



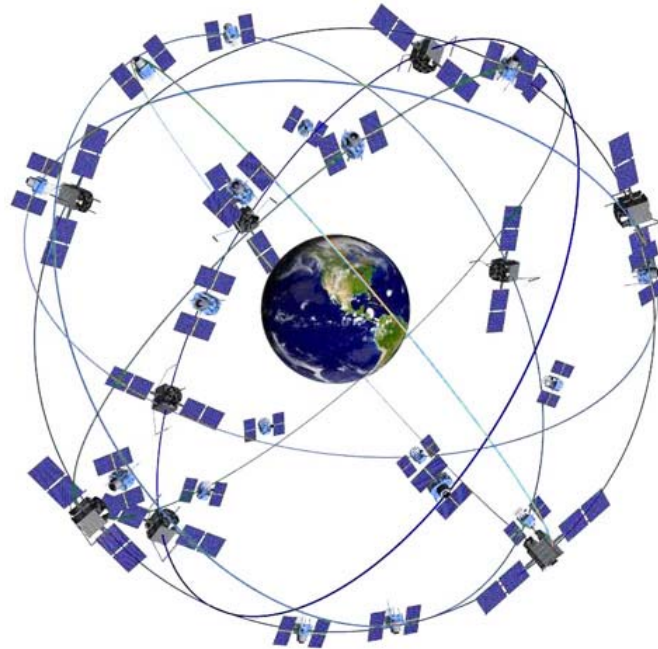
# ***Space Weather Effects on GPS***

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# *How GPS works*



- **Triangulation from known satellite positions**
- **Distance calculated based on radio signal travel time**
- **Must correct for delays due to propagation through the atmosphere**



# GPS Error Sources

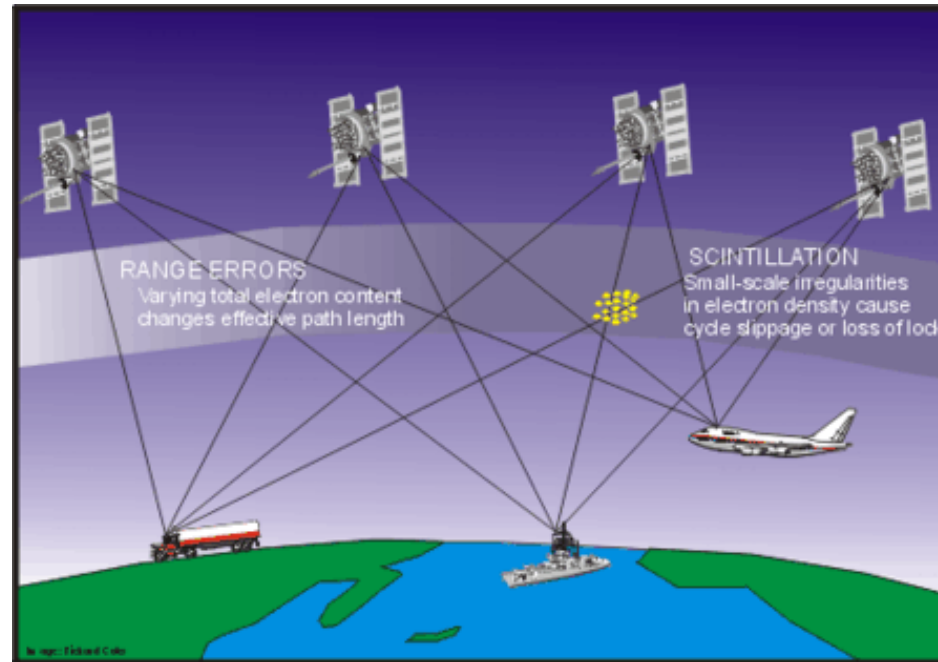


<b>Typical Error in Meters (per satellites)</b>	<b>Standard GPS</b>	<b>Differential GPS</b>
• <b>Satellite Clocks</b>	<b>1.5</b>	<b>0</b>
• <b>Orbit Errors</b>	<b>2.5</b>	<b>0</b>
• <b>Ionosphere</b>	<b>5.0</b>	<b>0.4</b>
• <b>Troposphere</b>	<b>0.5</b>	<b>0.2</b>
• <b>Receiver Noise</b>	<b>0.3</b>	<b>0.3</b>
• <b>Multipath</b>	<b>0.6</b>	<b>0.6</b>

**The ionosphere is the largest source of error for Standard GPS and second largest for Differential GPS**



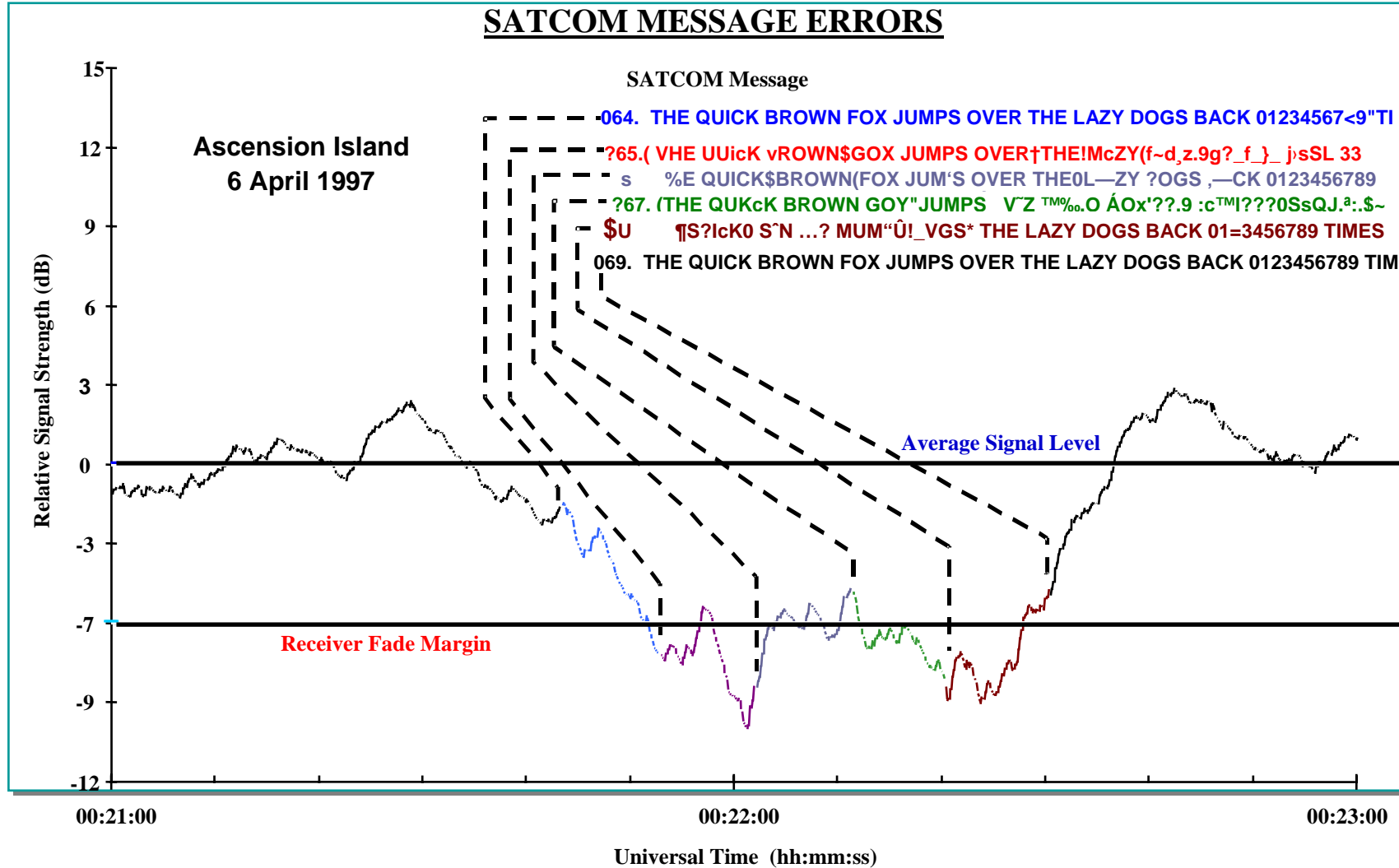
# *Ionosphere Effects on GPS*



**The ionosphere is defined as the region of the upper atmosphere where radio signal propagation is affected by charged particles.**

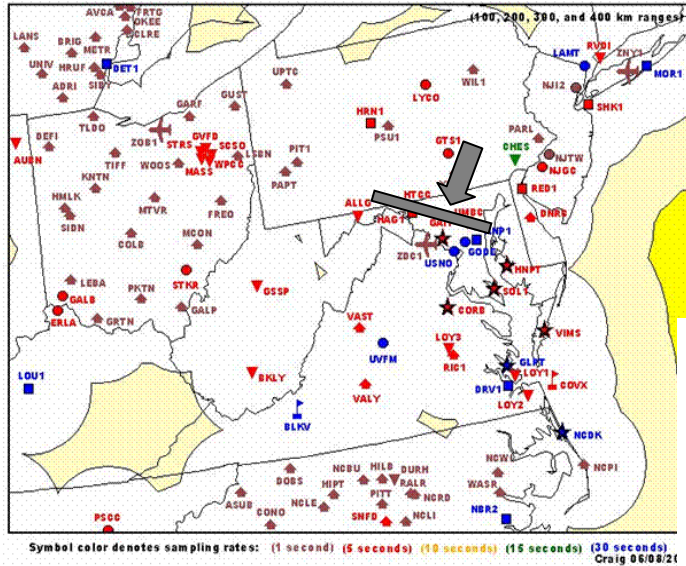


# Scintillation Effects



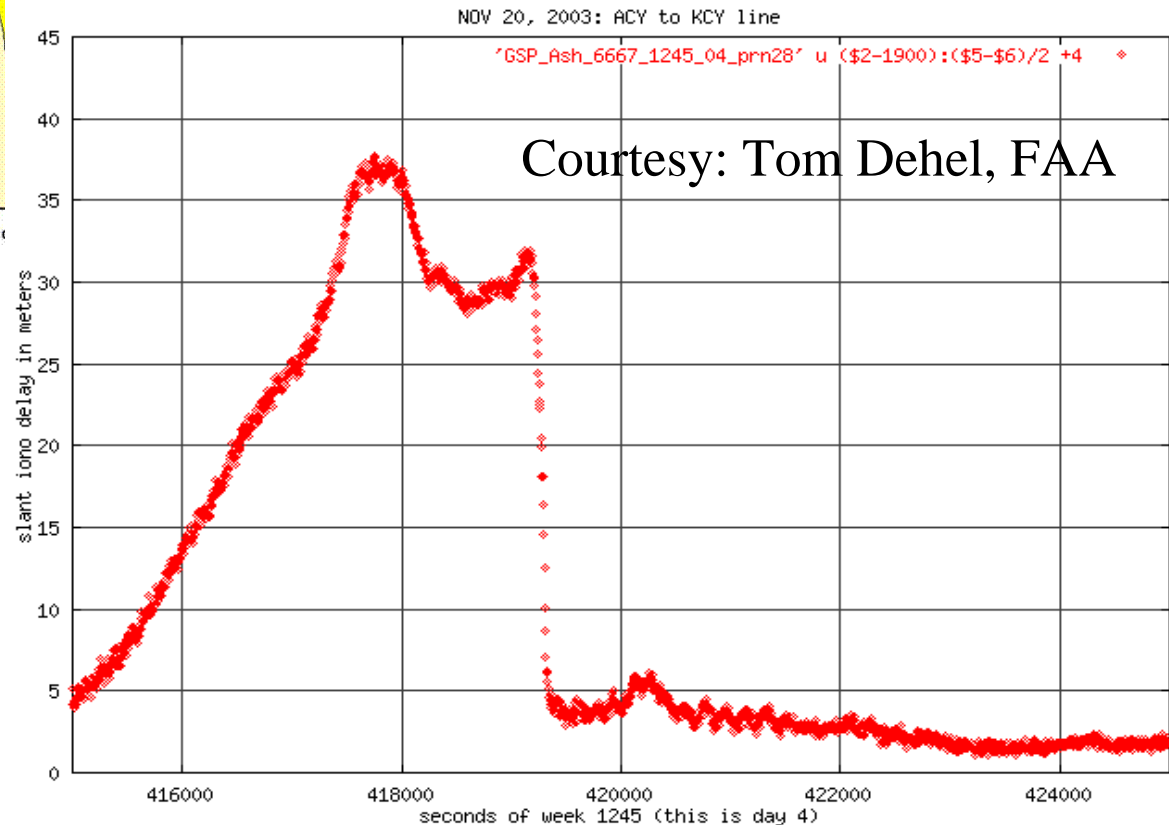


# Ionosphere Challenges



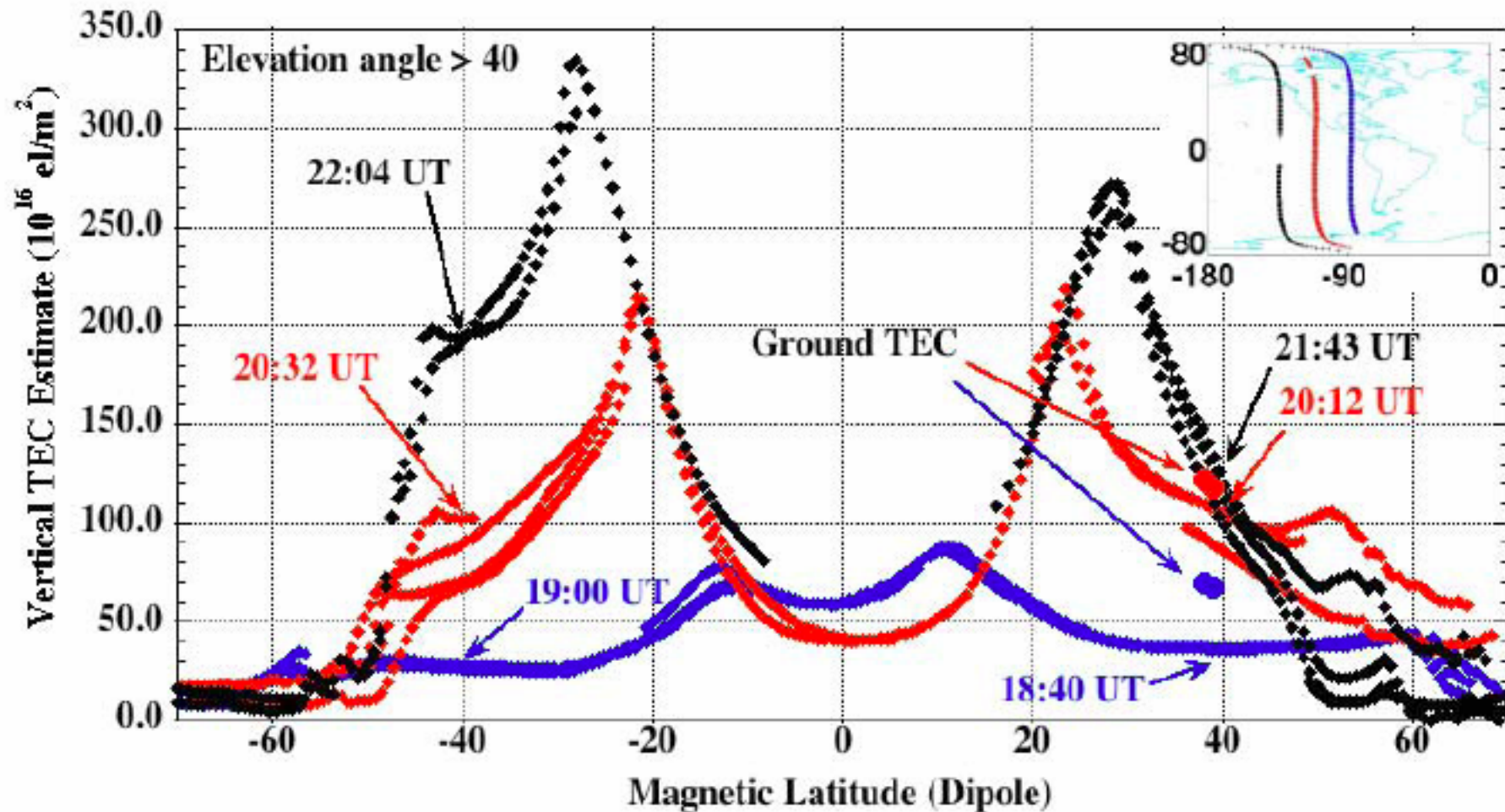
**October 29<sup>th</sup>, 2003**  
**“walls” of TEC challenge**  
**provision of integrity with**  
**differential GPS**

TEC “walls”:  
130 TEC units over 50 km  
20 m of GPS delay;  
walls move 100 to 500 m/s





# Anomaly crests

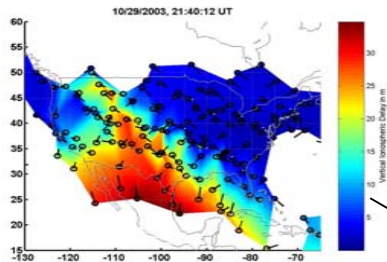


1 TECU =  $10^{16}$  electrons  $\text{m}^{-2}$

Mannucci et al., 2005

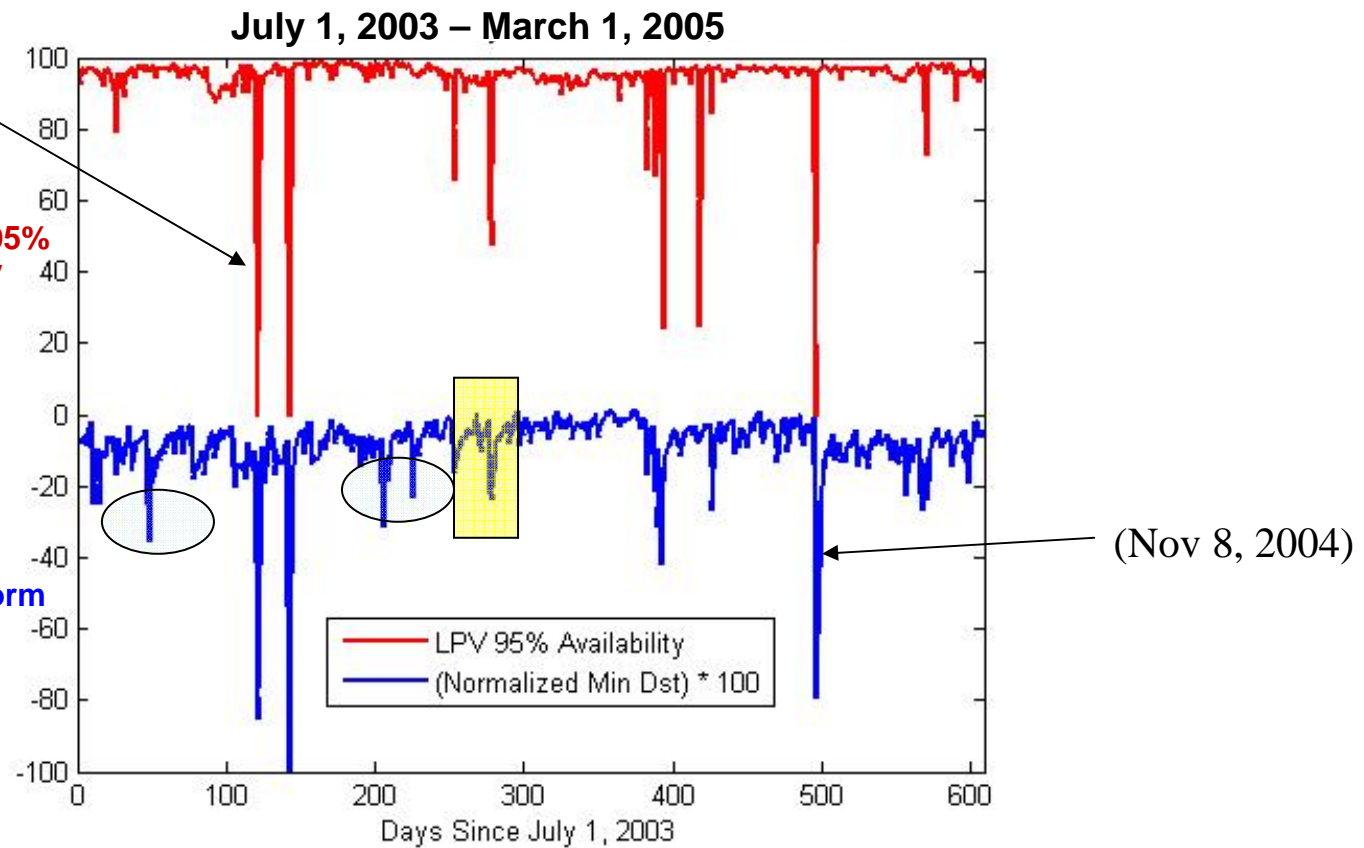


# Space Weather Effects on WAAS



**% CONUS at 95% Availability**

**Magnetic Storm Index**



**15 hour loss on 10/29; 11.3 hour loss on 10/30, shorter losses on 11/20/2003;**





# ***Ionosphere Corrections***



- Need to model the ionosphere to compute corrections
- Empirical climatological models: Klobuchar Coefficients
- Physics based numerical models: CTIPe, TIE-GCM
- Data assimilation schemes: WAAS, US-TEC, GAIM

Models can provide specification and forecast

The ionosphere is highly variable in space and time



# *US-TEC Product*



***<http://www.sec.noaa.gov/ustec>***

- Current NOAA capability for characterizing the total number of free electrons (TEC) in the ionosphere, with parallel input data streams for reliability
- Since 2004, a product characterizing the ionospheric TEC over the continental US (CONUS) has been running in real-time at NOAA's Space Environment Center (SEC)
- The ionospheric data assimilation model uses a Kalman filter and ingests ground-based GPS data to produce 2-D maps of total electron content over the CONUS
- Product evolved from a collaboration between SEC and NOAA's National Geodetic Survey (NGS), National Geophysical Data Center (NGDC), and Forecast Systems Laboratory (FSL)

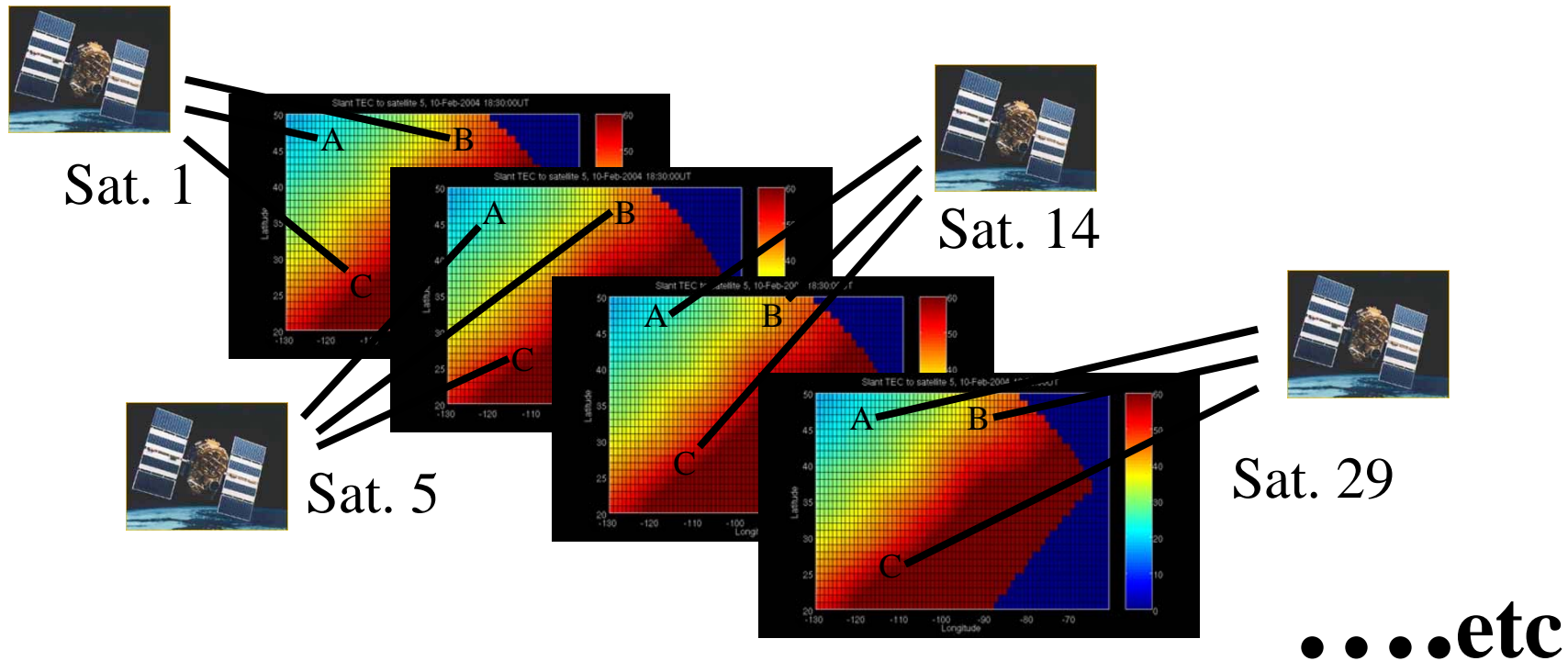
## **Primary Product:**

**Real-time ionospheric maps of total electron content every 15 minutes. Currently uses about 100 real-time GPS stations from the CORS network**

QuickTime™ and a  
TIFF (PackBits) decompressor  
are needed to see this picture.



# Slant-Path TEC Maps



## Applications:

Ionospheric correction for single frequency GPS; NDGPS positioning; dual-frequency integer ambiguity resolution for rapid centimeter accuracy positioning (OPUS).



# *US-TEC Validation Summary*



Differential TEC:

Slant = 2.4 TEC units

Vertical = 1.7 TEC units

“Absolute” FORTE ray tracing:

Slant = 2.7 TEC units

Vertical = 1.9 TEC units

- Estimated US-TEC slant path total electron content uncertainty < 3 TEC units (equivalent to about 45 cm of signal delay at L1 frequencies)
- Estimate US-TEC vertical total electron content uncertainty < 2 TEC units (equivalent to about 30 cm of signal delay at L1 frequencies)



# *SWPC Ionosphere Goals*



## **Produce global real-time specification and forecast**

Web display of GAIM output from AFWA

Assimilation schemes using numerical models: CTIPe, IDEA

## **Improve US-TEC**

CONUS: Specification with 10 minute latency

US-TEC slant path total electron content uncertainty < 2 TECU

US-TEC vertical electron content uncertainty < 1 TECU

CONUS: Provide Forecast

1 hour forecast as good as specification

3 hour forecast: uncertainty < 3 TEC units

6-12 hour forecasts



# *Conclusions*



**Ionosphere Services is a fast growing area in Space Weather**

**SWPC is committed to offer improved products and tools**

**SWPC is ready to collaborate on:**

Data

Models and model results

Research

Services

**Solar Maximum is on the way (2012?)**