Boston College

# GPS Positioning Errors in Solar Cycle 24

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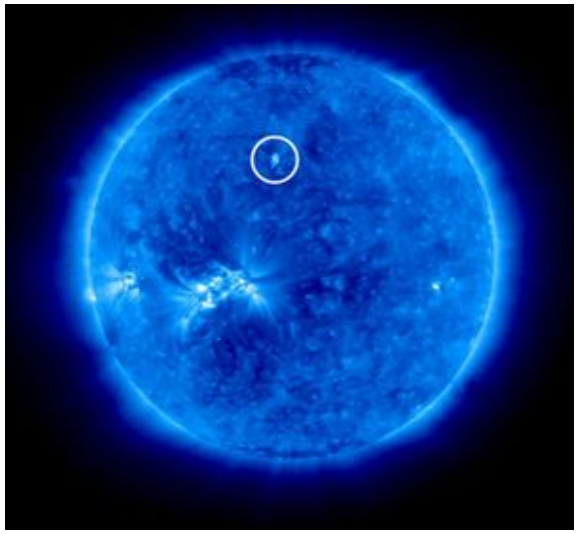
12-14 May 2015

# Outline

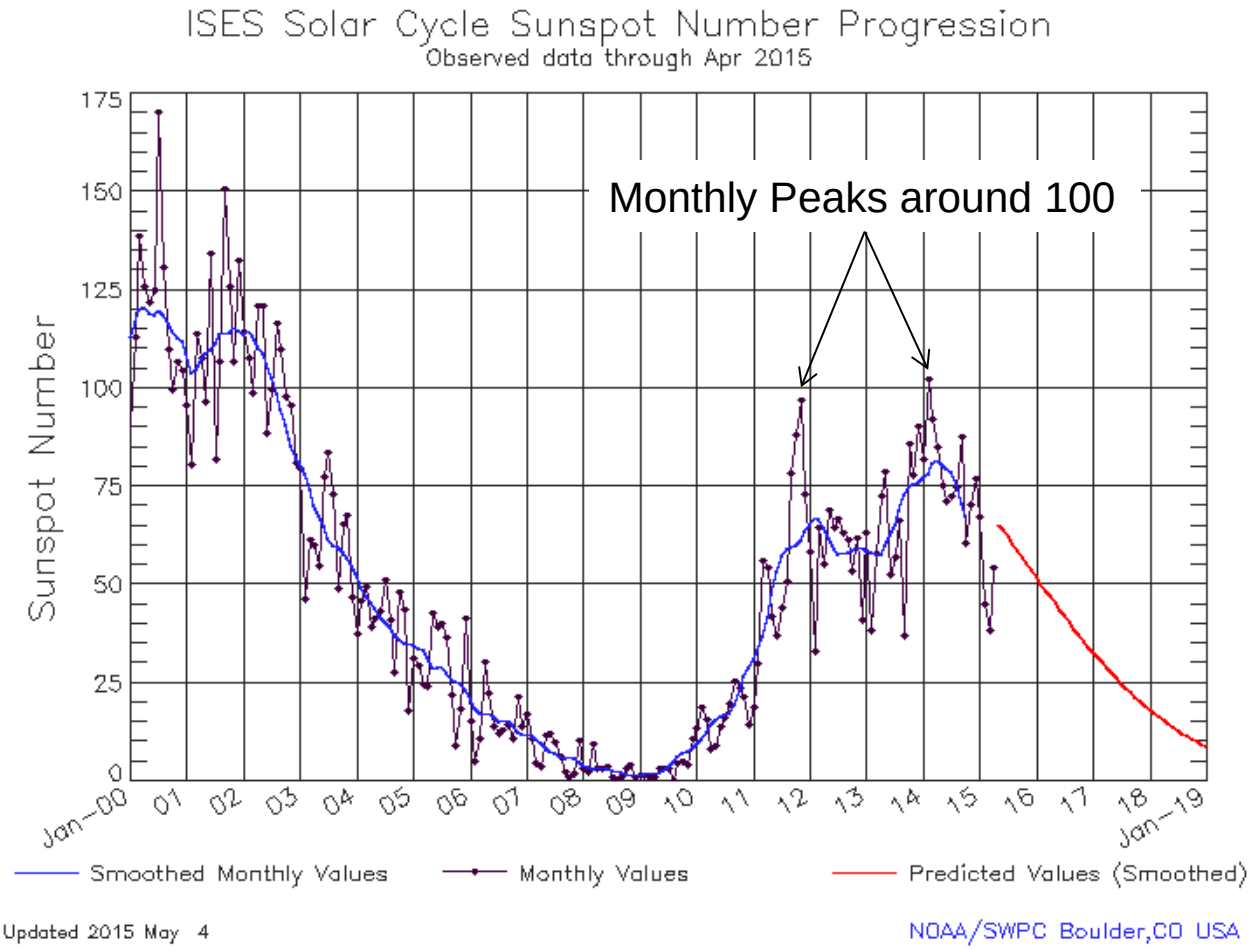
- Solar cycle review
- Case studies of positioning errors
- Latitude dependence of positioning errors
- Position errors during past and present solar cycles
- Summary

Birth of Solar Cycle 24
Jan 4, 2008



STEREO EUV Image
NASA

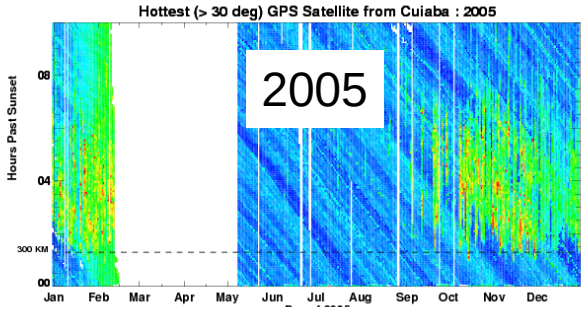
# NOAA Solar Cycle Data & Projection

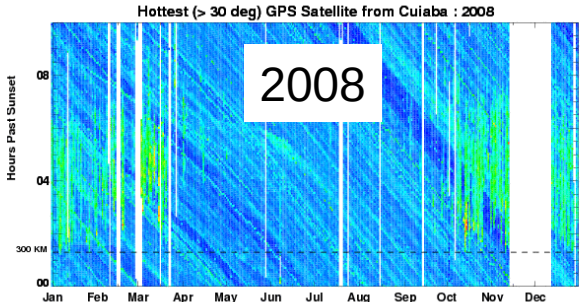


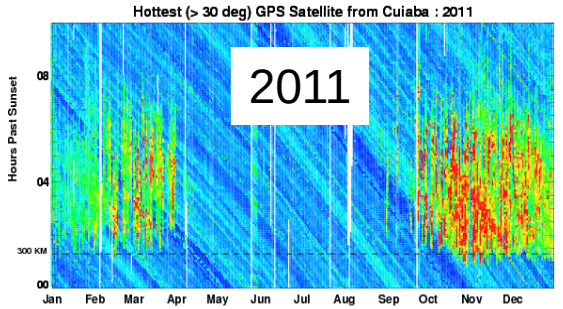

Solar Cycle 24 is somewhat less active than Solar Cycle 23, but note the peaks in late 2011 and early 2014.

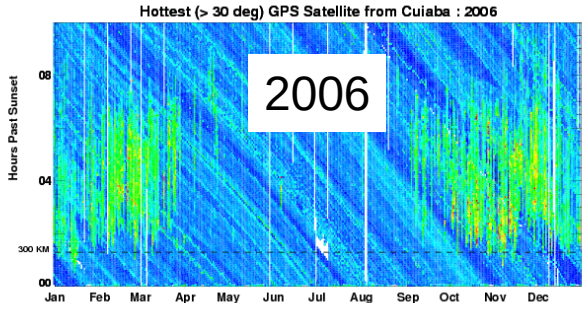
# Cuiaba, Brazil

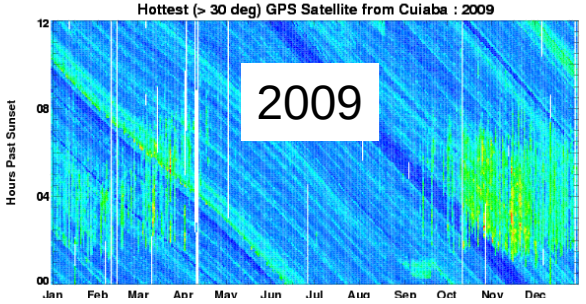
## Solar Cycle Variations in GPS Scintillations

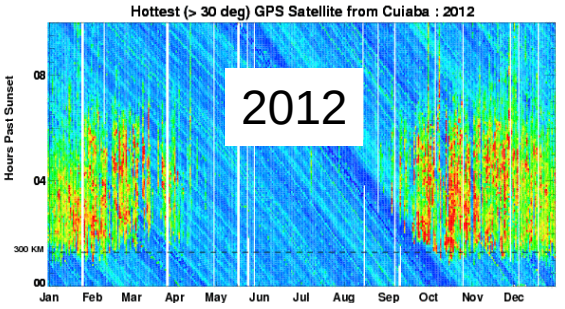


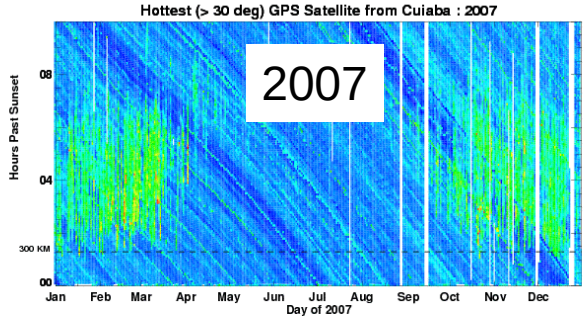



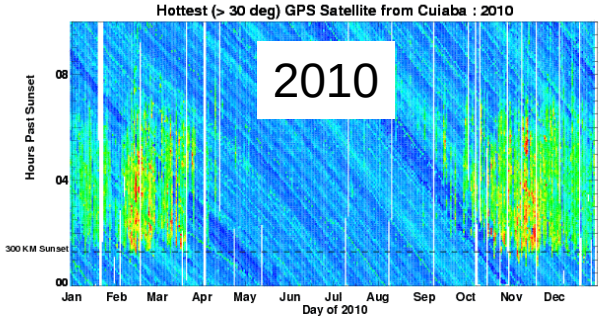



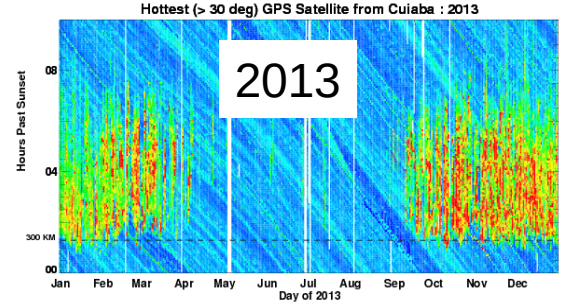



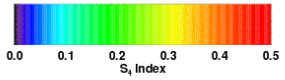



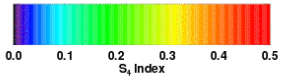



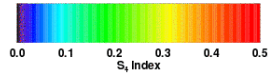



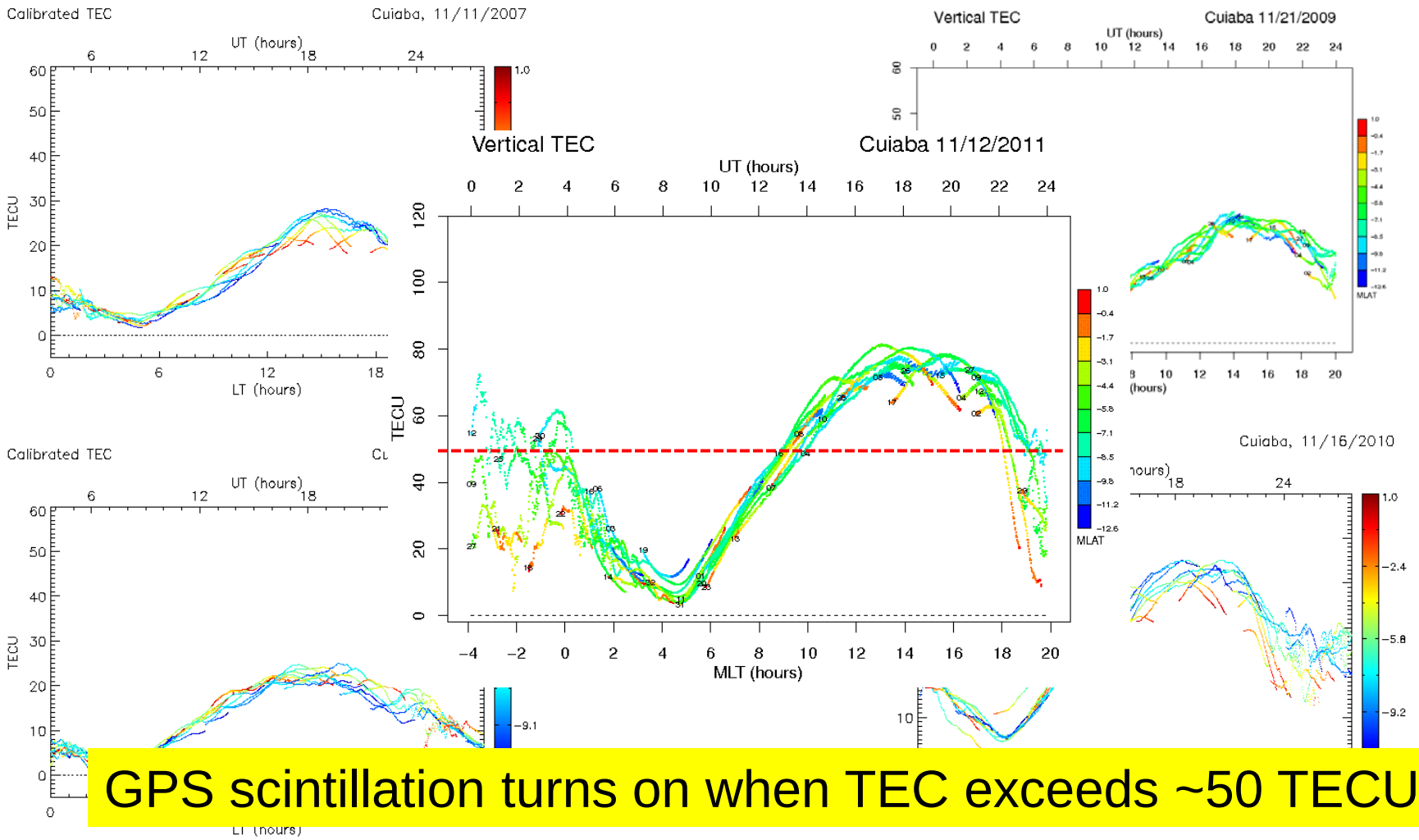



Wed Apr 2 21:22:58 UTC

Tue Jan 31 22:51:22 UTC 2012

Wed Jan 8 19:54:01 UTC 2014

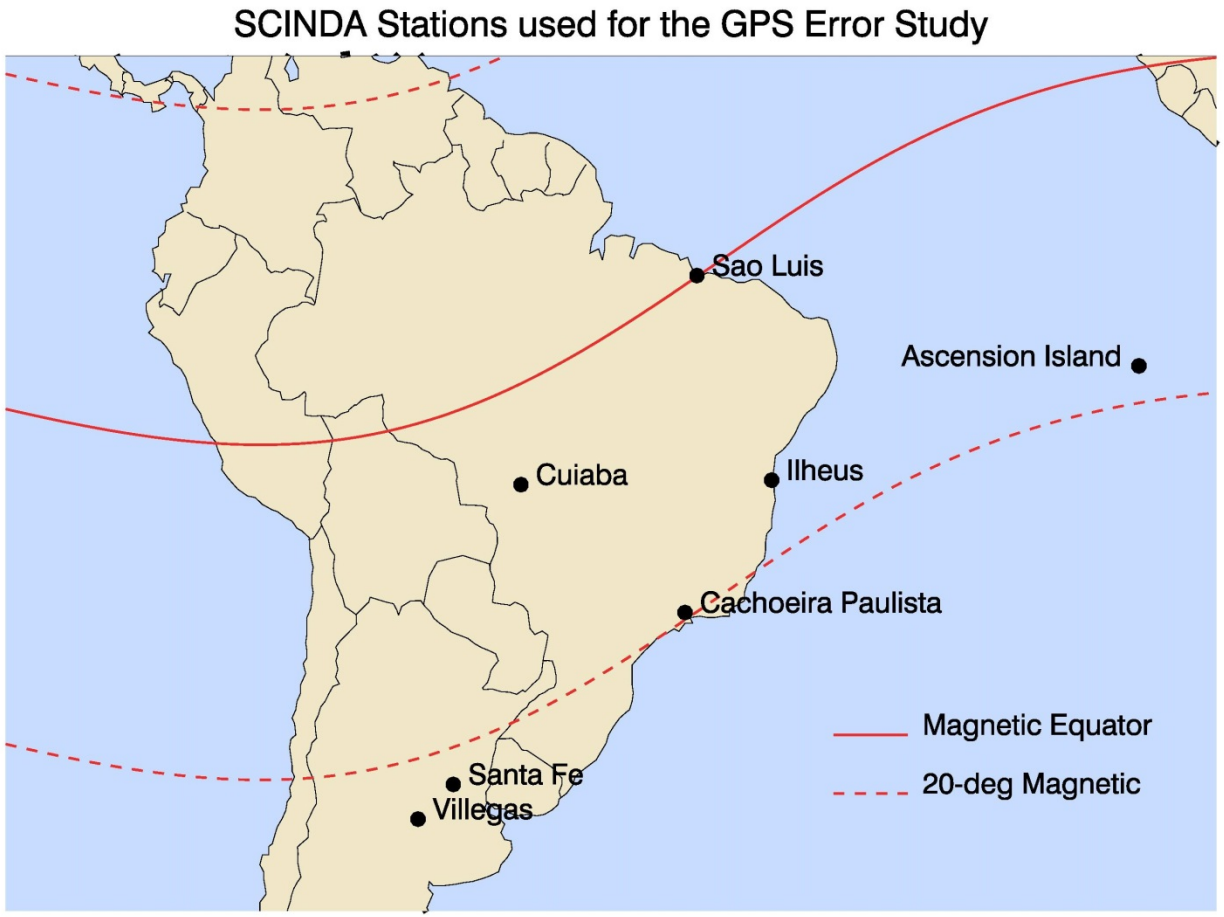
# Total Electron Content Variations with Solar Cycle



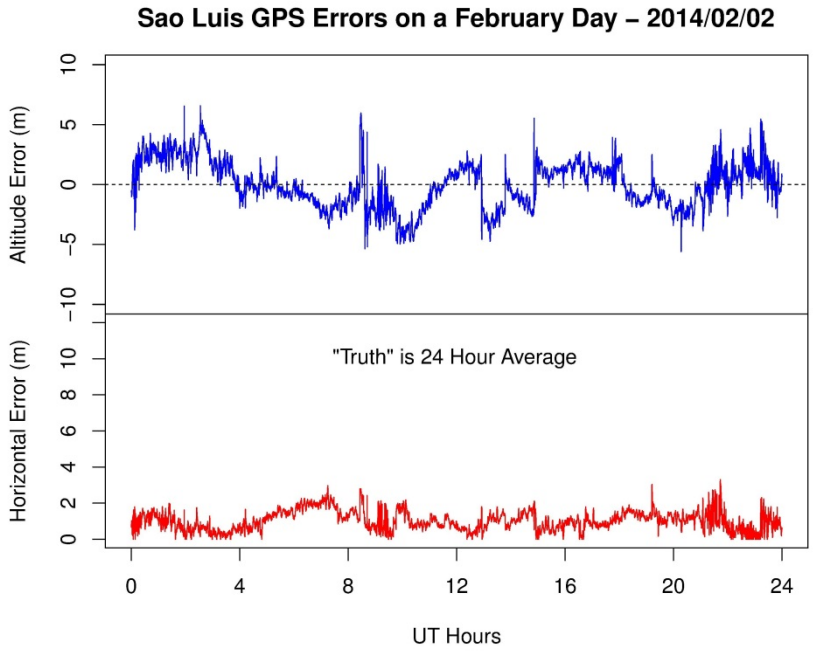

GPS scintillation turns on when TEC exceeds ~50 TECU

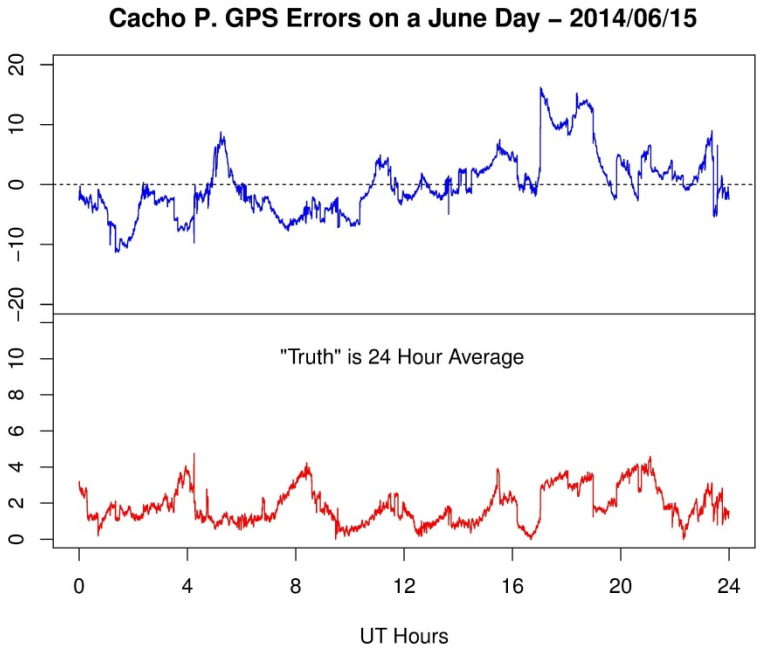
# A Study of GPS Positioning Errors

## Seven stations at varying magnetic latitudes



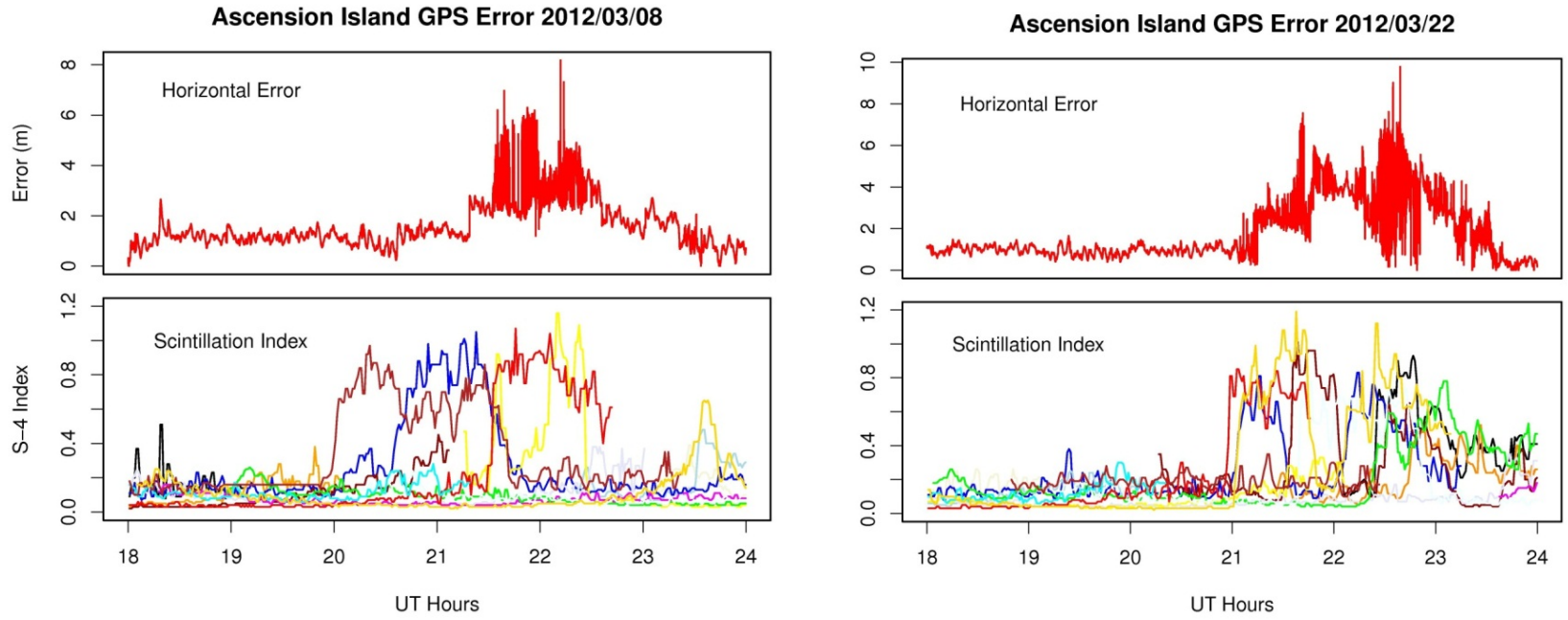
# Determining “Truth” Positions



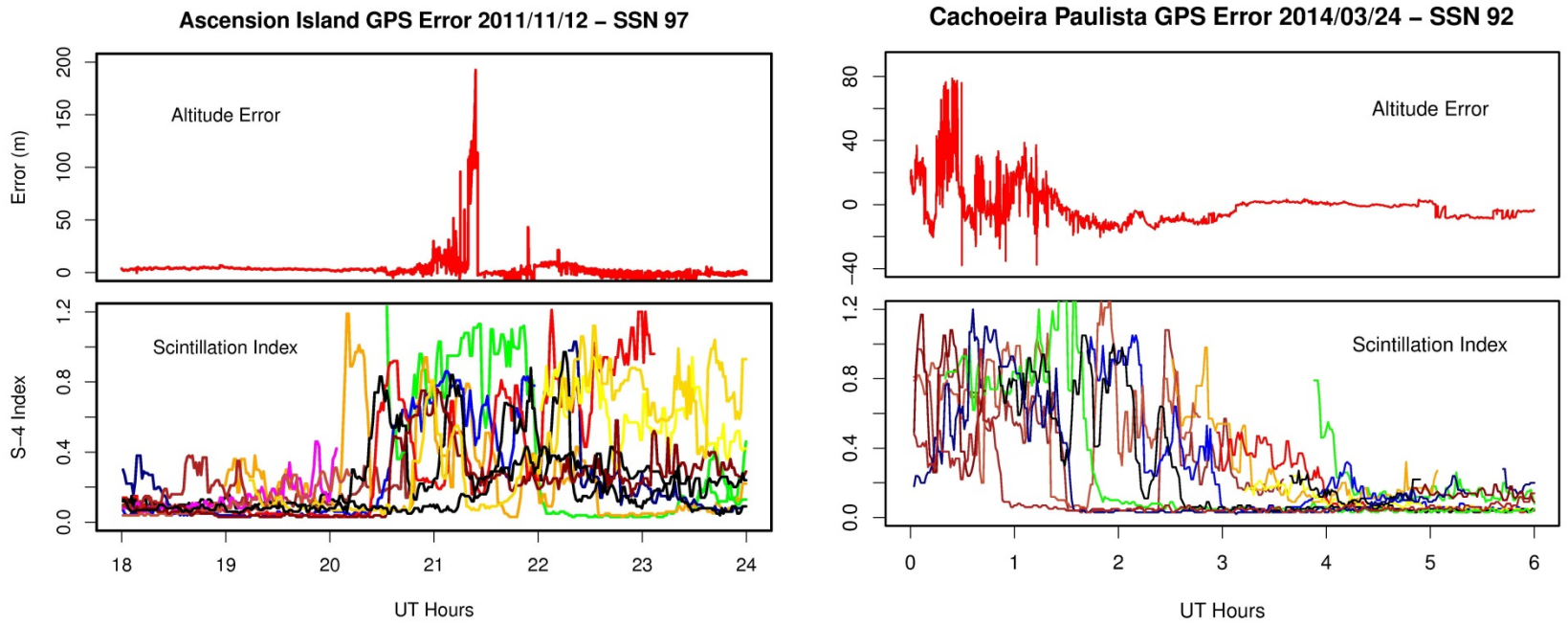

- We find the “truth” location from a 24-hour quiet period.
- Different receivers give different noise levels, but all noise levels are small compared to scintillation-induced errors.

# Examples from March 2012



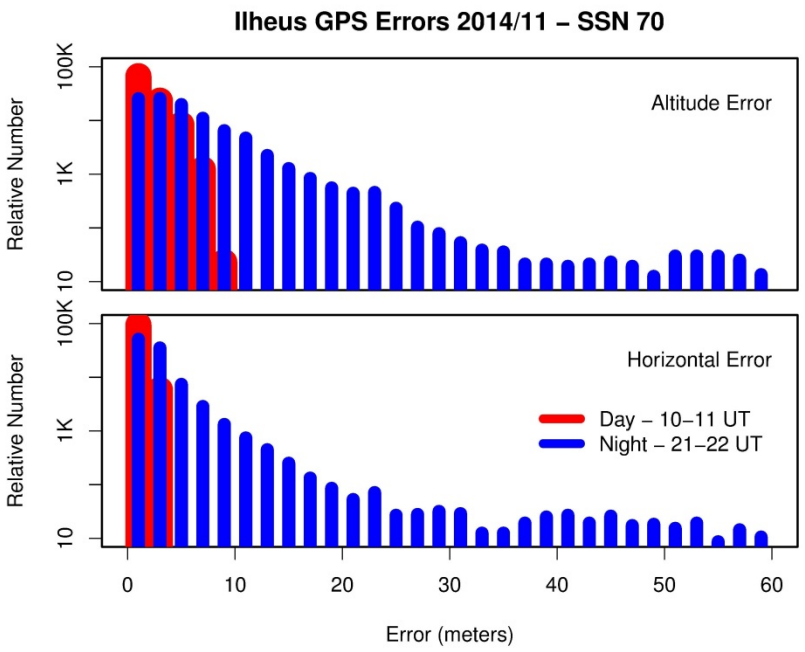

- Considering specific days we see direct correlation between scintillation and horizontal position errors.
- The scintillation-induced errors on these nights are small.

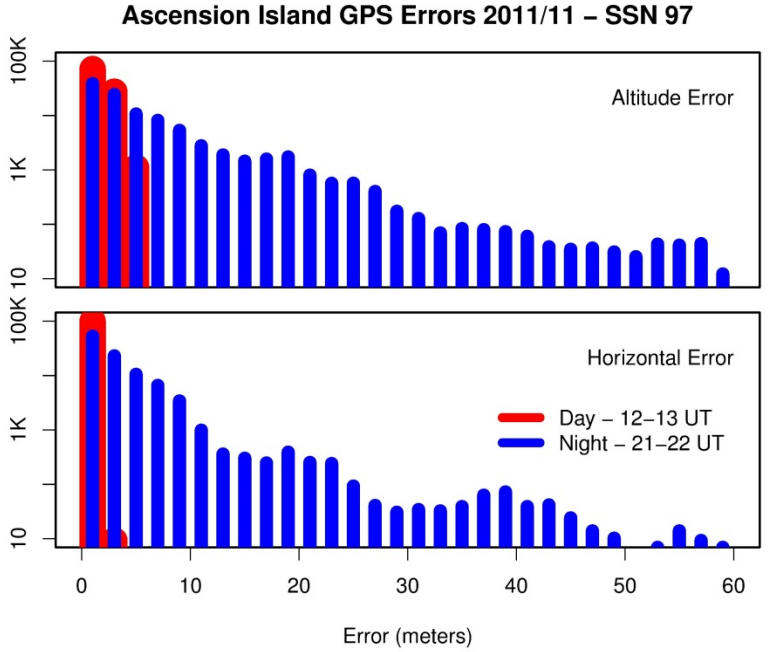
# Examples of Larger Errors




- We have found several days with errors of several 10's of meters in both the horizontal and the altitude.
- Some of these come as a constant offset and some more as random fluctuations.

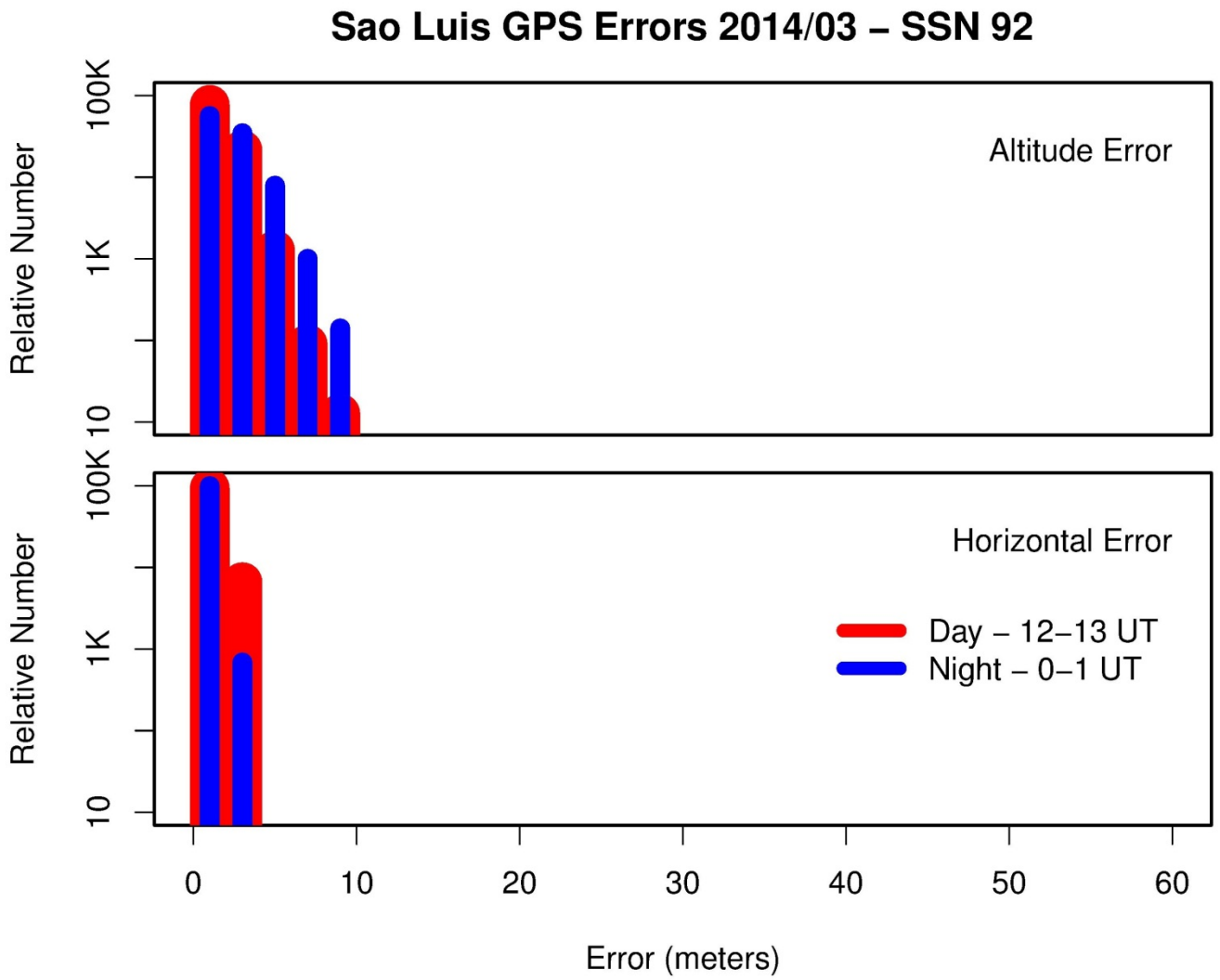
# Error Statistics



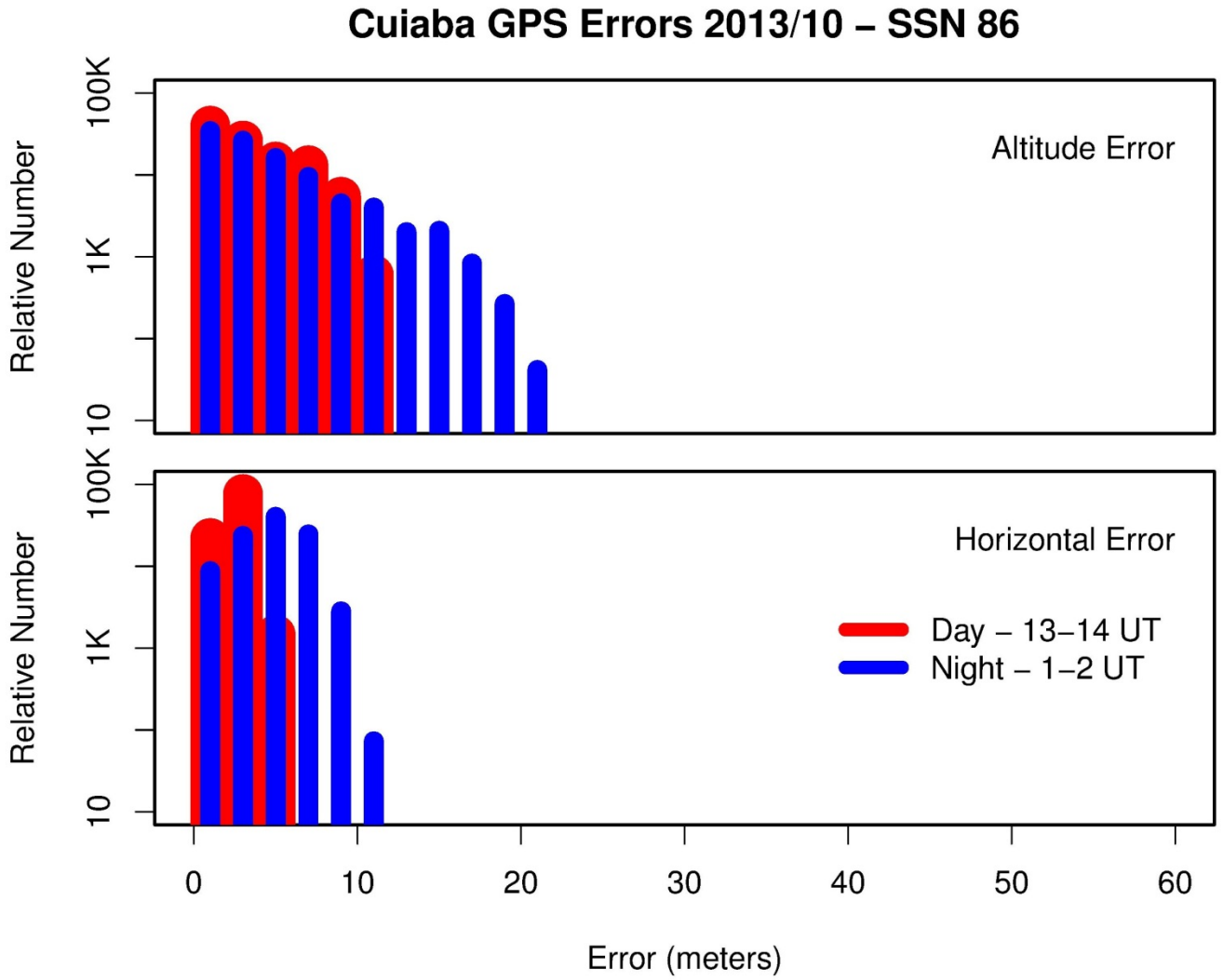




- We generated histograms of errors from the seven stations to examine the effect of magnetic latitude.
- The following slides show the progression as we go from the equator toward the south pole.

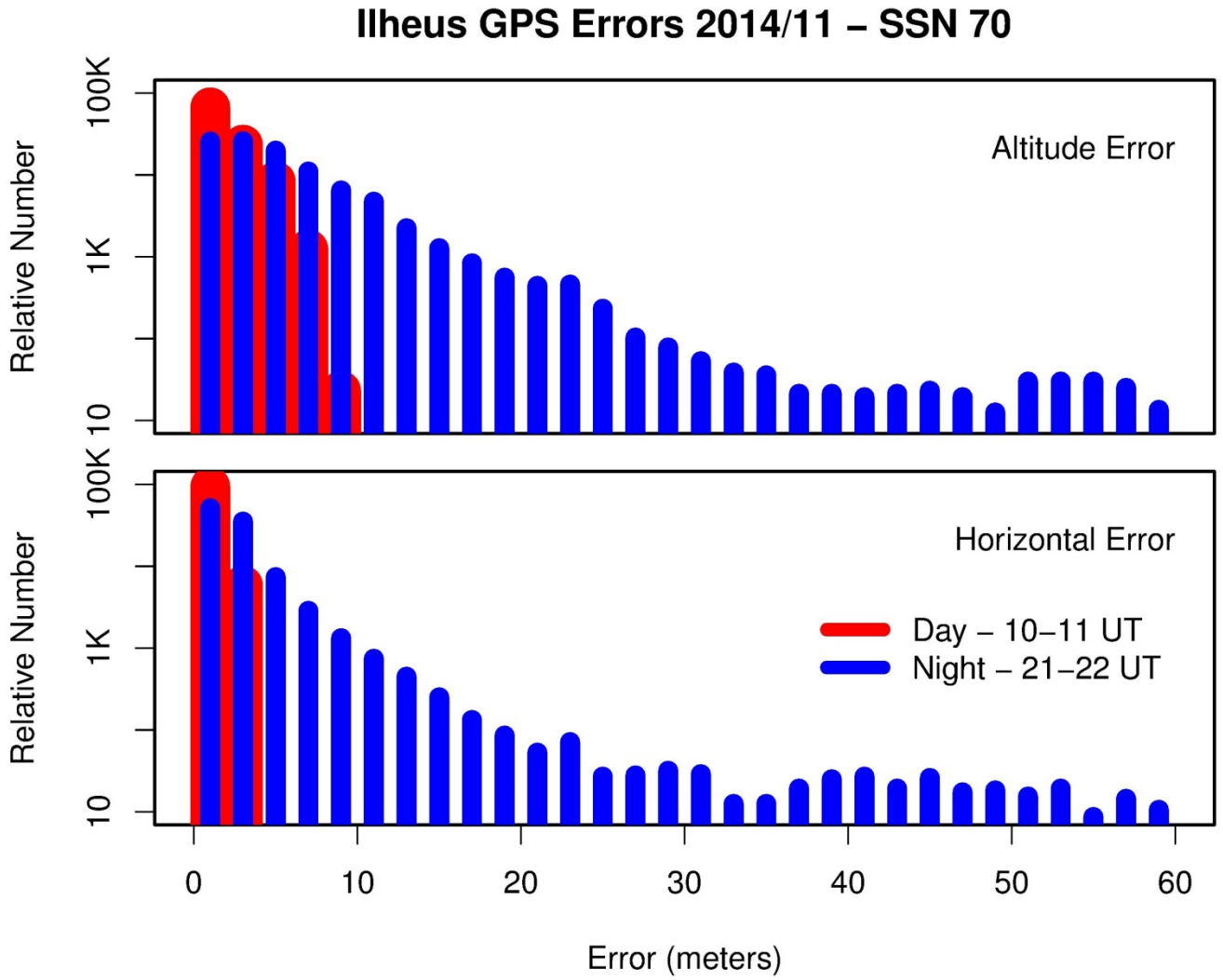
# Sao Luis – 0.1° MLat



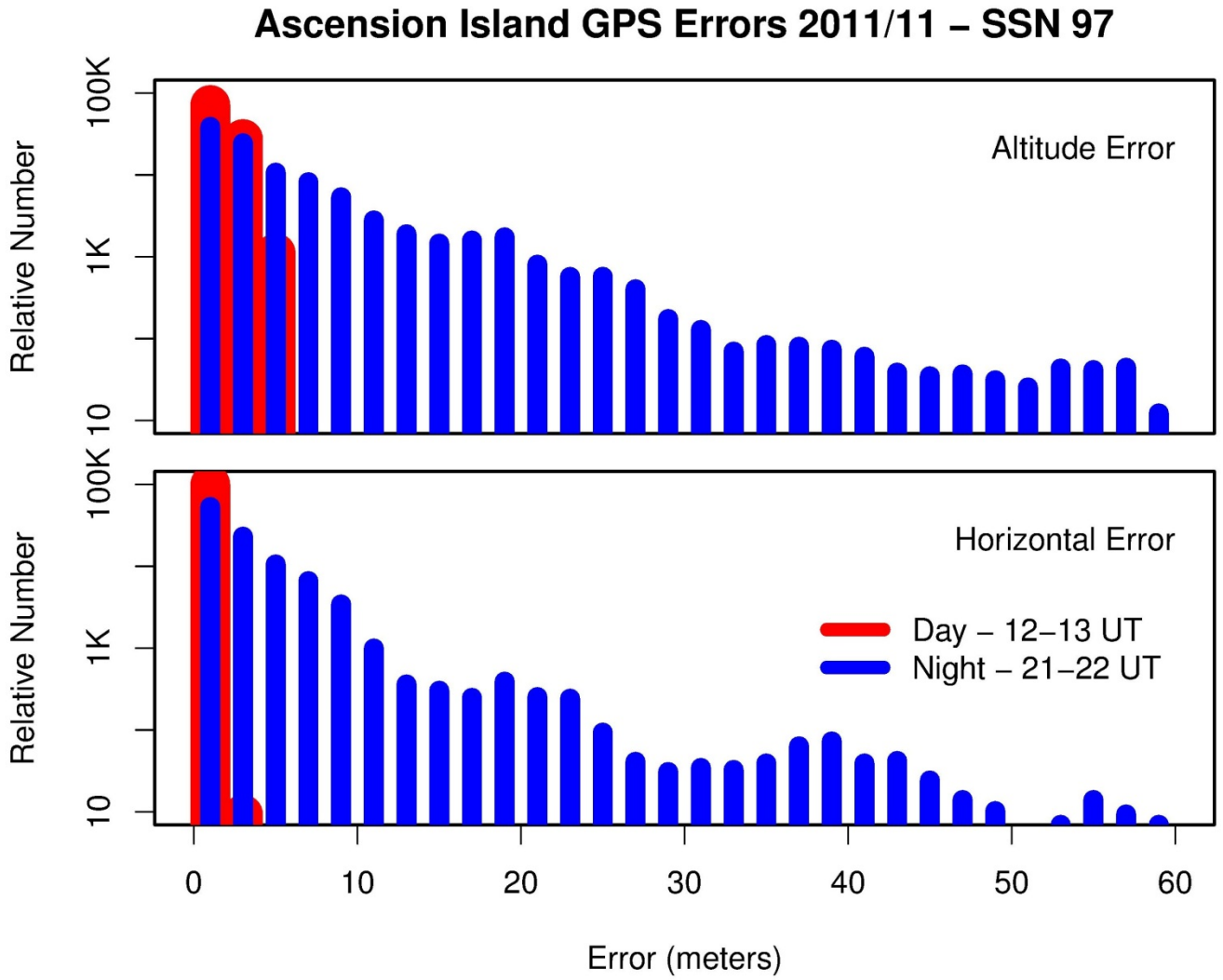
# Cuiaba – 6.5° MLat



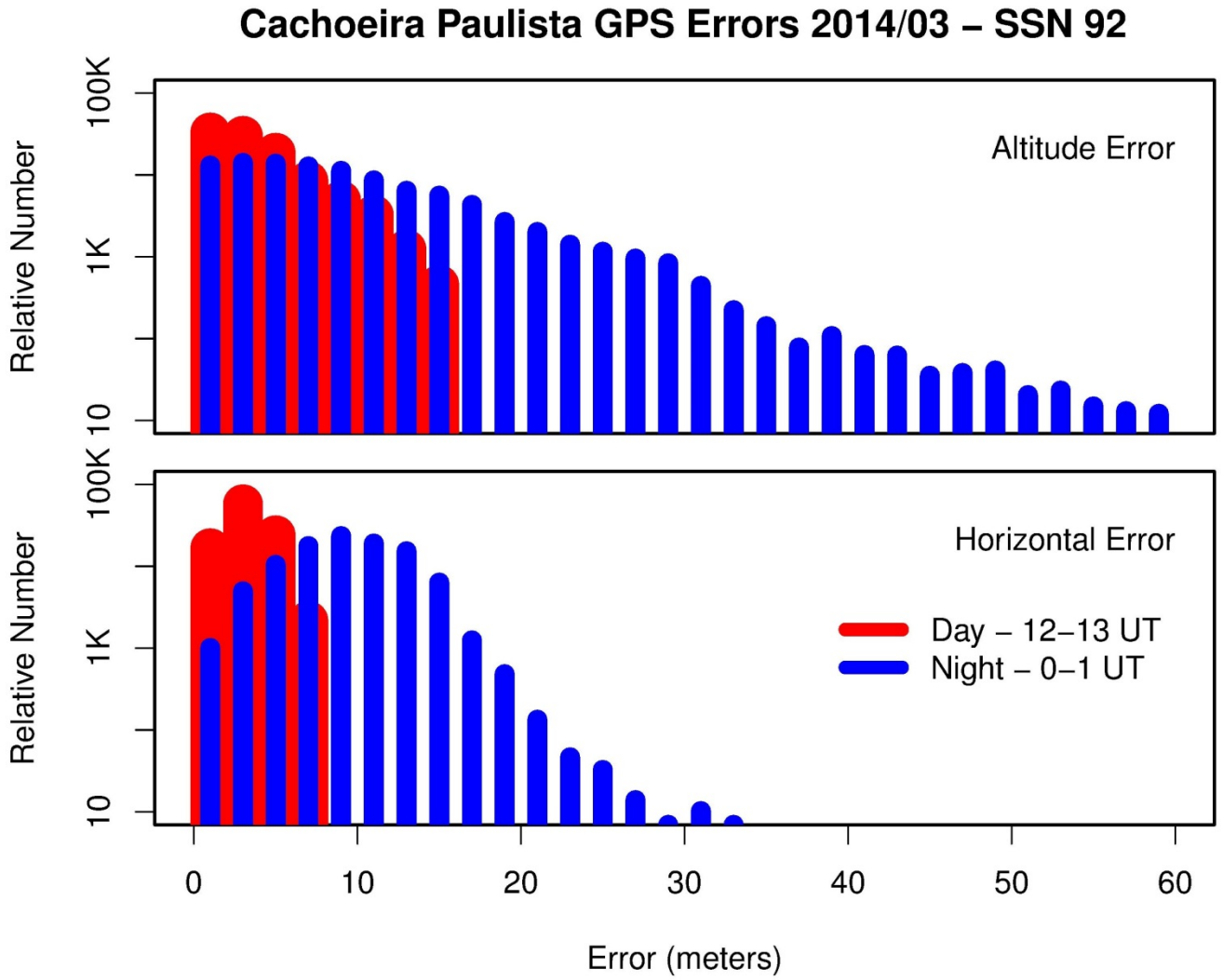
# Ilheus – 15.2° MLat



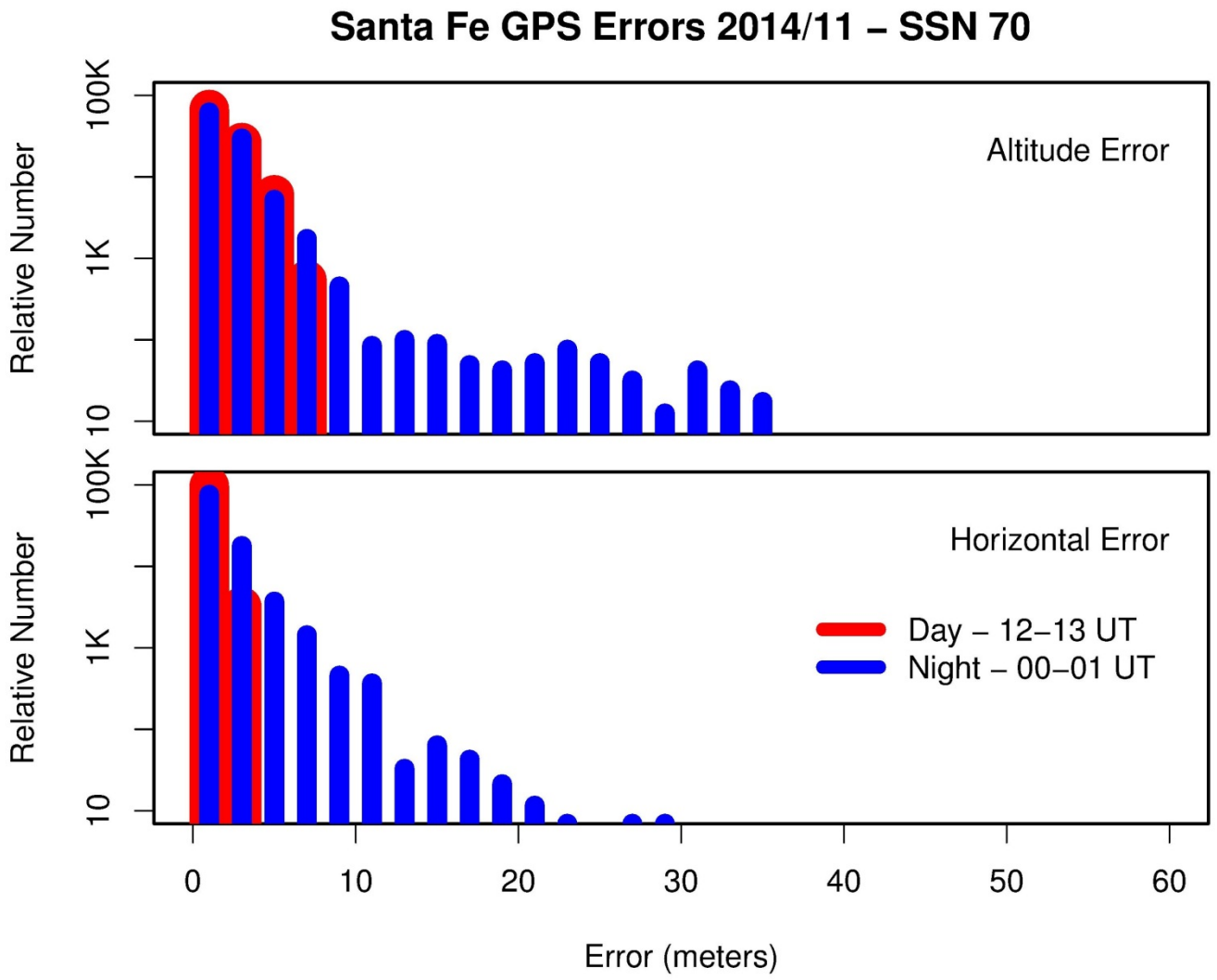
# Ascension Island – 17.8° MLat



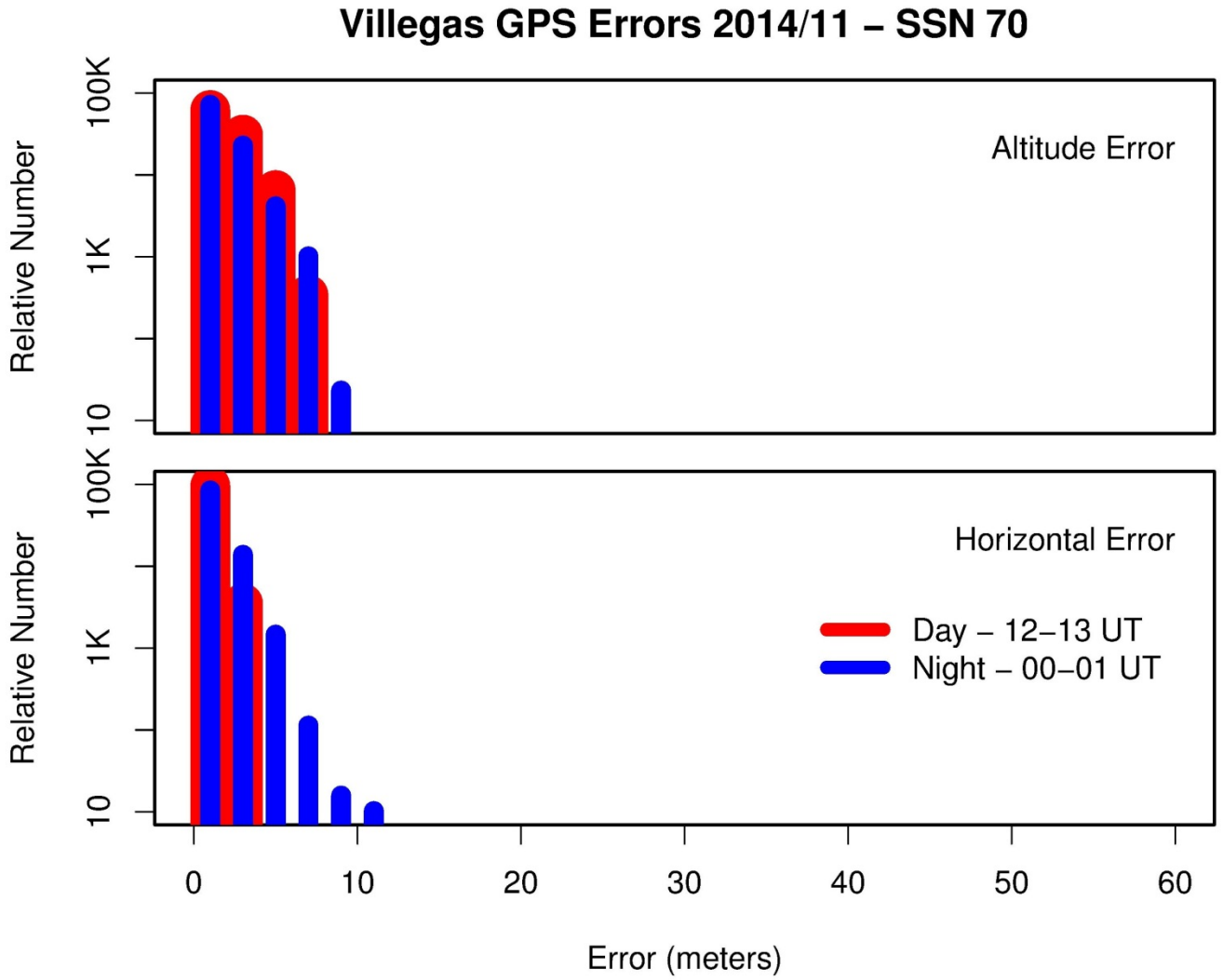
# Cachoeira Paulista – 19.6° MLat



# Santa Fe – 22.2° MLat



# Villegas – 23.6° MLat

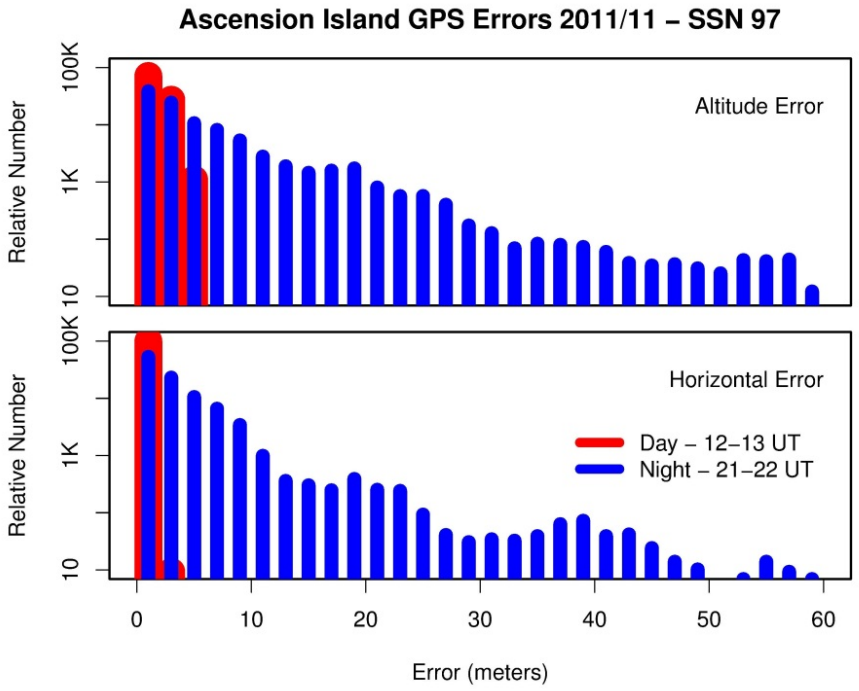


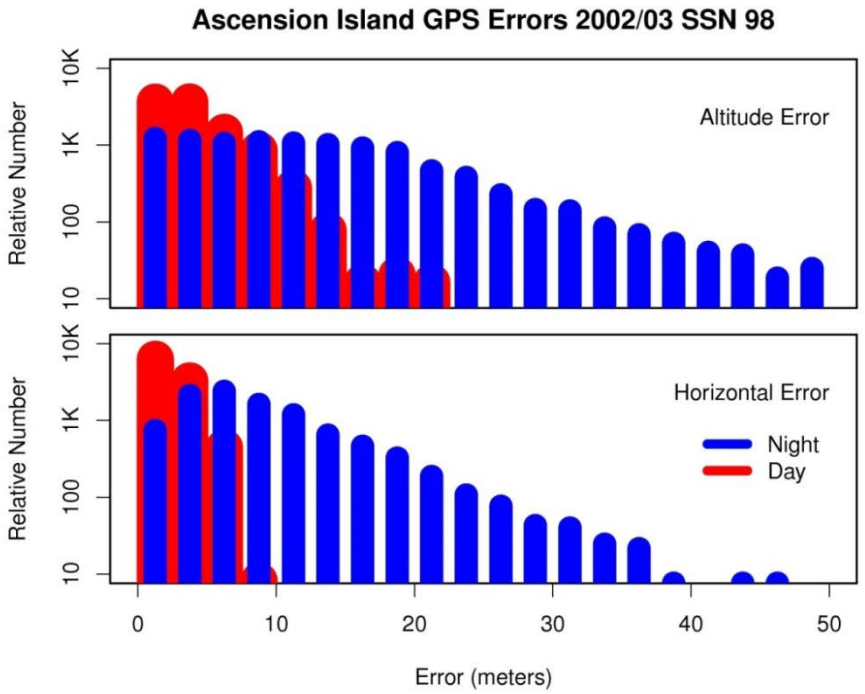
# Magnetic Latitude Dependence

| Station | Magnetic Latitude | Error Level |
|---|---|---|
| Sao Luis | 0.1° | None |
| Cuiaba | 6.5° | Weak |
| Ilheus | 15.2° | Strong |
| Ascension Island | 17.8° | Strong |
| Cachoeira Paulista | 19.6° | Strong |
| Santa Fe | 22.2° | Weak |
| Villegas | 23.6° | None |

- Qualitatively speaking, the errors are strongest under the anomaly crest, going to zero equatorward and poleward.
- The errors are limited to a band from about 7° to about 22° magnetic latitude.

# Position Errors at Ascension Island
## Comparison with Last Solar Cycle

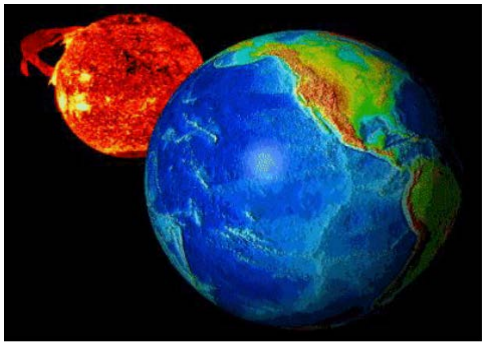


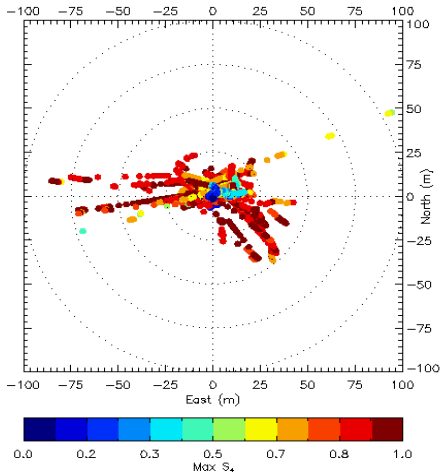




- Here we compare Fall of 2011 to Spring of 2002.
- We see that the errors are comparable for comparable monthly sunspot numbers.
- Here we are comparing two different receivers.

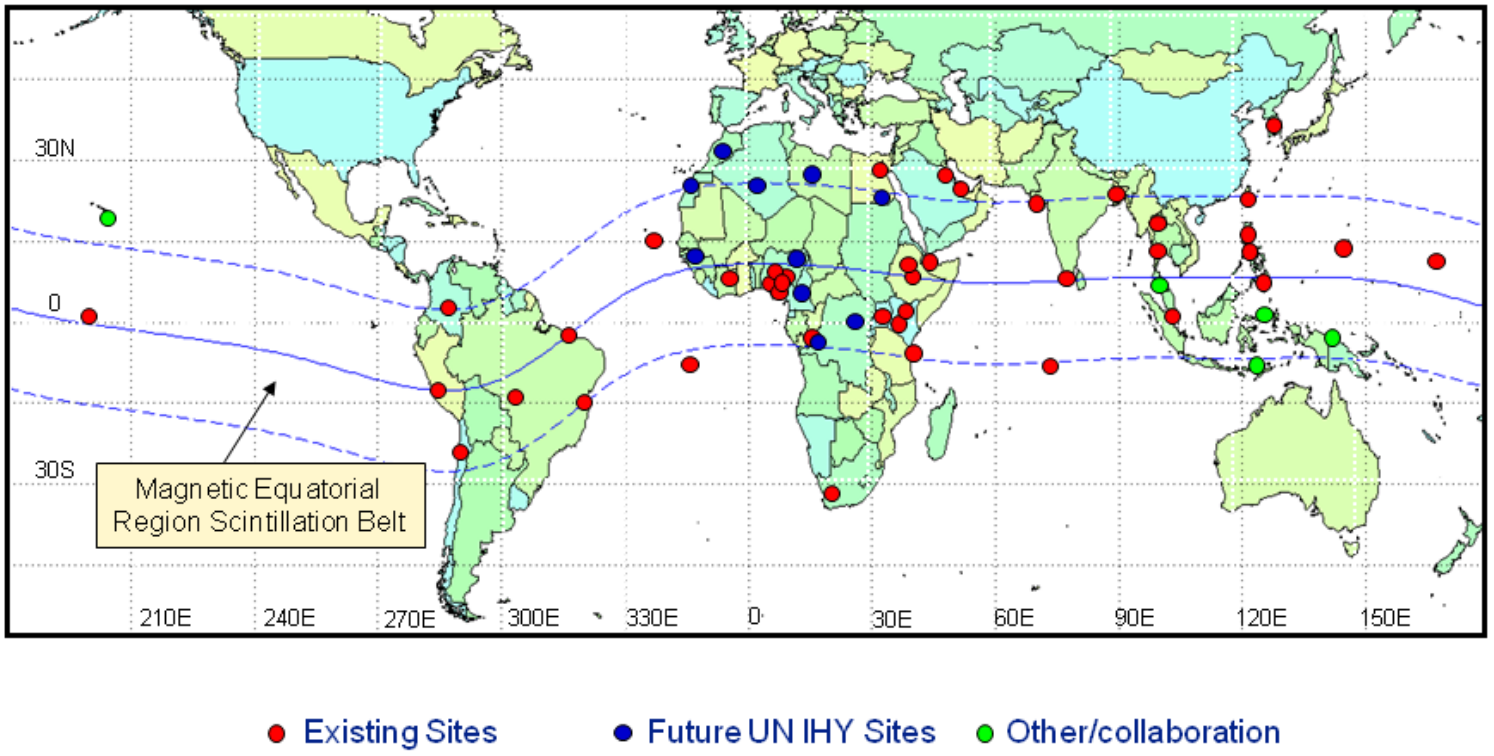
# Summary

- Ionospheric scintillation has recently entered the solar maximum phase of cycle 24
- Users should expect impacts on GPS systems through 2015
- We find errors up to 100 meters during periods of intense scintillation
- The errors are confined to a relatively broad band in magnetic latitude corresponding roughly to the latitudes of the equatorial anomaly
- GPS positioning equatorward of about 7$^{o}$ and poleward of about 22$^{o}$ is not impacted by equatorial scintillation..





# SCINDA Sites Map




Existing and expected sites through 2012

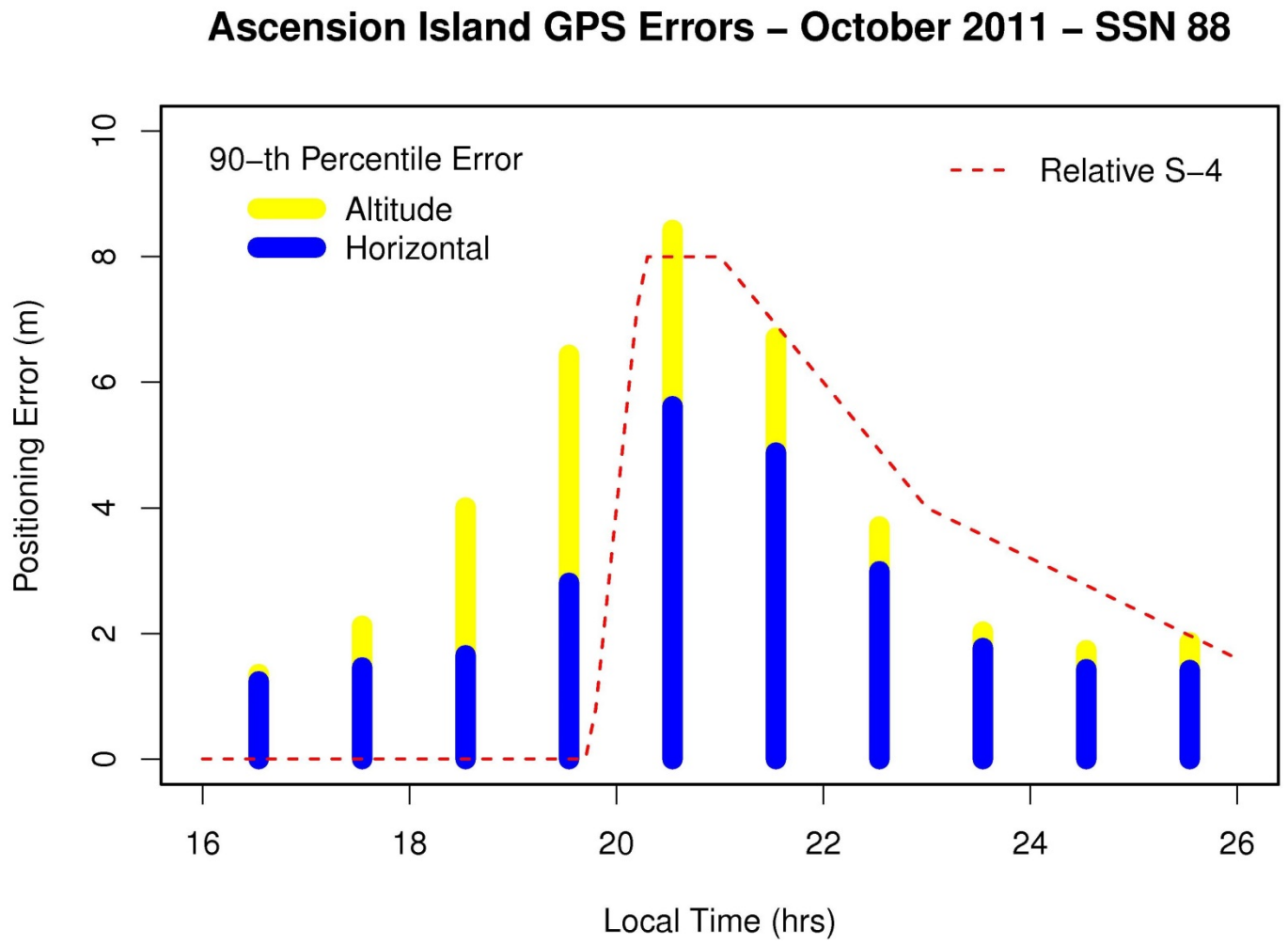
# How Important are These Errors?

The impacts of errors of this magnitude will of course depend on the application, but as a reference, we quote Seo *et al.* [2010]

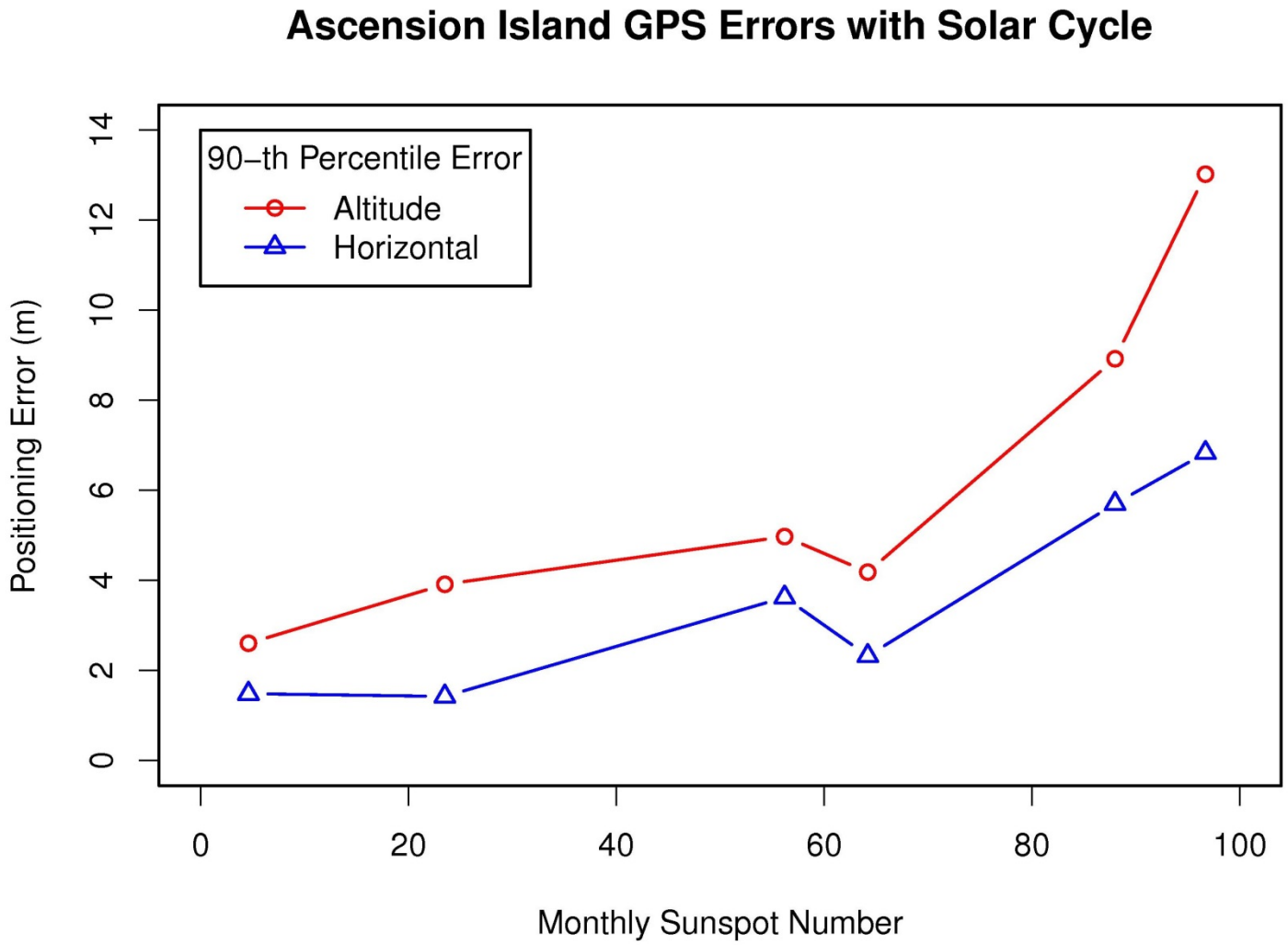
"The alert limits of the LPV-200 approach procedure are 40 meters in the horizontal and 35 meters in altitude.

Seo, J., T. Walter and P. Enge, Correlation of GPS signal fades due to ionospheric scintillation for aviation applications, *Adv. Space Res*, **47**, 1777 (2010)

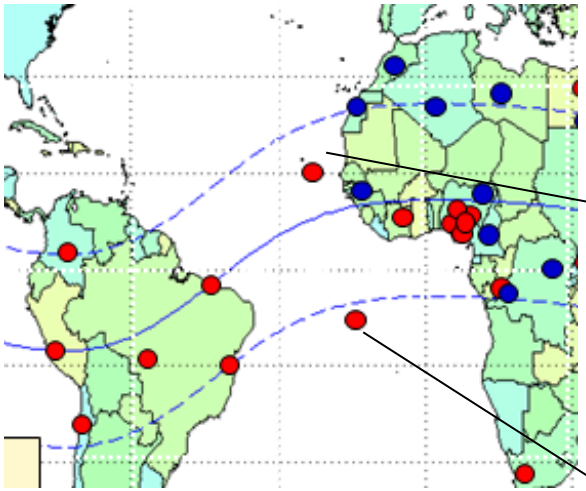
# Local Time Dependence

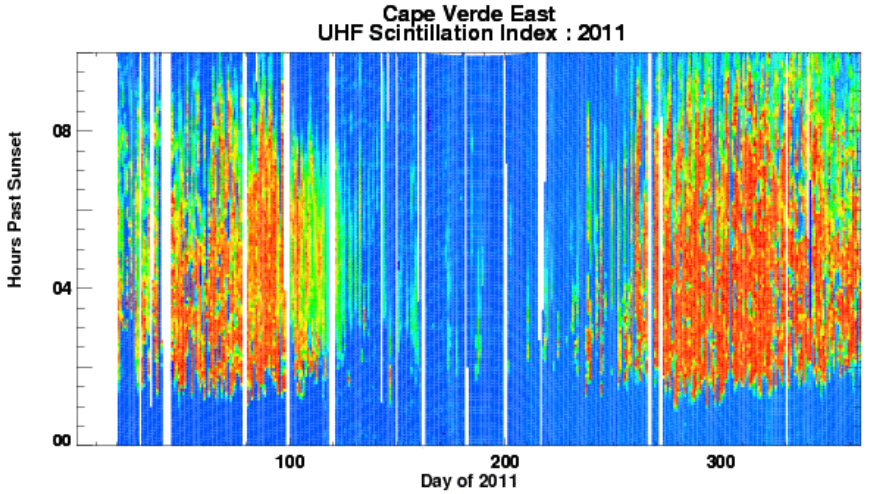


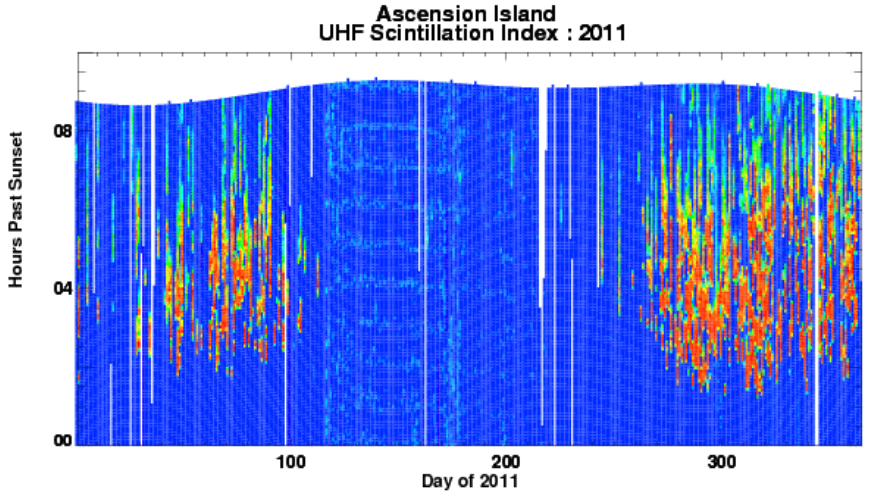
# Solar Cycle Dependence

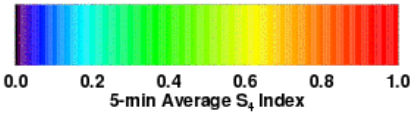


# Relative Occurrence of Bubbles Exceeding 1000 km Altitude






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