Rainfall Measurements on the *R/V Ronald H. Brown* during EPIC2001

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Accurate values of rainfall over the oceans are needed to determine surface layer stratification, ocean freshwater budgets and for models of ocean mixing. Large rainfall amounts can also be a significant component of the ocean surface energy budget. However, the accuracy of rainfall measurements from shipboard is often questionable. Funnel gauges, of the type commonly used at sea, are prone to underestimate as wind distortion deflects raindrops around the housing. The effect is well known in gauges of the observational network over land, where the loss is usually just a few percent. On ships, the loss is more severe because the wind is deflected over the bulk of the ship, not just the gauge, and wind speeds during rainstorms are often quite high and may be increased by the speed of the ship.

The loss due to this effect will depend on the gauge location and the relative wind direction. With relative wind over starboard, a funnel gauge mounted on starboard will be more affected than one experiencing some degree of shelter on the port side. The R/V Ron Brown is equipped with seven siphon (funnel) gauges, well exposed on the port and starboard rails of decks 2, 3, and 5 and on the winch house on the rear deck. In addition, she carries another siphon gauge as part of the IMET system, and a funnel gauge specially designed to overcome the wind deflection problem (Hasse et al. 1998), both mounted on the foremast. Yuter and Parker (2001) describe the above effects and instrument arrangements on the *R/V Ron Brown*.

Optical raingauges (ORGs) have been shown to operate well at sea, providing they are well calibrated (Godfrey et al. 1996; Bradley et al. 2000). For EPIC, ETL mounted two long-path and CSIRO two short-path ORGs on the bow tower, one of each with its optical path aligned athwartships, and the other pair aligned fore and aft. As found using an artificial rain facility, the short path instruments require slight correction for imperfect resolution of the vertical component of rainfall. In our analysis this has been applied to the long-path instruments as well, although it has not been tested.

This generous array and variety of raingauges enables us to overcome, to some extent but at least in a consistent and informed way, the instrumental and exposure problems described above. In regions of tropical convection, most of the rainfall accumulation comes from a relatively few intense storms. During the 24 observation days of EPIC, although there was some rain over the ship on every day except one, there were only about 10 events producing more than 20 mm of rain. There was strong diurnal influence (only twice did storm activity bridge GMT midnight) so a clear indication of the behaviour of particular gauges is possible from the individual daily rainfall accumulations.

Figure 1. Siphon raingauges

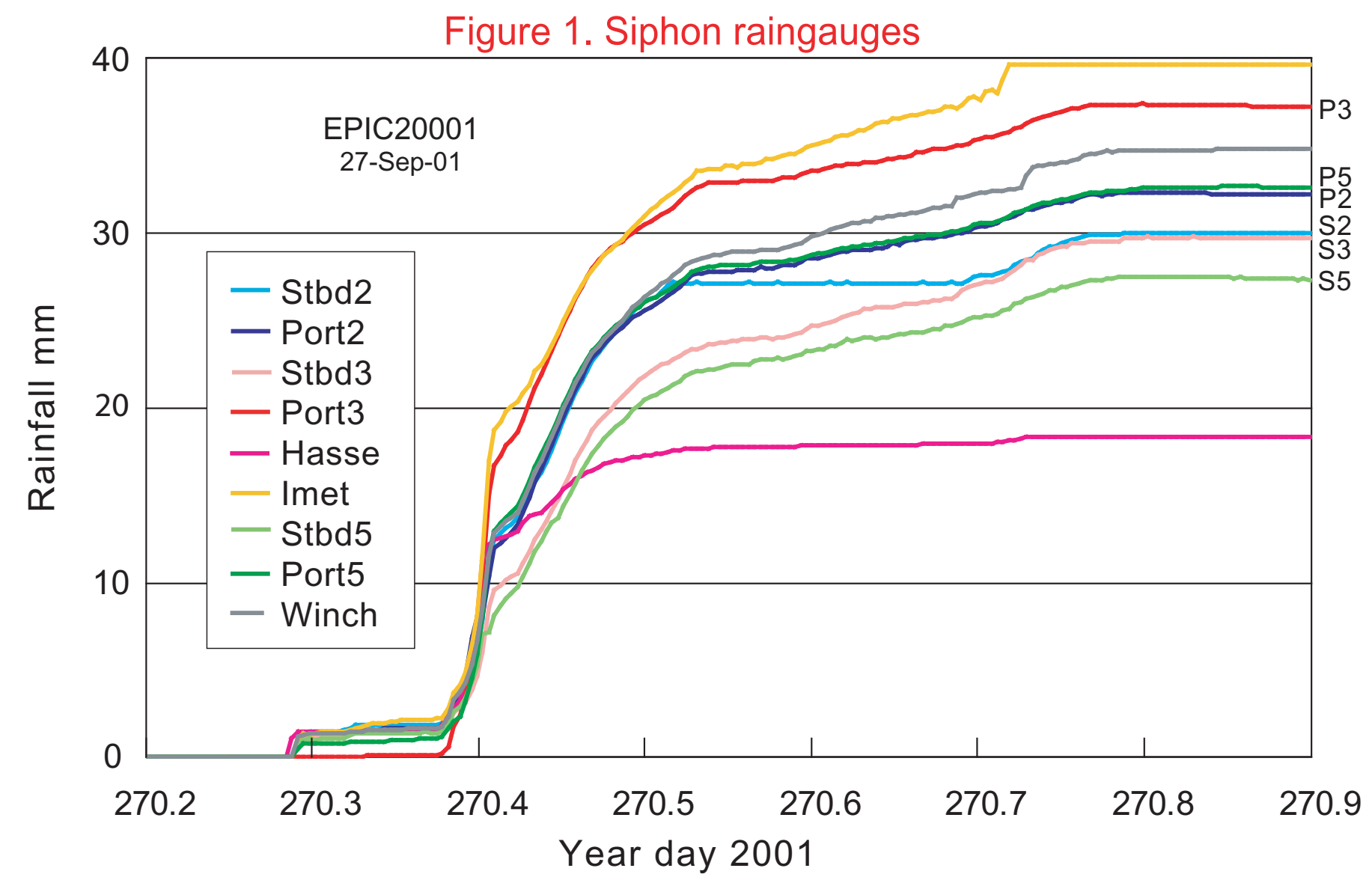


Figure 1 shows rainfall accumulation over one day (September 27), as measured by siphon gauges at different locations on the ship. This storm began with typical vigour; 5-minute average rainrate of 50 mm hr-1, subsequently reducing in intensity to around 3 mm hr-1. The relative wind was 7-10 ms-1 over the starboard beam, and as expected the three starboard raingauges each accumulated less rain than their counterparts to port, by between 12% and 21%. Note, however, that the Stbd2 gauge failed to siphon properly at one point. This is a not infrequent occurrence with these instruments, only detected by close scrutiny of comparative time traces. The IMET gauge registers high compared to the other siphon gauges, and the Hasse gauge substantially lower, characteristics which were consistent throughout the cruise. We have not used data from either IMET or Hasse in our analysis. The siphon gauge on the winch house invariably recorded higher rainfall than the other siphons, and has also not been used. Being usually in the wake of the ship's superstructure there is the possibility that it intercepted water falling from the ship. For our best estimate of rainfall from the siphon gauges, we have averaged the 5-minute data from the three gauges on whichever side of the ship had the highest accumulation on each day, excluding any which displayed an anomaly such as Stbd2.

Figure 2. Optical raingauges (ORGs)

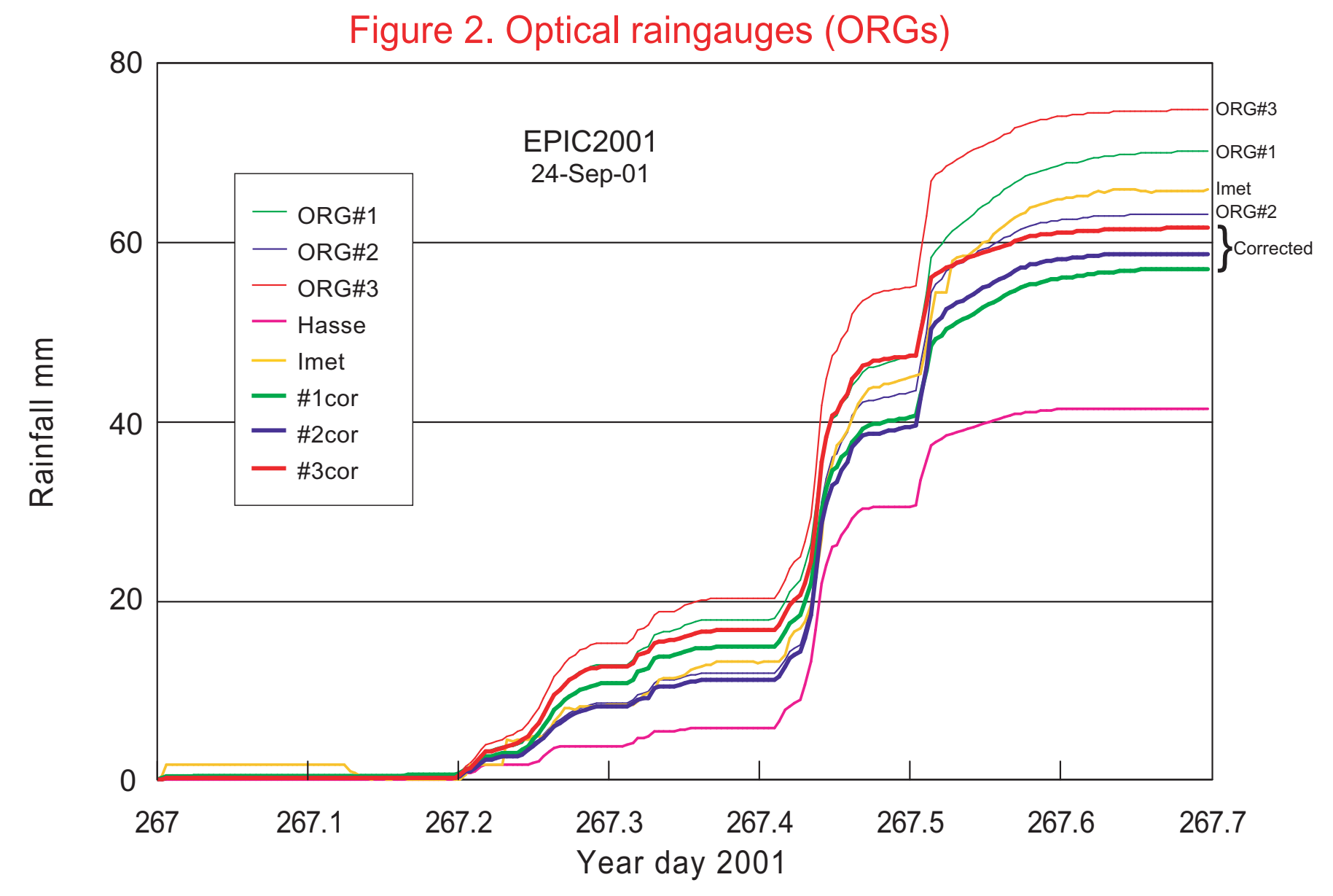
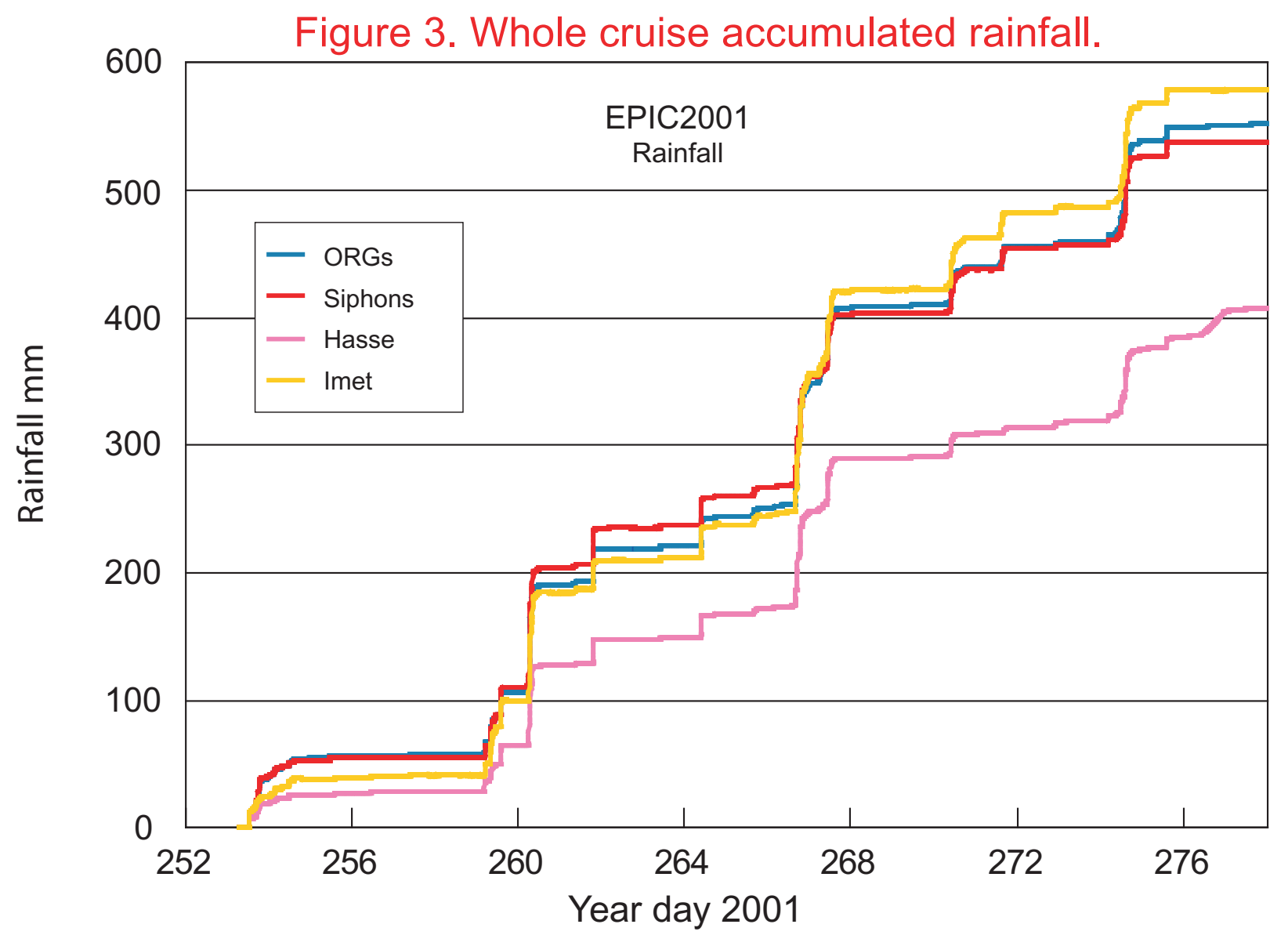


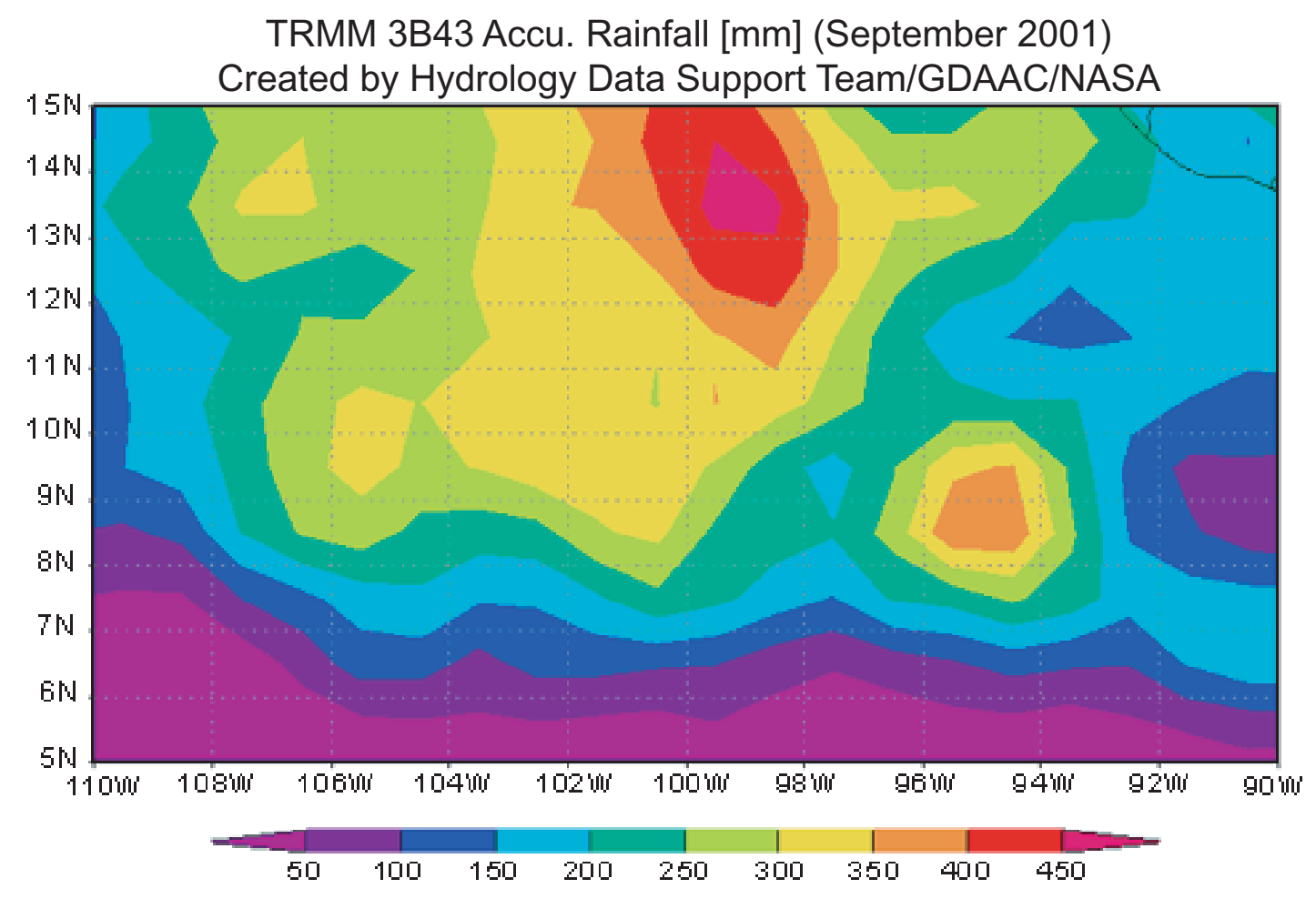
Figure 2 shows the effect of the empirical "cosine" correction to the ORGs at different orientations to the wind direction. On this day (September 24) there was a sequence of rainstorms of various intensities, during which the 5-minute relative wind was 6-10 ms-1 over the bow. The optical paths of ORG #1 (long-path) and ORG #3 (short-path) were across the ship, while ORG #2 (long-path) was aligned fore-and-aft (ORG #4 was found to have a variable offset and its data has not been used). The wind direction was therefore approximately orthogonal to the optical paths of numbers 1 and 3 but parallel to number 2. The correction to the two orientations is therefore calculated differently, but brings them into substantial agreement in this instance. It is not always so successful. The rainfall accumulation by the IMET and Hasse siphon gauges on the foremast are also shown, and again are respectively higher and lower than the other gauges. Our rainfall estimate from the ORGs is an average of the 5-minute corrected values of all three instruments, excluding #1 during 6 days near the end of the cruise when it failed.

Figure 3. Whole cruise accumulated rainfall.



Using these best estimates from the ORGs and the siphon array, we obtain the rainfall accumulation throughout the cruise (Figure 3). Although the two traces diverge at particular storms, over the entire cruise they agree to within 3%, the ORG total being 552mm and the siphons 537mm. Excluding the period after we began steaming south on October 1 (Day 274), both sets of raingauges had accumulated 460mm. This is considerably in excess of the Legates and Willmott (1990) climatology for the month of September, which at 10N, 95W is 246 mm.

Figure 4. TRMM rainfall estimate



The TRMM total rainfall estimate for the period 10-30 September 2001, while the ship occupied 10N, 95W (Figure 4) is about 300mm, also considerably less than our measurement. This may be partly due to the difference in sampling, the ship being a continuous point measurement where TRMM (and radar) products are successive area samples requiring interpolation and smoothing.

Figure 5. Diurnal rainfall pattern.

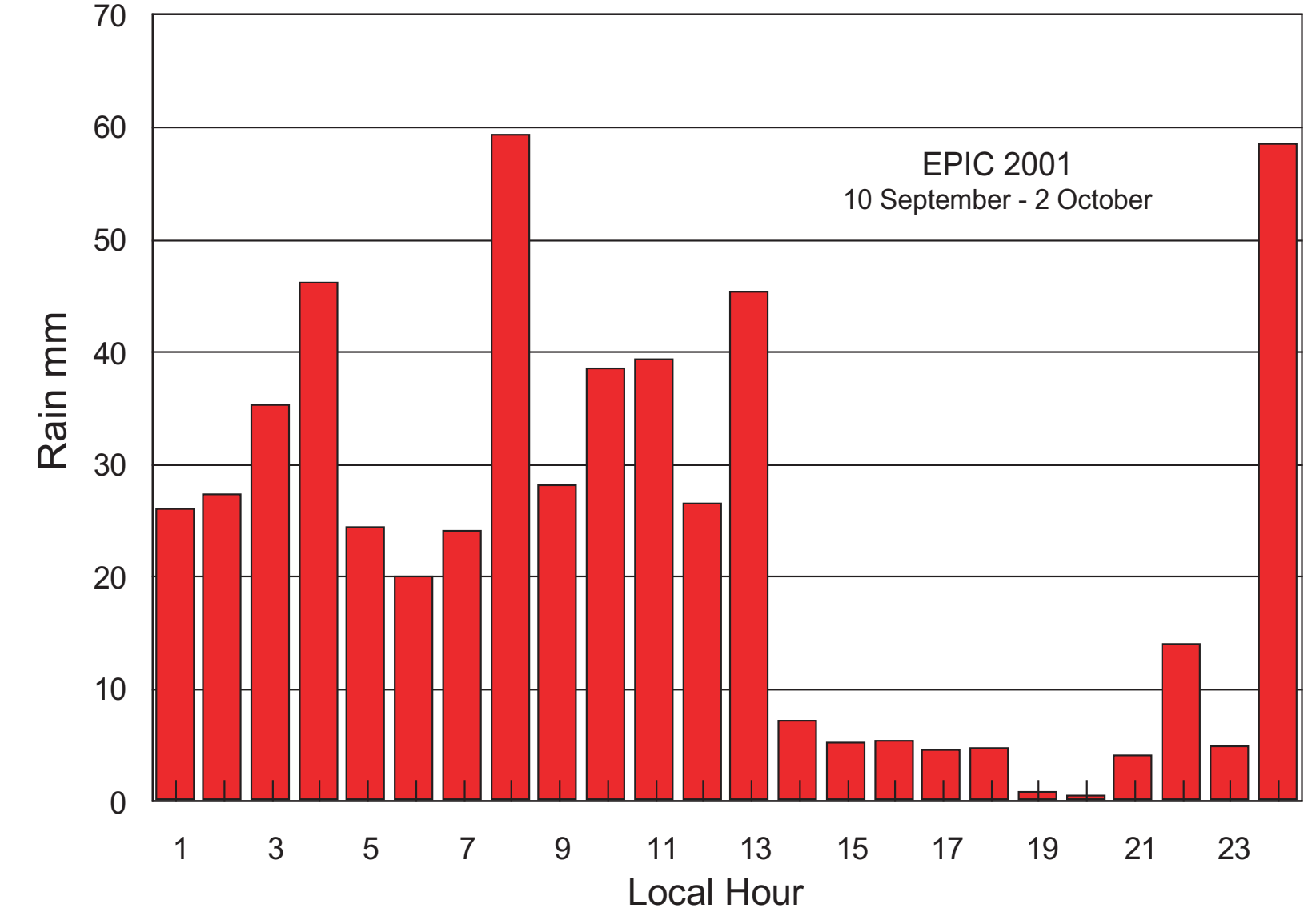
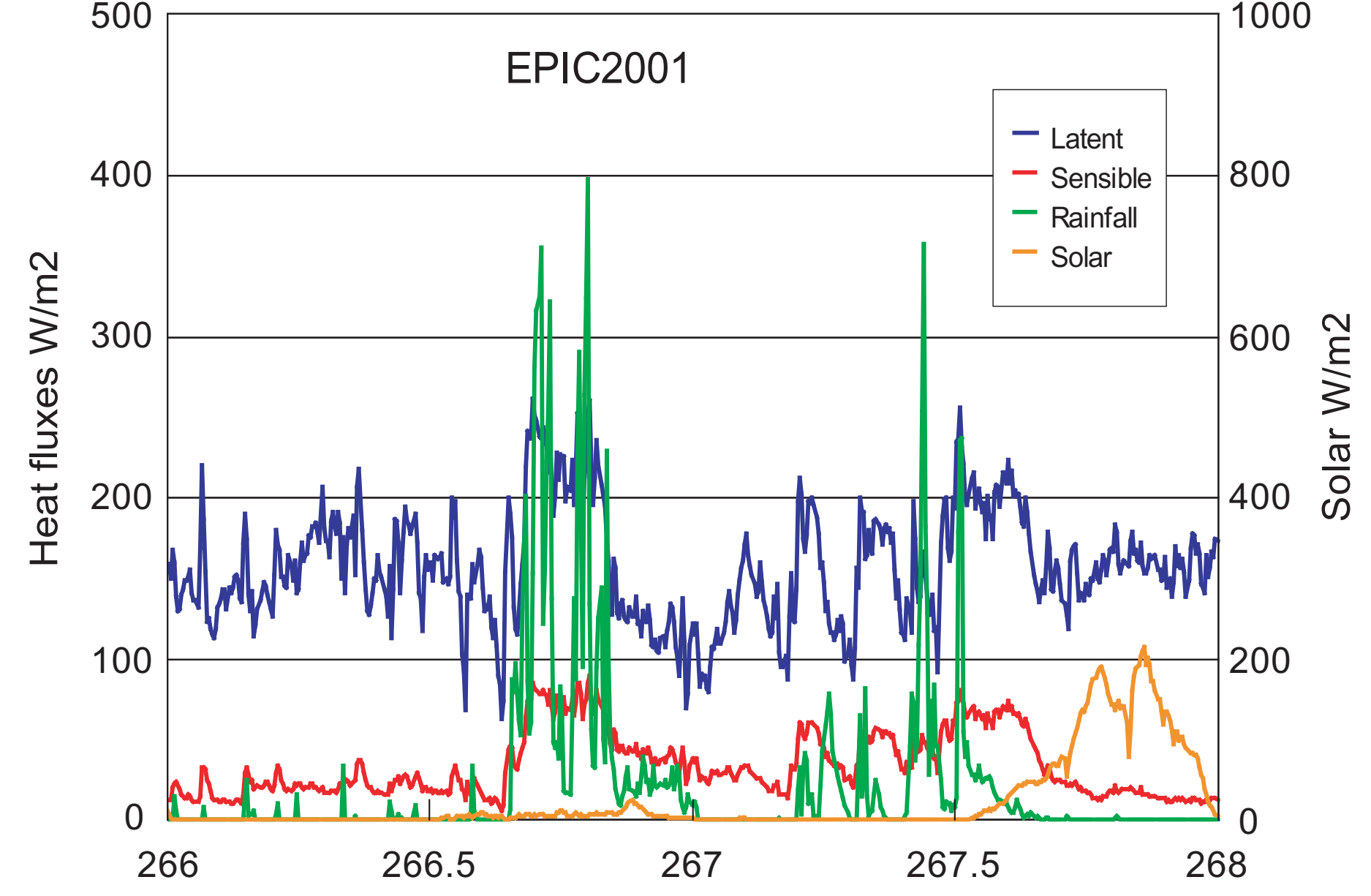


Figure 5 shows total rainfall by hour of day, local time. The strong diurnal cycle, with rainfall starting around midnight and continuing during the morning hours, was similar to that experienced during the JASMINE experiment to the Bay of Bengal during the onset of the summer monsoon in June 1999. However, the diurnal effect was much weaker during the TOGA-COARE 4-month campaign from November 1992 to the western equatorial Pacific, perhaps because the latter was more remote from deep convection occurring over large land masses.

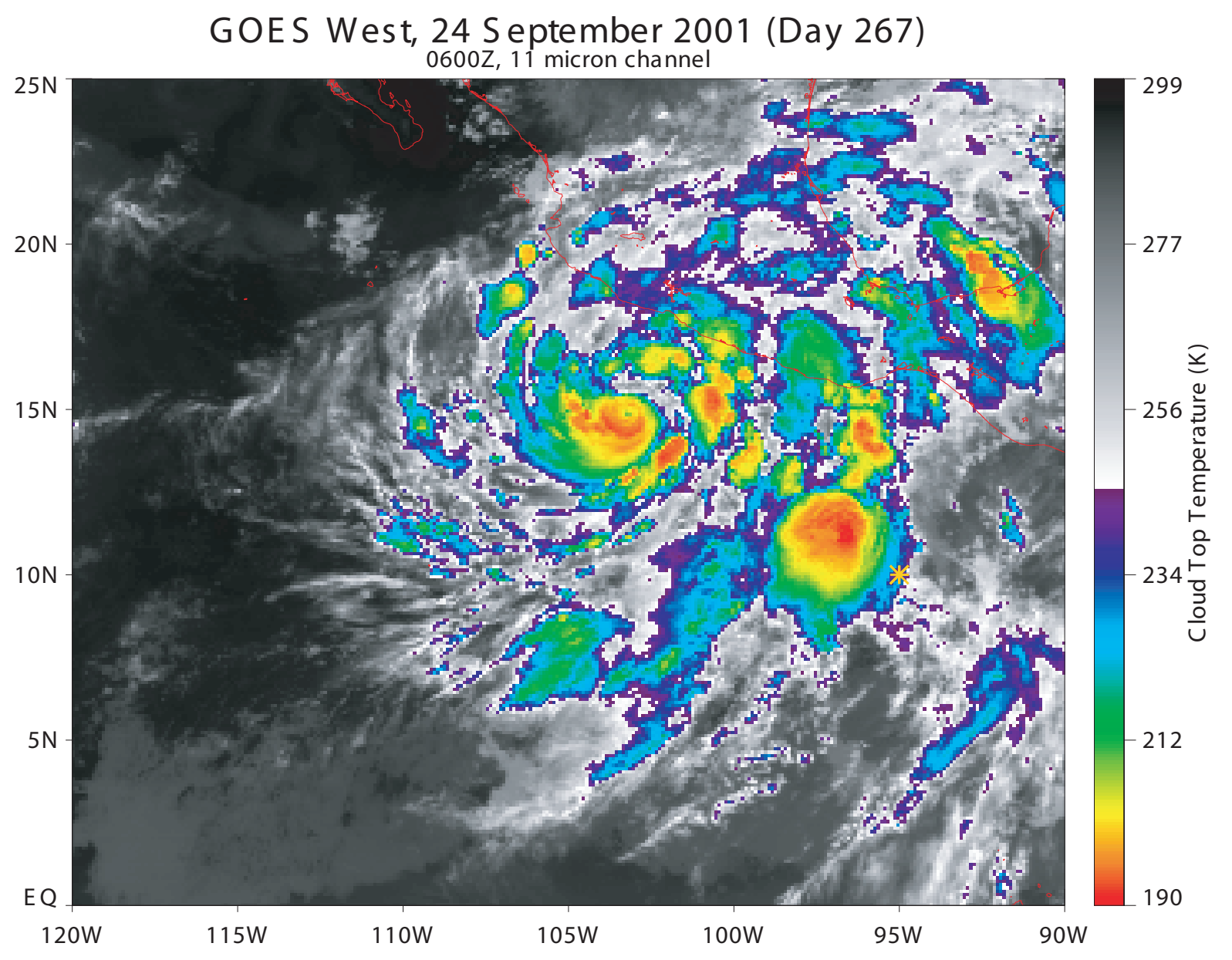
Figure 6. Air-sea heat fluxes, including heat transfer by rainfall



As well as its implication for upper ocean stratification and the freshwater budget, the large amount of cold rain deposited in the ocean can also contribute significantly to the air-sea energy budget over short time scales. (Figure 6) shows time series of the heat fluxes for September 23-24, during which 150mm of rain fell, computed with the COARE version 3.0 bulk flux algorithm (Fairall et al. 2002). The rainfall flux is obtained following Gosnell et al. (1995), assuming that the rain reaches the surface close to the wet bulb temperature. Cruise averages were 19.2 and 123.4 Wm-2 for sensible and latent heat flux respectively, with 7.5 Wm-2 from rainfall. The COARE algorithm also returns the momentum flux imparted to the ocean surface by rainfall after Caldwell and Elliott (1971). In EPIC this amounted to 4% of the average stress.

It is of interest to relate the individual rainfall events shown in Figure 3 to the prevailing synoptic conditions. The storms on days 253-254 were associated with tropical depression "Ivo" to our north, which caused heavy weather as we steamed toward our survey location at 10N, 95W. In the wake of "Ivo" the region was under the influence of a dry air mass which maintained suppressed conditions for several days. From about day 258, convection re-established along the ITCZ, leading to a succession of convective storms until day 262 when conditions were again suppressed. This cycle of enhanced convection followed by suppressed conditions is associated with a succession of easterly atmospheric waves crossing the region. On day 264 tropical storm Juliette, which formed in the Caribbean, passed 400km north of our position heading westerly and intensifying. The 150mm or so which fell during days 266-267, were caused by the rainbands and a cold upper atmosphere within the influence of Juliette as illustrated in (Figure 7).

Figure 7. 11-micron brightness temperature from GOES-West satellite.
Ship position at 10N, 95W is indicated with an asterisk.
(Courtesy of Gary Wick, NOAA/ETL)



The few days following movement of Juliette to the northwest saw the return of convective activity in the region producing a succession of rainstorms. On days 274-275 we encountered a small convective cluster on our course south which produced about 100mm of rain.

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