

JASMINE: The Field Phase

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Abstract

We describe methods and initial results of an extensive process study, the Joint Air-Sea Monsoon Interaction Experiment (JASMINE), held in the Indian Ocean during the summer of 1999. The experimental design was based on the precept that the monsoon sways back and forth from active to inactive (or break) phases and that these intraseasonal oscillations are coupled ocean-atmosphere phenomena that are important components of the monsoon system. JASMINE is the first comprehensive study of the coupled ocean-atmosphere system in the eastern Indian Ocean and the southern Bay of Bengal. Two research vessels, the NOAA Ship Ronald H. Brown and the Australian Research Vessel Franklin, totalled 52 days of surveillance in April-June and September, with 388 CTD (conductivity, temperature and depth) casts and 272 radiosonde ascents. In addition, both ships carried identical flux systems to measure the ocean-atmosphere interaction. The Brown had five radar systems and profilers including a cloud radar and a Doppler C-band rain radar.

Active and break periods of the monsoon, and the transitions between these phases, and the onset of the 1999 summer South Asian monsoon occurred during JASMINE. The undisturbed and disturbed periods had vast differences in the net heating of the ocean, ranging from daily averages of $+150 \text{ W m}^{-2}$ during the former to -100 W m^{-2} in the latter. Accompanying these changes in phase of the monsoon were distinct states of the upper ocean and the atmosphere, including complete reversals of the near-equatorial currents on the time scales of weeks. Diurnal variability occurred in both phases of the monsoon particularly in near-surface thermodynamical quantities in undisturbed periods and in convection when conditions were disturbed. The JASMINE observations and analyses are compared with those from other tropical regions. Differences in the surface fluxes between disturbed and undisturbed periods appear to be greater in the monsoon than in the western Pacific Ocean. However, in both regions, the configuration of convection and vertical wind shear acts as a positive feedback to accelerate low level westerly winds. Questions and tentative plans for the future are also raised.

1. Introduction

Monsoon intraseasonal variability provides the largest perturbation of weather during the established summer monsoon. The variability has also been shown to have influence on the climate of the winter hemisphere (e.g., Lau and Sui, 1996, Fasullo and Webster 1999) and invoke strong intraseasonal cycles in ocean heat transport and near-equatorial currents. But,

beyond these casual associations, little is known about how the ocean and atmosphere interact on these time scales or what processes lead to their genesis.

The Joint Air-Sea Monsoon Interaction Experiment (JASMINE) was a new and significant step in identifying and measuring these fundamental coupled processes in the monsoon system.

JASMINE was designed to provide basic information about the oceanic and atmospheric character of the monsoon intraseasonal oscillation. JASMINE measured the heat and momentum fluxes between the atmosphere and the ocean, the state of the upper ocean, and the organization of convection and its interaction with the larger scale environment. The project aimed to document these fluxes throughout the transitions between active and break periods of the monsoon, as well as to document during these periods the mixed layer and barrier layer structures, and the upper ocean budgets of heat, salt and momentum. JASMINE also was designed to acquire statistics of surface turbulent and radiative fluxes for comparison with previous tropical Pacific field programs. Furthermore the program aimed to document and acquire statistics of convection in order to understand the nature and organization of cloud systems during active and break periods of the monsoon and to compare these statistics with convective organizations in other dynamic regimes in the tropics.

2. Implementation of JASMINE

The field phase of JASMINE held in the eastern Indian Ocean and the southern Bay of Bengal for a total of 52 days during April, May, June and September, 1999. In the April-June period, the NOAA Ship Ronald H. Brown (hereafter referred to as the Brown) was used. During September, the Australian Research Vessel Franklin (the Franklin) operated in the region. The project featured an ensemble of in situ and remote sensing instruments to measure the ocean and atmosphere. A summary of instrumentation on the Brown is given in Table 1. Collectively, measurements were made with Global Positioning System (GPS) rawinsondes, bulk near-surface meteorological measurements, air-sea turbulent fluxes, radiative fluxes, numerous rain gauges, three profiling Doppler radars, microwave and IR radiometers, a cloud ceilometer, and a scanning C-band Doppler precipitation radar. The state of the upper ocean was measured using CTD (conductivity, temperature and depth) instruments, near-surface thermosalinographs, and current profilers (see sidebar).

In addition to the data collected from the ships, high-resolution satellite data from NOAA-12, NOAA-14, NOAA-15 was accessed in aboard the Brown. Furthermore, the European

geostationary satellite METEOSAT-5 was repositioned over the Indian Ocean for INDOEX and remained operational throughout JASMINE. Three-hourly data for the JASMINE period was made available to JASMINE investigators by the European Space Agency after the experiment. Also, the European Centre for Medium-Range Weather Forecasts (ECMWF) provided 3-hourly analyses at standard levels and single point data available to the investigators.

JASMINE was planned for the eastern Indian Ocean and southern Bay of Bengal for 12 May to 20 June aboard the Brown and in September aboard the Franklin. These periods were chosen to maximize the chances of encountering a full cycle of an intraseasonal oscillation as documented by Webster and Tomas (1999). The experiment acquired an additional two weeks of ship time following INDOEX while the Brown relocated from the Maldives to Singapore (see Table 2).

The aim of the operations plan was to sample changes in the ocean-atmosphere system through the full life-cycle of an monsoon intraseasonal oscillation. Figure 2 shows the basic course of the research vessels—a latitude-time section along 89(E relative to the composite monsoon intraseasonal oscillation configured from the data shown in Figure 6, Part 1. With satellite information the scheme could have been adjusted in the field to match actual conditions, but in fact this proved unnecessary. The weather encountered matched the composite weather remarkably well.

The experimental design called for a series of transects along 89E which ensured that the Brown and the Franklin remained in international waters between 5S and 10N. Two stops near (10N, 89E) were made during Phase II of JASMINE for periods of 5 days during which the Brown traced a star pattern for oceanographic reasons (see Figure 3). The Franklin performed triangular patterns at the same location.

3. Initial Results from the Field Phase

Synoptic situation

During Phase I in April (Figure 4a), a relatively weak disturbance persisted in the Bay of Bengal with the ship passing through the disturbance near Julian day 103. The first half of Phase II (Figure 4b) encountered only minimal convection and was, consequently, a period of high insolation. However, during the second half of Phase II the atmosphere was greatly disturbed with extensive deep convection. During this time a monsoon intraseasonal oscillation as described by Webster (2001) propagated northward. The monsoon intraseasonal oscillation encountered

during the JASMINE field phase (Figure 4b) was similar to the composite oscillation in Figure 2. The brightness temperature distributions show that the range of weather during Phase II fulfilled the requirements set out in the planning. Phase III (Figure 4e) was essentially a quiescent period during the late summer monsoon.

The pre-onset and the active monsoon periods encountered in JASMINE appear indicative of active and break periods in the established monsoon. For example, the buoy data from the Indian surface moorings in the Bay of Bengal (Sengupta and Ravichandran 2001) show SST oscillations on intraseasonal time scales of about 1.5C which match those observed during JASMINE. Also, using surface wind data from NCEP/NCAR reanalysis and OLR data indicates that the conditions in each phase were representative of active and break periods (Table 5). Compared to a climatology of active and break periods, the Star 2 period was indicative of a stronger than average active period. Star 1 represented a strong break period. In this context, a "strong break period" is one with higher than average OLR and lower than average surface wind speed. The criteria for active and break days was defined by Webster et al. (1998).

Moderate winds during the first northward transect in Phase 1 lessened to $< 6 \text{ m s}^{-1}$ during Star 1 (Figure 5). Moderate upper tropospheric easterlies were evident during the same period. However, during the second northerly transect, the winds steadily increased in strength in both the upper and lower troposphere and reached gale force at the surface during Star 2. Strong winds persisted for over 10 days as the intraseasonal event moved northward through the Bay of Bengal. Coincident with the increase of convection in the northern Bay of Bengal during Star 2, the upper tropospheric winds accelerated to speeds greater than 20 m s^{-1} and then intensified to 30 m s^{-1} during the last southward transect. The acceleration of the upper tropospheric easterlies heralded the arrival of the monsoonal easterly jetstream for the 1999 summer monsoon. An intraseasonal component to the strength of the easterly jetstream is also apparent.

Figure 6 shows that during 12–15 May 1999 (Star 1), the surface pressure gradients were slack prior to the onset of the southwest monsoon and only scattered low level cumulus were observed from the Brown. During 22–25 May (Star 2), the southwest monsoon commenced as the monsoon intraseasonal oscillation moved northward. The surface pressure gradient became very tight and strong cyclonic surface wind shear existed over the entire Bay of Bengal. The flow was essentially southwesterly and possessed a strong ageostrophic component towards the low pressure trough located in the northern Bay. Deep cloud covered most of the Bay.

Upper ocean structure

A major goal of JASMINE was to determine the variability in the upper ocean fields that occur during the intraseasonal transitions of the monsoon. The concentrated upper ocean observations during JASMINE constituted the first ever documentation of the onset period of the southwest monsoon. As described in Hacker et al. (2001), the ocean structure showed marked intraseasonal variability.

JASMINE documented strong intraseasonal variability of upper ocean temperature, salinity and velocity. Energetic equatorial jets and off-equator circulation features changed (reversed) over periods of weeks. The temperature and salinity fields and their associated mixed and barrier layer structures responded to intraseasonally varying currents and air-sea fluxes.

During April (Phase I) strong eastward near-equatorial currents between 5(S to 7(N had peak speeds near 1 m s⁻¹ (Figure 7a). By about 25 days later (Phase II), the zonal currents had reversed direction over nearly the entire section with peak speeds to the west near the equator of 0.8 m s⁻¹. By the time of the last transect in May, the currents near the equator have reversed once again. The strong flow to the east in April is consistent with the spring equatorial jet determined observationally by Wyrtki (1973) and with model simulations that interpret the jet as a Kelvin wave response to wind forcing (Han et al. 1999; Han et al. 2001). As pointed out by Hacker et al. (2001), the strong flow to the west near the equator during most of May 1999 is opposite to the climatological equatorial jet (Wyrtki 1973). However, the near-equatorial surface current variability is most certainly the result of the intraseasonal oscillation of the lower tropospheric wind field. Han et al. (2001) have managed to reproduce many aspects of the near-equatorial current field observed in JASMINE using ECMWF wind forcing.

The temporal variability of the temperature and salinity fields near the equator is, in large part, the result of the energetic changes in the near-equatorial velocity field. The top of the thermocline is fairly well represented by the 28°C isotherm, which is near a depth of 100 m at the equator and shoals to about 50 m near 10N within the Bay of Bengal. The layer above the 28°C isotherm contains both the mixed layer and the barrier layer (Lukas and Lindstrom 1991). The vertical temperature structure in Figure 7b shows large changes in the depth of the top of the thermocline. The changes are consistent with geostrophic adjustment associated with the reversal of the zonal currents. The largest isotherm depth changes occur near 5S and 5N with the 25°C isotherm varying between 50-150 m (Hacker et al. 2001). The large changes in the thickness of the surface layer (mixed layer plus barrier layer) above the top of the thermocline appear to be the result of near-equatorial dynamics. Another interesting feature of the thermocline is the sharp

vertical temperature gradient near the equator compared to the more diffuse thermocline structure further to the north within the Bay of Bengal. The mixed layer and barrier layer structure are discussed more fully in Hacker et al. (2001). The mixed layer depth varies from less than 1 m to over 100 m depending air-sea flux forcing and background ocean density structure. In JASMINE the deepest mixed layers and thickest barrier layers were found within six degrees of the equator. Barrier layer thicknesses of order 100 m were observed near the equator during low wind conditions.

Salinity appears to be critically important to ocean dynamics. Thus salinity needs to be observed systemically and included in upper ocean model simulations. The primary feature in the upper ocean salinity structure along the five transects (Figure 7c) is the fresh water front located near 8-10N (Hacker et al. 1998; Hacker et al. 2001). In historical data, the front extends from the southeast towards the northwest in the eastern region of the Bay of Bengal. The location and structure of the front vary considerably during April and May 1999. Each of the sections in Figure 7c also show a detached blob of fresher water to the south of the main fresh water pool. As pointed out in Hacker et al. (2001), the observations suggest either a convoluted frontal structure or the advection of fresh water blobs away from the frontal boundary. The front appears to be a horizontal stirring region between the fresher water to the north and the saltier water to the south, and it affects local upper ocean mixed layer and barrier layer structure as well as temperature and salinity as a result of air-sea fluxes. While these layers were as deep as 100 m near the equator, the deepest mixed and barrier layer thicknesses north of the front were typically 30-40 meters during Phase I and II of JASMINE (Hacker et al. 2001).

During Star 1, an undisturbed period, waters above 30 m show a net warming and freshening (Figure 8a). The warming is consistent with the air-sea flux data, but the freshening is inconsistent with the observed evaporation. Preliminary calculations (research in progress: University of Hawaii) indicate the importance of horizontal advection in the local heat and salt budgets, and suggest that the observed evaporation is correct but overshadowed by advection of fresh water into the survey domain. The cycle of diurnal heating and cooling is also apparent: The deepest mixed layers (about 40 m) during Star 1 occur during the nighttime cooling, and the shallow mixed layers and the deepest barrier layers (about 30 m) occurred during the day.

Figure 8b shows a net cooling and freshening above 30 m during the active Star 2 period. In this case the cooling and freshening are consistent with the air-sea flux data, which show a net heat flux out of the ocean and a net precipitation minus evaporation flux into the ocean.

The diurnal cycle is only weakly apparent during the first two days of Star 2. The mixed layer deepens linearly from about 20 m to 40 m over the 5 day survey. The barrier layer is generally thinner during Star 2 compared to Star 1 with typical thicknesses between 0-20 m.

For both Star 1 and Star 2, which were conducted north of the freshwater front (see Figure 7c), the salinity effect on density is critical and often dominates over the effect of temperature. This is apparent in Figures 8a and 8b over the depth interval of 40-60 m just below the deepest mixed layers. Over that depth interval, the temperature changes by about 1C while the salinity changes by 1 psu. The effect of salinity on density is about 4 times as great as temperature in this region.

The Triangle survey of JASMINE Phase III was conducted during an undisturbed period of net heat flux into the ocean and low net evaporation but also net freshening (Figure 8c). As during Star 1, preliminary budget calculations show that horizontal advection must be important. Another interesting result shown in Figure 8c is that after a 4-month monsoon the depth of the 28C isotherm is still at about 40 m in the Bay, the same as during Star 2. The top of the thermocline has not deepened here. The data suggest that the strong salinity stratification may isolate the upper 40 meters of the water column from the deeper layers during typical monsoon conditions within the fresh water pool in the Bay of Bengal.

Atmospheric Structure

During Star 1 (see Figure 9), the winds were very light throughout the column. Moist air was confined to the boundary layer where light southwesterlies persisted. There is little convection, although thin cirrus cloud persisted during much of the period. The cirrus, although only barely discernible for the ship, occasionally was 2–5 km thick. During Star 2 the winds freshened. Speeds are a factor of two greater than in Star 1 and also stronger than winds found in TOGA COARE. Strong northwesterlies up to 400 mb and very strong northeasterlies in the upper levels produced strong negative vertical shear throughout the troposphere. Individual winds in the upper troposphere had magnitudes $> 30 \text{ m s}^{-1}$, while lower tropospheric winds exceeded 20 m s^{-1} for considerable periods. Compared to Star 1, the entire troposphere had moistened remarkably during the intervening week. This moistening accompanied the penetration of convection into the upper troposphere. Deep convection is an order of magnitude more abundant during the night than during the day during the disturbed period.

In general, the Star 2 disturbed period were 40% more moist in the mid-troposphere than in undisturbed periods and 20% moister than TOGA COARE. Especially evident is the dry layer

above a strong temperature inversion during the undisturbed Star 1 period. These characteristics appear similar to profiles found during the early period of TOGA COARE (e.g., Parsons et al. 2000).

The tropospheric structure changes significantly through a monsoon intraseasonal oscillation. In the quiescent phases, the troposphere is remarkably dry above the boundary layer with weak upper level easterly winds surmounting weak surface southwesterlies. During the disturbed phase, the entire troposphere becomes very moist and the weak wind structure is replaced by strong lower level southwesterlies and upper level northeasterlies. The undisturbed phase is similar to the November period in TOGA COARE (Parsons et al. 2000). For example, early in the TOGA COARE field phase (see TC-period 1 in Table 4) the middle and troposphere were uncharacteristically dry following subductions of higher latitude continental air (Parsons et al. 2000). Parsons et al. (2000) found that the exaggerated atmospheric stability at this time precluded the formation of deep convection. As a result, the 24-hour net solar radiation reaching the surface was nearly 40 W m^{-2} more than during the remainder of TOGA COARE.

Surface flux variability

One of the major objectives of the JASMINE pilot study was to document surface fluxes to measure ocean-atmosphere interaction. The results suggest that Indian Ocean intraseasonal variability of surface fluxes may be larger in amplitude than that encountered during TOGA COARE (cf, Godfrey et al. 1998).

Two very different distributions of surface heat flux components were found in the Star 1 and 2 (Figure 10 and Table 4).

The change in net longwave radiation at the surface was due primarily to the increase of the downwelling radiation component associated with more extensive low level cloud, and to the increase of moisture found throughout the entire troposphere during disturbed periods (Figure 9b). Instantaneous values of latent heat flux, the major surface cooling agent, range from -50 W m^{-2} during periods of Star 1 to over -300 W m^{-2} with the passage of nocturnal gust fronts during the Star 2 period.

The change from a net heating of the upper ocean to a net cooling between disturbed and undisturbed periods is a combined result of changes in solar radiation and evaporation. These two fluxes are generally positively correlated. Furthermore, the sensible heat loss by the ocean due to turbulent transfer and rain cooling was not important during the undisturbed period,

but became moderately important during Star 2 in which increased winds enhanced turbulence. Also, instantaneous values of the sensible heat loss due to rain cooling of the ocean surface was occasionally greater than -200 W m^{-2} . Overall, the differences were caused by a severe reduction in net surface radiation, and increases in the turbulent fluxes, offset slightly by a decrease in net longwave radiation loss. The changes in turbulent fluxes can be accounted for, to a large degree, by the large increases in surface wind strength.

Table 4 shows a similar relationship in the TOGA COARE data. The first TOGA COARE period (November 1992) was a relative quiescent period with net flux of $+65 \text{ Wm}^{-2}$, while the second TOGA COARE period (December 1992, January 1993) contained one of the strongest westerly wind bursts recorded in the western Pacific Ocean. The net flux for this burst period was -12 W m^{-2} compared to -89 W m^{-2} during Star 2. The third TOGA COARE period (February 1993) possessed above average winds and showed a net flux of $+13 \text{ W m}^{-2}$ into the ocean.

The mean net heat flux into the ocean for Phase II is $+27 \text{ W m}^{-2}$ but this mean value is made up from vastly different contributions during the undisturbed and disturbed times (Figure 11). During Phase III of JASMINE, the mean fluxes were generally strong and positive. Much of Phase III appears to have been in a break phase of the monsoon or after the final retreat of the monsoon.

The average net surface flux for JASMINE Phase II is very similar to the average flux into the ocean for the TOGA COARE period (Curry et al. 1999) and the recent Nauru-99 experiment (C. E. Fairall, personal communication). However, this similarity may be deceptive and masks the large intraseasonal variability encountered in the Indian Ocean. While the Pacific Ocean fluxes vary between $+65$ and -12 W m^{-2} between undisturbed and disturbed conditions, the Indian Ocean fluxes oscillated between $+90$ and -90 W m^{-2} throughout the lifetime of an monsoon intraseasonal oscillation. There appear to be two major factors that determine the flux characteristics of the two warm pools: The winds are stronger during Indian Ocean disturbed periods and they persist for a longer time, and, the cloudiness remains higher during undisturbed periods in the Pacific Ocean than in the Indian Ocean.

Diurnal variability

One of the general characteristics of the tropical atmosphere is the strong diurnal variability of convection, SST and surface fluxes as were noted, for example, in the western Pacific Ocean during TOGA COARE (Webster 1994, Webster et al. 1996, Godfrey et al. 1998). The largest diurnal variability at the surface there was observed during undisturbed periods when

insolation was strong and the winds were light (Webster 1994). Comparing the two Star periods for JASMINE, however, shows that, contrary to expectation, a surprising amount of diurnal variability exists during disturbed periods.

One of the striking features of the brightness temperature distribution in the Bay of Bengal is the extremely strong diurnal variability occurring during the disturbed period of Phase II. This variability can be identified as southward propagating deep convection with nocturnal maxima. Sections for June and July (Figures 4c-d) indicate similar diurnal disturbances are present during each disturbed phase of an monsoon intraseasonal oscillation.

During Star 1, maximum values of SST and air temperature occur in late Afternoon. A similar pattern, though with greater amplitude, was observed in undisturbed periods in the western Pacific during TOGA COARE (e.g., Webster et al. 1996). During Star 1, the upper ocean temperature and salinity structure showed a diurnal variability that was similar to that found in TOGA COARE (R. Lukas, University of Hawaii, personal communication).

During the disturbed Star 2 period, the SST shows little or no diurnal variability although the air temperature showed an extremely large variation (Figure 12). The nocturnal cooling of the boundary layer was caused by the convective downbursts associated with the nocturnal squall lines that propagated southward each night during Star 2. Also in Star 2, there are universally stronger surface winds with larger variability at night (not shown) but associated with the reoccurring surges that were apparent in the latent heat fluxes shown in Figure 10b. However, most evident is the very strong nighttime maximum in rainfall rate. Again, the nocturnal maximum is associated with the propagating disturbances.

The latent heating distributions (Figure 13a) largely follow the mean diurnal variation of the winds (Fig. 12b), as does the variation of the sensible heat. However, the latter flux is enhanced in Star 2 by the strong nocturnal decrease in 10 m air temperature. The solar radiation is severely reduced and the downwelling infrared radiation is higher during the disturbed period. Very strong negative surface shortwave forcing is apparent in the Star 2 period during the day time because of the generally overcast conditions during the disturbance.

Large-Scale Convection

The nocturnal convection appeared to have a form that was unique to the region with strong propagating convective bands that moved southward from the head of the Bay of Bengal in directions orthogonal to the wind direction at all levels. These propagating disturbances severely

perturbed the surface fluxes as they propagated southward past the ship (Figure 10). Furthermore, there is evidence that the propagations continued into the southern hemisphere as far south as 10(S (Figure 4 and 14). Along a track, the amplitude of the convection appears to decrease during the next local daytime but grows once again further to the south during the following night.

During each of the intraseasonal events throughout the summer of 1999, propagations occur along trajectories that may be possibly 2000–3000 km in length and appear to remain as discrete entities for about two days. The disturbances appear to form in the early afternoon in the northern reaches of the Bay of Bengal in the vicinity of the surface trough running along the western Indian coast from Bangladesh to the south. The disturbances adopt a southwest-northeast orientation roughly parallel to the surface isobars (Figure 6b) and extend in that direction for scales of about 300–500 km. In the direction of propagation, the disturbances are much narrower (50 km).

Using a global cloud archive, Yang and Slingo (2001) find persistent diurnal propagations in the Bay of Bengal with convection commencing over the land at the head of the bay. Prior to Yang and Slingo (2001) and the observations from JASMINE, these vigorous diurnal convective events appear not to have been documented.

In between the nocturnal episodes of deep and intense convection that passed the Brown each evening are extensive, deep nimbostratus decks (Figure 14). Similarly, Figure 16 shows broad bands of deep convection within the larger-scale mesoscale convective system. To a large degree, these two JASMINE systems appear to be similar to the "superconvective" systems defined by Chen et al. (1996) for the western Pacific Ocean. The subregions of the convective systems had developed stratiform precipitation over the ship (Figure 16a, panel i) on May 23. On the other hand, the superconvective system of May 24 (Figure 16b) was in a highly convective stage and had yet to produce an extensive stratiform region. The convective cells were deep and intense with echo top heights of at least 18 km (Figure 16b, panel ii). On this day, the 30 dBz echo reached to 11 km and the radial velocity perturbations associated with these cells (Figure 16b, panel iii) were also strong with speed differences of 5 ms⁻¹ between the inside and the outside of the convective cells.

C-band Doppler radar data obtained during Star 2 may suggest cooperative interactions between convection and the large-scale flow. The low-level momentum during Star 2 was southwesterly, and not as strong as the northwesterly flow in the mid-troposphere (Figures 5, 9b, 16a, b). The downward momentum flux in the convective and stratiform regions evidently increased the westerly component speed and made the wind veer slightly. As a result, the large-

scale westerly component was accelerated by the convection, and low-level convergence with the ambient southwesterly component was created to generate still more deep convection. In the stratiform region there is a midlevel layer of northwesterly momentum air flowing into the system between the 4 and 8 km level, where the environmental wind was strongly northwesterly as shown in Figure 9. Doppler wind data shows inflow sloping downward, transporting the strong northwesterly flow towards the surface.

The observations suggest similarity between organized convection in JASMINE and TOGA COARE. This type of sloping midlevel inflow transporting momentum downward in the stratiform region was identified by Kingsmill and Houze (1999a) and Houze et al. (2000) from TOGA COARE ship and aircraft Doppler radar data. Houze et al. (2000) determined that this midlevel downward inflow acted as a positive feedback enhancing the low-level westerlies in the warm pool intraseasonal oscillation. Thus, all the elements of a positive momentum feedback appear to have been present in the Bay of Bengal region.

4. Conclusions, Questions and Plans for Further Research

Whereas JASMINE provided substantial insight into the coupled ocean-atmosphere structure in the Indian Ocean region, there remain many unanswered questions. We highlight below a number of questions that require further investigation:

The intraseasonal variability observed during JASMINE indicates very strong ocean-atmosphere interactions in the Bay of Bengal and the eastern Indian Ocean. What is the impact of the intraseasonal wind forcing on the broader scale Indian Ocean and its overall heat balance? JASMINE made detailed observations of an intraseasonal oscillation during its mature phase in the Bay of Bengal. But the oscillation appears to be a basin-wide phenomena (e.g., Webster 2001). What are the coupled ocean-atmosphere processes that generate monsoon intraseasonal oscillations? There appears to be some similarity in the surface fluxes and the tropospheric moisture distribution between the undisturbed STAR 1 period and the TOGA COARE period 1. Parsons et al. (2000) suggest that subsiding dry continental air was responsible for the TOGA COARE conditions in November, 1992. Is the source of midtropospheric air during the break periods of the monsoon also of continental higher latitude origin? The JASMINE observations suggest a very strong interaction between the atmosphere and the ocean on interactive time scales which is both dynamical and thermodynamical. Given that most atmospheric general circulation models have a near absence of intraseasonal oscillations in model simulations (e.g., Slingo et al. 1996), do the JASMINE results suggest a modeling strategy for the simulation of intraseasonal

oscillations? Is it possible that the degree of interaction between the ocean and the atmosphere is so important (or subtle) that coupled model strategies may be necessary? Is there sufficient predictability for active and break periods of the monsoon to be forecast with sufficient accuracy and lead time to be of use to a user community?

Based upon what was found in the JASMINE Pilot Study and on the newly emerging ideas regarding phenomenology in the Indian Ocean-monsoon regime, several research plans are under consideration. One is to conduct a more expansive survey of the coupled ocean-atmosphere interaction on intraseasonal time scales in the central and eastern Indian Ocean during 2003–4. The aim would be to obtain detailed surface flux and evolving ocean and atmospheric structures for a longer period during the established summer monsoon. Major emphases might be the determination of the wider field responses of the upper ocean to intraseasonal atmospheric forcing and the determination of the spatial and temporal patterns of interface fluxes. The timing of a JASMINE II would be crucial and tied to the maximum coverage of satellites during 2002–2005. The process study is planned to take place within the GEWEX Coordinated Enhanced Observing Period (CEOPS). Another plan is to develop an Indian Ocean Monsoon Observing System to study and monitor the Indian Ocean Zonal Mode (Webster et al. 1999, Saji et al. 1999, Yu and Rienecker 1999, 2000). This mode is also referred to as the Indian Ocean Dipole. Such an effort requires the maintenance and expansion of XBT lines already in the Indian Ocean and the deployment of moored buoys in the eastern and western Indian Ocean. These two major plans are being considered in detail by the Asian-Australian Monsoon Panel of World Climate Research Programme's Climate Variability and Predictability Study (CLIVAR).

Appendix

JASMINE was a bilateral effort of the United States and Australia under the auspices of CLIVAR. Four U.S. research groups and an Australian group collaborated in the planning and execution of JASMINE, each with specific responsibilities. The University of Colorado (Principal Investigator (PI): P. J. Webster) and the NOAA Environmental Technology (NOAA/ETL PI: C. W. Fairall) were responsible for the measurement of the air-seas fluxes. The University of Hawaii group (PIs: P. Hacker, R. Lukas and E. Firing) was responsible for the measurement and analysis of the upper ocean temperature, salinity and velocity fields during the monsoon onset period. The University of Washington group (PIs: R. Houze Jr., S. Yuter and Y. Serra) documented the evolution of convection and its relationship to monsoon transitions. Both the University

of Colorado/NOAA-ETL and the University of Washington groups maintained an upper air sounding program throughout JASMINE. These four principal research groups used the Brown as their principal observing platform. The fifth research group participating in JASMINE was from the Australian CSIRO Marine Sciences Division (PIs: J. S. Godfrey and E. F. Bradley) which used the Franklin. They were responsible for measuring upper ocean heat, salt, and momentum budgets; air-sea fluxes; and atmospheric structure during the late summer monsoon. E. F. Bradley also represented the Australian group aboard the Brown.

Acknowledgments:The planning for JASMINE emerged out of the St. Michael's Conference on the Variability of the Asian-Australian monsoon system held in July, 1998, funded by the Climate Dynamics and Large Scale Dynamic Meteorology Programs of the Atmospheric Sciences Division (ATM) of the National Science Foundation (NSF), the National Oceanographic and Atmospheric Administration (NOAA) Office of Global Programs (OGP), and NASA. Funding for the JASMINE Pilot Study field phase came from NSF/ATM and Physical Oceanography Program of the Oceanography (OCE) of NSF, and the NOAA OGP. Support was provided through NSF Grants ATM-9900710, NSF-ATM-9820531 and NOAA/OGP Grant NA67RJ0154 for the University of Colorado and NOAA/ETL. The University of Washington group received support from NSF ATM-9900710 and through the Joint Institute for the Study of the Atmosphere and the Ocean (JISAO) under the Cooperative Agreement NA67RJO155. The University of Hawaii group was supported by NSF grant NSF ATM-9820531 and NOAA/OGP NA67RJ0154. Financial support from NASA allowed the deployment of the cloud radar. The NOAA Environmental Technology Laboratories provided equipment and resources. Support for the Australian part of the field phase came from the Marine Sciences Division of CSIRO.

ECMWF made their data available for the period of the cruise for analysis. For this we appreciate the efforts of Drs. M. Miller and A. Hollingsworth. Geostationary satellite data from the METEOSAT-5 was made available by the European Space Agency through the efforts of Drs. R. Sadourny, J-L. Monge and M. Dubois. We would like to thank the crew of the NOAA Ship Ronald H. Brown and the Franklin. We would also like to acknowledge the constructive comments of Prof. J. A. Curry.

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Figure Captions:

Figure 1: Principal platform used in the first two phases (April and May, 1999) of JASMINE was the NOAA Research Ship Ronald H. Brown. Numbers on the figure refer to the location of many of the instruments used during JASMINE and noted in Table 1. During third phase of JASMINE (September 1999), the Australian Research Ship Franklin was deployed.

Figure 2: Composite precipitation pattern associated with monsoon intraseasonal oscillations as a function of time and latitude based on 39 monsoon intraseasonal events identified in Webster et al. (1998). The pattern was used for experimental design with the proposed cruise path shown as a black line. Plans called for sampling the atmosphere and ocean in an "undisturbed" state before the advent of an monsoon intraseasonal oscillation, and in the "disturbed" state after the monsoon intraseasonal oscillation had formed. Two sampling techniques were to be used: north-south transects along 89E and two "on-station" periods near 5N. As it turned out, the sequence of meteorological events encountered in the eastern Indian Ocean followed the composite almost exactly (see Figure 4b). Gadgil and Sanjani (1998) show similar disparities to the sample but for all monsoon regions.

Figure 3: Three phases of the field phase of JASMINE showing the cruise paths in Julian days. Phase I (panel a) was made up of transects along 89E. In Phase II (panel b), transects along 89E were accompanied by "on-station" periods, each five days in duration, where star patterns were executed (Star 1 and 2: see inset). Each star pattern was planned to take 18 hours so that about 6 circuits were completed during each 5-day period. During Phase III (panel c), the Australians executed triangle maneuvers (see inset) each taking 8 hours. During the cruise, CTD casts and upper-atmosphere radiosonde measurements were made. The number of these observations by Phase are recorded in Table 3. All other instruments described in Table 1, or shown in Figure 1, were run in continual mode. Way-points are noted in the figure and cross-referenced to Table 2.

SIDEBAR for Figure 3:

Observations during Transects

- ADCP velocity profiles at 1 km horizontal resolution.

- CTD stations to 1000 m at whole degrees and to 500 m at the intervening 1/2 intervals. At each station the ship was positioned to optimize eddy correlation flux estimates to correct for distortions (Edson et al. 1998) and mean meteorological and SST measurements were gathered to compute turbulent fluxes (Fairall et al. 1996a, Chang and Grossman, 1999) that were compared with the accurate direct covariance flux measurements.
- Continuous Longwave and shortwave radiative fluxes monitoring.
- Continuous Doppler radar measurements at 3-GHz and 915-MHz to resolve mesoscale.
- Circulation structure: Radiosonde measurements (6 times per day on the Brown; four times per day on the Franklin) at internationally agreed times for upper atmosphere soundings.

All other instrumentation operated in continuous mode.

Star and Triangle Periods

The star needed to be large enough to sample the horizontal gradients associated with the dominant advective processes, yet needed to be completed in a short time compared to important periods of variability. The legs of the star were 44.4 km long with stations every 14.8 km. The circuit took about 18 hours to complete, with a circuit around the inner pentagon of stations every 9 hours. This circuit time was short compared to the inertial period at 10(N and minimized diurnal biases over the five-day period.

The Franklin took 8 hours to make its triangle (see Figure 3). Experience in the equatorial East Indian Ocean (Godfrey et al., 1999) had shown this pattern to be effective in upper ocean budget closure experiments. The triangle and stars took place at the same location.

Measurements during these on-station observation periods:

- CTD station frequency increased to 14.8 km spacing with about 15 "on-station" observing periods for all parameters (atmospheric, air-sea flux and oceanic) on the star, six CTD casts on the triangle.
- Upper air soundings: still four per day on the Franklin; increased to eight per day on the Brown. All other measurements on the same schedule as during the transects

All other instrumentation operated in continuous mode.

Figure 4: Time-latitude sections of brightness temperature (see color-coded scale) from the European Space Agency METEOSAT-5 geostationary satellite (a) April, (b) May, (c) June, (d) July, and (e) September of 1999. All sections are averaged between

85E and 90E. Ship tracks for Phase I, II and III are shown in panels (a) (b) and (e), respectively. August 1999 has been omitted because of poor data quality. Cold temperatures are indicative of high cloud tops while relatively clear periods appear as warm temperatures representing infrared radiation emitted at the surface, the moist boundary layer, or from low tropospheric clouds.

Figure 5: Daily averaged (a) 925 mb and (b) 200 mb vector winds from ECMWF along 89E for Phase II of JASMINE. Color coding denotes wind speed relative to the scale to the right of the panel.

Figure 6: (a) Synoptic situation during Star 1 of JASMINE. Both 24-hour average brightness temperature and surface pressure fields are shown for the period 12–15 May, 1999. The period is highlighted by weak surface winds and strong insolation. (b) Same as (a) except for the disturbed and convective Star 2 period during 22–25 May, 1999. The white dot denotes the location of the Brown.

Figure 7: (a) Zonal current (m s^{-1}) of the upper ocean for the five transects of Phase I and II of JASMINE plotted as a function of depth and latitude. Vertical lines are one day apart. Sections are arranged from north to south and the arrows indicate the direction of the transects. The star patterns indicate the time of the on-station budget surveys conducted near the northern end of the transects, to the north of the fresh water front. Note the reversal of zonal current with latitude. Near the equator, the zonal current reverses direction twice, going through a complete oscillation in a 50-day period. There is also some evidence of vertical wave propagation in the structure. Overall, the ocean currents show a strong intraseasonal oscillation. (b) Same as (a) except for the temperature structure (C); (c) Same as (a) except for salinity (psu). Note the large difference in the salinity between the northern and southern ends of the Bay of Bengal.

Figure 8: (a) Temperature (upper panel) and salinity (lower panel) plotted as a function of depth for Star 1. (b) Same as (a) except for Star 2. Note cooling and deepening and slight freshening of upper 30 m. (c) Same as (a) except for Phase III from the Franklin. Time in Julian days. Vertical line denotes 00 UTC of each day. Although the position of the ship varies during each of the surveys, the sections represent the space-time evolution of the fields plotted only as a function of time.

Figure 9: A more detailed view of the convective and dynamic structure of the atmosphere compared to Figures 4 and 5. (a) Time-height sections of horizontal wind (vectors:

m s⁻¹) and relative humidity (%) (upper panels) and radar reflectivity (lower panels percent with values $15 \text{ dBz} < Z < 35 \text{ dBz}$ in blue and $Z > 35 \text{ dBz}$ in red) for (i) Star 1 and (ii) Star 2. During the undisturbed period (Star 1) the middle and upper troposphere is extremely dry. Little convection beyond trade cumuli existed at this time. During the disturbed period (Star 2) the middle and upper troposphere has markedly moistened, stronger winds prevail throughout the column and convection is deeper and stronger. Note the marked nocturnal maximum in the convection. Time in Julian days. The two radar reflectivity curves show the percent area within 100 km of the Brown with reflectivity in the range 15 dBz to 35 dBz (blue curve) and $> 35 \text{ dBz}$ (red curve). (b) Left-hand panel shows a comparison of the mean vertical relative humidity distribution (%) for Star 1 (black), Star 2 (gray) and TOGA COARE (dashed). Center panel shows the vertical distribution of the mean temperature differences (C) between the two Star periods, and between each Star period and TOGA COARE. Third panel shows the mean vertical wind distributions for the Star 1, Star 2 and the TOGA COARE periods.

Figure 10: Components of the surface energy balance (W m^{-2}) for (a) Star 1, and (b) Star 2. Five surface fluxes are shown: the solar radiative flux, sensible turbulent heat flux, latent turbulent heat flux, net longwave flux (outgoing surface minus incoming atmospheric), and the sensible heat flux of rainfall. Units W m^{-2} .

Figure 11: Daily averaged net heat flux into the ocean during (a) Phase II and (b) Phase III. The shaded areas indicate the on-station star patterns (Phase II) or the triangle patterns (Phase III). Units W m^{-2} .

Figure 12: Average diurnal variability of the (a) surface and 10 m air temperature (SST, TA: C), (b) surface wind speed (WS: m s^{-1}), and (c) rain rate (R: mm hr^{-1}) for the Star 1 (dashed lines) and Star 2 (solid lines).

Figure 13: Diurnal variation of the surface fluxes between the atmosphere and the ocean for the periods of Star 1 (dashed) and Star 2 (solid): (a) the surface turbulent fluxes and the net longwave radiation, (b) the solar and downwelling longwave radiation, and (c) calculations of the diurnal variability of the shortwave and longwave surface cloud forcing. Units W m^{-2} .

Figure 14: Detail of the brightness temperatures (K) plotted as a function of latitude and time with twice the resolution from Figure 4b. Sloping lines represent phase lines of 60

km hr⁻¹. A-A and B-B refer to convective events shown in Figures 15 and 16.

Figure 15: Height-time sections of 35 GHz (K-Band) profiling "cloud radar" reflectivity between 1200 UTC 22 May 1999, to 1200 UTC 25 May 1999 during the Star 2 period.

Figure 16: C-band Doppler radar depictions of disturbed conditions on (a) 0110 UTC 23 May, 1999, and (b) 1810 UTC 24 May 1999. The times of scans are marked as A-A and B-B on Figure 14 and A and B on Figure 15, respectively. For each situation, three sections are shown: Panel (i): Reflectivity as a function of latitude and longitude (dBz), Panel (ii): Cross section of reflectivity (dBz) along the line marked X-Y in Panel i, and Panel (iii): Radial wind speeds along X-Y (m s⁻¹) as determined by the Doppler radar. In (b), a section of the lower troposphere has been expanded.

Table Captions:

Table 1: Observation system on the Brown. Left hand column indicates the instrument number which is used to show the location of the instrument in Figure 1. The second column lists the instrument and the third column shows its utility. Basic references for the instrumentation are given in the third column.

SIDEBAR for Table 1:

*Two Sea-Bird CTD instruments (14) were used to measure upper-ocean structure: the Brown's shipboard single sensor system during the April 1999 leg, and the University of Hawaii's dual temperature/conductivity sensor system during the May-June 1999 leg. All sensors were calibrated before and after the cruise, and have measurement accuracies better than 0.01C (temperature) and 0.01 psu (salinity) below five meters. **The Brown's thermosalinograph (18) provided continuous, high-resolution measurements of temperature and salinity in the surface layer at a depth of 5.6 meters. ***Horizontal currents over the depth range of 17 to 400 meters, typically, were measured with the ship's RDI 150 kHz narrowband acoustic Doppler current profiler (ADCP) together with a Ring LASER gyroscope and P-code navigation. The ADCP data were stored as two-minute ensembles with a vertical resolution of 8 meters. In addition, 25 surface drifters were deployed as part of the global drifter array to measure near-surface currents and temperatures, and two Argo-type profiling temperature and salinity floats were deployed from the Brown during JASMINE.

One of the unique characteristics of the Brown is the permanently installed, stabilized scanning C-band Doppler radar. The C-band reflectivity observations document the basic three-dimensional structure of the precipitation patterns. Single-Doppler measures radial velocity and the observations can be used to determine the circulation of convective and mesoscale systems. Analysis of this basic documentation, enables the determination of the key levels in the atmosphere where convective systems interact with the large-scale circulation (Kingsmill and Houze, 1998a, b). The range of the radar is about 240 km, although the effective range for Doppler determinations is approximately 100 km. The C-band has a 5 cm wavelength and a 1 beam width. Both surveillance and volume scans were used during JASMINE and were designed to provide comparisons with the upward-looking cloud radar described below. Details of the volume scan sets given at http://www.atmos.washington.edu/~serra/JASMINE/jasmine_overview.html.

Profiling Doppler radars and radiometers on the Brown helped define the structure of the marine boundary layer and to provide diagnostics of precipitating systems. The Brown carried a 915 MHz wind profiler; a 3 GHz S-band precipitation profiler; a 35 GHz (K-band) profiling Doppler cloud radar with a short wavelength (8 mm) making the radar sufficiently sensitive to observe cloud droplets (thus, it is often referred to as a "cloud radar"). JASMINE is only the second deployment of a cloud radar on a ship. It was used in combination with a microwave radiometer for retrieving total integrated vapor and integrated water. The radiometer is an essential complement to the cloud radar for retrievals of cloud droplet size information (Frisch et al. 1995). Additional cloud information was obtained from a commercial lidar ceilometer, which is not "blinded" by precipitation so it is more capable of detecting cloud base than the cloud radar.

While single-Doppler radar observations are useful in analyzing the interaction of convective and large-scale circulations, observations of the ambient large-scale thermodynamic and wind stratification in the vicinity of the mesoscale convective systems are also necessary. To meet these needs, a series of upper air soundings were taken from the Brown. The GPS tracking system provided great accuracy in wind measurements. In conjunction with the soundings, high-frequency surface meteorology measurements were maintained aboard ship. A similar system was used on the Franklin. Overall, 272 successful radiosonde ascents were undertaken (Table 3). Over 95% of the soundings reached the Global Telecommunications System and were used as initial data by major numerical centers throughout the world.

Note: The Franklin carried an identical flux system to that on the Brown. The location of

instruments on the Franklin was generally as illustrated in Godfrey et al. (1999, see their Figure 5), although no Seasoar or buoy was deployed in JASMINE. The ship was equipped with a boom that extended 10 m forward of the bow to carry instruments clear of ship's influence. Others instruments were mounted on an arm near the top of the foremast and some were located at various positions along the yardarm on the main mast. The Franklin oceanographic measurement system mirrored that of the Brown, except that (i) the CTD used was a Neil Brown Mark III and that the Franklin measurements included nitrate and phosphate samples and bottle samples of salinity.

Table 2: Three phases of JASMINE showing the dates of the north-south transects and their way-points. During Phase II and III there were periods where the ship remained "on station" executing maneuvers around a specific point for a number of days. These are referred to as Stars or triangles, depending on the shape of the manoeuvre. The NOAA Research Ship Brown was the principal research platform used during Phase I and II. The Australian CSIRO Research Ship Franklin was used during Phase III. Numbers in the right-hand column refer to way-points in Figure 3.

Table 3: Total number of upper atmosphere soundings and CTDs by Phase and leg. Overall 272 radiosonde ascents and 388 CTD casts were made during the 52 days of JASMINE.

Table 4: Comparison of Indian Ocean fluxes obtained during JASMINE with those obtained in process experiments in the western Pacific Ocean. Units $W m^{-2}$.

Table 5: Comparison of average conditions of active and break periods in the Bay of Bengal compared to conditions during Star 1 and 2. Comparisons are made with OLR ($W m^{-2}$) and 1000 mb wind speed (ms^{-1}). There were 59 active and 49 break periods used in compiling the climatology using criteria described in the text. NCEP reanalysis wind data set was used.

TABLE 1:

	SYSTEM	MEASUREMENT	REFERENCES
1	Air-sea flux system	Motion corrected turbulent fluxes	Fairall et al. (1996a, 1997), Edson et al (1997)
2	Pyranometer & Pyrgeometer	Downward solar radiative, IR flux	Godfrey et al. (1999), Fairall et al. (1998)
3	Bulk meteorology	SST, air T, RH, wind speed & direction	Fairall et al. (1996a, 1997), Godfrey et al. (1999)
4	Ceilometer	Cloud-base height	Fairall et al. (1997)
5	0.92 & 3 GHz Doppler radar profiler	Wind & precipitation profiles	Eklund et al. (1988, 1997), Gage et al. (1996, 1999)
6	Raingauges	Rain rate	Fairall et al. (1996a)
7	Rawinsonde	Wind, temperature, humidity profiles	NCAR ATD
8	35 GHz Doppler cloud radar	Cloud microphysical properties	Moran et al. (1998), Frisch et al. (1995)
9	20, 31 GHz wave radiometer	Integrated cloud liquid water, total vapor	Snider and Hazen (1998), Hogg et al. (1983)
10	WHOI LICOR 6262 system	Fast CO ₂ air concentrations	Fairall et al. (2000)
11	Upward pointed IR thermometer	Cloud-base radiative temperature	
12	BNL Portable Radiation	Direct and diffuse solar, IR fluxes	
13	Scanning C-band Doppler radar	Precipitation 3-D structure, wind	KWAJEX (1999)
14	CTD	Ocean T, S profiles	Lukas et al. (2001), Godfrey et al. (1999)
15	ADCP	Ocean current profiles	
16	Satellite/SCS	NOAA, GMS data	
17	Navigation/SCS	Position, course, speed, heading, etc	
18	Thermosalinograph	Near-surface T, S	
19	AOML underway CO ₂ system	Water-air CO ₂ concentrations	Fairall et al. (2000)
20	Autosal	Water salinity calibrations	

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Floating thermistor

Near-surface (5 cm) sea temperature

Fairall et al. (1996a), Donlon et al. (1998)

TABLE 2:

PHASE	SECTION	DATES 1999	WAY POINTS	FIG 3
PHASE I: MALE-SINGAPORE April 7-22 <i>Ronald H. Brown</i>	transect 1	April 10 - April 16	4.8°S-88.0°E, 16.3°N-88.0°E	1 - 2
	transect 2	April 16 - April 18	15.7°N-88.0°E, 8.0°N-88.0°E	2 - 3
PHASE II: SINGAPORE-DARWIN May 1-June 8, 1999 <i>Ronald H. Brown</i>	transect 1	May 5 - May 10	0°N-89.0°E, 13.5°N-88.8°E	1 - 2
	star 1	May 10 - May 15	11.9°N-88.6°E	2
	transect 2	May 15 - May 18	11.6°N-88.5°E, 0°N-86.5°E	2 - 3
	transect 3	May 18 - May 21	0°N-88.5°E, 11°N-88.2°E	3 - 4
	star 2	May 21 - May 26	11.2°N-89.3°E	4
PHASE III: DARWIN-SINGAPORE Sept. 2-28 <i>R/V Franklin</i>	transect 1	Sept 12 - Sept 16	0.5°S-88.5°E, 11.5°N-88.5°E	1 - 2
	triangle	Sept 16 - Sept 23	11.7°N-88.7°E, 11.2°N-89.8°E	2 - 3
	transect 2	Sept 23 -		

TABLE 3:

PHASE	SECTION	SONDES	CTDs
PHASE I:	transect 1,2	23	44
PHASE II:	transect 1,2,3,4	108 (at 6/day)	124
	star 1,2	85 (at 8/day)	103, 97
PHASE III:	transect 1,2	32 (1/day for 8 days and 4/day for 6 days)	20 CTD plus 22 XBTs
	triangle	28 (4/day)	126

TABLE 4:

EXPERIMENT	SOLAR	LW	SEN	LH	RAIN	NET
<u>PACIFIC</u>						
TOGA-COARE PIIot	+197	-43	-12	-116	-3	+22
TIWE	+219	-51	-4	-101	-0	+61
TC-period 1	+222	-58	-7	-89	-1	+65
TC-period 2	+166	-46	-11	-117	-4	-12
TC-period 3	+190	-51	-10	-112	-3	+13
CSP	+225	-48	-6	-109	-2	+59
Nauru-99	+216	-54	-5	-123	-1	+33
Average TOGA COARE	+205	-50	-8	-110	-2	+34
Average Pacific	+176	-52	-9	-106	-2	+22
Average TC satellite	+226	-66	-6	-110	-2	+41
<u>INDIAN</u>						
JASMINE Phase II	+205	-43	-9	-125	-2	+27
Phase II: Satr 1	+260	-49	-5	-115	-0	+92
Phase II: Satr 2	+162	-31	-17	-162	-7	-89
JASMINE Phase III	+229	-38	-3	-92	-1	+96
Average JASMINE (II+III)	+217	-42	-6	-109	-2	+62

TABLE 5:

	Break Periods (49 events)	STAR 1	Active Periods (59 events)	STAR 2
OLR (W m^{-2})	242 ± 17	253	167 ± 16	140
1000 mb wind speed (m s^{-1})	7.6 ± 2.3	4.5	10.1 ± 4.8	9.9