Characteristics and Limitations of GPS L1 Observations from Submerged Antennas

Ladina Steiner and Alain Geiger

Institute of Geodesy and Photogrammetry, ETH Zurich, Switzerland

Motivation

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

Experimental Set-up in Water

- A geodetic and a low-cost antenna are placed in a pool
- The water level is at the antenna surfaces (zero water level) and is increased daily by 2 mm steps until 55 mm above the antenna surfaces
- A geodetic reference station for differential processing is installed within a 10 m baseline (Leica AS10 antenna, GR10 receiver)

Conclusions

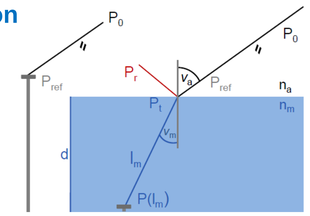
- Water is the main limiting factor in sub-snow GPS observations
- Theory and experiment agree within measurement set-up
- The water level is estimated with submillimeter accuracy
- The derived model is able to correct the influence of water

Theoretical Signal Propagation in Snow, Ice, or Water

2.1 Overview of GPS L1 signal propagation processes at air/snow boundary

a) Reflection
b) Transmission
c) Refraction
d) Attenuation

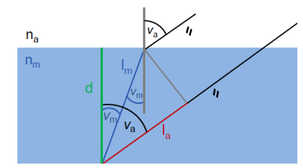
High dependence on snow wetness and the incident angle



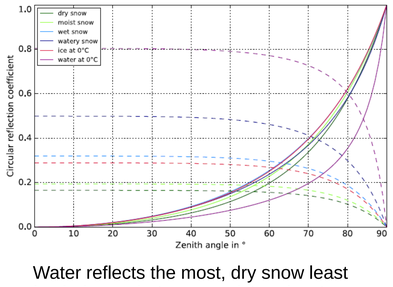
2.2 Derived model for the excess path due to signal propagation in water

$$\delta L = d(\sqrt{n_w^2 - sin^2 z} - \cos z)$$

- Allows to correct water influence
- Estimation of water depth d possible

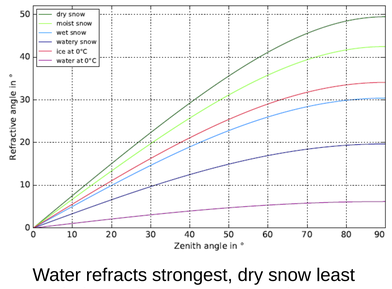


a) Reflection:



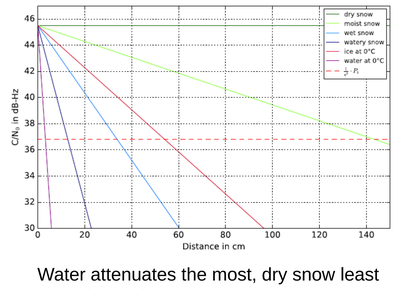
Water reflects the most, dry snow least
Ice behaves between moist and wet snow

c) Refraction



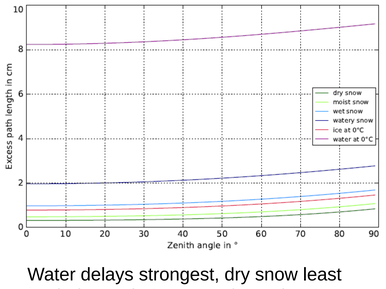
Water refracts strongest, dry snow least
Ice behaves between moist and wet snow

d) Attenuation



Water attenuates the most, dry snow least
Ice behaves between moist and wet snow

e) Excess path length

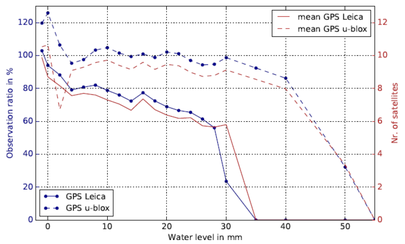


Water delays strongest, dry snow least
Ice behaves between moist and wet snow

→ **Signal is least transmitted, strongest refracted, most attenuated, and highest delayed in water**

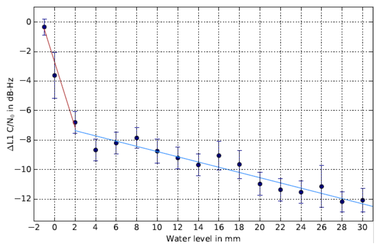
Results of Experimental GPS L1 Double Differences

4.1 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

4.2 Attenuation of signal strength

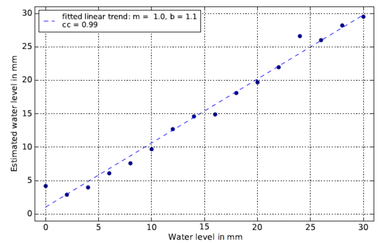


Fit log attenuation function:

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

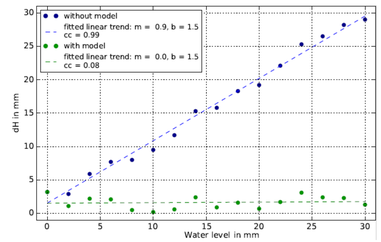
- Strong depletion in the $\Delta C/N_0$ by changing the antenna environment from air to water and linear decrease with increasing water level

4.3 Water depth estimation



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

4.4 Height solution



- Influence of water above the antenna affects directly the height component
- When model is applied, influence is corrected 100%