ETH zürich

# Characteristics and Limitations of GPS L1 Observations from Submerged Antennas

Ladina Steiner, Michael Meindl and Alain Geiger

IGP
Institut für Geodäsie und Photogrammetrie

# Motivation

- Extensive amount of water stored in snow covers has a high impact on flood development during snow melting periods
- Early assessment of the water storage in mountain environments enhances early warning and prevents major impacts
- GNSS is affordable, flexible, and provides accurate and continuous observations independent on weather conditions

→ What is the potential and the limitations of submerged GPS antennas for the quantification of stored water content in snow covers?

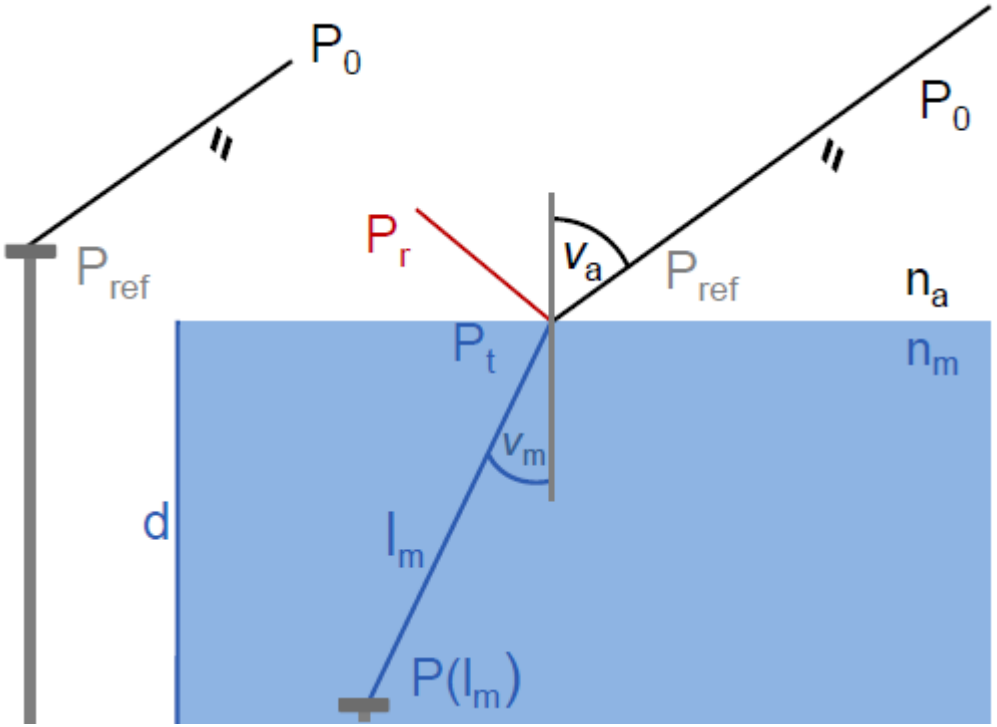
→ Analysis of

- signal penetration depth
- attenuation of signal strength
- quality of solutions

# Theoretical Signal Propagation in Snow, Ice, or Water

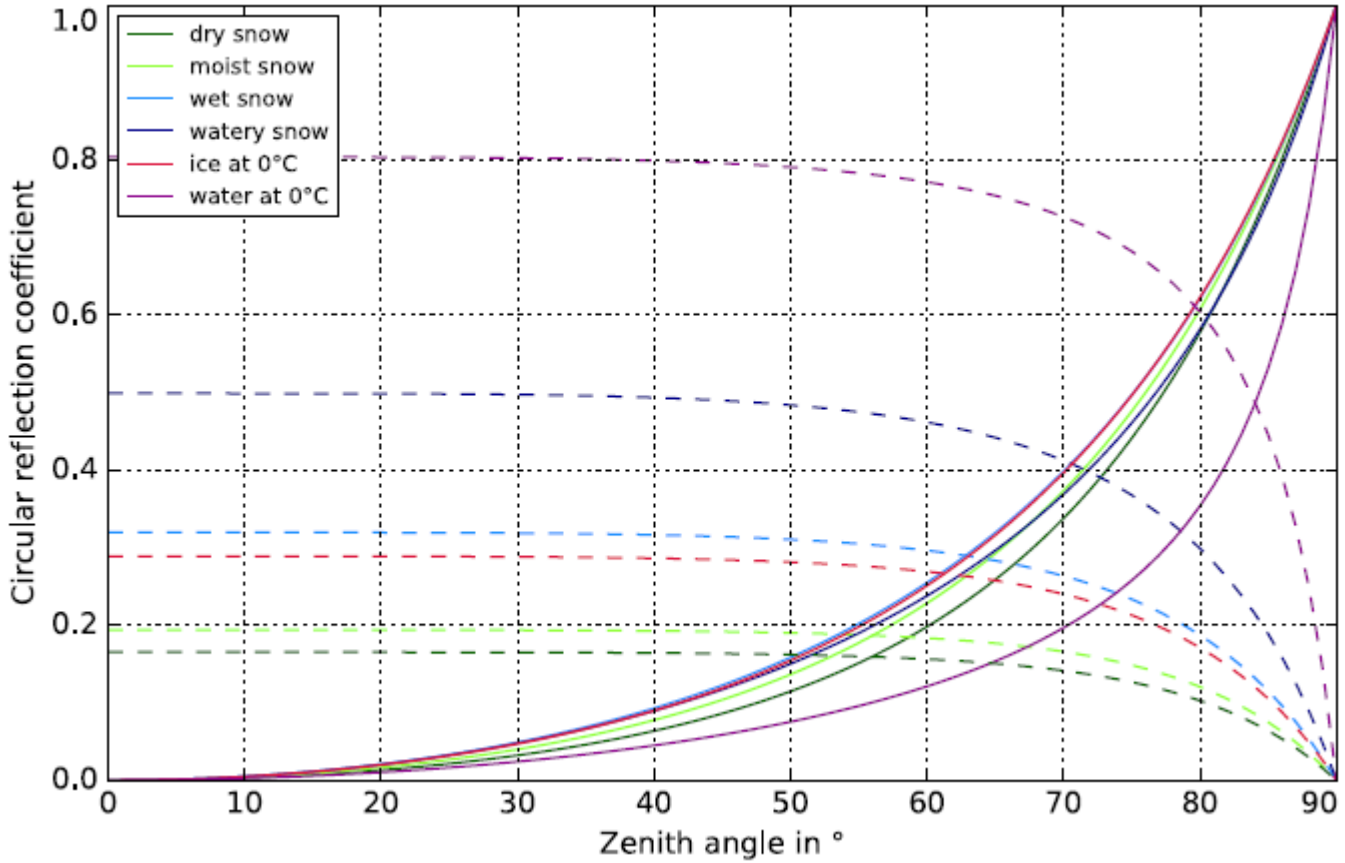
- Overview of GPS L1 signal propagation:
  - Reflection
  - Transmission
  - Refraction
  - Attenuation

High dependence on snow wetness and the incident angle

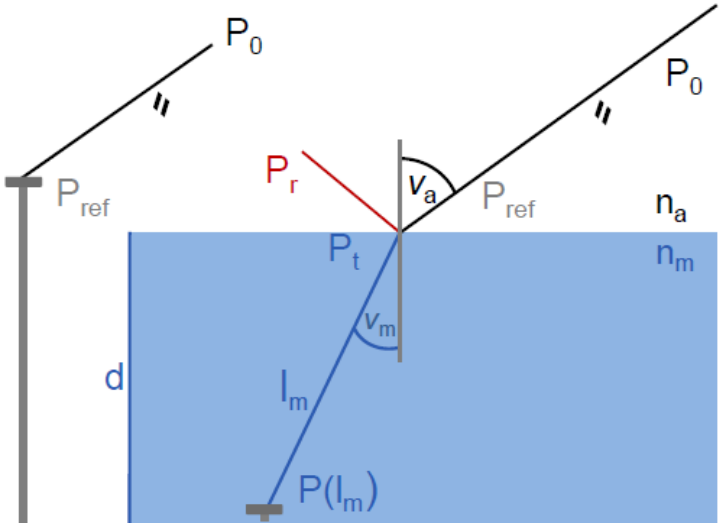


# Theoretical Signal Propagation in Snow, Ice, or Water

- Reflection

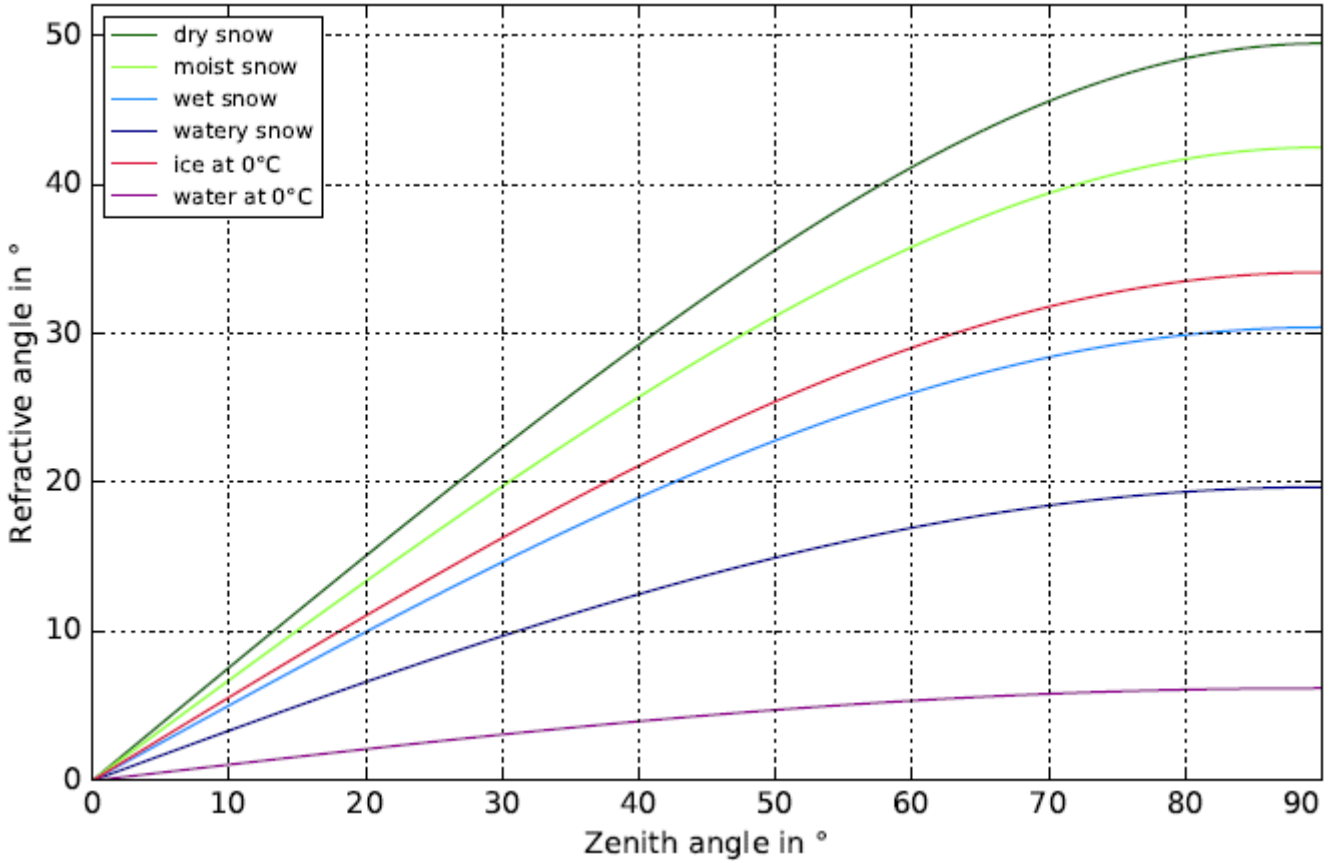



- Water reflects the most
- Dry snow least
- Ice behaves between moist and wet snow

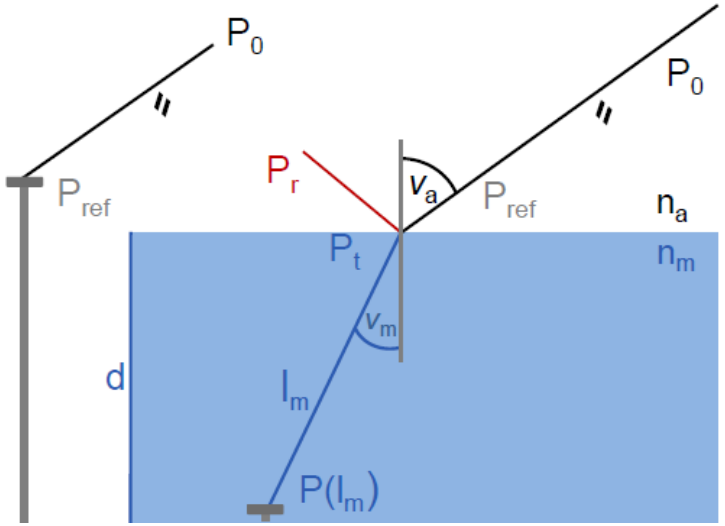


# Theoretical Signal Propagation in Snow, Ice, or Water

- Refraction

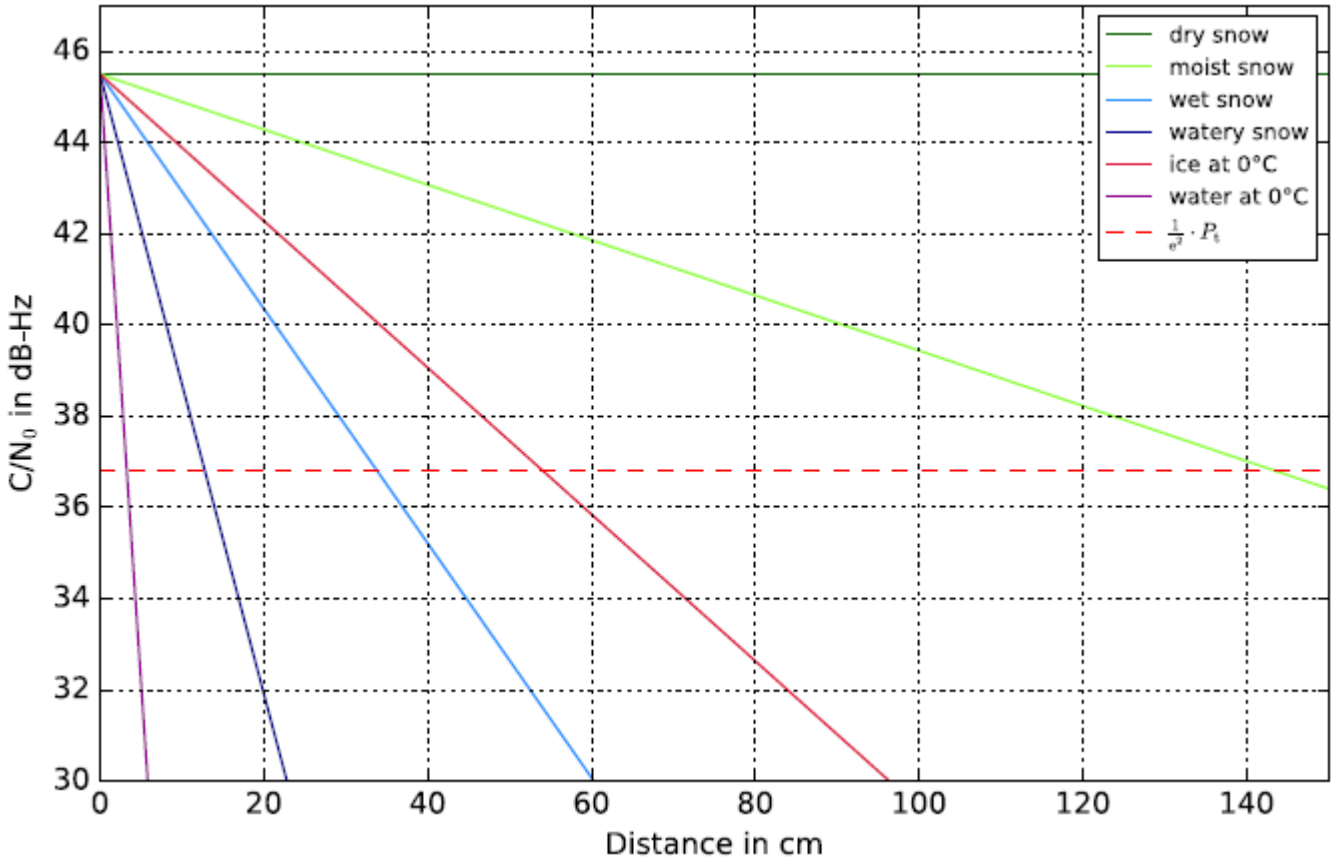



- Water refracts strongest
- Dry snow least
- Ice behaves between moist and wet snow

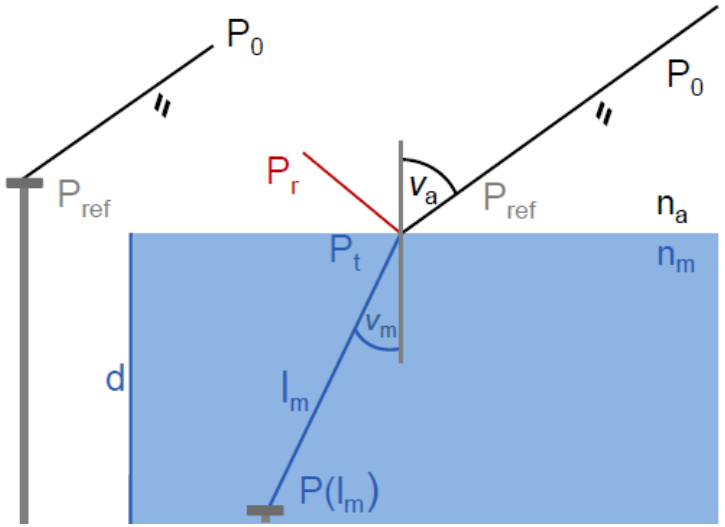


# Theoretical Signal Propagation in Snow, Ice, or Water

- Attenuation

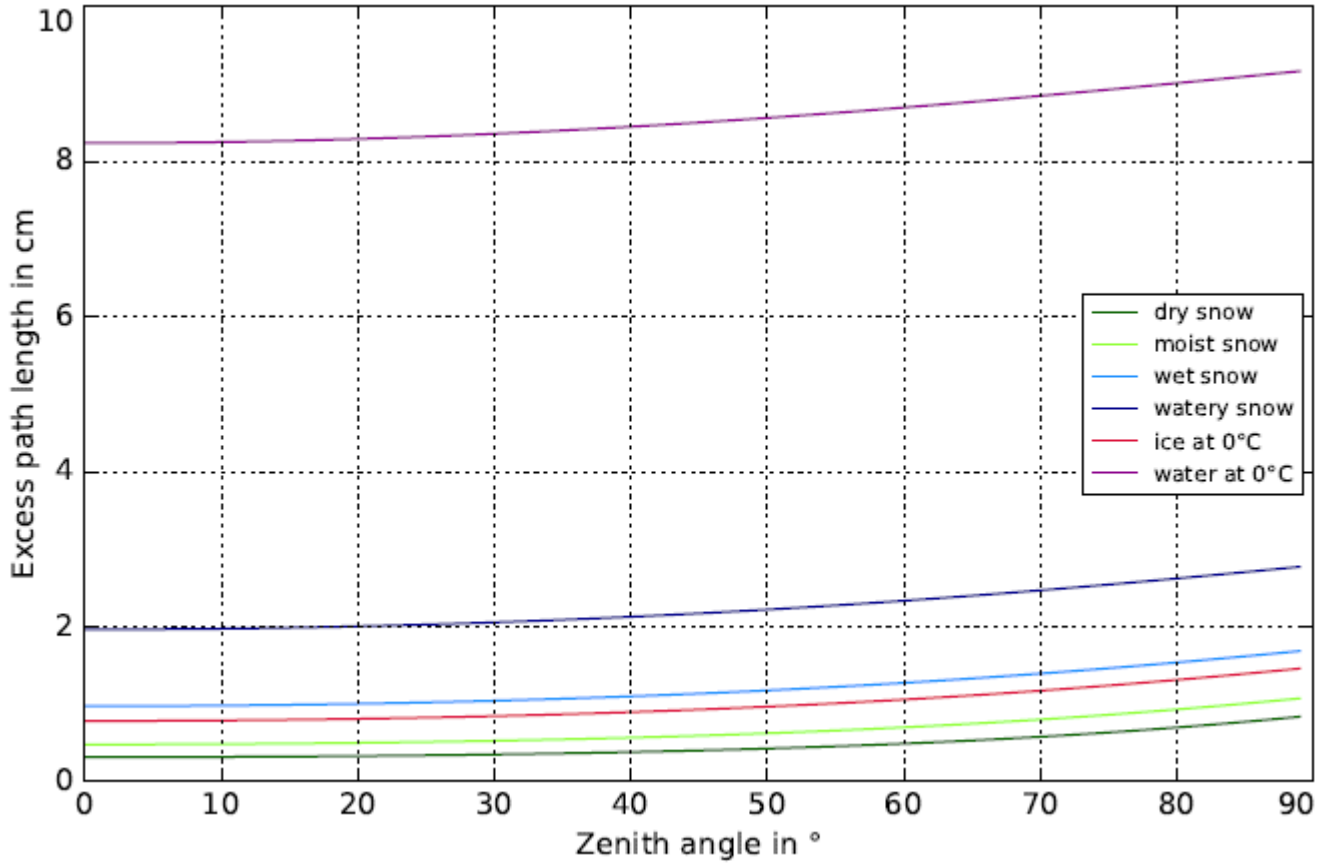



- Water attenuates the most
- Dry snow least
- Ice behaves between moist and wet snow

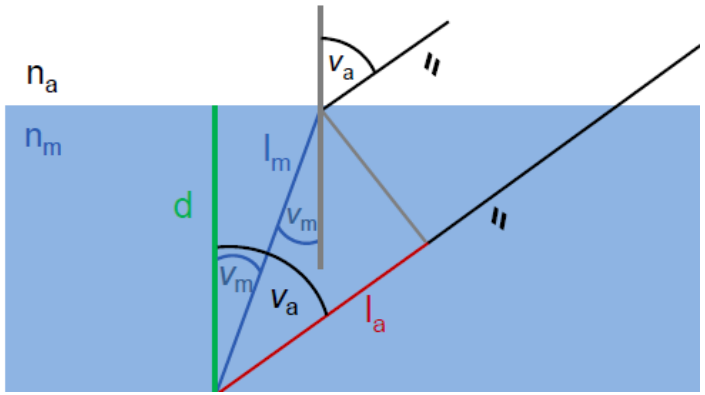


# Theoretical Signal Propagation in Snow, Ice, or Water

- Excess path




- Water delays strongest
- Dry snow least
- Ice behaves between moist and wet snow

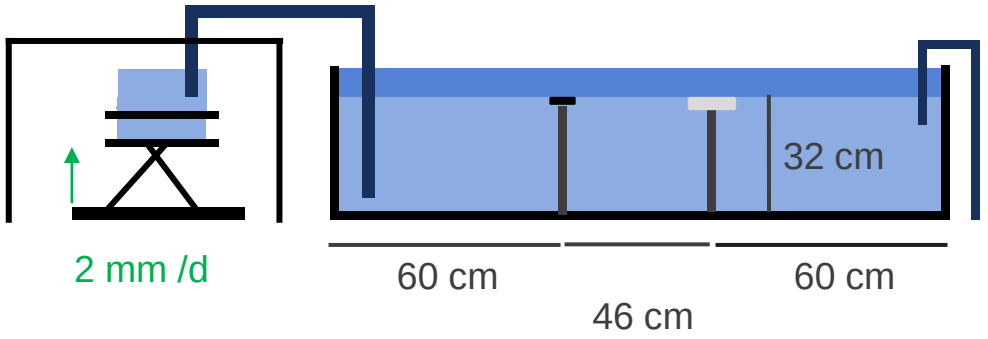


# Theoretical Signal Propagation - Conclusions

- Water is the most critical parameter in snow cover for GNSS observations
  - Highest reflection, refraction, and attenuation
  - Longest path extension when propagating through water
  - Non matching antenna impedance to water environment

- Set-up an experiment to investigate GPS L1 signal propagation in water
  - ➡ Find a model to correct excess path length
  - ➡ Effect on height estimation
  - ➡ Estimate water depth

# Experimental Set-Up




Box with Leica GR10 receiver and u-blox EVK 6

Connecting pipes

Levelled reference basin

Animals

Water level sensor (0.1 mm accuracy)

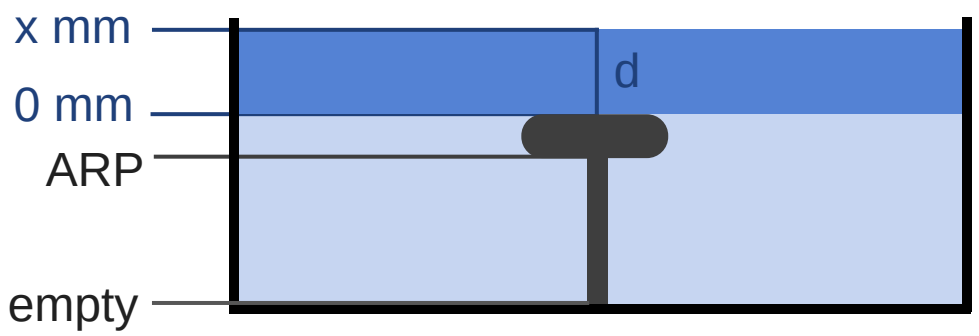
Low-cost antenna (u-blox)

Geodetic antenna (Leica AS10)

# Experimental Set-Up

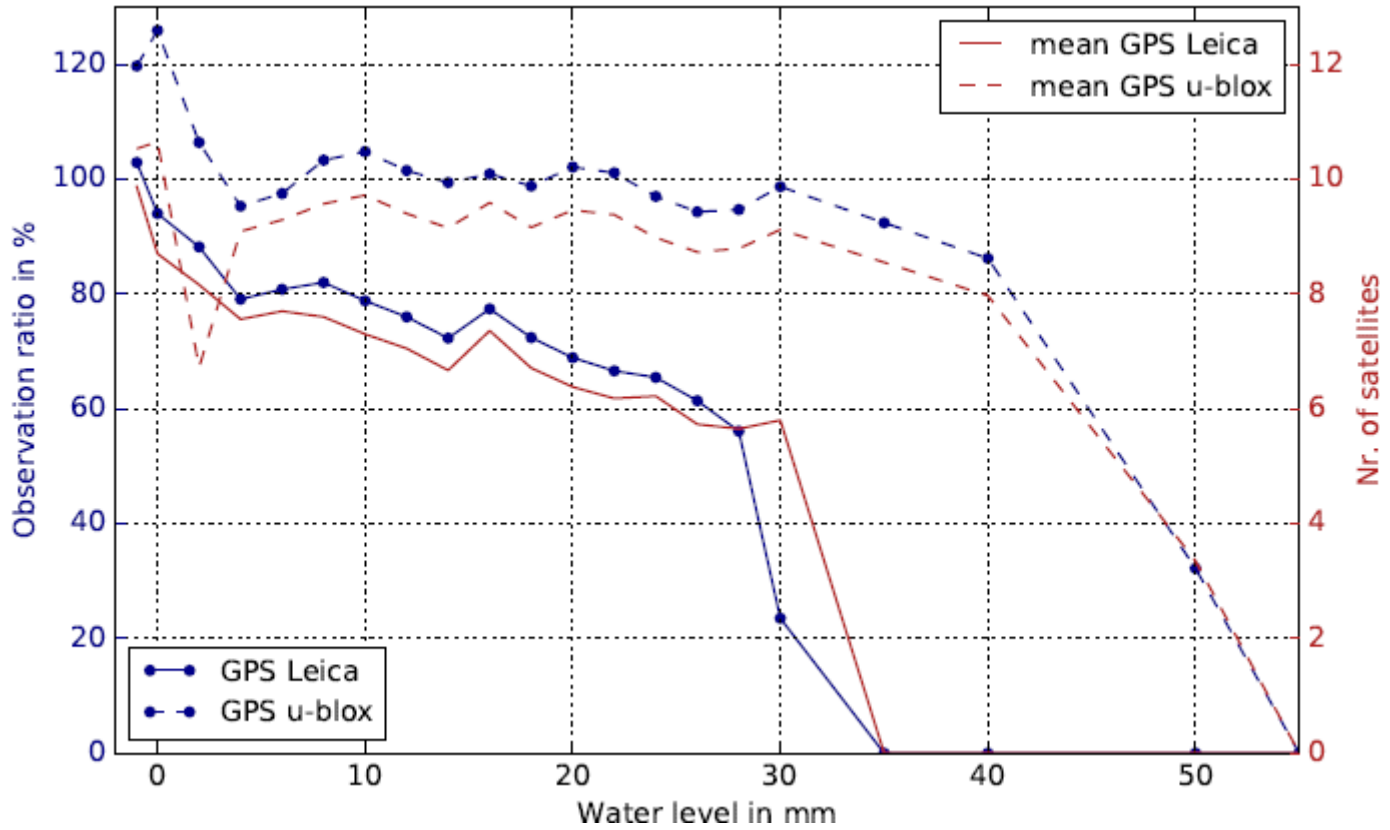
- Empty basin as reference: combined solution from 7 days
- Water level at ARP
- Water level = 0: water until top of antenna
- Increase of 2 mm up to 30 mm water over antenna

- 3 reference stations with 5 - 10 m baselines
- In total: 2 month of observation period



# Results of Experimental GPS L1 Double Differences

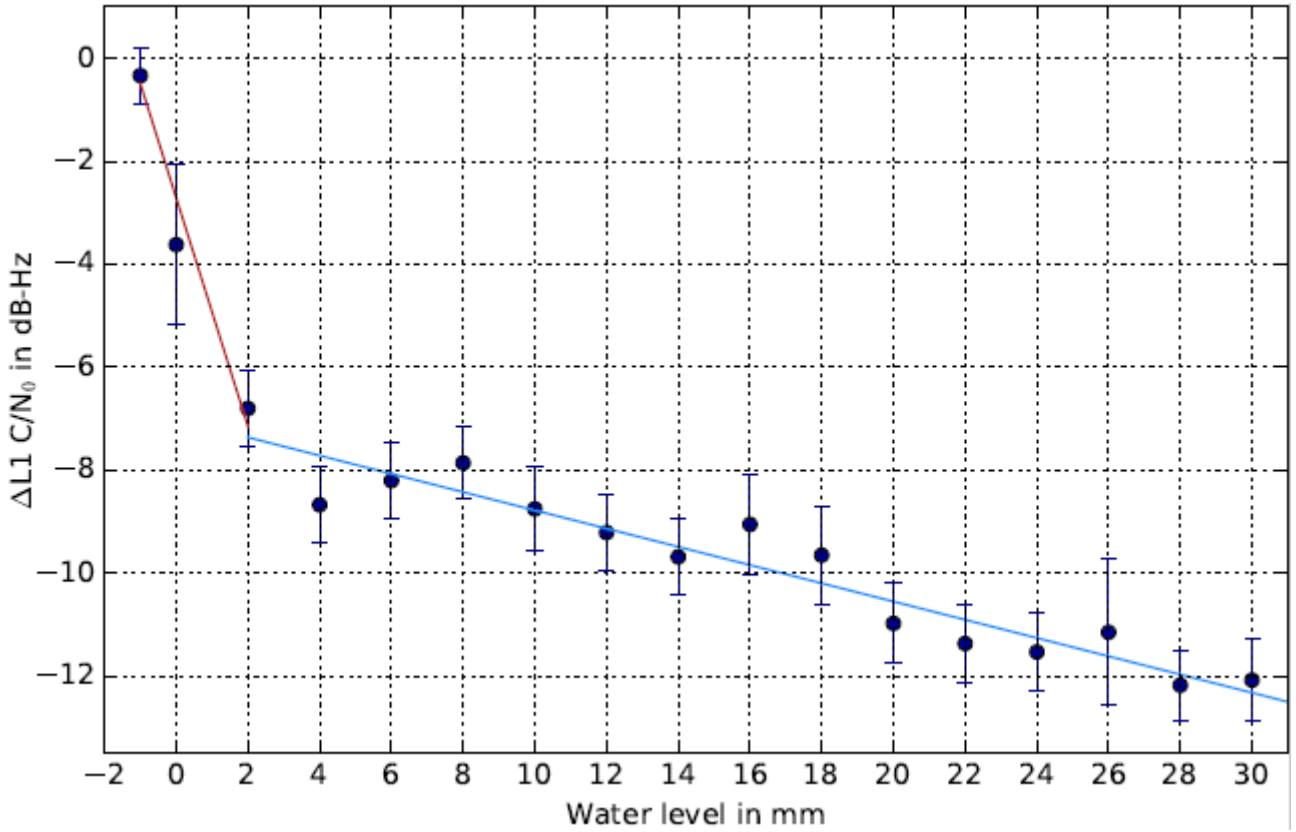
- Tracking performance




- Signals are tracked until 30 and 50 mm of water above the submerged antenna
- Low-cost receiver tracks generally more and longer than the submerged geodetic system

# Results of Experimental GPS L1 Double Differences

- Attenuation of signal strength



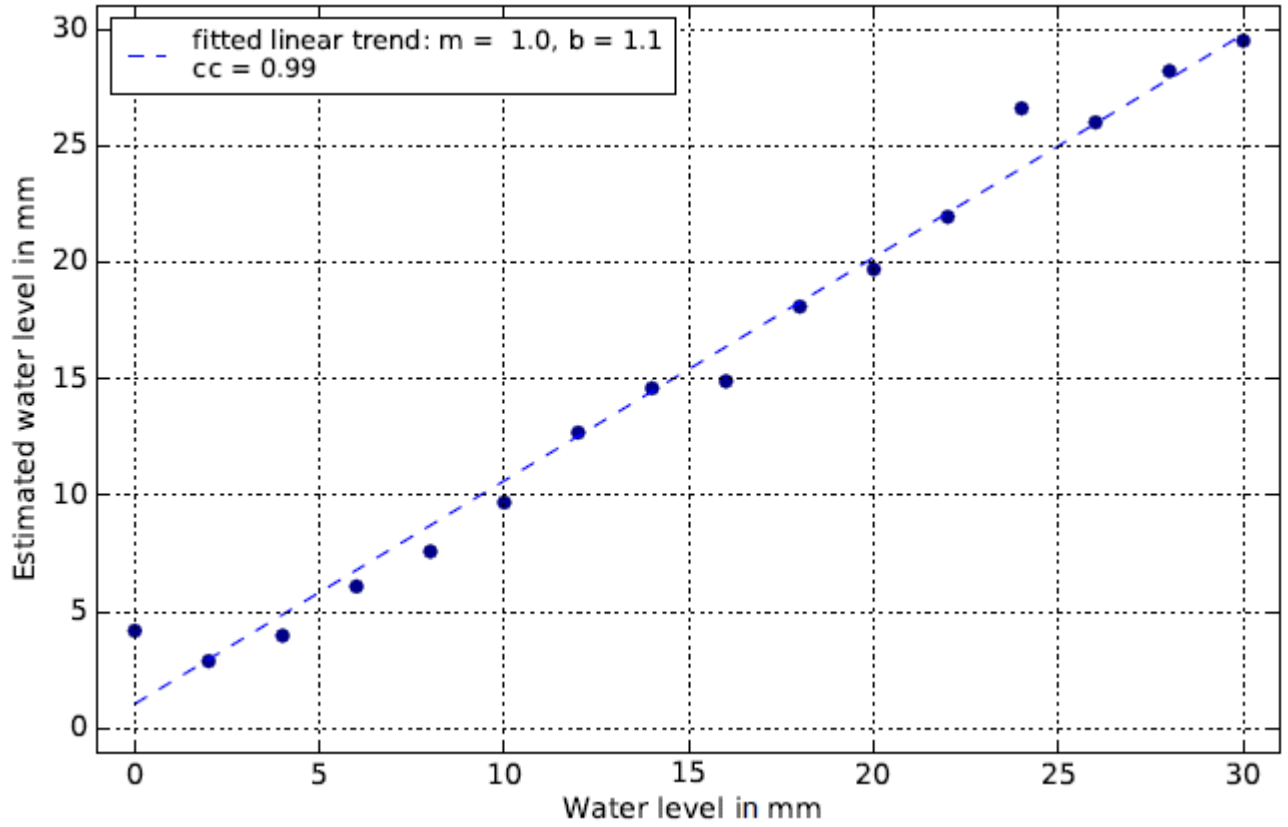

**Fit log attenuation function:**

$$\Delta C/N_0\,(z) = \log_{10}(1 - r_{\mathrm{co}}) - 2\alpha z * \log_{10}\mathrm{e}$$

Strong depletion in the $\Delta C/N_0$ by changing the antenna environment from air to water and linear decrease with increasing water level

# Results of Experimental GPS L1 Double Differences

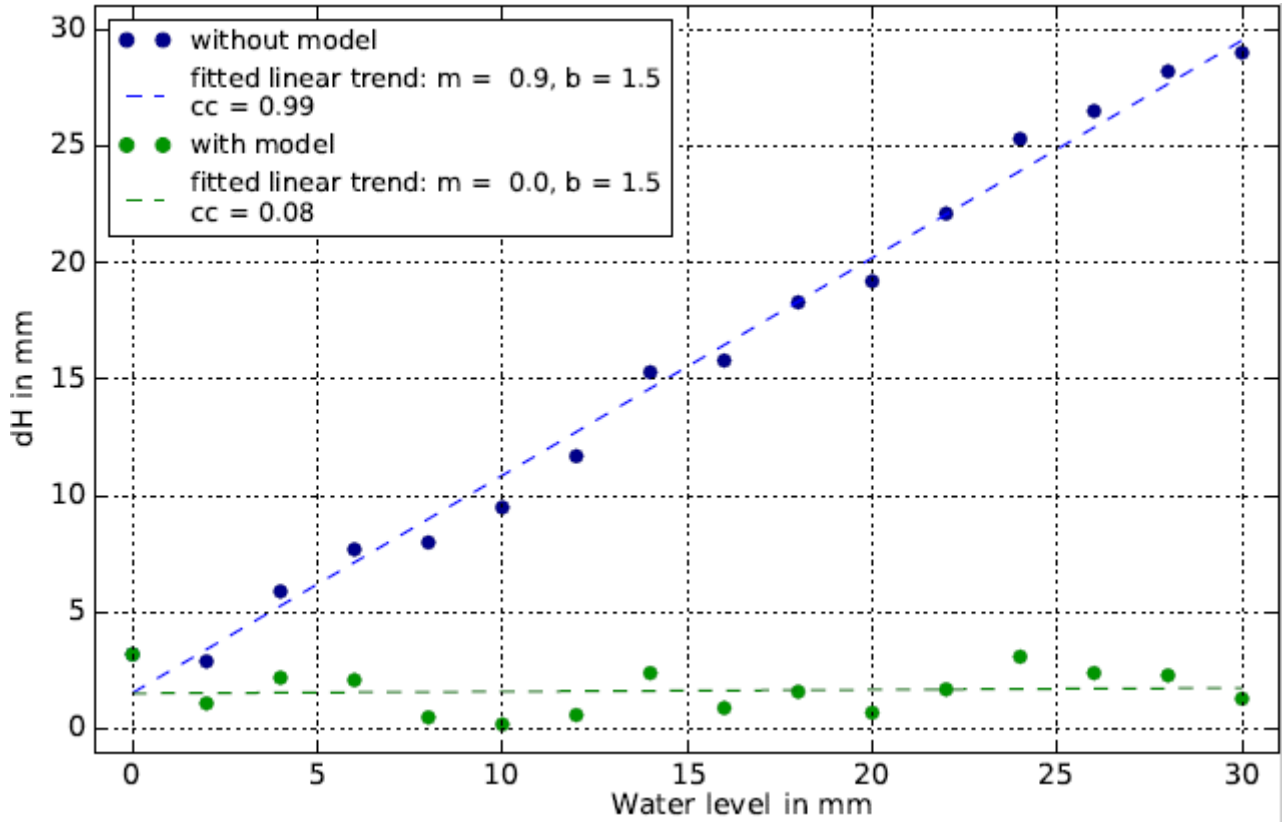
- Water depth estimation




Model is able to estimate water depth above submerged antenna with high correlation: cc = 0.99

# Results of Experimental GPS L1 Double Differences

- Height solution




Influence of water above the antenna affects directly the height component

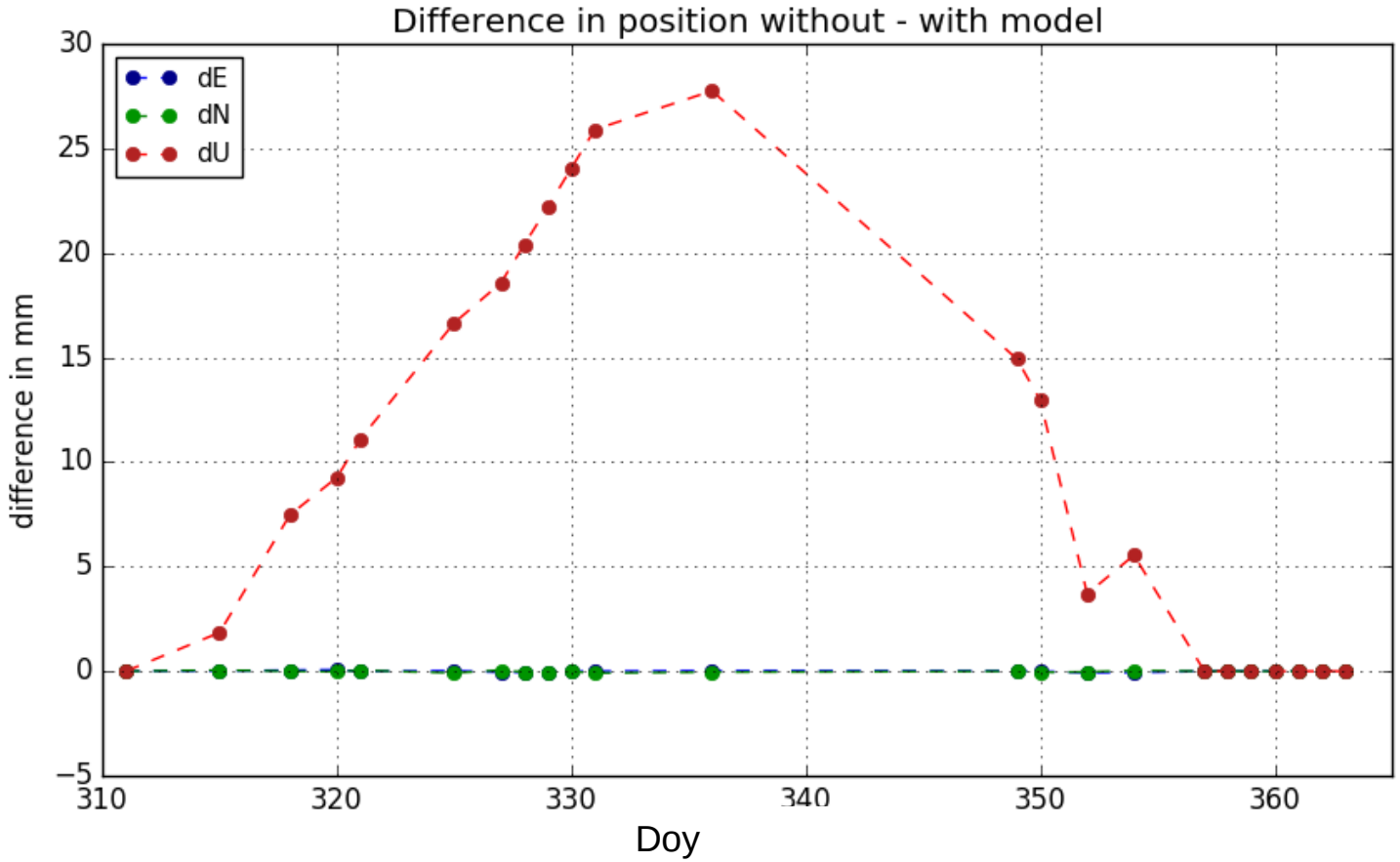
When model is applied, influence is corrected 100%

# Conclusions

- Water is the main limiting factor in sub-snow GPS observations
- Theory and experiment agree within measurement set-up
- The water level is estimated with submillimeter accuracy
- The derived model is able to correct the influence of water

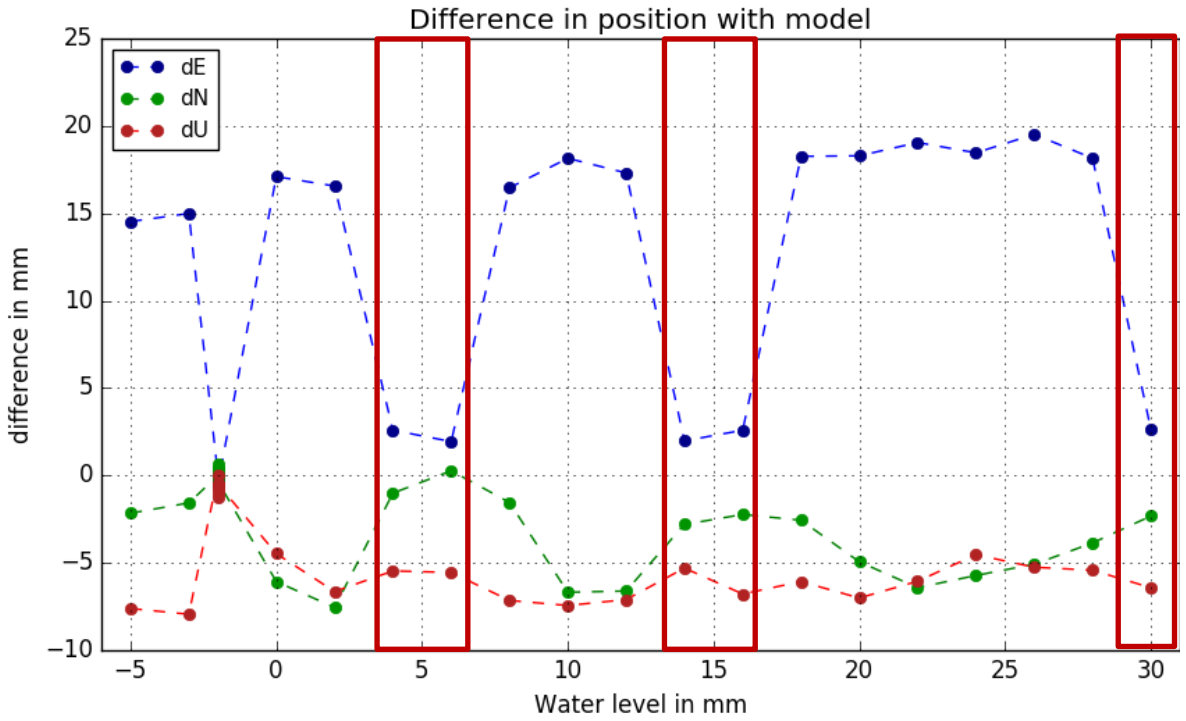
# Questions?

# Position Estimation without - with Model

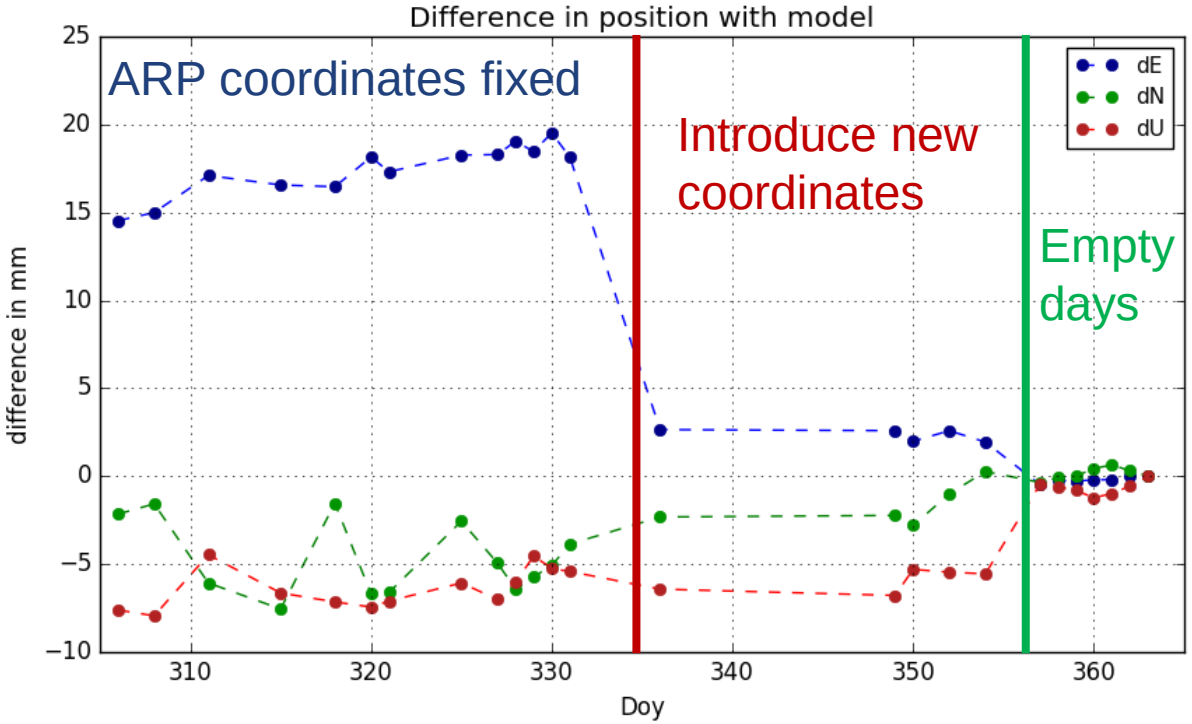



- No effect on east and north component

# Position Estimation with Model




- Break in east component of 1.5 cm at different water levels




- Break is a temporal effect!
- 3D position different for non empty days!