Space Weather Effects on GNSS Applications

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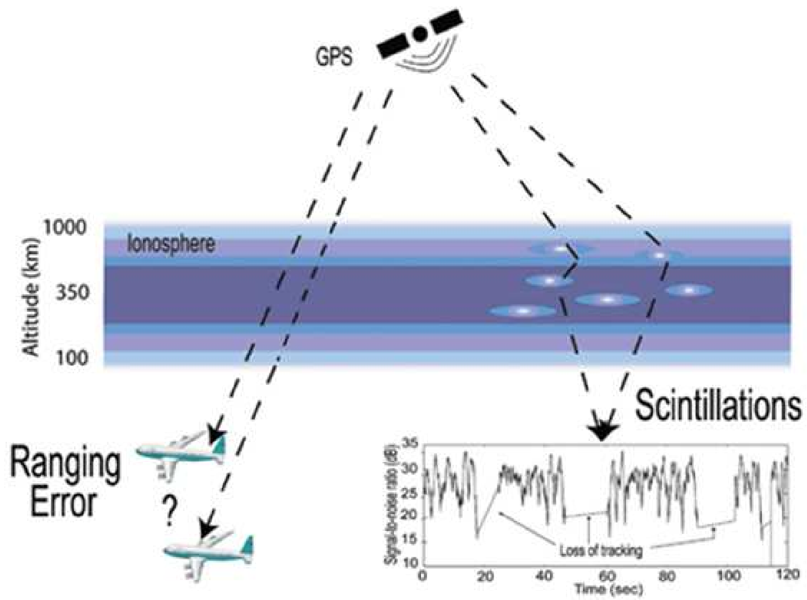


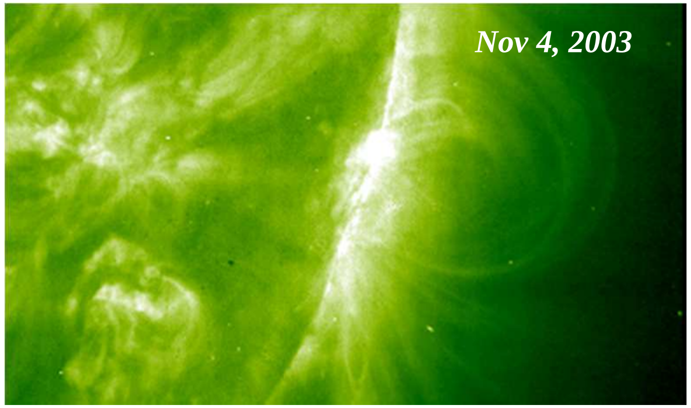
(Courtesy P. Kintner)

United Nations/Nepal Workshop on the Applications of Global Navigation Satellite Systems

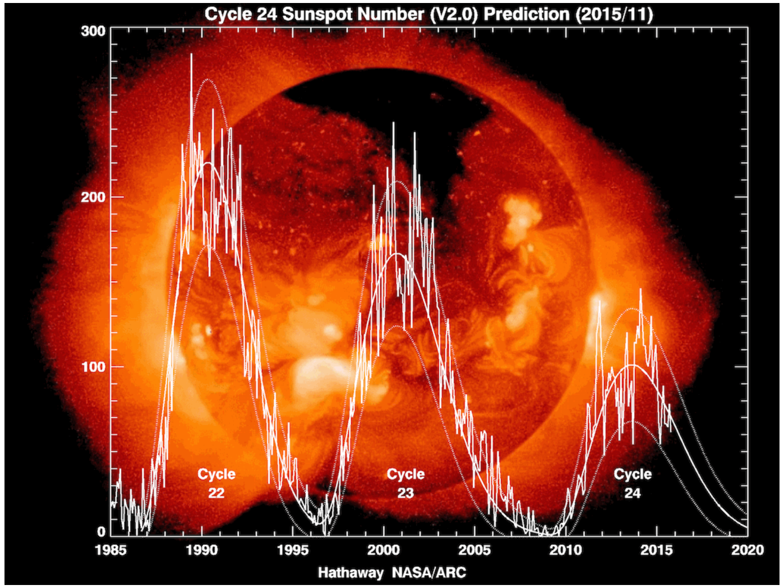
Kathmandu, Nepal 12 - 16 December 2016

Outline

- The BIG 3
  - Systems Most Seriously Affected by Space Weather
- GNSS Applications
  - affected by Space Weather
  - Aviation Augmentation Systems
  - SBAS & GBAS
  - SBAS Performance (WAAS)
    - Nominal Conditions
    - Disturbed Conditions
    - Solar Cycle 23 vs Cycle 24
- Worldwide SBAS Systems
- Summary



from sohowww.nascom.nasa.gov



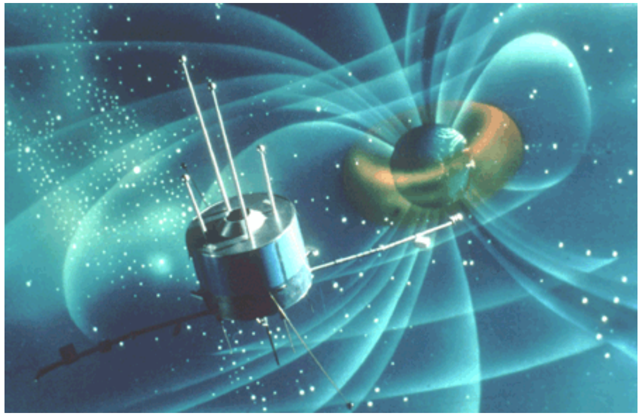
Space Weather Effects – The Big 3!

- Damage to Electric Power Grids
  - Changes in the magnetic field can produce surges in power lines and transformers.
  - National Academies Report 2009 – estimated the impact of a space weather induced grid collapse to be ~$1trillion dollars

- Damage to Satellites
  - Energetic ions can damage solar panels
  - Energized plasmas can cause electrical charges that can damage the electronics
  - Increase satellite drag
  - Economic value of satellite enterprise >$100Billion

- Health Risks due to Radiation Hazards
  - Exposure at high altitudes
  - Astronauts
  - High flying jets
  - Crews/passengers flying over the poles
  - Redirecting these flights can cost $100,000

Damage to power grids.



Damage to satellites.

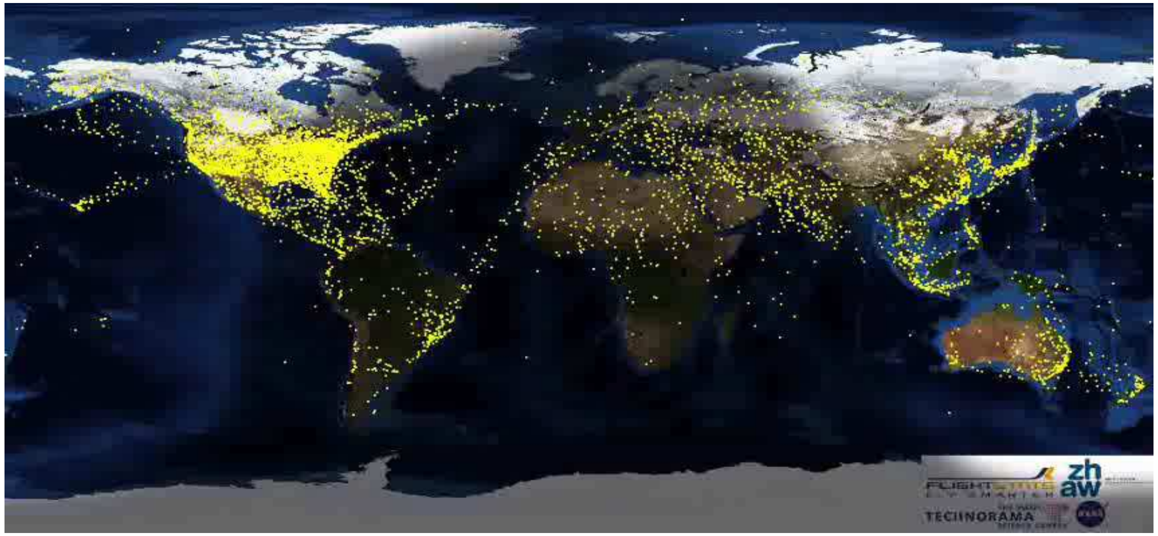
Radiation Exposure.

Space Weather Effects on GNSS Applications

- Cell Phones
- Pipelines
- Geologic Exploration
- Surveying
- Continental Cables
- FiberOptic Cable
- Surveillance
- Banking
- Remote Sensing
- Emergency Location
- Natural Resource Monitoring
- All modes of transportation

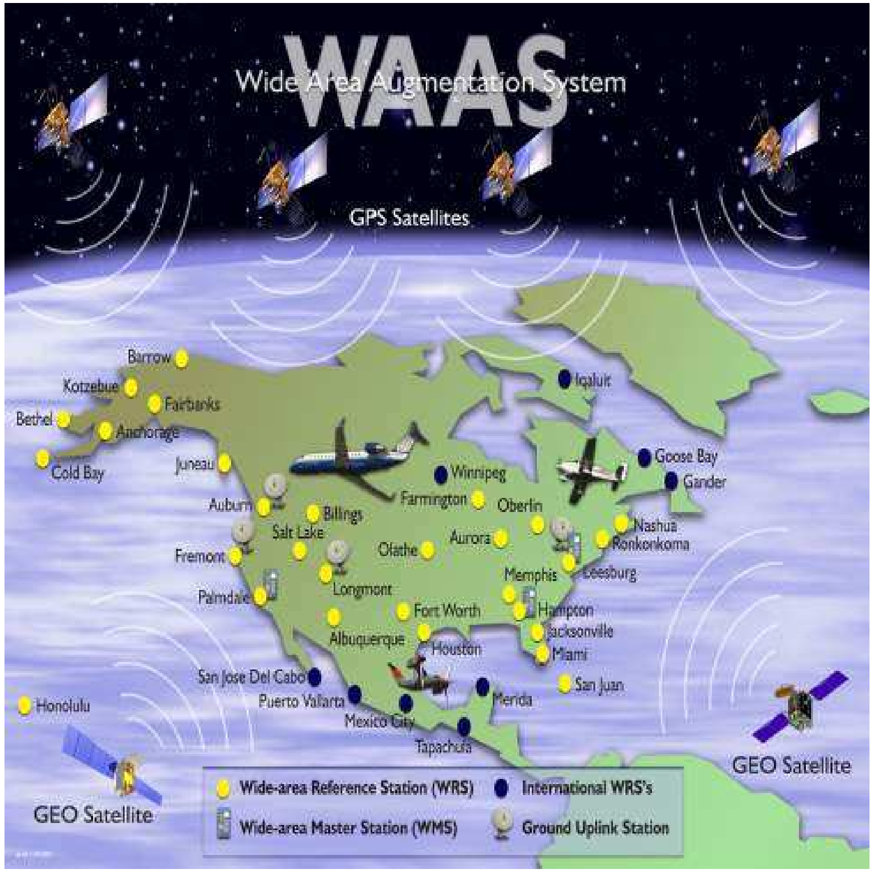
Aviation Augmentation Systems

- Satellite Based Augmentation Systems (SBAS)
- Ground Based Augmentation Systems (GBAS)

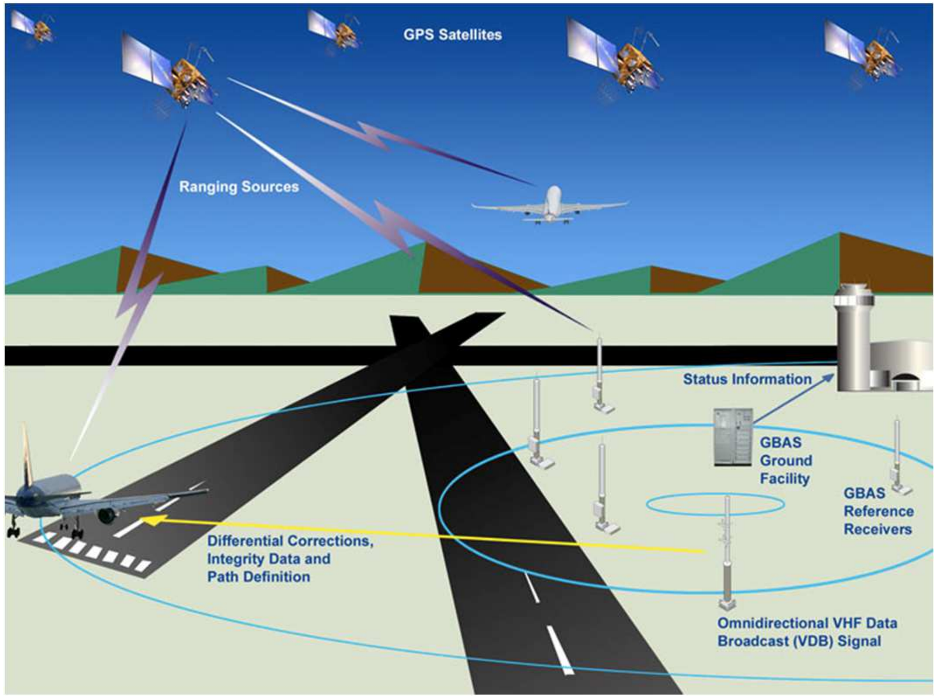


http://www.dailymotion.com/video/x4drryl_world-air-traffic-within-24-hours

SBAS and GBAS Systems



- important roles in aviation safety to ensure accuracy, availability and integrity of navigation information
- broadcast routine correction messages, allowing navigation/control systems to take ionospheric delays into account for precise positioning calculations
- steep ionospheric TEC gradients and scintillations can be serious threats



SBAS – Wide-area or regional scale

- Precision and Non-Precision Approach

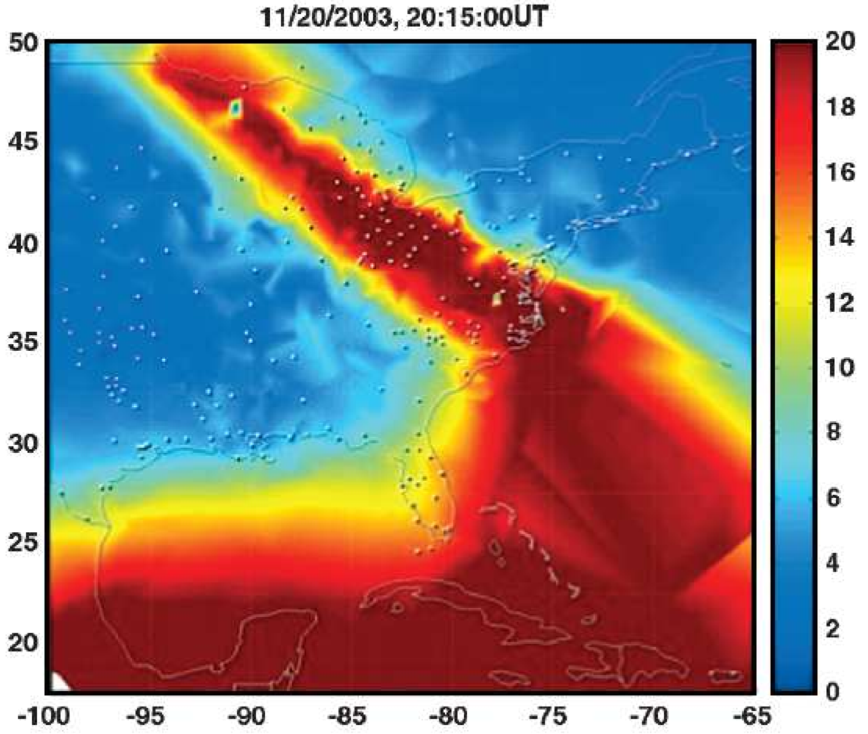
GBAS – Local area & airport service

- Precision Approach in airport vicinity

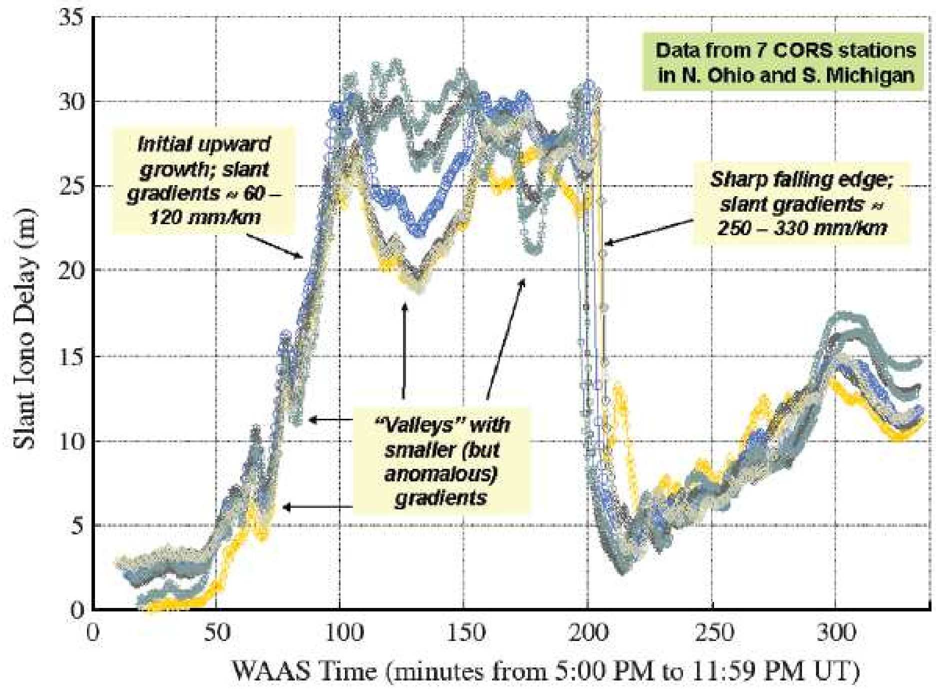
(Figures: www.faa.gov)

Midlatitude Threat: Storm-Enhanced Density

(main threat to SBAS and GBAS Systems)



(Datta-Barua et al., 2010)



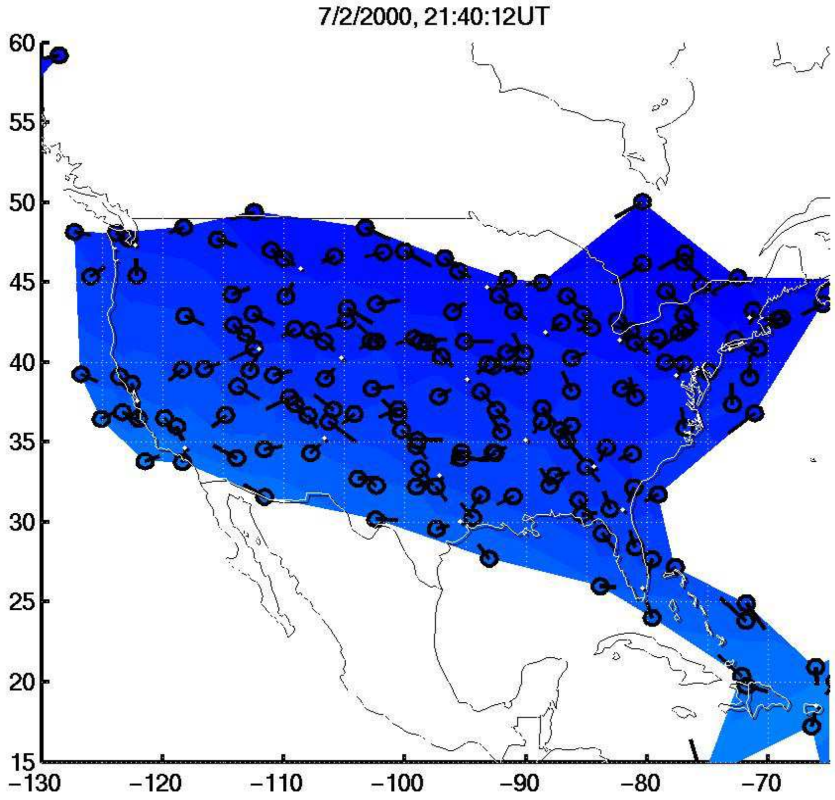
- Nominal upper bound for CONUS during SED: ~425 mm/km at GPS L1 frequency
- Quiet time TEC gradients for CONUS: ~40mm/km or lower
- On the average, 30 geomagnetic storms per year, where 30% of them are major geomagnetic storms

(Refs: Datta-Barua et al., 2010; Lekshmi et al., 2011)

Space Weather Effects on SBAS

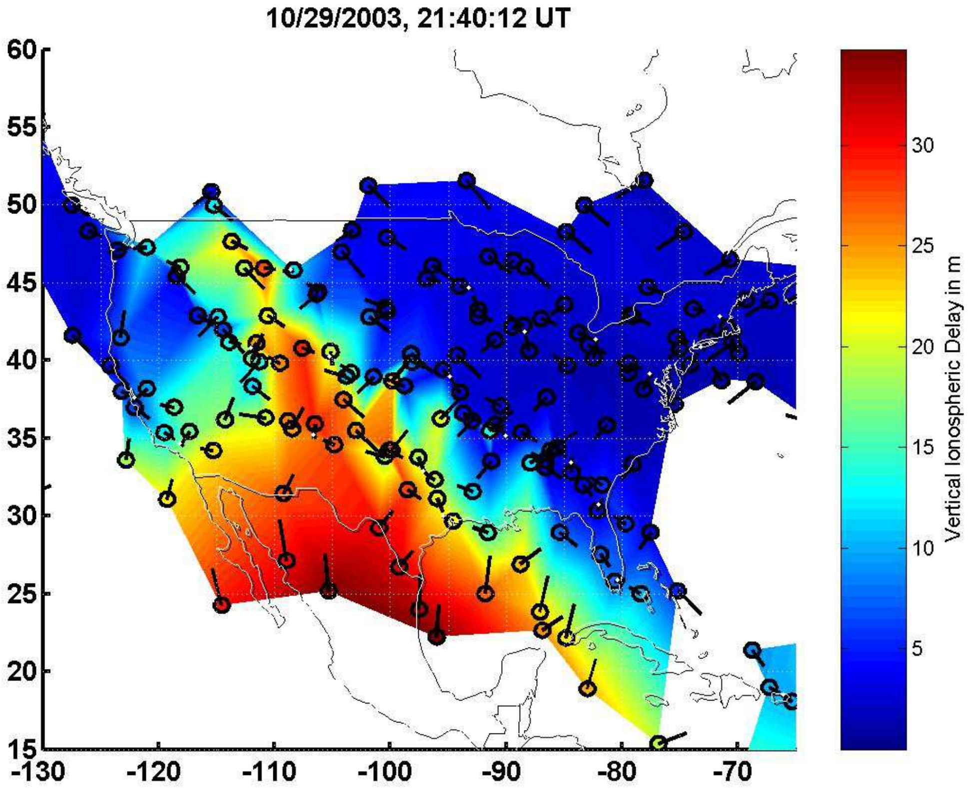
FAA's Wide Area Augmentation System (WAAS)

Quiet Ionosphere



CONUS RANGE ERRORS ARE BETWEEN 1 and 5M

Disturbed Ionosphere



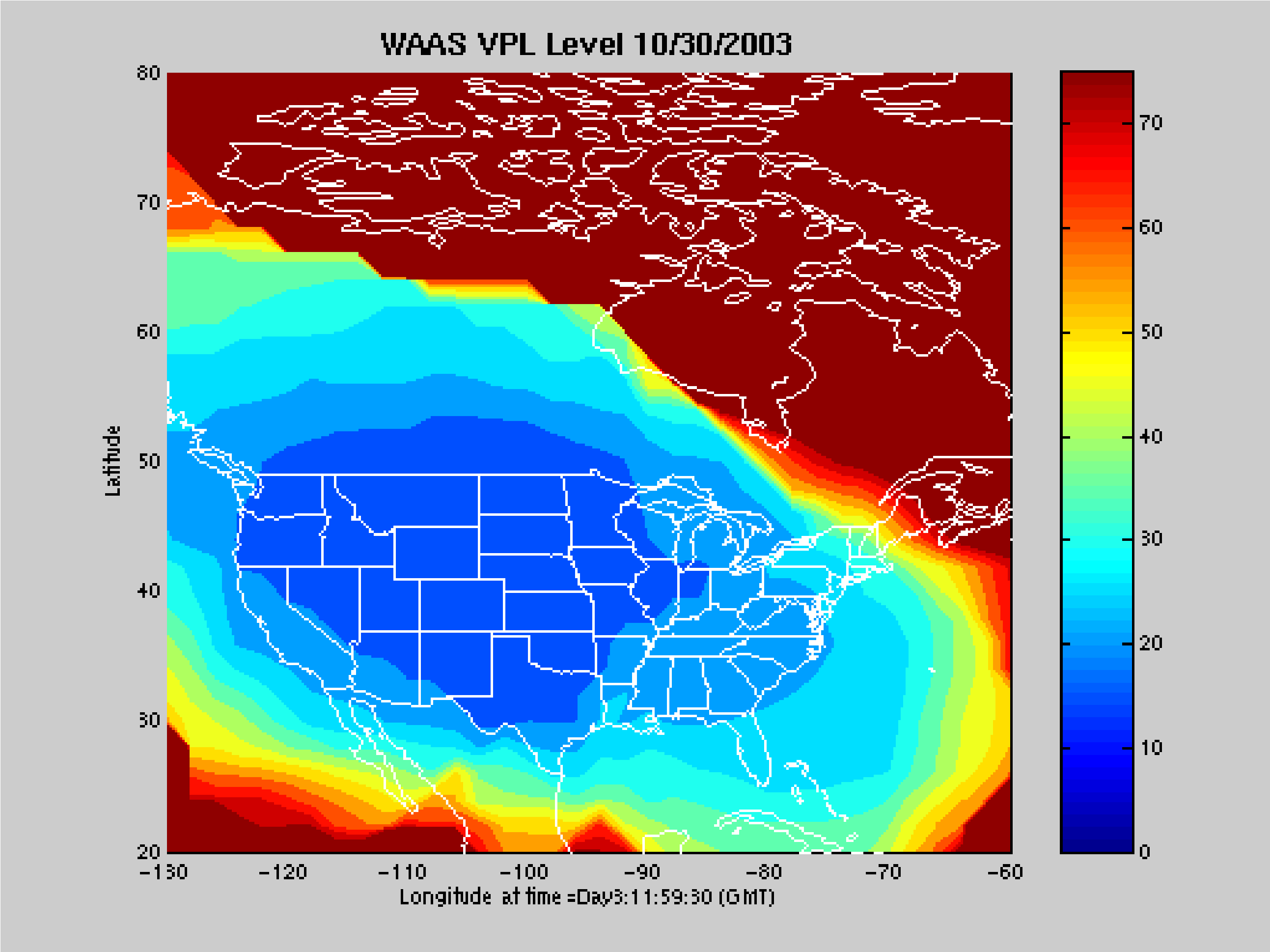
CONUS RANGE ERRORS ARE BETWEEN 1 and >35M

WAAS Response: Interrupt availability of PA Service

Figure Courtesy of S.Datta-Barua

Space Weather Effects of Solar Cycle 23

WAAS Service Availability Challenged -- October 30, 2003



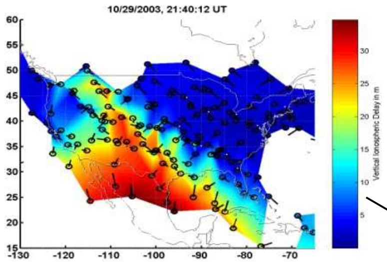
Vertical Navigation Capability

(Animation Courtesy of FAA NSTB)

Space Weather Effects of Solar Cycle 23

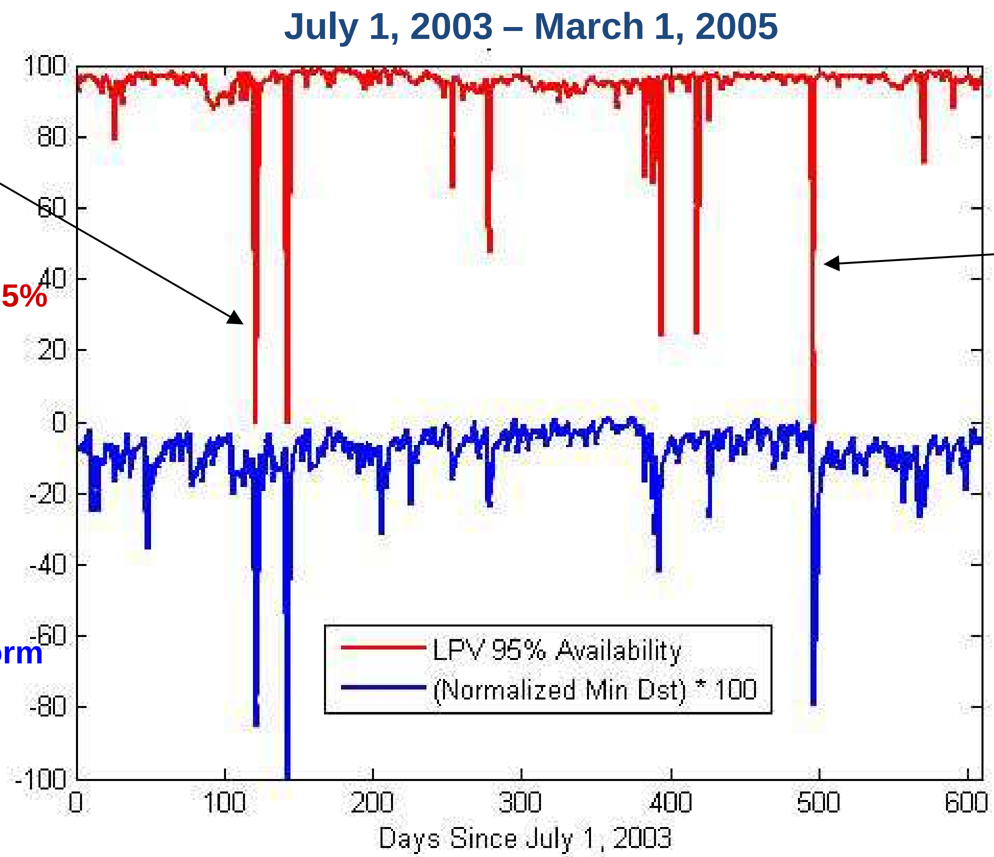
(Oct 30, 2003)

Full loss of availability for nearly 15 hours)



% CONUS at 95% Availability

Magnetic Storm Index

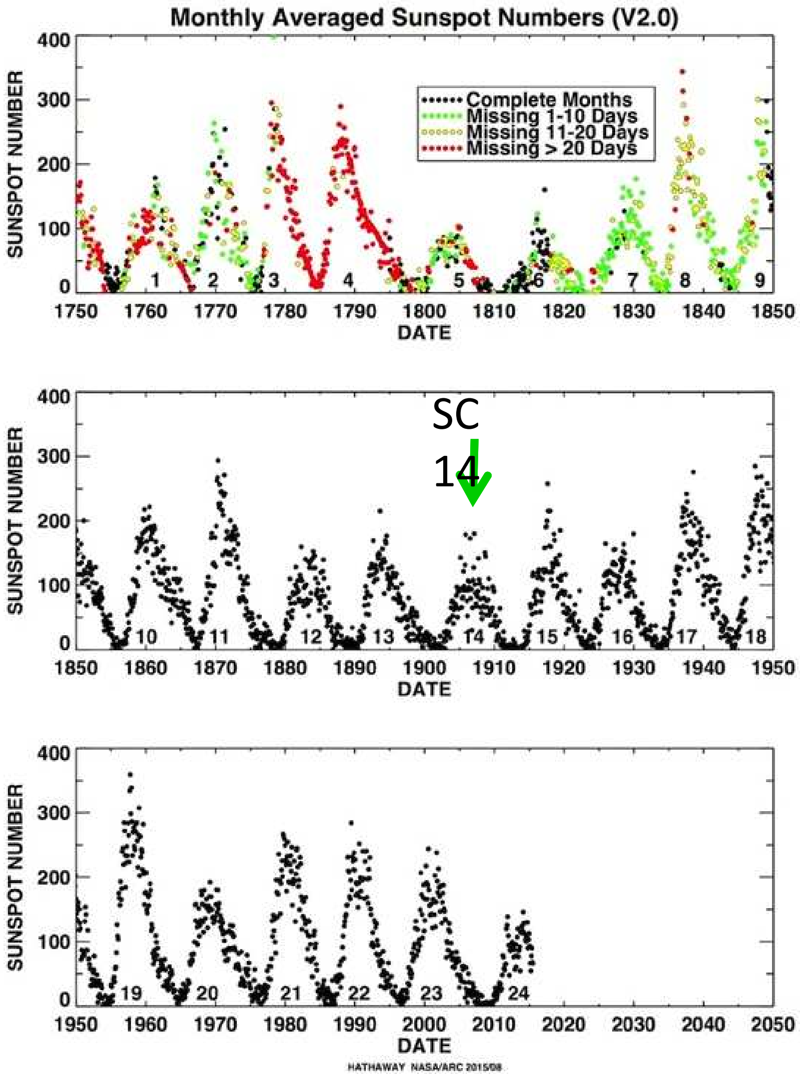


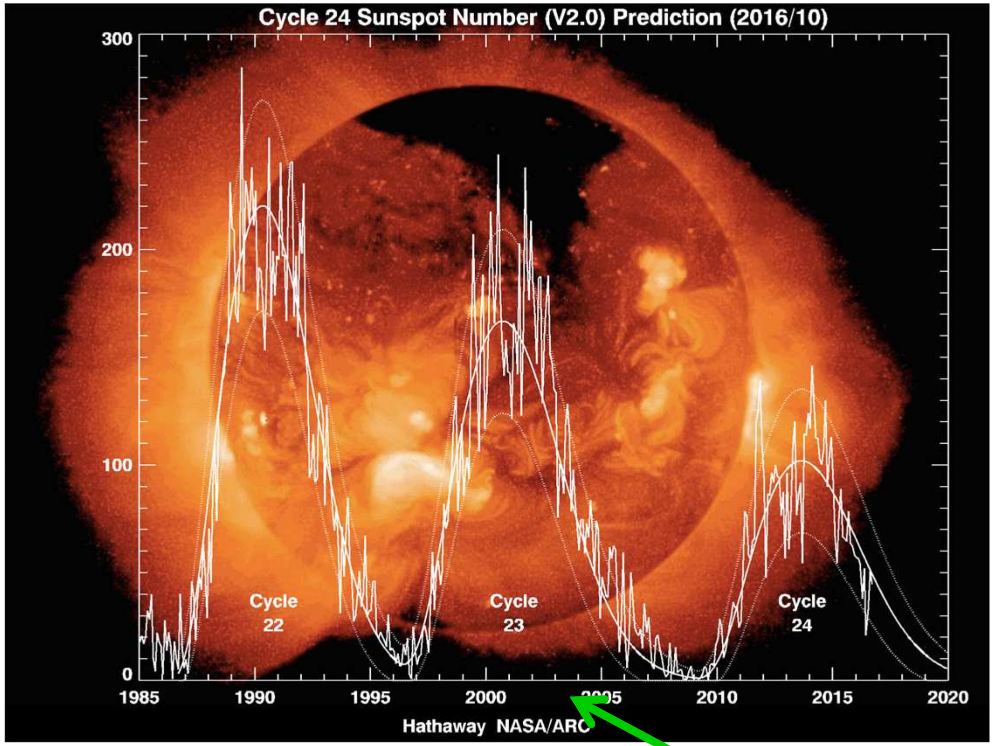
(Nov 8, 2004)

Based on work by S.Datta-Barua

Solar Cycle 24

Lowest solar cycle in over 100 years

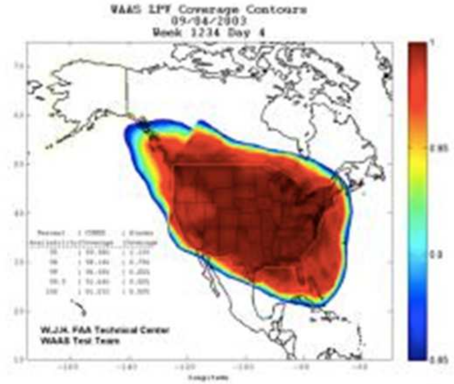




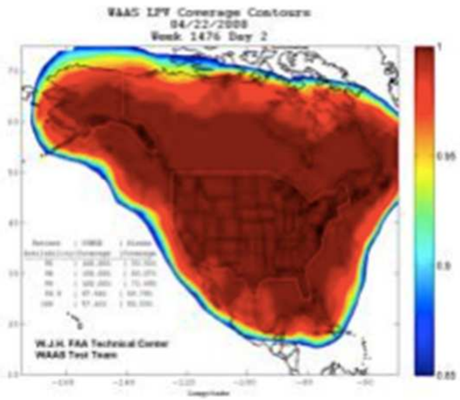
WAAS July 2003

- WAAS became operational in July 2003
- It was met with significant challenges from storms in 2003 and 2004
- SC 24 the lowest since SC 14 in 1906
- Peaked in April 2014 (SSN 116)
- SC 24 has been kinder to WAAS

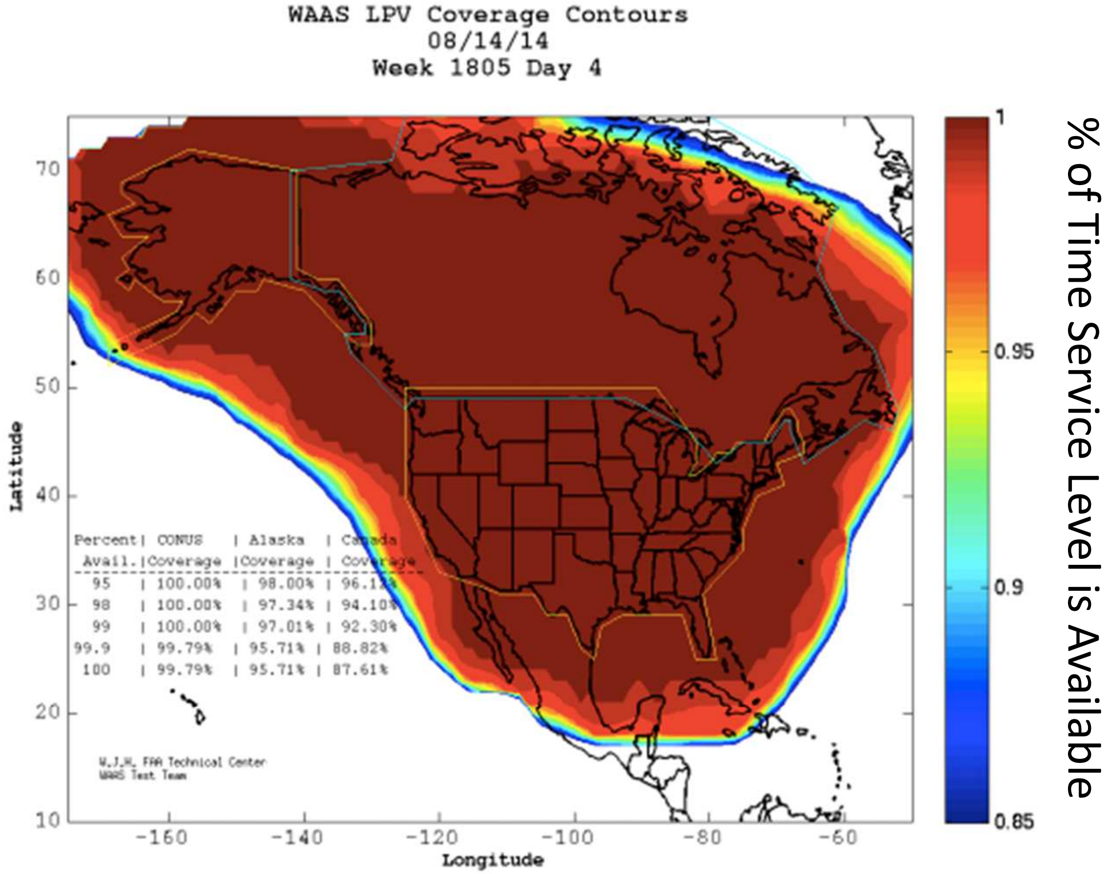
WAAS Coverage Improvements



2003 IOC – LPV Coverage in lower 48 states only



2008 Coverage - Full LPV 200 Coverage in CONUS (2 Satellites)

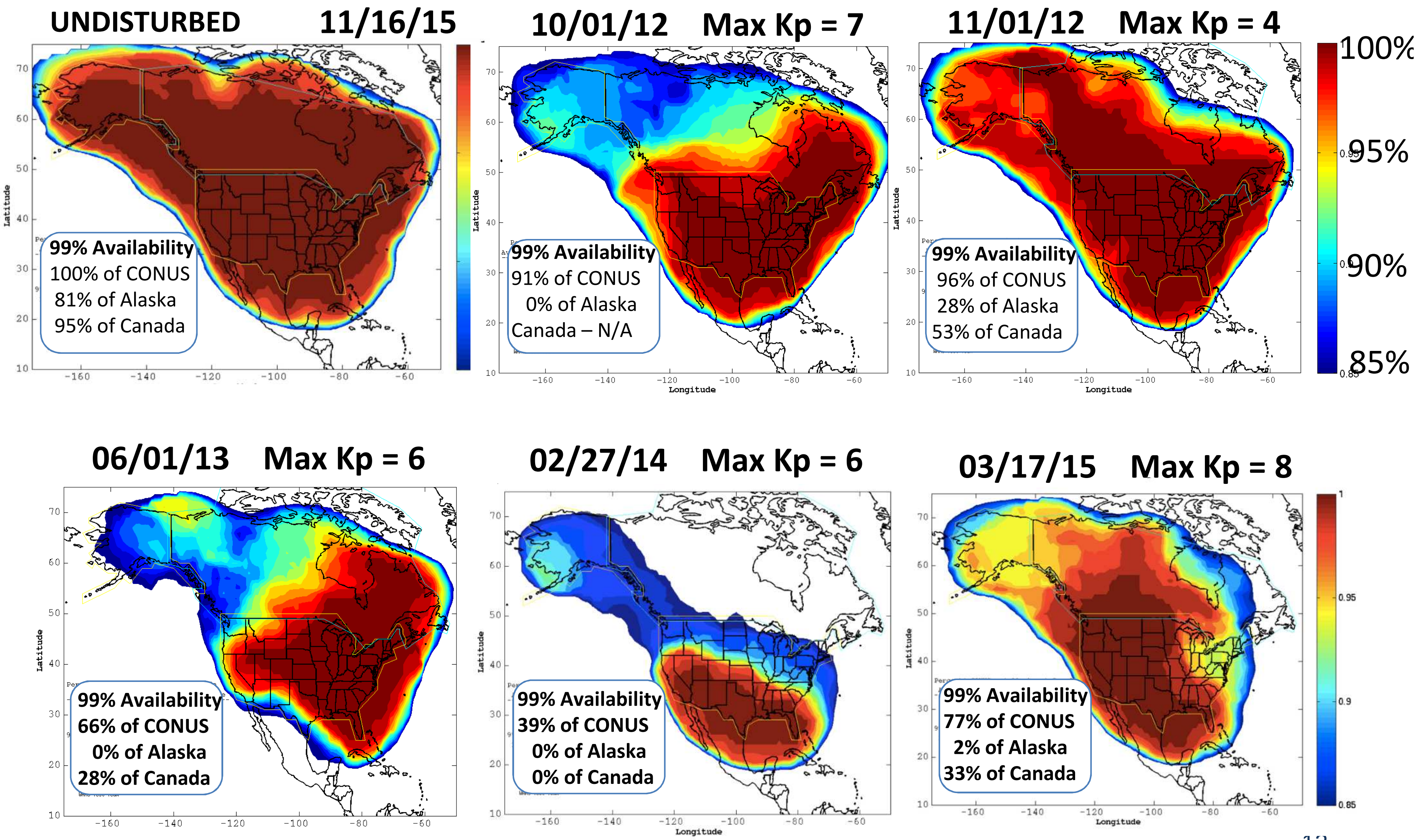


2014 Coverage - Full LPV 200 Coverage in CONUS (3 Satellites)

(Figure Courtesy of D. Bunce, FAA)

Advancing the Space Weather Enterprise:

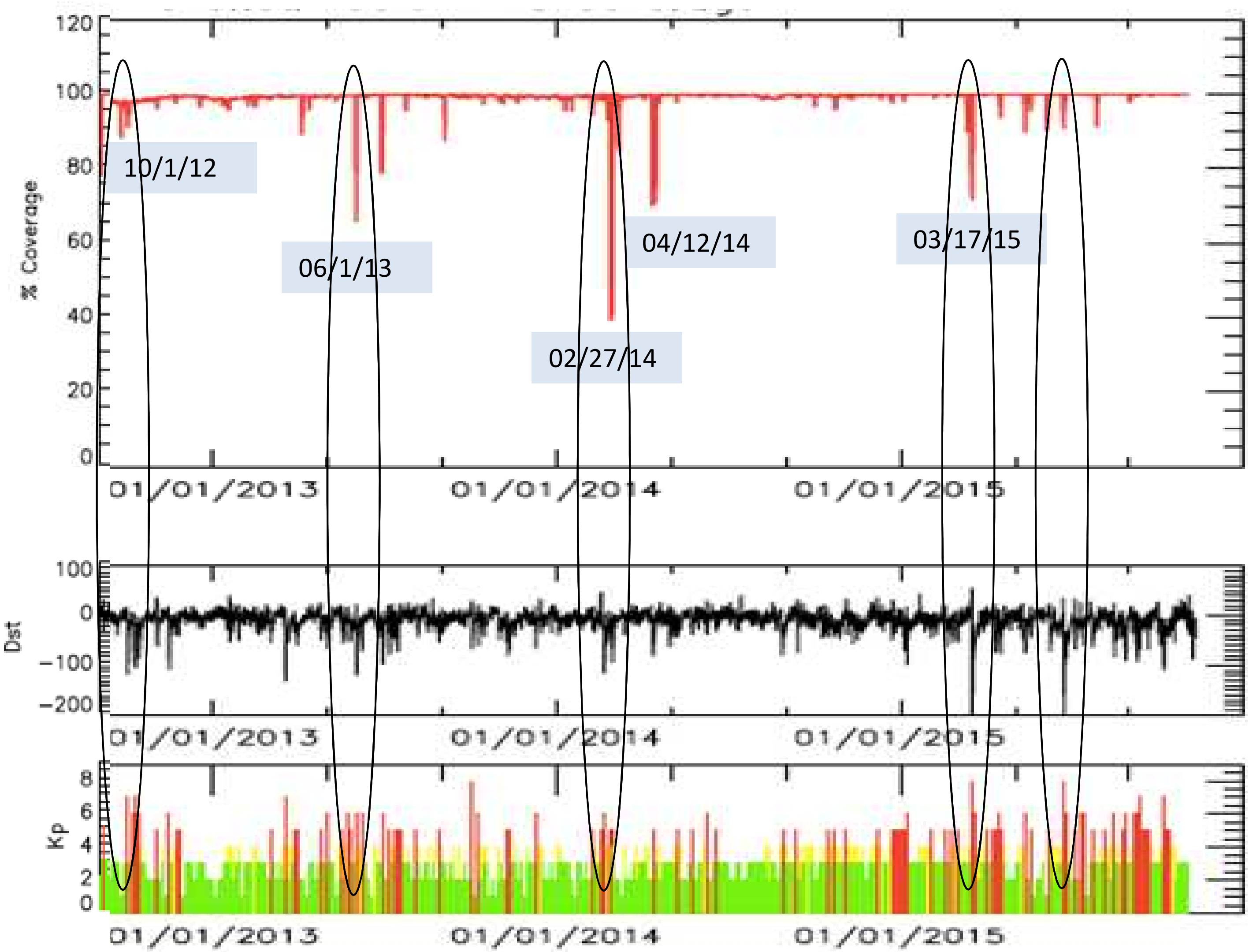
SC24 SW Effects on WAAS LPV200 Coverage



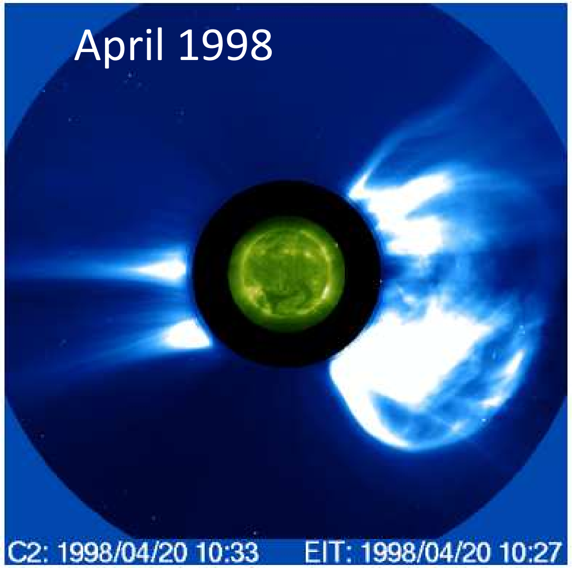
www.nstb.tc.faa.giv/24Hr_Waaslpv200.htm

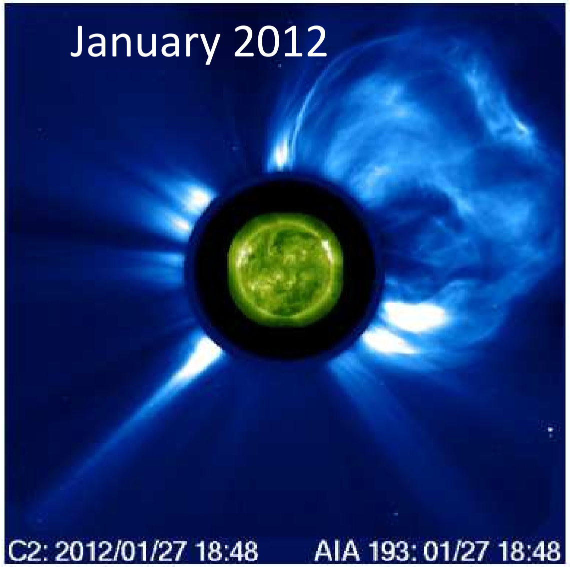
Summary - SC 24 Space Weather Effects in CONUS

CONUS Coverage at 99% Availability



Why are Cycle 24 Space Weather Events Weak?





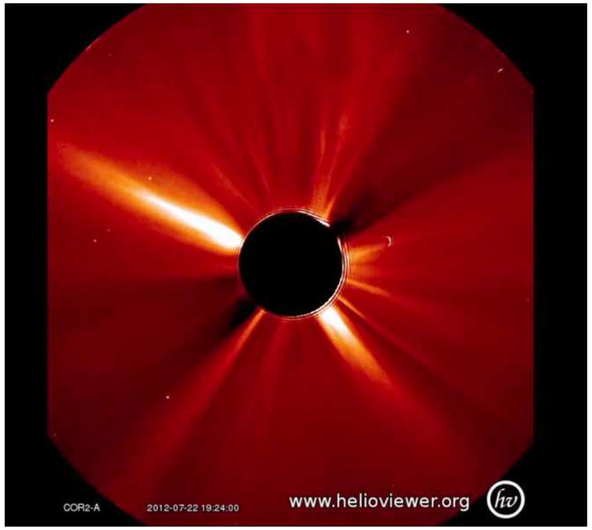
CMEs – gigantic bubbles of electrified gas that billow away from the Sun carrying as much as 10 billion tons of solar material and can trigger spectacular geomagnetic storms if they hit the Earth's magnetosphere. They travel at speeds between 500 and 1500 km/s, take 2-3 days to reach Earth.

CME occurrence rate is about the same for SC23 and SC24

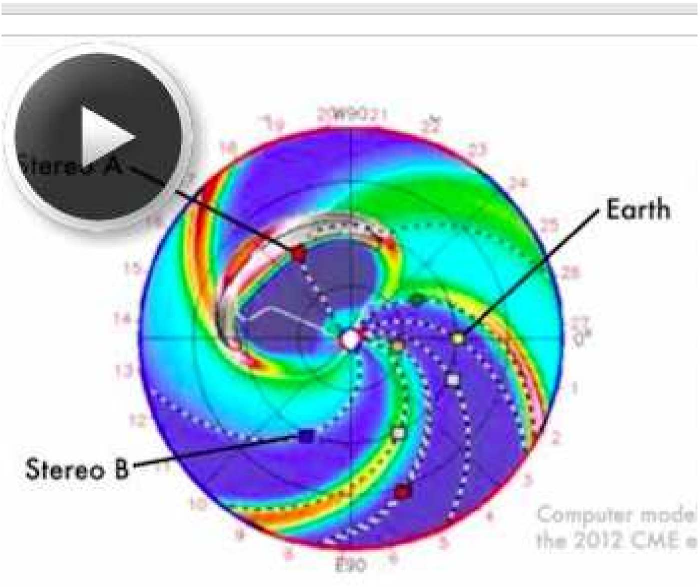
- CME width are wider in SC24
    - For CMEs >1000kms – widths higher by 40%
- ACE and WIND instruments showed that magnetic pressure and plasma pressure in the heliosphere was reduced by ~40%
- CMEs released into this lower pressure medium expand more than usual resulting in weaker magnetic fields
- 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



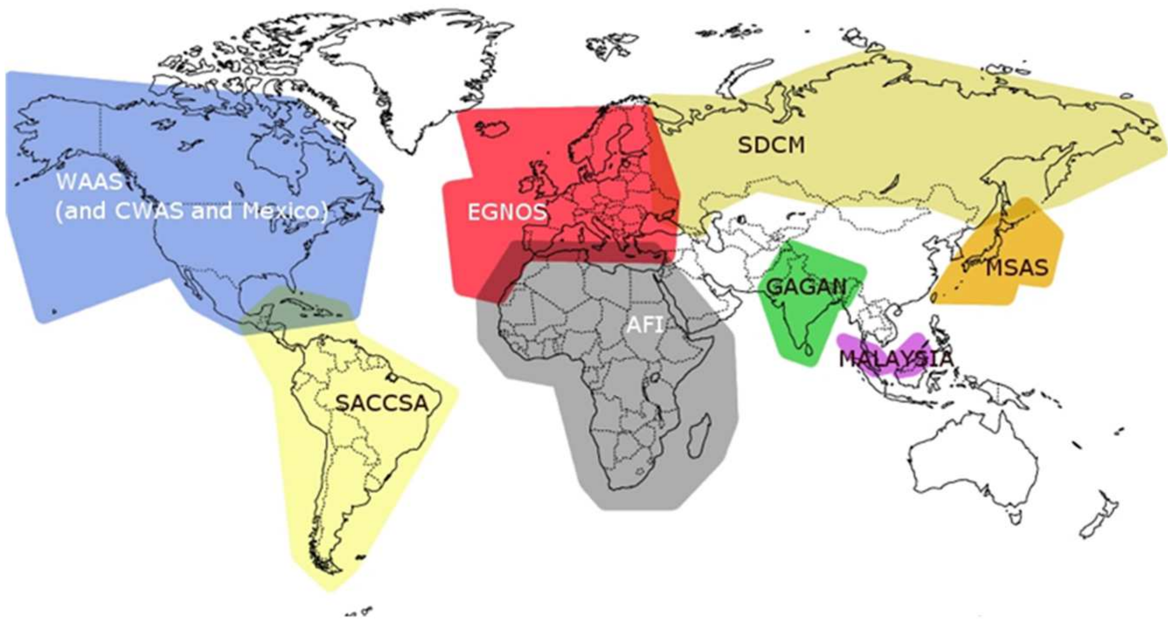
- Huge CME left the Sun at 3000 km/s
- Narrowly missed the Earth
- 1 week earlier, it would have hit Earth directly
- Much like the 1859 Carrington Event that
  - Hit Earth directly
  - Sparked northern lights as far south as Tahiti
  - Caused telegraph lines to spark setting fire to telegraph offices
  - A similar storm today could be catastrophic



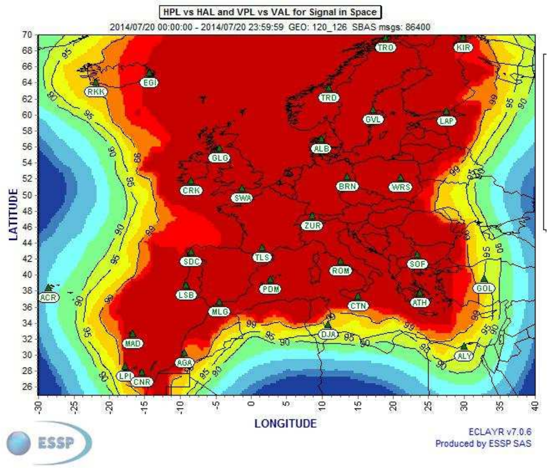
National Academy of Science has estimated that a Carrington event today would cause 2 trillion dollars of damage in North America alone – and it would take years to make the repairs. Why?

Much of our infrastructure and technology is dependent on satellite and space technology – GNSS, communication systems, aviation systems, the internet, and so much more…

Worldwide SBAS Systems



EGNOS – Typical Coverage



28 February 2014

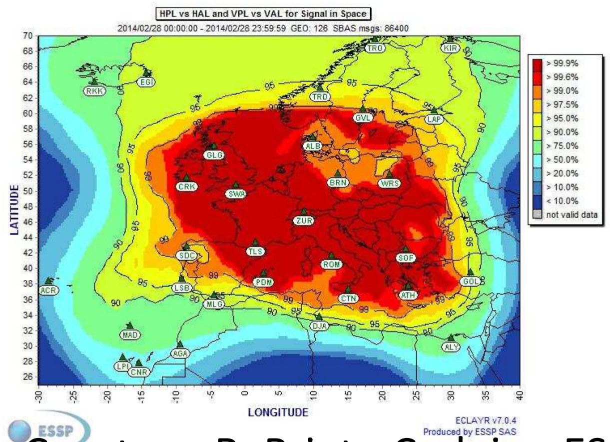


Figure Courtesy, R. Prieto Cedeira, ESA

Operational:

Certified for Precision Approach

WAAS (US), EGNOS (EU)

Limited for Non-Precision Approach

MSAS (Japan), GAGAN (India)

Under Development: SDCM, Beidou SBAS, SACCSA, others

Summary

- **Reviewed the Big 3**
  - Power grid damage, satellite damage, radiation exposure
- **Many GNSS applications affected by space weather**
- **Our focus today was on aviation augmentation systems**
  - SBAS & GBAS
  - Most significant threats are strong gradients (SEDs)
  - 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 is declining but space weather can happen at any time – more likely near the peak of the solar cycle.**

Thank you for your attention!

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Boston College thanks the Federal Aviation Administration for support under Cooperative Agreement FAA-11-G-006.