The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization
IAEA

2333-29

Workshop on Science Applications of GNSS in Developing Countries (11-27 April), followed by the: Seminar on Development and Use of the Ionospheric NeQuick Model (30 April-1 May)

11 April - 1 May, 2012

GPS Positioning Errors in Solar Cycle 24

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GPS Positioning Errors in Solar Cycle 24

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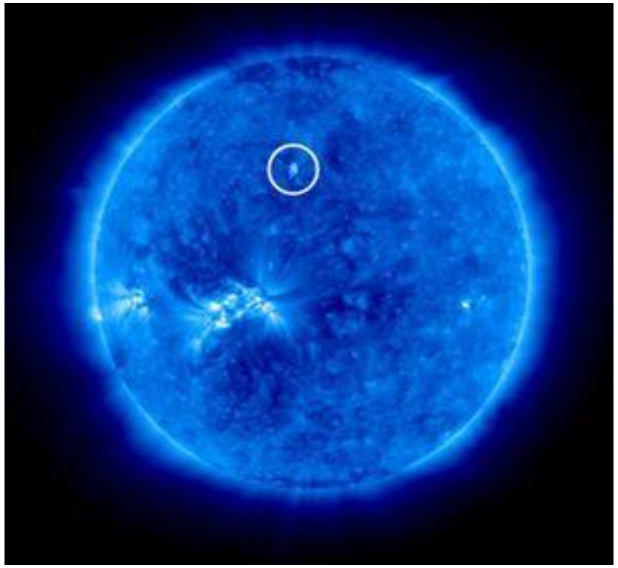
Workshop on Science Applications of GNSS in Developing Countries
11-27 April 2012

Outline

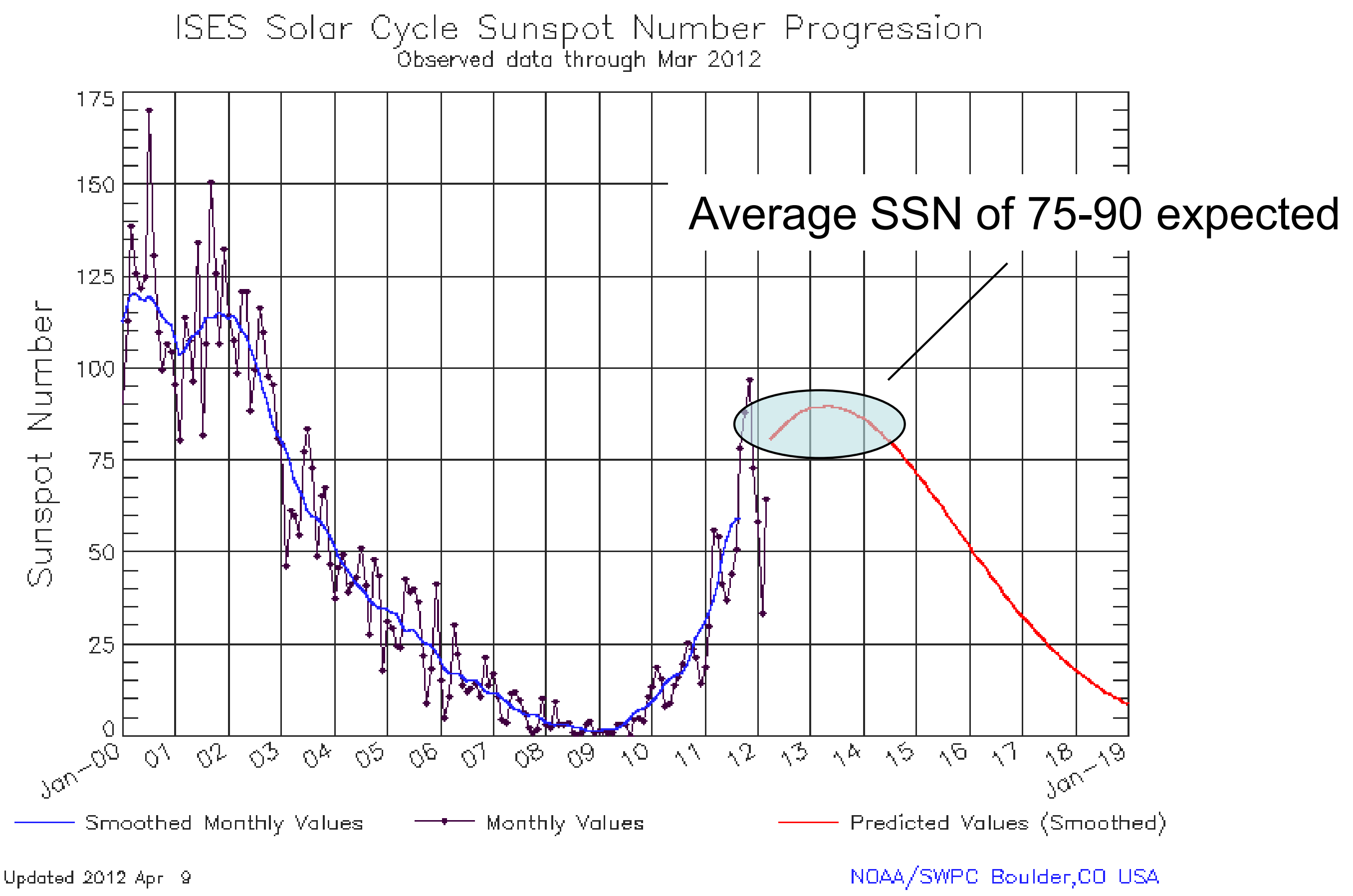
- Solar cycle review
- Solar cycle changes in ionospheric parameters and bubbles
- Position errors during past and present solar cycles
- Summary

Birth of Solar Cycle 24
Jan 4, 2008



STEREO EUV Image
NASA

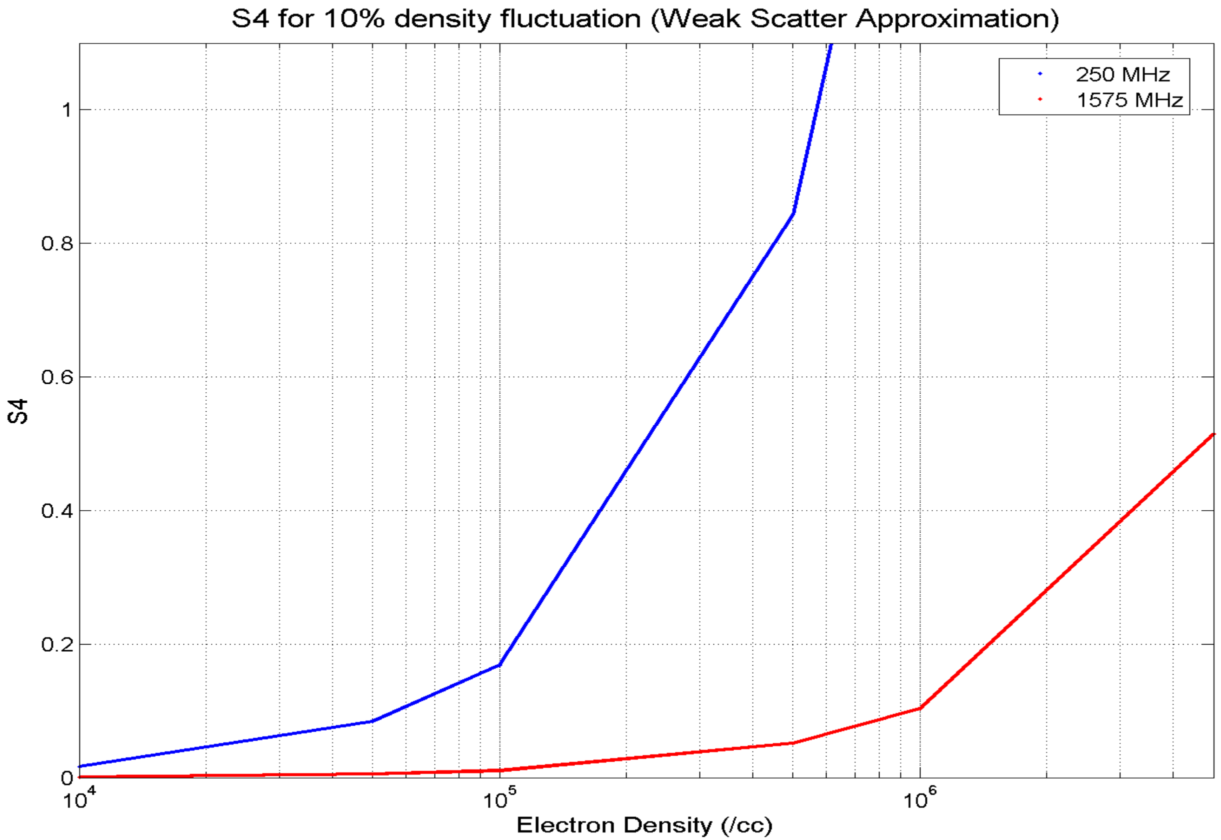
NOAA Solar Cycle Data & Projection



If the projections are correct, we would expect the next three years to be similar to conditions in 1998-99 and 2003-04

Effect of Electron Density on S4

- Significant relative density fluctuations will not cause scintillation if the background electron density is too low
- Must exceed ~1e5/cc for VHF, ~1e6 for GPS (~50 TEC units)
- Density during post-midnight hours frequently too low

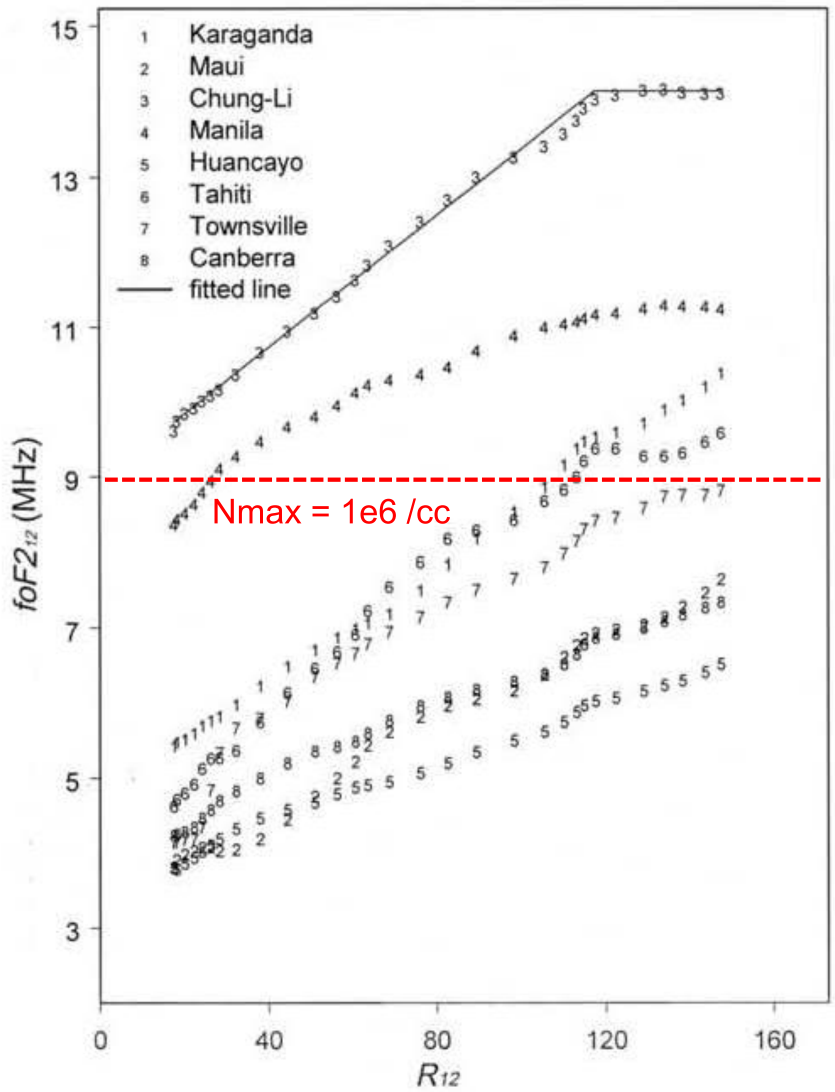


$$N\sigma_{N/\Delta N} = S_4^{thresh} \left\{ 2\pi r_e^2 \lambda^2 \, q_0 L \sec\theta \left(\frac{\lambda z_R \sec\theta}{4\pi} \right) \right\}^{-1/2}$$

Weak Scatter Approximation

Solar Flux and Electron Density

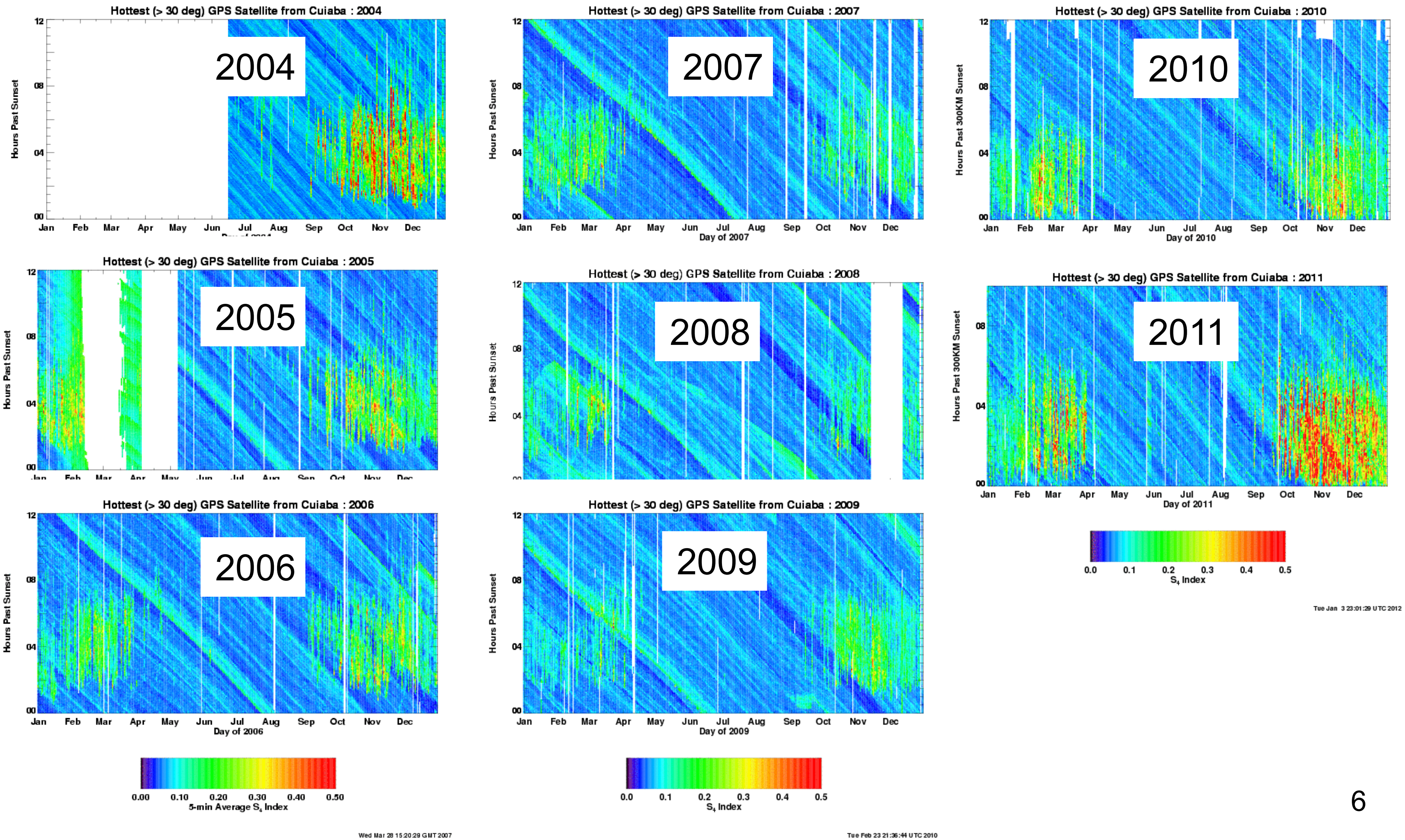
- FOF2 increases linearly with increasing sunspot number ($Ne \propto f_p^2$)
- Hypothesis that scintillation (S4) also increases ~ linearly with f_p increase (i.e., $\Delta N \sim Ne$)
- Effects on GPS will be latitude-dependent (weaker at magnetic equator, stronger at anomaly peaks)



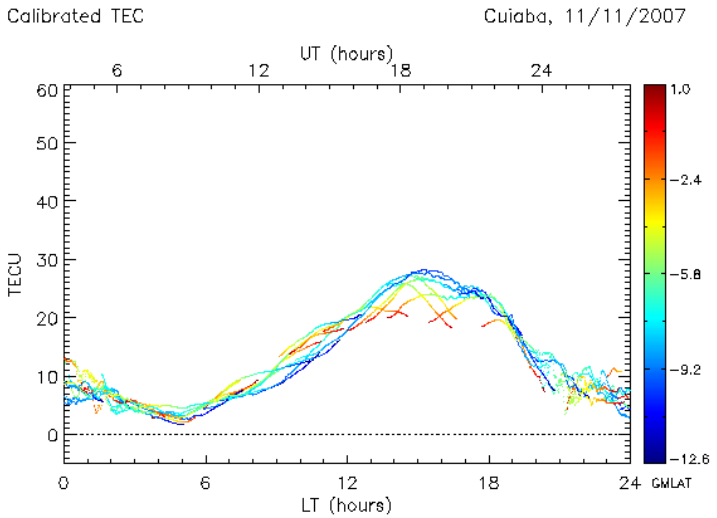
From Liu et al., *JGR*, 2003

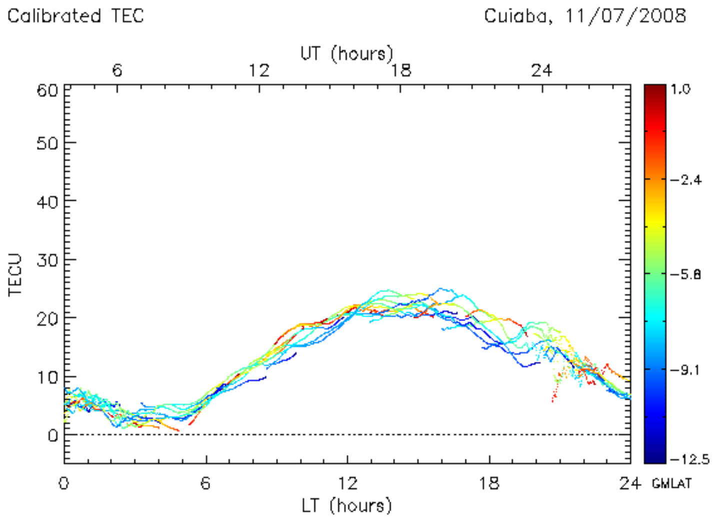
Cuiaba, Brazil

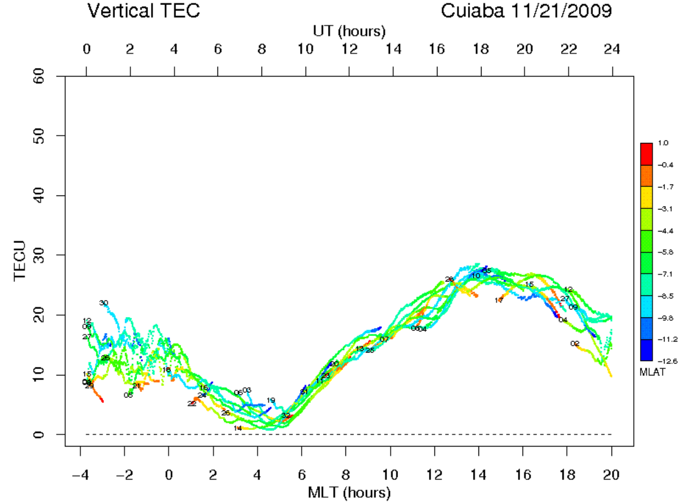
Solar Cycle Variations in GPS Scintillations

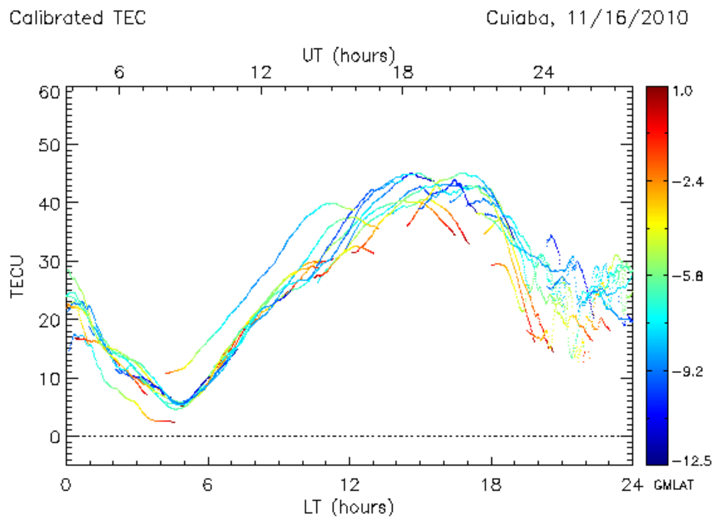


Total Electron Content Variations with Solar Cycle

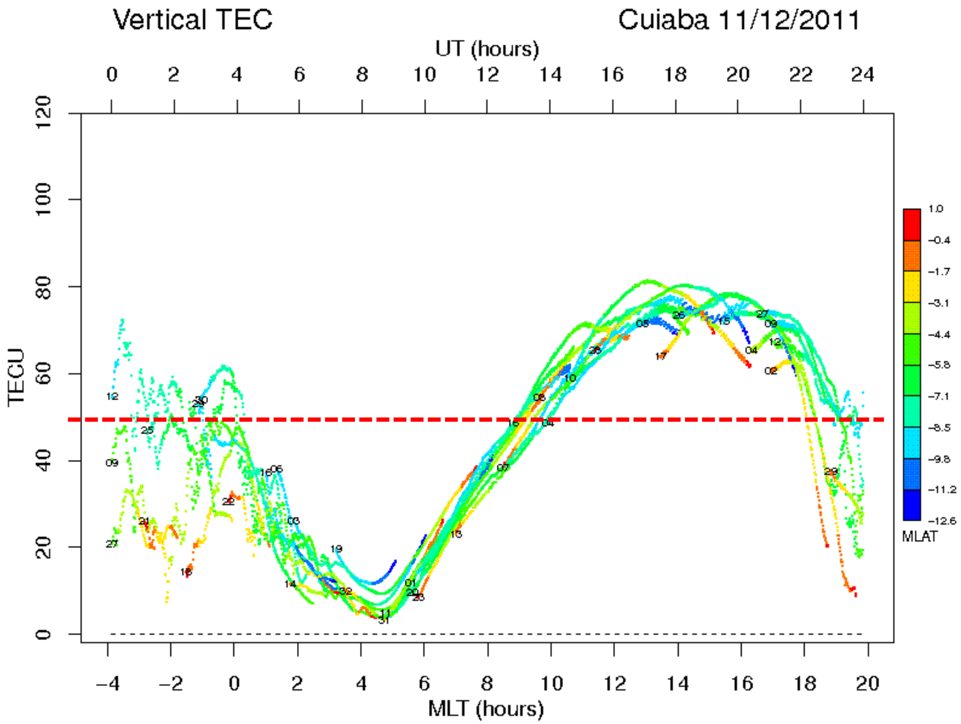








Total Electron Content Variations with Solar Cycle

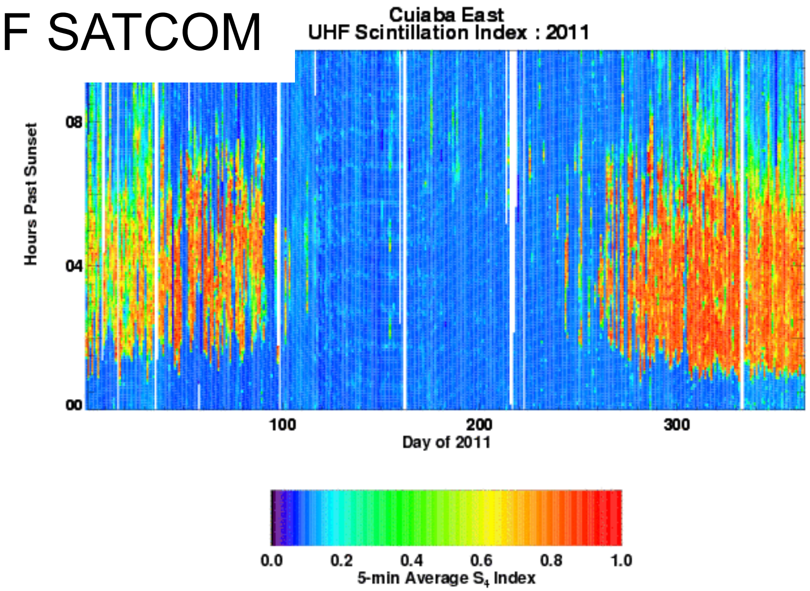


GPS scintillation turns on when TEC exceeds ~50 TECU

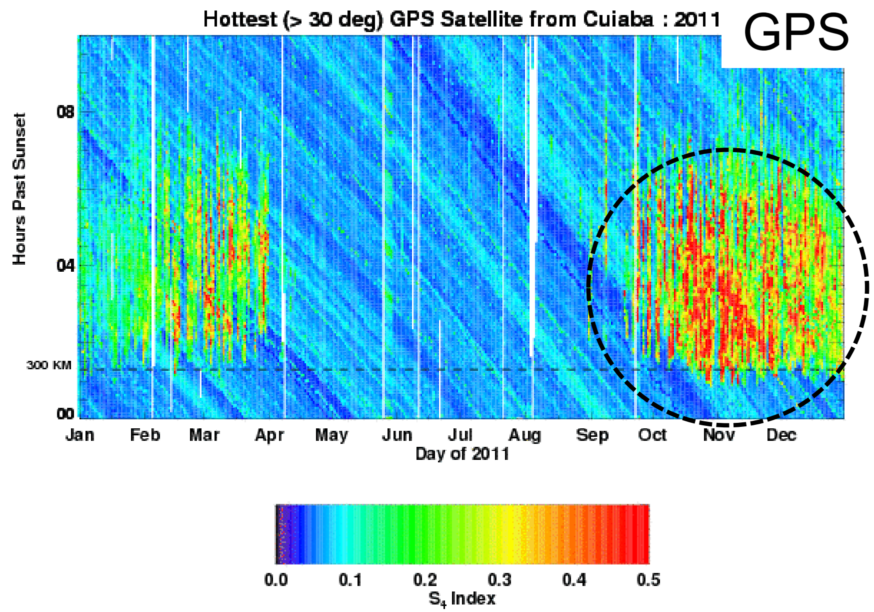
Cuiaba, Brazil

UHF & GPS Comparison

UHF SATCOM

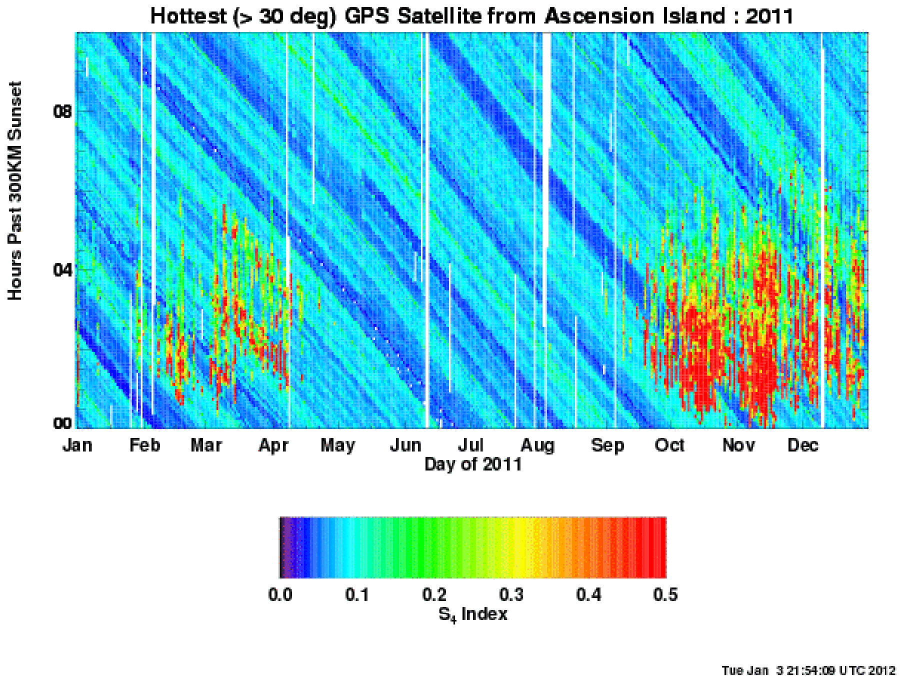


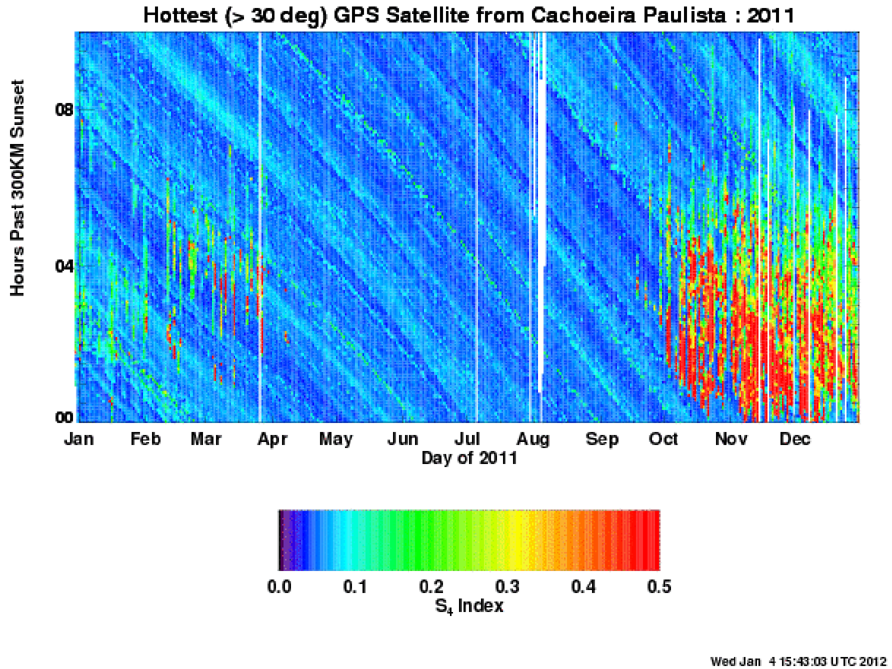
GPS



- Virtually no GPS scintillations were observed worldwide from 2007-2009
- Moderate GPS scintillations began in 2010 thru mid 2011
- The last half of 2011 GPS scintillation increased markedly
- We expect these levels to increase further in 2012-2014

More Evidence from Other Sites

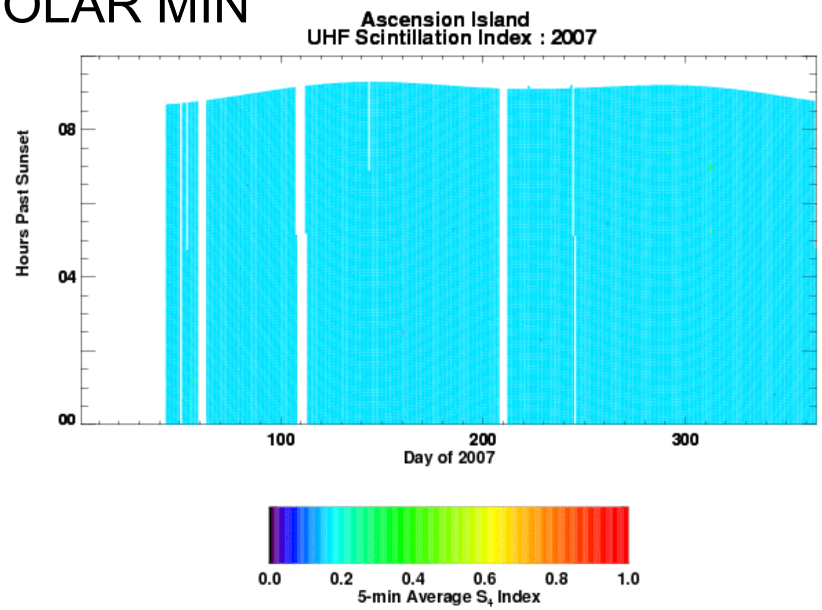




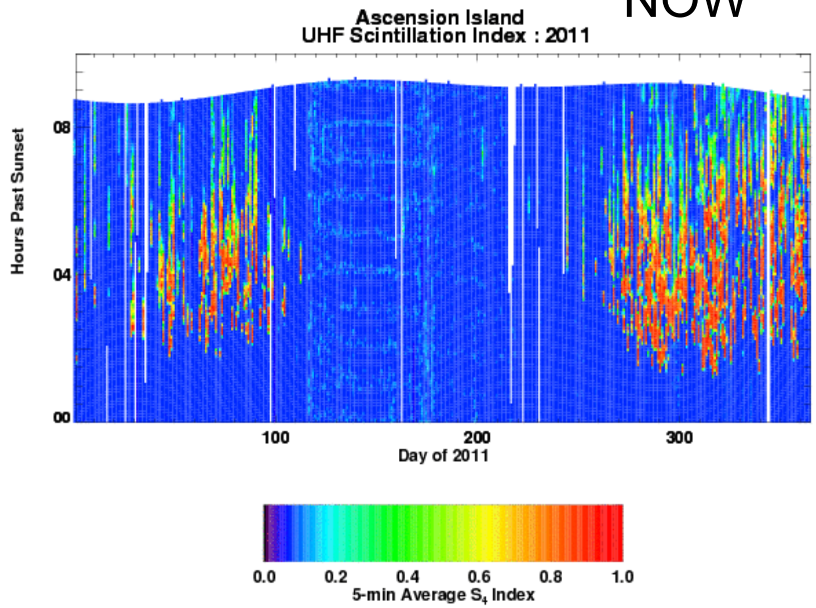
- Marked “turn-on” in GPS scintillations in the latter half of 2011
- Driven completely by increasing solar flux responsible for increased electron density

What About the Size of the Bubbles?

SOLAR MIN

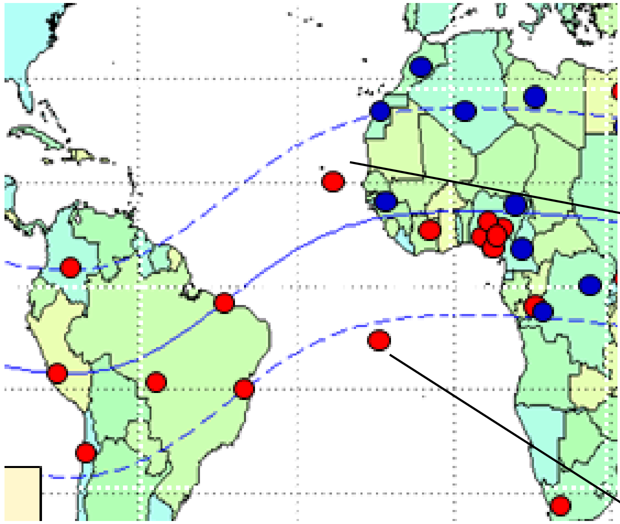


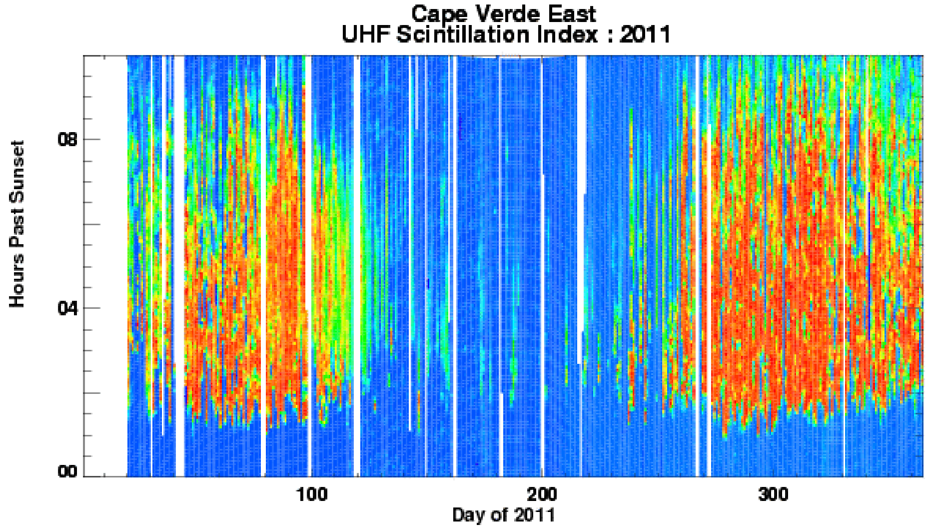
NOW



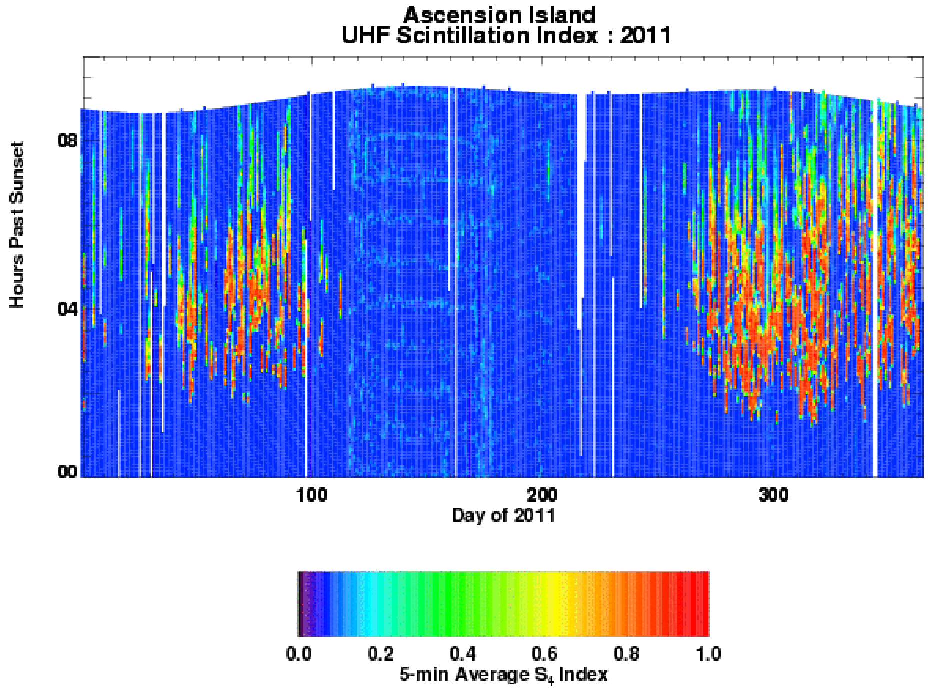
- For scintillation activity to reach Ascension Island, bubbles must rise to more than 1000 km altitude, spreading to over 3000 km N-S extent
- During solar minimum, almost no bubbles reach these altitudes; N-S extent typically ~ 2000 km

Relative Occurrence of Bubbles Exceeding 1000 km Altitude



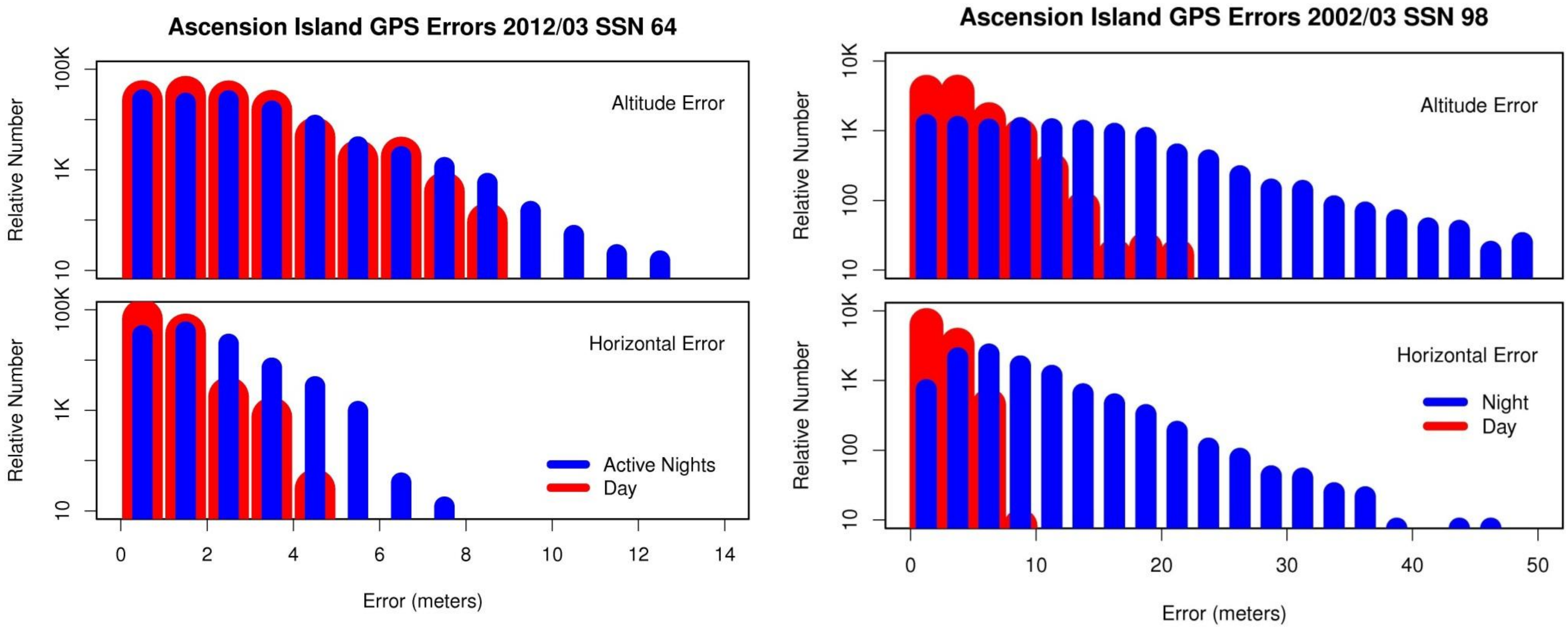


- Sites at different latitudes see different levels of activity depending on bubble altitude



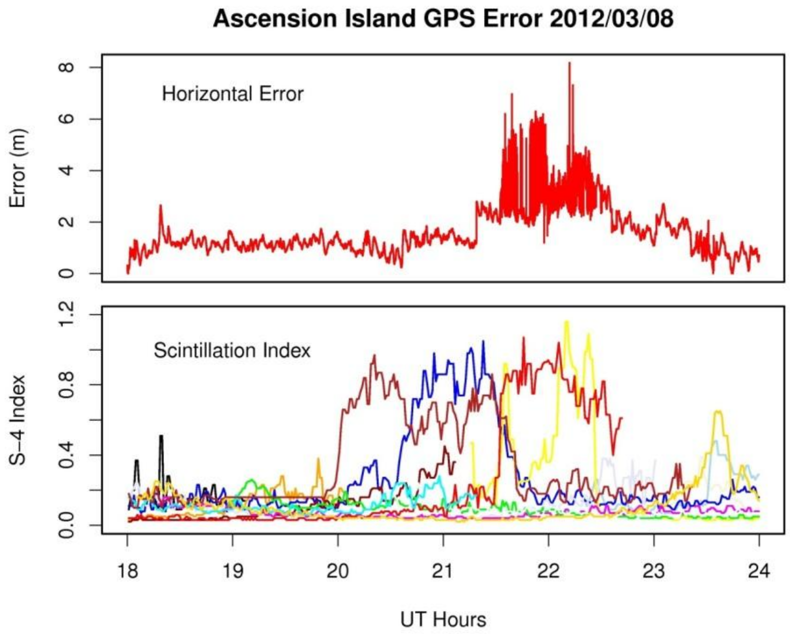
Position Errors at Ascension Island

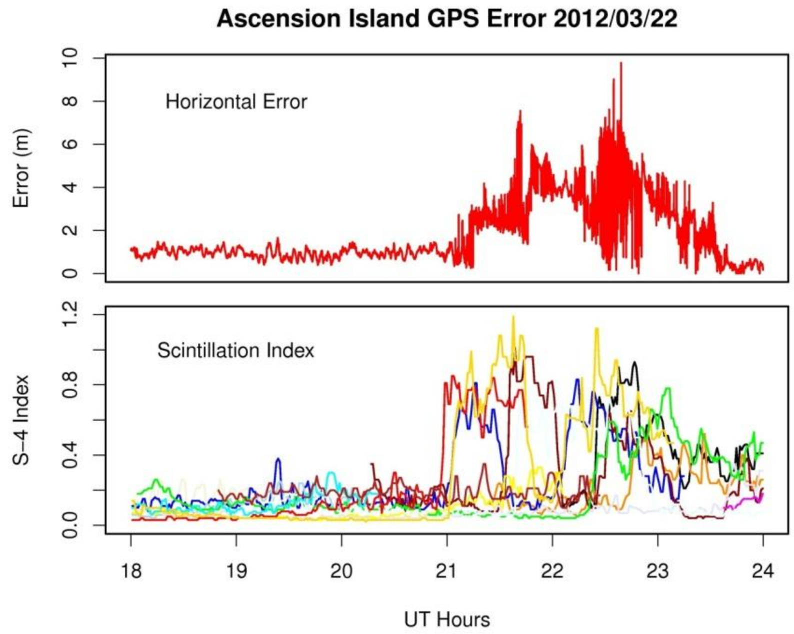
A statistical perspective



- Equinox 2012 (SSN ~ ***64***) errors increased significantly during nighttime periods
- Equinox 2002 (SSN ~ ***96***) illustrates results from last solar maximum

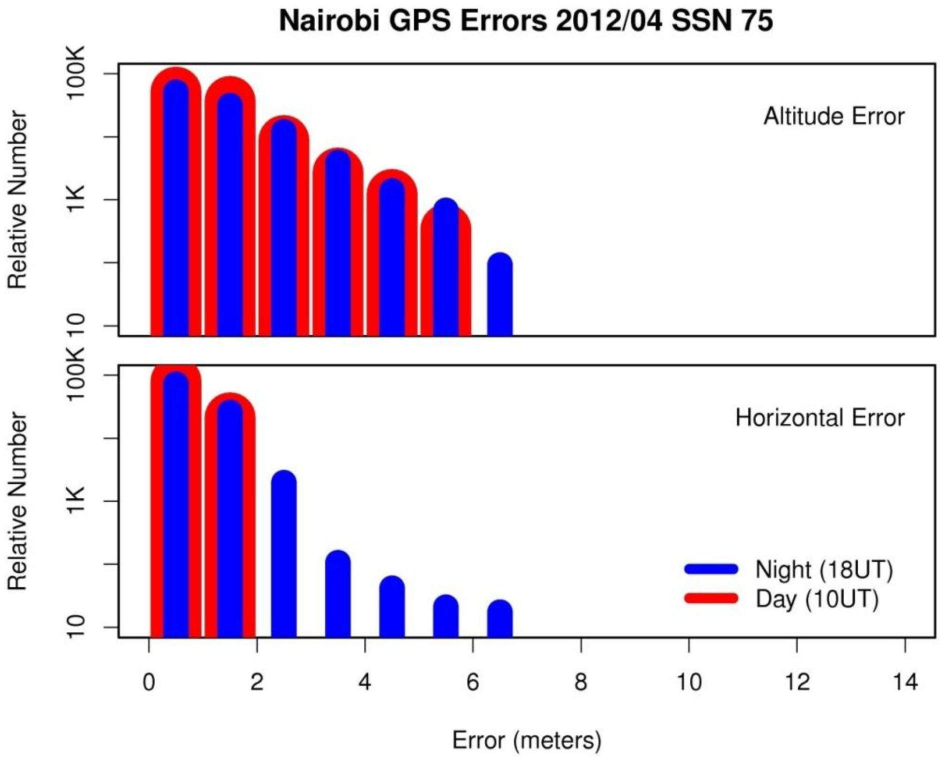
Examples from March 2012

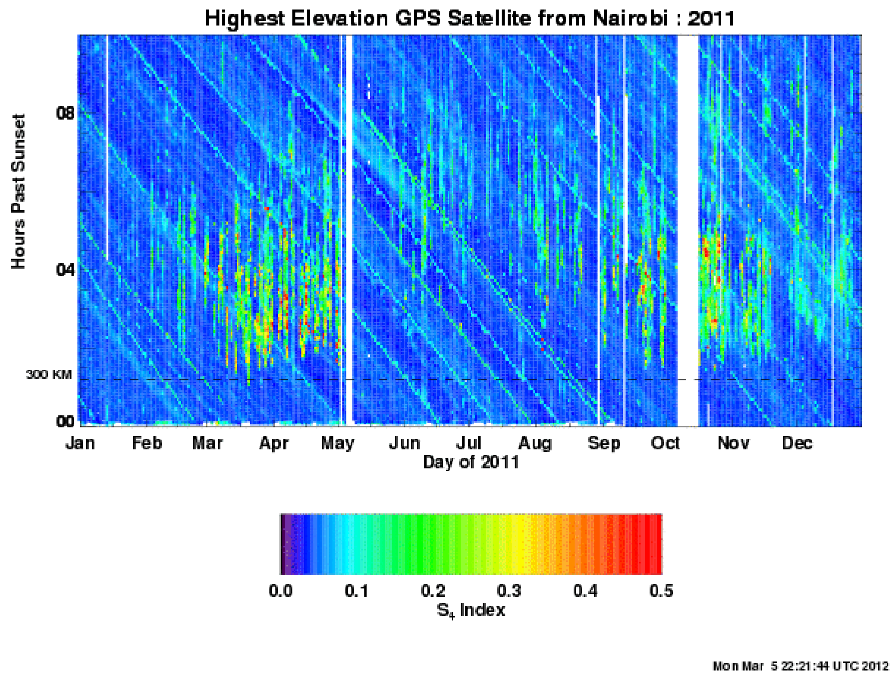




- Considering specific days we see direct correlation between scintillation and horizontal position errors approaching 10 meters
- But the number and severity of links affected is less overall relative to the previous solar maximum period

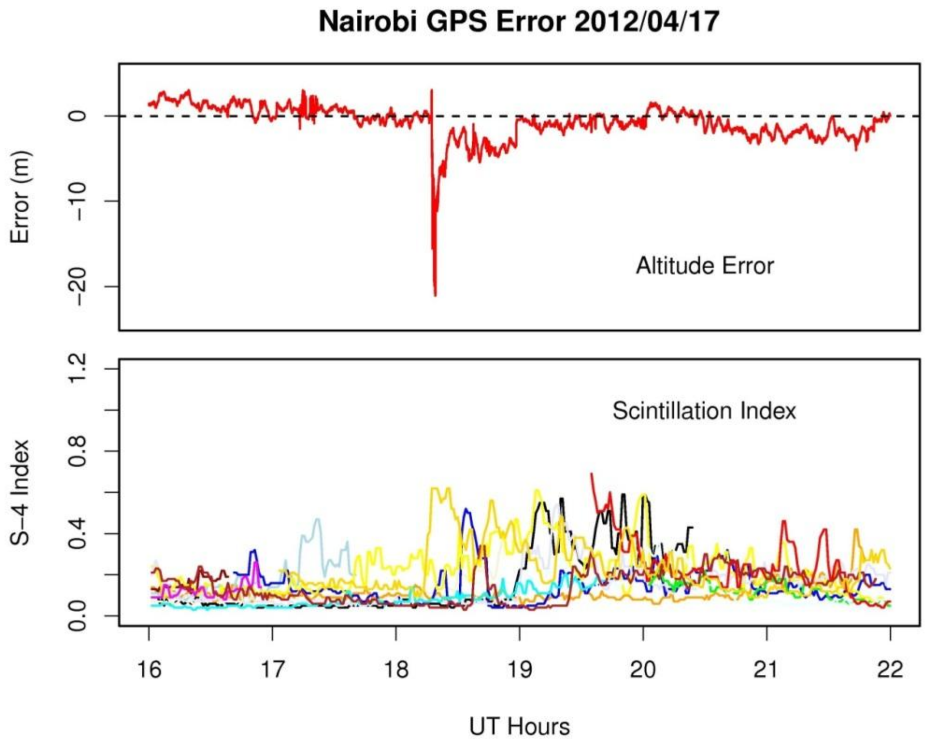
Nairobi, Kenya
Paul Baki PI

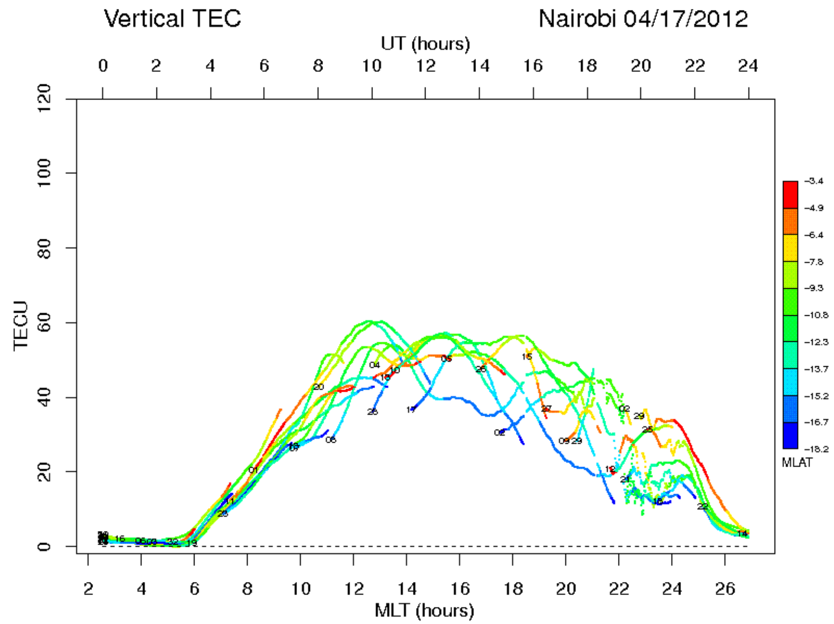




- Errors in Nairobi smaller on average than Ascension Island in current solar cycle
- Correspondingly weaker scintillation levels; magnetic latitude is about 8 deg S

Position Errors at Nairobi 17 April 2012

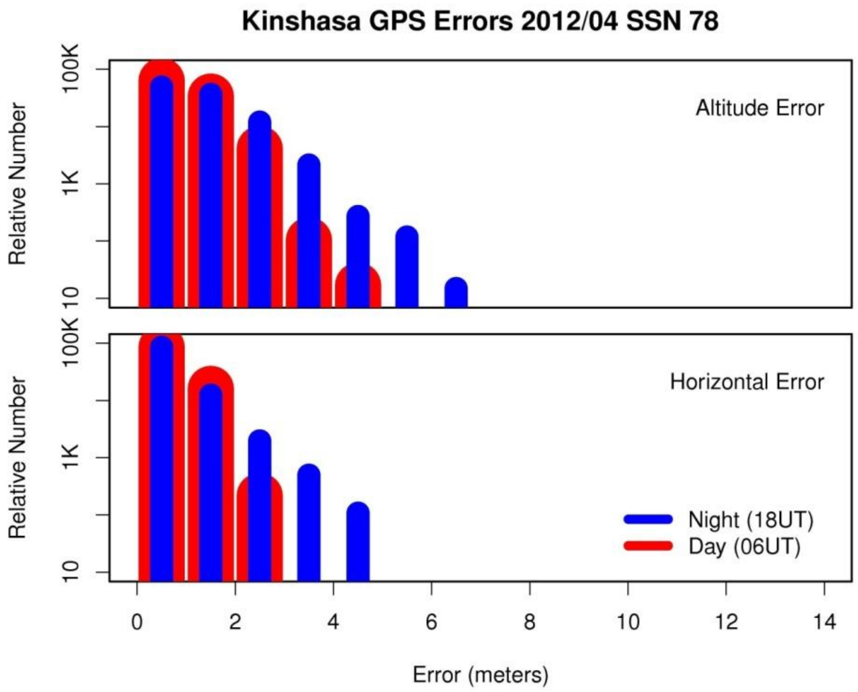


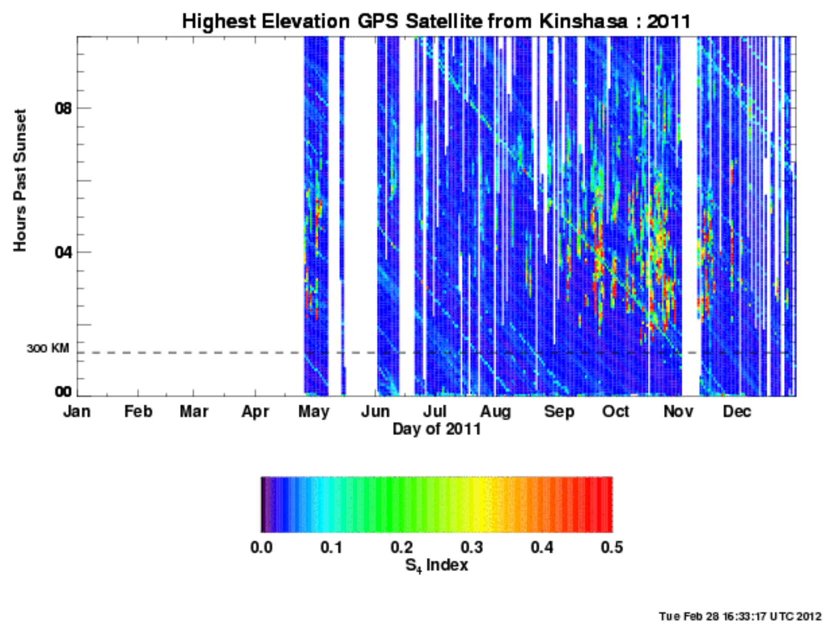


- Although numerous GPS satellites are affected the observed errors are relatively modest
- A small increase in solar flux will likely yield a non-linear increase in GPS position errors in Kenya

Position Errors at Kinshasa, DRC

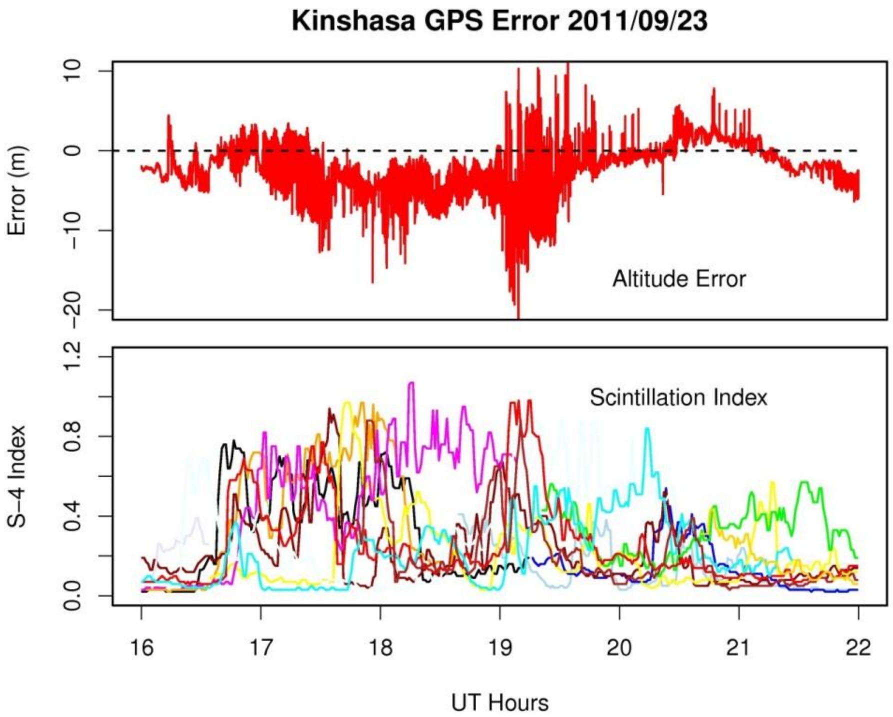
Bruno Kahindo, PI

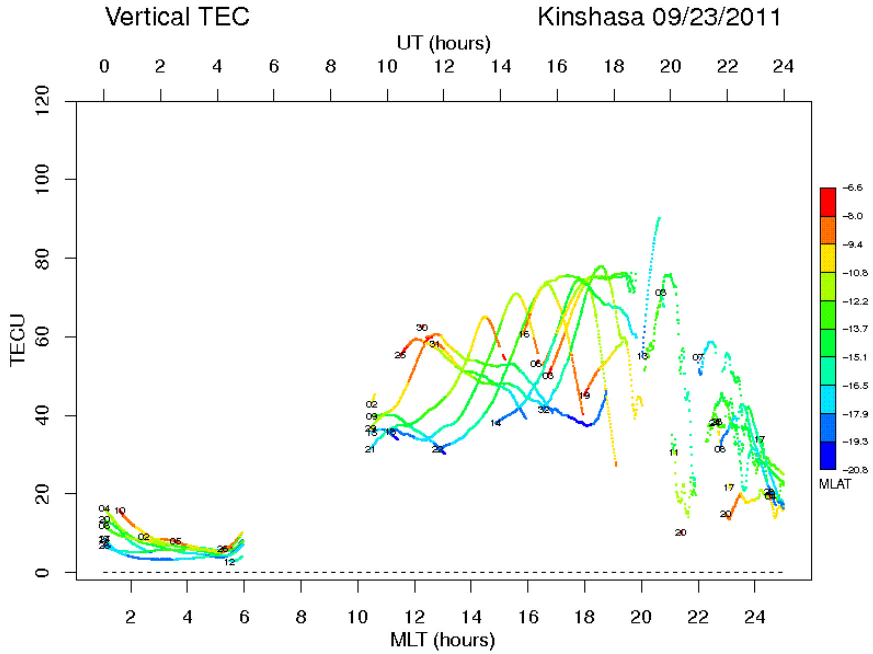




- Scintillation levels at Kinshasa appear moderately stronger as expected due to higher magnetic latitude than Nairobi
- Statistical distribution does not show larger errors (note this is for April 2012)

Example from Kinshasa in 2011

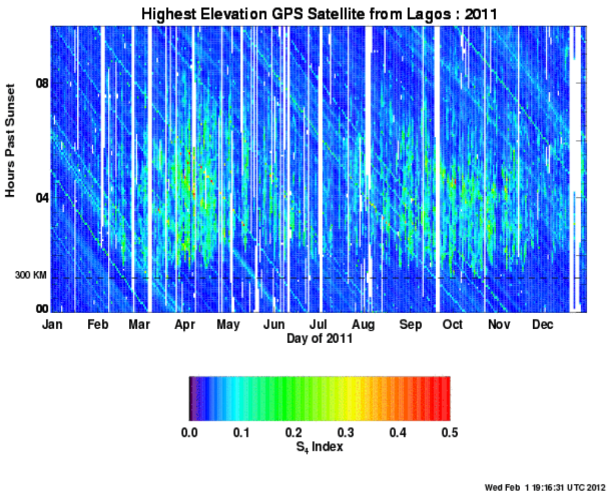




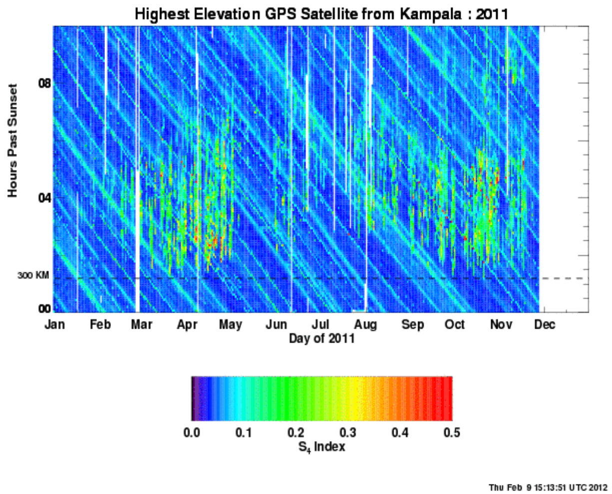
- Scintillation widespread on Sep 23 2011with corresponding positioning errors
- TEC shows clear evidence of strong equatorial anomaly (large N-S gradients)

Possible Sites for More Investigation

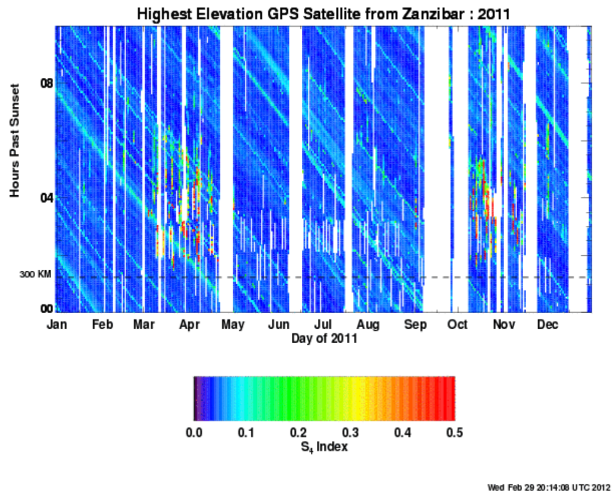
Lagos (Nigeria)



Kampala



Zanzibar

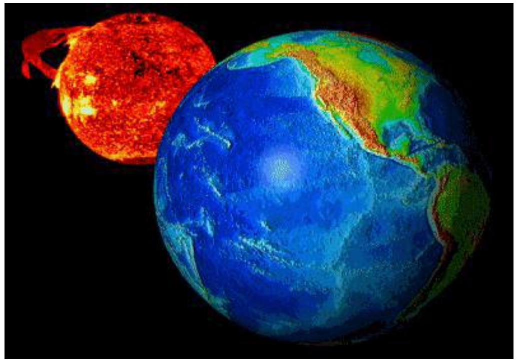


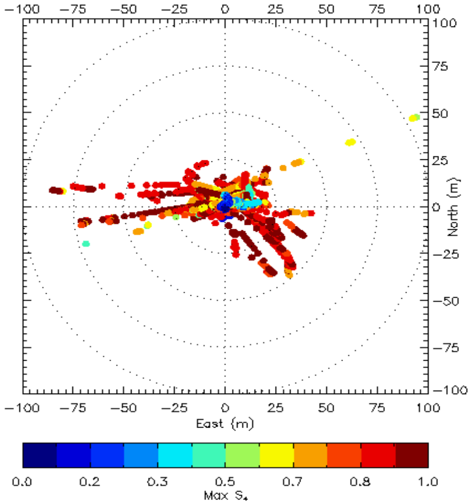
Magnetic Latitude →

- More comprehensive analysis is needed, both statistically and day-to-day to understand relationship between scintillation and positioning errors
- Other parameters (e.g, phase variations) may be important to understand impacts more fully

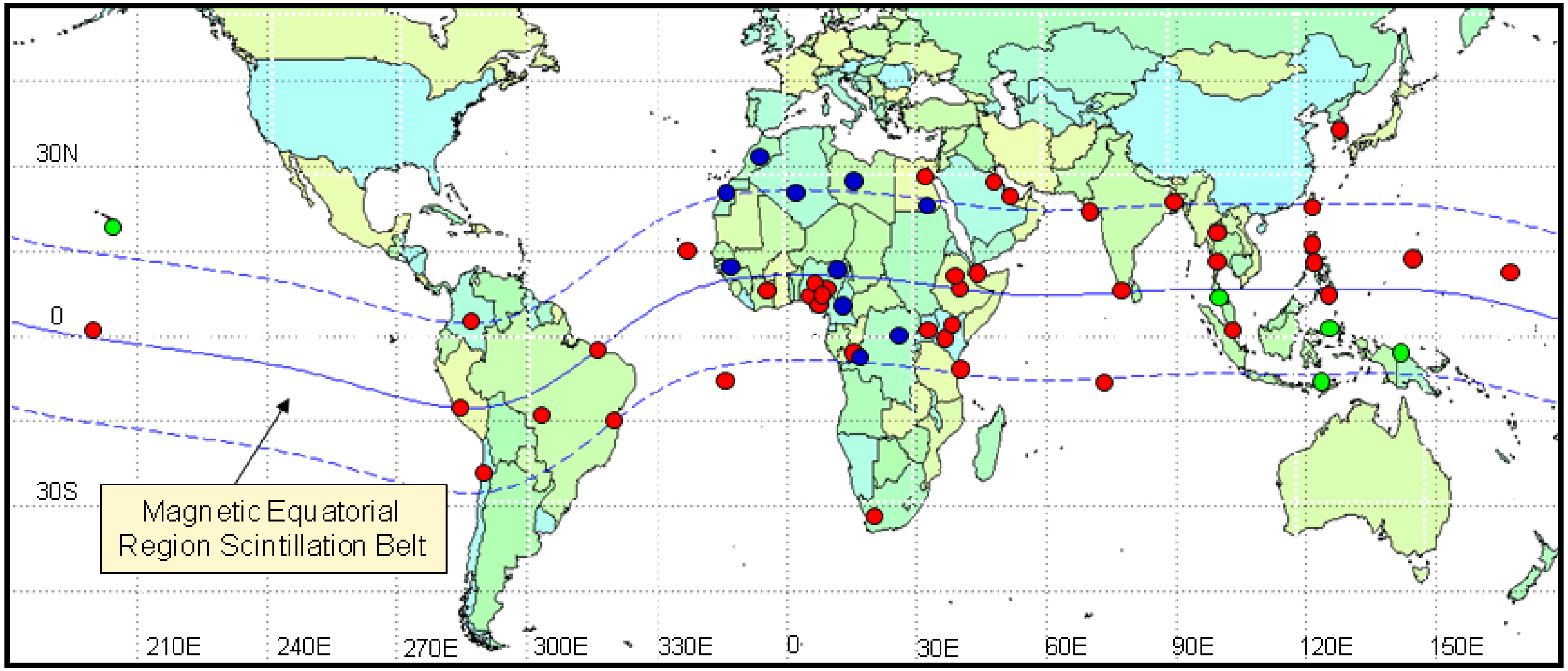
Summary

- Ionospheric scintillation has recently entered the solar maximum phase
- Users should expect more severe impacts on GNSS systems through 2014
- It is expected that effects on performance will not be as severe in solar cycle 24 as they were in the previous solar cycle
- A thorough comparison of scintillation activity, ionospheric parameters and positioning errors as a function of latitude and longitude would be of great interest to the user community





SCINDA Sites Map



● Existing Sites ● Future UN IHY Sites ● Other/collaboration

Existing and expected sites through 2012