ClimateBasis Zackenberg Manual

Version 2 – August 2025

This edition of the ClimateBasis Manual

Please note that ClimateBasis procedures are subject to ongoing changes and improvements and therefore, the manual is per definition always under construction/preliminary. If you have questions or comments to this edition, please contact:

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1. Introduction

1.1 The ClimateBasis program

The ClimateBasis monitoring programme in Zackenberg was initiated in 1995. It is a subprogram of the environmental monitoring programme Greenland Ecosystem Monitoring (GEM) and is one out of three ClimateBasis programs in Greenland with sister programs in Zackenberg (NE Greenland) and Qeqertarsuaq (Disko Bay, West Greenland) representing the Low Arctic, the High Arctic and border between the Low and High Arctic, respectively. The ClimateBasis program in Zackenberg is funded by the Government of Greenland.

The primary objective of the ClimateBasis monitoring program in Zackenberg is to establish baseline knowledge on climate and hydrology within a high arctic environment to allow the study of trends and variability of this sensitive and rapidly changing environment.

The ClimateBasis program in Zackenberg collects, processes and studies climate data by means of two automated weather station (AWS); an automated hydrometric station; and an hemispheric camera. This manual describes in detail the monitoring sites and the measured parameters.

The ClimateBasis program is closely supported by the GeoBasis program whom have a continual presence at Zackenberg station throughout the open season. GeoBasis staff undertake many of the manual hydrology measurements necessary throughout the season that allow the continuous discharge time series to be determined.

1.2 ClimateBasis data availability

Data from the ClimateBasis Zackenberg monitoring program is freely available through the GEM database https://data.g-e-m.dk/ . Any questions regarding the ClimateBasis Zackenberg data can be addressed to Kirsty Langley (kal@asiaq.gl).

All ClimateBasis data are public domain. However, when using ClimateBasis data, the DOI for each dataset must be cited and the following acknowledgement must be included: Data from the Greenland Monitoring Program were provided by Asiaq – Greenland Survey.

All timestamps referred to in the database are in UTC. Selected data from each field season is published in the 'GEM Annual Report Cards, published by Aarhus University. Prior to 2016 data were published in the 'GEM Annual Report'.

1.3 Access to Zackenberg

The Zackenberg research station is owned by the Government of Greenland and operated by the Department of Ecoscience, Aarhus University. Details on booking the facilities, use of the infrastructure and safety can be found on the web site https://zackenberg.dk/ along with the site

manual:
https://zackenberg.dk/fileadmin/Resources/DMU/GEM/Zackenberg/pdf/Site_Manual_2024_5_Maj_2025_WEB.pdf

1.4 Equipment and storage

ClimateBasis has a shelf in House 9 for storage of tools, equipment and reserve parts (Figure 1.1). The climate masts and the water level sensors on the bridge require the use of certified climbing equipment. There are 2 climbing harnesses, helmets and a rescue bag for this purpose. The safety equipment for work in the river includes a drysuit and life vest. These are used most frequently by the GeoBasis assistants and thus is stored along with other GeoBasis equipment and described in the GeoBasis Manual: https://g-e-m.dk/fileadmin/g-e-m/GEM/GeoBasis_Manual_Comp_2023_zac.pdf

Figure 1.1 ClimateBasis shelf in House 9.

2 Site Descriptions

The climate monitoring program includes four stations; two climate stations, one hydrometric station, and one hemispheric sky camera. A total of fourteen stations have existed at Zackenberg since the beginning of operations in 1995. Some have been closed down due to assembly of sensors at other stations, and some have been moved to other locations, see Figure 2.1 for locations of all stations. Table 2.1 gives the geographical location of the current and past ClimateBasis measuring sites.

Zackenberg is situated in a valley, which acts as drainage basin for the surrounding mountains and glaciers. Two climate stations (640 and 641) are located central in the valley, close to the river. The hydrological monitoring consists of one permanent hydrometric station (642_2). The stations measure all year round. The hemispheric camera (661) is placed on the roof of House5 at Zackenberg station and is in operation during the summer opening of the station. Details of the historic stations are given in section 6.

The stations are surrounded by high mountains. The highest mountain in the area is Dombjerg (1442 m) located northwest of the stations. The Palnatoke Bjerg mountain north of the stations is 1056 m, and Zackenberg mountain west of the stations is 1372 m high. On all three mountains glaciers are present on north facing slopes.

The southeast catchment of A.P.Olsen Ice Cap lies within the Zackenberg river catchment. GlacioBasis Zackenberg runs the monitoring program on the ice cap and eastern outlet glacier. Meltwater drains via the Store Sødal lake into the Zackenberg river. Intermittent draining of a glacier dammed lake, located on the northern margin of the eastern outlet glacier, causes floods in the Zackenberg river.

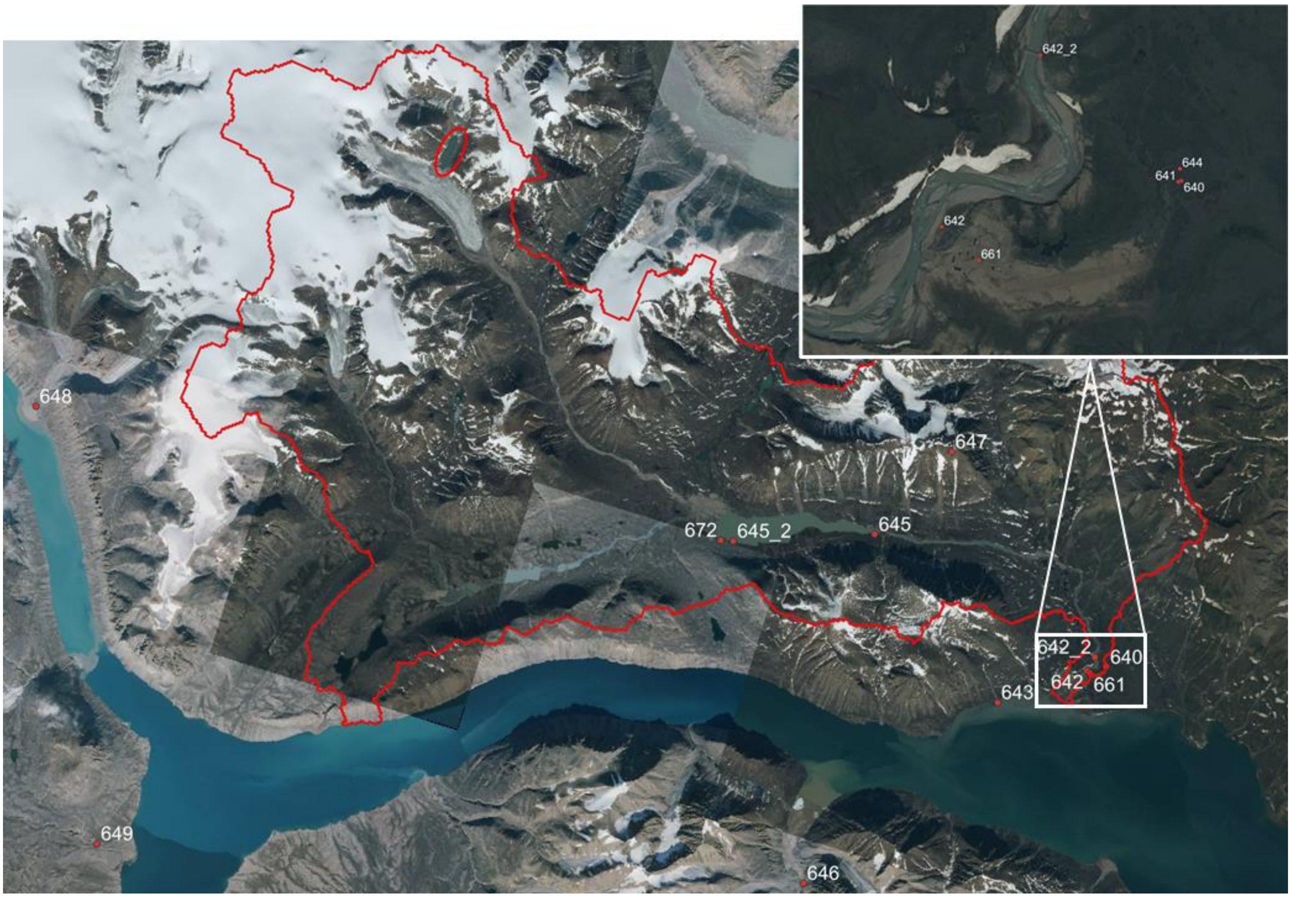

Figure 2.1 Map of ClimateBasis measuring sites in Zackenberg, including historic stations. Red oval indicates the glacier dammed lake flanking A.P. Olsen glacier. Thin red line indicates the river catchment (Mankoff et al., 2020)

Station Name	Asiaq Station Number	Latitude	Longitude	Elevation (m)
Zackenberg East Climate Station	640	N74° 28'18.9"	W20° 33'7.5"	44
Zackenberg West Climate Station	641	N74° 28'18.8"	W20° 33'8.6"	43
Zackenberg Hydrometric Station	642_2	N74°28'31.28"	W20°33'59.18"	22
Zackenberg Hemispheric camera	661	N74°28'11.08"	W20°34'22.25"	40
Zackenberg Hydrometric Station	*642*	*N74° 28'14.5"*	*W20° 34'36.3"*	*21*
Zackenberg Tidal Water Station	*643*	*N74° 27'36.0"*	*W20° 41'30.0"*	*4*
Zackenberg Snow Station	*644*	*N74° 28'20.1"*	*W20° 33'8.0"*	*41*
Zackenberg Hydrology Station	*645*	*N74° 31'5.3"*	*W20° 50'56.0"*	*166*
Zackenberg Diver Station	*645_2*	*N74° 30'56.54"*	*W21° 01'39.48"*	*168*
Zackenberg Timelapse Camera	*672*	*N74° 30'57.59"*	*W21° 02'41.99"*	*168*
Zackenberg Hydrometry	*646*	*N74° 28'12.0"*	*W20° 34'23.0"*	*30*
Zackenberg Hydrometry	*648*	*N74° 33'35.35"*	*W21° 55'52.30"*	*30*
Zackenberg Hydrometry	*649*	*N74° 24'35.25"*	*W21° 50'24.53"*	*30*
Zackenberg Dombjerg Station	*647*	*N74° 32'46.9"*	*W20° 44'57.9"*	*1282*

Table 2.1 Positions of ClimateBasis measuring sites incl. historic stations (*italic types*). Positions are measured with a handheld gps.

2.1 The Climate Monitoring Stations 640 and 641

The two almost identical climate stations, 640 and 641, are placed in the same microclimatic environment in the central valley of Zackenberg river drainage basin. This drainage basin includes Zackenberg valley, Store Sødal, Lindemansdalen and Slettedalen, and covers an area of 512 km^2, of which 106 km^2 are covered by glaciers. The masts are placed on a uniform and planar remnant of a meltwater plain approximately 43 m above mean sea level. The vegetation underneath the masts is a homogeneous cover of Cassiope vegetation which is 0-20 cm high. The location is representative of large parts of the landscape and vegetation in the valley.

The climate monitoring program utilizes a double mast setup, with independent sensors and power supply to give redundant measurements, increasing the robustness of the timeseries. Each climate station consists of a 7.5m main mast (erected in 1995), a 2m mast used for windspeed and radiation on station 640 and for snow depth on station 641 (both erected in 1997), and a precipitation gauge (erected in 1995), see Figure 2.2.

Station 640 is equipped with an Iridium modem transferring data to Asiaq once per day. A radio link is used to establish contact between 640 and 641, and 640 and the hydrometric Station 642_2 for the data transfer. To assist with data processing and quality control, a small timelapse camera is attached to the 641 main mast with a view of the snow depth sensors and the precipitation gauge. Images are taken once per day.

The parameters measured and instrumentation on each mast is given in Table 3.1.

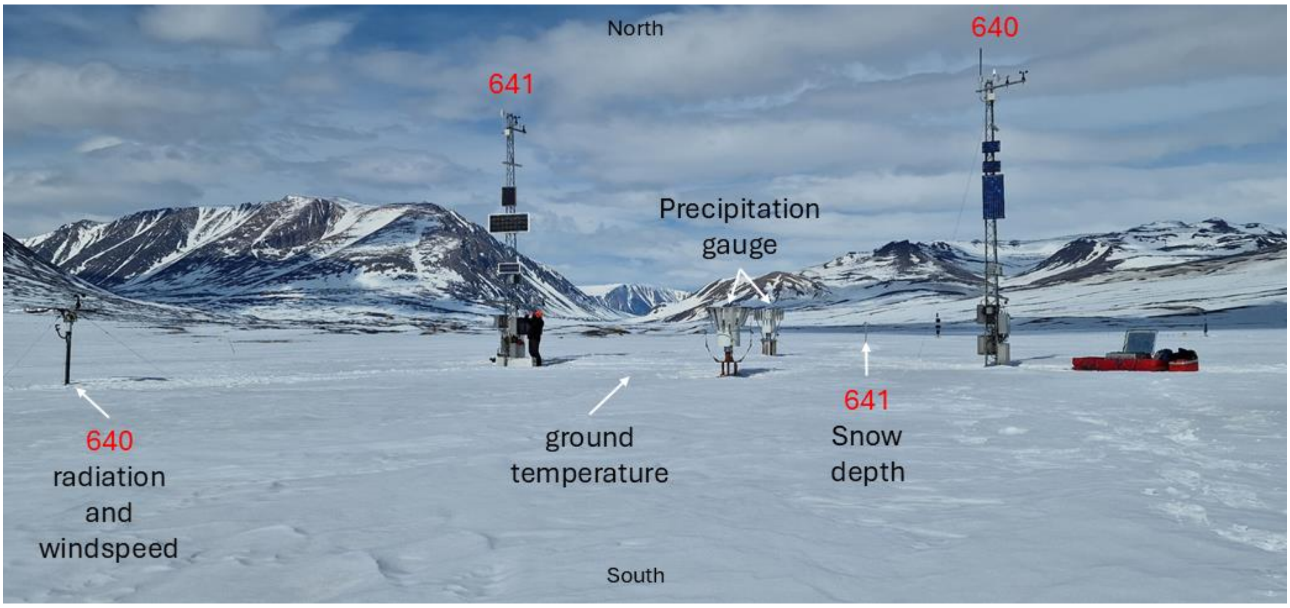

Figure 2.2 An overview of the double mast climate station 640 and 641.

2.2 Hydrometric Station 642_2

The hydrometric station 642_2 is located by the Zackenberg River, 600m NW from the climate stations 640 and 641 and approximately 2 km from the Zackenberg Bay, 22 m above sea level.

The hydrometric station was first established as station 642 in August 29th 1995 on the western bank of the river, close to the Zackenberg station (Figure 2.1). In 1998 the station was moved to the eastern bank of the river after problems with it being buried beneath a thick snowdrift each winter. In 1999 the hydrometric station was flushed away in a spring Glacier Lake Outburst Flood (GLOF). This happened again in July 2005 in a major GLOF. Due to a change in the river cross profile, the station was rebuilt on August 5th 2005, 30-40 m south of the old location, still on the eastern bank. In late November 2009 the sensor and part of the cross arm were ripped off in a GLOF. In August 2012 the entire hydrometric station, including the setup for the discharge cross-section, was destroyed in a major GLOF which once again caused major changes to the riverbed. After the flood, the data logger box was moved approx. 100 meters downstream.

In spring 2014 the hydrometric station 642_2 was mounted on the new bridge crossing the Zackenberg River. The bridge is located approximately 650m north of the Zackenberg research station (Figure 2.1).

2.2.1 Bridge sensors

The station has sensors mounted on the bridge running autonomously measuring water level, water temperature, water surface velocity, air temperature and humidity. In addition, two pressure transducers are mounted on a metal frame placed on the riverbed, as a backup to the water level measurements. The data logger box, batteries, solar panel and air temperature and humidity sensor are on the bridge foundation on the eastern bank, see Figure 2.3. The parameters measured and instrumentation is given in Table 3.2

2.2.2 Timelapse Cameras

Since 2017, a timelapse camera is attached to the bridge support on each side of the river. The images are used to help identify the river break up and freeze in, if the station is unmanned, and for the processing and quality control of the river data. The cameras take images once per hour while the Zackenberg station is staffed and once per day during the winter.

2.2.3 Discharge Measurements

Discharge measurements are carried out on a cross section just downstream of the bridge, using the bridge as a line anchor, see Figure 2.3.

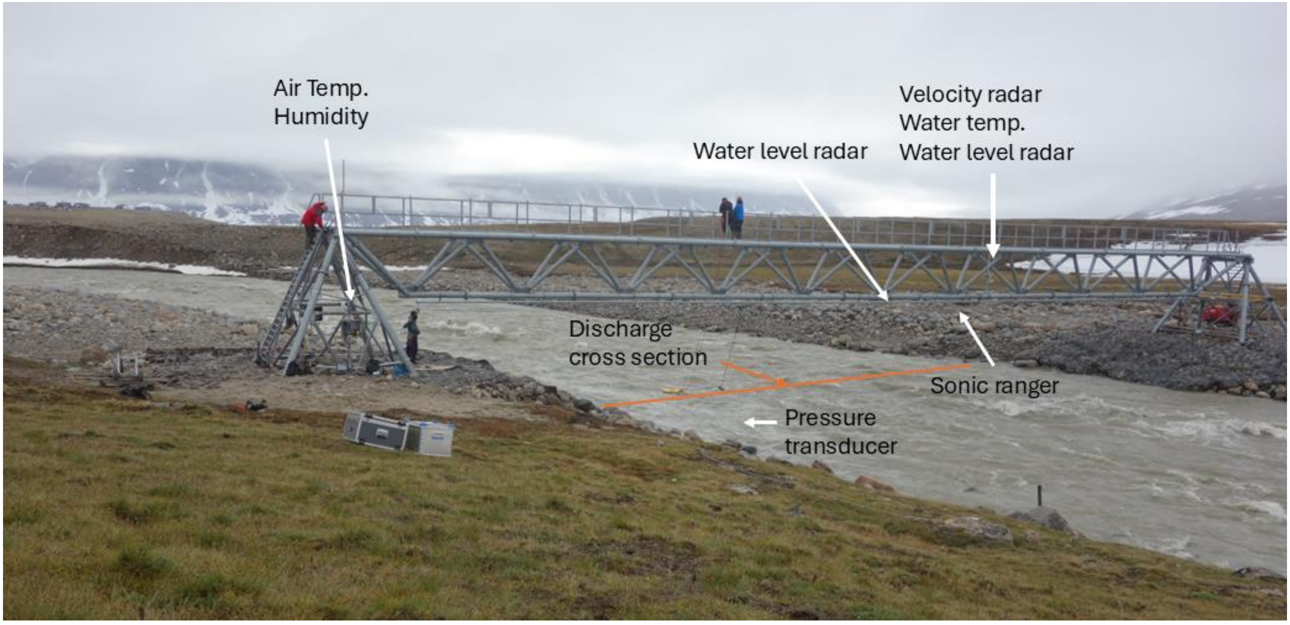

Figure 2.3 Hydrometric Station 642_2.

2.2.4 Fixed Reference points

Five reference points are located near the hydrometric station enabling establishment of a local, regional, and global reference system. This is used to determine the water level during discharge measurements. Reference point locations can be seen in Figure 2.4 and coordinates and elevations are given in Table 2.2.

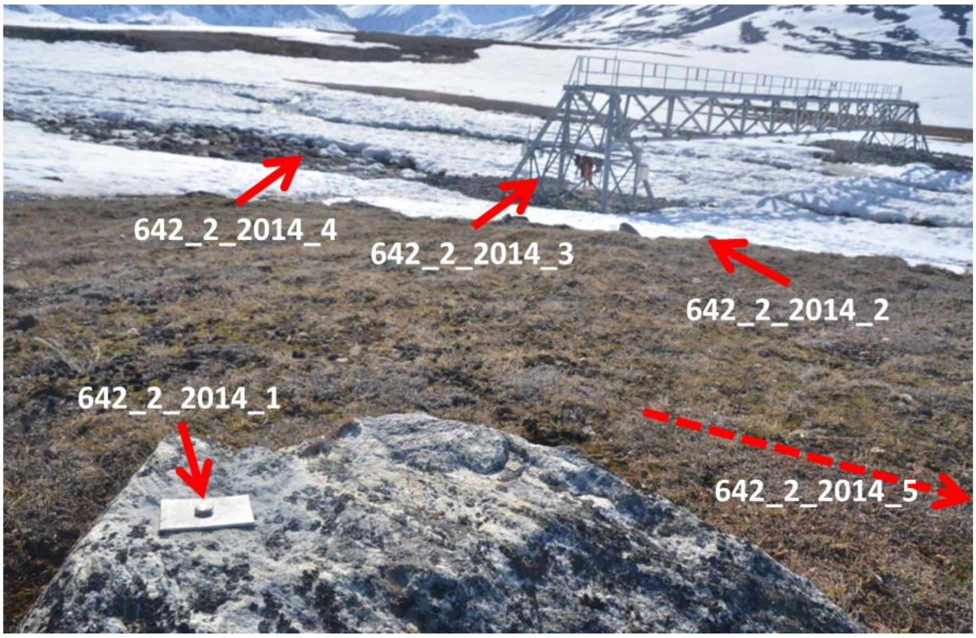

Figure 2.4 Fixed points at station 642_2

Reference point	Northing	Easting	Elevation (m)
642_2_2014 1	8265128.226	512980.189	79.405
642_2_2014 2	8265146.124	512958.242	76.111
642_2_2014 3	8265119.925	512952.838	75.130
642_2_2014 4	8265104.565	512942.097	74.207
642_2_2014 5	8265276.000	513100.000	86.093

Table 2.2 Positions of ClimateBasis reference points as measured in 2014 using DGPS and levelling from 642_2_2014 1.

2.3 Hemispheric Camera

In order to derive fractional cloud cover with the algorithm by Wacker et al. (2015), a hemispherical camera is operated during the summer months. The camera is setup and installed by the GeoBasis assistant when the station opens in spring and is taken down again in the autumn at the end of the station season. The camera is placed on the roof of House5 and has been in operation since 2016.

The camera used is a security camera from the manufacturer Mobotix. Purpose-made cameras for scientific purposes exist and have certain advantages over the type used here (e.g. a shading device to block out direct sunlight similar to what is used to measure diffuse solar radiation; also, a known mathematical model for the lens distortion – in the case of security cameras this is inaccessible proprietary information). However, besides cost, the primary advantage of the camera used here is its sturdiness with respect to weather influences. The original algorithm is being improved and adapted to arctic conditions.

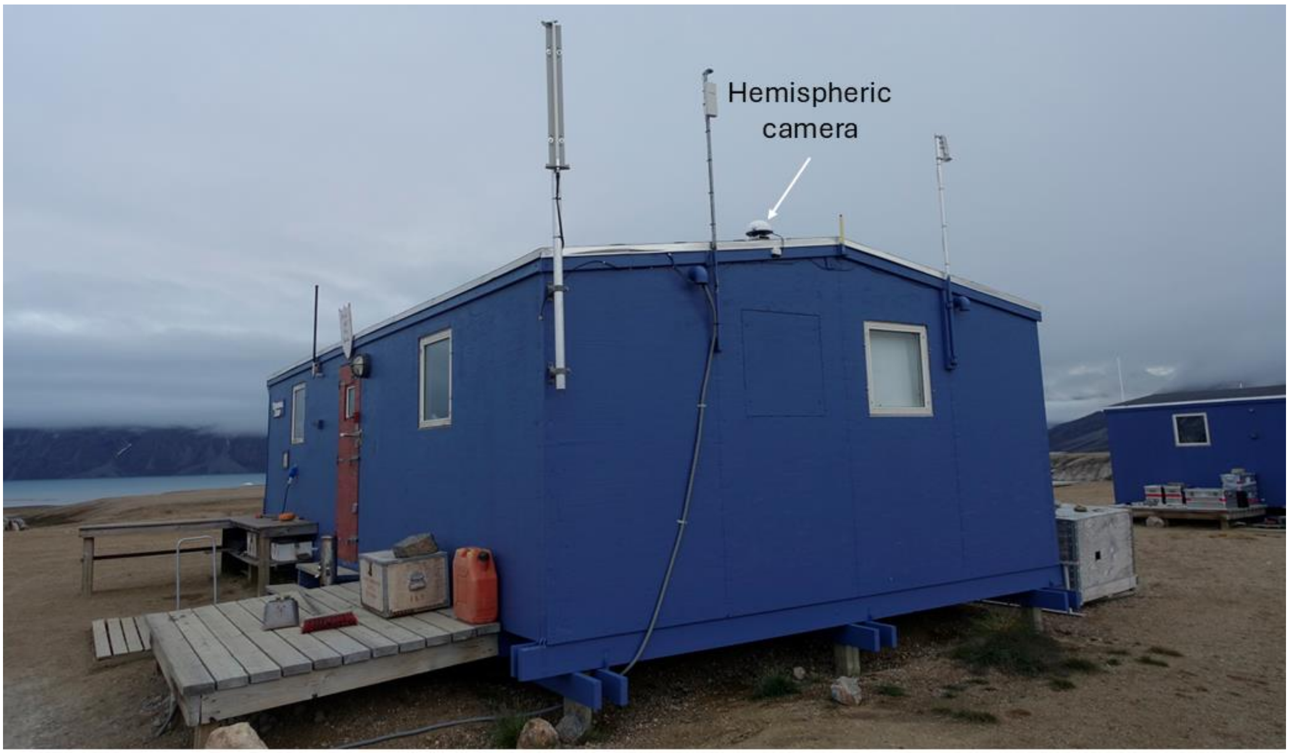

Figure 2.5 Hemispheric camera on House5

3 Measured Parameters

3.1 The Climate Stations, 640 and 641

At the climate stations, 640 and 641, 15 different parameters are measured. In Table 3.1 the parameter, current sensor type, sensor height above terrain and specifications are seen with the aggregation method.

parameter	sensor	range	sensitivity	accuracy	valid at
air temperature	Rotronic, HC2A-S3	-50–100 °C	0.1 °C	± 0.1 °C	23 °C
		2 m	30 - sample, ave, min, max		
		7.5 m	30 - sample, ave, min, max		
relative humidity		0–100 %	0.1 %	± 0.8 %	23 °C
		2 m	30 - sample, ave		
		7.5 m	30 - sample, ave		
air pressure	Vaisala, PTB110	600–1060 hPa	0.1 hPa	± 0.3 hPa	20 °C
		1.6 m	30 – average		
wind speed	Theodor Friedrichs 4037.1400	0.3–60 ms^{-1}	0.5 ms^{-1}	±0.3 ms^{-1}	>15 ms^{-1}
				± 2 %	<15 ms^{-1}
		2 m	10 – ave, max		
		7.5 m	10 – ave, max		
wind direction	Theodor Friedrichs 4137.1400	360°	0.35°	± 1°	0.2 ms^{-1}
		7.5 m	10 – ave, std		
radiation Shortwave Longwave	Kipp & Zonen, CNR4	300-2800nm 4500-42000nm	5 -20 $\mu V/W/m^2$	±5% < ±10%	daily
		2 m	5 – ave		
UV-B	Solar Light, 501A*	0–10 $MEDh^{-1}$		± 5 %	daily
		2 m	5 – ave		
PAR	Kipp & Zonen, PAR Lite	0–10000 $\mu mol/m^2s$	4–10 $\mu V/\mu mol/m^2s$	± 3 %	
		2 m	5 – ave		
Relative vegetation index	Skye Inst. SKR110*	<500 $\mu mol/m^2s$	100 $\mu mol/m^2s$	± 10 %	
		2 m	5 – ave		
precipitation	Ott, Pluvio^2	6 - 1800 mm/hr	6 mmh^{-1}	6 mmh^{-1}	
			60 – sample		
snow depth	Campbell Scientific, SR50A	0.5–10 m	0.25 mm	± 1 cm or 0.4 %	
		2 m	ave over last 2 of every 60 minutes		
ground temperature	Campbell Scientific, 107 probe	-35 - 50 °C		±0.4 °C ±0.9 °C	–24 to 48 °C –35 to 50 °C
		0, 0.025, 0.05, 0.1, 0.2, 0.4, 0.6, 0.8, 1, 1.3 m	60 – sample		

Table 3.1: Parameters measured at climate station 640 and 641. For each parameter, the parts of the table underlain in blue give the sampling scheme currently in use. For several sensor types, more than one sensor is mounted at different heights, which are given in the first column, whereas the second column gives the sampling type for a given sampling frequency. For example, | 2 m | 10 - sample; 60 - sample, ave, min, max | means that for the sensor mounted at 2 m above ground, point samples are archived every 10 minutes, whereas samples, averages over the whole sampling period, minimum and maximum values over the sampling period are archived every 60 minutes. (*) Only on 641.

3.2 The Hydrometric Station 642_2

At the Hydrometric Station 642_2 seven parameters are measured. In Table 3.2 the parameter, sensor type, sensor height above terrain and specifications are seen with the aggregation method.

parameter	sensor	range	sensitivity	accuracy	
					valid at
air temperature	Rotronic, HC2A-S3	-50–100 °C	0.1 °C	± 0.1 °C	23 °C
		+2 m	30 - sample, ave, min, max		
relative humidity		0–100 %	0.1 %	± 0.8 %	23 °C
		+2 m	30 - sample, ave		
Water level 1+3	Vegapuls (10° beam angle)	200mm – 15m	1 mm	± 3 mm	-40-80 °C
		Approx. 4 m	15 - sample, ave		
Water level 2	Campbell Scientific, SR50A	0.5–10 m	0.25 mm	± 1 cm or 0.4 %	
		Approx. 4 m	15 - sample, ave		
Water level 4+5	Van Essen Inst. Diver D1801	0 - 10 mH2O	0.002 mH2O	0.005 mH2O	
		Approx. -2 m	15 – sample		
Water temperature 4+5	Van Essen Inst. Diver D1801	-20 - 80 °C	0.01 °C	± 0.1 °C	
		Approx. -2 m	15 – sample		
Surface Water temperature	Campbell Scientific IR100	-25 - 60 °C		± 0.2 °C	-25 – 25°C
		Approx. 4 m	15 – sample		
Surface water velocity	Sommer RG-30a	0.3 – 15 m/s	1 mm/s	± 0.02m/s; ± 1%	-35 – 60°C
		Approx. 4 m	15 – sample		

Table 3.2: Parameters measured at hydrometric station 642_2. For each parameter, the parts of the table underlain in blue give the sampling scheme currently in use. For several sensor types, more than one sensor is mounted at different heights, which are given in the first column, whereas the second column gives the sampling type for a given sampling frequency. For example, | 2 m | 10 - sample; 60 - sample, ave, min, max | means that for the sensor mounted at 2 m above ground, point samples are archived every 10 minutes, whereas samples, averages over the whole sampling period, minimum and maximum values over the sampling period are archived every 60 minutes.

4 Procedures

4.1 Climate Station Maintenance

Once per year, the climate station is visited by Asiaq personnel to perform maintenance and reference testing. This includes a check of the installation's hardware and a change of sensors where necessary. Sensors are replaced in regular intervals by freshly calibrated ones (1-2 years for temperature and humidity sensors, 2-4 years for radiation sensors; wind sensors have their ball bearings replaced every 2-4 years and the acoustic snow depth sensor has its membrane changed every 1-2 years). Malfunctioning sensors are replaced as soon as possible.

Reference tests are conducted with calibrated sensors upon arrival at the station and at the end of the visit, after sensors have been replaced. Table 5: Conducted reference tests and allowable deviations between installed and reference sensors. shows the reference tests conducted and the respective permitted tolerances for the tests.

The sensor measuring UV-B radiation is always left in place, but a calibrated reference sensor is installed and collects data during each station visit. The measurements collected by the fixed sensor are then corrected with the help of the temporary / calibrated sensor.

sensor	**tolerance**
air temperature	± 0.5 K
relative humidity	± 3 %
wind speed	± 1 m s^{-1}
wind direction	± 10˚
atmospheric pressure	± 0.5 hPa
shortwave radiation	± 15 W m^{-2}
snow depth	± 1 cm

Table 5: Conducted reference tests and allowable deviations between installed and reference sensors.

Field reports, detailed log sheets and photos are filled out and collected during each visit, including the serial numbers of installed sensors.

4.2 Hydrometric Station Maintenance

Many of the hydrometric station manual measurements are carried out by the GeoBasis Assistants whom have a continuous presence in Zackenberg during the open season.

4.2.1 Automated Measurements

Once per year, the climate station is visited by Asiaq personnel to perform maintenance and reference testing. This includes a check of the installation's hardware and a change of sensors where necessary. Sensors are replaced in regular intervals by freshly calibrated ones (1-2 years for temperature and humidity sensors, acoustic snow depth sensor has its membrane changed every 1-2 years). The remaining water level, surface water temperature and velocity sensors on the bridge are maintenance-free. The divers are attached to a frame that is put into the river as soon as possible after the river breakup, once the river bed is ice and snow free. It is removed again at the end of the season before the river freezes in.

4.2.2 Manual water level measurements

Manual water level measurements are made with a laser range finder. Distance is measured from the water surface to a known target beneath the bridge. Measurements are made on a daily basis after river break-up and until there is water flowing beneath one of the automated bridge sensors. A measurement is also made in conjunction with manual discharge measurements (section 2.2.3), and if the frame housing the divers is moved.

4.2.3 Discharge measurements

Manual discharge measurements are made at a cross section under the bridge (Figure 2.3). These are necessary to establish and verify the stage-discharge relation used to derive the full discharge record from the water level times series. In years with large GLOFs, the bed profile can be altered requiring enough discharge measurements to establish a new stage-discharge relation.

The method used and frequency of measurements depends on the water depth and flow conditions. For water depths between 0.5-5 m, an Acoustic Doppler Current Profiler (ADCP) of type OTT Q-Liner is used to obtain a vertical velocity profile at set distances across the river. For water depths < 0.5 m a Valeport electromagnetic flowmeter is used. While there is snow and ice in the channel at the start and end of the season an attempt is made to make measurements every 1 to 3 days. During GLOFs, measurements are made as often as possible. At other times, measurements are made at relevant water levels to supplement the stage-discharge relation.

4.2.4 Levelling of fixed points

The area around the bridge is not solid bedrock, thus, in order to control that the sensors on the bridge are stationary, fixed points close to the bridge, the bridge eastern foot, and the water level sensors attached to the bridge are levelled in relation to each other 3 times per season using a Wild NA2 level instrument.

4.2.5 DGPS of the river bed

The profile of the bed at the discharge cross section is necessary to accurately determine discharge. To supplement the bed profile obtained with the discharge measurements, the bed profile is measured with DGPS equipment. This is done once per year at the end of each season when water level is very low.

4.3 Hemispheric camera

The camera features a high resolution 6 Mega pixel colour sensor with a fish eye lens (10 mm objective). The camera is placed in a ventilation and heating unit which allows a continuous air flow to be blown over the lens in order to impede the formation and accumulation of ice and snow. The camera is set up on the roof of the building by the GeoBasis Assistant at the beginning of each season and taken down again at the end of the season. The camera is basically maintenance free requiring only the download of images at the end of each season.

5 Data Quality Control

Quality control of the archived data is performed annually. Every timeseries is manually checked for unlikely values on the basis of expert knowledge. The double sensor setup is used for comparison to detect outlying values. The same parameter measured by different sensors, and at different heights on the climate mast (as with air temperature, relative humidity and wind speed) is also used for comparisons.

5.1.1 Precipitation

The precipitation is measured at the climate stations with the accumulating Ott Pluvio^2 rain gauge. In order to minimize evaporation and prevent freezing during the winter, a mixture of antifreeze and oil (6 l / 0.5 l, respectively) is added to the gauge after emptying it during a station visit. The sensitive pressure cell of the gauge registers some noise, whose sources are still under investigation. Wind, which is usually strong during rain or snow events, presumably leads to vibrations which may be reinforced / more easily transmitted in the presence of ice and snow in and around the gauge.
The data is therefore transformed into hourly rainfall increments by first applying the “neutral aggregating filter” (NAF) by Pan et al. (2016; Smith et al., 2019) and then differencing the accumulated timeseries.
No attempt is made to correct for wind-induced undercatch; however, it should be noted that we found that the amount of solid precipitation (snow) caught by the gauge typically exceeds water equivalent calculations based on other sources (e.g. snow depth sensor).

6 Historic Stations

6.1 Hydrometric Station 642

Active: 1995-2015
Parameters: Water level, Water temperature, Conductivity, Turbidity, Discharge, Air Pressure, Air temperature

6.2 Tidewater Station 643

Active: 1996 – 1998
Parameters: Water level, Water temperature, Conductivity

6.3 Snow Station 644

Active: 1997-2009
Parameters: 2m Air temperature, 0m Surface temperature, Snow depth

6.4 Store Sødal stations

6.4.1 Hydrometric Station 645

Active: 2000 - 2006
Parameters: Water level, Water temperature, 2m Air temperature,

6.4.2 Diver stations 645 and 645_2

Active: 2018 - 2020
Parameters: Water level, Water temperature

6.4.3 Timelapse camera 672

Active: 2018 - 2020

6.5 Diver Stations 646, 648, 649

Active: summer 2012
Parameters: Water level, Water temperature, Air pressure, Air temperature, Discharge

6.6 Dombjerg Climate Station 647

Active: 2006 - 2007
Parameters: 2m Air temperature, Surface temperature, Relative humidity, Wind speed, Wind direction, Snow depth