Quality control and flux sampling analysis of the BOREAS Electra data

Dean Vickers
College of Oceanic and Atmospheric Sciences
Oregon State University
Corvallis, OR 97331 USA

September 16, 1996

1 Introduction

The series of automated tests developed for tower and aircraft time series described in Vickers and Mahrt (1996) are applied to the BOREAS Electra aircraft data. The automated procedures serve as a safety net for quality controlling data.

The tests are implemented by specifying critical values for parameters representing each specific error. When these values are exceeded, the record is either hard or soft flagged. *Hard flags* identify abnormalities which may result from instrumental or data recording problems. *Soft flags* identify unusual behavior which appears to be physical but might be removed for certain calculations or reserved for special studies. Data initially hard flagged by the automated quality control procedures requires visual inspection to determine if the flagged behavior is physically plausible or an instrumental problem. In the former case, the hard flag is changed to a soft flag. In the later case, the hard flag is verified as an instrumental problem. The visual (graphical) inspection includes examination of all the concurrent data.

A brief summary of the quality control and flux sampling procedures is presented in Section 2. The BOREAS Electra data set considered here is discussed in Section 3. The results of the quality control and flux sampling analysis are summarized in Section 4.

2 Tests and procedures

In this section, we introduce each of the qualtity control and flux sampling flags. The procedures presented and the critical values used to assign hard and soft flags are fully described in Vickers and Mahrt (1996). The primary fast response variables subjected to these tests include $u, v, V, w, T, q, CO_2, O_3$. All flags listed in the tables of the Results Section are mentioned here and shown in *italic*.

2.1 Quality control

Data *spikes* can be caused by random electronic spikes in the monitoring or recording systems. Records are hard flagged when the number of spikes is large. Spikes are removed from the data prior to all subsequent quality control and flux sampling calculations. The *resolution* hard flag identifies records where the amplitude resolution of the recorded data may not be sufficiently fine to capture the typical fluctuations, leading to a step ladder appearance in the data. *Dropouts* are defined as locations where the time series "sticks" at a constant value. Records are hard flagged when the number of dropouts exceeds certain critical values which depend on the value that the data is stuck on. The *absolute limits* hard flag identifies unrealistic data values. Higher moment statistics (*skewness* and *kurtosis*) are used to detect possible instrument or recording problems and physical but unusual behavior. A skewness or kurtosis value outside the expected range is hard or soft flagged, depending on the value.

Discontinuities in the data are detected using the Haar transform (Mahrt, 1991). Large values of the transform identify changes which are coherent on the scale of the window. The *Haar mean* criteria is hard or soft flagged when the absolute value of any single normalized transform of the mean exceeds threshold values. The *Haar variance* criteria is hard or soft flagged when the value of any single normalized transform of the variance exceeds threshold values.

The *wind speed ratio* is soft flagged when the ratio of the speed of the vector averaged wind to the averaged speed falls below a threshold value. The relative nonstationarity of the horizontal wind components, *RNu* and *RNv*, and the vector wind relative nonstationarity, *RNS*, are soft flagged when they exceed threshold values.

Lag correlation between temperature, specific humidity, carbon dioxide and ozone with the vertical velocity is soft flagged when the absolute value maximum correlation coefficient at any lag up to plus or minus 2 seconds exceeds the zero lag correlation by a specified amout. While a lagged correlation with vertical velocity may be physical in certain instances, systematic lag signals possible instrumentation problems, and may cause underestimation of the fluxes.

Correlation between fluctuations in aircraft altitude and in mean quantities are examined. A soft flag is raised when the correlation coefficient between radiometric altitude *R(altitude,means)* and the wind components temperature, specific humidity, carbon dioxide or ozone exceeds the threshold value. This test is repeated using altitude calculated from the pressure and hypsometric equation (pressure altitude *R(pressure,means)*).

2.2 Flux sampling

The flux sampling analysis assigns only soft flags. *RFE* is a measure of the relative flux sampling error, due to an inadequate sample of the main transporting eddies as a consequence of inadequate record length. *RN* detects linear trend in the flux possibly due to mesoscale variability associated with nonstationarity or surface heterogeneity. The *Event* flag detects isolated large flux events or outliers. *RSE* is a measure of the systematic flux error, due to the failure to capture all of the largest transporting scales, typically leading to an underestimation of the flux. The *Fr* flag tests the adequacy of the spatial (temporal) resolution of the data to capture the smallest scale turbulent flux.

The *Sf* flag examines the flux due to a correlation of the vertical velocity fluctuations with the aircraft altitude fluctuations, as measured by the radio altimeter, *Ra*, and the pressure altitude, *Pa*. This flux is partly superficial due to computed fluctuations associated with changes of aircraft elevation and mean vertical gradients. We estimate mean vertical gradients of wind speed, potential temperature, specific humidity, carbon dioxide and ozone using the flux-profile relationships of Monin-Obukhov similarity theory and the observed fluxes (Businger et al., 1971 and Dyer, 1974). The flux ratio, S_f, is defined as the ratio of the altitude induced flux to the turbulent flux. The S_f ratio is soft flagged when it exceeds a threshold value.

2.3 Slow response variables

The *absolute limits* test is applied to selected slow response (1 Hz) variables. The variables tested and the threshold limits used are presented in the next section.

3 BOREAS Electra

The analysis described here is applied to the Boreal Ecosystem-Atmosphere Study (BOREAS) Electra aircraft data collected over the Boreal forest region of Canada (Sellers, 1995). The Electra aircraft is from the National Center for Atmospheric Research (NCAR) in Boulder, CO. The primary fast response (25 Hz) variables tested here are shown in Table 1. The selection of a fast response humidity field to use is based on a pre-analysis of both the Lyman-alpha and LI-COR instruments (see below). The fields averaged from 25 Hz to 1Hz and treated as slow response secondary fields for the quality control analysis are shown in Table 2. Additional slow response (true 1 Hz) variables tested are shown in Table 3. The PRT-5 instrument (RSTB) was used for surface radiative temperature for flights 1-8. Begining with flight 9, the XKT19 variable was used.

The fast response fields (Table 1) are the primary data fields input to the quality control and flux sampling. Ozone and carbon dioxide mixing ratios (not discussed in Vickers and Mahrt, 1996) are subjected to all the same tests as humidity and temperature, including all the flux sampling tests. All slow response fields are only tested with the *absolute limits* criteria.

The OSU archive of BOREAS Electra data includes all the low level flight legs (100-200 m above the canopy) for 25 flights; from flight 1 on 25 May 1994 through flight 25 on 16 September 1994. The raw data for each flight was processed from the NCAR mass store system archive under RAF 1994 818 HRT RFXX, where XX is the flight number (01-25). The OSU data is stored in a separate data file for each flight number and each flight leg number. The leg number is specific to the OSU archive and refers to the sequential low level flight leg for each flight. Low level flight legs are delimited by aircraft ascents, descents and sharp turns.

3.1 Humidity instruments

The OSU archive includes fast response humidity measurements from two instruments; the Lyman-alpha (MRLA) and the LI-COR (XMRLI). Because of frequent problems with both of these instruments, a pre-analysis program was run to identify when each instrument was functioning properly (see Table 4). The fast response humidity field used in the quality control and flux sampling was selected based on this pre-analysis. When the Lyman-alpha instrument is functioning properly it is selected. During times when there is an obvious problem with the Lyman-alpha but the LI-COR humidities are reasonable, the LI-COR data is used. When both humidity instruments are malfunctioning, the flight leg is not included in the quality control or flux sampling. In some cases, the humidity from either instrument malfunctions only at the start or end of a low level flight leg. In these cases, the start or end of the leg is discarded, so that humidity data with an obvious problem is not input to the quality control. The humidity field selected can change between low level flight legs on the same flight day (Table 4).

In Table 4, "ok" indicates the data appears plausible, while "bad" identifies cases where there is an obvious problem with the instrument, the data recording or processing. In this context, both measurements can be deemed "ok" and still disagree with each other in some respects. In general, the Lyman-alpha measured mixing ratio is smaller in magnitude than the LI-COR value, and in several cases the turbulent scale fluctuations measured by the Lyman-alpha are larger than those from the LI-COR. When both mixing ratios are "ok", the two signals are highly correlated. It is not uncommon for the "start" or "end" of a low level flight leg to exhibit an instrument problem for either humidity instrument. In Table 4, these words indicate that most of the leg is retained by removing the offending section at the start or end of the leg. When "start" or "end" is not modifying "leg", then the entire leg is deemed bad. The "Legs" column in Table 4 is the total number of low level legs in the archive for each Electra flight.

3.2 Aircraft ascent and descent

While the OSU archive is intended to include only approximately constant altitude, low level flight legs, pre-analysis shows that the beginning and end of each flight leg can sometimes include the end of an aircraft descent or the beginning of an ascent. A pre-analysis was done in an attempt to remove these ascent and descent features from each flight leg.

3.3 Records

After removing data for humidity instrument problems and aircraft descent or ascent (see previous subsections), each flight leg on each flight day was partitioned into approximately 20 km length records for purposes of the quality control and flux sampling analysis. The low level leg is paritioned with the requirement that the minimum record length be 16 km, the entire leg be used, and all records be of equal length, except for the last record where the length is reduced to extend out to the end of the leg.

For example, for flight 1, five low level flight legs were found. The five legs were split into 7,28,10,7 and 7 records, respectively, resulting in 59 quality control records for flight number 1. The first 6 records for leg 1 have a record length of 23.0 km and the last record, which extends to the end of the leg, has a record length of 17.7 km.

A list of all data records is generated by the pre-analysis program which identifys each quality control record by flight number, leg number, start and stop time, start and stop longitude and latitude, mean altitude, record length and humidity instrument identifier. This list of records is used as input to the quality control and flux sampling program to define each record of data. The pre-analysis program identifies at total of 883 records.

3.4 Local averaging scale

The local length scale chosen for the quality control and flux sampling analysis is 2 km. This is equivalent to approximately 20 seconds of data since the Electra flys at about 100 m/s. This scale is used to define a local mean, variance and range for some of the quality control calculations.

The length scale of 2 km is also used in the flux sampling analysis as L_1 in RSh (L_2=4 km), and as the sub-record width in RFE, RN, and $Event$. A local averaging length scale of 2 km and our requirement that a record be at least 16 km in length, always results in at least 8 independent samples of the flux for flux sampling analysis.

3.5 Internal data processing

In this subsection we detail all the processing performed by the quality control program on the Electra data before the actual quality control and flux sampling tests begin. This processing is internal to the quality control program. The data files in the OSU archive do not include this processing.

First, the record is identified from the list of records. The flight number, leg number start and stop times and humidity instrument selection enables extraction of the record from the OSU archive.

The nominally 20 km record legnth mean is removed from the vertical velocity. This is done primarily because the vertical motion is known only relative to an undetermined constant.

To compute the stress in the along-wind direction, and to differentiate between the along-wind and the cross-wind stress, the horizontal wind components are rotated into the mean wind direction. The rotation is performed after the wind components have been despiked.

All mixing ratios in Tables 1-3 are converted to specific humidities. The ozone concentration is converted to ug/kg and the carbon dioxide concentration is converted to mg/kg.

The carbon dioxide (XCO2C) and humidity (XMRLI) from the LI-COR instrument suffer a known lag with the vertical velocity (WIC) (Steve Oncley, NCAR). Accordingly, XCO2C and XMRLI are phase shifted forward to remove the lag. The phase shift is 0.50 seconds for flights RF01-04, 0.28 seconds for RF05-08 and 0.48 seconds for RF09-RF25. It is also known apriori that the ozone instrument (O3FC) lags the vertical velocity by 0.16 seconds for all flights (Steve Oncley, NCAR). Accordingly, O3FC is phase shifted forward by the quality control program to remove the lag correlation.

For flights RF01 and RF02 it is suspected that the air temperature (ATB) and the humidity from the Lyman-alpha (MRLA) may be lagged, as there was an electronic filter on the aquisition of these fields (Steve Oncley, NCAR). However, we do not phase shift either ATB or MRLA in the quality control program. The quality control test for lag correlation will be used to determine if there is systematic lag.

4 Results

In this section, we summarize the results of applying the tests outlined in Section 2 to the BOREAS Electra data described in Section 3.

A total of 95 records (out of 883) raised at least one hard flag for at least one of the fast response data fields considered (Table 1). The number of records initially hard flagged and subsequently verified as an instrument problem by each criteria for each variable individually is shown in Table 5. Note that a single data record can and often does have multiple hard flags.

The *absolute limits* test for the slow response variables raised at least one hard flag for at least one of the variables considered (see Tables 2-3) in 15 records. All of these flags were raised when the aircraft roll angle exceeded 25 degrees. After visual inspection, large aircraft roll was classified as an instrument "problem" in only one record, where the roll is associated with large vertical velocities and may be the result of contamination of the wind components.

Considering both the fast and slow response fields together, at least one hard flag for at least one of the variables was raised in 107 (out of 883) records. Of the 107 automated (tentative) hard flagged records, only 17 are verified as instrumental problems by visual (graphical) inspection. The list of BOREAS

Electra records with verified hard flags is shown in Table 6. The hard flags for the other 90 records are changed to soft flags. Most of the automated hard flags are classified as plausible physical behavior after visual inspection. The records initially hard flagged by the automated procedure but classified as plausible after visual inspection are shown in Table 7a-7d. Many of these records are characterized by large surface heterogeneity, internal boundary layers and fronts.

The percent of records (excluding the 107 initially hard flagged records) that are soft flagged by the various quality control criteria are shown in Table 8, and the percent soft flagged by the flux sampling criteria are shown in Table 9.

The soft flag for large correlation of the temperature and the aircraft altitude calculated from the pressure and the hypsometric equation is raised in 30% of the records. For all records, the mean correlation coefficient is -0.28.

The soft flag for lag correlation of CO_2 and the vertical velocity is raised in 45 % of the records. However, the lag of maximum correlation is not systematic. The mean of the lag that maximizes the correlation for all records is less than one 25 Hz data point or 0.04 seconds.

The flux sampling analysis shows frequent large random sampling error (RFE) for the stress (Table 9). The flag for systematic underestimation of the flux (RSE) using a local flux averaging scale of 2 km is most often raised for the stress. For the vector stress, these two flux sampling error estimates (RFE and RSE) are highly correlated (R=0.71).

4.1 Conclusions

After careful selection of the data records based on pre-analysis for obvious humidity instrument problems and aircraft descents and ascents, a very small percentage (2 %) of the remaining data is found to have instrumental problems. The pre-analysis removed 159 records before the quality control procedure.

Excluding CO_2 and O_3 from the analysis, only 7 records have verified hard flags (Table 6). 5 of these 7 are flagged for the vertical velocity and 2 are flagged for *dropouts* in humidity. There are no verified hard flags for the horizontal wind components or air temperature.

With the exception of some obvious instrument problems for CO_2, and a few cases of unphysically large vertical velocities, most of the automated hard flags are all classified as plausible after visual inspection. The BOREAS site is characterized by large surface heterogeneity which leads to small scale discontinuities and large higher moment statistics in the winds, temperature and moisture which appear to be physical.

Table 1. Fast response (25 Hz) fields.

name	description	threshold limits
UIC	GPS-Corrected Wind Vector, East Comp m/s	-30,30
VIC	GPS-Corrected Wind Vector, North Comp m/s	-30,30
WIC	GPS-corrected Wind vector, Vertical Gust m/s	-5.5,5.5
ATB	Ambient Temperature, Radome C	-20,60
MRLA	Mixing Ratio: Lyman-alpha g/kg	0,30
XMRLI	LI-COR Water Mixing Ratio g/kg	0,30
PSFDC	Corrected Static Pressure, Fuselage Digi mb	NA
O3FC	Corrected Fast-Response Ozone $ppbv$	1,200
XCO2C	LI-COR CO2 concentration $ppmv$	50,1000

MRLA and XMRLI are converted to specific humidity before comparing to the threshold limits. O3FC is converted to micro-grams/kg and XCO2C is converted to milli-grams/kg before comparing to the threshold limits.

Table 2. Fast response fields averaged to slow response.

name	description	threshold limits
WV862	Vegetation meter, 862 nm	0,10
WV650	Vegetation meter, 650 nm	0,10
THETA	Potential Temperature K	270,300
XMRLI	LI-COR Water Mixing Ratio g/kg	0,30

XMRLI is converted to specific humidity before comparing to the threshold limits.

Table 3. Slow response (1 Hz) fields.

name	description	threshold limits
GLAT	GPS Latitude deg	50,62
GLON	GPS Longitude deg	-110,-94
HGM	Geometric (Radio) Altitude m	0,250
SWB	Shortwave Irradiance, Bottom W/m^2	-5,500
SWT	Shortwave Irradiance, Top W/m^2	0,1300
IRBC	Corrected Infrared Irradiance, Bottom W/m^2	0,700
IRTC	Corrected Infrared Irradiance, Top W/m^2	0,700
RSTT	Radiometric Sky/Cloud-Base Temperature C	-100,50
MR	Mixing Ratio: T-Electric g/kg	0,30
RSTB	Radiometric Surface Temperature PRT-5 C	-10,70
XKT19	Radiometric Surface Temperature C	-10,70
ROLL	IRS aircraft roll attitude deg	-25,25
PITCH	IRS aircraft pitch attitude deg	-3,7

MR is converted to specific humidity before comparing to the threshold limits.

Table 4. BOREAS Electra fast response humidity instruments.

Flt	Legs	MRLA (Lyman-alpha)	XMRLI (LI-COR)
1	5	ok	ok
2	3	ok	ok
3	4	bad	bad end legs 1-4
4	4	bad leg 1	bad start leg 2, bad end leg 3
5	7	ok	ok
6	4	ok	ok
7	4	ok	bad end leg 1
8	4	bad legs 1-2	bad
9	2	bad	ok
10	6	ok	ok
11	4	ok	ok
12	4	bad	ok
13	4	bad leg 1	ok
14	8	bad start legs 1,4	ok
15	6	bad leg 1, bad leg 4	bad leg 1, bad leg 4
16	5	bad leg 1	bad leg 1
17	2	bad start leg 1	ok
18	6	ok	ok
19	6	ok	ok
20	4	bad leg 4	bad leg 4
21	4	ok	bad leg 1, bad end leg 2
22	5	ok	bad start leg 1, bad leg 3
23	4	bad legs 2-3	bad start leg 1, bad legs 2-3
24	6	bad end leg 2, bad leg 3	bad start leg 1, bad leg 3
25	5	ok	bad start leg 1, bad end leg 3

Table 5. Number of records initially hard flagged (and verified instrument problems) by the automated quality control criteria for the fast response fields.

criteria	u	v	w	T	q	CO2	O3
spikes	0	0	0	0	0	0	0
resolution	0	0	0	0	0	0	0
dropouts	0	0	0	0	6 (2)	3 (3)	0
absolute limits	0	0	6 (5)	0	0	4 (4)	0
skewness	0	0	0	0	3 (0)	7 (5)	1 (1)
kurtosis	0	0	0	3 (0)	4 (0)	12 (6)	2 (1)
Haar mean	5 (0)	9 (0)	0	0	14 (0)	6 (4)	6 (1)
Haar variance	11 (0)	6 (0)	10 (1)	6 (0)	17 (0)	9 (5)	9 (0)

Table 6. Records with verified hard flags.

flt	leg	start	stop	hard flag(s)
6	4	73047	73246	dropouts q
6	4	73247	73409	dropouts q
8	3	60233	60482	dropouts abs limits Haar mean CO2
8	4	66647	66846	dropouts abs limits Haar mean CO2
8	4	66847	67046	abs limits CO2
8	4	67047	67246	dropouts abs limits Haar mean CO2
16	5	78147	78356	abs limits w
20	2	63083	63312	kurtosis Haar variance CO2
20	2	64693	64922	skewness kurtosis Haar mean CO2 O3
20	2	64923	65152	skewness kurtosis Haar variance CO2
20	2	65843	66072	skewness kurtosis Haar variance CO2
21	1	60988	61187	skewness kurtosis Haar variance CO2
21	2	69982	70211	abs limits w ROLL
21	2	70672	70901	skewness kurtosis Haar variance CO2
22	4	75590	75799	abs limits w
24	4	65741	65940	abs limits w Haar variance w
25	4	72411	72577	abs limits w

Table 7a. Records initially hard flagged but classified as physical.

flt	leg	start	stop	hard flag(s)
1	1	60062	60291	Haar mean v
1	2	66016	66225	Haar mean q O3
1	2	66226	66435	Haar mean v
1	2	66436	66645	dropouts q Haar variance w
1	2	66646	66855	Haar variance q O3
1	2	67486	67695	kurtosis q Haar variance w
1	3	71824	72053	dropouts q Haar mean Haar variance u q
1	3	72744	72973	Haar variance v
1	4	74134	74383	Haar mean u
1	4	74884	75133	dropouts q
2	1	61504	61703	Haar mean v Haar variance q
3	1	60605	60825	Haar mean v
3	3	69295	69514	Haar variance T
3	3	69515	69734	Haar variance w
4	1	60917	61126	Haar mean vabs limits RO
4	1	61337	61546	Haar mean q
4	1	62387	62596	Haar mean u
4	2	65767	65966	Haar mean CO2
4	3	71013	71272	kurtosis T Haar mean Haar variance q
4	4	76447	76666	Haar mean v Haar variance w
4	4	77327	77546	abs limits ROLL
4	4	77987	78206	abs limits ROLL
4	4	78867	79086	Haar variance w

Table 7b. Records initially hard flagged but classified as physical.

flt	leg	start	stop	hard flag(s)
5	4	65385	65604	Haar variance CO2
5	5	67292	67511	Haar mean q
5	6	72899	73077	Haar mean q
5	7	73581	73780	Haar variance u
6	1	54741	54980	Haar variance u
6	1	56421	56633	Haar variance u
6	4	72647	72846	dropouts q
7	1	61035	61244	abs limits ROLL
7	2	63681	63900	Haar variance u
7	2	63901	64120	Haar mean u
7	3	73035	73244	Haar variance v
7	3	74505	74714	Haar variance u
7	4	75697	75906	Haar variance u
7	4	76537	76746	Haar mean u Haar variance u v
8	3	61983	62232	Haar mean v
8	4	67447	67607	abs limits ROLL
9	2	73621	73830	Haar variance u
10	1	63531	63750	kurtosis CO2 Haar variance q
10	1	63751	63970	skewness kurtosis Haar mean variance CO2
10	4	71835	72034	Haar variance q
10	5	75963	76202	Haar variance T
10	5	76203	76442	Haar variance T

Table 7c. Records initially hard flagged but classified as physical.

flt	leg	start	stop	hard flag(s)
11	1	57256	57455	abs limits ROLL
11	1	58256	58455	Haar variance q
11	2	59992	60251	Haar variance w
11	4	73324	73553	Haar variance T
12	1	57047	57246	Haar variance v
12	1	57247	57446	skewness kurtosis CO2
12	1	57847	58046	Haar variance q O3
12	1	58247	58446	Haar mean Haar variance q
12	1	58447	58646	abs limits ROLL
12	1	59047	59246	abs limits ROLL
12	1	59247	59446	skewness kurtosis Haar variance O3
12	2	60515	60754	Haar mean q O3
12	2	61475	61714	Haar variance v
12	4	67095	67294	Haar variance u
13	2	65483	65702	Haar variance w
14	2	60954	61163	Haar variance T
14	3	61810	62059	Haar variance q O3
14	5	65584	65813	Haar variance w
14	6	67098	67307	Haar mean O3
14	8	75162	75381	Haar variance v
15	6	78049	78258	Haar variance q
16	3	73117	73316	abs limits ROLL
16	3	73317	73516	abs limits ROLL
16	3	73517	73716	abs limits ROLL
16	3	75117	75316	Haar variance u
16	5	78567	78769	Haar mean v

Table 7d. Records initially hard flagged but classified as physical.

flt	leg	start	stop	hard flag(s)
17	1	64077	64306	kurtosis T Haar mean Haar variance O3
17	1	64307	64536	Haar variance q
17	1	64537	64755	Haar mean q
18	1	59432	59641	abs limits ROLL
18	1	60272	60470	Haar variance q
18	2	61070	61279	Haar mean q O3 Haar variance O3
18	3	63886	64105	Haar mean q
19	4	68032	68292	kurtosis Haar variance CO2
20	3	69067	69296	abs limits ROLL
21	2	66762	66991	abs limits w
22	4	75800	76009	Haar variance q
23	1	60845	61054	kurtosis CO2
23	1	61055	61264	kurtosis CO2
24	1	59375	59654	Haar mean Haar variance q abs limits ROLL
24	1	59935	60214	Haar variance w
24	2	61839	62048	Haar variance O3
25	1	61071	61270	Haar mean q
25	4	72201	72410	Haar variance q
25	5	75677	75896	skewness kurtosis Haar variance q

Table 8. Percent of records soft flagged.

criteria	u	v	V	w	T	q	CO2	O3
skewness	0	0	-	0	18	3	1	1
kurtosis	0	1	-	1	6	3	2	1
Haar mean	35	46	-	5	16	26	4	9
Haar variance	10	7	-	13	6	11	1	2
wind speed ratio	-	-	21	-	-	-	-	-
RN(u,v,s)	-	-	29	-	-	-	-	-
R(altitude,means)	1	2	-	0	6	4	3	2
R(pressure,means)	4	6	-	0	30	16	16	13
lag correlation	-	-	-	-	11	10	45	8

Table 9. Precent of records soft flagged by flux sampling criteria.

criteria	wu	wV	wT	wq	wCO2	wO3
RFE	44	63	20	15	44	29
RN	3	5	5	1	7	3
Event	12	33	13	9	18	2
RSE	20	32	14	15	26	19
Fr	1	0	0	0	6	0
Sf ratio Ra	3	-	1	0	1	0
Sf ratio Pa	2	-	1	0	2	0

References

Businger, J.A., J.C. Wyngaard, Y. Izumi, and E.F. Bradley, 1971: Flux profile relationships in the atmospheric surface layer. *J. Atmos. Sci.*, 28, 181-189.

Dyer, A.J., 1974: A review of flux-profile relationships. *Boundary-Layer Meteorol.*, **7**, 363-372.

Mahrt, L., 1991: Eddy asymmetry in the sheared heated boundary layer. *J. Atmos. Sci.*, 48, 472-492.

Sellers, P.J., F.G. Hall, H. Margollis, B. Kelly, D. Baldocchi, J. den Hartog, J. Cihlar, M. Ryan, B. Goodison, P. Crill, J. Ranson, D. Lettenmaier, and D.E. Wickland, 1995: The Boreal Ecosystem-Atmospheric Study (BOREAS): an overview and early results from the 1994 field year. *Bull. Amer. Meteor. Soc.*, 76, 1549-1577.

Vickers, D., and L. Mahrt, 1997: Quality control and flux sampling problems for tower and aircraft data. submitted to *J. Atmos. Oceanic Technol.*.