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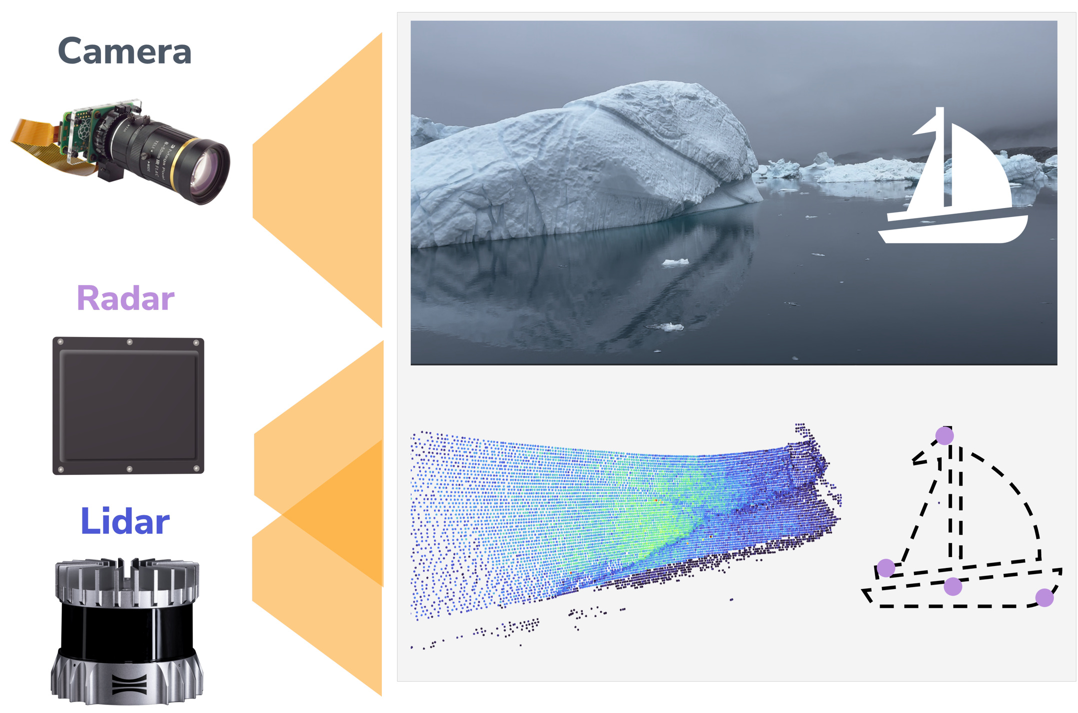
christoph.gaisberger@uni-graz.at

MOSEP - A Multi-Sensor Platform for Environmental Monitoring: Bridging the Scale Gap in Precipitation Measurement

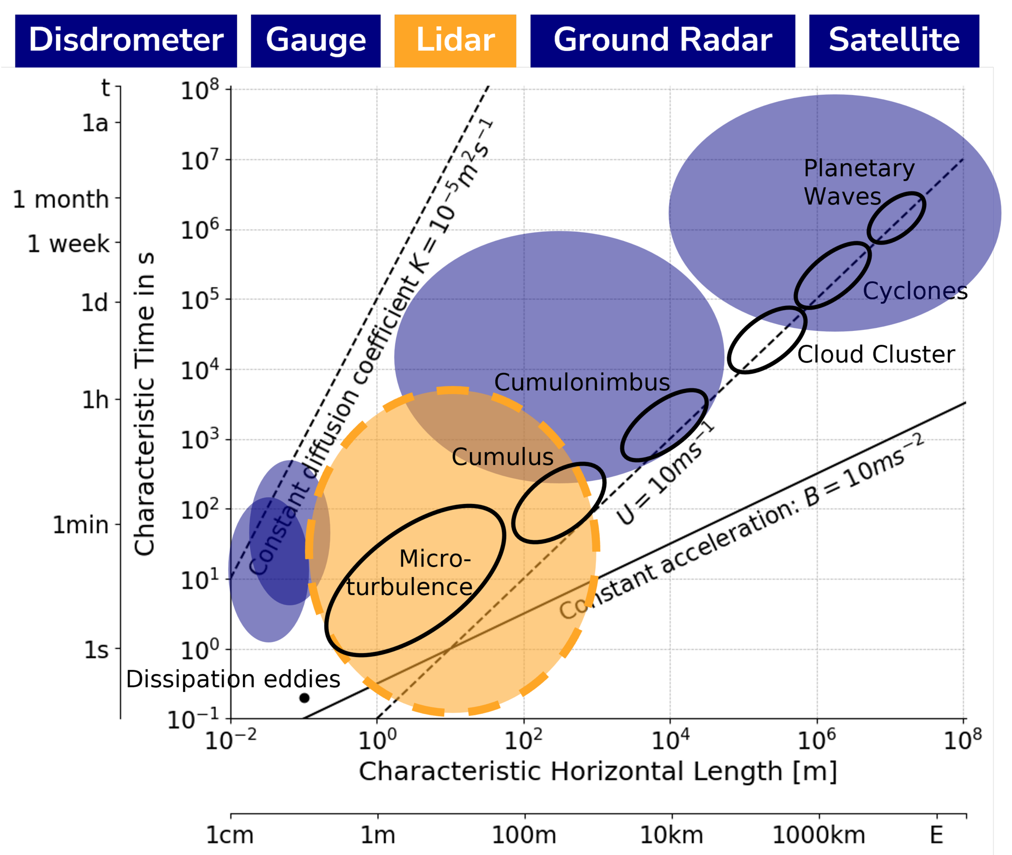
Christoph Gaisberger[1], Stefan Muckenhuber[1,2,3], Thomas Gölles[1,3], Birgit Schlager[3,1], Benjamin Schrei[1], Wolfgang Schöner[1]

Context and Motivation

Newly emerging affordable lidar sensors could play a pivotal role in future weather measurements by bridging the scale gap between localized, point-based measurements and rain radar. We are investigating the **performance of perception sensors such as cameras, lidar, and radar under adverse weather conditions**. This research is conducted to enhance the reliability and safety of autonomous vehicle operations and explore potential geoscientific applications. Gaining a **deeper understanding of weather influences also opens the possibility of infering weather information** from perception sensors. It has become apparent during our research that automotive lidar is particularly significant in this context, due to its sensitivity to precipitation, fog, or dust, and its ability to capture 3D spatial information. Both the **range and received intensity are reduced,** while **noise in the point cloud increases** with the severity of the weather influence. To explore this relationship and the overall potential of new perception sensors in geosciences, we developed the **Modular Multi-Sensor System for Environment Perception (MOSEP).**



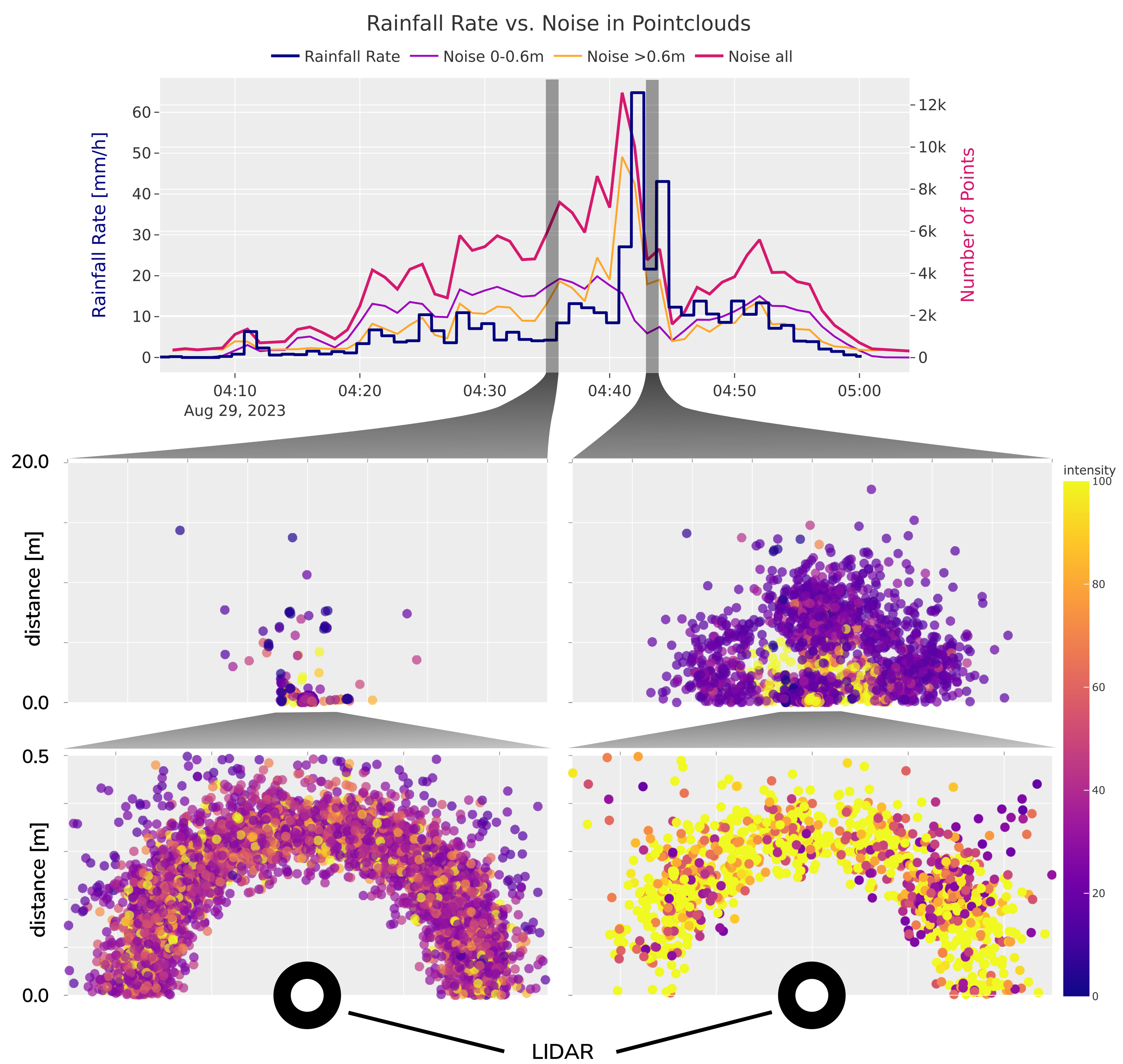
A Iceberg in Sermilik Fjord, East Greenland. Camera, radar, and lidar can be utilized in sensor fusion to capture various aspects of the environment, collectively offering more information than individual sensors alone.



B Spatiotemporal Scales of Weather Phenomena and Measurement Techniques. Atmospheric processes mapped to their spatial and temporal scales, with core areas marked by black ovals. Blue/orange circles represent common measurement techniques and their spatiotemporal resolutions. Atmospheric processes cluster around a characteristic velocity of 10 m/s (dissipation rate U). Adapted from Kraus, H. (2004).

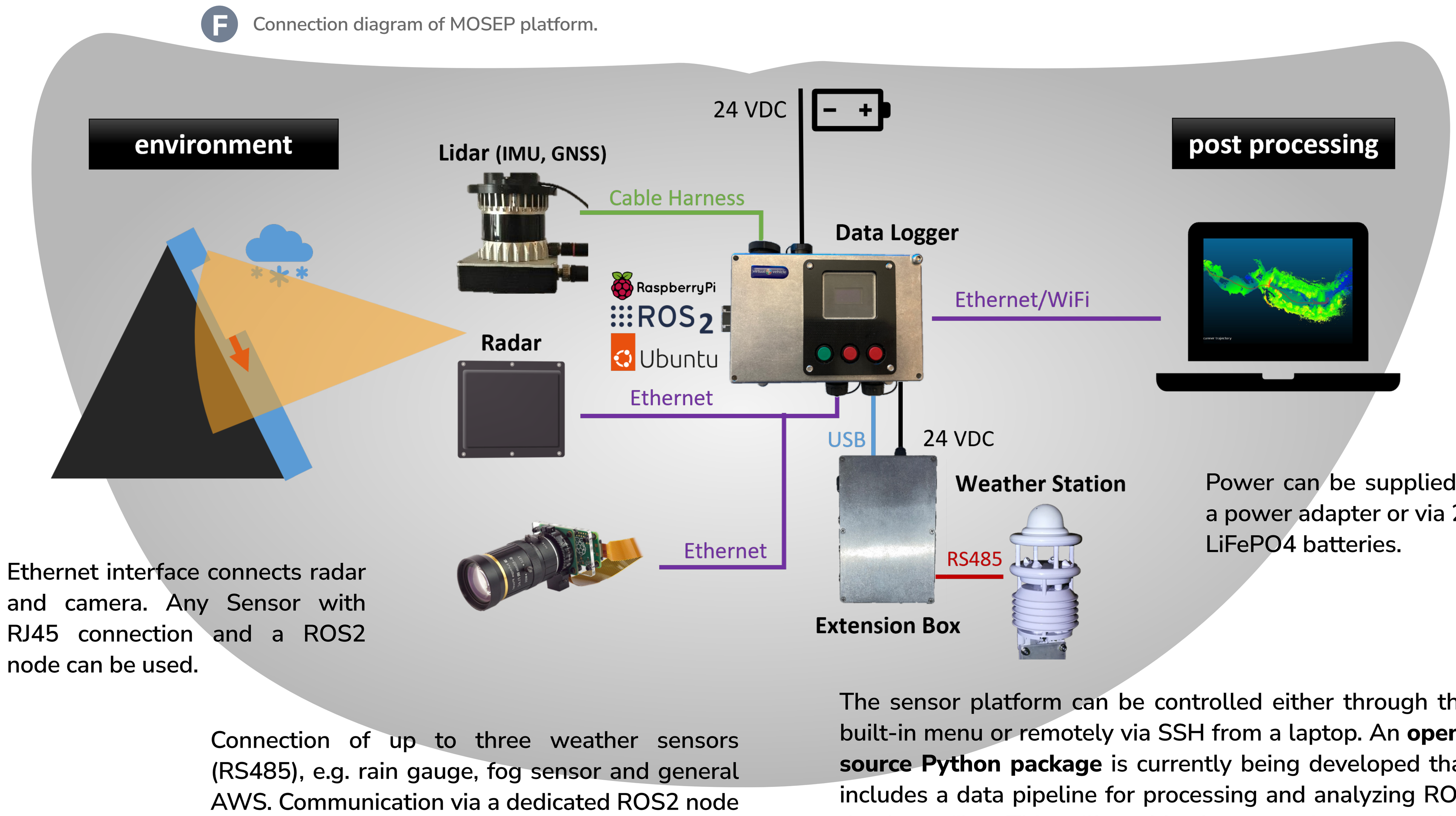
To ensure comprehension of the system, the observation scales in both space and time must be smaller than the scales of the system as a whole. This distinction leads to two key concepts:
- The scale (or magnitude) in space and time exhibited by an atmospheric process or system, and
- The observation scale

With its **temporal resolution of 20 Hz** and a **range of up to 400 m**, modern lidar systems have the potential to bridge the gap in precipitation measurements. They **operate** in one of three wavelengths in the **near infrared**. This means that they generally penetrate the atmosphere



E Top: Relationship between rainfall rate and noise in lidar point clouds during a thunderstorm with liquid precipitation. Middle: Top-down view of cumulative noise in the point cloud before (left) and during (right) the peak of a passing thunderstorm up to 20 m. Bottom: Zoomed-in view of the middle panel up to 0.5 m. A shift in noise distribution can be observed.

F Connection diagram of MOSEP platform.



Ethernet interface connects radar and camera. Any Sensor with RJ45 connection and a ROS2 node can be used.

Power can be supplied via a power adapter or via 24V LiFePO4 batteries.

Connection of up to three weather sensors (RS485), e.g. rain gauge, fog sensor and general AWS. Communication via a dedicated ROS2 node for Lufft UMB sensors.

The sensor platform can be controlled either through the built-in menu or remotely via SSH from a laptop. An **open-source Python package** is currently being developed that includes a data pipeline for processing and analyzing ROS database files. This will enable the extraction of weather data, along with point cloud or image data from the sensors, as **synchronised time series.**

MOSEP Platform

The sensor platform is divided into two main components: a primary logging unit and an extension unit. The primary unit encompasses the central computing core, alongside a data recording solid-state drive and a LTE modem. The extension unit is designed to provide additional RS485 connections and power supply for up to three weather sensors. Engineered for durability, the entire assembly is rainproof and can be powered from 24-volt batteries. Initially conceptualized around the Ouster lidar sensor, incorporating RTK GPS and an IMU, the system has since been expanded to integrate additional sensors, including radar, camera and AWS.

Sensor Platform

Core Components:
- **Primary Unit:** Houses Raspberry Pi 4, SSD, lidar interface, GPS module, LTE modem, voltage converters, and ethernet switch.
- **Extension Unit:** Offers RS485 connections and power for up to three weather sensors.

Durability and Power:
- Rain and dustproof design.
- External power supply or 24-volt batteries
- Can be transported in a single backpack

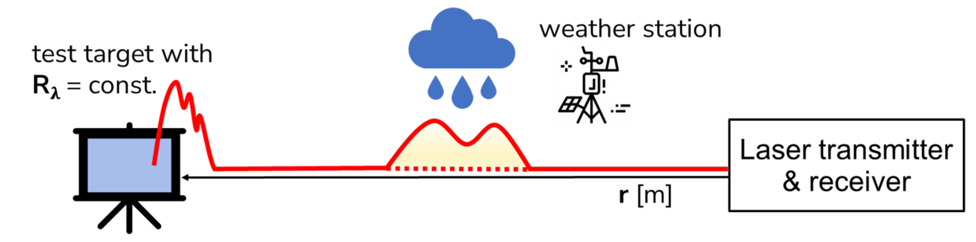
Sensor Integration:
- Ouster lidar OS1/OS2
- RTK GPS and IMU
- Smartmicro radar UMRR11-132
- Raspberry Pi HQ camera (+Pi 4)
- Lufft UMB weather stations

Software Architecture

Middleware: ROS2 Humble on Ubuntu 22.04
Data Recording: Time-synchronous data streams recorded into a unified database ('bag file').
Development: Software built on Docker and Git, open-sourced on GitHub.
Usability: Simplified operation with a menu-driven interface for field work; LTE for remote access.
Monitoring Routine: A dedicated ROS node activates sensors and measurement initiation upon rain detection for energy and storage conservation.

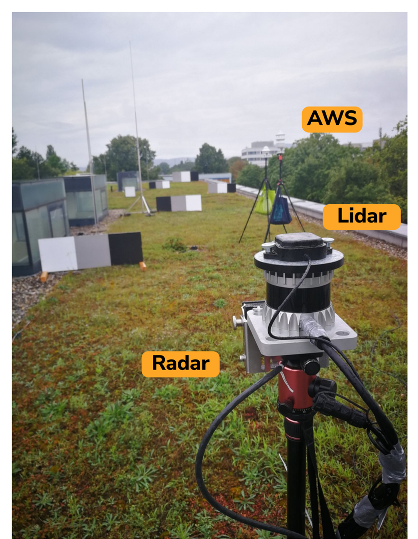
Data Analysis

Python Package: Enables easy and performant loading and analysis of 'bag files', facilitating point cloud and time series data. (Dask for lazy loading and evaluation.)



C Measurement concept of lidar in rain with a fixed target. Red curve indicates the received waveform.

Multiple passing thunderstorms were recorded, with mean rainfall rates reaching up to 65 mm/h. Below, the relationship between the measured rainfall rate (in mm/h) and the number of points (noise) detected by the lidar in the atmosphere is shown. Around 04:40, a shift in the noise distribution from close to the sensor to further away can be observed.



D Top: Long term measurements of liquid precipitation at roof top with five targets. Bottom left: Foam rubber as lambertian targets. Bottom right: Measurement campaing with lidar and radar in snowfall and three targets (T1-T3) at various distances.

SOURCES: Kraus, H. (Hrsg.) (2004): Die Skalendenkweise. In: (2004): Die Atmosphäre der Erde: Eine Einführung in die Meteorologie. Berlin, Heidelberg: 9–13. Internet: https://doi.org/10.1007/3-540-35017-9_2 (13.12.2022).

[1] Institute of Geography and Regional Sciences, University of Graz, Heinrichstraße 36, 8010 Graz, Austria
[2] Institute of Industrial Management, FH Joanneum Graz, Werk-VI-Straße 46, 8605 Kapfenberg, Austria
[3] Virtual Vehicle Research GmbH, Inffeldgasse 21a, 8010 Graz, Austria