Improving the Accuracy of Flux Measurement: Experiences of the TOGA-COARE Air-Sea Interaction Group

i.e. the COARE "Flux" Group

Co-Chairs: Frank Bradley and Bob Weller

Improving Flux Measurement Accuracy: Experiences of the TOGA-COARE Air-Sea Interaction (Flux) Group

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The TOGA Coupled Ocean-Atmosphere Response Experiment (COARE) was a four-month process study in the western Pacific warm pool which ended exactly 10 years ago (28 February 1993), but aspects of the subsequent data analysis remain relevant to this workshop. The "Flux Group" was formed to facilitate timely analysis and exchange of the surface met. and ocean data-sets obtained on the 10 ships and the central IMET mooring, and to ensure the quality and availability of flux fields needed for various research projects, mapping and modelling. COARE planners had set a goal of 10 Wm^{-2} for the accuracy of monthly averaged net heat exchange. In the context of bulk fluxes, this implied that sea and air temperatures, humidity, and wind speed must be measured to within 0.2K, 0.2g/kg, and 0.2ms^{-1} respectively (Fairall et al. 1996).

First analysis of two days of underway inter-comparisons between the ships, near the IMET buoy, revealed discrepancies in these variables and also the radiative flux components which exceeded the10 Wm^{-2} target. For example, the spread of wind speed exceeded 1 ms^{-1} on both days, as shown in the left-hand graphs. On the right, corrections have been made for surface currents (to get wind speed relative to the water), errors in ship speed, and adjustment to standard 10m height, and agreement is much closer. Also, initially the spread of shortwave radiation measurements around their peak value was about 100 Wm^{-2}. Grouping all instruments for inter-comparison, then re-calibrating one of them by an independent facility, reduced the differences to an acceptable level.

All longwave radiation instruments were contaminated by the solar flux, except that on the Moana Wave where the body and dome temperatures were recorded, enabling the full pyrgeometer equation to be used. An empirical function of solar flux was used to correct the others, and biases removed to match the Wave. In the process, the usual form of the pyrgeometer equation was found to contain an error equivalent to almost 10 Wm^{-2}. This was subsequently verified against a radiative transfer model RRTM (Fairall et al. 1998). The accuracy of pyrgeometers is about 5 Wm^{-2} if dome and case temperatures were measured, degrading to at least 20 Wm^{-2} when the manufacturer's internal compensation is used. Since radiation instruments used aboard ships today are mostly identical to these it is crucial to calibrate frequently, to avoid the internal compensation option in pyrgeometers, and to use the correct form of the equation.

In the COARE inter-comparisons, Franklin's wet and dry bulb psychrometers were taken as reference for temperature and humidity, on the basis that the platinum thermometers were stable, well calibrated, and serviced daily. The comparison on Ron Brown during JASMINE shows a more recent Vaisala instrument, and the ship's IMET sensor, both performing well. The latter did fail later, however, and without close monitoring may well have remained unnoticed until next due for calibration.

During the intercomparisons, all ships agreed to within 0.1°C for sea temperature during nighttime, presumably because ships' thermo-salinographs are accurate, well maintained and calibrated. The various SST datasets only differed during daytime when the sea temperature depended on the depth of measurement, as illustrated by Franklin's profiling CTD on a sunny, light wind day. Heat and moisture transfer depend on the interface sea temperature, approximated by an infra-red (IR) radiometer measurement, nowadays capable of 0.1°C accuracy. The first time-series from

EPIC2001 show temperatures from an IR radiometer (CIRIMS), a sensor (Seasnake) towed at nominal depth of 5cm, and the Ron Brown thermo-salinograph at 5.6m depth. Surface warming is seen by both the Seasnake and CIRIMS, their difference of about 0.3°C being the cool skin. Warming is greatly attenuated at 5.6m and lags the surface by about 3 hours. The red line is the interface temperature computed by cool skin and warm layer models, based on the Seasnake measurement, which captures the diurnal warming but not the cool skin. Extrapolating the measurement at 5.6m to the interface, the cool skin is modelled well but the warm layer is slightly underestimated. However, the phase is largely restored and modelled interface temperature is clearly more realistic for use in a bulk flux algorithm than the raw 5.6m measurement. Given a reliable model the "bulk" temperature may be preferred over a near-surface measurement, being more uniform and less noisy.

The accuracy of rainfall measurements from the variety of sensors used during COARE remained uncertain until recently. Johnson and Ciesielski (2000; hereafter JC), calculated atmospheric moisture budgets to show that the basic problem in comparing estimates of rainfall is its spatial and temporal variability. For the same time periods and area (1 -3°S; 153-157°E) considered by JC, we have re-examined as much archived rainfall data as could be located, and calculated rainfall accumulations. The gradient from 11 mm day^{-1} at 157°E to 7 mm day^{-1} at 154°E found by JC, corresponds almost exactly with the difference in ORG estimates by the three survey ships operating near IMET (average 11.03 mm day^{-1}), and by PRC#5 located at the rainfall minimum (7.02 mm day^{-1}).

The ongoing issue is why the ship rainfall was so much higher than the radar estimates. The period between Days 355 and 375 included a strong westerly wind event, which triggered widespread storm activity. The radar time series above the I MET mooring shows that the intensity of some rainfall seems to be missed by the radar, for example the storms around days 358 and 369. Overestimation by ORGs is unlikely, because the intensity of these storms is also seen by Wecoma's siphon gauges. The EPIC2001 rainfall accumulations show that correction procedures developed for both siphon and ORGs lead to agreement, and that the IMET raingauge performs well.

In the Algorithm Intercomparison Project (AIP-3; Ebert and Manton 1998), 57 satellite rainfall algorithms were compared with the COARE radar rainfall because the *in situ* rainfall results were judged "unreliable". On average the algorithms overestimated precipitation by about 30% relative to the radars. It's probable that the conclusions of the AIP-3 project were unnecessarily pessimistic, and that use of the COARE radar data may underestimate rainfall.

References

Ebert, E.E , and M.J. Manton, 1998: performance of satellite rainfall estimation algorithms during TOGA-COARE. *J. Atmos Sci*., **55**, 1537-1557.

Fairall, C.W, P.O.G. Persson, E.F. Bradley, R.E. Payne, and S. Anderson, 1998: A new look at calibration and use of Eppley Precision Infrared radiometers: Part I, theory and applications. *J Atmos. Oceanic. Tech*., **15**, 1230-1243.

Johnson, R.H., and P.E. Ciesielski, P.E., 2000: Rainfall and radiative heating rates from TOGA COARE atmospheric budgets. *J. Atmos. Sci.*, **57**, 1497-1514.

TOGA-COARE accuracy target – ±10 Wm^{-2} for monthly averaged net air-sea energy exchange

Partition equally between radiative and turbulent components

Implies: $\delta S \approx 0.2\ ms^{-1}$

$\delta T_s \approx 0.2$ K

$\delta T_a \approx 0.2$ K

$\delta Q_a \approx 0.2\ g\ kg^{-1}$

NOTES - JAPANESE/AUSTRALIAN INTERCOMPARISON GROUP

Present: K.Takeuchi, Kanari, H.Ishida, A.Tsukamoto, T.Fujitani F.Bradley, P.Coppin, S.Godfrey

The window of opportunity for intercomparison of fluxes and ocean microstructure between the Japanese and Australian ships is very restricted, because of the various ship schedules within the IFA. These are:

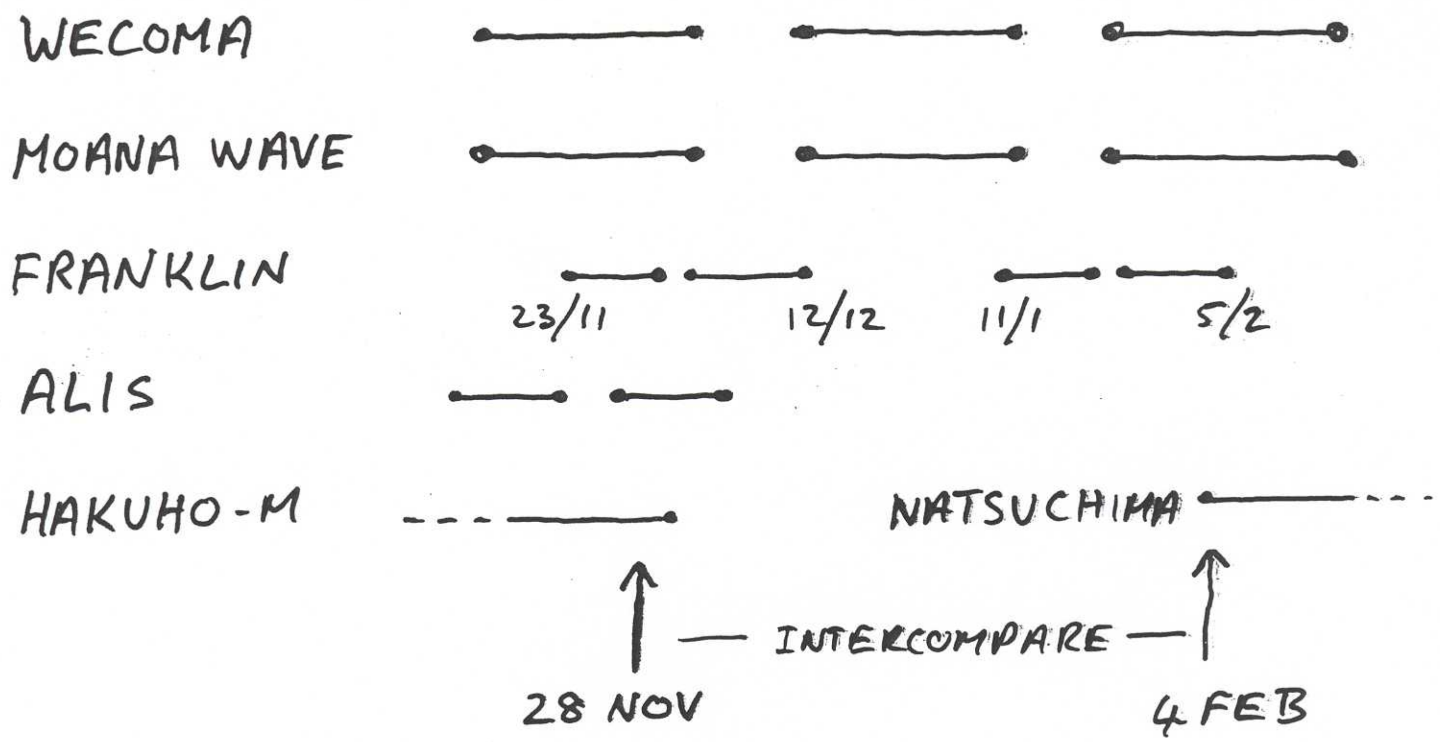
Franklin	22/11-17/12 1992 and 8/1-4/2 1993 at 2S
Hakuho Maru	11/11-29/11 1992 on equator
Natsuchima	3/2-15/2 1993 on equator.

The intercomparison between Franklin and Hakuho will take place on 27th or 28th November, depending on weather conditions. The two ships will steam into wind at about 3 knots making atmospheric flux measurements along parallel tracks separated by 3 cables (say 500m) for 2.5-3 hours ending in the vicinity of the microstructure ship (Moana Wave). An intercomparison of ocean mixing will be made (about 75 mins for 2 casts), then the ships will retrace their tracks at 12 knots which will take about 3/4 hour. This pattern will be repeated continuously for 24 hours during which time the microstructure comparisons will be made about 5 times.

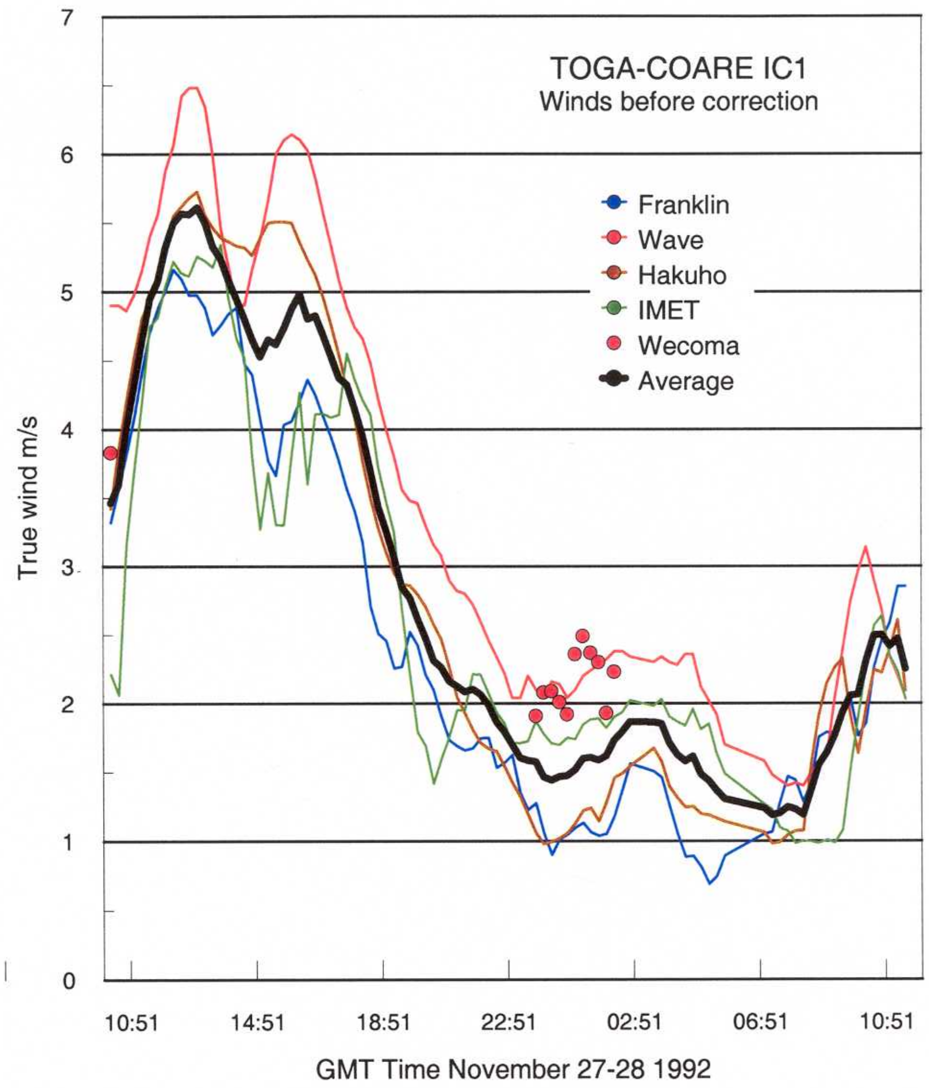
If winds are very light and variable, it may be better to steam faster (and further) upwind so that the relative wind is closer to the ship direction.

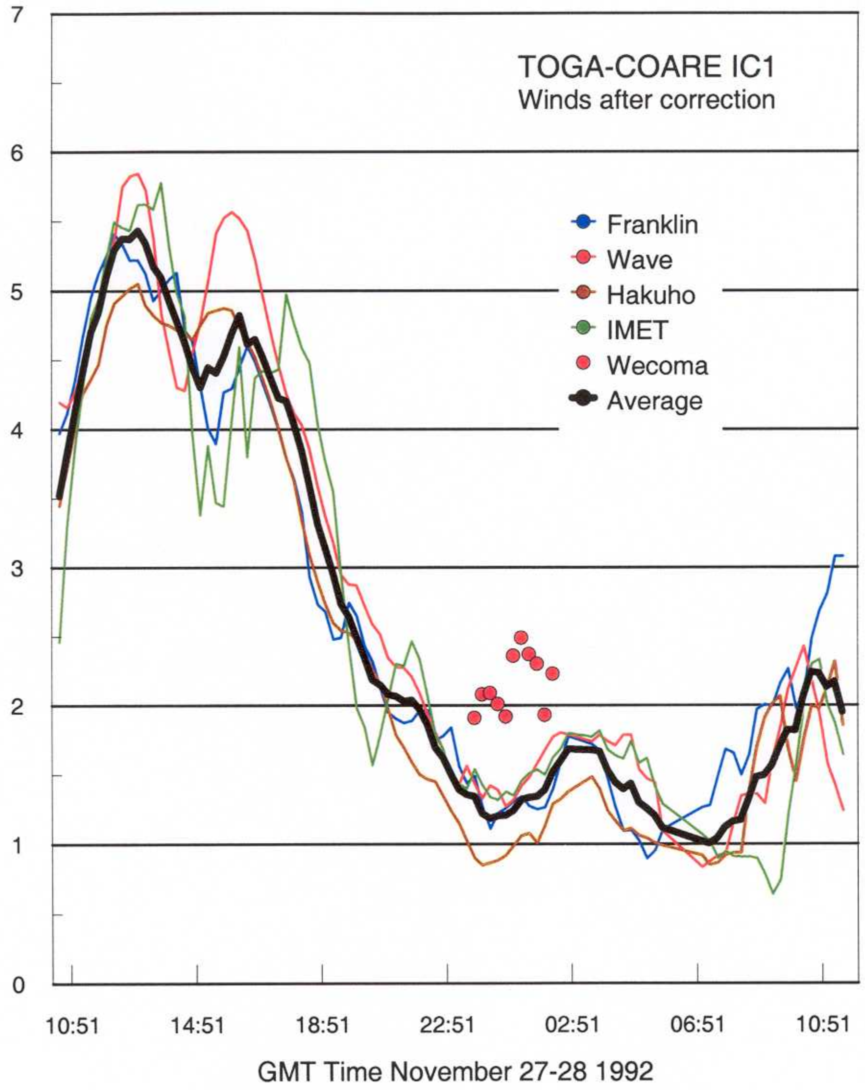
Communications between the ships will be best by Fax.

There is only one day possible for the Natsushima/Franklin intercomparison, 4th February, and we may need to schedule to within an hour to get a full 24-hour period. This is the last day before Franklin must leave for Townsville, and Natsuchima will come directly to 2S from Ponapei.



TOGA-COARE FLUX-MEASURING SHIPS


TOGA-COARE IC1
Winds before correction
Franklin
Wave
Hakuho
IMET
Wecoma
Average
True wind m/s
0
1
2
3
4
5
6
7
10:51
14:51
18:51
22:51
02:51
06:51
10:51
GMT Time November 27-28 1992


TOGA-COARE IC1
Winds after correction
Franklin
Wave
Hakuho
IMET
Wecoma
Average
0
1
2
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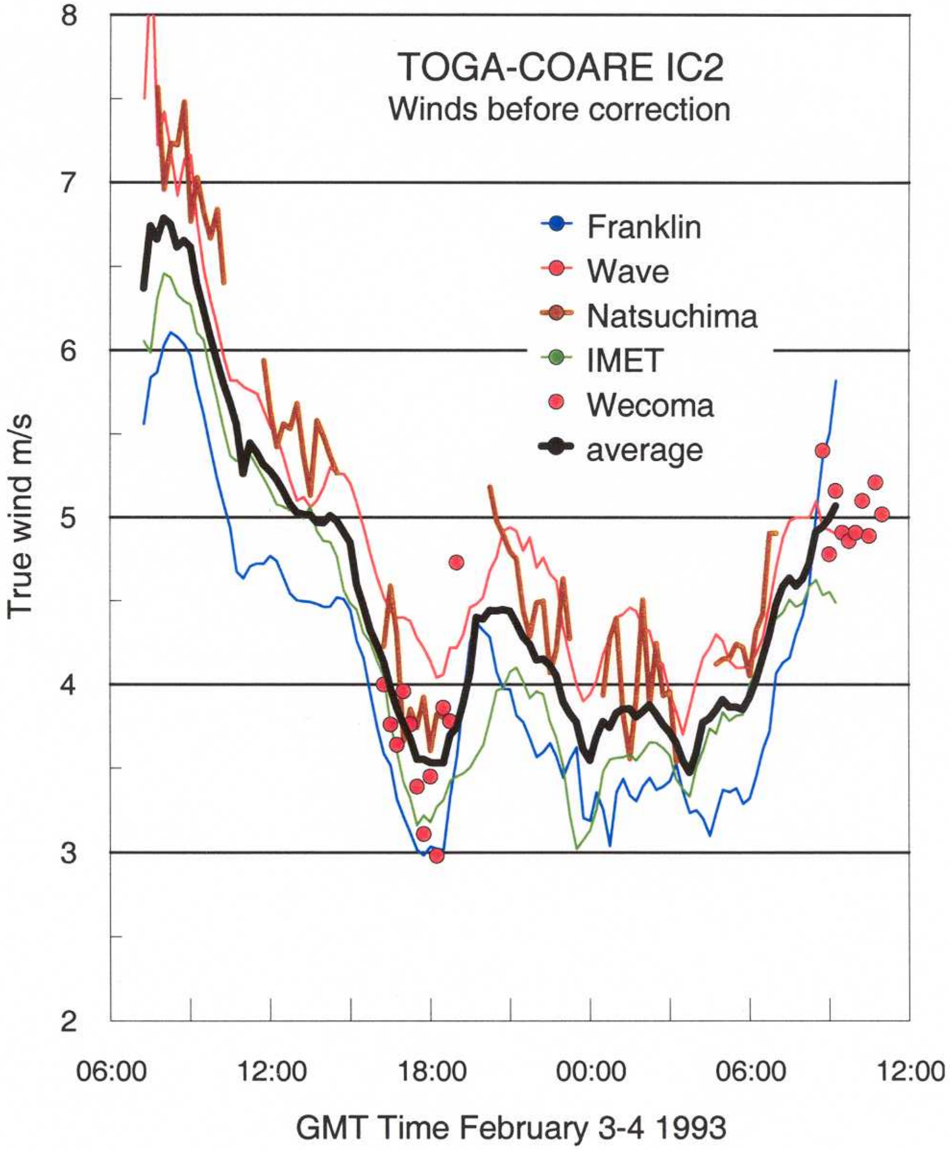
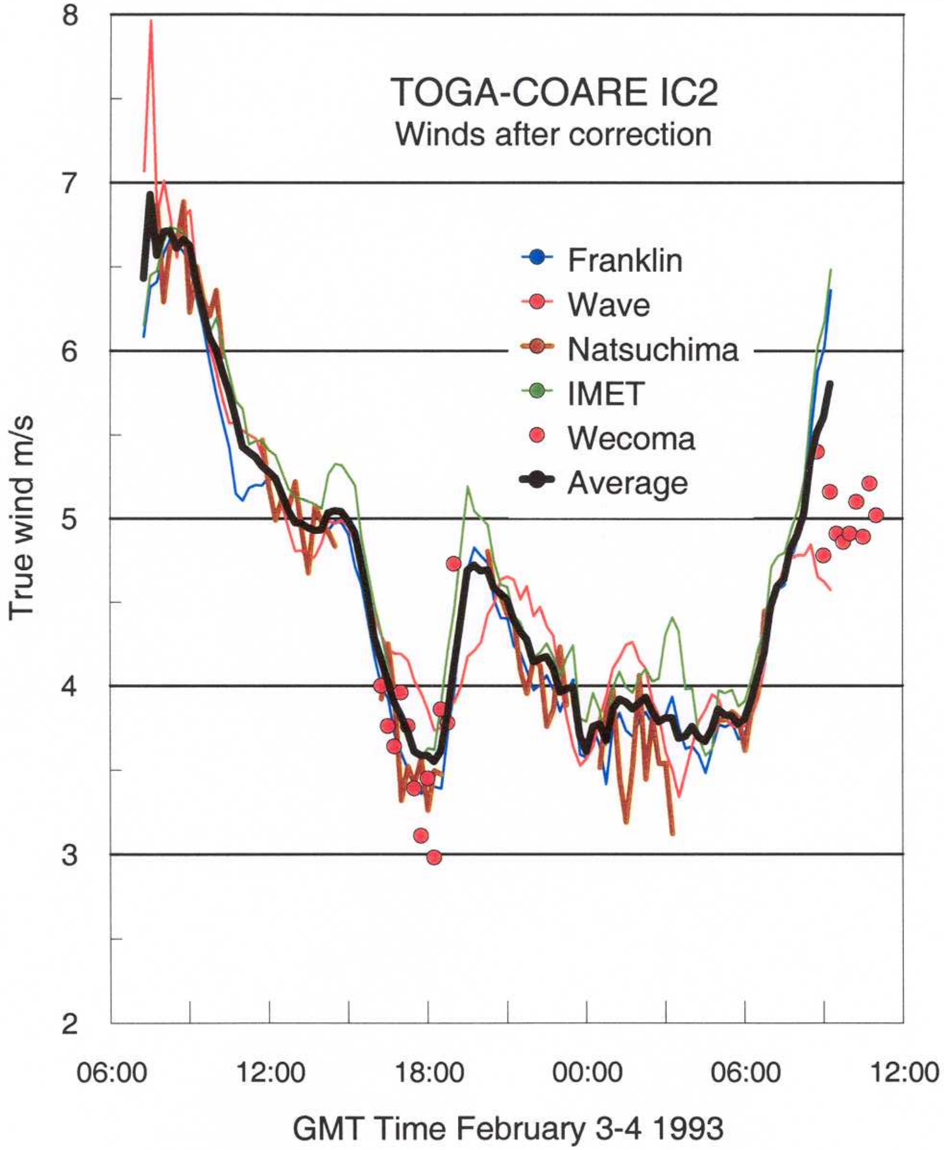
7
10:51
14:51
18:51
22:51
02:51
06:51
10:51
GMT Time November 27-28 1992


TOGA-COARE IC2
Winds before correction
Franklin
Wave
Natsuchima
IMET
Wecoma
average
True wind m/s
8
7
6
5
4
3
2
06:00
12:00
18:00
00:00
06:00
12:00
GMT Time February 3-4 1993


TOGA-COARE IC2
Winds after correction
Franklin
Wave
Natsuchima
IMET
Wecoma
Average
True wind m/s
8
7
6
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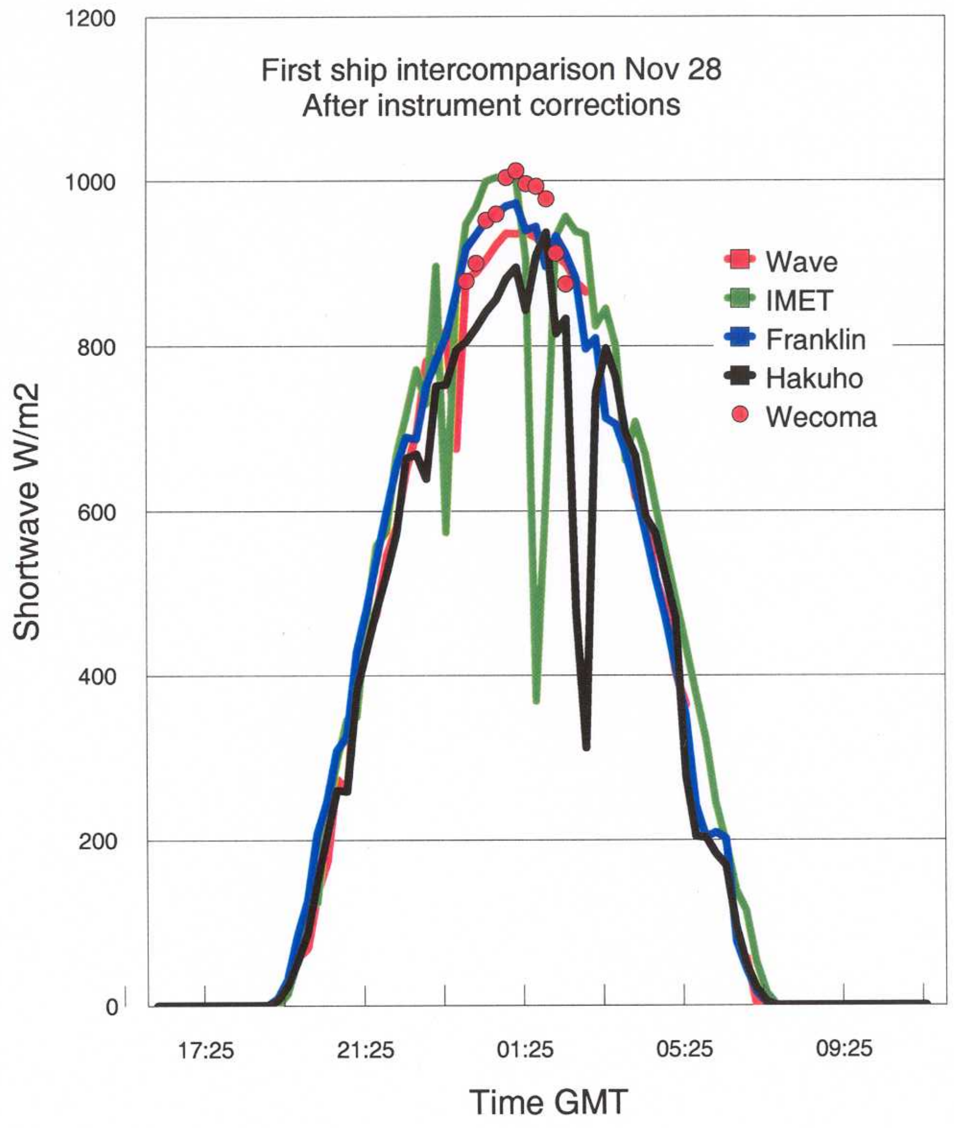
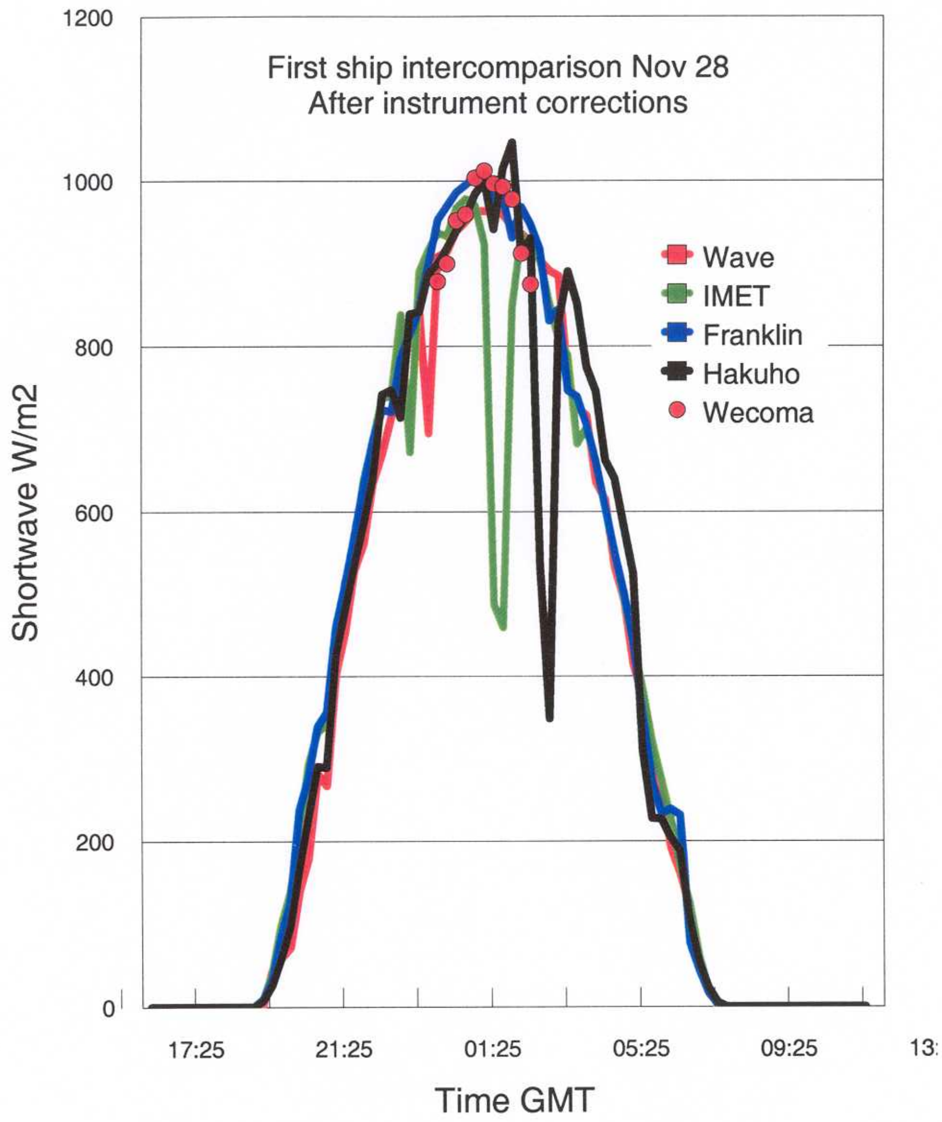
4
3
2
06:00
12:00
18:00
00:00
06:00
12:00
GMT Time February 3-4 1993


First ship intercomparison Nov 28
After instrument corrections
Wave
IMET
Franklin
Hakuho
Wecoma
Shortwave W/m2
Time GMT
1200
1000
800
600
400
200
0
17:25
21:25
01:25
05:25
09:25


First ship intercomparison Nov 28
After instrument corrections
Wave
IMET
Franklin
Hakuho
Wecoma
Shortwave W/m2
Time GMT
1200
1000
800
600
400
200
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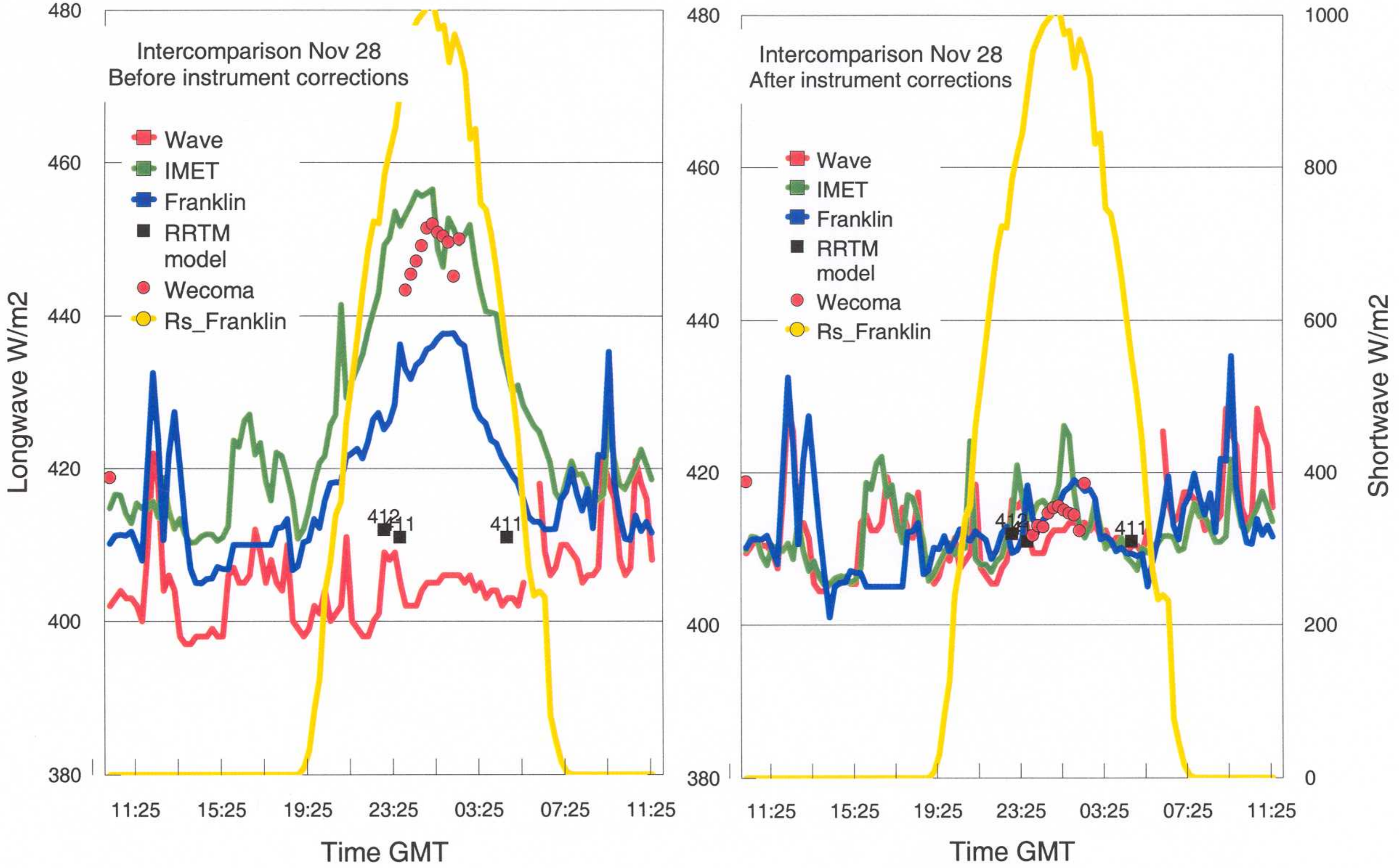
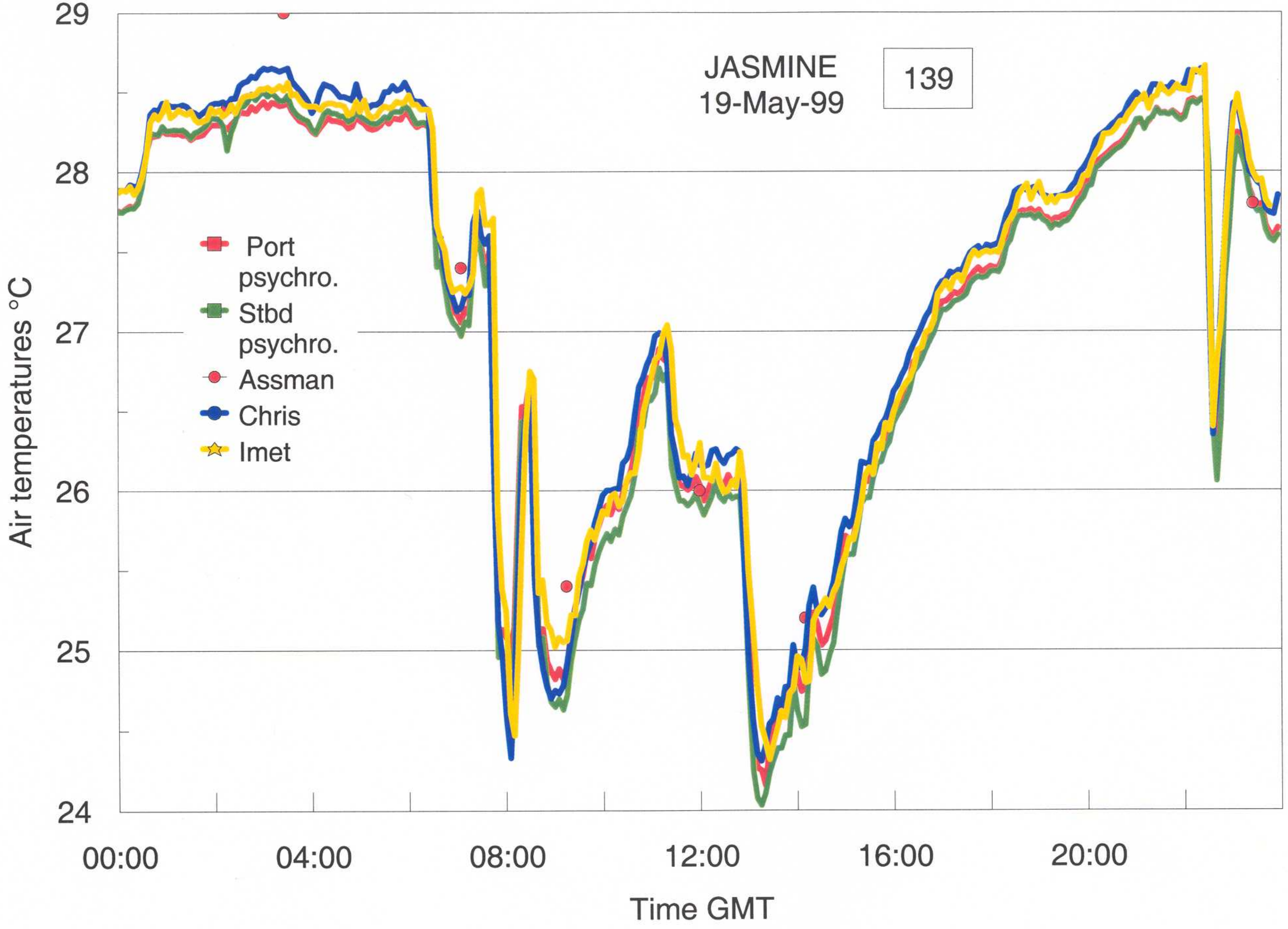
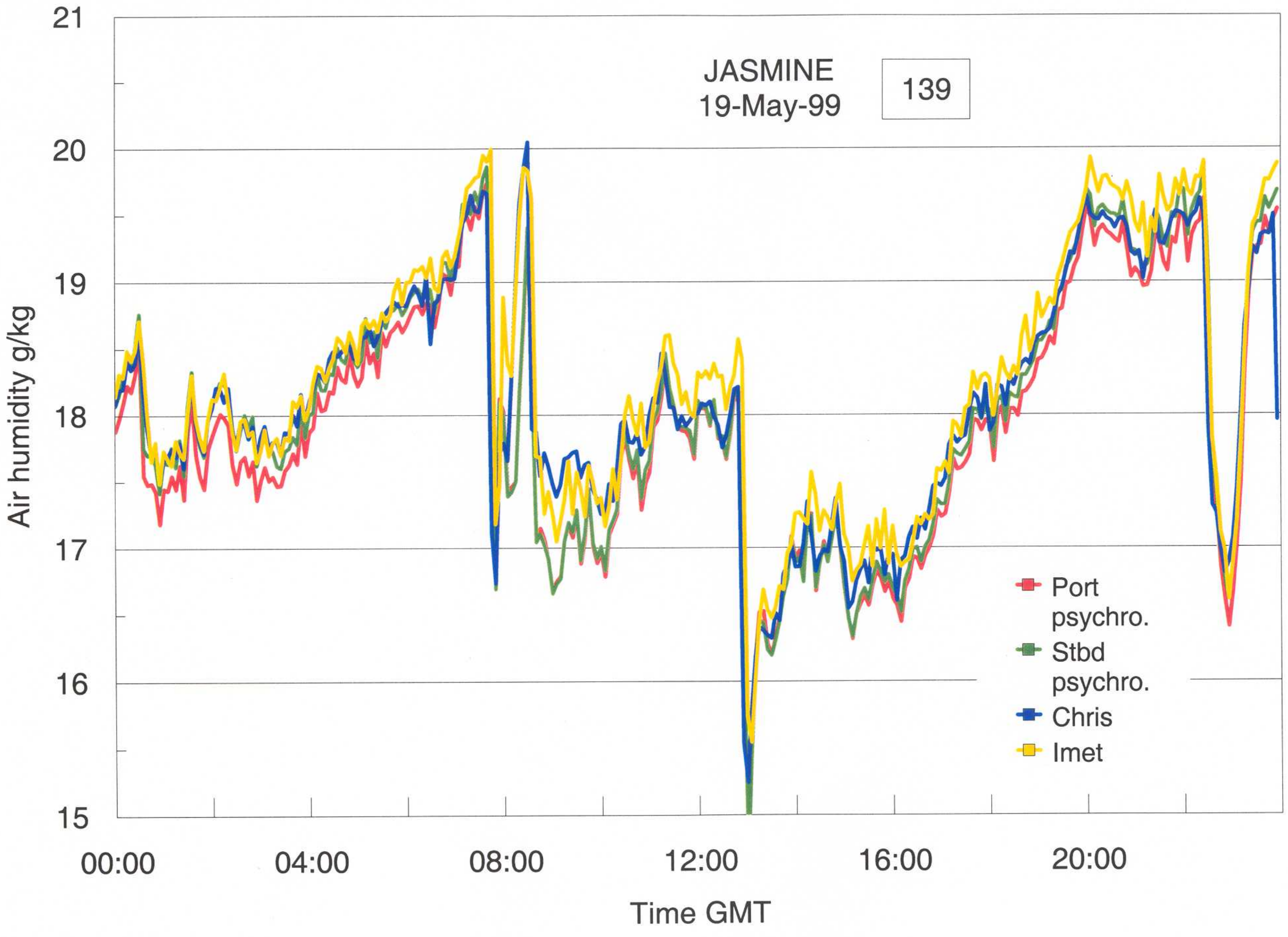
17:25
21:25
01:25
05:25
09:25

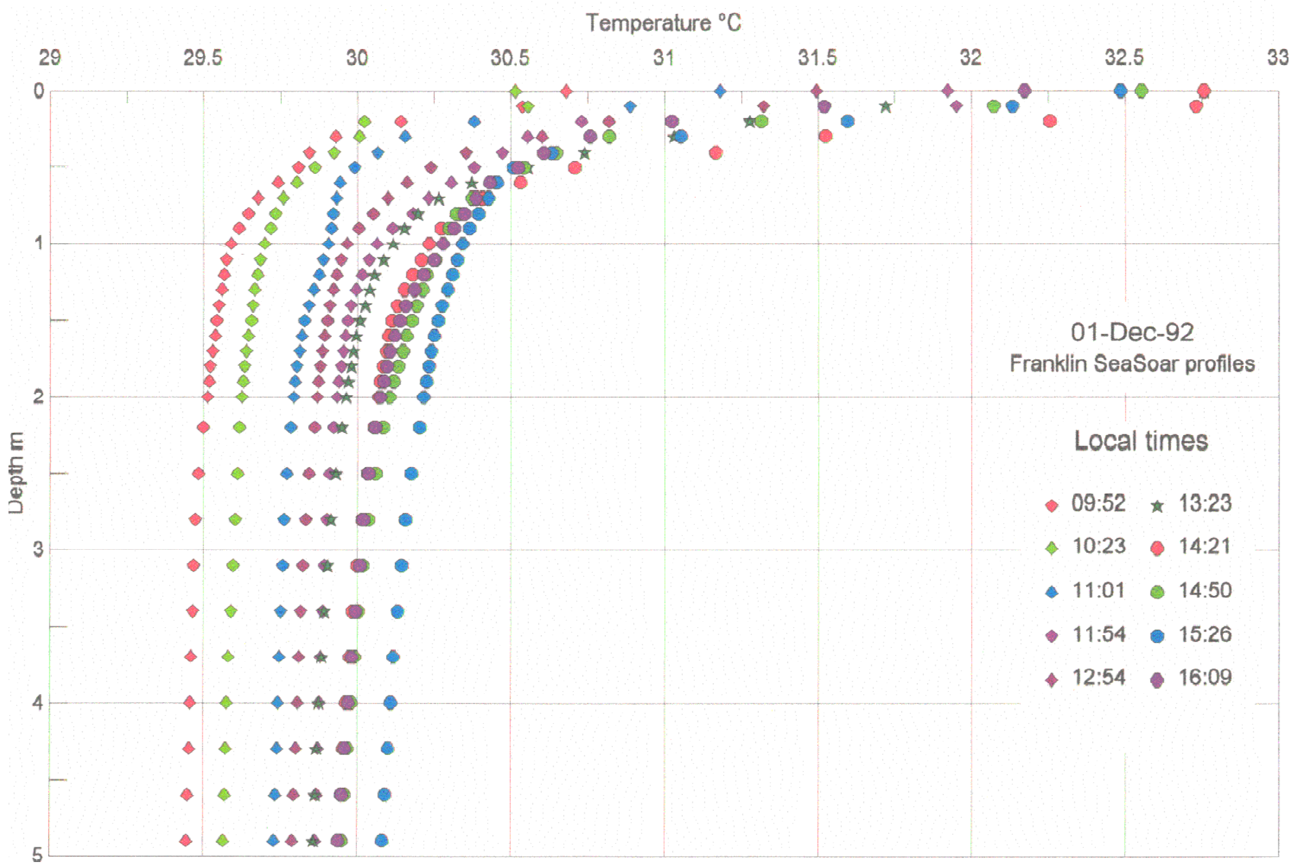


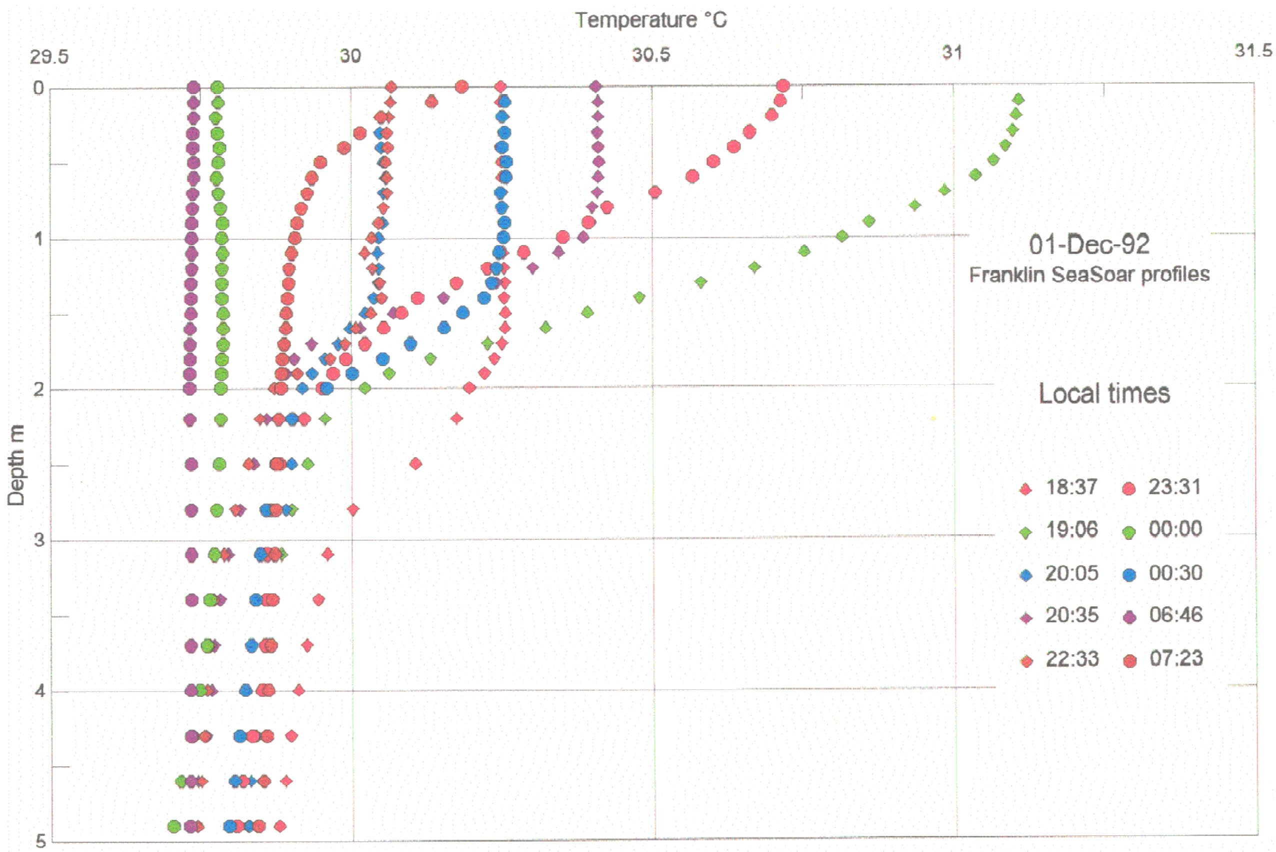
Intercomparison Nov 28
Before instrument corrections
Wave
IMET
Franklin
RRTM model
Wecoma
Rs_Franklin
Longwave W/m2
480
460
440
420
400
380
412
411
411
11:25
15:25
19:25
23:25
03:25
07:25
11:25
Time GMT
Intercomparison Nov 28
After instrument corrections
Wave
IMET
Franklin
RRTM model
Wecoma
Rs_Franklin
480
460
440
420
400
380
1000
800
600
400
200
0
Shortwave W/m2
412
411
11:25
15:25
19:25
23:25
03:25
07:25
11:25
Time GMT


JASMINE
19-May-99
139
Port psychro.
Stbd psychro.
Assman
Chris
Imet
Air temperatures °C
29
28
27
26
25
24
00:00
04:00
08:00
12:00
16:00
20:00
Time GMT

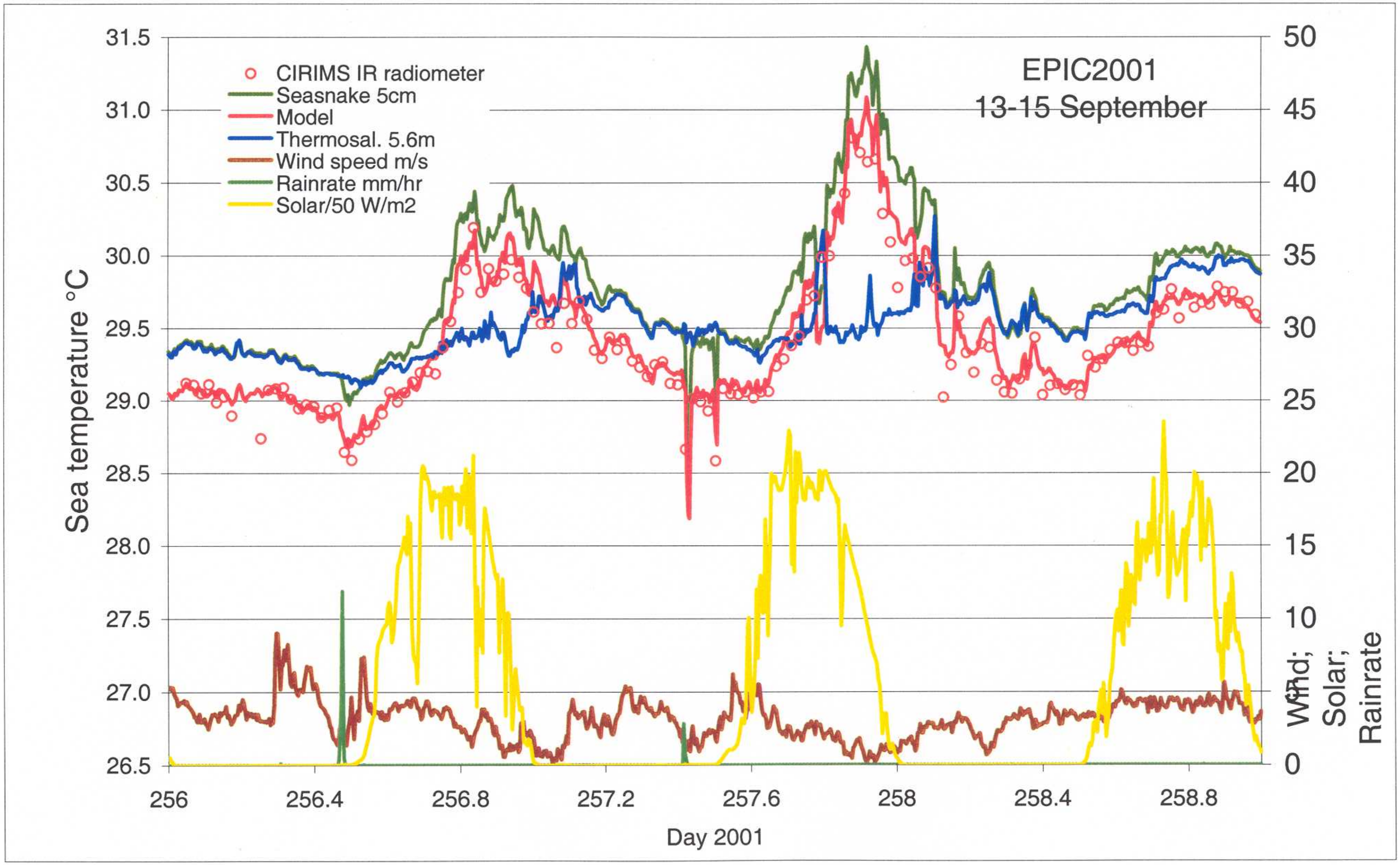


JASMINE
19-May-99
139
Air humidity g/kg
21
20
19
18
17
16
15
00:00
04:00
08:00
12:00
16:00
20:00
Time GMT
Port psychro.
Stbd psychro.
Chris
Imet

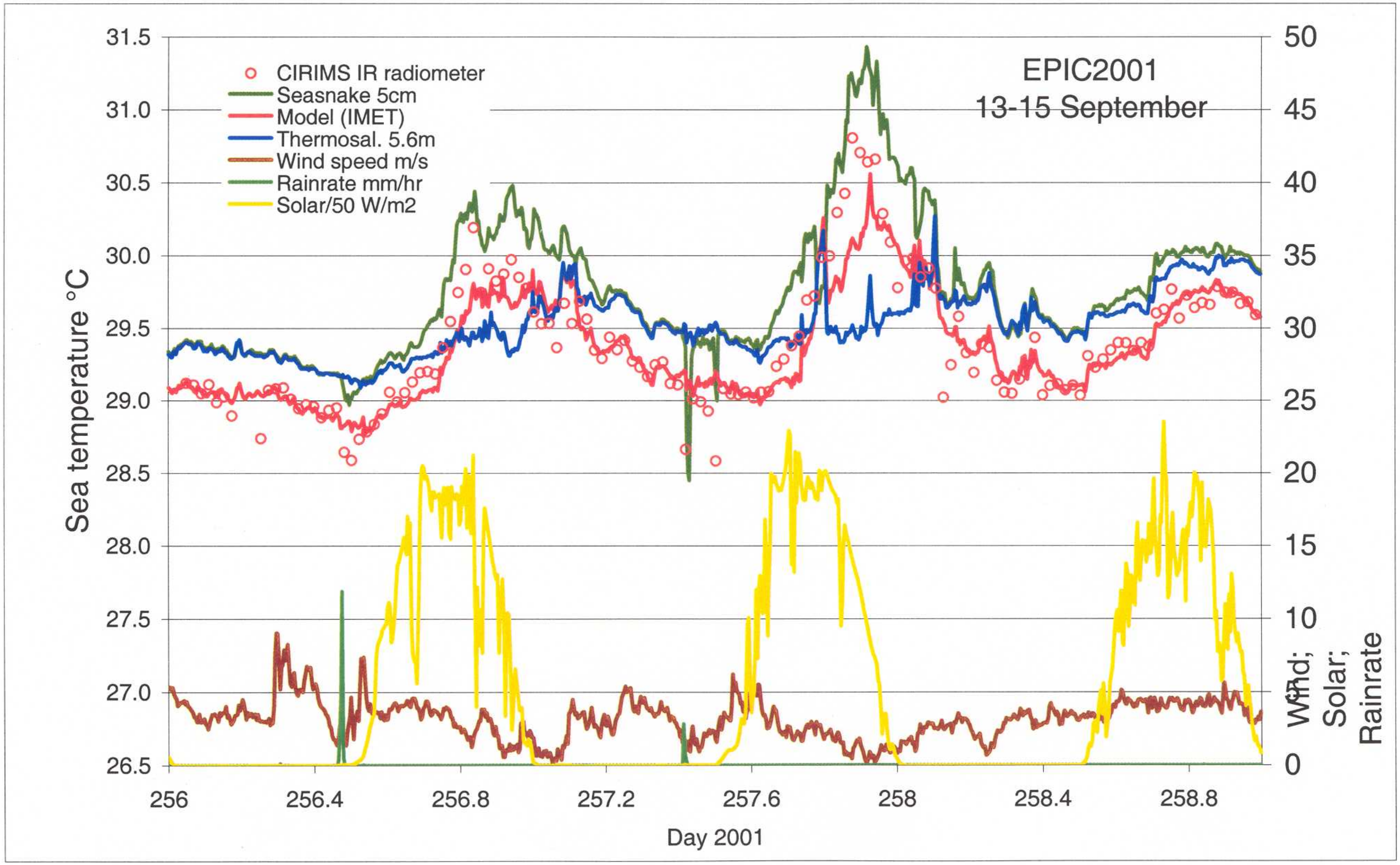

Temperature °C
29
29.5
30
30.5
31
31.5
32
32.5
33
0
1
2
3
4
5
Depth m
01-Dec-92
Franklin SeaSoar profiles
Local times
09:52
13:23
10:23
14:21
11:01
14:50
11:54
15:26
12:54
16:09



Temperature °C
29.5
30
30.5
31
31.5
0
1
2
3
4
5
Depth m
01-Dec-92
Franklin SeaSoar profiles
Local times
18:37
23:31
19:06
00:00
20:05
00:30
20:35
06:46
22:33
07:23



EPIC2001
13-15 September
CIRIMS IR radiometer
Seasnake 5cm
Model
Thermosal. 5.6m
Wind speed m/s
Rainrate mm/hr
Solar/50 W/m2
Sea temperature °C
Wind; Solar; Rainrate
Day 2001
31.5
31.0
30.5
30.0
29.5
29.0
28.5
28.0
27.5
27.0
26.5
50
45
40
35
30
25
20
15
10
5
0
256
256.4
256.8
257.2
257.6
258
258.4
258.8



EPIC2001
13-15 September
CIRIMS IR radiometer
Seasnake 5cm
Model (IMET)
Thermosal. 5.6m
Wind speed m/s
Rainrate mm/hr
Solar/50 W/m2
Sea temperature °C
Wind; Solar; Rainrate
Day 2001
31.5
31.0
30.5
30.0
29.5
29.0
28.5
28.0
27.5
27.0
26.5
50
45
40
35
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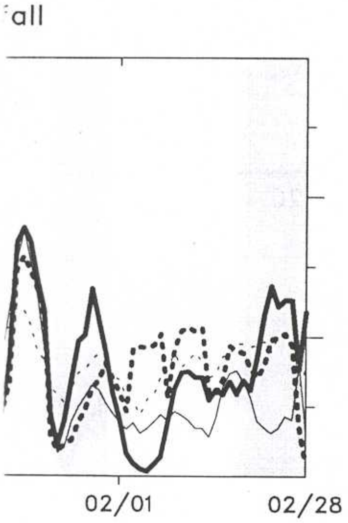
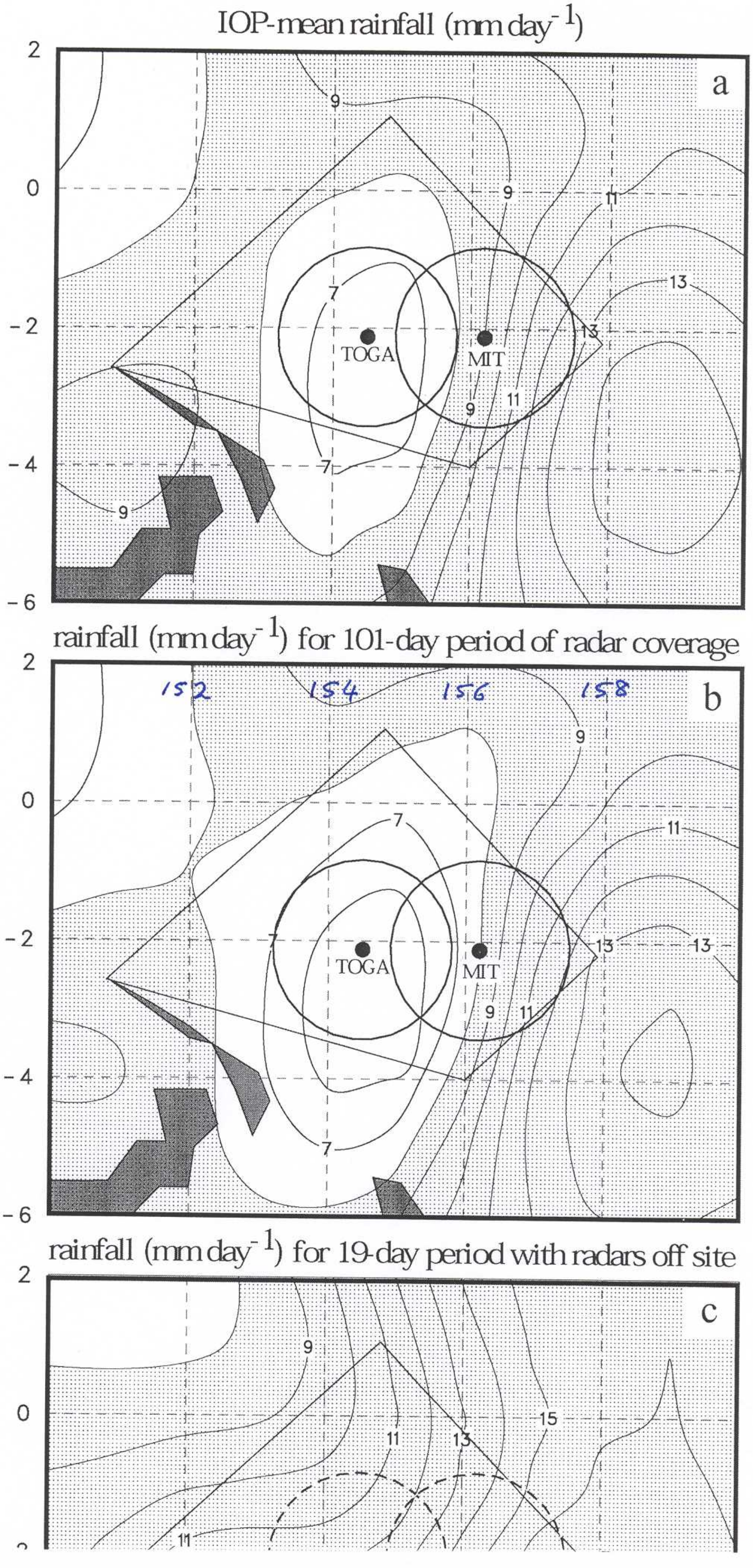
257.2
257.6
258
258.4
258.8

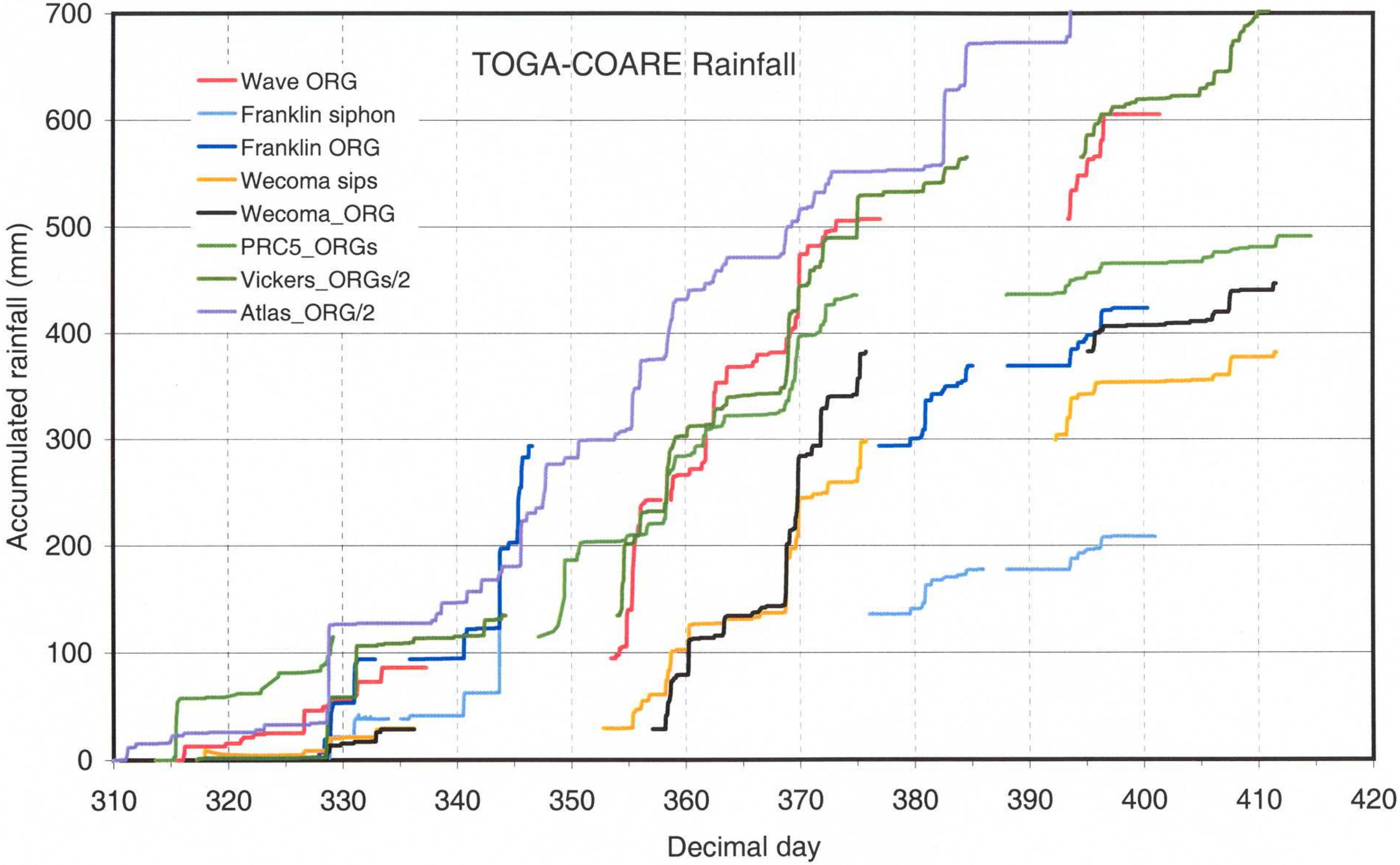


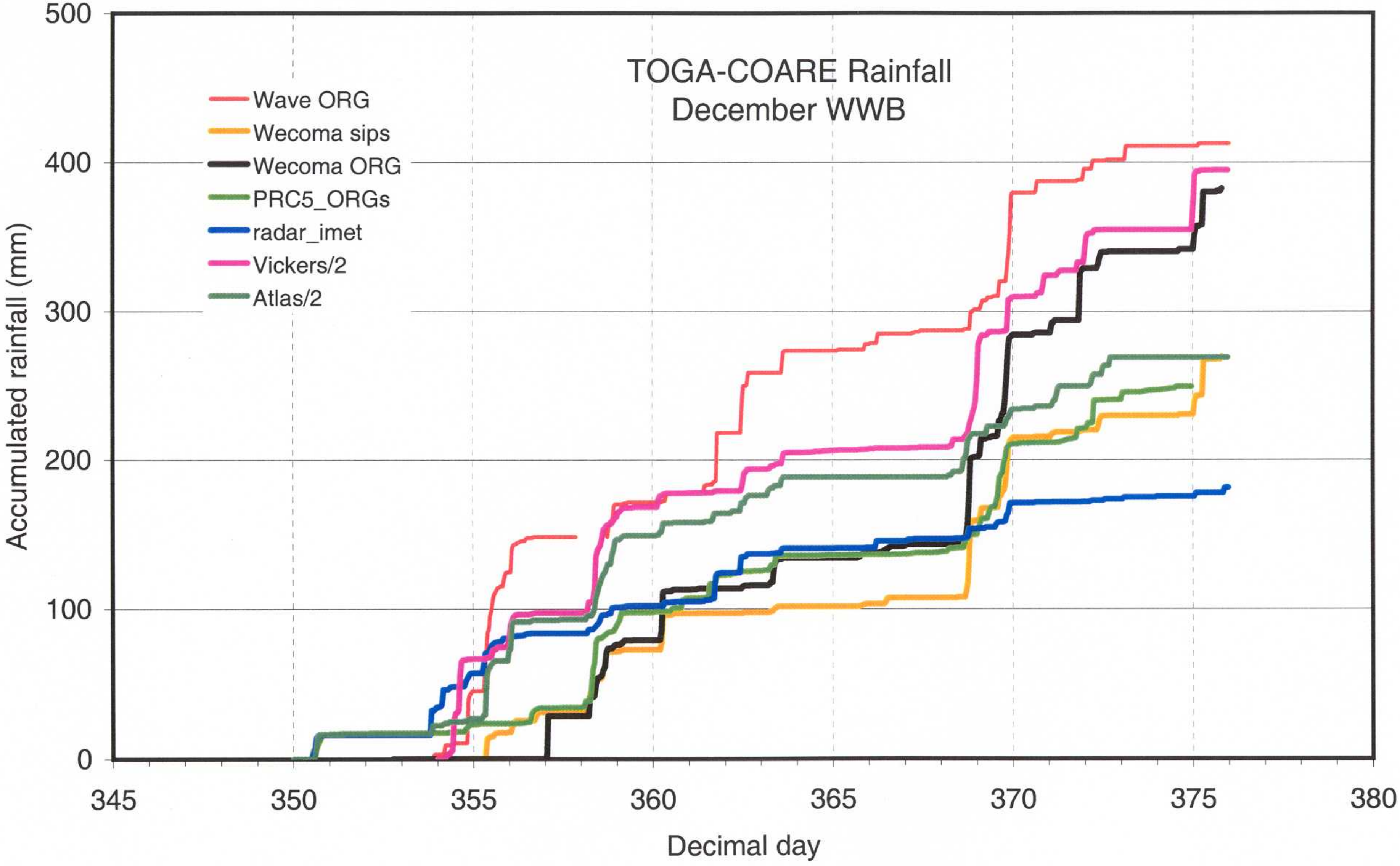
fall (mm day^{-1}) for at-
9) mixed satellite algo-
alysis. Rates have been
hading indicates periods

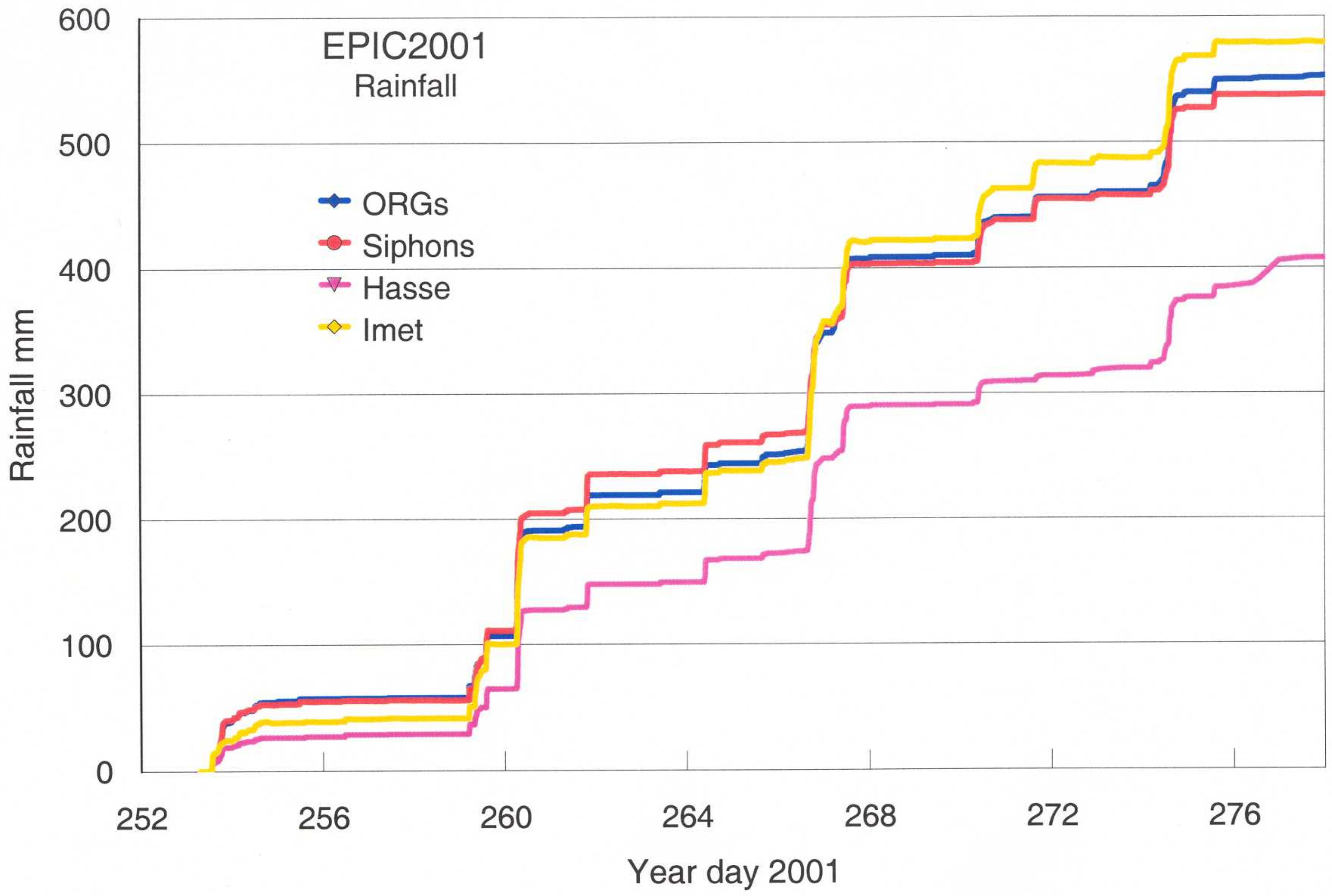


ocean mixed layer.
uce about the same
reas at all times, as
rees quite well with
do the results for
NCEP value of 8.4
CMWF is somewhat
between the MQD
is significant at the
erences with MQD

ates (5-day running
tellite algorithm of
udget, NCEP, and
g. 7. As mentioned
to day) the neglect
eable effect on the
98) has shown that
a heat source char-
n lead to complica-
from coarse rawin-
shows close agree-
thm and MQD. The
lose to each other,


TOGA-COARE Rainfall
Wave ORG
Franklin siphon
Franklin ORG
Wecoma sips
Wecoma_ORG
PRC5_ORGs
Vickers_ORGs/2
Atlas_ORG/2
Accumulated rainfall (mm)
0
100
200
300
400
500
600
700
Decimal day
310
320
330
340
350
360
370
380
390
400
410
420


TOGA-COARE Rainfall
December WWB
Wave ORG
Wecoma sips
Wecoma ORG
PRC5_ORGs
radar_imet
Vickers/2
Atlas/2
Accumulated rainfall (mm)
0
100
200
300
400
500
345
350
355
360
365
370
375
380
Decimal day


EPIC2001
Rainfall
ORGs
Siphons
Hasse
Imet
Rainfall mm
600
500
400
300
200
100
0
252
256
260
264
268
272
276
Year day 2001

Things going for COARE Flux working group

Flux accuracy target to aim at

Time allowed in cruise plans for dedicated intercomparisons

Close collaboration between the surface met. investigators during analysis phase

Timeline established early with waypoints and annual workshops to focus effort

Communal bulk flux algorithm available

Secure funding for 3 years analysis (although not long enough)

Suggestions to enhance reliability of Obs.

Bracket cruises with instrument calibrations

Particularly radiometers

Monitor instrument performance

Standardize on a bulk flux algorithm

If no IR radiometer available, use warm/cool model

Replicate sensors, especially raingauges

Intercompare with other platforms where possible

Include atmospheric soundings on research vessels

Establish readily accessed, enduring archive