



ATMOSPHERIC & SPACE TECHNOLOGY RESEARCH ASSOCIATES

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

# ***Space Weather: Severe Geomagnetic Storm ReCap***

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**ASTRA**  
**Boulder, Colorado**  
**USA**

*19<sup>th</sup> Cross Polar Working Group*  
*JCAB, Tokyo*  
*May 11-15, 2015*

## ***Highlights in 2015***

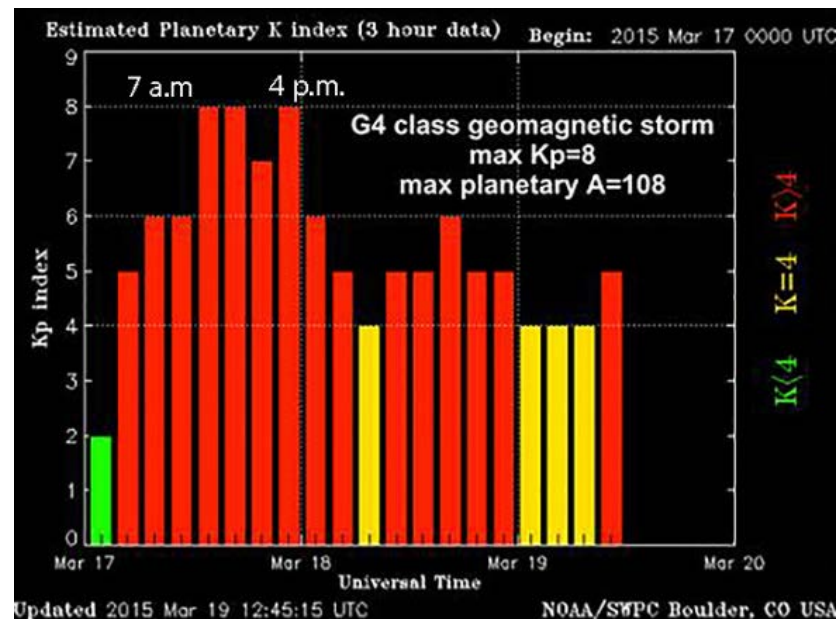
- G4 (Severe) Geomagnetic Storm March 17
  - G4 events rare, included impacts to
    - WAAS
    - Power Grid
    - HF Communications
- Occasional smaller storms occurred; the Sun is setting up for more repeatable geomagnetic storms this point of the cycle.
- Cycle 24 continues to weaken.

# March 17 Geomagnetic Storm

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

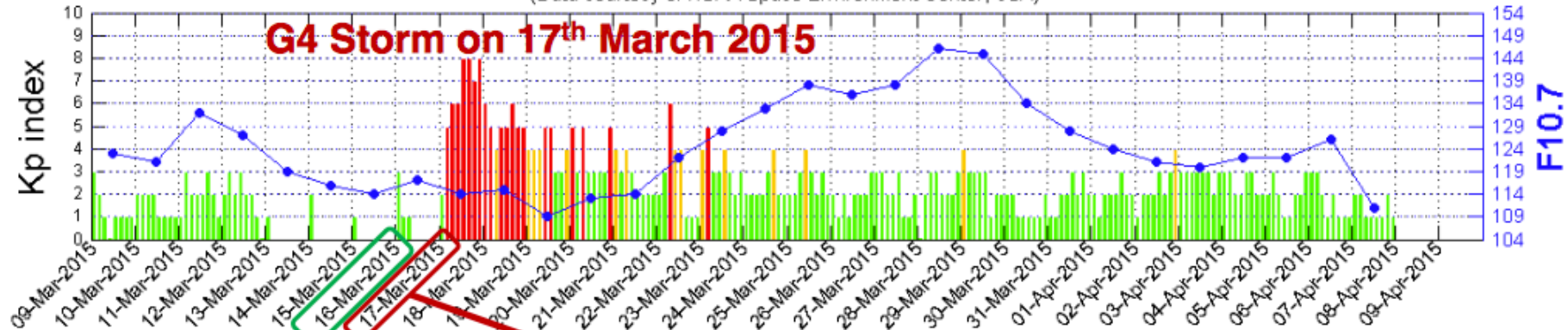
St. Patrick's Day  
Storm of 2015

Image by Ronn and Marketa Murray



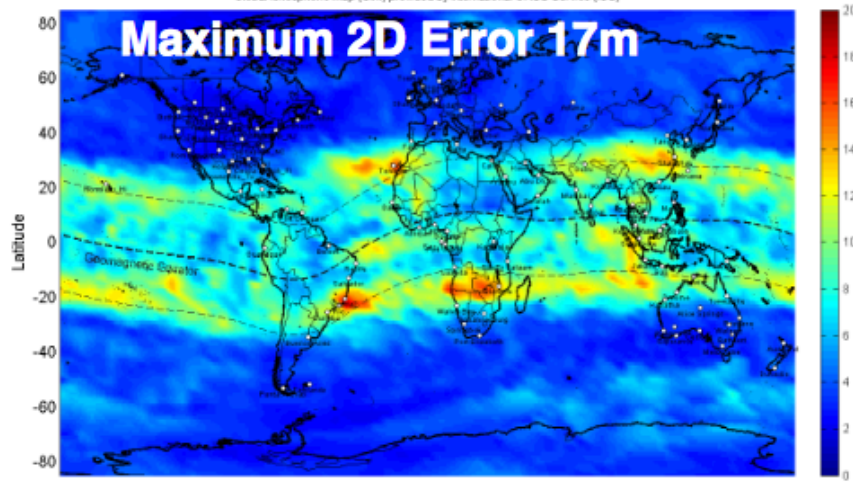
# GPS Error Footprint Increase

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



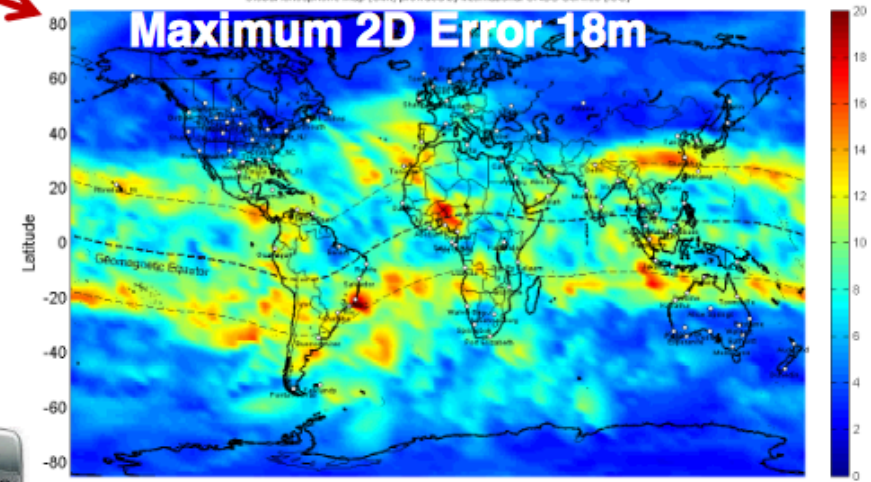
Max horizontal error for L1 GPS users on 16-Mar-2015 [m]

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)



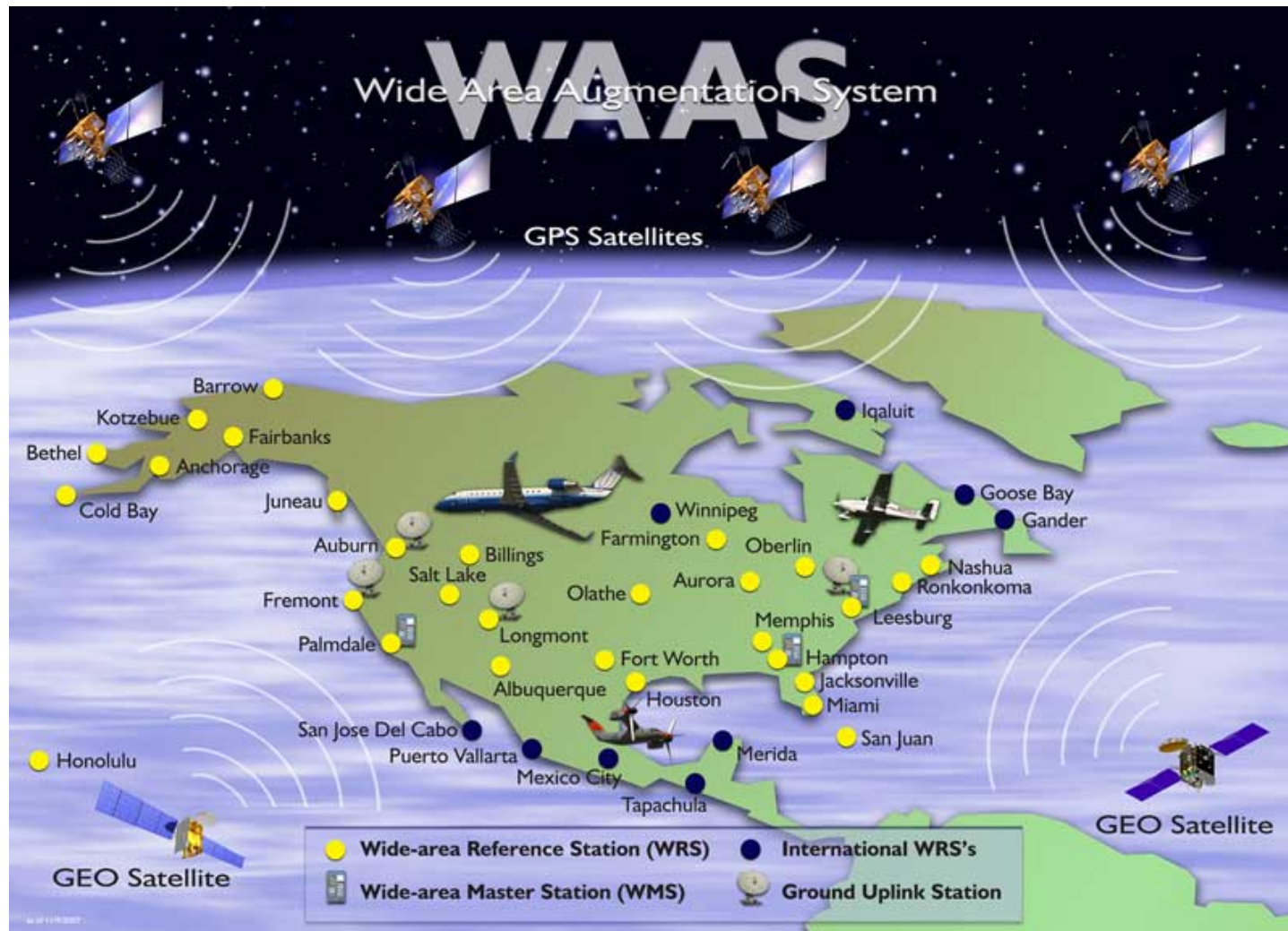
Max horizontal error for L1 GPS users on 17-Mar-2015 [m]

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

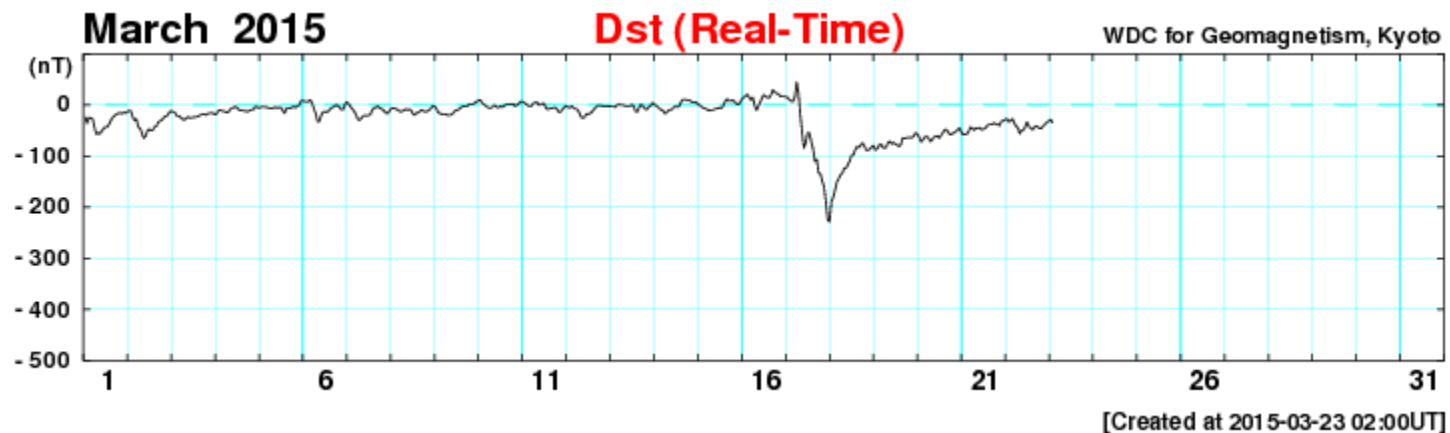


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**ERIC GAKSTATTER**  
**PRESENTATION**

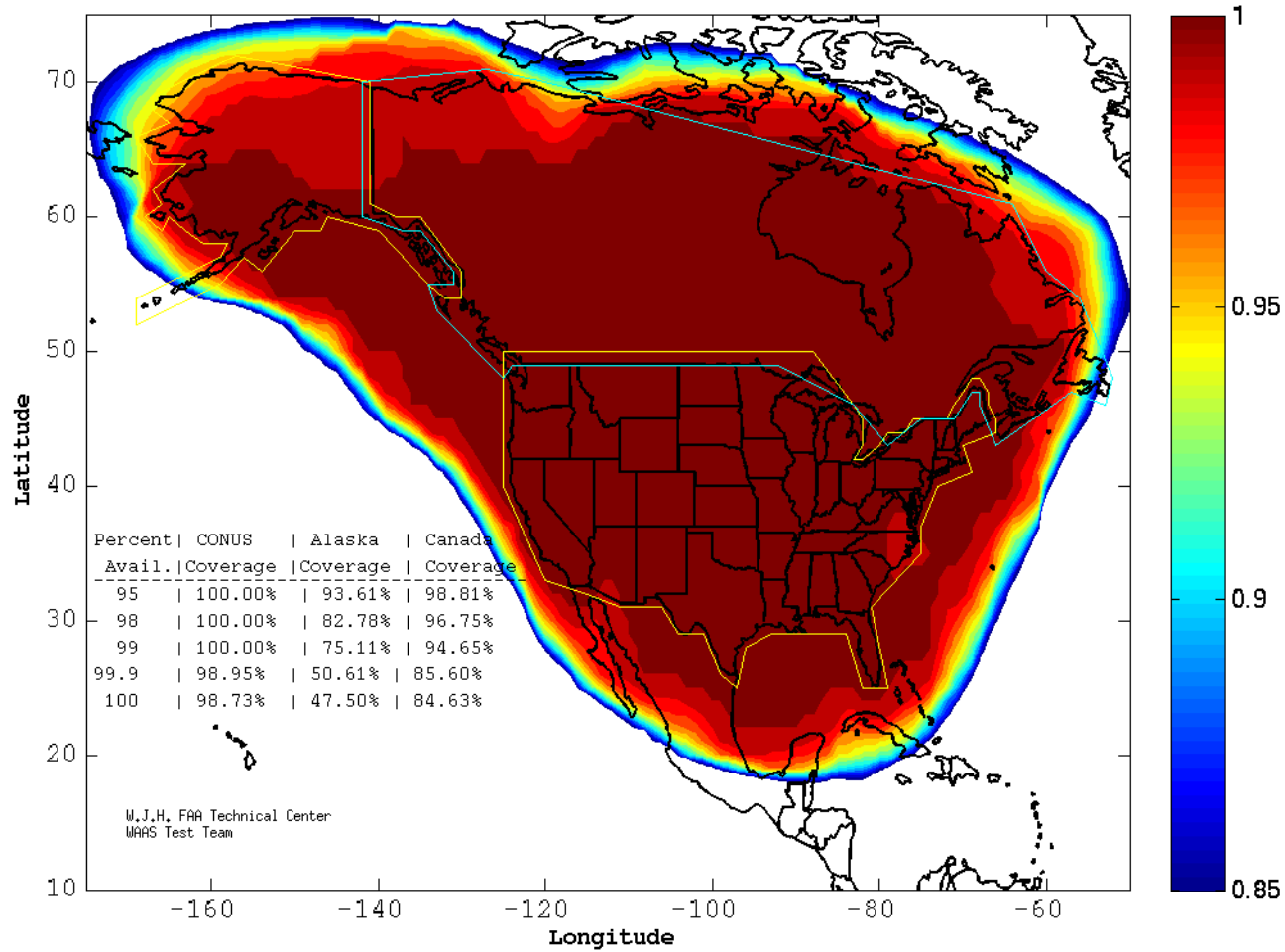
brought to you by **GPS World** Geospatial solutions

# 2015 St. Patrick's Day Storm Impact on WAAS



Credit: Mia Stålnacke

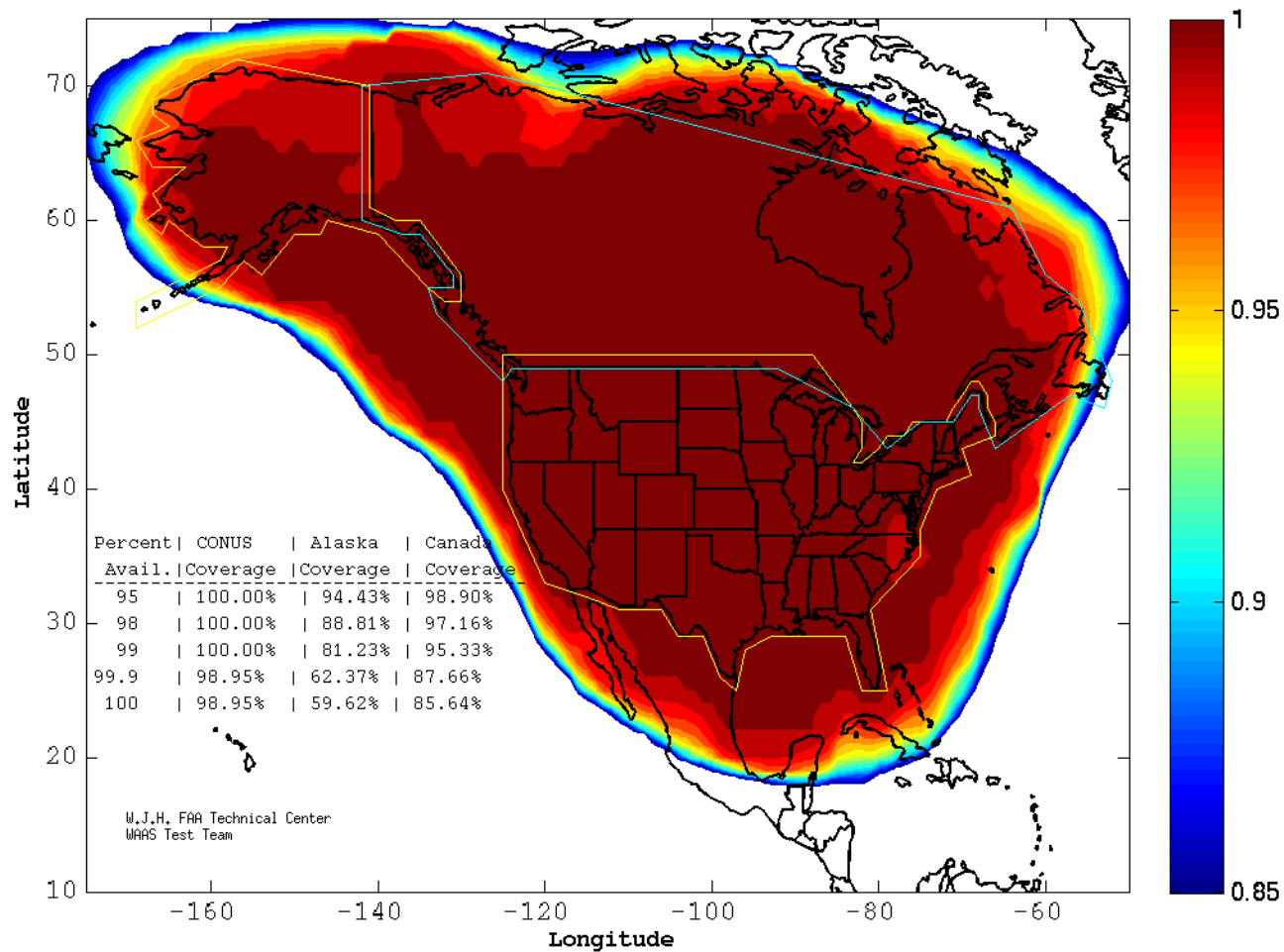
WAAS LPV200 Coverage Contours  
03/15/15  
Week 1836 Day 0



# WAAS LPV200 Coverage Contours

03/16/15

Week 1836 Day 1

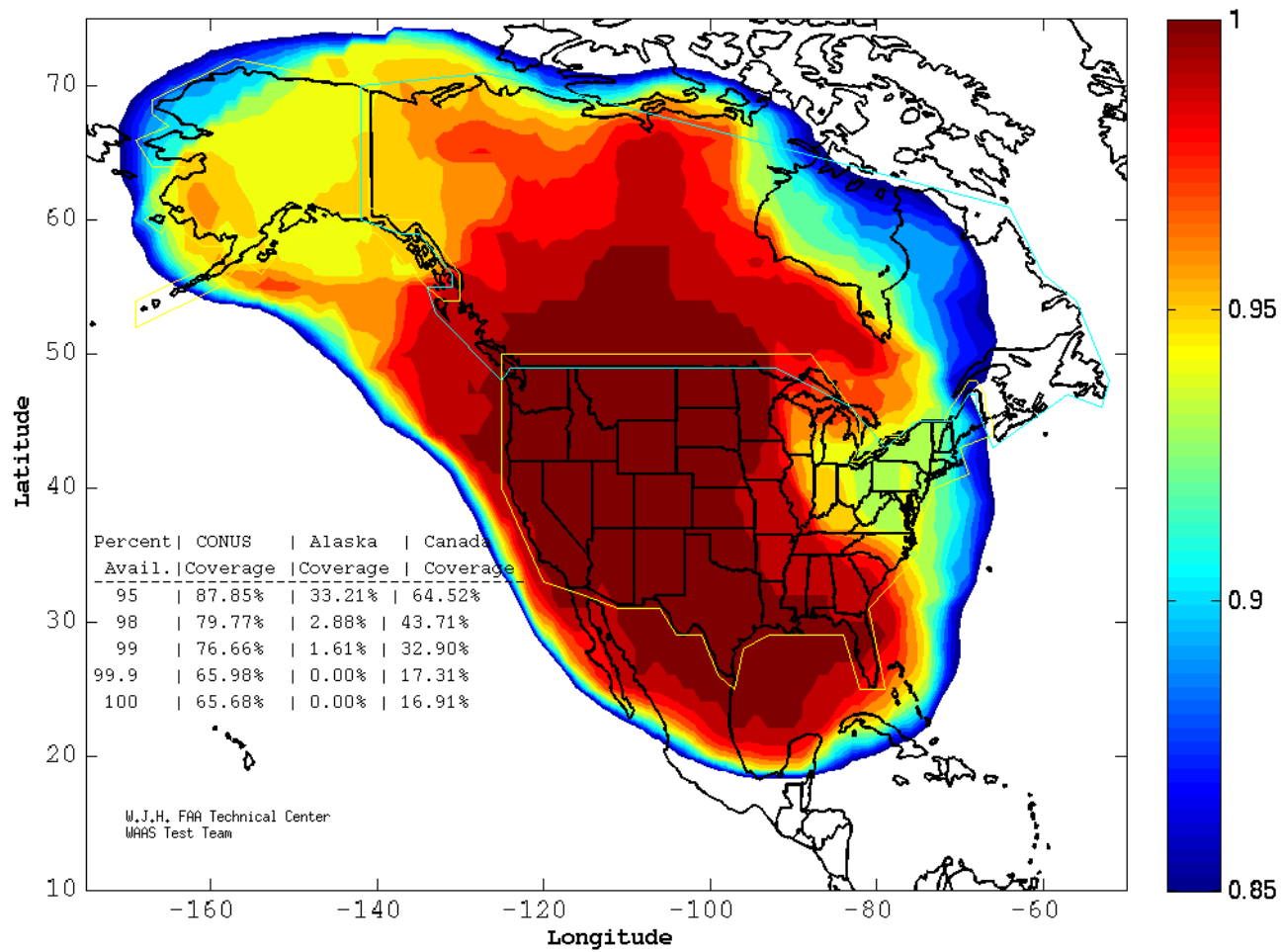




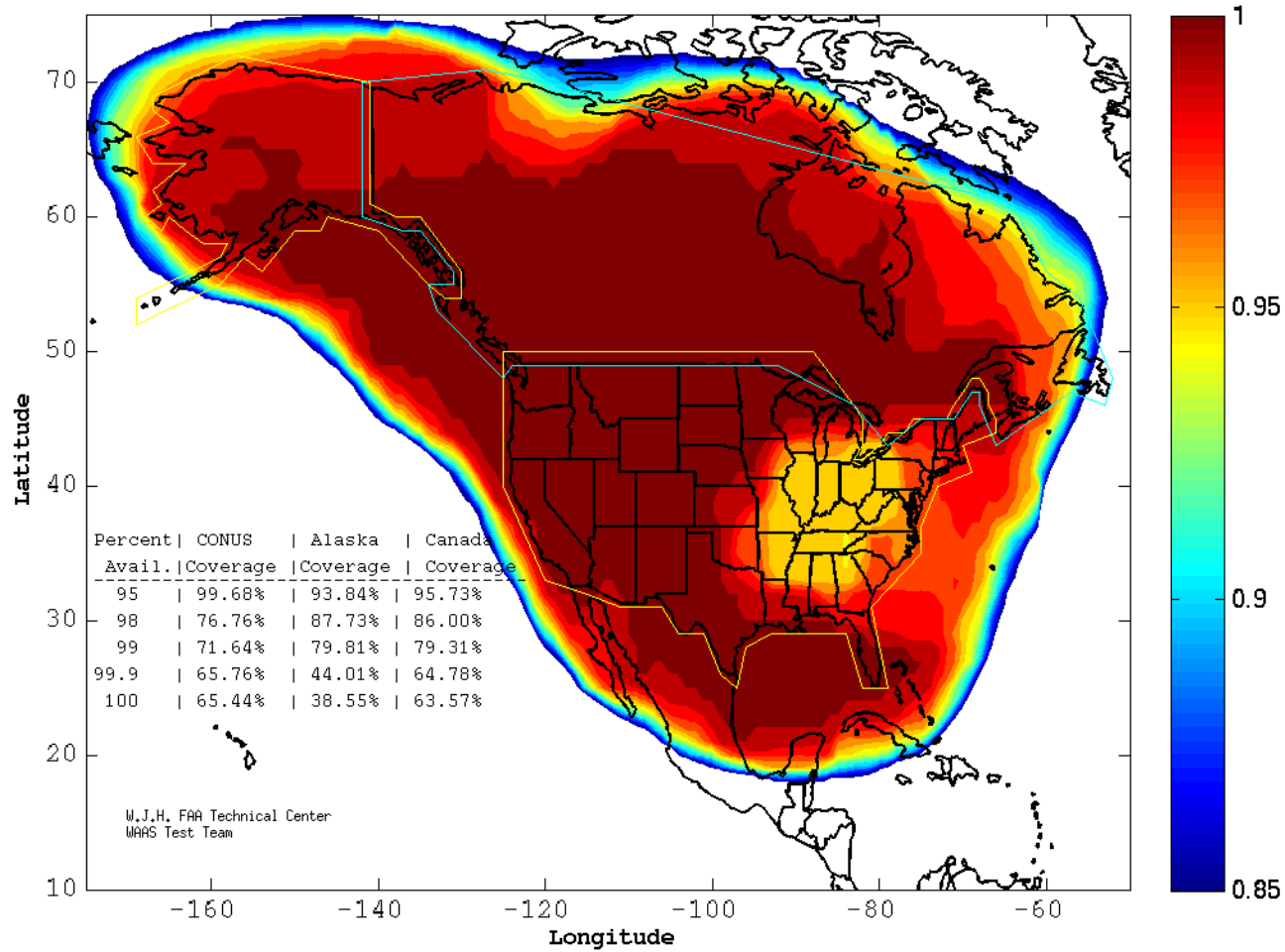
# WAAS LPV200 Coverage Contours

03/17/15

Week 1836 Day 2



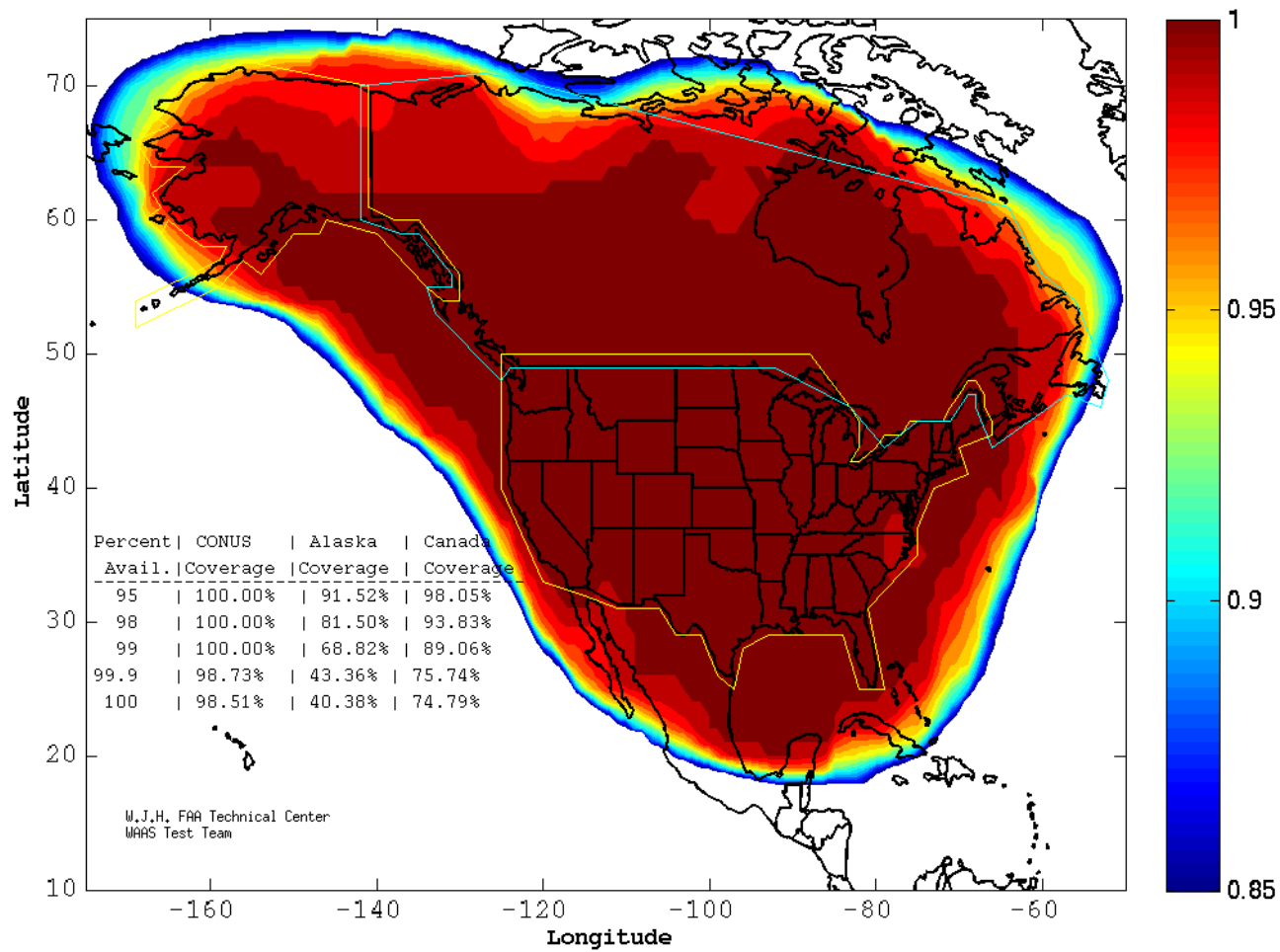
WAAS LPV200 Coverage Contours  
03/18/15  
Week 1836 Day 3

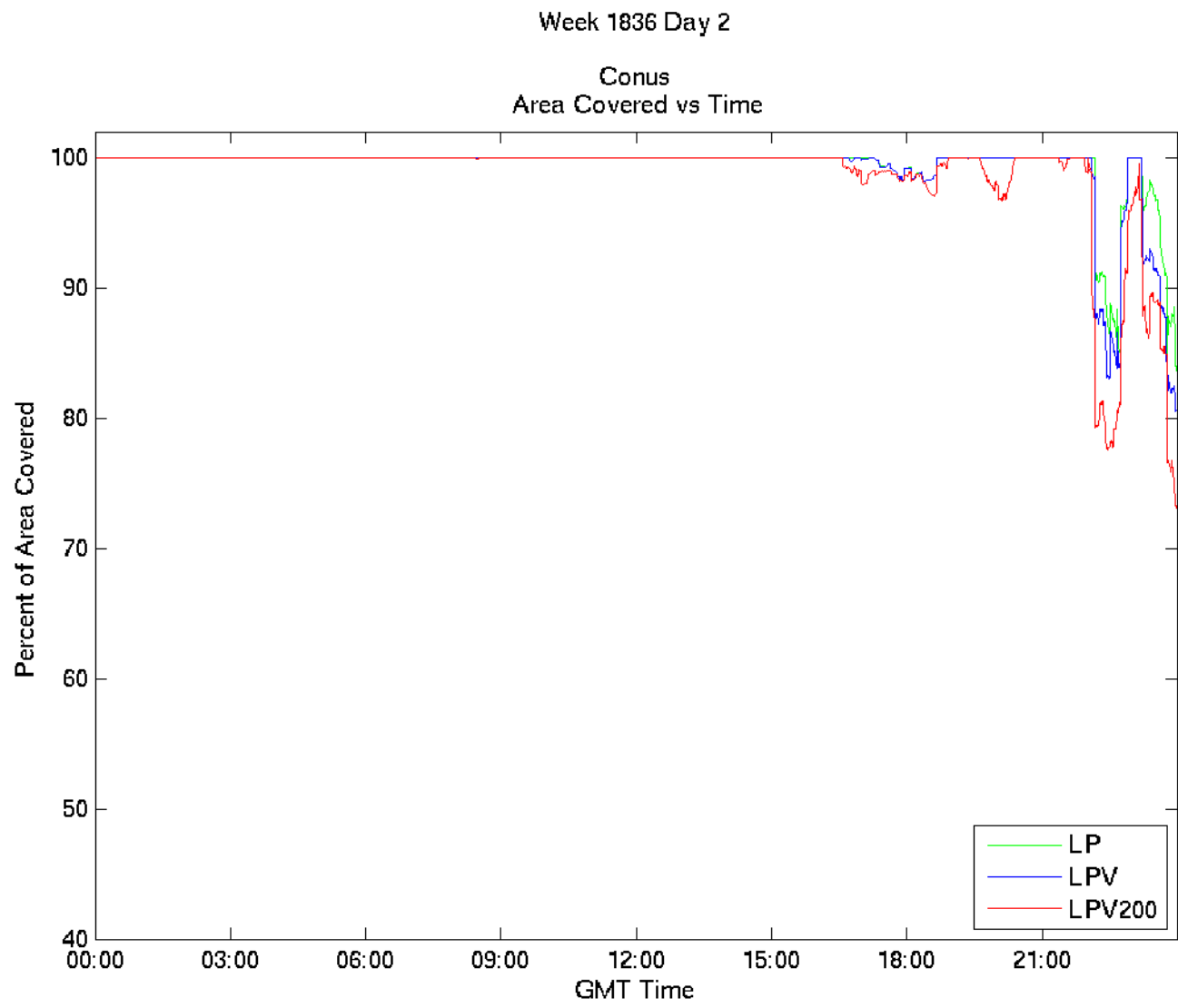


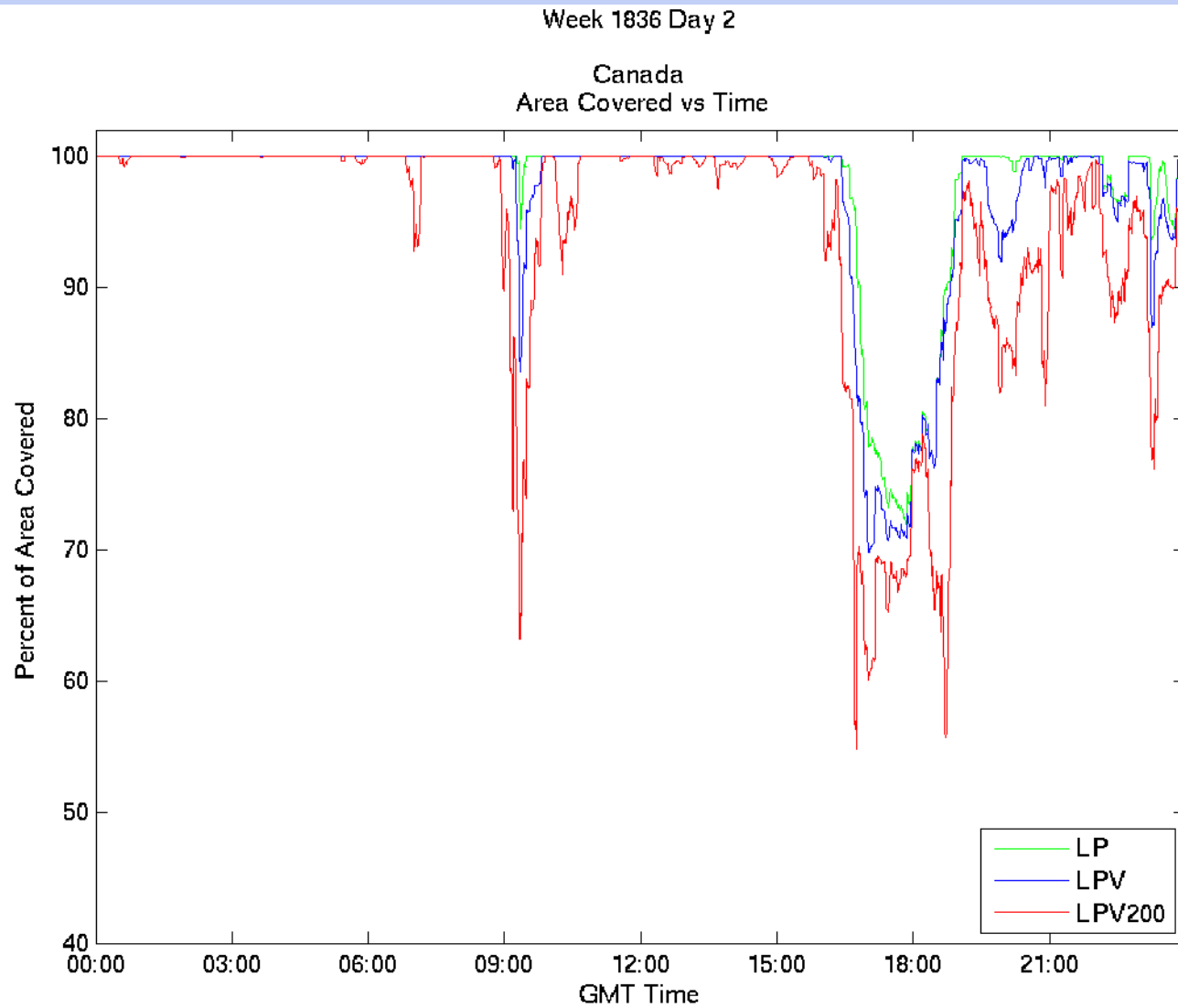
# WAAS LPV200 Coverage Contours

03/19/15

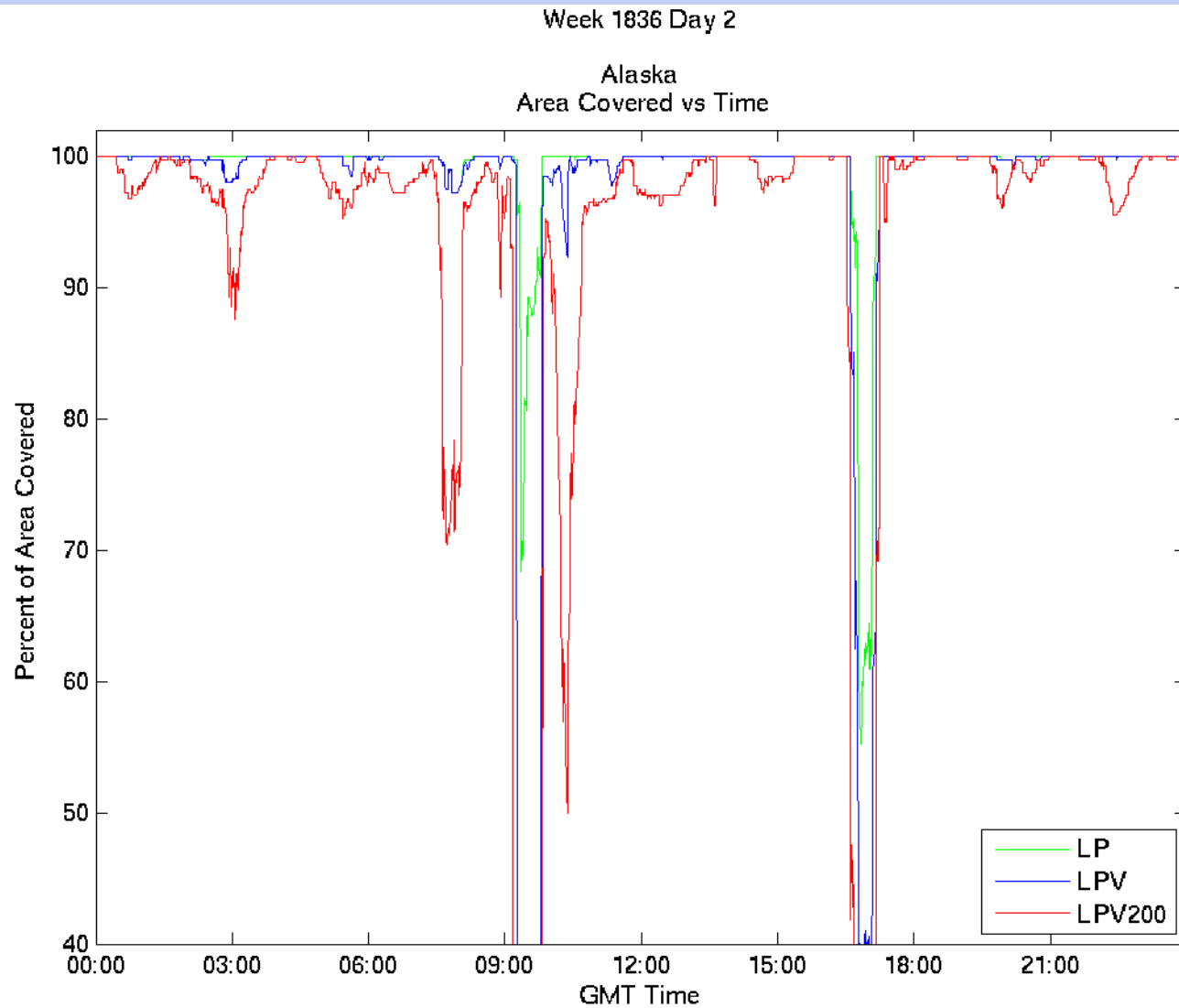
Week 1836 Day 4



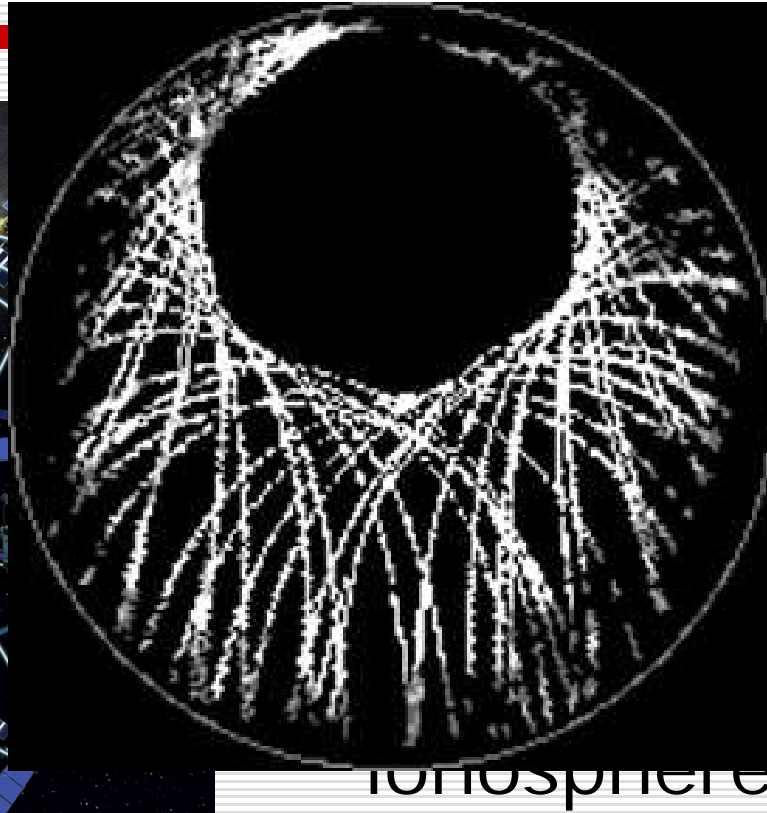
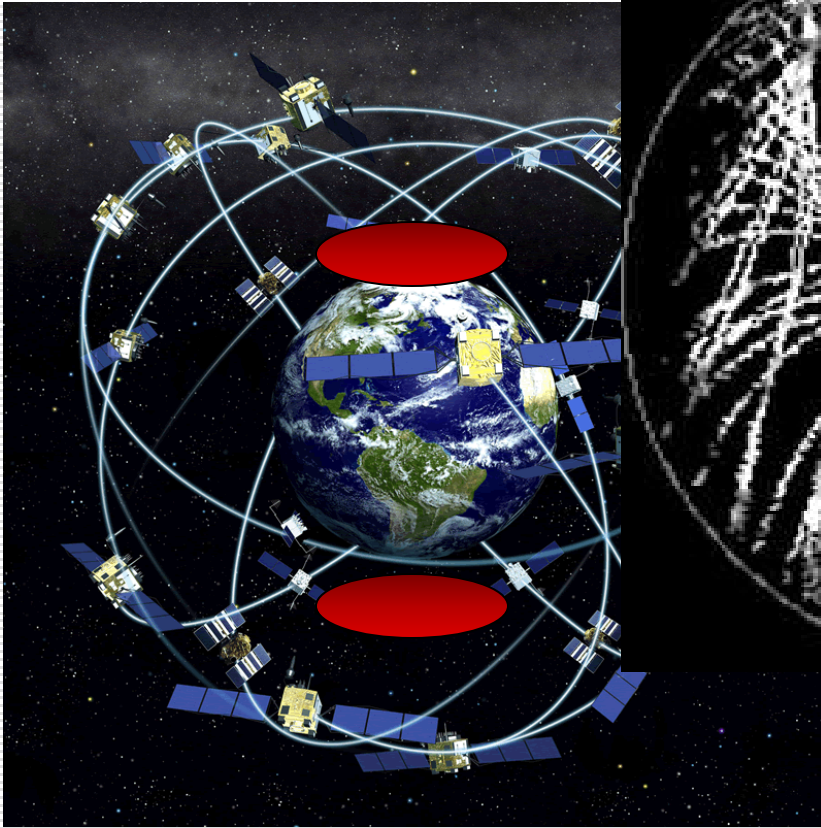








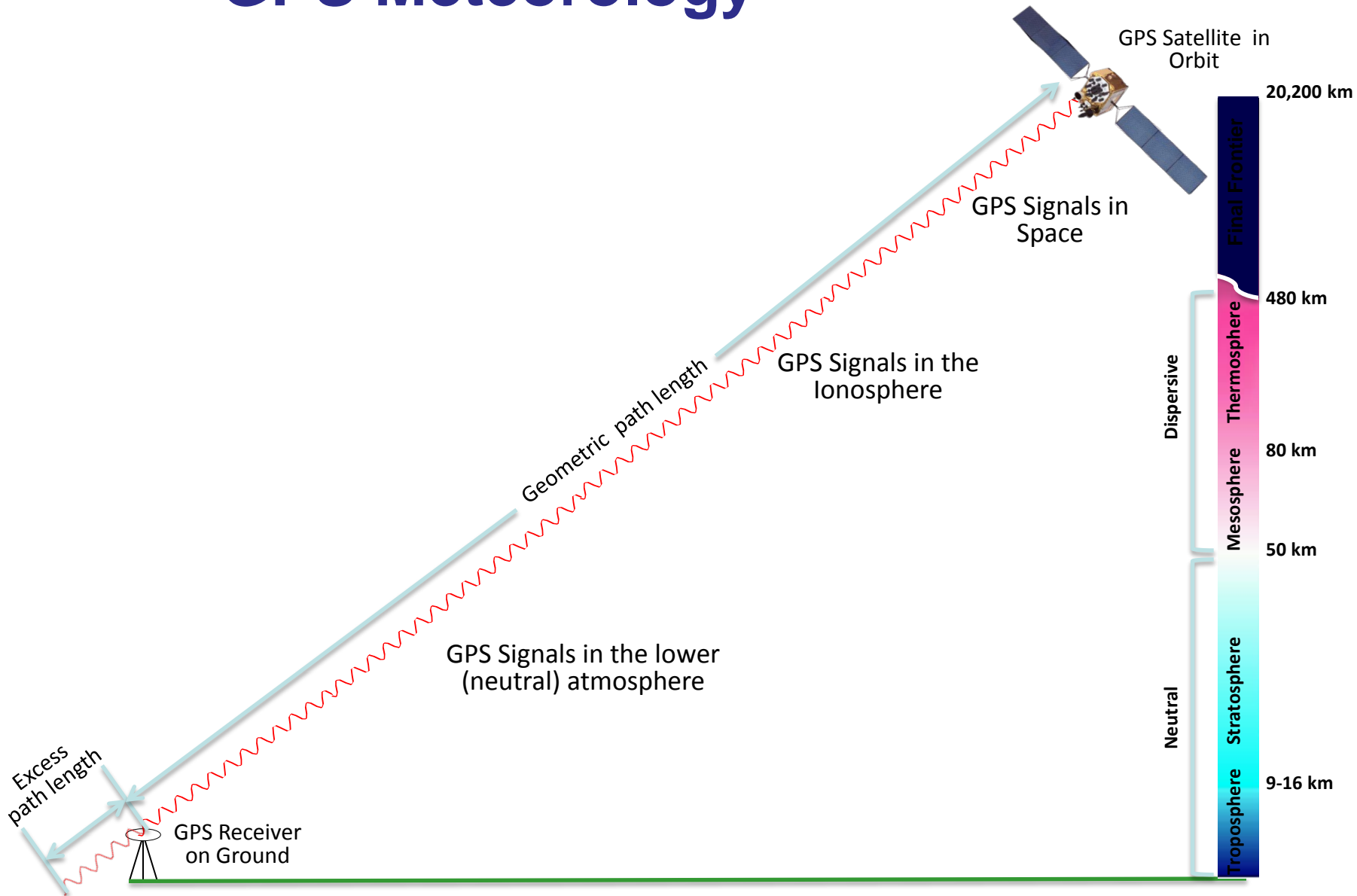
# ***GPS: Consequences of a 55° Inclination***



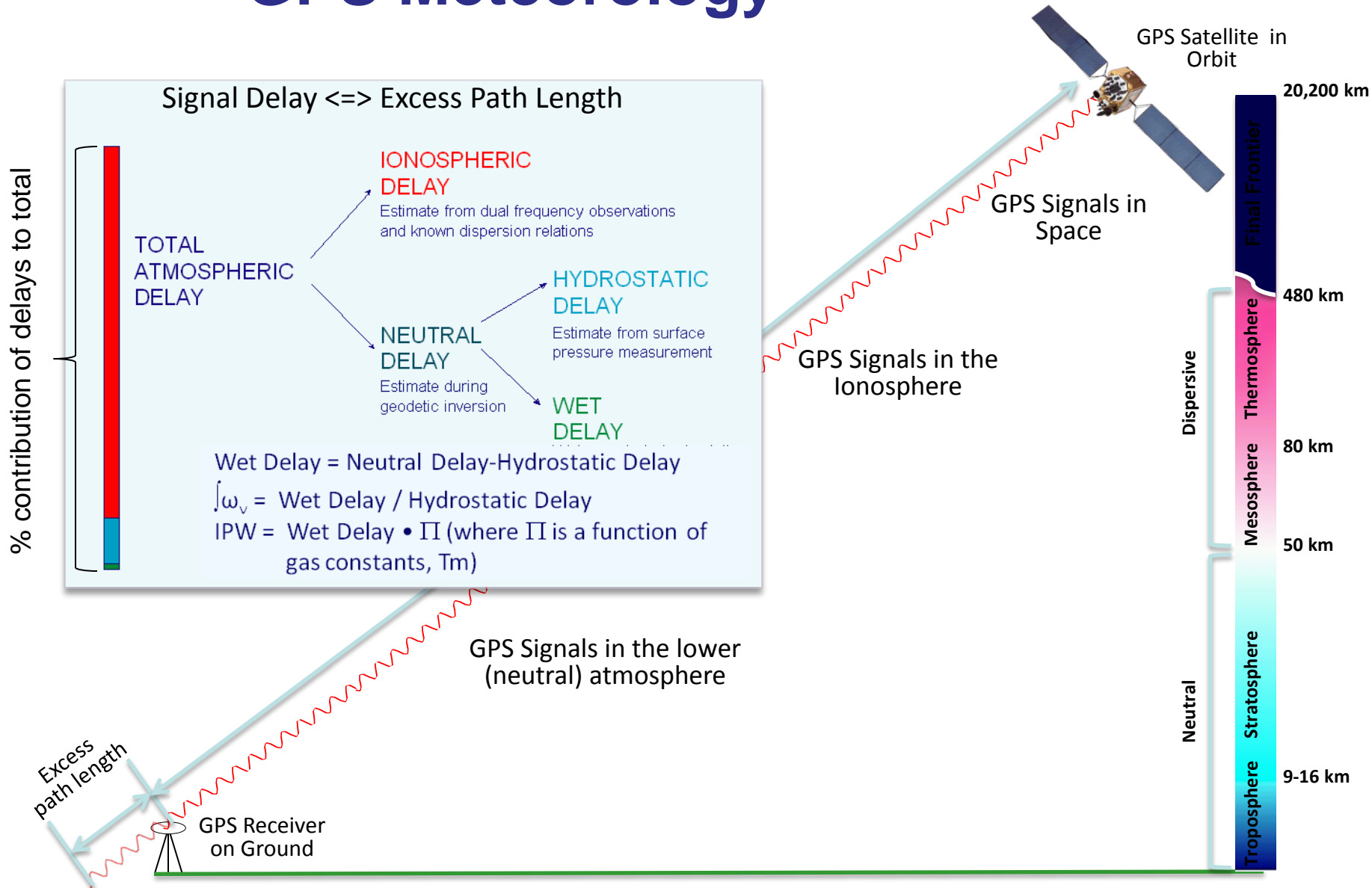
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# GPS Meteorology



# GPS Meteorology



# ASTRA: Overview

❖ Science

❖ Technology

❖ Applications

*Bringing It All Together*



## Modeling

Physics-Based  
Modeling  
(TIMEGCM)

Real-Time  
Specification  
of  
Ionosphere/  
Thermosphere

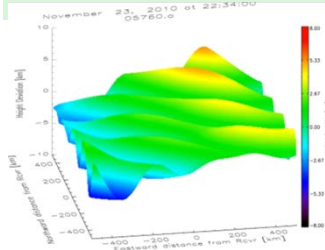
## Data Assimilation

High-latitude  
Electrodynamics  
(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

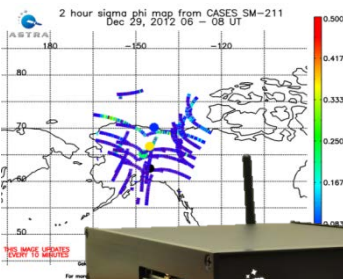
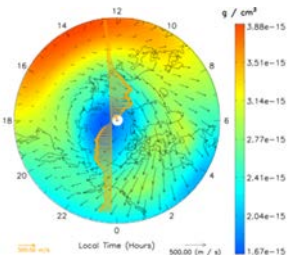
E-field Double Probe

Topside Sounder

Wind Profiler

GPS-based Space  
Weather Monitor

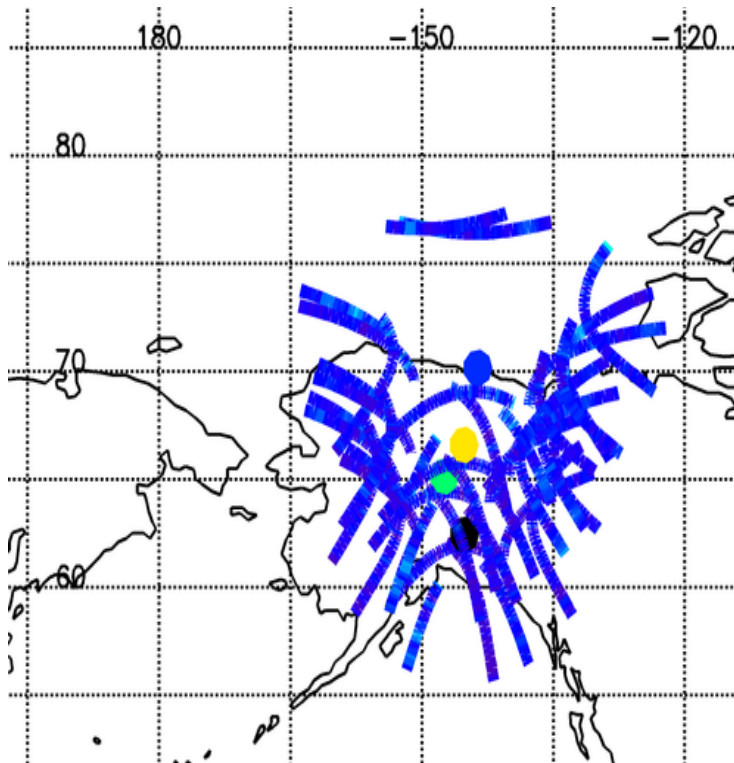
Satellite  
Aerodynamics



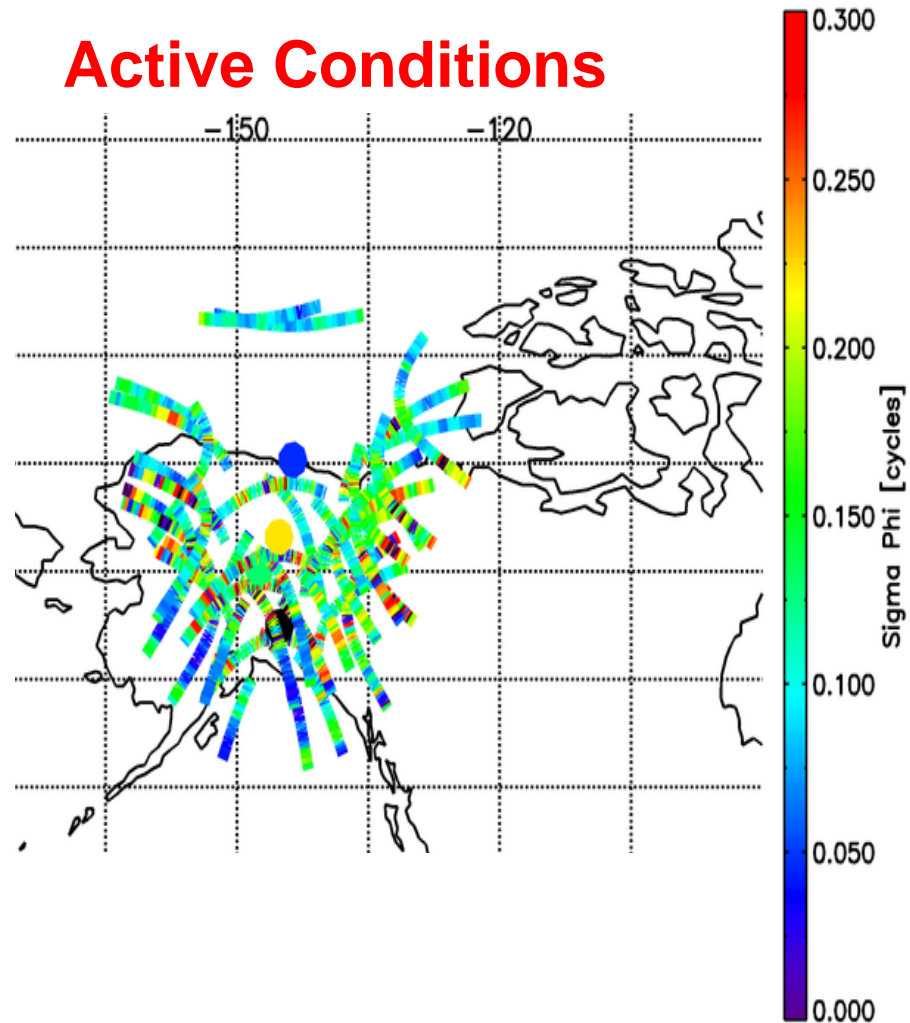


<http://www.youtube.com/4spaceweather>

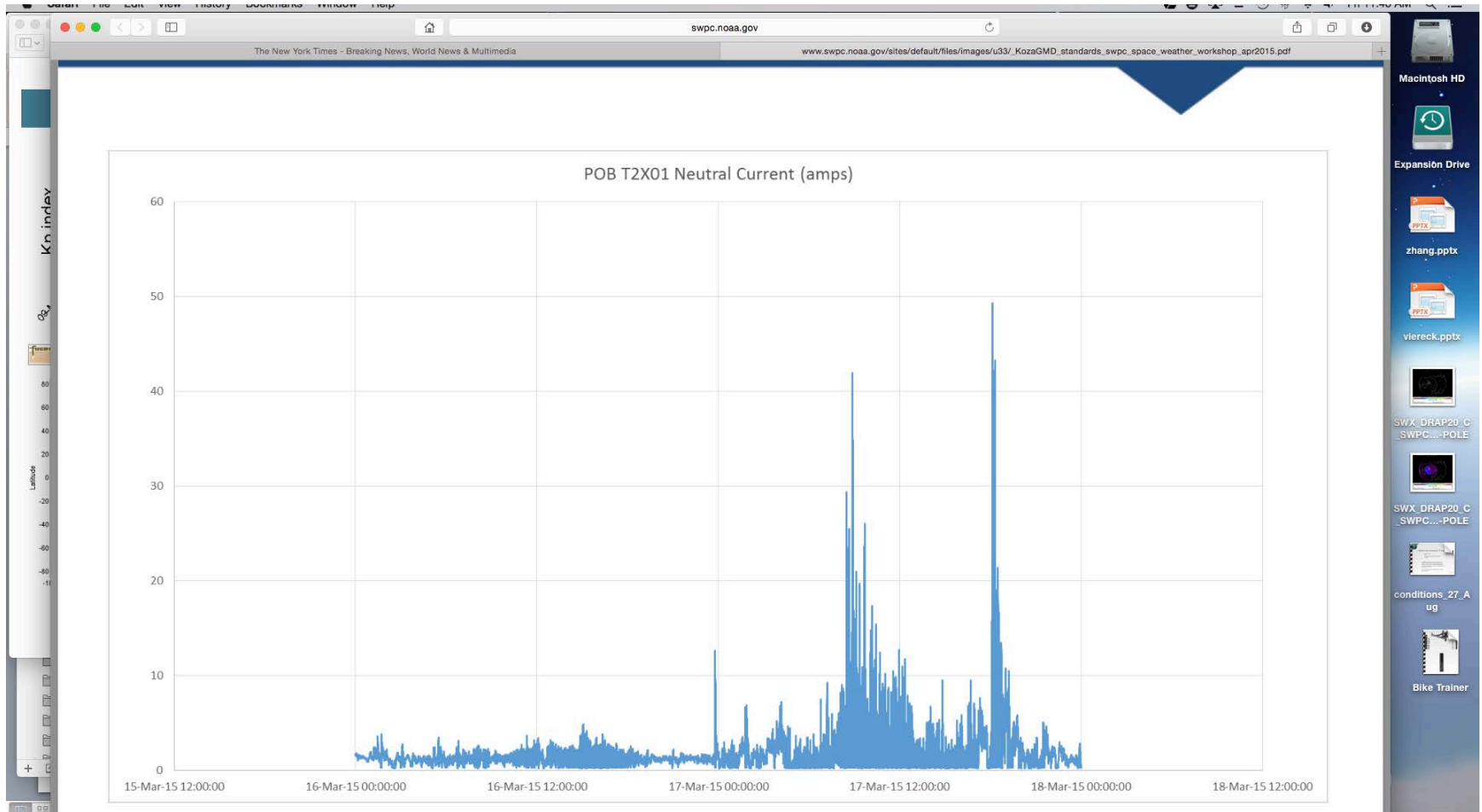
## Quiet Conditions



## 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.

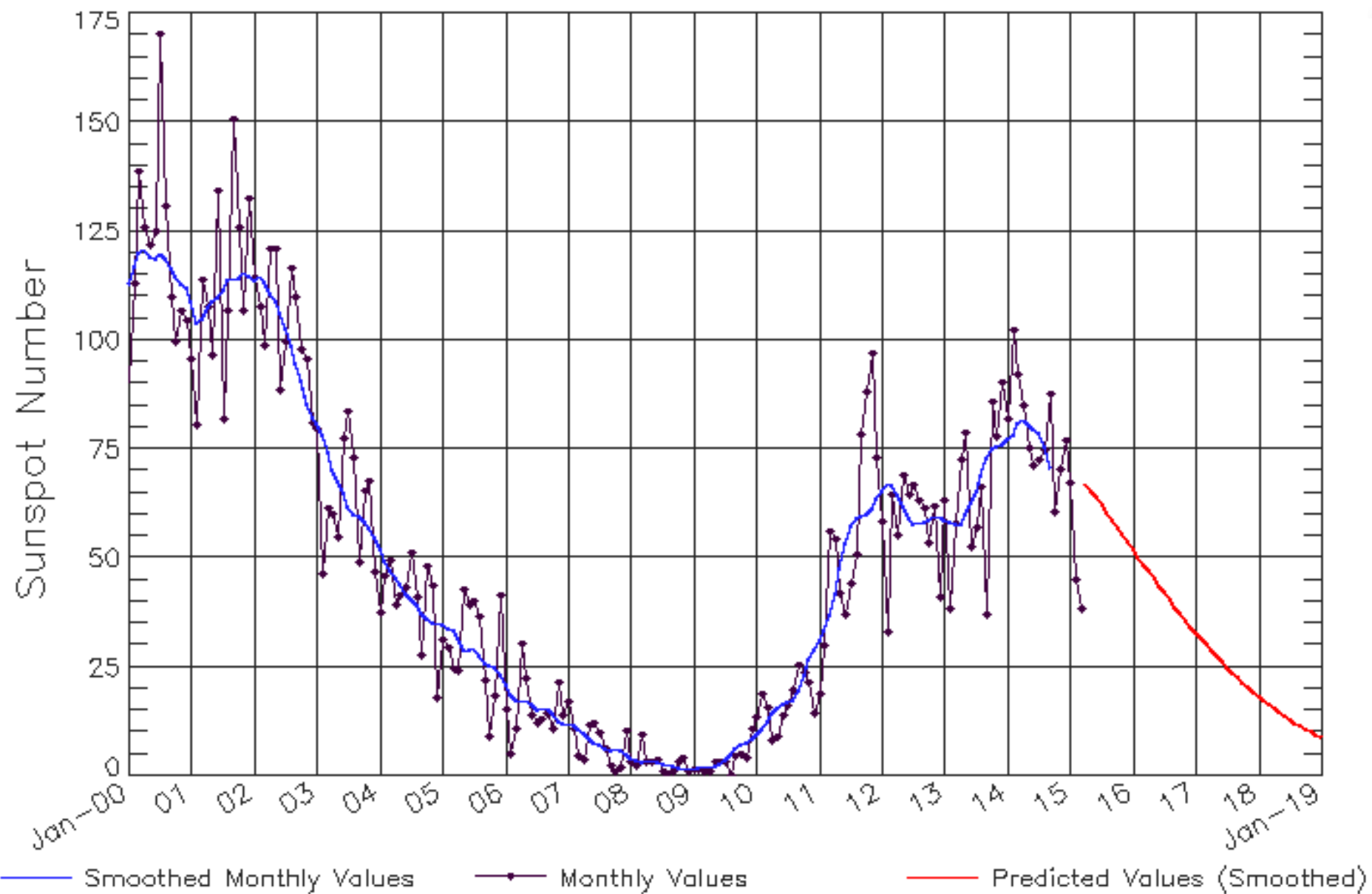
The eruption on March 9th at 2353Z, (X-Ray flux exceeding M5 – NOAA scale R2-Moderate) over the Pacific that marginal impact to HF Comms at the SFO Comm Center from approximately 2353Z – 0045Z.



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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