



ATMOSPHERIC & SPACE TECHNOLOGY RESEARCH ASSOCIATES

SCIENCE + TECHNOLOGY + APPLICATIONS // *Bringing it all together*

Space Weather: Severe Geomagnetic Storm ReCap

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USA

19th Cross Polar Working Group

JCAB, Tokyo

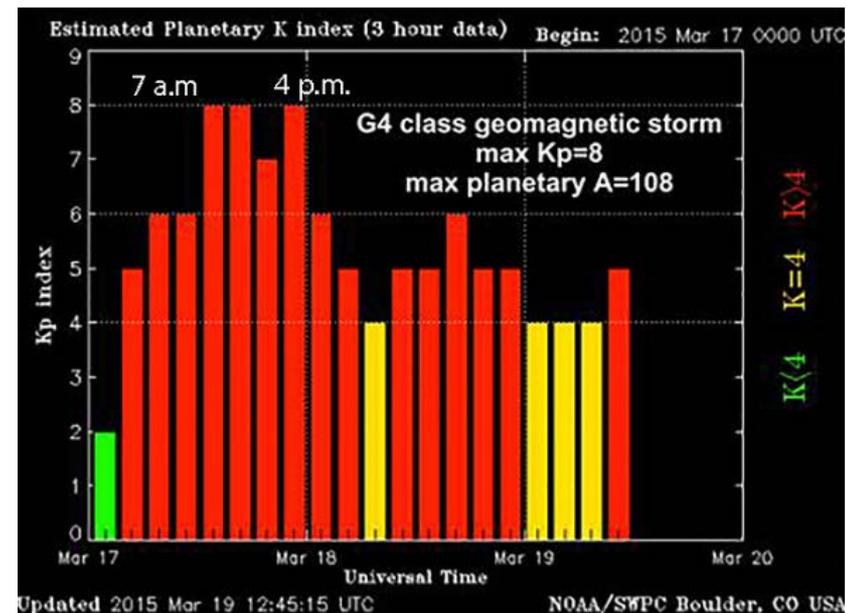
May 11-15, 2015

Highlights in 2015

- G4 (Severe) Geomagnetic Storm March 17
 - G4 events rare, included impacts to
 - WAAS
 - Power Grid
 - HF Communications
- Occasional smaller storms occurred; the Sun is setting up for more repeatable geomagnetic storms this point of the cycle.
- Cycle 24 continues to weaken.

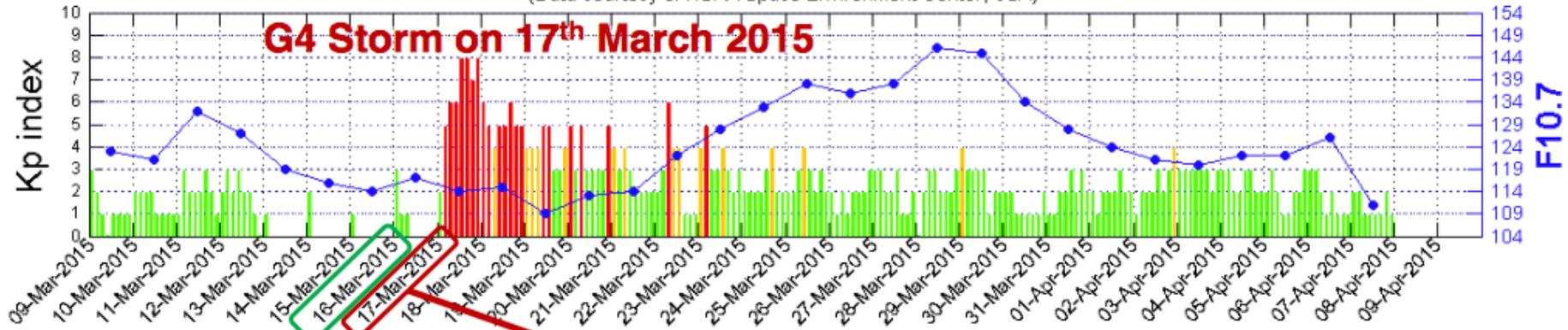
March 17 Geomagnetic Storm

- Spawned by 2 CMEs on March 15
- Reached G4 – much higher than the predicted G1
- Lingered thru March 20

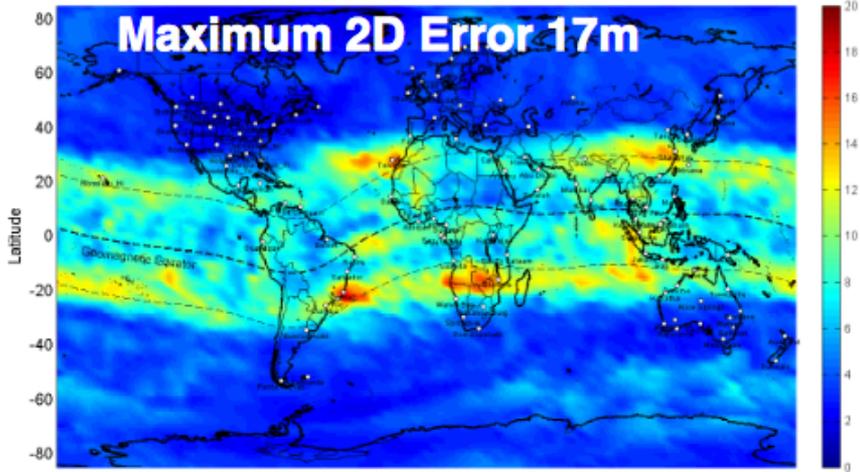


GPS Error Footprint Increase

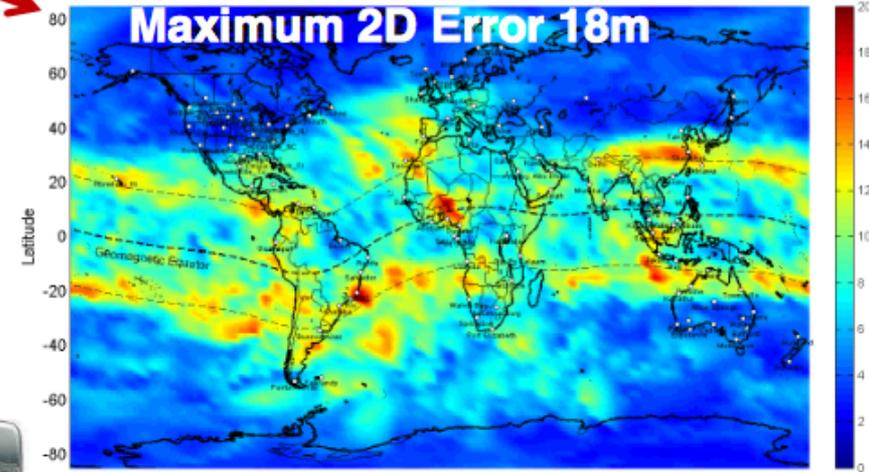
3-hourly Planetary Kp index, $K_p < 4$, $K_p = 4$, $K_p > 4$
 (Data courtesy of NOAA Space Environment Center, USA)



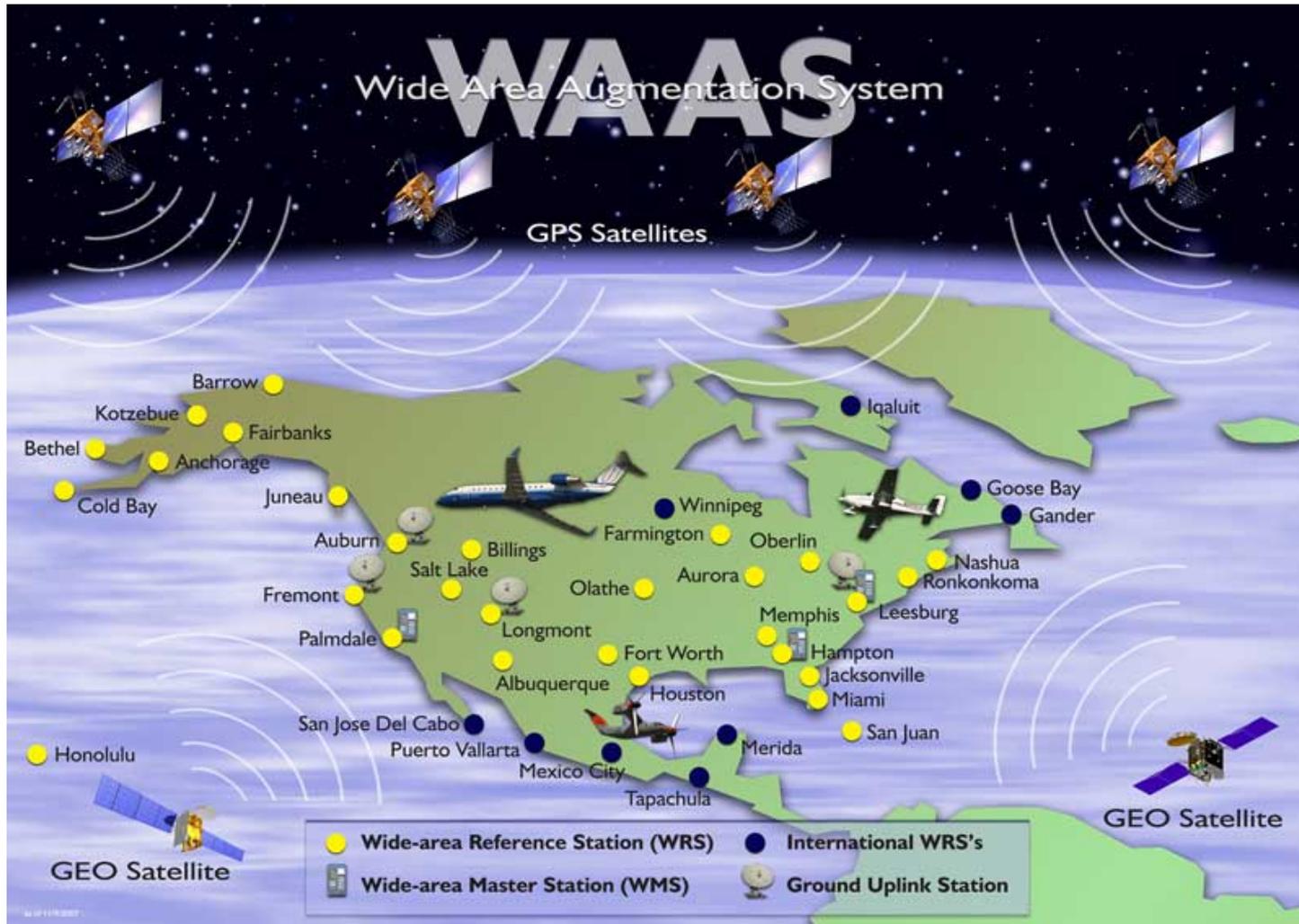
Max horizontal error for L1 GPS users on 16-Mar-2015 [m]
 Using Klobuchar model error (discrepancy between slant ionospheric delays computed by IGM and Klobuchar model)
 Global Ionospheric Map (IGM) provided by International GNSS Service (IGS)



Max horizontal error for L1 GPS users on 17-Mar-2015 [m]
 Using Klobuchar model error (discrepancy between slant ionospheric delays computed by IGM and Klobuchar model)
 Global Ionospheric Map (IGM) provided by International GNSS Service (IGS)



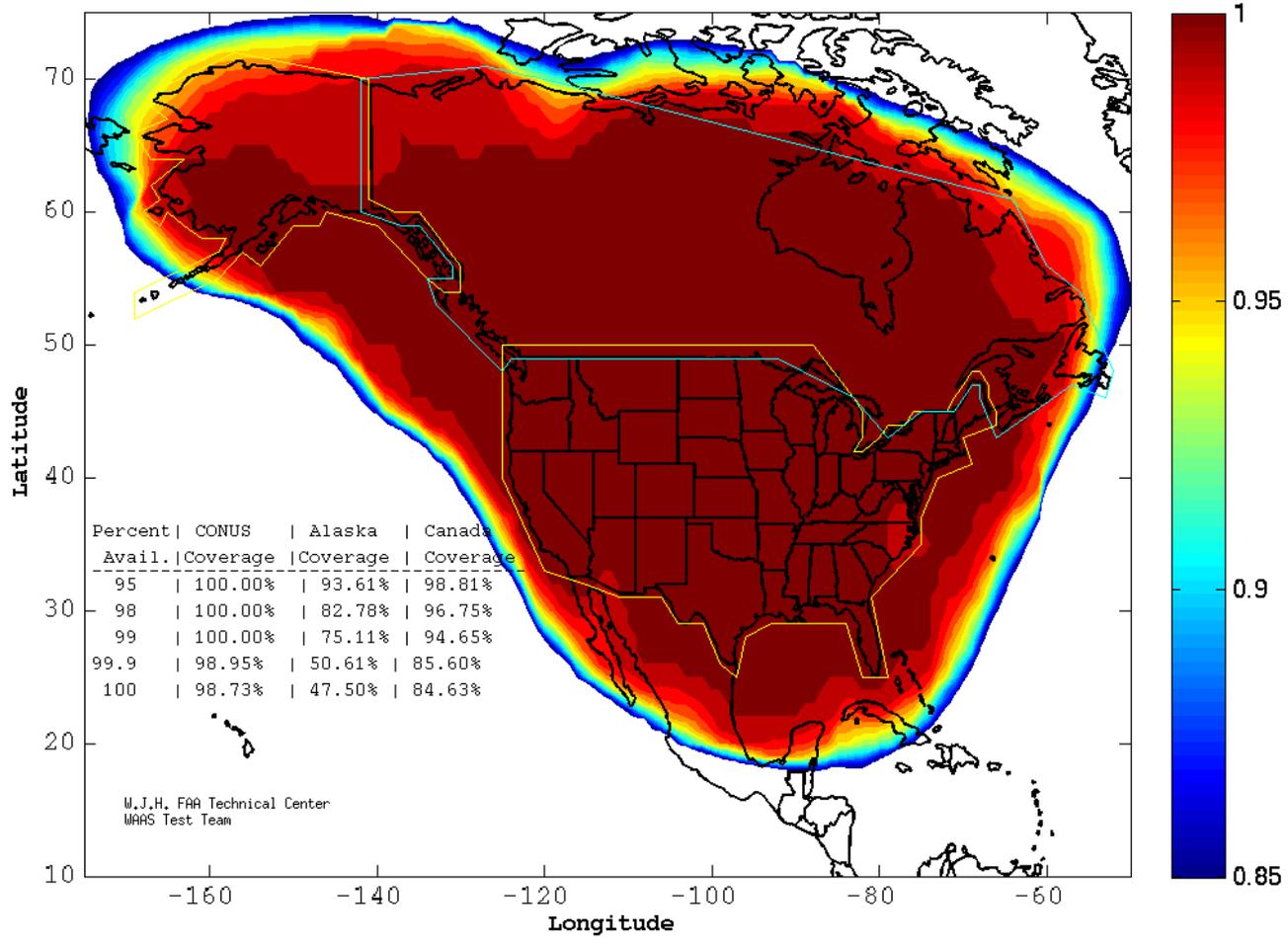
SBAS (WAAS) Infrastructure



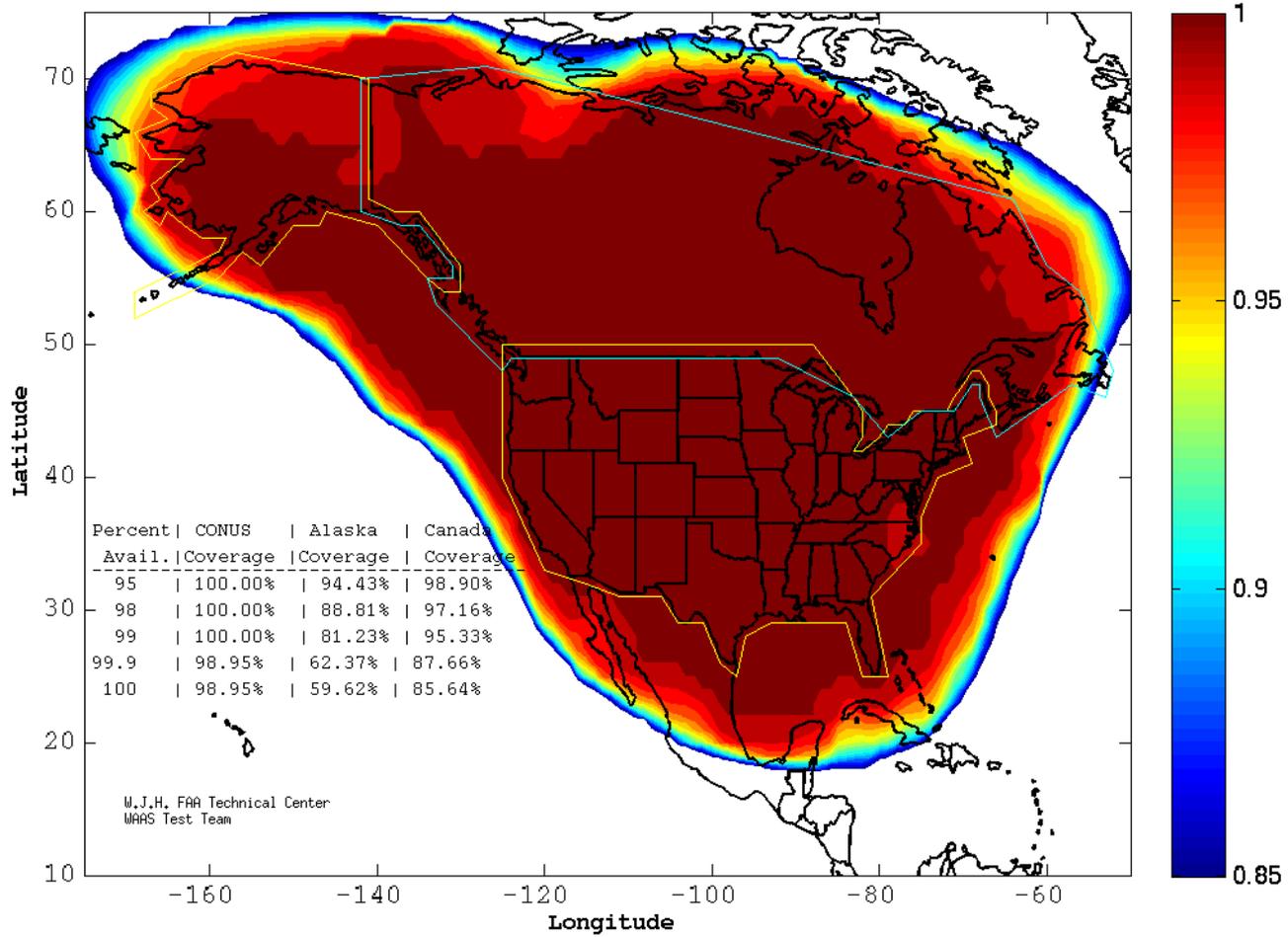
2015 St. Patrick's Day Storm Impact on WAAS



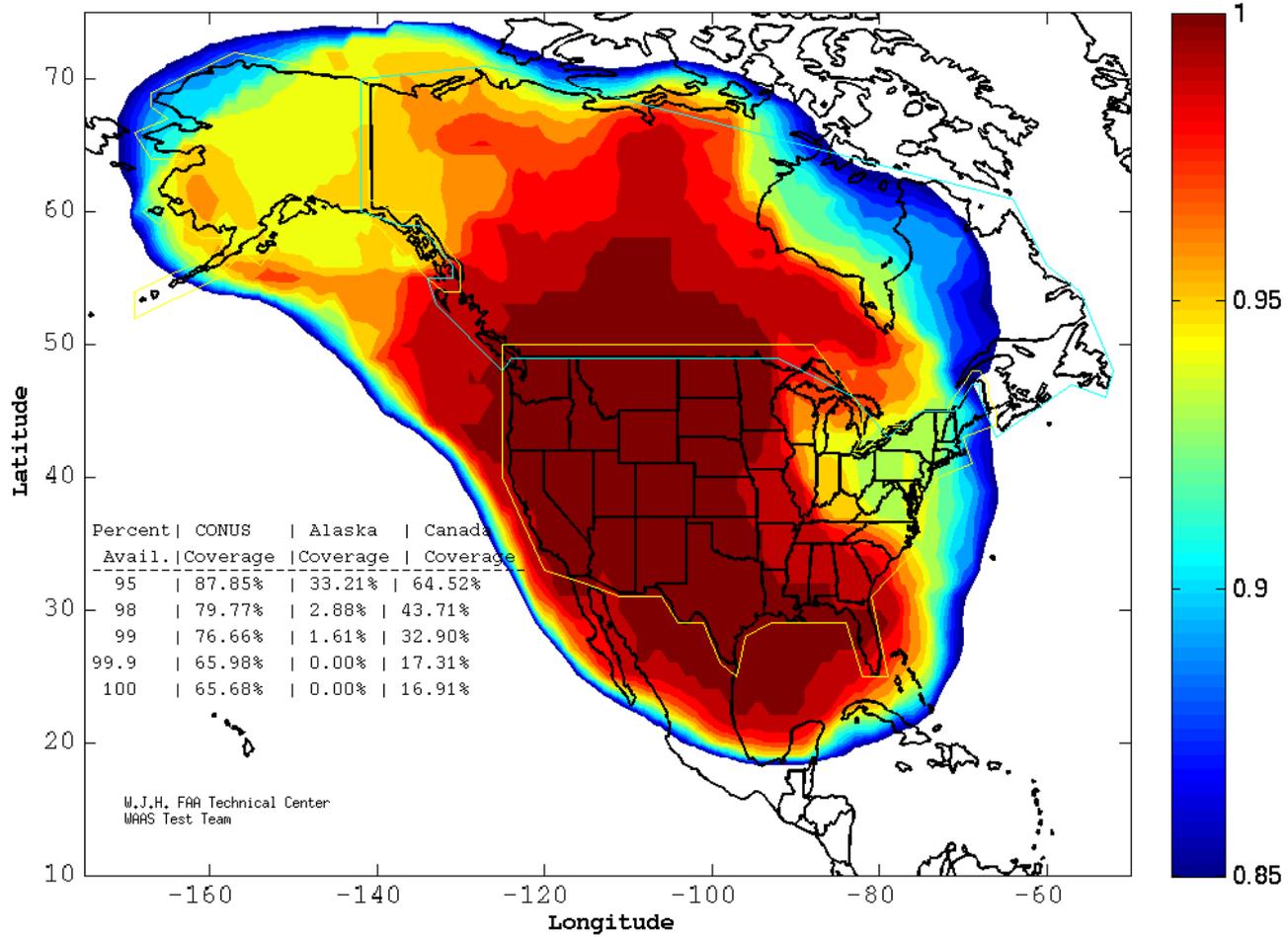
WAAS LPV200 Coverage Contours
 03/15/15
 Week 1836 Day 0



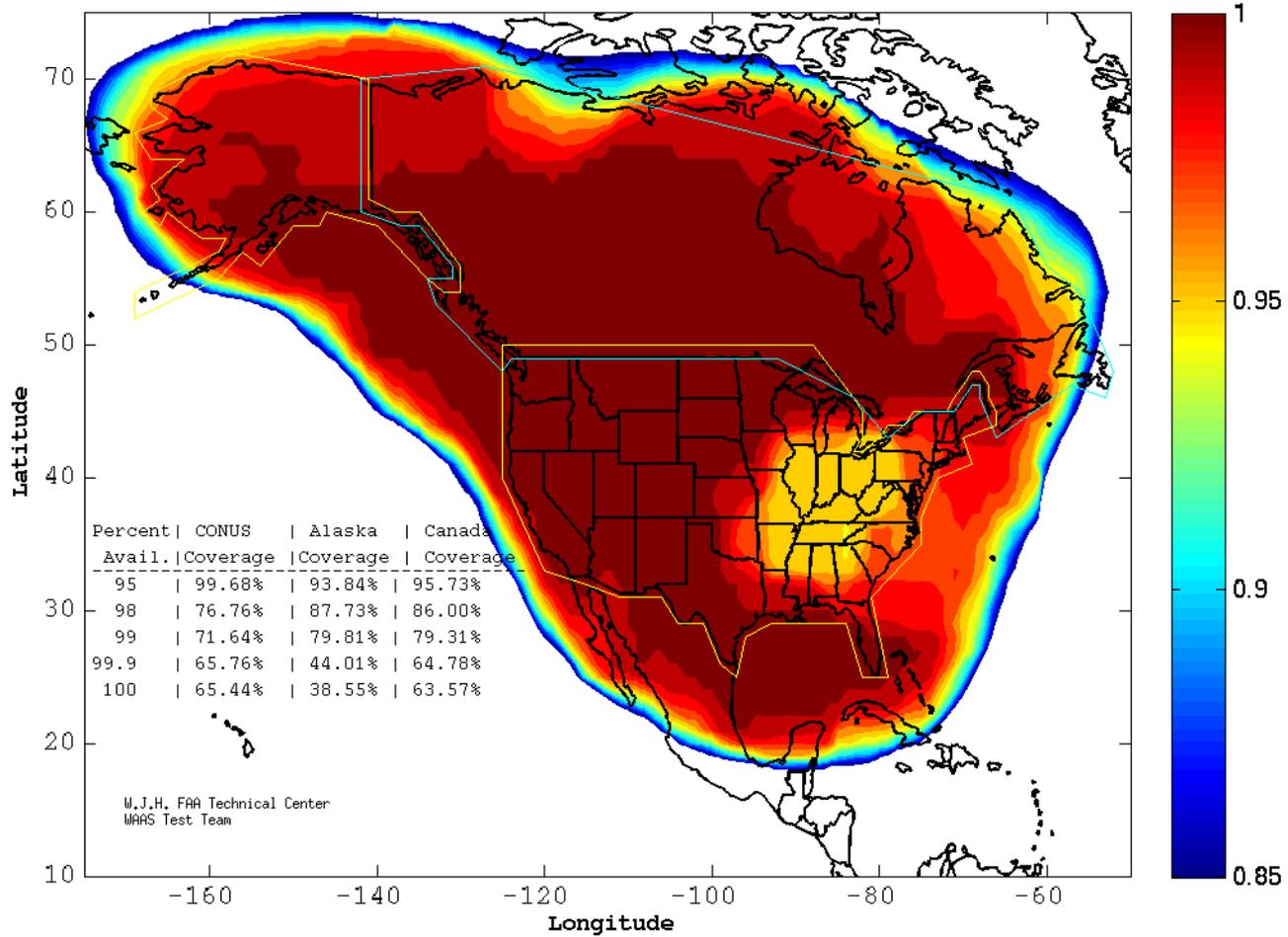
WAAS LPV200 Coverage Contours
 03/16/15
 Week 1836 Day 1



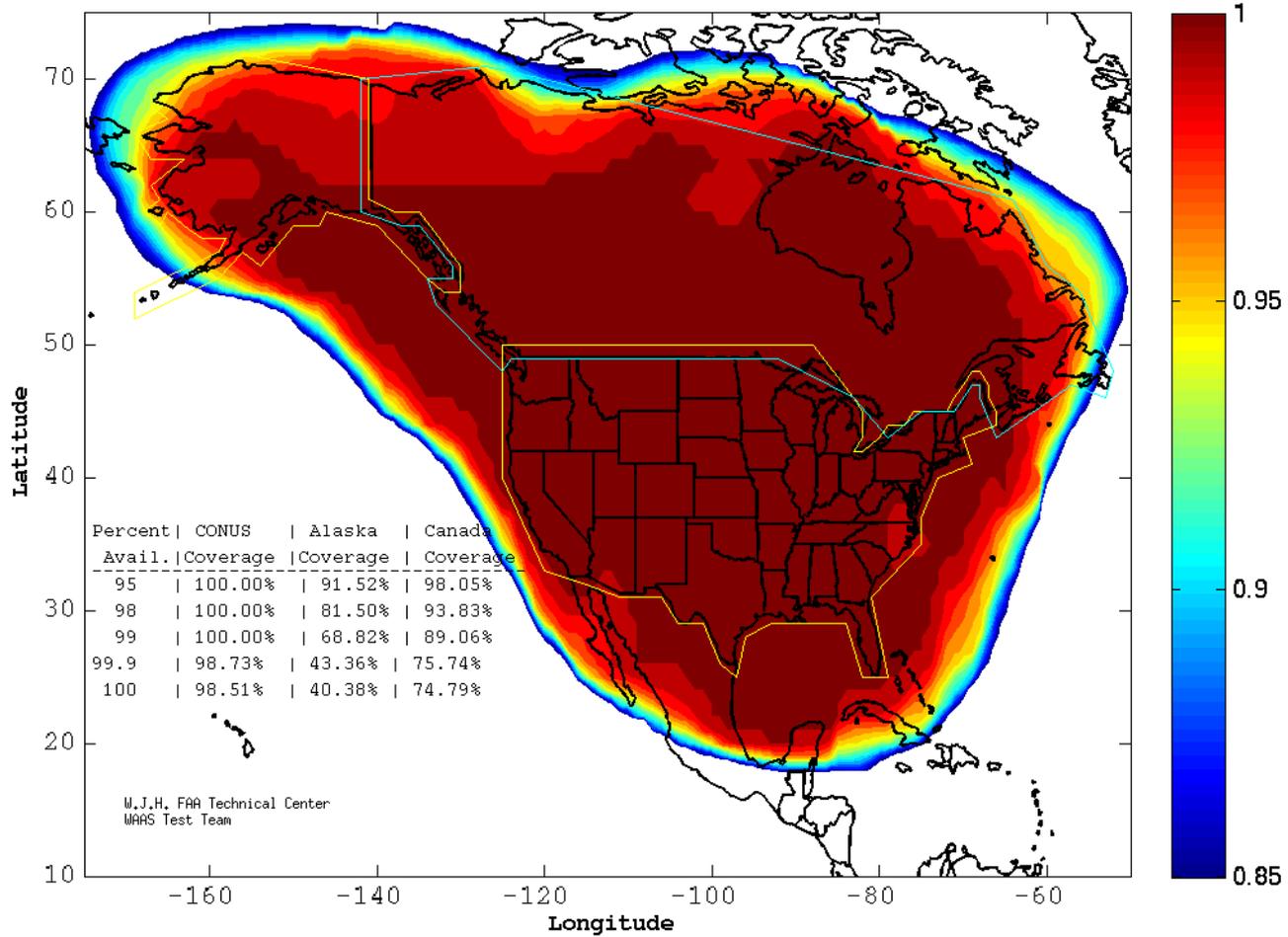
WAAS LPV200 Coverage Contours
 03/17/15
 Week 1836 Day 2



WAAS LPV200 Coverage Contours
 03/18/15
 Week 1836 Day 3

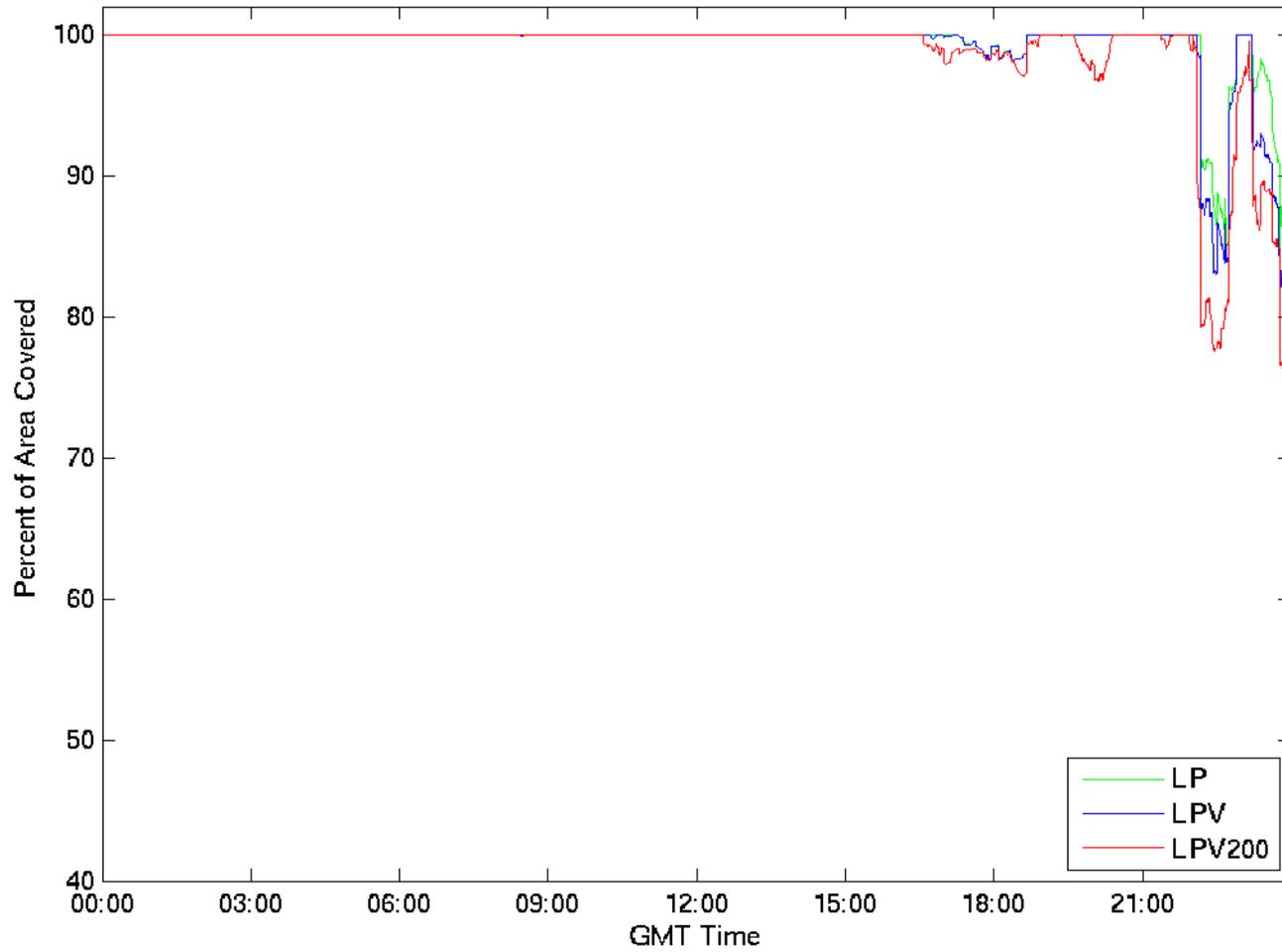


WAAS LPV200 Coverage Contours
 03/19/15
 Week 1836 Day 4



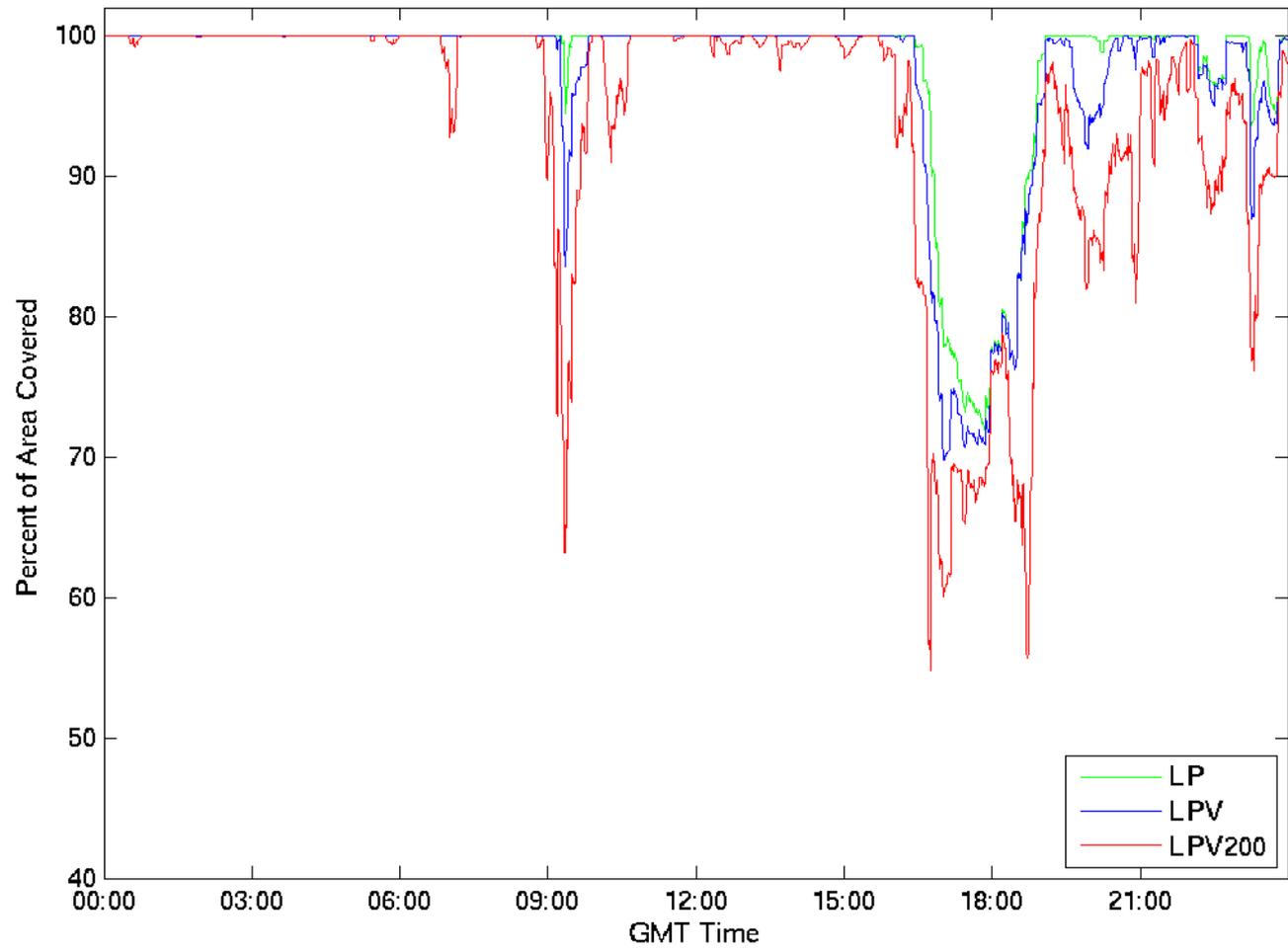
Week 1836 Day 2

Conus
Area Covered vs Time



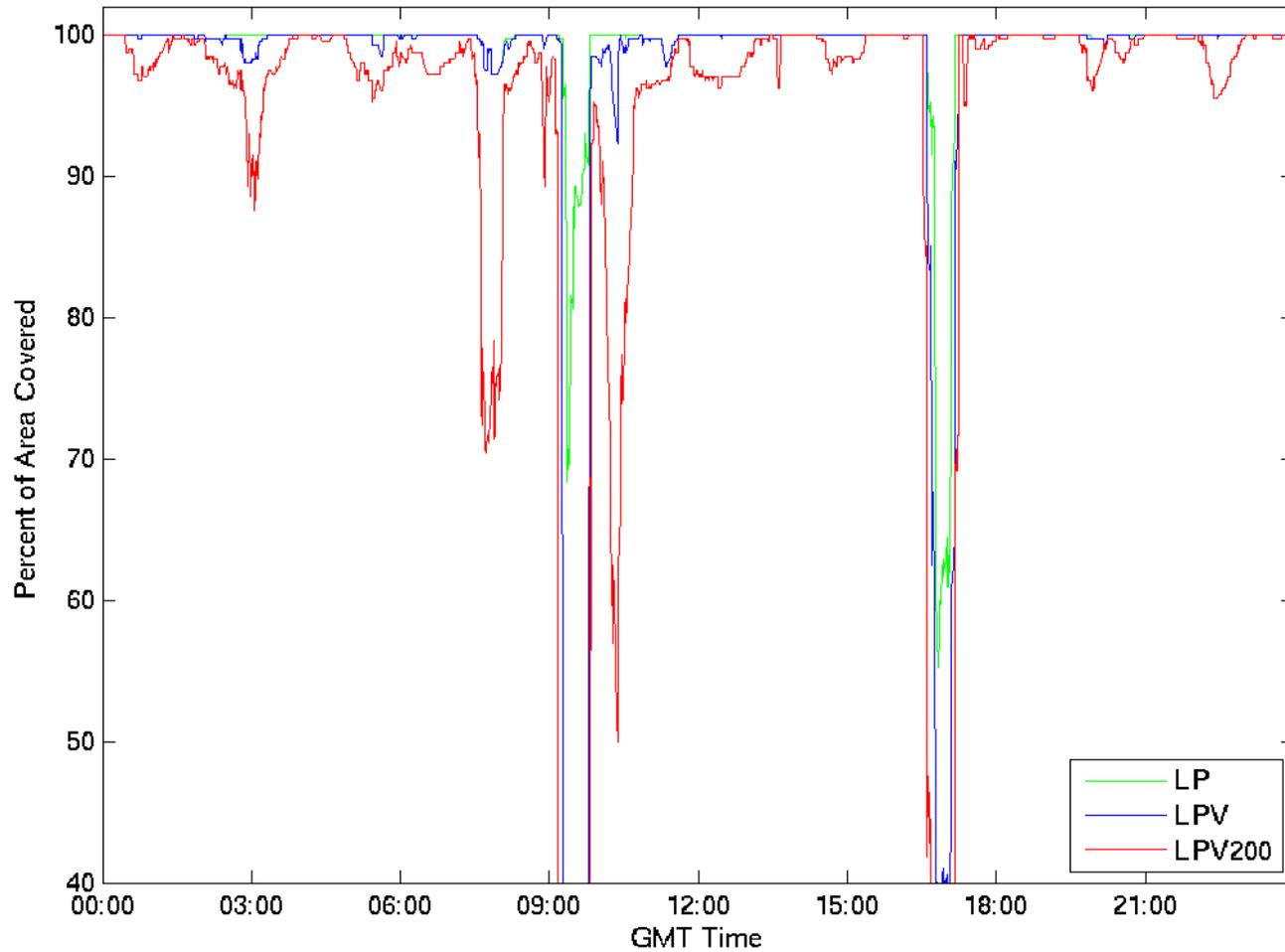
Week 1836 Day 2

Canada
Area Covered vs Time

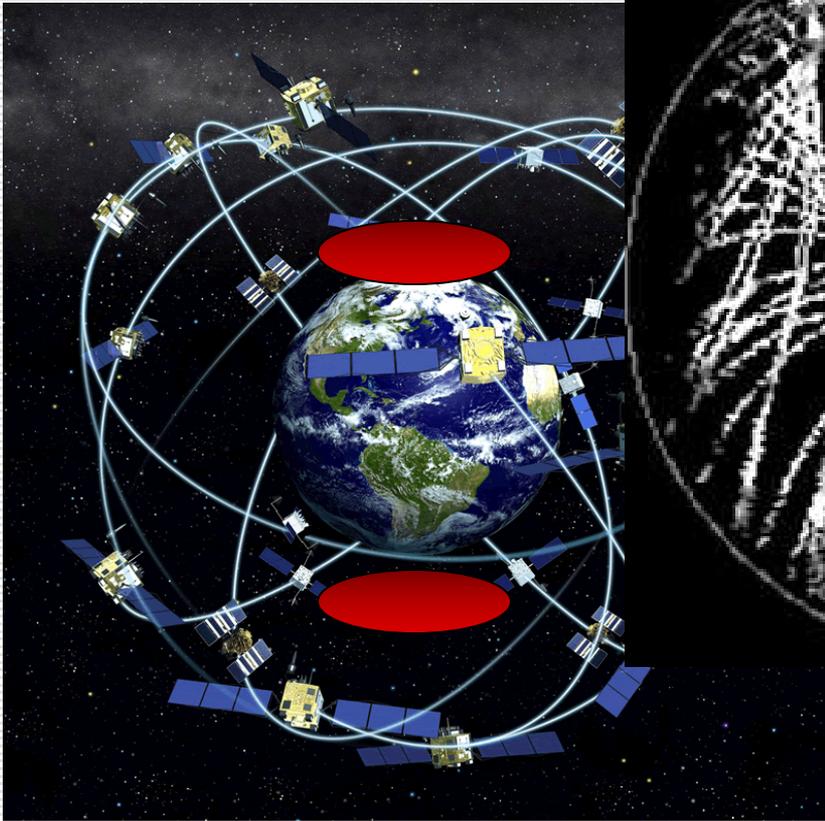


Week 1836 Day 2

Alaska
Area Covered vs Time



GPS: Consequences of a 55° Inclination

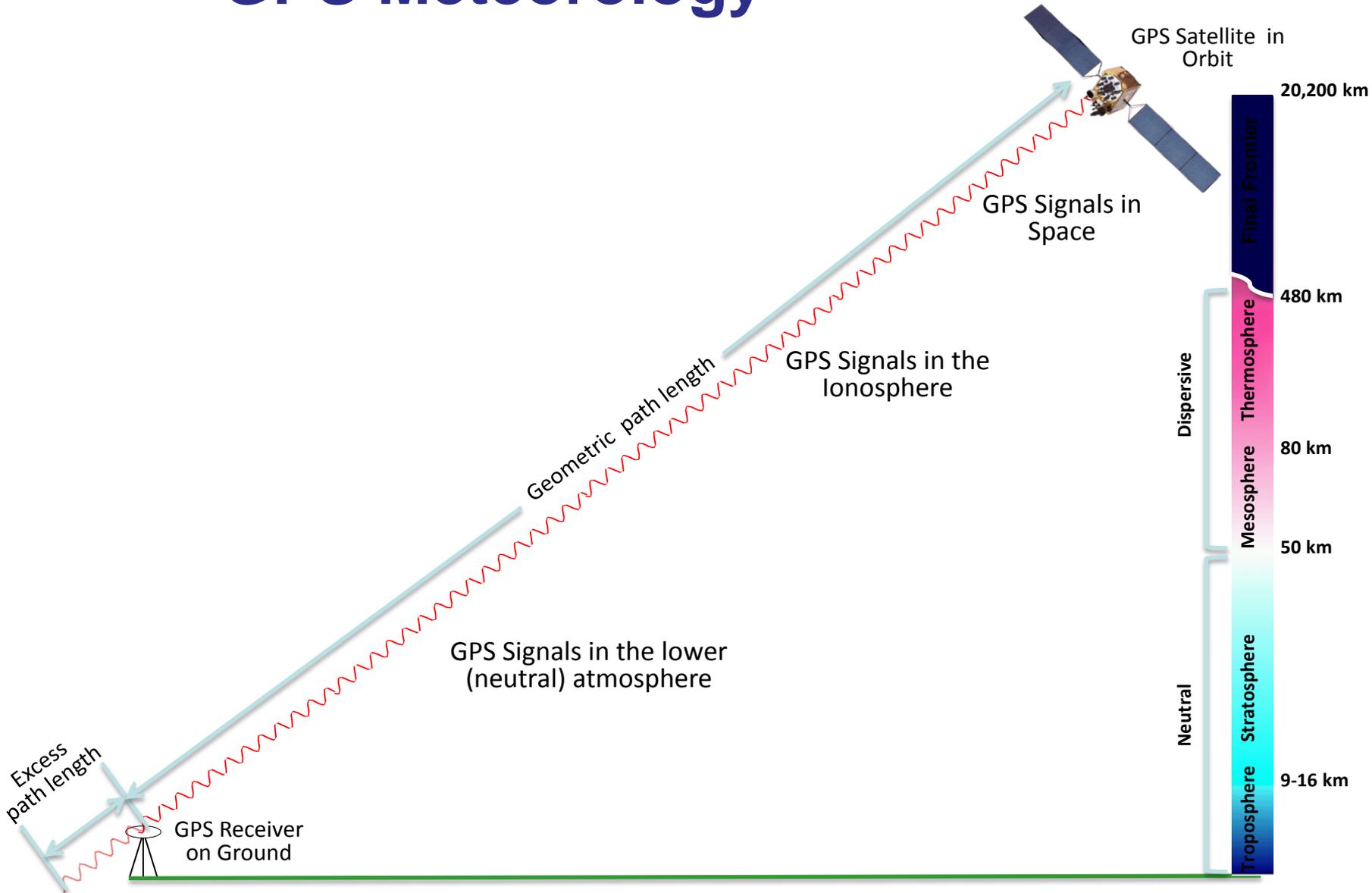


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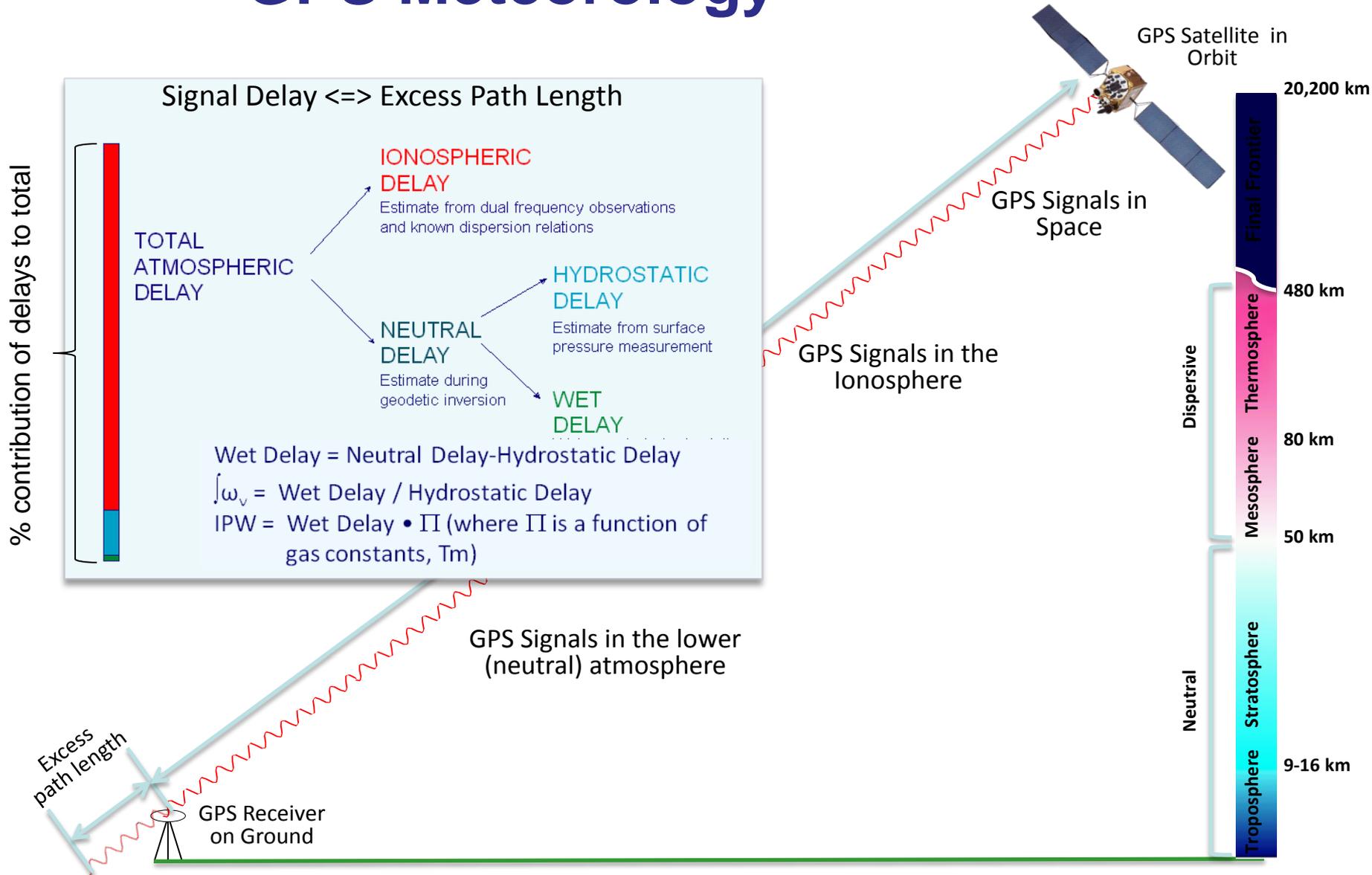
ionosphere



GPS Meteorology



GPS Meteorology



ASTRA: Overview

❖ Science

❖ Technology

❖ Applications

Bringing It All Together



Modeling

Physics-Based Modeling
(TIMEGCM)

Real-Time Specification of Ionosphere/Thermosphere

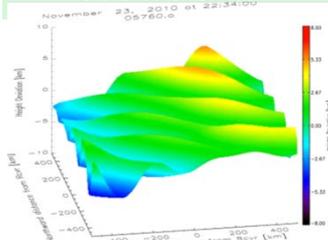
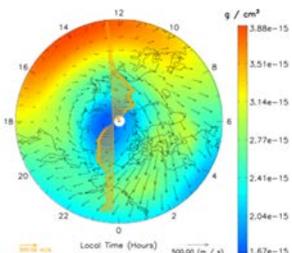
Data Assimilation

High-latitude Electroynamics (AMIE)

Global Ionosphere (IDA4D)

Thermospheric Neutral Density (ADAM)

Satellite Drag & Ballistic Coefficients



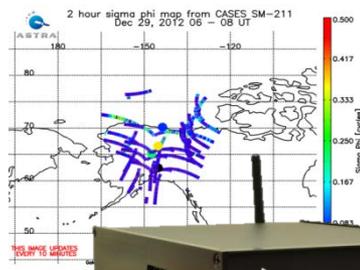
Data Services

Space Based Data

Ground Based Data

Forensic Space Weather Analysis

Space weather Phone Apps



Ground-based Instrument Development

GPS-based Space Weather Monitor

Low Power Ionospheric Sounder

HF TID Mapper

Laser Bathymetry

Lidar Systems



Space Systems

CubeSat Missions

NSF DICE Cubesat

SMC SENSE

AF DIME Cubesat

Plug-N-Play Avionics

CubeSat Instruments

Scanning UV Photometer

E-field Double Probe

Topside Sounder

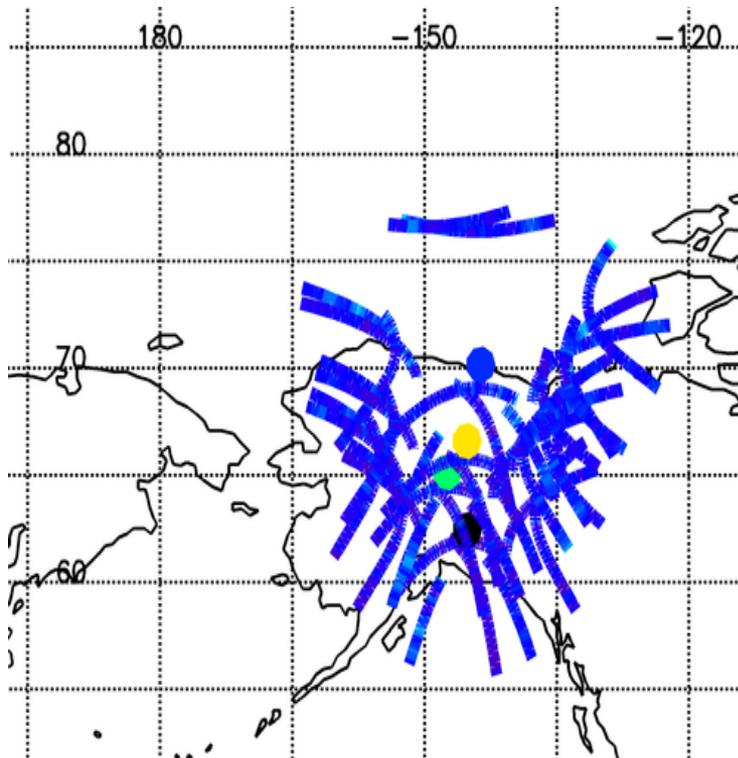
Wind Profiler

GPS-based Space Weather Monitor

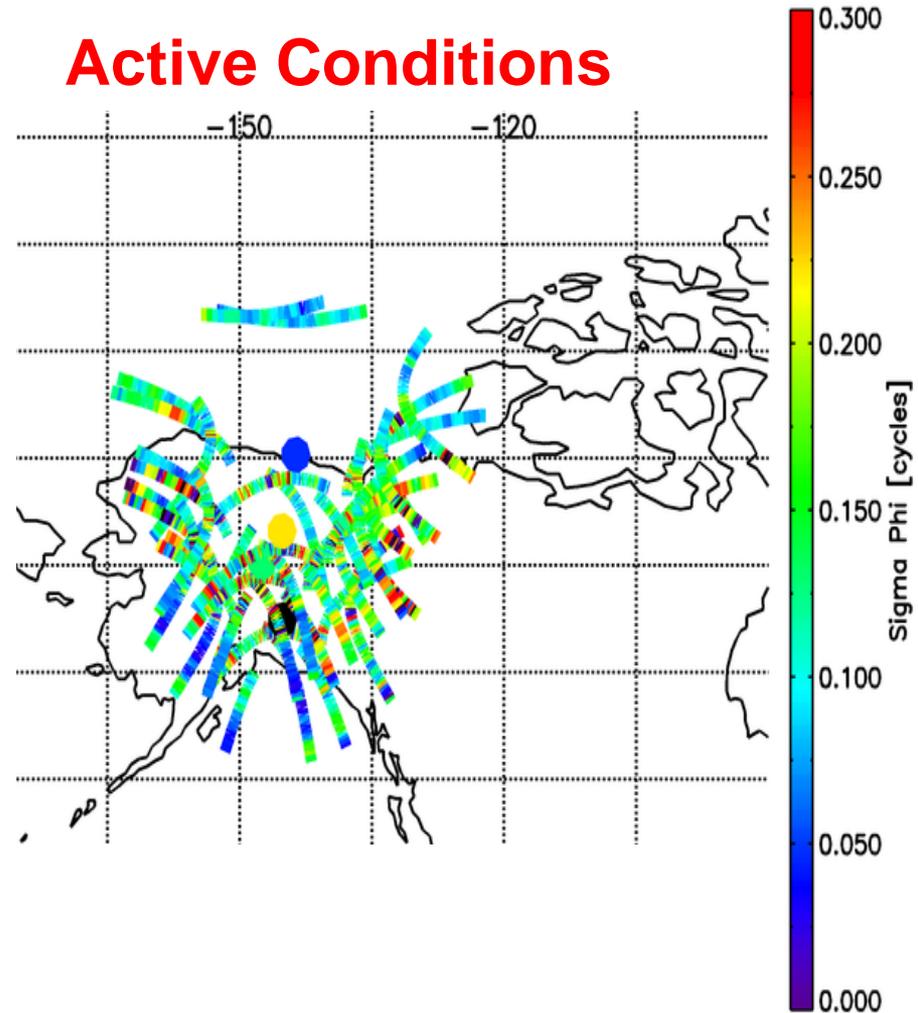
Satellite Aerodynamics

<http://www.youtube.com/4spaceweather>

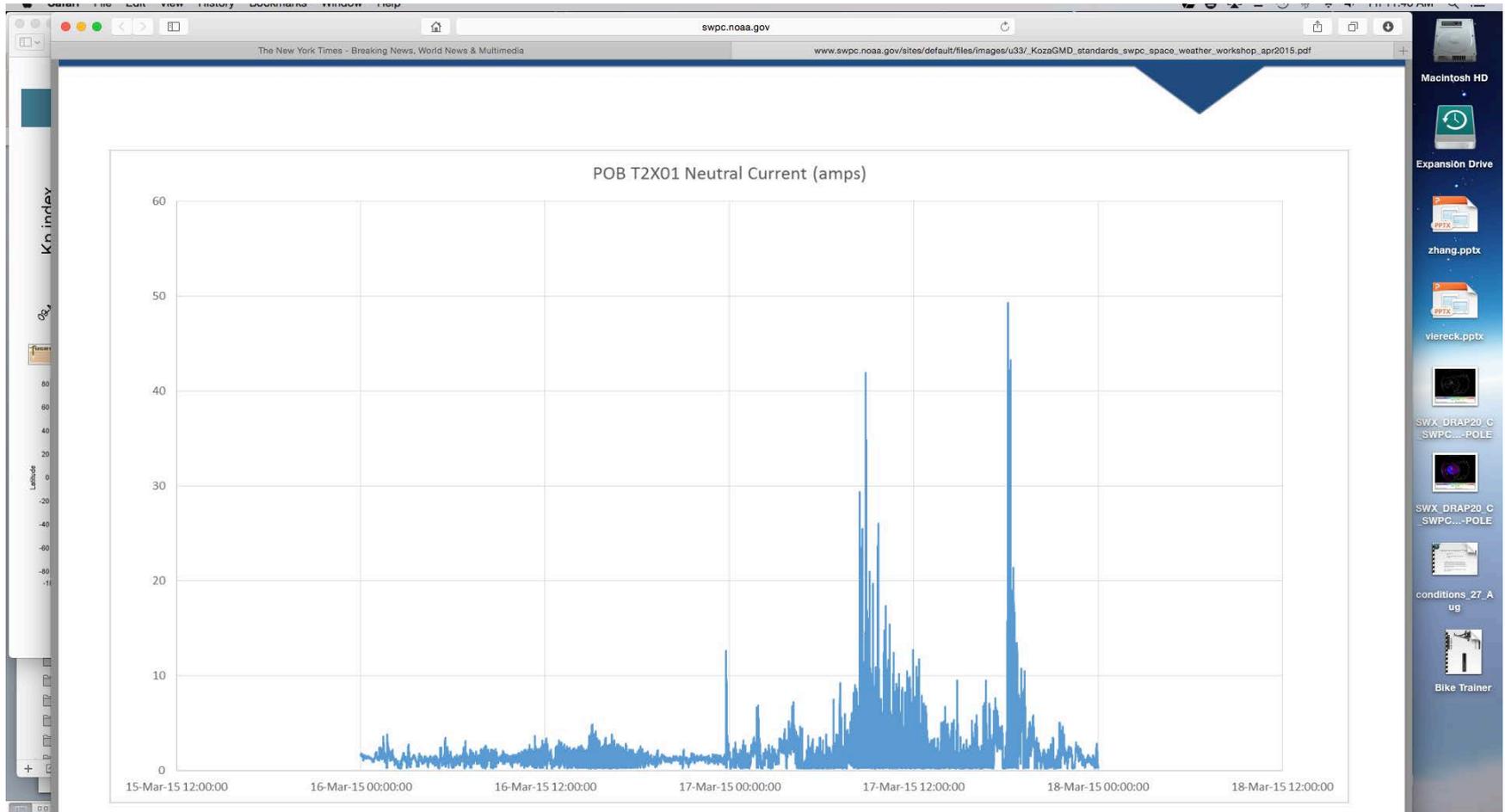
Quiet Conditions



Active Conditions



Power Grid – Induced Current



HF Communications

- Significant impacts reported, as far south as Oregon in the US

Effects of Solar Activity on HF Radio

When sunspot 2297 began tracking across the surface of the Sun, Operations was briefed during the NYC morning meetings.

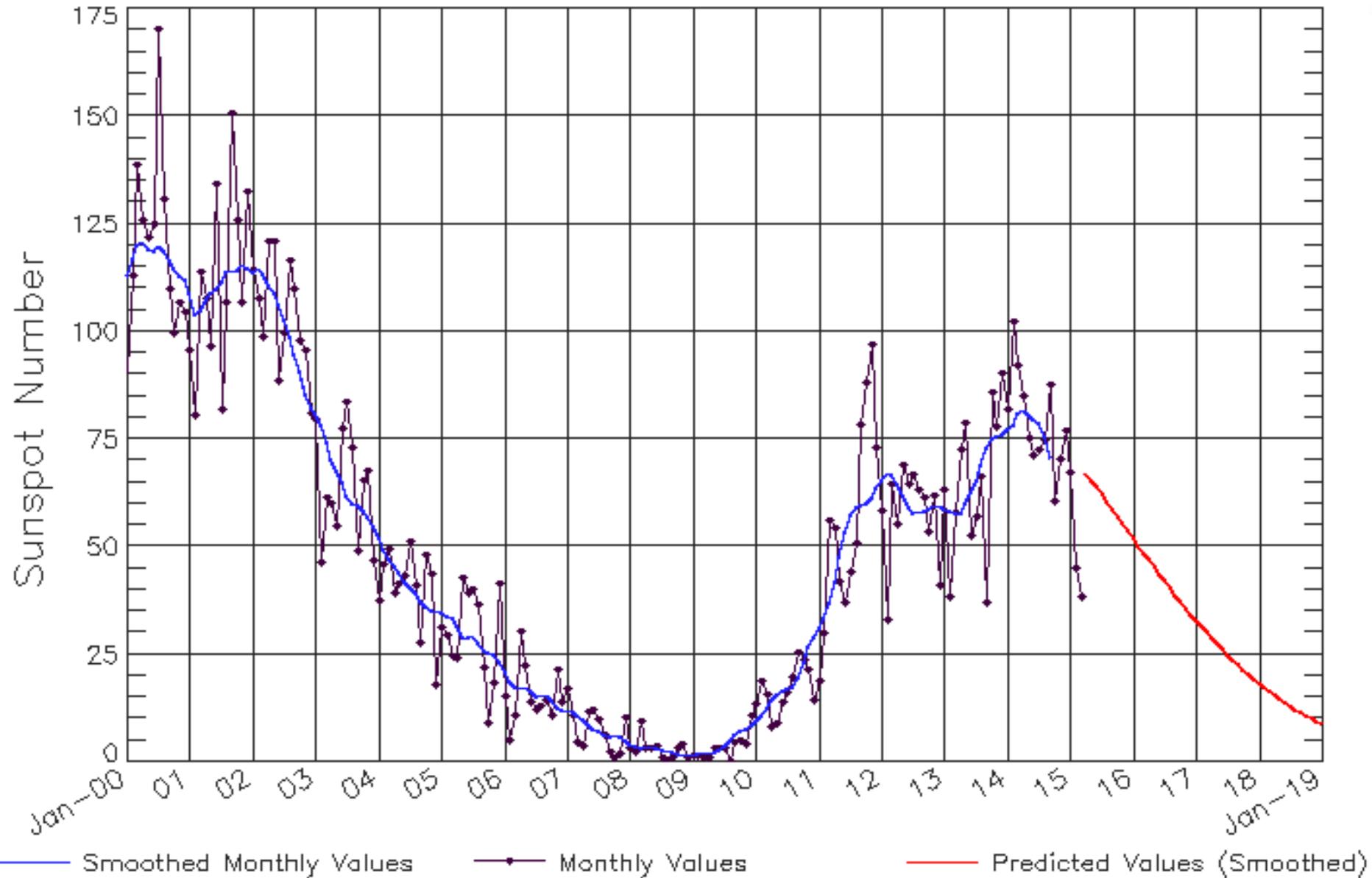
The eruption on March 9th at 2353Z, (X-Ray flux exceeding M5 – NOAA scale R2- Moderate) over the Pacific that marginal impact to HF Comms at the SFO Comm Center from approximately 2353Z – 0045Z.



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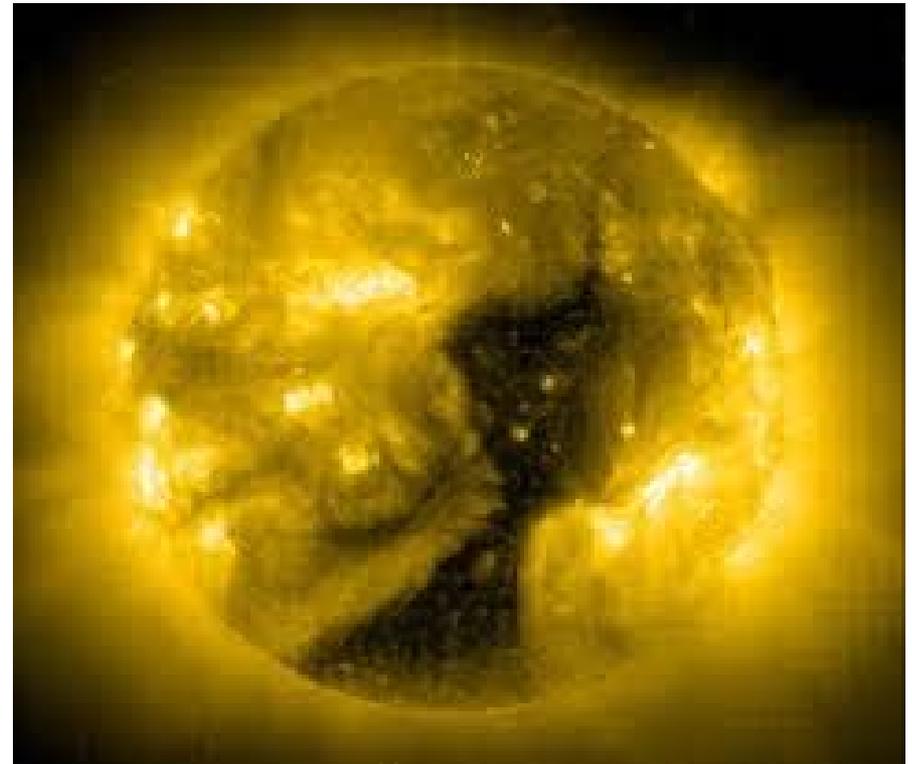
ISES Solar Cycle Sunspot Number Progression

Observed data through Mar 2015



Coronal Holes

- Long-lived structures, allow fast solar wind to stream out
- Recur on a 27-day period
- Fast solar wind causes G1-G2 (minor to moderate) storming



Summary

- Severe Geomagnetic Storm March 17
- Navigation, electric power, and communications performance all affected
- Solar conditions now occurring enabling improved prediction of geomagnetic storms
- Polar operations can benefit from tailored services from ASTRA