Space Weather Effects on the Wide Area Augmentation System

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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
The Wide Area Augmentation System (WAAS)

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

WAAS message provides:
• corrections for satellite orbits, time and the ionospheric
• estimates of the uncertainty of those corrections

• 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 Accuracy: ~1–3 m
Space Weather Effects on WAAS

Quiet Ionosphere

CONUS RANGE ERRORS ARE BETWEEN 1 and 5M

Disturbed Ionosphere

CONUS RANGE ERRORS ARE BETWEEN 1 and >35M

WAAS availability interrupted

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

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

July 1, 2003 – March 1, 2005

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% availability

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

www.nstb.tc.faa.gov/24Hr_Waaslpv.htm
www.nstb.tc.faa.gov/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 LPV200 Coverage Contours
06/01/13
Week 1742 Day 6

WAAS LPV200 Coverage Contours
02/27/14
Week 1781 Day 4

NOAA estimated Kp-index
Estimated Planetary K index (3 hour data) Begin: 2013 May 31 0000 UTC

Percent | CONUS | Alaska | Canada
--- | --- | --- | ---
95 | 83.53% | 0.00% | 44.71%
99 | 61.05% | 0.00% | 34.09%
99.9 | 59.45% | 0.00% | 22.58%
100 | 58.86% | 0.00% | 21.86%

Updated 2013 Jun 3 02:55:08 UTC
NOAA/SWPC Boulder, CO USA

NOAA estimated Kp-index
Estimated Planetary K index (3 hour data) Begin: 2014 Feb 26 0000 UTC

Percent | CONUS | Alaska | Canada
--- | --- | --- | ---
95 | 49.66% | 0.00% | 0.00%
98 | 43.45% | 0.00% | 0.00%
99 | 39.21% | 0.00% | 0.00%
99.9 | 33.12% | 0.00% | 0.00%
100 | 32.36% | 0.00% | 0.00%

Updated 2014 Mar 1 02:55:06 UTC
NOAA/SWPC Boulder, CO USA
WAAS – Coverage Contours vs % Availability

Disturbed conditions of Solar Cycle 24)
Summary - SC 24 Space Weather Effects in CONUS

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

10/1/12
06/1/13
02/27/14
04/12/14
03/17/15
Summary - SC 24 Space Weather Effects in Alaska

Alaska Coverage at 99% Availability

[Graph showing % Coverage with dates 10/1/12, 06/1/13, 04/12/14, 02/27/14, 03/17/15]
Summary - SC 24 Space Weather Effects in Canada

Canada Coverage at 99% Availability

[Graph showing coverage percentage from 01/01/2013 to 01/01/2015 with specific dates marked: 06/1/13, 02/27/14, 04/12/14, 03/17/15]
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 and 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

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
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: Increase International Cooperation
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

**EGNOS – Typical Coverage**

![EGNOS Coverage Map](image)

*Figure Courtesy, R. Prieto Cedeira, ESA*

*Availability as a function of user location*

- `<50%`
- `>50%`
- `>75%`
- `>85%`
- `>90%`
- `>95%`
- `>99%`
- `>99.5%`
- `>99.9%`

*Availability with VAL = 50, HAL = 40, Coverage(99%) = 14.42%*

*Figure Courtesy, T. Walter, Stanford*
Thank you for your attention!

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