Hydrometeorological Data from a Remotely Operated Multi-Parameter Station network in Central Asia

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Abstract

The Regional Research Network „Water in Central Asia" (CAWa) funded by the German Federal Foreign Office consists of 18 remotely operated multi-parameter stations (ROMPS) in Central Asia. These stations were installed by the German Research Centre for Geosciences (GFZ) in Potsdam, Germany in close cooperation with the Central-Asian Institute for Applied Geosciences (CAIAG) in Bishkek, Kyrgyzstan, the national hydrometeorological services in Tajikistan and Uzbekistan, the Ulugh Beg Astronomical Institute in Tashkent, Uzbekistan, and the Kabul Polytechnic University, Afghanistan. The primary objective of these stations is to support the establishment of a reliable data basis of meteorological and hydrological data especially in remote areas with extreme climate conditions for applications in climate and water monitoring in Central Asia. Up to now, ten years of data are provided for an area of scarce station distribution and with limited open access data which can be used for a wide range of scientific or engineering applications. The data described in this manuscript is made publicly available with the Digital Object Identifier (DOI) https://doi.org/10.5880/GFZ.1.2.2020.002 (Zech et al., 2020) or via the Sensor Data Storage System (SDSS) at http://sdss.caiag.kg.

1. Introduction

Central Asia with its former Soviet republics Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan is a region that varies from high mountains to deep valleys, vast deserts and fertile river basins. Due to this wide range of natural diversity, large differences in climate forming factors like temperature, precipitation and snow cover occur. Especially, the high mountains such as the Pamir and Tien Shan where most of the water

originates from glaciers and snow packs provide important water resources for the entire
region (Unger-Shayesteh et al., 2013). During the Soviet time, a large number of manually-
controlled monitoring stations for meteorological and hydrological observations have been
operated for extended periods of time. Specifically, the river discharge data was used to
infer the melt-water of the snow covered mountains of Tajikistan and Kyrgyzstan with the
demand for water in the arid but agricultural used land of Kazakhstan, Turkmenistan and
Uzbekistan in exchange for coal, oil and gas (Bernauer and Siegfried, 2012). After the
collapse of the Soviet Union in 1991, the sharing of resources became difficult and thus
subject to frequent disputes between the now independent countries. Especially, the water
availability and its different utilisation are the most challenging problems. While the water
from the mountainous areas is used for the generation of hydropower due to the lack of
other energy providing resources in the upstream countries, the demand for agricultural
irrigation in the downstream countries in summer contrasts with the release of water from
the reservoirs during the winter season (Siegfried et al., 2012). Additionally, after 1991, the
monitoring network degraded significantly in this region (Finaev, 2009; Glazirin, 2009;
Kuzmichenok, 2009) mainly due to economic shortening resulting in a lack of information
urgently needed for water availability decisions (Unger-Shayesteh et al., 2015). To support
the Central Asian countries in transboundary water resource management based on reliable
in situ and remote sensing data and to make water a subject of peaceful cooperation, the
German Federal Foreign Office launched the Central Asian Water Initiative ("Berlin Process")
in April 2008. The primary goal was to assist the cooperation between the Central Asian
countries with regard to energy and water management on the political, scientific-technical
and educational level.

The scientific-technical level aimed at the establishment of a reliable data basis of
hydrological and meteorological data and the implementation of new technical monitoring
and data distribution solutions. These goals were addressed by the Regional Research
Network „Water in Central Asia" (CAWa) funded by the German Federal Foreign Office and
coordinated by the German Research Centre for Geosciences (GFZ) in Potsdam, Germany. To
support the reconstruction of the degraded network of meteorological and hydrological
station infrastructure and to provide near real-time hydrometeorological data, a network of
Remotely Operated Multi-Parameter Stations (ROMPS) (Schöne et al., 2013) together with a
remote-sensing monitoring system of rivers, reservoirs, and lake levels (Schöne et al., 2018a)
has been established over the past ten years. To support the activities and to strengthen the
geoscientific cooperation between the five Central Asian countries and Afghanistan,
additional funding has been provided by GFZ through the "Global Change Observatory –
Central Asia" (GCO) and the "Advanced Remote Sensing – Ground-truth Demo and Test
Facilities" (ACROSS) projects of the Helmholtz Association (Helmholtz Society 2015). While
some of these stations have been installed to additionally monitor the tectonically active
parts of the Pamir and Tien Shan mountain areas with Global Navigation Satellite System
(GNSS) (Zubovich et al., 2016), others are dedicated to monitor glacier dynamics and glacier

lake outburst floods (Zech et al., 2016) and to re-establish glacier monitoring for mass
65 balance studies (Hoelzle et al., 2012).

The objective of this paper is to describe the near-real time meteorological and hydrological observations provided by the CAWa, GCO and ACROSS station network. An overview of the station locations, the methods of data collection including their known quality issues and further documentation is given in the next sections.

2. Station network

To support the construction of new hydrometeorological stations, close cooperation between different agencies and institutes in Central Asia has been developed. One of the main partners is the Central Asian Institute for Applied Geosciences (CAIAG) in Bishkek, Kyrgyzstan, which was founded in 2004 by the Government of the Kyrgyz Republic and the
75 GFZ. Additionally, cooperation with the national hydrometeorological services (Hydromet services) in Kyrgyzstan (KgHM), Tajikistan (TjHM) and Uzbekistan (UzHM), the Ulugh Beg Astronomical Institute (UBAI) in Tashkent, Uzbekistan, as well as with the Kabul Polytechnic University (KPU), Afghanistan, have been established. In joint collaboration with these partners, 18 stations have been installed and are jointly operated altogether. Thereof, eight
80 stations from Kyrgyzstan, three stations from Uzbekistan, two stations from Tajikistan and one station from Afghanistan are providing data. Figure 1 shows the station distribution in Central Asia.

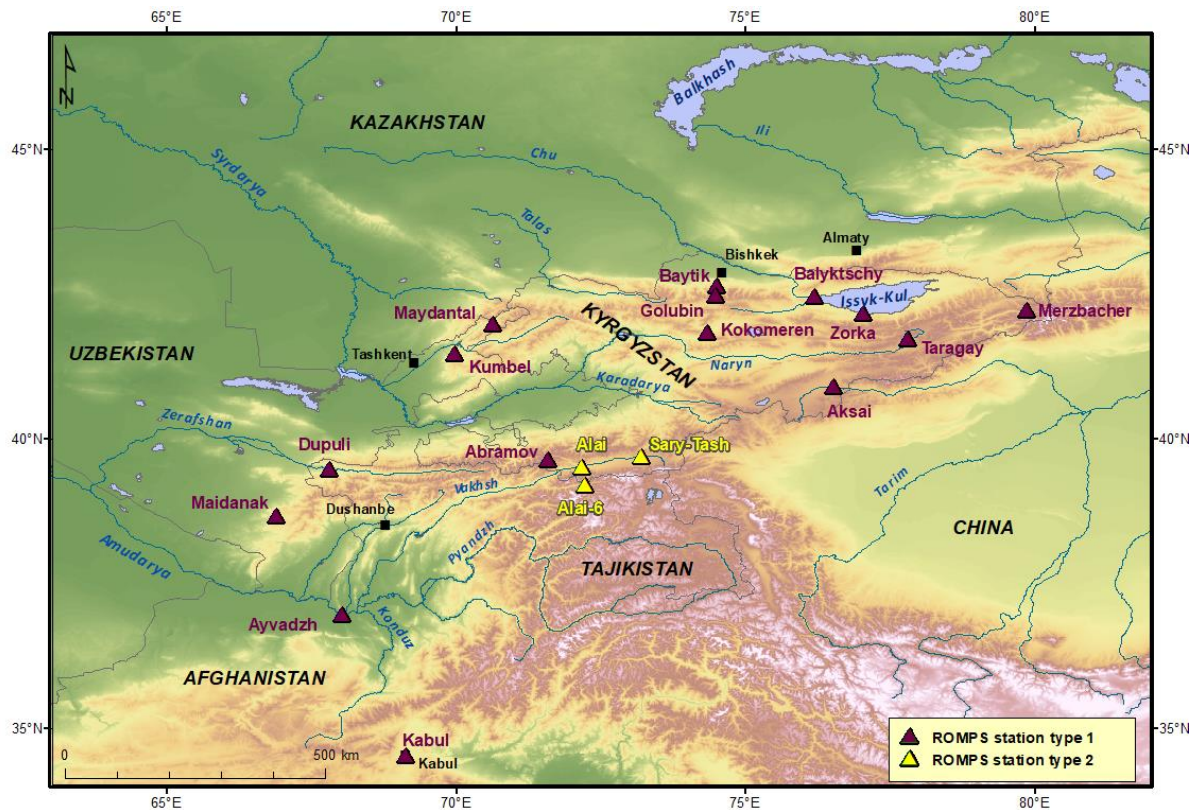



Figure 1: ROMPS network in Central Asia with the two different station types (see chapter 3) marked in purple for station type one with individual sensors and station type two with the compact weather transmitter (credits to NOAA for the DEM)

The stations are located in different climatic regions, reaching from high altitudes (4124m a.s.l.) in the mountains and at glaciers down to low elevations (318m a.s.l.) in flat and dry areas covering three different Central Asian countries and Afghanistan (Schöne et al., 2018b; Schöne et al., 2019). The station locations were selected together with the Hydromet Services and partners with regard to previous network coverage, meteorological information content, possibility of satellite data transfer and station security aspects. However, some stations have been installed at existing meteorological stations or 'Hydroposts' with manual readings done by a local operator. The intention was to combine and compare the manual with the digital measurements as well as to ensure the safety of the equipment.

3. Instruments and Data Storage

The stations are designed for the operation in remote areas and high altitudes, especially under extreme climate conditions with temperatures ranging from +60°C to -60°C (Schöne et al., 2013). To keep the maintenance efforts low, the general technical setup of all ROMPS is identical at most locations. The system operates independently and automatically in order to reduce the need for manual interventions of a local operator. All stations consist of outside connected sensors and a water-proof (IP66) station main box (see Figure 6) integrating the central electronic components for the general operation such as the station computer

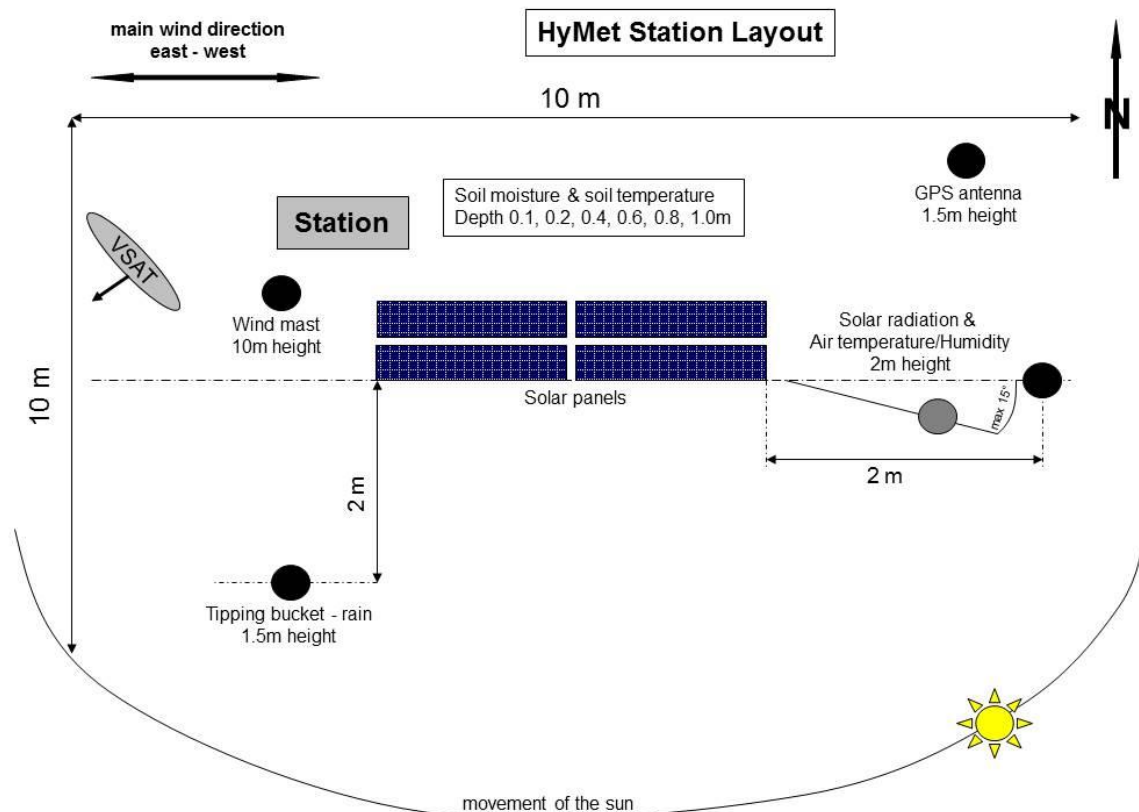
105 system, independent (solar) power supply, and data communication systems. Two alternative communication lines were chosen, either two different satellite systems (Very Small Aperture Terminal - VSAT and Iridium) or depending on the signal coverage one satellite (VSAT) and one ground communication line (Global System for Mobile Communication – GSM). Due to their independence from local infrastructures (power, data

110 transmission and manual interaction), the stations are suitable for remote areas with difficult accessibility.

Figure 2: Station type one with meteorological sensors and a snow pack analyzing system (SPA, left front) at the station Golubin Glacier (GOLU)

Figure 3: Station type two with a compact weather transmitter connected at the pole between the solar panels at the station Alai-6 (ALA6)

The station outline is determined by the selection of meteorological sensors and can be differentiated into two types. The first type consists of a set of separate sensors complying with the World Meteorological Organization (WMO) requirements (WMO, 2018) that are

115 arranged around the station main box to avoid interferences with each other (Figure 2). At the second type of station (Figure 3), a compact weather transmitter is used. Figure 4 shows a typical station outline for station type one but depending on the local environment, the sensors are arranged differently at other stations.

120   Figure 4: Typical station outline for station type one with the arrangement of sensors around the
       station area to avoid interferences or shadowing with other technical equipment

All stations are equipped with a standard set of meteorological sensors. The following table
lists the measured parameters for each station type:

125   Table 1: Measured parameters for each station type

Type one	Type two
Air temperature and relative humidity	Air temperature and relative humidity
Barometric air pressure	Barometric air pressure
Wind speed and direction	Wind speed and direction
Precipitation	Precipitation and hail
Solar radiation	
Soil water content	
Soil temperature	

At selected locations, the stations have been augmented with a river discharge monitoring
system and/or a snow measuring system. While the snow system is usually located adjacent
to the other sensors (see Figure 2 to the left), the discharge system is installed directly at
130   rivers which can be separated from the station main box (see Figure 5) by several hundred
meters. It consists of an independent power supply and the data is transmitted in regular
intervals by a radio link to the main station. The snow system measures the following
parameters:

- snow depth (reversed distance),
135
- content of liquid water and ice,
- snow density, and
- snow water equivalent (SWE).

The river discharge system provides the parameters:
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- water level,
- surface flow velocity, and
- (computed) river discharge volume.

Figure 5: River discharge system at station MTAL with a solar panel and the boom for the sensor.
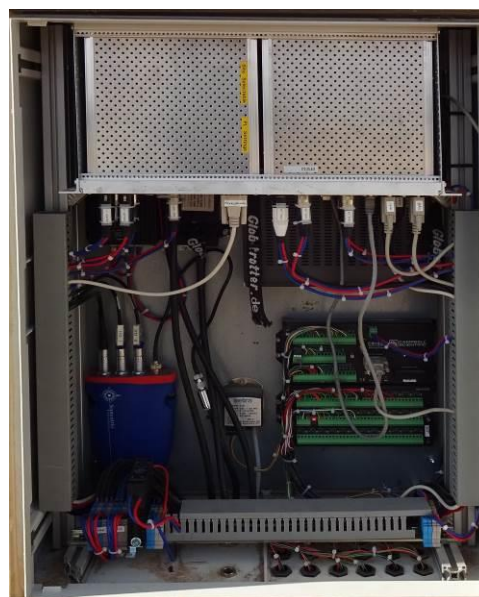
Figure 6: Station main box. Topside, the computer and power module is visible. The VSAT and Iridium modem are located in the back. Below is the GNSS receiver (left), the barometric sensor (middle) and the Campbell® datalogger (Schöne et al., 2013).

145 The primary service of the CAWa ROMPS network is to provide meteorological and hydrological data (Schöne et al., 2018b and 2019), especially from the high mountain areas of Central Asia supporting the national Hydromet services and the regional and international scientific community. The stations with their installed sensor systems and start of operation are listed in Table 2. The start of operation does not necessarily match with the start of all
150 sensor systems. In some cases, individual sensors were installed at a later date.

Table 2: Station list with their start of operation dates and the installed sensors systems. While the column 'meteorological sensors' refer to various individual sensors, the 'weather sensor' column refers to the compact weather transmitter (station type two).

Station	Country	Partner	Name	Start of operation	Meteo. Sensors	Weather Sensor	River discharge	Snow para-meters

					(type one)	(type two)		
ABRA	KGZ	CAIAG	Abramov Glacier	08/2011	✓	✗	✗	✗
ALAI	KGZ	CAIAG	Alai	05/2017	✗	✓	✗	✗
ALA6	KGZ	CAIAG	Alai-6	10/2015	✗	✓	✗	✗
ASAI	KGZ	CAIAG	Aksai	07/2012	✓	✗	✗	✗
AYVA	TAJ	TjHM	Ayvadzh	06/2012	✓	✗	✗	✗
BALY	KGZ	CAIAG	Balyktschy	06/2017	✓	✗	✗	✗
DUPU	TAJ	TjHM	Dupuli	05/2012 decom. 12/2012	✓	✗	✓	✗
GOLU	KGZ	CAIAG	Golubin Glacier	09/2013	✓	✗	✗	✓
HM01	KGZ	CAIAG	Baytik	12/2010	✓	✗	✗	✓
KABU	AFG	KPU	Kabul	04/2015	✓	✗	✗	✗
KEKI	KGZ	CAIAG	Kokomeren	11/2010	✓	✗	✓	✗
KMBL	UZB	UzHM	Kumbel	09/2015	✓	✗	✗	✓
MADK	UZB	UBAI	Maidanak	11/2012	✓	✗	✗	✗
MRZ1	KGZ	CAIAG	Merzbacher	08/2011	✓	✗	✗	✗
MTAL	UZB	UzHM	Maydantal	09/2014	✓	✗	✓	✓
OYGA[1]	UZB	UzHM	Oygaing	10/2018	✗	✗	✓	✗
SARY	KGZ	CAIAG	Sary-Tash	08/2015	✗	✓	✗	✗
TARA	KGZ	CAIAG	Taragay	09/2010	✓	✗	✗	✗
ZOKA	KGZ	CAIAG	Zorka	09/2016	✓	✗	✗	✗

155 Additional to the hydrometeorological data acquisition, some stations integrate other sensors, such as broadband seismometers for the GEOFON network (GEOFON, 2020), automated cameras for glacier monitoring and mass balance calculations (Hoelzle et al., 2017) operated by the University of Fribourg, Switzerland (UniFr), GNSS receivers for investigation of glacier dynamics and Glacier Lake Outburst Flood (GLOF) monitoring (Zech et al., 2016 and 2018) operated by GFZ or measurements of snow water equivalent (SWE) with

160 Cosmic-Ray Neutron Sensing (e.g., Schattan et al., 2018) installed by the University of Innsbruck, Austria (UIbk). Table 3 gives an overview about the sites of the additionally installed sensors.

Table 3: Station list with additionally installed sensors. The column "Partner" in this table does not refer
165 to the institute that is operating the station, but to the owner of the additionally installed sensor.

Station	Name	Country	Partner	Seismometer	GNSS	SWE	Camera
ABRA	Abramov	KGZ	UniFr	✗	✓	✗	✓

[1] OYGA (Oygaing) consists of a river discharge system only that is located close to and connected to the station MTAL (Maydantal).

	Glacier						
ASAI	Aksai	KGZ	GFZ	✓	✓	✗	✗
GOLU	Golubin Glacier	KGZ	UniFr, Ulbk	✗	✓	✓	✓
KEKI	Kokomeren	KGZ	GFZ	✓	✓	✗	✗
MRZ1	Merzbacher	KGZ	GFZ	✓	✓	✗	✓

3.1 Meteorological sensors

The compact Weather Transmitter (Vaisala WXT520 or WXT530) offers six meteorological parameters in one compact unit. It measures wind speed and direction, precipitation, atmospheric pressure, air temperature and relative humidity. The wind is estimated by transit time through three equally spaced ultrasonic transducers on a horizontal plane. The precipitation sensor on top of the transmitter, detects the impact of individual raindrops by noise detection with a piezoelectric sensor. Each raindrop produces a signal that can be converted directly to accumulated rainfall and hail (Vaisala WXT520, 2012) and to rain/hail intensity and duration. The PTU (pressure, temperature, humidity) module measures the atmospheric pressure, air temperature and humidity with a capacitive silicon element for the pressure, a capacitive ceramic element for the temperature and a capacitive thin film polymer element for the humidity. The PTU component is fixed insight a radiation shield to protect the sensor from direct sun light.

The combined Temperature and Humidity Sensor (Vaisala HMP45, Vaisala HMP155, Campbell® Scientific CS215 or Galltec+Mela KPK 1/5-ME) provides air temperature and relative humidity data. The humidity measurement is based on the capacitive thin-film polymer probe which either absorbs or releases water vapour that changes the dielectric properties and, therefore, the capacitance of the sensor. The temperature measurement is based on the resistive platinum probe. Both probes are located at the tip of the sensor and are protected by a sintered Teflon filter. The sensor is fixed inside a radiation shield to protect the sensor from direct sun light and is mounted on a steel mast.

The Barometric Pressure Transducer (Setra 278 or Campbell® Scientific CS115) measures the actual local atmospheric pressure. The sensor is fixed inside the station main box but is led to the outside of the box with a connecting air tube.

The alpine Wind Monitor (RM Young 05103-45) is used to measure the horizontal wind speed and direction. The wind speed is measured with a helicoid-shaped, four-blade propeller. The rotation of the propeller produces a signal proportional to the wind speed. The position of the vane is transmitted by a potentiometer and its output voltage is proportional to the wind direction. The wind sensor is mounted on top of a 10m steel mast.

The Tipping Bucket Rain Gauge (RM Young 52203 or Thies 5.4032.35.008) measures liquid precipitation with a tipping bucket mechanism. The measured liquid rain drains through a collection tube for verification of the total rainfall by mechanically tipping a scale. As the

tipping bucket is not heated, winter precipitation is strongly biased in regions with frequent temperatures around or below 0°C. The rain sensor is installed on a steel mast which is fixed with tensioning wires to reduce the influence of wind induced vibrations.

The Net Radiometer (Hukseflux NR01) measures the incoming short-wave and long-wave infrared radiation as well as the surface-reflected short-wave and outgoing long-wave infrared radiation. It consists of a pyranometer and a pyrgeometer pair that faces upward and a complementary pair that faces downward. The pyranometers and pyrgeometers measure the short-wave and the far infrared radiation, respectively. The sensor is fixed at a steel mast.

The Water Content Reflectometer (Campbell® Scientific CS616) measures the volumetric water content of porous media. It uses time-domain measurement methods that are sensitive to the dielectric permittivity of the used medium which changes with the water content of the soil material. In our installations, typically six sensors are installed in the ground at different depths.

The Soil Temperature Probe (Campbell® Scientific T107) uses a thermistor to measure the temperature and, therefore, can be used in air, water, and soil. Typically, six sensors are installed in the ground at different depths adjacent to the Water Content Reflectometers.

3.2   Hydrological sensors

The Discharge Measurement System (Sommer RQ24) enables the contact-free measurement of the surface flow velocity plus the water level and automatically calculates the discharge quantity of the water using a user-defined river cross section. The measurement of flow velocity is based on the Doppler Shift principle. The sensor calculates local flow by comparing an emitted frequency with the frequency reflected by the water surface (Doppler shift). The water level is measured by using time-delay measurements. The pulse radar emits impulses with a specific length in the lower micro-second range perpendicular to the water surface. The time delay between emission and reception of the impulse is proportional to the distance from the water surface. The calculation of the discharge is based on the continuity equation and determined from the cross section depending on the measured water level, the measured surface velocity and a pre-defined related k-factor which represents the hydraulic properties of the river (e.g., roughness of river bed). While the water level and surface velocity are measured continuously, the cross-section and k-factor are pre-defined during the installation or changed during maintenance visits.

The Snow Pack Analyzer (Sommer SPA) in combination with a Snow Depth Sensor (Sommer USH8) provides different parameters of snow (see Figure 7) like snow density, snow water equivalent (SWE) as well as contents of liquid water and ice. The snow depth is measured with an ultrasonic pulse as a distance between the sensor and the (snow) surface. To estimate the volume contents of the individual snow elements (ice, water, air), the complex

impedance along a flat ribbon sensor is measured with different frequencies in the snow pack. Since the individual components have different dielectric constants, the volume contents of the liquid water and ice can be determined (Sommer SPA, 2014). The specific volume contents and the liquid water and ice content in the snow are used to calculate the snow density. A combination of the snow depth and the snow density defines the SWE. The content of liquid water and ice is measured at different positions in the snow pack with one sloping sensor (sensor 1) and three horizontal sensors with typical positions of 10 cm (sensor 2), 30 cm (sensor 3), and 50 cm (sensor 4) above ground. Therefore, the sensor provides four different values for the snow density, the SWE, and content of liquid water and ice. The USH8 snow depth sensor can also be operated independently without the SPA. Then, the snow depth is measured only.

Figure 7: Snow Pack Analyzer (SPA) with the ultrasonic snow depth sensor (USH8) and the four flat ribbon sensors (three horizontal and one sloping sensor) at the station Maydantal (MTAL).

Due to the remoteness of most stations, regular calibrations of sensors could not be performed. But sensors have been exchanged when problems occurred. Notes to the station documentation can be found in chapter 6.

4. Datasets

The datasets comprise the data from all stations and their different sensor systems. The meteorological data has been sampled in 1-minute intervals and then converted (average "_Avg", maximum "_Max", time of maximum "_TMax", minimum "_Min", or total "_Tot") to 5-minute data that is stored in meteorological files separated for each station. The time consistency is achieved by daily synchronizing the system with a GPS time signal.

4.1 Meteorological data

Table 4 lists all meteorological parameters for the first type of station (individual sensors) for each parameter with their abbreviation, unit and type of sampling to a 5-minute value.

Table 4: List of meteorological parameters measured by the individual sensors (station type one)

Measurement parameter	Description	Unit	Type of sampling
AirTC	Air temperature	°C	Sample
RH	Relative humidity	%	Sample
Baro	Barometric air pressure	hPa	Sample
WindSp_Avg	Wind speed	m/s	Average
WindSp_Max	Wind speed maximum (gust)	m/s	Maximum
WindSP_TMax	Time of wind speed maximum	Date and Time	Date and Time of Maximum
WindDir	Wind direction	° (degree)	Sample
Rain_Tot	Precipitation	mm	Total
RadSW_Up_Avg	Incoming short-wave solar radiation	W/m^2	Average
RadSW_Dn_Avg	Outgoing (reflected) short-wave solar radiation	W/m^2	Average
RadLW_Un_Avg	Incoming long-wave solar radiation	W/m^2	Average
RadLW_Dn_Avg	Outgoing (reflected) long-wave solar radiation	W/m^2	Average
NR01TC_Avg	Temperature at the solar radiation sensor in degrees Celsius	°C	Average
NR01TK_Avg	Temperature at the solar radiation sensor in Kelvin	K	Average
NetRs_Avg	Net short-wave solar radiation	W/m^2	Calculated[2]
NetRl_Avg	Net long-wave solar radiation	W/m^2	Calculated[2]
Albedo_Avg	Proportion of the incident light or radiation that is reflected by a surface		Calculated[2]
UpTot_Avg	Total incoming solar radiation	W/m^2	Calculated[2]
DnTot_Avg	Total outgoing solar radiation	W/m^2	Calculated[2]
NetTot_Avg	Total Net solar radiation	$W/m^{\wedge 2}$	Calculated[2]
RadLW_UpCo_Avg	Temperature corrected incoming long-wave solar radiation	W/m^2	Calculated[2]
RadLW_DnCo_Avg	Temperature corrected outgoing (reflected) long-wave solar radiation	W/m^2	Calculated[2]
VW_#[3]	Volumetric soil water content at local position	n/a	Sample
PA_#[3]	Measured travel time of the EM-wave along the probe at local position	µSec	Sample
T107_#[3]	Soil temperature at local position	°C	Sample

Within the datasets of all meteorological sensors, additional technical values (e.g., battery voltage, record number) are provided but not listed in Table 4 and Table 5. Detailed information can be found in the data format specification which is part of the supplementary material. Table 5 lists all meteorological parameters for the compact weather transmitter (station type two).

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[2] These values are calculated by the datalogger according to the manufacturer's instructions.

[3] With #: Sensor 1..6

Table 5: List of meteorological parameters measured by the compact weather transmitter (station type two)

Measurement parameter	Description	Unit	Type of sampling
Ta	Air temperature	°C	Sample
Ua	Relative humidity	%	Sample
Pa	Barometric air pressure	hPa	Sample
Dn	Wind direction minimum	° (degree)	Minimum
Dm	Wind direction average	° (degree)	Average
Dx	Wind direction maximum	° (degree)	Maximum
Sn	Wind speed minimum	m/s	Minimum
Sm	Wind speed average	m/s	Average
Sx	Wind speed maximum	m/s	Maximum
Rc	Rain accumulation	mm	Total
Rd	Rain duration	s	Time
Ri	Rain intensity	mm/h	Total
Hc	Hail accumulation	$hits/cm^2$	Total
Hd	Hail duration	s	Time
Hi	Hail intensity	$hits/cm^2h$	Total

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4.2   Hydrological data

The snow parameters are measured every 15 minutes and stored in files, separately from the meteorological data. Table 6 lists the parameters of the snow system that are mainly used for hydrological studies. The system provides additional technical parameters to control the system. A detailed description can be found in the data format specification which is part of the supplementary material.

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Table 6: List of snow parameters

Name of parameter	Description	Unit
SH	Snow depth	m
S#_dens[4]	Snow density at position #	Kg/m^3
S#_SWE[4]	Snow water equivalent (SWE) at position #	mm
S#_ice[4]	Content of ice at position #	%
S#_water[4]	Content of liquid water at position #	%

The river discharge system performs several consecutive scans of the water surface and checks the reflected value for spikes and weak signals before providing the measurement result. This can cause different measurement intervals depending on the turbulence of the water surface. Like the snow parameters, the discharge measurements are stored in separated files. Table 7 lists the hydrological parameters of the river discharge system. The system provides additional technical parameters to monitor the system state. The detailed

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[4] With #: Sensor 1..4

285 description can be found in the data format specification which is part of the supplementary material.

Table 7: List of river discharge parameters

Name of parameter	Description	Unit
R_WL	Water level	mm
R_vel	Surface flow velocity	mm/s
R_Q	Calculated river discharge	m^3/s

4.3 Sensor Data Storage System

290 The easy and open-access provision of meteorological and hydrological data has been the main objective of the ROMPS network operation. The data is open for the usage in environmental research, public information services such as the Hydromet services provide, and to support information based decision-making processes especially in the fields of water and land management and climate adaption. The files coming from the stations are

295 forwarded directly to the open-access Sensor Data Storage System (SDSS) developed and hosted at CAIAG in Bishkek, Kyrgyzstan, and are therefore immediately available to the public. A graphical user interface (in English, Russian, and German language) offers the possibility to request the data interactively by selecting particular stations on a map or from a list of parameters. These values can be displayed as time series and downloaded as an

300 Extensible Markup Language (XML) file. The SDSS web-page is accessible through the following link: http://sdss.caiag.kg.

4.4 Data completeness

All stations are supplying data continuously since they were installed. But it should be noted that most of the stations are located in remote areas and could not be visited regularly or

305 immediately after technical problems occurred. Therefore, failover procedures to check for stalled software programs and automatic restart scripts have been implemented to minimize or avoid resolvable errors or gaps. Nonetheless, hardware cannot always be secured against outages, especially in remote areas. Major data problems or severe sensor failures that emerged are listed in section 5.

310 Additionally, due to errors in the datalogger configuration, the data was not always sampled in five minute intervals. At some stations, the data was sampled every minute or with other intervals which especially had an impact to the rain value and the wind speed maximum (gust) that should be a total over five minutes instead of, e.g., one minute.

5. Data Quality

315 The available data has to be considered as raw data coming directly from the stations and have not undergone any quality control (QC). The primary purpose of the network is to

provide near real-time data for the Hydromet services without major time delay. A consistency or QC on this dataset is beyond the scope of the network operation. QC is supposed to be done at each Hydromet service individually as they are the responsible national agency for international data exchange or accordingly, for each single user.

5.1 General problems

Nevertheless, there are known quality issues that emerged during the operation of the station and are mentioned in this paper to support further user quality management procedures. Especially the known problems such as incorrect configurations, wrong sensor installations or sensor failures that are not obvious for data users are explained below.

The rain sensor with a tipping bucket measurement principle is installed on a steel pillar which tends to vibrate during strong gust. This can cause the tipping beam to tilt and hence falsely produce a tip, particularly in areas exposed to strong winds. As a consequence, all rain sensors have been equipped with additional supporting crossbars to avoid this problem during the years 2013 and 2016. In the winter time, the measurement of snow or the differentiation between snow and rain is challenging as the sensor is not heated. While parts of the snow in the sensor's cone evaporate, other parts melt and are registered as a measurement. Furthermore, the water from the rain drops has to pass a small funnel to reach the tipping bucket. This funnel can become blocked due to leaves or other dirt which may hamper the measurements and can lead to underestimated or delayed rain data. As there are no local operators at most stations or they are not living close to the station, the rain sensors could be cleaned only during maintenance visits.

The soil sensors tend to have jumps in the measurements with so far unknown reasons and different time spans although the sensors haven't been touched. In some areas, these sensors are affected by animals (e.g. at TARA by marmots) that nibble the cables. These jumps and sensor failures will not be mentioned in the following listings as these erroneous data is clearly identifiable.

All calculated values (see Table 4) of the solar radiation sensor but specifically the albedo provides suspicious values close to sunrise and sunset. The albedo is calculated by the datalogger as the quotient from the reflected and the incoming short-wave radiation. This can lead to erroneous results when the incoming values tend to be close to zero when it is (nearly) dark.

5.2 Problems in the meteorological measurements

Most problems resulted from sensor failures, errors or inconsistencies in the configuration, or incorrect technical installations of sensors. Table 8 lists all known problems of meteorological sensors at the stations. Erroneous data has not been removed from this data set as it is the raw data coming directly from the station without any quality control. Details about sensor changes or cleaning of sensors can be found in the station documentation (section 6).

355 Table 8: List of problems in the meteorological data

Station	System	Parameter	Description of error	Time
ASAI	Rain	Rain_Tot	Sensor failure, rain could not be measured	Until 11.07.2017
	Solar radiation	RadLW_Dn	Sensor failure, values incorrect	11.07.2017-04.10.2018
BALY	Temperature	AirTC	Incorrect configuration	Until 17.05.2018
HM01	Temperature	AirTC	Sensor failure, values incorrect	23.06.2012-02.10.2013
	Humidity	RH	Sensor failure, values incorrect	23.06.2012-02.10.2013
	Air pressure	Baro	Incorrect configuration	Until 11.07.2012
	Wind	Wind_Dir	Incorrect configuration	Until 09.07.2010
KEKI	Air Pressure	Baro	Incorrect configuration	Until 18.04.2013 and 05.07.2017 -14.03.2019
KMBL	Rain	Rain_Tot	Wrong sensor installation, no values	Until 07.10.2018
MRZ1	Temperature	AirTC	Sensor failure, values incorrect	01.05.2014-08.07.2015
	Humidity	RH	Sensor failure, values incorrect	01.05.2014-08.07.2015
	Wind	Wind_Sp, Wind_Dir	Sensor broken, no values	19.05.2015-08.07.2016
	Rain	Rain_Tot	Sensor broken, no values	Unclear[5] - 08.07.2016
	Rain	Rain_Tot	Sensor broken, no values	Unclear[6] - 23.08.2019
TARA	Temperature	AirTC	Sensor failure, values incorrect	14.07.2012-26.06.2013
	Humidity	RH	Sensor failure, values incorrect	14.07.2012-26.06.2013
	Air pressure	Baro	Incorrect configuration	Until 13.07.2012
	Solar radiation	RadSW_Up	Sensor failure, values incorrect	31.08.2016-15.06.2017
	Solar radiation	RadLW_Up	Incorrect configuration	Until 11.09.2012
	Solar	RadLW_Dn	Sensor failure, values incorrect	09.22.2017-

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[5] May have been broken at any time between the maintenance visits on 24.07.2014 and 08.07.2015.
[6] May have been broken at any time between the maintenance visits on 29.07.2017 and 13.08.2019.

| | radiation | | | | 15.06.2017 |

5.3 Problems in the hydrological measurements

Beside incorrectly configured or connected sensors, problems with the snow depth sensor (values SH) occurred when referencing the time-delay distance measurement to a zero level of the snow or ground, respectively. Due to the accuracy of the system of ± 4mm and the condition of the ground reflection during the referencing process (e.g. fresh vegetation in spring or flat and dry in autumn), negative values close to zero can occur. Furthermore during the summer season at some places, growing grass can affect the measurement by producing a feigned snow depth. The signals of growing grass and sometimes the cutting of grass is clearly visibly as well as the time delay between melting of the snow and growing of grass or first snow in autumn, respectively.

The calculated discharge values provided by the river discharge system are the combination from the measurements of the water level and surface velocity with the cross profile of the river and a k-factor which accounts for the hydraulic model of the river flow. Especially, the river cross profile could not always be determined directly at the sensor's installation side, but only some meters away. In addition, the cross section profile may change over time leading to different k-factors. Therefore, these values should be used with caution. The discharge values are always influenced by the inaccuracy of the cross profile of the river. Table 9 lists the known problems with the snow and the river discharge system.

Table 9: List of problems in the hydrological parameters

Station	System	Parameter	Description of error	Time
GOLU	Snow	All	Sensors connected incorrectly	Until 11.06.2014
KMBL	Snow	SH	Sensor connected incorrectly	Until 05.05.2016
KMBL	Snow	S1_ice, S1_water, S1_dens, S1_SWE	Sensor failures during winter time	Winter 2017, 2019
KEKI	River	All	Sensor failure	12.7.17-20.9.17
MTAL	River	R_vel, R_Q	During low water levels, a big stone appeared in the sensor's measuring footprint. The water flow became turbulent causing erroneous measurements. The problem was fixed on 26.09.2019.	Autumn until spring in 2016, 2017 and 2018
OYGA	River	R_vel, R_Q	Test measurements during installation, not representative for the river	14.10.2018

These are only the known and documented errors. This list is not intended to be exhaustive. For further usage of the data, different quality control procedures following WMO or national standards should be implemented. An outlook and suggestion gives section 8. Additionally, more detailed information about the stations and installed sensors is provided by the station documentation (section 6).

6. Station documentation

For each station an extensive documentation exists describing the location and its surrounding, the technical installation of the station and the local conditions which might be useful to further interpret certain variations in the sensor data. As the installations had to be adjusted to the local environment, installation maps and specific sensor installation (e.g. height/depth of sensors) are included in the documentation. Due to the spatial expansion and the difficult accessibility, maintenance activities could not be performed on a regular basis. Therefore, the documentation also lists all station visits and exchanges of sensors. The file containing the documentation is named as follows XXXX-HMT-SED-GFZ.pdf with

- XXXX: 4-letter code for station name,
- HMT: HyMet station,
- SED: Station Exposure description, and
- GFZ: Agency of originator

These files are part of the supplementary material.

7. File Name Convention and Data Format

7.1 File names

All data are stored in files in the American Standard Code for Information Interchange (ASCII) format containing typically one hour of data (with sometimes different storage intervals). The different data types are separated into different files. The file name convention provides unique identifiers to distinguish between the different types of measurements as follows:

`XXXX-<type-of-data>-<timestamp>.log` with

- XXXX: 4-letter leading identifier for station abbreviation (see Table 2),
- <type of data>: hymetd   for meteorological parameters (station type one),
  - meteod   for meteorological parameters (station type two),
  - RQ24   for river discharge parameters,
  - snow   for snow parameters,
  - USH8   for snow depth values, and
- <timestamp>: Unix time (seconds since 01.01.1970).

Due to historical reasons, a second file name convention exists which is used for the second type of stations. These files are named as follows:

`XXXXWWWWD.met` with

- XXXX: 4-letter leading identifier for station abbreviation (see Table 2),
415
- WWWW: GPS week (weeks since 06.01.1980), and
- D: Day of week with Sunday=0.

The individual data files are packed into an archive with tar (Petersen, 2007) that contains one month of data files. This monthly file is additionally compressed with bzip2 (Petersen,
420 2007) to reduce the memory requirements.

The monthly archive files are named as follows:

`XXXX-<type-of-data>-<year>-<month>.tar.bz2` with

- XXXX: 4-letter leading identifier for station abbreviation (see Table 2),
- <type of data>: hymetd   for meteorological parameters (station type one),
425   meteod   for meteorological parameters (station type two),
                       RQ24   for river discharge parameters,
                       snow   for snow parameters,
                       USH8   for snow depth values,
- <year>: 4-digit year, and
430
- <month>: 2-digit month of the year.

After one year, these twelve monthly files are further archived and compressed to one file. The yearly files follow the same file name convention as the monthly files but the month is missing in this file name.

435   `XXXX-<type-of-data>-<year>.tar.bz2`.

7.2 Data format

Two data formats exist for the different station types. As the sensors for station type one are connected to a Campbell® data logger, the file format largely corresponds to the ASCII Campbell® data format. It can be separated into header and data sections. The header
440 section can be further divided into four parts containing one line each as follows:

1. General station information,
2. Types of measured parameters listed with their abbreviation,
3. Units of measured parameters, and
4. Quantity representation (type of sampling) of measured parameters.

445 After this header section, the data section follows starting with date and time. All values corresponding to the same measurement time are written in one line and are comma-

separated. A detailed description of all parts of the data format can be found in the data format specification (Schöne et al., 2020b) which is part of the supplementary material.

The sensor at station type two provides data from a compact VAISALA weather transmitter retrieved directly to the PC by dedicated software. Therefore, the ASCII data format is different but can be also divided into a header and a data section.

The header section provides information about the following parameters:

1. Requesting program name and version,
2. Date and starting time of the measurements in this file,
3. Sensor type, and
4. Sampling rate.

After this section, the data section follows with the time of the measurement. All values are comma-separated but are divided into several lines depending on the meteorological parameter. A detailed description of all parts of the data format can be found in the data format specification (Schöne et al., 2020a) which is part of the supplementary material.

8. Outlook

To monitor the quality of the sensor data prior to their use in computation of climate variables, basic QC procedures should be applied. In accordance with international guidelines on QC procedures (WMO, 2017; WMO, 2004; WMO, 2018) different levels of QC procedures are suggested and should be considered before using the data. The provided data can be seen as raw data without any QC implied. We recommend performing the following QC steps before using the data:

1. Integrity and syntax check:
   Test to search for gross errors in the data (e.g. transmission or data storage errors like wrong characters).
2. Plausibility check (tolerance test for each sensor):
   All instantaneous values shall be checked against configurable range limits (e.g. sensor range limit specification). These limits are different for each meteorological/hydrological parameter.
3. Time consistency check:
   Check of the rate of change to the previous value, to test for the maximum allowed variability.
4. Persistence check:
   Check of the rate of change to the previous values, to test for the minimum required variability.
5. Internal consistency check
   Test to check parameters against each other for plausibility.

Initial efforts have already been made to implement the first two tests in the SDSS but the remaining tests have not been developed, yet. Additionally, the authors intend to prepare a
485   publication of a quality controlled data set at a later time.

9. Data availability

The data described in this manuscript will be made publicly available as monthly and yearly data files separated for each station with the DOI https://doi.org/10.5880/GFZ.1.2.2020.002 (Zech et al., 2020). Additionally, the near real-time data can be displayed and downloaded without any registration from the user interface SDSS at http://sdss.caiag.kg.

10. Summary

In Central Asia, the access to hydrometeorological data especially from remote areas is still limited. Within the CAWa project funded by the German Federal Foreign Office and with the
490   support of the "Global Change Observatory – Central Asia" (GCO-CA, GFZ) and the ACROSS (Helmholtz Association) initiative, a network of remotely operated multi-parameter stations (ROMPS) have been installed in Kyrgyzstan, Tajikistan, Uzbekistan, and Afghanistan. The technical concept has proven to withstand harsh and varying climate conditions without the necessity of permanent human interaction. The data presented in this paper is the result of
495   the operation of these stations in the past ten years. The stations provide raw hydrometeorological information such as air temperature, relative humidity, air pressure, wind speed and direction, precipitation, solar radiation, soil moisture and soil temperature as well as snow and river discharge information where available. The data can be used for different applications ranging from scientific investigations of climate change, ground-
500   truthing of remote sensing based technologies and improvement of weather forecasts, to more politically based decisions on water management considerations and climate adaption strategies.

Supplement

The supplementary material to this article consists of the data format specification and the station documentation for each station. As most stations are operational, changes in these documents will occur but will be specified in the change log of each document. The supplementary material is provided with the DOI https://doi.org/10.5880/GFZ.1.2.2020.002 (Zech et al., 2020).

Author contributions

505   CZ organized several fieldworks for station installation and maintenance works, compiled the data archives, the known quality issues and the supplementary documentation with support by JI and TS. The continuous station operation was done jointly by CZ, JI and TS. NS, TQ, MK and HT prepared and assembled the technical parts of the system and supported the on-site

technical installations. AZ designed and implemented the SDSS and keeps it operational. The partners from the Central Asian countries Kyrgyzstan, Tajikistan, Uzbekistan, and Afghanistan provided the necessary permits for the station installations, essential support for building and maintaining the stations and continuous data transmission during the last years in their countries. This applies in particular to AZ and AS for the stations ABRA, ALAI, ALA6, ASAI, BALY, GOLU, HM01, KEKI, MRZ1, SARY, TAR and ZOKA in Kyrgyzstan, KZ and KT for the stations MTAL, OYGA and KMBL in Uzbekistan, YT for the station MADK in Uzbekistan, SO for the stations DUPU and AYVA in Tajikistan, and ZP for the station KABU in Afghanistan. KUS drafted a very first version of this paper many years ago. AG fostered the cooperation and negotiations especially between UzHydromet and GFZ and supported the fieldworks. BM enabled the numerous station installations in Kyrgyzstan by providing support from CAIAG. CZ wrote this paper with essential support by TS. All authors revised and approved the content of the paper.

Competing interests

The authors declare that they have no conflict of interest.

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