Semi-Open Loop Carrier Tracking for GNSS Signals Experiencing Strong Equatorial Ionospheric Scintillation

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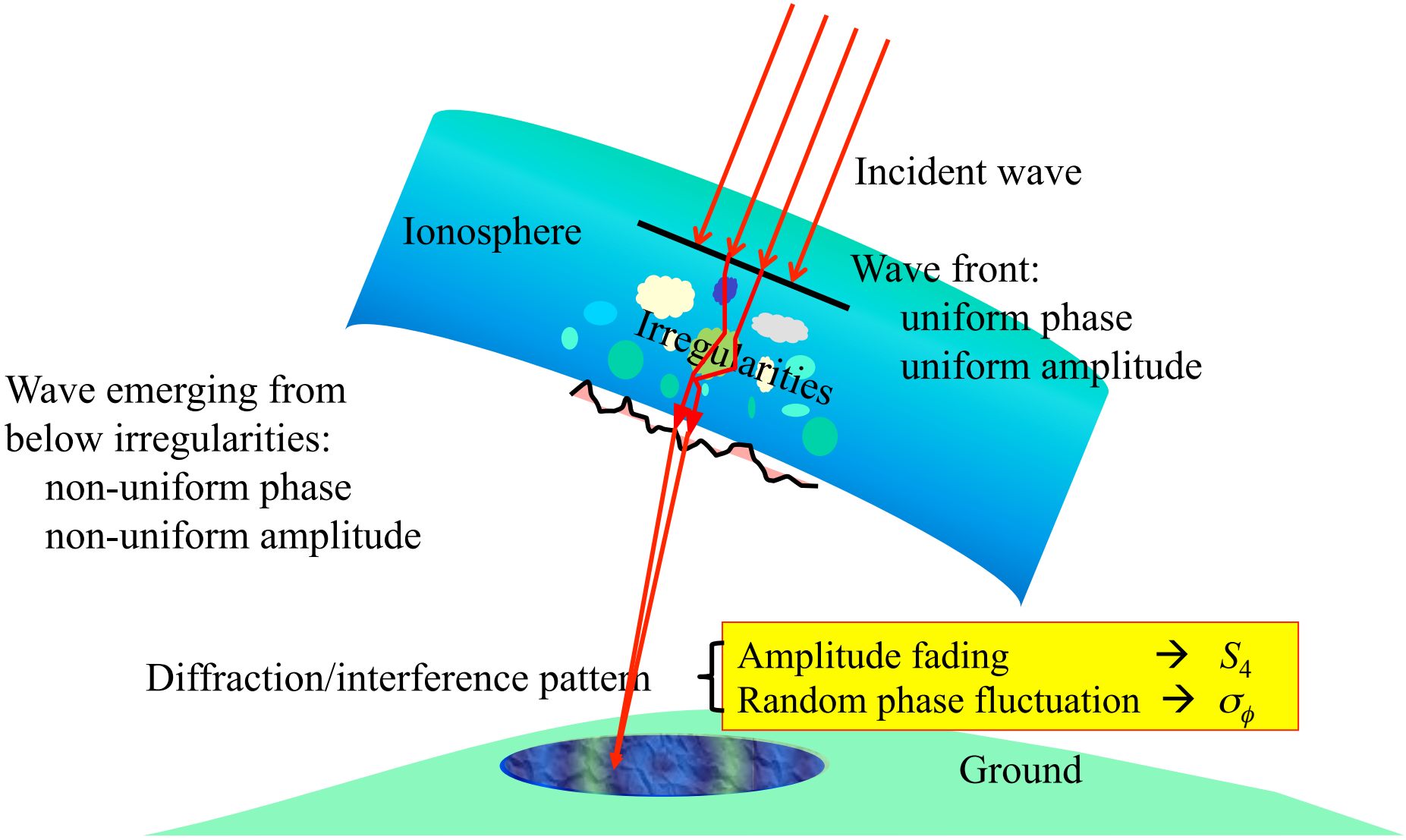
Presentation Outline

- Background
- Data Collection Systems
- Methodology
- Processing Results
- Conclusions

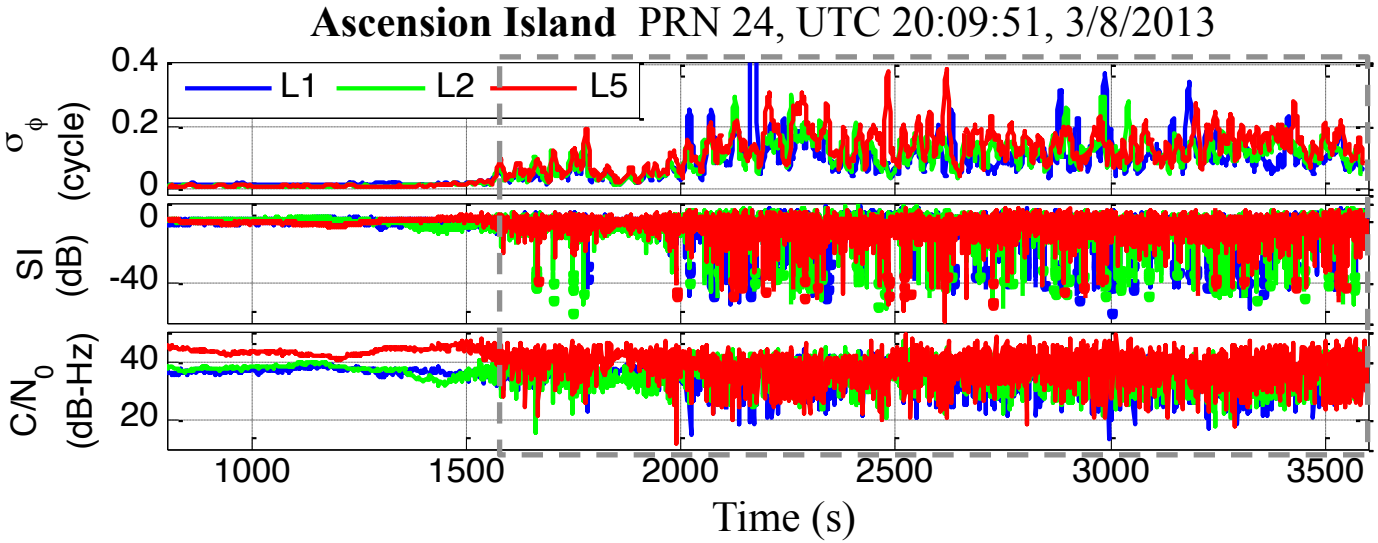
Ionospheric Scintillation Phenomena



Real Equatorial Scintillation Overview

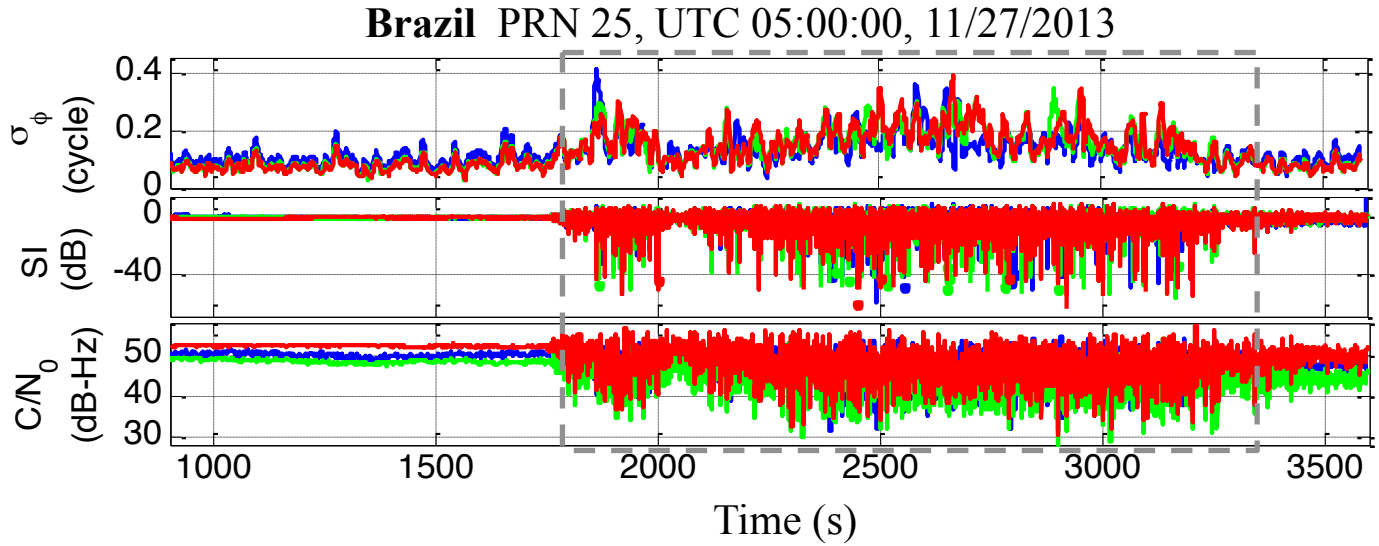
σ_ϕ baseline value:
~0.01 (cycles)

Nominal C/N_0
(dB-Hz)
L1/L2: 38
L5: 44

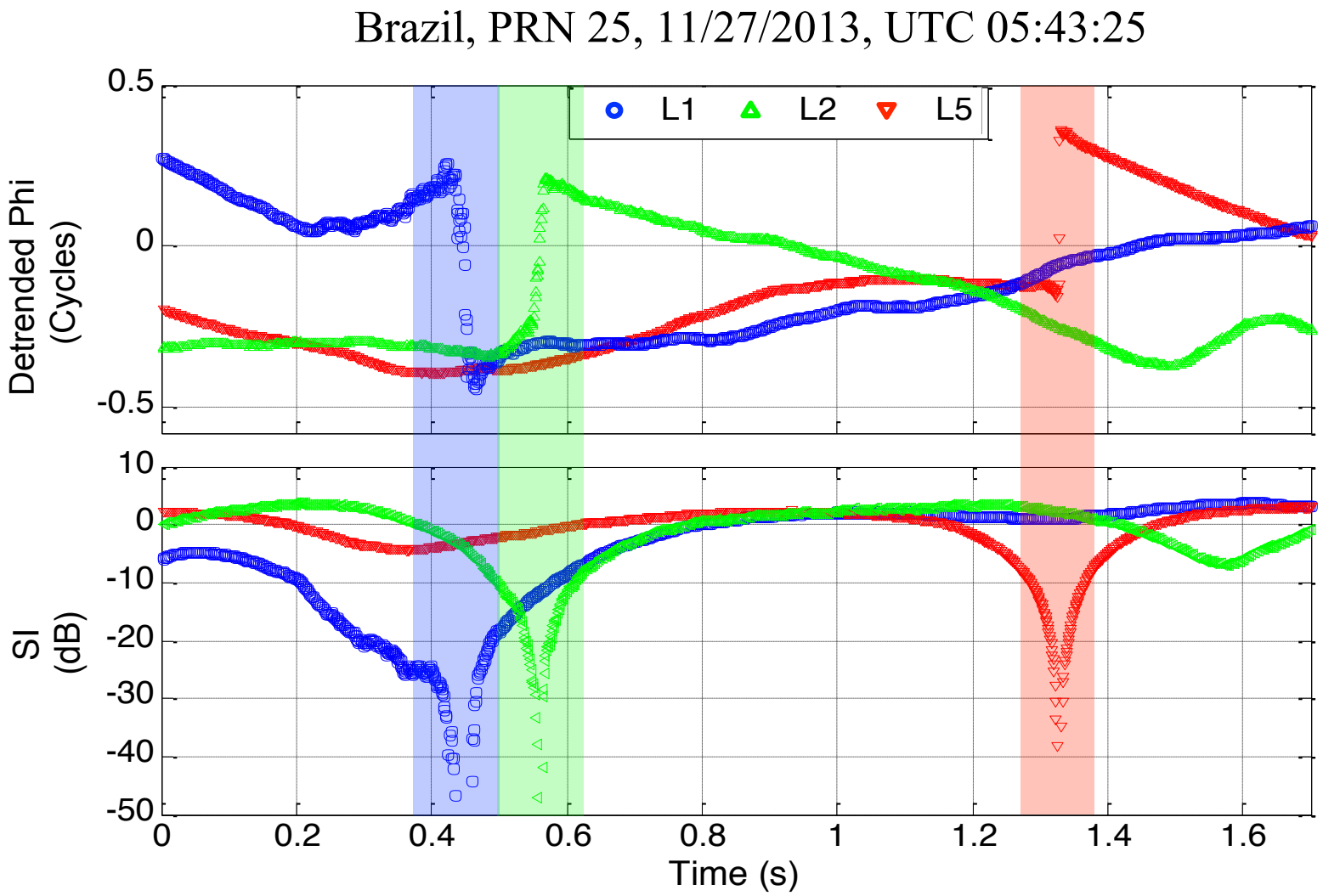


σ_ϕ baseline value:
~0.1 (cycles)

Nominal C/N_0
(dB-Hz)
L1: 50
L2: 48
L5: 53



Strong ES Features: Deep fading + Sudden Phase Change



Objectives and Approaches

Strong equatorial scintillation:

Deep amplitude fading + Rapid carrier phase changes

How deep?
How long?

How are they related?

How often?
How fast?

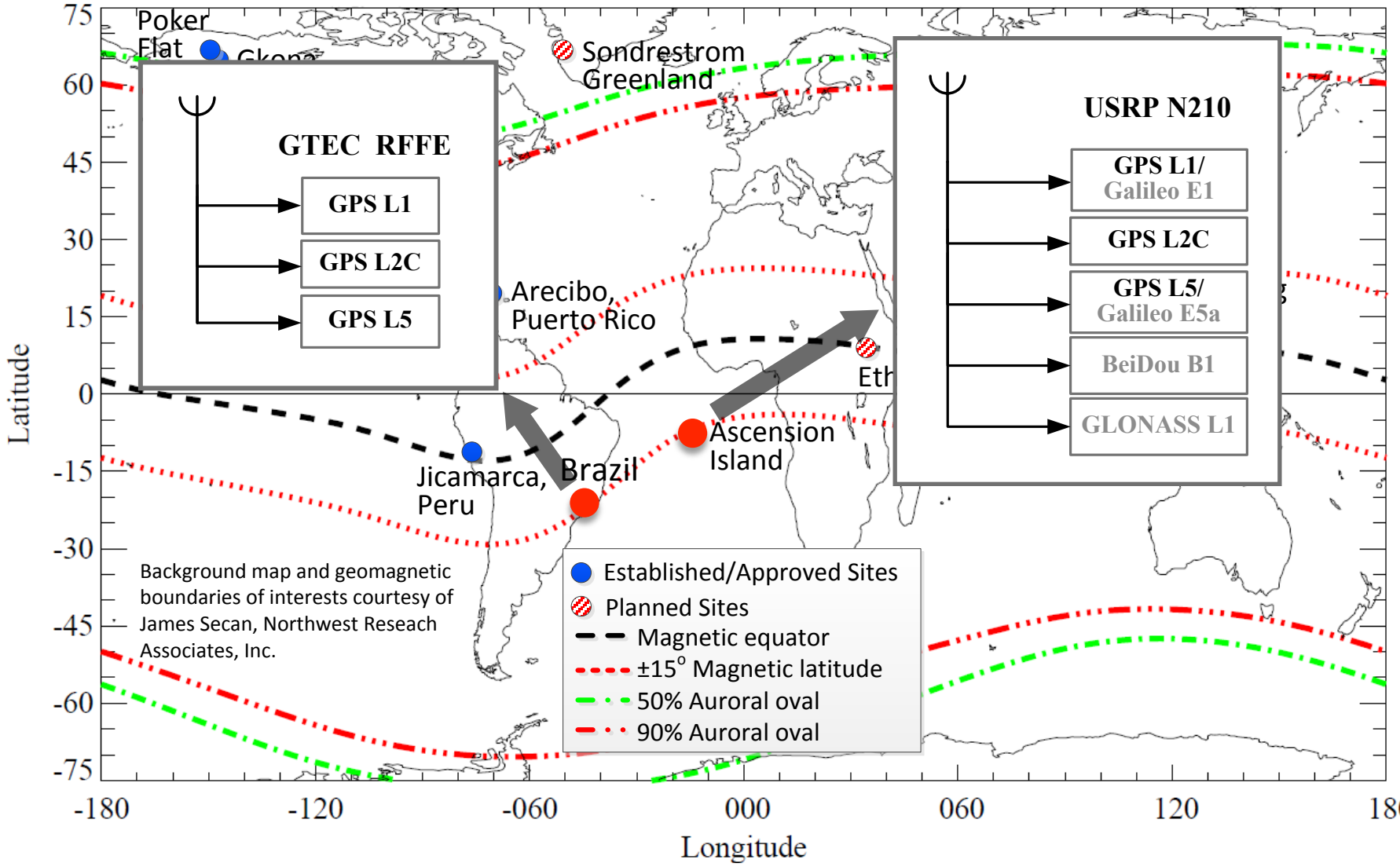
Real data processing

- ✧ Triple frequency strong scintillation: S_4 >0.75, σ_φ> 0.2 cycle
- ✧ Ascension Island: 7.9°S, 14.4°W; 173 minutes
- ✧ Brazil: 23.2°S, 45.9°W; 44 minutes

Semi-open-loop (SOL) tracking algorithm

- ✧ Extended integration time → Improve signal intensity
- ✧ Moving window integration → Finer temporal features

Data Collection Systems

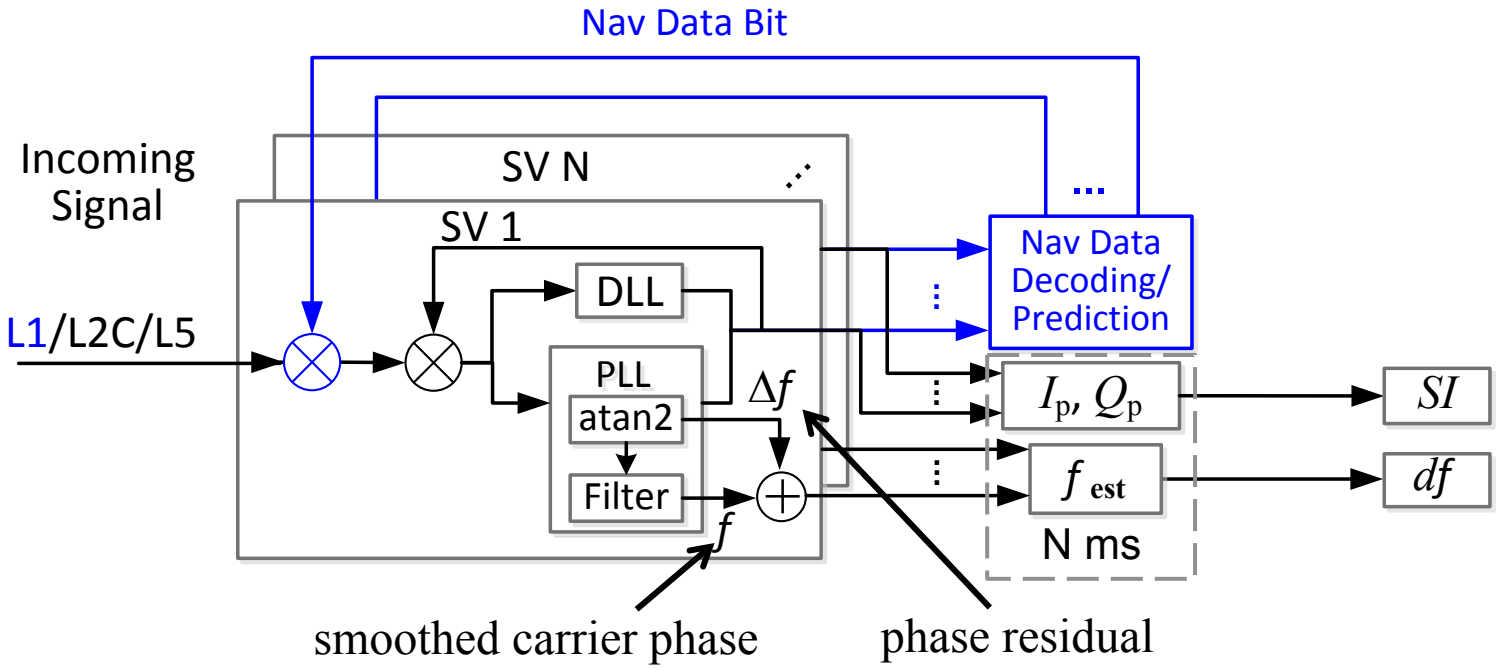


More Details on Data

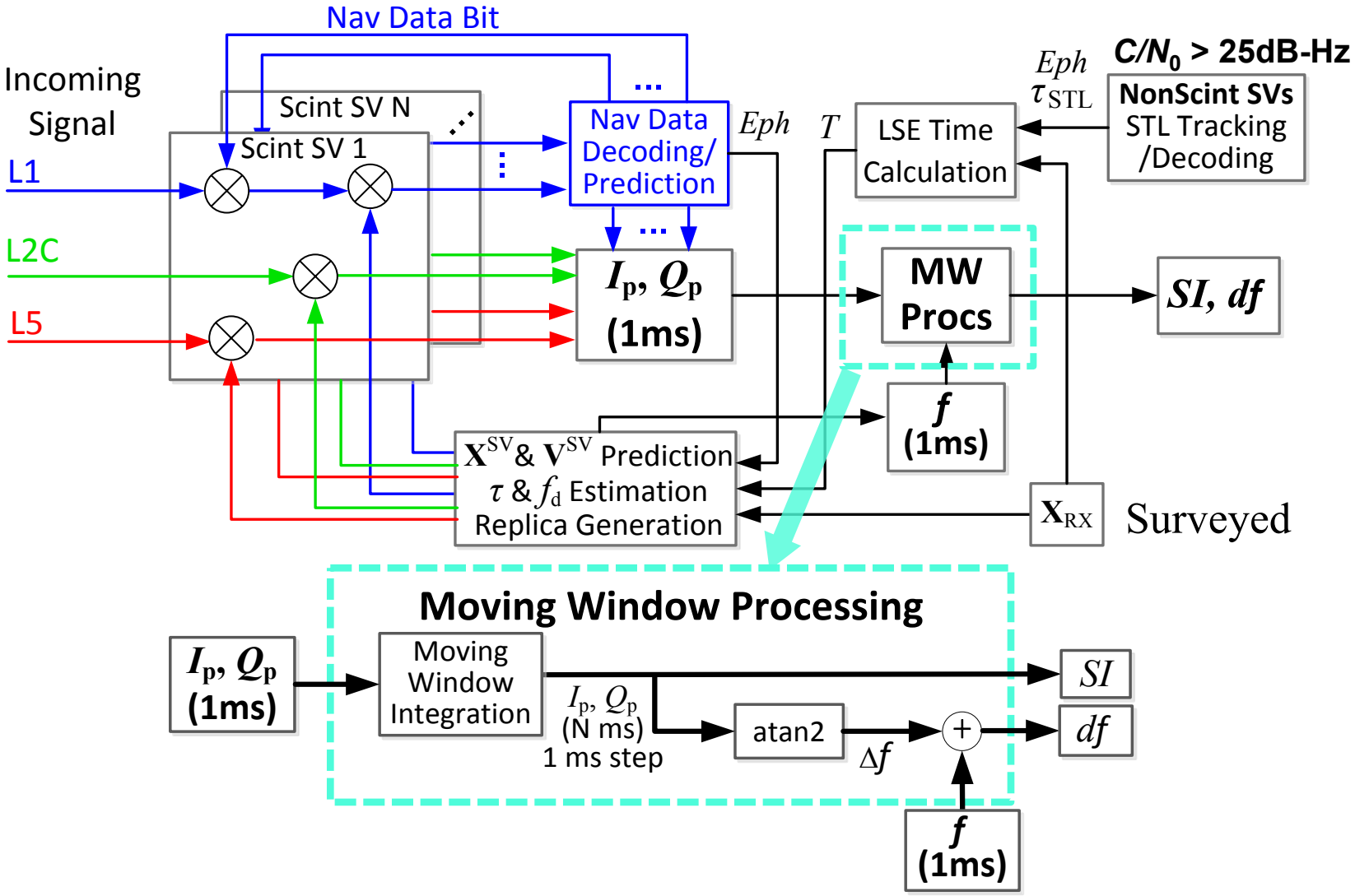
Ascension Island	Dates	March 7-10, 2013
	Data Length	174 minutes
	Sampling Frequency	L1 & L5: 25MHz L2C: 5MHz
Brazil	Dates	Nov 14 & 17, 2013
	Data Length	43 minutes
	Sampling Frequency	L1, L2C & L5: 20MHz

Scalar Tracking Loop (STL) Scheme

	Integration time	Tracking loop bandwidth
High dynamics (phase scintillation)	↓ 10ms	↑ 2Hz
High noise (amplitude scintillation)	↑	↓

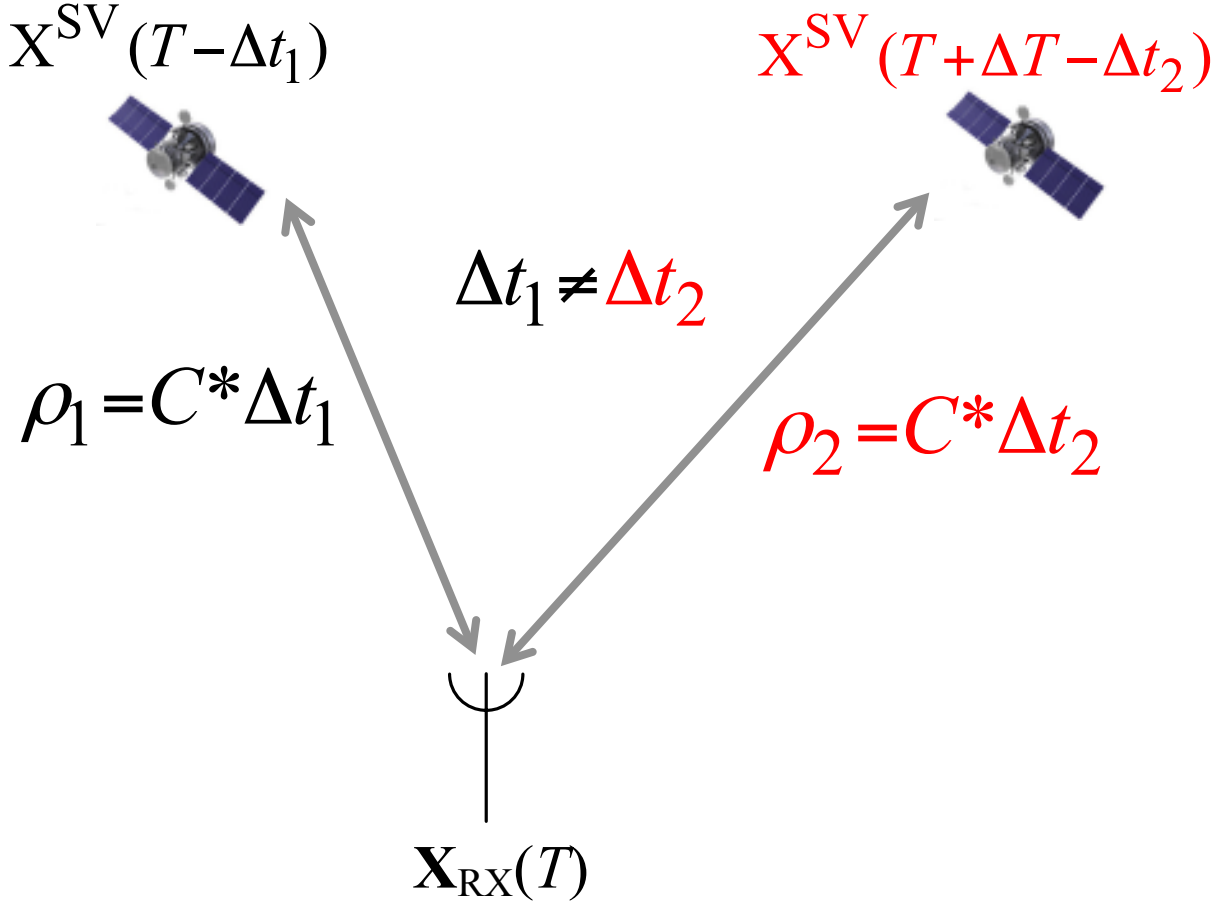


SOL Tracking Scheme



SOL Tracking: Code Phase Prediction

$\mathbf{X}^{SV}$: Computed from ephemeris

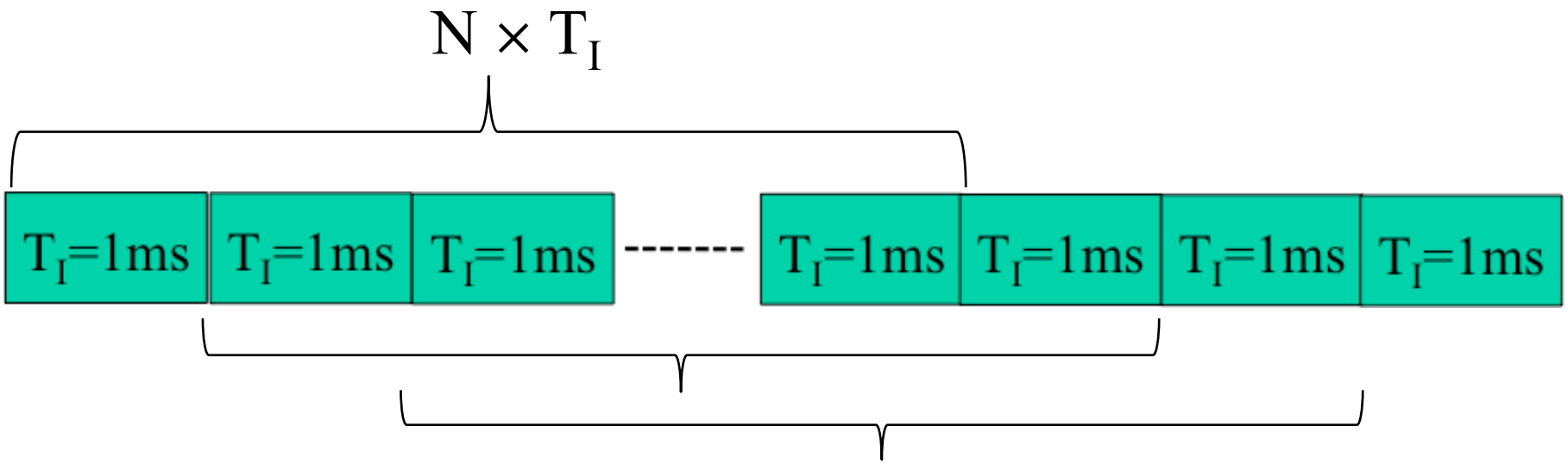


RX Position: Fixed $\mathbf{X}_{RX}(T)=\mathbf{X}_{RX}(T+\Delta T)$

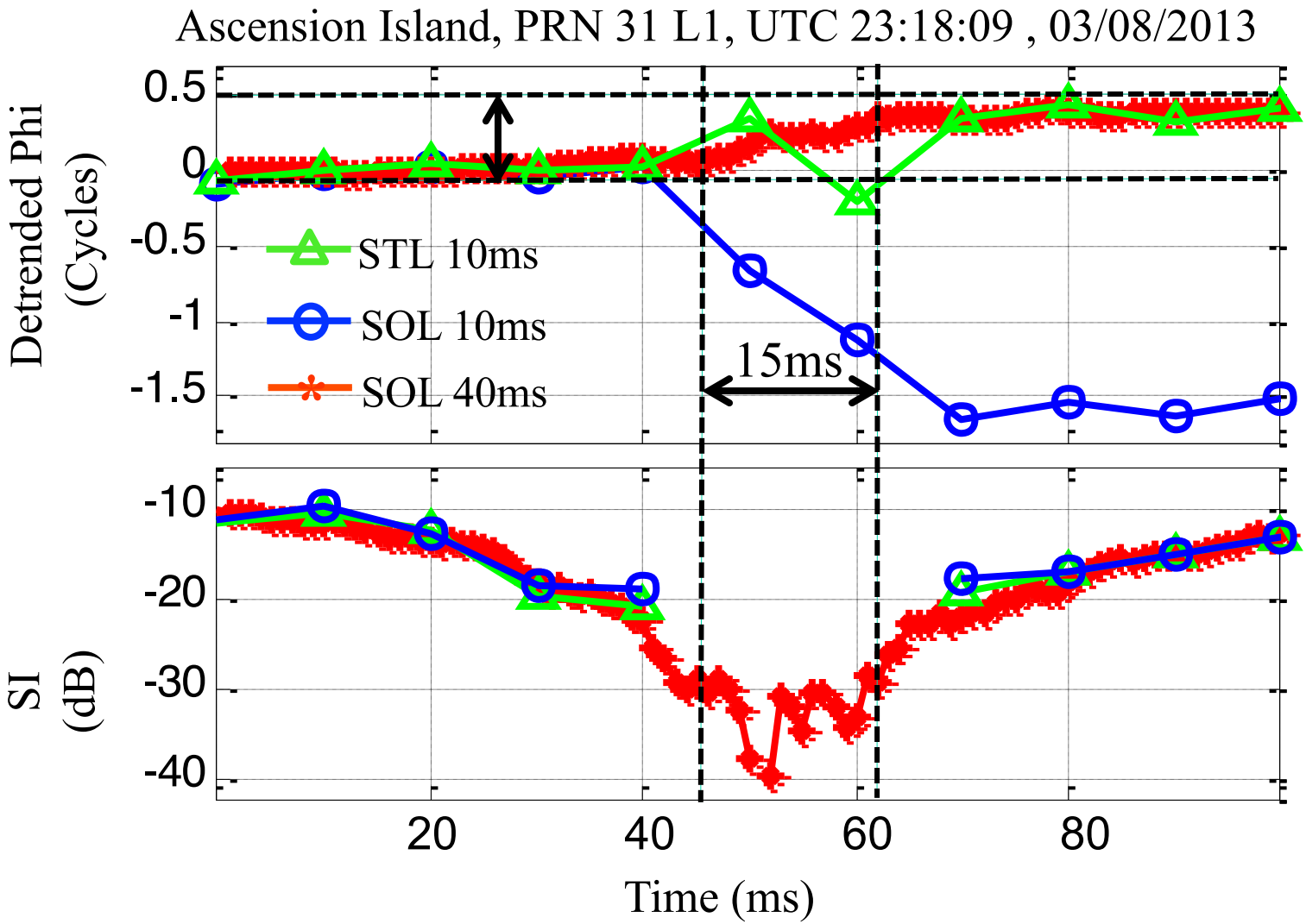
SOL Tracking: f_d Prediction and MW Integration

$$\hat{f}_{d\_SOL}(T+\Delta T) = \mathbf{l}_{RX\rightarrow SV} \bullet \mathbf{V}^{SV}\left(T+\Delta T-\Delta t_2\right)/\lambda + f_{Clk}$$

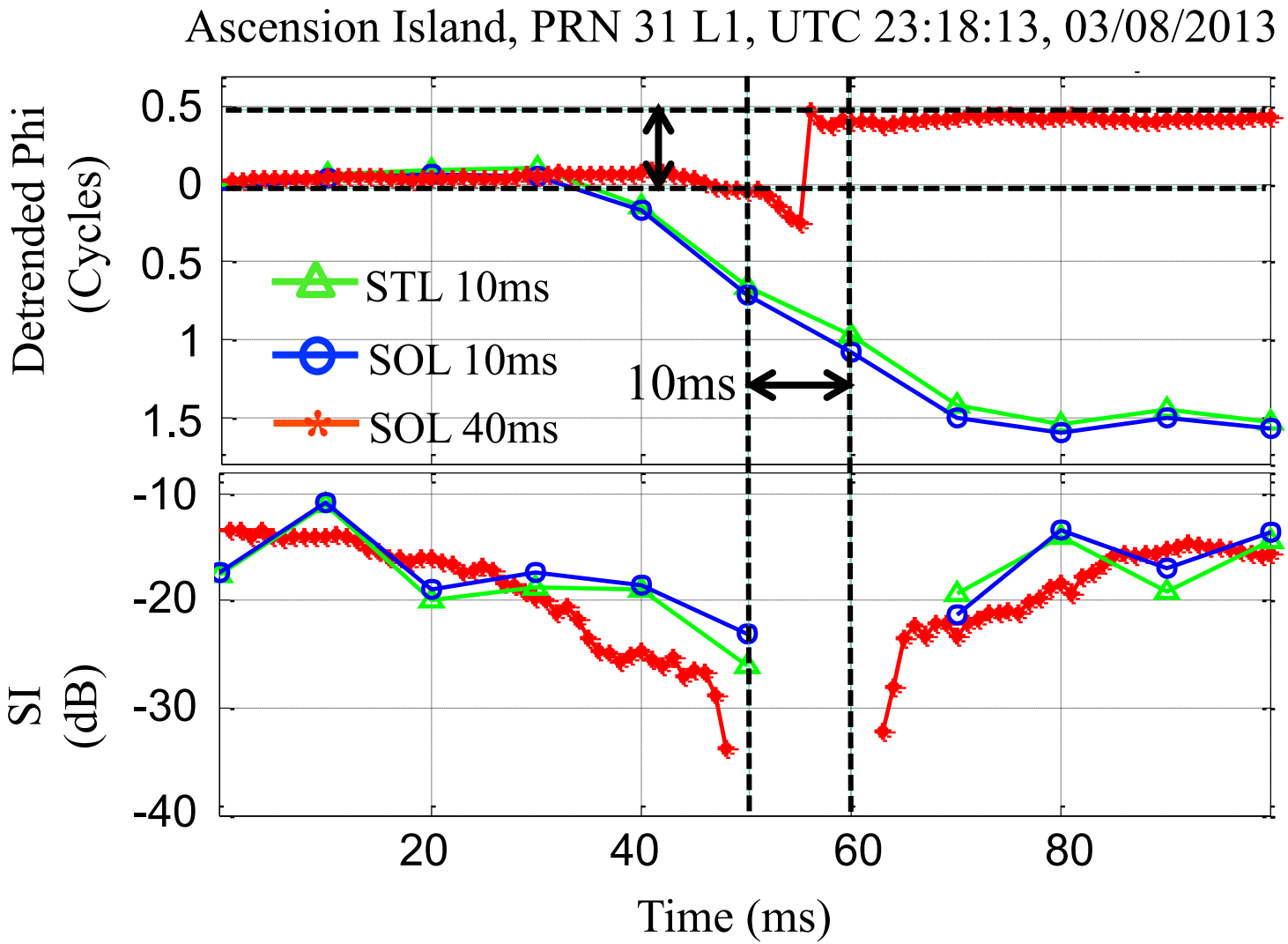
$$\hat{f}_{d\_STL}(t) = \mathbf{l}_{RX\rightarrow SV} \bullet \mathbf{V}^{SV}\left(t-dt\right)/\lambda + f_{Clk}$$



Half-Cycle Phase Change: Example 1



Half-Cycle Phase Change: Example 2

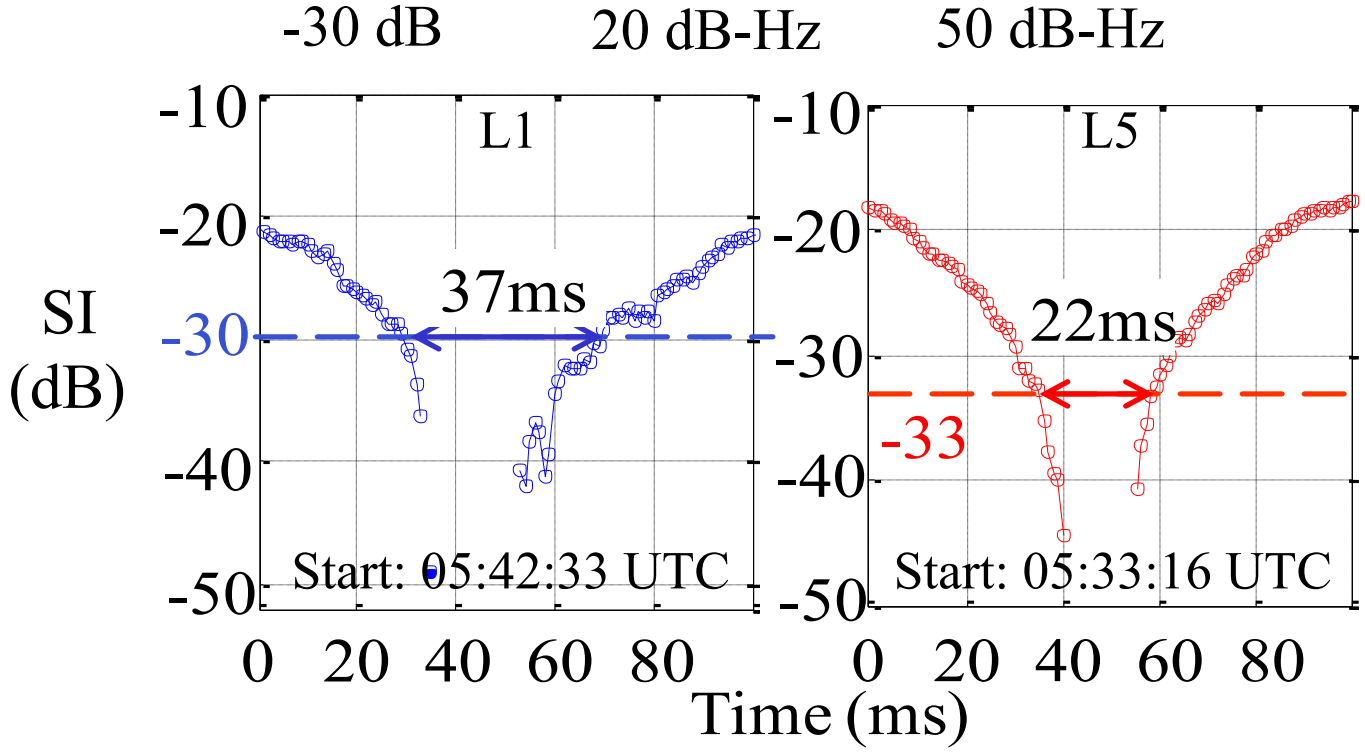


Fading Duration Quantitative Measures

C/N_0: Low time resolution

SI: Not a uniform measure of tracking challenge

$$SI_{Threshold} = C/N0_{Threshold} - C/N0_{Nominal}$$



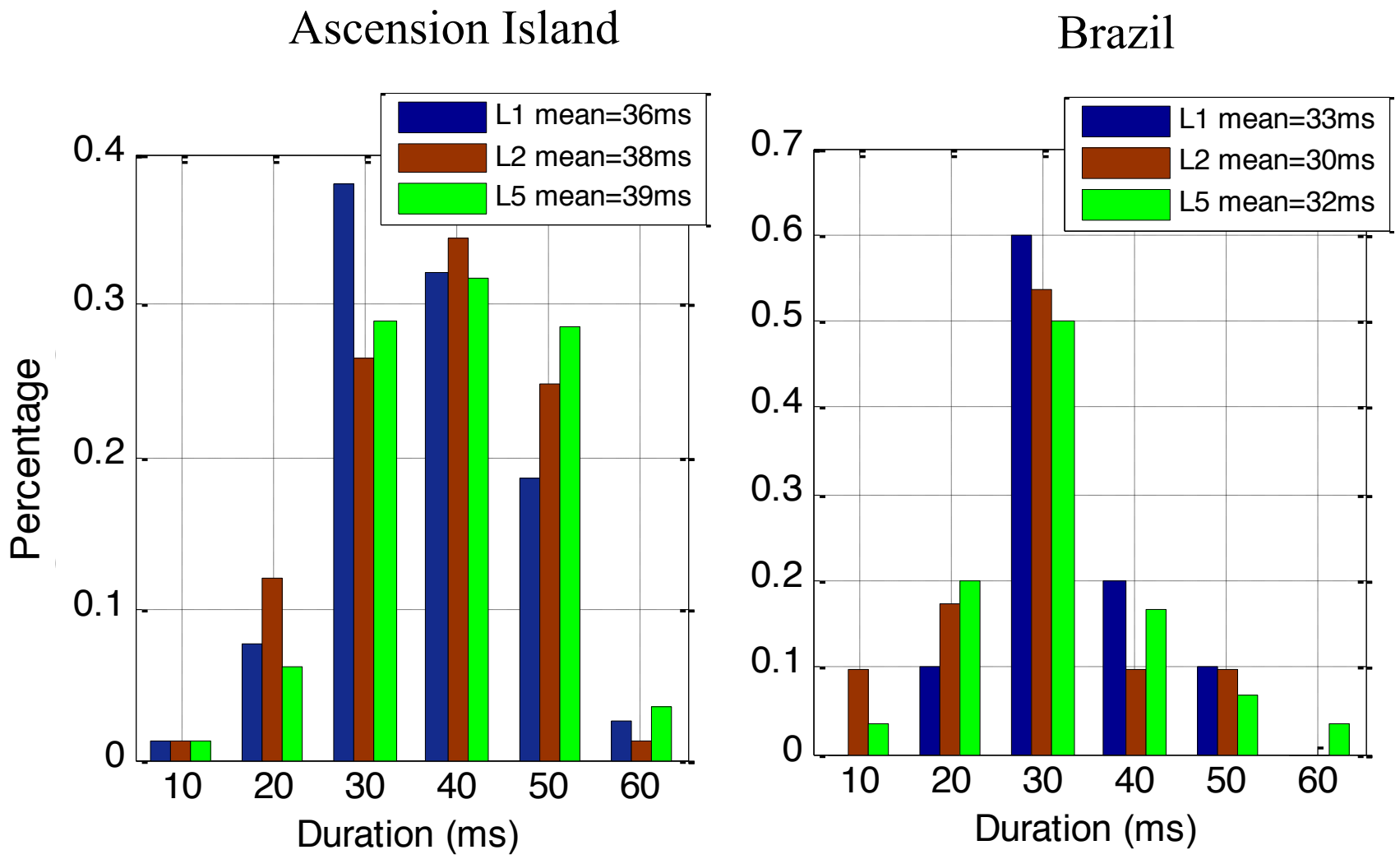
Brazil, PRN 25, 11/27/2013

Statistical Summary

Site	Date	PRN	Nominal C/N_0 (dB-Hz)	Fade No. (< 20 dB-Hz)	Phase Changes (Cycles)			Data length
					Half	Full	Half+Full	
Aacension Island	3/7	6	38	252	16	2	1	22m 31s
		14	44	78	19	2	0	21m 55s
	3/8	24	38	230	6	4	1	34m 10s
			38	243	16	3	0	
			44	102	22	4	0	
		31	41	96	15	2	1	14m 03s
			41	129	24	2	0	
	3/9	14	43	98	25	2	0	13m 44s
		29	45	64	9	2	1	23m 24s
			45	95	12	0	2	
	3/10	24	38	104	0	3	0	17m 01s
			38	124	4	1	0	
			44	59	6	4	0	
		31	42	99	24	4	0	27m 01s
			42	146	31	1	0	
	Total			**1919**	**229**	**36**	**6**	**173m 49s**
Brazil	11/14	25	48	5	2	0	0	21m 15s
			46	51	4	0	0	
			51	23	5	0	0	
	11/27	25	50	24	8	0	0	22m 21s
			48	84	22	0	0	
			53	52	25	0	1	
	Total			**239**	**66**	**0**	**1**	**43m 36s**

L1
L2C
L5

Half-Cycle Phase Change Duration

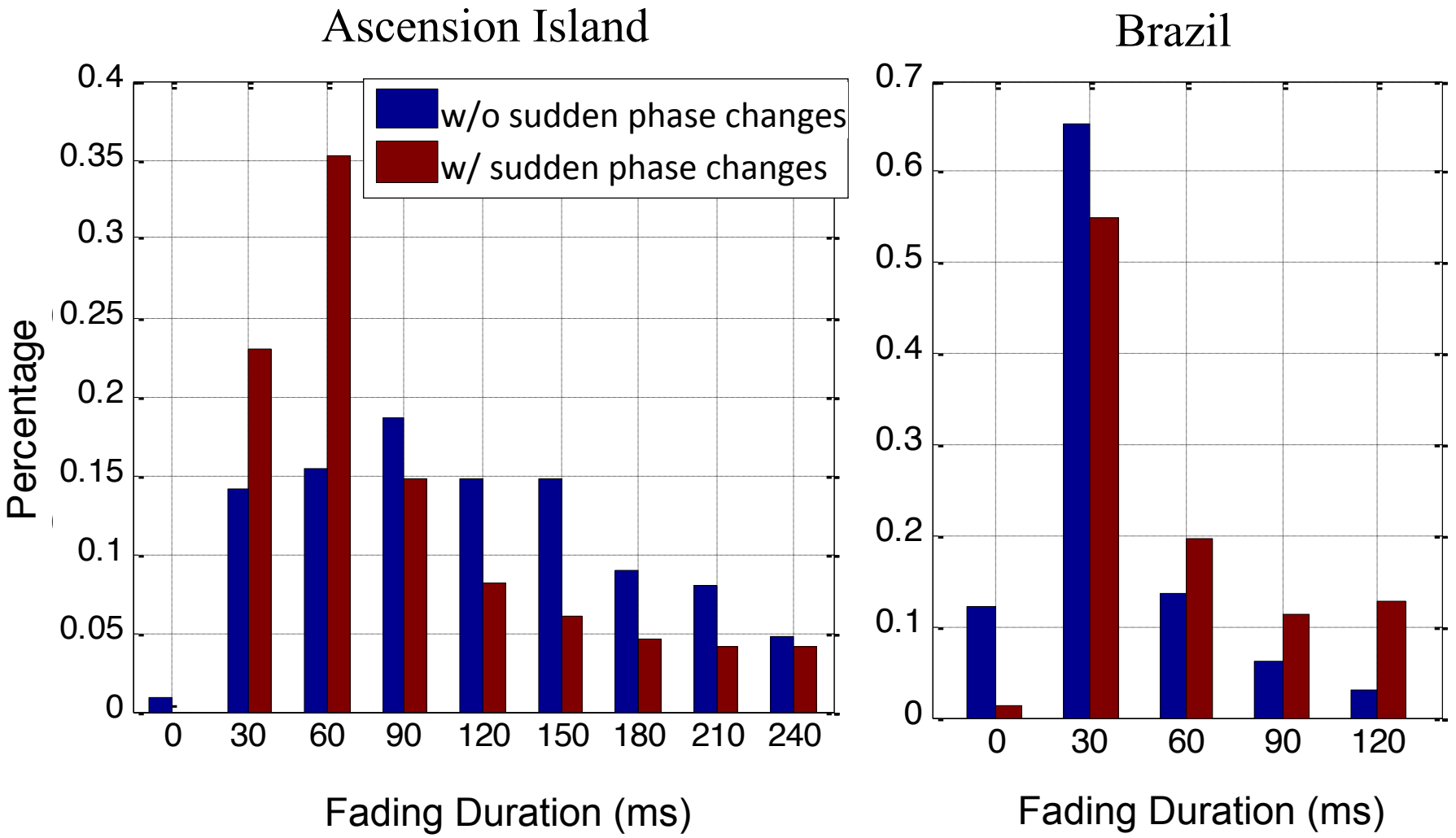


In order to further classify the deep amplitude fades listed in Table 2 (C/N_0 < 20 dB-Hz) and establish a closer correlation between deep fading and c

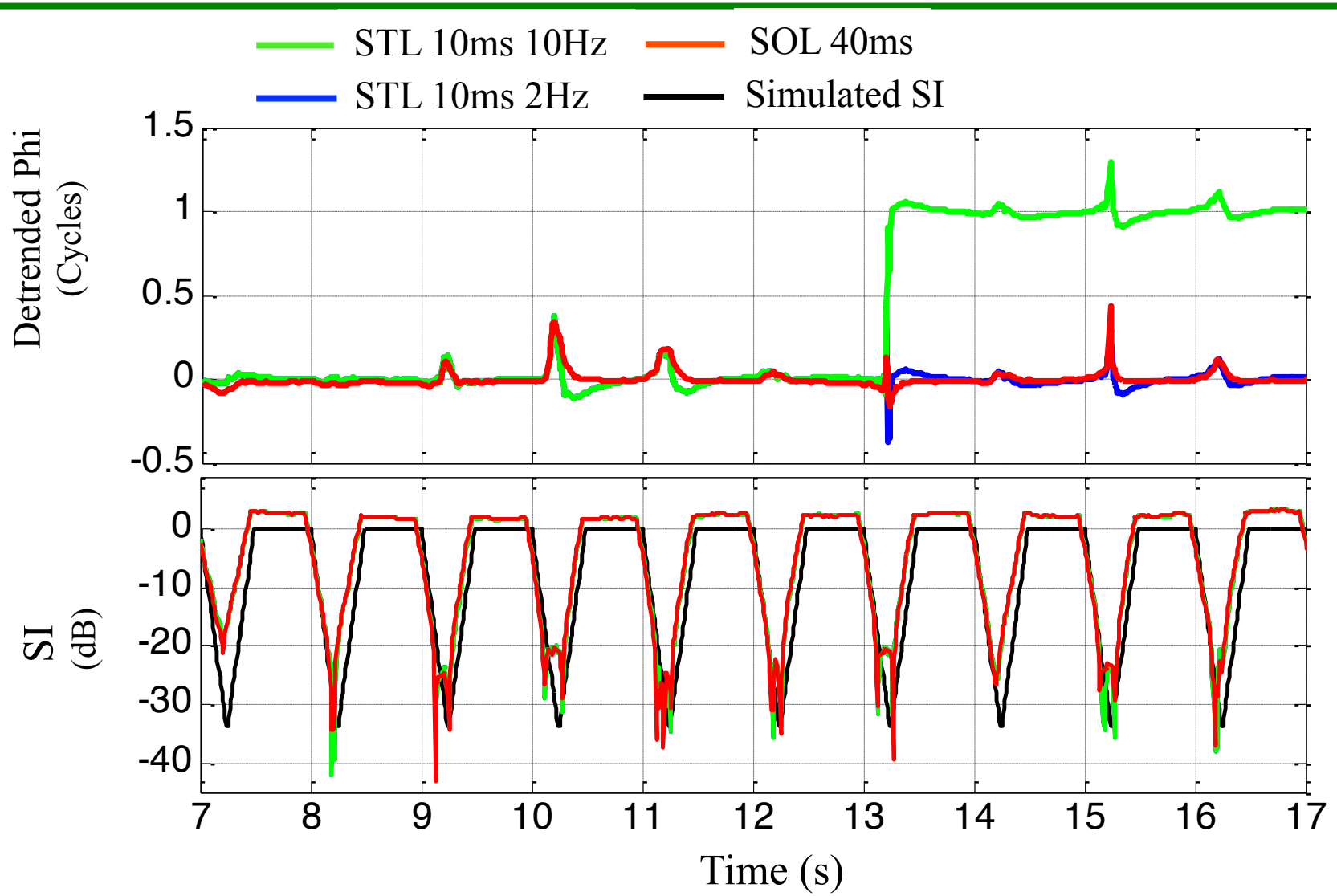
Fading Depth vs. Concurrent Phase Changes

Minimum C/N_0 (dB-Hz)	Perc. of fades	Perc. of phase changes
	Ascension Island / Brazil	
20 ~ 15	39.0% / 26.9%	0.4% / 1.4%
15 ~ 10	12.5% / 12.6%	2.2% / 5.9%
<10	**48.5% / 60.5%**	**97.4% / 92.7%**

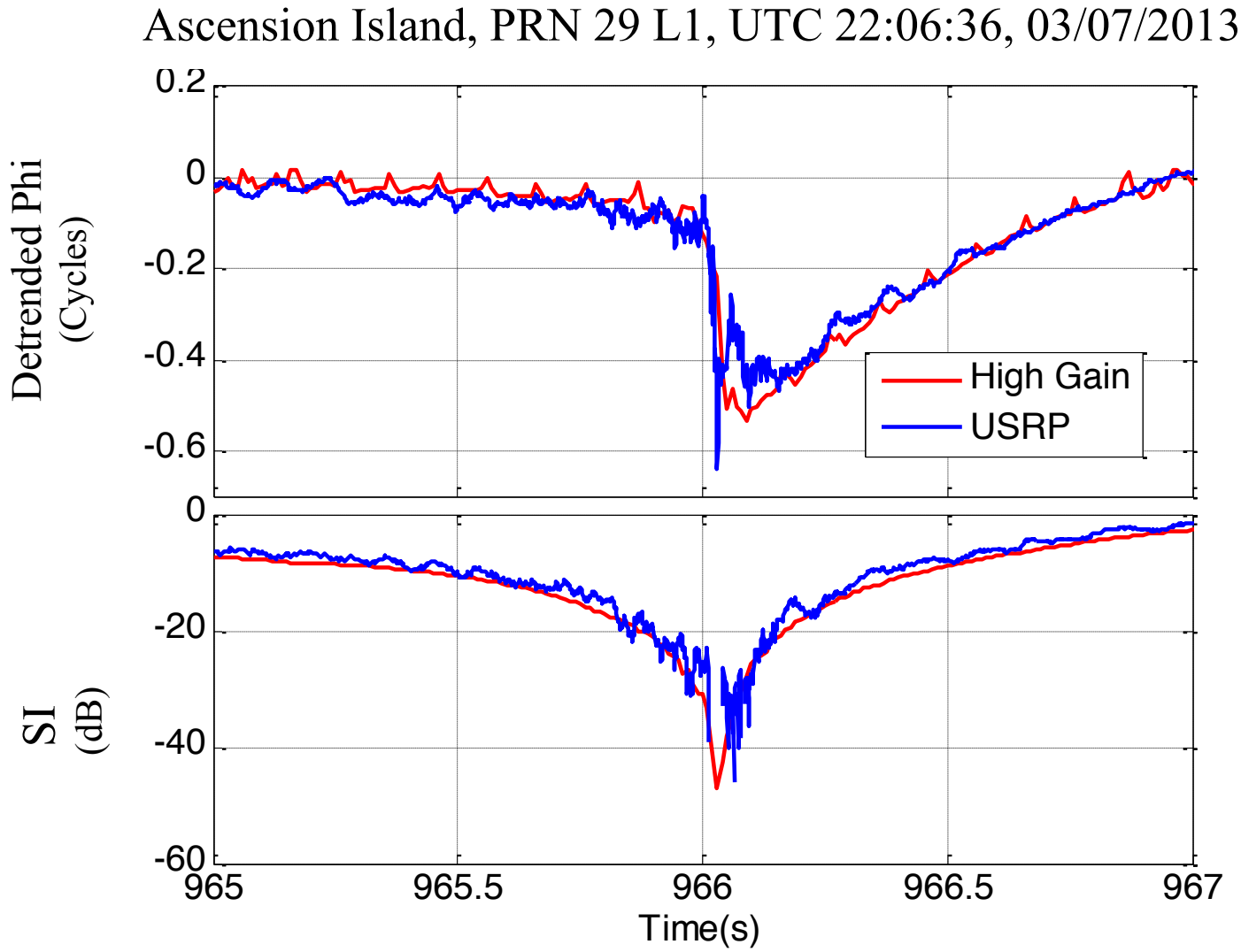
Extremely Deep Fading (< 10dB-Hz) Duration Distribution



Simulated Data: Fading without Phase Fluctuations



Comparison with High Gain Antenna Measurement



Conclusions

- Semi-open loop algorithm developed to track simultaneous deep fading and fast carrier phase changes during strong equatorial scintillation.
- Real GPS multi-frequency scintillation data from Ascension Island and Brazil are processed to characterize concurrent deep fades and fast phase changes.
- Number of phase change occurrence increase as carrier frequency decreases.
- Most fast phase changes are half-cycle changes.
- Fast phase change durations: mean interval 30~40ms
- Most fast phase changes occurr during deep fades <10 dB-Hz:
  - 97% on Ascension Island; 93% in Brazil

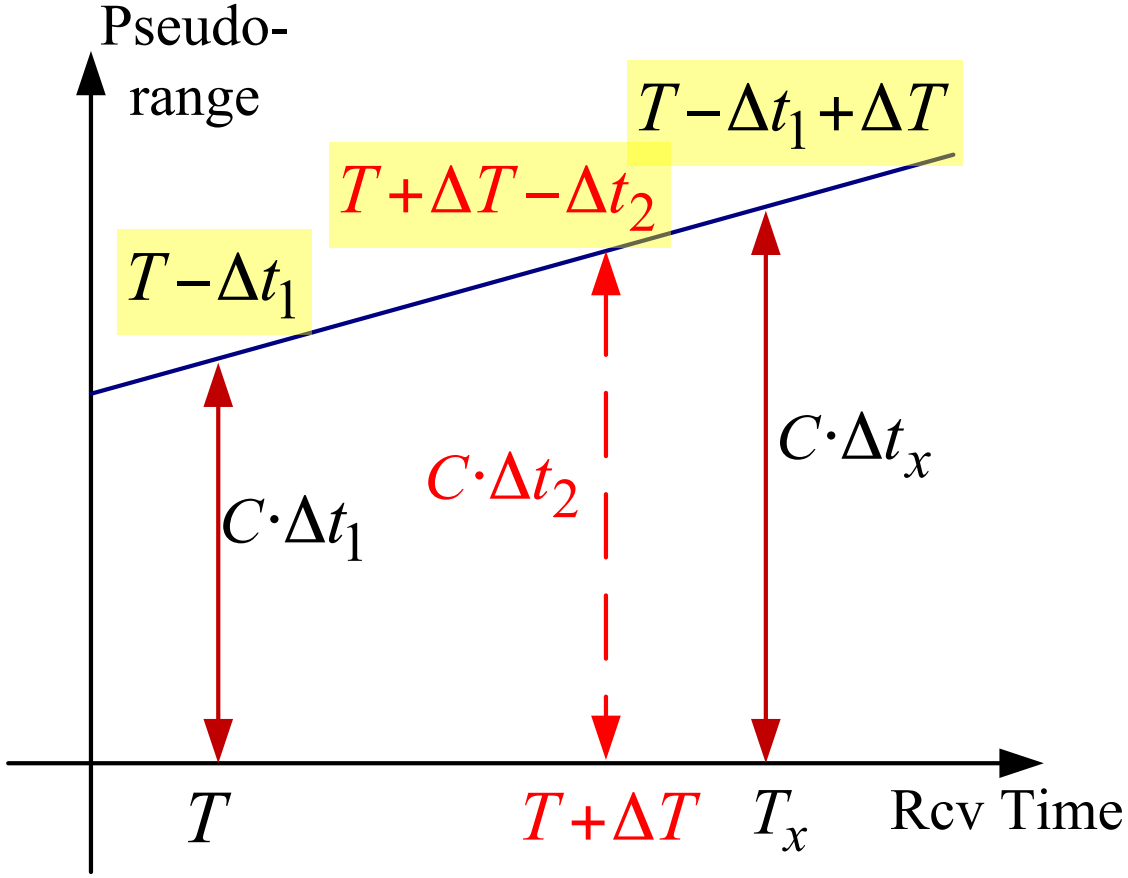
Acknowledgement

- Data collection:
  - CSU students Steve Taylor, Harrison Bourne for builiding the data collection system at the Ascension Island
  - Todd Pederson from AFRL Space Vehicle Directorate for bring the system to Ascension Island to collect the data
  - Dennis Akos (CU Boulder) and Todd Walter (Stanford) for providing the Brazil data
- Funding support:
  - AFRL Sensors Directorate for Ascension Island equipment funding support
  - CSU for supporting Dongyang Xu's study

Thank you!

Q&A

SOL Tracking: Code Phase Prediction



Full-Cycle Phase Change Duration at a Glance

Duration (ms)	Cycles	Number of Occurrence
30 - 45	1	31
55, 64, 65, 70, 90	1	1 each
25, 37, 40*, 41, 46, 50	1.5	1 each
88	2.5	1

*This is the only one full-cycle sudden phase change from Brazil

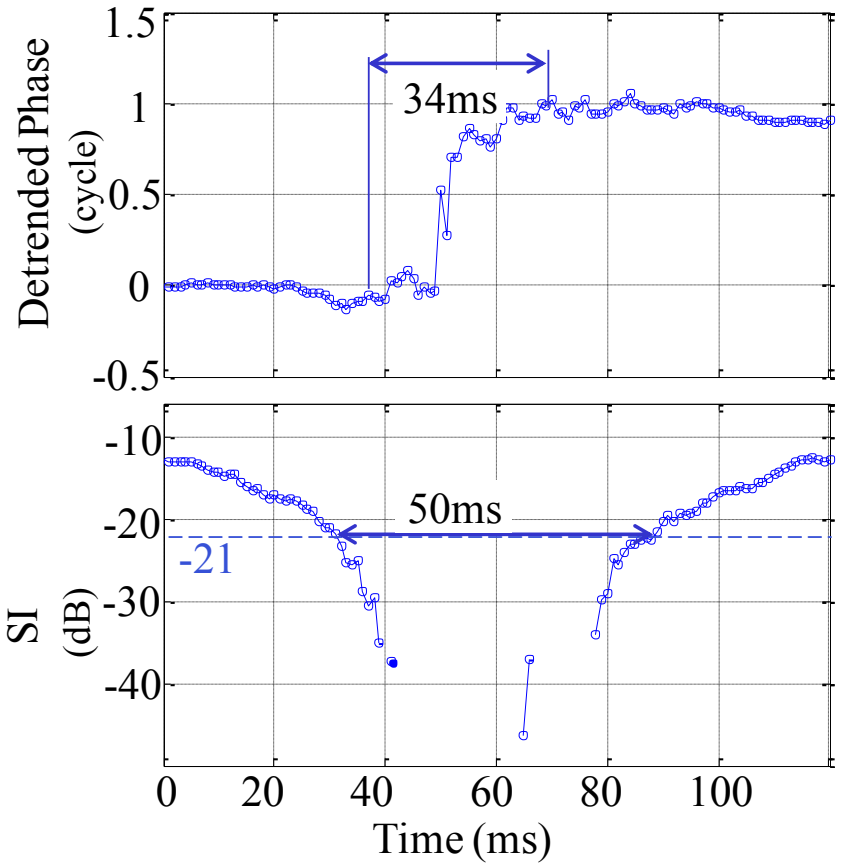
Data Specifics and Signal Tracking Configuration

IF Frequency	0MHz
Sampling Frequency	40MHz
Signal Type	GPS L1
Number of Files	6

Tracking loop used	Order	Integration Time	Bandwidth	Discriminator
DLL	2	10ms	0.25Hz	E-L Amplitude
PLL	3	10ms	2Hz	ATAN2

Full-cycle Sudden Carrier Phase Change

Ascension Island, PRN 31
3/8/2013 UTC 23:15:05
L1 Nominal C/N_0 = 41 dB-Hz



Brazil, PRN 25
11/27/2013 UTC 05:51:38
L5 Nominal C/N_0 = 53dB-Hz