Ionosphere Remote Sensing Using GNSS Signals

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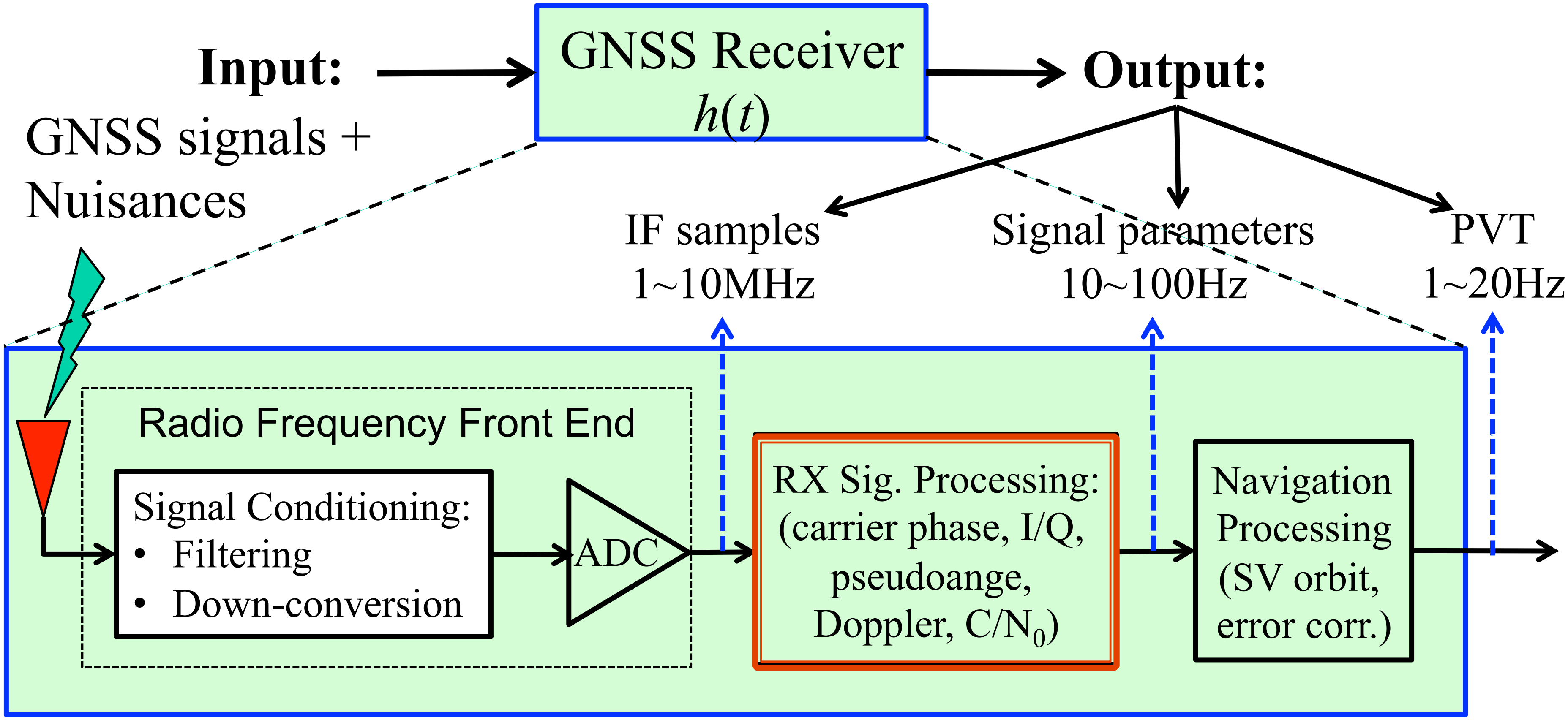
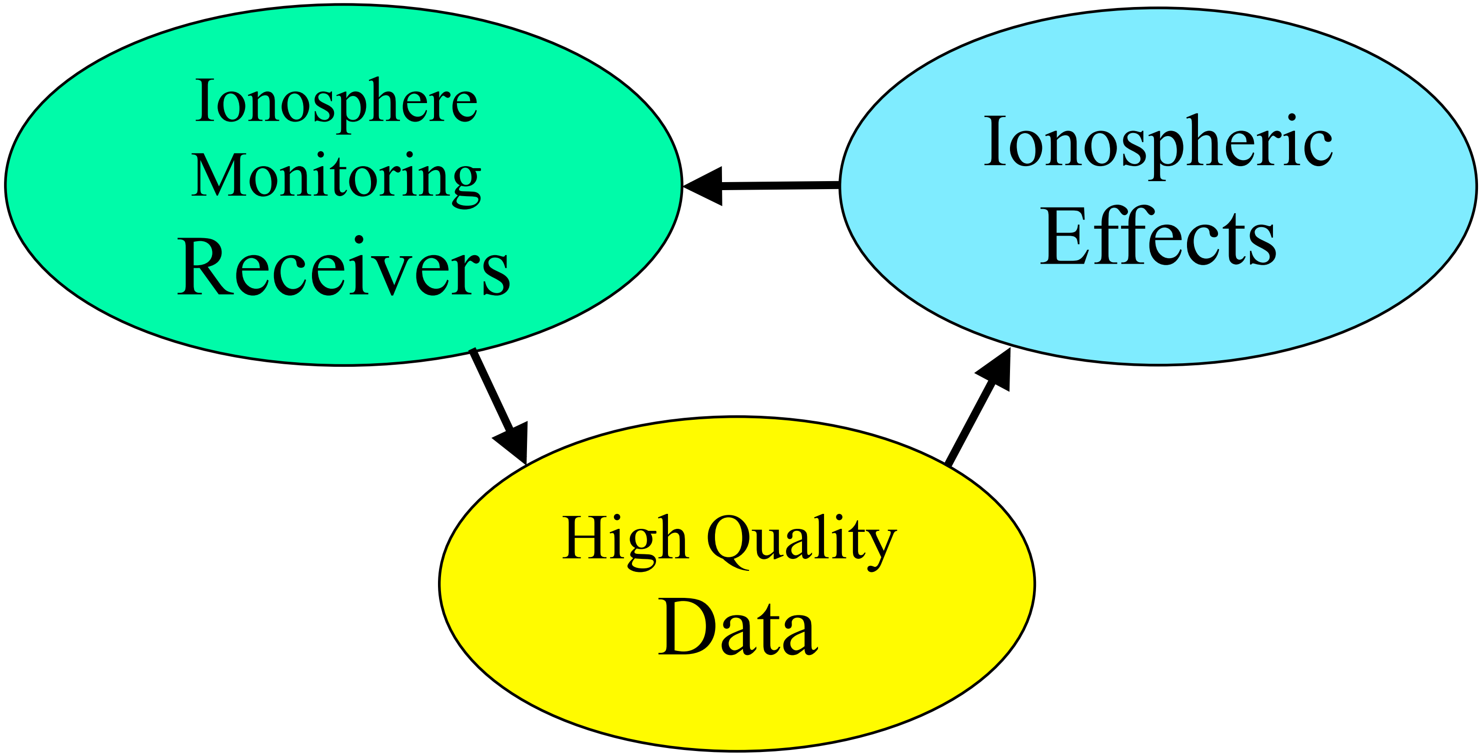
GNSS Receiver: Designed for Navigation

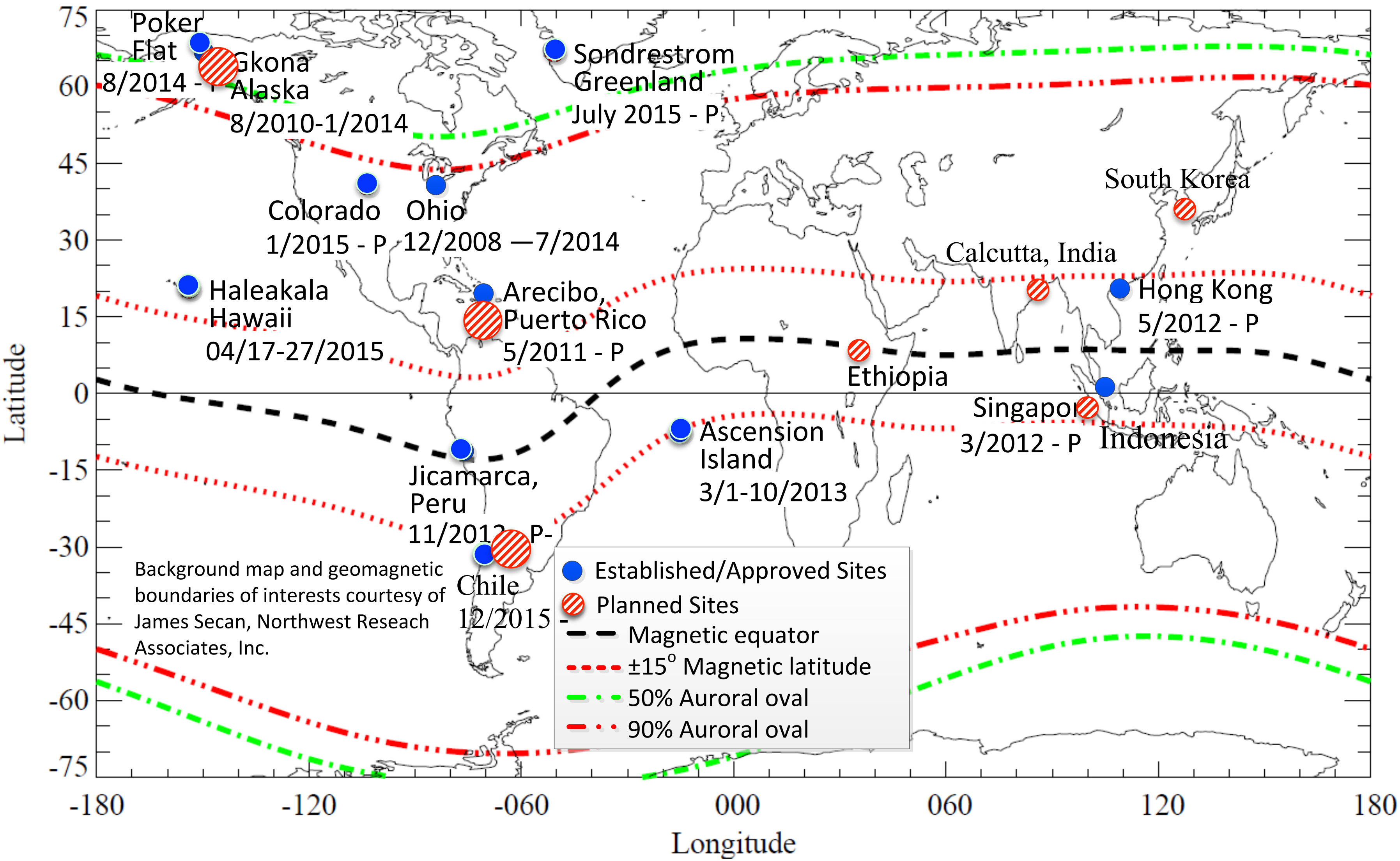


$(Signals + \not{Nuisances}) \otimes h(t) = Output$

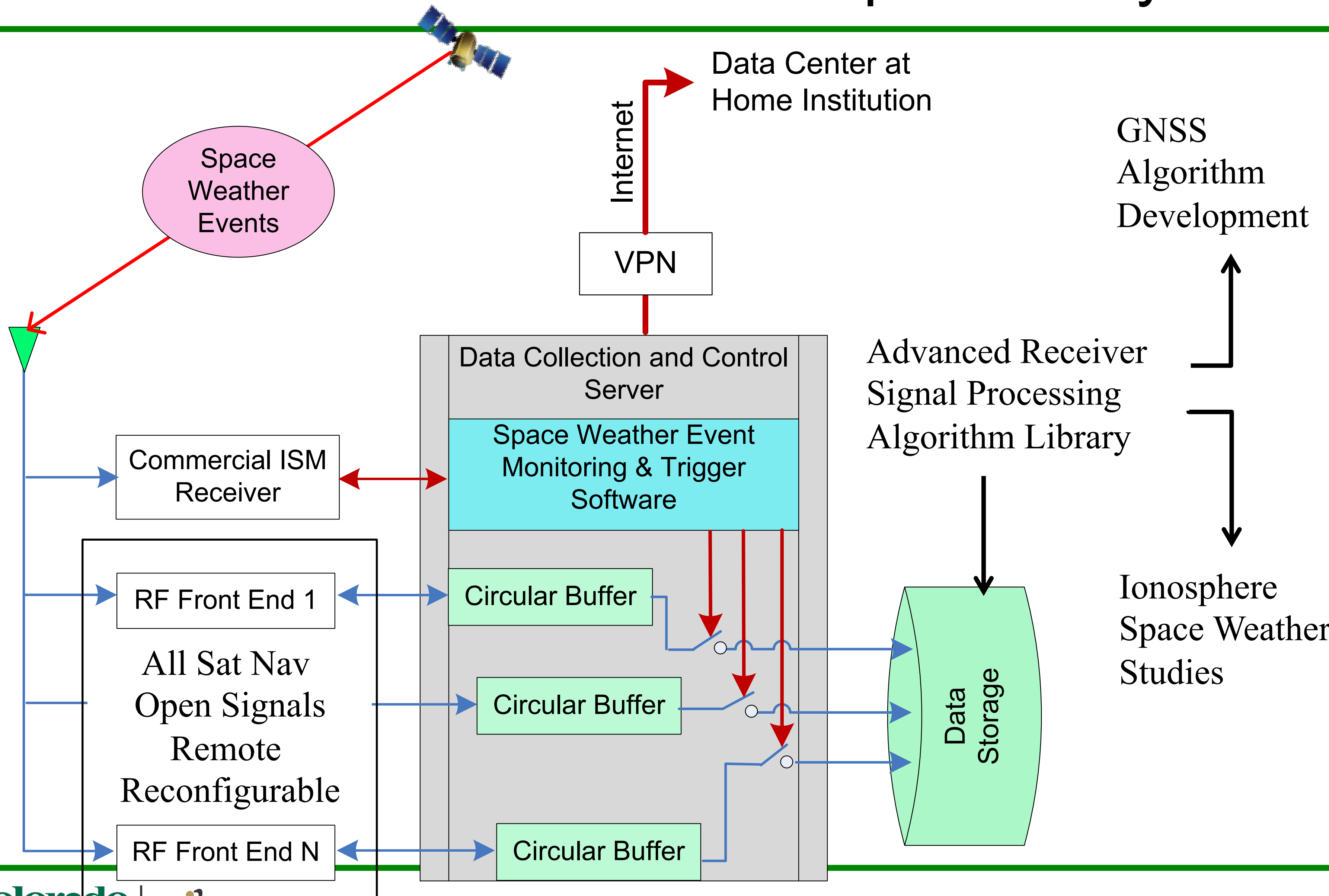
GNSS Remote Sensing Cycle



Data Collection Systems Deployment



E-DAS: Event-driven Data Acquisition System



Challenges/Questions

1. How to maintain lock of signals during strong scintillation?
2. How to design receivers to accurately capture ionosphere scintillation signatures?
3. How to interpret ionosphere states and processes from GNSS measurements?
4. How to improve navigation solutions accuracy and robustness during ionospheric scintillation?
5. **How to correctly compute TEC during scintillation?**

TEC 101

Pseudorange:

$$\rho_1 = r + \delta r + B_1 + I_1 + M_{\rho 1} + \varepsilon_{\rho 1}$$

$$\rho_2 = r + \delta r + B_2 + I_2 + M_{\rho 2} + \varepsilon_{\rho 2}$$

Dual frequency difference: $\Delta\rho = \Delta I + \Delta B + \Delta M + \Delta\varepsilon$

If: $\Delta M, \Delta\varepsilon \approx 0, \Delta B \, can\, be\, estimated \longrightarrow \Delta\rho - \Delta B = \Delta I$

Since: $I_f = \dfrac{40.3 TEC}{f^2} \longrightarrow \Delta I = \dfrac{1}{\beta} \times TEC$

$$TEC = \beta \times \left(\Delta\rho - \Delta B\right)$$

Pseudorange-based TEC estimation

But $\Delta M, \Delta\varepsilon \neq 0$

Carrier phase:

$$\phi_1 = r + \delta r + B_1 - I_1 + N_1\lambda_1 + \cancel{M_{\phi 1} + \varepsilon_{\phi 1}}$$

$$\phi_2 = r + \delta r + B_2 - I_2 + N_2\lambda_2 + \cancel{M_{\phi 2} + \varepsilon_{\phi 2}}$$

Code-Minus-Carrier observables:

$$\alpha_1 = \frac{2f_2^2}{f_2^2 - f_1^2} \qquad \alpha_2 = \frac{2f_1^2}{f_2^2 - f_1^2}$$

$$CMC_1 = \rho_1 - \phi_1 - \alpha_1(\phi_1 - \phi_2) = \boxed{M_{\rho 1} + \varepsilon_{\rho 1}} + b_1$$

$$CMC_2 = \rho_2 - \phi_2 - \alpha_2(\phi_1 - \phi_2) = \boxed{M_{\rho 2} + \varepsilon_{\rho 2}} + b_2$$

Multipath & receiver noise can be estimated using these observables to correct pseudoranges:

$$\rho_1 = r + \delta r + B_1 + I_1 + \boxed{M_{\rho 1} + \varepsilon_{\rho 1}}$$

$$\rho_2 = r + \delta r + B_2 + I_2 + \boxed{M_{\rho 2} + \varepsilon_{\rho 2}}$$

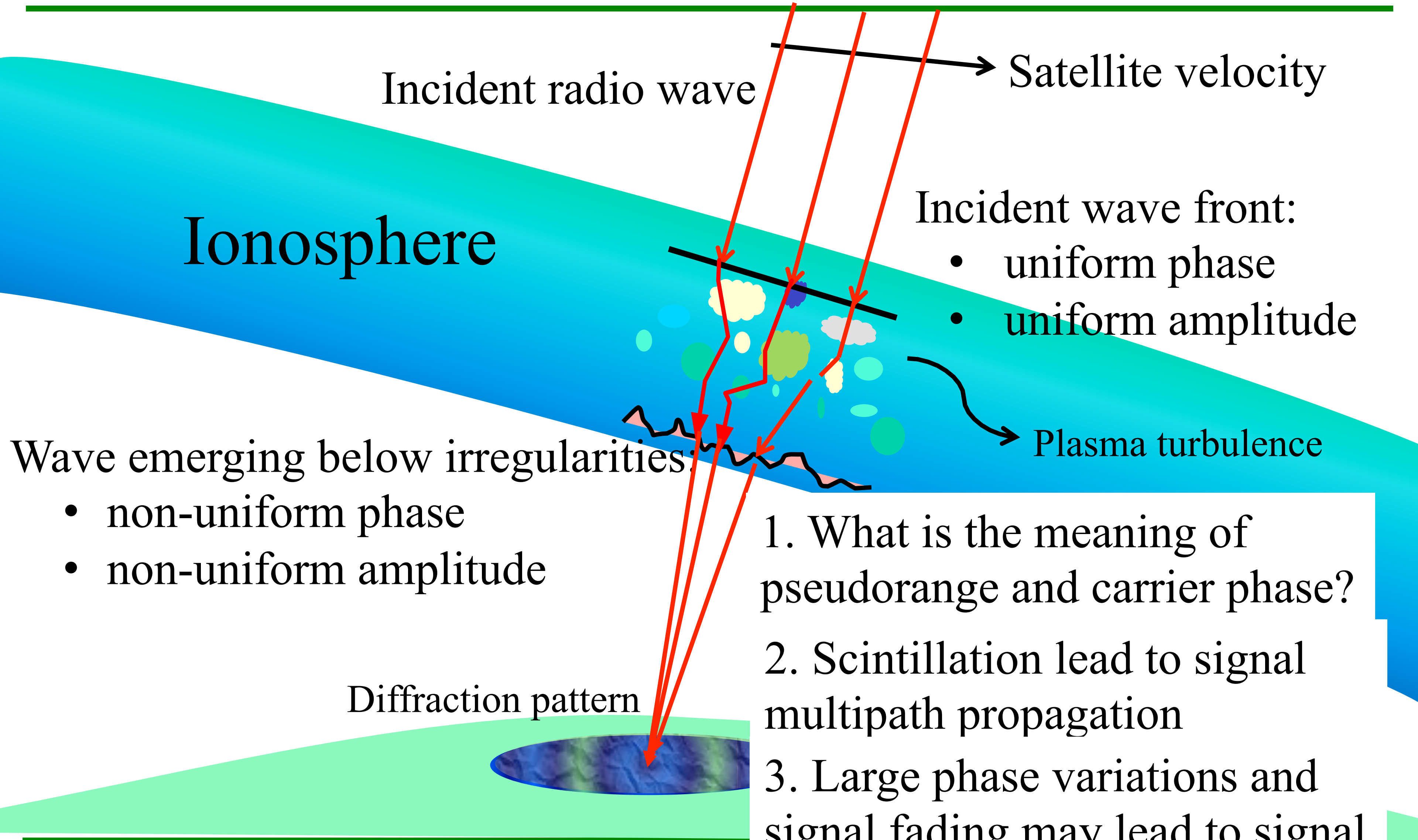
$$\rho_{1c} = \rho_1 - M_{\rho 1} - \varepsilon_{\rho 1} = r + \delta r + B_1 + I_1$$

$$\rho_{2c} = \rho_2 - M_{\rho 2} - \varepsilon_{\rho 2} = r + \delta r + B_2 + I_2$$

Pseudorange-corrected TEC

$$TEC = \beta \times \left(\Delta\rho_c - \Delta B\right)$$

Why Is it Difficult to Estimate TEC During Scintillation?



1. What is the meaning of pseudorange and carrier phase?

2. Scintillation lead to signal multipath propagation

3. Large phase variations and signal fading may lead to signal loss lock, and carrier cycle slips

To Make Things More Complicated: There Are Different Measurement Types

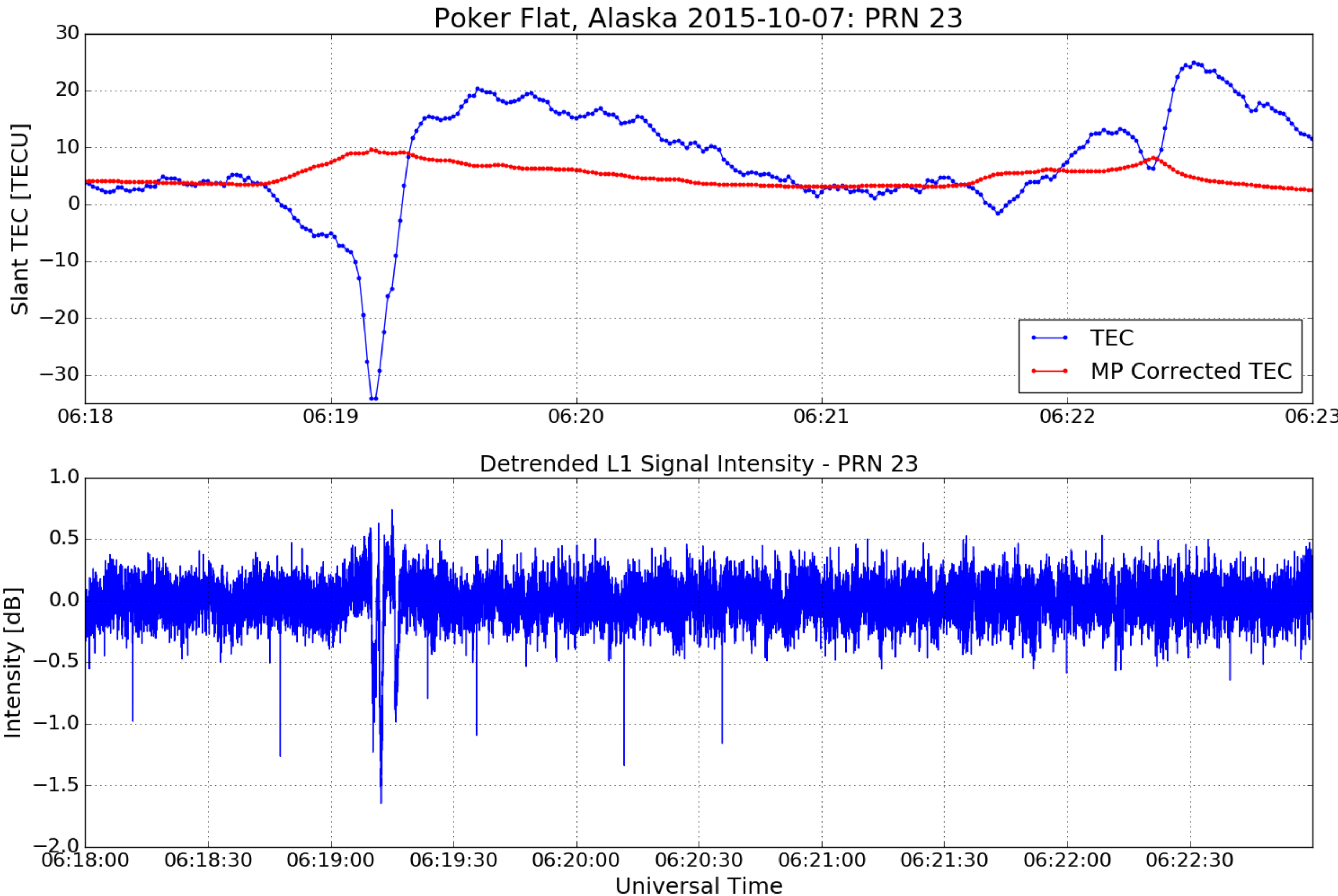
L1: Civil signal

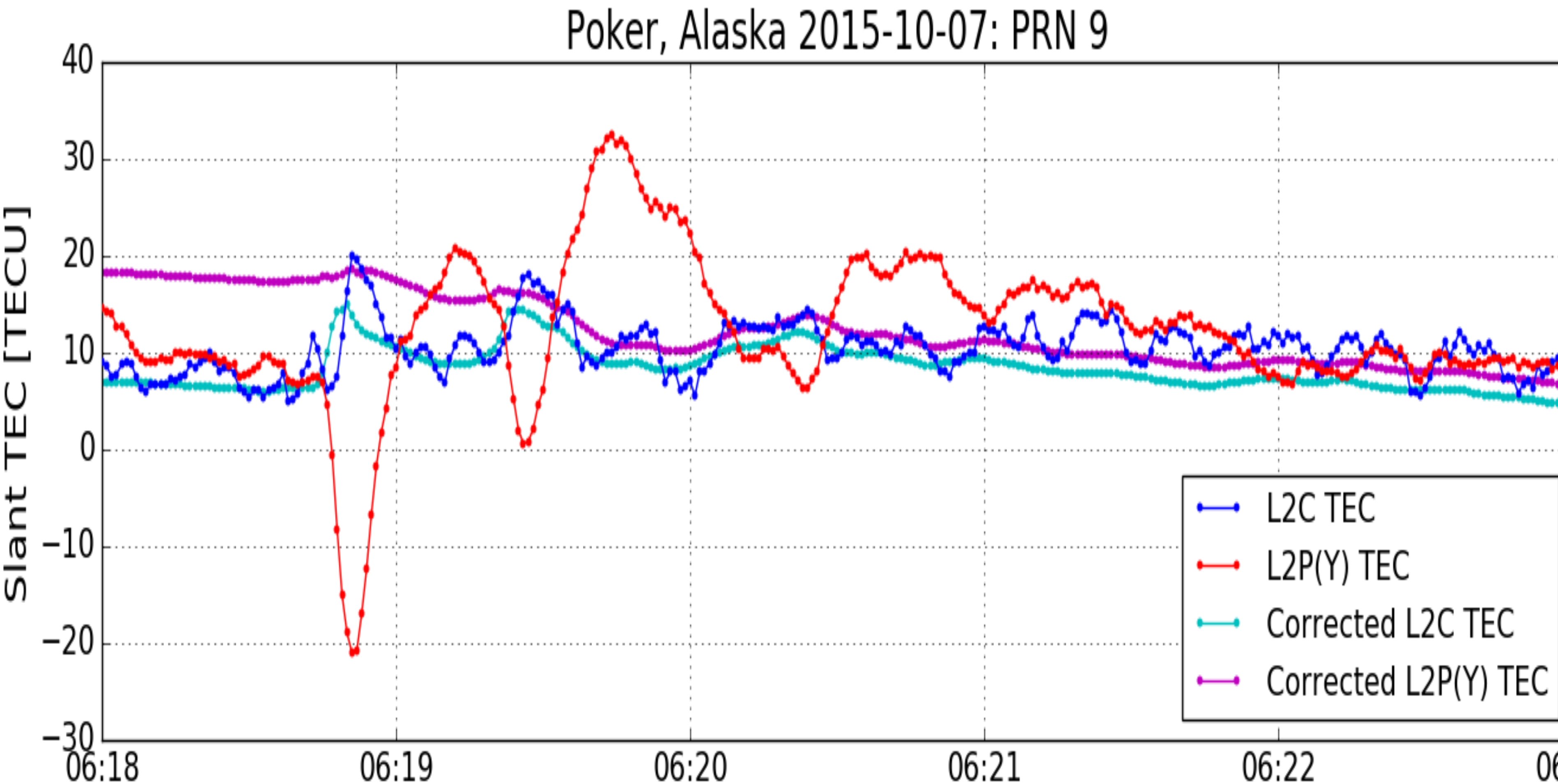
L2C: Civil signal. Only for satellites launched after 2005.

L2P: Protected signals. On all GPS satellites

- We do not have knowledge of its code modulation
- Lower signal power
- Carrier tracking is aided by L1 channel

TEC Calculation Across Auroral





Poker, Alaska 2015-10-07: PRN 9
Slant TEC [TECU]
40
30
20
10
0
−10
−20
−30
06:18
06:19
06:20
06:21
06:22
L2C TEC
L2P(Y) TEC
Corrected L2C TEC
Corrected L2P(Y) TEC

Conclusions

- Should try to use L2C whenever possible!
- Always correct multipath from pseudorange measurements!

But, Are we really computing TEC
using the conventional method?

Be careful
when interpreting your GPS receiver measurements