1.0 Instrument Details

1.1 Detailed Description

1.1.1 List of Components

- **Wind speed and direction sensors:** A pair of propeller anemometers and wind vanes, R. M. Young Model 05106 Wind Monitors.

- **Temperature and relative humidity sensor:** Platinum RTD and RH, Vaisala Model HMP45D Temperature and Relative Humidity Probe.

- **Barometric pressure sensor:** Digital barometer, Vaisala Model PTB201A or PTB220.

- **Precipitation:**
  - Tipping Bucket Rain Gauge: RIMCO 7499 Series.

- **Visibility, Present Weather and Precipitation Sensor:** Present Weather Detector, Vaisala, Inc. PWD-22. Installed at sites C1 and C3 only.

- **Data logger:** Campbell Scientific, Inc. Model CR23X.

1.1.2 System Configuration and Measurement Methods

The SMET sensors are mounted on a 10-meter mast, except for the rain gauge.

The wind monitor propeller anemometers produce a magnetically controlled AC output whose frequencies are proportional to the wind speed. The Wind Monitor direction vanes drive potentiometers, which are part of resistance bridges.

Two wind monitors are mounted on a cross-arm at a height of 10 m. One is mounted slightly above the other in order to minimize interference. The higher wind monitor is designated sensor #1 and the lower wind monitor is designated sensor #2.

The T-RH probe four-lead, platinum resistance thermometer is part of a resistance bridge. The Vaisala RH circuitry produces a voltage that is proportional to the capacitance of a water-vapor-absorbing thin polymer film. The T-RH probe is mounted in an R. M. Young Model 43408 Gill Aspirated Radiation Shield at a height of 2 m.

The barometric pressure sensor uses a silicon capacitive pressure sensor and is housed in an enclosure along with the data logger.
The optical precipitation gauge detects scintillation of an infrared beam caused by liquid water in the path. It is located near the tower. The following equations are used to convert the voltage signal to a rain rate.

For the ORG-815:

\[
\text{Rainrate (mm/hr)} = (25*V^{1.87} - 0.15)
\]

For the ORG-115:

\[
\text{Rainrate (mm/hr)} = (20*V^{2} - 0.05)
\]

The tipping bucket rain gauge is a siphon-controlled tipping bucket rain gauge. It is designed and constructed for long-term operation with minimal maintenance required. Any rain falling on the 203-mm collecting funnel is directed through a siphon control unit and discharges as a steady stream into a two-compartment bucket mounted in unstable equilibrium. As each compartment fills, the bucket tilts alternately about its axis. Each tip forces a momentary contact closure by magnetic means. The data logger senses each contact closure and applies 0.2 mm for each contact closure. At site C3 the rain gauge is connected only to the SMET system and is only part of the SMET system. At sites C1 and C2 the rain gauge is connected to the Bureau of Australian Meteorology (BoM) Automated Weather Station (AWS) and also the SMET systems at each site. The rain gauges at sites C1 and C2 belong to the AWS system and not to the SMET system.

The Present Weather Detector is an optical sensor that measures visibility, precipitation intensity, and precipitation type. It is mounted on the tower on a cross-arm. It measures visibility using the principle of forward-scatter measurement. In addition to the scatter, the PWD also contains the Vaisala RAINCAP® Rain Sensor. It uses a near-infrared LED with a peak wavelength of 875 nm. It is eye-safe in accordance with International Standard IEC/EN 60 825.1, edition 1.2.

The CR23X data logger measures each input once per second except for barometric pressure, which is measured once per minute, and logs 1-min averaged data. Vapor pressure is computed from the air temperature and relative humidity. The data logger produces:

- 1-min averages, minimums, maximums, and standard deviations of wind speed, air temperature, relative humidity, and rain rate
- 1-min vector-averaged wind speed and direction
- 1-min standard deviation of the wind direction computed by an algorithm
- 1-min averages and standard deviations of vapor pressure
- a reading of the barometric pressure, logger panel temperature, and the internal supply voltage.

### 1.1.3 Specifications

**Wind speed at 10 m:**

- Precision: 0.01 m/s
- Uncertainty: ± 2% for 2.5 to 30 m/s

**Wind direction at 10 m:**
• Precision: 0.1°
• Uncertainty: ± 5°

**Air temperature at 2 m:**
• Precision: 0.01 C
• Uncertainty: +/-0.57 C

**Relative humidity at 2 m**
• Precision: 0.1% RH
• Uncertainty: ± 2.06% RH (0% to 90% RH), ± 3.04% RH (90% to 100% RH)

**Barometric pressure at 1 m:**
• Precision: 0.01 kPa
• Uncertainty: ± 0.035 kPa

**Precipitation:**
• **Optical Rain Gauge:**
  – Precision: 0.1 mm/hr
  – Uncertainty: +/-0.1 mm/hr
• **Tipping Bucket Rain Gauge:**
  – Precision: 0.2 mm
  – Uncertainty +/- 0.2 mm (unknown during strong winds)

**Visibility, Present Weather and Precipitation Sensor:**
• Meteorological Optical Range: 10–20,000 m
• Precision +/- 10%, in the 10-m–10-km range, +/-15% in the 10-km–20-km range
• Uncertainty +/- 5%.

**Precipitation:**
• Precision: 0.01 mm
• Detection sensitivity is given as: 0.05 mm/h or less, within 10 minutes. No precision or uncertainty values are given.

**Overall Uncertainties for Primary Quantities Measured**

All SMET uncertainty analyses are based on manufacturer's specifications. Manufacturers specify accuracies in several ways. Some give absolute range of error, some give uncertainties as defined above, while others give rms errors. In this analysis, rms errors are multiplied by 2. This results in confidence limits of approximately 95%.
Data Acquisition Errors

The Campbell Scientific, Inc. CR23X data logger A–D converter accuracy is +/- 0.025% FSR for 0–40 C, +/- 0.05% FSR -25 to 50 C, +/- 0.075% FSR -40 to 80 C. The clock accuracy is +/- 1 minute per month for -25 to 50 C and +/- 2 minutes per month -40 to 80 C. The LoggerNet software checks the clock of the logger once per day and adjusts it if it is off by more than two seconds. The computer continuously maintains time synchronization with a GPS-based time reference using the NTPD protocol. The GPS based reference is local to each site.

For the system initially installed, the Coastal Environmental Systems ZENO-3200 A–D converter accuracy is +/-0.05% of full-scale range. The time base accuracy is +/-0.005%. The Site Data System checked the time-of-day clock once per day and corrected the logger clock if it was off by more than a minute.

Wind Speed

The NIST calibration uncertainty is specified as ± 2% for wind speeds from the sensor threshold to 30 m/s. The conversion error is negligible. The schedule of routine maintenance and sensor verification is designed to eliminate any long-term stability error.

The sensor threshold is specified as 1 m/s. The following estimates of the range of underestimation caused by the threshold assume a normal distribution of wind speeds about the mean.

- When the true wind speed is 1.0 m/s, the winds will be below the threshold 50% of the time. This will result in an underestimate of 0.5 m/s.
- When the true wind speed is 1.5 m/s, assuming the standard deviation will be between 0.25 and 1.00 m/s, the winds will be below the threshold between 2% and 31% of the time. This will result in an underestimate between 0.02 and 0.23 m/s.
- When the true wind speed is 2.0 m/s with a range of standard deviations between 0.25 and 1.00 m/s, the winds will be below the threshold between 0% and 16% of the time. This will result in an underestimate between 0 and 0.12 m/s.
- If the reported wind speed is 0.5 m/s, an underestimate of 0.5 is probable. This would bias the measurement by -0.5.
- If the reported wind speed is 1.0 m/s, an underestimate of 0.19 to 0.30 m/s is possible.
- If the reported wind speed is 1.5 m/s, an underestimate of 0.02 to 0.20 m/s is possible.
- If the reported wind speed is 2.0 m/s, an underestimate of 0 to 0.10 m/s is possible.

The uncertainty range with 95% confidence is approximately:

<table>
<thead>
<tr>
<th>Range</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>+/- 2%</td>
<td>for a reported wind speed from 2.5 to 30.0 m/s</td>
</tr>
<tr>
<td>-0.12 to +0.02 m/s</td>
<td>for a reported wind speed of 2.0 m/s</td>
</tr>
<tr>
<td>-0.22 to +0.00 m/s</td>
<td>for a reported wind speed of 1.5 m/s</td>
</tr>
<tr>
<td>-0.31 to -0.20 m/s</td>
<td>for a reported wind speed of 1.0 m/s</td>
</tr>
<tr>
<td>-0.51 to -0.49 m/s</td>
<td>for a reported wind speed of 0.5 m/s</td>
</tr>
</tbody>
</table>
Wind Direction

The sensor accuracy is specified as ± 3°. The A/D conversion accuracy is equivalent to ± 0.7° over a temperature range of 0° to 40°C for a period of one year. I have estimated sensor alignment to true north to be accurate within ± 3°. The uncertainty with 95% confidence is, therefore, approximately ± 5°.

Temperature

The accuracy of the temperature measurement is +/-0.4 C. The long-term stability is not known. The radiation error of the aspirated radiation shield is specified as +/-0.2 C rms. The uncertainty with 95% confidence of temperature sensors in this radiation shield is, therefore, +/- 0.57 C.

Relative Humidity

The accuracy of the RH sensor is specified as +/-2% RH for 0 to 90% RH and +/-3% RH for 90 to 100% RH. Errors considered in this accuracy are calibration uncertainty, repeatability, hysteresis, temperature dependence, and long-term stability over a period of one year. The A–D conversion accuracy is equivalent to +/-0.5% RH, which is negligible.

Barometric Pressure

The manufacturer's technical data contains an uncertainty analysis. Errors included in their analysis are linearity, hysteresis, calibration uncertainty, repeatability, temperature dependence, and long-term stability over a period of one year. Because the sensor has a digital output, no conversion error occurs in the data logger. The specified uncertainty with 95% confidence is +/-0.035 kPa. Note that the pressure behaves anomalously during rain events, even very mild ones. Normally, the pressure undergoes a smooth semi-diurnal oscillation with little higher-frequency variability. However, during and shortly after rain events, the pressure signal exhibits abrupt changes until the collection system was changed from the Zeno loggers in a pressure-sealed container to the Campbell Scientific loggers in a fiberglass enclosure.

Precipitation/Rainfall Rate

The Optical rain gauge has an uncertainty of +/-0.1 mm/hr. Values that fall between -0.1 mm/hr and +0.1 mm/hr should be considered 0 mm/hr. In other words, no rainfall is occurring. See the User Notes and Known Problems section for a more comprehensive explanation.

The tipping-bucket rain gauge produces a pulse output. The data logger counts the pulses for the period of integration. The uncertainty is, therefore, a minimum of one full bucket or 0.2 mm. For rain rates up to 250 mm/hr, the manufacturer states the accuracy is +/- 1%, and for rain rates above 250 mm/hr up to 500 mm/hr, the manufacturer states the accuracy is +/- 3%.

During heavy rain or strong gusty winds, the collection efficiency is reduced. Manufacturers have not attempted to specify accuracies for these conditions.

Visibility, Present Weather and Precipitation

- Meteorological Optical Range: Uncertainty +/- 5%.
- Precipitation: Detection sensitivity is given as: 0.05 mm/h or less, within 10 minutes. No uncertainty values are given.
The following is a description of the present weather codes produced by the PWD.

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>Clear</td>
</tr>
<tr>
<td>04</td>
<td>Haze or smoke, or dust in suspension in the air, visibility equal to, or</td>
</tr>
<tr>
<td></td>
<td>greater than, 1 km</td>
</tr>
<tr>
<td>05</td>
<td>Haze or smoke, or dust in suspension in the air, visibility less than 1 km</td>
</tr>
<tr>
<td>10</td>
<td>Mist</td>
</tr>
<tr>
<td>20</td>
<td>Fog</td>
</tr>
<tr>
<td>21</td>
<td>PRECIPITATION</td>
</tr>
<tr>
<td>22</td>
<td>Drizzle (not freezing) or snow grains</td>
</tr>
<tr>
<td>23</td>
<td>Rain (not freezing)</td>
</tr>
<tr>
<td>24</td>
<td>Snow</td>
</tr>
<tr>
<td>25</td>
<td>Freezing rain or freezing drizzle</td>
</tr>
</tbody>
</table>

Code figures 20 to 25 are used, if precipitation or fog was observed during the preceding hour but not at the time of observation.

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>FOG</td>
</tr>
<tr>
<td>31</td>
<td>Fog or ice fog, in patches</td>
</tr>
<tr>
<td>32</td>
<td>Fog or ice fog, has become thinner during the past hour</td>
</tr>
<tr>
<td>33</td>
<td>Fog or ice fog, no appreciable change during the past hour</td>
</tr>
<tr>
<td>34</td>
<td>Fog or ice fog, has begun or become thicker during the past hour</td>
</tr>
<tr>
<td>40</td>
<td>PRECIPITATION</td>
</tr>
<tr>
<td>41</td>
<td>Precipitation, slight or moderate</td>
</tr>
<tr>
<td>42</td>
<td>Precipitation, heavy</td>
</tr>
<tr>
<td>50</td>
<td>DRIZZLE</td>
</tr>
<tr>
<td>51</td>
<td>Drizzle, not freezing, slight</td>
</tr>
<tr>
<td>52</td>
<td>Drizzle, not freezing, moderate</td>
</tr>
<tr>
<td>53</td>
<td>Drizzle, not freezing, heavy</td>
</tr>
<tr>
<td>54</td>
<td>Drizzle, freezing, light</td>
</tr>
<tr>
<td>55</td>
<td>Drizzle, freezing, moderate</td>
</tr>
<tr>
<td>56</td>
<td>Drizzle, freezing, heavy</td>
</tr>
</tbody>
</table>
60 RAIN
61 Rain, light
62 Rain, moderate
63 Rain, heavy
64 Rain, freezing, light
65 Rain, freezing, moderate
66 Rain, freezing, heavy
67 Rain (or drizzle) and snow, light
68 Rain (or drizzle) and snow, moderate or heavy

70 SNOW
71 Snow, light
72 Snow, moderate
73 Snow, heavy
74 Ice pellets, light
75 Ice pellets, moderate
76 Ice pellets, heavy
77 Snow grains (from WMO 4677)
78 Ice crystals (from WMO 4677)

80 SHOWERS OR INTERMITTENT PRECIPITATION
81 Rain showers, light
82 Rain showers, moderate
83 Rain showers, heavy
84 Rain showers, violent ( >32 mm/h )
85 Snow showers, light
86 Snow showers, moderate
87 Snow showers, heavy
89 Showers of hail, with or without rain or rain and snow mixed, not associated with thunder (from WMO 4677)
1.2 Theory of Operation

Each of the primary measurements of wind speed, wind direction, air temperature, RH, barometric pressure, and rainfall are intended to represent self-standing datastreams that can be used independently or in combinations. The theory of operation of each of these sensors is similar to that for sensors typically used in other conventional surface meteorological stations. Some details can be found under System Configuration and Measurement Methods but further, greatly detailed description of theory of operation is not considered necessary for effective use of the data for these rather common types of measurements. The instrument mentor or the manufacturer can be contacted for further information.

1.3 Calibration

1.3.1 Theory

The SMET’s are not calibrated as systems. The sensors and the data logger (which includes the A–D converter) are calibrated separately. All systems are installed using components that have a current calibration. RESET personnel check the sensor and data logger calibrations in the field by comparison to calibrated references. Any sensor or data logger that fails a field check is returned to the manufacturer for recalibration. The Wind Monitors are returned to the manufacturer for recalibration after two years of use.

1.3.2 Procedures

Wind speed calibration is checked by rotating the propeller shaft at a series of fixed rpm's using an R.M Young Model 18810 Anemometer Drive. The reported wind speeds are compared to a table of expected values and tolerances. If the reported wind speeds are outside the tolerances for any rate of rotation, the sensor is replaced by one with a current calibration.

Wind direction calibration is checked by using a vane angle fixture, R. M. Young Model 18212, to position the vane at a series of angles. The reported wind directions are compared to the expected values. If any direction is in error by more than 5 degrees, the sensor is replaced by one with a current calibration.

Air temperature and relative humidity calibrations are checked by comparison with a reference Vaisala Model HMI31 Digital Relative Humidity and Temperature Meter and HMP35 Probe and a YSI 4600 Precision Thermometer. If the reported temperature and relative humidity vary by more than the sensor uncertainty from the reference, the probe is replaced by one with a current calibration.

The PWD is calibrated annually using the PWA11 calibration kit provided by the manufacturer. Any PWD that is unable to be calibrated is replaced and sent in for calibration and repair.

Barometric pressure calibration is checked by comparison with a reference Vaisala PA-11 Barometer. If the reported pressure varies by more than the sensor uncertainty from the reference, the sensor is replaced by one with a current calibration.

The data logger A–D converter is checked by using a Valhalla 2707A Programmable Precision DC Voltage/Current Standard as an input voltage reference, or they are sent in to the manufacturer for checks and repair.