High Latitude Scintillation Analysis for Marine and Aviation Applications

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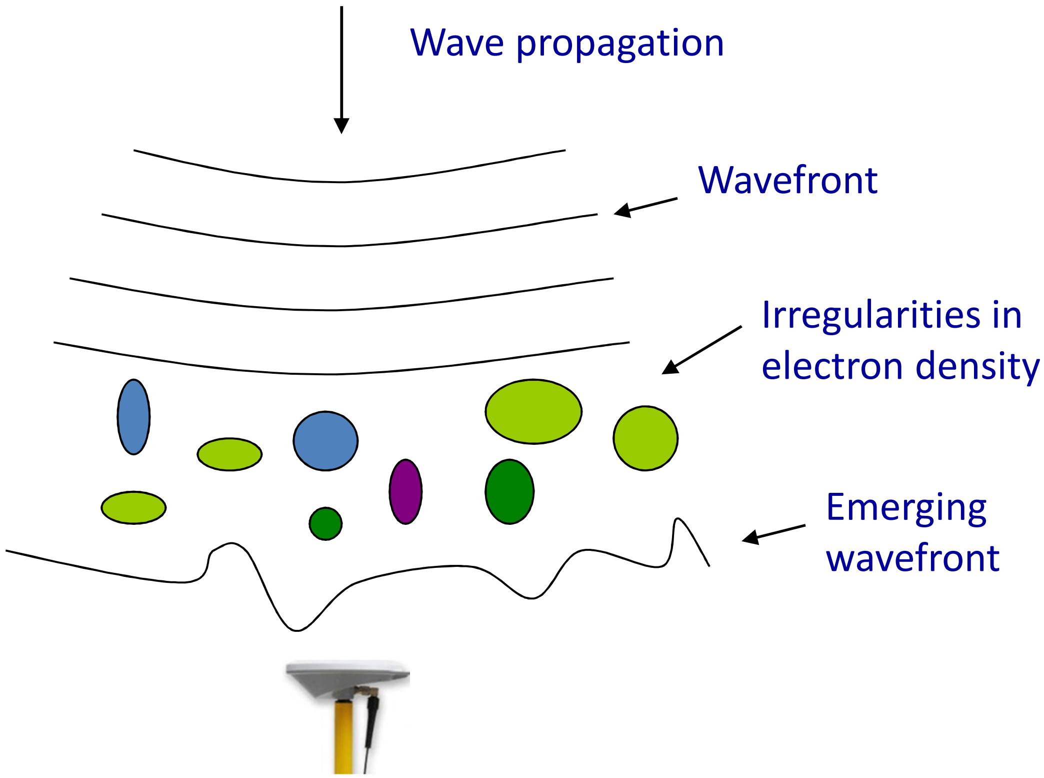
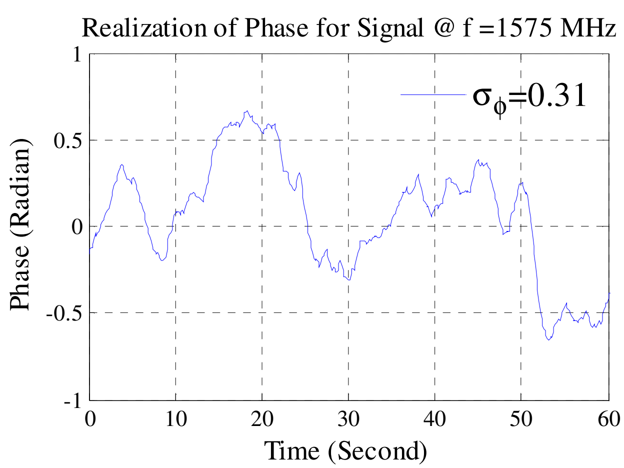
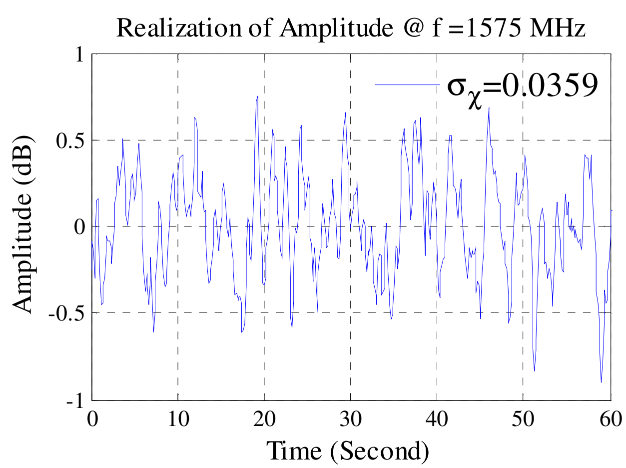
Outline

- Auroral/polar scintillation mechanisms
- Scintillation data set
- Simulation tools
- Results
- Summary

Ionospheric Scintillation

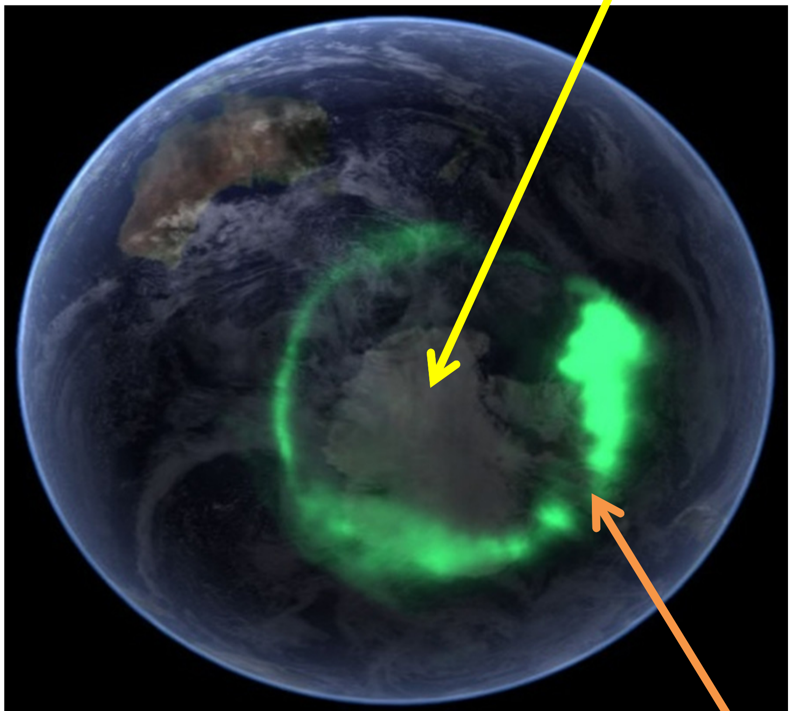


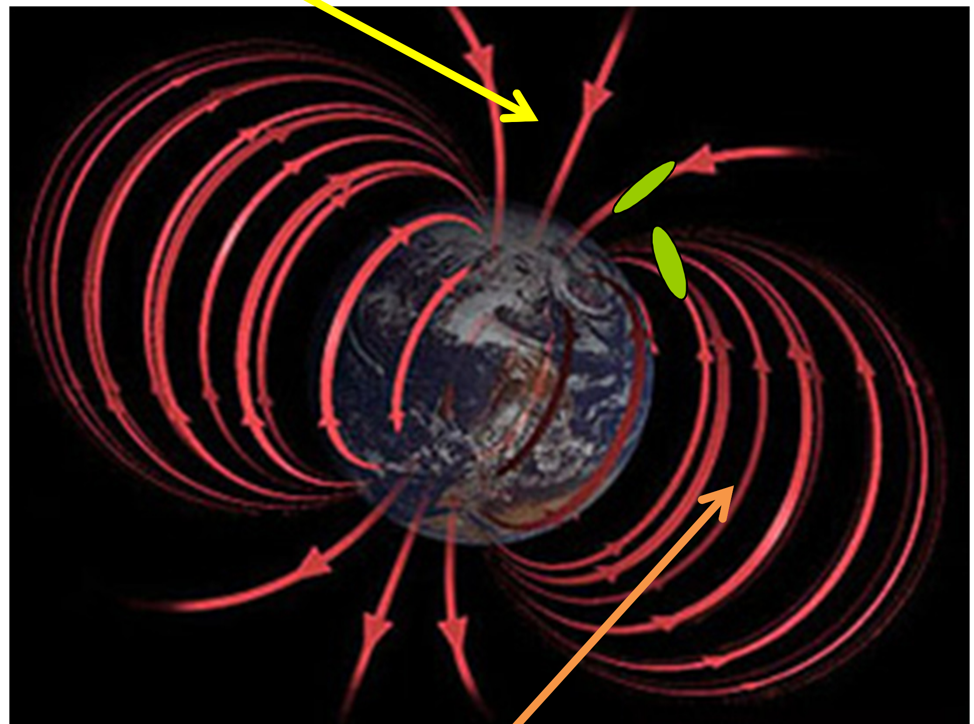




High Latitude Scintillations

Polar Cap

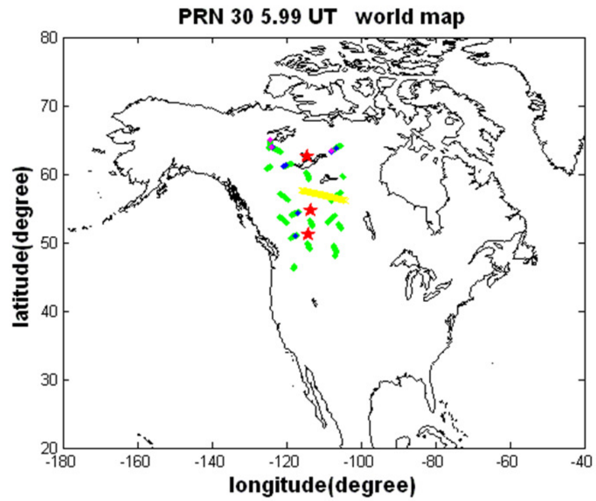


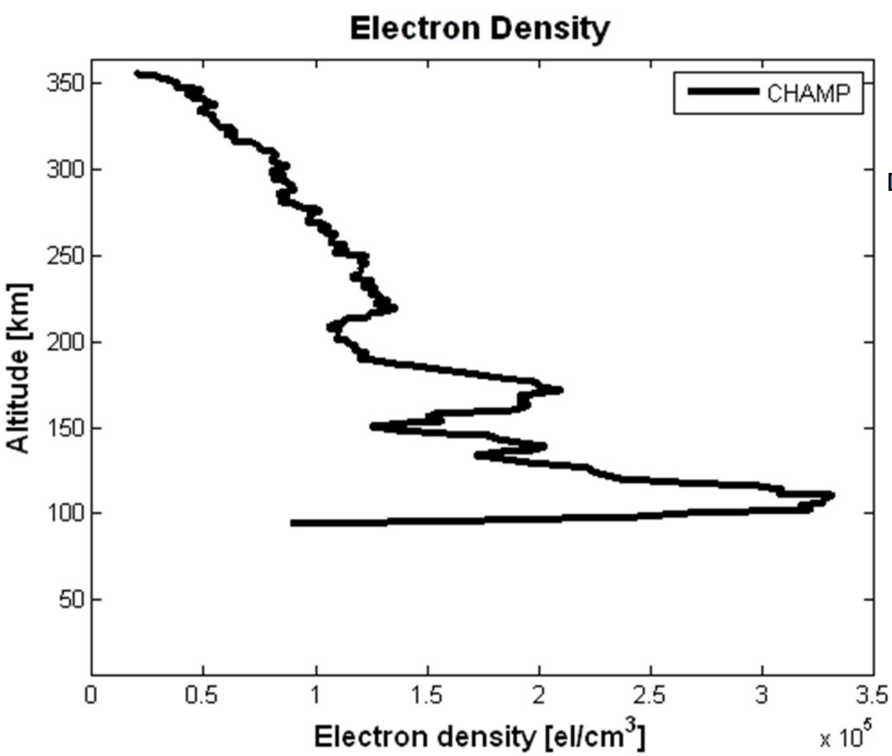


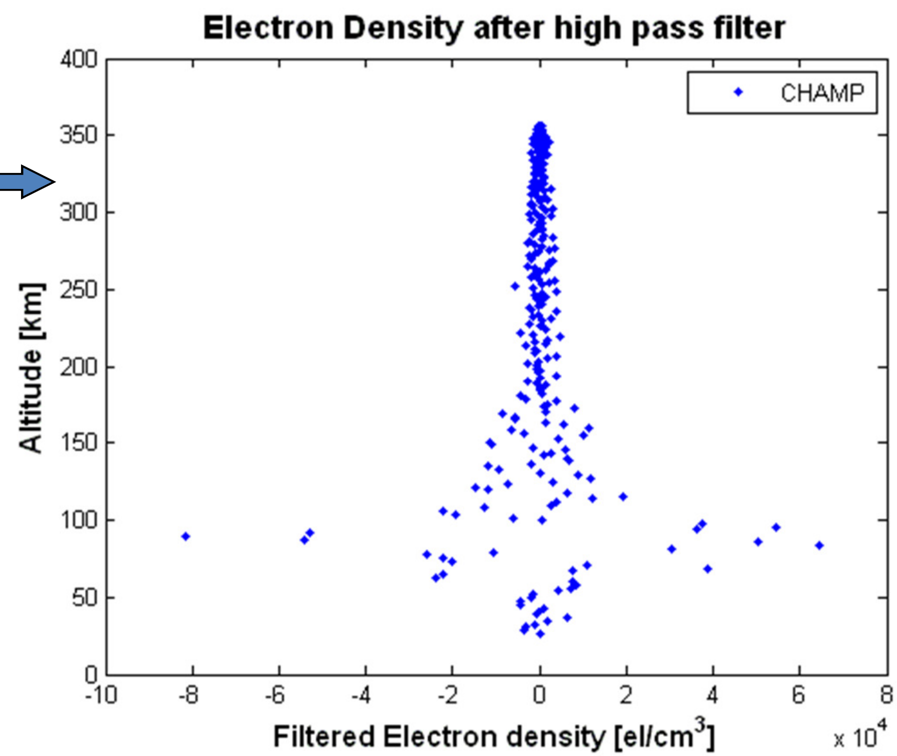
Auroral Oval

Auroral Irregularities

E-region:
October 1, 2006

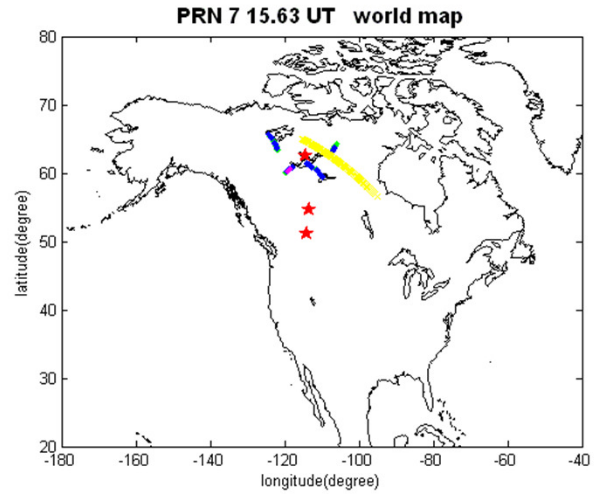


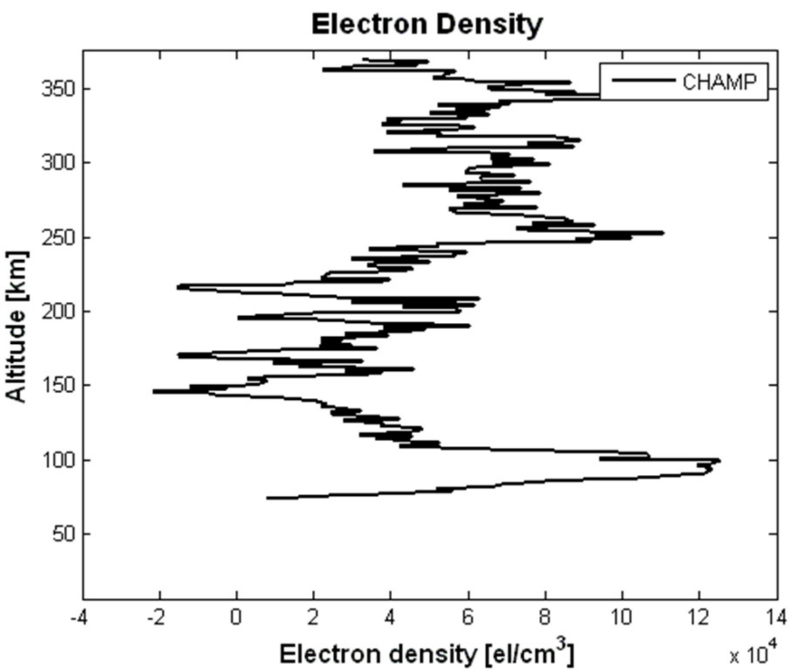


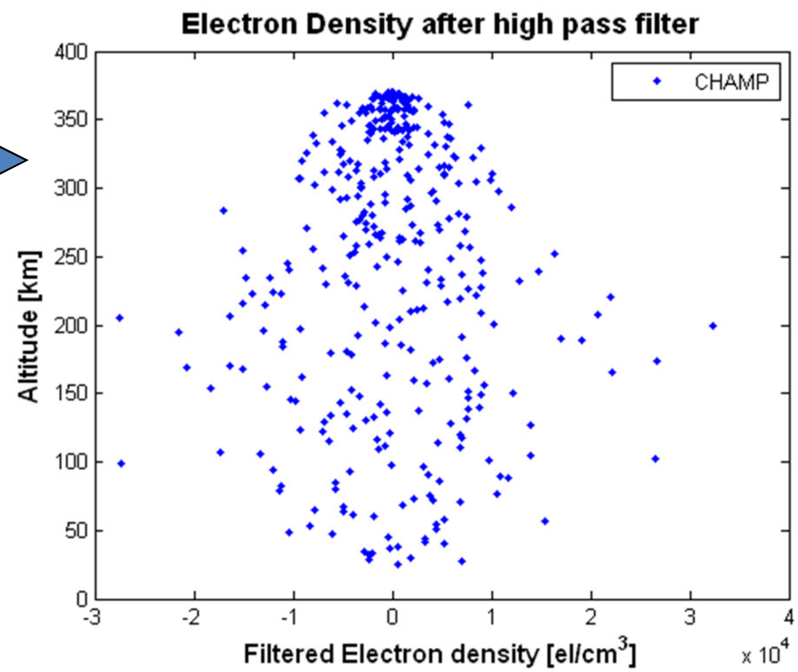


Polar Irregularities

E- & F-region:
January 7, 2005



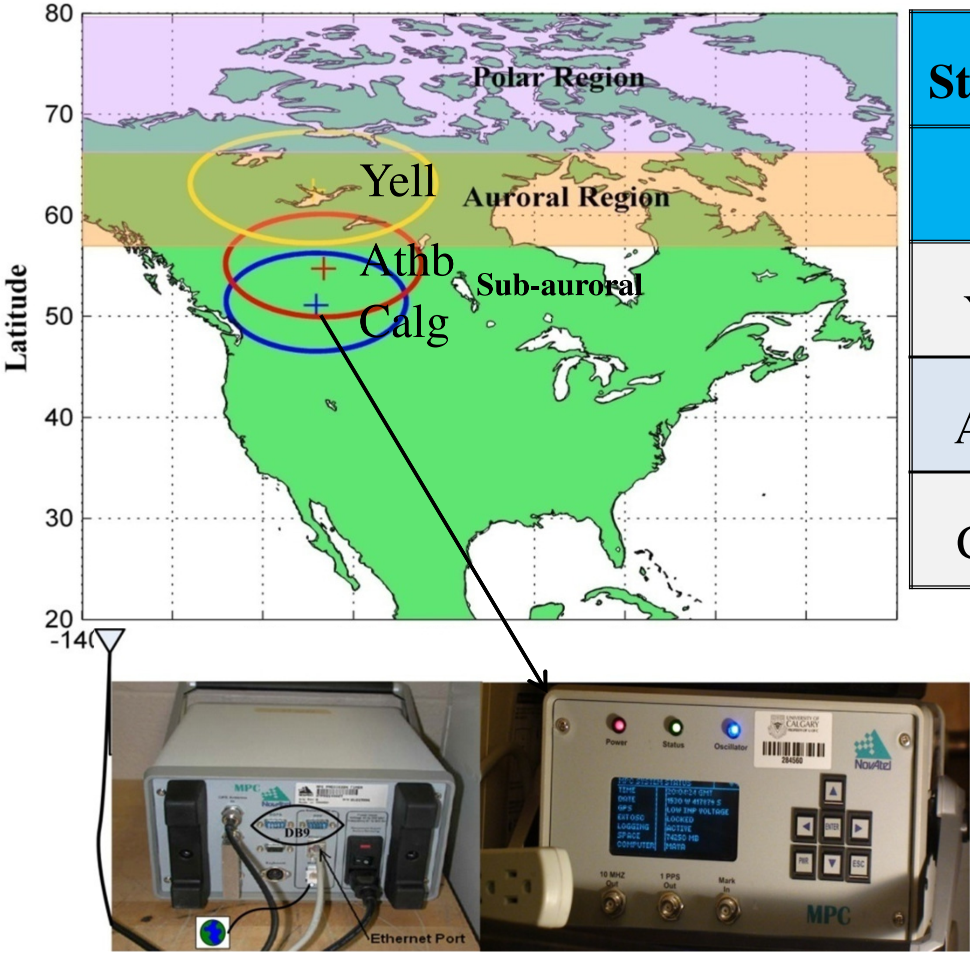




CANGIM Database

The CANGIM receivers measure

- 50 Hz raw GPS observations
- Phase scintillation index (σ)
- Amplitude scintillation index (S4)



Station	Geographic		Geomagnetic	
	Lat.	Long.	Lat.	Long.
Yell	62.48º	-114.48º	68.80º	298.37º
Athb	54.72º	-113.31º	61.52º	305.67º
Calg	51.08º	-114.13º	57.86º	306.43º

Note: - The coverage areas for IPP above 20º are indicated as circles.

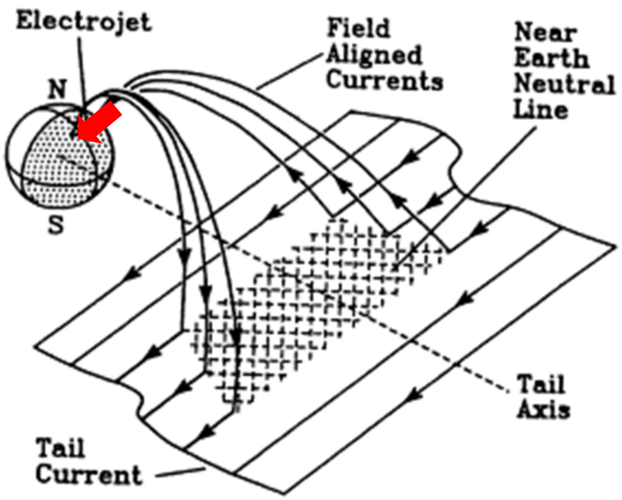
Objective

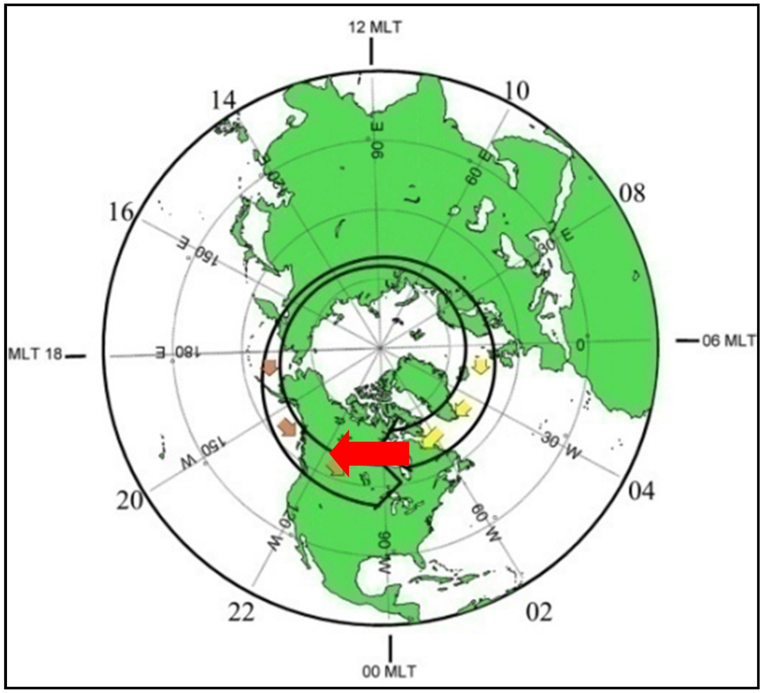
To develop flexible tools to study high latitude scintillation impact on receiver performance for various user groups (marine, aviation)

Method

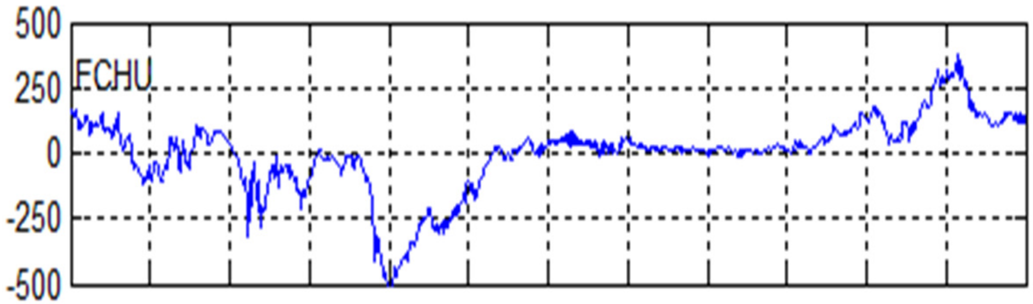
- Determine scintillation characteristics for auroral and polar regions (CANGIM)
- Develop simulation based on observed high latitude characteristics
- Develop flexible tracking loops to assess impact – determine thresholds for loss of lock
- Quantify duration and frequency of receiver impact, number of satellites affected, etc.

Auroral Substorm Current Wedge

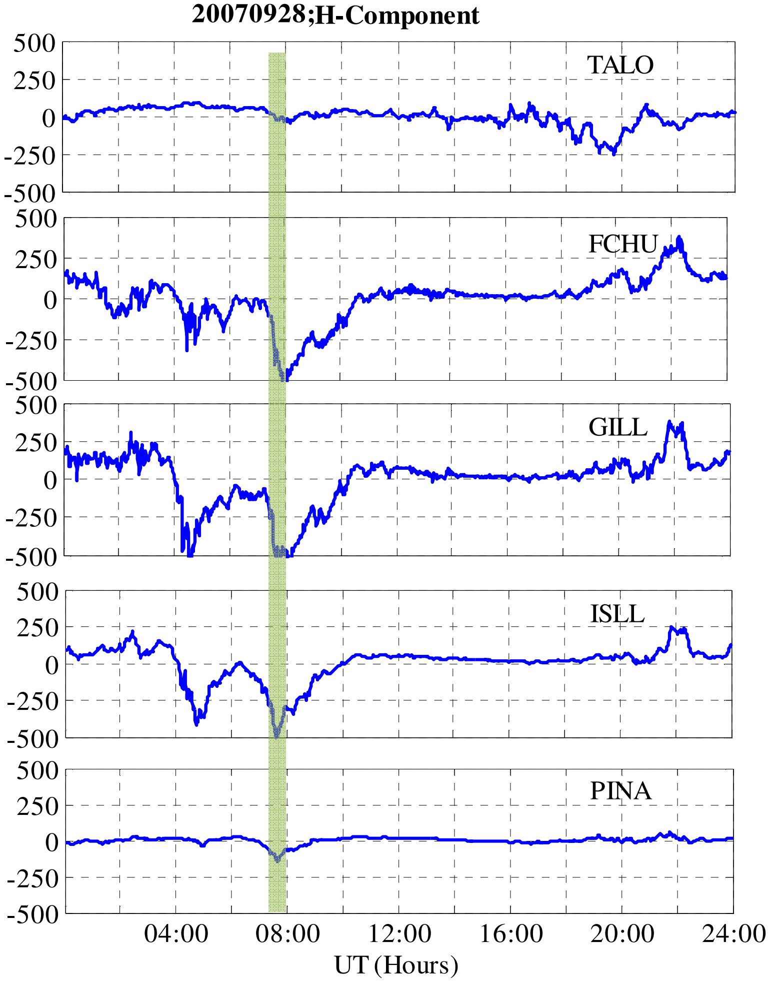


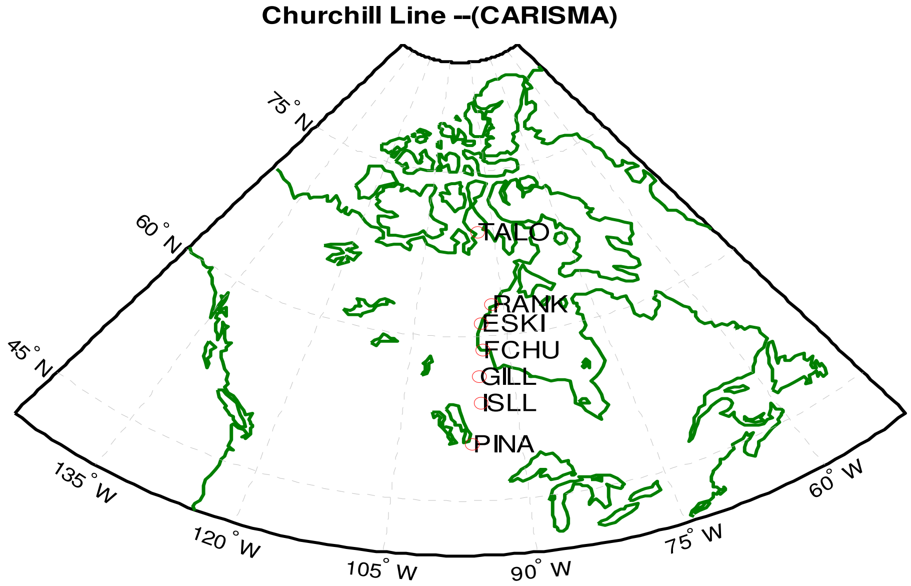


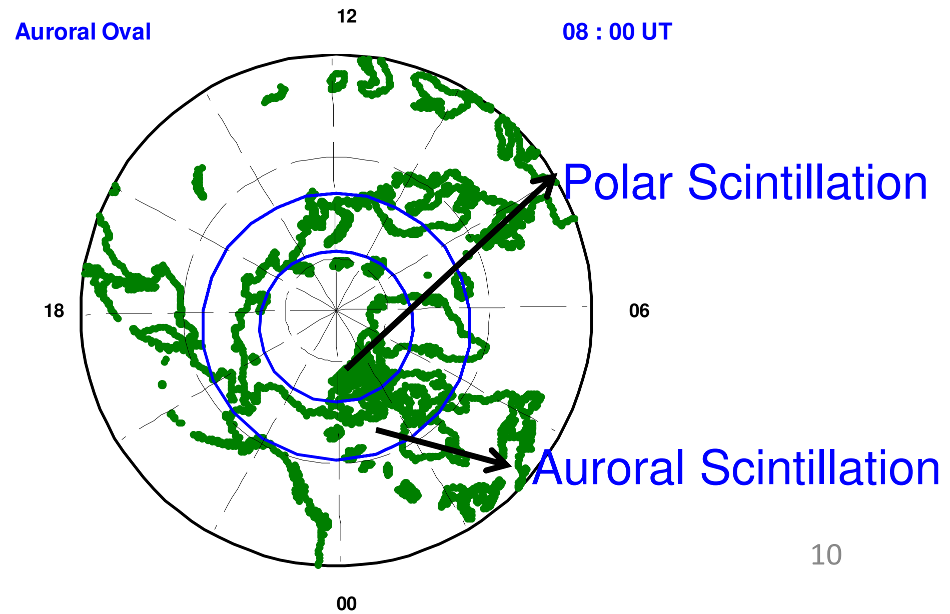
Magnetometer signature



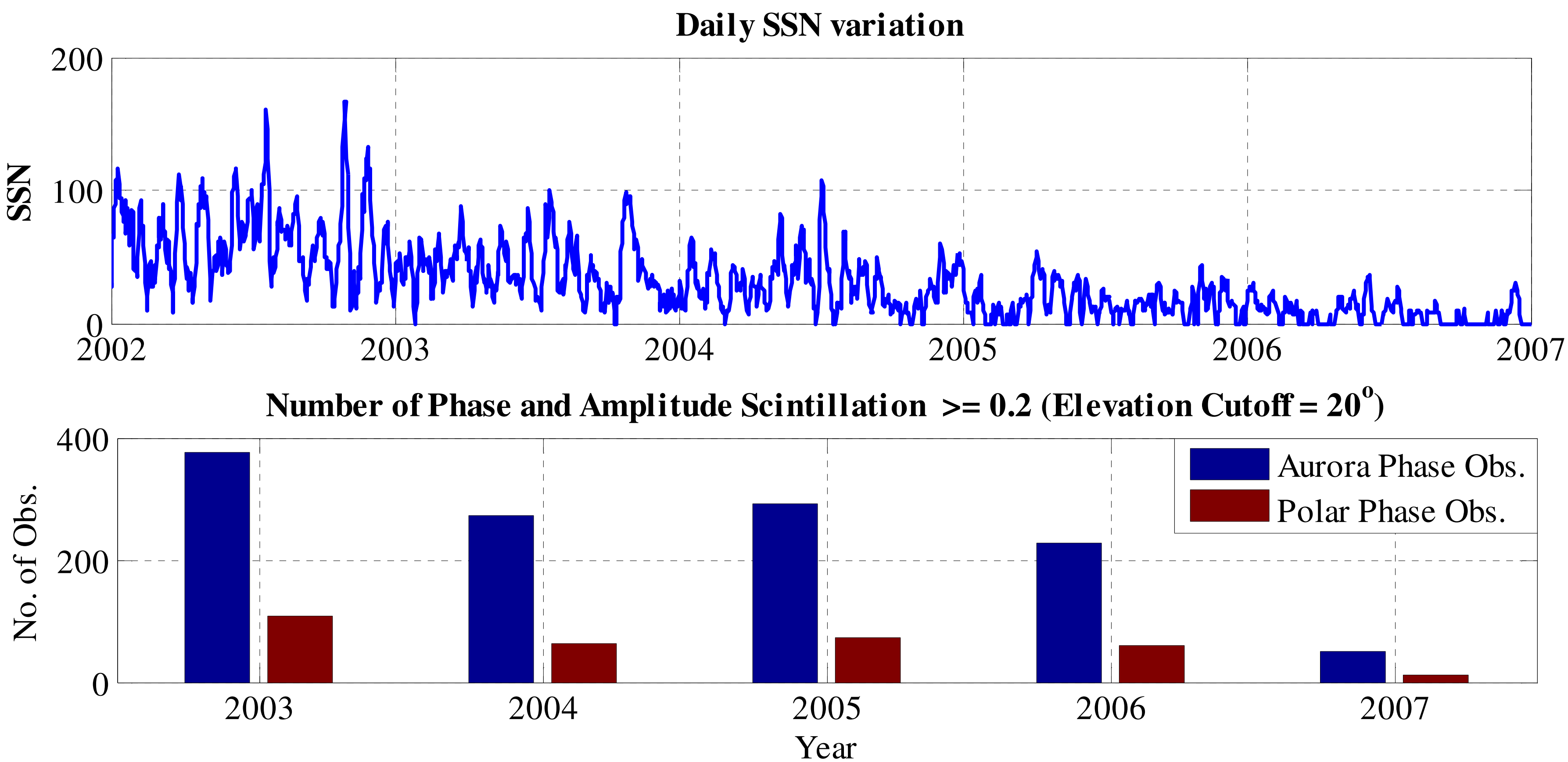
Auroral Boundary Estimation





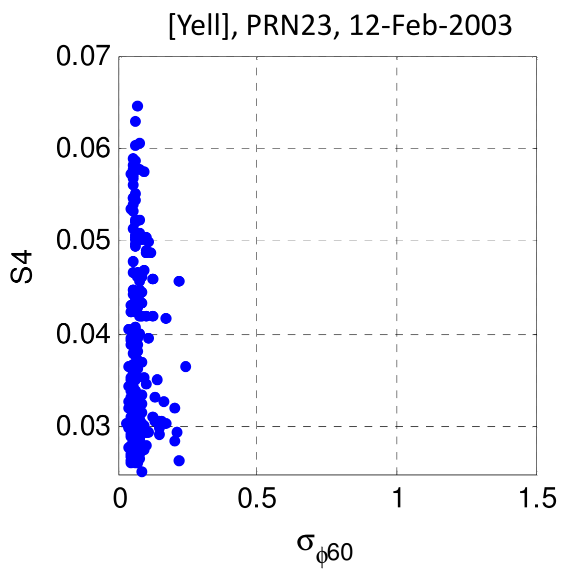


Event Selection

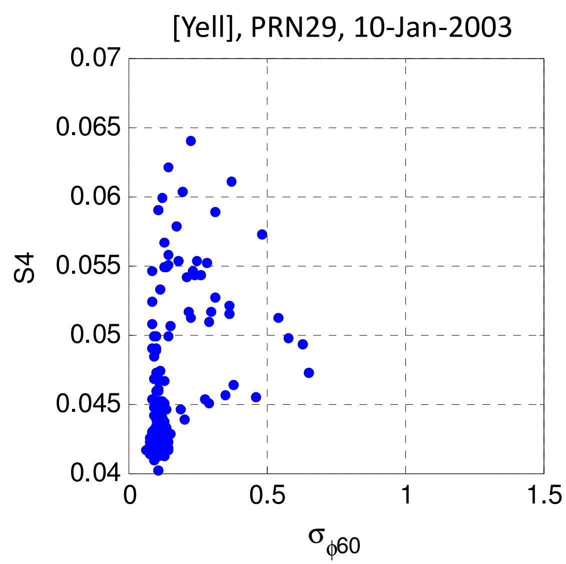


Auroral Scintillation Characteristics

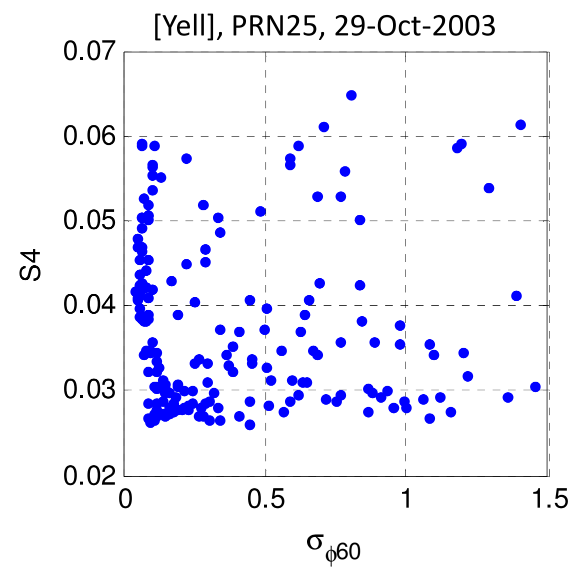
- Phase scintillation is dominant
- Low amplitude scintillation (S4<0.1) for all events



Weak Scintillation



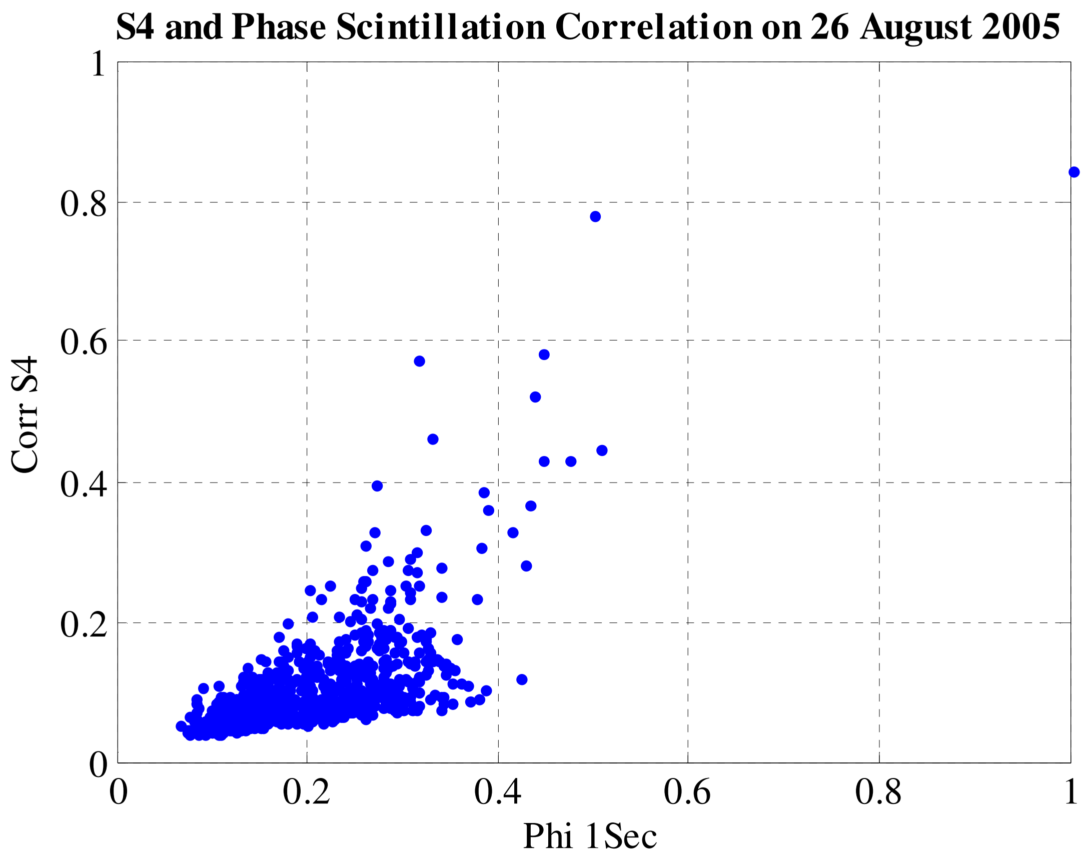
Moderate Scintillation



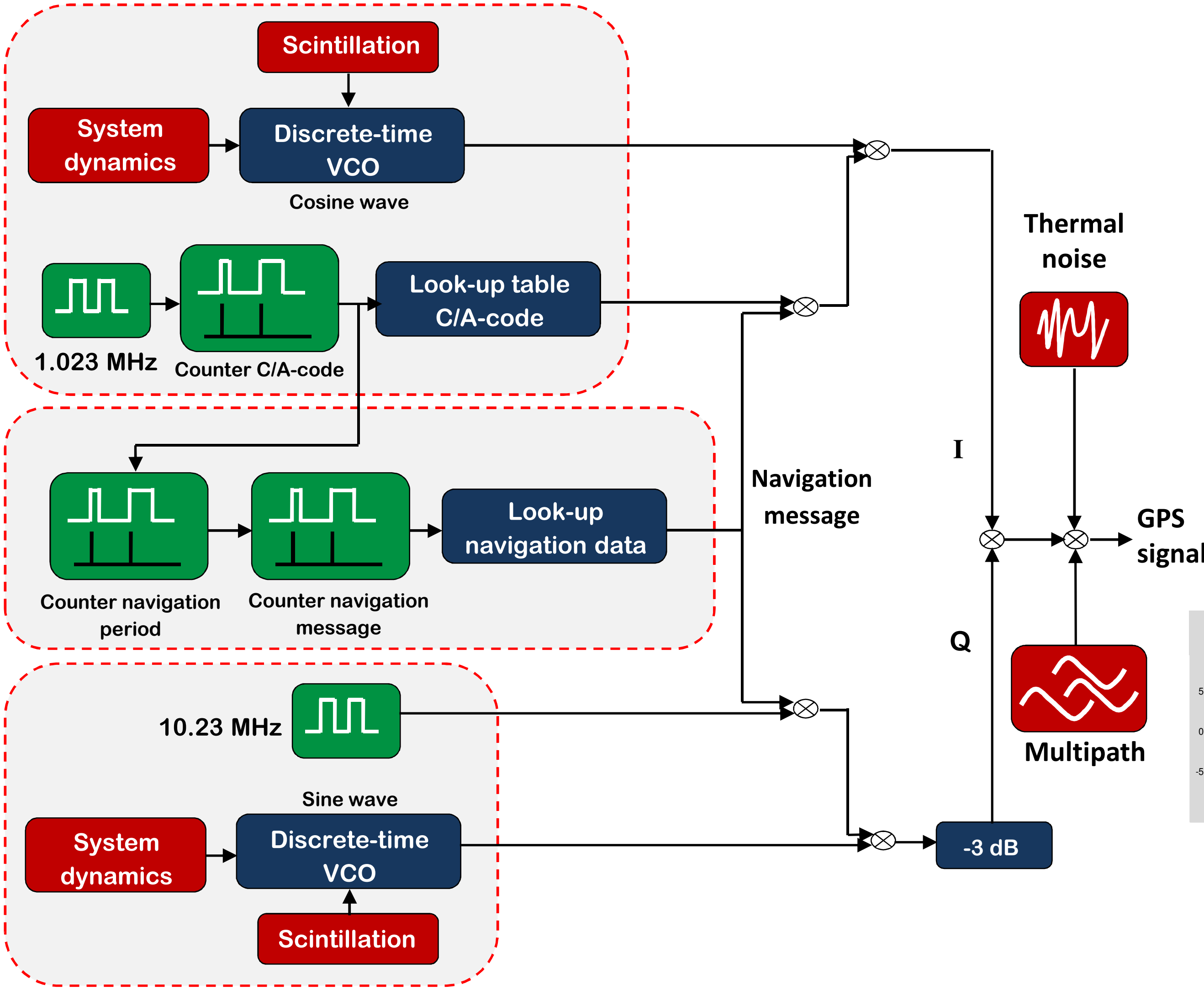
Strong Scintillation

Polar Scintillation Characteristics

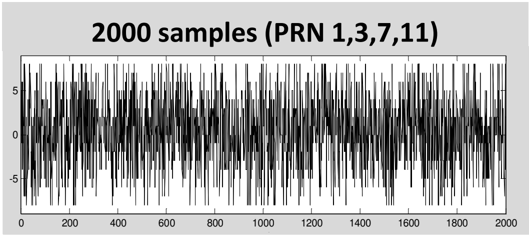
- Amplitude scintillation is significant
- S4 in range 0.4 to 0.8 for severe events
- Pairs (σ, S4) determined for scintillation simulations



GPS Signal Simulator



- Scintillation
- Thermal noise
- Multipath
- System dynamics
- **Conventional parameters for low-cost receivers**



Scintillation Simulator

Ionospheric **phase scintillation follows zero-mean Gaussian distribution** with standard deviation σ_ϕ.

$$f(\phi) = \frac{1}{\sqrt{2\pi}\sigma_\phi} e^{-\phi^2/2\sigma_\phi^2}$$

Ionospheric **intensity scintillation follows Nakagami-m distribution** with normalized standard deviation S4. The intensity scintillation signal can be generated using **bivariate gamma function** G(α,β) with marginal density function given as follows:

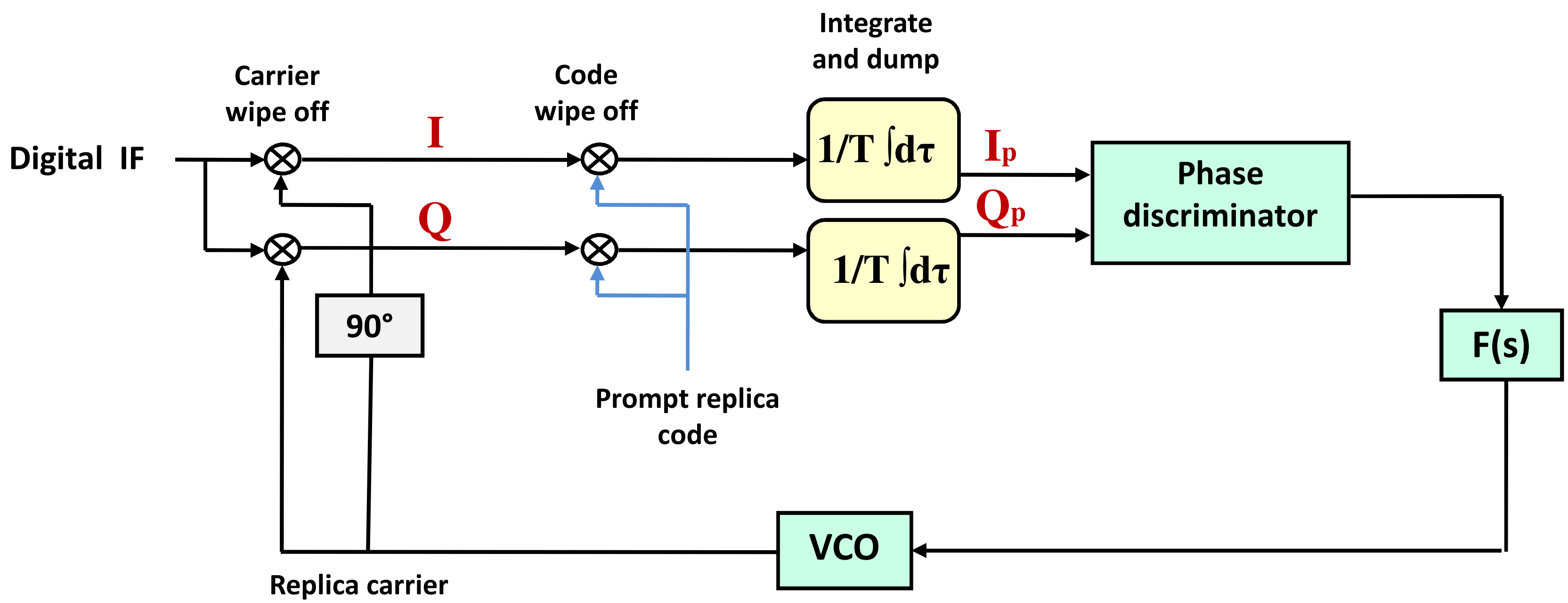
$$f(\delta I = x) = \underbrace{\frac{m^m \, \delta I^{\,m-1}}{\Gamma(m)\,\Omega^m} e^{-m\delta I/\Omega}}_{\text{Nakagami-m}} = \underbrace{\frac{(x/\beta)^{\alpha-1}}{\beta\,\Gamma(\alpha)} e^{-x/\beta}}_{\text{Bivariate Gamma}}$$

$$\alpha = m = \frac{1}{S_4^2}, \ \beta = \frac{1}{m} = S_4^2,$$

$$\Omega = 1$$

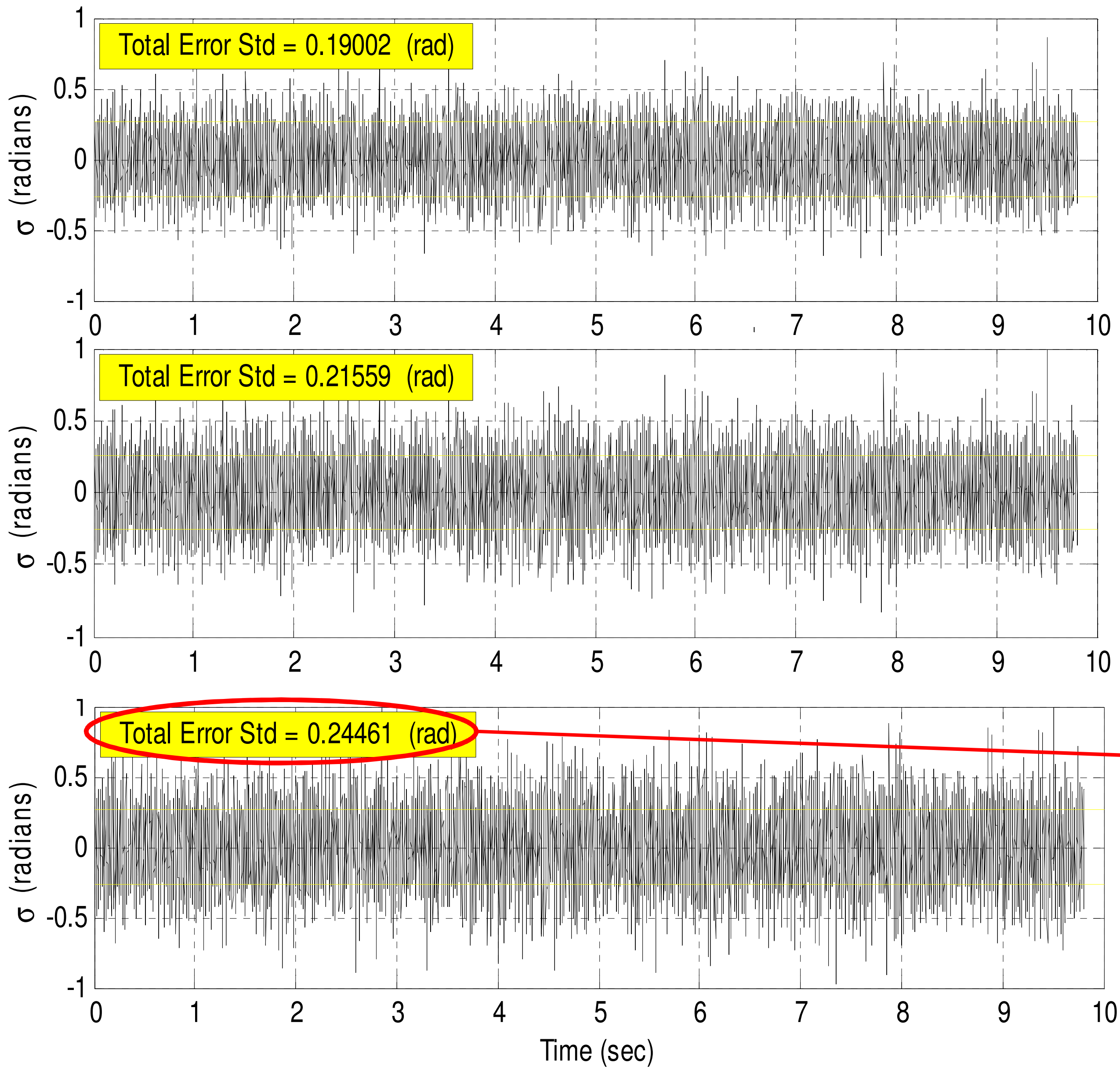
Tracking Loops

- Tracking loop bandwidth
- Pre-detection integration time



Generic Costas Carrier Tracking Loop

Carrier Tracking Error Auroral Region



Weak Scintillation

$\sigma_{\phi 60}$ = 0.1 rad
S4 = 0.05

Moderate Scintillation

$\sigma_{\phi 60}$ = 0.5 rad
S4 = 0.05

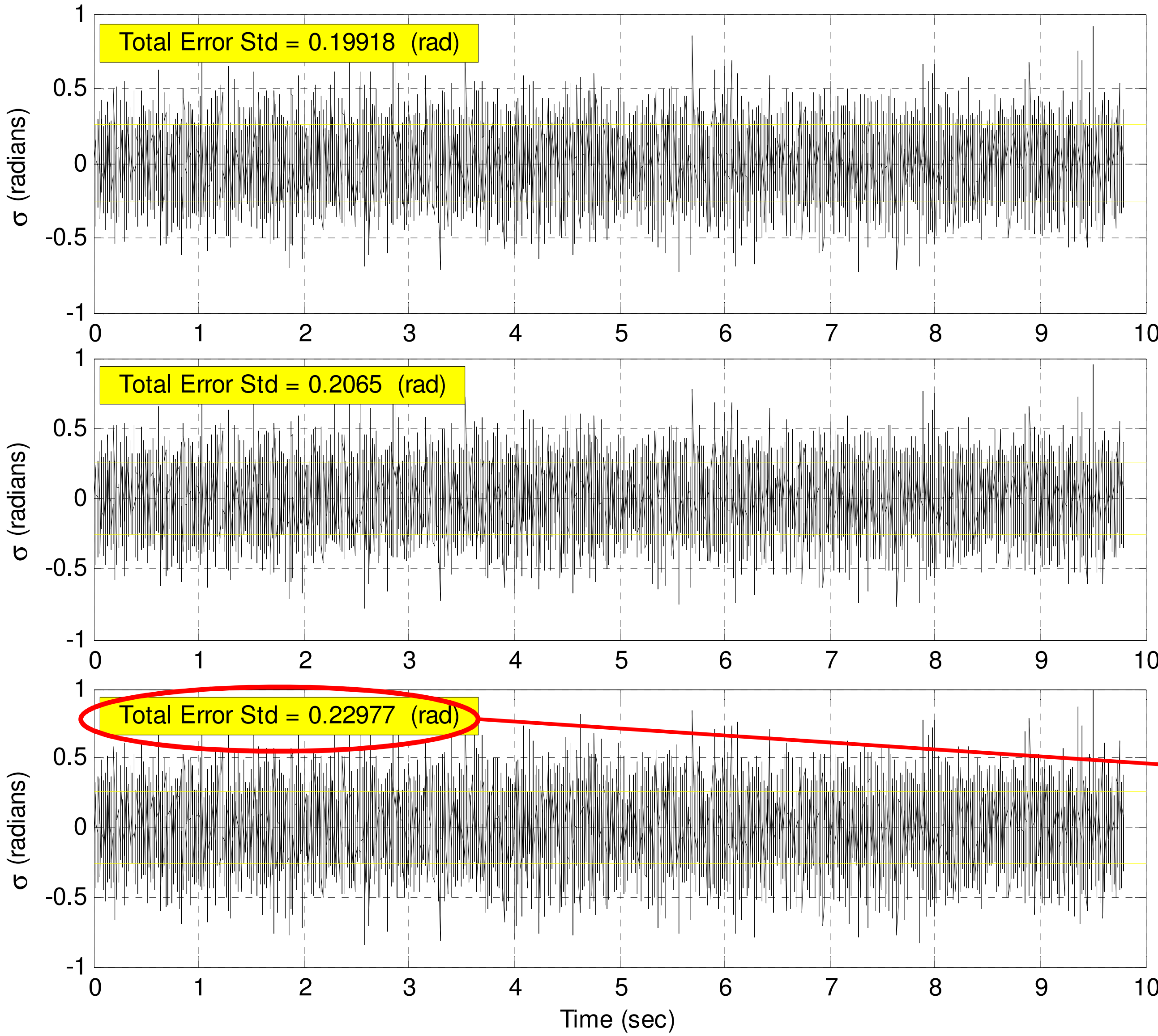
Near the tracking threshold

Strong Scintillation

$\sigma_{\phi 60}$ = 0.7 rad
S4 = 0.05

(B_n = 15 Hz, C/N_0 = 46 dB-Hz)

Carrier Tracking Error Polar Region



Weak Scintillation

σ_ϕ = 0.2 rad
S4 = 0.6

Moderate Scintillation

σ_ϕ = 0.4 rad
S4 = 0.6

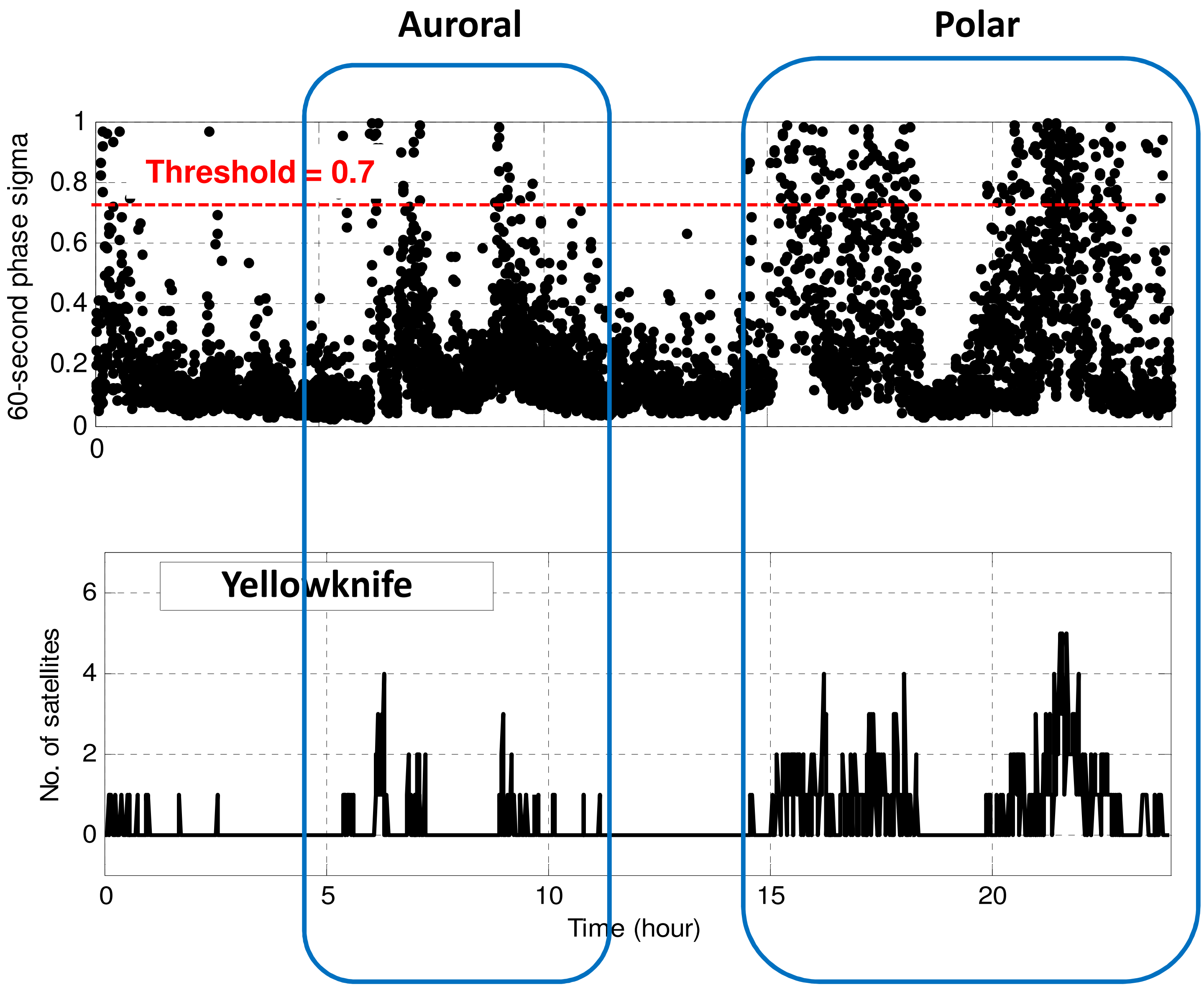
Near the tracking threshold

Strong Scintillation

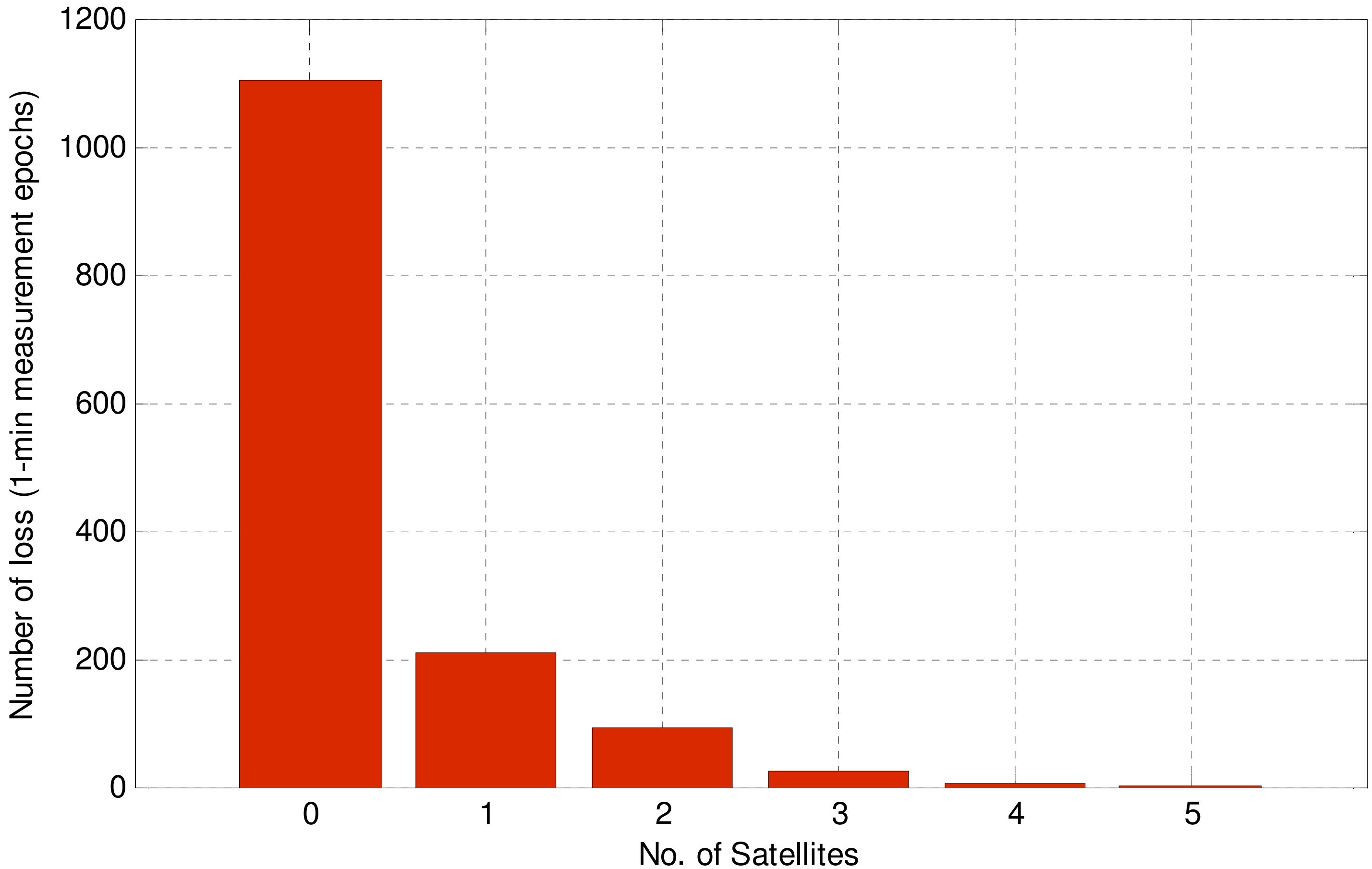
σ_ϕ = 0.6 rad
S4 = 0.6

(B_n = 15 Hz, C/N_0 = 46 dB-Hz)

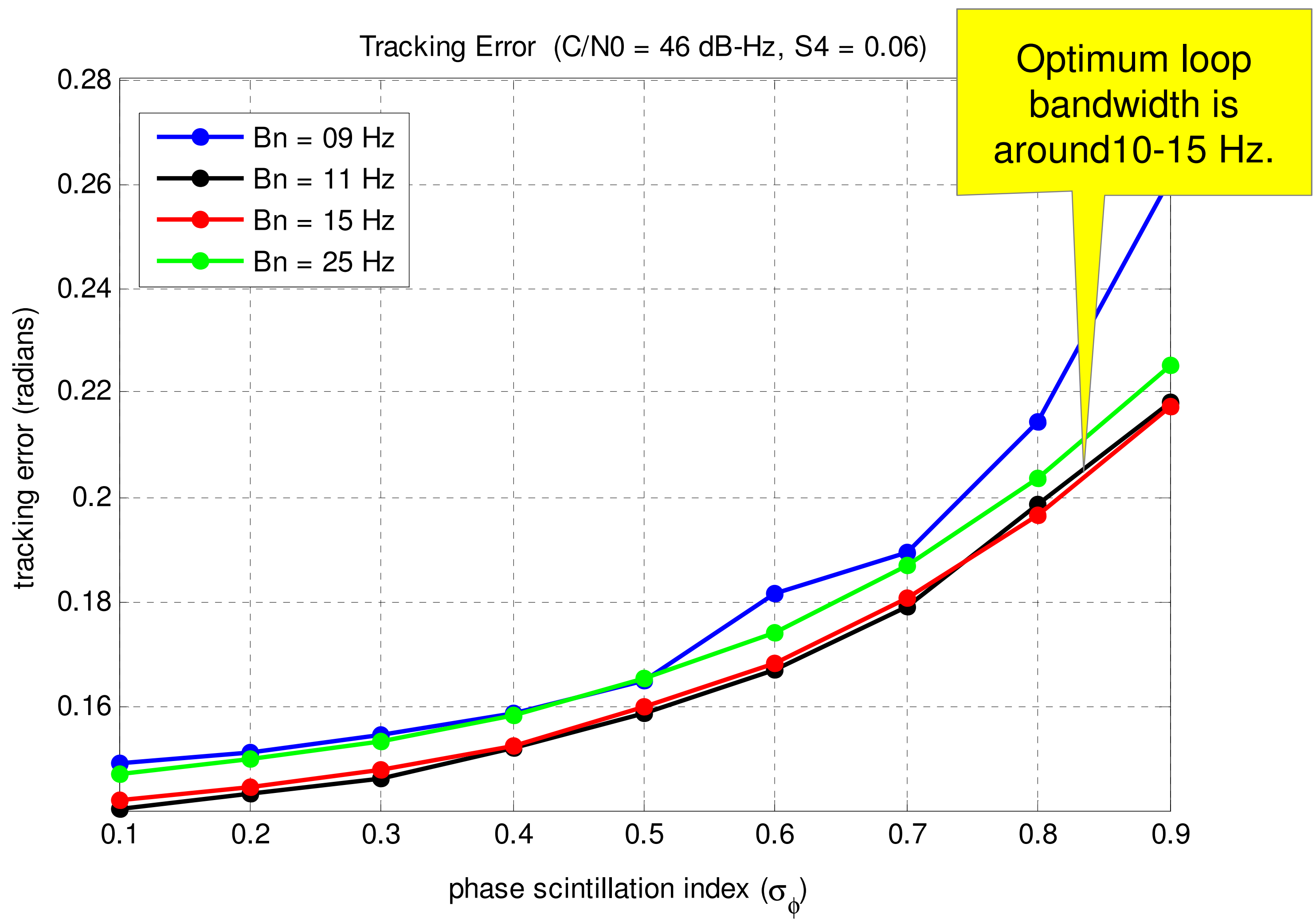
Example: Loss of Lock



Simultaneous Loss of Lock



Optimal Tracking Loop Bandwidth



(C/N0 = 46 dB-Hz, S4 = 0.06)

Summary

- High latitude scintillations are due to different physical drivers (auroral versus polar regions)
- Simulations developed for auroral and polar regions
- Carrier tracking loop performance evaluated for generic low-cost receiver
- Receiver tracking loops may be challenged during severe scintillation