Influence of snow on the integrative signal of a super-conducting gravimeter installed on top of Mount Zugspitze, Germany (Northern Calcareous Alps)

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Overview

- **Why is the study site Zugspitze so interesting?**
- **How are snow-hydro-gravimetric signals derived and how do they look like?**
- **What is the influence of the snowpack and other hydrological fluxes & states on the gravimetric signal?**
- **How can we estimate the snow-hydro-gravimetric footprint?**

OVERVIEW

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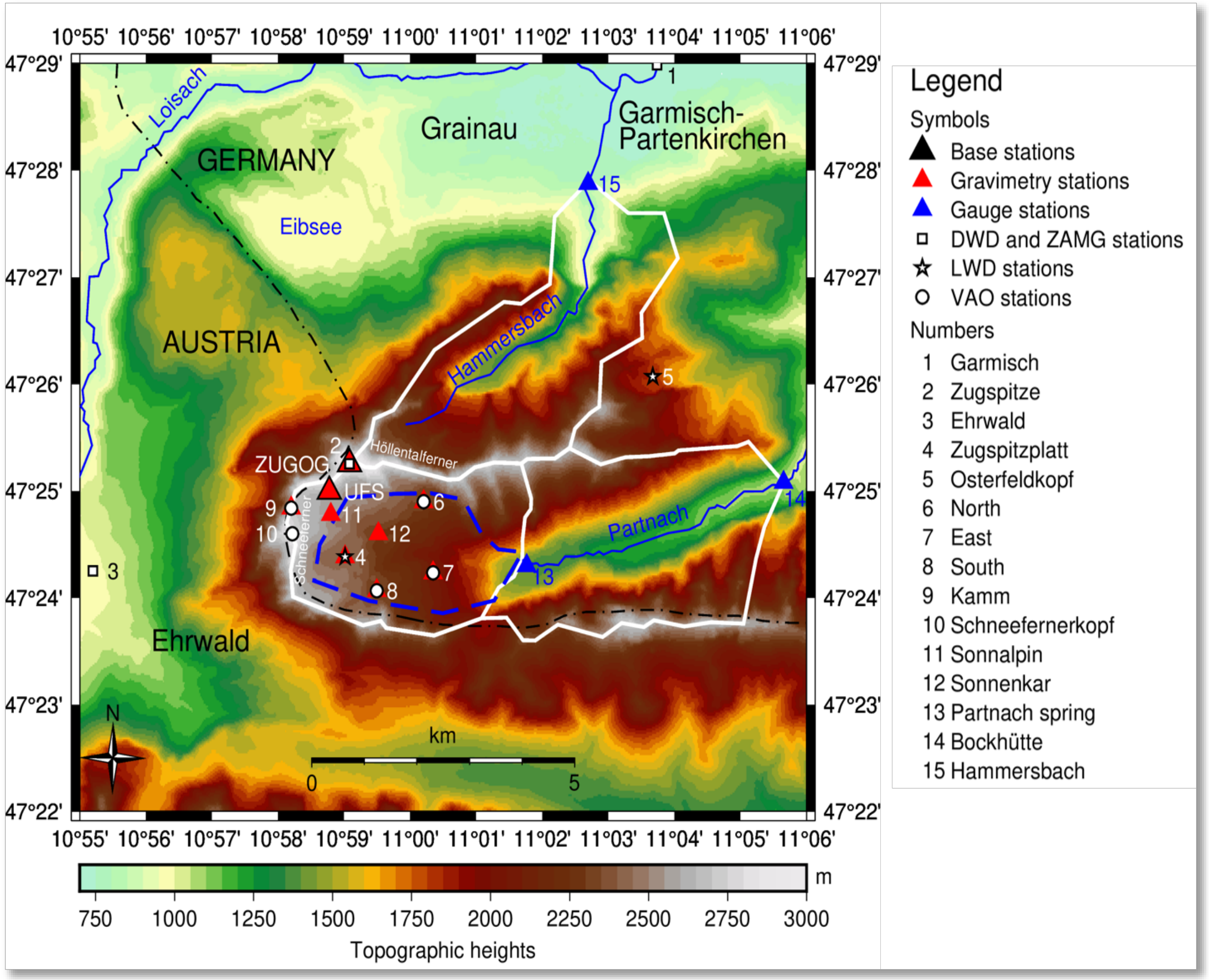
- **Why is the study site Zugspitze so interesting?**

Study Site Zugspitze – Instrumentation & Infrastructure



UMWELT FORSCHUNGSSTATION SCHNEEFERNERHAUS

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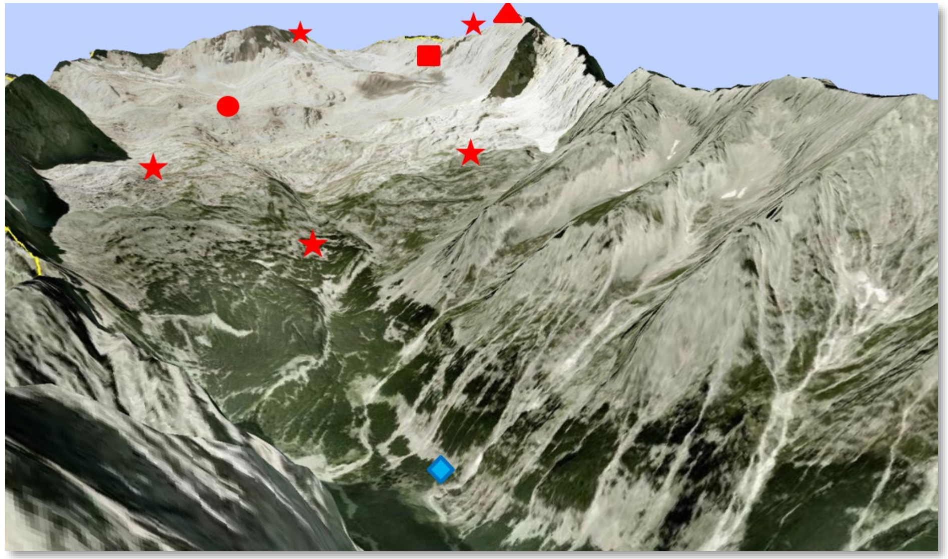

Catchment area	11.4 km²	Geology	Limestone, karstified
Highest point	2.962 m a.s.l.	Mean temperature	-4.5 °C
Lowest point	1.430 m a.s.l.	Precipitation	2080 mm
Diff. in altitude	1.532 m	Glacier extent	~ 16 ha (2018)

Study Site Zugspitze – Open Air Lab for Testing and Developing new Sensors & Approaches

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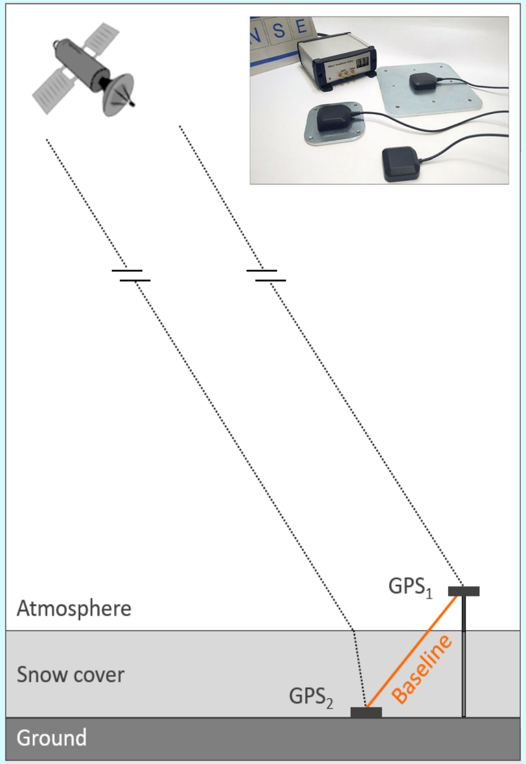
GNSS snow sensor development

Installation and testing of GNSS sensors and development of approaches, e.g., to derive SWE & LWC in steep slopes



High-alpine snow-hydro-gravimetry

Operation of a superconducting gravimeter (GFZ Potsdam)
Development of a joint snow-hydro-gravimetric approach

Overview

- Why is the study site Zugspitze so interesting?
- **How are snow-hydro-gravimetric signals derived and how do they look like?**

Components of Gravity (Accelleration)

$$g = 9.80\,724\,673... \; m/s^2$$

Earth‘s flattening and rotation

Mountains, ocean trenches

Mass variations in the Earth‘s interior

Large geological deposits

Polar motion

Atmospheric mass redistributions

Hydrological mass redistributions

Solid Earth and ocean tides

Static gravity variations

Temporal gravity variations

Spring gravimeter (Scintrex)

Superconducting gravimeter (GWR)

Absolute gravimeter (Micro g LaCoste)

GFZ Helmholtz Centre Potsdam

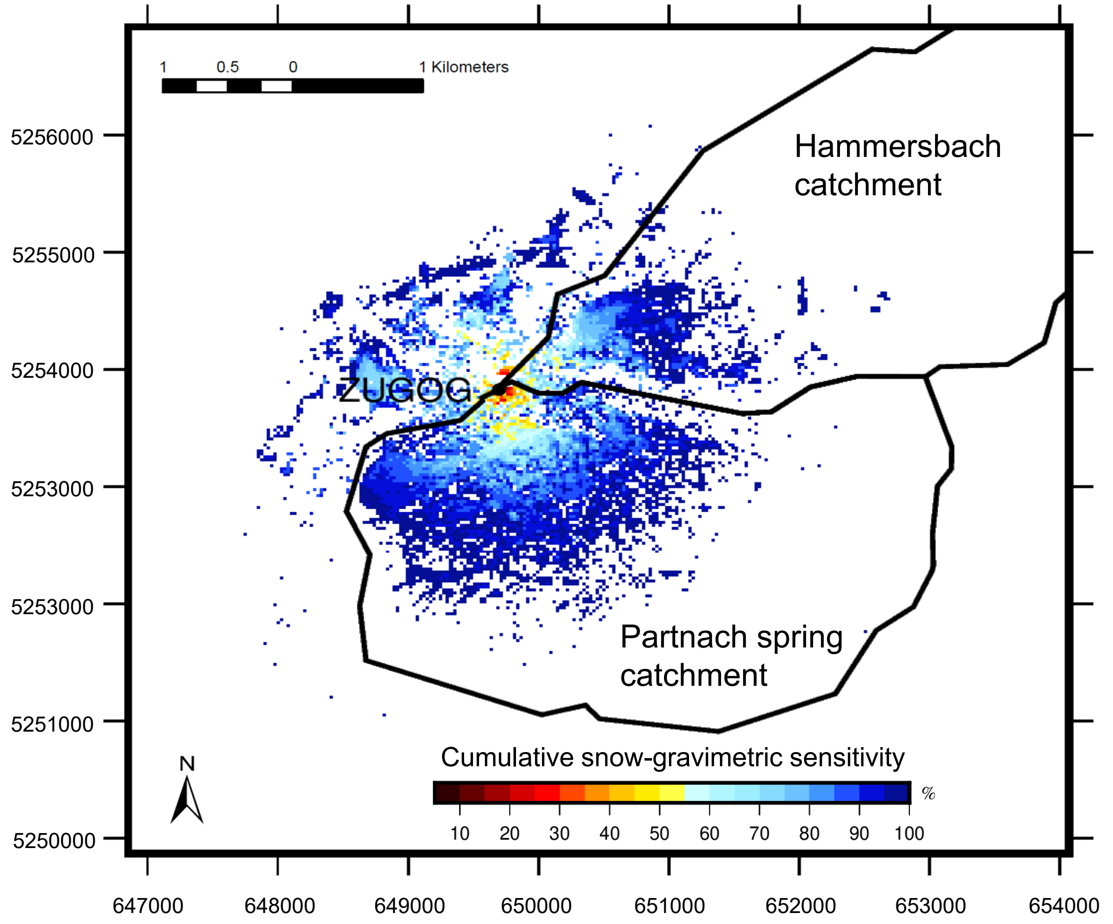
HELMHOLTZ

BOKU HyWa Institute for Hydrology and Water Management

Snow-hydro-Gravimetry – Footprint, Benefits & Challenges

Benefits	Challenges
Direct, integral and non-invasive monitoring of water storage variations	**Sensitivity diminishes with increasing distance d_s** to the gravimeter with $1/d_s^2$
Quantification of water storage variations up to a few km → suitable for high-alpine catchments	**Footprint is variable in time** depending on the spatial distribution of water storages
Wide temporal spectrum from 1 s to several years → Applicable for single events, seasonal changes, annual water balance and long-term trends	**Relatively complex** operation and analysis and **additional snow-hydrological observations and/or modelling required** for the analysis of individual phenomena

Footprint: Cumulative snow gravimetric sensitivities at 09 April 2021



Hydrological Gravity Changes over 3 Years (2019, 2020, 2021)

Voigt et al. 2021, HESS,
data updated until Jan 2022

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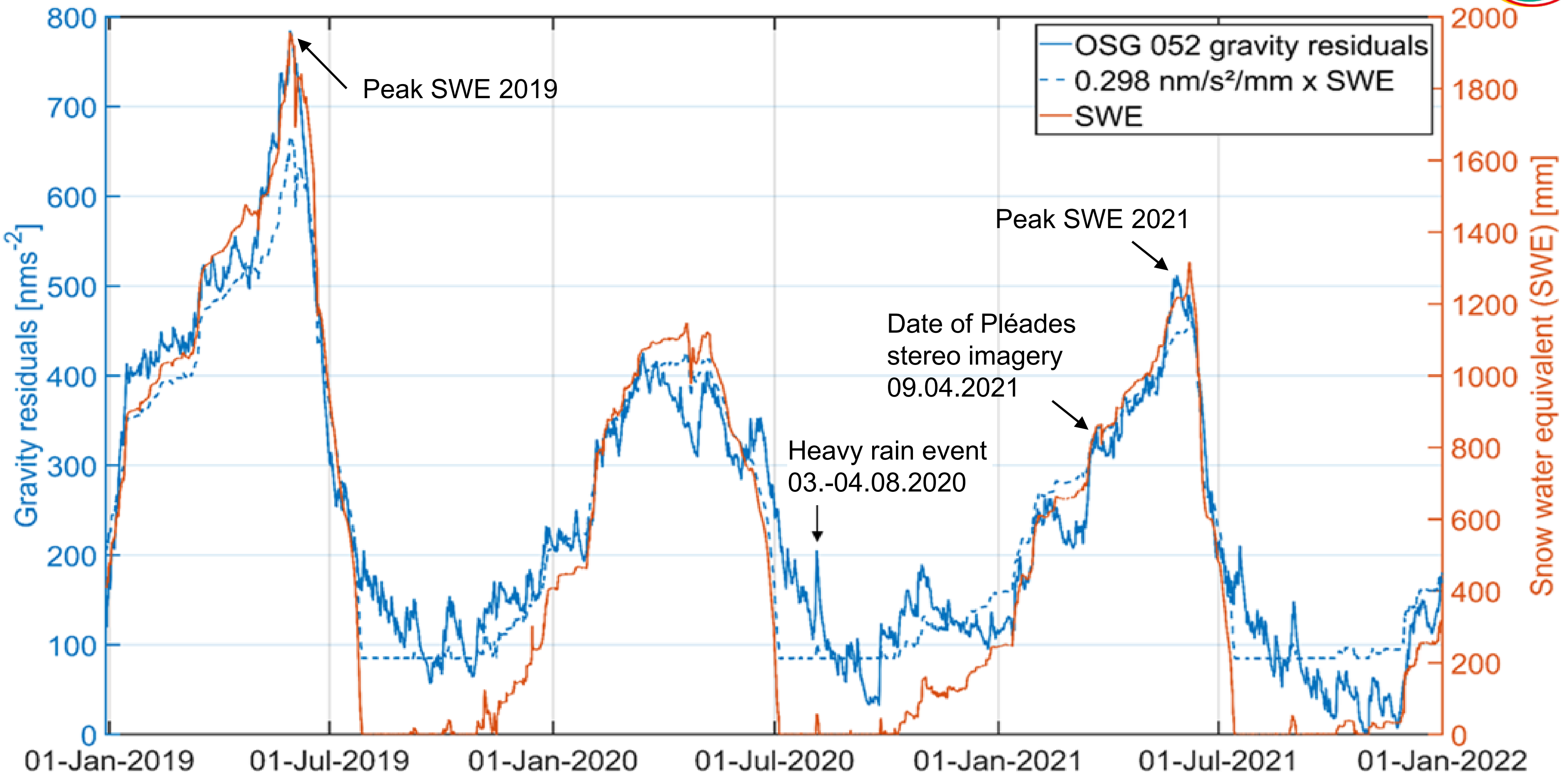
Gravity Residuals – Snowh-ydrological Mass Changes



→ High correlation of gravity residuals and in situ SWE measurements with *r* = 0.97
→ Besides the influence of the snowpack, further hydrological storages and fluxes involved

Voigt et al. 2021, HESS, data updated until Jan 2022

Gravity Residuals – Decreasing Trend of Minima

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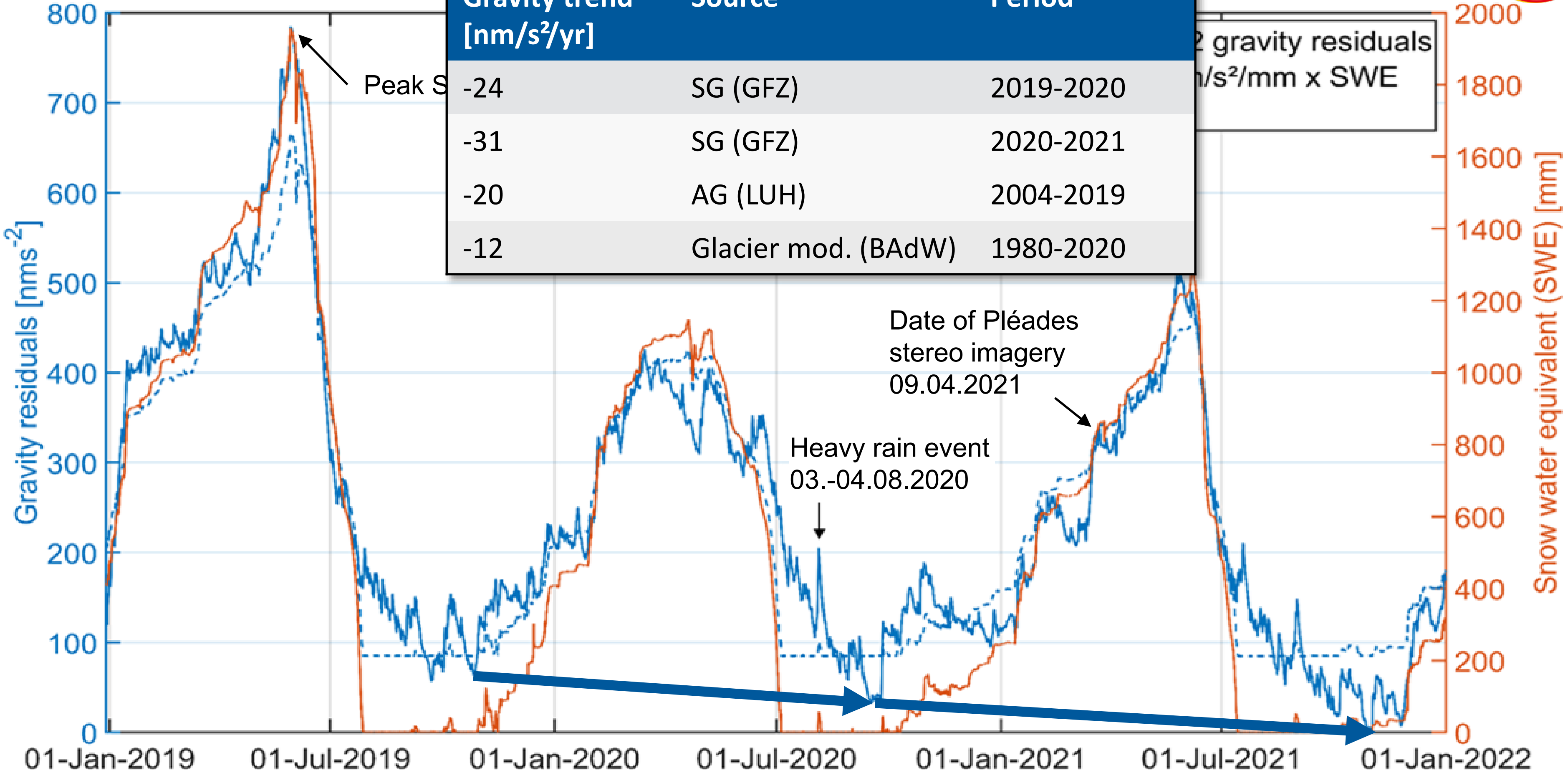
Gravity trend [nm/s²/yr]	Source	Period
-24	SG (GFZ)	2019-2020
-31	SG (GFZ)	2020-2021
-20	AG (LUH)	2004-2019
-12	Glacier mod. (BAdW)	1980-2020



→ Potential reasons: Decline in glaciers, permafrost and karst water, geomorphological redistributions, etc.
→ Decline in 2022 was 2-3 times larger → enormous glacier mass losses

Voigt et al. 2021, HESS, data updated until Jan 2022

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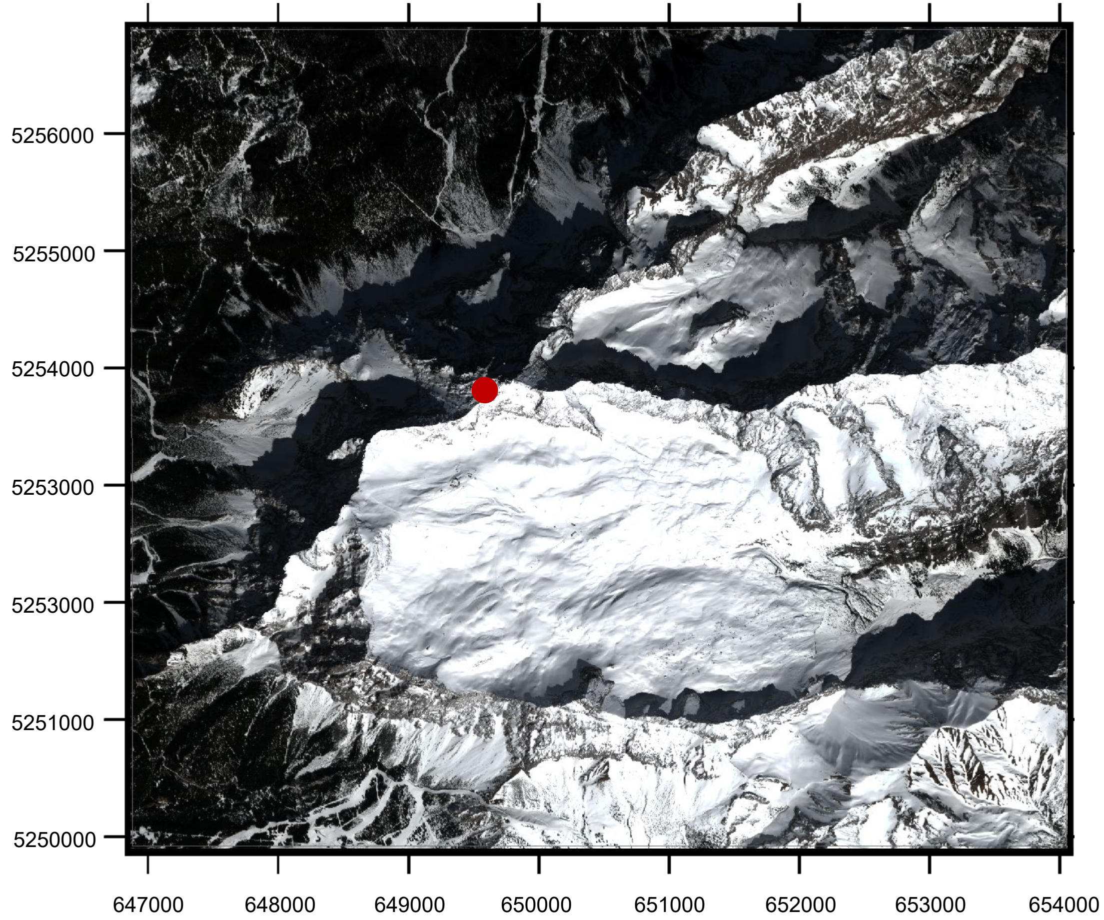
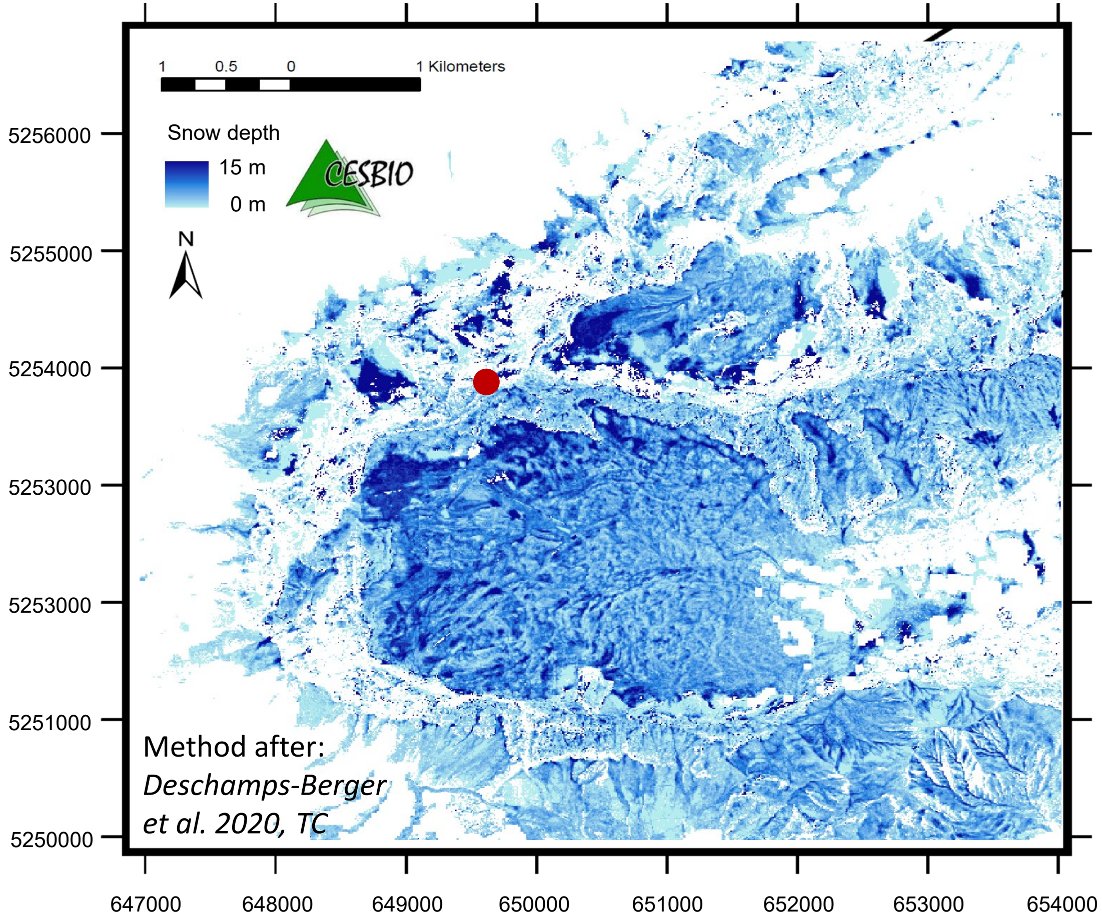
Snow-gravimetric Footprint - The Role of Satellite Photogrammetry

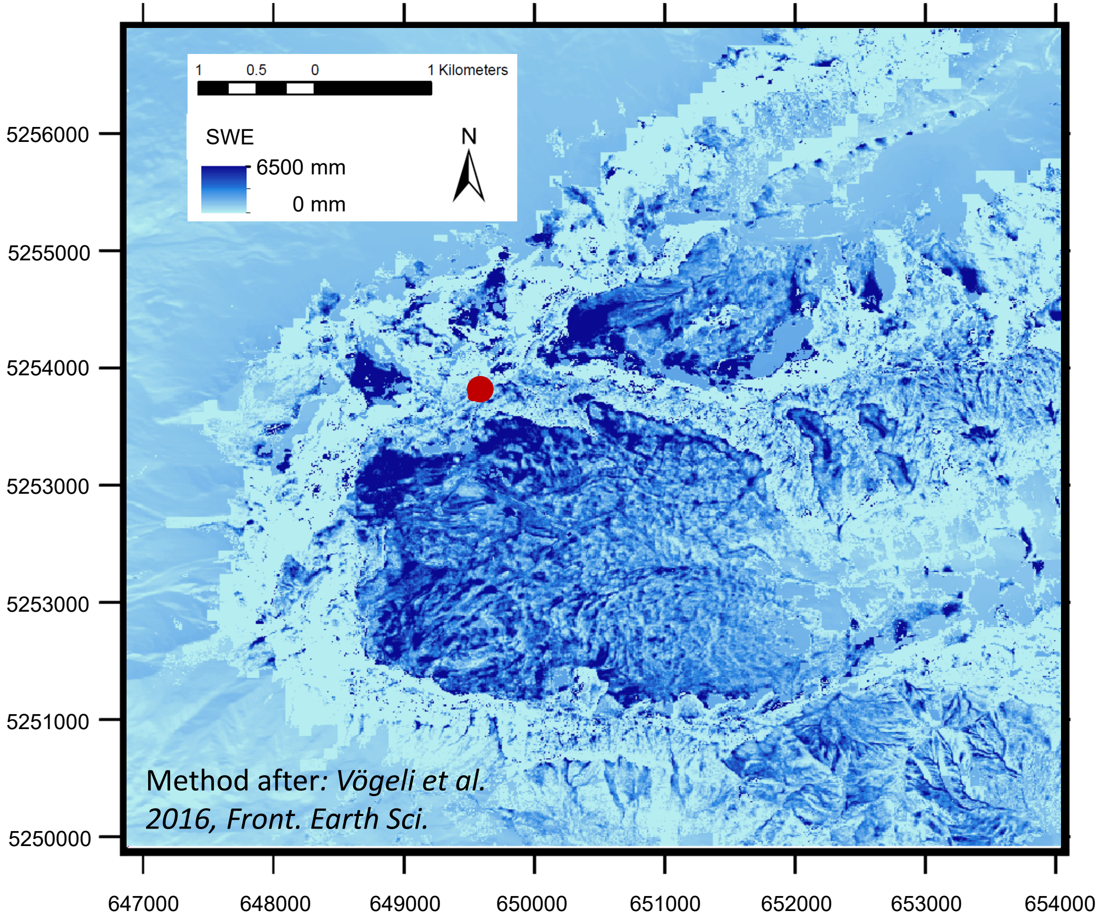
Derivation of a snow depth map based on Pléiades stereo images, date: 09.04.2021
The snow depth map serves as input for precipitation scaling for SWE modelling

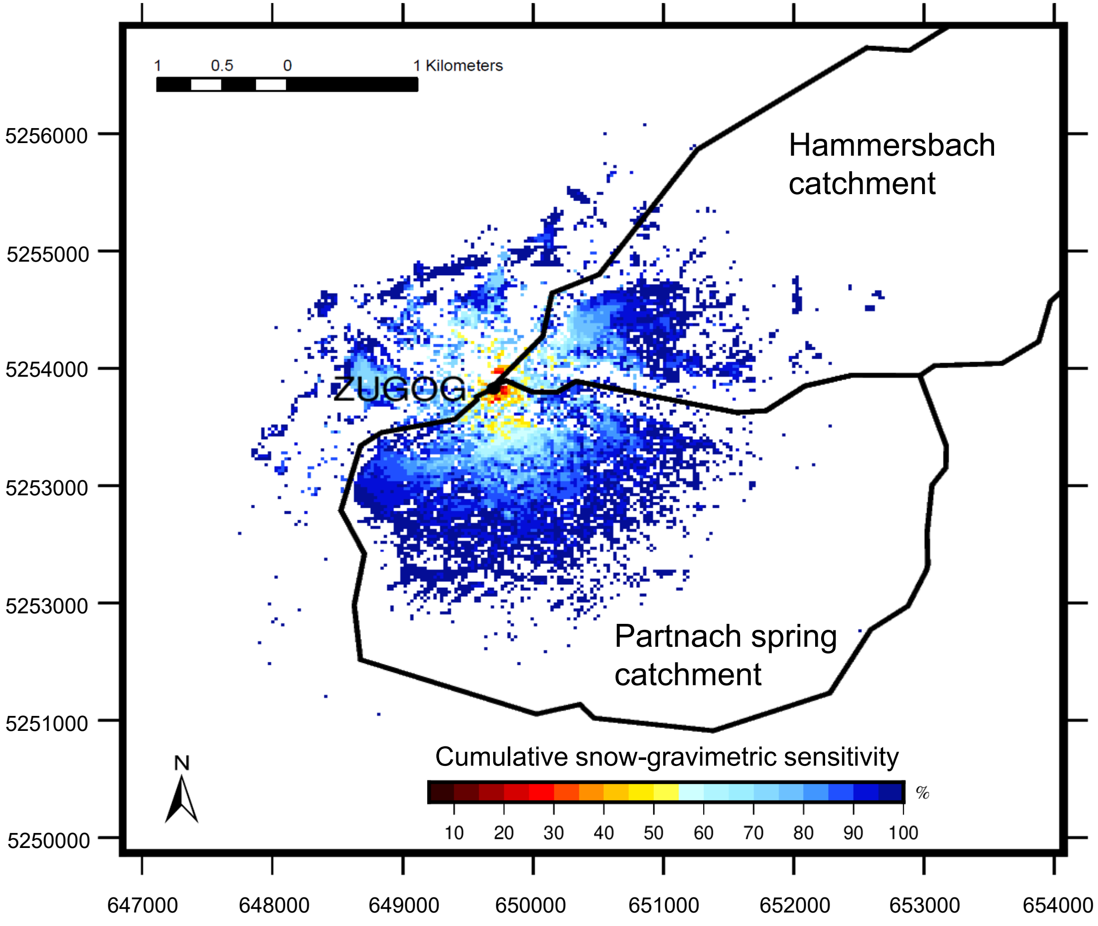




Snow-Gravimetric Footprint – SWE Simulation and Newton's Law

Derivation of cumulative snow-gravimetric sensitivities via Alpine3D simulation using precipitation scaling based on snow depth maps, topography information and Newton's Law of Gravitation





Conclusions

- **Why is the study site Zugspitze so interesting?**

  → Advantage of good instrumentation and infrastructure makes the site a snow-hydrological ‚open air lab'

  → First application of a superconducting gravimeter in high-alpine surrounding

- **How are snow-hydro-gravimetric signals derived and how do they look like?**
- **What is the influence of the snowpack and other hydrological fluxes & states on the gravimetric signal?**

  → Superconducting gravimeters are sensitive to monitor snow-hydrological mass variations in a direct, integral and non-invasive way in small high-alpine catchments

  → High correlation of the gravity residuals with in situ SWE observations

  → Influence of single rain events, annual karst water depletion as well as long-term changes (e.g. glacier melt) can be observed

- **How can we estimate the snow-hydro-gravimetric footprint?**

  → Combining snowpack simulations using precipitation scaling based on Pléiades snow depth maps, topography information and Newton's Law of Gravitation → Cumulative snow-gravimetric sensitivity

THANK YOU FOR YOUR ATTENTION

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Hydrology and Earth System Sciences
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Technical note: Introduction of a superconducting gravimeter as novel hydrological sensor for the Alpine research catchment Zugspitze

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G MONARCH

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Central research question:

To what extent can the hydro-gravimetric approach contribute to a better understanding and quantification of hydrological processes and storages in high-alpine catchments?