AA Technical Memorandum ERL ARL-147

A BASIC PROGRAM FOR EDDY CORRELATION IN NON-SIMPLE TERRAIN

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ABSTRACT. A system is described which calculates vertical fluxes of heat, moisture, momentum, and certain atmospheric pollutants in a manner which permits the eddy correlation technique to be used in more complex terrain than was normally thought possible. The system is assembled from commercially available components and is simple to operate. The required computer program allows for flexibility and interchangeability of instrumentation without recompilation. Fluxes, along with other turbulence parameters, are computed in real time and printed at the end of each averaging period. The main elements of the program are (1) "detrending" (by use of running mean removal), (2) calculation of the entire stress tensor (which allows three dimensional coordinate rotation to be performed on the covariances), (3) software-adjustable timing delays for each instrument channel, and (4) real-time graphic presentation of the raw data as stripchart images. The first two of the these program elements tend to relax the normal site and sensor-leveling requirements. Sample results are presented, and the sensitivities of the calculated quantities to coordinate rotation and to mean removal time are examined. A description of the program and a complete program listing are included as appendices.

1. INTRODUCTION

One of the primary areas of research in micrometeorology has been the investigation of turbulent fluxes of heat, moisture, and momentum. Increasing awareness of environmental problems has recently emphasized the need for measuring turbulent fluxes of atmospheric pollutants over different surfaces and in varying conditions. These quantities have traditionally been measured by a variety of techniques at carefully selected "ideal" sites, i.e., level terrain with a smooth homogeneous surface and good fetch; however, such locations are atypical of those usually encountered in the real world. The Atmospheric Turbulence and Diffusion Division (ATDD) is routinely measuring turbulent fluxes of heat, moisture, momentum, and pollutants above the forest canopy of the Walker Branch Watershed (WBW) in eastern Tennessee, and using the results to develop new techniques that will allow large scale assessment of acidic deposition. Terrain surrounding the WBW is complex, and the surface of the oak-hickory forest canopy is inhomogeneous, providing a poor site for application of traditional flux measurement techniques. This paper will demonstrate the validity of such measurements in complex terrain and briefly present the data acquisition system and algorithm used for the calculations. Further details of the data acquisition system and the algorithm can be found in the accompanying appendix.

Recent advances in micro-computer-controlled data acquisition systems have made real-time processing of digital turbulence data a viable alternative to post-processing. The major advantages of real-time processing are better quality control of the data, avoidance of a large backlog of turbulence data, and the ability for the investigator to quickly determine if correlations observed on the display screen are statistically significant. Several early eddy correlation systems, such as the "Evapotron" (Dyer and Maher, 1965) and the "Fluxatron" (Dyer et al., 1967), used analog computers, providing results in real-time, and this newer digital system is influenced by the techniques used for analog calculations. This program combines the advantages of an analog computer technique for running-mean removal with the more sophisticated and flexible data processing afforded by digital techniques.

A computer algorithm has been developed which runs on a micro-computer, and calculates turbulent fluxes in real-time for non-ideal sites such as the WBW location. Continuous display of real-time data allows the operator to monitor the status of each meteorological sensor. Real-time calculations of the variances and covariances of the signals allow the turbulent flux condi-tions to be continually assessed for improved quality assurance. The technique produces good results and has been implemented on several micro- and mini-computers.

2. THE EDDY CORRELATION TECHNIQUE

Assuming perfectly responding sensors and an infinitely fast sampling rate, the eddy correlation technique provides a direct measurement of the turbulent flux at the sampling location without error, regardless of the quality of the site. The meteorological "goodness" of the site determines the repeatability and representativeness of the measurement.

The fundamental aspects of eddy correlation are thoroughly discussed in standard meteorological texts (e.g., Priestley, 1959). Here, the emphasis is on the application of recent technological advances to extend eddy correlation methods to circumstances more complicated than previously thought suitable.

In a general sense, the total flux, F_{tot}, of an atmospheric quantity, C, including advective terms, can be defined as

$$F_{tot} = T^{-1}\rho \int_{o}^{T} vC \; dt \tag{1}$$

where v is the total wind vector, T is the averaging time, and ρ is the is the density of C. The advective flux, F_{ad}, which is by definition along the mean local streamline, can be defined as

$$F_{ad} = [T^{-1}\int_{o}^{T} v \; dt]*[T^{-1}\rho \int_{o}^{T} C \; dt] , \tag{2}$$

the product of the average total wind vector and the average of C for the averaging period, T. The difference between F_{tot} and F_{ad} is the turbulent flux, F_{turb} of C, which corresponds to transport across a plane determined by local streamlines. The vertical component of the F_{turb} is the desired vertical turbulent flux of the quantity C. In practice, it is usual to replace the integrals with summations

$$F_{turb} = (1/N)\rho \sum (v-\overline{v})*(C-\overline{C}) = (1/N)\rho \sum v'C' \quad (3)$$

where overbars denote a mean value and v' and C' are deviations from the mean or fluctuating components. This is the classical definition of the covariance of the quantities v and C. The vertical component, F_w, of the turbulent flux, F_{turb}, is generally the quantity of interest, although there may be occasions when it is necessary to evaluate turbulent fluxes in other directions. In this context, the concept of turbulent flux must be associated with transport across streamline walls. Since any turbulent component in the direction of the streamline will be small in comparison to the advective flux, the turbulent component may be thought of as perpendicular to the streamline wall.

Successful evaluation of covariances by the eddy correlation method requires that several conditions be met. The sensor response time must be sufficient to resolve the turbulence scales contributing to transport, which many studies have shown to occur within the normalized, dimensionless frequency (f=nz/u) range between .001 to 2 (Kanemasu, et al. 1979), where n is the natural frequency, z is the measuring height, and u is the mean wind speed. Early exploratory studies (e.g., Deacon, 1959) found that sensor frequency response should be at least 2u/z for neutral conditions, where u is the highest expected windspeed and z is the measurement height above the local displacement plane; while faster response is necessary in stable conditions, and somewhat slower response is adequate for unstable conditions.

Operating at greater heights allows use of a slower responding sensor, but requires a more uniform site because the sensor is exposed to air influenced by a greater upwind area. In order to satisfy the spatial homogeneity requirement, the maximum height for operation should be less than about 1/200th the distance of upwind uniform terrain. In practice, larger uniform fetches appear to be necessary over smooth surfaces (and/or in stable conditions), and smaller over rough surfaces (e.g., forests) and/or unstable conditions.

Several researchers (e.g., Pond, 1968; Kaimal and Haugen, 1969, and Dyer and Hicks, 1972), have reported large errors in the calculation of Reynolds stresses because of inappropriate orientation of the vertical wind sensor. The errors reported ranged from 8% to more than 100% per degree of misalignment. Since anemometers are often mounted on long booms to minimize flow distortion due to tower effects, tilt errors present a serious problem. The same errors occur if the sensor is indeed vertical but the flow streamline is not perfectly horizontal, a condition which results from obstruction by other sensors or from irregular terrain. For this reason, direct measurements of vertical fluxes at other than near-perfect sites have been considered difficult.

When evaluating fluxes in non-simple terrain, stationarity is always a problem, and it may be necessary to use a slightly different approach to assess turbulent fluxes. The averaging period must be long enough to obtain a valid statistical value from the product of two inherently noisy signals, yet short enough to assume weak stationarity of meteorological conditions, including solar insolation. In complex terrain, these two criteria are often mutually exclusive. Even in conditions of horizontally-uniform concentration fields, clear-sky insolation can change by about 15% per hour, causing major changes in turbulent exchange. Variability of wind direction is always a concern, but becomes a major problem when the surface is not spatially uniform. To satisfy the requirements of stationarity, an averaging period of no longer than 30 minutes is desirable, but in practice longer averaging periods are often necessary to reduce the statistical uncertainty to an acceptable level. Over a half hour period, the local meteorological conditions can change appreciably in complex terrain, making the assumption of stationarity problematic. Hence ensemble averaging is often required.

These problems, except for inadequate sensor response, are addressed by the software used for data analysis and will be discussed below. First order corrections for inadequate sensor response have been discussed elsewhere (Hicks, 1972).

3. THE EDDY CORRELATION SYSTEM

3.1 Sensing Systems

Field tests of the analysis procedures described here have been conducted with various meteorological and air-chemical sensors. Air velocity data have usually been measured with a three dimensional sonic anemometer manufactured by Applied Technology, Incl. The path length is 20 cm and the digital data are provided at 20 Hz frequency. A Kaijo-Denki DAT-310 sonic anemometer and an R. M. Young model UVW propeller anemometer have also been used with good results.

Air temperatures have been determined with a microbead thermistor with a response time of 0.1 seconds. Water vapor data have been taken with a Lyman-alpha UV open-path hygrometer manufactured by Electromagnetic Research Corporation, with a variable path length of about one cm and a response time of about 0.1 s.

Various pollutant sensors have been included in the tests, including specially modified flame-photometric sulfur analyzers, similar to those described by Garber, et al. (1981). Particle counters, and sensors of ozone, nitrogen oxides, and carbon dioxide have also been used. The only requirements for pollutant sensors are that the signal-to-noise ratio be sufficient to provide stable results, and that the response time be sufficient for the turbulence scale involved (typically $2u/z$ Hz).

3.2 Data Acquisition

The data acquisition system used is commercially-available, and consists of an IBM PC AT with a 20 Mbyte fixed disk storage system, a Tecmar 16-bit analog-to-digital converter, and a suitable printer. The Tecmar system has a 3000 Hz conversion rate, and provides program timing as well as signal conversion. A Mountain Computer streaming tape is used to store raw data. However, the software should run without modification on any hardware and software IBM-PC-compatible micro-computer. In the event that such a micro-computer is not available, the software can easily be converted to another machine.

3.3 Software

A BASIC program has been written which accounts for the problems associated with the eddy correlation method outlined above. It calculates in real time the vertical turbulent fluxes of several quantities, as well as selected turbulence parameters, and all raw data can be stored for later analysis. The covariances of all variables with each of the three wind velocity components are calculated, allowing for coordinate rotation of the covariances at the end of the averaging period, as described by Wesely (1970). Coordinate rotation aligns the coordinate system with the local streamline, effectively removing the advective flux from the total flux. Coordinate rotation improves results at most sites, as will be demonstrated later.

A circular buffer is used to correct for instrument time delays, usually due to some sort of measurement lag (e.g., transport time within tubing, for a pollutant sensor). That is, if it is know that signals provided by a particular sensor have a delay time T_d, then the processing of all other instrument channels can be delayed by T_d, so that the covariance or other computations are done on signals that were originally coincident in time in the atmosphere.

The fluctuating signals are continuously displayed in strip chart fashion on the computer screen in real time, permitting continuous monitoring of instrument behavior. The display is quite helpful for quality control of the data and also provides visual evidence of correlations between the various sensors.

The problem of stationarity is partially addressed by subtracting a running mean, estimated by a digital recursive filter, from incoming data. This high-pass filter detrends the data and partially corrects for sensor misalignment (Kraus, 1968). For this reason, covariances are not computed as described above (equation 3), but are computed by forming the cross-products of filtered components rather than the cross-products of the fluctuating terms calculated by removing the arithmetic mean, calculated over the entire averaging period, from the raw data. In effect, this procedure tends to remove the advective flux by approximating it with a running mean. This technique allows the determination of the advective terms over a different time period than that used for the covariance calculation. The consequences of this approximation have been described (McMillen, 1983), and will be elaborated upon below. A similar high-pass filter technique was first applied by Dyer et al. (1965) as a practical means to permit real-time analog calculation of fluxes. Relevant details are presented by Dyer (1973). Throughout the remainder of this paper, the term covariance and flux are used more or less interchangeably, but the reader should be aware that these are not covariances as computed using Reynolds averaging, but a close approximation to them.

A recursive digital filter is an exact analog of an ideal electronic R-C filter, with an easily specified time constant. The filter can be written, after Enochson and Otnes (1968)

$$y_{i+1} = \alpha x_i + (1-\alpha) y_i \qquad (4)$$

where x_i is an original datum at time t_i of time series data, y_i is the filtered datum at t_i, and a is defined by

$$\alpha = e^{-(\delta t/\tau)} \qquad (5)$$

where δt is the time interval between data scans and τ is the time constant of the filter in seconds. When $\delta t/\tau << 1$ then $\alpha \simeq 1-(\delta t/\tau)$.

3.4 Sensitivity Tests

Figure 1 depicts the sensitivity of normalized covariance of vertical wind velocity and SO_2 concentration to instrument delay times. The data consist of ensemble averages vertical SO_2 fluxes over 12 half-hour periods collected near State College, Pennsylvania on July 20, 1985. The site is located in a wide valley, and the fetch is good when the wind direction is along the valley. Measurement height was 7 meters. The upwind fetch was mixed agricultural crops, consisting mainly of corn, oats, and senescent barley. The error bars indicate ± one standard error of the ensemble. The figure was produced by rerunning the FLUX program on recorded raw data using different delay times for the SO_2 signal and is analogous to a cross-correlation function of the same signals plotted against the time series lag. The curve is peaked near the measured delay time of our instrument's intake manifold (approximately 1.9 seconds, as shown in Figure 2). The accuracy and validity of these results were examined by comparison with a lag cross-correllogram, calculated using standard Fourier analysis techniques. The dashed line in Figure 1 is the Correllogram. Differences between the two results are due to different averaging periods and the fact that slightly different data segments were used for the two calculations. Sensitivity to instrument delay time should be a function of the turbulence scales involved, and in some cases might be more sharply peaked than the figure shown. During stable conditions, sensitivity to instrument delay should be increased and delays and response times must be carefully measured if accurate measurements of covariances are to be made during stable conditions.

Figure 2 was produced from raw data to assess the delay and response time of an instrument. A solenoid actuated valve was used to inject a step function change of SO_2 concentration into the intake system of the SO_2 analyzer. The time series can be displayed graphically on the computer display and the delay and response time measured. Several trials should be averaged for best results.

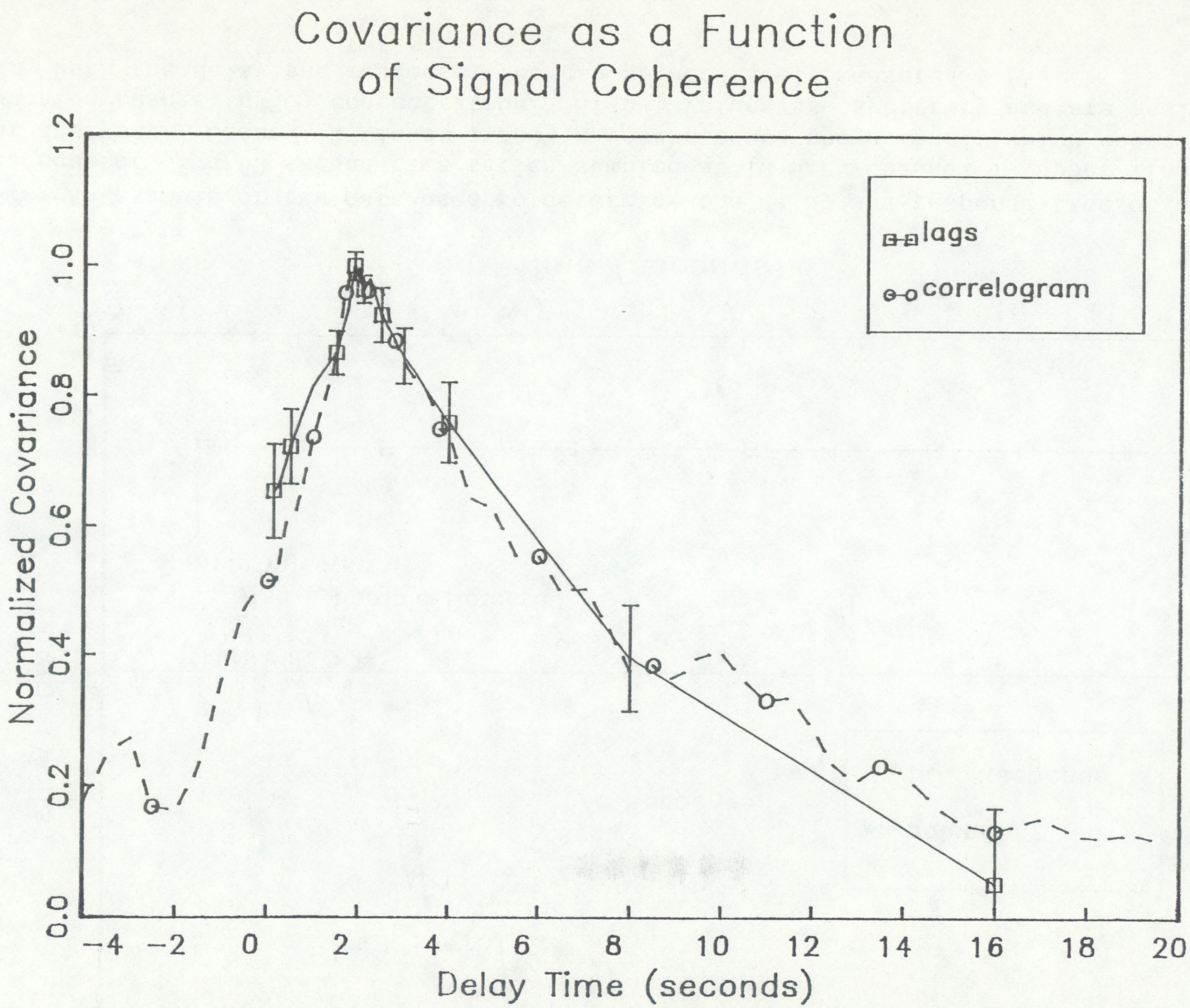

Figure 1.--Normalized covariance as a function of instrument delay time. The data consist of ensemble averages of 12 half-hour periods collected near State College, Pennsylvania on July 20, 1985. Response has been normalized by the maximum response. The errors shown are ± one standard error of the ensemble. The dashed line is a lag cross-correlogram of the same data computed using standard FFT techniques. The peak response occurs when a lag time of about 1.9 seconds is removed from the SO_2 signal, which is also the measured delay time of the SO_2 analyzer.

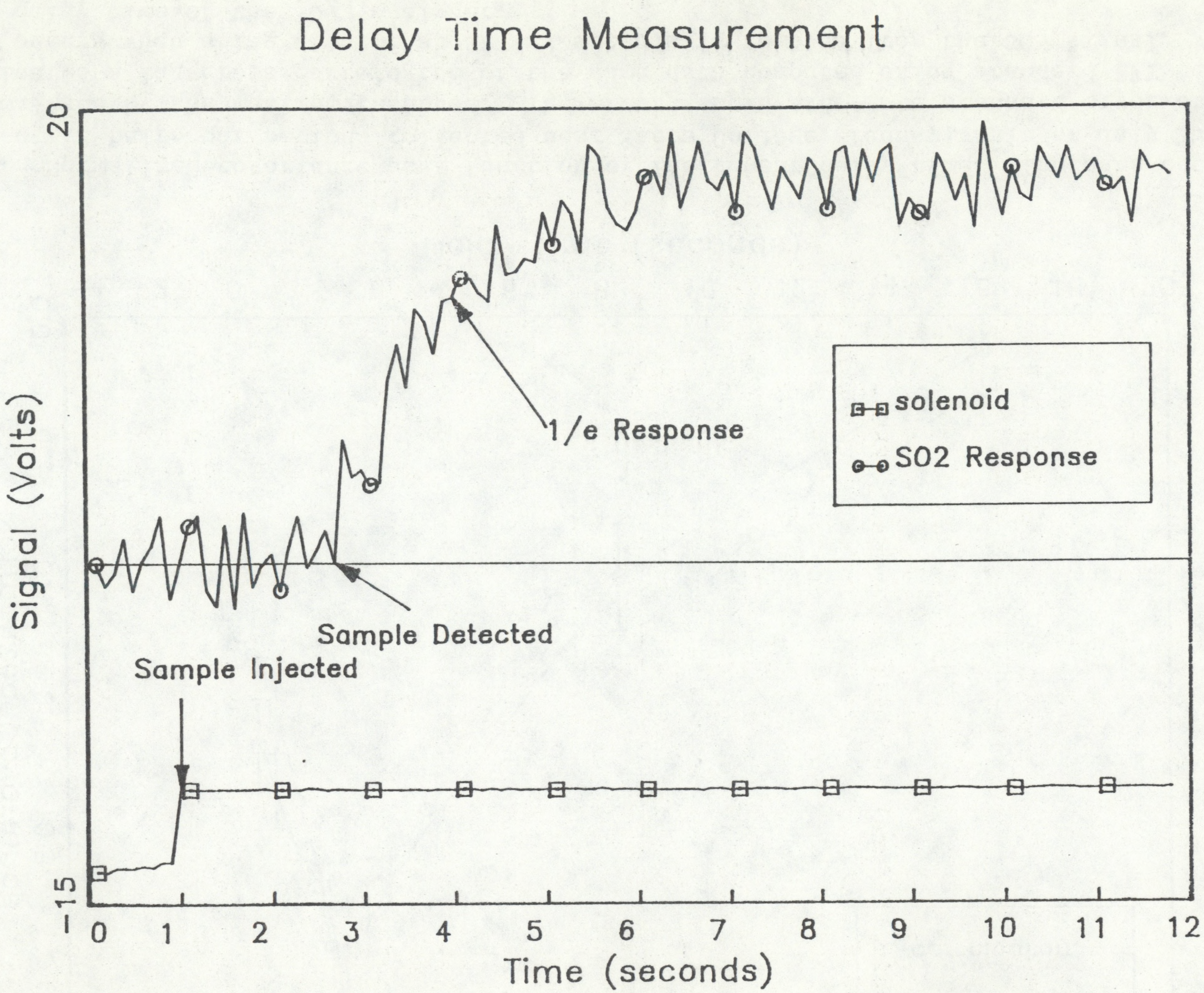

Figure 2.--An example of raw data used to determine the delay and response time of a pollutant sensor. The data consist of a 60 second time series sampled at 10 Hz. Channel 1 (upper line) is the output from a sulfur analyzer. Channel 2 (lower line) is connected to the solenoid which controls injection of a step function change in SO_2 concentration. Signal values are arbitrary and are scaled and offset for clarity. Both the delay and response time can be accurately measured.

Errors due to streamline misalignment are removed with a three-dimensional coordinate rotation of the stress tensor and mean wind vector. This rotation is performed once at the end of each 30-minute averaging period. The rotation angles are determined by the components of the mean wind vector, which is a function of the averaging period and is independent from the mean removal time. The coordinates are rotated such that $\bar{w}$ and $\bar{v}$ are zero, and the third rotation minimizes the $\overline{v'w'}$ covariance. The w' covariances now correspond to a vector normal to the tilted streamline rather than to the geopotential vertical, but angular difference is normally less than 5 degrees, and a cosine correction is ignored because the error for a 10 degree tilt is less than 2%. Coordinate rotation cannot remove Reynolds stress distortion errors due to streamline deformation caused by flow obstruction from measurement towers and instruments, as Wyngaard (1981) points out, but these errors are minimized by use of long mounting booms and instruments which present little obstruction to the flow. Distortion of Reynolds stress due to the surrounding terrain cannot, of course, be considered in the same way.

Figures 3 and 4 show Reynolds stresses calculated with and without coordinate rotation. The data in Fig. 3 were collected at a small airfield near Linkenheim, Federal Republic of Germany (FRG). The site was uniform in the upwind direction for about 800 meters. Measurement height was 7.5 AGL. The data in Fig. 4 were collected above the Black Forest near Freudenstadt, Federal Republic of Germany FRG. The site was very irregular, both in terrain and vegetation. Measurement height was 36.5 meters AGL, and about 12 meters above the estimated zero-displacement plane of the vegetation. The vegetation consisted of a managed forest of silver fir and Norway spruce with an estimated leaf area index of 9. The trees immediately below the measurement tower were 25 meters high, but the average height of trees in the area was estimated to be about 35 meters. The figures show that coordinate rotation improves the calculated stresses at both sites, since one can assume that, near the surface, momentum transfer is always to the surface and, thus, Reynolds stress should always be negative. The interesting point illustrated by these two figures is that coordinate rotation seems as necessary at the nearly ideal site at Linkenheim as at the far more complex site near Freudenstadt, suggesting improper leveling or non-horizontal streamlines at one or both sites.

Figure 5 shows the effect of different mean removal times (filter time constants) on calculated Reynolds stresses and various scalar quantities. The normalized covariances of both momentum and scalars seem to have a broad, flat peak between about 160 seconds and 640 seconds. Sensitivity to mean time removal is lower than expected. The maximum for SO_2 occurs at 160 seconds, while the maxima for heat and momentum occur at 320 seconds. The data suggest that a mean removal time of about 200 seconds would be a good compromise. The sensitivity of covariances to mean removal time may be site-specific and should be examined for each site. These data were collected near State College, Pennsylvania on July 20, 1985.

Eddy correlation has most often been used as a means of measuring sensible and latent heat in studies of evapotranspiration over various vegetated surfaces. Assuming stationarity, total (sensible plus latent) heat flux can be predicted from the relation

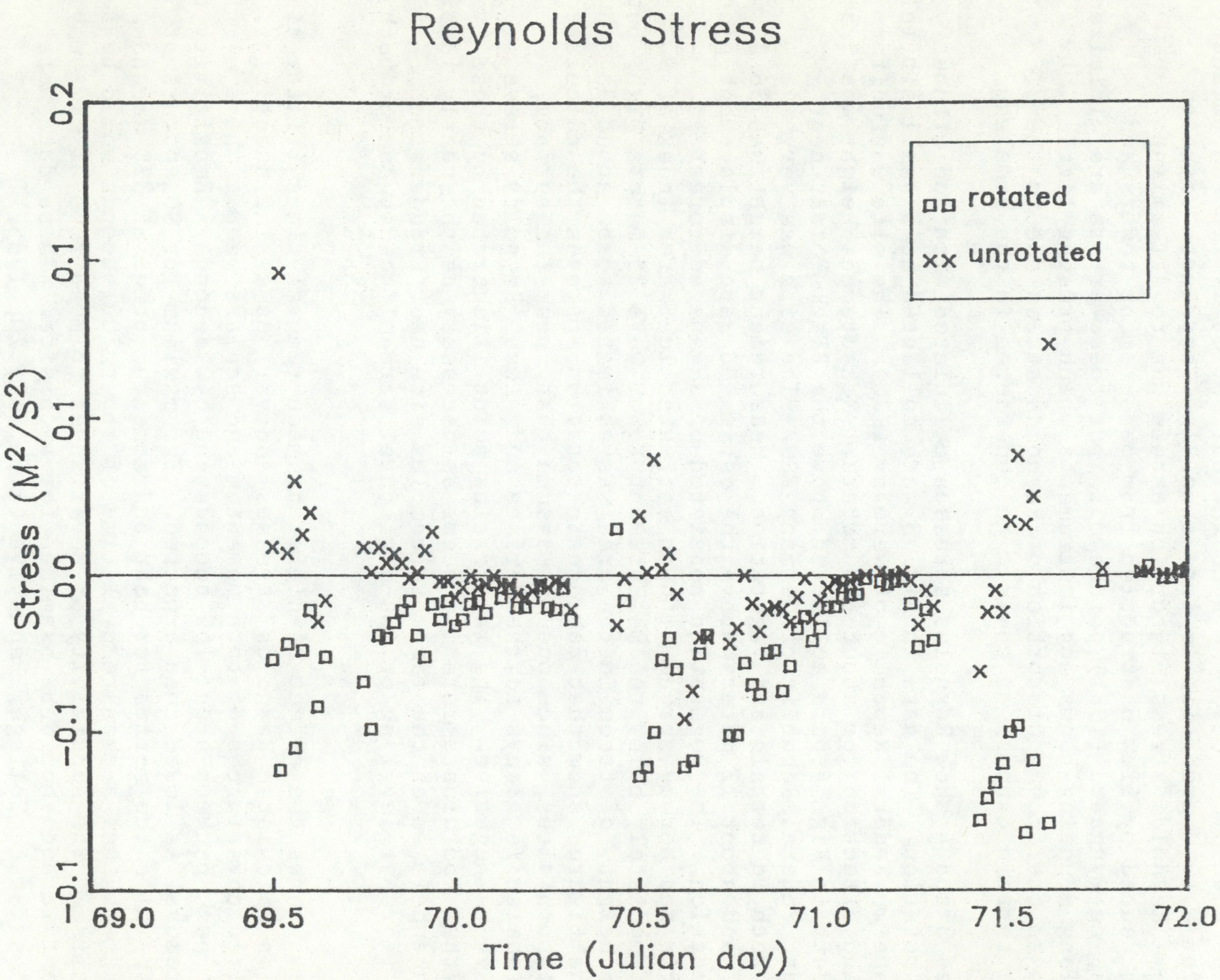

Figure 3.--Reynolds stress before and after coordinate rotation. These data consist of 126 half-hour averaging periods and were collected near Linkenheim, FRG. Stress is in units of m^2/s^2.

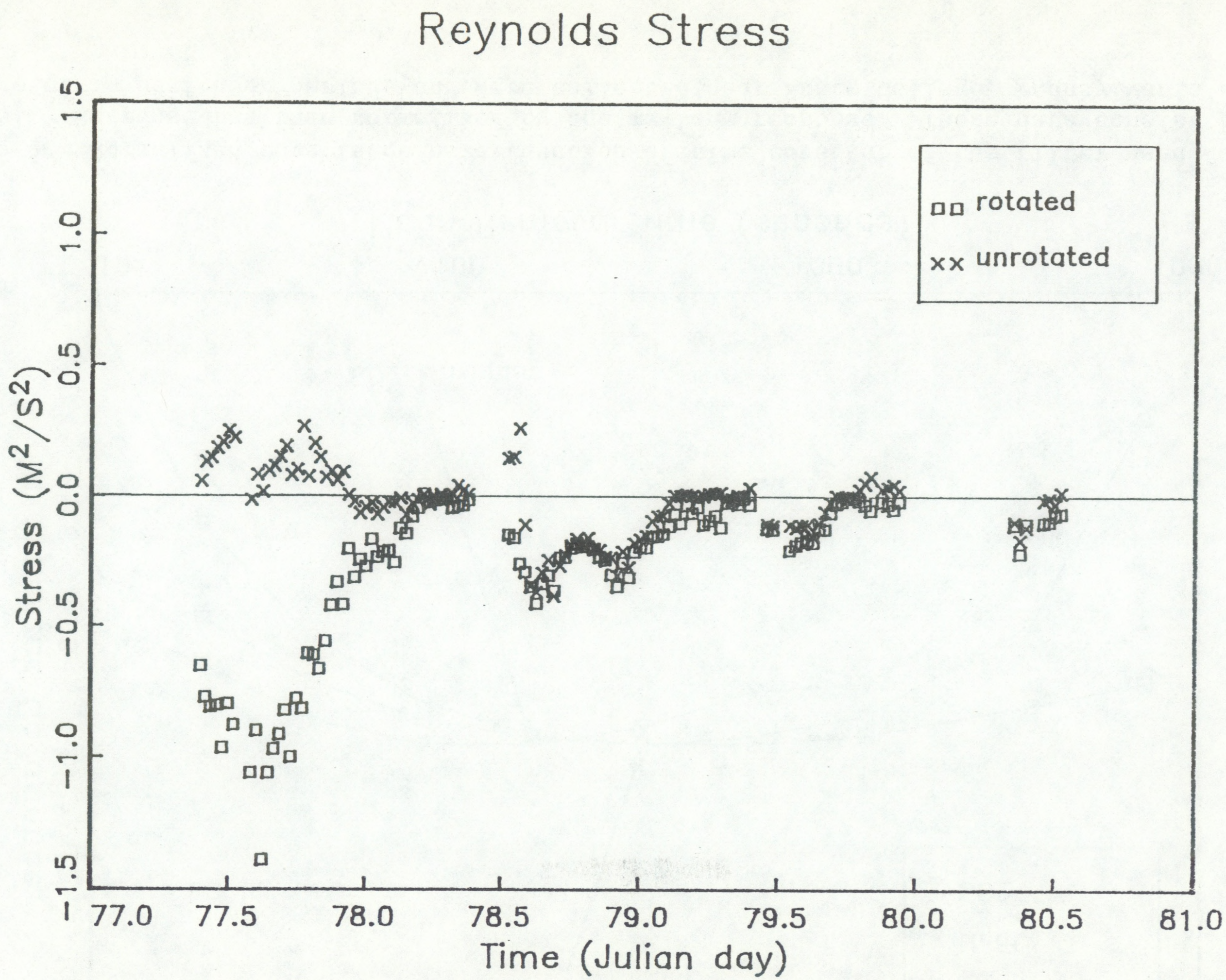

Figure 4.--Reynolds stress before and after coordinate rotation. These data consist of 128 half-hour averaging periods and were collected near Freudenstadt, FRG. Stress is in units of m^2/s^2.

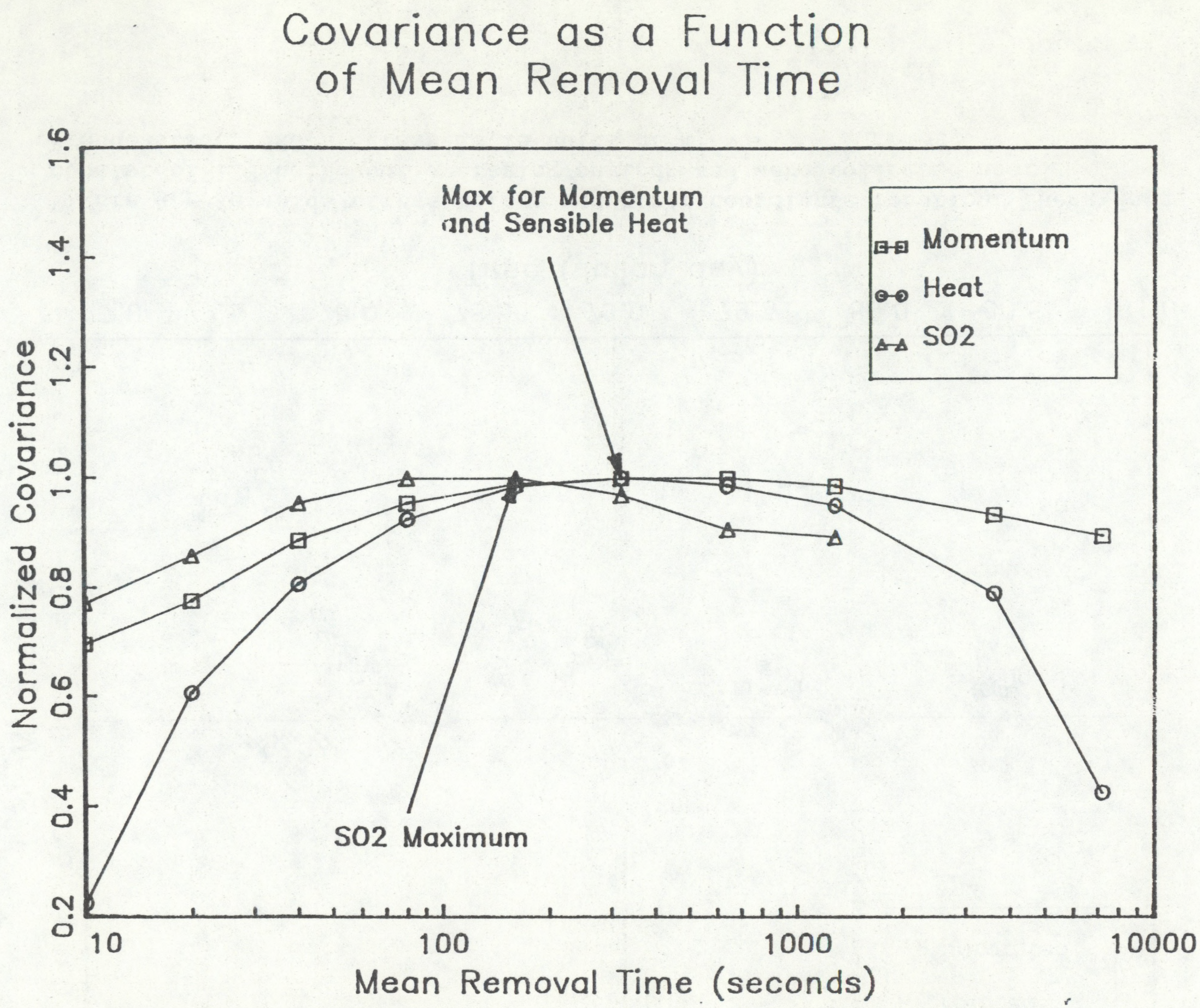

Figure 5.--Normalized covariance as a function of time constant of the filter used for running-mean removal. Response has been normalized by the maximum response. These data consist of an ensemble average of 16 half-hour periods and were collected near State College, Pennsylvania on July 20, 1985.

$$H + LE = R - J \qquad (6)$$

where H is sensible heat, LE is latent heat, R is net radiation, and J is the soil heat flux plus any atmospheric and vegetative heat storage below the operating height of the instruments. R can be measured quite accurately using a net radiometer, and J can be estimated if dT/dt, the time rate of change of air temperature, is known or can be estimated for the elements below the measuring height.

In complex terrain, an adequate test of the overall performance of the eddy correlation system is a comparison of the measured total heat flux with the predicted total heat flux. Figure 6 shows the response of the system as a function of the mean removal time. The quantity plotted is (H+LE)/(R-J). J is estimated from the air temperature and assumes a specific heat capacity of 1.0 and a biomass distribution of 82.6 kilograms per square meter (Tajchman, 1972). Soil heat flux is assumed to be negligible. The atmospheric storage term was calculated following Jarvis and Landsberg (1976). The figure shows a broadly peaked curve with a maximum of .99 occurring for mean removal times between 100 and 500 seconds. These data represent an ensemble average of 17 half-hour periods which occurred on March 23, 1985, and were collected at the Freudenstadt, FRG site previously described. The error bars indicate ± one standard error of the ensemble average.

Figure 7 demonstrates the effect of coordinate rotation on the cumulative heat flux. Coordinate rotation of sensible and latent heat significantly improves energy balance, as shown in Figure 7. The solid line is cumulative net radiation, minus the storage term, and the dotted and dashed lines are the cumulative total heat before and after coordinate rotation, respectively. In this case, the difference between rotated and unrotated total heats is about 30 percent.

Figure 8 is a flow chart of the FLUX program; a detailed description of the program and a listing are included as Appendix A.

4. CONCLUSIONS

Recent advances in small combined data acquisition and data processing systems enable researchers to use increasingly sophisticated and flexible techniques in the field. The combination of sensor lag time removal, three-dimensional coordinate rotation, and "detrending" seems to alleviate eddy correlation site requirements to the extent that evaluation of turbulent transfer is possible at sites previously deemed unsuitable.

Sensitivity to sensor lag time is higher than anticipated, and should always be accounted for. Coordinate rotation seems to significantly improve results in almost all cases and should be used routinely if three-dimensional wind data is available. Sensitivity to mean time removal is lower than expected, with the peak response for SO_2 occurring at 160 seconds and for heat occurring at 320 seconds. This suggests that a mean removal time of about 200 seconds would be ideal.

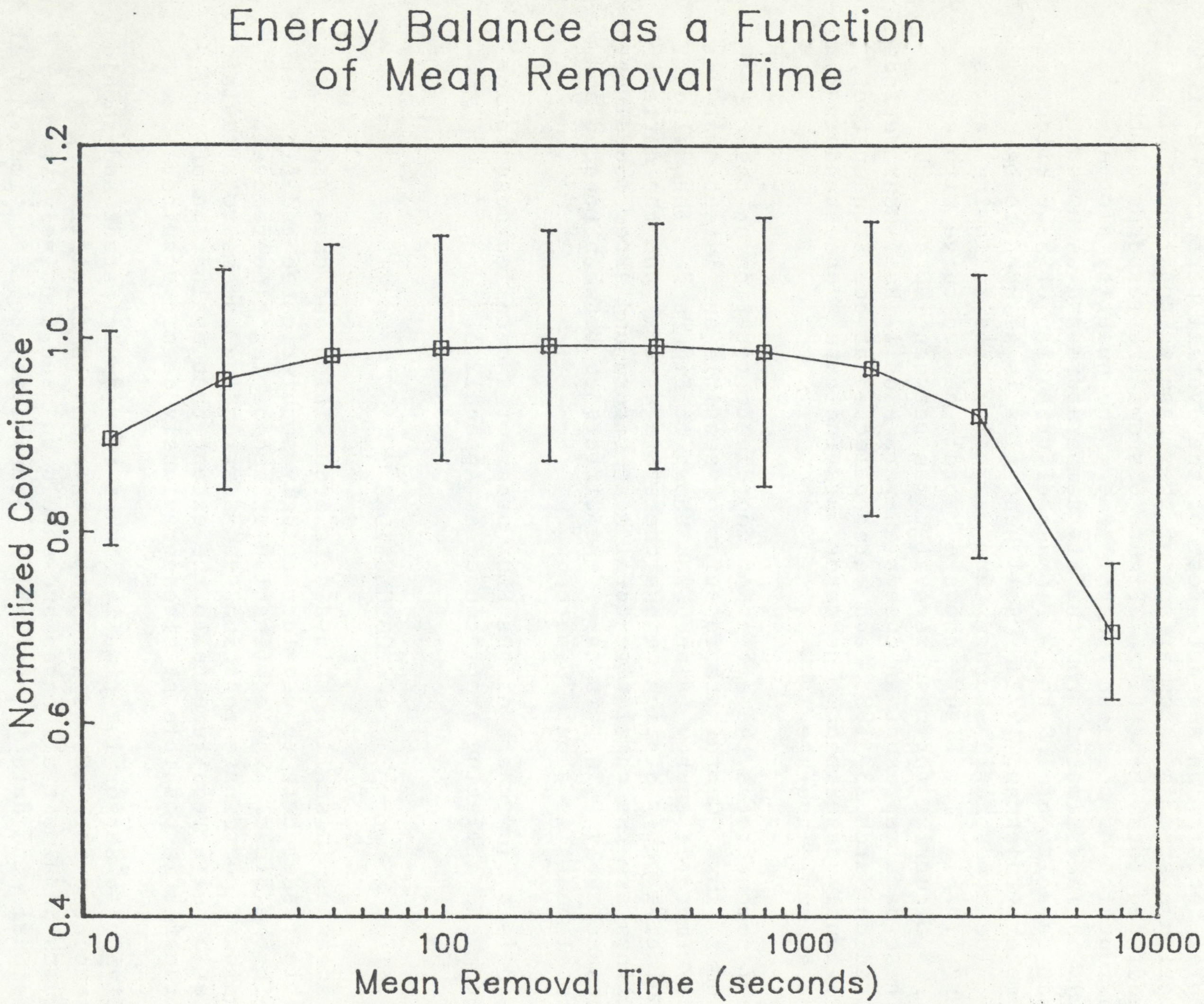

Figure 6.--Normalized energy balance as a function of time constant of the filter used for running-mean removal. These data consist of an ensemble average of 17 half-hour periods and were collected near Freudenstadt, FRG, on March 23, 1985. The error bars indicate ± one standard error of the ensemble average.

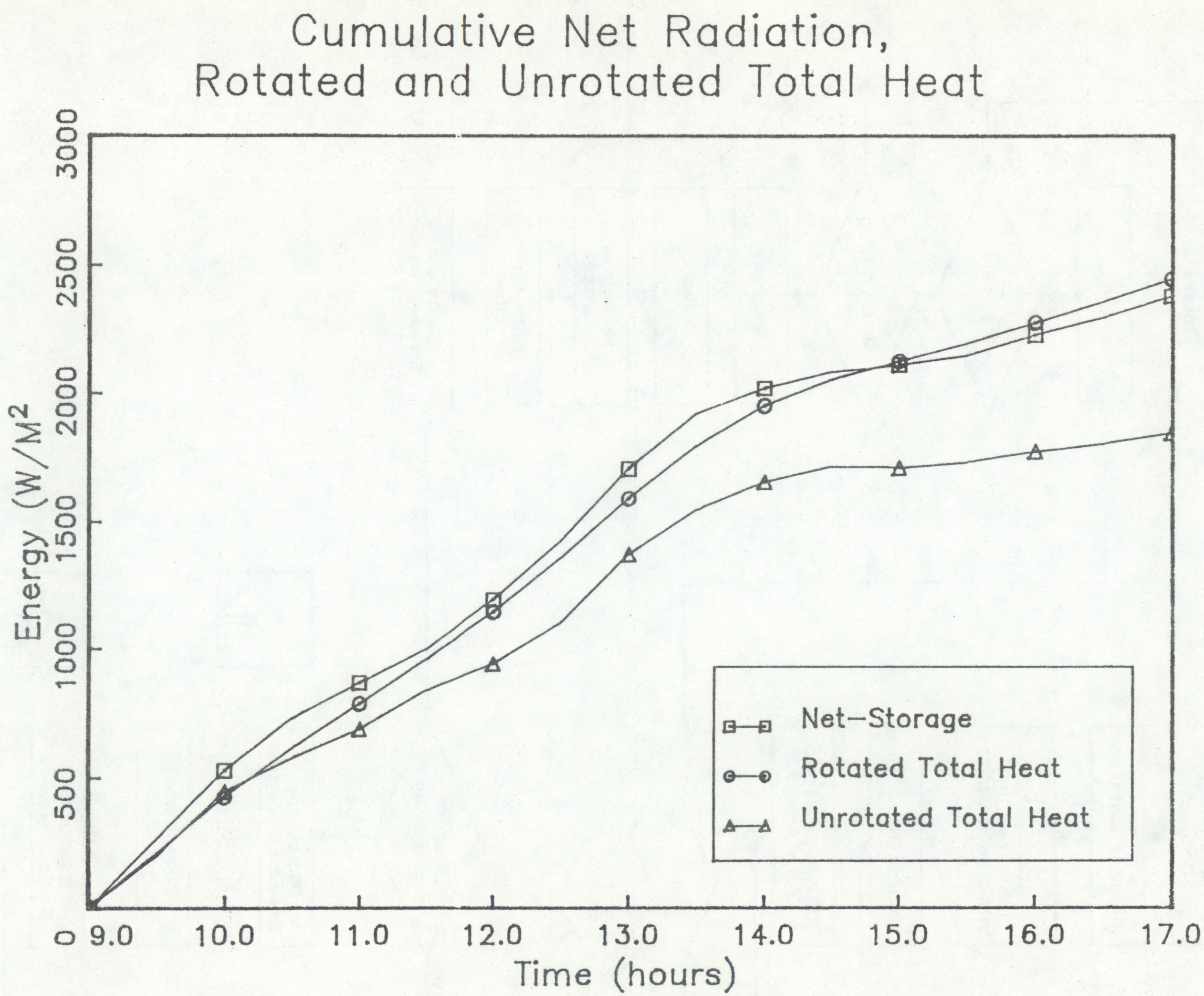

Figure 7.--Cumulative energy components as a function of time.

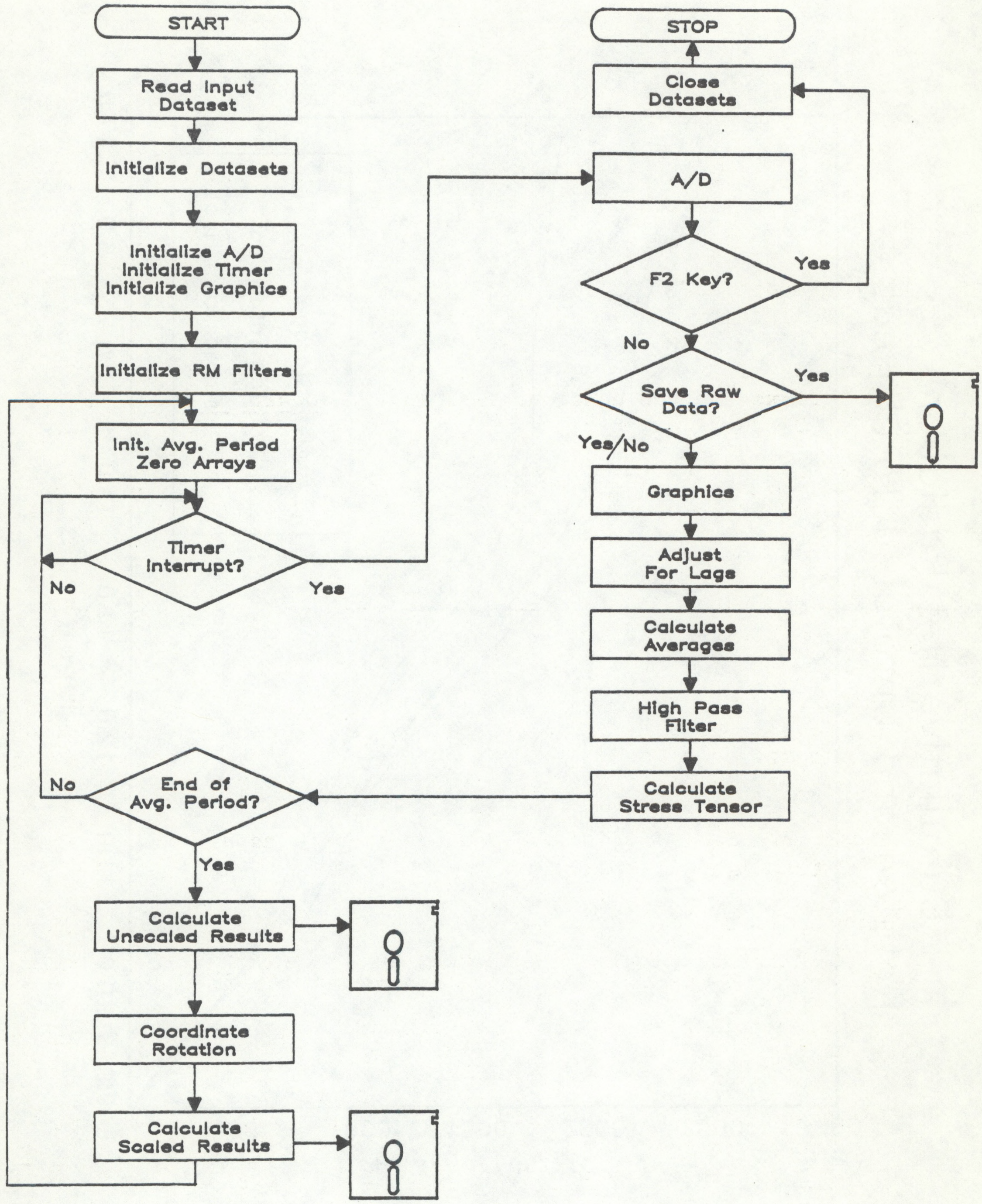

Figure 8.--The flow chart of the FLUX program.

The results produced seem to describe accurately the turbulent fluxes across the flow streamlines in most conditions. Apparently, the fluxes are correctly calculated in a physical sense in any situation where sensor response requirements are adequate, but that the representativeness, or meaningfulness, of the results are a function of the site. Whether these calculations are meaningful must therefore be evaluated by the researcher on a site-by-site basis.

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Appendix A: Programming details.

The program is written in MicroSoft BASIC, The most widely-available language for micro-computers, and compiled using the IBM BASIC compiler. It is designed for a Tecmar eight-channel, 16-bit analog-to-digital (A/D) converter and controller board. To use the program without modification, the computer must be fully-compatible with the IBM-PC. It is a trivial matter, however, to convert the program to run on almost any computer with A/D capabilities. The program has been compiled in FORTRAN, PASCAL, and BASIC for use with various micro- and mini-computers. A complete listing of the current version follows this discussion. The code is available on floppy diskette on an exchange diskette basis.

The maximum scan rate of the program is about 15 Hz on an IBM-PC AT while recording raw data, and about half that on a standard IBM-PC with an 8087 numeric coprocessor. An attempt has been made to keep the program modular, so that various features can be excluded if more speed is necessary. Leaving out the graphics section, for example, almost doubles the maximum scanning speed.

INPUT

Table 1 is a listing of the input data file called "SETUP". It can be modified with any text editor, and contains all the input parameters for the "FLUX" program. One of the many "pop-up" editors has been found to be ideal for SETUP file modification. The averaging time is normally 30 minutes and scan rate is usually 10 Hz. The number of channels, number of instruments, and number to print are usually 8. Boom direction refers to the anemometer orientation, and is used in calculation of the wind direction. The wind direction calculation is specific to the ATDD anemometer which has the u-direction offset 45 degrees to the east of the boom azimuth. This code is contained in line 2400 and can be changed to suit various anemometer configurations.

The "PRINT" switch can be set to zero if no printout is desired or if there is no printer available. The disk label defines the output dataset drive. The input dataset "SETUP" must reside on the default drive. The "RAW DATA" switch determines whether all the data are kept (0 for "NO", 1 for "YES"). We don't recommend keeping raw data if only floppy drives are available. At 10 Hz and 8 channels, 24 hours of data requires about 17 megabytes of disk space, or about one floppy disk per half-hour. There is no way to further decrease the amount of space required, other than to omit recording the time with each scan.

The "SCREEN SCALE" parameter is simply the scaling of the graphic signals for individual channels on the CRT and does not affect the calculations in any way. "INSTRUMENT NAME" is a label for the output of the various instruments.

"LAG TIME" is the measured or calculated delay time for an instrument. We use the program itself to determine lag time by placing a timing mark on some channel at the same time a step function is

Table A1. Sample printout of the input file (SETUP) to the FLUX program.

Avg. time	Scan rate	# of channels	# of inst.	# to prt	Boom dir
1	10	8	8	8	256

Print? (0/1)	Disk for output	Raw Data? (0/1)
1	"C"	0

Scrn. Scale	Instrument name	Lag time	Calib. Coeff.	Offset	Status
5	"W"	0	1	0	0
5	"U"	0	1	0	0
5	"V"	0	1	0	0
120	"T"	0	22.89	1.61	0
80	"Lyman-alpha "	0	10.89	1.265	0
20	"SO2 #1 "	1.6	5.07	4.35	0
100	"Ozone "	1.6	1	.032	0
100	"NO2 "	1.2	134.4	.0181	0

Table A2. Sample printout of the primary output file of the FLUX program.

12:30: 0 07-24-1985 freq. = 9.728 # of scans = 12222

Quantity	Average	Raw Avg.	Covariance	Variance	Vd	Error
W	-0.00	-0.00	0.462968	0.4630	0.0000	1.148825
U	2.28	2.28	-0.133381	2.2192	0.0000	1.402945
V	0.00	0.00	-0.000000	1.3736	0.0000	1.138518
T	2.79	2.79	0.000636	0.0401	0.0002	0.005174
Lyman-alph	2.25	2.25	0.012073	0.0282	0.0054	0.004319
SO2 #1	3.90	5.12	-0.051061	4.2347	-0.0131	2.843272
Ozone	0.27	0.30	0.020346	0.1942	0.0755	0.085234
NO2	25.81	0.21	0.197963	6.5915	0.0077	3.679449

Rey. Str.	U-bar	U*	Cd	Corr.Coef.	Wind Dir.
-0.133	2.28	0.365	0.02575	-0.05113	173.0

WXX MATRIX

1	0.46297	-0.13338	-0.00000	0.00064	0.01207	-0.05106	0.02035	0.19796
2	-0.13338	2.21918	0.07855	0.03493	0.01351	0.11411	-0.08388	-0.15256
3	-0.00000	0.07855	1.37355	0.03480	0.01284	0.11675	-0.08459	-0.16381

applied to the instrument. In the case of gas analyzers, a solenoid is used to inject a detectable gas sample into the sampling manifold of the instrument, while monitoring the solenoid activation circuit with one data channel and the instrument output on another. Examination of the raw data can provide the lag time as well as the instrument response time.

"CALIBRATION COEFFICIENT" and "OFFSET" are what their names imply. The data conversion is found in line 2450 (Y=CAL*(X-OFFSET)). Any other parameter changes require recompilation of the program.

OUTPUT

There are three output data sets. The primary data set is output to three different devices using the same format each time. Table 2 is a sample of the primary output data set. If the print switch is on, this data set is printed. It is always saved to disk using a dataset name determined by the program by combining the year, day of the year and hour when the data set is created. The primary output is also printed to the screen, but this is of little value since it is immediately erased by graphics unless graphics have been disabled. The first line of output contains the ending time and date of the averaging period, the frequency or scan rate and the number of scans included in the averaging period. Next is a line of titles followed by a line of data for each channel. Each data line includes the sensor label, the arithmetic mean scaled by the calibration coefficient and offset, the unscaled arithmetic mean, the scaled covariance, variance, deposition velocity and an error term, which represents the variance of the cross products. Following another line of titles, the Reynolds's stress, mean wind vector magnitude, friction velocity, drag coefficient, correlation coefficient, and wind direction are printed. The unscaled covariance tensor (8x3) follows its title. All values in this dataset, except for the averages of the scalar values, reflect the coordinate rotation.

The second output data set, normally named "OUTPUT.SAV", contains the unscaled, unrotated results of each averaging period. The "SETUP" table is also included each time the program is started. Each record in this data set is either the setup table, preceded by the ASCII characters "SETUP", or the calculated data of the averaging period, preceded by the characters "DATA". This data set is always appended to the existing "OUTPUT.SAV", which allows one data set to contain all the data for any length of time desired. For instance, it might contain all the data for a one week experiment including the setup table for each time the program is restarted. This allows easy recalculation of all the calculated data. An example might be that if calibration coefficients or offsets were found to be in error, they could be edited to the correct values in the recorded setup records and the data reprocessed by an appropriate program. A reprocessing program consists mainly of the output module of the flux program modified to read the "OUTPUT.SAV" dataset rather than write it, and a modification to read the setup tables as they occur in the dataset. We have found this to be an ideal way to reprocess data when the inevitable errors in calibration are discovered.

The fifth output data set is optional and consists of all raw data. It is a random data set since there is no way to write binary 26's (an end-of-file marker in a sequential data set) to a sequential dataset. The BASIC compiler currently being used allows only 32767 records in a random dataset, so a new dataset is started after each averaging period. Each record contains the time in hours, minutes, seconds, and hundredths of a second, followed by the output of the 16-bit A/D for each channel. A section of code beginning at line 4670 allows the flux program to playback the raw data as though it were arriving from the A/D. This is accomplished by removing the comment marks from line 850. This is a convenient way to analyze data for delay times and response times.

The realtime graphics display is also considered a part of the output. The data displayed on the screen is the fluctuating component (*i.e.*, the running mean is already removed) which makes the signal easier to display. If desired, the code can be modified to display the instantaneous fluxes.

PROGRAM MECHANICS

The main program loop will be described in some detail. All additional details are described in the program listing.

The main program loop begins with the loop pointer, NPTR, being incremented, which serves to increment the pointer for the circular buffer, PTR. Control is then transferred to the data acquisition subroutine, which waits for the timer interval, and then sequentially scans 8 channels of data. Maximum scanning speed can be obtained by commenting out line 3680 in the timer routine which will disable the timing loop. The data is plotted by the graphics subroutine and every 10th scan is printed to the screen. Next the array X is loaded with data from the buffer (this is the adjustment for individual instrument delays). All further calculations refer to the X array. The running mean, XA, is calculated and subtracted from X to form the high-pass-filtered data, XP. Finally, the arithmetic mean, XA1, the variance, X2, the error term, WXX2, and the covariance tensor, WXX, are accumulated. The time is checked for the end of the averaging period and control is transferred either back to the beginning of the main loop or to the output routine.

The timer and data acquisition subroutines operate at the board level and will have to be rewritten for use with a data acquisition board other than a Tecmar Labmaster. The timer is used to control scanning and to insure evenly spaced time series data.

PROGRAM LISTING (BASIC LANGUAGE)

```
10 '************************************************************************
20 '*                              FLUX                                     *
30 '*             A GENERAL PURPOSE EDDY-CORRELATION PROGRAM                *
40 '*                                                                       *
50 '*                        ROBERT T. MCMILLEN                             *
60 '*                ATMOSPHERIC AND DIFFUSION DIVISION                     *
70 '*                     AIR RESOURCES LABORATORY                          *
80 '*           NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION             *
90 '*                        POST OFFICE BOX "E"                            *
100 '*                     OAK RIDGE, TENNESSEE 37830                       *
110 '*                                                                      *
120 '*                                                                      *
130 '************************************************************************
140 DEFINT I-P
150 DIM X(16),XA(16),XA1(16),XC(16),WX(16),X2(16),XP(16),VD(16)
160 DIM NLAG(16),LAG(16),Z(16),DEPVEL(16),YOLD(16)
170 DIM DAT(8,200),LAB$(16),ZCH(16),XAT(16),ISTAT(16)
180 DIM D(10,10),CHAN(16),C(5000)
190 DIM WXX(16,3),W(16,3),WXX2(16),CAL(16),XSCAL(16),XOFF(16)
200 DIM XRAN$(16),X$(16)
210   '********************************************************
220 GOSUB 1490     ' INITILIZATION
230 GOSUB 580      ' A/D INITILIZATION
240 GOSUB 3280     ' TIMER INITILIZATION
250 GOSUB 1960     ' FILTER INITIALIZATION
260   '********************************************************
270 ' begin outer loop
280 GOSUB 970     'SET UP GRAPHICS
290 GOSUB 3000    'SET UP LOOP INITIALIZATION
300 '<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
310 ' begin inner loop                                          ^
320 KEY(2) STOP                'close and end                  '^
330 NPTR=NPTR+1                'main pointer                   '^
340 PTR=(NPTR MOD MLAG )       'circular pointer               '^
350 NLP=NLP+1                                                  '^
360 GOSUB 700        ' take data *********************         '^
370 GOSUB 1200       ' plot data *********************         '^
380 IF NLP<=MAXLAG GOTO 310                                     '^
390 FOR J=1 TO NINST
400 N=((PTR-NLAG(J)+MLAG2) MOD MLAG) 'pointer for channel      '^
410 X(J)=DAT(J,N)                    'raw data                 '^
420 XA(J)=X(J)*ALPHA+XA(J)*ALPHA1    'running mean             '^
430 XP(J)=X(J)-XA(J)                 'fluctuating component    '^
440 NEXT J                                                     '^
450 FOR J=1 TO NINST                                           '^
460 XA1(J)=XA1(J)+X(J)               'arithmetic average       '^
470 X2(J)=X2(J)+XP(J)*XP(J)          'variance term            '^
480 WXX2(J)=WXX2(J)+XP(J)*XP(J)*XP(1)*XP(1)  'error term       '^
490 FOR IJ=1 TO 3                                              '^
500 WXX(J,IJ)=WXX(J,IJ)+XP(J)*XP(IJ) 'covariance term          '^
```

```
510 NEXT IJ                                                   '^
520 NEXT J                                                    '^
530 KEY(2) ON                                                 '^
540 IF SEC<>0 THEN 310 ELSE IF MIN MOD ATIM <>0 THEN 310'>>>>>^
550 GOSUB 2130 ' CALL OUTPUT ROUTINE
560 GOTO 260   ' return to loop
570 END
580 '*****************  A/D INITIALIZATION *****************
590 IADDR=1808
600 IGAIN=1
610 IF IGAIN=1 THEN IREG4=128
620 OUT IADDR+4,IREG4
630 OUT IADDR+5,255
640 OUT IADDR+6,0
650 IF INP(IADDR+4)<128 THEN 650
660 X=INP(IADDR+6)
670 OUT IADDR+4,0
680 OUT IADDR+5,0
690 RETURN
700 '***************** Tecmar A/D ROUTINE ***************************
710  XLPO=XLPO+1
720  ''GOSUB 8000:RETURN  ' subroutine to playback raw data
730 GOSUB 3570    ' CHECK TIMER  must be omitted if a/d isn't tecmar
740 OUT IADDR+6,0
750 IF IRAW=0 THEN GOTO 800
760 HRMIN=HRS*100+MIN
770 SECTH=SEC*100+THS
780 LSET HRMIN$=MKI$(HRMIN)
790 LSET SECTH$=MKI$(SECTH)
800 FOR JKL=1 TO NINST
810 IF INP(IADDR+4)<128 THEN 810
820 ILOW=INP(IADDR+5)
830 IHIGH=INP(IADDR+6)
840 IF JKL<NINST THEN OUT IADDR+6,0
850  T=256*IHIGH+ILOW
860 IF  T> 32767 THEN  T= T-65536!
870  DAT(JKL,PTR)= T*XFACTOR             '****** USED FOR 16 BIT TECMAR BOARD
880 IF IRAW=1 THEN LSET XRAN$(JKL)=MKI$(T)      'used to write raw data
890 NEXT JKL
900 DAT(3,PTR)=-DAT(3,PTR)                 'ONLY FOR APPLIED TECHNOLOGY SONICS
910 IF IRAW=1 THEN PUT #3                  '******** use only to store raw data
920 'U=DAT(2,PTR)+DAT(3,PTR)        '********* NEXT 4 LINES ONLY FOR KAIJO-DENKI
930 'V=(DAT(2,PTR)-DAT(3,PTR))/1.732
940 'DAT(2,PTR)=U
950 'DAT(3,PTR)=V
960 RETURN
970  '************** GRAPHICS INITILIZATION *****************
980 IF NCH=0 THEN RETURN
990 SCREEN 0,0,0
1000 FOR I1=1 TO NCH+1
1010 Z(I1)=(180/NCH)*(I1-1/2)+20
1020 NEXT I1
1030 SCREEN 2,,0,0:CLS
```

```
1040 GET (100,0)-(107,199),C
1050 GOSUB 1070
1060 RETURN
1070  '****************** GRAPHICS ***************************
1080 IF NCH=0 THEN RETURN
1090 ' begin outer loop
1100 XOLD=0
1110 PUT (0,0),C,PSET
1120 X=0
1130 FOR I1=1 TO NCH
1140 LINE (550,Z(I1))-(600,Z(I1))
1150 IN=Z(I1)*(25/200)
1160 LOCATE IN,78
1170 PRINT MID$(LAB$(I1),1,2);
1180 NEXT I1
1190 RETURN
1200  '****************** GRAPHICS ***************************
1210 IF NCH=0 THEN RETURN
1220 ' begin inner loop
1230 NL=NL+1
1240  X=X+1
1250  IF X MOD 8 =0 THEN PUT (X,0),C,PSET
1260  IF X MOD 10 =0 THEN LOCATE 25,1:PRINT HRS;MIN;SEC;:LOCATE  1,1:
       FOR I1=1 TO NPRT:PRINT USING " ##.###";DAT(I1,PTR);:NEXT I1  '
       used for digital screen display of data
1270  FOR I1=1 TO NCH
1280  YN = -(DAT(ZCH(I1),PTR)-XA(ZCH(I1)))*XSCAL(I1)+Z(I1)
1290  LINE (XOLD,YOLD(I1))-(X,YN)         ' PLOT DATA
1300  YOLD(I1)=YN                         ' SAVE POINT
1310  NEXT I1
1320  XOLD=X
1330 IF X>630 THEN GOSUB 1070
1340 RETURN
1350 END
1360  '****************** CLOSE AND END ***********************
1370 ' key 2 subroutine
1380 PRINT "closing and ending"
1390 CLOSE #1:CLOSE #3
1400 END
1410  '******************* ERROR ROUTINE **********************
1420  OPEN "ERROR.LOG" FOR APPEND AS #2
1430  PRINT ERR,ERL
1440  PRINT #2,ERR,ERL
1450  PRINT #2,XOLD,YOLD(I),Y,YN,I
1460  CLOSE #2
1470 IF ERR=24 OR ERR=25 THEN IPRT=0
1480 RESUME  NEXT
1490  '****************** INITIALIZATION ROUTINE **************
1500 CLS
1510 KEY OFF
1520 KEY (2) ON
1530 ON KEY(2) GOSUB 1370
1540 TIMCONST=200                      'SET TIME CONSTANT FOR DIGITAL FILTER
```

```
1550 GOSUB 4360                    'GO READ SETUP FILE
1560 IF IPRT=1 THEN LPRINT CHR$(27)+"C"+CHR$(22);'set formlength to 22 lines
1570 MON=VAL(MID$(DATE$,1,2))
1580 DAY=VAL(MID$(DATE$,4,2))
1590 YER=VAL(MID$(DATE$,7,4))
1600 JULIAN=INT(30.57*MON)+DAY-30   'CALCULATE JULIAN DATE
1610 IF MON>2 AND INT(YER/4)=YER/4 THEN JULIAN=JULIAN-1 ELSE JULIAN=JULIAN-2
1620 PRINT "JULIAN DATE IS ";JULIAN
1630 DSNAME$="F"+MID$(DATE$,9,2)+STR$(JULIAN)+MID$(TIME$,1,2)
1640 N=INSTR(1,DSNAM$," ")
1650 IF N<>0 THEN DSNAM$=MID$(DSNAM$,1,N-1)+MID$(DSNAM$,N+1,LEN(DSNAM$)-N)
1660 N=INSTR(1,DSNAME$," ")
1670 IF N<>0 THEN DSNAME$=MID$(DSNAME$,1,N-1)+MID$(DSNAME$,N+1,LEN(DSNAME$)-N)
1680 DSNAME1$=DSK$+":"+DSNAME$+".DAT"
1690 DSNAME2$=DSK$+":OUTPUT.SAV"
1700 PRINT "DATASET NAME IS ";DSNAME1$
1710 OPEN DSNAME1$ FOR APPEND AS #1
1720 CLOSE #1
1730 OPEN DSNAME2$ FOR APPEND AS #2
1740 CLOSE #2
1750 IF IRAW=1 THEN GOSUB 2870
1760 GOSUB 4490
1770 ITIM=100/HZ
1780 RMEAN=1
1790 MLAG=200
1800 MLAG2=MLAG*5
1810 IGAIN=1
1820 XFACTOR=1/(IGAIN*3276.8)      ' A/D CALIBRATION FOR 16 BITS
1830 'XFACTOR=1/(IGAIN*204.8)      ' A/D CALIBRATION FOR 12 BITS
1840 PI=3.1415927#
1850 RADTDEG=360/(2*PI)
1860 GOSUB 590
1870 FOR I=1 TO NPRT
1880 NLAG(I)=HZ*LAG(I)
1890 IF NLAG(I)>MLAG THEN NLAG(I)=MLAG
1900 IF NLAG(I)>MAXLAG THEN MAXLAG=NLAG(I)
1910 NEXT I
1920 FOR I=1 TO NCH
1930 ZCH(I)=I
1940 NEXT I
1950 RETURN
1960  '******************** INITIALIZE R. MEANS *****************
1970 GOSUB 970       '********* initialize graphics
1980 PTR=1
1990 NLP1=1800
2000 FOR I=1 TO NLP1
2010 ALPHA=1/I
2020 ALPHA1=1-ALPHA
2030 GOSUB 700
2040 FOR J=1 TO NINST
2050 XA(J)=XA(J)*ALPHA1+DAT(J,1)*ALPHA
2060 NEXT J
2070 GOSUB 1200     '********* plot      graphics
```

```
2080 NEXT I
2090 FOR I=1 TO NINST
2100 PRINT "avg";I;XA(I)
2110 NEXT I
2120 RETURN
2130  '******************** OUTPUT MODULE ***********************
2140 IF IPRT=1 THEN LPRINT CHR$(27)+"C"+CHR$(22);'set formlength to 22 lines
2150 SCREEN 0,0,0
2160 OFFLIN$="**************************************************************"
2170 NINTERVALS=NINTERVALS+1
2180 SEC1=JULIAN*86400!+HRS*3600+MIN*60+SEC+THS/100
2190 IF MIN=60 THEN MIN=0:HRS=HRS+1
2200 IF HRS=24 THEN HRS=0:DAY=DAY+1:JULIAN=JULIAN+1
2210 TIM$=RIGHT$(STR$(HRS),2)+":"+RIGHT$(STR$(MIN),2)+":"+RIGHT$(STR$(SEC),2)
2220 XSEC=SEC1-STSEC
2230 CALHZ=NLP/XSEC
2240 OPEN DSNAME2$ FOR APPEND AS #2
2250 PRINT #2,"DATA ";
2260 PRINT #2,TIM$;DATE$;CALHZ;NLP;ALPHA;ISYSTAT;
2270 FOR I=1 TO NINST
2280 XA1(I)=XA1(I)/NLP
2290 WXX2(I)=WXX2(I)/NLP
2300 X2(I)=X2(I)/NLP
2310 PRINT #2,XA1(I);XA(I);X2(I);WXX2(I);ISTAT(I);
2320 FOR J=1 TO 3
2330 WXX(I,J)=WXX(I,J)/NLP
2340 PRINT #2,WXX(I,J);
2350 NEXT J
2360 NEXT I
2370 PRINT #2,"":CLOSE #2
2380 WNDDIR=ATN(XA1(3)/XA1(2))*RADTDEG
2390 IF XA1(2)<0 THEN WNDDIR=WNDDIR+180
2400 WNDDIR=BOOMAZIM-WNDDIR+45
2410 WNDDIR=(WNDDIR+360) MOD 360
2420 GOSUB 3720    '   covariance rotation
2430 FOR I=1 TO NINST
2440 XAT(I)=XA1(I)
2450 XA1(I)=CAL(I)*(XA1(I)-XOFF(I))
2460 WXX2(I)=CAL(1)^2*CAL(I)^2*WXX2(I)
2470 X2(I)=CAL(I)^2*X2(I)
2480 FOR J=1 TO 3
2490 WXX(I,J)=CAL(I)*CAL(J)*WXX(I,J)
2500 NEXT J
2510 IF I>3 AND XA1(I)<> 0 THEN DEPVEL(I)=WXX(I,1)/XA1(I)
2520 NEXT I
2530 R=WXX(1,2):U=XA1(2):V=0
2540 U2=ABS(R)^.5
2550 C8=(U2/U)^2
2560 C9=R/(X2(2)^2+X2(3)^2)^.5
2570 TITO$=TIM$+"  "+DATE$
2580 TITO$=TITO$+"  freq. = "+MID$(STR$(CALHZ),1,6)+"  # of scans = "+STR$(NLP)
2590 IMAGE$="\         \ ###.#### ###.#### ###.###### ###.#### ##.####
##.######"
```

```
2600 IMAGE2$="###.###    ####.##    ####.###    ##.#####    ##.#####    #####.#"
2610 TIT$= "Quantity      Average     Raw Avg.     Covariance     Variance       Vd  Erro
2620 OPEN DSNAME1$ FOR APPEND AS #1:GOSUB 2660:CLOSE #1
2630 'OPEN "o",#1,"con:":GOSUB 2670:CLOSE #1
2640 IF IPRT=1 THEN OPEN "o",#1,"lpt1:":GOSUB 2660:PRINT #1,CHR$(12):CLOSE #1
2650 RETURN
2660 '***************** print subroutine *********************************
2670 PRINT #1,TITO$
2680 PRINT #1,TIT$
2690 FOR I=1 TO NINST
2700 IF ISTAT(I)=1 THEN PRINT OFF$:PRINT #1,OFF$:GOTO 2720
2710 PRINT #1,USING IMAGE$;LAB$(I),XA1(I),XAT(I),WXX(I,1),X2(I),DEPVEL(I),WXX2(I)
2720 NEXT I
2730 PRINT #1,"Rey. Str.    U-bar      U*       Cd       Corr.Coef.   Wind Dir."
2740 PRINT #1,USING IMAGE2$;R,U,U2,C8,C9,WNDDIR
2750 PRINT #1,"WXX MATRIX"
2760 FOR J=1 TO 3
2770 PRINT #1,J;
2780 FOR I=1 TO 8
2790 PRINT #1, USING "##.##### ";WXX(I,J);
2800 NEXT I
2810 PRINT #1,""
2820 NEXT J
2830 RETURN
2840 '**************** raw data setup    N *********************
2850 IF IRAW=0 THEN RETURN
2860 CLOSE #3
2870 '**************** raw data setup initial entry point *****
2880 DSNAM$="F"+MID$(DATE$,4,2)+MID$(TIME$,1,2)+MID$(TIME$,4,2)+".raw"
2890 N=INSTR(1,DSNAM$," ")
2900 IF N<>0 THEN DSNAM$=MID$(DSNAM$,1,N-1)+MID$(DSNAM$,N+1,LEN(DSNAM$)-N)
2910 DSNAME3$=DSK$+":"+DSNAM$
2920 OPEN "r",#3,DSNAME3$,22  'only for raw data
2930 FIELD #3,2 AS HRMIN$,2 AS SECTH$
2940 OFFSET=4
2950 FOR I=1 TO 8
2960 FIELD #3,OFFSET AS DUMMY$,2 AS XRAN$(I)
2970 OFFSET=OFFSET+2
2980 NEXT I
2990 RETURN
3000 '**************** LOOP INITIALIZATION ********************
3010 GOSUB 2840
3020 MAXLAG=0
3030 FOR I=1 TO NINST
3040 NLAG(I)=HZ*LAG(I)
3050 IF NLAG(I)>MAXLAG THEN MAXLAG=NLAG(I)
3060 NEXT I
3070 FOR I=1 TO NINST
3080 NLAG(I)=MAXLAG-NLAG(I)
3090 NEXT I
3100 ALPHA=1/(TIMCONST*HZ)
3110 ALPHA1=1-ALPHA
3120 ON ERROR GOTO 1410
```

```
3130 NLP=0
3140 ISYSTAT=0
3150 FOR I=1 TO NINST
3160 XA1(I)=0
3170 WX(I)=0
3180 WXX2(I)=0
3190 X2(I)=0
3200 FOR J=1 TO 3
3210 WXX(I,J)=0
3220 NEXT J
3230 NEXT I
3240 NLP=0
3250 NPTR=0
3260 STSEC=JULIAN*86400!+HRS*3600*MIN*60+SEC+THS/100
3270 RETURN
3280  '****************** INITIALIZE TIMER ********************
3290 IADDR=1808
3300 DEF FNRCONV(X)=X+6*INT(X/10)
3310 DEF FNCONV(X)=X-6*INT(X/16)
3320 SEC=VAL(MID$(TIME$,7,2))
3330 HRS=VAL(MID$(TIME$,1,2))
3340 MIN=VAL(MID$(TIME$,4,2))
3350 OUT IADDR+9,23
3360 OUT IADDR+8,3
3370 OUT IADDR+8,129
3380 OUT IADDR+9,1
3390 OUT IADDR+8,57
3400 OUT IADDR+8,31
3410 OUT IADDR+8,0
3420 OUT IADDR+8,FNRCONV(SEC)
3430 OUT IADDR+9,2
3440 OUT IADDR+8,57
3450 OUT IADDR+8,16
3460 OUT IADDR+8,FNRCONV(MIN)
3470 OUT IADDR+8,FNRCONV(HRS)
3480 OUT IADDR+9,71
3490 OUT IADDR+9,9
3500 OUT IADDR+8,0
3510 OUT IADDR+8,0
3520 OUT IADDR+9,10
3530 OUT IADDR+8,0
3540 OUT IADDR+8,0
3550 OUT IADDR+9,39
3560 RETURN
3570  '*********************** TIMER ***************************
3580 OUT IADDR+9,163
3590 OUT IADDR+9,17
3600 THS=FNCONV(INP(IADDR+8))
3610 SEC=FNCONV(INP(IADDR+8))
3620 IF THS+SEC=0 THEN OUT IADDR+9,162
3630 OUT IADDR+9,18
3640 MIN=FNCONV(INP(IADDR+8))
3650 HRS=FNCONV(INP(IADDR+8))
```

```
3660 IF THS+SEC=0 THEN MIN=MIN+1
3670 ITH=SEC*100+THS
3680 IF ITH MOD ITIM=0 THEN RETURN ELSE 3570
3690 RETURN
3700 STOP
3710 '********************** TIMER ****************************
3720 '*************** COORDINATE ROTATION - TWO ANGLE    **********
3730 DIM WXXB(8,8),WXXC(8,8)
3740 WS=(XA1(2)^2+XA1(3)^2)^.5
3750 TW=(XA1(1)^2+XA1(2)^2+XA1(3)^2)^.5
3760 ETA=ATN(XA1(3)/XA1(2))
3770 THETA=(XA1(1)/WS)
3780 CE=XA1(2)/WS          'COS(ETA)
3790 SE=XA1(3)/WS          'SIN(ETA)
3800 CT=WS/TW             'COS(THETA)
3810 ST=XA1(1)/TW          'SIN(THETA)
3820 UB=XA1(2)*CT*CE+XA1(3)*CT*SE+XA1(1)*ST
3830 VB=XA1(3)*CE-XA1(2)*SE
3840 WB=XA1(1)*CT-XA1(2)*ST*CE-XA1(3)*ST*SE
3850 WXXB(2,2)=WXX(2,2)*CT^2*CE^2+WXX(3,3)*CT^2*SE^2+WXX(1,1)*ST^2+
      2*WXX(2,3)*CT^2*CE*SE+2*WXX(1,2)*CT*ST*CE+2*WXX(1,3)*CT*ST*SE
3860 X2(2)=WXXB(2,2)
3870 WXXB(3,3)=WXX(3,3)*CE^2+WXX(2,2)*SE^2-2*WXX(2,3)*CE*SE
3880 X2(3)=WXXB(3,3)
3890 WXXB(1,1)=WXX(1,1)*CT^2+WXX(2,2)*ST^2*CE^2+WXX(3,3)*ST^2*SE^2+
      2*WXX(1,2)*CT*ST*CE+2*WXX(1,3)*CT*ST*SE+2*WXX(2,3)*ST^2*CE*SE
3900 X2(1)=WXXB(1,1)
3910 WXXB(1,2)=WXX(1,2)*CE*(CT^2-ST^2)-2*WXX(2,3)*CT*ST*SE*CE+
      WXX(1,3)*SE*(CT^2-ST^2)-WXX(2,2)*CT*ST*CE^2-
      WXX(3,3)*CT*ST*SE^2+WXX(1,1)*CT*ST
3920 WXXB(2,1)=WXXB(1,2)
3930 WXXB(2,3)=WXX(2,3)*CT*(CE^2-SE^2)+WXX(1,3)*ST*SE -WXX(1,2)*ST*SE-
      WXX(2,2)*CT*CE*SE+WXX(3,3)*CT*CE*SE
3940 WXXB(3,2)=WXXB(2,3)
3950 WXXB(1,3)=WXX(1,3)*CT*CE-WXX(1,2)*CT*SE-WXX(2,3)*ST*(CE^2-SE^2)+
      WXX(2,2)*ST*CE*SE-WXX(3,3)*ST*CE*SE
3960 WXXB(3,1)=WXXB(1,3)
3970 FOR J=4 TO 8
3980 WXXB(J,2)=WXX(J,2)*CT*CE+WXX(J,3)*CT*SE+WXX(J,1)*ST
3990 WXXB(J,3)=WXX(J,3)*CE-WXX(J,2)*SE
4000 WXXB(J,1)=WXX(J,1)*CT-WXX(J,2)*ST*SE-WXX(J,3)*ST*SE
4010 NEXT J
4020 FOR I=1 TO 8
4030 FOR J=1 TO 3                        ' SIN(BETA)
4040 WXX(I,J)=WXXB(I,J)
4050 NEXT J
4060 NEXT I
4070 XA1(1)=WB
4080 XA1(2)=UB
4090 XA1(3)=VB
4100 'RETURN
4110 '*************** COORDINATE ROTATION - 3RD ROTATION **********
4120 K!=WXXB(1,3)/(WXXB(3,3)-WXXB(1,1))
```

```
4130 CB=1                                    ' COS(BETA)
4140 SB=0                                    ' SIN(BETA)
4150 OSB!=SB:OCB!=CB
4160 SB=(-CB+(CB^2+8*K!^2)^.5)/(4*K!)
4170 CB=(1-SB^2)^.5
4180 IF ABS(OSB!-SB)>.00001 OR ABS(OCB!-CB)>.00001 THEN GOTO 4150
4190 'IF IPRT=1 THEN LPRINT "SB";SB;"CB";CB;"beta";ATN(SB/CB)*RADTDEG
4200 WXX(3,3)=WXXB(3,3)*CB^2+2*WXXB(1,3)*CB*SB+WXXB(1,1)*SB^2
4210 WXX(1,1)=WXXB(1,1)*CB^2-2*WXXB(1,3)*CB*SB+WXXB(3,3)*SB^2
4220 WXX(1,2)=WXXB(1,2)*CB-WXXB(2,3)*SB
4230 WXX(2,1)=WXX(1,2)
4240 WXX(2,3)=WXXB(2,3)*CB+WXXB(1,2)*SB
4250 WXX(3,2)=WXX(2,3)
4260 WXX(1,3)=WXXB(1,3)*(CB^2-SB^2)+WXXB(1,1)*CB*SB-WXXB(3,3)*CB*SB
4270 WXX(3,1)=WXX(1,3)
4280 WXX(2,2)=WXXB(2,2)
4290 FOR J=4 TO 8
4300 WXX(J,2)=WXXB(J,2)
4310 WXX(J,3)=WXXB(J,3)*CB+WXXB(J,1)*SB
4320 WXX(J,1)=WXXB(J,1)*CB-WXXB(J,3)*SB
4330 NEXT J
4340 RETURN
4350  '**************** COORDINATE ROTATION - END *******************
4360  '********************** rsetup ***************************
4370 DSSET$="setup"
4380 OPEN "i",#1,DSSET$
4390 LINE INPUT #1,A$
4400 INPUT #1,ATIM,HZ,NCH,NINST,NPRT,BOOMAZIM
4410 LINE INPUT #1,A$
4420 INPUT #1,IPRT,DSK$,IRAW
4430 LINE INPUT #1,A$
4440 FOR I=1 TO NPRT
4450 INPUT #1,XSCAL(I),LAB$(I),LAG(I),CAL(I),XOFF(I),ISTAT(I)
4460 NEXT I
4470 CLOSE #1
4480 RETURN
4490 '*********
4500 OPEN "i",#1,DSSET$
4510 OPEN DSNAME2$ FOR APPEND AS #2
4520 PRINT #2,"SETUP  ";
4530 FOR I=1 TO 13
4540 LINE INPUT #1,A$
4550 IF IPRT=1 THEN LPRINT A$
4560 NEXT I
4570 IF IPRT=1 THEN LPRINT DSNAME1$
4580 PRINT #2,ATIM;HZ;NCH;NINST;NPRT;BOOMAZIM;IPRT;DSK$;IRAW;
4590 FOR I=1 TO NPRT
4600 PRINT #2,LAB$(I);LAG(I);CAL(I);XOFF(I);ISTAT(I);
4610 NEXT I
4620 PRINT #2," "
4630 CLOSE #1
4640 CLOSE #2
4650 IF IPRT=1 THEN LPRINT CHR$(12);
```

```
4660 RETURN
4670  '*************** playback old data        ********************
4680 IF IDUMDAT=0 THEN INPUT "Enter name of data set ",A$:OPEN "I",#4,A$:IDUMDAT=1
4690    FIELD #4,2 AS HRMIN$,2 AS SECTH$
4700    OFFSET=4
4710    FOR I=1 TO 8
4720    FIELD #4,OFFSET AS DUMMY$,2 AS X$(I)
4730    OFFSET=OFFSET+2
4740    NEXT I
4750 FOR I=1 TO 1000
4760 LOCATE 5,5
4770 GET #4,I
4780 HRMIN=CVI(HRMIN$)
4790 SECTH=CVI(SECTH$)
4800 PRINT I,HRMIN;SECTH
4810 LOCATE 10,5
4820 FOR J=1 TO 8
4830 X=CVI(X$(J))
4840 X=X/204.7
4850 'PRINT USING "###.### ";X;
4860 DAT(J,PTR)=X
4870 NEXT J
4880 'PRINT
4890 NEXT I
4900 RETURN
```