MRU Cardington Instrumentation Facility

A.M. Kerr-Munslow and J McGregor

November 29, 2011

Draft 1

Met Office Met Research Unit Field Site Cardington Airfield Shortstown Bedford MK42 0SY.

Tel 01234 744650 Email amanda.kerr-munslow@metoffice.gov.uk www.metoffice.gov.uk

Contents

1 Introduction

The Met. Research Unit, located at Cardington in Bedfordshire (52° 06′ N, 00° 25′ W, 29 m amsl), maintains a suite of surface-based and mast-mounted instrumentation. The main purpose of this instrumentation site, which is logged 24 hours a day, is to provide data for atmospheric processes research, and for the testing and validation of numerical model output and performance.

The Cardington site has an open fetch in all directions, with the exception of to the north, where the presence of two large airship hangars have a major influence on the air flow. Measurements of turbulence therefore, when the wind is coming from a direction of roughly 355° to 035°, should be treated with caution.

Figure 1: Cardington airship hangars (with instrumented 10 m mast in foreground).

N.B. The inclusion in this document of the name of a company does not constitute any endorsement or recommendation by the Met Office of that company's products or services.

2 Wind and turbulence measurement

Three *Gill Solent* HS-50 Horizontally Symmetrical Research ultrasonic anemometers, are used for making fast response wind measurements, which can be used in eddy correlation calculations. A fast response temperature measurement is also generated. Measurements are made at heights of 10 m, 25 m and 50 m.

Figure 2: Ultrasonic anemometer mounted at the top of the 25 m mast. (Also present: temperature and humidity sensors inside aspirated screens.

2.1 *Gill Solent* Ultrasonic Anemometer

2.1.1 Purpose of Instrument

The ultrasonic anemometer is used for making rapid response measurements of the 3-dimensional wind field. A fast response temperature measurement is also generated. Data obtained from the instruments allows a range of turbulence parameters and fluxes to be derived, using eddy correlation methods, in addition to obtaining the mean horizontal wind.

Currently, three *HS-50* model sonic anemometers are deployed on the site, (located at the tops of masts of heights 10 m, 25 m and 50 m), but a number of *HS* model anemometers are also available for use. These two instruments are essentially the same, except that the *HS-50* measures at a raw sampling rate of 50 Hz as opposed to 100 Hz.

The anemometers are logged at a rate of 10 Hz (block averages over the raw sampling rate). This rate is sufficient to resolve the small scale eddies in the atmosphere at the three measurement heights.

2.1.2 Principles of Operation

The sensor head of the anemometer consists of an array of three pairs of transducers orientated at different angles across the measurement region. Each pair of transducers act alternately as transmitters and receivers, sending pulses of ultrasound between them. By measuring the time of flight of the pulse in both directions, the velocity component of the air flow along the line of the transducer pair can be determined using equation 1.

$$v = 0.5L \times \left(\frac{1}{t_1} - \frac{1}{t_2}\right) \tag{1}$$

where t_1 and t_2 are the measured times for the pulses to travel in each direction, and L is the distance between the transducers.

This measurement is carried out for each of the three transducer pairs in turn. A mathematical transformation is then performed, to convert the resulting three wind vectors into U, V, W format, where U and V are the horizontal wind components parallel and perpendicular to the instrument axis, and W is the vertical wind component. A correction is then applied, to calibrate out the affects of the transducers and instrument frame on the airflow.

In addition to computing the wind vectors, the sonic anemometer also uses the time-of-flight measurement to calculate the speed of sound (c) along each axis. From this, the sonic temperature (equivalent to the virtual temperature, T_v) of the air is derived, using equation 2.

$$T_v = \frac{c^2}{403} \tag{2}$$

Figure 3: Gill HS ultrasonic anemometer

The speed of sound value used in equation 2 is the mean quantity derived from each of the three axes. A correction must then be applied to take into account the effect of the cross-wind normal to the measurement axes. The resulting virtual temperature, can then be converted into a true temperature, assuming that the pressure and humidity are known.

Note that the accuracy of the sonic derived temperature, is not generally good enough to be relied on as a true temperature measurement. (It can be up to 2–3° C off.) This is largely due to the fact that it is highly sensitive to very small errors in the speed of sound measurement. However, this is not particularly important, because the primary purpose of the sonic temperature is as a fast response measurement which can be combined with the W wind component in order to calculate heat fluxes. A separate PRT sensor is normally used for absolute measurements of temperature.

The electronics box of the anemometer is equipped with 6 analogue input channels, plus a dedicated PRT temperature sensor input. This allows external sensors to be connected to the sonic and logged at the same time.

Each complete measurement cycle is carried out at a rate of 100 Hz (or 50 Hz for the HS50 anemometer). The wind and sonic temperature data is then averaged over the desired number of cycles, and sent to the serial output of the instrument, along with the digitised output from any external sensors connected to the anemometer. The output from an inbuilt inclinometer is also included in the data stream. This information can be used in subsequent data processing to correct for errors in alignment of the instrument.

Further information on the *Gill* HS sonic anemometers can be found at the *Gill* website.

2.1.3 Operational Notes

These instruments have an acceptance angle, relative to the instrument axis, of approximately ±120 degrees, from where the uninterruped wind flow may be measured. If the wind is outside this sector, then the airflow becomes distorted, resulting in the turbulence measurements becoming unreliable. To counter this possibility, the masts are rotated on a regular basis, so that the anemometers remain pointing into the prevailing wind.

3 Temperature measurement

Temperature measurements are made using PRT (*Platinum Resistance Thermometer*) probes. These are located at four heights: 1.2 m, 10 m, 25 m and 50 m, and are housed in aspirated, shielded screens. The 1.2 m measurement incorporates an *SDL* probe and an *Automatic Systems Laboratories* model F250 high precision temperature bridge. The remaining three sensors are *Vector Instruments* model T302 sensors.

4 Humidity measurement

Fast response humidity measurements are made using a *LI-COR* LI-7500 open path CO_2/H_20 gas analyser, located at the top of the 10 m tower. In addition to measuring water vapour, this instrument is capable of measuring atmospheric carbon dioxide concentration. When combined with simultaneous data from a sonic anemometer, humidity and CO_2 fluxes can be calculated.

Three *Vaisala humicaps* are employed for measurement of relative humidity. These are located at heights of 1.2 m, 25 m and 50 m and are housed in aspirated screens. Estimates of humidity flux at 25 and 50 m are also made by correlating the humicap outputs with data from the sonic anemometers.

A *Michell* Series 3000 dewpoint hygrometer is situated at a height of 1.2 m above ground level. This is mounted inside the 1.2 m temperature screen.

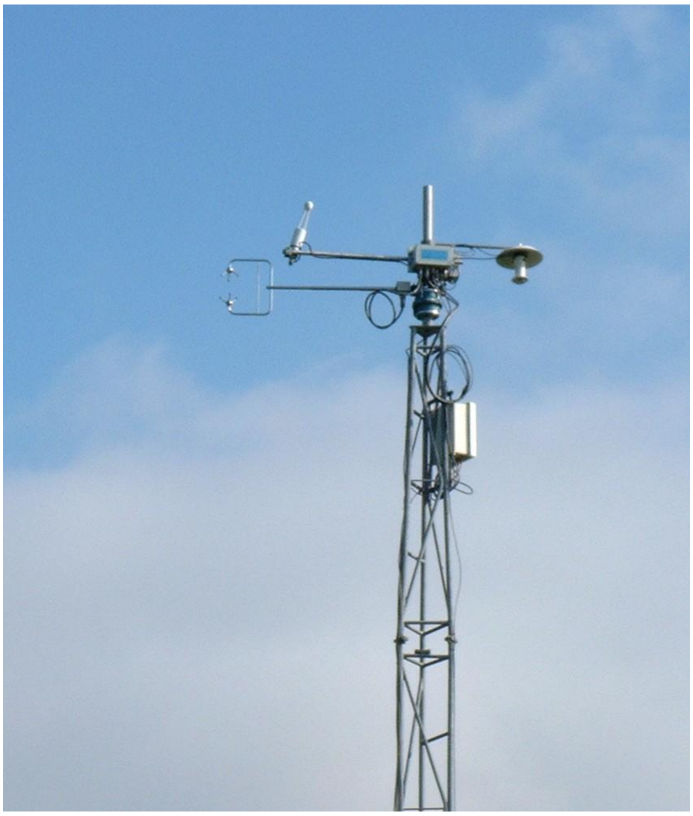

Figure 4: The *LI-COR* LI-7500 gas analyser co-located with a sonic anemometer, on the 10 m tower.

4.1 *LI-COR* LI-7500 Gas Analyser

Figure 5: *LI-COR* LI-7500 gas analyser.

4.1.1 Purpose of Instrument

The *LI-COR LI-7500 Gas Analyser* is used to make rapid response measurements of water vapour and carbon dioxide concentration in the atmosphere. When combined with simultaneous measurements from a co-located sonic anemometer, humidity and CO_2 fluxes can be calculated, using the eddy-covariance method.

4.1.2 Principles of Operation

The *LI-COR LI-7500 Gas Analyser* operates by measuring the absorption of infrared radiation at different wavelengths. The picture above shows the sensor head of the instrument. Sapphire windows protect the infrared source and detector. The optical path length is 12.5 cm.

For each gas, the power recieved from the infrared source is measured at two wavelengths—one at a wavelength that is absorbed by the gas, and the other at a non-absorbing reference wavelength. The absorbance a_i is then approximated by equation 3.

$$a_i = 1 - \frac{A_i}{A_{io}} \tag{3}$$

where A_i is the power received at the absorbing wavelength and A_{io} is the power received at the reference wavelength. This measurement is carried out by the *LI-7500* at a rate of 152 Hz. A value of a is thus obtained for both H_20 and CO_2 (after making a correction for the cross-sensitivity between the two gases), and this is used by the *LI-7500* to produce a calibrated output of the number densities (in mmol/m^3) of the gases (or, alternatively mass density, which is obtained by simply multipying the molar concentration by the molecular weight of each of the gases.)

There is a small pressure dependency in the conversion of the absorbances of the gases to number density (and for CO_2, also a temperature dependency), which the *LI-COR* accounts for using sensors built into the electronics enclosure. The accuracy of these measurements does not have to be very high.

In order to convert the output of the *LI-7500* into more useful quantities, however, (such as converting H_20 number density into a specific humidity [g/kg], or CO_2 number density into molar fraction [ppm]), accurate pressure and temperature measurements of the air are required. Post-processing of the *LI-COR* data uses pressure and temperature sensors located on the 10 m mast to perform these calculations.

Further information on this instrument can be obtained from the *LI-COR* website.

4.1.3 Operational Notes

Problems have been found to occur with this instrument in the presence of precipitation. In fact, all data from the instrument, when there is rain, snow, fog or ice on the windows, should be treated with caution.

Figure 6: *Michell 3000* sensor head.

4.2 *Michell* Series 3000 Dewpoint Hygrometer

4.2.1 Purpose of Instrument

The *Michell* dewpoint hygrometer uses the chilled-mirror principle, described below, to make a direct measurement of the dewpoint of the air. This is a fundamental humidity parameter, that is independent of other parameters, such as the ambient pressure and temperature.

4.2.2 Principles of Operation

The sensor consists of a mirror, fixed onto a *Peltier* cooling module. A platinum resistance thermometer (PRT) is embedded in the mirror. An LED light source is directed at the mirror, and the light is reflected back to a detector. The light detector acts in conjunction with the Peltier pump, cooling the mirror until dew or frost begins to form on it. This point is signalled by a drop in the light level received by the detector. In this manner, the temperature of the mirror is maintained at the temperature of the dewpoint of the ambient air, which is output by the PRT probe.

Every 3 hours or so, the sensor undergoes an *Automatic Balance Compensation (ABC)* cycle. This consists of the system heating the mirror to a high temperature to dry the surface, and allows the system to automatically compensate for any contaminants that have built up on the mirror. During this ABC cycle, the logging software ignores the data from the hygrometer.

The airflow rate over the sensor needs to be kept below 1.5 litres/minute to reduce the thermal load on the sensor. The output becomes unstable if this is exceeded. Note that the response time of this sensor is of the order of several minutes.

4.2.3 Sensor installation

The sensor head is mounted inside the 1.2 m temperature screen (aspirated). In order to restrict the airflow over the sensor, a porous cover (sintered material) is placed over it. This also acts as a filter for particulates.

4.2.4 Maintenance

The build up of dirt on the mirror happens continuously, but in normal operation this is compensated for by the *ABC* operation. However if the optics become badly contaminated, then a warning light is illuminated on the control panel, and the optics must be cleaned manually. If left unattended, this typically occurs after 3–4 weeks of operation. Performance of the sensor can then become unreliable.

To prevent this happening, the policy is to check the unit every week, and clean the optics whenever the warning light is on, or at least once a month. Cleaning of the optics is carried out using a cotton bud soaked in isopropyl alcohol, followed by distilled water.

5 Radiation measurement

The surface site consists of a full suite of radiometers, measuring all the main components of the radiation budget.

- Three *Kipp & Zonen* CM21/CM22 pyranometers, are used to measure global incoming, diffuse, and relected solar irradiances. The diffuse measurement involves shading the sensor from the direct solar beam using a solar tracker.

- Two *Kipp & Zonen* CG4 pyrgeometers are used, for measuring the incoming and outgoing longwave irradiances (with a spectral range of 4.5 to about 40 μm.)
- The surface radiative temperature is measured using a *Heitronics* KT15D Infrared radiation pyrometer pointed at the ground.

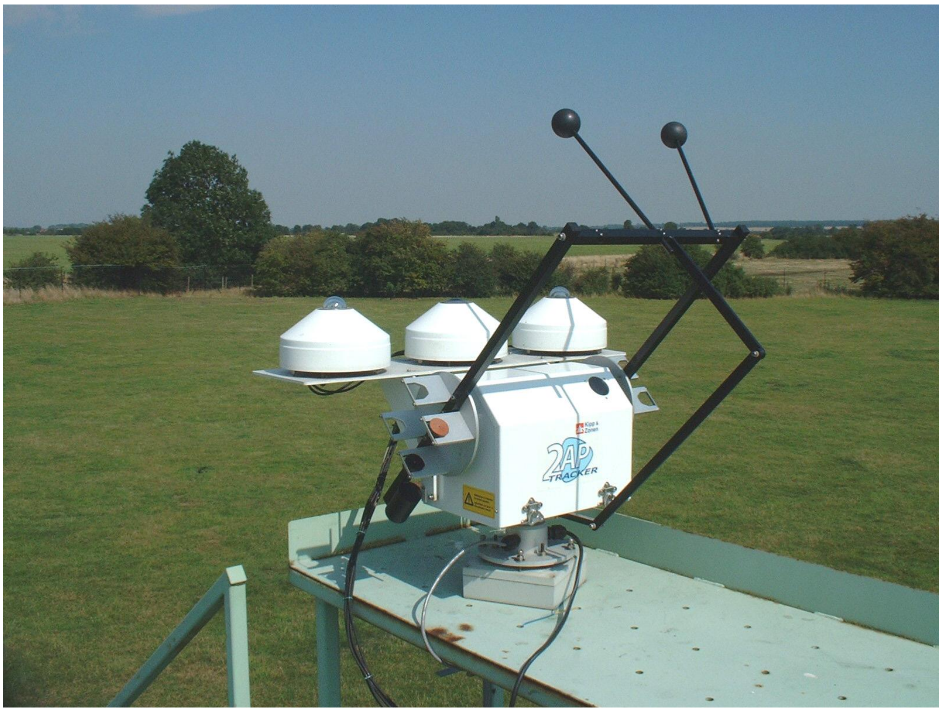

Figure 7: Radiometers mounted on a *Kipp & Zonen* solar tracker.

5.1 *Kipp & Zonen* CM21/CM22 Pyranometer

5.1.1 Purpose of Instrument

The pyranometers are used to measure the downward and upward (i.e. reflected) solar irradiance through a horizontal surface (in W m^{-2}). A *Kipp & Zonen* CM22 pyranometer is used for the global downwelling component, and a model CM21, from which the direct beam of the sun is obscured, gives the diffuse irradiance. A downward pointing CM21 is used to measure the upwelling component over a grass surface.

Figure 8: Downward-facing pyrgeometer at end of boom, and *Heitronics* IRT pointing at the ground.

5.1.2 Principles of Operation

Each instrument has a thermopile which has one set of black-coated junctions exposed to solar radiation and the other set buried within the instrument body, which acts as a heatsink. Incoming solar radiation heats the exposed junctions, generating a voltage difference proportional to the irradiance on that surface. The pyranometers have a nominal sensitivity of 5–10 $\mu V / Wm^{-2}$.

The spectral range is set by two quartz domes. For the CM21, this is:

- 305–2800 nm (50% transmittance points)
- 340–2200 nm (95% transmittance points)

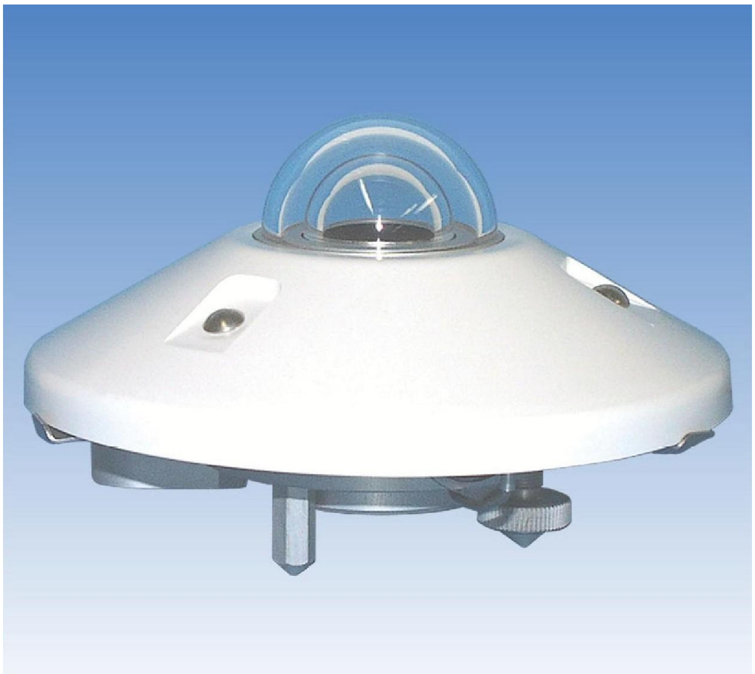

Figure 9: *Kipp & Zonen* CM21 pyranometer.

For the CM22, the range is:

- 200–3600 nm (50% transmittance points)
- 280–2800 nm (95% transmittance points)

The inner dome helps to reduce convective heat losses and shields the thermopile from longwave exchange with the outer dome. When the effective sky temperature is very low a negative zero offset can develop, most noticeably on clear nights. For well ventilated instruments, the zero offset should be $<3\,\mathrm{Wm^{-2}}$ for the CM22 and $<7\,\mathrm{Wm^{-2}}$; for the CM21.

The cosine response of the CM22 is quoted by the manufacturer as within $\pm1\%$ of ideal at a solar zenith angle of $60°$ and $\pm3\%$ at $80°$.

Further information on the CM21 and CM22 pyranometers can be found from the *Kipp & Zonen* website.

5.1.3 Instrument setup

To measure the diffuse irradiance, the CM21 is mounted on a *Kipp & Zonen* 2AP solar tracker.

This device follows the sun through the sky, so that a small black sphere is positioned to continuously shade the pyranometer thermopile from the direct beam of the sun. The CM22 measuring global solar irradiance is mounted next to the CM21 on the solar tracker, but this is just for convenience and is not shaded.

For measuring the reflected solar irradiance, the CM21 is mounted, facing downwards, at the end of a boom, clamped to a mast, at a height of 2 m. The boom extends out approximately 1.5 m towards the south, and the mast is painted matt black. This eliminates unwanted influences from shadowing and reflections from the mast.

All three instruments are ventilated using a fan which blows air over the domes. This prevents frost and dew etc. from forming on the domes.

5.1.4 Calibration

The sensitivity of each instrument is determined initially by the manufacturer by comparison against a standard pyranometer, which has itself been calibrated at the World Radiation Centre in Davos. A spare reference pyranometer is held at Cardington, for intercomparisons.

5.1.5 Maintenance

The following tasks are carried out on a weekly basis: checking the operation of the ventilators, checking for dirt on the domes and checking the condition of the dessicant. The domes are cleaned when required. For the diffuse measurement, the alignment of the solar tracker must also be checked.

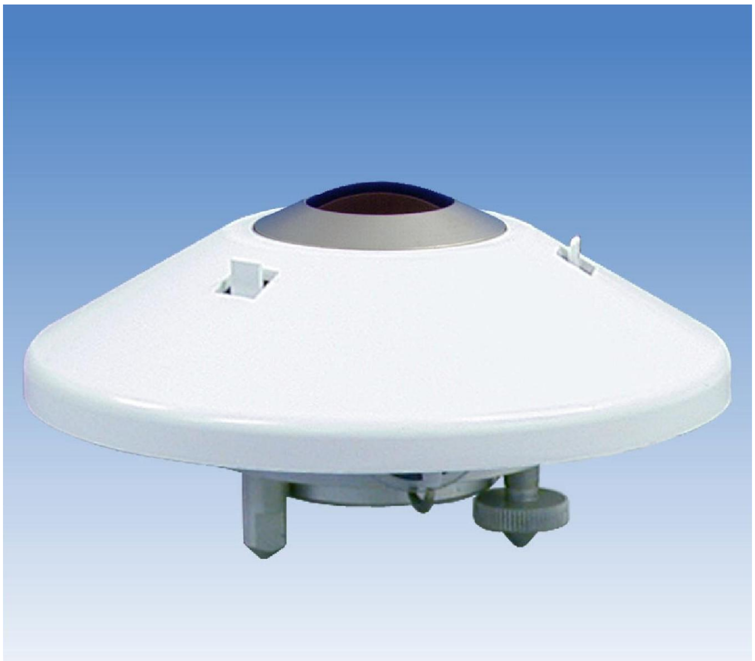

Figure 10: *Kipp & Zonen* CG4 pyrgeometer.

5.2 *Kipp & Zonen* CG4 Pyrgeometer

5.2.1 Purpose of Instrument

The CG4 pyrgeometers are used for the measurement of upwelling and downwelling components of LW irradiance (in $\mathrm{W\,m^{-2}}$). The instruments are sensitive to infrared radiation in a wavelength range of 4.5 to approx. 40 μm, and have a field of view of 180°, with a cosine response.

5.2.2 Principles of Operation

The CG4 pyrgeometer uses a thermopile to detect thermal gradients caused by incoming radiant energy. The detecting element is a black painted disk, which absorbs the incoming radiation, and the heat flows through to the heatsink, which is the instrument body. The thermal gradient across the thermopile produces a voltage which is proportional to the net radiation (i.e. the difference between the radiation received at the detector, and the radiation emitted by the pyrgeometer itself). The nominal sensitivity of the thermopile is 10 $\mu\mathrm{V/Wm^{-2}}$

.

The spectral range of the incoming radiation is restricted by a specially coated silicon window, which filters out unwanted solar radiation below wavelengths of 4.5 μm. The silicon window is also required to protect the instrument from environmental effects, such as wind and rain. The curve in figure 5.2.2 shows the transmittance characteristics of the silicon window.

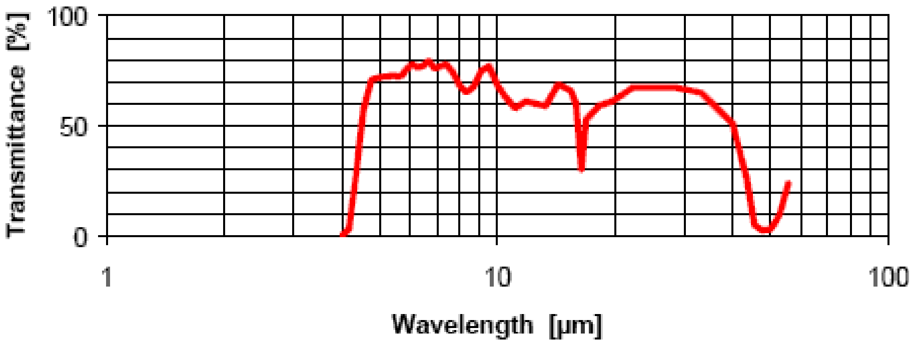

Figure 11: CG4 Transmittance characteristics graph, source *Kipp & Zonen* CG4 manual.

In order to calculate the incoming LW irradiance at the detector, the temperature of the pyrgeometer body must be known. This is measured using a thermistor (type YSI44031), which is located beside the cold junctions of the thermopile. The downward (or upward) longwave radiation is then calculated using equation 4.

$$\mathrm{LW} = \frac{U_{\mathrm{emf}}}{S} + \left(5.67 \times 10^{-8} \times T_b^4\right) \tag{4}$$

where U_{emf} is the output voltage from the thermopile, S is the calibration constant of the instrument, and T_b is the pyrgeometer body temperature, measured by the thermistor, in degrees Kelvin.

Note that for an upward facing pyrgeometer, the thermopile output voltage will in most instances be negative. This is because the upwelling irradiance from the pyrgeometer is likely to be greater then the incoming irradiance from the sky.

Window heating affects (caused by solar radiation creating a thermal gradient between the window and the thermopile detector) are very small in the CG4. The manufacturer has estimated that in full sunlight, the heating offset is less than 4 Wm^{-2}. However, to minimise this effect, the direct beam of the sun can be obscured by use of a solar track. (see section on instrument setup).

Further information on the CG4 pyrgeometer can be obtained from the *Kipp & Zonen* website.

5.2.3 Instrument setup

The CG4 pyrgeometer measuring the downwelling LW irradiance, is mounted on a *Kipp & Zonen 2AP* solar tracker. This tracks the sun through the sky, such that the dome is continuously shaded from the direct beam of the sun by a small black sphere. This reason for this is to eliminate any window heating affects as described above.

For measuring the upwelling LW irradiance from the ground, the CG4 pyrgeometer is mounted, facing downwards, at the end of a boom, clamped onto a mast at a height of 2 m. The boom extends out about 1.5 m in a southerly direction. The ground beneath the instrument, is short grass, and is representative of the whole of thesite.

Both the instruments are ventilated by a fan which blows air across the domes. This prevents dew and rain droplets etc. from collecting.

5.2.4 Calibration

The sensitivity of each instrument is determined initially, by the manufacturer by comparison against a standard instrument, traceable back to the World Radiation Centre in Davos. A spare, reference CG4 is held at Cardington for intercomparisons.

5.2.5 Maintenance

The following tasks are carried out on a weekly basis: checking the operation of the ventilators, checking for dirt on the domes and checking the condition of the dessicant. The domes are cleaned when required.

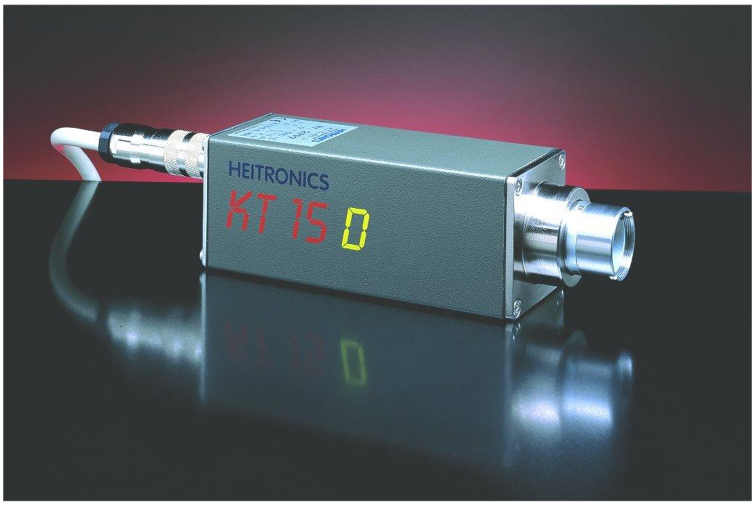

Figure 12: *Heitronics* KT15.82D Infrared thermometer

5.3 *Heitronics* KT15D Infrared Thermometer

5.3.1 Purpose of Instrument

The Infrared thermometer is used to measure the radiation temperature of the grass surface. With knowledge of the emissivity, the true temperature can be calculated.

5.3.2 Principles of Operation

The instrument measures the thermal radiation emitted by a body. This is dependent on two factors; the temperature of the body and its emissivity. The instrument has a programmable switch allowing the emissivity to be adjusted, depending on the nature of the surface being measured. The calculated temperature is then output. For practical purposes, however, the emissivity is always kept at 1. Adjustments can always be made during post-processing to allow for varying emissivities. The instrument outputs both an analogue signal proportional to the measured temperature, and as serial data.

The spectral sensitivity of the KT15.82D infrared thermometer is 8 to 14 μm, and the temperature measurement range is -25–$75°$ C. The spectral response curve of the instrument is shown in figure 5.3.2.

Further information on this instrument can be found on the *Heitronics* website.

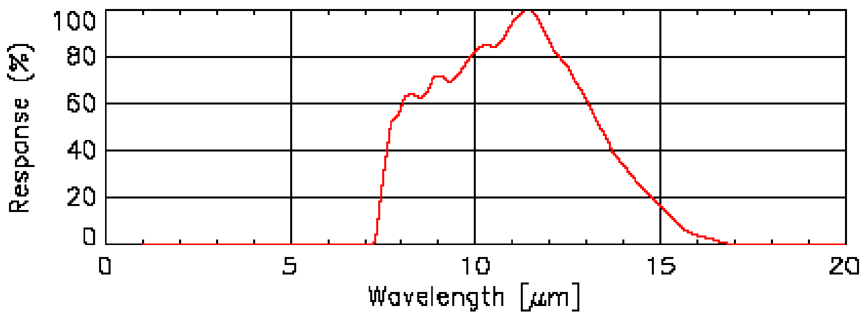

Figure 13: Spectral response curve of KT15.82D

5.3.3 Instrument setup

The IRT is housed in a waterproof shield, and mounted on a mast at a height of 2.5 m above the ground. It is tilted at an angle of approximately 20° to the vertical and the surface below is short grass, which is representative of the site as a whole.

The detector is a "type A" and an "M6" lens is used on the unit. This particular setup, this gives an effective target area on the ground of roughly 1 metre diameter.

6 Visibility and aerosol measurements

Visibility is measured using a *Belfort* model 6230A visibility sensor. An *MRI* integrating nephelometer (model 1550B) measures the atmospheric scattering coefficient of dry aerosols.

6.1 *Belfort* MRI Integrating Nephelometer (Model1550B)

6.1.1 Background

The MRI Integrating nephelometer is used to measure the scattering coefficient of the air, caused by aerosol particulates. This is the oldest piece of equipment currently in use at Cardington. Previously, it was installed on the MRF research aircraft, before undergoing a refurbishment and being deployed on the site.

Figure 14: Nephelometer control unit

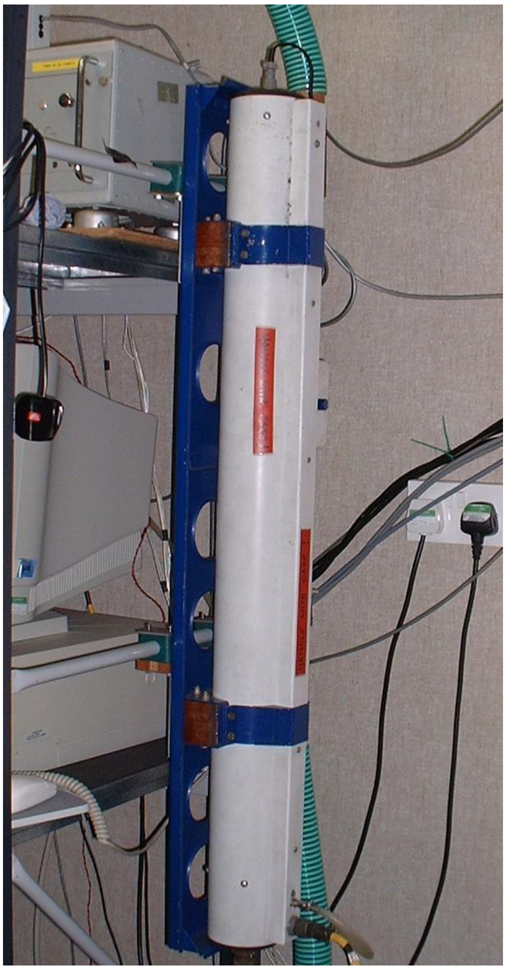

Figure 15: Nephelometer optical assembly

Figure 16: Nephelometer air inlet pipe outside hut.

6.1.2 Principles of Operation

Air is drawn into the the device from outside the hut using a pump, and is then passed through a heater before entering the nephelometer. The purpose of the heating is to dry the air so that the nephelometer measures the scattering coefficient of a dry aerosol population. A humidity sensor, located in the inlet pipe between the heater and the nephelometer is used to monitor the effectiveness of the dehyration, and a PRT sensor measures the temperature of the air, which is maintained at a maximum of 30° C.

The air being sampled, enters the optical assembly, which is approximately 1.2 m long, and has a photomultiplier at one end of it. A xenon flashlamp illuminates the chamber, and the photomultiplier detects the light scattered from the particles in the defined sampling area. Another light detector placed below the flashlamp, is used as a reference. The xenon lamp is set to flash at a rate of once every 4 seconds.

The measurement of the scattering coefficient of light through the air, is related to the mass concentration of particulates suspended in the air, and to the visibility. Unlike, a standard visibility sensor, however this nephelometer only samples the dry aerosol population.

6.1.3 Maintenance

Routine checks are carried out on the instrument to ensure that

- the pump is operating correctly,
- the xenon lamp is flashing and
- the air heater is working properly—this can be done by checking the digital readout of the humicap and temperature sensor. The relative humidity should be around 30% and the temperature 30° C.

6.1.4 Calibration

Calibration of the nephelometer is achieved by pumping gases of known scattering coefficients through the system. Pure carbon dioxide is used for this, and additionally, a clean air calibration is carried out by passing filtered air through the system.

7 Sub-soil sensors

A number of sub-soil sensors are deployed. These sensors are situated at two different locations in the Cardington field site (designated the "west" site and the "south" site.):

- Volumetric soil moisture content measurements are made using *Delta-T* ThetaProbes, located at depths of 10 cm, 22 cm, 57 cm and 1.6 m below the surface, at both the *west* and *south* sites.
- Sub-soil platinum resistance thermometer probes measure the soil temperature at depths of 1 cm, 4 cm, 7 cm, 10 cm, 17 cm, 35 cm, 65 cm and 1 m. (These are located at the *south* site only.)

- Water table depth below the surface is measured at the *west* and *south* sites. This is obtained using *Druck* 1830 series pressure transducers, located inside boreholes in the ground.

7.1 *Delta-T* ThetaProbe Soil Moisture Sensor

Figure 17: *Delta-T* ThetaProbe

7.1.1 Purpose of Instrument

The *Delta-T* ThetaProbe is used to measure the volumetric moisture content (q_v) of the soil. This is defined by equation 5

$$q_v = \left(\frac{V_w}{V_s}\right) \times 100\% \tag{5}$$

where V_w is the volume of water and V_s is the total volume of the soil sample. A value of 0% indicates that the soil is completely dry soil, and 100% is pure water. Typically, for fully saturated soil, q_v will be about 50%.

7.1.2 Principles of Operation

The *ThetaProbe* works on the principle that the volumetric soil moisture content is related to the apparent dielectric constant (e) of the soil, with there being a linear correlation between

q_v and the square root of e. This relationship has been shown to be valid for many different soil types.

The probe consists of a waterproof housing, containing the electronics, with four stainless steel spikes attached to one end, which are inserted into the soil. A 100 MHz sinusoidal signal is applied to the spikes, and changes in the impedance between them, due to changes in the dielectric constant of the soil, are detected. The probe then outputs an analogue voltage between 0 and 1 V DC, which is virtually proportional to the soil moisture content.

The precise relationship between soil moisture content and the square-root of e is dependent on the soil type, but after carrying out tests on the soil at Cardington, it was decided to use the manufacterers generalisied calibration coefficients for a mineral soil.

Further information on the *ThetaProbes* can be found on the *Delta-T* website.

7.1.3 Sensor installation

The sensors were installed in the ground, by digging a large hole, and inserting the probes into the side wall of the hole at the desired depths. In this way, disturbance to the structure of the soil being measured, was kept to a minimum. The hole was then filled in, replacing the soil in the order that it came out, and the grass resown on top.

8 Miscellaneous sensors

A standard Met Office tipping bucket rain-gauge (Mk 5) is used for the recording of rainfall.

Barometric pressure is measured to 0.1 hPa using a *Setra Model 270* transducer (located at a height of 1.5 m above ground level.)

Figure 18: Tipping Bucket

8.1 Tipping bucket rain gauge (Mk 5)

8.1.1 Purpose of Instrument

The tipping bucket raingauge is used to measure the quantity and rate of rainfall.

8.1.2 Principles of Operation

The rain gauge consists of two stainless-steel buckets on a pivot, located beneath the collecting funnel (750 cm^2). The buckets are situated such that only one of them collects rain at a time. When approximately 15 cc of water has been collected (this is equivalent to 0.2 mm of rainfall), the bucket tips and empties, bringing the other bucket under the funnel, and in the process activates a reed switch. Each tip is counted by the data logger, and this is converted to a an accumulated rainfall amount over the desired measurement period.

Note that since the instrument only records rain in discrete quantities of approx 0.2 mm, it is possible that during periods of light rain or drizzle, the instrument will not register any tips. Also, any snow that collects in the funnel will not be measured until it melts.

8.1.3 Calibration

Initial calibration of the raingauge, is carried out by pouring known volumes of water into the funnel, in order to ascertain the average quantity required to produce one tip of the mechanism. Then, using the equivalence 15 cc = 0.2 mm, a value for *mm per tip* can be calculated.

Further calibration checks can be carried out when the sensor is deployed in the field, by cross checking the ammount measured after a significant rainfall, with the accumulated rain collected in a standard 5in raingauge. Typically, these values are within 5% of each other. If a consistent error is found, then an "ad-hoc calibration" is applied to the tipping bucket calibration figure.

8.1.4 Maintentance

The chief maintenance task is to ensure that the collecting funnel does not become blocked with dirt or debris. Weekly inspections are carried out, and the funnel and mechanism are cleaned as required.

9 Data Logging

The overall structure of the logging system is illustrated in figure 9.

The three sonic anemometers are logged at a rate of 10 Hz on a PC running windows XP, using software developed in-house. The other sensors that are mounted on the 10, 25 and 50 m masts are connected to the analogue inputs of the anemometers and are logged in the same data streams. Data from the 25 m and 50 m sonics is transmitted to the logging PC, via pairs of radio modems.

All the remaining sensors are logged using three commercially available *dataTaker* DT800 loggers. The loggers use a raw sampling rate of 0.5 Hz, and one minute averaged data is logged. Another PC running windows XP interrogates these loggers at regular intervals, and downloads the data from them.

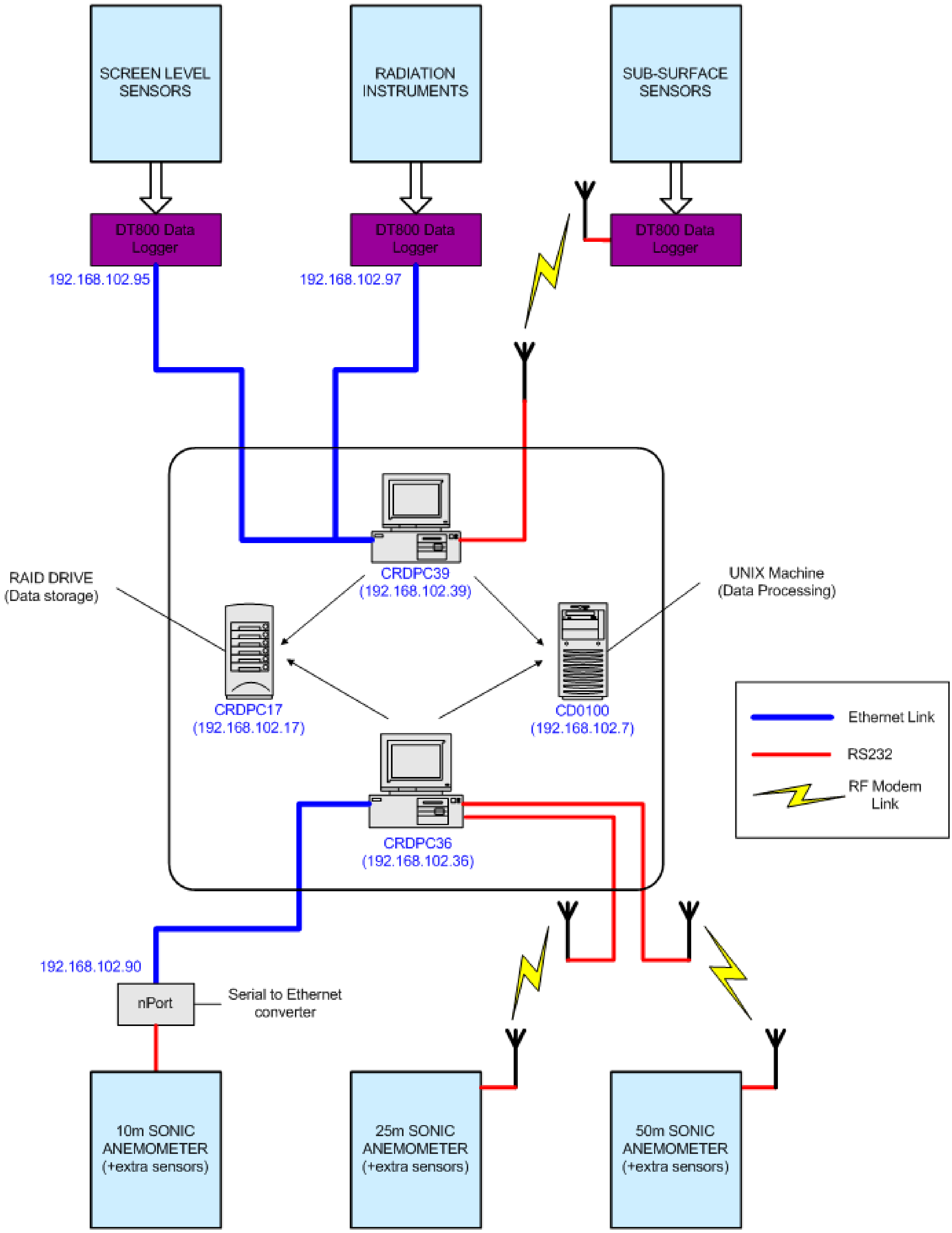

Figure 19: Logging schematic diagram.

Further information can be found at the *dataTaker* website.

10 Data Processing and Format

The data processing routines output three files per day. These contain data averaged over time periods of 1 minute, 10 minutes and 30 minutes. Turbulence quantities and data from slow response sensors are included in the 10 minute and 30 minute datasets only.

10.1 Data Filenames

Data files are named using the following convention:

card_YYYYMMDD_xx.dat

where *YYYY* is the year, *MM* is the month, *DD* is the day and *xx* the averaging period of the data in minutes (eg. 01, 10 or 30).

10.2 Data File Format

The datasets are ascii files, which begin with a header section. This consists of a list of the variables contained within the file. Each line in the variable list is made up of three elements—a data prefix, a variable label, and a long-hand description of the parameter.

The prefix refers to the source of the data within the logging system. For instance, variables with a *50 m* prefix refers to instruments on the 50 m sonic mast, and *rad* refers to the radiation instrumentation data logger. Some parameters, which are measured at more than one height, may be allocated the same variable label, but have different data prefixes. A full list of parameters available in the files, is given in section 10.3.

Data is then aligned in columns, beneath the relevent variable labels and prefixes. Each data element is preceded by a symbol, representing the quality control status of the instrument. Possible values for the quality control flags are as follows:

| = data OK

X = data flagged as bad

m = data missing

? = possibly suspect data

c = calibration suspect

D = sonic orientation bad for wind direction

H = wind coming from hangar direction

A dummy value ($1 \mathrm{x} 10^{11}$) is substituted for any data which has been assigned an 'X' flag. 'D' and 'H' flags are applied to data derived from the sonic anemometers only, and indicate that the wind, and turbulence data in particular, may not be reliable.

To read in data from a single file, the PVWAVE/IDL function *read_proc_file.pro*, may be used. This program returns an unnmamed structure consisting of a 2-D data array, and arrays containing the labels, prefixes and QC flags.

10.3 Data Parameter List

The table below shows a list of the parameters currently contained within the datasets.

Some of the parameter labels are common to more than one data prefix and so reference must be made to both the variable label and the prefix when extracting the desired data from the file. For example, to access the mean windspeed at 25 m, the variable labelled 'UTOT', and having a prefix '25 m' should be accessed. Other variables on the other hand, are unique to a single data prefix, and so reference need only be made to the variable label (eg. 'VISI' for the visibility).

Parameter	**Label**	**Prefix**	**Notes**
Time [hrs]	HOUR	time	Midpoint of averaging period
Temperature [° C]	TEMP	screen, 10 m, 25 m, 50 m	"screen" temperature and humidity sensors located at 1.2 m above ground level
Relative humidity from Humicap [%]	RHHU	screen	
Dewpoint from *Michell* hygrometer [° C]	DEWP	screen	
Specific humidity from *Michell* hygrometer [%]	QMIC	screen	
Relative humidity from *Michell* hygrometer [%]	RHMI	screen	
Relative humidity from Humicap [%]	MRH	25 m, 50 m	
Specific humidity [$g\,kg^{-1}$]	QLIC	10 m	from *LI-COR*
$C0_2$ concentration [ppm]	MCO2	10 m	

Parameter	**Label**	**Prefix**	**Notes**
Mean wind speed [m/s]	UTOT	10 m, 25 m, 50 m	Magnitude and direction of the mean wind vector
Wind direction [deg]	DIR	10 m, 25 m, 50 m	
Maximum gust$^{(1)}$ [m/s]	UMAX	10 m, 25 m, 50 m	Peak scalar windspeed during averaging period
Variance U wind component$^{(1)}$ [m^2/s^2]	UU	10 m, 25 m, 50 m	Turbulence Statistics The three wind components are defined as follows: U is the horizontal wind in the direction of the mean wind vector. V is the horizontal wind perpendicular to the mean wind vector. (mean $V = 0$) W is the vertical wind component. (upwards positive) T is the sonic-derived temperature Q is the specific humidity derived from either the *LI-COR* (10 m) or humicaps (25 m and 50 m) CO_2 concentration is derived from the *LI-COR*
Variance V wind component$^{(1)}$ [$m^2\,s^{-2}$]	VV	10 m, 25 m, 50 m	
Variance W wind component$^{(1)}$ [$m^2\,s^{-2}$]	WW	10 m, 25 m, 50 m	
Variance Sonic Temperature$^{(1)}$ [K^2]	TT	10 m, 25 m, 50 m	
Covariance U and $W^{(1)}$ [$m^2\,s^{-2}$]	UW	10 m, 25 m, 50 m	
Covariance V and $W^{(1)}$ [$m^2\,s^{-2}$]	VW	10 m, 25 m, 50 m	
Covariance U and $V^{(1)}$ [$m^2\,s^{-2}$]	UV	10 m, 25 m, 50 m	
Covariance W and $T^{(1)}$ [$K\,m\,s^{-1}$]	WT	10 m, 25 m, 50 m	
Covariance W and $Q^{(1)}$ [$kg\,m^{-2}\,s^{-1}$]	WQL	10 m	
Covariance W and $Q^{(1)}$ [$kg\,m^{-2}\,s^{-1}$]	WQH	25 m, 50 m	
Covariance W and $CO_2{}^{(1)}$ [$kg\,m^{-2}\,s^{-1}$]	FCO2	10 m	

Parameter	**Label**	**Prefix**	**Notes**
Global solar irradiance [$W\,m^{-2}$]	SWDN	rad	
Maximum global solar irradiance(1) [$W\,m^{-2}$]	SWMX	rad	
Diffuse solar irradiance [$W\,m^{-2}$]	SWDF	rad	
Reflected solar irradiance [$W\,m^{-2}$]	SWUP	rad	
Downwelling LW irradiance [$W\,m^{-2}$]	LWDN	rad	
Upwelling LW irradiance [$W\,m^{-2}$]	LWUP	rad	
Surface radiation temperature [° C]	IRTG	rad	
Visibilty [km]	VISI	screen	
Nephelometer scattering coefficient [km^{-1}]	NEPH	rad	
Barometric pressure [hPa]	PRES	screen	1.2 m above ground level
Rainfall(1) [mm]	RAIN	screen	Accumulation over averaging period
Soil Moisture (south site)(1) [%vol]	SMxx	subsoil_s	xx is depth of the sensor 10 = 10 cm 22 = 22 cm
Soil Moisture (west site)(1) [%vol]	WMxx	screen	57 = 57 cm 2M = 1.6 m
Soil Temperature (south site)(1) [° C]	STxx	subsoil_s	xx is depth of the sensor: 01, 04, 07, 10, 17, 35 or 65 cm
Water table depth (west site)(1) [mm]	WTWE	screen	Depth below ground level
Water table depth (south site)(1) [mm]	WTSO	subsoil_s	

(1) Note that the parameters indicated above are not output in the 1 minute datasets. This includes the various turbulence quantities derived from the sonic anemometers, plus the slow response measurements (i.e. soil moistures and temperatures.)