Snow Parameter Estimation with Multi-Frequency and Multi-Constellation Global Navigation Satellite System Signals

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Abstract

The Snow Water Equivalent (SWE) describes the amount of water stored in snow. The SWE is a key parameter for various applications including meteorological information systems, run-off predictions for hydro power plants, and roof load monitoring. The SWE as well as the snow height and liquid water content can be determined with Global Navigation Satellite System (GNSS) signals. The set-up consists of two GNSS antennas where as one antenna is placed on the ground below the snow and the second one is placed on a pole above the snow, and serves as reference antenna. The differential GNSS signals are affected by the relative position between the antennas, the snow and the GNSS carrier phase ambiguities. The GNSS signals are refracted at the air-snow interface, and attenuated and delayed in the snow pack. The contribution of this talk is three-fold: First, we have extended our snow parameter estimation [2,3] from a single-frequency, dual constellation (GPS + Galileo) solution to a multi-frequency, triple-constellation (GPS + Galileo + Beidou) solution [1]. Secondly, we have used a Kalman filter to continuously estimate the SWE and carrier phase ambiguities [1] instead of a least-squares estimation. Third, the float ambiguity estimates are now fixed to integer numbers with the Least-Squares Ambiguity Decorrelation Adjustment (LAMBDA) method. The first results are very promising and indicate that the measurement period for snow parameter estimation can be reduced from several hours to less than 30 minutes. References: [1] Julian Weiss: "Snow Parameter Estimation with Multi-Frequency and Multi-Constellation GNSS", Master thesis, Techn. Univ. Muenchen, Germany, 2021. [2] Patrick Henkel, Franziska Koch, Florian Appel, Heike Bach, Monika Prasch, Lino Schmid, Juerg Schweizer, and Wolfram Mauser: "Snow Water Equivalent of Dry Snow Derived from GNSS Carrier Phases", in: IEEE Transactions on Geoscience and Remote Sensing, vol. 56, issue 6, pp. 3561 – 3572, Jun. 2018. [3] Franziska Koch, Patrick Henkel, Florian Appel, Lino Schmid, Heike Bach, Markus Lamm, Monika Prasch, Juerg Schweizer, and Wolfram Mauser: "Retrieval of snow water equivalent, liquid water content, and snow height of dry and wet snow by combining GPS signal attenuation and time delay", in Water Resources Research, vol. 55, issue 5, pp. 4465 – 4487, May 2019.

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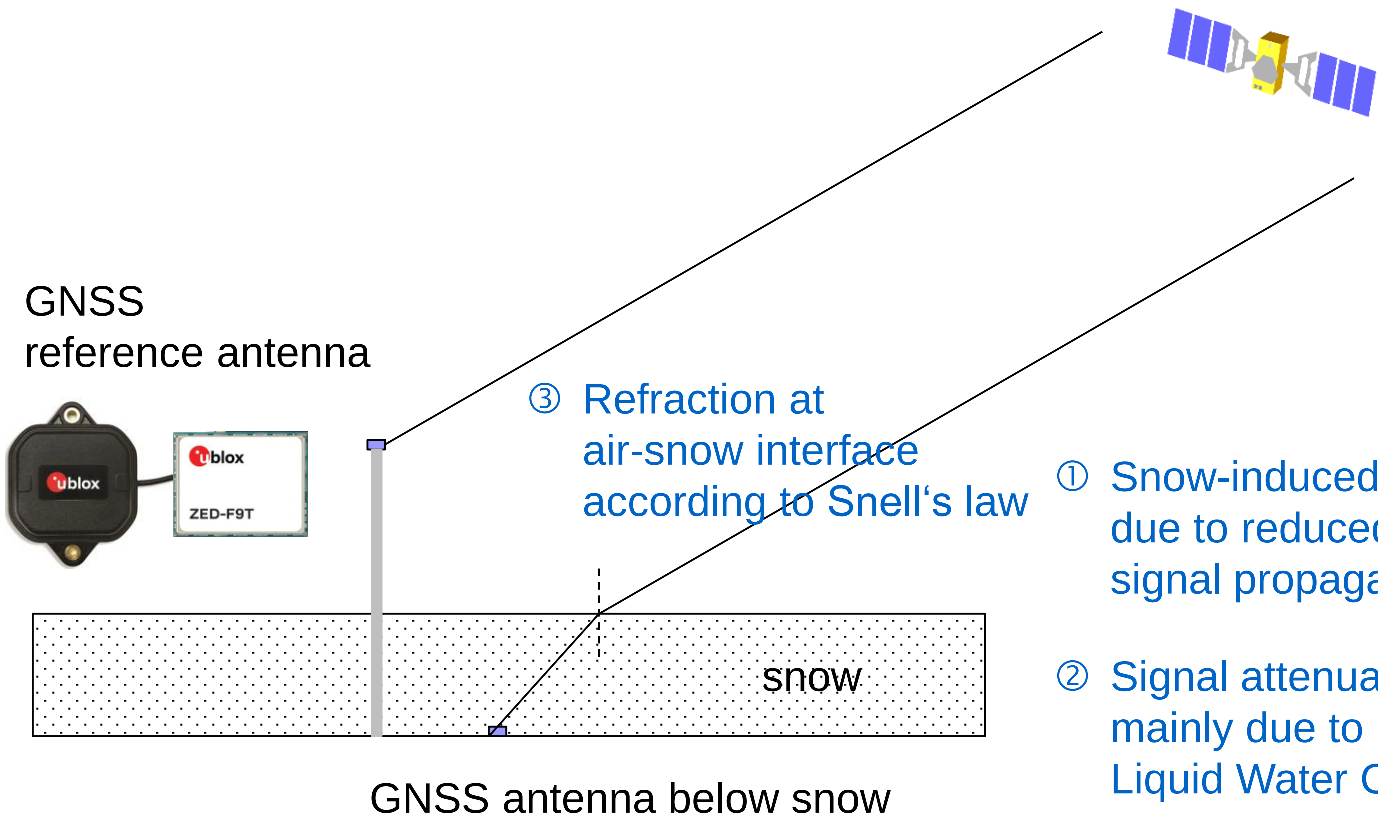
AGU Fall Meeting

Session G32B: Applications of Low-Cost, Mass-Market, and Consumer-Grade GNSS in Geosciences (eLightning)

Snow Monitoring Station Set-Up



① Snow-induced time delay due to reduced speed of signal propagation in snow

② Signal attenuation due to snow, mainly due to Liquid Water Content (LWC)

Snow Monitoring Site at Zugspitze

Snow Monitoring Site at Zugspitze

Snow Monitoring Site at Zugspitze

Latitude: 47.406342436° N
Longitude: 10.983476867° E
Height: 2420 m

09.09.2021

13.12.2021

GNSS-based Snow Parameter Estimation

Double differenced carrier phase measurement between two GNSS receivers and two satellites:

$$\lambda_m \varphi_{12,m}^{kl} = \vec{e}^{\,kl} \vec{b}_{12} + m_{\mathrm{s}}^{kl} \frac{v_{\mathrm{a}}}{v_{\mathrm{s}}} \cdot \mathrm{SWE} + \lambda_m N_{12,m}^{kl} + \varepsilon_{12,m}^{kl}$$

Integer Ambiguity

Snow Water Equivalent (SWE)

Relative position („baseline“) between both GNSS receivers

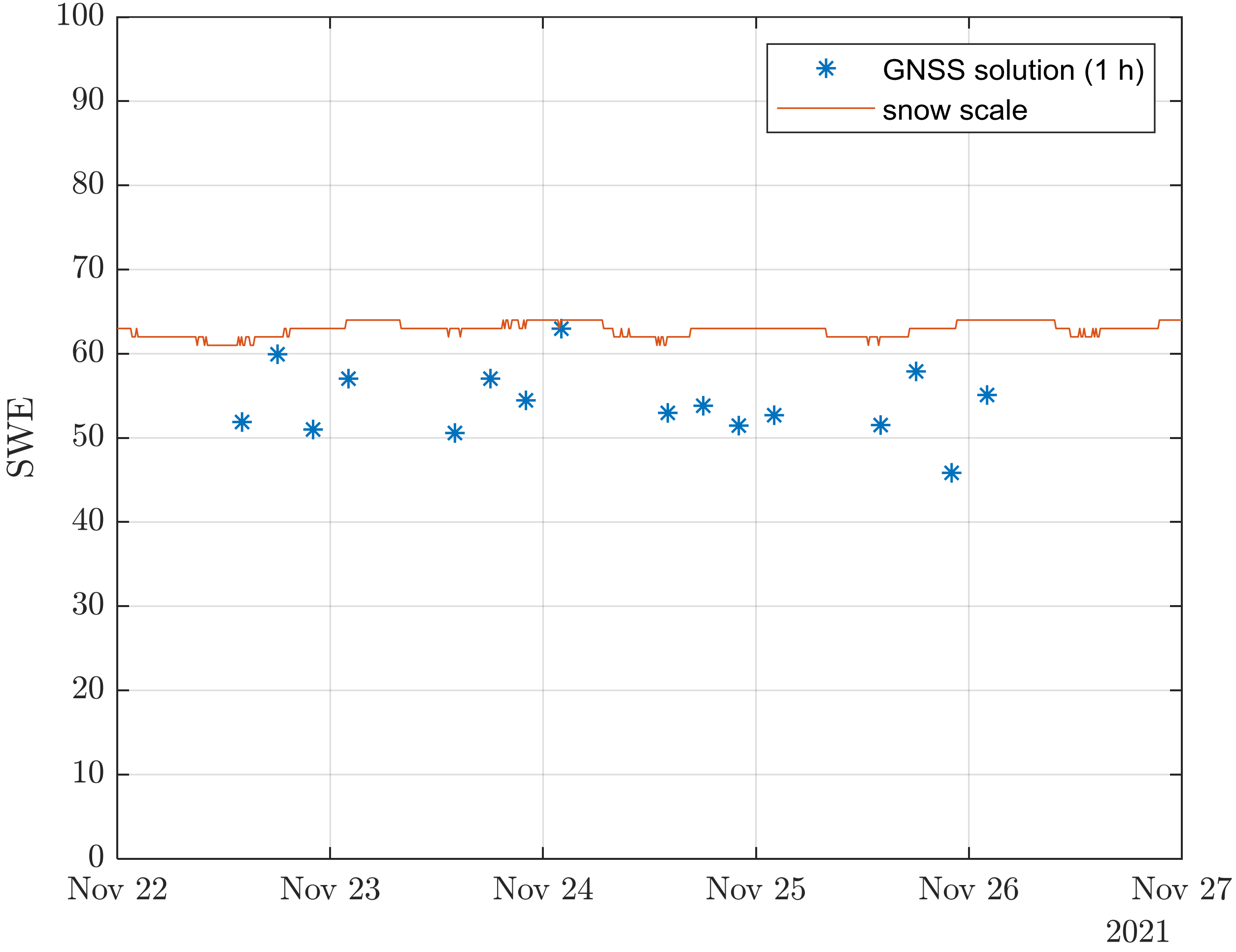
Parameter Estimation

① Calibration, i.e. RTK Positioning in snow-free conditions

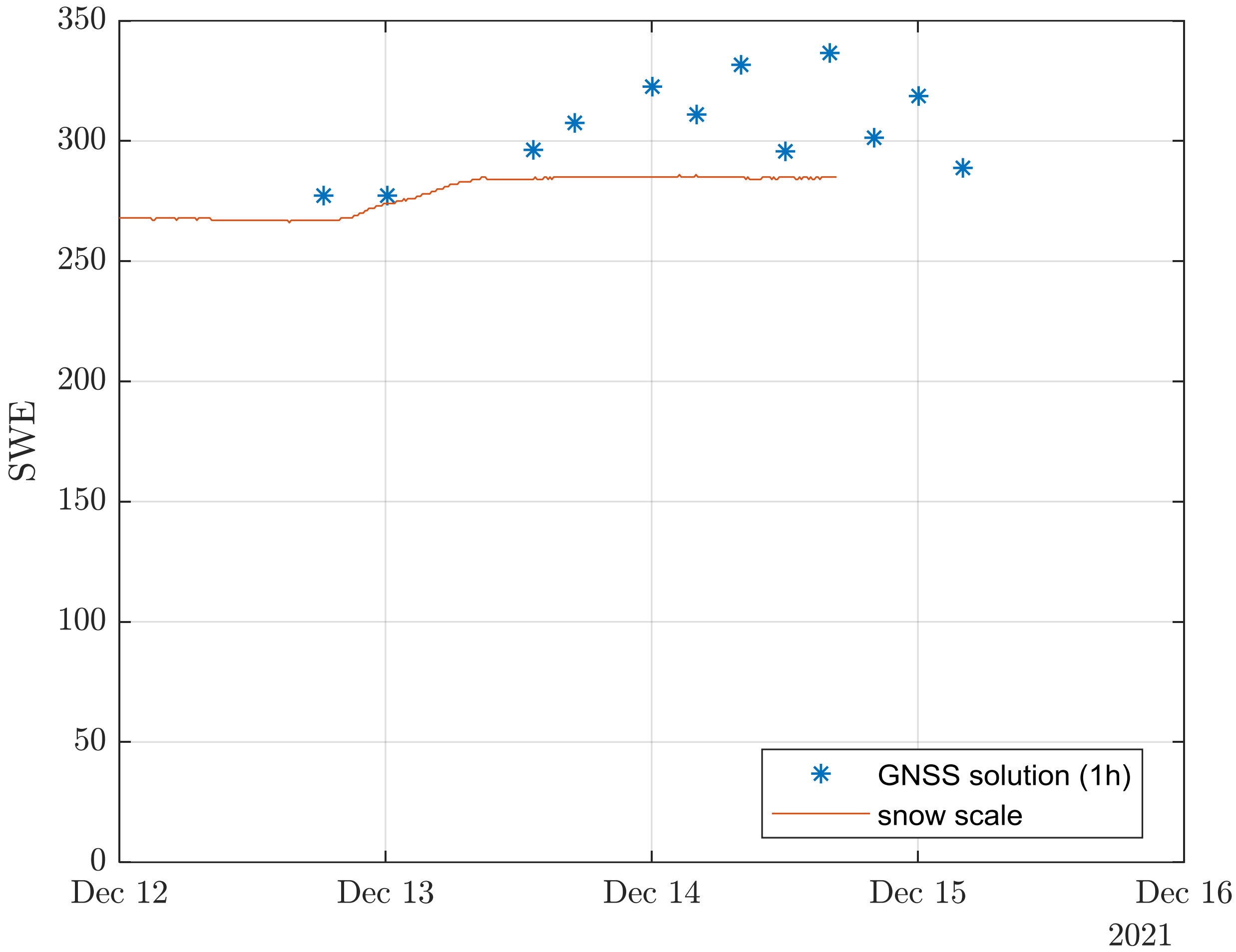
② Snow Parameter Estimation using baseline estimate from ①

- Kalman Filter based estimation of SWE and float ambiguities
- Integer Ambiguity Fixing with LAMBDA method
- Adjustment of SWE estimates
- Determination of snow height, LWC and speed of light in snow

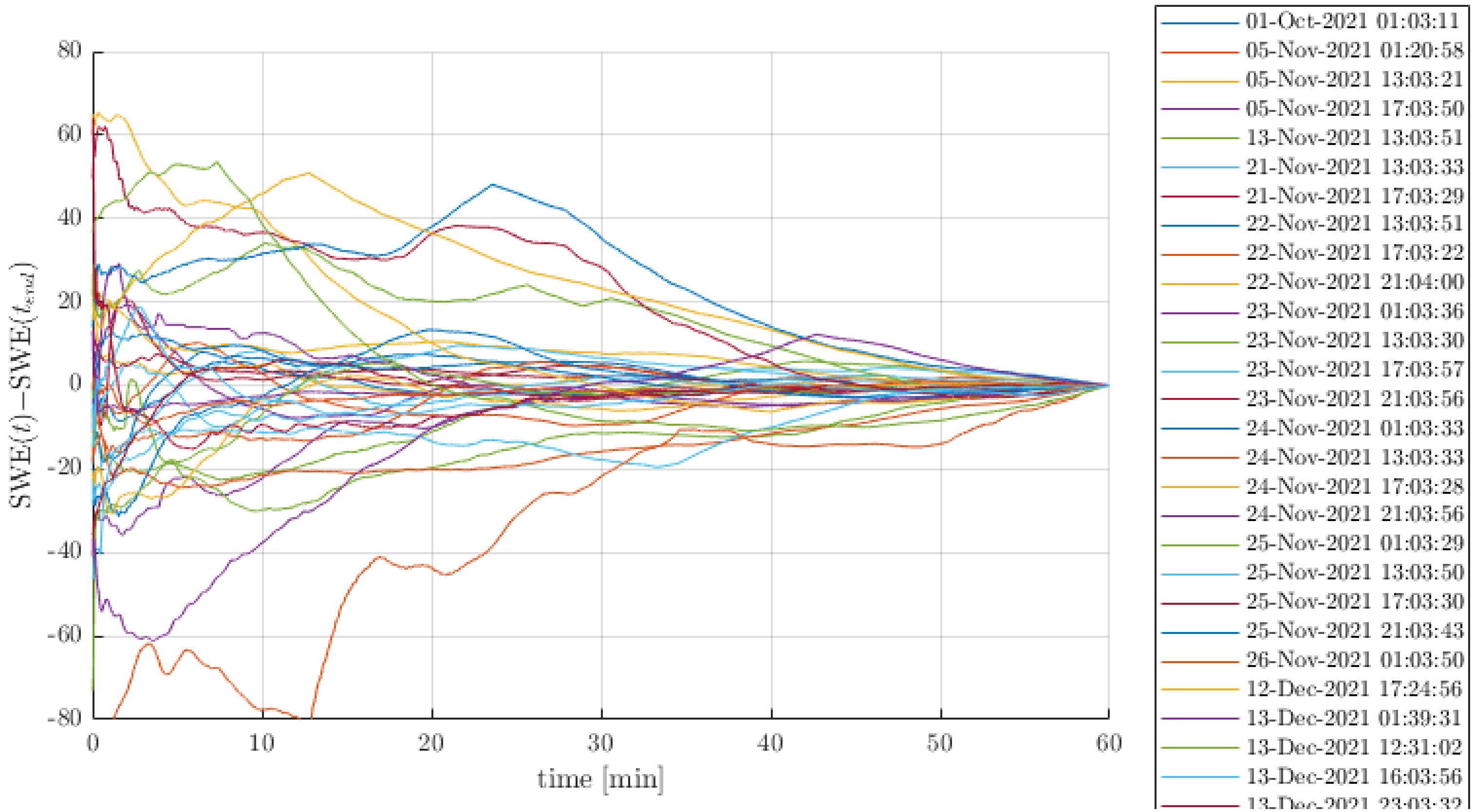
Measurement results: SWE in November



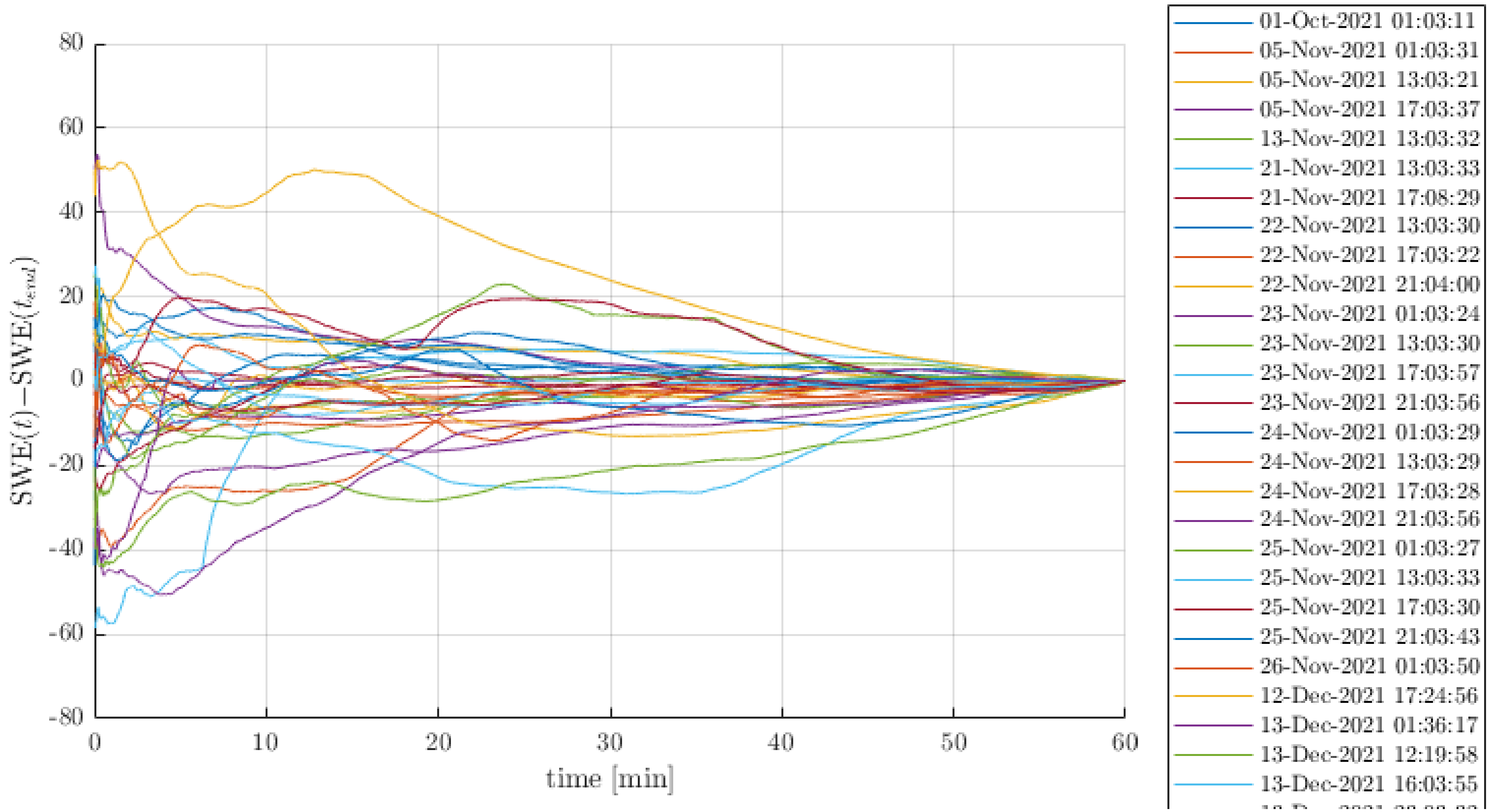
Measurement results: SWE in last few days



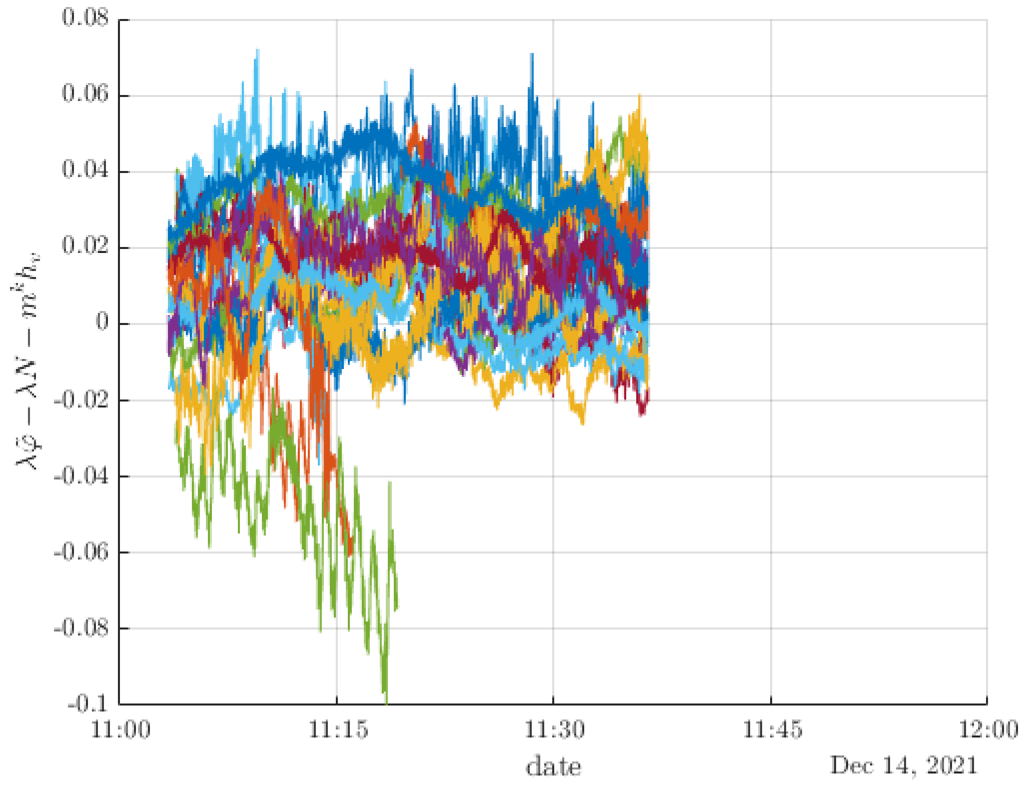
Measurement results:
Convergence of SWE (Single Frequency GNSS)



Measurement results:
Convergence of SWE (Multi-Frequency GNSS)



Measurement results: Accuracy Assessment based on Fixed Carrier Phase Residuals



Different colors refer to different satellites, constellations and frequencies.

Potential Applications




Product Summary

ANavS snow monitoring station for remote locations

Overview

The ANavS snow monitoring stations provide accurate snow pack information based on Global Navigation Satellite System (GNSS) signals. The Snow Water Equivalent (SWE), snow height and Liquid Water Content (LWC) are determined with innovative algorithms within the stations.
The snow pack properties are transferred via satellite communications or cellular networks. Access to the snow information is provided via email or web service. The stations operate autonomously with an integrated solar-power supply and wireless communication, and can be set up permanently or temporarily.

Application

- Meteorological information systems
- Optimized operation of hydro-power plants enabled by accurate run-off prediction
- Monitoring of roof load caused by snow
- Scientific research on snow pack modeling and avalanches

Installation

- Compact design of all components for easy transportation and installation
- Station components can be easily carried by two persons and set-up within 2 hours
- Standalone installation or Integration in existing mast infrastructure
- No special mechanical tools required

Maintenance

- No maintenance during winter operation
- Clearance of measurement spot, visual and manual inspection advisable before winter season
- Battery replacement every 3-5 years recommended

Key Features

- Accurate determination of SWE, snow height and LWC based on differential GNSS measurements
- Cost-efficient monitoring instead of time-consuming manual measurements
- Weather-independent operations by no use of optical sensors/ lasers
- Outperformance of snow scales as GNSS measurements are independent of bridging effects
- Solar power supply for remote installations
- Efficient power management with extremely low power sleep mode and configurable schedule
- Iridium or cellular wireless communication for remote installations
- Access to GNSS raw measurements
- Processing of GNSS raw measurements within snow monitoring station
- Remote re-calibration of station via satellite communication (Iridium)

Product Summary

ANavS remote snow monitoring station

Technical Data for Standard Configuration

Power Supply	Internal 12V system with 3 x 20-Watt Solar Panel + 20 Ah Battery
	External 5 – 20 Volts
Power Consumption	Peak: (during calculation & communication) < 5 Watt
	Standby 0.01 Watt / Sleep 0.001 Watt
	Daily consumption for typical measurement cycles (e.g. 1 X SWE per day): 0.25 Ah
Temperature Range	-40° to + 40° Celsius
Measurement Range	Up to 5.000 mm SWE (dry snow) 0.0 – 10.0 Vol.% LWC
Measurement Accuracy	SWE < + - 10 mm (good conditions)
Area of measurement	Integrative spot: diameter of 0.5 m to 5 m (depending on snow depth)
Measurement Cycles	1 - 4 times per day for SWE (typically: 1) 1 - 4 times per day for LWC (typically: 4)
Data transmission	Embedded Iridium satellite communication module or GSM/ LTE module, allows wireless transmission of snow parameters from station to snow monitoring facilities, data access via web-service
Dimensions	Mast: 3 m x 0.05 m (typically), can be extended Core electronics Unit: 225 x 165 x 55 mm Box with Power Supply and Electronics: 375 x 270 x 125 mm Antennas: 38 x 38 x 12 mm Ground Plate: 160 x 160 x 5 mm
Packaging	1200 x 400 x 400 mm (full system) 25 kg (without battery)

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