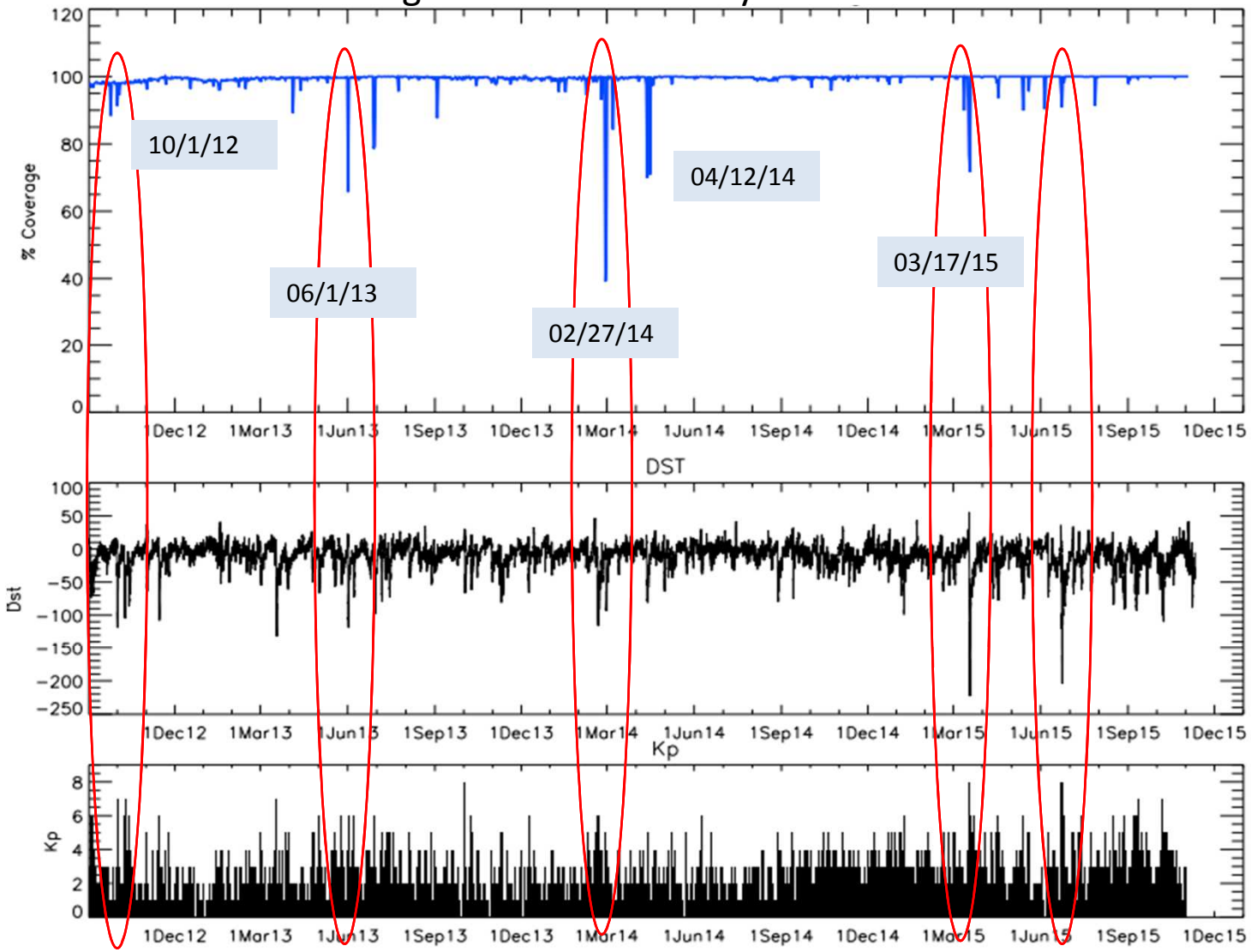


Percent Avail.	CONUS Coverage	Alaska Coverage	Canada Coverage
95	87.85%	33.21%	64.52%
98	79.77%	2.88%	43.71%
99	76.66%	1.61%	32.90%
99.9	65.98%	0.00%	17.31%
100	65.68%	0.00%	16.91%

Percent Avail.	CONUS Coverage	Alaska Coverage	Canada Coverage
95	99.68%	93.84%	95.73%
98	76.76%	87.73%	86.00%
99	71.64%	79.81%	79.31%
99.9	65.76%	44.01%	64.78%
100	65.44%	38.55%	63.57%

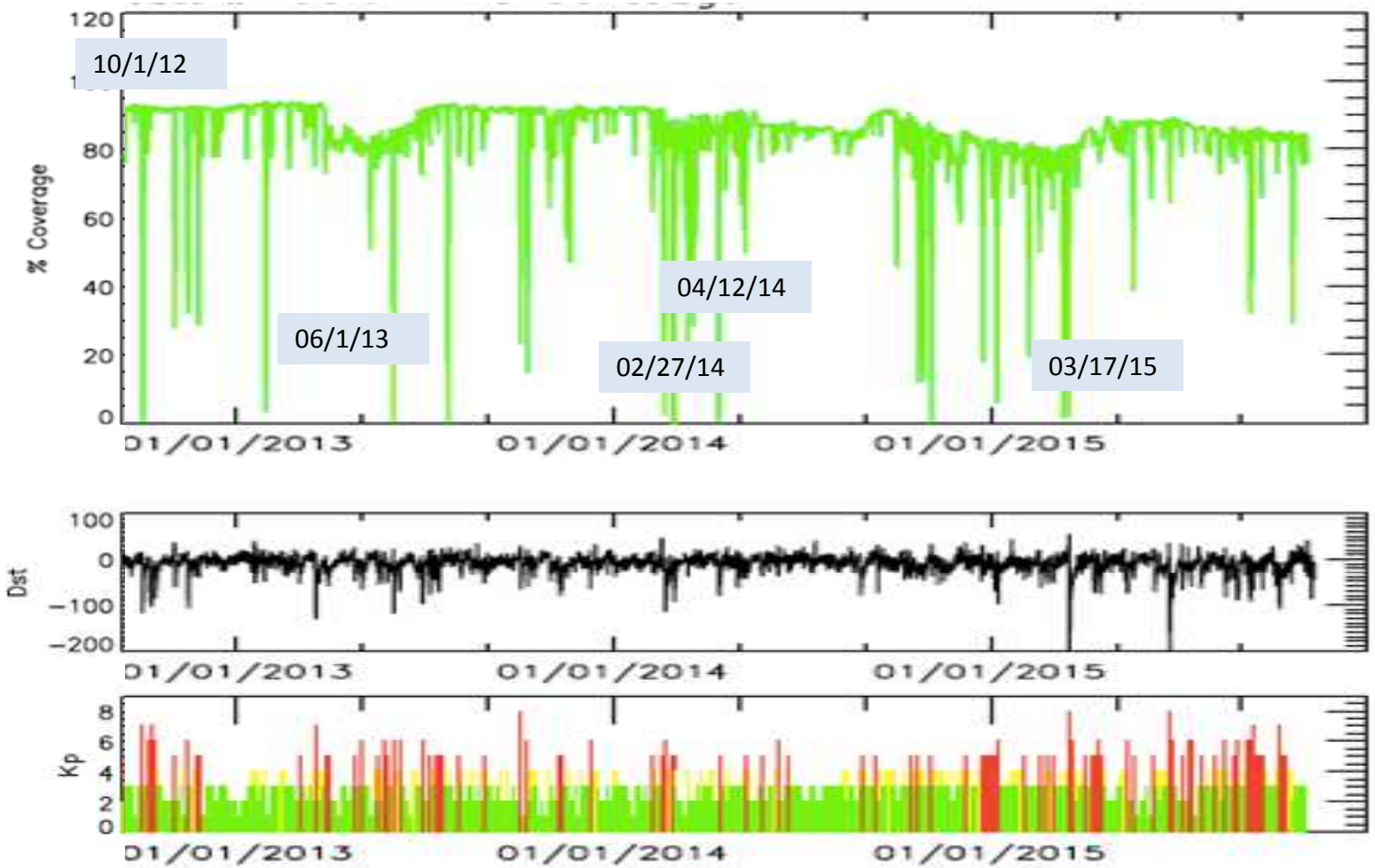
Summary - SC 24 Space Weather Effects in CONUS

CONUS Coverage at 99% Availability – Not as intense as SC23



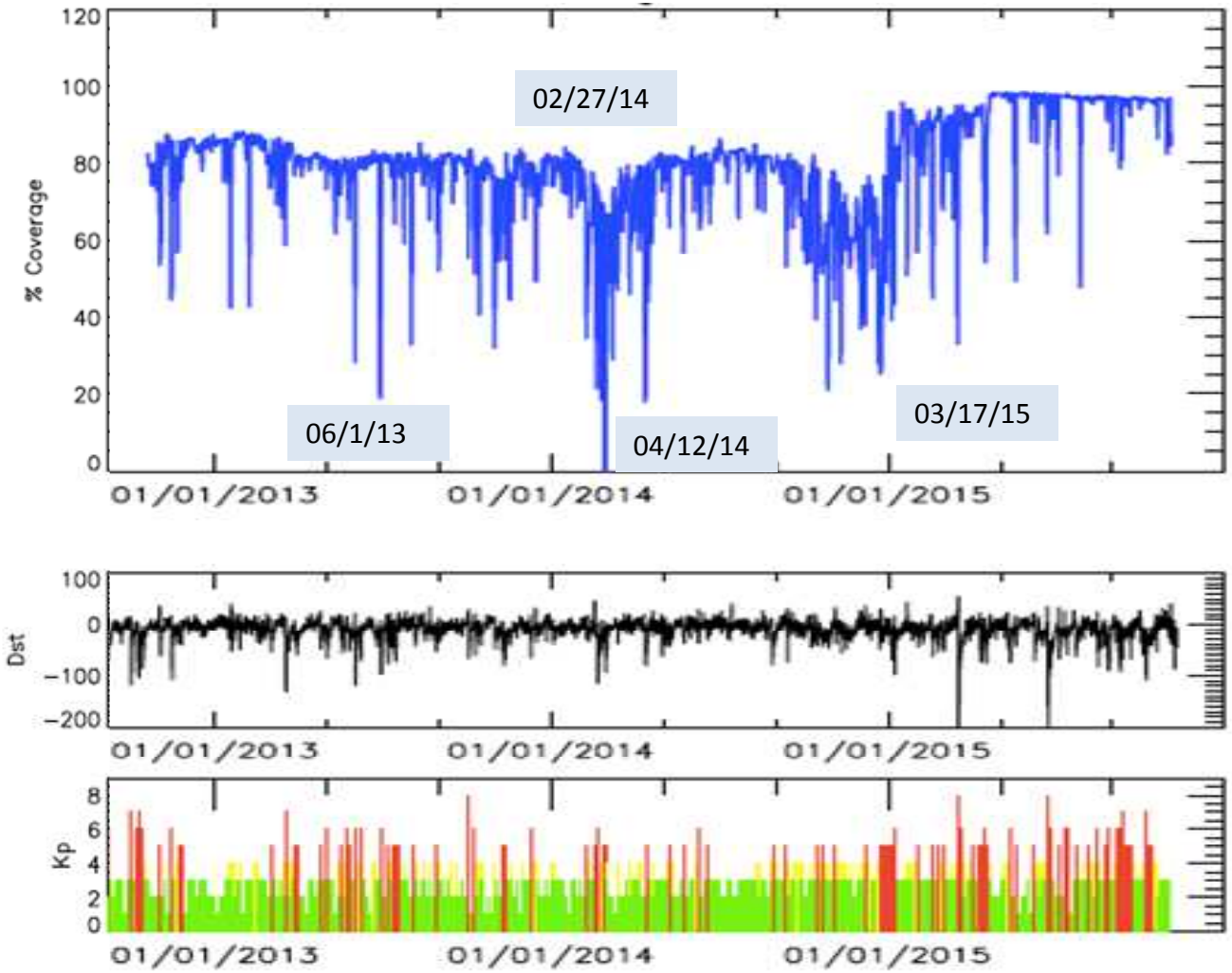
Summary - SC 24 Space Weather Effects in Alaska

Alaska Coverage at 99% Availability

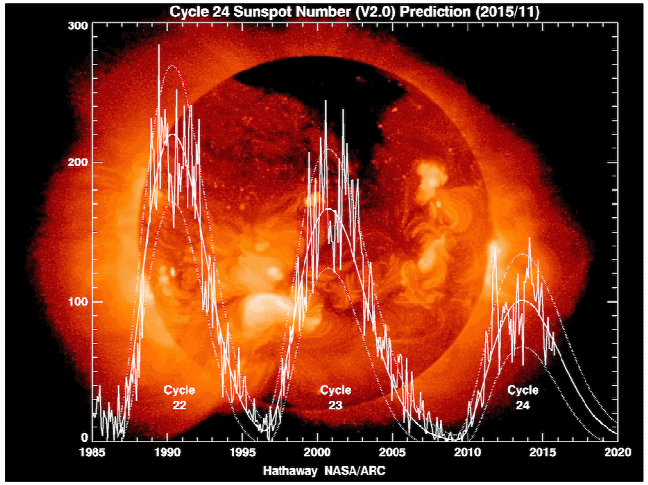


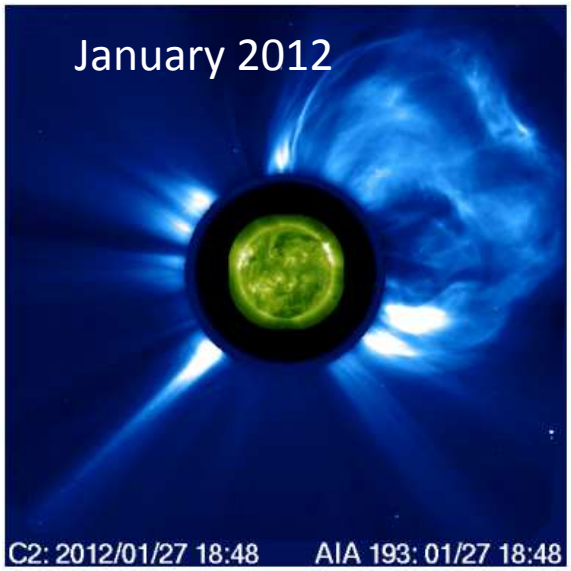
Summary - SC 24 Space Weather Effects in Canada

Canada Coverage at 99% Availability



Why are Cycle 24 Space Weather Events Weak?



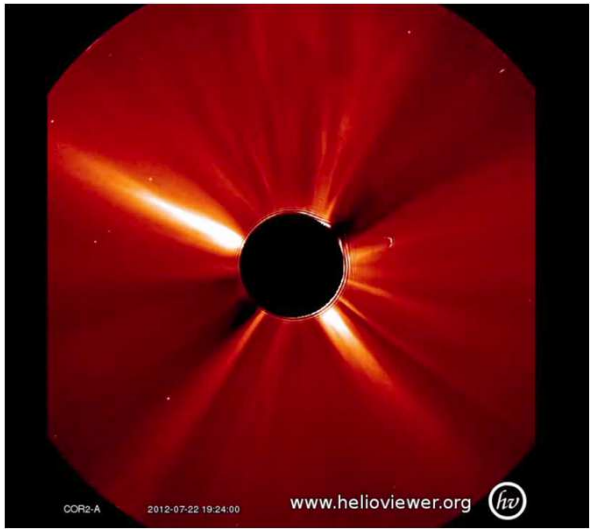


- Solar Cycle 24 is the lowest in 100 years
- CME occurrence rate is about the same for SC23 an SC24
- CME width and speed are wider in SC24
  - For CMEs >1000kms – widths higher by 40%
- ACE and WIND instruments showed that magnetic pressure and plasma pressure in the heliosphere was reduced by ~40%
- CMEs released into this lower pressure medium expand more than usual resulting in weaker magnetic fields

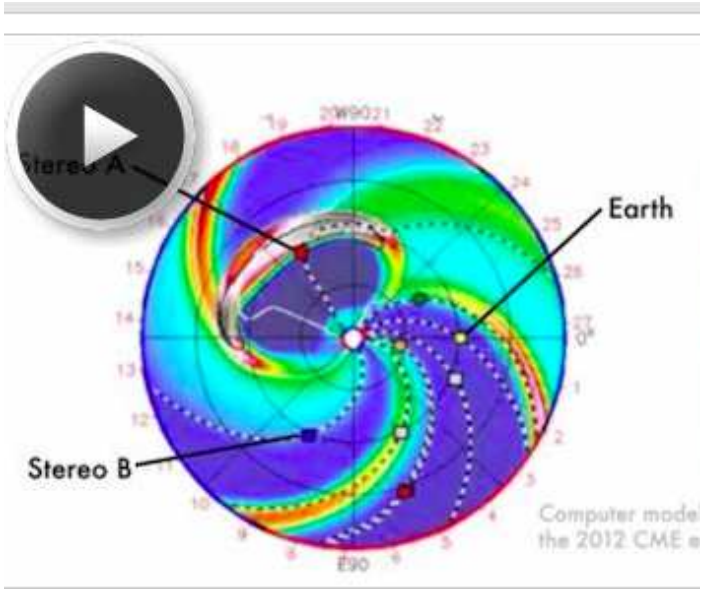
- Magnetic field strength in CMEs determines the intensity of geomagnetic storms

Goplaswamy, N., S. Akiyama, S. Yashiro, H. Xie, P. Makela and G. Michalek (2014), Anomalous expansion of coronal mass ejections during solar cycel 24 and it space weather implications, GRL, 31, 2673-2680, doi:10.1002/2014GL059858.

Extreme CME of July 23, 2012



- Huge CME left the Sun at 3000 km/s
- Narrowly missed the Earth
- 1 week earlier, it would have hit Earth directly



- Much like the 1859 Carrington Event
  - Hit Earth directly
  - Sparked northern lights as far south as Tahiti
  - Caused telegraph lines to spark setting fire to telegraph offices
  - A similar storm today could be catastrophic

U.S. National Space Weather Strategy

Motivation

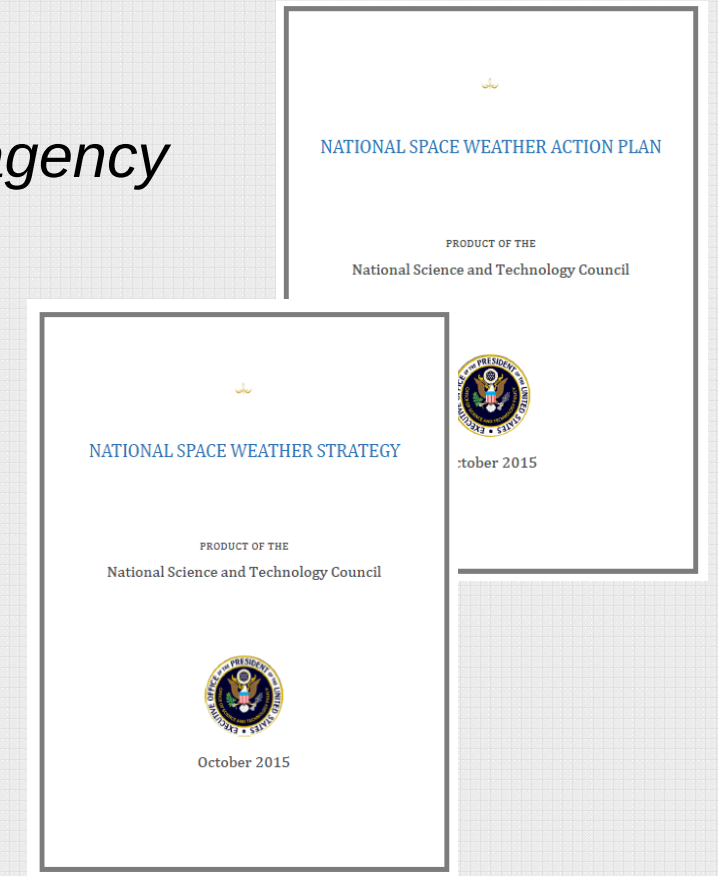
- *Reliance on advanced technology vulnerable to space weather*
- *New awareness of extreme space weather and its potential effects*

***Nov 2014** – White House charters multi-agency Space Weather Task Force*

***Oct 2015** – A cohesive all-of-government Strategy and Action Plan delivered to mitigate, respond to and recover from a major space weather storm*

Strategy articulates six high-level goals

- *Goal 6: <u>Increase International Cooperation</u>*



Released on 29 October 2015

Summary

- WAAS is a combined ground-based and space-based system that augments the GPS Standard Positioning Service (SPS) to meet the stringent requirements for civil aviation
- Greatest challenges for WAAS in Solar Cycle 23 were geomagnetic storms in 2003 and 2004 (significant decrease in availability)
- Solar Cycle 24 has also presented challenges but much less intense than Solar Cycle 23
- Near Carrington like event – missed Earth in July 2012
- Solar activity will continue to be intense for the next few years
- White House recently released a National Space Weather Strategy and Action Plan – International Cooperation is a major goal

WAAS, EGNOS, GAGAN, MSAS and SDCM

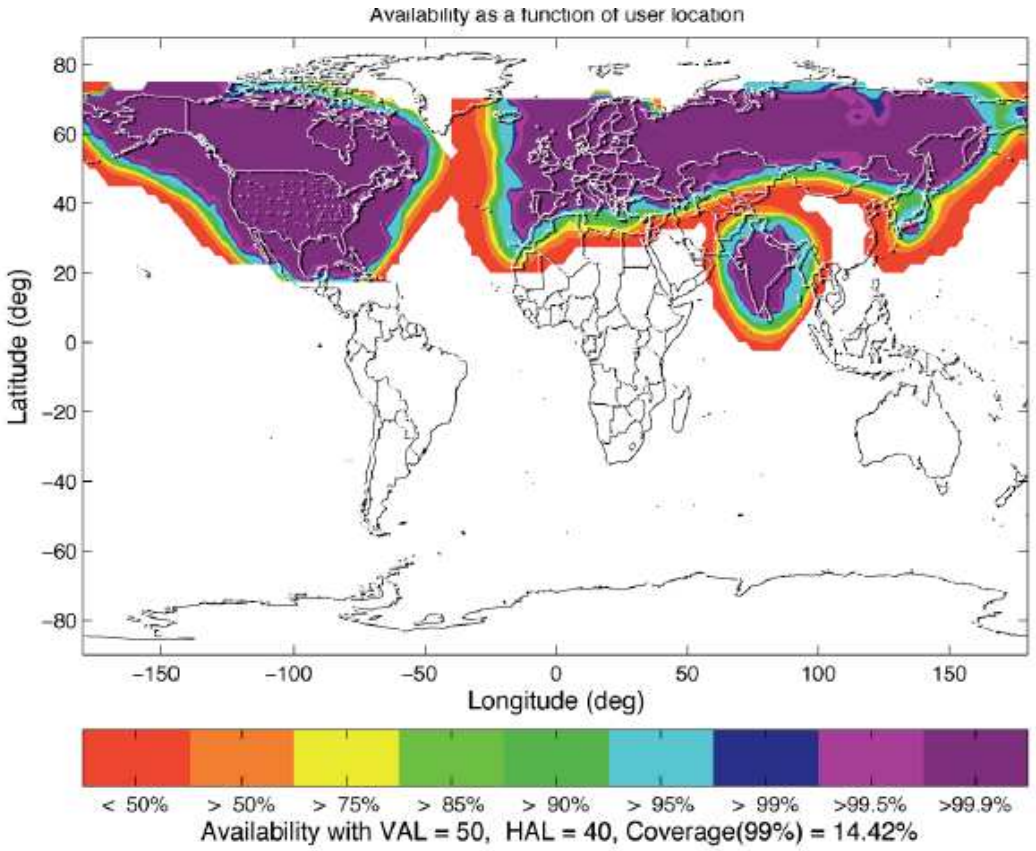


Figure Courtesy, T. Walter, Stanford

EGNOS – Typical Coverage

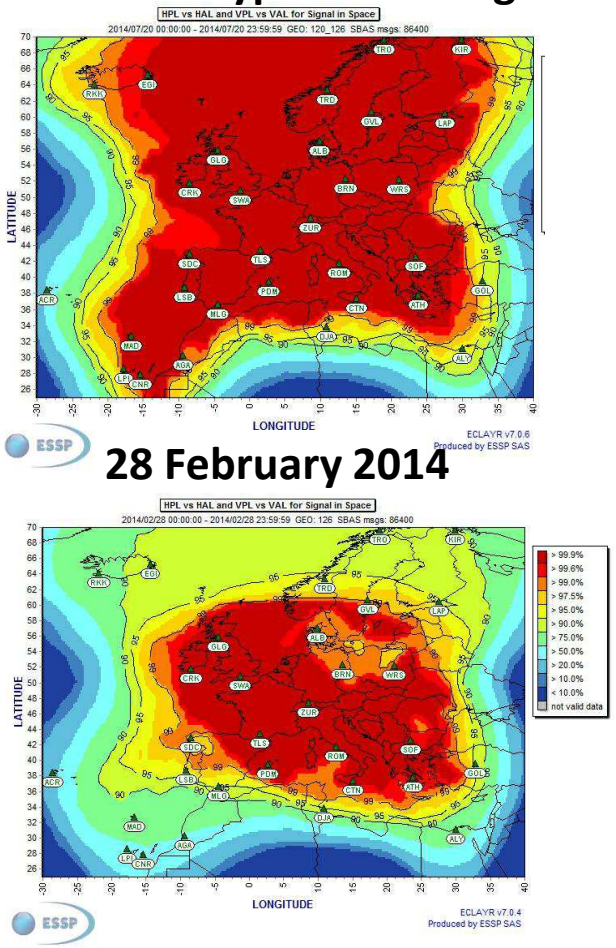


Figure Courtesy, R. Prieto Cedeira, ESA

Thank you for your attention!

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