The Global Positioning System: Update and Capabilities

GPS III Satellite (www.gps.gov)

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Outline

- GPS Overview
- Current Performance
- Augmentation Systems
- GPS Modernization
- Applications
  - Practical
  - Scientific
- Summary

GPS IIF-8 satellite launched Oct 29. Photo courtesy of United Launch Alliance.

Global Positioning System (GPS) Overview

- **Worldwide Radio-Navigation System**
  - Developed and maintained by U.S. DoD
  - Original intended use was military
  - Civilian use enabled (SA turned off in 200
- **Provide 3D Positioning, Navigation and T**
  - 24hrs/day,7 days/week, everywhere!
- **Two Levels of Service**
  - Standard Positioning Service (SPS) - Civili
  - Precise Positioning Service (PPS) - Militar
- **Based on Satellite Ranging**
  - Users determine position by measuring th distance from a group of satellites in space
- **GPS Consists of Three Segments**
  - Space Segment
  - Control Segment
  - User Segment

Space Segment

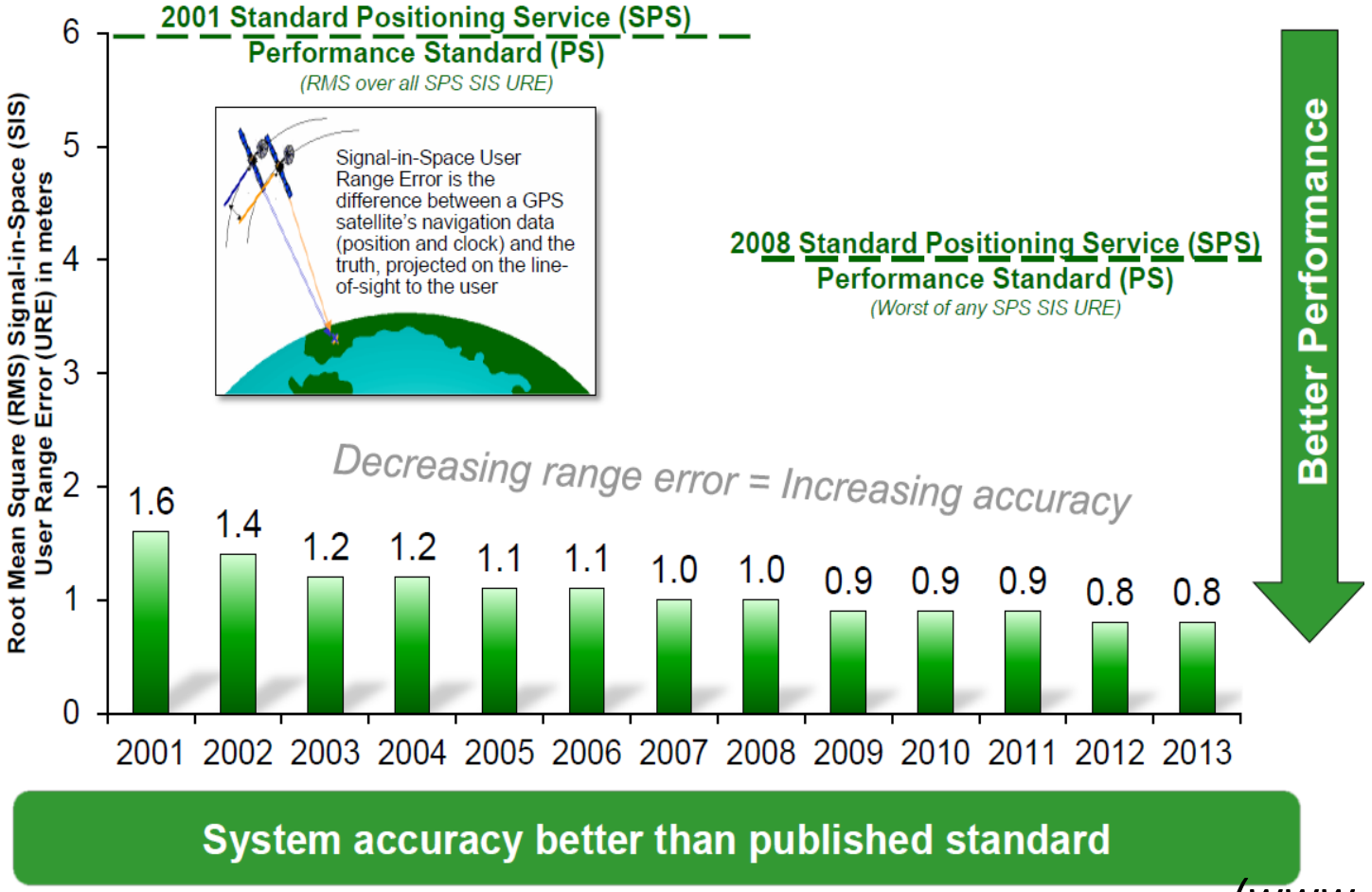
User Segment:
You, me and >200 Million other people

GPS Control Segment

GPS IIR-M	7		
GPS IIF	7	1.8	4.4
Constellation	31	10.3	23.9

GPS SPS Signal in Space Performance

Signal in Space User Range Errors have been steadily decreasing since 2001.



System accuracy better than published standard

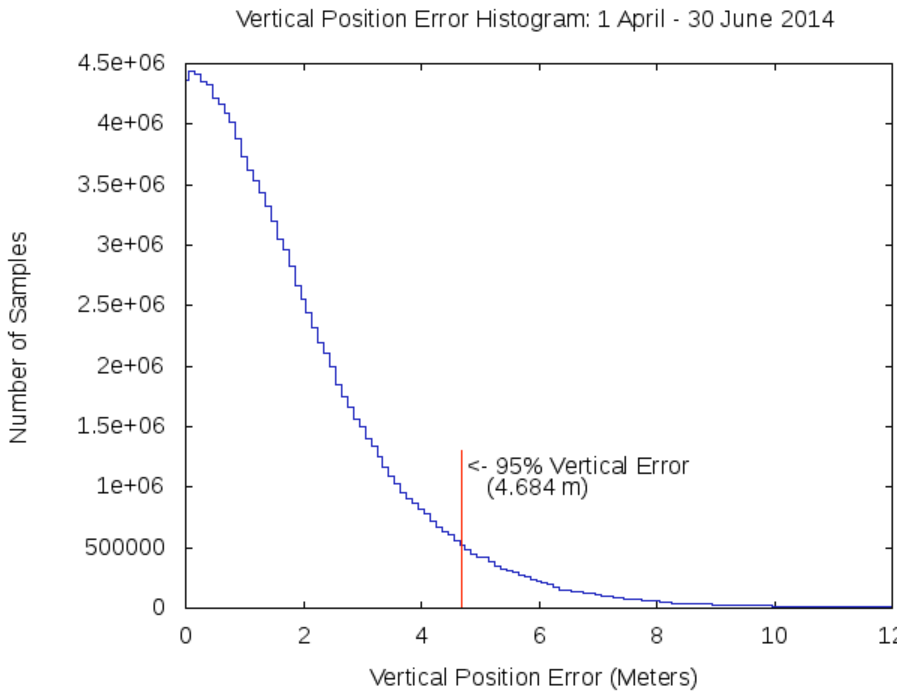
(www.gps.gov)

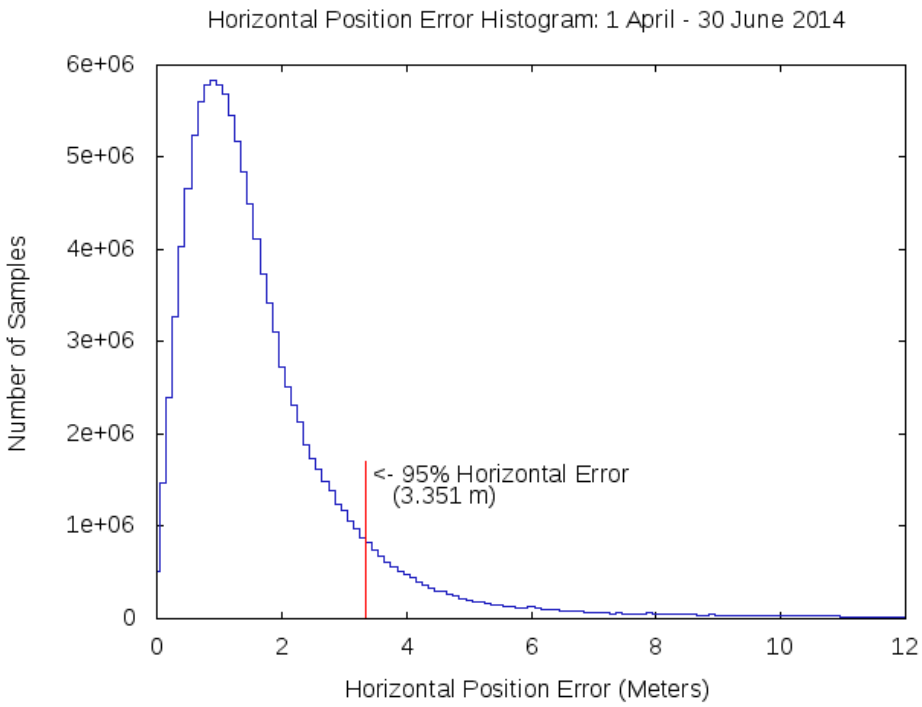
This is not the same as the user accuracy. Pseudorange is simply the distance from a GPS satellite to a receiver.

User accuracy depends on uncontrollable factors – including atmospheric effects, sky blockage and receiver quality.

User Accuracy from FAA GPS SPS Receivers

(Vertical and Horizontal Position Errors (April – June 2014)



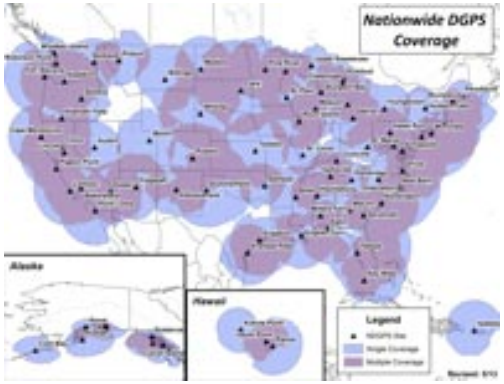


(www.nstb.tc.faa.gov/reports/PAN86_714.pdf)

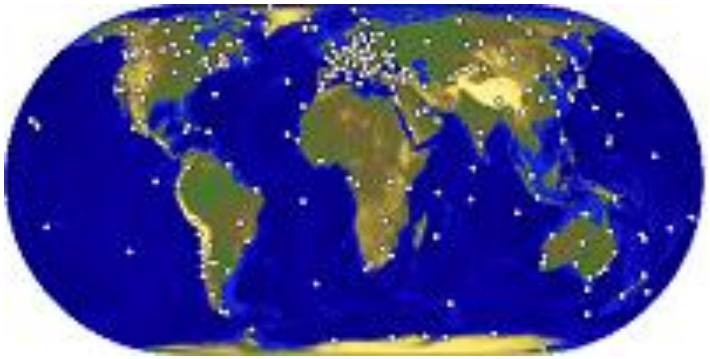
Augmentation Systems

Systems that aid GPS by providing improvements that are not part of GPS

NDGPS Network



IGS Network



U.S. CORS Network

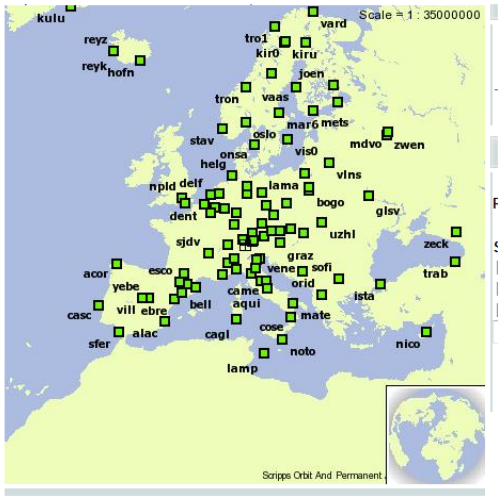
Japan's Geonet

FAA WAAS System

Other SBAS systens
EGNOS, MSAS, GAGAN

GDGPS

EUREF



GPS Modernization – New Civil Signals

Second Civil Frequency (L2C; 1227 MHz)

- Designed for commercial needs
- Combined with L1 C/A – enables ionospheric correction
- Broadcasts at a higher power
- First satellite launched with L2C in 2005 (without data msg)
- Currently 15 SVs broadcasting L2C

Third Civil Frequency (L5; 1176 MHz)

- Designed for safety-of-life transportation
- Broadcasts at a radio band reserved for aviation
- L1 C/A, L2C and L5 – together provide robust service
- First satellite launched with L5 in 2010 (without data msg)
- 8 SVs launched to date

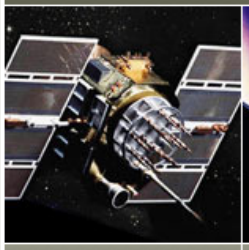
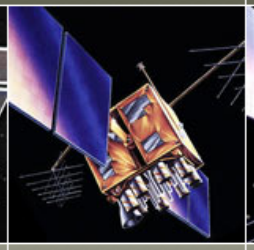
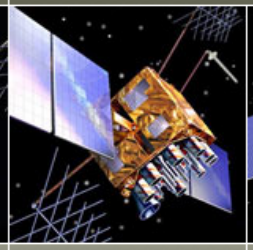
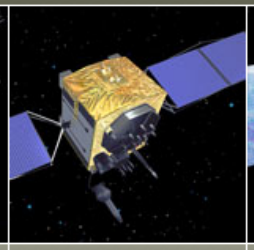
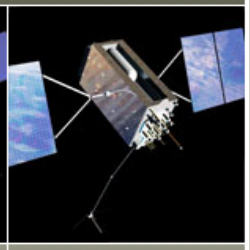
Fourth Civil Frequency (L1C; 1575 MHz)

- Designed for GNSS interoperability
- US and Europe designed as a common signal for GPS and Galileo
- QZSS, IRNSS and Compass – also plan to broadcast L1C
- GPS plans to launch first satellite with L1C in 2016
- Will enhance performance in challenging environments

Urban Canyons

Some New Signals Already Available

GPS Constellation - A Mix of Old and New Satellites

LEGACY SATELLITES		MODERNIZED SATELLITES		
				
BLOCK IIA	BLOCK IIR	BLOCK IIR(M)	BLOCK IIF	GPS III
4 operational	12 operational	7 operational	7 operational	Now in production
▪ Coarse Acquisition (C/A) code on L1 frequency for civil users ▪ Precise P(Y) code on L1 & L2 frequencies for military users ▪ 7.5-year design lifespan ▪ Launched in 1990-1997	▪ C/A code on L1 ▪ P(Y) code on L1 & L2 ▪ On-board clock monitoring ▪ 7.5-year design lifespan ▪ Launched in 1997-2004 *VIEW AIR FORCE FACT SHEET* ➡	▪ All legacy signals ▪ 2nd civil signal on L2 (L2C) *LEARN MORE* ➡ ▪ New military M code signals for enhanced jam resistance ▪ Flexible power levels for military signals ▪ 7.5-year design lifespan ▪ Launched in 2005-2009 *VIEW AIR FORCE FACT SHEET* ➡	▪ All Block IIR(M) signals ▪ 3rd civil signal on L5 frequency (L5) *LEARN MORE* ➡ ▪ Advanced atomic clocks ▪ Improved accuracy, signal strength, and quality ▪ 12-year design lifespan ▪ Launched since 2010 *VIEW AIR FORCE FACT SHEET* ➡	▪ All Block IIF signals ▪ 4th civil signal on L1 (L1C) *LEARN MORE* ➡ ▪ Enhanced signal reliability, accuracy, and integrity ▪ No Selective Availability *LEARN MORE* ➡ ▪ Satellites 9+: laser reflectors; search & rescue payload ▪ 15-year design lifespan ▪ Begins launching in 2016 *VIEW AIR FORCE FACT SHEET* ➡

(www.gps.gov)

L2C – available on 24 SVs around 2018.

L5 – available on 24 SVs around 2021. 8th vehicle launched in October 2014.

L1C – begins launching with GPS III in 2016. Available on 24 SVs around 2026.

Plan to phase out the use of Semi-codeless/ codeless receivers once the L2C and L5 SVs are fully operational.

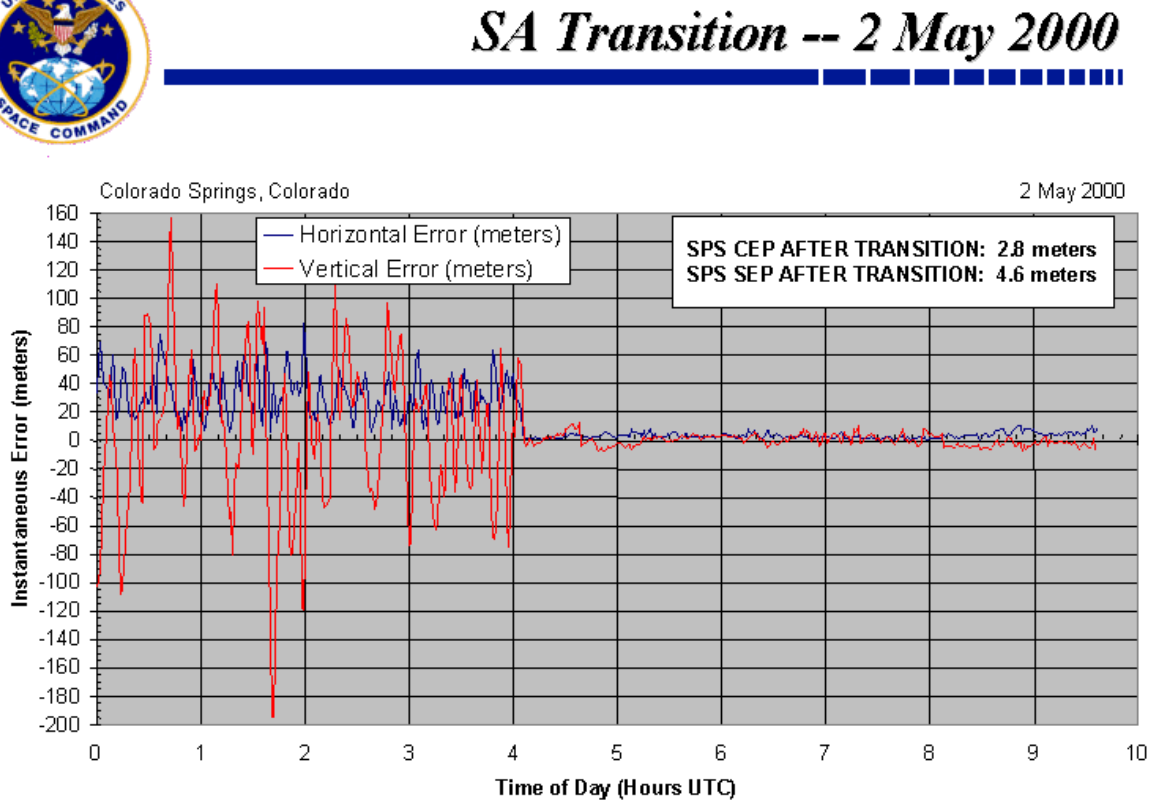
GPS Modernization – Control Segment

- **Legacy Accuracy Improvement Initiative (L-AII)**
  - Completed in 2008
  - Expanded monitoring sites from 6 to 16
  - Added 10 operational GPS monitoring sites with the NGA
- **Architecture Evolution Plan – Current Efforts**
  - Replaced the original, mainframe-based master control station
  - Improved monitor stations and ground antennas
  - Capable of monitoring all satellites in the constellation
  - Features a fully operational backup master control station
  - CNAV messages started in April 2014
- **Next Generation Operational Control System (OCX)**
  - Contract awarded to Raytheon to develop a next gen system
  - New capabilities - Fully control the modernized signals (l2C, L5 and L1C)
  - OCX Block 1 will launch and check out the GPS III satellites (~2018)
  - OCX Block 2 will support, monitor and control additional navigation signals, including L1C and L5.

Monitor Station

GPS III

What about Selective Availability (SA)?



- During the 1990s, GPS used a feature called Selective Availability that degraded civilian accuracy on a global basis
- In May 2000, at the direction of President Bill Clinton, the U.S. government ended its use of SA in order to make GPS more responsive to civil users worldwide.

The United States has no intent to use Selective Availability again. In fact, the future generation of GPS, GPS III, will not have SA features.

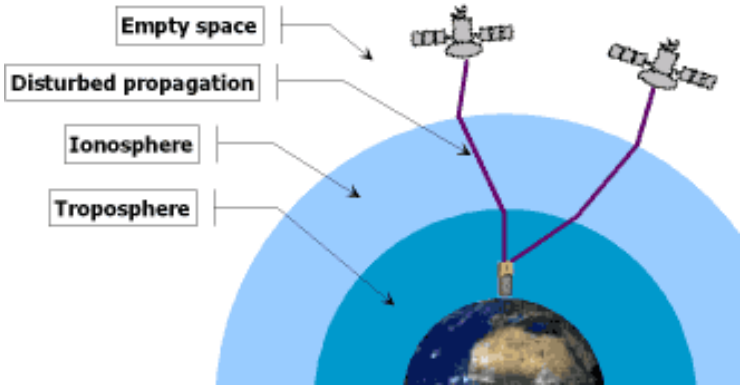
Applications

Annual Commerce in GPS Products and Services > $15billion
>200 Million Users

Scientific Exploration with GNSS

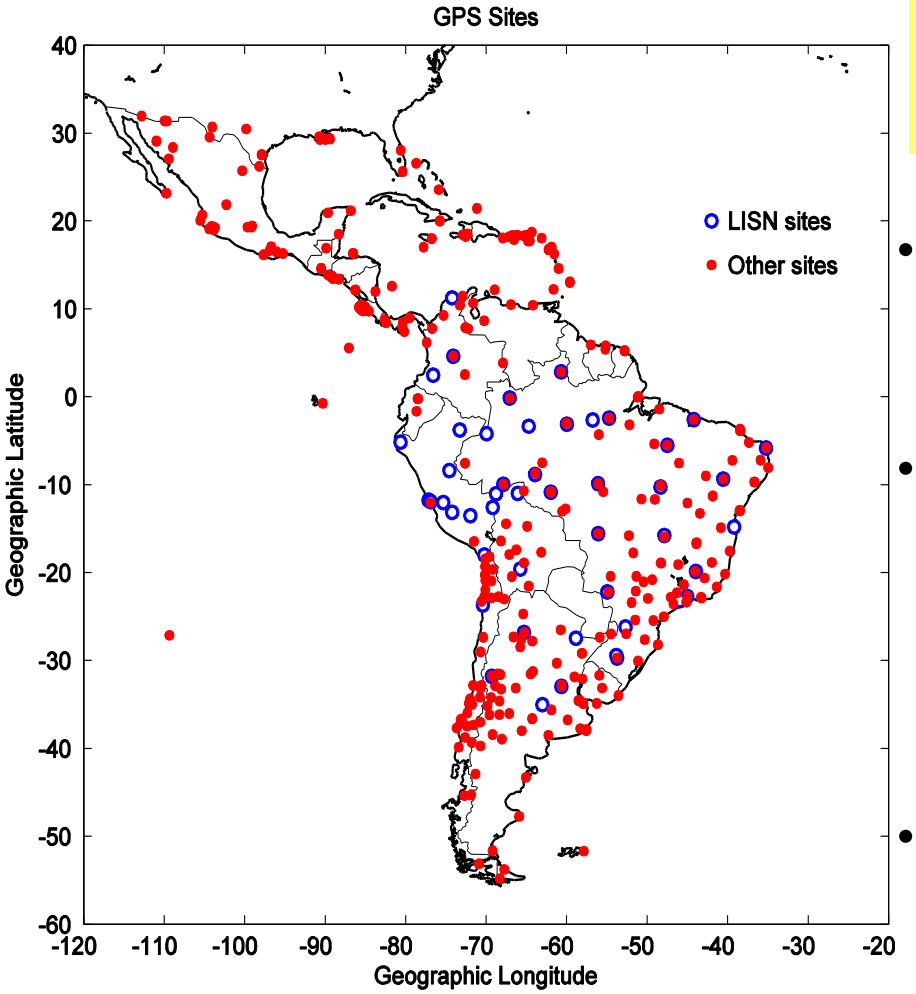
- Biology
- Archeology
- Seismic monitoring
- Tsunami studies
- Ozone layer monitoring
- Climate change
- Gravity fields
- Atmospheric science
  - ground water vapor
  - the ionosphere
  - space weather

All using GPS data…



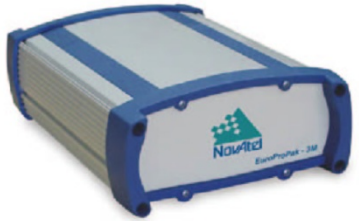
The Low Latitude Ionospheric Sensor Network (LISN)

LISN GPS Network



•To address key questions about the physics of the equatorial ionosphere

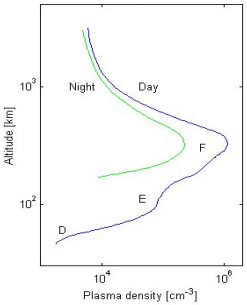
•Develop nowcast/forecasts capabilities on the onset of Spread F



•50+ GPS Receivers

- •TEC, Depletions, TID
- •Scintillation (~30)

•5 Ionosondes



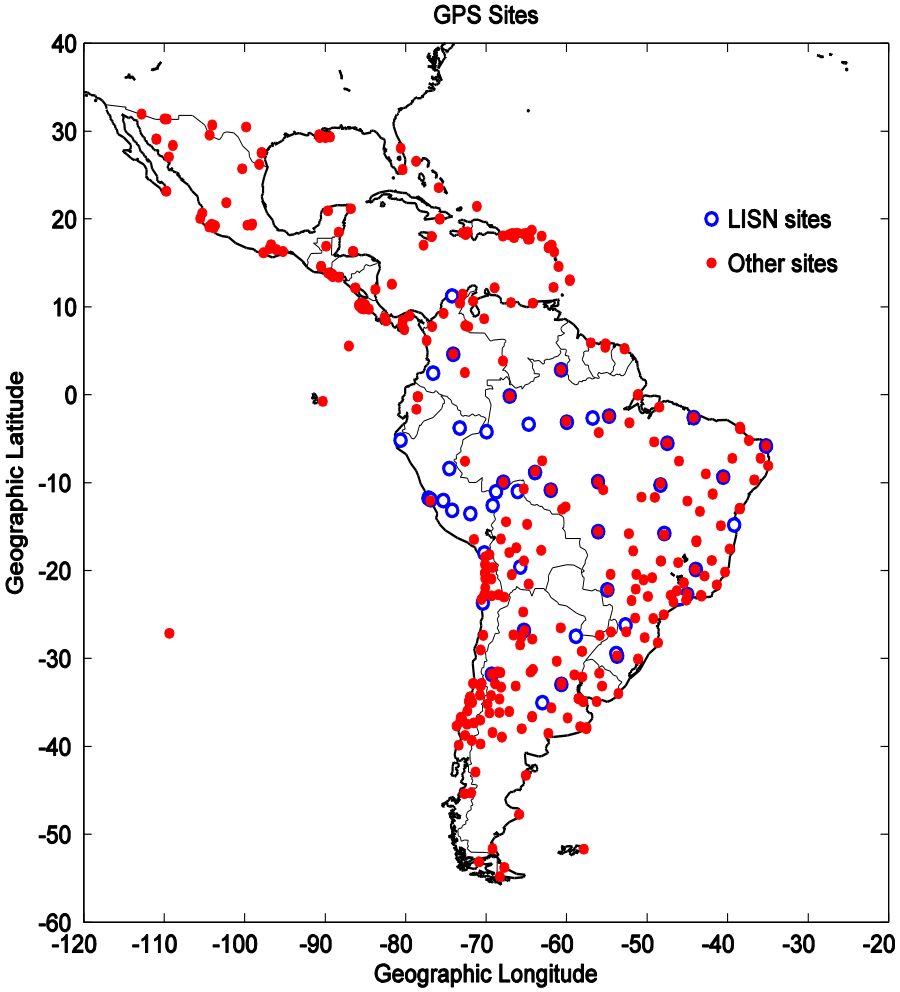
- •Virtual height
- •Bottomside density profiles
- •Meridional winds
- •Nighttime capability

•5 Magnetometers

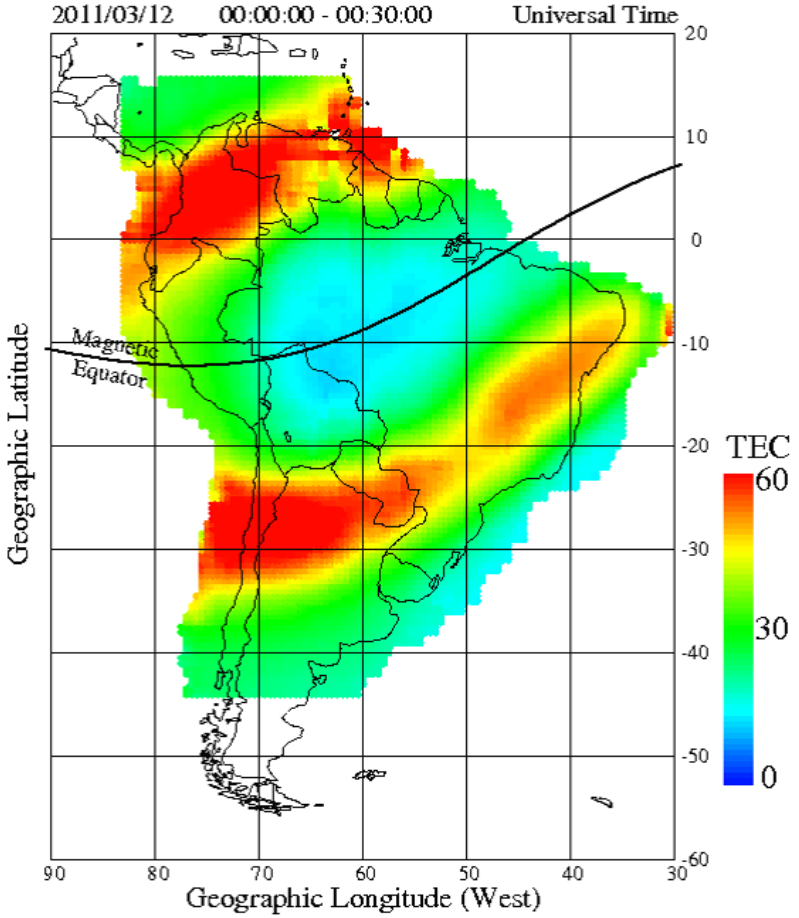
- •Monitor ionospheric currents
- •Measure Vertical plasma drifts

The Low Latitude Ionospheric Sensor Network (LISN)

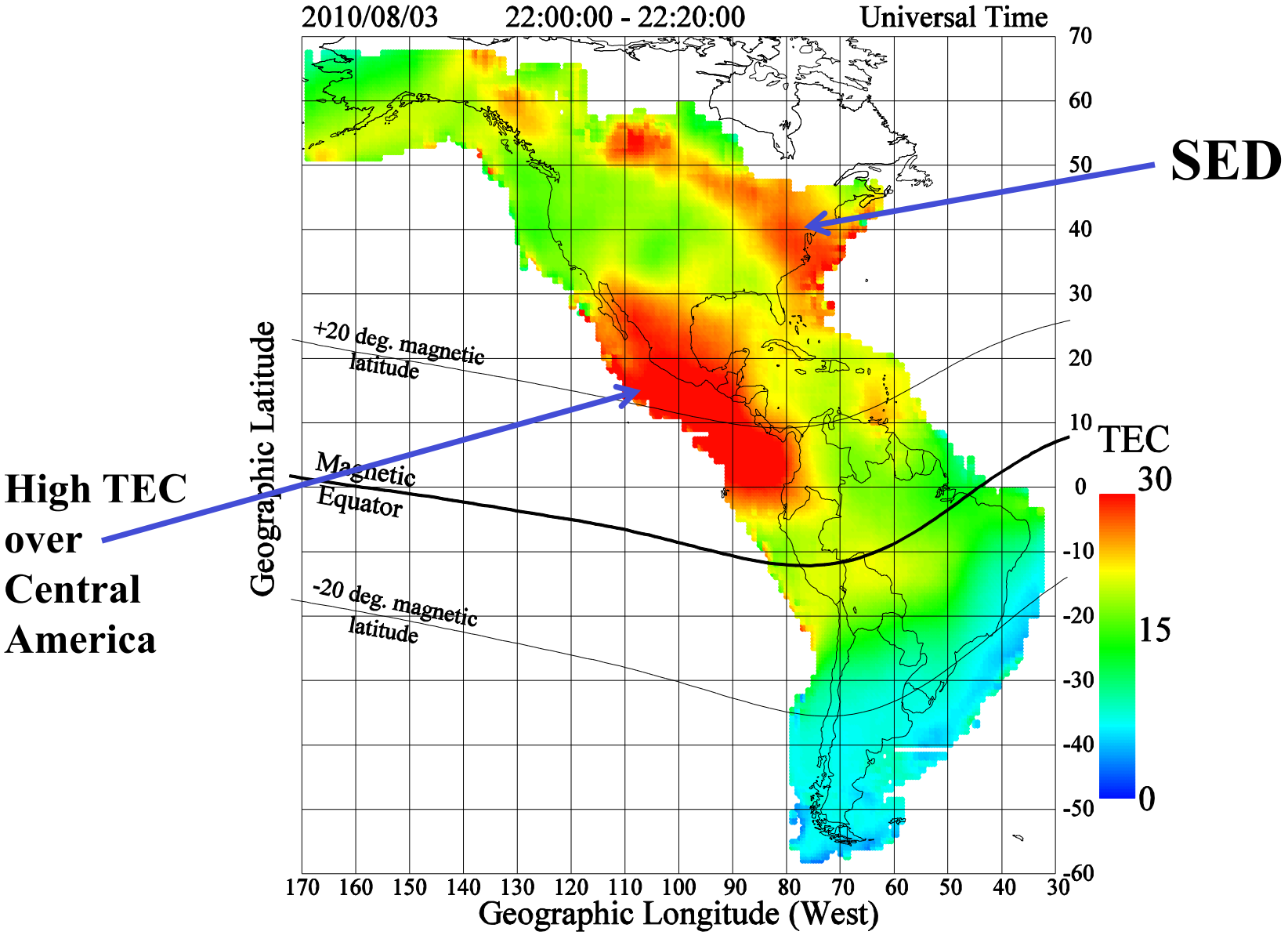
LISN GPS Network



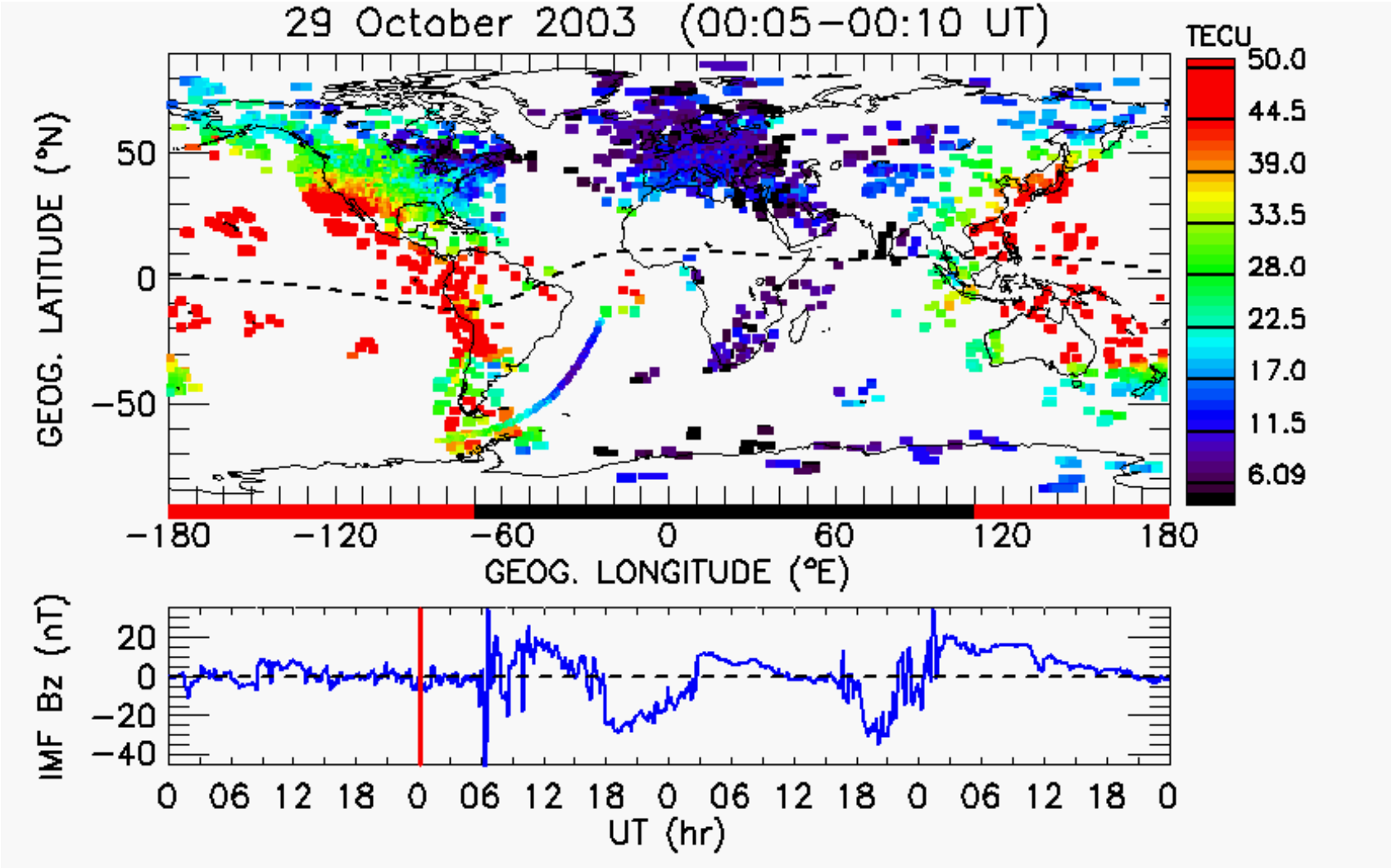
Development and Decay of the Equatorial Anomaly



Two channels of high TEC formed over the Americas on August 3, 2010, during a magnetic storm.



Ionospheric Storm Studies



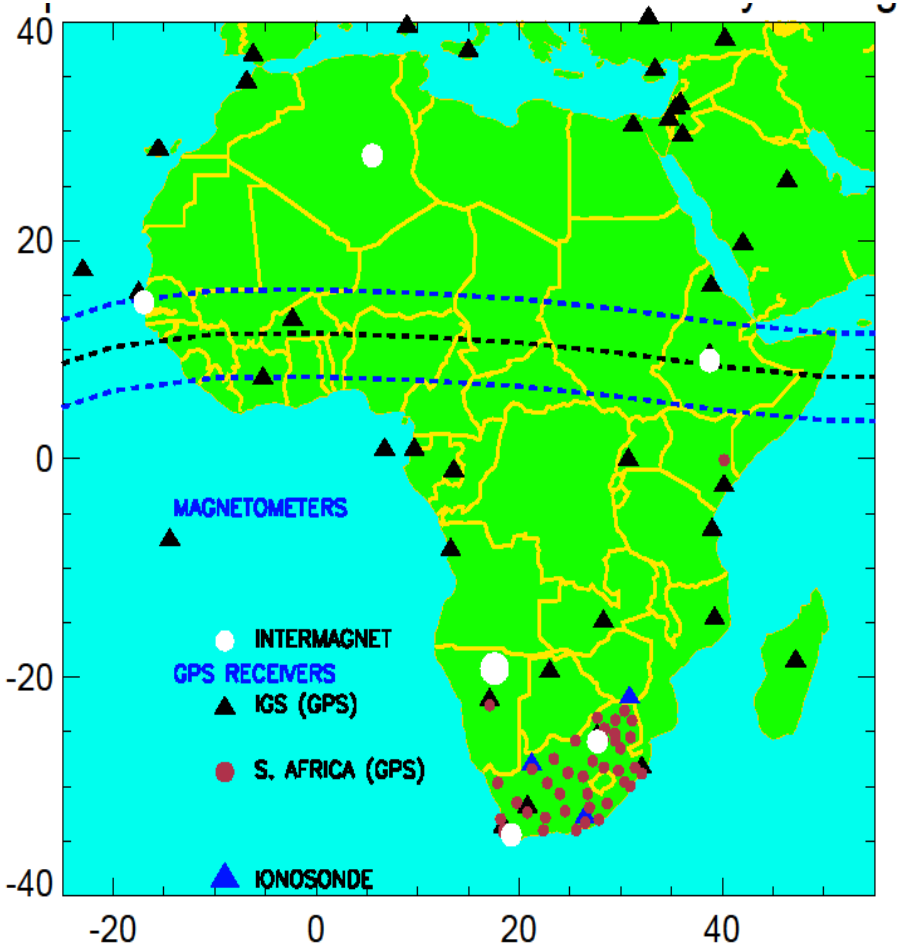
Ionospheric Monitors in Africa

- Magnetometers (MAGDAS, AMBER/SAMBA)
- >50 units of GPS - IGS, SCINDA, BC/ICTP, ESA
- Many other regional networks

Additional monitors planned:

VIPIR Ionosondes in Addis Ababa, Ethiopia and Maseno, Kenya (2013 completion anticipated)

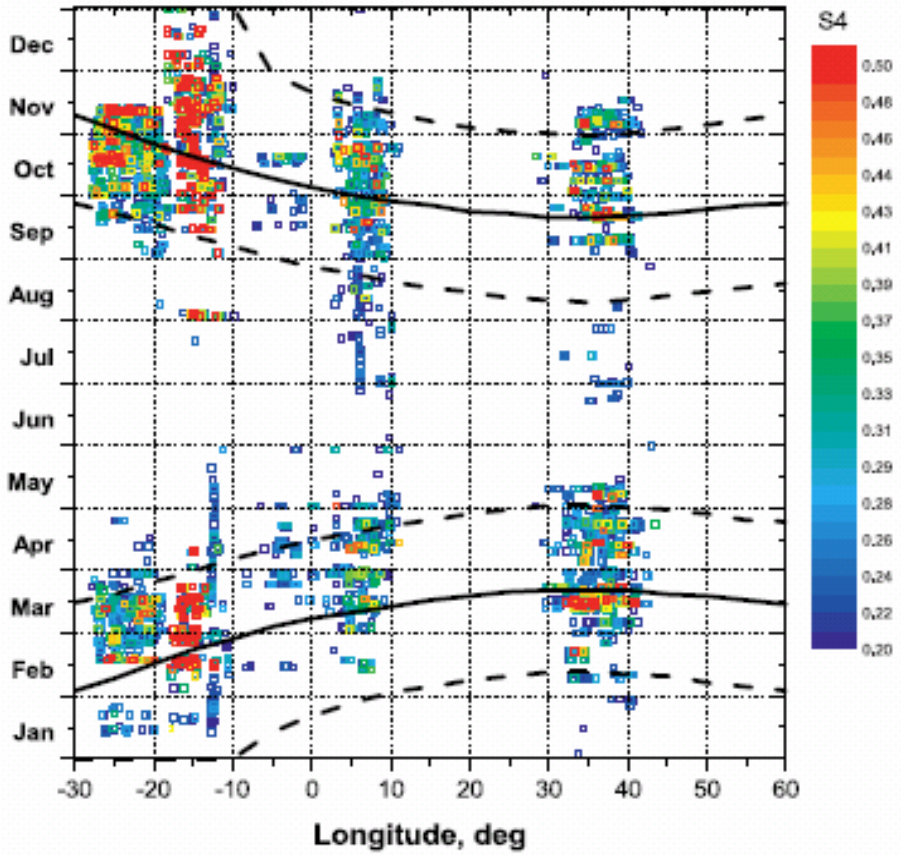
GPS (with new L5 signals)



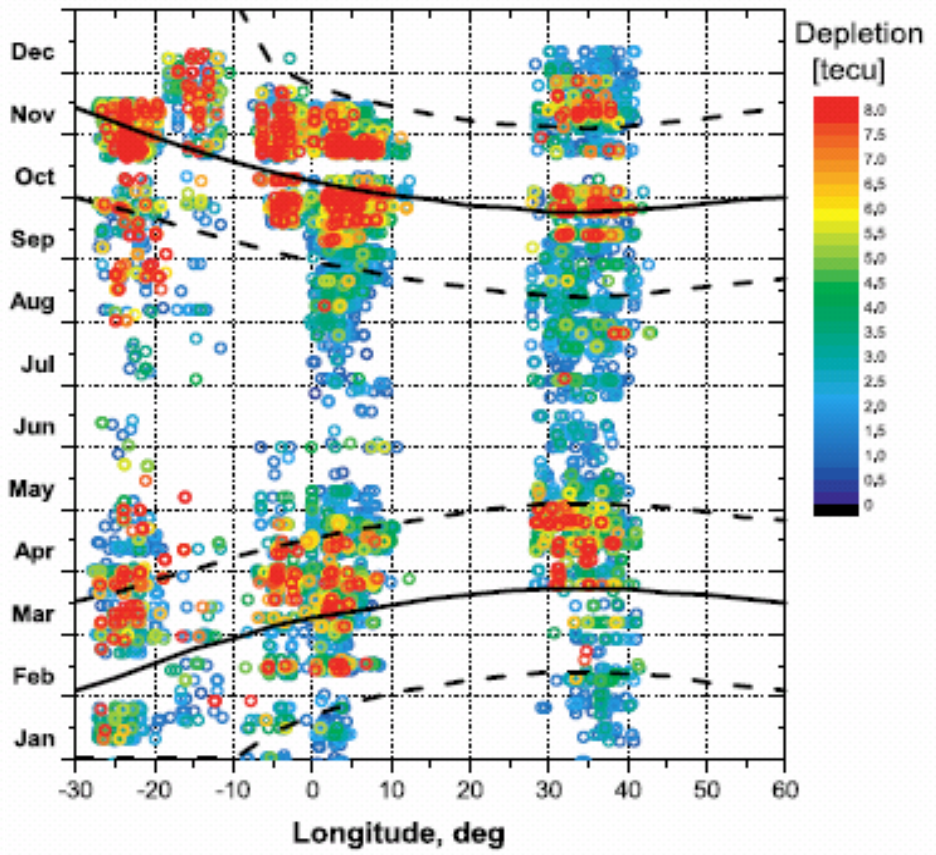
data obtained from these facilities are being used to improve our understanding of global space weather as it affects the performance of GNSS

Scintillation and Equatorial Plasma Bubble (EPB) Climatologies over Africa -2010

Scintillations



EPBs



Overalll climatologies agree.

Most activity where magnetic field aligns with the solar terminator.

EPBs outside the bands – especially in May-Aug months.- a curious result

Studies like this not possible without GPS!

A Simple Summary

GPS has proven to be a valuable utility for both practical applications and scientific exploration.

It is getting even better with new satellites, new signals and improved ground system.

With GLONASS, GALILEO, QZSS, IRNSS and Compass – the best is yet to come!

GPS Block 111A Satellite

Thank you for your attention!

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Disclaimer: This presentation was prepared by P. Doherty of Boston College. Materials on the GPS system are based on information obtained from the gps.gov website and other publicly released information.