COLORADO
Air Pollution Control Division
Department of Public Health & Environment

Technical Services Program

APPENDIX GM5A

Standard Operating Procedure for Meteorological Monitoring with a Mobile Tower

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1 Scope and Applicability

The majority of information regarding meteorological monitoring are covered in the parent Appendix GM5 - Meteorology and will not be repeated here.

1.1 Introduction

The APCD/TSP has designed and deployed a meteorology tripod at approximately 4 meters tall that measures temperature, relative humidity, wind direction, wind speed, barometric pressure, and solar radiation. The measurements are collected by a Gill MaxiMet 501, which is self-northing with an internal compass.

1.2 Format and Purpose

This appendix is written for analysis that does not result in data stored in EPA AQS. As such, it is only loosely based on the 2007 EPA guidance on preparing standard operating procedures. Parts of that guidance not found here are assumed to be in the parent Appendix GM5 – Meteorology SOP.

2 Summary of Method

The design of the mobile meteorological tripod is intended to be autonomous and temporary. It is designed around a 12 volt power source capable of running the sensor and data logger.

2.1 Meteorological Measurements

2.1.1 Sensors

The mobile meteorological tripod uses a Gill MaxiMet GMX501 compact weather station.

Temperature, humidity, and pressure are measured by a combination instrument mounted inside three double louvered, naturally aspirated radiation shields with no moving parts. Temperature is measured in degrees Celsius, humidity is measured in percent, and pressure is measured in hectopascals.

Solar radiation is measured by a pyranometer, using a thermal sensor mounted at the base and protected by a single glass dome. Solar radiation is measured in watts per square meter.

Wind speed and direction are measured by an ultrasonic sensor, or sonic anemometer. Speed is measured in average and gust in meters per second and direction is measured in degrees.

Other measurements are made by the GMX501 and not covered here, since they are derivative. Examples include wet bulb temperature, hours of daylight, et cetera.

2.1.2 Instrument Shelter

A weather-proof Campbell Scientific ENC10/12 fiberglass enclosure (or similar) contains the power system and data logger. Figure 1 shows the layout of the enclosure. The data logger and battery (though the battery is sealed) are above the bottom of the enclosure in the event water pools at the bottom.

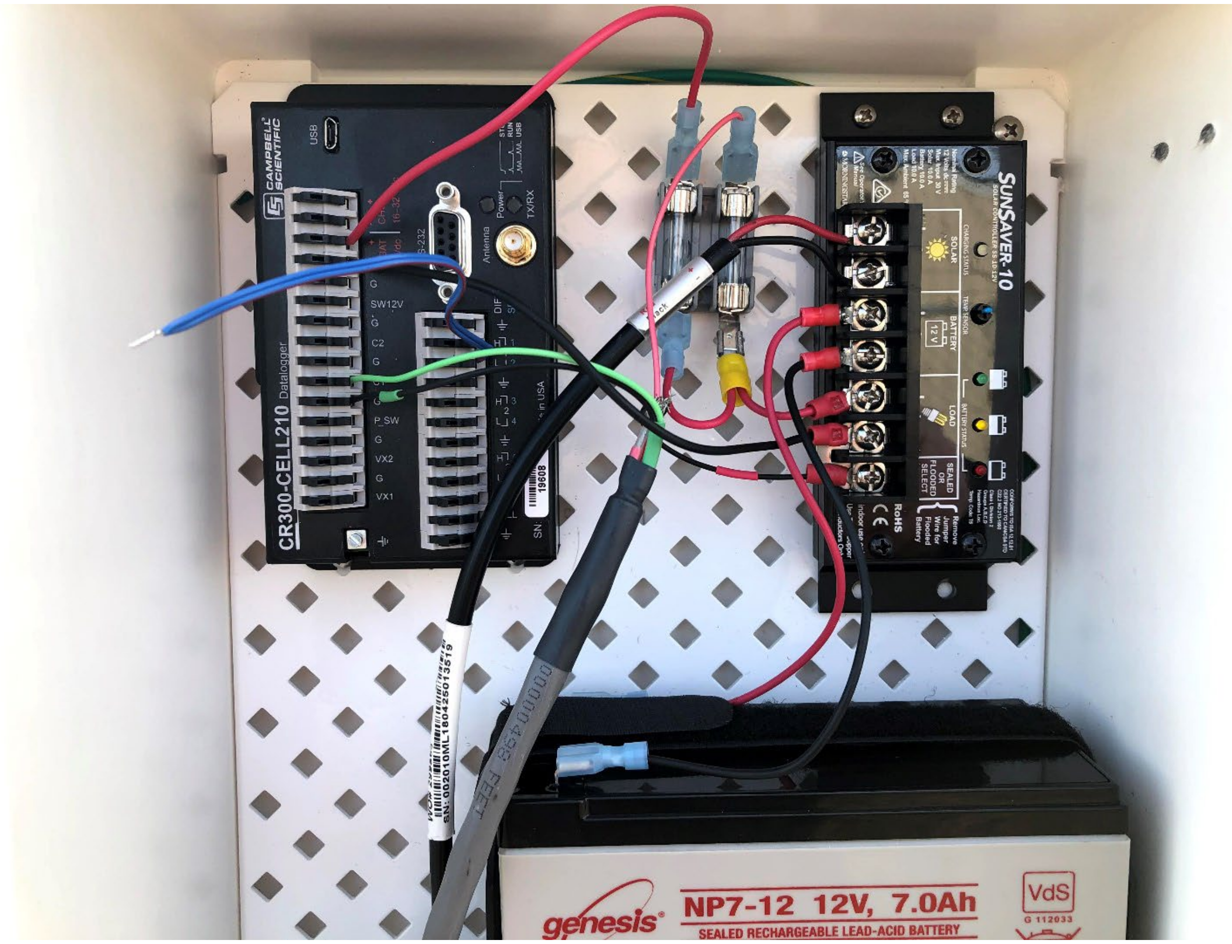

Figure 1. Internal Station Setup showing the CR300 data logger and modem, the SunSaver voltage regulator, and the Genesis 12v 7Ah battery

The enclosure is based on a 12 volt system including a solar panel, a voltage regulator, and a lead acid storage battery. Under normal summer conditions the system shown is sufficient to run all equipment therein including modems that have limited connectivity, thereby increasing their common draw. Figure 2 shows the outside configuration of the tripod.

Figure 2. Exterior Enclosure Setup showing the data logger enclosure, the solar panel, and the GMX501 sensor

The tripod is a Campbell Scientific CM106B galvanized steel tube tripod that can be between 7 and 10 feet tall, with the use of an extension arm as shown in Figure 2. The legs of the tripod fold up such that the enclosure and solar panel need to be removed before collapsing. Also shown in Figure 2 are three sand bags at 60 pounds each draped over the feet of the tripod. This is to ensure the tripod is stable without having to penetrate the ground. The tripod was tested in high winds and did not tip over.

2.1.3 Data Acquisition System

A Campbell Scientific CR300 data logger with built-in modem is used to gather, aggregate, and store data. Details about the CR300 can be found in the owner's manual.

For troubleshooting purposes, Figure 3 provides an illustration of how the CR300 should be wired. Note this diagram is limited to the data logger and the subsequent relays. It is implied that the wiring continues from the relays to the appropriate systems.

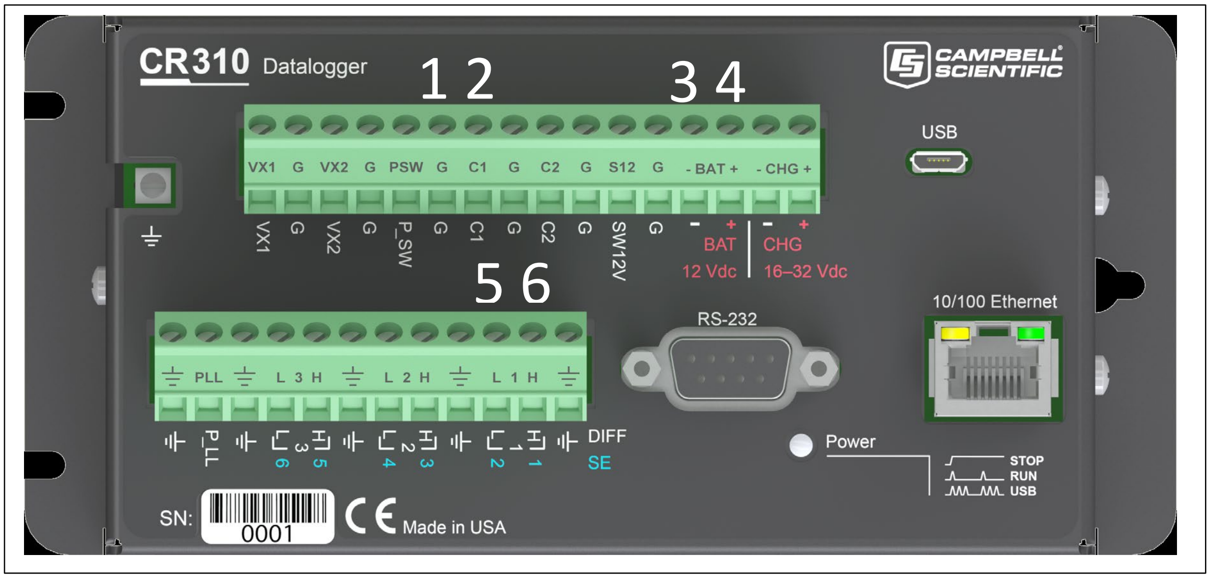

Figure 3. CR300 Wiring Diagram showing 1 and 2 as ground and signal from the sensor, 3 and 4 as ground and voltage from the battery, and 5 and 6 as ground and signal from the internal thermistor

The CR300 has three ports, one RS-232, one Ethernet, and one USB. All can be used to connect a laptop or other device to collect data with the USB being the simplest. Refer to the CR300 user manual and PC208 help for details.

2.1.4 Wiring, Tubing, and Fittings

The solar panel is wired into the voltage regulator following labeling on the voltage regulator. The battery should be wired to the voltage regulator again following the labeling. Power for all internal components should be pre-wired. The circuitry is protected by two 2-amp tube fuses.

2.1.5 Spare Parts and Incidental Supplies

Tube fuses may blow, it is best to have spare 2-amp tube fuses on hand. In shady areas or in cases where the best sun angle cannot be achieved for the solar panel, a spare lead acid battery should be maintained on a battery cycling tender and used to swap when voltages drop below 11.5 volts.

3 Definitions

See the parent GM8A Meteorology appendix.

4 Health and Safety Warnings

Do not climb the tripod. It is not designed, even with ballast, to support any substantial weight.

Do not touch bare copper inside the shelter, even if the unit is believed to be de-energized. There is no fuse protection between the battery, voltage regulator, and solar panel.

5 Cautions

See the parent GM5 Meteorology appendix.

6 INTERFERENCES

See the parent GM5 Meteorology SOP

7 PERSONNEL QUALIFICATIONS

See the parent GM5 Meteorology SOP

8 APPARATUS AND MATERIALS

For materials directly related to the mobile meteorological tripod, see Section 2 of this SOP. For ancillary materials, see the parent GM5 – Meteorology SOP.

8.1 GMX501 Programming

For reference, the program, which can be edited in a text editor, and exported to the data logger, is listed here:

```
'Declare Variables and Units
Public BattV
Public PTemp_C
Public Temp_C
Public SDI12(4)
Public SDI12_2(9)
Public SDI12_3(5)
Public SDI12_4(5)
Public SDI12_5(8)

Alias SDI12(1)=WD
Alias SDI12(2)=WS
Alias SDI12(3)=cWD
Alias SDI12(4)=cWS
Alias SDI12_2(1)=Temperature
Alias SDI12_2(2)=RH
Alias SDI12_2(3)=Dewpoint
Alias SDI12_2(4)=Pressure
Alias SDI12_2(5)=Status
Alias SDI12_2(6)=WindChill
Alias SDI12_2(7)=HeatIndex
Alias SDI12_2(8)=AirDensity
Alias SDI12_2(9)=WBTemp
Alias SDI12_3(1)=SolarRadiation
Alias SDI12_3(2)=SunshineHours
Alias SDI12_3(3)=XTilt
Alias SDI12_3(4)=YTilt
Alias SDI12_3(5)=ZOrientation
Alias SDI12_4(1)=Latitude
Alias SDI12_4(2)=Latitude2
Alias SDI12_4(3)=Longitude
Alias SDI12_4(4)=Longitude2
Alias SDI12_4(5)=AboveMSL
Alias SDI12_5(1)=Sunrise
Alias SDI12_5(2)=SolarNoon
```

```
Alias SDI12_5(3)=Sunset
Alias SDI12_5(4)=Azimuth
Alias SDI12_5(5)=SolarElevation
Alias SDI12_5(6)=Twilight1
Alias SDI12_5(7)=Twilight2
Alias SDI12_5(8)=Twilight3

Units BattV=Volts
Units PTemp_C=Deg C
Units Temp_C=Deg C
Units WD=degrees
Units WS=m/s
Units cWD=degrees
Units cWS=m/s
Units Temperature=C
Units RH=%
Units Dewpoint=C
Units Pressure=hPa
Units Status=unit
Units WindChill=C
Units HeatIndex=C
Units AirDensity=hPa
Units WBTemp=C
Units SolarRadiation=W/m2
Units SunshineHours=unit
Units XTilt=degrees
Units YTilt=degrees
Units ZOrientation=degrees
Units Latitude=integer
Units Latitude2=fraction
Units Longitude=integer
Units Longitude2=fraction
Units AboveMSL=m
Units Sunrise=time
Units SolarNoon=time
Units Sunset=time
Units Azimuth=degrees
Units SolarElevation=m
Units Twilight1=civil
Units Twilight2=nautical
Units Twilight3=astronomical

'Define Data Tables
DataTable(MinuteData,True,-1)
	DataInterval(0,1,Min,10)
	Average(1,BattV,FP2,False)
	Average(1,PTemp_C,FP2,False)
	Average(1,Temp_C,FP2,False)
	Sample(1,WD,FP2)
	Average(1,WS,FP2,False)
	Sample(1,cWD,FP2)
	Average(1,cWS,FP2,False)
	Average(1,Temperature,FP2,False)
```

```
        Average(1,RH,FP2,False)
        Average(1,Dewpoint,FP2,False)
        Average(1,Pressure,FP2,False)
        Average(1,Status,FP2,False)
        Average(1,WindChill,FP2,False)
        Average(1,HeatIndex,FP2,False)
        Average(1,AirDensity,FP2,False)
        Average(1,WBTemp,FP2,False)
        Average(1,SolarRadiation,FP2,False)
        Average(1,SunshineHours,FP2,False)
        Average(1,XTilt,FP2,False)
        Average(1,YTilt,FP2,False)
        Average(1,ZOrientation,FP2,False)
        Average(1,Latitude,FP2,False)
        Average(1,Latitude2,FP2,False)
        Average(1,Longitude,FP2,False)
        Average(1,Longitude2,FP2,False)
        Average(1,AboveMSL,FP2,False)
        Average(1,Sunrise,FP2,False)
        Average(1,SolarNoon,FP2,False)
        Average(1,Sunset,FP2,False)
        Average(1,Azimuth,FP2,False)
        Average(1,SolarElevation,FP2,False)
        Average(1,Twilight1,FP2,False)
        Average(1,Twilight2,FP2,False)
        Average(1,Twilight3,FP2,False)
EndTable

DataTable(HourData,True,-1)
        DataInterval(0,1,Hr,10)
        Minimum(1,BattV,FP2,False,False)
        Average(1,BattV,FP2,False)
        Average(1,PTemp_C,FP2,False)
        Average(1,Temp_C,FP2,False)
        WindVector(1,WS,WD,FP2,False,0,0,0)
        FieldNames("WS_S_WVT,WD_D1_WVT,WD_SD1_WVT")
        Average(1,WS,FP2,False)
        WindVector(1,WS,WD,FP2,False,0,0,0)
        FieldNames("cWS_S_WVT,cWD_D1_WVT,cWD_SD1_WVT")
        Average(1,Temperature,FP2,False)
        Average(1,RH,FP2,False)
        Average(1,Dewpoint,FP2,False)
        Average(1,Pressure,FP2,False)
        Average(1,Status,FP2,False)
        Average(1,WindChill,FP2,False)
        Average(1,HeatIndex,FP2,False)
        Average(1,AirDensity,FP2,False)
        Average(1,WBTemp,FP2,False)
        Average(1,SolarRadiation,FP2,False)
        Average(1,SunshineHours,FP2,False)
        Average(1,XTilt,FP2,False)
        Average(1,YTilt,FP2,False)
        Average(1,ZOrientation,FP2,False)
```

```
		Average(1,Latitude,FP2,False)
		Average(1,Latitude2,FP2,False)
		Average(1,Longitude,FP2,False)
		Average(1,Longitude2,FP2,False)
		Average(1,AboveMSL,FP2,False)
		Average(1,Sunrise,FP2,False)
		Average(1,SolarNoon,FP2,False)
		Average(1,Sunset,FP2,False)
		Average(1,Azimuth,FP2,False)
		Average(1,SolarElevation,FP2,False)
		Average(1,Twilight1,FP2,False)
		Average(1,Twilight2,FP2,False)
		Average(1,Twilight3,FP2,False)
EndTable

'Main Program
BeginProg
		'Main Scan
		Scan(10,Sec,1,0)
				'Default CR300 Datalogger Battery Voltage measurement 'BattV'
				Battery(BattV)
				'Default CR300 Datalogger Processor Temperature measurement 'PTemp_C'
				PanelTemp(PTemp_C,60)
				'Type T Thermocouple measurements 'Temp_C'
				TCDiff(Temp_C,1,mv34,1,TypeT,PTemp_C,True,0,60,1,0)
				SDI12Recorder(SDI12(),C1,"0","M!",1,0,-1)
				'Reset all Generic SDI-12 Sensor measurements if NAN is returned to SDI12(1)
				If SDI12(1)=NAN Then Move(SDI12(),4,NAN,1)
				SDI12Recorder(SDI12_2(),C1,"0","M1!",1,0,-1)
				'Reset all Generic SDI-12 Sensor measurements if NAN is returned to SDI12_2(1)
				If SDI12_2(1)=NAN Then Move(SDI12_2(),9,NAN,1)
				SDI12Recorder(SDI12_3(),C1,"0","M4!",1,0,-1)
				'Reset all Generic SDI-12 Sensor measurements if NAN is returned to SDI12_3(1)
				If SDI12_3(1)=NAN Then Move(SDI12_3(),5,NAN,1)
				SDI12Recorder(SDI12_4(),C1,"0","M5!",1,0,-1)
				'Reset all Generic SDI-12 Sensor measurements if NAN is returned to SDI12_4(1)
				If SDI12_4(1)=NAN Then Move(SDI12_4(),5,NAN,1)
				SDI12Recorder(SDI12_5(),C1,"0","M7!",1,0,-1)
				'Reset all Generic SDI-12 Sensor measurements if NAN is returned to SDI12_5(1)
				If SDI12_5(1)=NAN Then Move(SDI12_5(),8,NAN,1)
				'Call Data Tables and Store Data
				CallTable MinuteData
				CallTable HourData
		NextScan
EndProg
```

9 CALIBRATION

No parts of the GMX501 are able to be calibrated by the end user. Verification can occur by collocation of a standard traceable sensor. In pretesting the GMX501 against a tower of known quality, the GMX501 performed acceptably well. This process should be repeated whenever data is suspect, or annually.

10 OPERATION AND MAINTENANCE

10.1 Tripod Location and Setup

Setup of the mobile meteorological tripod requires a magnetic bubble level, a half-inch wrench, and a standard (Phillips) screwdriver #2.

To be folded down, the enclosure and solar panel must be removed.

The tripod can be stored and transported assembled with the GMX501 attached and wires run through the center mast. In this state, the tripod is more than three meters long so transport requires a larger vehicle. Alternatively, the extension arm can be removed from the main center mast by removing the four ½ inch bolts, which thread into the mast and require no nuts, from the extension arm and carefully removing the wiring from the main mast. In this state, the tripod is about two meters long. The former more fully assembled state is preferred since wires are not removed and inserted past sharp edges on the tripod.

The position of the legs of the tripod are held by a locking bracket with a ½ inch bolt. Tightening the bolt locks the leg in place. See Figure 4.

Figure 4. Leg locking clamps with ½ inch bolts

Lay the tripod in a collapsed state on the ground. The three legs will move independently. Expand one leg at a time, raising the tripod in the process. In its final position, the tripod will have the solar panel mounted to one of the three legs. Orient the tripod so that one leg is facing due south for optimum solar gain. With the center mast in an upright position, and the three legs loose, lean the tripod mast away from one leg and tighten the locking bolt on that leg. Repeat this for all three legs until the bottom of the center mast is roughly ½ meter above the ground. This is illustrated in Figure 5 where the center mast is removed.

Figure 5. Base of the tripod as erect without center mast

The mast must be plumb for proper operation of the GMX501. Using a magnetic level affixed to the center mast, adjust the three legs until the mast is plumb. Be sure to check the plumb on at least two planes of the center mast.

If the center mast is not connected to the extension arm, it should be connected to the center mast before being inserted into the tripod. It is too tall in the fully upright position to reasonably do after erection. Lay both the center mast and the extension arm on the ground, protecting the GMX501. Feed the signal wire through the center mast, being careful of the sharp edges inside the mast, especially at the ends. Bolt the four ½ inch connector bolts between the extension arm and the center mast.

If the center mast is not inserted in the tripod base, it is best attached to the tripod base after the base is erect, because the legs of the tripod collapse up and block working surfaces at the center. In the center of the tripod base are three plates of galvanized steel with bronze nuts, shown in Figure 6. In total there are six bronze nuts (there are more galvanized nuts but they do not require adjustment). Loosen the six bronze nuts until they are flush with the end of the bolts. Insert the mast into the erect tripod until the bottom of the mast reaches the stop tabs on the galvanized plates. This can require considerable force. If the sensor wire is already threaded through the mast, be sure it exits below the bottom of the bottom two bronze nuts before fully inserting the mast or the wire will be pinched between the mast and the bolt shaft. Once the center mast is fully inserted, tighten the six bronze nuts.

With the tripod erected and the mast inserted, weigh the three feet of the tripod down with 60-pound tube sand bags.

Figure 6. Galvanized plates with bronze nuts at the center of the tripod base

10.2 Enclosure and Solar Panel Assembly

Attach the solar panel to the south facing leg of the tripod with a U-bolt. The mounting bracket of the solar panel has a black plastic cradle that fits securely to the leg.

Attach the enclosure to the center mast with two U-bolts. The enclosure has two metal tab pairs, top and bottom, designed to match the diameter of the mast. Make sure the enclosure is at least 15 centimeters above the top of the tripod base so that tightening the U-bolt at the bottom is reasonable, and opposite the solar panel so that it does not shade the panel. See Figure 7.

Figure 7. Solar panel mounting hardware (left), Enclosure mounting hardware top (center) and bottom (right)

The GMX501 has a connector outside the enclosure, shown in Figure 7 (right). It can only be assembled in the proper orientation. Tighten the weather nut once connected. The solar panel needs to be wired into the voltage regulator, see Figure 1. Insert the solar panel leads through the bottom port on the enclosure. Connect the red lead to the + side of the Solar group, and the black lead to the – side, and tighten with a #2 Phillips screwdriver. Use putty to weather-seal the port. Assemble any excess cabling and connect to a leg of the tripod with zip ties. Do not leave cabling in contact with the ground.

The finished assembly should resemble Figure 8.

Figure 8. Fully assembled solar panel and enclosure

11 HANDLING AND PRESERVATION

See the parent GM5 Meteorology appendix.

12 SAMPLE PRESERVATION AND ANALYSIS

See the parent GM5 Meteorology appendix.

13 TROUBLESHOOTING

The CR300 will have a flashing light if it is on and reading. For details on flash patterns and their indications refer to the CR300 manual. If there is no light on at all on the CR300, make sure all power connections are secure and not corroded. Check the left-hand tube fuse. Make sure the battery has at least 11 volts and charge as necessary with an appropriate trickle charger or battery tender (the solar panel will accomplish this in daylight).

The voltage regulator has battery level indicator lights that can assist in determining a proper charge on the battery. There is also a charging light that will confirm correct connection to the solar panel during the day. In ideal conditions, the battery will indicate fully charged and the charging status light will be flashing (this indicates a float charge, refer to the SunSaver manual).

The GMX501 has no indication that it has power outside of data collection. If power to the GMX501 is suspect, check the supply connections on the voltage regulator, and the right-hand tube fuse.

14 Data Acquisition, Calculations, and Data Reduction

The CR300 has a built-in data modem with a static IP address. It also has a web interface that allows for data monitoring and collection.

In a web browser, type in the static IP address of the CR300 (63.42.42.96 for example). The index page will default to a status display providing the serial number, time stamp, OS, panel and battery (internal) voltage, as well as memory usage and errors. At the top of the browser (or under the three bars on a mobile device) select Data.

By default the Public table will be displayed, as indicated by "Public" being highlighted at the left of the page. This is the live data being collected by the CR300.

Saving data to a mobile device has not been researched and is not recommended. To collect data, select either the HourData or MinuteData tables from the Table List. Note that these table names are dictated in the programming in the CR300 and may change. Once on the appropriate page, the most recent average will be displayed in the main table. Click the "Save" button and provide a file format (CSV is the default and is recommended) and timeframe filter (options include All Data, Most Recent Intervals, and Most Recent # of Records, the latter two of which require a numeric limitation), and click Save. By default the data will be saved to the standard download location for the browser.

The CSV will have as its first few lines the measurement parameter and the unit. Subsequent data lines will have a time stamp.

15 Computer Hardware and Software

See the parent GM5 Meteorology appendix.

16 Data Management and Records Management

See the parent GM5 Meteorology appendix.

17 References

See the parent GM5 Meteorology appendix.