OWNER'S MANUAL

CLOUDBURST WEIGHING PRECIPITATION GAUGE

Models SG-400, SG-410, SG-420, SG-430

Rev: 30-Oct-2023

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TABLE OF CONTENTS

CERTIFICATE OF COMPLIANCE

EU Declaration of Conformity

This declaration of conformity is issued under the sole responsibility of the manufacturer:

Apogee Instruments, Inc.
721 W 1800 N
Logan, Utah 84321
USA

for the following product(s):

Models: SG-400, SG-410, SG-420, SG-430

Type: Weighing Precipitation Gauge

The object of the declaration described above is in conformity with the relevant Union harmonization legislation:

2014/30/EU	Electromagnetic Compatibility (EMC) Directive
2011/65/EU	Restriction of Hazardous Substances (RoHS 2) Directive
2015/863/EU	Amending Annex II to Directive 2011/65/EU (RoHS 3)

Standards referenced during compliance assessment:

EN 61326-1:2013	Electrical equipment for measurement, control, and laboratory use – EMC requirements
EN 63000:2018	Technical documentation for the assessment of electrical and electronic products with respect to the restriction of hazardous substances

Please be advised that based on the information available to us from our raw material suppliers, the products manufactured by us do not contain, as intentional additives, any of the restricted materials including lead (see note below), mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB), polybrominated diphenyls (PBDE), bis (2-ethylhexyl) phthalate (DEHP), butyl benzyl phthalate (BBP), dibutyl phthalate (DBP), and diisobutyl phthalate (DIBP). However, please note that articles containing greater than 0.1 % lead concentration are RoHS 3 compliant using exemption 6c.

Further note that Apogee Instruments does not specifically run any analysis on our raw materials or end products for the presence of these substances, but we rely on the information provided to us by our material suppliers.

Signed for and on behalf of:
Apogee Instruments, October 2023

Bruce Bugbee
President
Apogee Instruments, Inc.

CERTIFICATE OF COMPLIANCE

UK Declaration of Conformity

This declaration of conformity is issued under the sole responsibility of the manufacturer:

Apogee Instruments, Inc.
721 W 1800 N
Logan, Utah 84321
USA

for the following product(s):

Models: SG-400, SG-410, SG-420, SG-430
Type: Weighing Precipitation Gauge

The object of the declaration described above is in conformity with the relevant UK Statutory Instruments and their amendments:

2016 No. 1091	The Electromagnetic Compatibility Regulations 2016
2012 No. 3032	The Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations 2012

Standards referenced during compliance assessment:

BS EN 61326-1:2013	Electrical equipment for measurement, control, and laboratory use – EMC requirements
BS EN 63000:2018	Technical documentation for the assessment of electrical and electronic products with respect to the restriction of hazardous substances

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President
Apogee Instruments, Inc.

UK
CA

INTRODUCTION

Precipitation is a fundamental weather variable and is widely measured. Precipitation is highly variable, with timing, duration, intensity, amount, and phase all changing based on location, season, weather patterns, and atmospheric conditions.

Precipitation gauges are instruments designed to collect and measure total amount and rate (intensity) of precipitation. Some precipitation gauges (e.g., unheated tipping bucket) can only measure rain, while others (e.g., heated tipping bucket, weighing gauge, optical gauge) can measure rain and solid precipitation (e.g., snow, hail). The principle of weighing precipitation gauges is measurement of weight of accumulated water via a sensitive weighing platform. A major advantage of weighing precipitation gauges is the ability to measure total precipitation--liquid or solid--without the large power requirement of a heated inlet. Power for inlet heating can be difficult or impossible to source at some field sites. If necessary, weighing precipitation gauges can be fitted with a heated inlet to prevent snow from bridging/capping over the inlet. Snow capping can occur in locations with cold temperatures and high winds during snowfall.

In addition to being preferred for hail and snowfall, weighing gauges are more accurate for measuring all forms of precipitation, particularly at high rates. Maximum rate specifications for tipping bucket gauges are typically in the range of 12 to 20 mm per min (720 to 1200 mm per hr), and the uncertainty of the measurement is often unspecified beyond 8 mm per min. Conversely, maximum rate specifications for weighing gauges are in the range of 30 to 120 mm per min (1800 to 7200 mm per hr), and uncertainty is specified across the entire measurement range. Weighing gauges can also measure smaller amounts of precipitation. Depending on the model, tipping bucket gauges require 0.1 mm or 0.25 mm of precipitation to trigger a tip of the bucket, in addition to precipitation needed to wet the funnel. Weighing gauges are more sensitive, where events as low as 0.025 to 0.05 mm can be detected.

Typical applications of precipitation gauges include monitoring of instantaneous, daily, monthly, and annual precipitation in weather networks and measurement in water balance studies. Precipitation is often the limiting factor to plant growth, and as a result, influences crop and forest productivity. Precipitation data are required for estimating availability of water resources, forecasting floods, and monitoring droughts. Weighing precipitation gauges are becoming more widely used because of the advantages over tipping bucket gauges, particularly in regions with mixed or solid precipitation.

Apogee Instruments SG-400 series total precipitation gauges are affordable, all-weather weighing gauges with no moving parts. They use a high accuracy, stable load cell to measure weight of water collected in a bucket mounted on the cell. Inlet options meet the National Weather Service (NWS) and World Meteorological Organization (WMO) recommendations, 8-inch diameter/324 cm^2 area and 6.3-inch diameter/200 cm^2 area, respectively. An 8 gallon/30 L bucket is used to provide 35 in/900 mm (NWS inlet) or 59 in/1500 mm (WMO inlet) capacity. The gauge is housed in a lightweight, durable plastic shroud, with a powder-coated stainless-steel inlet. Analog to digital circuitry is used to convert the signal from the load cell to an SDI-12 output. A filtering algorithm is used to minimize the influence of evaporation, vibration (from wind), and temperature change on the precipitation signal.

SENSOR MODELS

There are four models of Apogee SG-400 series weighing precipitation gauges. **All four models have SDI-12 output**.

SG-400: 8-inch inlet diameter/324 cm^2 inlet area inlet (National Weather Service standard diameter), no inlet heater.

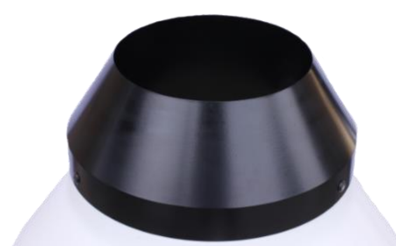
SG-410: 8-inch inlet diameter/324 cm^2 inlet area (National Weather Service standard diameter), 50 Watt inlet heater (heater includes a thermistor to measure inlet temperature and provide control if desired).

SG-420: 6.3-inch inlet diameter/200 cm^2 inlet area (World Meteorological Organization recommended area), no inlet heater.

SG-430: 6.3-inch inlet diameter/200 cm^2 inlet area (World Meteorological Organization recommended area), 50 Watt inlet heater (heater includes a thermistor to measure inlet temperature and provide control if desired).

	NWS Inlet	**WMO Inlet**
No Heater	SG-400	SG-420
Heater	SG-410	SG-430

NWS Inlet



WMO Inlet

Cloudburst model number and serial number are located on the inside of the load cell. If manufacturing and calibration information are required, please contact Apogee Instruments with the serial number of the Cloudburst.

Please note that all models will be labeled with the “SG-400 Series” model number.

SPECIFICATIONS

	SG-400	SG-410	SG-420	SG-430
Precipitation Type	Liquid, solid, mixed			
Inlet Diameter/Area	8-inch inlet diameter / 324 cm^2 inlet area (NWS)		6.3-inch inlet diameter / 200 cm^2 inlet area (WMO)	
Precipitation Capacity	900 mm / 35 in (NWS inlet)		1500 mm / 59 in (WMO inlet)	
Bucket Capacity	30 L / 8 gal			
Inlet Heater	No Heater	Heater	No Heater	Heater
Rate (Intensity) Range	0 to 3,000 mm $hour^{-1}$ (0 to 50 mm min^{-1})			
Rate (Intensity) Threshold (1 min data)	6 mm hr^{-1} (0.1 mm min^{-1})			
Calibration Accuracy (for Cumulative Amount)	0.1 mm for < 5 mm, 1 % for > 5 mm			
Calibration Accuracy (for Rate/Intensity)	5 % for > 2 mm hr^{-1}			
Measurement Resolution	0.01 mm			
Communication Interface	SDI-12 v 1.4			
Output Interval	1 min (unfiltered data), 1 to 30 min (filtered data)			
Temperature Sensitivity	± 0.01 mm C^{-1}			
Long-term Drift (Non-stability)	< 0.5 % yr^{-1}			
Non-linearity	Less than 0.1 mm			
Transducer	Stainless steel strain-gauge bridge load cell			
Voltage Input	5.5 to 26 V DC			
Current Draw	20 mA			
Power Requirement	240 mW at 12 V DC			
Operating Environment	-20 to 60 C, 0 to 100% relative humidity			
IP Rating	IP67 (load cell and circuitry)			
Dimensions	38 cm diameter, 80 cm height			
Mass	12 kg (empty bucket)			
Cable	5 m of 3-conductor wire, M8 connector (IP67)			
Mounting	Holes for 6 in / 15.24 cm wood post, Adapter for 4 in / 10.16 cm pipe			
Inlet Heater Voltage Requirement	-	24 V DC	-	24 V DC
Inlet Heater Current Draw	-	2.1 A	-	2.1 A
Inlet Heater Power Requirement	-	50 W (maximum)	-	50 W (maximum)

Calibration Traceability

Load cells in Apogee Instruments SG-400 series precipitation gauges are calibrated to mass using a set of reference weights in the laboratory. Mass of each reference weight is determined by a mass balance that is calibrated with a 10 kg Class 6 weight.

DEPLOYMENT AND INSTALLATION

Apogee SG-400 series precipitation gauges come partially assembled, facilitating easy transport and deployment. Component parts include base plate, load cell, cable, cord grip, collection bucket/cistern, and shroud/inlet. The AG-002 pole adapter accessory is sold separately.

Base plate

Pole adapter (AG-002 accessory)

Cord grip

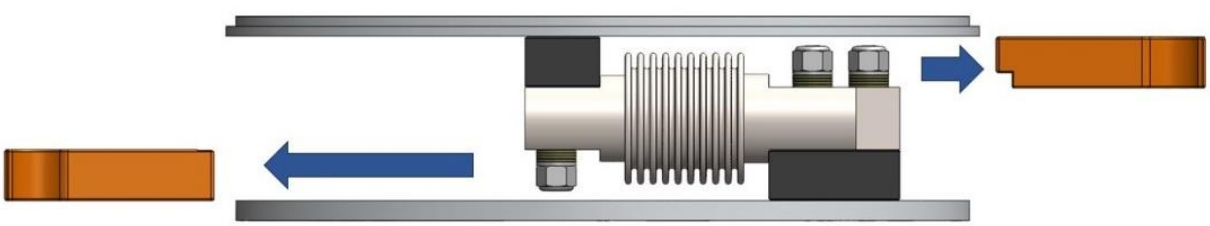
Inlet/outer housing

Bucket/cistern

Cable/wiring

Load cell

IMPORTANT NOTE: There are orange plastic spacers between the load cell and attached plates, one between load cell and bottom plate and one between load cell and top plate. Spacers are installed to prevent damage to the load cell during shipping and must be removed once the load cell is installed and the bucket is placed on the load cell.



IMPORTANT NOTE: There must not be any contact between the bucket and inlet or shroud. Ensure the bucket is properly fitted over the top plate of the weighing assembly before placing the shroud over the bucket.

Gauge Placement:

Wind flow can be altered by obstructions and shelter a gauge, which may lead to under- or over-catch. Under- and over-catch is a deficiency in precipitation or excess in precipitation being measured. The catch depends on gauge position relative to surface obstructions and direction of wind. Improper placement of precipitation gauges is potentially a large source of error. Ideal siting for a weighing gauge is placing it in vegetation of relatively uniform height and the same height as the inlet of the gauge. For example, in vegetation like hedges, as shown in Figure 1 below.

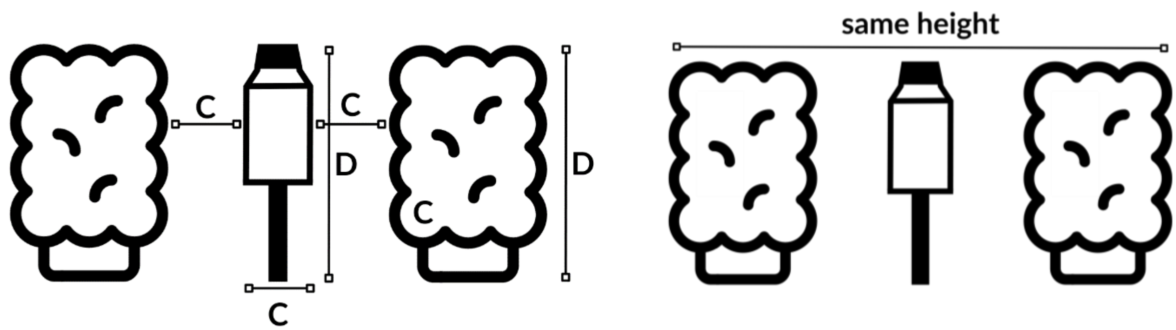


Figure 1: Apogee SG-400 series weighing precipitation gauge mounted in vegetation, where height of vegetation is same height as gauge inlet (left side) and height of vegetation is uniform (right side).

Mounting a gauge in uniform vegetation the same height as the inlet of the gauge is often impractical. The next best option is to measure the horizontal distance from a gauge to surface obstructions, such as buildings or vegetation. The distance between the gauge and obstructions should be at least two times the vertical distance from the top of the gauge inlet to the top of the obstruction, as shown in Figure 2 below. Clearings within a stand of trees or shrubs and brush are good locations because the vegetation serves as a natural wind shield. Siting a gauge within vegetation still needs to meet the horizontal distance rule (distance from gauge to vegetation should be twice the vertical distance from top of gauge to top of vegetation). Avoid placing gauges on sloped surfaces and tops of buildings.

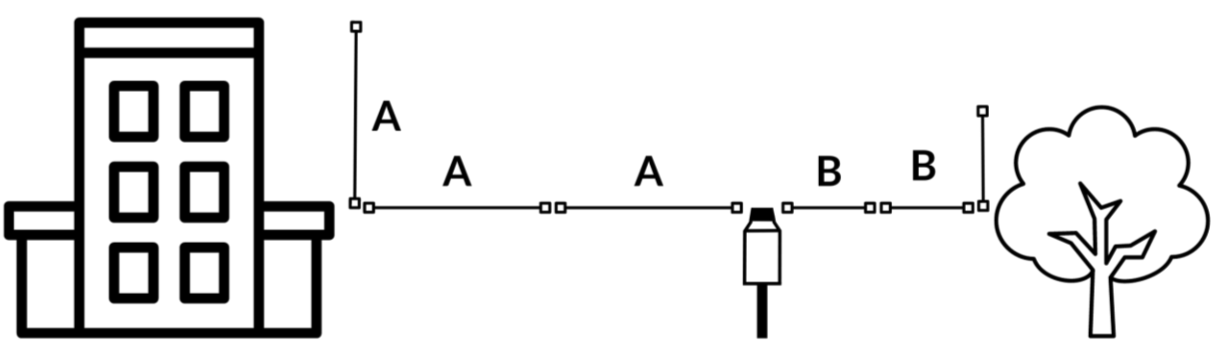


Figure 2: Apogee SG-400 series weighing precipitation gauge mounted properly mounted away from surface obstructions, where horizontal distance from gauge to obstructions is at least two times the distance from the top of the gauge to the top of the obstructions.

For more detailed information on gauge siting, see part 3. Precipitation, in Annex 1.B. Siting Classifications for Surface Observing Stations on Land, in Chapter 1. General, of the WMO Guide to Meteorological Instruments and Methods of Observation (CIMO Guide).

Pedestal:

SG-400 series gauges can be mounted to a wood post or metal pipe (adapter that fits to bottom of base plate is required to mount on metal pipe; Apogee AG-002 accessory). Movement and vibration of the post or pipe due to wind, frost heave, and loosening of soil should be prevented by fixing post/pipe in place with cement. A hole of at least 18 in / 45 cm depth is recommended. Care should be taken to ensure wood post or metal pipe is level before cement sets. Wood posts should be at least 6 in x 6 in / 15.24 cm x 15.24 cm. The pipe adapter can be used on a metal pipe with diameter up to 4 in / 10.16 cm.

For wood posts, use four 5/16 in lag screws to secure base plate directly to the post. For metal pipes, install the pipe mounting bracket attached to the base plate to the pipe using the six bolts in the bracket to secure it in place. There is a bubble level in the base plate that can be used to ensure the base plate is level on the wood post or pipe mount. If the gauge isn't level, it may under-collect when the inlet is tilted downwind and over-collect when the inlet is tilted upwind.

When mounting the load cell (weighing mechanism) on the base plate, point the gray cable coming out of the load cell to the north in the northern hemisphere and to the south in the southern hemisphere.

In locations where precipitation falls as snow, gauge orifice should be mounted above the anticipated snow depth. To minimize blowing snow entering the gauge it is recommended the inlet be mounted at least 20 in / 50 cm above expected snow depth. SG-400 series gauges are approximately 31.5 in / 80 cm tall from bottom of base plate to top of inlet. Height of the mounting pedestal can be determined by adding 50 cm to the expected snow depth and subtracting 80 cm (gauge height). For example, if the expected snow depth is 100 cm, the pedestal height should be at least 70 cm above the ground surface (100 cm + 50 cm – 80 cm = 70 cm).

Alter Shield:

To reduce wind-induced under-catch an Alter shield can be used with the gauge. Apogee does not manufacture an Alter shield. Novalynx model 260-953 is recommended.

Bucket Preparation:

When SG-400 series gauges are used in locations where temperatures drop below freezing, antifreeze must be added to the bucket to keep the collected precipitation aqueous. If solid precipitation is not melted in antifreeze, gauge capacity is significantly reduced (snow stacks up in the bucket). And, if liquid precipitation freezes inside the bucket, it may be damaged. Antifreeze is not required in locations where temperature does not drop below freezing. Recharging gauges in late September, right before the beginning of the next water year, is good practice because it is the beginning of the cold season, thus less antifreeze is required if the bucket is emptied and recharged before winter when freezing temperatures are expected.

A 50:50 propylene glycol-ethanol (PGE) mix is recommended for anti-freeze, based on the information in McGurk (1992). Table 3 in the paper lists the amount of PGE required for the expected minimum temperature and annual precipitation.

Data in Table 1 on the following page were taken from Figure 1 in McGurk (1993) and provide parts PGE to parts water to maintain an aqueous mix of water and antifreeze in the bucket at temperatures below freezing.

Table 1: Maintaining an Aqueous Mix of Water and Antifreeze

Temperature [C]	Temperature [F]	Parts 50:50 PGE	Parts Water
-5	23	1	7
-15	5	1	2.5
-25	-13	1	1.5
-35	-31	1	1
-40	-49	1	0.66

Data in Table 1 can be used to estimate the amount of PGE required to maintain aqueous mix in the bucket if an estimate of expected amount of water in the bucket is available for the time when the coldest temperature at the site is expected.

Determining Minimal Antifreeze Level

Three variables need to be defined when determining the minimal antifreeze level.

1. Coldest expected temperature
2. Expected precipitation amount from the first empty bucket date to the coldest expected date
3. Parts water - With the information from Table 1, use the coldest expected temperature and find the corresponding parts water variable (e.g., at -25 C, use 1.5 parts water)

Enter the corresponding variables from Table 1 to the appropriate equation below.

NWS Inlet

$$\frac{(0.5289) \times (\text{expected precipitation [in]})}{\text{parts water}}$$

WMO Inlet

$$\frac{(0.328) \times (\text{expected precipitation [in]})}{\text{parts water}}$$

For example, if you are using a gauge with an NWS inlet, where the coldest temperature is -25 C and the expected precipitation amount is 8 inches, Table 1 indicates you need 1.5 parts water.

NWS Inlet

$$\frac{(0.5289) \times (\text{expected precipitation [in]})}{\text{parts water}} \qquad \frac{(0.5289) \times (8\ \text{in})}{1.5} \qquad 4.2312/1.5 = 2.8\ \text{inches}$$

Under the above conditions, you would need at least 2.8 inches of antifreeze fluid (measured from the bottom of the cistern) to prevent freezing. While you can add more antifreeze, these equations are used to determine the recommended minimal level.

Some users of weighing precipitation gauges (e.g., national and state weather networks) have specific protocols for antifreeze. PGE is recommended because it is relatively environmentally friendly, but it is not required. Other types of antifreeze can be used. A 50:50 mix of PGE can be purchased from Campbell Scientific (https://www.campbellsci.com/p10869), but shipping jugs of antifreeze is expensive, and sourcing it locally may be more cost effective.

Adding Oil

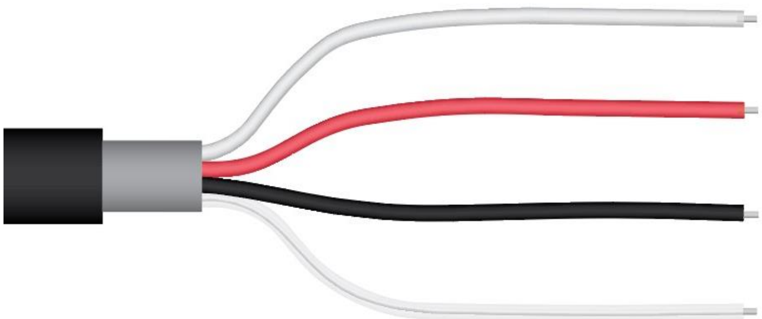
To keep water from evaporating, which causes a decrease in unfiltered cumulative precipitation, a layer of oil (e.g., mineral oil, hydraulic fluid) must be added on top of the water/antifreeze. The oil must be less dense than the antifreeze, otherwise it will not float on the surface and provide a barrier to evaporation. An oil layer thickness of 6.4 mm (0.25 in) is recommended. A volume of 400 mL of oil is required for a depth of approximately 6.4 mm. Mineral oil is recommended because it is environmentally friendly compared to some other options and is readily available, but it is not required. Other oils can be used for the oil layer.

IMPORTANT NOTE: When removing a bucket from the load cell or placing a bucket on the load cell be careful not to drop the bucket onto the load cell, as it may damage the load cell. The weight of a completely full bucket is about 32.5 kg (72 pounds). It is recommended a siphon be used to empty buckets before removing them from the load cell. **It is also highly recommended the orange protection spacers be installed when removing a bucket from the weighing mechanism and placing a bucket on the weighing mechanism.**

OPERATION AND MEASUREMENT

Apogee SG-400 series precipitation gauges have an SDI-12 output, where measured data are returned in digital format. Collecting data requires a measurement device with SDI-12 functionality that includes the M or C command.

Wiring



White: Positive (signal from sensor)

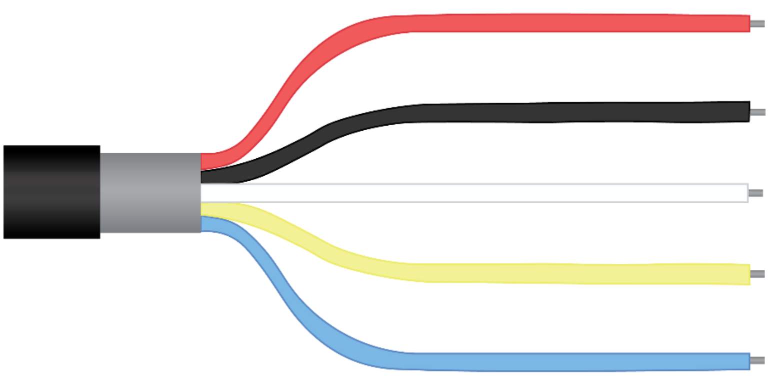
Red: Input Power

Black: Ground (for sensor signal and output power)

Clear: Shield

Inlet Heating
A heated inlet is not required to measure precipitation with a weighing gauge. In conditions where snow capping over the inlet may be a problem, both models SG-410 (NWS) and SG-430 (WMO) have the option of a 50 W heater to prevent snow capping. The heater includes a thermistor to measure inlet temperature and provide power control if desired.

Heater cable wiring:



Red: Excitation

Black: Ground

White: Signal

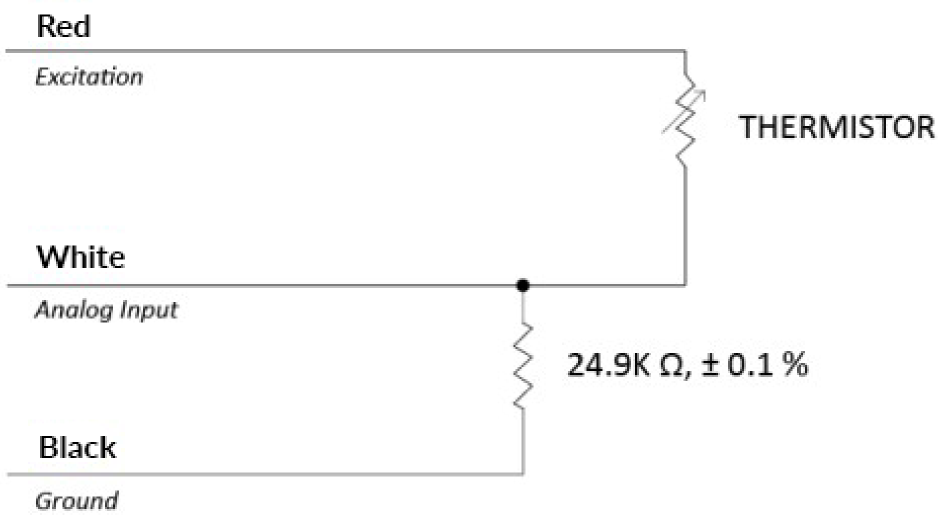
Yellow: Heater + (24 V DC)

Blue: Heater -

To conserve power the heater can be switched on and off based on inlet temperature. For example, if the inlet temperature drops below freezing, the inlet heater could be turned on. Conversely, when the inlet temperature rises above freezing, the heater could be turned off. Gauges with a heated inlet include a thermistor to measure inlet temperature.

Inlet Temperature Measurement with Thermistor

Measurement devices (e.g., dataloggers) do not measure resistance directly, but determine resistance from a half-bridge measurement, where an excitation voltage is input across the thermistor and an output voltage is measured across the bridge resistor.



An excitation voltage of 2.5 V DC is recommended to minimize self-heating and current drain, while still maintaining adequate measurement sensitivity (mV output from thermistor circuit per C). However, other excitation voltages can be used. Decreasing the excitation voltage will decrease self-heating and current drain but will also decrease thermistor measurement sensitivity. Increasing the excitation voltage will increase thermistor measurement sensitivity but will also increase self-heating and current drain.

The internal thermistor provides a temperature reference for calculation of target temperature. Resistance of the thermistor changes with temperature. Thermistor resistance (R_T, in Ω) is measured with a half-bridge measurement, requiring an excitation voltage input (V_{EX}) and a measurement of output voltage (V_{OUT}):

$$R_T = 24900\left(\frac{V_{EX}}{V_{OUT}} - 1\right) \qquad (1)$$

where 24900 is the resistance of the bridge resistor in Ω. From resistance, temperature (T_K, in Kelvin) is calculated with the Steinhart-Hart equation and thermistor specific coefficients:

$$T_K = \frac{1}{A + B\ln(R_T) + C(\ln(R_T))^3} \qquad (2)$$

where A = 1.129241 x 10^{-3}, B = 2.341077 x 10^{-4}, and C = 8.775468 x 10^{-8} (Steinhart-Hart coefficients).

If desired, measured temperature in Kelvin can be converted to Celsius (T_C):

$$T_C = T_K - 273.15\,. \qquad (3)$$

Gauge Calibration and Conversion of Signal to Precipitation

Load cells in Apogee SG-400 series precipitation gauges have sensor-specific calibration coefficients determined during the mass calibration process. Coefficients are programmed into the gauge microcontroller at the factory. The calibration coefficients applied to the signal output by the load cell [mV V^{-1}] are slope [kg / mV V^{-1}] and intercept [kg] (linear regression coefficients) that convert the signal [mV V^{-1}] to mass [kg]. Signal output by the load cell is voltage output from the resistor circuit [mV] divided by voltage input to the resistor circuit [V].

Conversion of mass to depth of water:

Mass [kg] multiplied by 1000 to convert to [g].
Mass [g] divided by density of water [g cm^{-3}] to convert to volume of water [cm^3].
Volume of water [cm^3] divided by area of the inlet [cm^2] to convert to depth of water [cm].
Depth of water [cm] multiplied by 10 to convert units [mm].

SDI-12 Interface

The following is a brief explanation of the serial digital interface SDI-12 protocol instructions used in Apogee SG-400 precipitation gauges. For questions on the implementation of this protocol, please refer to the official version of the SDI-12 protocol: http://www.sdi-12.org/specification.php (version 1.4, August 10, 2016).

Overview

During normal communication, the data recorder sends a packet of data to the sensor that consists of an address and a command. Then, the sensor sends a response. In the following descriptions, SDI-12 commands and responses are enclosed in quotes. The SDI-12 address and the command/response terminators are defined as follows:

Sensors come from the factory with the address of "0" for use in single sensor systems. Addresses "1 to 9" and "A to Z", or "a to z", can be used for additional sensors connected to the same SDI-12 bus.

"!" is the last character of a command instruction. To be compliant with SDI-12 protocol, all commands must be terminated with a "!". SDI-12 language supports a variety of commands. Supported commands for the Apogee Instruments SG-400 series precipitation gauges are listed below ("a" is the sensor address. The following ASCII Characters are valid addresses: "0-9" or "A-Z").

String returned by I! command:

A14Apogee MMMMMMVVVBBBSSSS
A = SDI-12 address
14 = SDI-12 version 1.4
Apogee = company name
MMMMMM = model number of precipitation gauge
VVV = firmware version
BBB = circuit board revision number, with B as first character
SSSS = serial number of precipitation gauge

Example: 014Apogee SG-4100.1B011132

where 0 is SDI-12 address, 14 indicates SDI-12 version 1.4, Apogee is company name, SG-410 is gauge model number, 0.1 is firmware version, B01 is circuit board revision number, and 1132 is gauge serial number.

Definition of the variables in the array returned by the "M1!" command:

The "M1!" Command (or "C1!") command outputs an array of nine variables:

1. Temperature-corrected cumulative precipitation [mm] (running average of past minute, only correction is for temperature response of load cell), includes tare for bucket/antifreeze if tare command is used.
2. Filtered cumulative precipitation [mm] (value updated every minute, may be delayed by up to half hour by filtering process), includes tare for bucket/antifreeze if tare command is used.
3. Precipitation rate [mm hr^{-1}] (value updated every minute and output when it is greater than 6 mm hr^{-1}, zero is output if value is less than 6 mm hr^{-1}).
4. Filtered precipitation rate [mm hr^{-1}] (value updated every minute, may be delayed by up to half hour by filtering process).
5. Cumulative precipitation [mm] (running average of past minute, where only correction is for temperature response of load cell), does not include tare for bucket/antifreeze.

6. Bucket total [%] (running average of past minute, total precipitation, including bucket and antifreeze/oil, currently on load cell divided by capacity of gauge).
7. Mass from load cell [kg] (running average of past minute).
8. Signal from load cell [mV V^{-1}] (running average of past minute, raw value output by load cell - voltage output by load cell circuit divided by excitation voltage input to load cell circuit).
9. Circuitry temperature [C] (running average of past minute).

Aside from the filtered precipitation (array values 2 and 4 above), the gauge operates using one minute average measurements, meaning the SDI-12 command returns the most recent one-minute average. If the SDI-12 command is executed quicker than one minute, array values 2 and 4 will not change.

Temperature-corrected precipitation has a temperature correction applied to the signal output by the load cell [mV V^{-1}] before mass is calculated and converted to depth of water. A correction factor is added (or subtracted if the sign is negative) to the measured signal [mV V^{-1}]. Then, this corrected signal is converted to mass, and mass is converted to depth of water as described above.

Algorithm-filtered precipitation is temperature-corrected precipitation with wind effects, evaporation, and false positive precipitation events caused by rapid temperature changes (thermal gradients across the load cell) filtered out with a proprietary algorithm. The filtering process may delay output by as much as half hour. The filtering process is designed to minimize false positive precipitation, but may eliminate some light precipitation events.

Additional SDI-12 Commands

Default units are [mm] for cumulative precipitation and [mm hr^{-1}] for precipitation rate. Units can be changed to [in] for cumulative precipitation and [in hr^{-1}] for precipitation rate with the extended command "**0XUIN!"**, where 0 is the SDI-12 address. If the address is not 0, then the extended command must be changed to the different address. The extended command "**0XUMM!"** changes units back to [mm] and [mm hr^{-1}]. Units can be queried with the extended command "**0XU!"**. The response will be 0 mm or 0 in.

The instantaneous temperature-corrected cumulative precipitation (array value 1) can be tared or set to 0 using the extended command "**0XITARE!"**, where 0 is the SDI-12 address. This command uses current measurements of the mass on the load cell and has an averaging time of one minute. Therefore, the mass on the load cell should be steady for at least one minute before sending this extended command. The tare can be reset/removed with the extended command "**aXRITA!"**.

The instantaneous temperature-corrected cumulative precipitation (array value 1) can be set to a given value with the extended command "**0XITARE<+/-desired output>!"** where **0** is the address, and **<+/-desired output>** is the signed desired output. The mass on the load cell must be steady for at least one minute before sending this command. For example, if the instantaneous temperature-corrected cumulative precipitation (array value 1) reads 12.45 after a bucket change, but the desired output is 252.457, the extended command "**0XITARE+252.457!"** would be sent.

The cumulative filtered precipitation (array value 2) can be tared or set to 0 using the extended command "**0XFTARE!"**, where 0 is the SDI-12 address. It can also be set to a given value using the extended command "**0XFTARE<+/-desired output>!"** where 0 is the SDI-12 address, and **<+/-desired output>** is the signed desired output. For example, if the cumulative filtered precipitation (array value 2) is 45.23, but the desired output is 5.99, the extended command "**0XFTARE+5.99!"** would be sent.

MAINTENANCE AND RECALIBRATION

Recharging Bucket

Service the gauge whenever the bucket is full (to avoid overflow), or at least once per year. It is good practice to use fresh oil when refilling the bucket with antifreeze. Used oil often contains dust, debris, and insects, which may impede precipitation movement through the oil layer and may increase evaporation. If the oil layer is not being replaced, a siphon may be used to collect the water/antifreeze mixture below the oil layer, instead of pouring the bucket to collect. Please properly dispose of used antifreeze to help protect the environment.

Clean the bucket and add the required antifreeze (and oil, if necessary). With the bucket removed from the weighing assembly, make sure the base plate drain hole vent is clean and clear. Carefully replace the bucket on the top plate of the weighing assembly, centering the bucket on the plate. When covering the gauge with the housing, be careful not to off center the bucket.

Load Cell Stability and Recalibration

Measurement of load cell long-term stability indicates load cell calibration changes by less than 0.5 % per year. It is recommended that a calibration check should be performed every year to determine if there was any drift in the load cell. A calibration check can be performed by placing known weight standards on the top plate of the weighing assembly (without the bucket). See the Apogee webpage for details regarding return of sensors for recalibration (http://www.apogeeinstruments.com/tech-support-recalibration-repairs/).

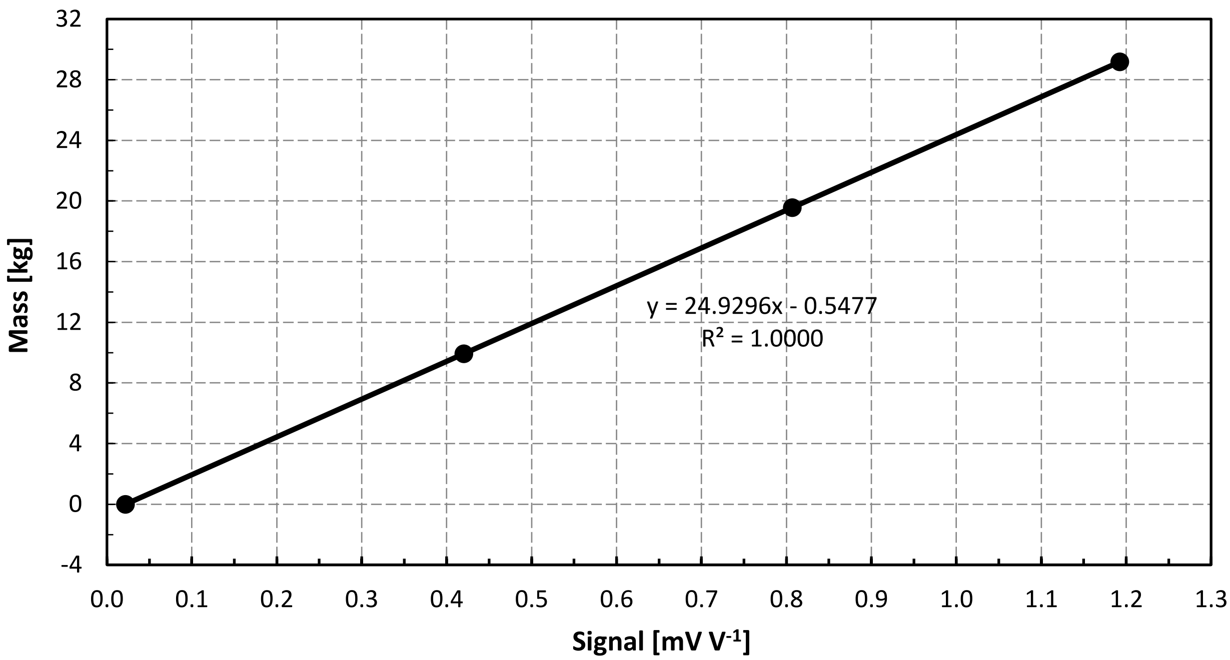
Load cells can be recalibrated with weights of known mass. Signal output by the load cell is linearly related to mass. To calibrate a load cell, known masses must be placed on the top plate of the load cell and the signal stabilized for at least one minute to account for averaging. That signal is then recorded. When load cells are calibrated at the factory, three 10 kg weights are used. This isn't required, but at least two weights that roughly approximate the 30 kg measurement range of the device are recommended (e.g., two 15 kg weights). Mass should be plotted against measured signal and a linear equation fit to the data to derive slope and intercept (see example data in Table 2 below and Graph 1 on following page).

	(increasing mass)	(decreasing mass)	
Mass [kg]	Signal [mV V^{-1}]	Signal [mV V^{-1}]	Mean Signal [mV V^{-1}]
0	0.021971	0.021833	0.021902
9.929	0.420243	0.420405	0.420324
19.567	0.806812	0.807047	0.806930
29.181	1.192412	1.192465	1.192439

Data in Table 2 above were collected during laboratory calibration of load cell.

- The first column is mass, where three weights near 10 kg were used for the calibration.
- The second column is signal output by the load cell at each mass during the process of adding the weights to the load cell.
- The third column is signal output by the load cells at each mass during the process of removing weights from the load cell.
- The fourth column is the mean of signal.

Graph 1 is a plot of mean signal versus mass. A linear equation is fit to these data to derive the calibration coefficients (slope and intercept) used to convert signal output by the load cell to mass.



Plot of mean signal versus mass (data were collected during laboratory calibration of load cell). A linear equation is fit to these data to derive the calibration coefficients (slope and intercept) used to convert signal output by the load cell to mass. Slope in this example is 24.9296 kg per mV V^{-1} and intercept is -0.5477 kg.

TROUBLESHOOTING AND CUSTOMER SUPPORT

Independent Verification of Functionality:

The simplest way to check functionality of an SG-400 is to tare the load cell (without the bucket on the weighing assembly), then place a known weight on the top plate of the weighing assembly. Leave the weight on the assembly for at least sixty seconds, then send the aM1! command to initiate a measurement, followed by the aD0! command to retrieve a measurement. The gauge should return nine values, the seventh number in the array being the measured mass in kilograms (the first number in the array is the corresponding depth of water in mm or in).

If the sensor does not communicate with the measurement device, use an ammeter to check the current drain. It should be near 20 mA when the sensor is not communicating and increase to 6 mA when the sensor is communicating. Any current drain greater than 6 mA indicates a problem with power supply to the sensor, wiring of the sensor, or sensor electronics.

Compatible Measurement Devices (Dataloggers/Controllers/Meters):

Any datalogger or meter with SDI-12 functionality that includes the M or C command.

An example datalogger program for Campbell Scientific dataloggers can be found on the Apogee webpage at http://www.apogeeinstruments.com/content/Total-Precipitation-Gauge.CR1.

Modifying Cable Length:

SDI-12 protocol limits cable length to 60 meters. For multiple sensors connected to the same data line, the maximum is 600 meters of total cable (e.g., ten sensors with 60 meters of cable per sensor). See Apogee webpage for details on how to extend sensor cable length (http://www.apogeeinstruments.com/how-to-make-a-weatherproof-cable-splice/).

RETURN AND WARRANTY POLICY

RETURN POLICY

Apogee Instruments will accept returns within 30 days of purchase as long as the product is in new condition (to be determined by Apogee). Returns are subject to a 10 % restocking fee.

WARRANTY POLICY

What is Covered
All products manufactured by Apogee Instruments are warranted to be free from defects in materials and craftsmanship for a period of four (4) years from the date of shipment from our factory. To be considered for warranty coverage an item must be evaluated by Apogee.

Products not manufactured by Apogee (spectroradiometers, chlorophyll content meters, EE08-SS probes) are covered for a period of one (1) year.

What is Not Covered
The customer is responsible for all costs associated with the removal, reinstallation, and shipping of suspected warranty items to our factory.

The warranty does not cover equipment that has been damaged due to the following conditions:

1. Improper installation, use, or abuse.

2. Operation of the instrument outside of its specified operating range.

3. Natural occurrences such as lightning, fire, etc.

4. Unauthorized modification.

5. Improper or unauthorized repair.

Please note that nominal accuracy drift is normal over time. Routine recalibration of sensors/meters is considered part of proper maintenance and is not covered under warranty.

Who is Covered
This warranty covers the original purchaser of the product or other party who may own it during the warranty period.

What Apogee Will Do
At no charge Apogee will:

1. Either repair or replace (at our discretion) the item under warranty.

2. Ship the item back to the customer by the carrier of our choice.

Different or expedited shipping methods will be at the customer’s expense.

How To Return An Item

1. Please do not send any products back to Apogee Instruments until you have received a Return Merchandise Authorization (RMA) number from our technical support department by submitting an online RMA form at www.apogeeinstruments.com/tech-support-recalibration-repairs/. We will use your RMA number for tracking of the service item. Call (435) 245-8012 or email techsupport@apogeeinstruments.com with questions.

2. For warranty evaluations, send all RMA sensors and meters back in the following condition: Clean the sensor's exterior and cord. Do not modify the sensors or wires, including splicing, cutting wire leads, etc. If a connector has been attached to the cable end, please include the mating connector – otherwise the sensor connector will be removed in order to complete the repair/recalibration. ***Note:*** *When sending back sensors for routine calibration that have Apogee's standard stainless-steel connectors, you only need to send the sensor with the 30 cm section of cable and one-half of the connector. We have mating connectors at our factory that can be used for calibrating the sensor.*

3. Please write the RMA number on the outside of the shipping container.

4. Return the item with freight pre-paid and fully insured to our factory address shown below. We are not responsible for any costs associated with the transportation of products across international borders.

Apogee Instruments, Inc.
721 West 1800 North Logan, UT
84321, USA

5. Upon receipt, Apogee Instruments will determine the cause of failure. If the product is found to be defective in terms of operation to the published specifications due to a failure of product materials or craftsmanship, Apogee Instruments will repair or replace the items free of charge. If it is determined that your product is not covered under warranty, you will be informed and given an estimated repair/replacement cost.

PRODUCTS BEYOND THE WARRANTY PERIOD

For issues with sensors beyond the warranty period, please contact Apogee at techsupport@apogeeinstruments.com to discuss repair or replacement options.

OTHER TERMS

The available remedy of defects under this warranty is for the repair or replacement of the original product, and Apogee Instruments is not responsible for any direct, indirect, incidental, or consequential damages, including but not limited to loss of income, loss of revenue, loss of profit, loss of data, loss of wages, loss of time, loss of sales, accruement of debts or expenses, injury to personal property, or injury to any person or any other type of damage or loss.

This limited warranty and any disputes arising out of or in connection with this limited warranty ("Disputes") shall be governed by the laws of the State of Utah, USA, excluding conflicts of law principles and excluding the Convention for the International Sale of Goods. The courts located in the State of Utah, USA, shall have exclusive jurisdiction over any Disputes.

This limited warranty gives you specific legal rights, and you may also have other rights, which vary from state to state and jurisdiction to jurisdiction, and which shall not be affected by this limited warranty. This warranty extends only to you and cannot be transferred or assigned. If any provision of this limited warranty is unlawful, void, or unenforceable, that provision shall be deemed severable and shall not affect any remaining provisions. In case of any inconsistency between the English and other versions of this limited warranty, the English version shall prevail.

This warranty cannot be changed, assumed, or amended by any other person or agreement.