Previous Chapter

4.0 Data

4.1 General

The output of the sensors was transferred to the PAM base and archived for future analysis. The data transfer was by spread spectrum direct RF linkage from the individual stations to the PAM base at the Bondville site. For Station 1, which employed both an enhanced flux-PAM and elements of the ASTER facility, data was both acquired by ADAM and transmitted directly to the PAM base, and also processed *in situ* by EVE and the data products transmitted to the PAM base. For Stations 2 and 3 only the latter mode was used. In addition to the direct RF linkage to the PAM base the flux-PAM's also transmitted their data products via GOES, Boulder Earth-base and then by internet to the PAM base at Bondville. A further redundancy was provided by local storage at the flux-PAMs. Table 9 and 10 outline the various data streams and data products of the FLATLAND96 program and indicate their availability for different time intervals for the three stations

TABLE 9 Data available from sensors at Stations 1, 2 and 3

Parameter	Units	Station 1				Station 2 and 3	
		0.1 s	1 s	60 s	300s	60 s	300s
Sonic w	m.s-1	X	-	-	X	-	X
Sonic u	m.s-1	X	-	-	X	-	X
Sonic v	m.s-1	X	-	-	X	-	X
Sonic Tc,	m.s-1	X	-	-	X	-	X
Kr hygrometer q	g.m-3	X	-	-	X	-	X
Kr hygrometer relative humidity	%	X	-	-	X	-	X
Kr hygrometer mixing ratio	g Kg-1	X	-	-	X	-	X
Kok ozone, mixing ratio	ppbv	X	-	-	X	-	-
SECL ozone, mixing ratio	ppbv	X	-	-	X	-	-
ThermoElectron ozone, mixing ratio	ppbv	-	X	-	X	-	-
Band pass hygrometer, temperature	o C						
Band pass hygrometer, RH	%						
Hygrothermometer, temperature	o C	-	X	X	X	X	-
Hygrothermometer, relative humidity	%	-	X	X	X	X	-
Propvane, wind speed	m.s-1	-	X	X	X	X	-
Propvane, wind direction	o Azimuth	-	X	X	X	X	-
Barometric pressure	mB	-	X	X	X	X	-
Surface temperature	o C	-	X	X	X	X	-
Net radiation	W.m-2	-	X	X	X	X	-
Solar radiation	W.m-2	-	X	X	X	X	-
Soil temperature	o C	-	-	-	X	-	X
Soil heat flux	W.m-2	-	-	-	X	-	X
Rain fall rate	mm.s-1	-	-	-	X	-	X
Rainfall accumulation	mm	-	-	-	X	-	X
Momentum flux	W.m-2	-	-	-	X	-	X
Sensible heat flux	W.m-2	-	-	-	X	-	X
Latent heat flux	W.m-2	-	-	-	X	-	X
Kok ozone flux	g.m-2.s-1	-	-	-	X	-	-
SECL ozone flux	g.m-2.s-1	-	-	-	X	-	-

TABLE 10 Data products available for FLATLAND96

Parameter	Mean	Covariances	Variance	3nd moment	4nd moment
u	u	u'v' , u'w' , u'tc' , u'q' , u'Ok' , u'Ok'	u'u'	u'u'u'	u'u'u'u'
v	v	v'w' , v'tc' , v'q', v'Ok' , v'Ok'	v'v'	v'v'v'	v'v'v'v'
w	w	w'tc' , v'q', v'Ok' , v'Ok'	w'w'	w'w'w'	w'w'w'w'
tc	tc	-	tc'tc'	tc'tc'tc'	tc'tc'tc'tc'

q	q	-	q'q'	q'q'q'	q'q'q'q'
Kok Ozone	Ok	-	Ok'Ok'	-	-
Seclod Ozone	Os	-	Os'Os'	-	-
Wind speed	Wsp	-	-	-	-
Wind direction	Wdir	-	-	-	-
Pressure	P	-	-	-	-
Surface Temperature	Tsurf	-	-	-	-
Net radiation	Rn	-	-	-	-
Solar radiation	Solrad	-	-	-	-
Soil temperature	soilT	-	-	-	-
Soil moisture	soilq	-	-	-	-
Rainfall	rain	-	-	-	-

All data acquired during the deployment is archived. The application of the appropriate calibration and delay functions convert this raw data to engineering or scientific units. This processed data is available as 1, 5 or 10 minute block means, variances and covariances obtained from the initial processing of the variables measured.

4.2 Available Data

The FLATLAND96 data available as netcdf files is given in Table 11.

TABLE 11 FLATLANDS96 data available as netcdf files

Netcdf variable	**Measurement**	**Time resolution**	**Units**	**Station**	**Comments**
VAIS.PRES.AVG	pressure	1 min	mB	1, 2 & 3	Vaisala PTB 220
TRH.Tdry.AVG	temperature	1 min	degC	1, 2 & 3	NCAR hygrothermometer
TRH.rh.AVG	humidity	1 min	%	1, 2 & 3	NCAR hygrothermometer
LOGR.ETI.TOTAL	rain rate	1 min	.01" tips min-1	1, 2 & 3	ETI rain gauge
LOGR.ETI.NZTOTAL	rain accum	1 min	.01" tips	1, 2 & 3	ETI rain gauge
WIND.Vavg	v wind	1 min	ms-1	1, 2 & 3	prop-vane wind
WIND.Uavg	u wind	1 min	ms-1	1, 2 & 3	prop-vane wind
WIND.max	max wind	1 min	ms-1	1, 2 & 3	prop-vane wind
ATI.freq	frequency	5 min	Hz	1, 2 & 3	sonic freq
ATI.cnt	samples	5 min	counts	1, 2 & 3	# of sonic samples
ATI.U.AVG	u wind	5 min	ms-1	1, 2 & 3	sonic wind
ATI.V.AVG	v wind	5 min	ms-1	1, 2 & 3	sonic wind
ATI.W.AVG	w wind	5 min	ms-1	1, 2 & 3	sonic wind
ATI.Tsonic.AVG	Virtual T	5 min	degC	1, 2 & 3	sonic virtual T
ATI.Uspikes	u spikes	5 min	counts	1, 2 & 3	sonic spike counts
ATI.Vspikes	v spikes	5 min	counts	1, 2 & 3	sonic spike counts
ATI.Wspikes	w spikes	5 min	counts	1, 2 & 3	sonic spike counts
ATI.Tsonicspikes	sonic T spikes	5 min	counts	1, 2 & 3	sonic spike counts
ATI.alev.AVG	a level	5 min	degrees	1, 2 & 3	N-S
ATI.blev.AVG	b level	5 min	degrees	1, 2 & 3	E-W
ATI.Tdry.AVG	temperature	5 min	degC	1, 2 & 3	bandpass T
ATI.rh.AVG	humidity	5 min	%	1, 2 & 3	bandpass RH
ATI.mr.AVG	mixing ratio	5 min	gkg-1	1, 2 & 3	bandpass mixing ratio
ATI.UU	u'u'	5 min	m2s-2	1, 2 & 3	sonic-sonic covariance
ATI.UV	u'v'	5 min	m2s-2	1, 2 & 3	sonic-sonic variance
ATI.UW	u'w'	5 min	m2s-2	1, 2 & 3	sonic-sonic variance
ATI.UTs	u't'	5 min	ms-1 degC	1, 2 & 3	sonic-sonic variance
ATI.Umr	u'q'	5 min	ms-1 gkg-1	1, 2 & 3	sonic-sonic variance
ATI.VV	v'v'	5 min	m2s-2	1, 2 & 3	sonic-sonic covariance
ATI.VW	v'w'	5 min	m2s-2	1, 2 & 3	sonic-sonic variance
ATI.VTs	v't'	5 min	ms-1degC	1, 2 & 3	sonic-sonic variance
ATI.Vmr	v'q'	5 min	ms-1 gkg-1	1, 2 & 3	sonic-sonic variance
ATI.WW	w'w'	5 min	m2s-2	1, 2 & 3	sonic-sonic covariance
ATI.WTs	w't'	5 min	ms-1 degC	1, 2 & 3	sonic-sonic variance
ATI.Wmr	w'q'	5 min	ms-1 gkg-1	1, 2 & 3	sonic-sonic variance
ATI.TsTs	t't'	5 min	degC2	1, 2 & 3	sonic-sonic covariance
ATI.TT	tdry'tdry'	5 min	degC2	1, 2 & 3	bp-bp covariance
ATI.mrmr	q'q'	5 min	g2kg-2	1, 2 & 3	bp-bp covariance
ATI.a	bandpass a	10 min	ms -1gkg-1	1, 2 & 3	bandpass coeff
ATI.b	bandpass b	10 min	gkg-1degC1	1, 2 & 3	bandpass coeff
ATI.rSqrd	bandpass rsqrd	10 min	none	1, 2 & 3	bandpass coeff
ATI.N	bandpass N	10 min	points	1, 2 & 3	bandpass coeff
ATI.wq	bandpass wq	10 min	ms-1 gkg-1	1, 2 & 3	bandpass
ATI.wt	highpass wt	10 min	ms-1 degC	1, 2 & 3	bandpass

ATI.wtx	highpass wq	10 min	ms-1gkg-1	1, 2 & 3	bandpass
LOGR.Soldn.AVG	sol_dn	5 min	wm-2	1, 2 & 3	Licor LI200
LOGR.Rnet.AVG	Net Rad	5 min	wm-2	1, 2 & 3	Q7
Everest.Tsfc.AVG	surface T	5 min	degC	1, 2 & 3	Everest surface T
LOGR.SoilT.AVG	soil T	5 min	degC	1, 2 & 3	1 - 5 cm PRT
LOGR.SoilHF.AVG	soil heat flux	5 min	wm-2	1, 2 & 3	5 cm REBS plate
SoilMois.AVG	soil moisture	5 min	% vol	1, 2 & 3	Campbell Scientific 615
Soil Mois.PCmass.AVG	soil moisture	5 min	% mass	1, 2 & 3	Campbell Scientific 615
SoilMois.Gravimetric	Gravimetric soil moisture	Infrequently	% mass	1, 2 & 3	gravimetric
O3.kok.AVG	fast O3 mean	5 min	ppb	1	Kok gpcl
O3.kok.VAR	fast O3 covariance	5 min	ppb2	1	Kok gpcl
uO3	u'O3'	5 min	ms-1 ppb	1	Kok-sonic
vO3	v'O3'	5 min	ms-1 ppb	1	Kok-sonic
wO3	w'O3'	5 min	ms-1 ppb	1	Kok-sonic
O3.teco	accurate O3 mean	5 min	ppb	1	ThermoElectron uvab
O3.kok.cnt	Kok O3	5 min	counts	1	# of data points in 5 min
O3.teco.cnttime	Teco O3	5 min	counts	1	# of data points in 5 min

4.3 Turbulence

The data from the sonic anemometers, throughout the deployment, was subject to despiking to remove spurious values. The percentage of the data rejected is recorded as the "sonic flag". A criteria of < 3% rejection was established as a quality control for the sonic anemometer data. In post-project analysis the sonic anemometer data was corrected for biases due to changes of offset and/or actual physical tilt and lean of the sensors. This was done by separating the data of each sonic anemometer into sets corresponding to those periods when the physical configuration was constant. Logbook entries were examined and the day by day output of the anemometers inspected. Tables 11 and 12 show the boom azimuth and heights for the three sonic anemometers throughout the deployment. Changes of anemometer elevation often altered the configuration but routine maintenance involving the lowing and raising of the tower only occasionally crested in a change. Longer data sets, encompassing more complete wind speed and direction variations allowed a greater statistical accuracy in the determination of offsets and biases, however, care was taken not to ensemble data corresponding to periods of actual different tilt and/or lean. The records for the sonic anemometers at each of the three sites were examined in order to ascertain the time intervals over which to integrate data to define legitimate ensemble periods.

TABLE 12 Sonic anemometer boom azimuth

Station	Angle	Start	Stop
Station 1	221o 23' 00"	Jun 18, 00:00	Jul 9, 18:00
	224o 51' 12"	Jul 9, 18:00	Aug 23, 14:00
Station 2	215o 10' 48"	Jun 18, 00:00	Jul 3, 14:00
	213o 58' 25"	Jul 3, 14:00	Aug 23, 14:00
Station 3	230 11' 50"	Jun 18, 00:00	Aug 23, 14:00

TABLE 13 Sonic anemometer heights

Station	Height, m	Start	Stop
Station 1	3.20	18 Jun, 00:00	Jun 27, 22:00
	4.50	Jun 27, 22:00	Jul 9, 18:00
	5.70	Jul 9, 18:00	Aug 23, 14:00
Station 2	4.54	18 Jun, 00:00	Jul 3, 14:00
	5.67	Jul 3, 14:00	Aug 23, 14:00
Station 3	3.21	18 Jun, 00:00	Jul 26, 16:00
	4.00	Jul 26, 16:00	Aug 23, 14:00

Based upon this analysis, each of the sonic anemometer data sets were divided into between four and six periods. Table 14 shows the periods for the three stations and the offsets and coefficients derived for each individual period. The data was subjected to analysis and the offsets and tilt coefficients calculated. These offsets and coefficients were then use to calculate the correct turbulence for the entire deployment.

TABLE 14 Sonic anemometer data periods

	Start	Stop	Interval	woffset	lean	leanaz
			Station 1			
A	00:00, 18 Jun	22:00, 27 Jun	09 day, 22 hr	-0.038	1.605	57.7
B	22:00, 27 Jun	18:00, 09 Jul	11 day, 20 hr	-0.039	1.48	50.4
C	18:00, 09 Jul	17:00, 19 Jul	09 day, 23 hr	-0.031	1.178	69.3
D	17:00, 19 Jul	21:00, 02 Aug	14 day, 04 hr	-0.030	1.041	67.9
E	21:00, 02 Aug	14:00, 23 Aug	20 day, 17 hr	-0.033	0.515	110.2
			Station 2			
A	00:00, 18 Jun	14:00, 03 Jul	15 day, 14 hr	-0.015	0.932	52.1
B	14:00, 03 Jul	21:00, 10 Jul	07 day, 07 hr	-0.067	0.531	149.5
C	21:00, 10 Jul	16:00, 13 Jul	02 day, 19 hr	-0.006	0.688	125.4
D	16:00, 13 Jul	14:00, 23 Aug	40 day, 22 hr	-0.008	0.696	117.4
			Station 3			
A	00:00, 18 Jun	00:00, 20 Jul	32 day, 00 hr	-0.038	1.413	-173.0
B	00:00, 20 Jul	16:00, 26 Jul	06 day, 16 hr	-0.069	1.605	-164.0
C	16:00, 26 Jul	15:00, 04 Aug	08 day, 23 hr	-0.057	1.683	-171.7
D	15:00, 04 Aug	12:00, 17 Aug	12 day, 21 hr	-0.042	1.561	-161.0
E	12:00, 17 Aug	15:00, 19 Aug	02 day, 03 hr	bad data period		
F	15:00, 19 Aug	14:00, 23 Aug	03 day, 23 hr	-0.051	2.979	154.5

Note that wind direction information obtained from the sonic anemometers is expressed in the coordinate system of the sonic anemometer. The boom azimuth angles for the three sonic anemometers re given in Table 12.

4.4 Fast temperature

The fast temperature data is derived from the speed of sound measured by the sonic anemometer. This fast temperature is used with the turbulence data to calculate the sensible heat flux. This temperature is actually a virtual temperature, which is a linear combination of temperature and humidity. By subtracting the contribution from independently measured, humidity fluctuations the sensible heat flux is obtained.

4.5 Fast Humidity

For Station 1 the primarily fast humidity data was derived from the Campbell Scientific Krypton hygrometer. This data was used in conjunction with the turbulence data to calculate latent heat fluxes. At all three Stations the band pass covariance technique was also used to derive latent heat fluxes. This technique allows a relatively slow-response humidity sensor, when used in conjunction with fast response turbulence and thermal sensors, to derive latent heat fluxes. Due to scalar similarity, the relationship between the covariances, w'T' and w'q', is assumed to extend over the full frequency range. The covariances, w'T' and w'q' are matched at lower frequencies, and then the relationship is extended to the higher frequencies. In this manner w'q' can be defined to higher frequency than themoisture sensor can actually attain. The matching of the covariances is undertaken using a fast-Fourier transform of the time series in the frequency domain.

4.6 Wind, 10m

The wind direction data is derived by combining the sensor coordinate signal with the azimuthal alignment of the sensor boom. The wind speed data is derived from the wind tunnel calibration of the individual propeller. Post project calibration revealed an error in the prop pitch values used during FLATLAND96. This resulted in correction factors being applied to the NETCDF data set. The raw data set was not modified.

4.7 Air temperature

The air temperature was determined from the response of the NCAR hygrothermometers which were calibrated in the NCAR calibration lab.

4.8 Air humidity

The air humidity was determined from the response of the NCAR hygrothermometers which were calibrated in the NCAR calibration lab.

4.9 Ozone

Three ozone sensors were deployed during the FLATLAND96 program; "Tecod", the commercial ThermoElectron Model 49, a slow accurate ultraviolet absorption device; "Kokod", the custom developed, fast, gas phase, NO/O3 chemiluminescence device; and "Seclod", the adapted dropsonde prototype, fast, surface effect chemiluminescence device. Tecod measures the volume mixing ratio of ozone in air by an intrinsically accurate method and, given that the monitored operation of the sensor was maintained, the sensor output may be taken to be correct. Kokod and Seclod both depended upon Tecod for calibration.

The response of the three ozone sensors had first to be synchronized to the sonic anemometer. Sample air for Kokod was drawn from the immediate vicinity of the sonic anemometer, along 10 m of quarter inch teflon tubing, through a mass flow controller and into the low pressure reaction chamber. The time offset was invariant and was calculated by reference to the cross correlation between Kokod and the vertical component of turbulence. A value of 0.3 seconds time delay was determined. Seclod was mounted on the boom 70 cm behind the sonic anemometer. The time offset was again calculated by reference to the cross correlation with the vertical component of turbulence. In this case the time offset varied with wind speed and direction. Sample air for Tecod was also drawn from the immediate vicinity of the sonic anemometer, along 10 m of quarter inch teflon tubing. Tecod operates at near ambient pressure and the flow rate through the intake was much slower than for Kokod. Again the time offset was invariant, but calculation by cross correlation between Tecod and the vertical component of turbulence gave only a crude estimate of 20 seconds delay. This was due to the ten second resolution of the Tecod data and the manner in which Tecod reports data. Tecod has two absorption cells through which sample air is drawn. Alternately the air is switched to pass through a manganese oxide scrubber to remove ozone. Air flow for 7 seconds flushes the cell and then a 3 seconds measurement period allows the ultraviolet light intensity to be determined. The value for the ozone mixing ratio is calculated and then reported for the duration of the following 10 seconds. In the post-project data analysis the data point at the center of the 10 second reporting period was assigned to the midpoint of the previous cell flushing period, a delay of 11.5 seconds An additional delay of 6 seconds due to inlet flow time was added resulting in a total time offset of 17.5 seconds. The combination of a slow accurate sensor, to provide the low frequency components, and a fast sensor, to complete the higher frequency components, enables two separate sensors to be used when neither has quite the operational range required. For the FLATLAND96 deployment, Tecod provides the low frequency data (directly in units of ppbv mixing ratio), and Kokod or Seclod provide the high frequency data (in raw output voltage). The output of the fast sensors needs to be calibrated and the high frequency-reliable and the low frequency-reliable data streams need to be spiced together within some range of common reliability. For the Tecod/Kokod combination the task is quite easy. The sensitivity (volt/ppbv) of Kokod is stable over long periods and the output can be trusted to quite low frequencies. A comparison of the daily set of 300 second mean values, for both sensors, yielded a linear calibration for the higher frequency Kokod. Specific gains and offsets were generated for each day and application of these coefficients enabled a continuous set of calibrated high frequency ozone data to be generated. For theTecod/Seclod combination the task is more difficult. The sensitivity (volts/ppbv) of Seclod is not stable over long periods. The sensitivity of Seclod is known to respond to changes in humidity with a time constant of ~300 second. In addition, when exposed to ozone the cumarin/silicagel system exhibits a complex autosensitization, with a time constant of > 300 seconds. This low-frequency unreliability made it necessary to define and apply a calibration function which varied over a time period of < 300 seconds.

The data from the Tecod/Kokod combination is available but treatment of the corresponding Tecod/Seclod data is still ongoing.

4.10 Radiation

The Q7 net radiometers used at all three stations were calibrated, prior to the deployment, by REBS. Different calibration coefficients were provided to be used for periods of net up-welling and for periods of net down-welling radiation. The net radiometric fluxes reported here are generated using these coefficients applied to the net radiometer output. REBS has announced that these coefficients will need to be revised in light of their subsequent appreciation that further corrections need to be applied to the Eppley pyranometer and pyrgeometer data which they used during all previous Q7 calibrations.

The values for incoming solar, visible radiation fluxes reported at all three stations were generate from the Licor pyranometer output using calibration coefficients supplied by the manufacturer at the last calibration in August, 1984.

4.11 Rainfall

The rainfall-rate data prior to 29 June is seriously under reported. The analysis of the field calibration data suggests that the reported rate could be as low as 20% of the true rate. After that date, when the eprom in the datalogger was replaced, the rainfall rate is correct.

4.12 Soil temperature, 5 cm heat flux, soil moisture and surface heat flux

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The surface-5 cm soil temperatures and 5 cm soil heat flux data is dependent upon the REBS calibration of the sensors. The sensors were calibrated by REBS prior to deployment. The bulk densities of the soil at the three stations were determined to be:

Station 1 1.54 g cm-3

Station 2 1.64 g cm-3

Station 3 1.49 g cm-3

The continuously-output data for soil moisture given by the soil moisture sensors were first corrected to reduce the effect of the temperature response and were then normalized to best fit the periodic gravimetric soil sample points. There is a discernible diurnal variation in the soil moisture trace at all three sites. This variation is most extreme early in the deployment, particularly for the soybean site and diminishes as the canopy develops. This indicates the effect is driven by solar heating of the bare soil. The effect could be due to imperfect temperature compensation or it could be due to daytime desiccation of the upper layers followed by subsequent nocturnal capillary refill by moisture from deeper in the soil.

Surface heat fluxes can be calculated using the value of the flux at 5 cm below the soil surface corrected by a term for the thermal capacity of the top 5 cm of soil. This thermal capacity was calculated from the temperature and the heat capacity of the top 5 cm of soil. The thermal capacity is calculated from the bulk density and the water content of the soil.

4.13 Weather plots

Plots of a subset of the data were produced daily to provide a review of the operations. These plots are readily available but may be regarded as informative rather than as truly accurate, as more intensive data processing may be required to produce truly accurate values.

The four day weather plots show values determined at Station 1 for:

- temperature, humidity, pressure and rainfall.
- wind speed and direction.
- net radiation, sensible heat flux, latent heat flux and soil heat flux,
- Z/L, u*, and Bowen ratio

The values plotted for temperature, humidity, pressure, rainfall, wind speed and direction, net radiation and soil heat flux are 5 minute averages, while the values plotted for the sensible heat flux, the latent heat flux, Z/L, u*, Bowen ratio are 20 minute averages.

Weather plots for Station 1 are available as postscript files:

steam:/netaster/projects/FLATLAND96/results/plots/

Table 15 Station 1 weather plots

wx960615.ps	wx960619.ps	wx960623.ps	wx960627.ps		
wx960701.ps	wx960705.ps	wx960709.ps	wx960713.ps	wx960717.ps	wx960721.ps
				wx960725.ps	wx960729.ps
wx960802.ps	wx960806.ps	wx960810.ps	wx960814.ps	wx960818.ps	wx960822.ps

4.14 Logbook

An electronic logbook was maintained during the field program. A total of ~500 entries were made during the FLATLAND96 deployment in 21 different categories:

TABLE 16 Logbook categories

```
------------------------------------------------
 ADAMS/NETWORK   BAROMETERS   BAND PASS HYGROMETER
     DATA           EVE           GOES/RF
     HYGRO          LOG          LOGISTICS
     OZONE         PROPS         RADIATION
     RAIN         SOFTWARE         SOIL
    SONICS         STATUS       TAPE_ARCHIVE
     UNIX        VISIT_LOG         WEATHER

------------------------------------------------
```

The electronic logbook is available to complement this report.