A review of recent advances in GNSS-MR

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Outline

- **SNR- based GNSS multipath reflectometry**
- **Forward/Inverse modeling**
  - Snow depth
  - Soil moisture
  - Sea level
- **Conclusions**

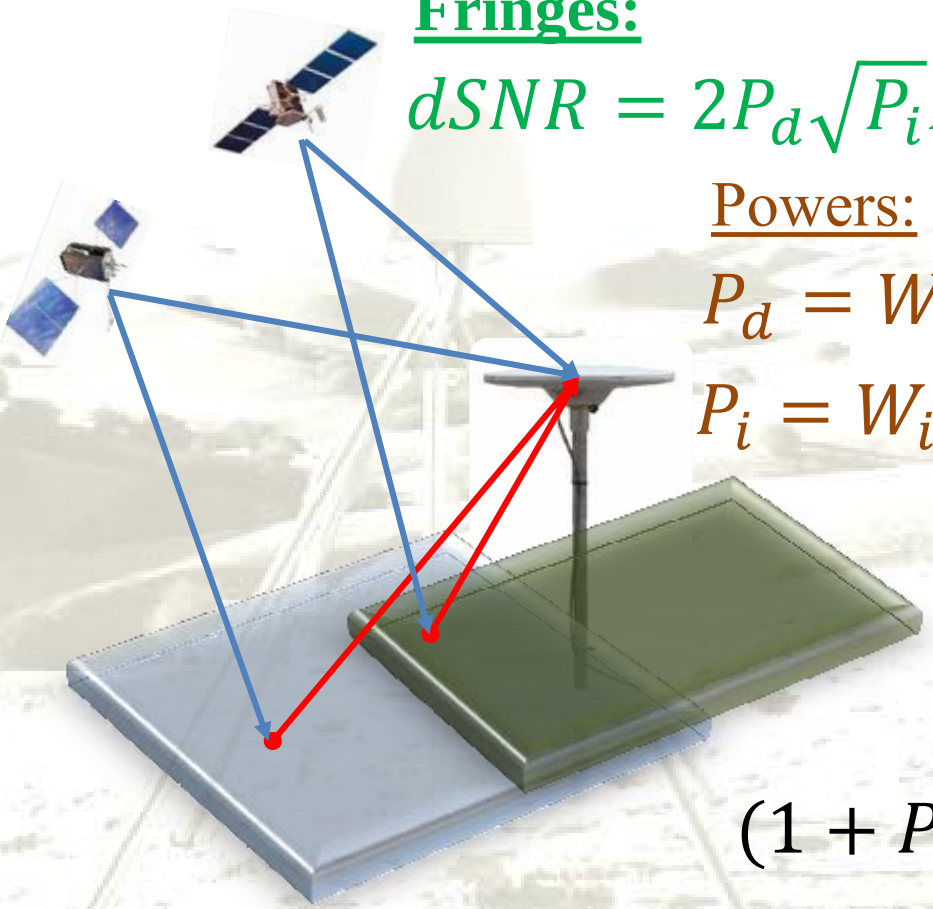
GNSS-MR:
GPS-MR & GLONASS-MR

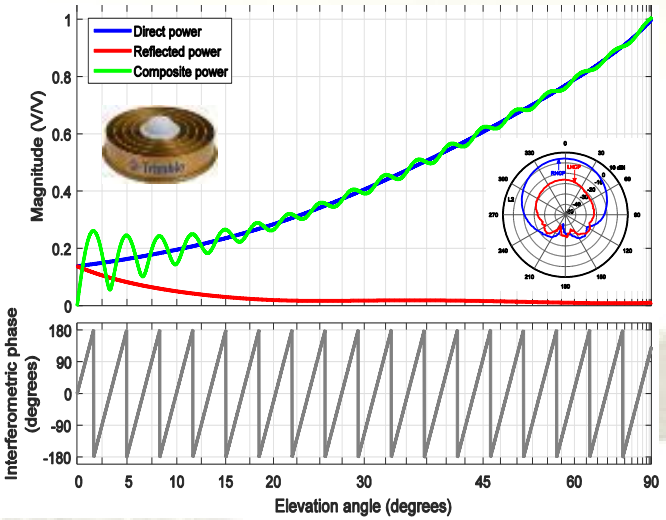
Trend:

$$tSNR = P_d(1 + P_i)P_n^{-1}$$

Fringes:

$$dSNR = 2P_d\sqrt{P_i}P_n^{-1}cos\phi_i$$





Powers:

$$P_d = W_d P_d^R G_d^R$$

$$P_i = W_i X^2 S^2 / G_d^R$$

Phase:

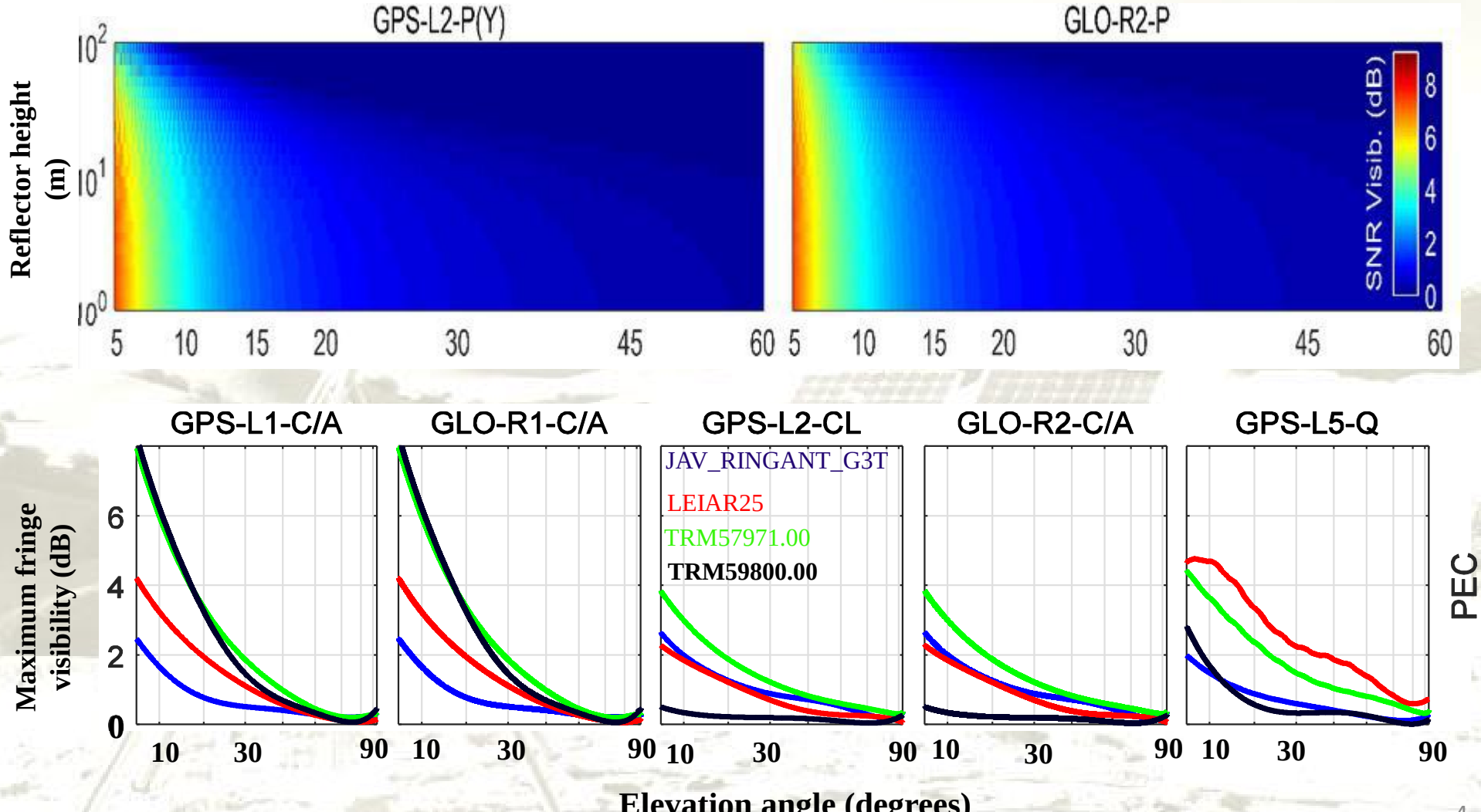
$$\phi_i = \phi_X + \phi_I - \Phi_d^R$$

$$SNR = P_d P_n^{-1} K^{-2}$$

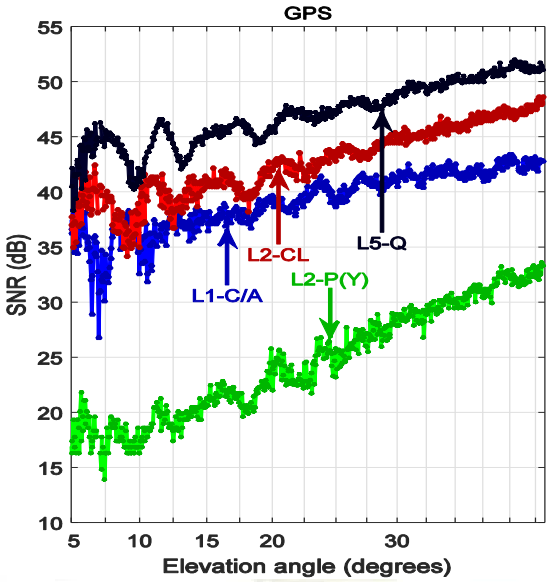
$$(1 + P_i B^{-2} + 2\sqrt{P_i}|B|^{-1}\cos\phi_i)$$

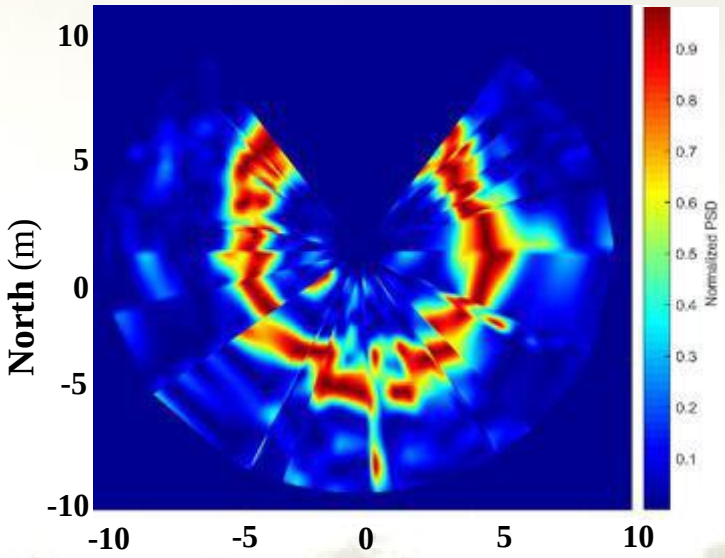
Fringe visibility

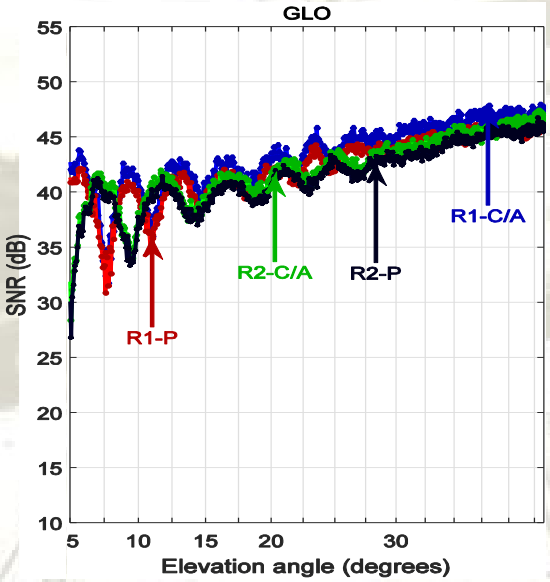
$$vSNR_{dB} = (1 + \frac{dSNR}{tSNR})_{dB}$$

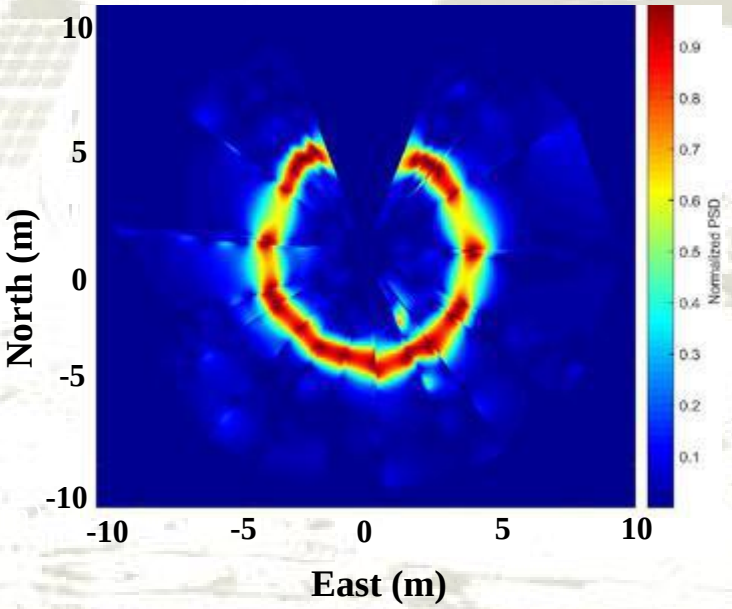


SNR observations



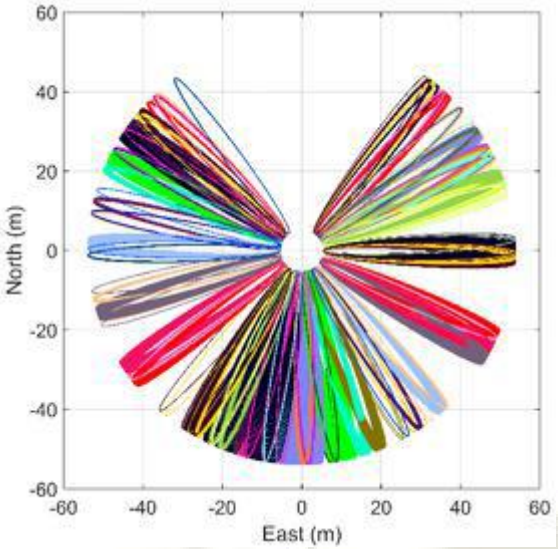


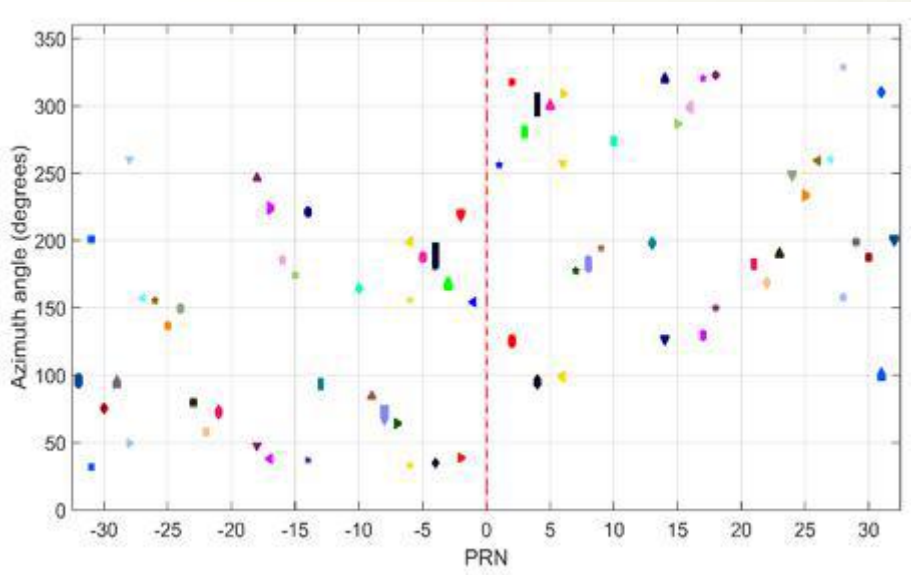




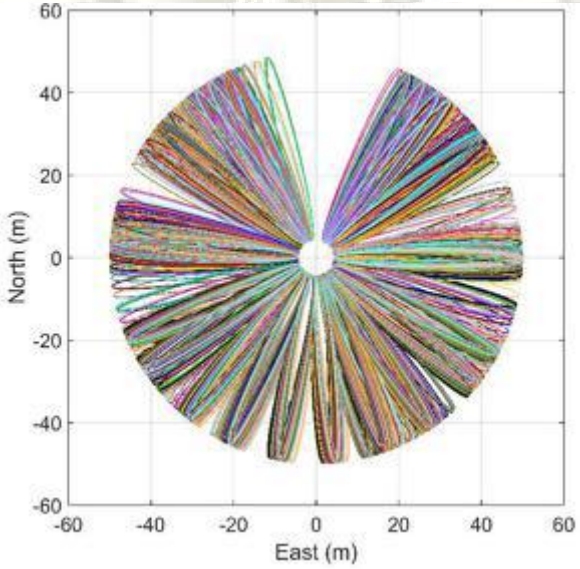
Track clustering

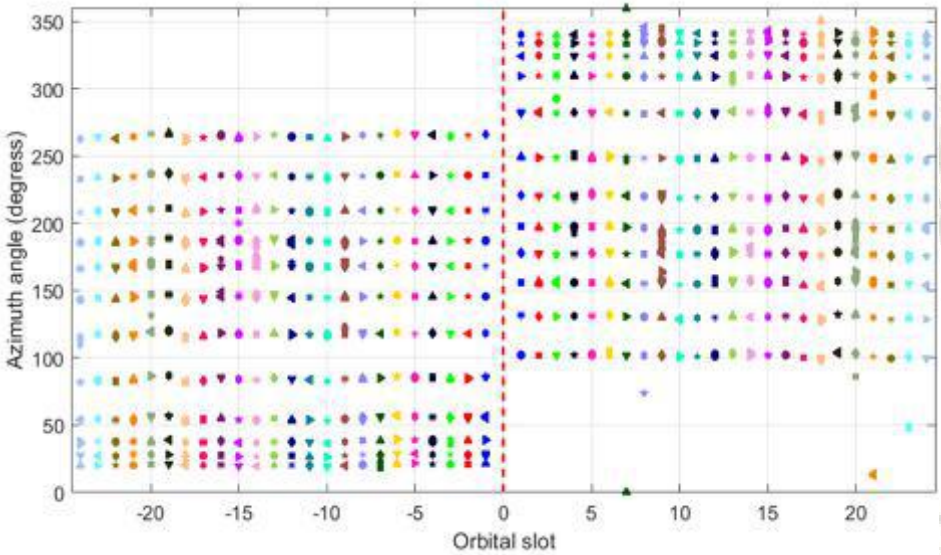
GPS



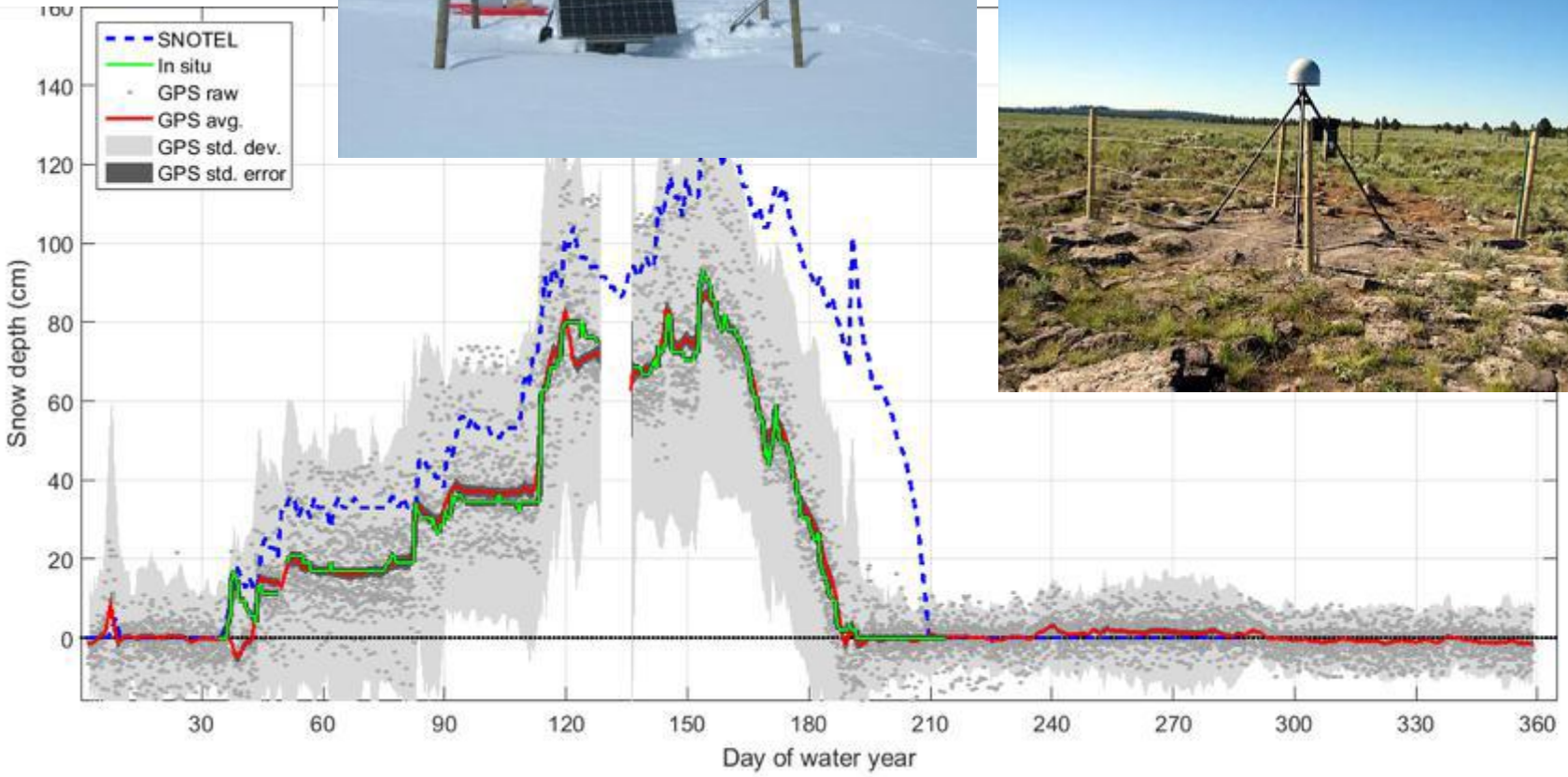


GLONASS

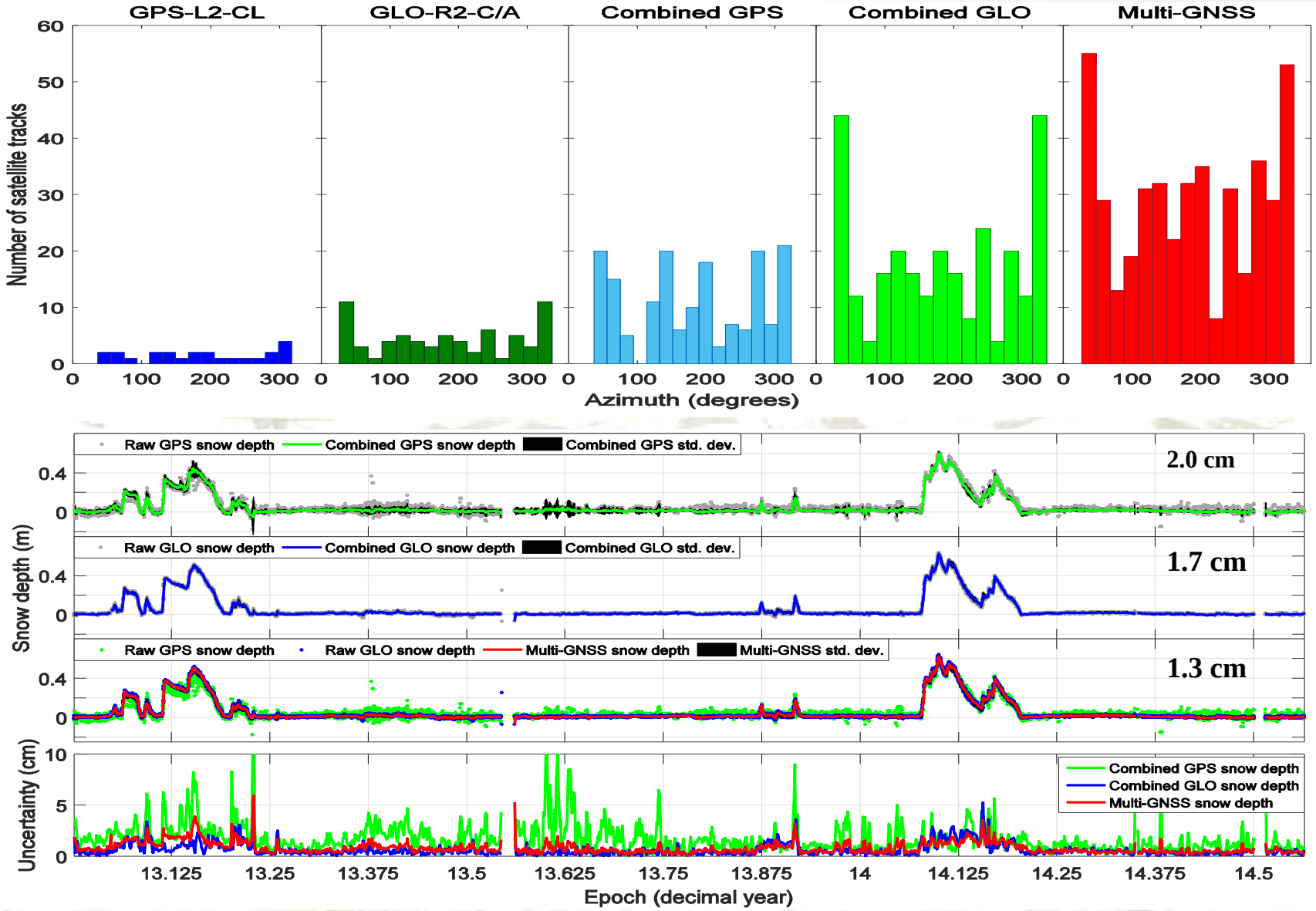




Signal-specific snow depth

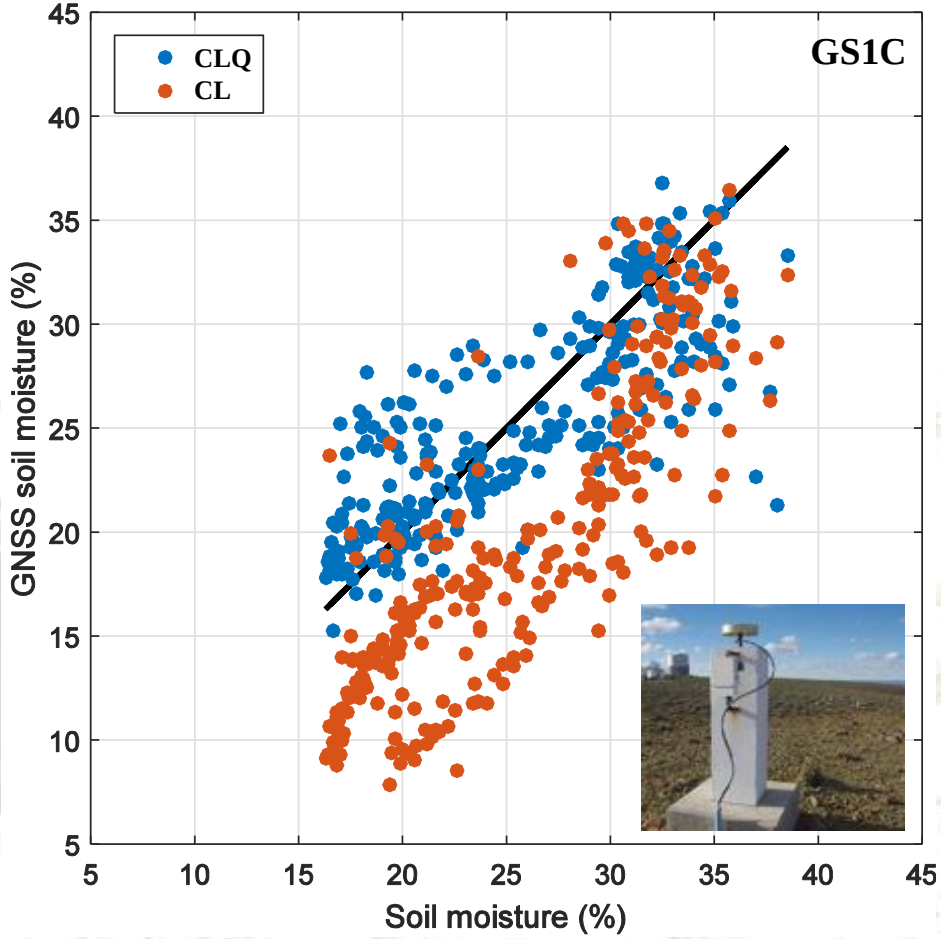


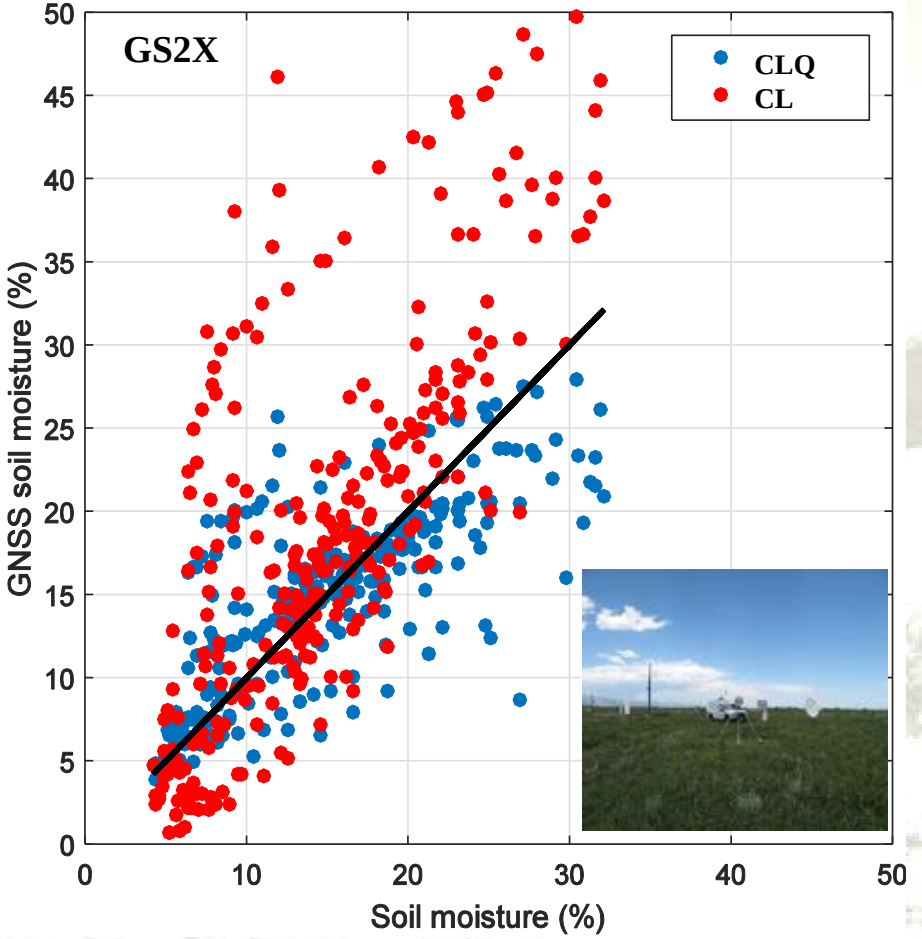
Multi-GNSS combined retrieval



GNSS-MR for soil moisture

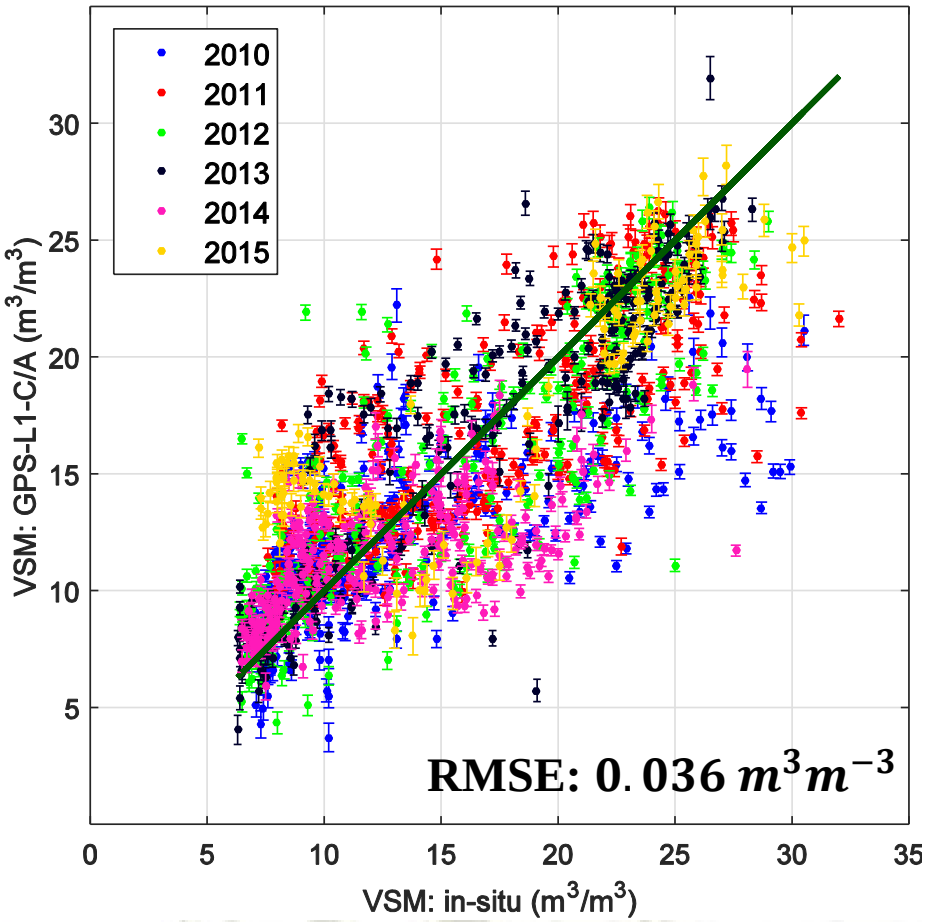
$$\phi_i = \phi_0 + \phi_1 \sin e + \phi_2 \sin^2 e$$



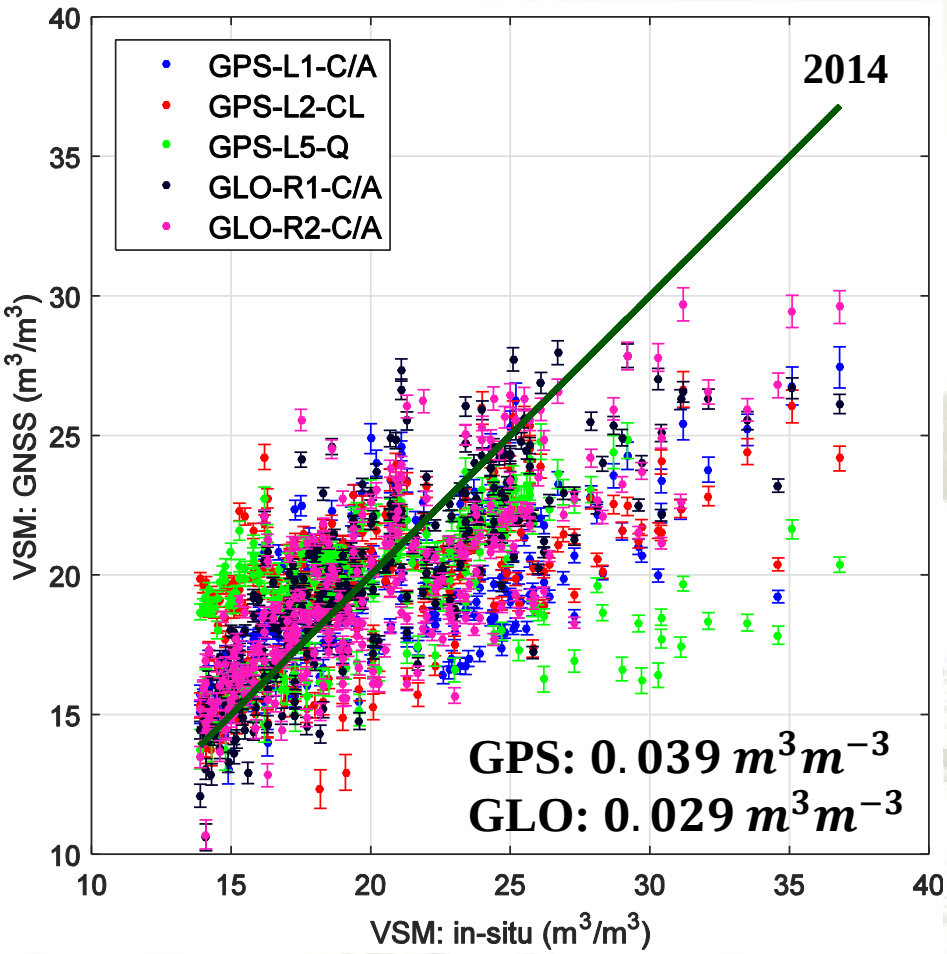


GNSS-MR for soil moisture

Horizontal



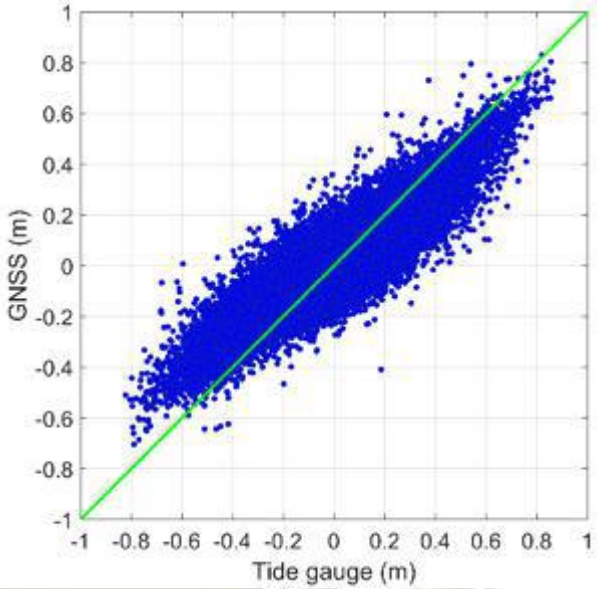
Vertical



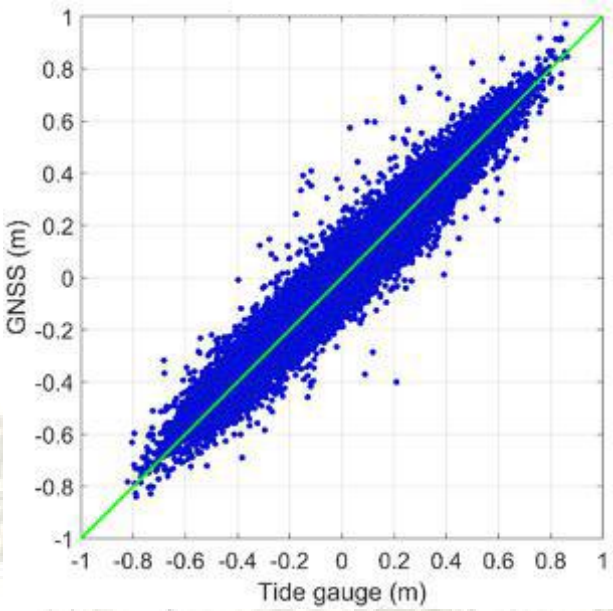
GNSS-MR for sea level monitoring

$$d\phi_i/dk_z = H + k_z \underbrace{dH\ /\ (dk_z)}_{(\dot{H}+\ddot{H}\Delta t)\tan e/\dot{e}}$$

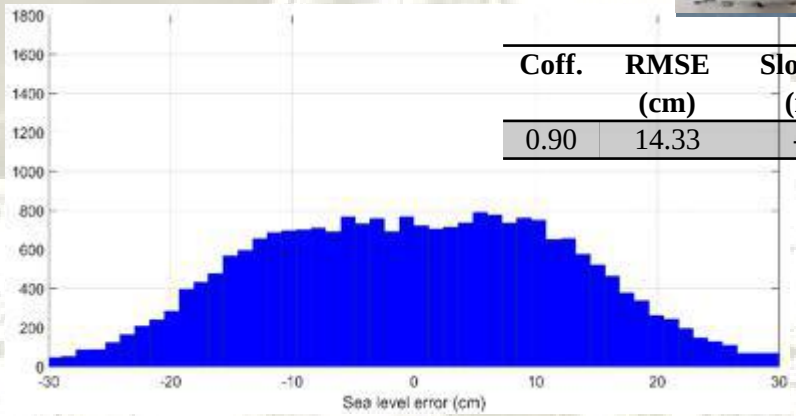
Basic



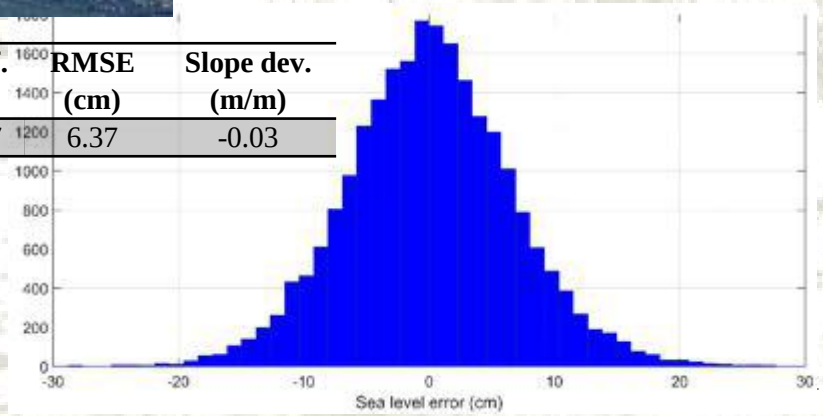
EDM



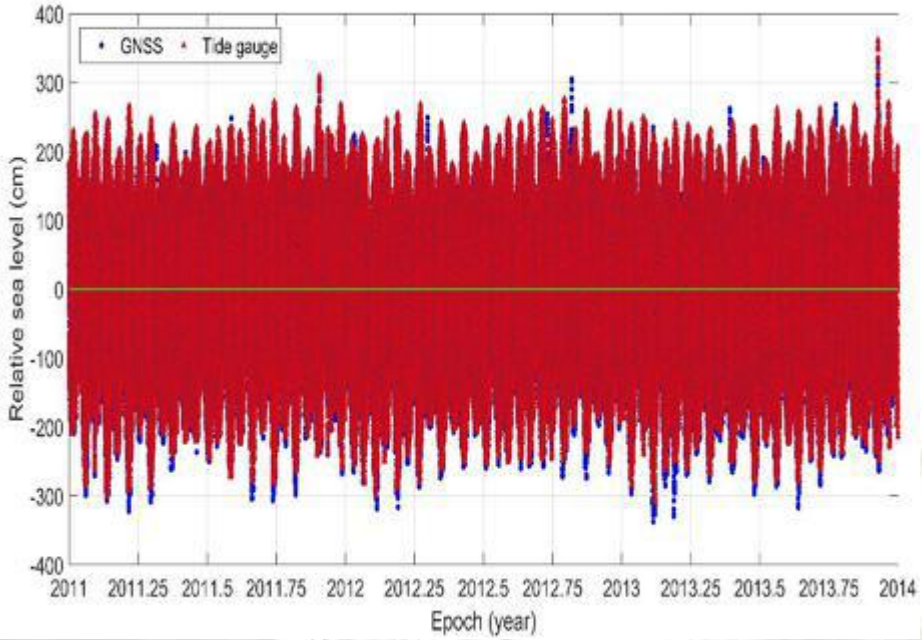
Coff.	RMSE (cm)	Slope dev. (m/m)
0.90	14.33	-0.26

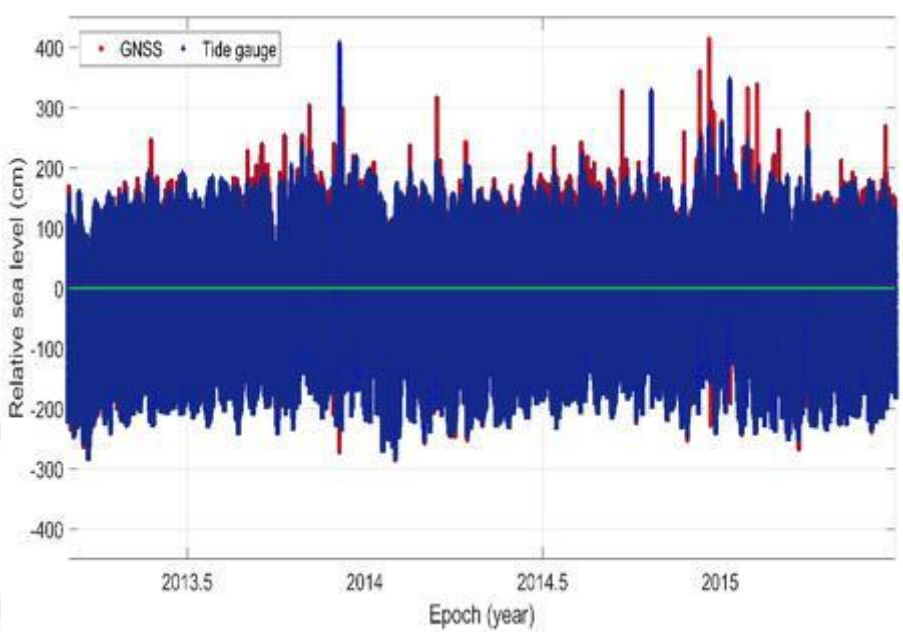


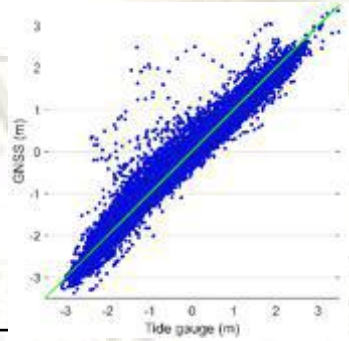
Coff.	RMSE (cm)	Slope dev. (m/m)
0.97	6.37	-0.03



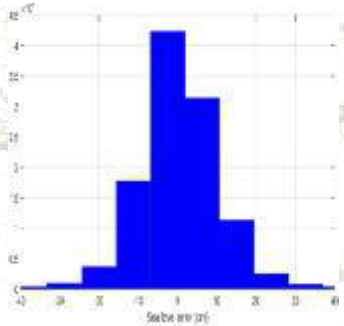
GNSS-MR for sea level monitoring





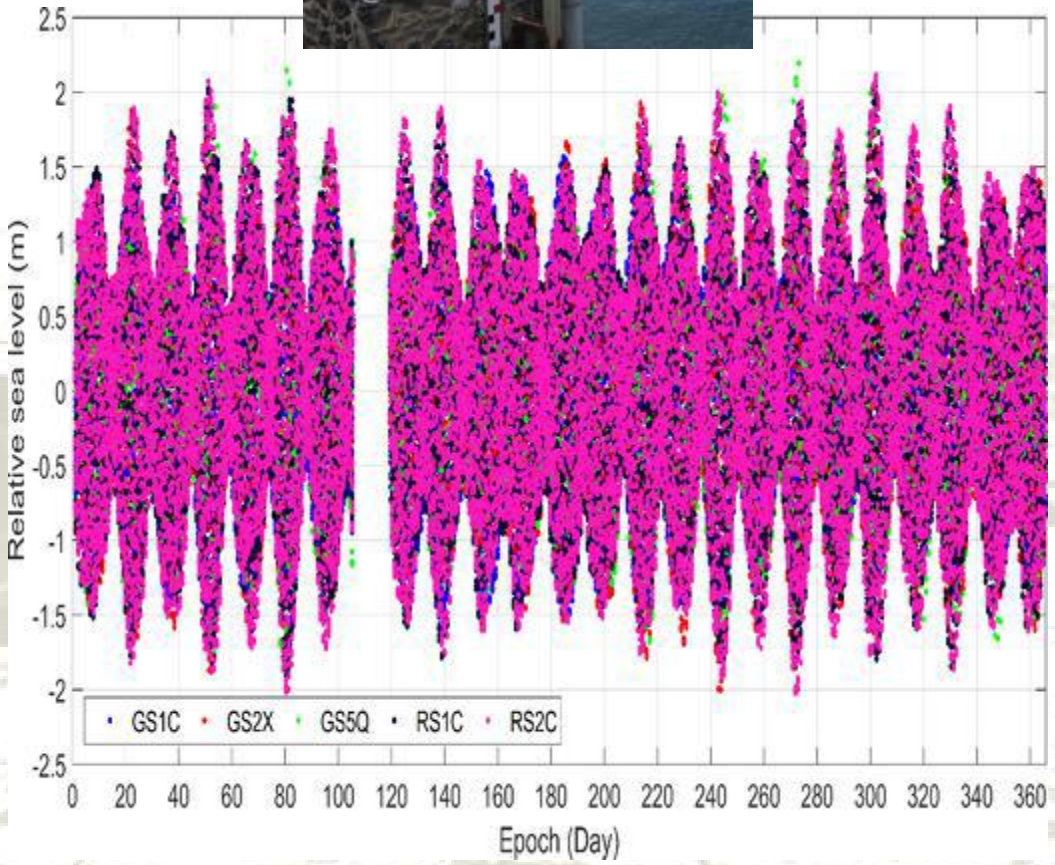


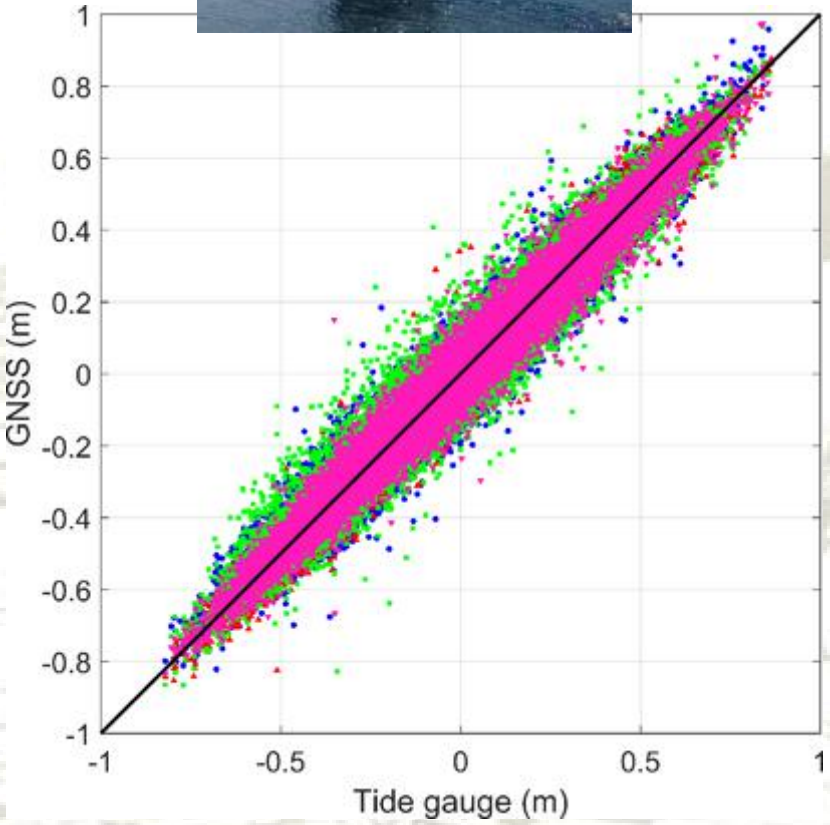
Coff.	RMSE (cm)	Slope dev. (m/m)
0.99	9.69	-0.02



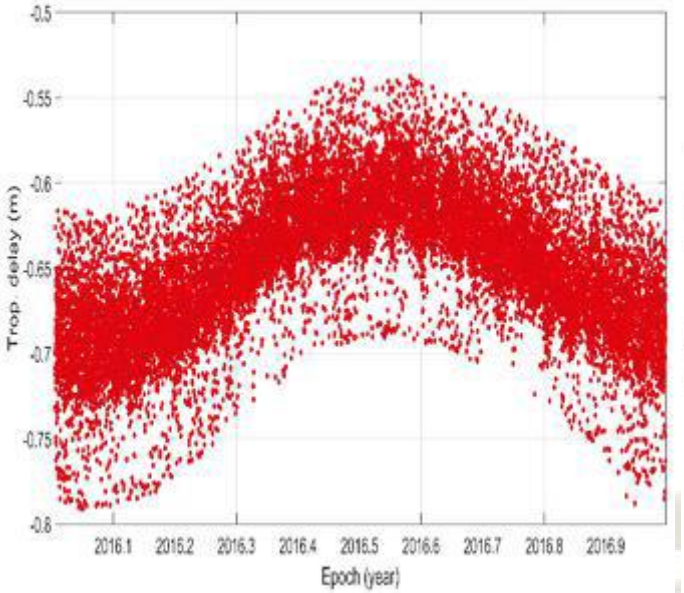
Coff.	RMSE (cm)	Slope dev. (m/m)
0.98	8.99	-0.03

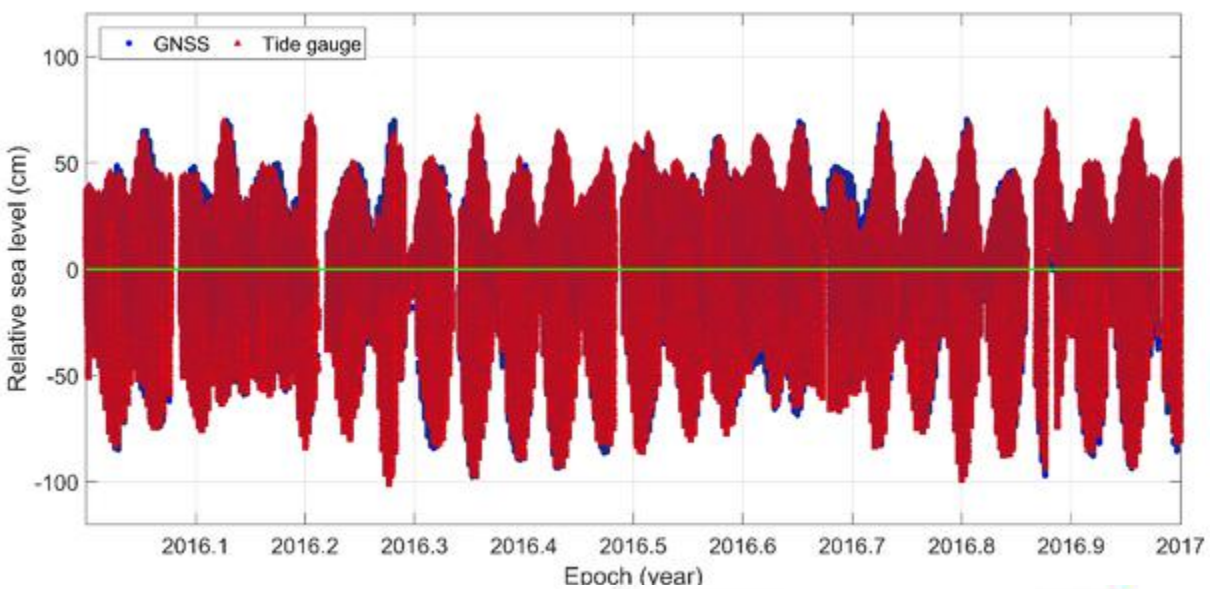
GNSS retrieval consistency

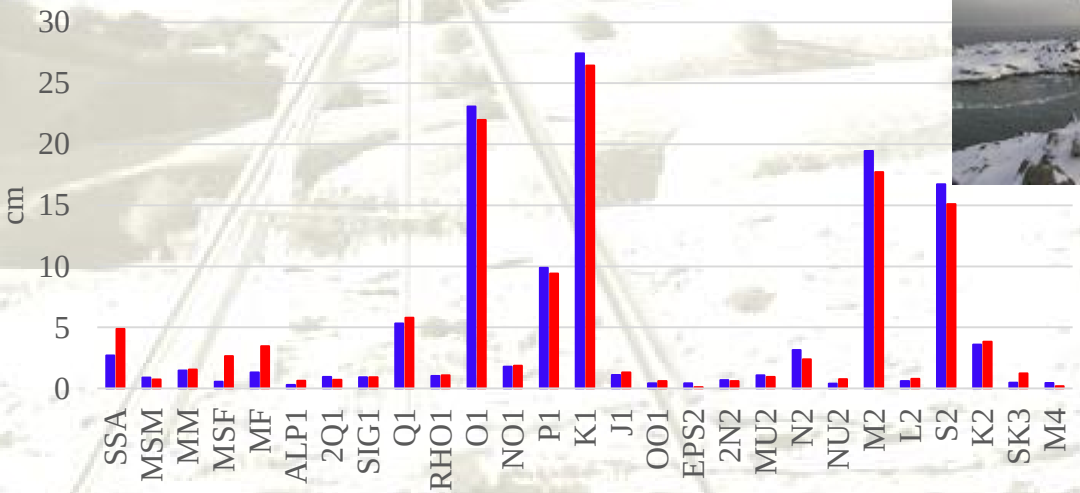


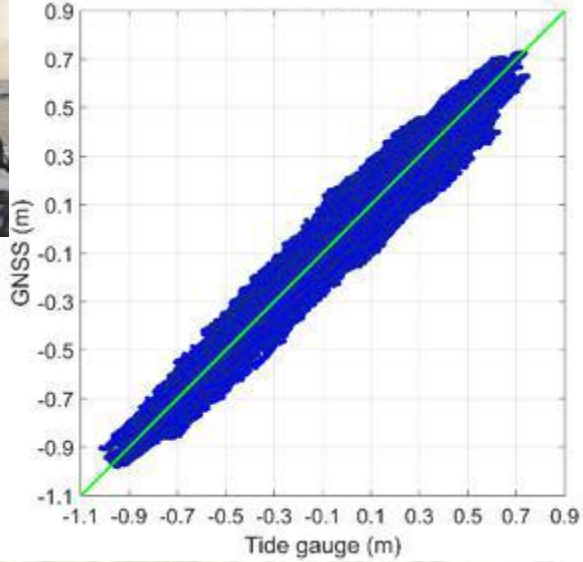


POLENET sea level

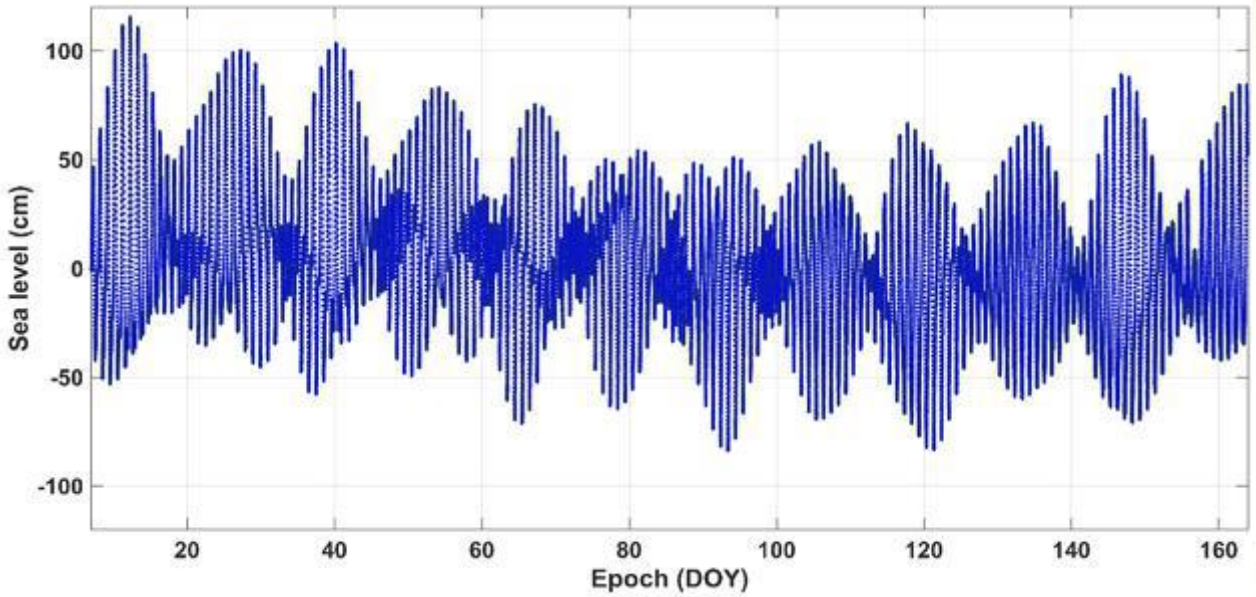


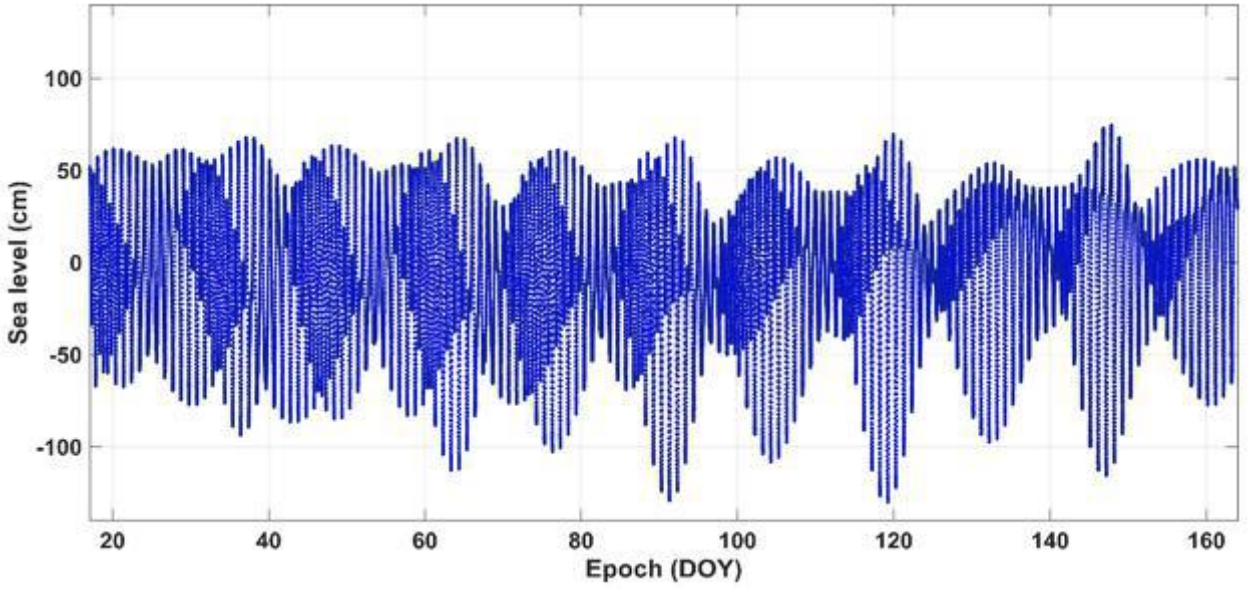






POLENET sea level





Conclusions

- **GLONASS and GPS retrievals agree well**
  - After GPS legacy filtering/pre-processing
- **Need to estimate steps due to equipment changes**
  - Antenna, receiver, and firmware!
- **GLONASS channel wavelengths with 1 mm**
  - Does not harm reflector height
  - Does not harm phase biases
- **Snow depth: negligible inter-frequency and inter-code biases**

- **Soil moisture: significant inter-frequency, inter-system, and inter-antenna biases**
  - Respective model for each signal-antenna combination
- **Sea level: very high correlation and centimeter-level error**

- **Multi-GNSS combination is more precise**

- **<u>Extend IGS site guidelines: make GNSS sites more useful for GNSS-MR</u>**

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