2.2 AutoFlux – the autonomous air-sea interaction system Robin Pascal

2.2.1. Introduction

AutoFlux is an autonomous, stand-alone system which obtains direct, near real-time (2 hr) measurements of the air-sea turbulent fluxes of momentum and sensible and latent heat in addition to various mean meteorological parameters. The main aims of the present deployment were to test the new Licor sensor to determine its suitability for making direct measurements of the air-sea CO_2 flux. The AutoFlux system was mobilized at SOC in September 2004 prior to the start of cruise D284 and left to run autonomously until the beginning of D285. OED staff then joined the ship to service the sensors and develop the system during D285. Previously, the system obtained flux measurements using the inertial dissipation (ID) method that relies on good sensor response at frequencies up to 10 Hz. The ID method has the advantage that the flux results a) are insensitive to the motion of the ship and b) can be corrected for the effects of the presence of the ship distorting the air flow to the sensors. Momentum and latent heat flux measurements have been successfully made using this method for a number of years. Sensible heat and CO_2 flux measurements are made more difficult by the lack of sensors with the required high frequency response. For these fluxes the eddy correlation (EC) method provides an alternative. This method requires good sensor response up to only about 2 to 3 Hz, but is a) very sensitive to ship motion and b) can not be corrected for the effect of air flow distortion. Once EC fluxes are obtained they can be corrected for flow distortion effects by comparison with the ID fluxes where available. Since the scalar fluxes (sensible and latent heat and CO_2) are all affected by flow distortion in the same fashion, only one ID scalar flux is required. If the new CO_2 sensor performs adequately at low frequencies, direct measurements of the air-sea CO_2 flux will thus be obtained. In collaboration with the UEA carbon team, any successful CO_2 flux measurements will be used to improve the parameterization of the CO_2 transfer velocity.

The development work on this cruise entailed improving the stability of the software to achieve better results when the system is in stand alone mode. Throughout the cruise near real time flux data and mean met parameters were emailed back to SOC via an Orbcomm Satellite communicator. Data was then daily published on the SOC web site and used in computer modeling, results of which were then sent to the ship.

This report describes the AutoFlux instrumentation (Section 2.2.2). A brief discussion of the performance of the mean meteorological sensors is given in Section 2.2.3, where comparisons are made between the ship's instruments with those of AutoFlux where possible. As part of a separate project, visual observations of the cloud cover were made by the ship's officers (Section 2.2.3). Initial flux results are described in Section 2.2.4. Appendix A lists significant events such as periods when data logging was stopped, and Appendix B contains figures showing time series of the mean meteorological and flux data. All times refer to GMT.

More information on air-sea fluxes and the AutoFlux project in particular can be found under http://www.soc.soton.ac.uk/JRD/MET/AUTOFLUX

2.2.2. Instrumentation

The SOC Meteorology Team instrumented the Discovery with a variety of meteorological sensors. The mean meteorological sensors (Table 2.1) measured air temperature and humidity, pressure and incoming longwave (4-50 micron) radiation. The surface fluxes of momentum, heat, moisture and CO2 were obtained using the fast-response instruments in Table 2.2. The HS and R3 sonic anemometers provided mean wind speed and direction data in addition to the momentum and sensible heat flux estimates.

To obtain EC fluxes, ship motion data from the MotionPak system has to be synchronized with those from the other fast response sensors. In order to achieve this the MotionPak output was logged via the analogue input channel of the HS anemometer. In addition, a timer circuit was added in to the HS sonic interface unit. This circuit generated a square wave sync signal which was input to the analogue channels of the Licor and R3, and to the PRT input to the HS. Once allowance was made for the 0.185 second delay in the H_2O and CO_2 output from the Licor, this enabled synchronization of all fast response data. Unfortunately On day 265 the analogue input to the R3 sonic failed, so from that time on the R3 was unsynchronized

Navigation data were logged in real time at 2 second intervals, using the ship's data stream rather than the separate AutoFlux GPS and compass. These data are used to convert the relative (measured) wind speed and direction to true wind speed and direction. The ship's mean meteorological data were also logged in real time at 2 second intervals. The details of the ship's meteorological instruments are given in Table 2.3.

All data were acquired continuously, using a 58 minute sampling period every hour (the remaining 2 minutes being used for initial data processing), and logged on “nimbus”, a SunBlade 100 workstation. Processing of all data and calculation of the ID fluxes was performed automatically on “nimbus” during the following hour. Program monitoring software monitored all acquisition and processing programs and automatically restarted those that crashed (2.2 Appendix A). A time sync program was used to keep the workstation time synchronised with the GPS time stamp contained in the navigation data. Both “nimbus” and all the AutoFlux sensors were powered via a UPS. Any further data processing required was performed on a second SunBlade 100 (“cirrus”).

All of the instruments were mounted on the ship's foremast (Figure 2.2) in order to obtain the best exposure. The psychrometers and the fast response sensors were located on the foremast platform and the radiation sensors were mounted on a platform installed at the top of the foremast extension. The heights of the instruments above the foremast platform were: HS sonic anemometer, 2.11 m; R3 sonic anemometer 2.86 m; psychrometers 1.85 m; Licor H2O/CO2 sensor 1.21 m.

Sensor	Channel variable na	Addres	Serial N	Calibration Y = C0 C1*X + C2*X^2 + C *X^3	Sensor positi	Parameter (accuracy)
Psychrometer	1 pds1	$ARD	HS1031 D	C0 –1.028209 C1 3.956719E-2 C2 3.04469E-7 C3 8.247377E-10	Port side of foremast platfo	Wet and dry b air temperatur and humidity (0.05°C)
Psychrometer	2 pws1	$BRD	HS1031 WET	C0 –1.242953 C1 4.008864-2 C2 –4.480979-7 C3 1.200651-10		
Psychrometer	3 pdp2	$CRD	IO2002 DRY	C0 –10.40584 C1 3.832149E-2 C2 2.019618-6 C3 5.050707E-11	Port side of foremast platfo	Wet and dry b air temperatur and humidity (0.05°C)
Psychrometer	4 pw2	$DRD	IO2002 W	C0 -10.41061 C1 3.938167-2 C2 7.661895-7 C3 5.436118E-10		
Epply LW dor temp.	6 Td1	$4RD	31170	C1 1	Top of forema platform, por position	Incoming longwave radiation (10 W/m2)
Body temp.	7 Ts1	$KRD	31170	C1 1		
Thermopile	8 E1	$LRD	31170	C1 1		
Epply LW dor temp	9 Td2	$MRD	31172	C1 1	Top of forema platform, stbdposition	Incoming longwave radiation (10 W/m2)
Body temp	10 Ts2	$NRD	31172	C1 1		
Thermopile	11 E2	$ORD	31172	C1 1		

Table 2.1 The mean meteorological sensors. From left to right the columns show; sensor type, channel number, rhopoint address, serial number of instrument, calibration applied, position on ship and the parameter measured.

Sensor	Program	Location	Data Rate (H	derived flux / parame
Gill HS Research Ultrasonic Anemometer serial no. 000027	gillhsd	stbd side of forem platform	20 Hz	momentum and hea
Licor-7500 CO_2 / H_2O sensor serial 75H0614	licor3	90 cm directly bene HS	20 Hz	H_2O and CO_2
Gill R3 Research Ultrasonic Anemometer serial no. 000227	gillr3d	94 cm to port of H	20 / 100 H	momentum and hea
MotionPak ship motion sensor seri no. 0682	via gillhsd	114 cm directly aft HS	20 Hz	EC motion correctio

Table 2.2 The fast response sensors.

Name	Sensor	Type	Serial no.	Sensitivity	Surfmet Cal
STIR	Kipp & Zonen CM6 (335 – 2200 nm)	Pyranometer	994132	11.43 µV /W/m2	8.688097E4
PTIR	Kipp & Zonen CM6 (335 – 2200 nm)	Pyranometer	973135	11.84µV/W/m2	9.737098E4
SPAR	ELE DRP-5 (0.35 to 0.7 µm)	PAR	30470	7.18µV/W/m2	1.5432099E5
PPAR	?	PAR?	unknown		1.17785E5
Pressure	Vaisala PTB100A	Barometric	S361 0008	800–1060 mbar	
wind speed	Vaisala WAA151	Anemometer	P50421	0.4-75 m/s	
Wind Dir	Vaisala WAV151	Wind Vane	S21208	-360 deg	
Air temp	Vaisala HMP44L	Temp	U 185 001	-20-60 degC	
humidity	Vaisala HMP44L	Humidity	U 185 001	0-100%	

Table 2.3 The ship's meteorological sensors, all logged by Vaisala QLI50 (R381005)

Note Correct Cal for SPAR should have been 1.39275E5.

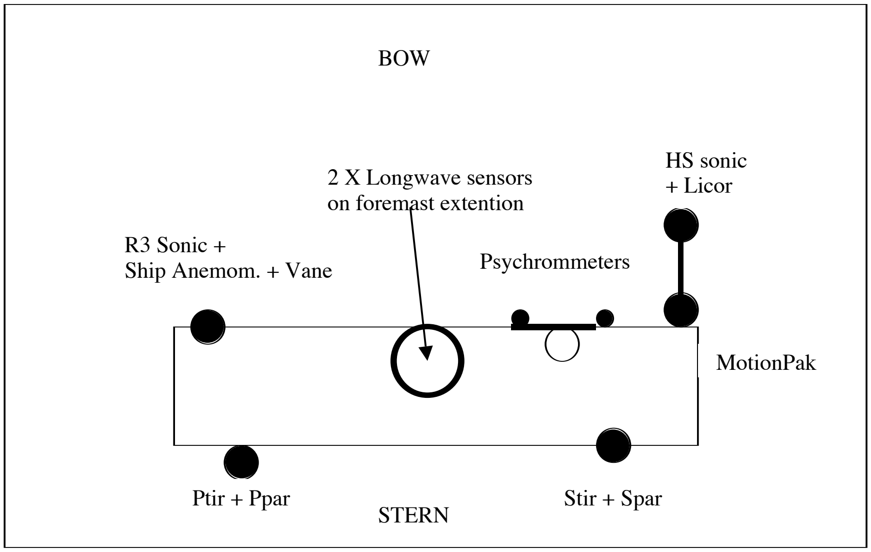

Fig. 2.2 Schematic plan view of the foremast platform, showing the positions of the sensors.

2.2.3. Mean meteorological parameters.

Air temperature and humidity

Two wet- and dry-bulb psychrometers were installed on the foremast at SOC for the start of D284. During D285 it was noticed that the dry bulb of psychrometer PDP2 (IO2002) was consistently reading higher than psychrometer PDS1 (HS1031). To ascertain which psychrometer was incorrect PDP2 (HS1031) was replaced on day 325 (10:00hrs) with sensor HS1026. During the calibration up date of this sensor it was noticed that IO2002 calibration was entered incorrectly and that an offset of -0.40584 deg was missing. With this corrected both psychrometers then agreed well. This did not cause any problems since the automatic processing chooses the lowest of the two dry bulb temperatures. Between Days 330 – 335 and 337 – 341 PDP2 (hs1026) became very noisy in damp conditions and was removed from the automatic processing. Allowing for the offset in PDP2, 1 minute averaged data from the two psychrometers showed that the mean difference between the dry bulb temperatures was only 0.007º (standard deviation of 0.12º): the large standard deviation is due to occasional drips from the wet bulbs falling on the dry bulbs. The difference between the wet bulb temperatures was only 0.02º (s.d. 0.073) well within the sensor specification. A comparison between the ship's air temperature sensor and the best psychrometer data showed that the former is biased slightly high by 0.022º (s.d. 0.11º).

Relative humidity was calculated from the psychrometer data and compared to the ship's humidity sensor. The ship's sensor read slightly lower by 0.24% (s.d 3.5%).

Wind speed and direction.

There were three anemometers mounted on the foremast platform (Fig. 2.2). On the port side were the ship's propeller anemometer and vane plus a fast response R3 Solent sonic anemometer. On the starboard side was the main AutoFlux fast response HS Solent sonic anemometer and MotionPak. Both fast response sensors measured all three components of wind speed and both are calibrated on a regular basis. The HS anemometer was the best exposed and will be used as the reference instrument in the following comparison. The measured wind speeds (uncorrected for ship speed) from each anemometer are compared to those from the HS in Fig. 2.3, which shows the wind speed difference (measured - HS measured) against relative wind direction for each anemometer. A wind blowing directly on to the bows is at a relative wind direction of 180 degrees. For a bow on wind, the R3 sonic and the ship anemometer read high by about 5%. Some of the biases will be due to flow distortion. Accurate flow distortion corrections have yet to be determined for the precise anemometer locations, but previous work (Yelland et al. 2002) has shown that the bias at the R3 and HS anemometer sites should be between -1 and +2%.. Since the HS and R3 sonics were located on the opposite side of the foremast extension to each other, roughly 50% of the trend in wind speed error seen in the latter is actually due to the variation in flow distortion with wind direction at the HS anemometer site. The large dips in the speed ratios at 90 and 270 degrees are due to the HS and R3 anemometers being in the wake of the foremast extension for winds from the port and starboard beams respectively. Fig. 2.4 shows the difference in relative wind direction as measured by each anemometer compared to that from the HS. It has been noted before (Yelland and Pascal., 2004) that the ship anemometer is mis-aligned by about 10 deg. From the bow-on winds the ships anemometer shows an error of 17 deg implying that the HS maybe mis-aligned by about 7 deg. This would also make the HS and R3 come to close agreement as they differ by about 10 deg.

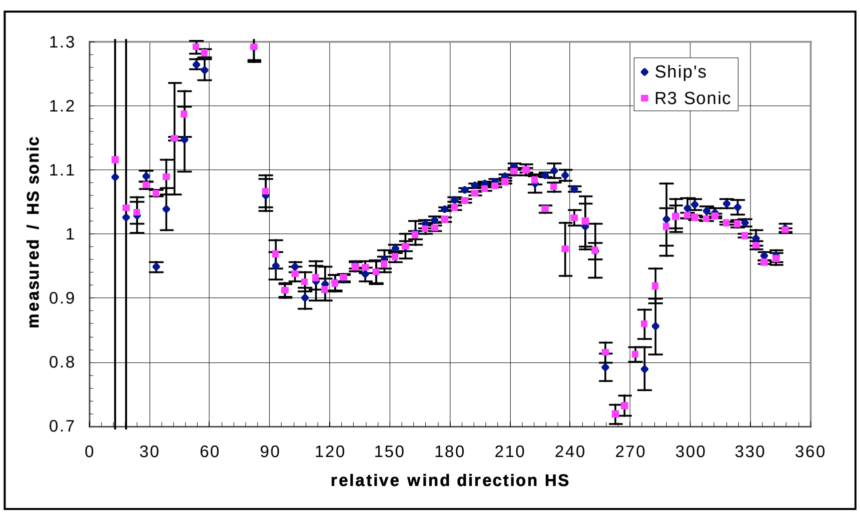

Figure 2.3. Measured wind speed / wind speed from the HS sonic for the R3 sonic and the ship's anemometer each binned against relative wind direction. A relative wind direction of 180 degrees indicates a flow directly on to the bow of the ship.

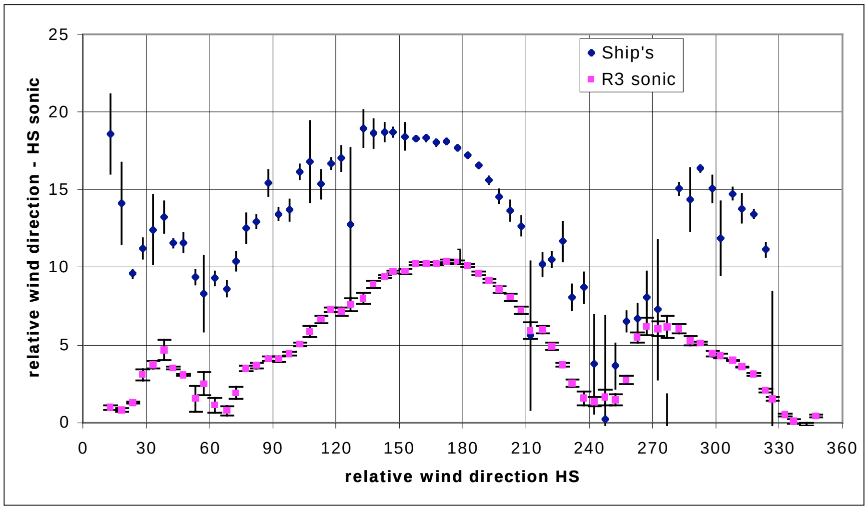

Fig. 2.4 As Fig. 2.3 but showing the difference (measured - HS) in the relative wind direction from the two anemometers.

TIR and PAR sensors.

The ship carried two total irradiance sensors, one (Ptir) on the port side of the foremast platform and the other (Stir) on the starboard. These measure downwelling radiation in the wavelength ranges given in Table 2.3. Both tir sensors functioned well throughout with a mean difference of less than 1 Watt (s.d. 16.4).

Mounted alongside each TIR sensor is a “PAR” (photosynthetically active radiation) sensor. Early examination of the data from these revealed that the starboard par sensor (Spar) produced significantly high values than the port sensor (Ppar). Later investigation of the sensors showed that the port sensor (Ppar) had no serial number, and the starboard sensor (Spar) serial no. 30470 had the wrong calibration applied. Correcting Spar to the right value then gave a mean difference of –0.4W (s.d. 1.6) showing that the sensors now agreed and that Ppar probably has the correct calibration applied..

Long wave radiation.

As part of the AutoFlux instrumentation, two Epply pyrgeometers were installed on top of the foremast extension. These sensor measure incoming long wave (LW) radiation. Following standard procedure (Pascal and Josey., 2000), three outputs from each sensor were recorded and a correction made for short-wave leakage. The Ptir data were used for this purpose. From 15 minute averages of the resulting LW data, the mean difference between the two sensors was 3.9(s.d. 2.9) W/m^2, with sensor 31170 reading relatively high. Although this is close to the expected accuracy of the sensors it appears that one sensors calibration has drifted. Applying the fit in Fig. 2.5 to LW31172 the mean difference drops to 0.002(s.d. 2.05) W/m^2.

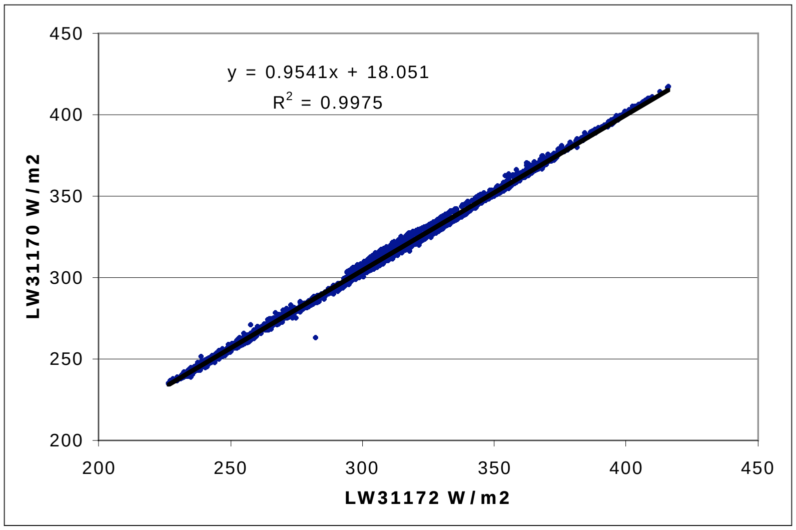

Fig. 2.5 LW31170 plotted against LW31172

Visual cloud observations.

During D284 and D285, visual cloud observations were made by the bridge officers as often as possible. These observations will be used to parameterise the downwelling longwave radiation in terms of cloud cover and type. The parameterisation will allow calculation of the LW radiation to be made from the visual observations routinely obtained by the 7000-strong Voluntary Observing Ship fleet, thus ultimately improving the accuracy of weather forecast models.

Sea surface temperature.

Sea surface temperature (SST) data from the thermosalinograph (TSG) were logged on the AutoFlux acquisition workstation as part of the "surfmet" data stream. Daily pstar files are produced as part of the normal AutoFlux processing and these were moved over to discovery2 at the end of the cruise.

Ship borne wave recorder.

The SBWR which had been faulty was fixed prior to D284 and the system was started for D284 and continued to operate thoughout D285 without problems. An attempt to install a network card in to the SBWR PC failed , so that data had to be downloaded periodically by floppy disc.

2.2.4 Initial flux results.

Inertial dissipation (ID) flux measurements.

The **ID momentum flux** obtained from the HS sonic anemometer is shown in Fig. 2.6 where the drag (transfer) coefficient is shown against the true wind speed corrected to a height of 10 m and neutral atmospheric stability. The drag coefficient is defined as (10^3 * momentum flux / wind speed ^{2})

Although flow distortion corrections have not yet been determined for the exact HS anemometer position, it has been shown that the vertical displacement of the flow varies little with anemometer position or relative wind direction (Yelland et al. 2002). In contrast, the mean bias in the measured wind speed is sensitive to both these factors. A 5% bias in the drag coefficient could be explained by a bias in the measured wind speed of only 1 to 2%, possibly due to a combination of calibration error and/or the effect of flow distortion on the mean wind speed. All the anemometers will be re-calibrated after the cruise, and accurate flow distortion corrections applied.

Fig. 2.7 shows the **ID latent heat flux** obtained from the Licor H_2O data. In general the results are in agreement with data from previous experiments, but some high values are evident. During the cruise it was noted that the licor sensor was sensitive to both rain and fog and during periods where these occur, high values of the latent heat flux can be produced.

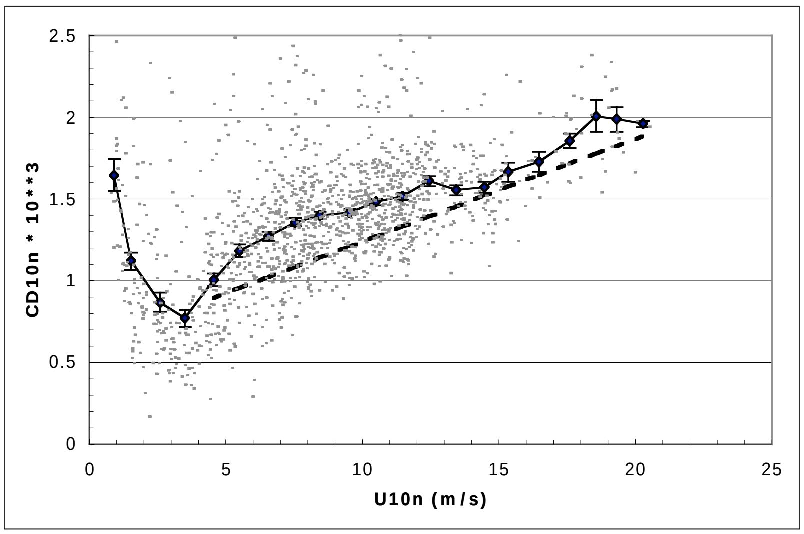

Fig. 2.6 Fifteen minute averaged values of the measured ID drag coefficient (dots), plus the mean results (solid line) binned against the 10 m neutral wind speed. The Smith 80 relationship is shown by the dashed line.

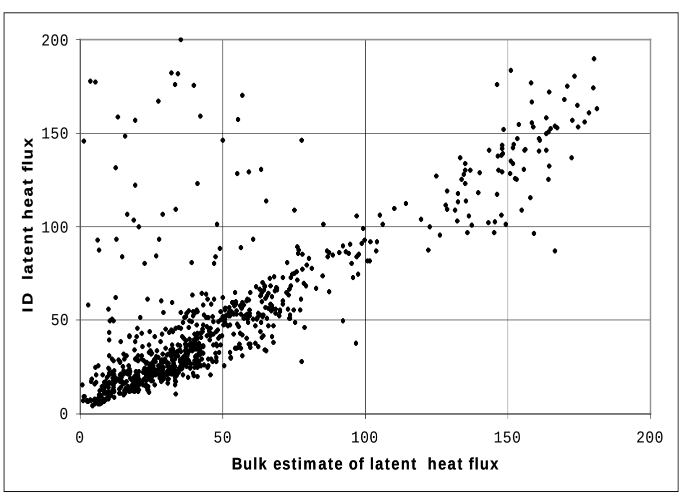

Fig.2.7 Direct measurements of the kinematic latent heat flux from the ID method (dots) shown against a flux estimated from a bulk formula for bow on winds

2.2.5 Additional Data Processing

The AutoFlux final data file and Underway (TSG) datafile were further processed and combined to produce a single weekly 15 minute averaged data file, from which weekly plots and ascii data files were produced for other cruise participants.

The AutoFlux system automatically logs a number of data streams such as mean met, winds, navigation from the GPS4000 and the underway TSG data. These data are stored in daily files which have been converted into PSTAR files. Further processing for the AutoFLux Fluxes then merges the variables needed to complete the flux processing in to one final merged file. Filename of the form mergeD285.ddd.

To produce the Met and Underway plots for the cruise report it necessary to merged the Tsg data in to this file as well. The mergeD285.ddd file also includes many variables not required for general Met and Underway parameters so while merging the TSG on it is also advisable to copy only the required variables across to the new file. This file can then be used to generate ascii data for those who are not familar with PSTAR.

The variable list from Autoflux merged file:

No: 1, 21, 23, 25, 27, 29, 31, 35, 37, 39, 41, 43, 44, 50, 51, 52, 85, 87, 90, 91, 112.

Var: jday, reldd, spdENV, press.M, Ptir.M, Stir.M, LW3117.M, pdUSE.M, pwUSE.M, cog.M, sog.M, latUSE.M, lonUSE.M,

heading, TRUspd, TRUdd, sst, U10BSL, SENBSL, LATBSL, RH.

Variable list from TSG:

No: 1, 2, 3, 4, 5, 6, 11, 12, 13, 14, 15, 16, 17, 22, 23, 24.

Var: jday, Htemp, Rtemp, Cond, Flour, Trans, Press, Ppar, Spar, Speed, Dir, Airtemp, Hum, Ptir, Stir, Salinity.

Note AutoFlux merged file variables: sst, press.M, Ptir, Stir are the same data as TSG Rtemp, Press, Ptir, Stir.

AutoFlux Variables:

jday = Julian Day in fraction of a day.

reldd = relative wind direction as measured by the HS Sonic Anemometer located Starboard side opn the Foremast BOW=180.

spdENV = relative wind speed as measure by theh Sonic HS.

press.M = Atmosphereic Air Pressure with no height correction. (inlet on foremast at 18m height).

Ptir.M = Calibrated port side Total Iradiance (Kipp & Zonen CM6B) taken from tsg data.

Stir.M = CAlibarted stbd side Total Iradiance (Kipp & Zonen CM6B) taken from tsg data.

LW3117.M = Calibrated Longwave data measured using a Eppley Pyronometer on top of the foremast .

pdUSE.M = Psychrometer Dry bulb temperature (with simple quality control bewteen two psychrometers on fore mast).

pwUSE.M = Psychrometer Wet bulb temperature (with simple quality control bewteen two psychrometers on fore mast).

cog.M = Course over ground from GPS 4000.

sog.M = Speed over ground from GPS 4000 m/s.

latUSE.M = latitude from GPS 4000.

lonUSE.M = longitude from GPS 4000.

heading = Ship gyro heading.

TRUspd = True speed of Sonic HS as measured on the STBD side of foremast.

TRUdd = True Direction of Sonic HS as measured on the STBD side of foremast.

sst = TSG Rtemp which is sea surface temperature at about 5m depth.

U10BSL = True windspeed normalized to 10m height and netural conditions.

SENBSL = Sensible heat flux derived from bulk measurements.

LATBSL = Latent heat flux derived from bulk measurements.

TSG Variables:

jday = Julian Day in fraction of a day.

Htemp = Housing temperature ie Non toxic water temperature at tsg location in water bottle annex.

Rtemp = Non Toxic water temperature at inlet at approx 5m depth.

Cond = Conductivity measured by tsg from non toxic in water bottle annex.

Flour = Fluorometer data from tsg from non toxic in water bottle annex.

Trans = Transmissometer data from tsg from non toxic in bottle annex.

Press = Atmosphereic Air Pressure with no height correction. (inlet on foremast at 18m height). Vaisala PTB100A

Ppar = Port Par Sensor (350 - 700 nm) on Foremast

Spar = Starboard Par Sensor (350 - 700 nm) on Foremast

Speed = Vaisala WAA151 cup anemometer port side of Foremast

Dir = Vaisala WAV151 Vane port side of Foremast

Ptir = Calibrated port side Total Iradiance Kipp & Zonen CM6B (335 - 2200nm).

Stir = CAlibarted stbd side Total Iradiance Kipp & Zonen CM6B (335 - 2200nm).

Salinity = calculated from Conducivity and H temperature.

Airtemp = Temperature from Vaisala HMP44L air temp and humidity sensor on foremast

Hum = Humidity from Vaisala HMP44L air temp and humidity sensor on foremast

2.2 References

Yelland, M. J. and R. W. Pascal, 2004: RRS Discovery D279, ROPEX, 4th April – 10 May 2004. Southampton Oceanography Centre, Cruise Report.

Pascal, R. W. and S. A. Josey, 2000: Accurate radiometric measurement of the atmospheric longwave flux at the sea surface. *J. Atmos. Oceanic Technol*., 17, 1271-1282, 2000.

2.2 Appendix A. List of significant events.

Day 265: 4 days after sailing from SOC the analogue input to the R3 sonic failed stopping the R3 synchronization.

Day 307: Licor program modified, Cleaned Licor, LW and TIR sensors.

Day 309: TSG started 0700 gmt.

Day 315: nimbus hung and had to be rebooted and fsck run manually.

Day 316: R3 sonic stops working.

Day 319: 10:00 gmt Cleaned Licor, LW and TIR sensors. Found loose wire on R3 on foremast, 10:30 gmt R3 working again but no sync.

Day 325: 10:00 Cleaned Licor, LW and TIR sensors. Replaced psychrometer HS1031 with HS1026, corrected error in psy IO2002 dry bulb cal causing a positive offset of +0.40584.

Day 328: Progmon program modified to clear launch no. at midday.

Day 329: Progmon modified so that disk stats sent by Orbcomm.

Day 331: Progmon modified so that disk stats sent only once per hour.

Day 332: Progmon crashed, had to put 10 sec delay back in.

Day 334: Psy dry bulb PDS1 (HS1026) started to be very noisy when damp. Changed scrp.amet so only PDP2 dry bulb used in AutoFlux processing.

Day 338: Orbcomm stopped working.

Day 340: Modified “amet.edit.windows” so longwave does not go out of range.

Modified daily.scrp so that tsg daily file and merg daily file automatically copied to cirrus for further processing. Modified ‘cvibat’ on nimbus so cirrus mounted to /mnt on bootup.

Day 344: 11:30 gmt Change Psy HS1026 back to HS1031, Cleaned Licor, LW and TIR sensors. 13:00 gmt. Changed scrp.amet so both dry bulbs used.