Supporting GPS/GNSS Users With Products to Help Identify and Mitigate the Impacts of Space Weather

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Space Weather Prediction Center

National Centers for Environmental Prediction

National Weather Service

NOAA

54th Meeting of the Civil GPS Service Interface Committee

9 September 2014

Outline

- **Customer Requirements**
- **Current Products and Services**
- **Future Products and Forecasts**

NOAA Space Weather Services:

Protecting technologies from space weather since 1946

Operational 24/7 Space Weather Forecast Office

- **GPS**
  - Single biggest source of error is ionosphere
  - Strong growth in applications – surveying, drilling, precision agriculture, navigation, aviation

- **Aviation**
  - Polar route use – ~13,000 flights in 2013
  - Next Generation Air Transportation System – GPS based

- **Communication**
  - HF radio communication heavily relied upon by airlines, DOD, Emergency Managers, Search and Rescue, etc…

- **Electric Utilities**
  - Potential for significant disruption of service due to geomagnetic storm with $Trillion consequences
  - FEMA addressing potential impacts related to space weather events through simulated exercise

- **Space Systems**
  - World satellite industry revenues in 2013: >$190 billion
  - Space weather support is critical for manned space flight and NASA robotic missions

GPS Customers

- Airlines
  - WAAS and NextGen
- Shipping and Transportation
- Precision Agriculture/Construction/Surveys
- Precision Navigation
  - Autonomous vehicles and UAVs
  - Zero visibility driving
- Exploration
  - Oil
  - Minerals
- DOD, FAA, FEMA, DHS, Coast Guard, etc…

New Customers at High Latitudes

- **Navigation:**
  - **Shipping through the NW passage saves 6000km off of a 22000km trip from New York to Hong Kong (28%)**
    - **Avoiding ice and navigating in the arctic requires precise GPS positioning information**
  - **Oil and mineral exploration in arctic regions**
    - **Drilling and surveying require precision GPS**
  - **Airlines use polar routes extensively (13000/year)**
- **Space Weather Impacts at High Latitudes**
  - **Stronger storms**
  - **Poorer GPS Satellite Viewing**

"When Aurora is Strong, GPS is wrong"

Arctic Shipping Lanes Require New GPS Services

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Iron Ore Mi… Dig Out of a Hc…

BUSINESS

Energy Companies Try Arctic Shipping Shortcut Between Europe and Asia

Northern Sea Route Reduces Costs, Bypasses Fractious Suez Canal Region

The First-Ever Bulk Freighter To Pass Through The Arctic Was Carrying Coal

BY ARI PHILLIPS POSTED ON SEPTEMBER 26, 2013 AT 1:44 PM UPDATED: SEPTEMBER 30, 2013 AT 9:26 AM

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Sometime earlier this week a cargo ship passed through the Northwest Passage into Baffin Bay, along Greenland's southwestern coast, making it the first bulk carrier ever to make the voyage. This journey was completed by the Nordic Orion, a 225-meter, ice-strengthened vessel loaded with coal in Vancouver, British Columbia and headed for Finland.

The Nordic Orion along the Northern Sea Route.

CREDIT: NAVAL MATTERS

Long eyed as a commercial route, the

THE WALL STREET JOURNAL.

TRANSPORTATION

More: AFP China

China Begins Using Arctic Shipping Route That Could 'Change The Face Of World Trade'

BILL SAVADOVE, AGENCY FRANCE-PRESSE

AUG. 16, 2013, 6:27 AM | 30,948 | 78

Customer Wish List

- 24 hour lead time forecast of regional amplitude scintillation, in units of S4 (dimensionless) with S4 = .5 a critical threshold
- 24 hour lead time forecast of regional phase scintillation, in units of sigma phi (radians), with sigma phi = .7 a critical threshold
- 24 hour lead time forecast of bulk TEC change from current conditions, with a change of 50% (up or down) a critical threshold
- Nowcast of regional amplitude scintillation (similar to #1)
- Nowcast of regional phase scintillation (similar to #2)
- NOAA Ionosphere (I) Scale, starting with a meridional chain of software receivers through N. America broadcasting data to SWPC
- More ground-based stations taking data for USTEC to capture small scale irregularities causing scintillation
- Alerts of L-band solar radio bursts with right-hand circular polarization of a magnitude affecting codeless/semi-codeless/radio occultation GPS
- With USTEC as the basis, find gradients and generate warnings of regions with heightened probability of scintillation activity
- Link the daily geomagnetic activity forecasts as a flag in the display of USTEC, alerting users of the higher probability of abnormal conditions

Requirements

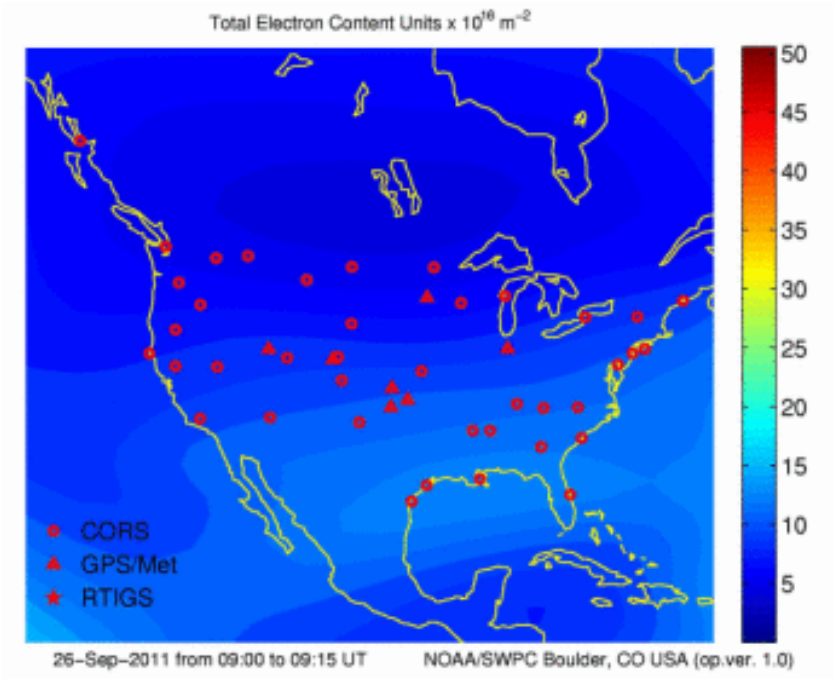
- **Improved specification products for single frequency users.**
- **Development of specification products for dual frequency users**
- **One-day forecasts of conditions relevant to both single and dual frequency users**
- **Simple products**

How Well Are We Doing?

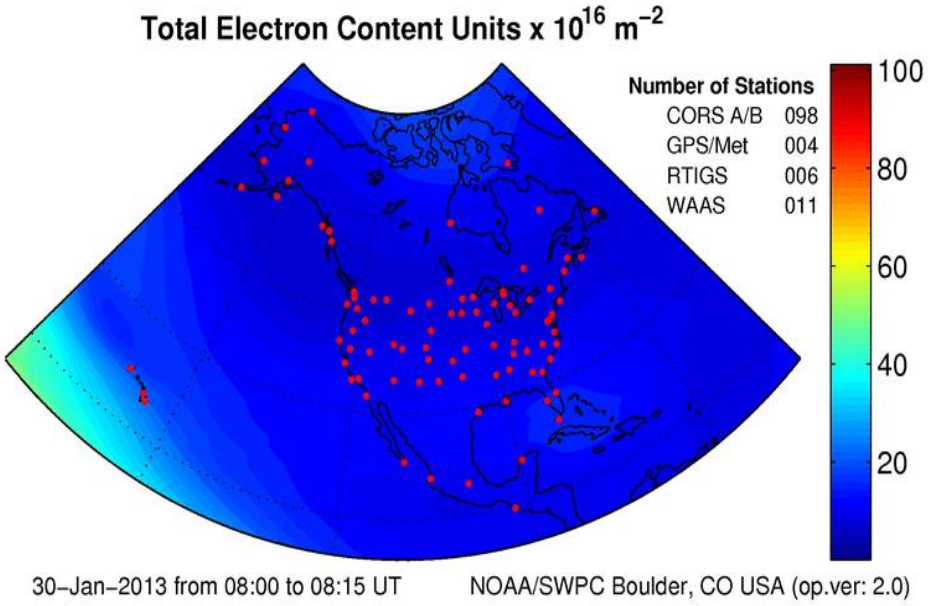
Now	1 Yr	5 Yr	Request
			24 hour lead time forecast of regional amplitude scintillation,
			24 hour lead time forecast of regional phase scintillation, in units of sigma phi (radians)
			24 hour lead time forecast of bulk TEC change from current conditions
			Nowcast of regional amplitude scintillation
			Nowcast of regional phase scintillation
			Nowcast of regional TEC
			NOAA Ionosphere (I) Scale, starting with a meridional chain of software receivers through N. America broadcasting data to SWPC
			More ground-based stations taking data for USTEC to capture small scale irregularities causing scintillation
			Alerts of L-band solar radio bursts with right-hand circular polarization of a magnitude affecting codeless/semi-codeless/radio occultation GPS
			With USTEC as the basis, find gradients and generate warnings of regions with heightened probability of scintillation activity
			Link the daily geomagnetic activity forecasts as a flag in the display of USTEC, alerting users of the higher probability of abnormal conditions

Current Products: Regional Specification

Current:
US-TEC: Provides real-time specification of Total Electron Content over the US

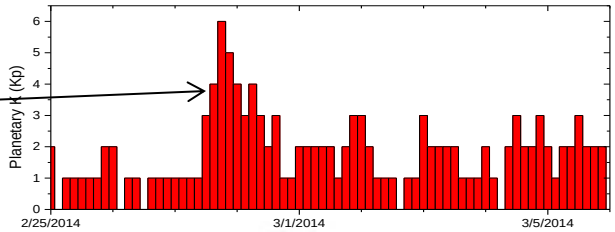


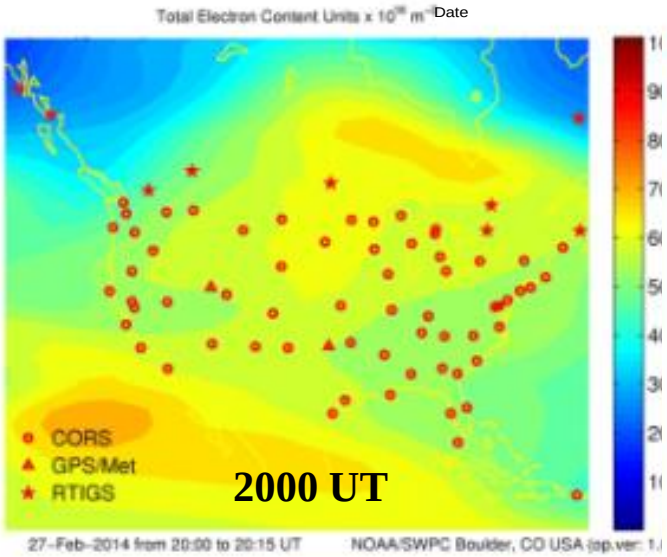
Upgrade:
North America-TEC: Provide real-time specification of Total Electron Content over the North America (Operational in 2015)

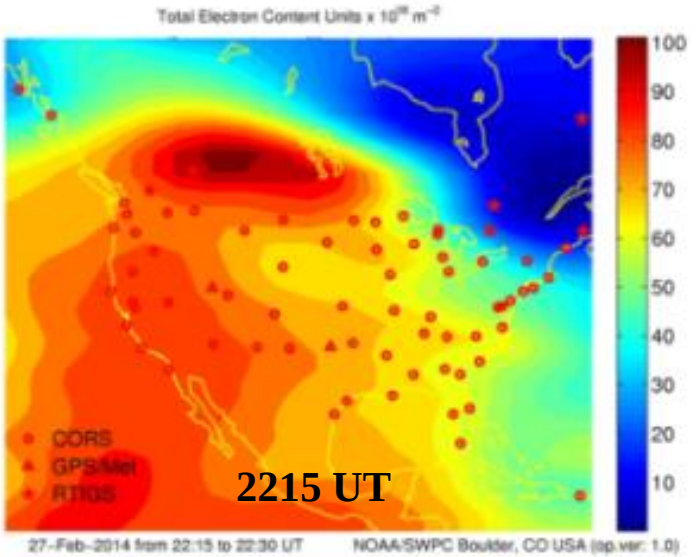


Impact of a Moderate Geomagnetic Storm

Moderate Geomagnetic Storm:
Kp of 6 on a scale of 0-9







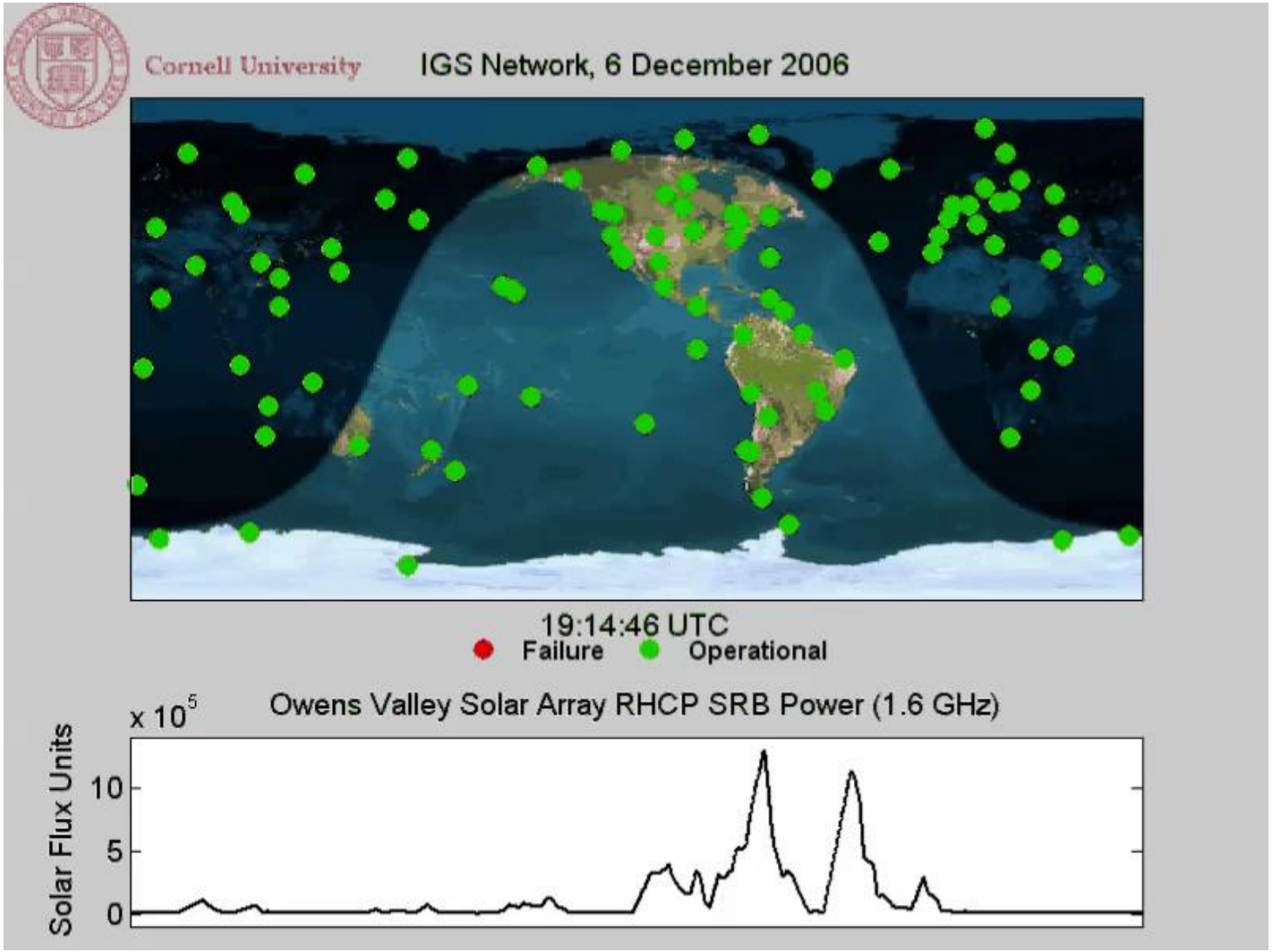
FAA Msg to SWPC

"An Ionospheric Storm began on 2/27/14. The Satellite Operations Specialists were alerted at the WAAS O&M by a Significant Event 757 at 2120 Zulu. So far, LPV and LPV200 service has not been available in Eastern Alaska and Northeastern CONUS. At times, North Central CONUS and all of Alaska have lost LPV and LPV200 Service."

Note: LPV is Localizer Performance with Vertical Guidance which takes the aircraft down to 250 ft altitude

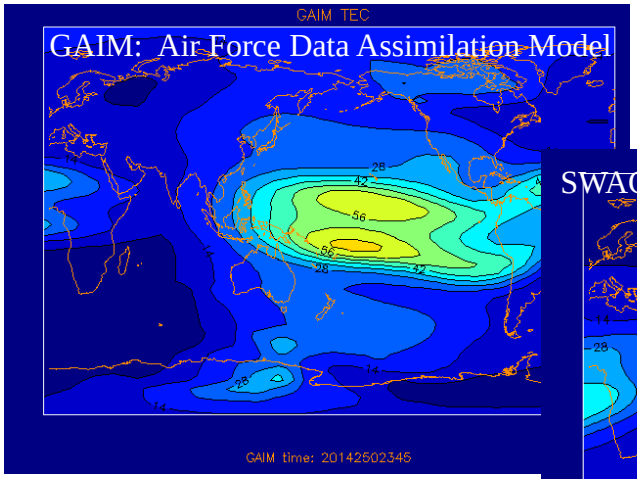
Impact of Solar Flare

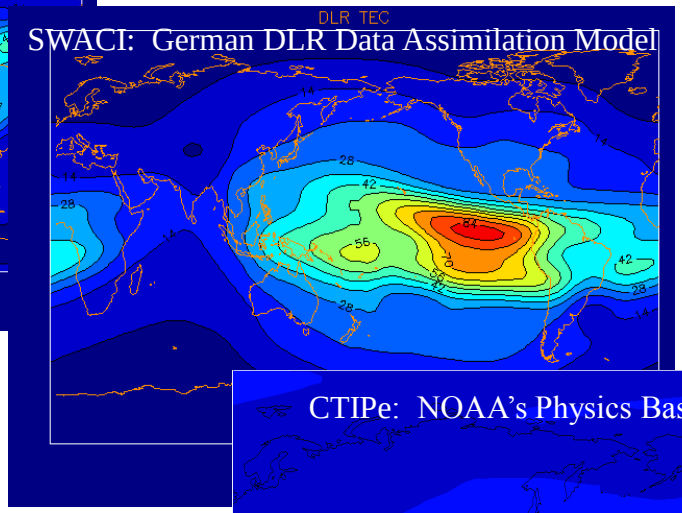
Solar Radio Burst at GPS Frequencies

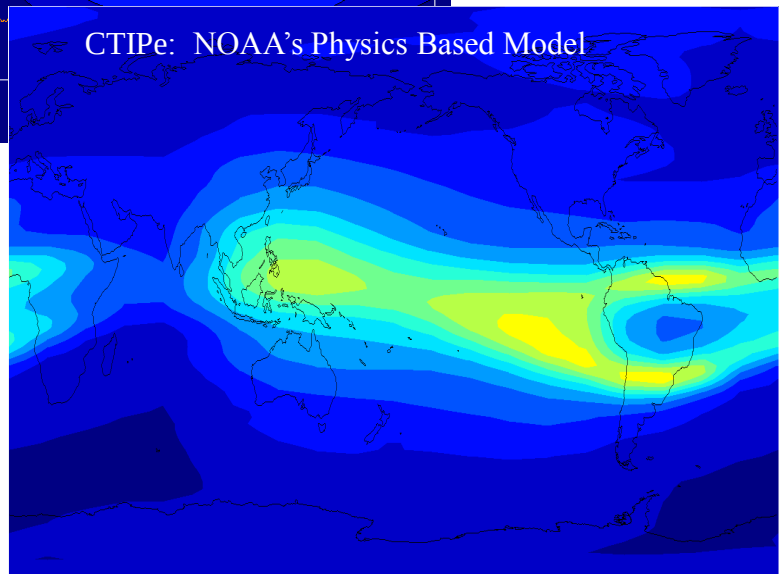


Radio interference on GPS receiver

Developing Global Specification Product







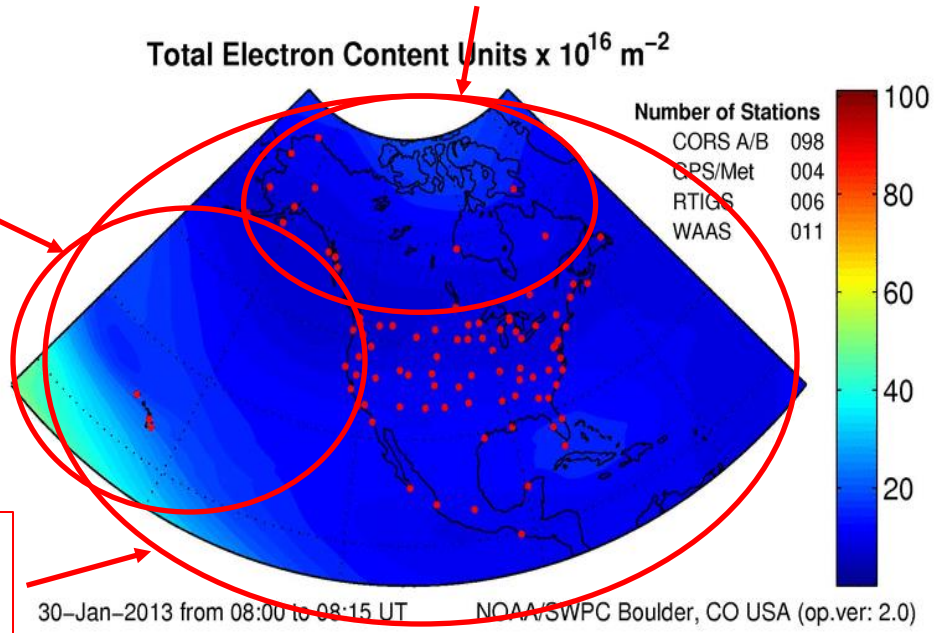
- **NOAA is testing global TEC models:**
  - **Air Force GAIM**
  - **DLR SWACI**
  - **NOAA CTIPe**
  - **A prototype product will be available in FY15**

More Data

- **Current products limited by lack of global data coverage**
  - **Need more data in the arctic**
  - **Need data over oceans**

- Working to get more real-time GPS data from arctic regions
  - Use of N-Trip to access more data
  - Plate Boundary Observatory

- Air Force SBIR: Partner with USAF and ASTRA to develop a ground GPS receiver and data processing system that will work on ocean buoys
  - NOAA Data Buoy Center will assist with design and deploy test models on the TAO Buoys in the mid Pacific

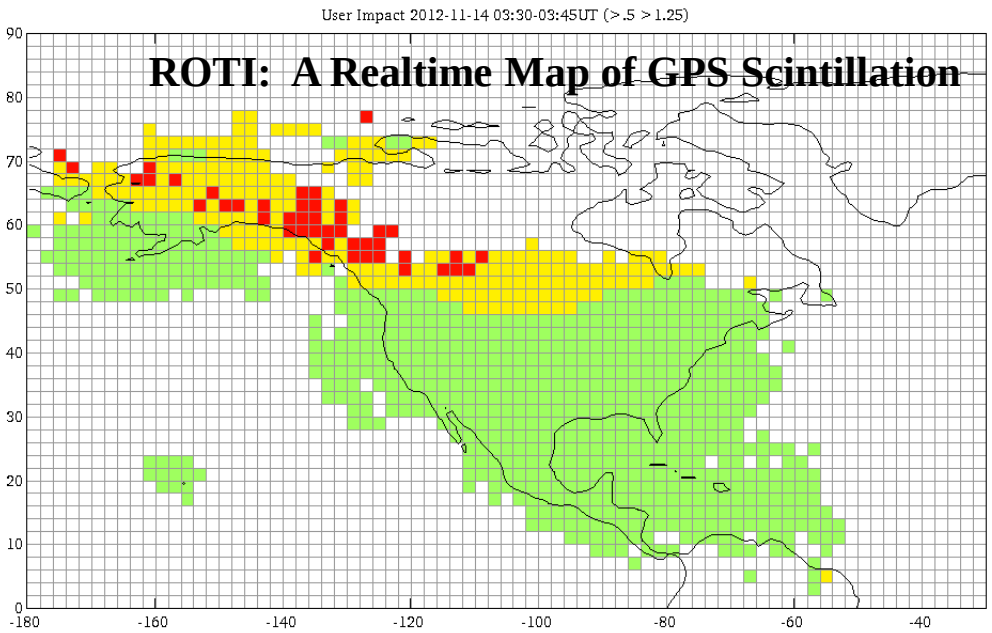


- Developing data assimilation techniques to use COSMIC II data

Products for Precision GPS

- **Specification of ionosphere/thermosphere conditions that lead to GPS/GNSS errors and outages**
  - **Rate Of TEC Index (ROTI) provides dual-frequency GPS users with estimates of scintillation**
  - **Proxy for S4 index based on single frequency GPS data**
  - **NOAA SBIR: Partner with Propagation Research Associates to develop maps of scintillation for dual-frequency GPS error based on ground-base**

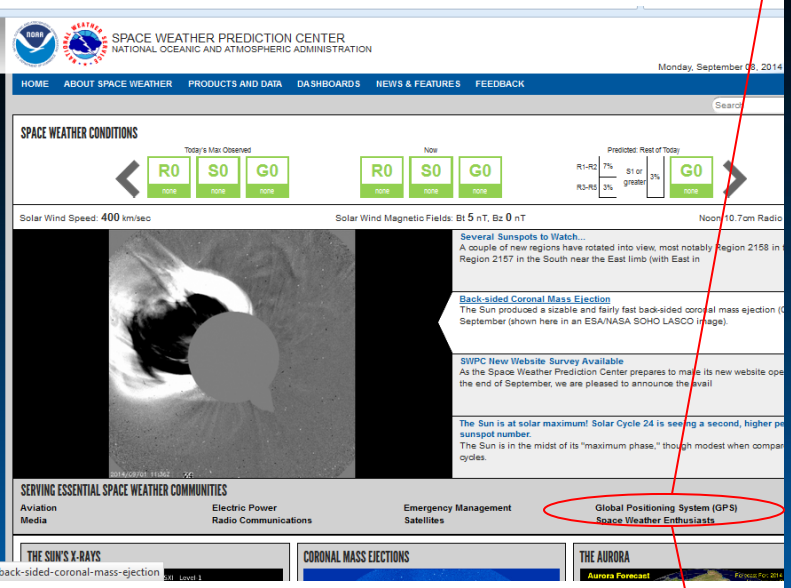
    GPS receivers
  - **Test Product in 2015**



SWPC Introduces a Web Page for GPS Users

- **Prototype Web Site for Space Weather:**

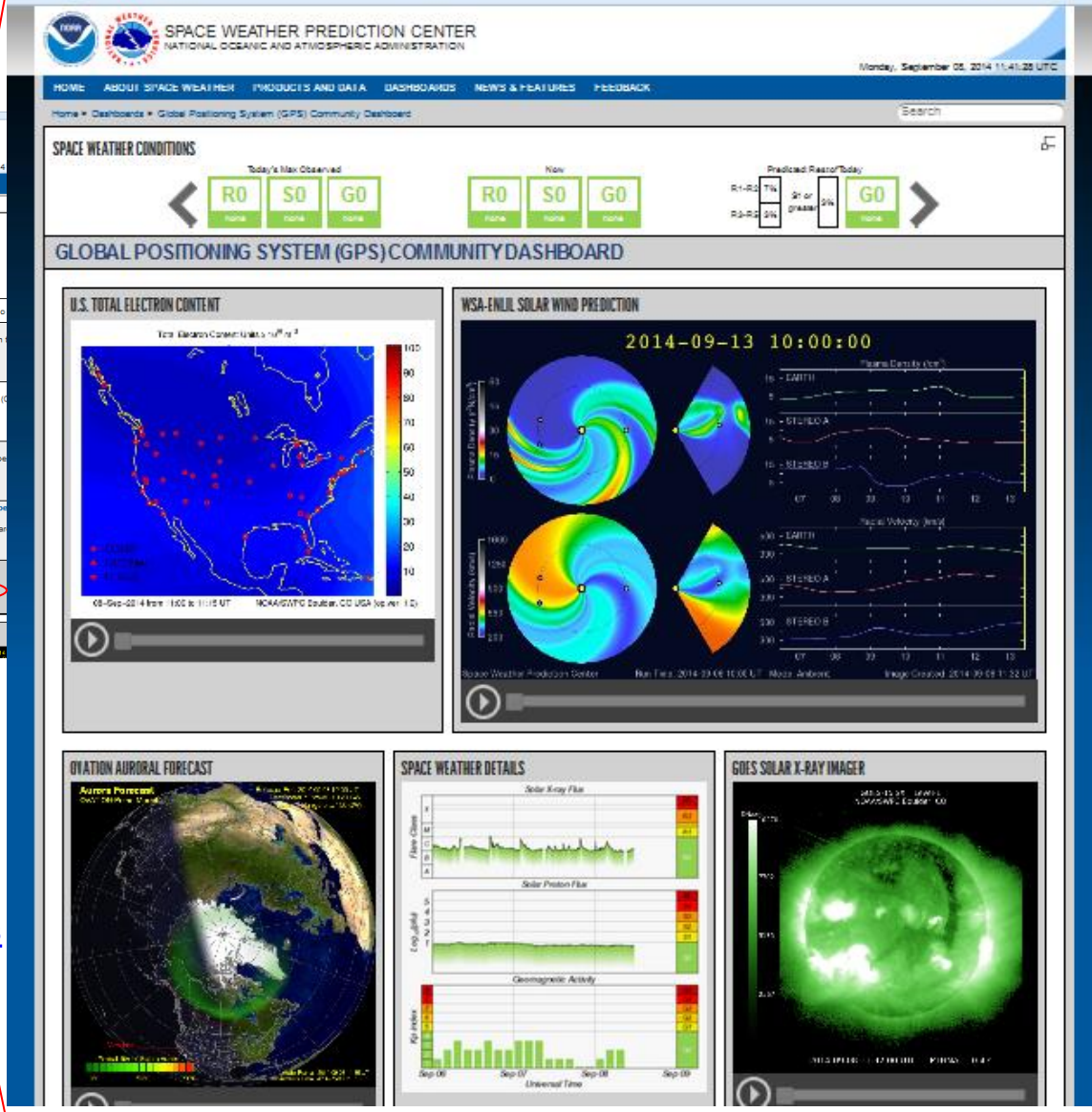
  Origin-www.swpc.noaa.gov



- **GPS Dashboard:**

  A single site for space weather information relevant to GPS users.

http://origin-www.swpc.noaa.gov/communities/gps



Forecasting Space Weather Conditions for GPS

- **High to Mid Latitudes**
  - **Primary driver is geomagnetic activity and the aurora**

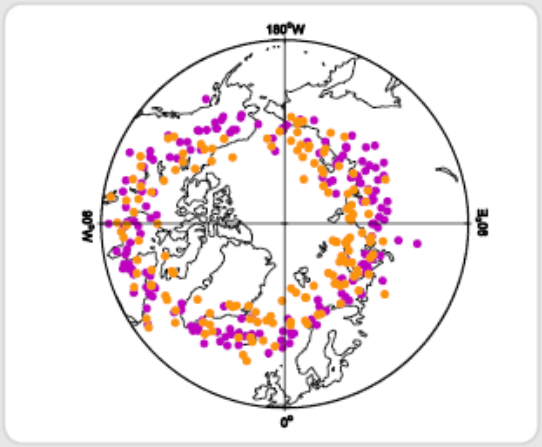
- **Mid to Low Latitudes**
  - **A major driver is the lower atmosphere**
    - **Requires forecast modeling of the whole atmosphere from the ground to space.**

High Latitude GPS Issues Strongly Correlated with the Aurora

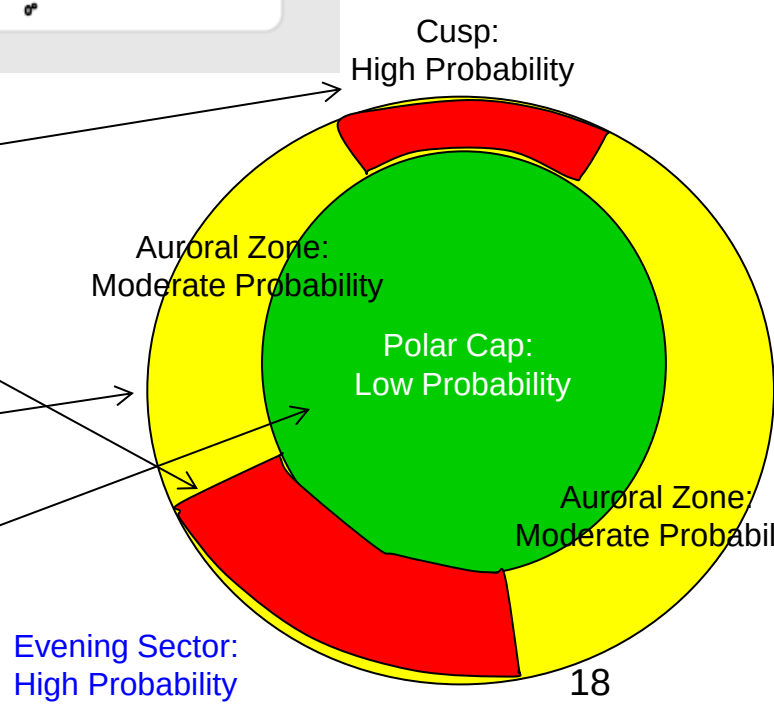
Locations of substorm events:

Figure 4:
Location of substorm onsets
and ionospheric irregularities

of events in the pre-midnight substorm onset sector. The irregularities plotted here occur within 90 minutes of a sub-storm onset. Typically they scatter within the auroral oval.



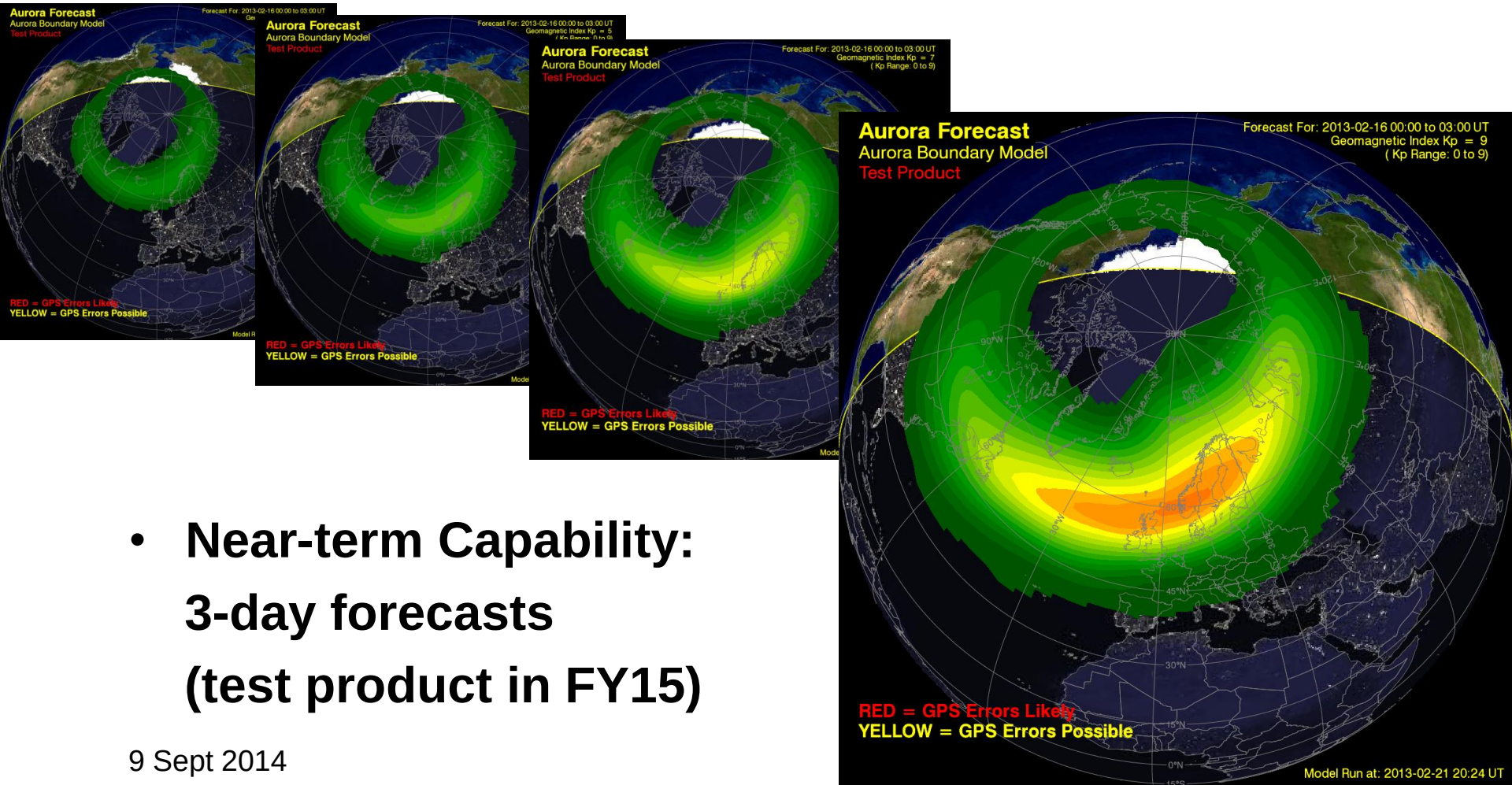
- **Cusp (Day Side): High coincidence of irregularities and Field Aligned Current Density Structures**
- **Pre Midnight Sector: High coincidence of irregularities and Field Aligned Current Density Structures**
- **Aurora Zone: Moderate coincidence of irregularities**
- **Polar Cap: No irregularities or Field Aligned Current Density Structures**



Aurora Forecast

- **Current Capability: Lead-time of 45 minutes**

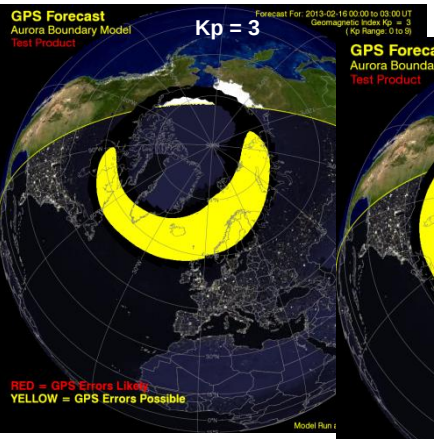
http://origin-www.swpc.noaa.gov/products/ovation-auroral-forecast

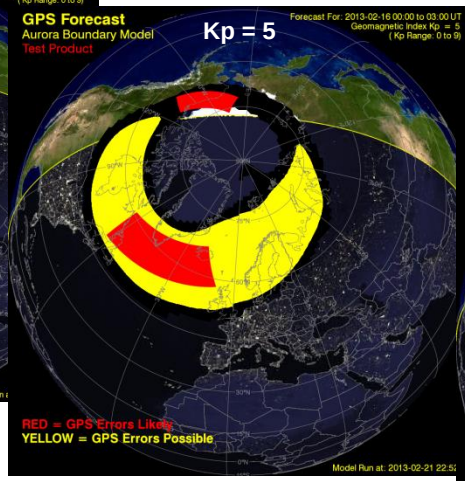


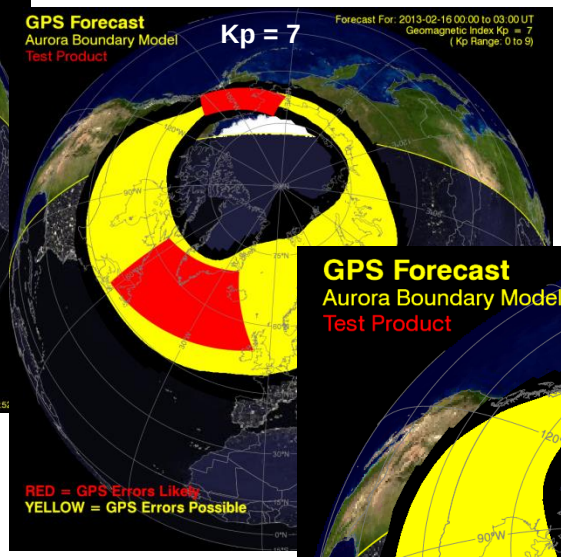
- **Near-term Capability:**
  3-day forecasts
  (test product in FY15)

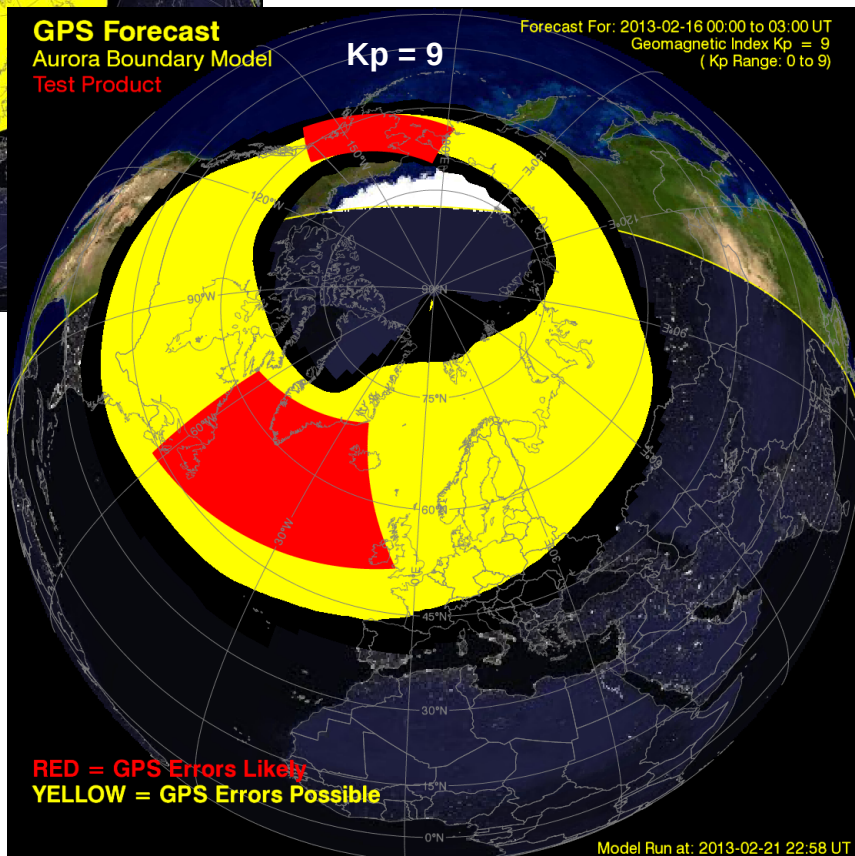
High Latitude GPS Forecast

(Product Concept)









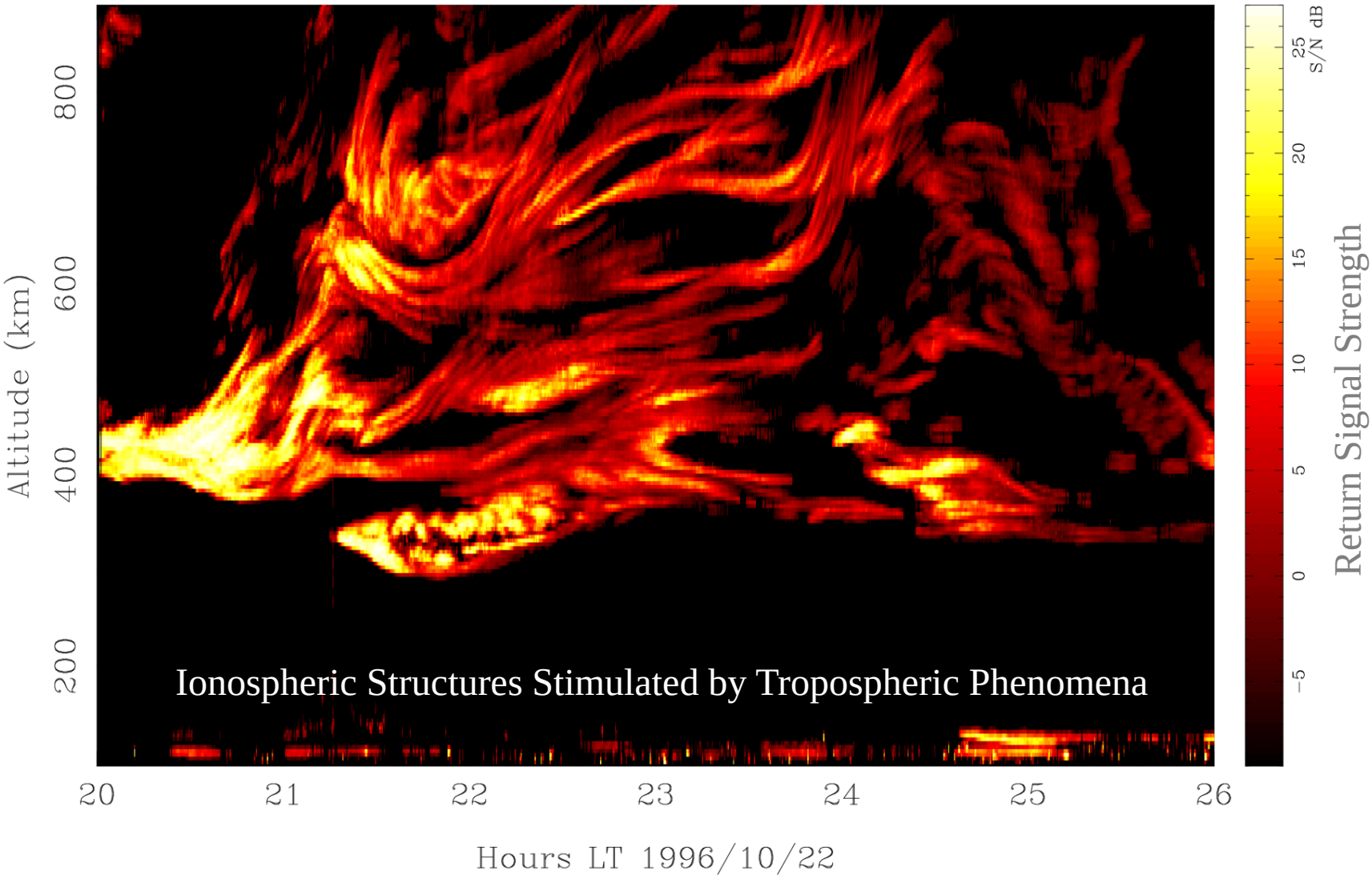
- **Forecast of High Latitude GPS Conditions**
  - **Red = High Probability of Problems**
  - **Yellow = Moderate Probability of Problems**
- **Clearly a need for validation**
  - **High Latitude Ground Based GPS receivers**
  - **High Latitude Scintillation monitors**

Whole Atmosphere Modeling

From the Ground to Space

- **Challenge: Fine structures in the ionosphere affect GPS signals and modify radio transmission paths or block transmission altogether**
  - **Changes in Total Electron Content (TEC) impact GPS radio navigation**
  - **Ionospheric irregularities impact dual frequency GPS and satellite communication.**
  - **The lower atmosphere drives variability in the Ionosphere/Thermosphere system**
    - **Planetary waves, gravity waves, tides, etc… propagate upward to the thermosphere.**
    - **The ionosphere is strongly coupled to the thermosphere**
- **Solution: Develop the Whole Atmosphere Model and couple it with an Ionosphere Model**

Many low and mid latitude ionospheric structures are driven from below



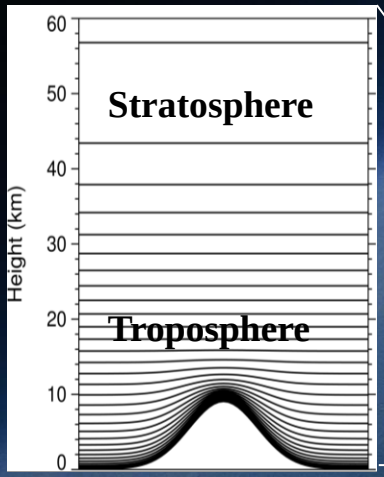
Forecasting the Ionosphere: Integrated Dynamics in Earth's Atmosphere (IDEA)

Whole Atmosphere Model (WAM = Extended GFS)
Ionosphere Plasmasphere Electrodynamics (IPE)
Integrated Dynamics in Earth's Atmosphere (IDEA = WAM+IPE)

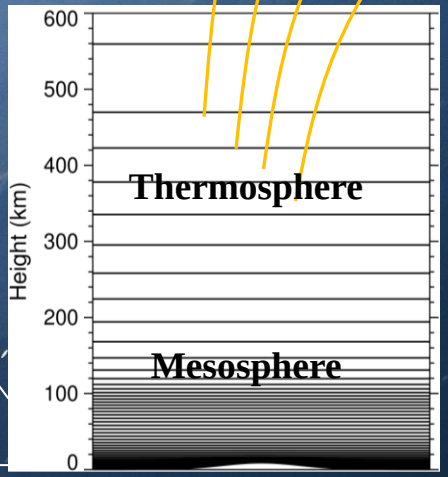
Multi-day forecasts for GPS and radio communication customers

FY15 Deliverable: Prototype 2-day ionospheric forecast using WAM (with data assimilation) and preliminary ionospheric model

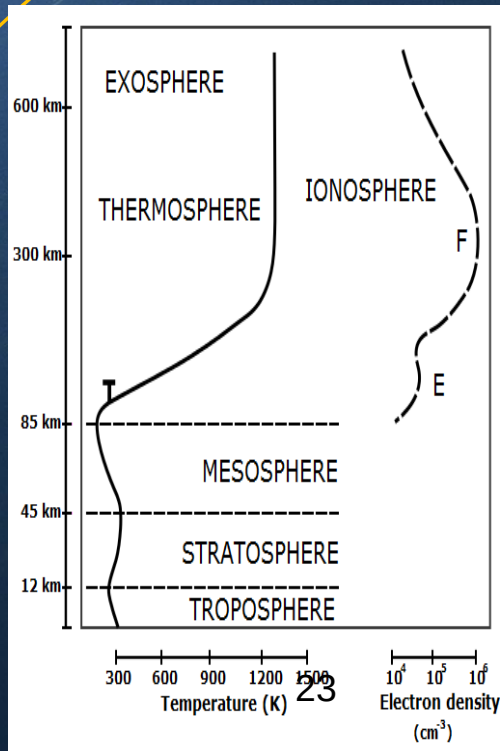
NOAA Global Forecast System Model 0 – 60 km



WAM Extend GFS up to 600 km

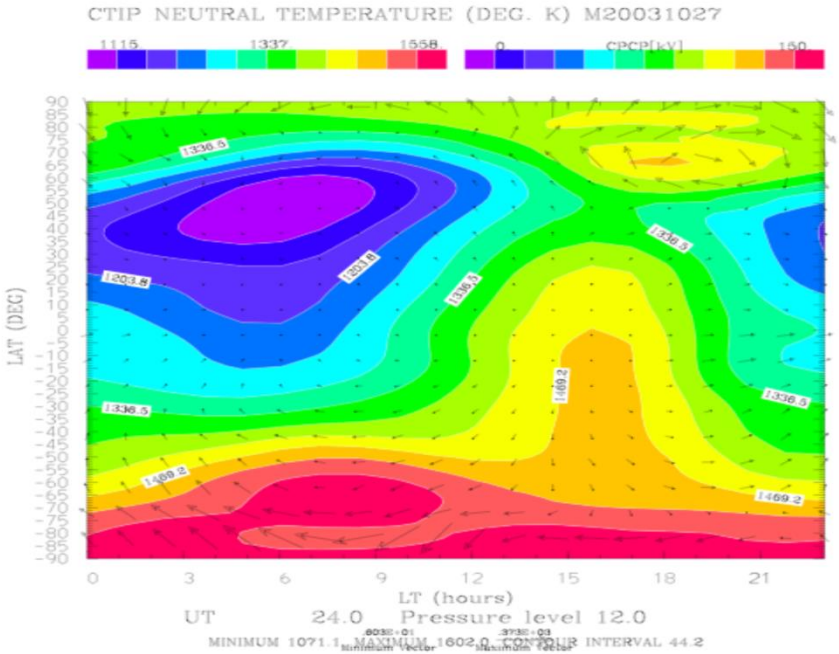


IPE Model

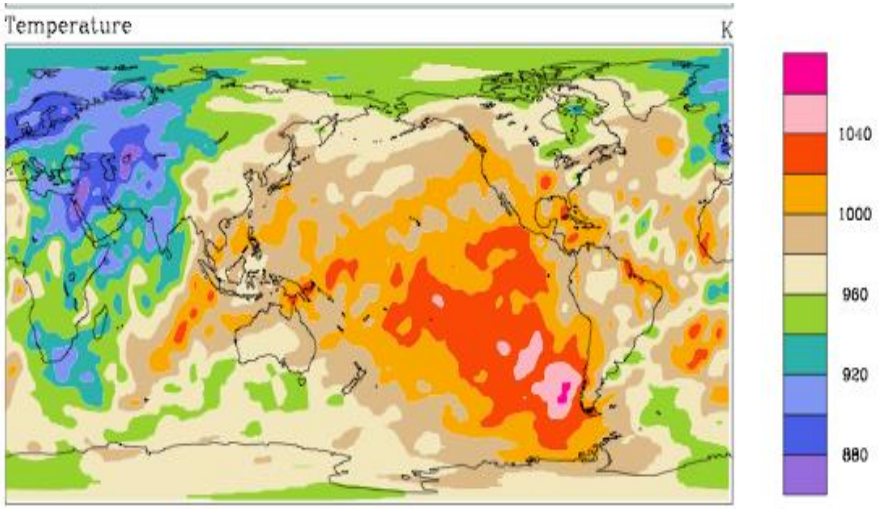


With and Without IDEA: Adding the Lower Atmosphere

Typical ionosphere-thermosphere model: Global maps show little fine structure



Ionosphere-thermosphere model coupled to the lower atmosphere: Global maps show structure relevant to GPS accuracy and available



Developing an Ionospheric Index

- **Challange: GPS/GNSS is affected by several space weather phenomena**
  - **Large scale (100 km) ionospheric structures**
  - **Small scale (1 km) ionospheric structures**
  - **Aurora (geomagnetic storms)**
  - **Equatorial scintillation**
  - **Solar radio bursts**
- **It is very difficult to develop a simple ionosphere index that captures all of them**
- **Solution: Develop an alert product based on several types of space weather**

TEC: How Well Can We Do?

Today

TEC	Nowcast	24 Hr Forecast
High Latitude	Need More Data	Need better physics
Mid Latitude	Ground GPS Data	Need to transition IDEA
Low Latitude	Ground GPS Data	Need to transition IDEA

1 Year

TEC	Nowcast	24 Hr Forecast
High Latitude	Ground GPS Data	IRI/CTIPe/IPE
Mid Latitude	Ground GPS Data	Need to transition IDEA
Low Latitude	Ground GPS Data	Need to transition IDEA

5 Years

TEC	Nowcast	24 Hr Forecast
High Latitude	Ground GPS	IPE/WAM/Geospace
Mid Latitude	COSMIC II	IDEA
Low Latitude	COSMIC II	IDEA

Scintillation: How Well Can We Do?

Today

Scintillation	Nowcast	24 Hr Forecast
High Latitude	Need More Data	Need better physics
Mid Latitude	Ground GPS Data	Need to transition IDEA
Low Latitude	Ground GPS Data	Need to transition IDEA

1 Year

Scintillation	Nowcast	24 Hr Forecast
High Latitude	ROTI Test Product	IRI/CTIPe/IPE
Mid Latitude	ROTI Test Product	Need to transition IDEA
Low Latitude	ROTI Test Product	Need to transition IDEA

5 Years

Scintillation	Nowcast	24 Hr Forecast
High Latitude	ROTI Product	IPE/WAM/Geospace
Mid Latitude	ROTI Product	IDEA
Low Latitude	ROTI Product	IDEA

Operations to Research

- **Working with research funding agencies to guide and prioritize research**
  - **Understanding the tropospheric drivers of ionosphere**
    - **Gravity waves, tides, planetary waves**
  - **Understanding the geomagnetic storm impacts**
    - **On high latitude systems**
    - **On mid latitude ionosphere**
  - **Developing forecasts of the other two ionospheric drivers**
    - **Solar EUV irradiance**
    - **Geomagnetic Storms**

Summary

- **SWPC has surveyed a number of GPS/GNSS users and user groups**
- **New specification products and new capabilities are currently in various stages of development.**
  - **Expanding observations and broadening the current regional products to global scale**
- **Multi-day forecast products based on new physics and new models are under development**
  - **Forecasts of high latitude conditions using aurora forecast models**
  - **Forecasts of mid and low latitude conditions using a whole atmosphere model coupled with ionosphere model (IDEA)**