Space Weather Effects on GPS

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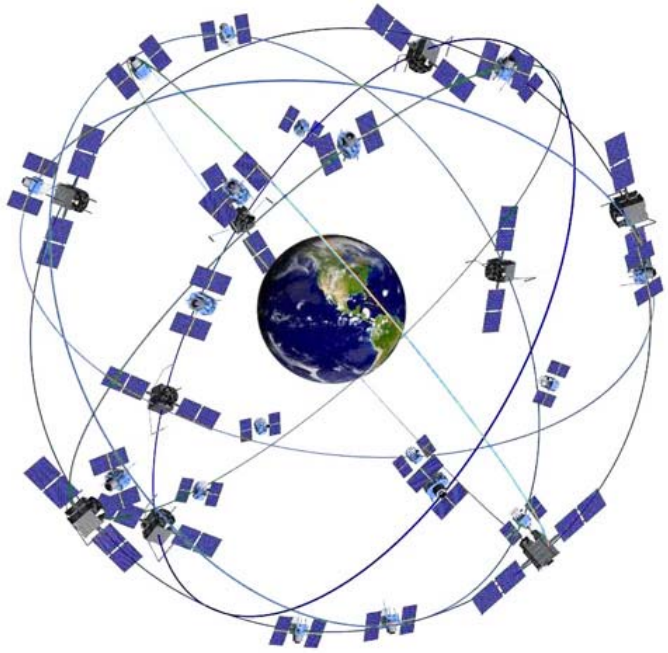
How GPS works



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

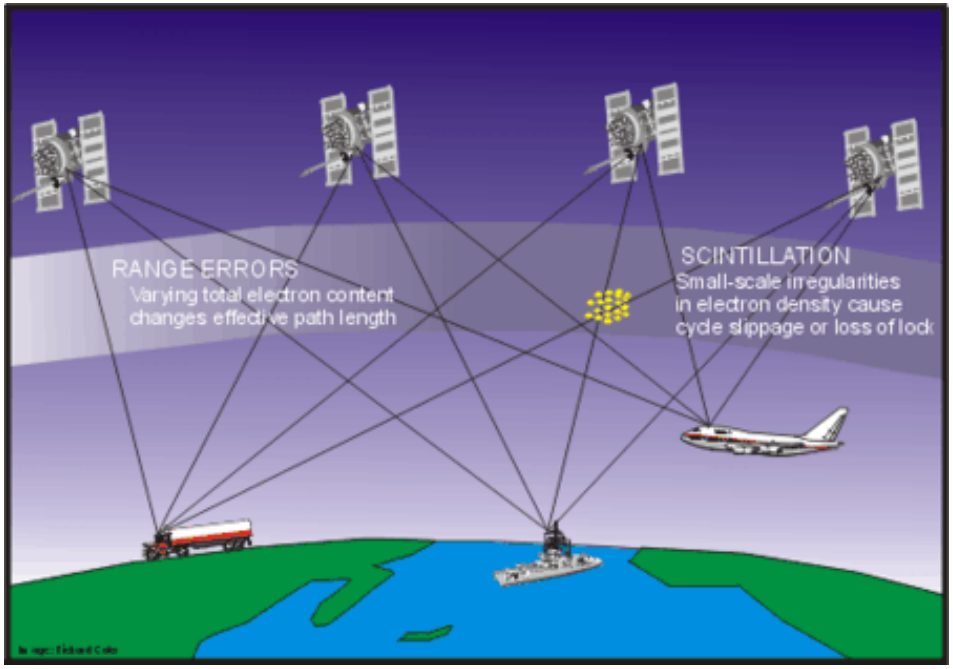
GPS Error Sources

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

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

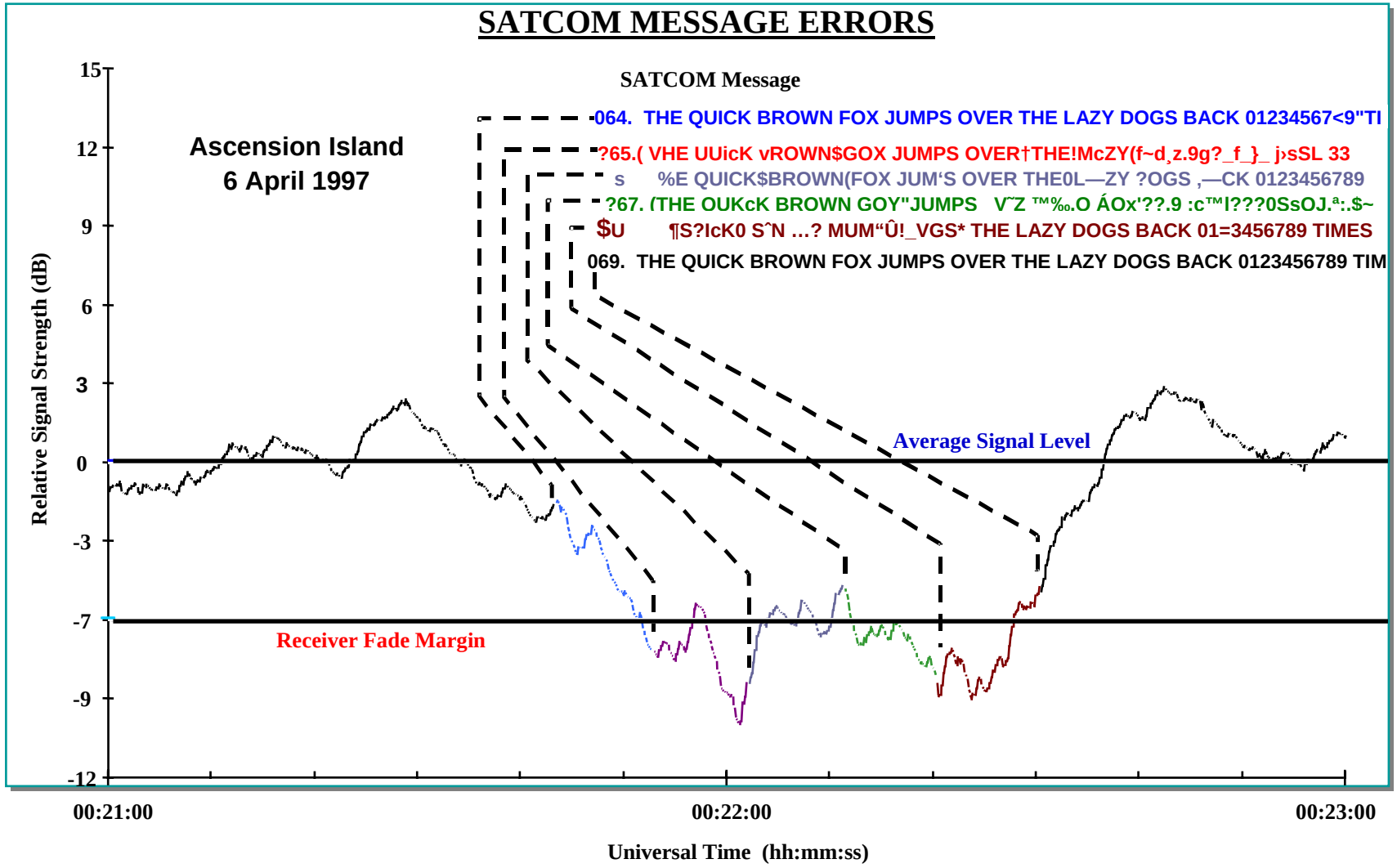
http://www.trimble.com/gps/howgps-error2.shtml#3

Ionosphere Effects on GPS



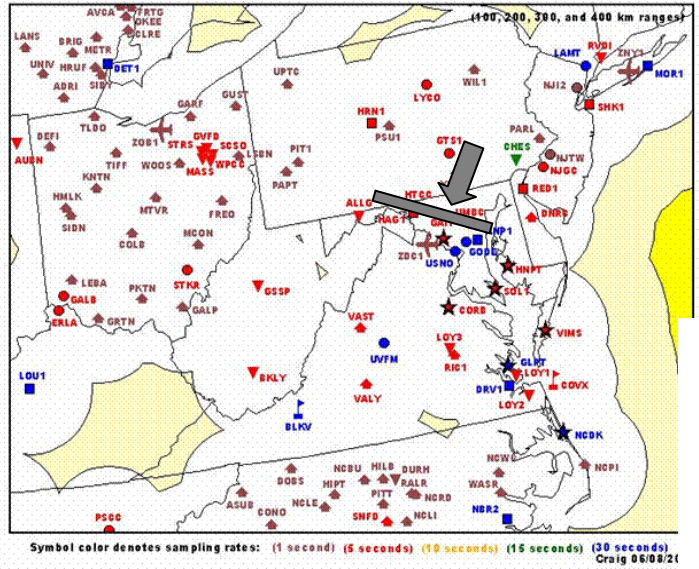
The ionosphere is defined as the region of the upper atmosphere where radio signal propagation is affected by charged particles.

Scintillation Effects



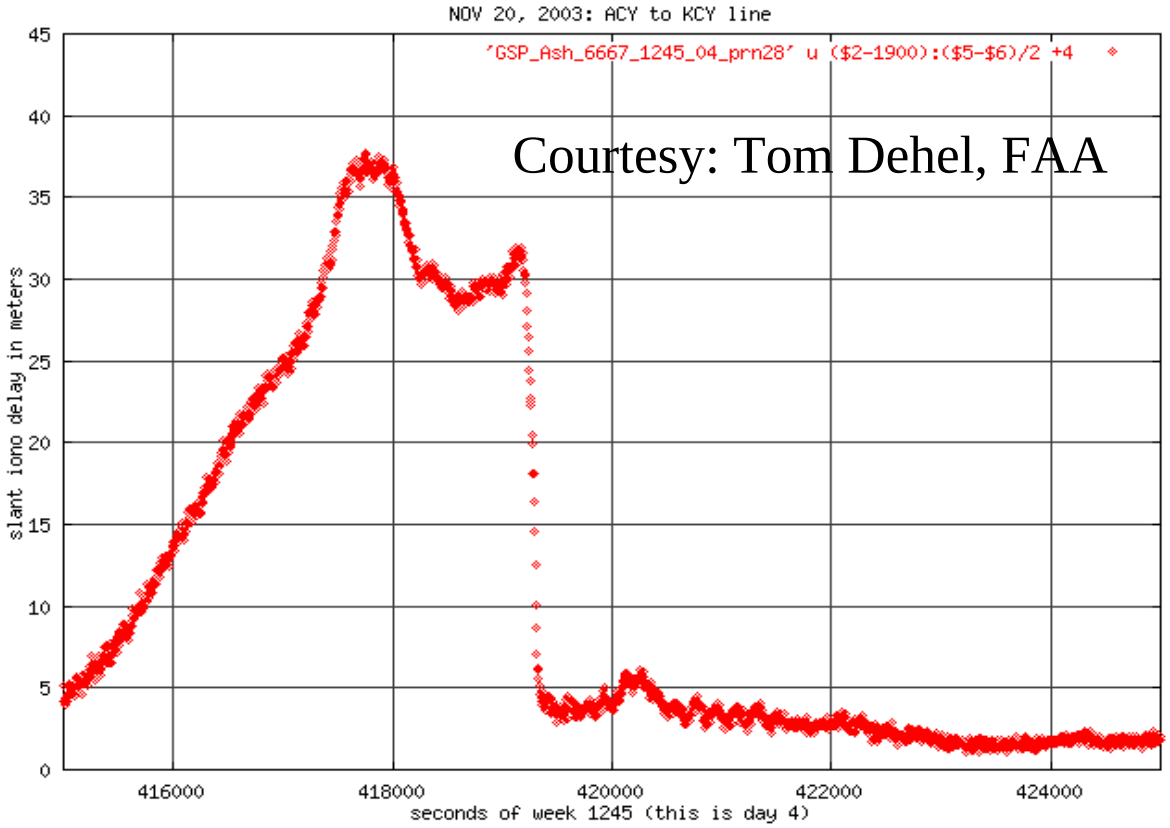
S. Basu, private communication

Ionosphere Challenges

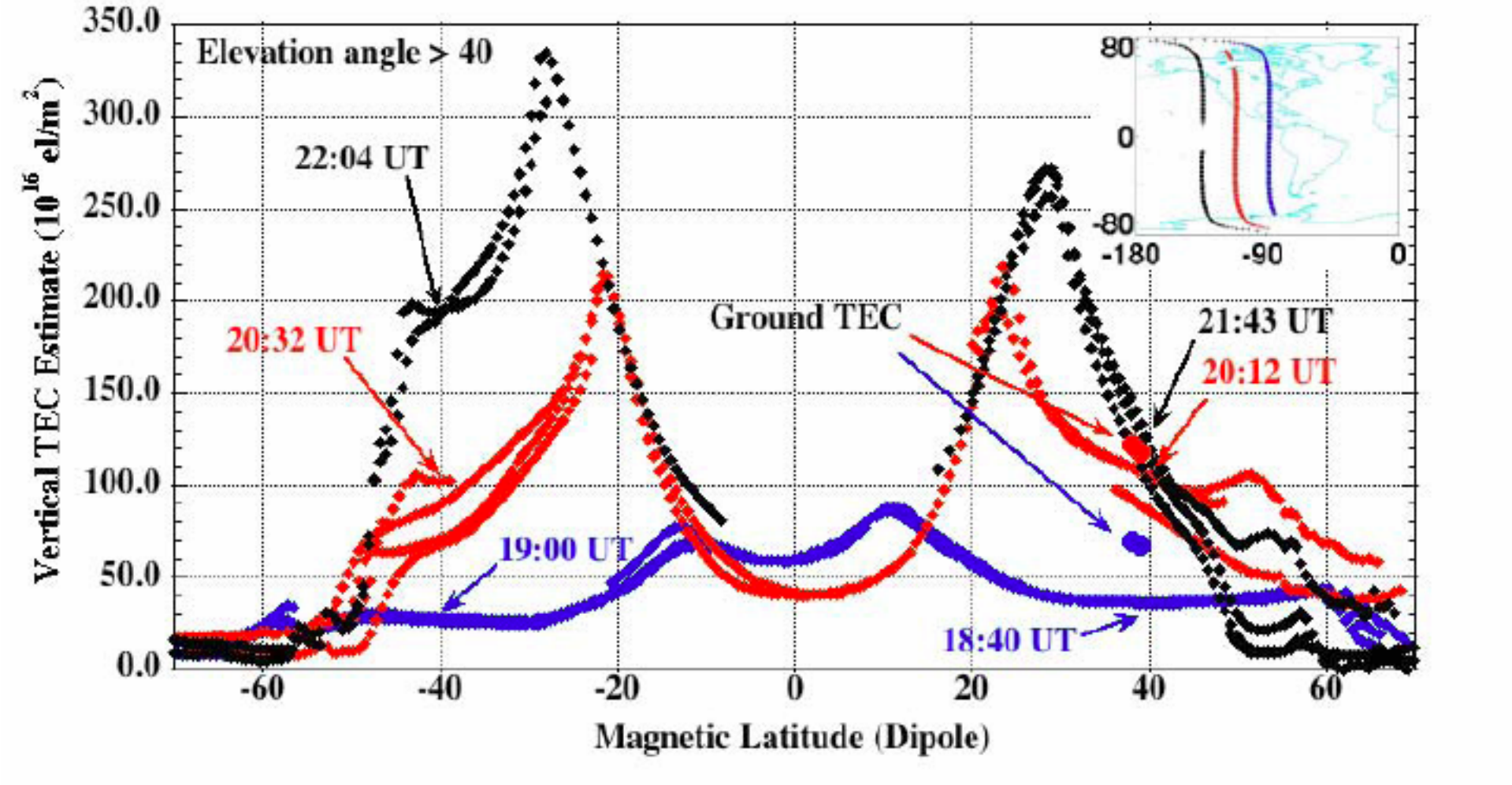


October 29th, 2003
"walls" of TEC challenge
provision of integrity with
differential GPS

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



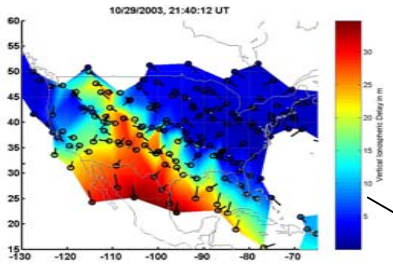
Anomaly crests



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

Mannucci et al., 2005

Space Weather Effects on WAAS

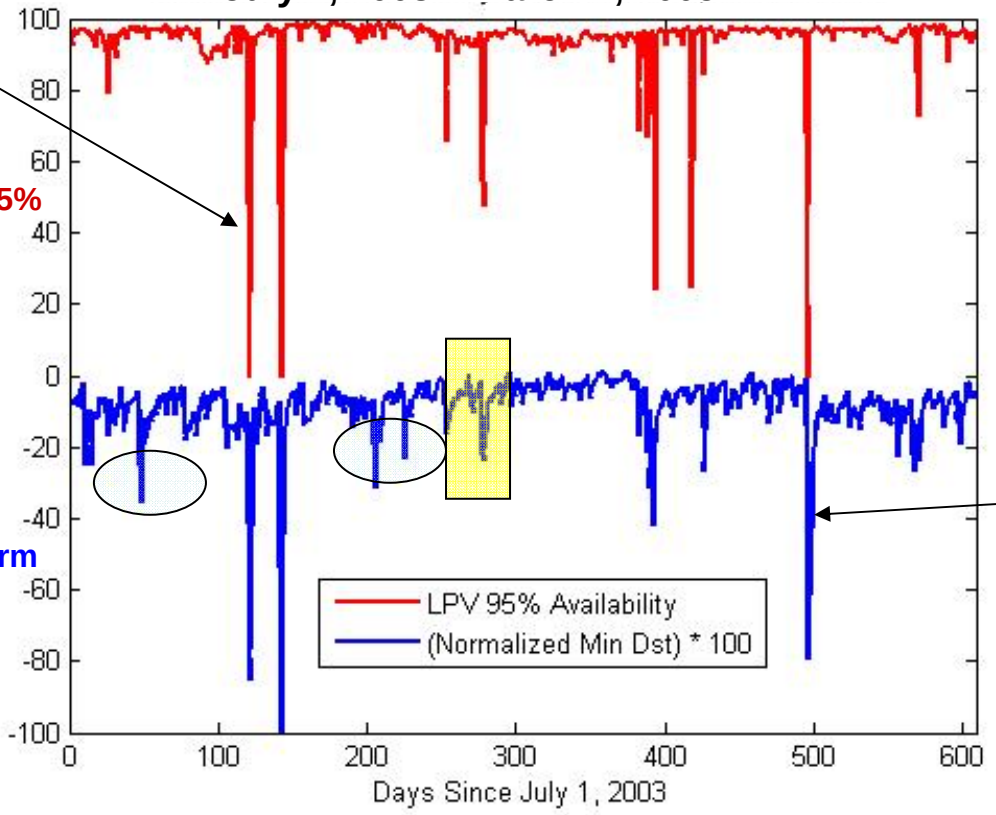


July 1, 2003 – March 1, 2005

% CONUS at 95% Availability

Magnetic Storm Index

(Nov 8, 2004)



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

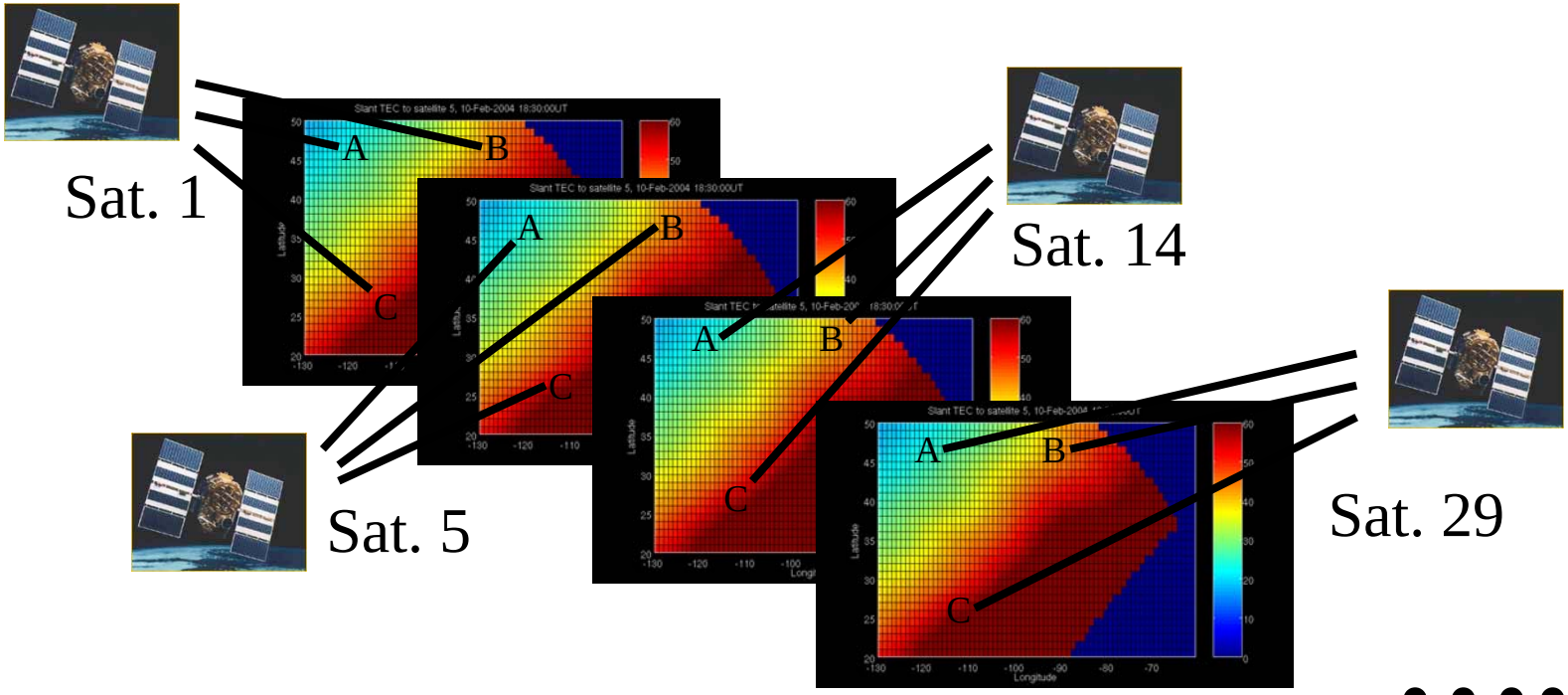
http://www.sec.noaa.gov/ustec

- 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



….etc

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?)