

BLLAST – uniform processing of Eddy-Covariance data

Student report

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1 Introduction

In the summer of 2011 a large measurement campaign was conducted in the south of France, near the Pyrenees' mountain range – the Boundary Layer Late Afternoon and Sunset Turbulence (BLLAST) experiment (Pino et al. 2011). This experiment brought together roughly forty scientists from about ten different countries to study the transition for one month.

The aim of this experiment was to gain more knowledge about the transitory part of the day. In particular, the focus was on the transition from an unstable regime during the day to a stable regime in the night. More details on the BLLAST experiment will be given in chapter 2.

The BLLAST measurement campaign was hosted by the Centre de Recherches Atmospheriques in Lannemezan, France. On and around the grounds of this centre, several surface stations and remote sensing devices were set up and several airborne measurement platforms were deployed. Involved in BLLAST was an international group of boundary layer researchers, bringing a diverse set of (sometimes experimental) measurement techniques. Several groups from France, Spain, Germany, The Netherlands, Switzerland, Italy, Norway and the United States brought instruments.

Apart from ground based measurements like eddy covariance stations, radiation measurements and sky monitoring, many remote sensing instruments were used like SODARs, LIDARs, vertical radars (VHF and UHF), IR-camera's, scintillometers and data from continuous remote sensing platforms, like satellites. There were also a large number of air-borne platforms.

Some raw data, like eddy covariance or scintillometer data, cannot be used directly, but need to be processed in order to obtain very useful derived quantities like fluxes, covariances and flow properties. To be able to make an intercomparison between the fluxes at the different EC-stations, all data should be processed in the same way. This avoids differences between the stations related to the processing itself. This report will focus on this uniform processing of the EC stations.

Firstly, the experiment itself will be briefly introduced. This includes the aims, location of the experiment and the different measuring techniques and measuring platforms. After that, the set-up of the EC-stations and instruments will be explained. The data from these stations will be uniformly processed by the EC-pack program.

The EC-pack processing program will be explained, including the data-flow. This starts with the raw data, then two pre-processing programs, and finally the program which calculates the fluxes. The input and output of these programs will be discussed as well as the settings and choices made during the processing. We will elaborate on how specific input data for the program has been obtained. Some intermediate results will also be shown, as these results influence subsequent settings for the EC-pack program.

Several output files are generated during the processing. These different products will be explained, including the kind of data these files contain. Some results of the processing will also be shown. Conclusions will follow, preceded by a few recommendations concerning choices for processing, and lastly the results.

2 BLLAST (Boundary Layer Late Afternoon and Sunset Turbulence)

The BLLAST experiment was designed to gain more understanding about the late afternoon and sunset transition. During this period, there is a regime change from unstable daytime conditions to a stable nocturnal boundary layer. The most important objectives of BLLAST are summarised here:

- During the day, the surface is heated by the sun and warm and moist eddies rise to the top of the boundary layer due to buoyancy near the surface. Entrainment occurs at the top of the boundary layer and cooler and dryer downdrafts make their way back to the surface. In the late afternoon, the solar radiation become less intense and the surface heating diminishes. As a result, the sensible heat flux also diminishes and the eddies that are generated from the surface become less strong. The boundary layer needs to adapt to this decrease of turbulence production. This period is still badly known and different features are still unexplained:
- The decrease of the turbulence and a simultaneous increase of the eddies scale is not yet well understood.
- The input of turbulent kinetic energy (TKE) in the boundary layer becomes less than the dissipation. The typical length scales for transport and exchange also change during this period. These changes might lead to the decoupling of different layers within the boundary layer with sometimes a persisting turbulence in the upper part, though this has to be investigated.
- The impact this transition can have on the spreading of scalars, like water vapour or pollutants, from the boundary layer to the free troposphere also needs attention.

After sunset, the surface continues to cool and a stable layer is formed near the ground surface. During this period, the entire regime changes and a new boundary layer is built, starting again at the surface.

The behaviour of the boundary layer during this period, from the late afternoon into the sunset, is poorly understood. With intensive observations the BLLAST study intends to gain deeper understanding in this transitional period. Supplementary to these intensive observations there is a large modelling community, which, making use of the experimental data, will try to incorporate the gained knowledge into our current understanding of the boundary layer.

Apart from ground based measurements like eddy covariance stations, radiation measurements and sky monitoring, many remote sensing instruments were used. These included SODARs, LIDARs, a vertical radar, IR-camera's, scintillometers and more routine based remote sensing, like satellites. A number of air-based platforms were also present, varying from routine radiosonde vertical soundings to a novel frequent radiosounding system and tethered balloons. In addition there were two manned aircrafts measuring turbulence and a large number of unmanned aircrafts, taking both fast turbulence measurements and slow measurements of different quantities. A number of new measurement systems were tested on the unmanned aircrafts.

3 EC-surface Stations

3.1 Site location and relief

The BLLAST experimental site is situated on a plateau with a height of approximately 600 meter above sea level and close to the Pyrenees' mountain range to the south. At the edges of the plateau (10-20 km from the measurement site) the terrain is somewhat undulating and there are small streams that cut small valleys of several hundreds of meters wide and 50-100m deep. The Pyrenean mountain range is located at roughly 30km to the south of the main measurement site and is oriented in an east-west direction. The mountains rise quickly to a height of 2000-3000m. The measurement site is relatively far from the sea, about 160km to the east of the Atlantic Ocean and 220km to the west of the Mediterranean Sea. In Figure 1 the layout of the surroundings of the experimental site is given, i.e. terrain height and land-use.

3.2 EC-stations

In the BLLAST experiment, 9 sites (Figure 2) were equipped with a total of 32 fast response sensors (see appendix I). Properties measured were: wind, temperature, CO₂ concentration and water vapour concentration. In Table 1 a list is given of all sites with the typical land-use, their height above sea level and all the atmospheric properties that were measured.

Table 1 BLLAST EC-sites, land-use, height above sea level and properties that were measured at this station

Site name	Land use	Height ASL [m]	Atmospheric properties measured
Corn	Corn	645	Temperature, wind, H ₂ O, CO ₂ , pressure, radiation, rain, soil temperature, soil humidity, soil heat flux
Moor	Patchy dry grass and shrubs	641	Temperature, wind, H ₂ O, CO ₂ , pressure, radiation, rain, soil temperature, soil humidity, soil heat flux
Forest	Pine	620	Temperature, wind, H ₂ O, CO ₂ , pressure
Valimev	Mixed	602	Temperature, wind, H ₂ O, CO ₂ , pressure, radiation
MicroSite	Grass and shrubs	602	Temperature, wind, H ₂ O, CO ₂ , pressure, radiation
SkinFlow	Grass	591	Temperature, wind
Wheat	Wheat, rye and peas	582	Temperature, wind, H ₂ O, CO ₂ , pressure, wet-bulb-temperature, soil temperature, soil humidity, soil heat flux
Grass	Grass	580	Temperature, wind, H ₂ O, CO ₂ , pressure, wet-bulb-temperature, soil temperature, soil humidity, soil heat flux
Edge	Mixed	580	Temperature, wind, H ₂ O, CO ₂ , pressure

The first aim of the surface stations was to get a clear picture of the behaviour of turbulence near the surface as well as providing sensible and latent heat fluxes in the diverse landscape that is the BLLAST experimental site. These fluxes can then be complementary to airborne measurements. In combining these datasets, a comprehensive picture of the boundary layer structure can be made.

Beyond this, there were different extra research aims for each EC-surface station.

- To the south, where the Corn, Moor and Forest sites were located, three large areas with relatively homogeneous vegetation can be compared. This site is also referred to as Supersite 2. The vegetation at these three sites can be seen as representative for the surrounding area. The size of these three fields is sufficient to study the differences between the timing of the transition and possible local circulations between the different surfaces. The EC-data here is complimented with tethered balloons and unmanned aircraft data. In addition, the tower at the forest is instrumented at two levels, one level just at canopy height, and one 6 meters higher. With these two levels, the flow near the canopy can be studied.
- At the MicroSite the main focus is on small heterogeneities. The MicroSite itself is a hundred meter square flat terrain. This square consists of a mix of bare soil, grass, small bushes and (dry) pools. These surfaces make a very heterogeneous landscape, where soil characteristics (temperature, humidity) have been extensively mapped. Together with the EC-station, a vertical profile of temperature up to 1.5m and radiation.
- The 60m tower (Valimev) is equipped with high frequency (10Hz) sensors at three levels. With this mast, a vertical profile can be made in and above the surface layer. This mast is a permanent platform at the CRA and provides year-round flux-data for three levels.
- The SkinFlow-mast is a 10m high mast equipped with a total of 6 sonic anemometers. The aim of this set-up is to investigate the skin-flow close to the surface and near-surface divergence of the sensible heat flux. The lowest sonic is at a height of less than one meter. Complimentary to the sonic anemometers is a set of fast thermocouples, close to the ground. In a twin tower located near the SkinFlow-mast two-component longwave radiation was measured at 1m, 2m, 3m 5m and 8m above the ground. These two masts combined give a picture on the divergence of the heat flux and the divergence of the longwave radiation close to the ground.
- At the edge site, a set-up of three masts, all equipped with sonic anemometers and fast water vapour and CO₂ sensors, is used to validate a flux-footprint model. Two stations are set up in a grass and wheat field respectively and one station is located at the edge. With a model that includes the land uses in the surrounding area, representative fluxes can be reconstructed.

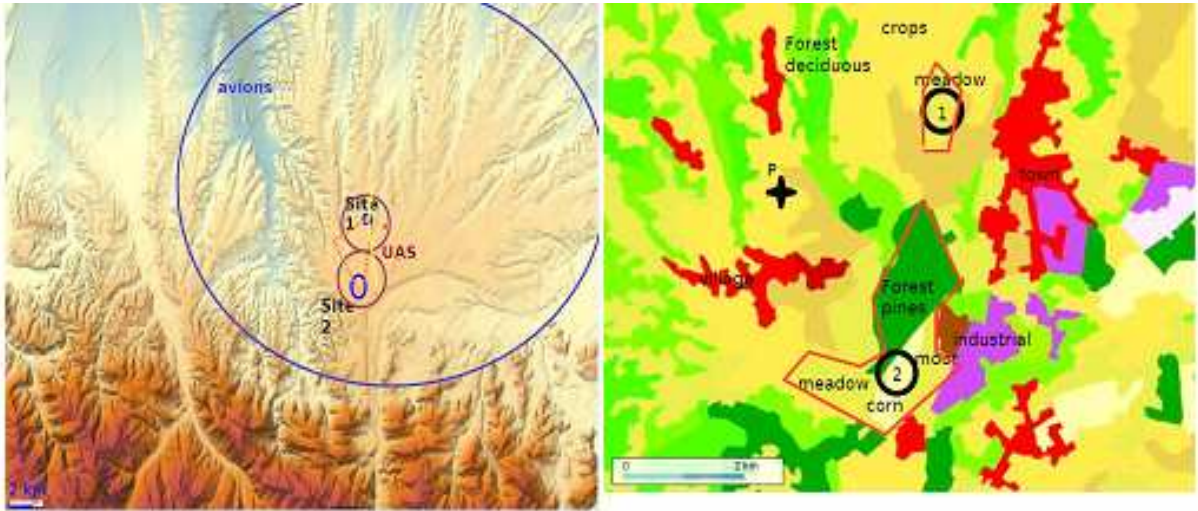


Figure 1 Left panel: relief of the Lannemezan plateau, with location of SuperSite 1 and SuperSite 2. Right panel: vegetation cover over the Lannemezan Plateau.

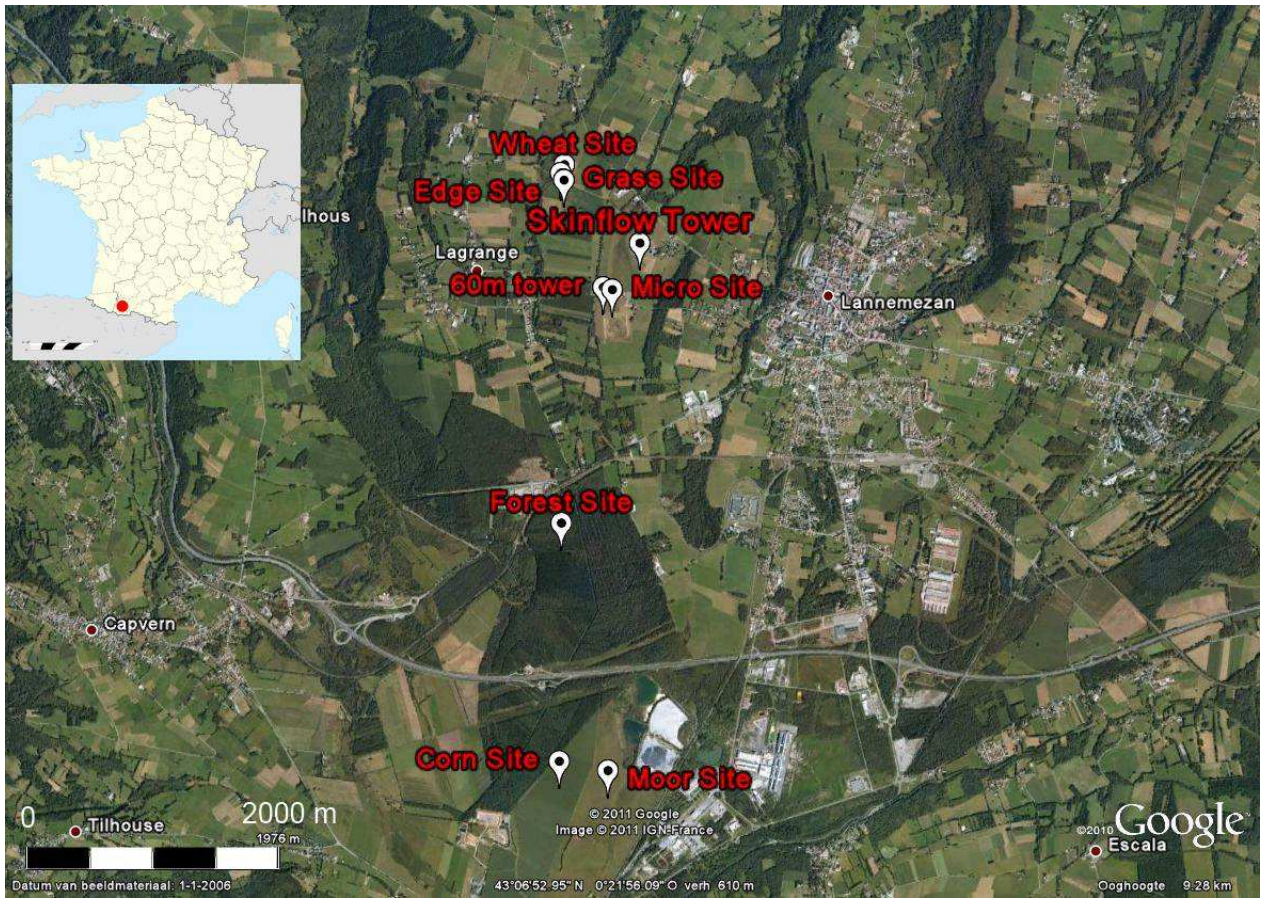


Figure 2 Map of locations of BLLAST EC-stations

4 Programs and data

The program used to do the uniform processing is a software package called EC-pack (van Dijk et al, 2004). This is a software package that includes three programs: CSI2NetCDF, Planang and EC-pack. Figure 3 gives a general flow chart of the programs. First the raw data files will be described, then each program in the order of the processing procedure.

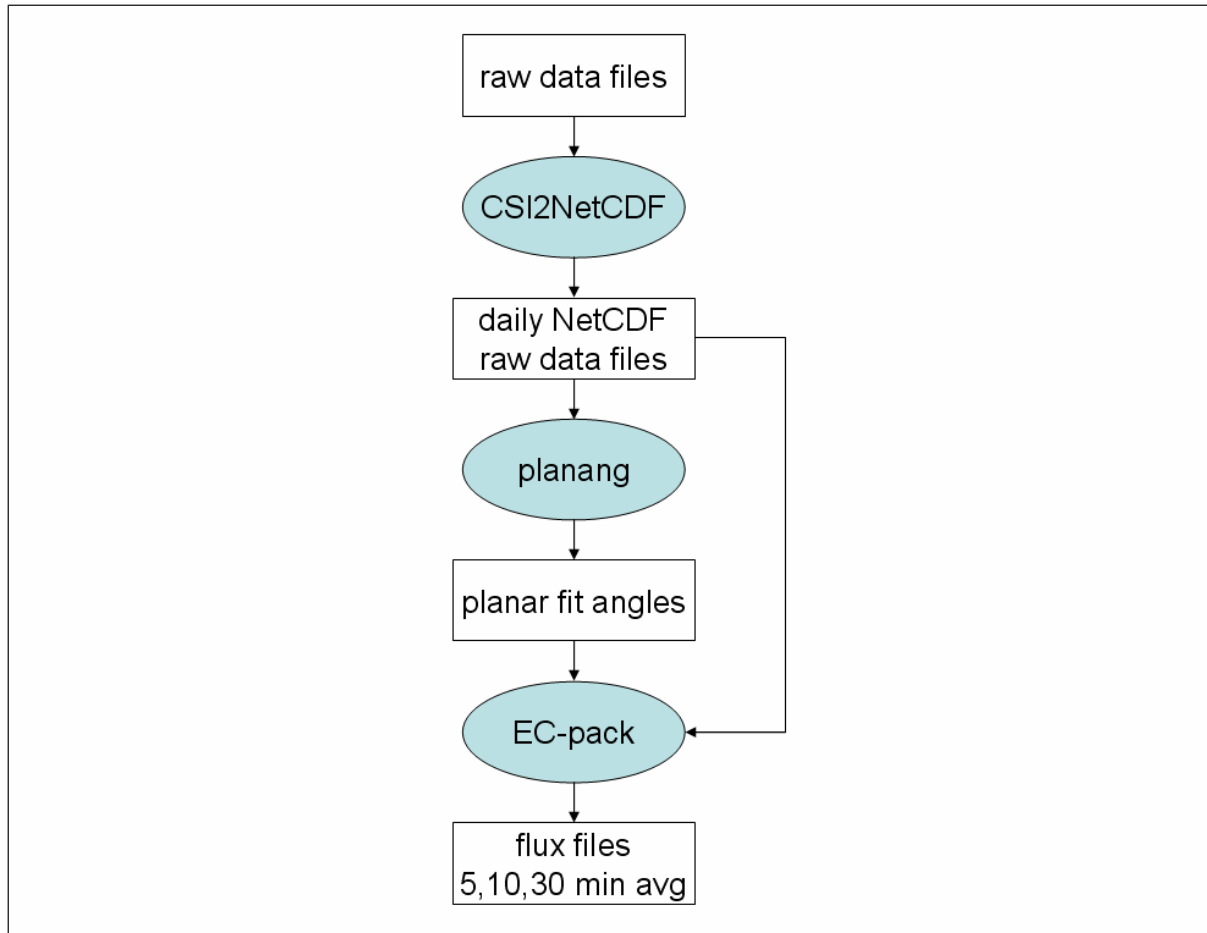


Figure 3 General flow chart of the processing using CSI2NetCDF, planang and EC-pack. Programs are displayed in circles with blue/grey colour as background.

4.1 Raw data

The raw data files have been provided by the PIs (Principal Investigators) of each EC-station. Different raw data formats have been processed, including TOA5, TOB1, TOB3 and text files. The first three formats are Campbell Scientific formats, where TOA5 is an ASCII format and TOB1 and TOB3 are binary formats. Using CSI2NetCDF these formats are read and converted to NetCDF format.

4.2 CSI2NetCDF

CSI2NetCDF (csi2ncdf, 2011) is a program that has been developed to convert different data formats (specifically different Campbell data formats) to NetCDF-files (Rew et al, 1997). The NetCDF is a self-descriptive file-format, so meta-data is included in the file.

In the files that are generated by CSI2NetCDF the date is formatted as: Year, DOY, HHMM, seconds. It is also possible to give a title in CSI2NetCDF. For BLLAST these include the name and year of the experiment, the names of the instruments, their serial numbers and the owners of the instruments. LI7500 is designated as “LI-COR” in the titles. The NetCDF files also include a ‘history’ where the version of CSI2NetCDF is stated.

The BLLAST raw EC-data have been ordered in daily NetCDF files for each EC station. Not all variables in the NetCDF files are used for the processing described in this report. The variables are listed per type in Table 2, as well as an indication for each site which variables are processed. Most sites have NetCDF files per EC stations (usually a combination of wind & temperature and a water vapour & CO₂ sensor). Only the NetCDF files of the Skinfo and Forest site include data from EC stations at different levels. Therefore some variables in Table 2 appear for more EC stations in the same NetCDF files.

Table 2 Variables that are included in the NetCDF files are indicated with a grey background. The units are also given. The variables that were used in the processing in this report are indicated with a mark.

Variable & unit	Skin Flow	Edge	Grass	Wheat	Micro Site	Valimev 30m	Valimev 45m	Valimev 60m	Corn	Forest	Moor
u (m/s)	X	X	X	X	X	X	X	X	X	X	X
v (m/s)	X	X	X	X	X	X	X	X	X	X	X
w (m/s)	X	X	X	X	X	X	X	X	X	X	X
T sonic (°C)	X	X	X	X	X	X	X	X	X	X	X
diag. csat (-)											
T T-couple (°C)	X									X	
CO2 (mg/m3)		X	X	X	X*	X*			X**	X	X**
H2O (g/m3)		X	X	X	X*	X*		X	X	X	X
P licor (kPa)											
diag. irga (-)											
Signal KH20 (mV)											
O3 (ppb)											
T cor (°C)											
T HMP (°C)											
RH HMP (%)											

* mmol/m³

** g/m³

The variables u , v and w are the three wind components measured by the sonic. The temperature measured by the sonic is indicated by T_{sonic} and the diagnostic value is indicated by diag. csat . Thermocouple temperature is indicated by $T_{\text{T-couple}}$. LI7500 variables are carbon dioxide (CO_2), water vapour (H_2O), pressure (P_{licor}) and its diagnostic value (diag. irga , where irga stands for infrared gas analyser). The Krypton hygrometer gives output in millivolts (Signal KH20). Ozone is measured at 30m in the Valimev tower. T_{cor} stands for corrected temperature, which is the sonic temperature corrected for humidity (see the first note under Table 5 in section 5.2). As EC-pack also calculates this corrected temperature, T_{cor} from the raw data files is not used in the uniform processing. The Forest also includes temperature and relative humidity from a HMP45 in the raw data files (T_{HMP} and RH_{HMP} , respectively).

A last remark has to be made on `_FillValue`. This option is used in CS12NetCDF when converting the raw data file to a NetCDF file. In this process a string that appears in a raw data file is replaced in the NetCDF file by a value. For example "NaN" would be changed into the value indicated with `_FillValue`, which is chosen by the user. The EC stations and the data columns where `_FillValue` is used, including the values themselves, are given in appendix II (the raw data of the SkinFlow site includes low height thermocouples data that were not used in the processing). These values have been found during checks of the raw data files and appeared in erroneous data.

4.3 Planang

Planang is a program that calculates planar fit angles (Wilczak et al., 2001) for turbulent wind data. This program uses NetCDF files as input. The period for which the planar fit should be calculated can be varied and it is possible to use multiple averaging periods. As output, the program provides three rotational angles as well as a rotational matrix. The period chosen for each station to calculate the planar fit angles will be specified in section 5.1.

4.4 EC-ncdf

EC-ncdf is the actual eddy-covariance processing program of EC-pack. This program uses the output of above mentioned programs. Input files should therefore be in the NetCDF file-format. A set of input files is used to provide EC-pack with certain settings. A main configuration file is used to set the path for input- output- and configuration data. In this file, the type of output can also be specified (e.g. averages, structure parameters, covariances, etc.). A calibration file is used for information on the calibration of an instrument that provides the raw data. An interval file specifies the intervals for which the program needs to calculate fluxes.

4.4.1 Time lag

An eddy can be recorded at different times with different sensors due to the time it takes for the measured signal to be recorded or because of sensor separation. One can shift the data to obtain maximum correlation. This is not done in EC-pack.

4.4.2 Despiking

Despiking is also not done by EC-pack. There are however physical boundaries for temperature, humidity and carbon dioxide concentrations to remove extreme values. Temperature lower than 243 K and higher than 333 K are rejected. For both the water vapour and carbon dioxide densities the boundaries are 0 and 1 kg m^{-3} .

5 Settings and input

The settings within EC-pack are described in this section. Figure 4 gives a more technical flow chart of EC-pack. Input files are indicated above the EC-pack box, input coming from BLLAST measurements on the left, EC station and instrument specific settings on the right, and output below the EC-pack box. In this chapter explanations are provided for each of the boxes.

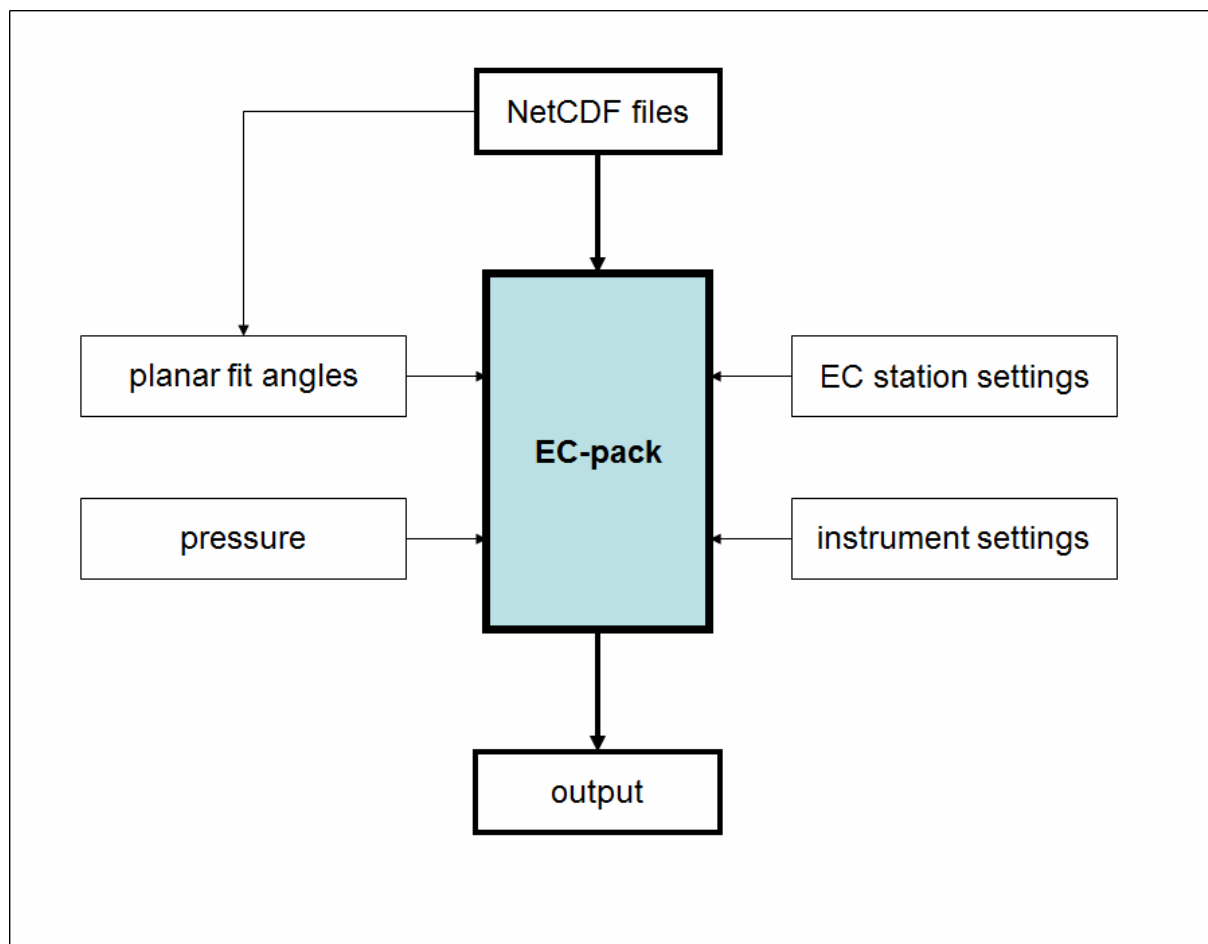


Figure 4 Technical flow chart of the processing with EC-pack. Input files are indicated above the EC-pack box, input coming from BLLAST measurements on the left, station and instrument specific settings on the right, and output below the EC-pack box.

5.1 Planar Fit

Planar fit angles are calculated to virtually rotate the sonic data into the mean flow. If the angles are small in absolute value, then the positioning of the instrument is good with regards to this mean flow. To have enough statistics to calculate meaningful planar fit angles, usually a period of at least a week is used in order to gather many different wind conditions. The use of several sets of planar fit angles defined over consecutive time periods is normally done when for example the mast of the EC station is disrupted or a change in crop height occurred during the experiment. As this information is not always available, it is necessary to determine whether weekly periods should be used or whether one period for the whole experiment (approximately one month) can be used. To do so, the planar fit angles are calculated for weekly periods for all stations over the BLLAST experiment. Table 3 lists the

3 planar fit angles for the first week for each EC-station, all computed with 30 minutes intervals. The α -component rotates around the y-axis, the β -component around the x-axis and the γ -component around the z-axis (Wilczak et al., 2001).

Table 3 List of planar fit angles for all BLLAST EC-stations for the first week of the data set.

	First week of experiment		
Station Name	angle in α -plane	angle in β -plane	angle in γ -plane
Edge	-0.95	3.60	141.28
Grass	1.89	1.62	128.03
Wheat	-1.28	2.40	124.99
MicroSite	-0.36	1.46	124.11
Valimev30m	-1.83	1.27	-142.80
Valimev45m	-1.29	-1.12	-148.89
Valimev60m	6.93	-3.30	-149.91
Corn	-1.14	-0.50	-36.02
Moor	-0.26	2.56	-33.89
Skinflow1mLower	-1.86	7.79	12.80
Skinflow1mUpper	0.02	1.75	127.57
Skinflow2m	0.26	1.38	128.61
Skinflow3m	0.52	1.29	125.59
Skinflow5m	0.27	0.93	121.16
Skinflow8m	0.36	1.30	126.42
Forest20m	-1.14	0.22	-36.04
Forest30m	2.44	-1.77	121.57

Then the angles of the first and last week are compared. When differences are small (order of 0 to 1 degrees), the planar fit angles can be calculated for the whole experiment. If large differences (order of a few degrees) are noticed, then the angles are calculated with weekly periods. The periods for every EC stations have been determined by taking the first and last 7 days with data. The days in between make up the middle weekly period. The experiment lasted from DOY 165 until DOY 190, but not all stations were operational on the first and/or last BLLAST days, so these weekly periods can vary in starting and ending date. The Forest20m station starts at DOY 175, the Valimev60m station starts at DOY 166, the MicroSite station starts at DOY 166 and ends at DOY 189, the Grass & Wheat stations end at DOY 188, all SkinFlow stations start at DOY 170, except the SkinFlow1mLower station which starts at DOY 174. Table 4 gives the difference for the angles, calculated by subtracting the first week angles from the last week angles. All are computed with 30 minutes intervals.

Table 4 Change of the planar fit angles between the first and last week of the data (in degrees). Large changes are depicted in bold.

Station Name	change [degrees] between first and last week	
	α -component	β -component
Edge	0.48	-0.47
Grass	0.31	-0.61
Wheat	0.42	-0.38
MicroSite	0.14	-0.88
Valimev30m	-0.46	-0.81
Valimev45m	-0.10	-0.14
Valimev60m	-8.04	2.53
Corn	1.15	-0.61
Moor	0.12	-0.38
Skinflow1mLower	-7.99	2.33
Skinflow1mUpper	0.87	0.15
Skinflow2m	0.45	-0.51
Skinflow3m	0.38	-0.35
Skinflow5m	0.77	-0.09
Skinflow8m	0.53	-0.72
Forest20m	-1.31	-0.55
Forest30m	-0.22	-0.36

From Table 4 large differences can be seen for the Valimev 60m tower at 60m and for the SkinFlow mast at 0.85m (1mLower). For these two stations the planar fit angles were calculated using weekly intervals. As the Valimev60m EC station has 24 days of data and the SkinFlow1mLower EC station 16 days, intervals of 8 days have been used in order for the intervals to be equally long.

5.2 Pressure

Pressure data (5, 10 and 30 minutes averaged) are used in EC-pack to calculate the density needed to determine the fluxes. These are obtained from low frequency sensors at the EC station. If no low frequency pressure is available, pressure measurements from a nearby low frequency pressure sensor are extrapolated to the EC station using the barometric formula (equation 1), where P_{new} is the extrapolated pressure, P_{ref} the reference pressure, g the gravitational acceleration, z the height difference between the pressure sensor and the EC station, R_d the gas constant for dry air and T the average temperature of the temperature at the pressure sensor and the temperature at the EC station (assuming a constant vertical temperature profile).

$$P_{new} = P_{ref} \cdot \exp\left(\frac{gz}{R_d T}\right) \quad (1)$$

This formula assumes a constant molar mass of the air. To account for the influence of water vapour on this molar mass, the virtual temperature should be used. However, as humidity data were not available at all locations, it has been decided not to use the virtual temperature. An exception has been made for the SkinFlow mast, where the sonic temperatures have been used (see the first note under Table 5). The error on the calculated densities is expected to be negligible.

The reference pressure data and the temperature data are if necessary first averaged to 1 minute (which is the lowest frequency of the reference pressure data) to be consistent for all stations. To minimize the error of linear averaging on the non-linear extrapolation, the extrapolated pressures are first calculated every minute and subsequently averaged over 5, 10 and 30 minutes. Table 5 gives an overview of the origin of the used (reference) pressure and temperature data. Missing intervals in the pressure data were filled linearly using the previous and the following available pressure. For missing intervals at the start or end of the whole period, the pressure is set equal to the first or last available pressure. The periods lacking pressure data are small, so the deviations from the actual pressures during these short periods are assumed to be small.

Table 5 This table indicates the origin of the pressure data for all EC stations. The origin of both the reference temperature data and EC station temperature data are also indicated when extrapolated pressure is used.

EC stations	Instrument measuring pressure	sampling period	Instrument measuring temperature	sampling period
SkinFlow all heights	Valimev PTB101B	10 sec.	HMP45 at 2m CSAT temp. at 3m	10 sec. 0.05 sec.
Edge	Edge LI7500	10 min.	-	-
Grass	Grass PTB100A	10 min.	-	-
Wheat	Wheat PTB100B	10 min.	-	-
MicroSite	Valimev PTB101B	10 sec.	-	-
Valimev30m	Valimev PTB101B	10 sec.	HMP45 at 2m HMP45 at 30m	10 sec. 1 sec.
Valimev45m	Valimev PTB101B	10 sec.	HMP45 at 2m HMP45 at 45m	10 sec. 1 sec.
Valimev60m	Valimev PTB101B	10 sec.	HMP45 at 2m HMP45 at 60m	10 sec. 1 sec.
Corn	Corn PTB210_PRE308	1 min.	-	-
Forest20m	Corn PTB210	1 min.	Corn ATEXIS PT1000 Forest HMP45 at 29m	1 min. 0.1 sec.
Forest30m	Corn PTB210	1 min.	Corn ATEXIS PT1000 Forest HMP45 at 29m	1 min. 0.1 sec.
Moor	Moor PTB210_PRE305	1 min.	-	-

Notes on the table above:

- The SkinFlow mast included thermocouples, but as they were not in the mast for most of the time, the sonic temperature is used for the extrapolations. Sonics measure the temperature equivalent to the virtual temperature (due to the influence of humidity on the speed of sound), so it should be corrected for humidity to get the actual temperature. As no humidity sensors were available, the temperatures as measured by the sonics are used for the extrapolations. Although all sonics measure sonic temperature data, the CSAT at 3 meter seemed to have less errors in the data, so these are used for the whole mast (assuming this does not have a significant effect on the calculated densities).
- The Edge EC station also included a Vaisala low frequency pressure sensor. However, part of the data was not reliable. Therefore the LI7500 pressure has been used. To calculate the 5 minutes

averaged pressure, a linear evolution has been assumed between all 10 minutes averaged pressures.

- As the MicroSite EC station is located at only a few decametres of the Valimev 60m tower and the height difference is only 0.55 meters, the Valimev ground pressure is used without extrapolation.
- The Valimev tower has a LI7500 at 30 meter, but as the measured pressures have an accuracy of only 1 hPa, these have not been used. Instead, the pressure at ground level has been extrapolated to 30, 45 and 60 meters.
- The Corn station had been removed around 13h on the last day of BLLAST (8 July 2011). Therefore no pressure data is available for the second half of this day for extrapolation to the Forest EC stations. For this missing part the pressure of the Forest LI7500 at 30 meter (10 Hz data) has been averaged to 1 minute and extrapolated to 20 meter, before finally averaging the pressures of each height to 5, 10 and 30 minutes. A jump of roughly 1.5 hPa can therefore be noticed around 13h in the used pressure data of that day. This does however not substantially change the calculated density.

5.3 EC station settings

This section describes settings related to the mounting of the instruments. These include heights, angles, and length scale used for structure parameters calculations for each instrument.

5.3.1 Heights and angles

The heights and angles are given for each instrument in appendix I.

5.3.2 Structure parameters

Structure parameters give insight in the turbulence for each scalar in the inertial subrange. A length scale is entered in EC-pack (called structure separation) to calculate the structure parameters. This length has to be within the inertial subrange. The lower limit is defined with the path length and the sampling frequency (10 or 20 Hz, depending on the raw data). It is estimated by multiplying the wind speed with the period of this frequency. A wind speed of 5 m/s has been chosen. The upper limit is estimated as half the height of the instrument (for BLLAST varying between roughly 1 and 60 m). The length scale is then determined as 2/3 of the difference between the lower and upper limit (rounded to 0 decimals for length scales above 5 m).

5.4 Instrument settings

The settings related to the instrument itself are worked out in this section. This includes the path lengths, the time constant for the thermocouples and the calibration coefficients. The path lengths are given in appendix I. The time constant is given in subsection 5.4.1 and an explanation on the calibration coefficients follows in the next subsection.

5.4.1 Time constant

For thermocouples a time constant is set in EC-pack. This constant depicts the measuring speed of the instrument. If the time constant is lower than the sampling interval (1/frequency), then the instrument is fast enough for the high frequency measuring. For the thin wire-thermocouples in BLLAST we used a time-constant of 0.01 seconds (Moene, 2003).

5.4.2 Calibrations

For all instruments EC-pack offers the possibility to enter calibration coefficients for a function to correct the drift of an instrument. LI7500s have more tendency than other instruments (like CSATs) to show drift, which is related to the measuring method. The errors can be caused by for example dirty windows. Two calibrations have been performed, one shortly before and one shortly after BLLAST. The resulting calibration coefficients are compared to determine if significant drift occurred during the experiment. If this is not the case, the data is processed as is. If there is significant drift, a calibration function is needed. Various types of functions can be entered in EC-pack, though in this report only linear (1st order) functions are used. The drift is calculated as the change in percentage of each coefficient, relative to the before-experiment calibration value. These coefficients can be found in appendix III. The drift of the Forest site LI7500 could not be calculated as it was not yet calibrated for the second time (after the experiment) at the time this report was written. In Table 6 the dates of the calibrations of the LI7500s and the drift between before- and after-experiment calibrations are listed.

All LI7500s, except for the Edge LI7500, have been actively calibrated before the start of BLLAST. This means that the LI7500s have been forced to give the correct output. The Edge LI7500 has been passively calibrated, which means that the calibration coefficients are read without changing the instrument output. For this reason no calibration function has been entered in EC-pack for all LI7500s, except for the Edge LI7500. For BLLAST the drift stayed under 10% (see Table 6) for all calibration coefficients. The calibration function for the Edge LI7500 is calculated using only information on the after-experiment calibration, because the before-experiment calibration was done too long before BLLAST. The calibration function of CO₂ includes an offset of 0.0000081 kg m⁻³ and a multiplier of 1.0267. For H₂O the offset is -0.001159 kg m⁻³ and the multiplier is 0.9809. Concerning the Forest LI7500, it had been actively calibrated before the start of BLLAST, so also for this LI7500 no calibration coefficients were used.

At 60 meters in the Valimev tower the high frequency humidity is measured by a Krypton hygrometer. Krypton hygrometers show more drift than other humidity sensors. Therefore the data in the supplied raw data files has already been calibrated. However, low frequency humidity is still used in EC-pack from the HMP45 at 60m, as it appeared to give slightly different results than without using the low frequency humidity.

Table 6 This table shows the drifts of the calibration coefficients per LI7500, including the dates of the before-experiment and after-experiment calibrations. Only the LI7500 from the Edge has been passively calibrated prior to BLLAST.

LI7500	before		after		coefficient
	date (dd-mm-yyyy)	active/passive	date (dd-mm-yyyy)	drift (%)	
Edge	21-07-2006	passive	20-07-2011	-0.60 1.26 1.26 5.77	zero CO2 span CO2 zero H2O span H2O
Grass	10-06-2011	active	06-07-2011	0.12 -0.42 -0.56 2.35	zero CO2 span CO2 zero H2O span H2O
Wheat	10-06-2011	active	06-07-2011	0.07 -0.34 -0.84 -4.23	zero CO2 span CO2 zero H2O span H2O
MicroSite	14-06-2011	active	12-07-2011	-0.23 -0.69 0.27 -8.52	zero CO2 span CO2 zero H2O span H2O
Valimev30m	10-06-2011	active	12-07-2011	0.08 -7.89 -0.48 -7.64	zero CO2 span CO2 zero H2O span H2O
Corn	21-04-2011	active	12-07-2011	-0.17 -4.47 0.13 5.79	zero CO2 span CO2 zero H2O span H2O
Forest	13-04-2011	active	<i>not yet done</i>	<i>not yet done</i> <i>not yet done</i> <i>not yet done</i> <i>not yet done</i>	zero CO2 span CO2 zero H2O span H2O
Moor	21-04-2011	active	12-07-2011	-0.17 -0.86 0.49 6.29	zero CO2 span CO2 zero H2O span H2O

6 Output

The flux processing generates three types of output: NetCDF-files of the raw data (used as input in EC-pack), the planar fit angles for the specified (either weekly or monthly) interval and the flux files.

6.1 Planar fit angles files

For every station, files are generated with the planar fit angles. These angles define the plane of the mean wind. In the Planar fit angles, the intervals are listed for which the planar fit is calculated. For every interval, the classical rotational angles are generated. Then the bias of w is given (for this processing, the bias is forced to 0). And last, the rotational matrix is given.

6.2 NetCDF raw data files

NetCDF files are essentially self-descriptive. The NetCDF files also contain a history. Because these files just contain the raw data, only the version of CSI2NetCDF which is used to create these files is listed here.

6.3 Flux files

The flux files are text files produced by EC-ncdf that contain columns with the calculated fluxes. These text files have also been converted to NetCDF format using CSI2NetCDF. First a description of the text files is given. The intervals for which the calculations have been done form the first set of columns. Then the number of samples that is included in the calculation is given for each variable. The list of variables is: u , v , w , T_{sonic} , $T_{\text{thermocouple}}$, Rho_v , q , Rho_{CO_2} and q_{CO_2} . Means, standard deviations and covariances with u , v and w are displayed in the next columns. The units are for wind speeds m s^{-1} , for temperatures K, for partial densities (Rho) kg m^{-3} and for specific concentrations (q) kg kg^{-1} . The length scale that is actually used by EC-pack, using the estimate described in section 5.3.2, is also given for each interval (R in meters), as well as its standard deviation (dR in meters).

The next sets of columns are formed by structure parameters and derived quantities. For the structure parameters all combinations of the variables are given. The physical quantities are in order of appearance: Rho sonic, Rho thermocouple, w before any rotation took place, the prevailing wind speed and direction, H sonic, H thermocouple, LvE cov , LvE Webb , LvE sum , u^* , τ , $\text{CO}_2 \text{ cov flux}$, $\text{CO}_2 \text{ Webb term}$ and $\text{CO}_2 \text{ flux sum}$. For each variables an extra column including the tolerance interval is added to indicate the margin of error of the calculated variables. Appendix IV gives the full list of columns that is generated in all EC-pack flux files (text format), and a short description. All flux files start at the first day the concerning EC station has data and end at the last day with data (see section 5.1 for starting and ending days). This means that some flux files start at a later DOY or end at an earlier DOY than the full BLLAST period. Intervals that do not contain data get the value -9999.0 assigned (-9999 for the columns indicating the number of variables).

The NetCDF flux files contain the same columns as the text flux files. There are two small differences: the NaNs and +Infinity and -Infinity that occasionally appear in the text flux files have been changed to -9999.0 in the NetCDF flux files by using `_FillValue` in CSI2NetCDF (see the last paragraph of section 4.2). The other difference is that the headers of some columns have been altered to more self-evident names.

7 Recommendations

This chapter gives some recommendations concerning the choices made during the processing.

- To account for any drift of the LI7500s, it might be more accurate to assume a linear drift during the whole experiment. Per day different coefficients could be used according to the (linear) drift. Creating a calibration function using the correlation between the humidity data and a slower sensor might even be a better method, as uncertainty remains about the nature of the drift. It might for example occur suddenly at some point during the experiment, rather than a gradual linear drift.
- Additional tests can be performed to check whether the whole period or weekly periods should be used for the planar fit angles. The fluxes of the EC stations that show large differences between the first and last week could be investigated. These fluxes should be calculated using weekly angles and using angles for the whole period. If substantial differences occur in the resulting fluxes and u^* , then weekly angles would seem more justified.
- An autocorrelation between different sensors could be a solution to find the time lag. This should then be done for each flux interval.

8 References

- csi2ncdf (Meteorology and Air Quality Group, Wageningen University, <http://www.met.wau.nl/projects/csi2ncdf>).
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Appendix I – List of relevant instruments for each EC-station

This appendix contains information on all instruments used in the processing described in this report.

Table 1 List of relevant instruments for each EC-station.

Site name	Measured property	Instrument name	Manufacturer	Serial number	Sampling rate	Height AGL [m]	Angle from north	Path length [m]
Moor	Turbulent wind speed and -direction	HS-50	Gill	1199HSE	20 Hz	2.93	305	0.147
	H ₂ O and CO ₂ concentration	LI-7500	LICOR Biosciences	1707	20 Hz	2.93	270	0.125
	Atmospheric pressure	PTB210	Vaisala	PRE308	1 min.	0	N/A	N/A
Corn	Turbulent wind speed and -direction	HS-50	Gill	1199HS	20 Hz	2.93	305	0.147
	H ₂ O and CO ₂ concentration	LI-7500	LICOR Biosciences	1224	20 Hz	2.93	270	0.125
	Atmospheric pressure	PTB210	Vaisala	PRE305	1 min.	0	N/A	N/A
Forest	Turbulent wind speed and -direction	CSAT3	Campbell Scientific Inc.	0297	10 Hz	20.84	5.6	0.1155
	Turbulent wind speed and -direction	CSAT3	Campbell Scientific Inc.	0434	10 Hz	31.55	10.5	0.1155
	H ₂ O and CO ₂ concentration	LI-7500	LICOR Biosciences	0477	10 Hz	31.55	10.5	0.125
	Temperature	Type T thermocouple	Campbell Scientific Inc.	N/A	10 Hz	20.84	N/A	N/A
	Temperature	Type T thermocouple	Campbell Scientific Inc.	N/A	10 Hz	31.55	N/A	N/A
	Temperature and humidity	Humicap HMP45	Vaisala	illegible	10 Hz	29.02	N/A	N/A
Valimev	pressure	PTB101B	Vaisala	X0940007	10 sec	1.4	N/A	N/A
	Temperature and humidity	Humicap HMP45	Vaisala	Z0320015	10 sec.	2	N/A	N/A
	Turbulent wind speed and -direction	CSAT3	Campbell Scientific Inc.	1315	10 Hz	29.3	318.71	0.1155
	H ₂ O and CO ₂ concentration	LI-7500	LICOR Biosciences	1907	10 Hz	29.3	318.71	0.125
	Temperature and humidity	Humicap HMP45	Vaisala	C4820004	1 Hz	29.4	N/A	N/A
	Turbulent wind speed and -direction	HS-50	Gill	73107	10 Hz	45.8	286.16	0.15

	Temperature and humidity	Humicap HMP45	Vaisala	C4820005	1 Hz	45.6	N/A	N/A
	Turbulent wind speed and -direction	CSAT3	Campbell Scientific Inc.	1298-2	10 Hz	61.4	329.71	0.1155
	H ₂ O and CO ₂ concentration	KH20	LICOR Biosciences	1548	10 Hz	61.4	329.71	0.0199
	Temperature and humidity	Humicap HMP45	Vaisala	B4630007	1 Hz	61.6	N/A	N/A
Micro	Turbulent wind speed and -direction	CSAT3	Campbell Scientific Inc.	1332-2	10 Hz	1.95	295	0.11551
	H ₂ O and CO ₂ concentration	LI-7500	LICOR Biosciences	1211	10 Hz	1.95	295	0.125
Skinflow	Turbulent wind speed and - temperature	KD-TR/90AH	Kaijo Corp.	01982887	20 Hz	0.85	120	0.05
	Turbulent wind speed and - temperature	KD-TR/90AH	Kaijo Corp.	01982888	20 Hz	1.12	120	0.05
	Turbulent wind speed and -direction	CSAT3	Campbell Scientific Inc.	0590	20 Hz	2.23	120	0.1155
	Turbulent wind speed and -direction	CSAT3	Campbell Scientific Inc.	0594	20 Hz	3.23	120	0.1155
	Turbulent wind speed and -direction	CSAT3	Campbell Scientific Inc.	0603	20 Hz	5.27	120	0.1155
	Turbulent wind speed and -direction	CSAT3	Campbell Scientific Inc.	0602-2	20 Hz	8.22	120	0.1155
	Temperature	Type T thermocouple	Campbell Scientific Inc.	N/A	20 Hz	0.85	N/A	N/A
	Temperature	Type T thermocouple	Campbell Scientific Inc.	N/A	20 Hz	1.12	N/A	N/A
	Temperature	Type T thermocouple	Campbell Scientific Inc.	N/A	20 Hz	2.23	N/A	N/A
	Temperature	Type T thermocouple	Campbell Scientific Inc.	N/A	20 Hz	3.23	N/A	N/A
	Temperature	Type T thermocouple	Campbell Scientific Inc.	N/A	20 Hz	5.27	N/A	N/A
	Temperature	Type T thermocouple	Campbell Scientific Inc.	N/A	20 Hz	8.22	N/A	N/A
	Turbulent wind speed and -direction	CSAT3	Campbell Scientific Inc.	1201-1	20 Hz	3.00	308	0.1155

Wheat	H ₂ O and CO ₂ concentration	LI-7500	LICOR Biosciences	0987	20 Hz	3.00	308	0.125
	Atmospheric pressure	PTB100B	Vaisala	U3610012	1 min.	0	N/A	N/A
Grass	Turbulent wind speed and -direction	CSAT3	Campbell Scientific Inc.	1747	20 Hz	2.55	308	0.1155
	H ₂ O and CO ₂ concentration	LI-7500	LICOR Biosciences	1323	20 Hz	2.55	308	0.125
	Atmospheric pressure	PTB100A	Vaisala	U4920017	1 min.	0	N/A	N/A
Edge	Turbulent wind speed and -direction	CSAT3	Campbell Scientific Inc.	0296-2	20 Hz	2.89	320	0.1155
	H ₂ O and CO ₂ concentration and pressure	LI-7500	LICOR Biosciences	0030	20 Hz	2.60	320	0.126

Appendix II – List of _FillValues used by CSI2NetCDF

This appendix contains all _FillValues used by CSI2NetCDF to produce the NetCDF files.

Table 2 Values used by CSI2NetCDF to replace strings in raw data for some of the EC stations.

EC station	variable	_FillValue
SkinFlow (all SkinFlow EC stations)	diag_csat_2m diag_csat_3m diag_csat_5m diag_csat_8m	61503
	Tcouple_09cm Tcouple_13cm Tcouple_19cm Tcouple_57cm Tcouple_1m_lower Tcouple_1m_upper Tcouple_2m Tcouple_3m Tcouple_5m Tcouple_8m	-8190
Grass & Wheat (Edge Site)	diag_csat	61503
MicroSite (Super Site 1)	diag_csat	7999
Corn (Super Site 2)	u v w T_sonic T_cor H2O CO2	3.40282347e+38
Forest (Super Site 2)	diag_csat_30m diag_csat_20m	61503
Moor (Super Site 2)	u v w T_sonic T_cor H2O CO2	3.40282347e+38

Appendix III – Calibration coefficients LI7500s

This appendix contains all calibration coefficients of the LI7500s used to calculate the drift during BLLAST.

Table 3 Calibration coefficients LI7500s.

LI7500	coefficient	before-experiment	after-experiment
Edge	zero CO2	0.9713	0.9655
	span CO2	0.9968	1.0094
	zero H2O	0.6185	0.6263
	span H2O	0.9980	1.0556
Grass	zero CO2	0.9016	0.9027
	span CO2	1.0010	0.9968
	zero H2O	0.9175	0.9124
	span H2O	0.9780	1.0010
Wheat	zero CO2	0.8167	0.8173
	span CO2	1.0072	1.0038
	zero H2O	0.6880	0.6822
	span H2O	1.0611	1.0162
MicroSite	zero CO2	0.9240	0.9219
	span CO2	1.0394	1.0322
	zero H2O	0.8604	0.8627
	span H2O	1.1688	1.0692
Valimev30m	zero CO2	0.8675	0.8682
	span CO2	0.9951	0.9166
	zero H2O	0.8549	0.8508
	span H2O	0.9968	0.9206
Corn	zero CO2	0.9241	0.9225
	span CO2	1.0022	0.9574
	zero H2O	0.7966	0.7976
	span H2O	1.0199	1.0790
Forest	zero CO2	0.8935	<i>not yet done</i>
	span CO2	2.3730	<i>not yet done</i>
	zero H2O	0.7142	<i>not yet done</i>
	span H2O	1.0946	<i>not yet done</i>
Moor	zero CO2	0.8173	0.8159
	span CO2	1.0015	0.9929
	zero H2O	0.8157	0.8197
	span H2O	1.0486	1.1146

Appendix IV – Output of EC-pack

This appendix contains the output of EC-pack that are included in the flux files in text format. The table starts in the left part for several pages and continues at the top in the right part.

Table 4 Output of EC-pack including variable, unit and short description.

Doy	[-]	Day of year of start of interval	R	[m]	length scale to calculate the stucture parameter
Hour	[-]	Hour of start of interval	dR	[m]	standard deviation of the length scale to calculate the stucture parameter
Min	[-]	Minute of start of interval	C_(u*u)	[m/s][m/s][m ^{-2/3}]	structure parameters and the tolerance interval for the structure parameters
Doy	[-]	Day of year of end of interval	TolC_(u*u)	[m/s][m/s][m ^{-2/3}]	
Hour	[-]	Hour of end of interval	C_(u*v)	[m/s][m/s][m ^{-2/3}]	
Min	[-]	Minute of end of interval	TolC_(u*v)	[m/s][m/s][m ^{-2/3}]	
DecDayB	[day]	Decimal day of start of interval	C_(u*w)	[m/s][m/s][m ^{-2/3}]	
DecDayE	[day]	Decimal day of end of interval	TolC_(u*w)	[m/s][m/s][m ^{-2/3}]	
DecHour B	[hr]	Decimal hour of start of interval	C_(u*TSon)	[m/s][K][m ^{-2/3}]	
DecHour E	[hr]	Decimal hour of end of interval	TolC_(u*TSon)	[m/s][K][m ^{-2/3}]	
DecSecB	[s]	Decimal sec of start of interval	C_(u*TCop)	[m/s][K][m ^{-2/3}]	
DecSecE	[s]	Decimal sec of end of interval	TolC_(u*TCop)	[m/s][K][m ^{-2/3}]	
#Samples	[-]	number of samples	C_(u*q)	[m/s][kg/kg][m ^{-2/3}]	
#u	[-]		TolC_(u*q)	[m/s][kg/kg][m ^{-2/3}]	
#v	[-]		C_(u*qCO2)	[m/s][kg/kg][m ^{-2/3}]	
#w	[-]		TolC_(u*qCO2)	[m/s][kg/kg][m ^{-2/3}]	
#TSon	[-]		C_(v*v)	[m/s][m/s][m ^{-2/3}]	
#TCop	[-]		TolC_(v*v)	[m/s][m/s][m ^{-2/3}]	
#rhoV	[-]		C_(v*w)	[m/s][m/s][m ^{-2/3}]	
#q	[-]		TolC_(v*w)	[m/s][m/s][m ^{-2/3}]	
#rhoCO2	[-]			C_(v*TSon)	[m/s][K][m ^{-2/3}]

#qCO2	[-]	
Mean(u)	[m/s]	means and tolerance intervals for means
TolMean(u)	[m/s]	
Mean(v)	[m/s]	
TolMean(v)	[m/s]	
Mean(w)	[m/s]	
TolMean(w)	[m/s]	
Mean(TSon)	[K]	
TolMean(TSon)	[K]	
Mean(TCop)	[K]	
TolMean(TCop)	[K]	
Mean(rhoV)	[kg/m ³]	
TolMean(rhoV)	[kg/m ³]	
Mean(q)	[kg/kg]	
TolMean(q)	[kg/kg]	
Mean(rhoCO2)	[kg/m ³]	
TolMean(rhoCO2)	[kg/m ³]	
Mean(qCO2)	[kg/kg]	standard deviations and tolerance intervals for standard deviations
TolMean(qCO2)	[kg/kg]	
Std(u)	[m/s]	
TolStd(u)	[m/s]	

n)		
TolC_(v*TSon)	[m/s][K][m ^{-2/3}]	structure parameters and the tolerance interval for the structure parameters
C_(v*TCop)	[m/s][K][m ^{-2/3}]	
TolC_(v*TCop)	[m/s][K][m ^{-2/3}]	
C_(v*q)	[m/s][kg/kg][m ^{-2/3}]	
TolC_(v*q)	[m/s][kg/kg][m ^{-2/3}]	
C_(v*qCO2)	[m/s][kg/kg][m ^{-2/3}]	
TolC_(v*qCO2)	[m/s][kg/kg][m ^{-2/3}]	
C_(w*w)	[m/s][m/s][m ^{-2/3}]	
TolC_(w*w)	[m/s][m/s][m ^{-2/3}]	
C_(w*TSon)	[m/s][K][m ^{-2/3}]	
TolC_(w*TSon)	[m/s][K][m ^{-2/3}]	
C_(w*TCop)	[m/s][K][m ^{-2/3}]	
TolC_(w*TCop)	[m/s][K][m ^{-2/3}]	
C_(w*q)	[m/s][kg/kg][m ^{-2/3}]	
TolC_(w*q)	[m/s][kg/kg][m ^{-2/3}]	
C_(w*qCO2)	[m/s][kg/kg][m ^{-2/3}]	
TolC_(w*qCO2)	[m/s][kg/kg][m ^{-2/3}]	
C_(TSon*TSon)	[K][K][m ^{-2/3}]	
TolC_(TSon*TSon)	[K][K][m ^{-2/3}]	
C_(TSon*TCop)	[K][K][m ^{-2/3}]	
TolC_(TSon*TCop)	[K][K][m ^{-2/3}]	

Std(v)	[m/s]	standard deviations and tolerance intervals for standard deviations
TolStd(v)	[m/s]	
Std(w)	[m/s]	
TolStd(w)	[m/s]	
Std(TSon)	[K]	
TolStd(TSon)	[K]	
Std(TCop)	[K]	
TolStd(TCop)	[K]	
Std(rhoV)	[kg/m^3]	
TolStd(rhoV)	[kg/m^3]	
Std(q)	[kg/kg]	
TolStd(q)	[kg/kg]	
Std(rhoCO2)	[kg/m^3]	
TolStd(rhoCO2)	[kg/m^3]	
Std(qCO2)	[kg/kg]	
TolStd(qCO2)	[kg/kg]	
Cov(u*v)	[m/s][m/s]	covariances and tolerance intervals for covariances
TolCov(u*v)	[m/s][m/s]	
Cov(u*w)	[m/s][m/s]	
TolCov(u*w)	[m/s][m/s]	
Cov(u*TSon)	[m/s][K]	
TolCov(u*TSon)	[m/s][K]	

C_(TSon*q)	[K][kg/kg][m^-2/3]	structure parameters and the tolerance interval for the structure parameters
TolC_(TSon*q)	[K][kg/kg][m^-2/3]	
C_(TSon*qCO2)	[K][kg/kg][m^-2/3]	
TolC_(TSon*qCO2)	[K][kg/kg][m^-2/3]	
C_(TCop*TCop)	[K][K][m^-2/3]	
TolC_(TCop*TCop)	[K][K][m^-2/3]	
C_(TCop*q)	[K][kg/kg][m^-2/3]	
TolC_(TCop*q)	[K][kg/kg][m^-2/3]	
C_(TCop*qCO2)	[K][kg/kg][m^-2/3]	
TolC_(TCop*qCO2)	[K][kg/kg][m^-2/3]	
C_(q*q)	[kg/kg][kg/kg][m^-2/]	
TolC_(q*q)	[kg/kg][kg/kg][m^-2/]	
C_(q*qCO2)	[kg/kg][kg/kg][m^-2/]	
TolC_(q*qCO2)	[kg/kg][kg/kg][m^-2/]	
C_(qCO2*qCO2)	[kg/kg][kg/kg][m^-2/]	
TolC_(qCO2*qCO2)	[kg/kg][kg/kg][m^-2/]	
RhoSon	[kg/m^3]	density calculated with sonic temperature
Tol(RhoSon)	[kg/m^3]	tolerance interval for density calculated with sonic temperature
RhoTc	[kg/m^3]	density calculated with thermocouple
Tol(RhoTc)	[kg/m^3]	tolerance interval for density calculated with thermocouple
Wnorot	[m/s]	vertical velocity when no rotation is applied
TolWnorot	[m/s]	tolerance interval for vertical velocity when no

*TSon)		covariances and tolerance intervals for covariances
Cov(u*TCop)	[m/s][K]	
TolCov(u*TCop)	[m/s][K]	
Cov(u*rhoV)	[m/s][kg/m ³]	
TolCov(u*rhoV)	[m/s][kg/m ³]	
Cov(u*q)	[m/s][kg/kg]	
TolCov(u*q)	[m/s][kg/kg]	
Cov(u*rhoCO2)	[m/s][kg/m ³]	
TolCov(u*rhoCO2)	[m/s][kg/m ³]	
Cov(u*qCO2)	[m/s][kg/kg]	
TolCov(u*qCO2)	[m/s][kg/kg]	
Cov(v*w)	[m/s][m/s]	
TolCov(v*w)	[m/s][m/s]	
Cov(v*TSon)	[m/s][K]	
TolCov(v*TSon)	[m/s][K]	
Cov(v*TCop)	[m/s][K]	
TolCov(v*TCop)	[m/s][K]	
Cov(v*rhoV)	[m/s][kg/m ³]	
TolCov(v*rhoV)	[m/s][kg/m ³]	
Cov(v*q)	[m/s][kg/kg]	
TolCov(v*q)	[m/s][kg/kg]	
Cov(v*rhoCO2)	[m/s][kg/m ³]	

ot)		rotation is applied
U_vect	[m/s]	streamwise component of windspeed
Tol(U_vect)	[m/s]	tolerance interval for streamwise component of windspeed
U_dir	[degr.]	direction of average wind speed
Tol(U_dir)	[degr.]	tolerance interval for direction of average wind speed
HSonic	[W/m ²]	sensible heat flux, using sonic temperature
Tol(HSonic)	[W/m ²]	tolerance interval for sensible heat flux, using sonic temperature
HTc	[W/m ²]	sensible heat flux, using thermocouple temperature
Tol(HTc)	[W/m ²]	tolerance interval for sensible heat flux, using thermocouple temperature
LvEcov	[W/m ²]	latent heat flux without Webb correction
Tol(LvEcov)	[W/m ²]	tolerance interval for latent heat flux without Webb correction
LvWebb	[W/m ²]	Webb correction for the latent heat flux
Tol(LvWebb)	[W/m ²]	tolerance interval for Webb correction for the latent heat flux
SumLvE	[W/m ²]	latent heat flux, including Webb correction
Tol(SumLvE)	[W/m ²]	tolerance interval for latent heat flux, including Webb correction
Ustar	[m/s]	friction velocity
Tol(Ustar)	[m/s]	tolerance interval for friction velocity
Tau	[N/m ²]	shear stress
Tol(Tau)	[N/m ²]	tolerance interval for shear stress
FCO2cov	[kg/m ² /s]	CO2 flux without Webb correction
Tol(FCO2cov)	[kg/m ² /s]	tolerance interval for CO2 flux without Webb correction
FCO2Webb	[kg/m ² /s]	Webb correction term for CO2 flux

TolCov(v *rhoCO2)	[m/s][kg/ m ³]	covariances and tolerance intervals for covariances
Cov(v*qC O2)	[m/s][kg/ kg]	
TolCov(v *qCO2)	[m/s][kg/ kg]	
Cov(w*TS on)	[m/s][K]	
TolCov(w *TSon)	[m/s][K]	
Cov(w*T Cop)	[m/s][K]	
TolCov(w *TCop)	[m/s][K]	
Cov(w*rh oV)	[m/s][kg/ m ³]	
TolCov(w *rhoV)	[m/s][kg/ m ³]	
Cov(w*q)	[m/s][kg/ kg]	
TolCov(w *q)	[m/s][kg/ kg]	
Cov(w*rh oCO2)	[m/s][kg/ m ³]	
TolCov(w *rhoCO2)	[m/s][kg/ m ³]	
Cov(w*q CO2)	[m/s][kg/ kg]	
TolCov(w *qCO2)	[m/s][kg/ kg]	

To(FCO2 Webb)	[kg/m ² /s]	tolarance interval for Webb correction term for CO2 flux
SumFCO2	[kg/m ² /s]	CO2 flux, including webb correction
To(SumF CO2)	[kg/m ² /s]	tolarance interval for CO2 flux, including webb correction