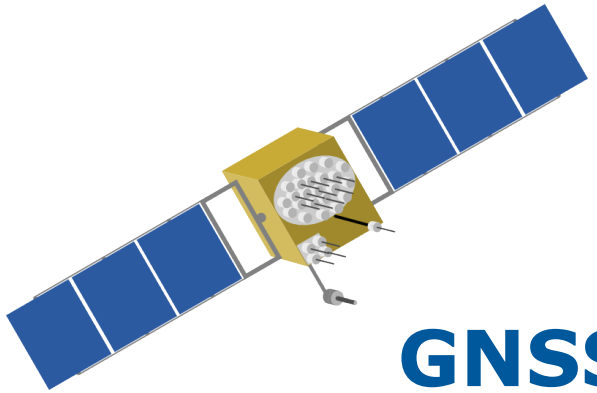

GNSS derived soil moisture from the global IGS permanent network

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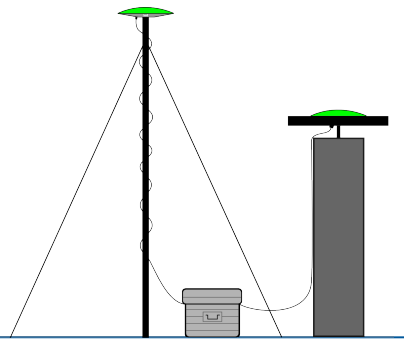

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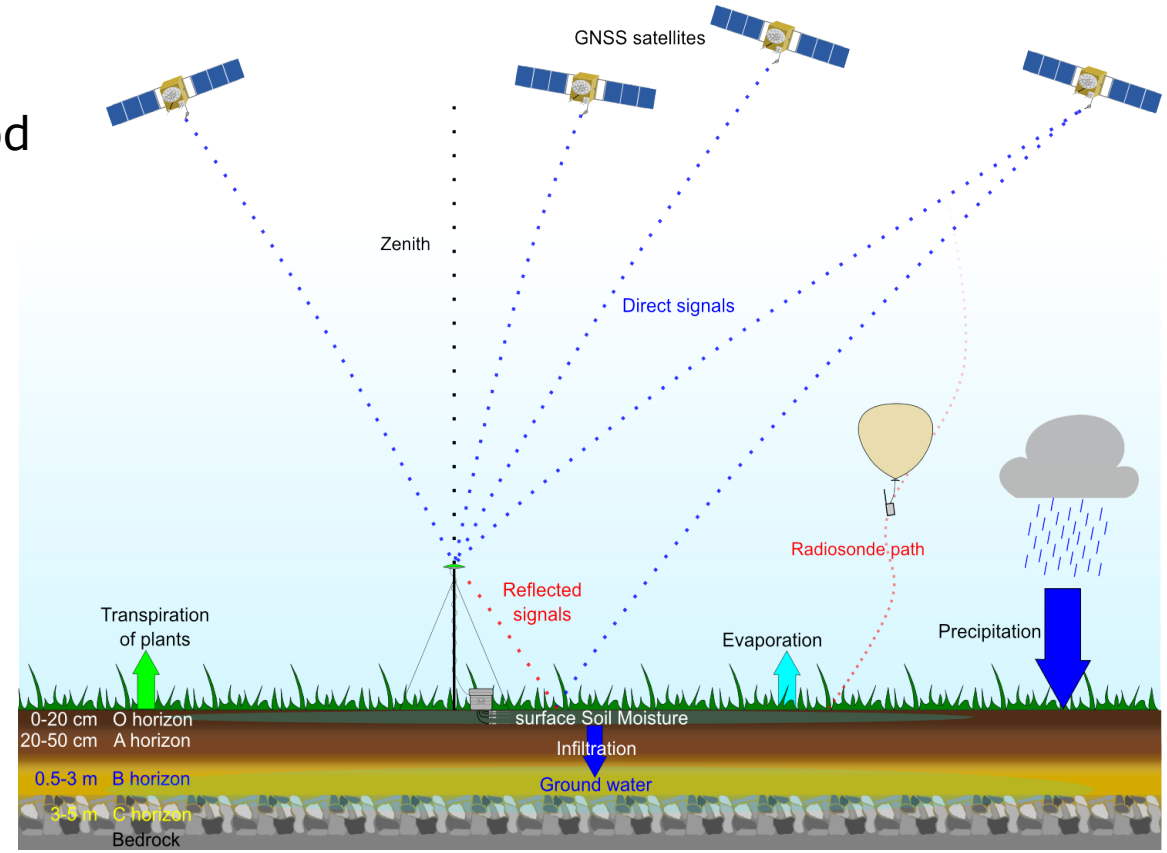
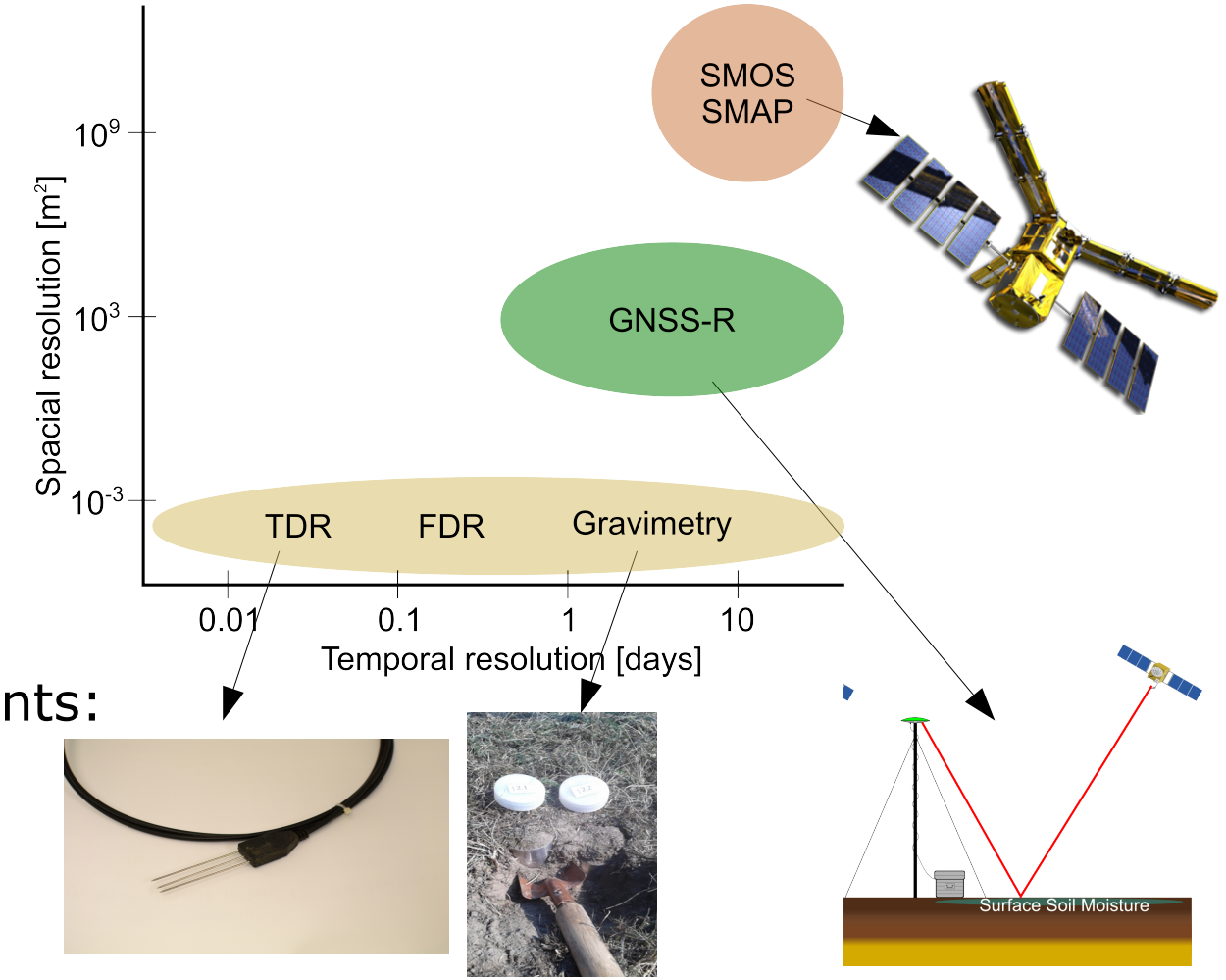
Outline

- Motivation
- Ground-based GNSS Reflectometry method
- Soil moisture dynamics and modelling
- The IGS network
- Soil moisture measurements in IGS stations
- Soil moisture and precipitation validation from ERA5
- Conclusions



Soil moisture measurement challenges

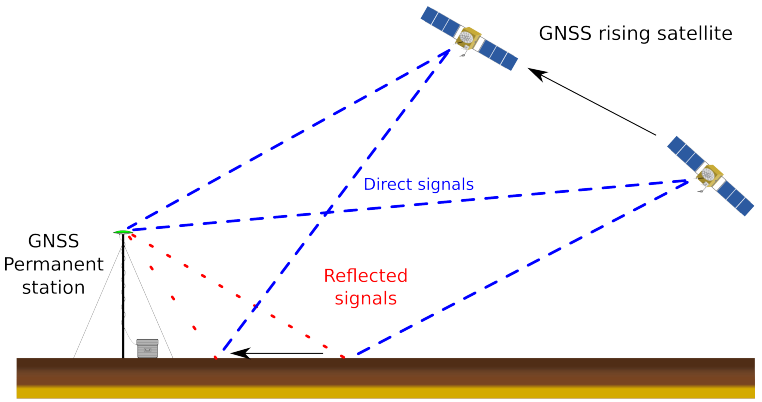
- Classical methods provide:
  - High accuracy direct measurement
  - High temporal resolution
  - Small spatial representability
- Satellite methods:
  - Lower accuracy remote estimation
  - Low temporal resolution
  - Large area footprint
- Hydrology & Agriculture requirements:
  - Daily resolution, or higher
  - Field-size representability

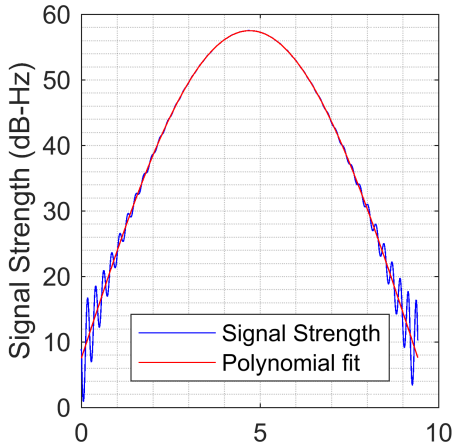


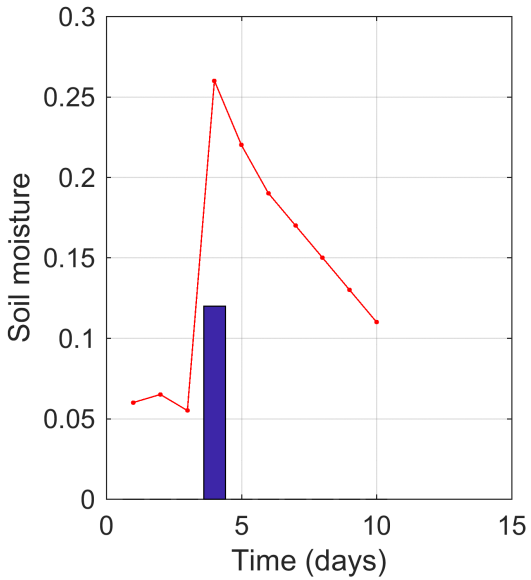
Principle of ground-based GNSS Reflectometry

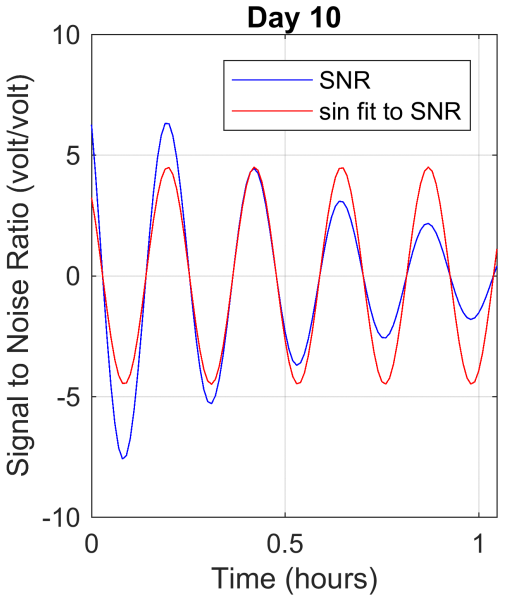
- Permanent GNSS station
- Receive direct and reflected signals
- Create long time series of observations
- Compare the differences of the observed reflected signals (phase, amplitude, reflector height)
- Calculate properties of reflective surfaces: soil moisture, vegetation, snow cover, etc.

$$SNR = A\cos(\frac{4\pi H_0}{\lambda}\sin E + \phi)$$





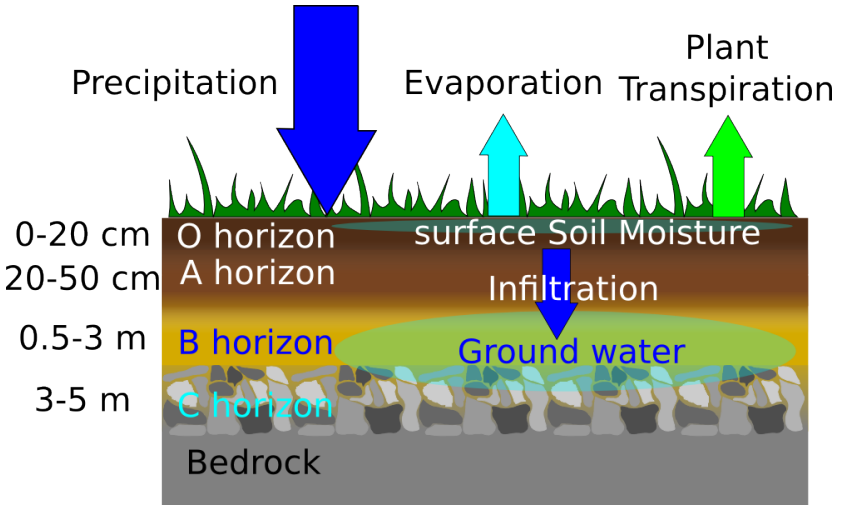


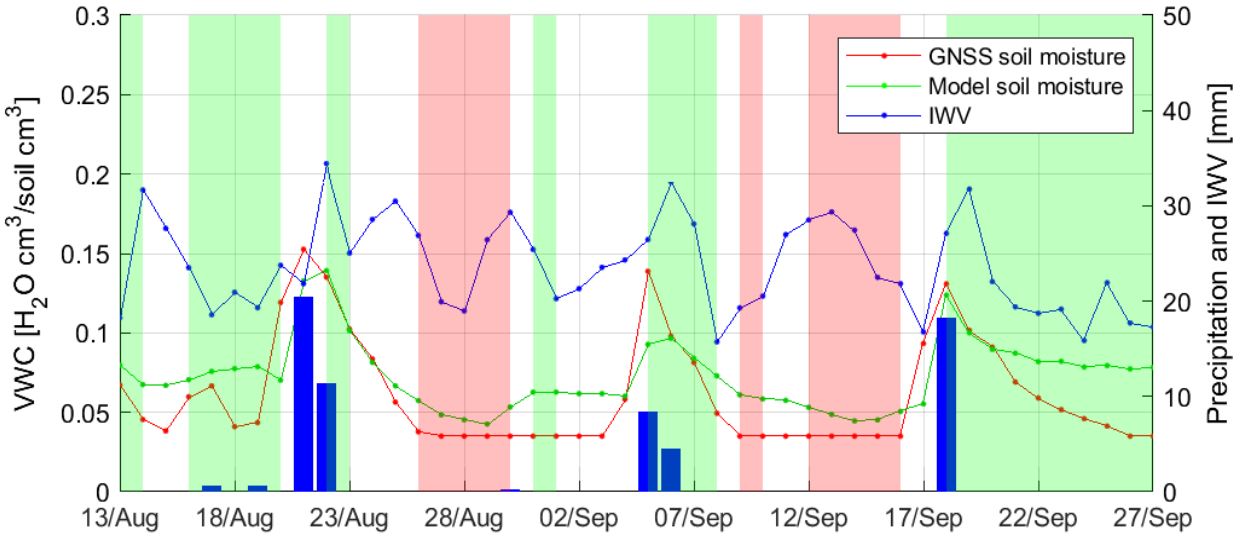


Soil moisture dynamics

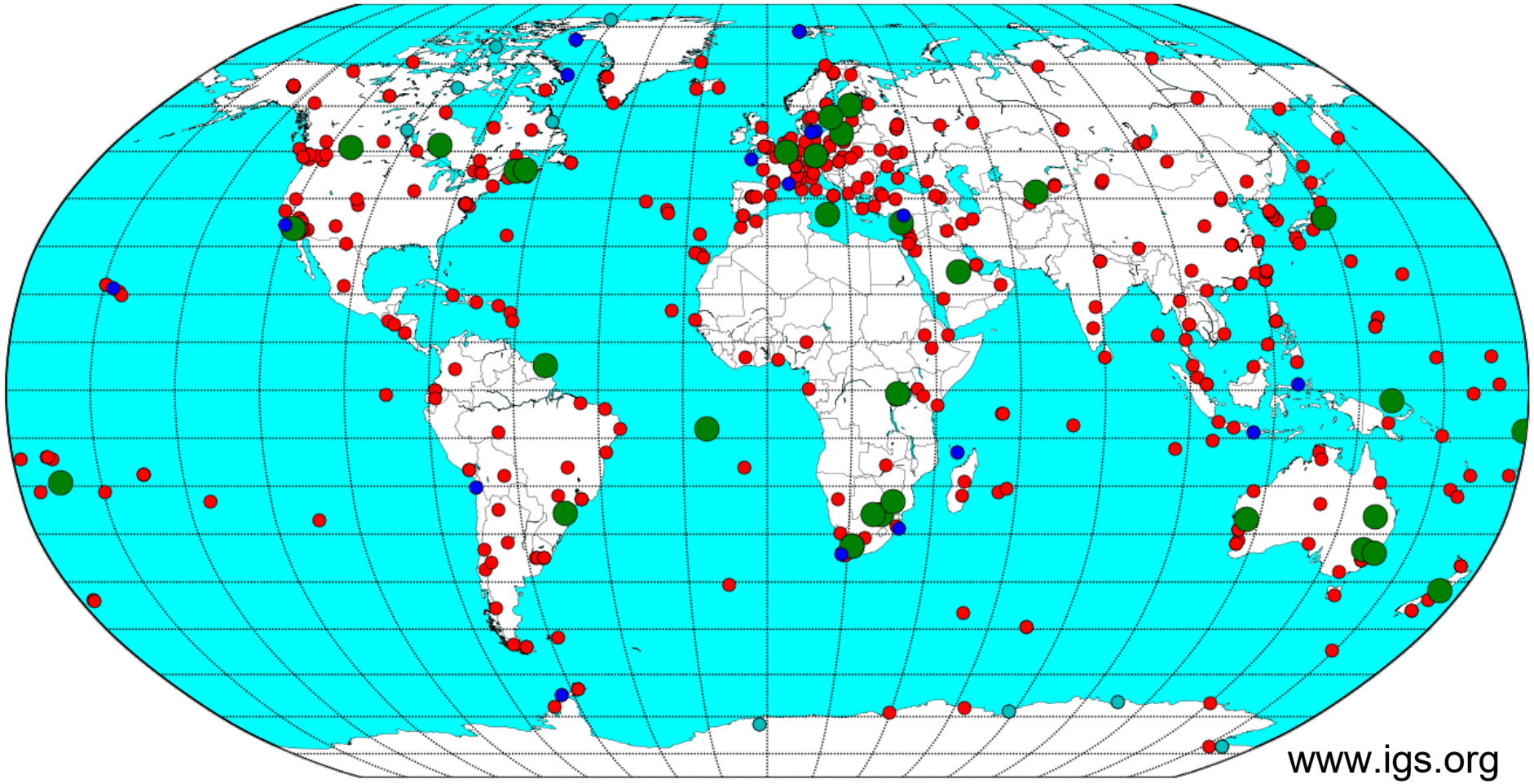
- Increases after Precipitation
- Decreases due to evapotranspiration, infiltration
- Soil moisture measured in cm^3_{H20}/cm^3_{soil}=100 Vol%
- Modeled using Temperature and Integrated Water Vapour
- IWV measured in parallel in the GNSS station

$$VWC_i = \alpha(IWV, T)VWC_{i-1} + \beta R + \gamma$$



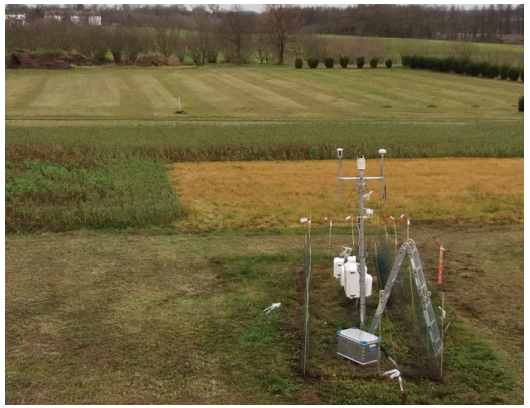


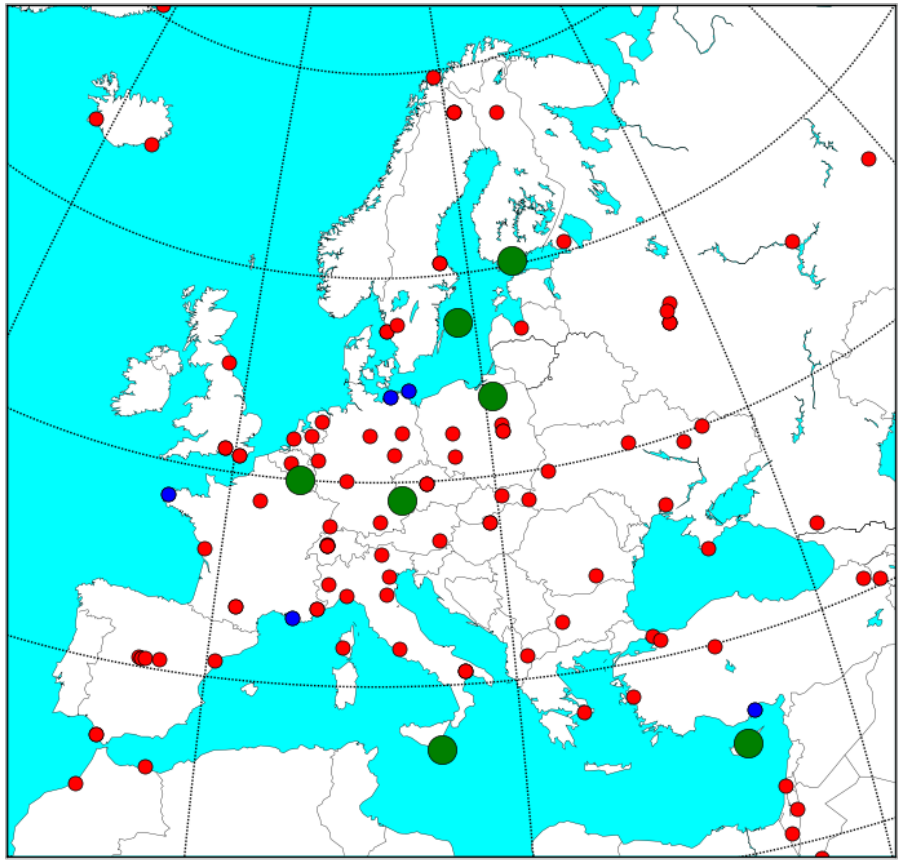
International GNSS Service network (IGS) – The potential soil moisture network



IGS network for GNSS reflectometry

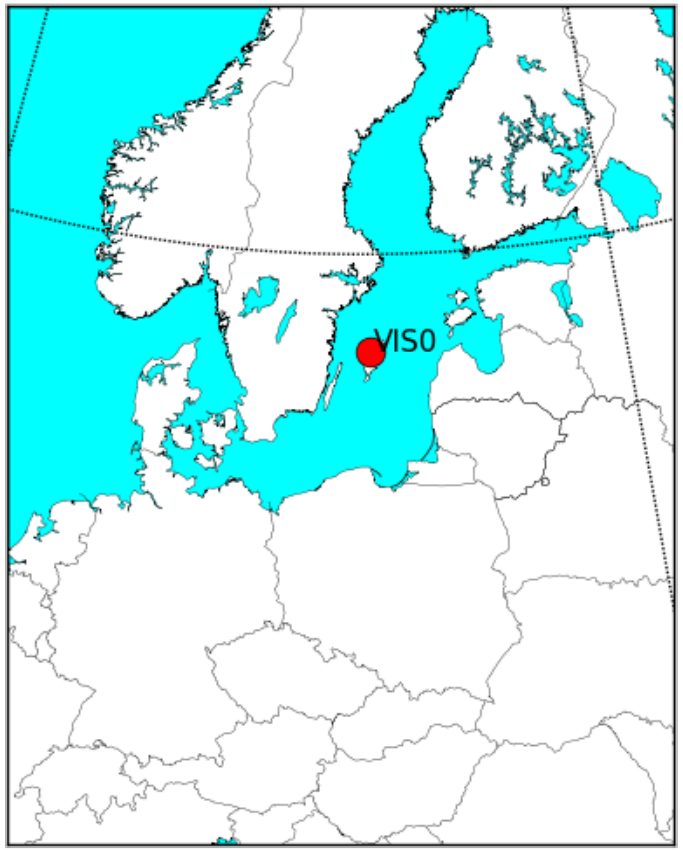
- 506 stations worldwide:
- 446 stations not suitable
- 31 stations with positive soil moisture retrievals
- 10 stations designated for snow height measurements
- 19 stations in coastal areas, envisaged for altimetry

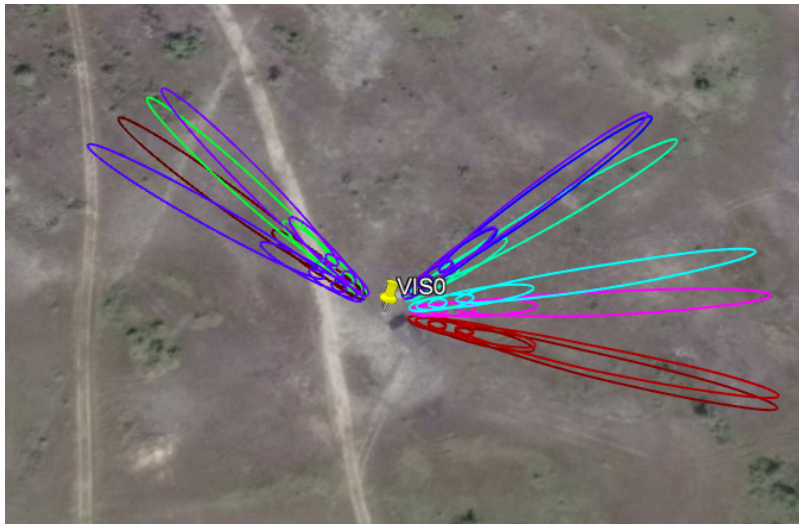




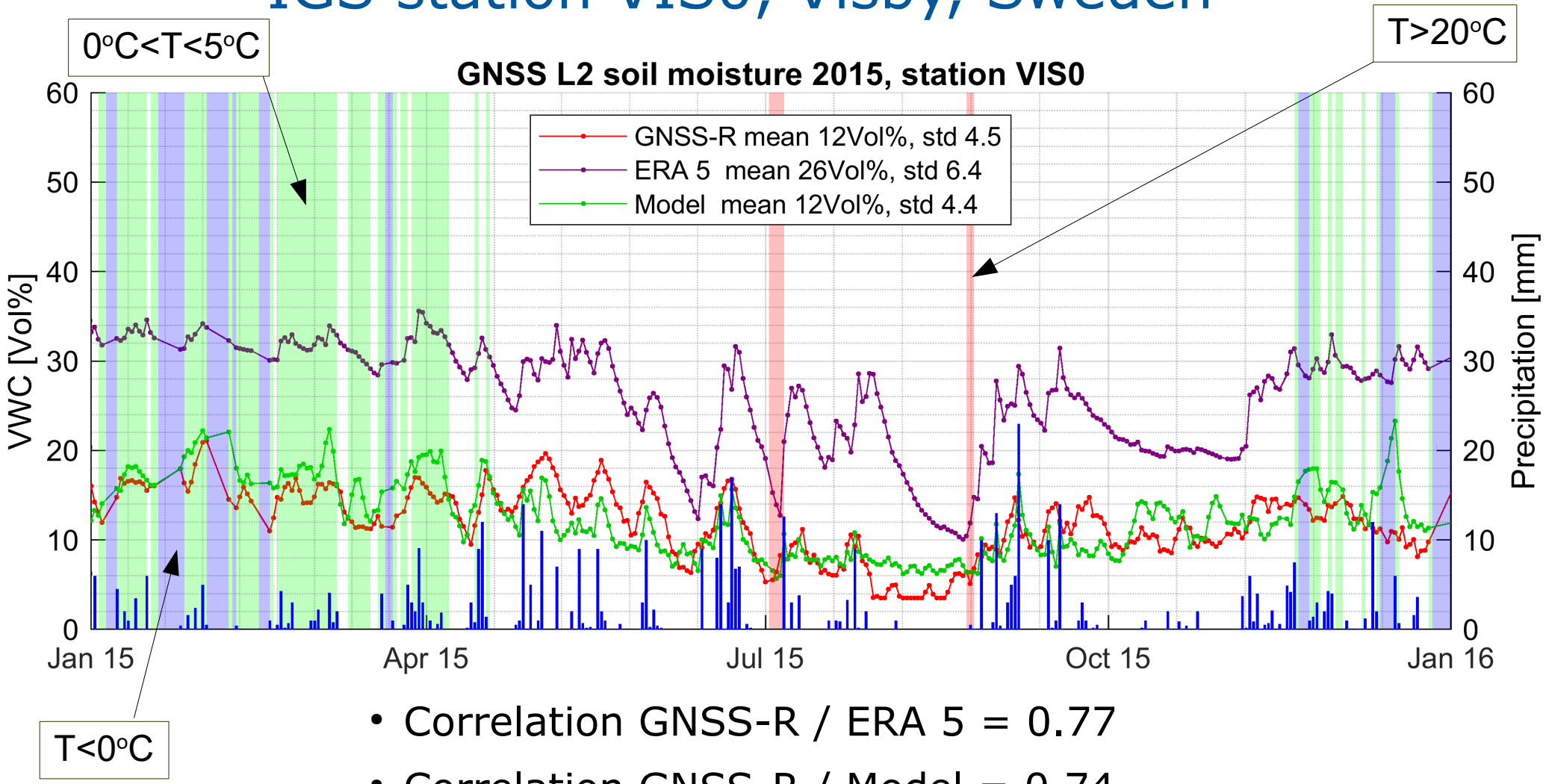
IGS station VIS0, Visby, Sweden

- Situated on Gotland island in Baltic sea
- Established in 1993
- Providing SNR data since 2004
- Mild oceanic climate with continental precipitation pattern
- 500mm/year Precipitation
- Mild winters (0°C) and cold summers (15°C)





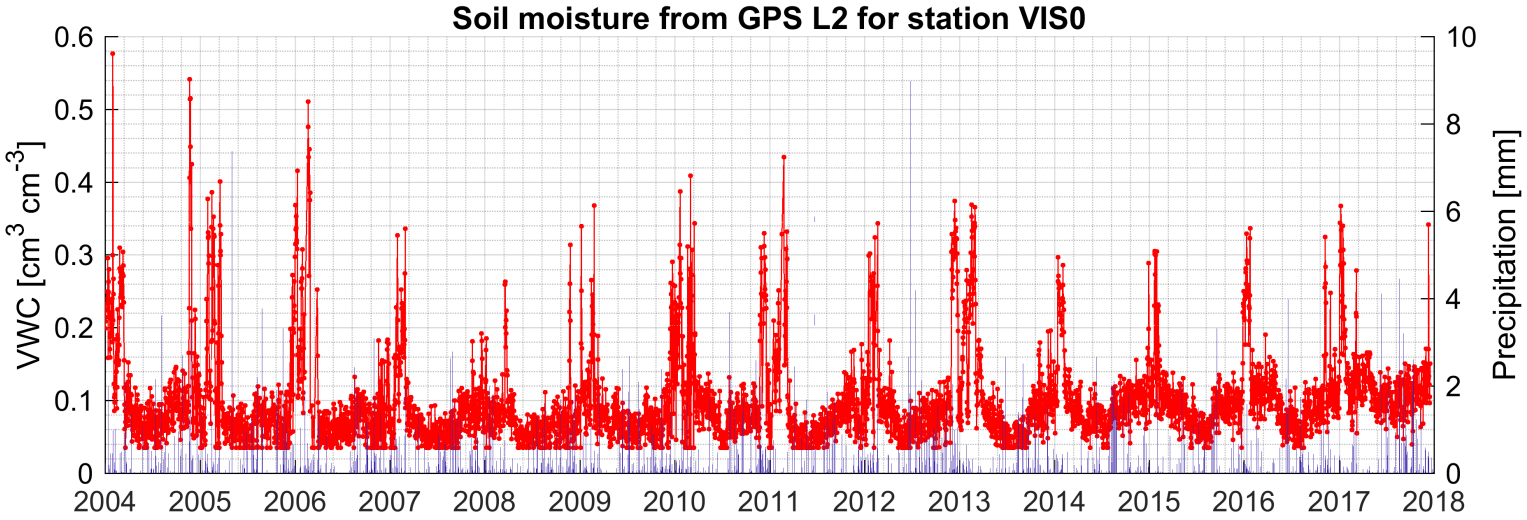
IGS station VIS0, Visby, Sweden



- Correlation GNSS-R / ERA 5 = 0.77
- Correlation GNSS-R / Model = 0.74

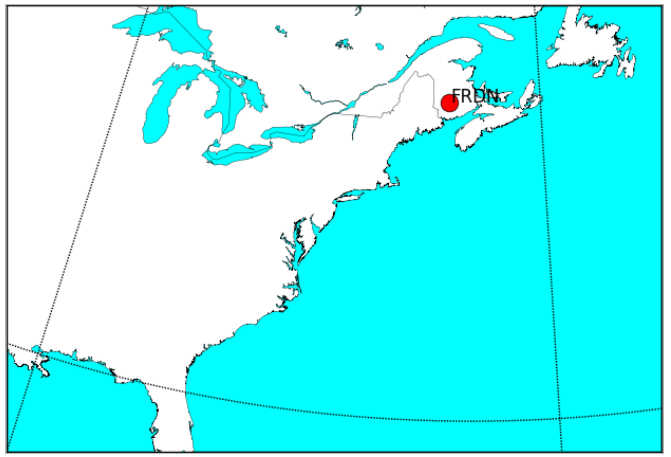
IGS station VIS0, Visby, Sweden

- Maximums during winter
- Minimums during summer
- High correlation between GNSS-R, Model and ERA-5
- Much higher values of ERA-5
- Correlation between VWC change and precipitation = 0.26
- Winter periods with snow cover

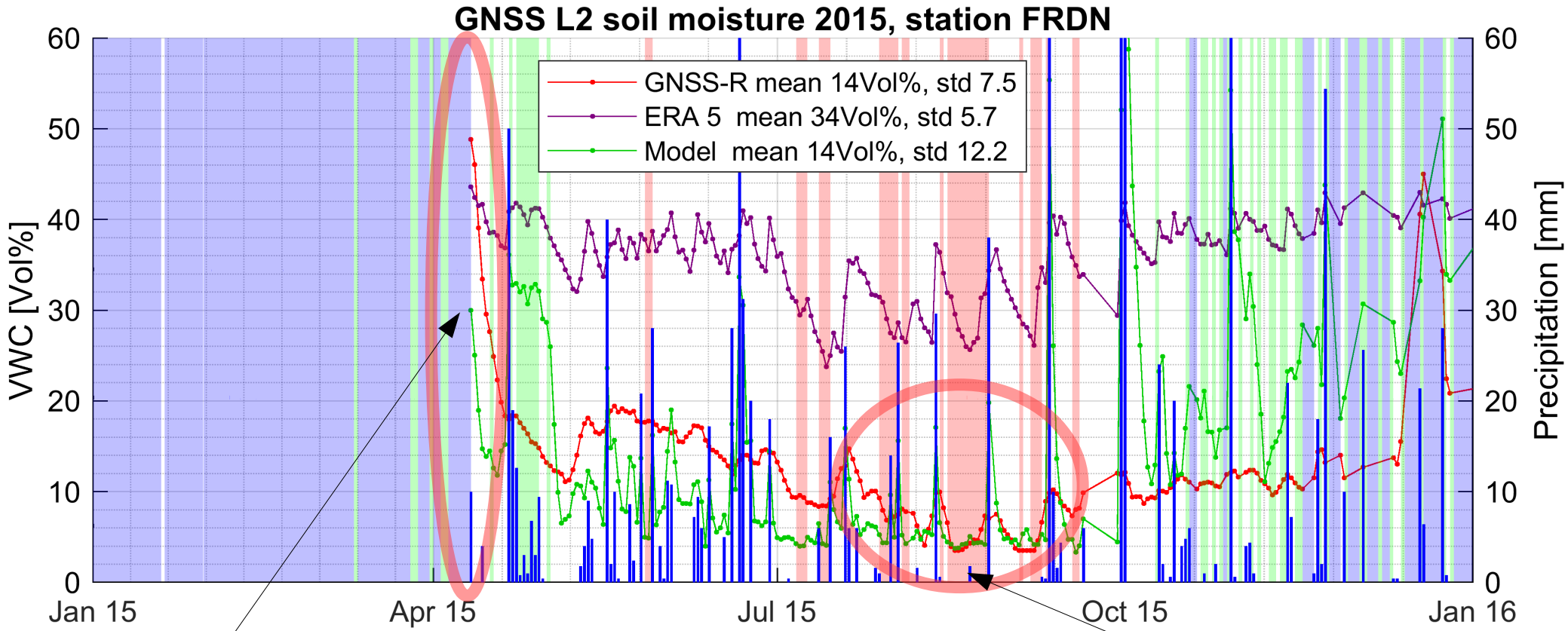


IGS station FRDN, Fredericton, Canada

- Situated in South-Eastern Canada
- Established in 2003
- Providing SNR data since 2004
- Warm summer continental climate
- 1000 mm/year Precipitation
- Cold winter (-3°C) mild summer (22°C)



IGS station FRDN, Fredericton, Canada



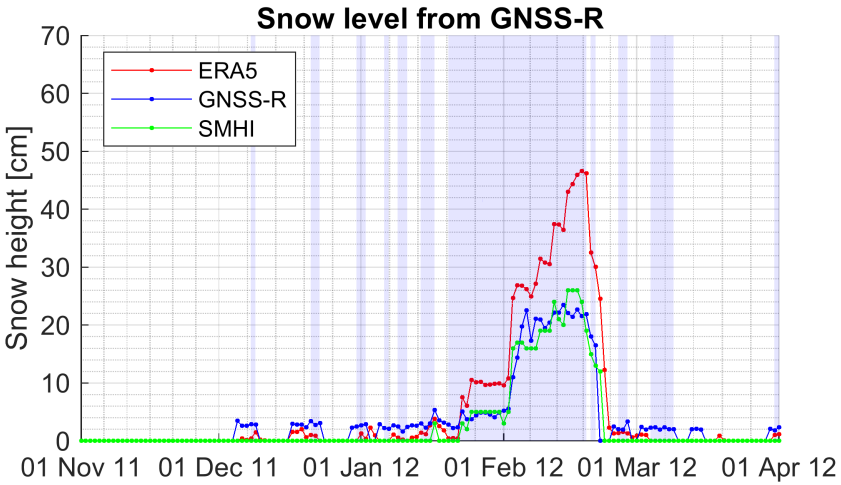
Melting snow

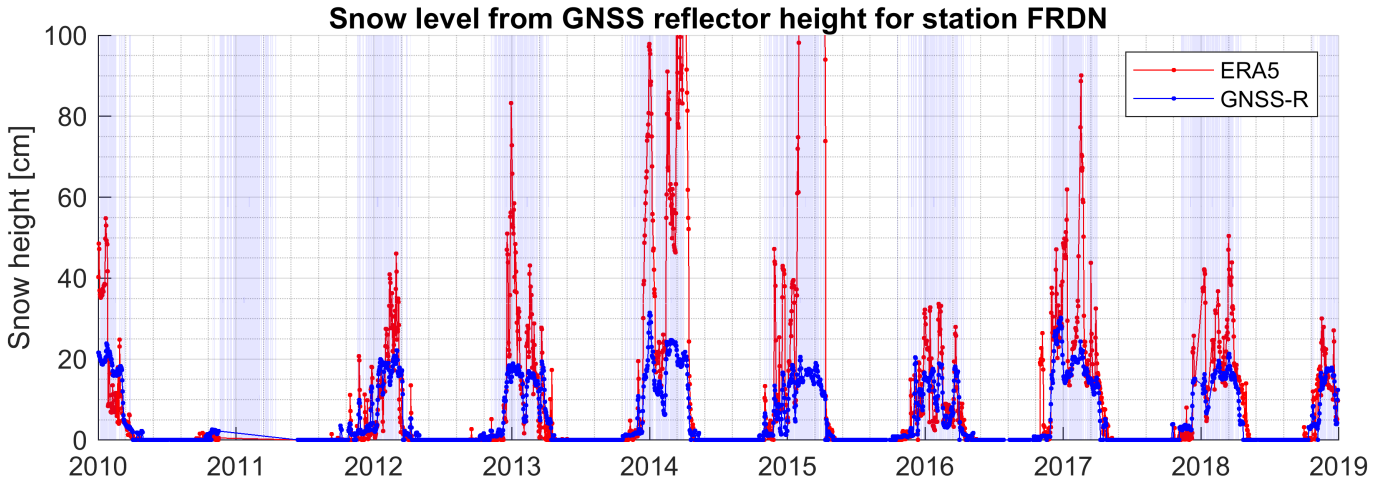
Hot and dry periods

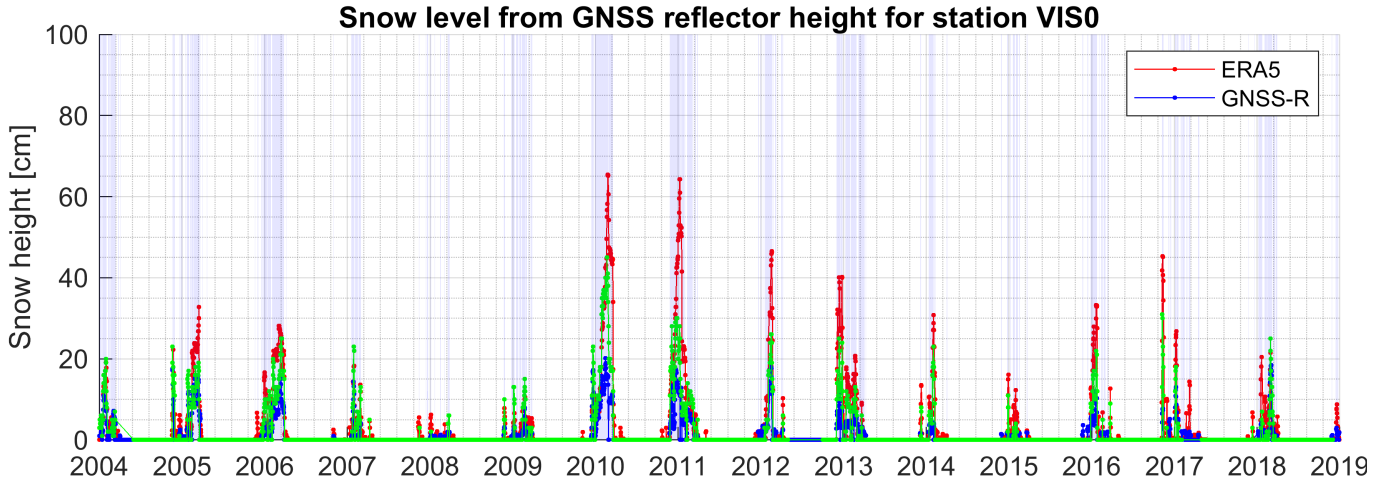
- Correlation GNSS-R / ERA 5 = 0.55
- Correlation GNSS-R / Model = 0.58

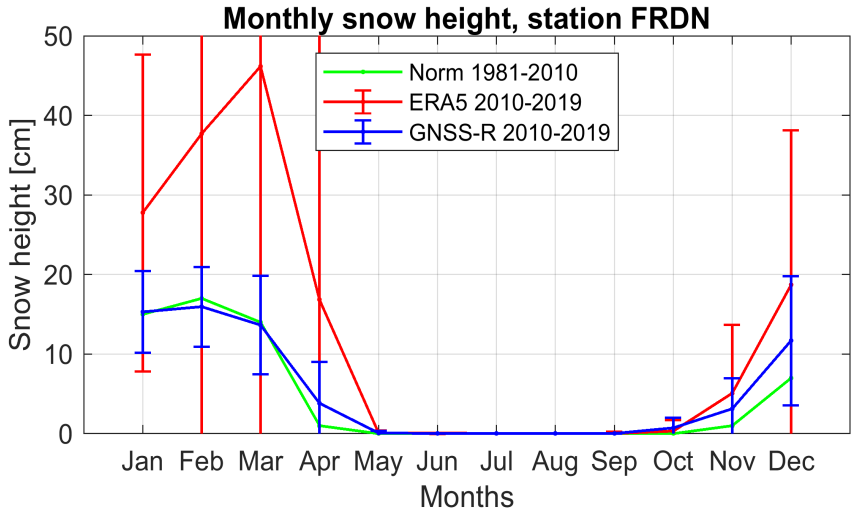
… one more thing

Snow height measurement in Visby and Fredericton



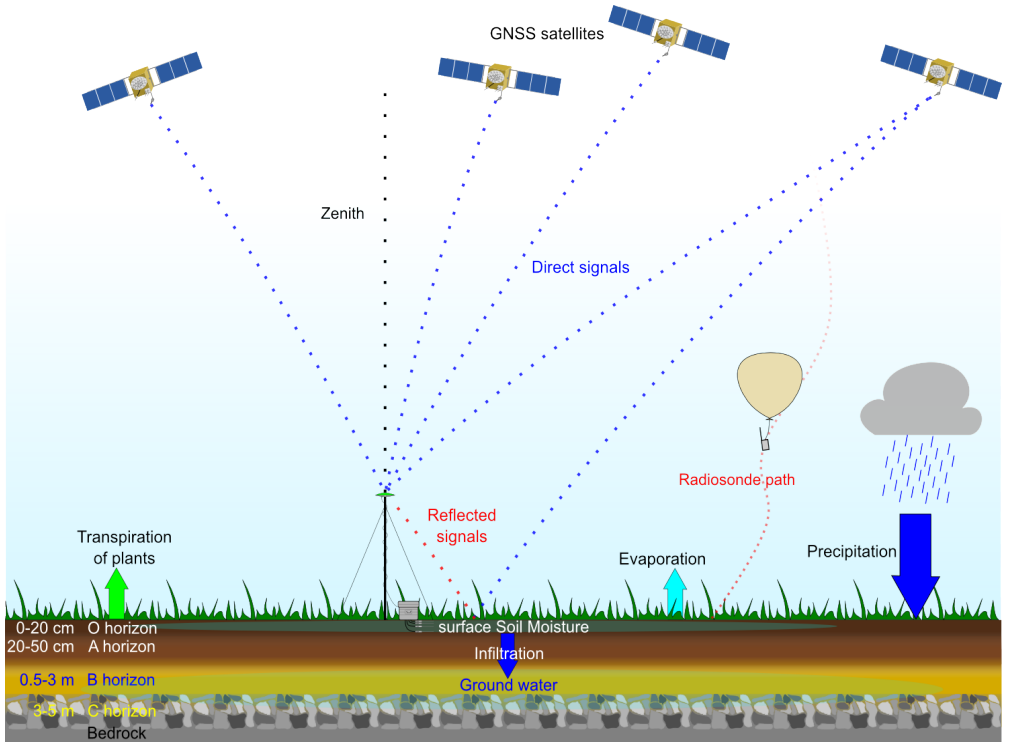






Conclusions

- The IGS network can provide soil moisture estimations
- Special set up is needed → only 7% of the IGS stations are usable for ground-based GNSS-R
- ERA5 shows good correlation with GNSS-R VWC, but bad agreement
- VWC model shows both high correlation and very good agreement with GNSS-R VWC
- GNSS ground stations are a highly consistent multi-purpose hydrological sensor
- GNSS-R VWC is cost effective and its spatial resolution is ideal for agriculture applications



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