COMPARISON OF SHIP AND AIRCRAFT FLUX MEASUREMENTS DURING NAURU'99

Eddy correlation flux measurement systems were deployed on three platforms during the Nauru'99 field campaing: the JAMSTEC research vessel *Mirai*, the NOAA ship *Ron Brown* and Airborne Research Australia's (ARA) Cessna aircraft. Because of its high speed relative to the mean wind the aircraft provides space samples of fluxes whilst the ships provide long time series at single locations. Combining spatial and temporal flux measurements can provide information about the atmosphere not available from single platforms only. If measurements from the three platforms are to be successfully combined it is first necessary to determine whether the calibrations of the measurement systems are in agreement and to develop corrrections if they are not. In this report we compare latent heat-, sensible heat- and momentum fluxes from the *Ron Brown* with those from the aircraft.

Gradients of mean meteorological variables encountered in the vicinity of the *Ron Brown* hampered attempts to make direct comparisons between the two platforms. In an attempt to deal with this problem the two set of meaurements were compared with the COARE v2.6a bulk flux algorithm. In addition, the bulk algorithm was used to attempt to estimate the expected differences in the direct 'fly-past' comparisons. Ship measurements agreed well with the bulk flux algorithm, while the aircraft over estimated H flux and underestimated LE and τ fluxes. The attempt to use the bulk algorithm to improve the fly-past comparisons was only partially successful and yielded little useful information.

1.1 Measurements

The *R.V. Ron Brown* was stationed at 164.4°E, 2°S from June 22nd to July 30th, 1999. During this time vertical fluxes of sensible heat, latent heat and momentum were made by the eddy-correlation method. Instruments were mounted on the bow of the ship, to avoid contamination of the airflow by the ship. The 3-d wind vector, humidity and temperature were recorded at 10Hz. The wind vector was corrected for ship motion and fluxes were calculated as 1-hour averages from the 10Hz data. Mean meteorology and radiative fluxes was also measured and by means of the COARE v.2.6a algorithm bulk fluxes were calculated. Instruments were mounted at 14.5 and 17.5m above the surface

The ARA Cessna-404 aircraft , *Investigator 2* (herafter referred to by its registration code 'EOS') aircraft flew 9 'big triangles' during the time the *Ron Brown* was at the above mentioned location. Using sensors mounted on the aircarft nose measurements were made of the 3-d wind vector, temperature and humidity. Eddy correlation fluxes were calculated using the cumulative cospectrum technique from 30-km long non-overlapping samples. Bulk fluxes were calculated using the COARE v2.6a algorithm. All flight legs were made at a nominal altitude of 30m.

1.2 Comparisons

Applying Taylor's frozen turbulence formula to the aircaft measurements, assuming a mean wind of 6m/s, each 30-km sample is equivalent to 83mins of sampling by a fixed platform. Thus for the range of wind speeds the occurred during Nauru'99 the aircraft and ship-board flux measurements should exhibit a similar level of statistical stability.

With few exceptions, the cumulative cospectra used to calculate aircraft fluxes exhibited a well defined plateau region, indicating that all flux carrying wavelengths were captured (Saucier et al 1991). So underestimation of fluxes due inadequate sampling by either platform is not expected to contribute to any difference between the fluxes measured.

When comparing fluxes made by different platforms differences due to systematic differences in the measurement equipment or processing algorithms may be confused by 2 further sources of error:

1. Random differences which result from the statisitcal nature of eddy-correlation measurements
2. Systematic differences due to the flux measuring systems sampling different flows

The first problem may be minimised by use of sufficiently long sampes and by making as many comparisons as possible, thus allowing the randomness to be treated by statistical methods. The second requires examination of the physical system to determine how reliably we may claim to be comparing like with like.

1.2.1 Spatial variation of mean variables

During the big triangle phase of Nauru'99 convection was suppressed and mean boundary layer parameters were largely homogeneous along the edges of the triangle, as seen in plots of aircraft data. One persistent inhomogeneity was higher SST in the vicinity of the *Ron Brown*, relative to the rest of the triangle, as seen in Figure 1.1. This feature persisted throughout the big triangle phase and can be seen in both the aircraft measurements and as the difference between SST measured by the *Ron Brown* and *Mirai* (all SST sensors have been presviously intercompared and differences corrected (see Matthews et al 2000)). The flight illlustrated in Figure 1.1 was the most inhomogeneous of the 9 flights (note the SST front halfway between Nauru and the *Mirai*), other days were more uniform.

The presence of the variation in SST near *Ron Brown* imposes restrictions on the possiblity of performing fly-past comparisons of flux measurements. Even those aircraft samples nearest to the *Ron Brown* were made under different mean conditions and systematic differences are to be expected. As a further complication, because there is a gradient in SST along the wind direction, the aircraft will be sampling air that is adjusting to the changing in SST and thus the turbulence measured cannot be assumed to be stationary.

A comparison of mean meteorological variables for the 18 flux legs that either began or ended at the *Ron Brown* are presented in Figure 1.2. This comparison was performed by using linear interpolation to match the ship data with the start times of the aircraft flux legs. Mean values and mean offsets are given in Table 1.1. The most significant difference is in SST. Smaller differences were measured in temperature, humidity and wind direction.

Table1.1 Mean variables for flypasts

	EOS	*Ron Brown*	Difference
Potential temperature (°C)	27.26	27.37	-0.10±0.12
Specific humidity (g/kg)	18.09	17.95	0.13±0.08
wind speed (m/s)	4.84	4.56	0.28±0.38
wind direction	109.3	103.6	5.7±5.0
SST (degC)	28.67	29.46	-0.79±0.35
S_{dn} (W/m^2)	782.5	751.1	31.4±39.5

The absence of any area within the big triangle with sufficiently high SST makes a true fly-past comparison impossible with the present data set. However, the difference in fluxes due to the difference in SST can be estimated using the COARE bulk flux algorithm (Fairall et al 1996). By comparing bulk fluxes calculated from mean variables during the flux sampling legs the expected difference in measurements can be estimated. This makes use of bulk flux algorithm as a portable standard and requires that the mean meteorological and radiation measurements are in agreement. Such agreement has been achieved (Matthews et al 2000). Before this can be done, it is necessary to establish the level of agreement between the individual EC meaurements and the bulk flux algorithm.

1.2.2 Comparison of the COARE v2.6 bulk flux algorithm with EC flux measurements

In comparing measurements made during fly pasts it will be necessary to restrict analysis to only those measurements. As a preliminary, bulk and eddy correlation measurements for the full aircraft data set, and for the *Ron Brown* data restricted to the big triangle days is presented. Bulk and EC fluxes are presented as scatter plots in Figure 1.3, with lines of best fit. A linear analysis is presented in Table 1.2.

As a consequence of the large relative scatter in H fluxes linear analysis renders little useful information, as indicated by the very small values of r^2. Comparing mean values, both platforms overestimate H: *Ron Brown* by 1.3 W/m^2 and EOS by 2.7 W/m^2. The difference in mean bulk H is due to the persistently larger temperature deficit in vicinity of the *Ron Brown* (see Section 1.2.1).

Excellent agreement was seen between *Ron Brown* bulk and EC measurements of LE and τ flux , mean values agree to better than 10%, as do the slopes of the best fit lines. Aircraft EC measurements are lower than the prediction of the bulk algorithm for both τ and LE fluxes. Mean τ flux is 20% lower than predicted and LE is 27% lower. The linear analysis suggests that the relative sensitivity of the aircraft EC system is 29% less than that of the bulk algorithm (Table 1.2).

Table 1.2 Comaprison of eddy correlation and bulk fluxes.

	flux	meanEC	meanBulk	slope[1]	r^2
Ron Brown	H	5.44	4.12	1.14	0.001
	LE	114.2	120.2	0.96	0.70
	τ	0.036	0.040	0.96	0.72
EOS	H	4.50	1.78	1.32	0.00
	LE	76.4	105.2	0.71	0.56
	τ	0.032	0.040	0.71	0.36

1.2.3 Fly past comparisons

Although the high SST near the *Ron Brown* strongly affects bulk H flux predictions (Table 1.2) LE and τ fluxes are less affected (mean τ predictions are in fact identical). In making fly past comparisons the COARE algorithm was used to estimate the expected difference between ship and aircraft EC measurements. This approach is justified only because good agreement was seen between the *Ron Brown* EC measurements and the bulk algorithm, and only for comparing mean values of several fly pasts.

Flux measurements and predictions for the 18 fly-pasts are presented in Table 1.3. Bulk and EC H fluxes from the *Ron Brown* are in good agreement, the difference being only 0.23 W/m^2. The bulk prediction for the aircraft runs is much lower than for the *Ron Brown*, as expected given the differences in SST. Aircraft EC H measurements, while lower than the *Ron Brown* EC measurements are still in excess of the bulk prediction.

The difference between measured and predicted LE flux for the *Ron Brown* is statistically significant so, although the prediction and measurements from the aircraft are lower than the ship, we cannot come to any useful conclusions from this comparison. Similarly, the differences between the τ predictions and measurements from the Ron Brown mean that the attempted use of the bulk formula as a transfer standard yeilds no useful results.

Table 1.3 Analysis of EC and bulk fluxes for fly pasts

	Ron Brown		EOS		Differences		
	Bulk	EC	Bulk	EC	RBbulk-RBEC	EOSbulk-RBbulk	EOSEC-RBEC
H (W/m^2)	6.62± 0.85	6.39± 1.28	2.52± 0.8	5.3± 0.62	0.23±1.6	-4.1±1.4	-1.09±1.11
LE (W/m^2)	111.4 ±13.5	96.8± 14.1	99.8± 13.8	83.5± 15.7	14.6±8.2	-11.6±7.5	13.3±14.4
τ (W/m^2)	0.028 ±0.01	0.019 ±0.01	0.040 ±0.01	0.38± 0.01	0.008±0.003	0.004±0.004	0.018±0.005

[1] Slope of line of best fit passing through (0,0)

1.3 Conclusions

Measurements collected during the Nauru'99 field campaign have been used in conjunction with the COARE v2.6a bulk flux algorithm to compare the flux measurement systems on the research vessel *Ron Brown* and ARA's Cessna aircraft

Bulk and EC Latent heat and momentum fluxes from the *Ron Brown* agreed to better than 10%, while mean H flux from the EC system was higher than that predicted by the bulk algorithm. In contrast, The aircraft EC system τ and LE fluxes were up to to 30% below the bulk prediction. Aircraft mean EC H flux was larger than predicted by the bulk algorithm. Because of the small range of H fluxes during Nauru'99 it was not possible to determine how well the sensitivities of the H measurement systems agreed.

Because of variation in SST in the vicinity of the *Ron Brown* direct fly-past comparisons of the flux measurment systems were not possible. An attempt was made to use the bulk flux algorithm as a transfer standard to effect a comparison. This method was useful for comparing H fluxes and indicated that, as with the bulk flux comparison, that the aircraft overestimates H. The technique did not provide useful results for the LE or τ flux comparisons.

In concluding, we recommend that if aircraft flux measurements are to be used in conjunction with ship measurements LE and τ fluxes should be increased by 40% (to compensate for the 29% underestimation). Although aircraft H fluxes appear too high, the range of fluxes encountered during Nauru'99 is too small to be able to formulate a correction.

1.4 References

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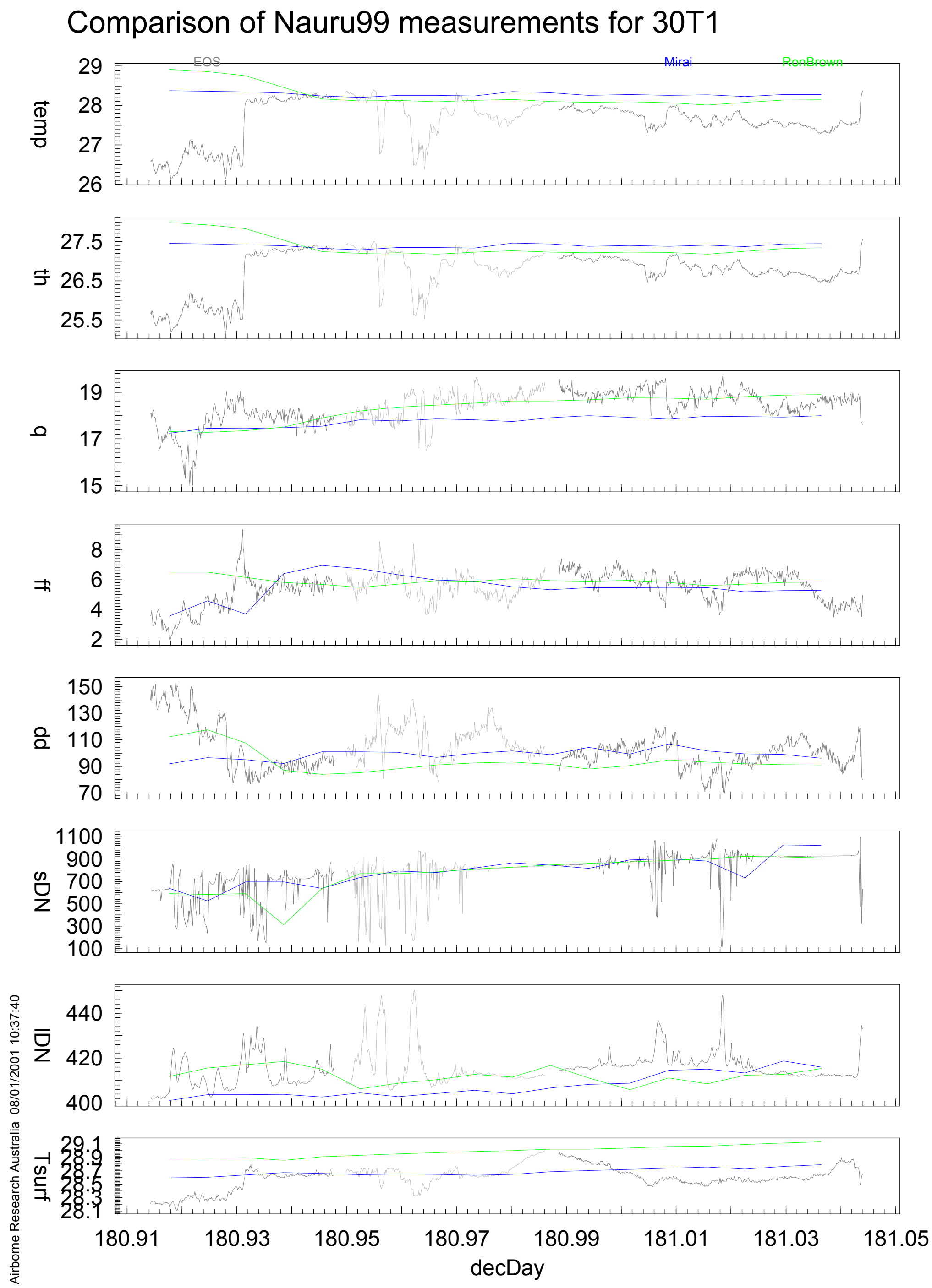

Figure 1.1 Spatial variation of meteorological and radiation parameters around the Big Triangle. Dark-, light- and dark-gray curve are aircraft legs from Nauru to the Mirai, Mirai to Ron Brown and Ron Brown to Nauru, respectively. The area of higher SST in the vicinity persisted throughout the Big Triangle flights. Note also the SST front beteen Nauru and the Mirai.

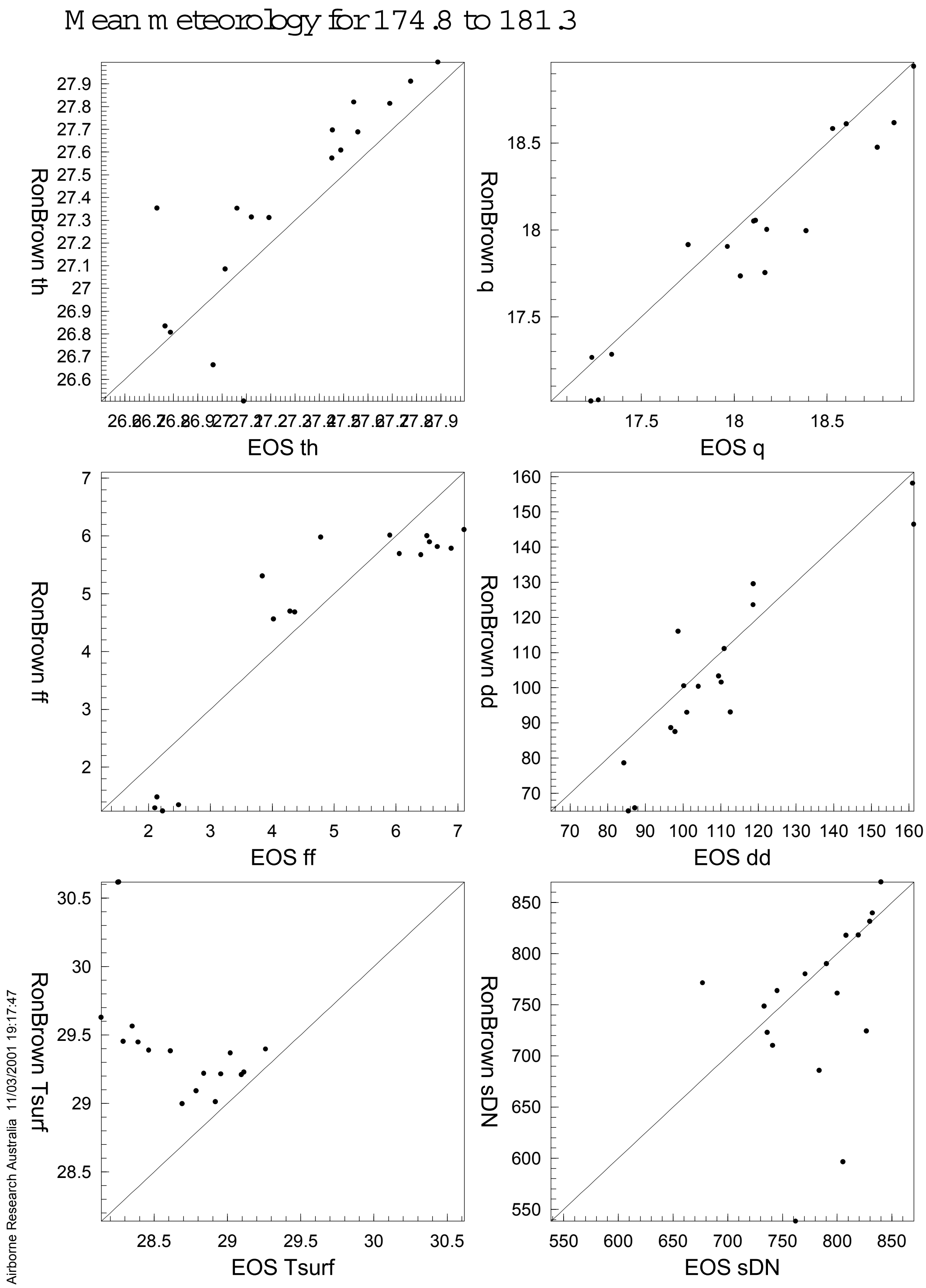

Figure 1.2 Mean meteorology and radiation for each of 18 fly-pasts. Note the consitently higher SST recorded by the Ron Brown

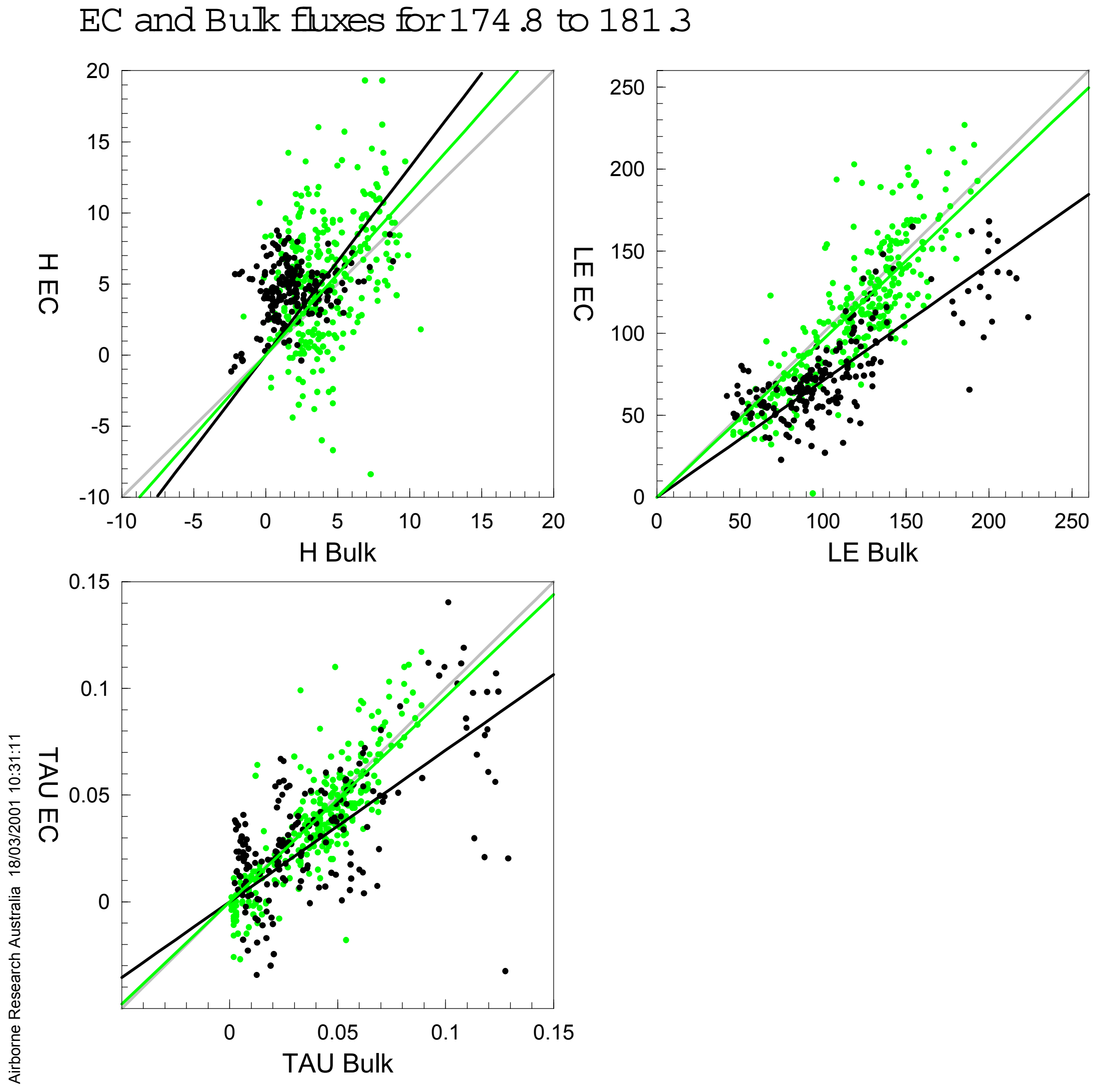

Figure 1.3 Comparison of bulk and EC flux measurements for all Big Triangle measurements. Lines of best fit by linear regression, forced through (0,0). Positive τ flux is into the ocean.

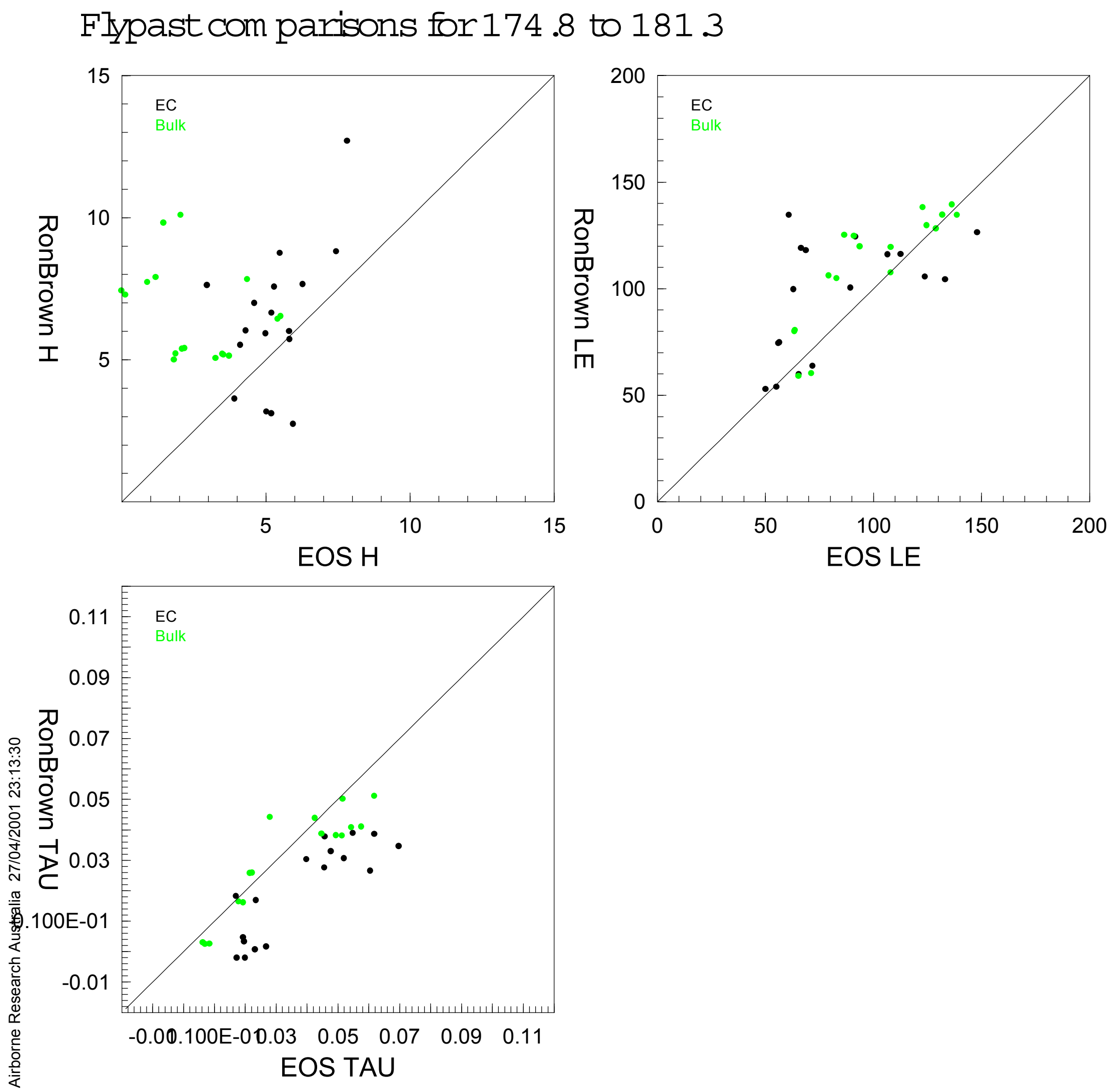

Figure 1.4 Fly-past comparisons. Aircraft fluxes from the 18 flight legs beginning or ending at the Ron Brown. Ship fluxes calculated by linear interpolation from flux time series.