Analysis of Scintillations recorded in the equatorial regions

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- GPS receiver characteristics wrt scintillations
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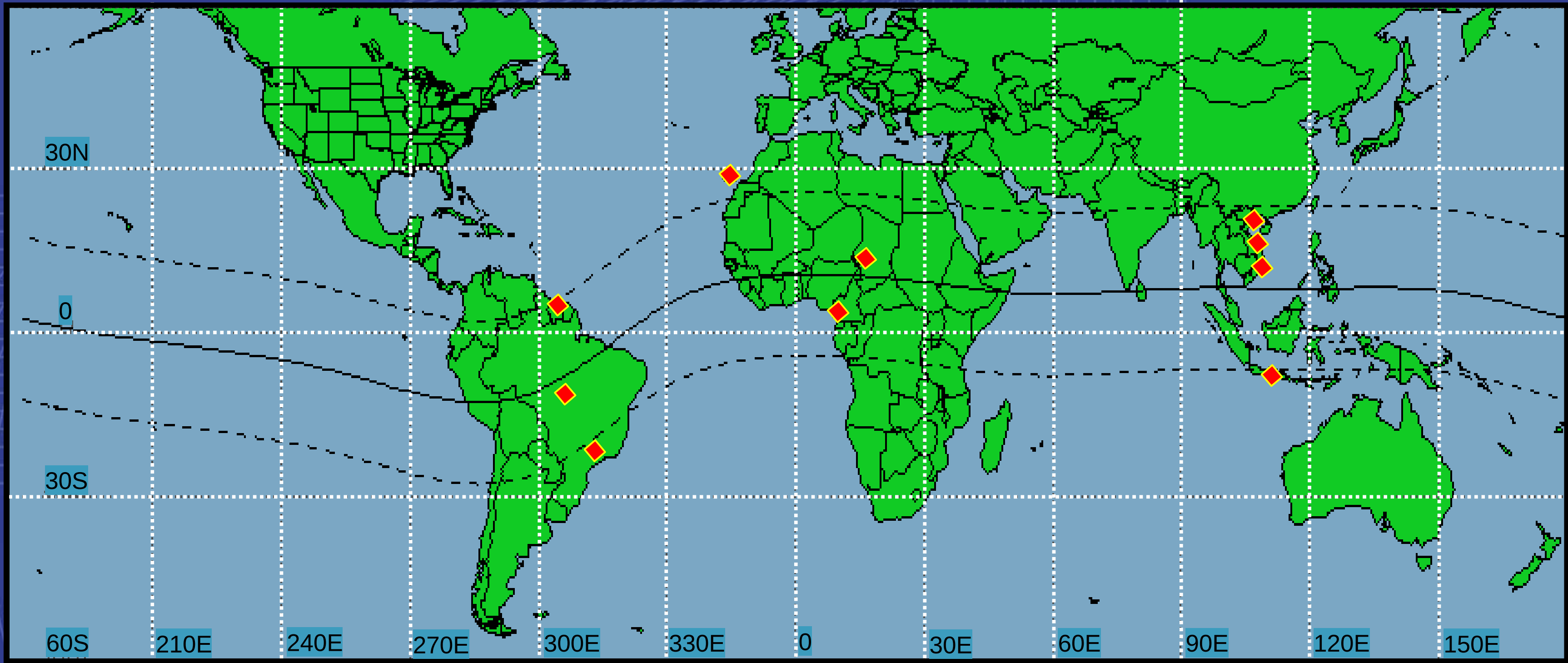
Measurement Campaign

Receivers deployment in the equatorial regions



Institutions : U. of Rennes & Brest (Fr), DLR (Ge), GMV (Sp), ESA/ESTEC, CLS (Fr), IEEA (Fr)

Receivers in use

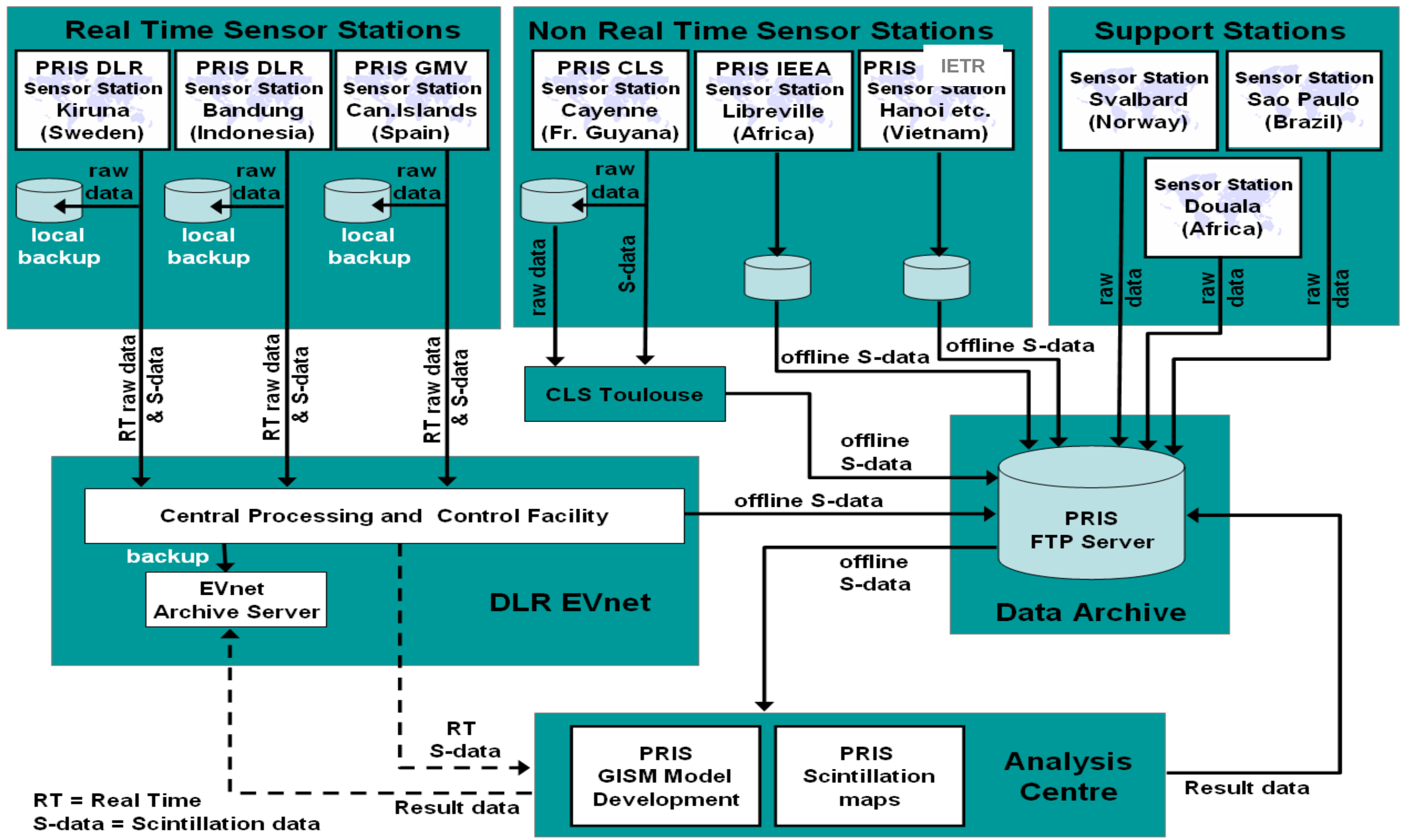
GSV 4004 : both phase & intensity : GPS + 3 GEOs

Cayenne, Africa, Vietnam

Javad : both intensity & phase : GPS

Indonesia , Canary Islands & Sweden

Data collection



Measurements from

N'Djamena (Tchad) (with support from ASECNA company)

Cayenne (French Guyana)

Douala (Cameroon)

N'Djamena (october 2006)

Provisory installation

371 299 samples → 29737 (S4 > 0.2) → 2981 (multipaths removed)

Only GPS satellites, no GEO at that time

3 GEOs may be tracked

Cayenne (same period of time)

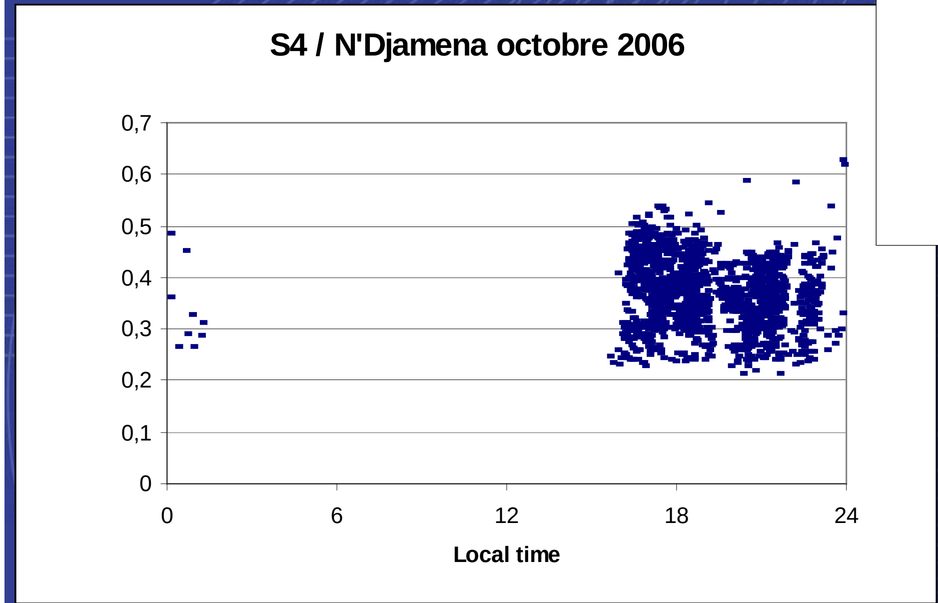
392709 samples → 19099 (S4 > 0.2) → 2322 (multipaths removed)

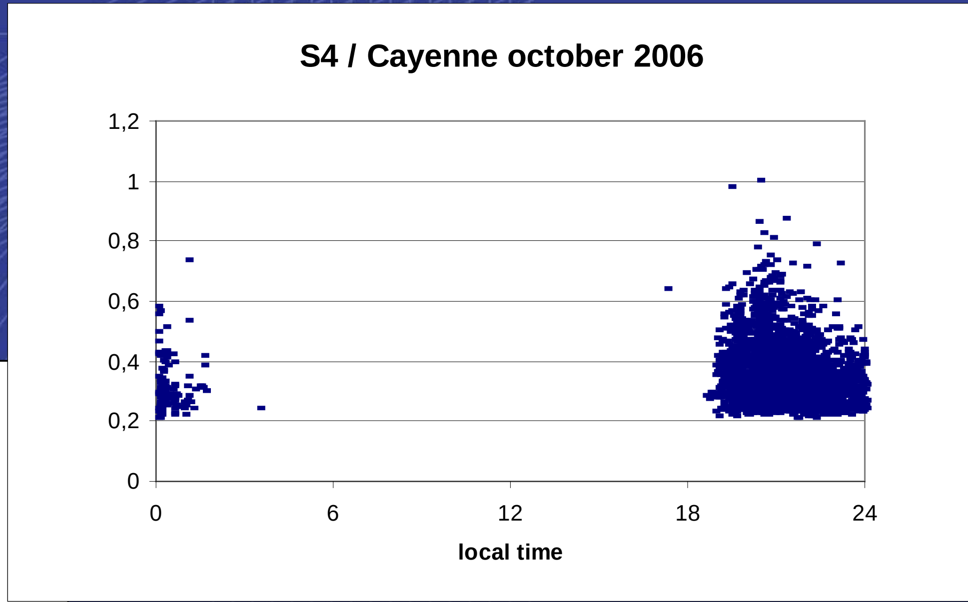
GPS + 1 GEO

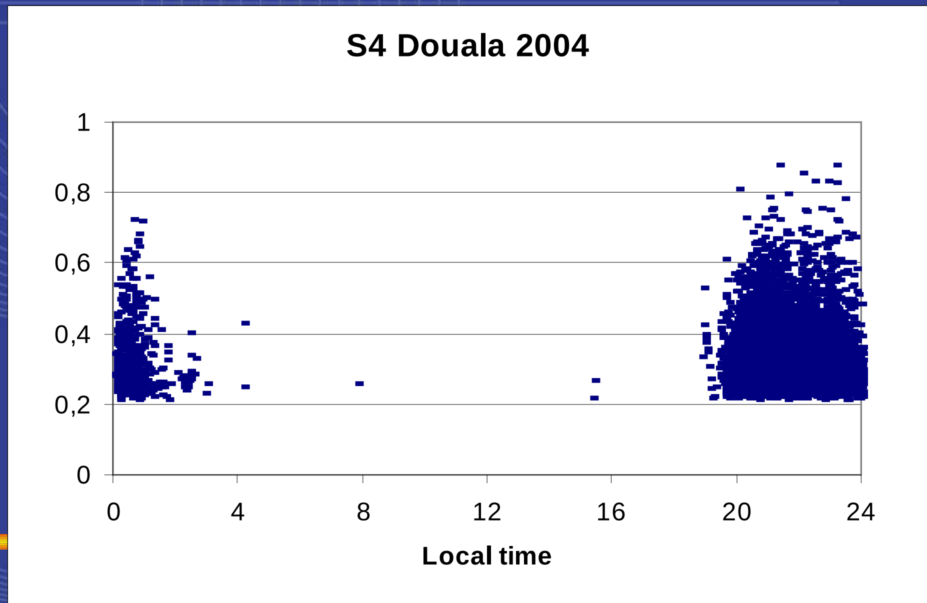
Douala (2004)

GPS + 1 GEO

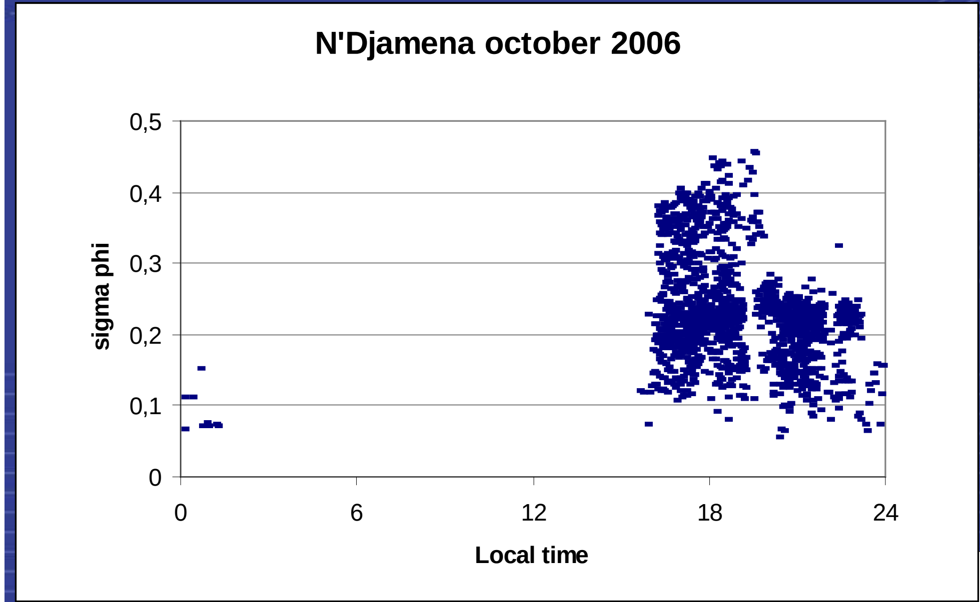
S4 occurrence

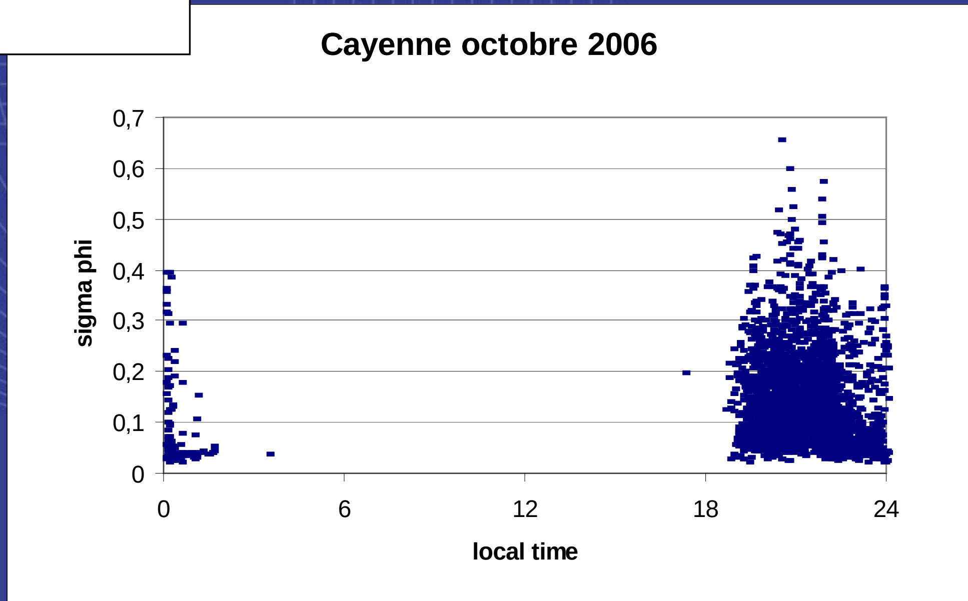




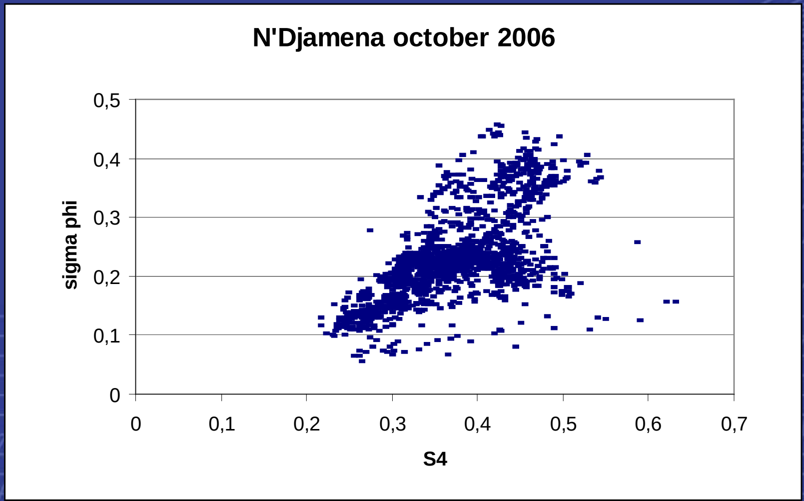


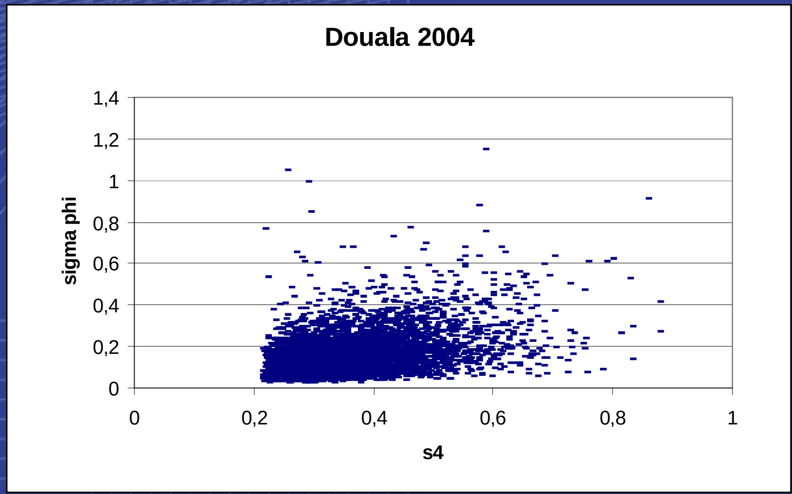
Sigma phi occurrence

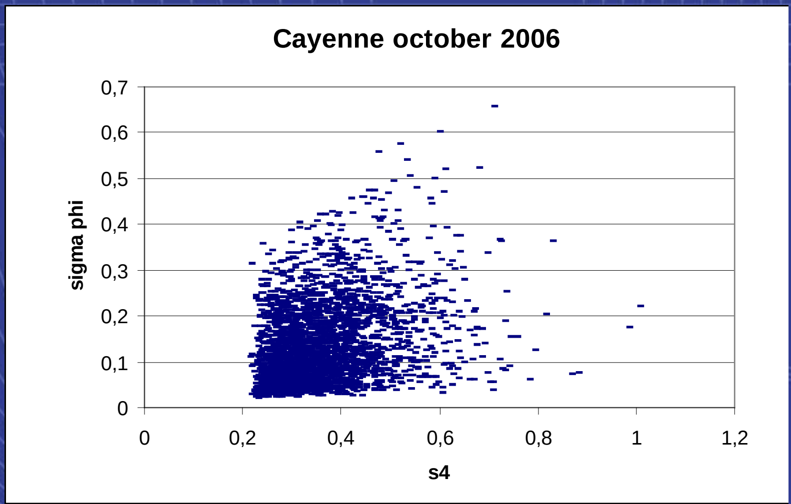




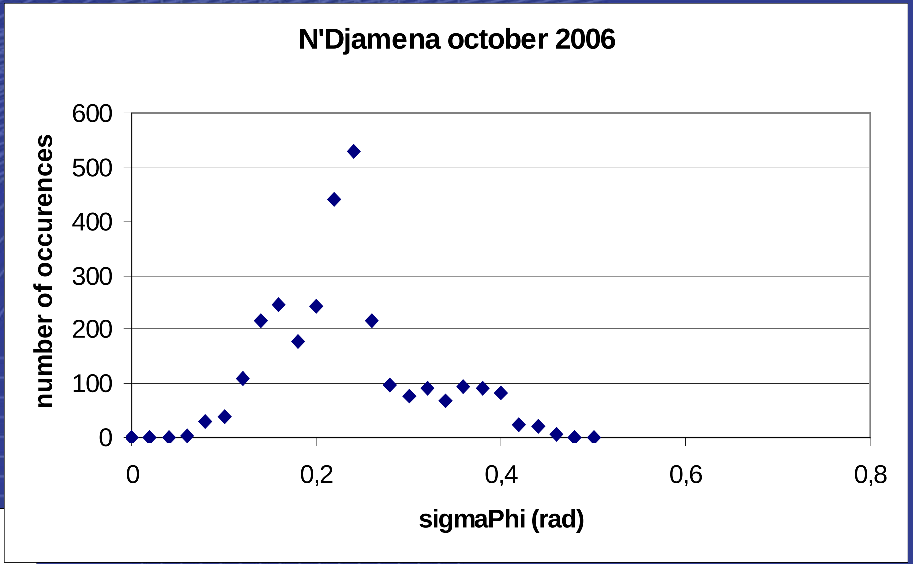
Phase vs intensity

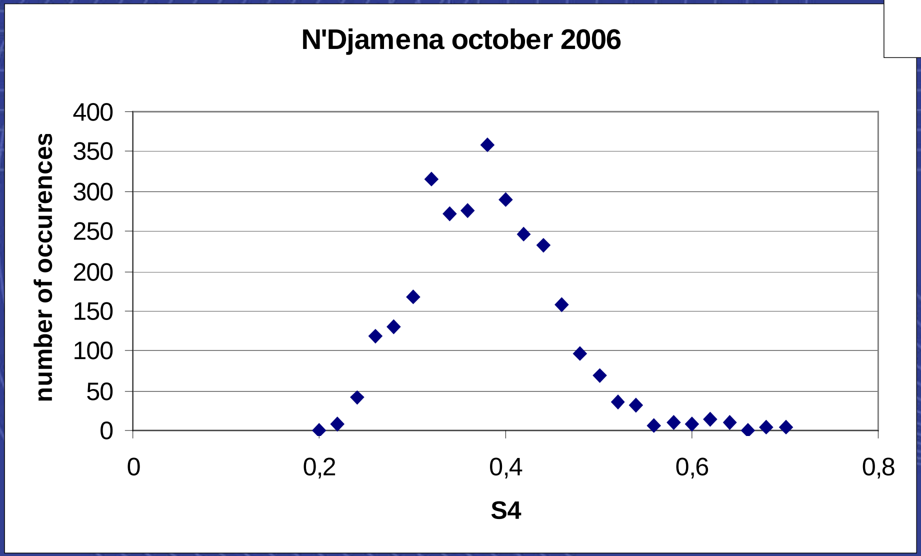






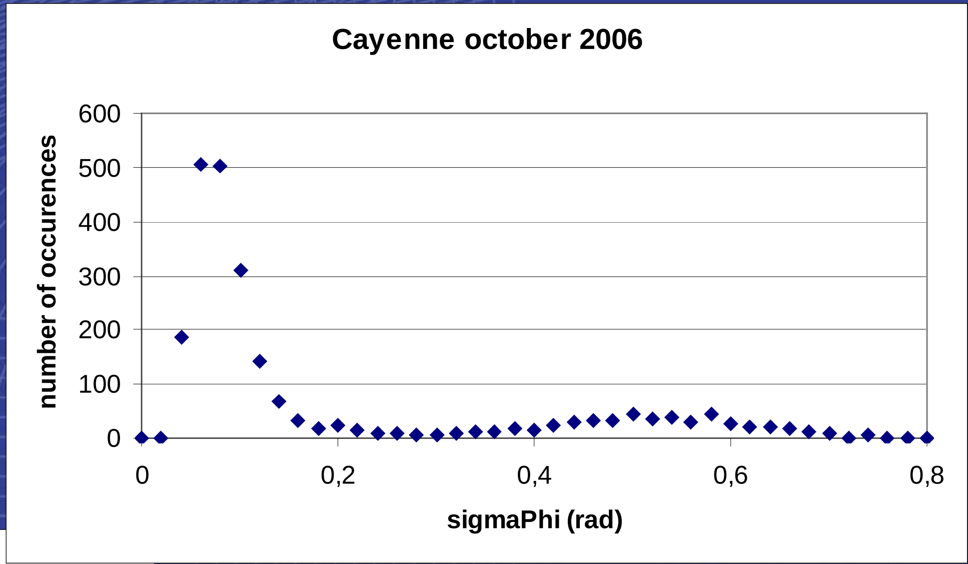
S4 & sigma phi distributions N’Djamena

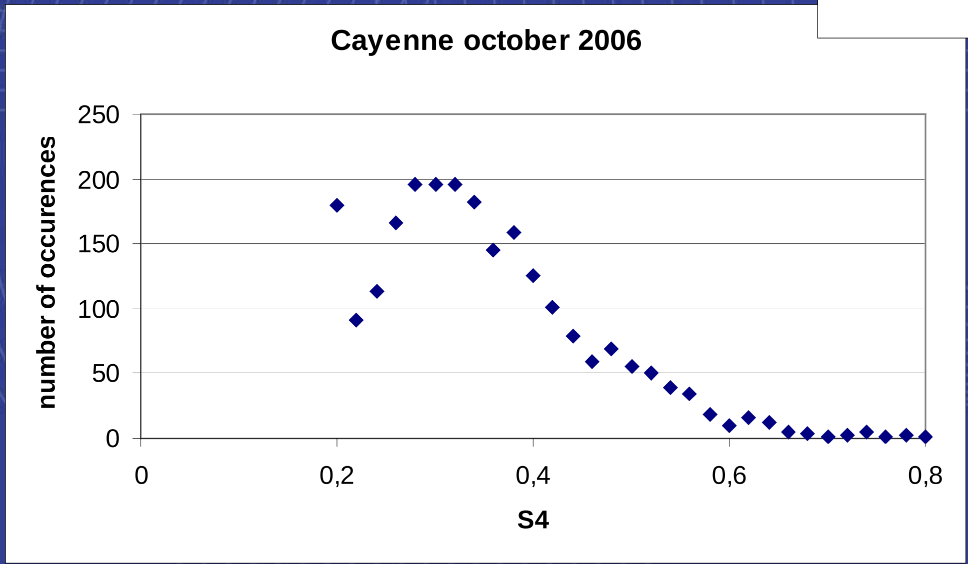




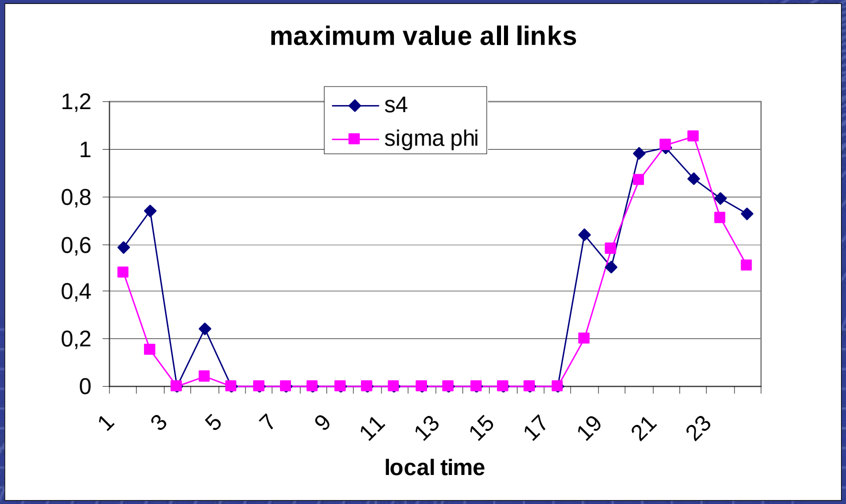
S4 & sigma phi distributions

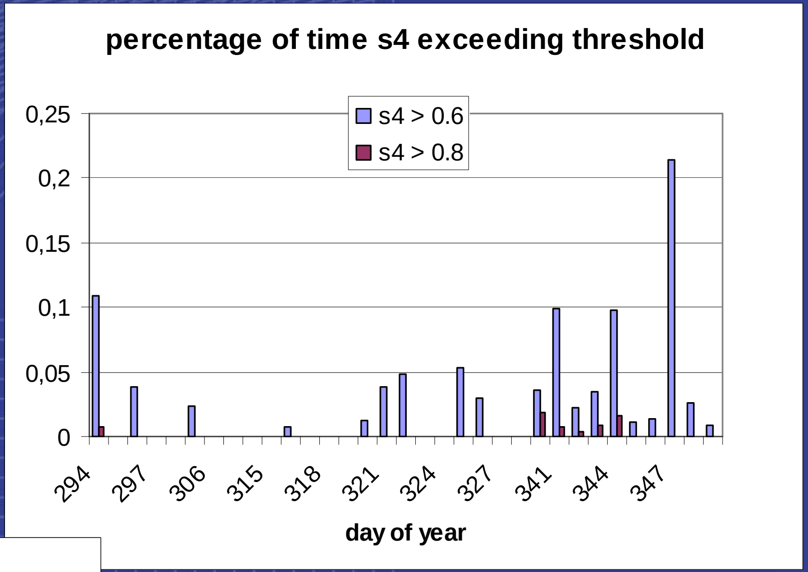
Cayenne

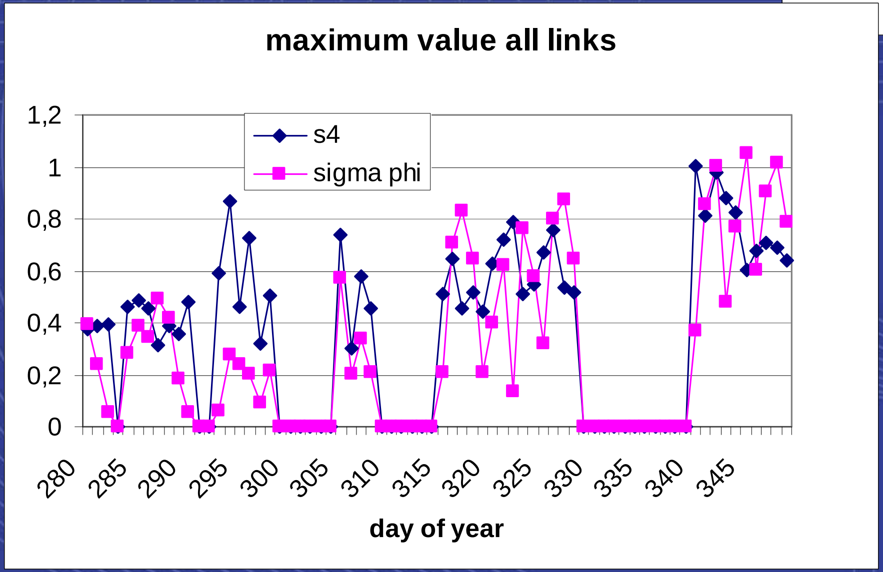




S4 statistics







GPS receiver characteristics with respect to scintillations

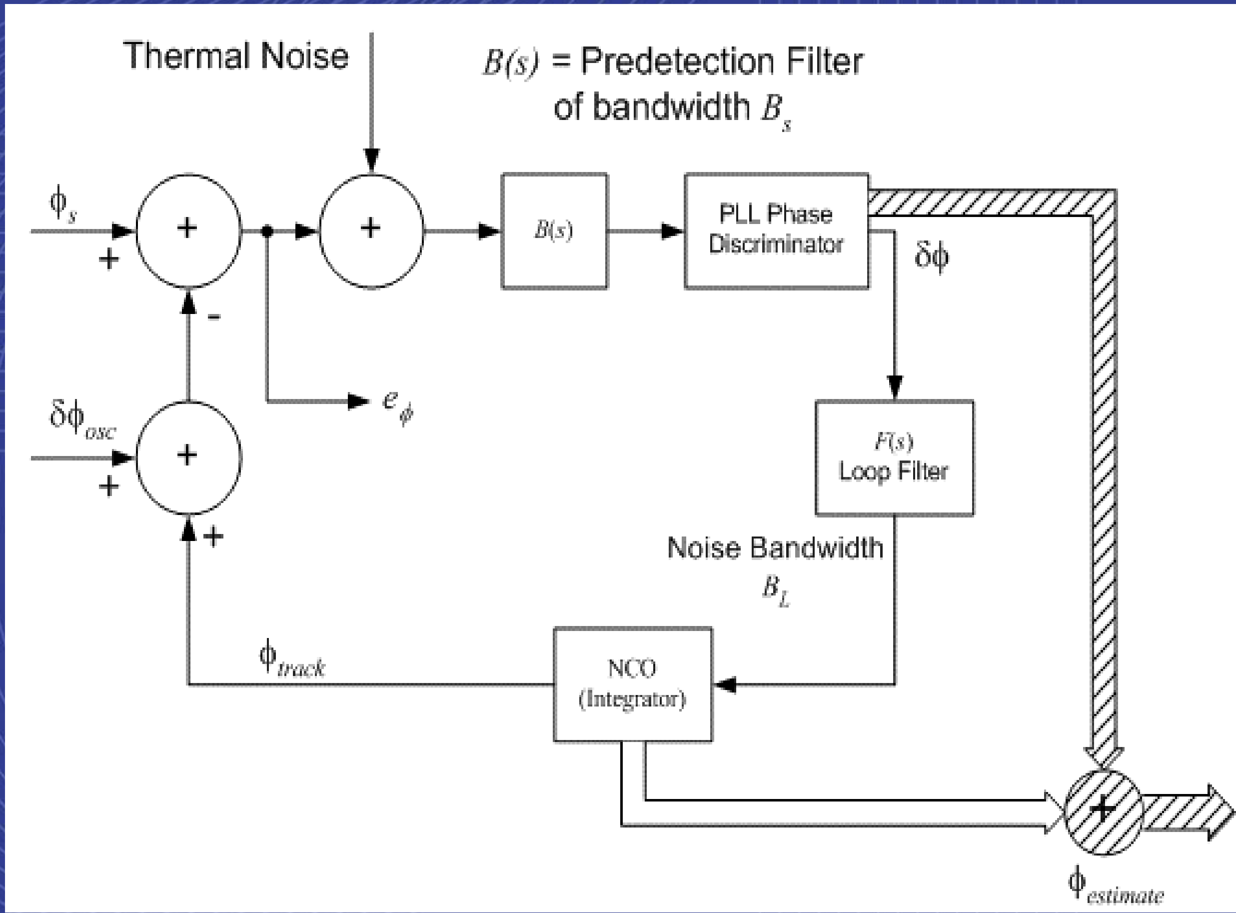
Measuring Amplitude Scintillation

- Amplitude Scintillation
  - Measure GPS signal-plus-noise power
  - Remove, as well as one can, noise power
  - Relatively straight-forward
    - Some “detrending” issues separating scintillation fades from multipath fading – a detrending bandwidth issue
    - Averaging proves to be more stable than filtering, but results in higher S4 due to multipath fading

Measuring Phase Scintillation Effects

- GPS receiver must track signal phase using a phase lock loop (PLL)
  - Weakest link in a GPS receiver
  - Measurements include perturbations of receiver and satellite oscillators
    - These perturbations cannot be removed with "detrending"
  - Also include signal Doppler, multipath and ionosphere TEC (and oscillator frequency offset), that can be removed with "detrending"
- Typically, measurement bandwidth is the PLL loop bandwidth
  - Wide bandwidth makes loop more sensitive to amplitude fading, and thus, loss of lock
  - Narrow bandwidth makes loop more robust, but filters out phase scintillation effects
- Loop can be configured to have narrow loop bandwidth, but still provide wide bandwidth phase data

PLL Model with Wideband Phase Estimator



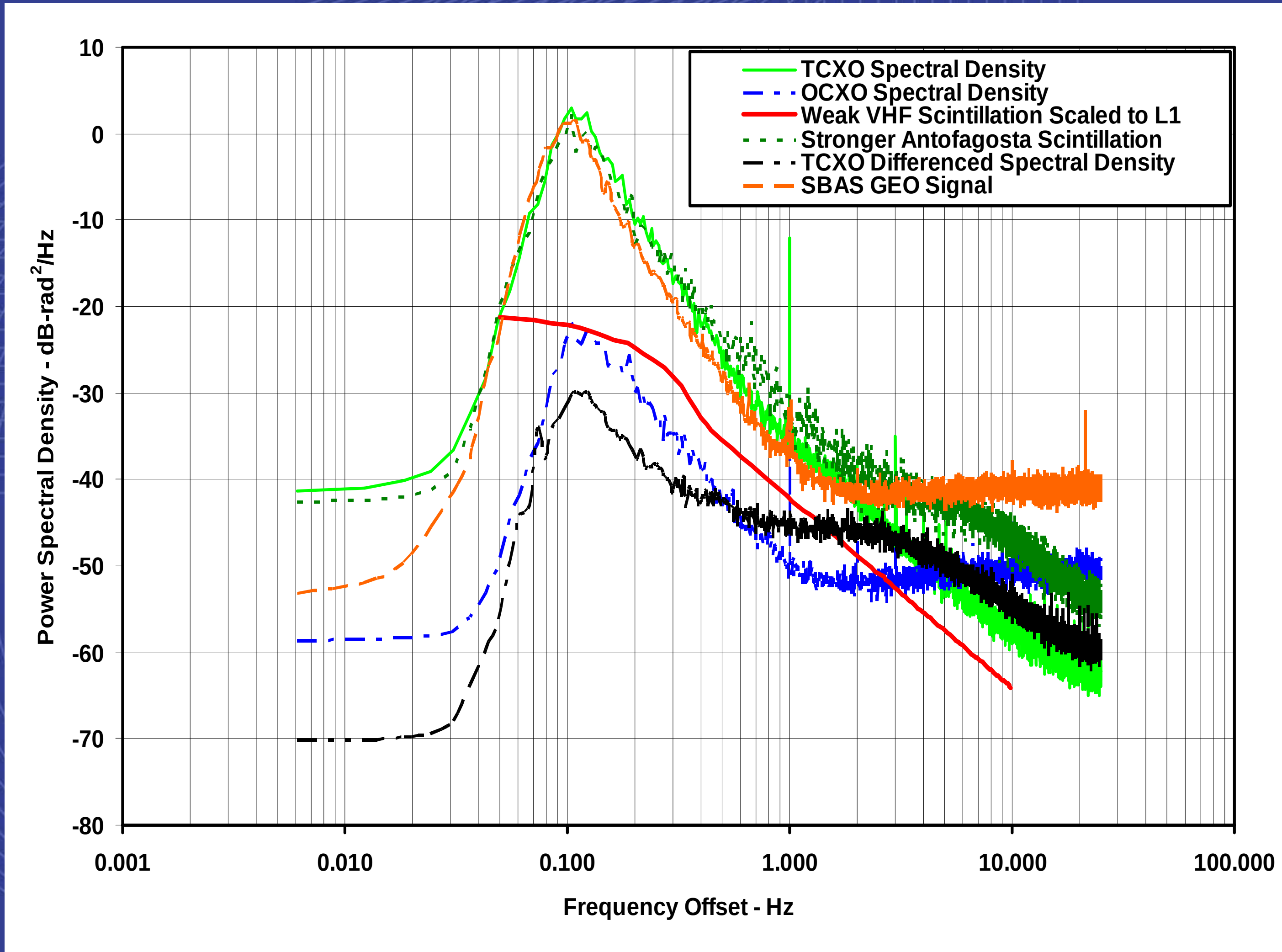
General GPS Receiver Limitations in Scintillation Environment

- Phase Scintillation
  - Generally not a problem at L1
    - No worse than low-grade TCXO
  - Severe problem for “semi-codeless” L2
    - Very narrow bandwidth PLL coupled with erroneous aiding with L1 phase (doesn’t agree with Doppler aiding)
- Amplitude Scintillation
  - Primary culprit for loss of phase lock at L1
    - Deep and long fades steal signal from PLL
    - Narrower bandwidth is better, but could require an better oscillator
    - False alarms from lock detectors during fades (apparent loss of lock)
  - Loss of data (symbols) from SBAS signals

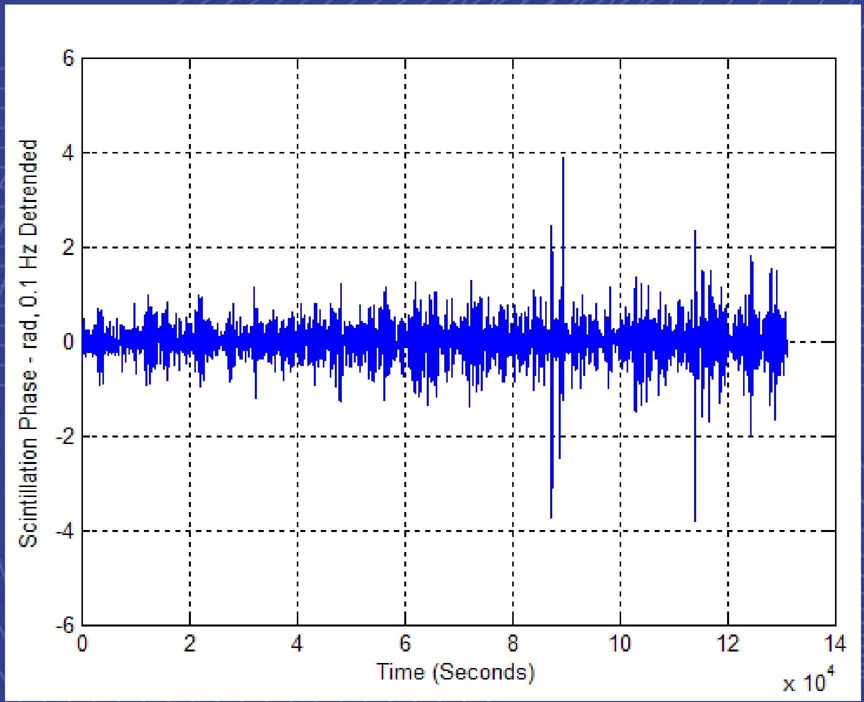
GPS Scintillation Monitor Limitations in Scintillation Environment I

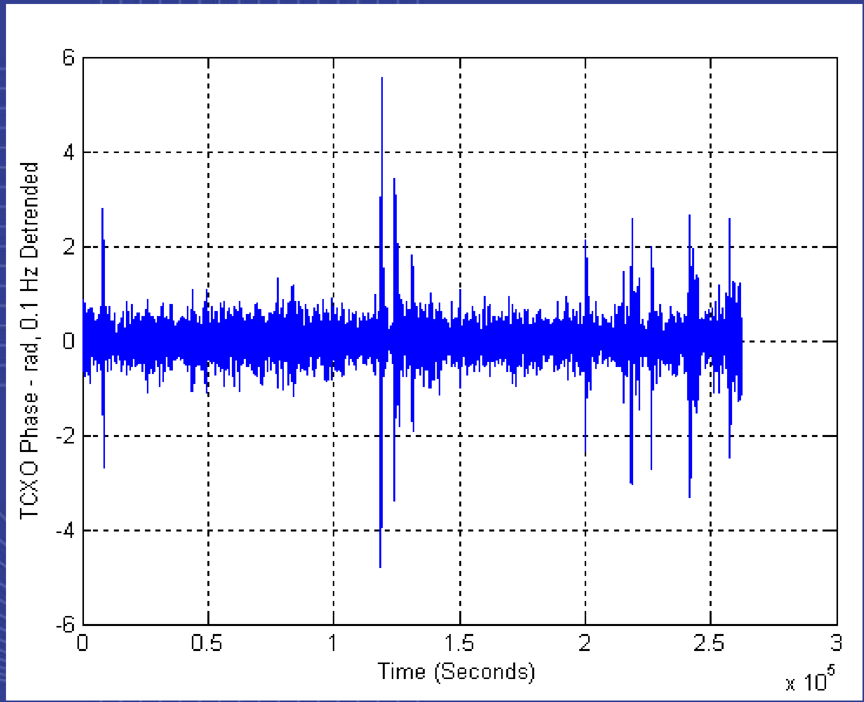
- Phase Scintillation
  - Can't measure scintillation at L2
  - Measurement limitations at L1 dominated by receiver oscillator
    - Typical receiver oscillator phase noise masks phase scintillation (See PSDs and plots in next charts)
    - Thermal Noise limitation is about 0.1 radian @ 30 dB-Hz
    - OCXO phase noise typically better than 0.05 radians
  - Limitation can be overcome by differencing phase between satellites
    - Creates a requirement for high-rate data collection and substantial post processing

Phase Noise PSD Comparisons



Antofogasta Phase Scintillation vs. TCXO Phase Noise





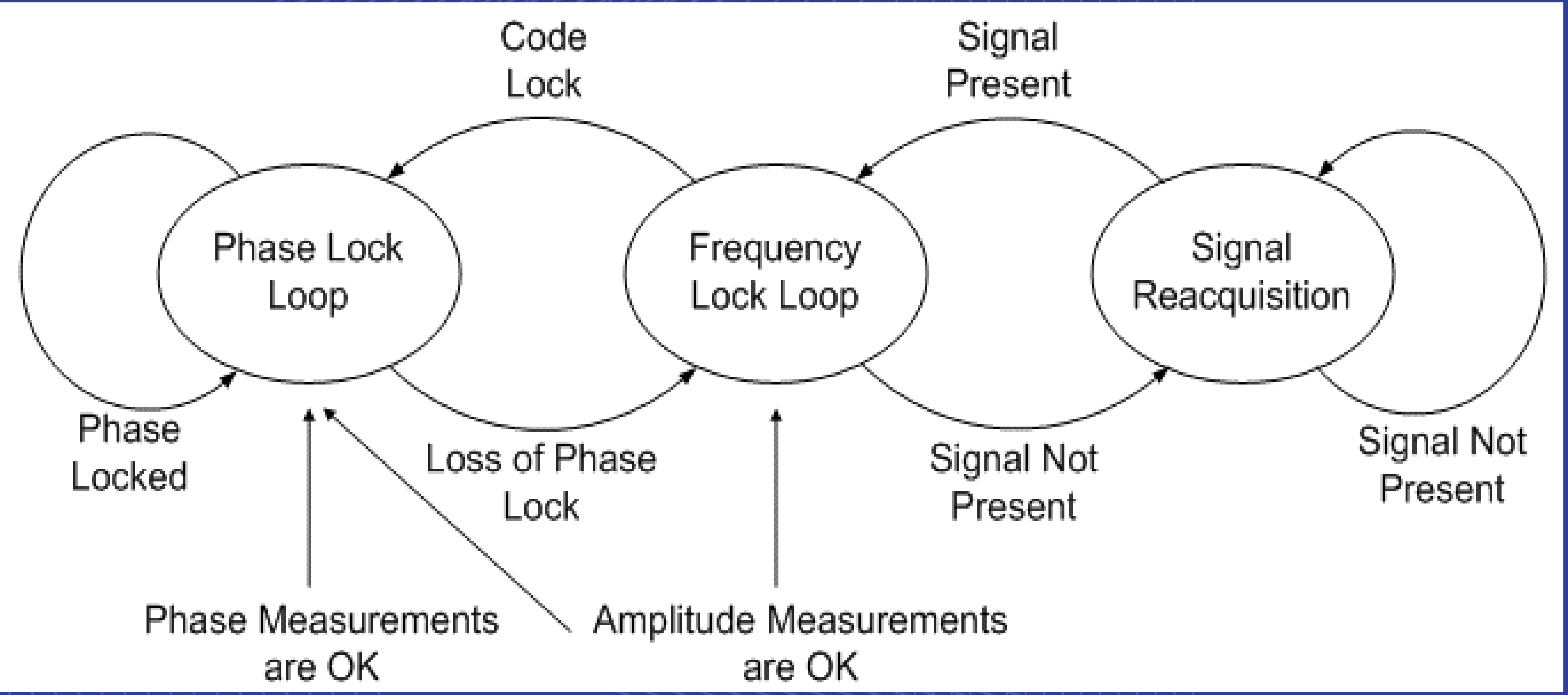
σ_ϕ = 0.396 radians

σ_ϕ = 0.46 radians

GPS Scintillation Monitor Limitations in Scintillation Environment II

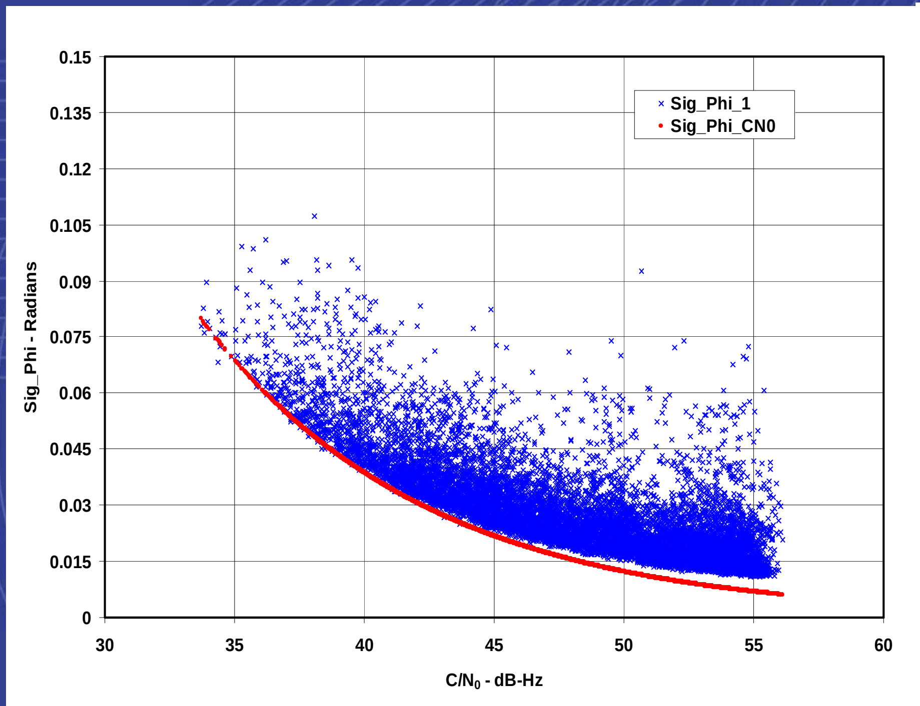
- Amplitude Scintillation
  - High S4 can cause loss of phase lock
    - Of course, that is still information
    - S4 is still usually valid – it is based upon non-coherent power measurements, at least for short to medium length fades
    - See state diagram
  - Multipath fading limits minimum S4 capability
    - Longer duration, but shallow fades
    - Can be detected and eliminated because multipath also causes code/carrier phase divergence – scintillation does not

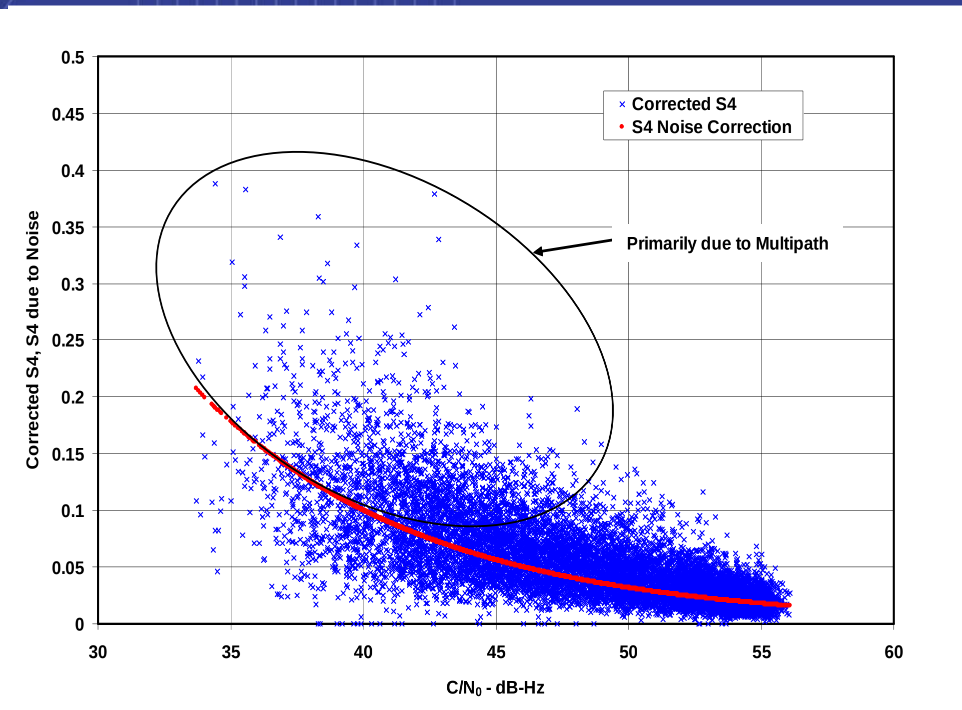
Signal Tracking State Diagram



- Not necessarily implemented in all receivers

Thermal Noise (C/N_0) Effects on Scintillation Parameters





Sigma Phi

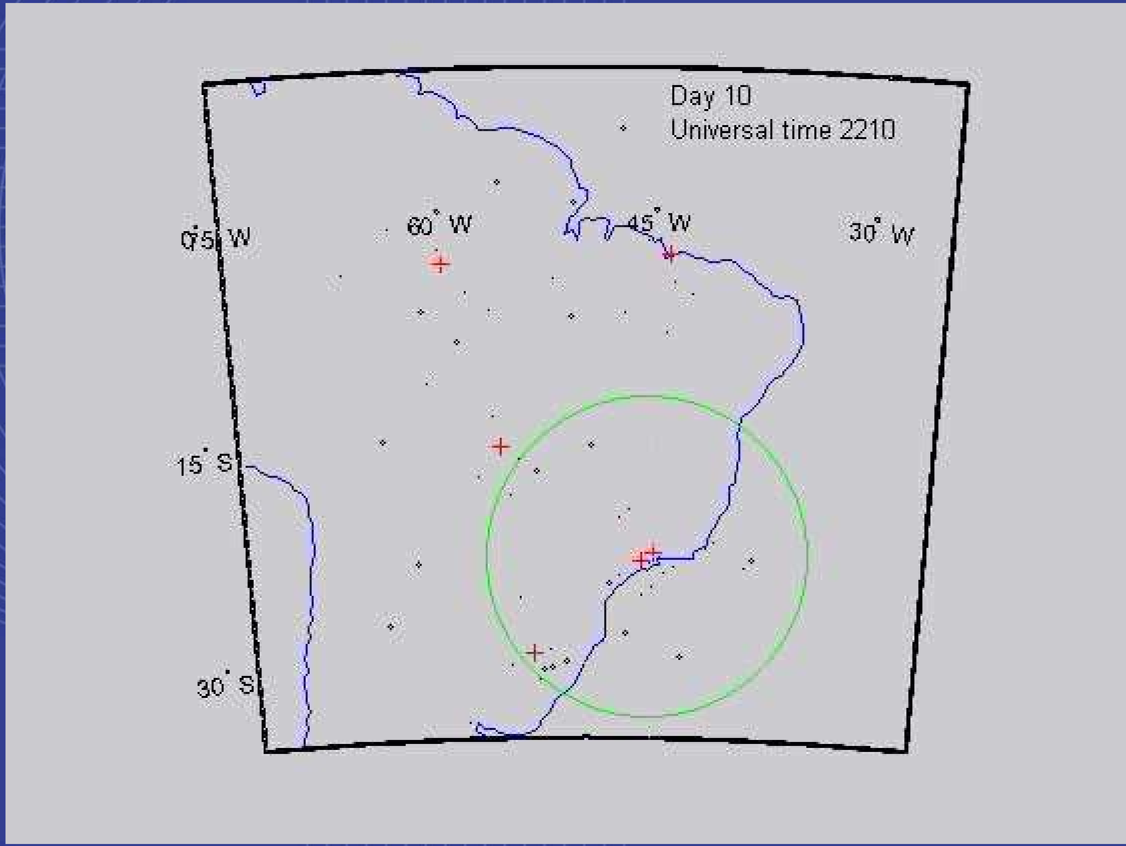
S4

Correlation distances

Scintillation measurements over Brazil with 6 stations

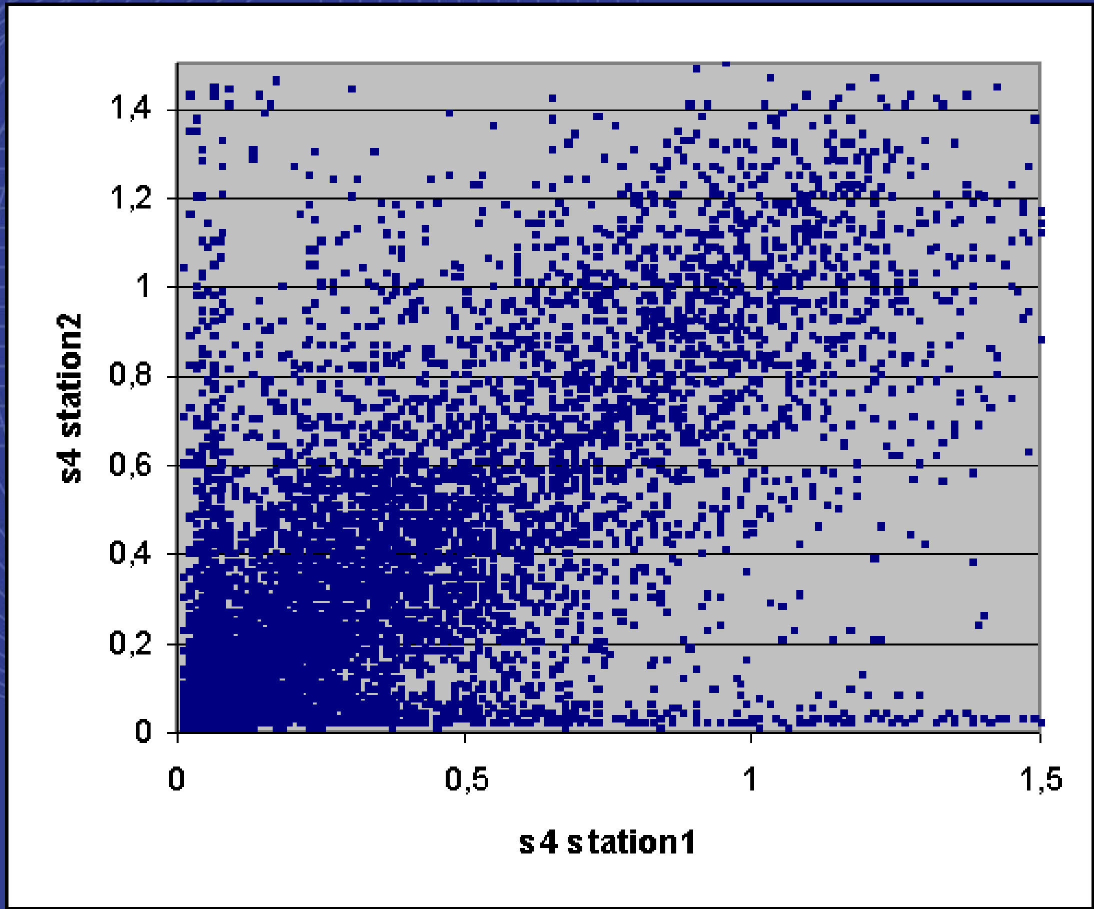
• The circle of each IPP is proportional to the measured S4

• 2 stations are almost collocated : distance = 100 km



Collocated stations (100 km)

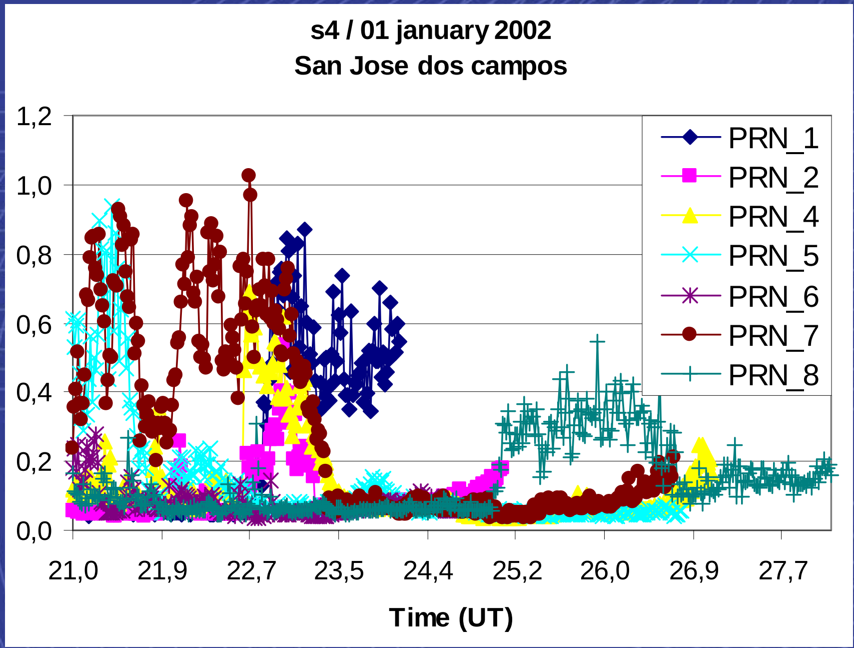
- 1 week of measurements
- All visible GPS satellites are considered
- Computed correlation coefficient : 0.8

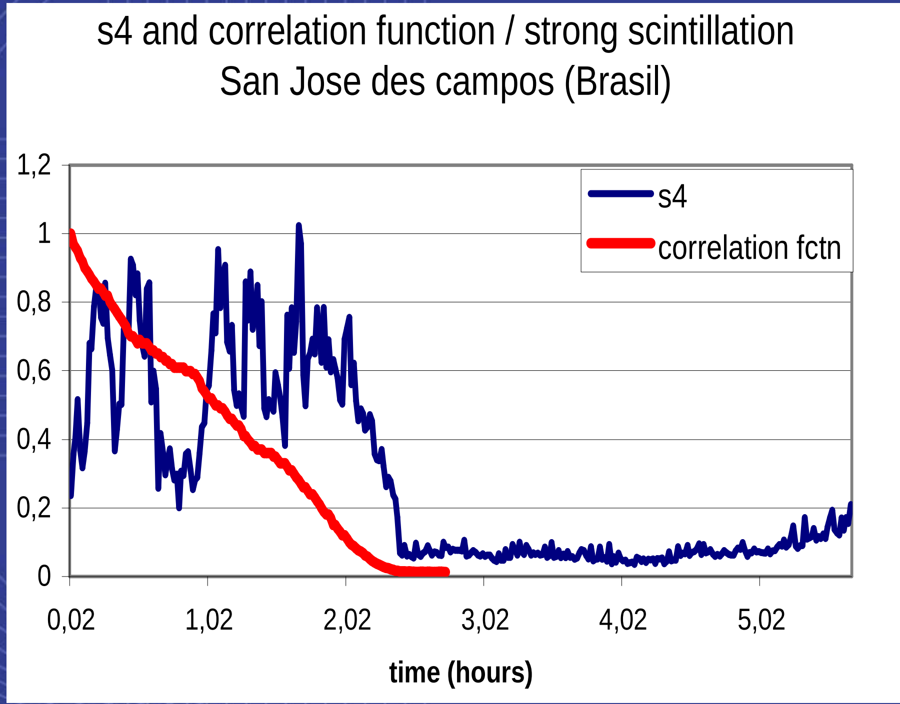


Correlation distance

- For a given satellite, the distance between the IPPs is approximately the same than the distance between the stations.
- The correlation coefficient between the S4 of 2 IPP is assumed to be a gaussian function of the distance : $c = \exp(-\alpha d^2)$
- Since c = 0.8 for d = 100 km, the deduced correlation distance (c = 0.5) is about 175 km.

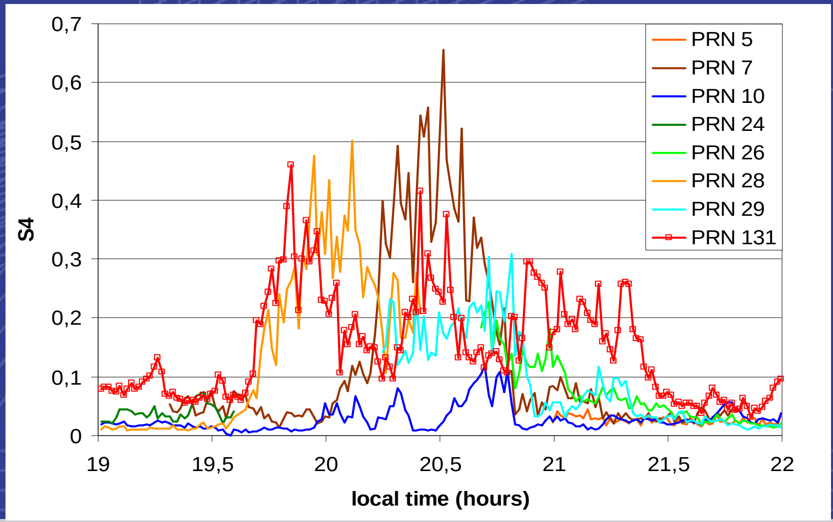
Scintillations extent : Brazil 2002 flux 190

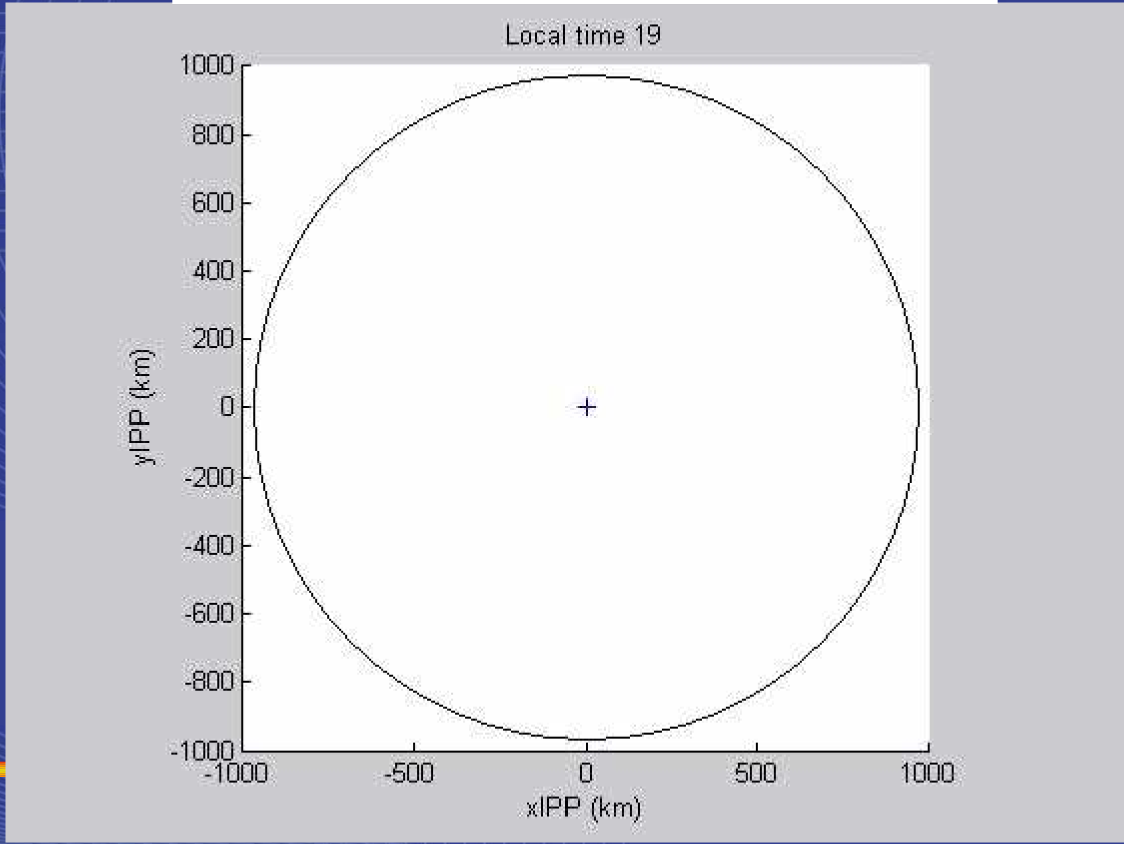




Average extent 400 km

GPS + GEO : (Douala)





- All the affected satellites are in the same part of the sky.
- The width of this region is about 500 km at the F layer altitude.

CONCLUSION

- Constitution of the data base is on progress

- Links with GEO satellites (3 channels on GSV receivers), will help to derive the scintillation characteristics

- Assimilation technique is under development, mixing model and data in order to obtain a forecasting model