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A DIAGNOSTIC ANALYSIS OF THE RELATIONSHIP BETWEEN THE FLUXES AND METEOROLOGICAL ELEMENTS OVER TROPICAL WESTERN PACIFIC*

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ABSTRACT: Through the use of the hourly wind, air temperature and humidity, sea surface temperature data measured on board the observing vessel Moana Wave and buoy in the warm pool of western Pacific during the IOP of TOGA COARE, we compute the fluxes over sea surface and analyze the characteristics of the variation of the latent heat flux with sea surface temperature. During weak rather than strong wind periods, a maximum value of latent heat flux appears at some points of SST, which is caused mainly by the variations of wind, then by the humidity difference between air and sea, and the transfer coefficient with SST. Using correlation analysis, we also analyze the relationship between the fluxes and meteorological elements during weak wind periods, westerly wind burst periods, and convective disturbed periods etc. The main conclusions are that the latent heat flux is mainly determined by wind, sensible heat flux by the potential temperature difference between air and sea, and the momentum flux by wind. The precipitation affects the sensible heat flux through the potential temperature difference and wind.

Key words: TOGA COARE; equatorial western Pacific; fluxes over sea

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Ⅰ. INTRODUCTION

The fluxes over the sea surface, especially over tropical ocean, are very important quantities in recent research on atmospheric circulation and climate, playing a significant role in the causality research of climate change and its prediction. Significant achievements have been made, with large amount of observations available, in this aspect, since the implementation of TOGA TAO and TOGA COARE projects. Qu et al. (1996), for example, study the fluxes characteristics for the westerly wind burst periods in the equatorial western Pacific by using the data collected by the Chinese vessel 'Experiment III' and the bulk transfer coefficients which depend on wind speed and stability. They find that the fluxes attain their maximum values during the westerly wind burst periods. Xu et al (1997) study the characteristics of the fluxes over the warm pool of western Pacific by using the data measured at the Chinese vessel 'Xiangyanghong IV' and the bulk transfer coefficient based on Businger-Dyer flux-profile relationship. In their research, they considered the scalar roughness corresponding to temperature and humidity and analyzed the relation between the fluxes and both wind and stability. Gao et al (1997) study the difference of

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the fluxes for different weather systems in the warm pool of the western Pacific using the data measured at the Chinese vessels 'Experiment III' and 'Science I'. They also concluded that the fluxes attained their maximum values during westerly wind burst periods. Recently, Lau et al (1996), Chen et al (1996), Lin et al (1996) analyze the evolutions of convection activity, rainfall, wind and fluxes in a large domain of western tropical Pacific, especially the warm pool region, by using the TOGA COARE data. Weller et al (1996) thoroughly analyze the WHOI buoys data of TOGA COARE , and in particular they obtained the characteristics of the temporal variation for the meteorological elements and fluxes during different periods in IOP of COARE over the warm pool in western Pacific. Zhang et al (1995) calculate the relationship between the latent heat flux (*LH*) and both SST and wind speed with the daily mean meteorological and oceanic data collected at the TOGA TAO buoys widely distributed in tropical Pacific and analyze the characteristics of *LH* for a long time scale. At present , the flux-profile relationship based on Monin-Obukhov similarity theory is used to compute the fluxes from wind speed, temperature and humidity in almost all the investigations. In view of their variation mechanism and the relationship between flux and meteorological elements, hourly mean observations should be more reasonable than the daily mean values. On the other hand, the relationship has not been fully understood for different weather background, i.e. time periods with different specific values and the expression of the flux-profile relation needs to be perfected further. The aim of this paper is 1) to analyze the relation between the fluxes and meteorological elements on the hourly scale with time periods with different specific values, using improved flux-profile relation and observations from TOGA COARE during IOP in the warm pool of western Pacific, mainly collected at the vessel 'Moana Wave' and supplemented by WHOI buoy data, to determine main meteorological factors affecting the variation characteristics of these fluxes, and 2) to study the relation between the fluxes over tropical western Pacific during IOP and the wind speed, the differences of temperature and humidity between air and sea, and rainfall etc by using correlation analysis method. Because the relation between the fluxes and meteorological elements on the hourly scale mainly depends on meso- and micro-scale weather systems, we focus the study on the relation caused by meso- and micro-scale systems, which is different from the large-scale interaction between air and sea.

II. THE FORMULA AND DATA

The computation of fluxes over ground surface in atmospheric models usually uses the bulk coefficient method with respect to wind speed and differences of temperature and humidity between air and sea. The bulk coefficients are, for the recent years, derived from the Businger-Dyer relation based on the similarity theory in surface meteorology, in addition to consideration of the roughness varying with wind speed and inclusion of the scalar roughness for temperature and humidity z_{0T} and z_{0q}, such as Xu et al (1997),Qu (1988), CCM3, ECMWF etc. Fairall et al (1996a, 1996b) suggest a new method, which partly includes the effect of free convection in the surface layer and the cold skin effect for sea surface temperature, in an attempt to account for the difference between sea surface temperature needed by the formula and the measured temperature at some depths below sea surface. Recently, Zeng et al (1998) suggests a new profile formula, which includes the effect of free convection in the B–D formula and derives new z_0, z_{0T} and z_{0q} formulas which depend on the friction velocity u_*. With the COARE data, the fluxes including momentum flux τ, sensible heat flux $-\rho c_p u_* \theta_*$ and latent heat flux $-\rho L u_* q_*$ can be computed using the wind speed, temperature and humidity at a given level above the sea surface and SST from following formulas:

$$u = \frac{u_*}{k}\{[\ln(\frac{\varsigma_m}{z_0}L_v) - \psi_m(\varsigma_m)] + 1.14[(-\varsigma)^{1/3} - (-\varsigma_m)^{1/3}]\}, \text{ when } \varsigma < \varsigma_m = -1{,}574 \quad (1)$$

$$u = \frac{u_*}{k}[\ln\frac{z}{z_0} - \psi_m(z)] \quad \text{when } \varsigma_m < \varsigma < 0 \quad (2)$$

$$u = \frac{u_*}{k}[\ln\frac{z}{z_0} + 5\varsigma] \quad \text{when } 0 < \varsigma < 1 \quad (3)$$

$$u = \frac{u_*}{k}[\ln\frac{L_v}{z_0} + 5 + 5\ln\varsigma + \varsigma - 1] \quad \text{when } \varsigma > 1 \quad (4)$$

$$\theta - \theta_s = \Delta\theta = \frac{\theta_*}{k}\{[\ln(\frac{\varsigma_h}{z_{0T}}L_v) - \psi_h(\varsigma_h)] + 0.8[(-\varsigma_h)^{-1/3} - (-\varsigma)^{-1/3}]\},$$

$$\text{when } \varsigma < \varsigma_h = -0.465 \quad (5)$$

$$\Delta\theta = \frac{\theta_*}{k}[\ln\frac{z}{z_{0T}} - \psi_h(\varsigma)] \quad \text{when } \varsigma_h < \varsigma < 0 \quad (6)$$

$$\Delta\theta = \frac{\theta_*}{k}[\ln\frac{z}{z_{0T}} + 5\varsigma] \quad \text{when } 0 < \varsigma < 1 \quad (7)$$

$$\Delta\theta = \frac{\theta_*}{k}[(\ln\frac{L_v}{z_{0T}} + 5) + 5\ln\varsigma + \varsigma - 1] \quad \text{when } \varsigma > 1 \quad (8)$$

where L is the evaporation latent heat, u_*, θ_*, q_* are the friction velocity, scale temperature and scale humidity respectively, $\zeta = z/L_v$, in which $L_v = \frac{\theta_v u_*^2}{kg\theta_{v*}}$, is the M-O length considering the effect of moisture, θ_v the virtual potential temperature, θ_{v*} the virtual scale temperature, k the Karman coefficient, ψ_m, ψ_h are the stability functions for momentum and heat respectively, they take the usual Businger-Dyer form. The formula for specific humidity q is the same as θ, i.e., it is derived by substituting Δq for $\Delta\theta$, z_{0q} for z_{0T}. The specific humidity over the sea surface is taken as:

$$q_s = 0.98 q_{sat}(T_s)$$

$q_{sat}(T_s)$ is the saturated specific humidity corresponding to sea surface temperature T_s. In order to consider the effect of turbulence in the case of slight wind, we use following formula in unstable condition:

$$u = [u_x^2 + u_y^2 + (\beta w_*)^2]^{1/2}$$

where $w_* = (-\frac{g}{\theta}\theta_{v*}u_* z_i)^{1/3}$ is the convective speed scale, u_x, u_y are wind components, $z_i = 1000$ m is the depth of the mixing layer. The roughness formulas are:

$$z_0 = a_1 \frac{u_*^2}{g} + a_2 \frac{v}{u_*} \tag{9}$$

$$\ln \frac{z_0}{z_{0T}} = b_1 re^{0.25} + b_2, \qquad z_{0q} = z_{0T} \tag{10}$$

$re = \frac{u_*}{v} z_0$, where v is the viscous coefficient of air, Zeng et al (1998) find that $a_1 = 0.013, a_2 = 0.11, b_1 = 2.67, b_2 = -2.57$ from the COARE data and they indicated that the result from Eqs.(1)-(8) was more in agreement with observation.

The vessel Moana Wave was located at 1.7°S, 156°E. The turbulent fluctuation velocity and temperature, mean wind speed were measured at the height of 15 m by acoustic anemometers, the eddy correlation and inertial dissipation methods were used to compute eddy fluxes, the fluctuated humidity was measured by infrared hygrometers, the mean temperature and humidity were measured by Vaisala HMP-35 thermometer and hygrometer, the mean temperature and humidity were also measured at 15 m, and the sea temperature was measured at 0.05 m below sea surface. Radiation, rainfall were also observed. The period of observation is from Nov. 1992 to Feb. 1993, the data were averaged over 10 min and recorded. The values averaged in 50 min were taken as the hourly value. The processed data were provided by Fairall. WHOI buoy was located at 1.71°S, 156°E, measuring temperature at the level of 2.78 m, humidity at 2.74 m, wind at 3.54 m, and sea temperature at 0.45 m below sea surface. There were also radiation and rainfall data. All the data were hourly values.

The data are analyzed in some specific periods during IOP (corresponding to different weather background). Weller et al (1996) prove that the fluxes computed from the buoy data are in agreement with the data taken from the vessel near it. Fairall et al (1996b) show that the model results are also in agreement with observed fluxes. In this paper, we shall use computed fluxes for analyses with the cold skin effect considered.

Lau et al (1996),Chen et al (1996), Lin et al (1996)analyze satellite imagery, radiosonde data and observed data near surface for general meteorological characteristics during IOP in the COARE area, especially, the IFA area where the above-mentioned vessels and buoy were located. In their analysis, the IOP were marked by undisturbed periods of low and high winds with strong convection (westerly wind burst periods, but the phase of the strongest westerly wind did not coincide with the strongest convection) appearing alternatively. Roughly speaking, the period from mid-Nov. to the first several days in Dec. was the undisturbed period with low wind (<2 m/s), during which both convection and rainfall were weak and SST was high. From the middle of Dec. to the beginning of Jan., there were westerly wind bursts, abundant rainfall and active convection. The convection tended to enhance and the wind speed increased from the first 10 days to the second 10 days of Dec., which is called a convectively disturbed period. From the first 10 days to second 10 days of Jan., the low wind appeared again. At the end of the second 10 days of Jan., there was a stronger rainfall, but with stronger easterly wind. From the final 10 days of Jan. to Feb., the speed of the westerly wind increased gradually when there were several short-lived wind events, i.e., the wind speed increased in a relatively short time with a decreasing temperature. After several days, the wind speed decreased and temperature raised again. Here we shall mainly analyze a typical undisturbed low wind period from the end of Nov. to the beginning days of Dec., a westerly wind burst period during Dec.20-24, a convectively disturbed period during Dec.7-17 and a wind event from the end of Jan. to the beginning of February.

III. THE SENSITIVITY OF LATENT HEAT FLUX TO SST

The recent research finds that the latent heat flux does not always increase with the increase of SST. Zhang et al (1995) compute the daily averaged fluxes from the daily averaged wind, temperature and humidity measured at many TOGA TAO buoys in tropical Pacific, revealing that LH decreased with the increase of SST when SST >300-301 K, the reverse was true as SST <300-301 K. His explanation is that wind speed and SST are negatively correlated for high SST and the reverse is true for low SST. Our computed relation between latent heat flux and SST, which is based on the hourly data of Moana Wave during undisturbed period from Nov.28-Dec.3, is shown in Fig.1. It is seen that during this undisturbed period, LH attained its maximum when SST=29.6°C, LH increased with the increase of SST when SST <29.6°C, and the reverse was true for SST >29.6°C. This critical temperature was different from Zhang's, the reason being that Zhang's results were daily mean values and based on the widely distributed buoys while our data are hourly ones and from a single buoy at which the SST was high.. The computation is more agreeable to physical rationale when the hourly values are used. Taking all the fluxes and SST data that satisfies the condition $|z/L_v| >1$, i.e., low wind and strong unstable condition for the Moana Wave in the analyze, similar conclusions are drawn, though with the peak value located at SST=28.8°C. It means that with different SST values in various periods, critical SST corresponding to peak fluxes of *LH* differs. The period for Fig.1 is just the high SST period during IOP.

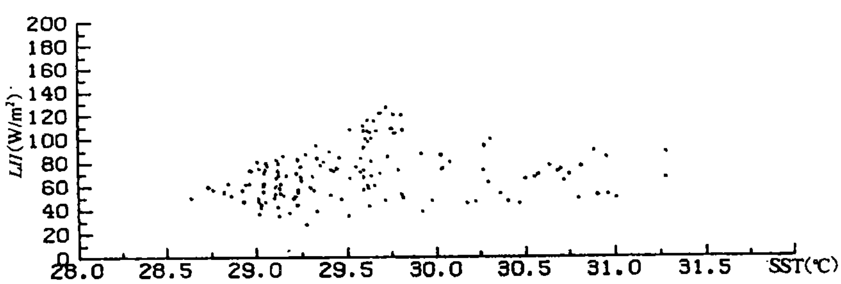

Fig.1. The relation between LH and SST for Moana Wave during Nov.28-Dec.3

Fig.2 is the relation between *u* and SST between Nov.28 and Dec.3. An opposite relation can be seen between *u* and SST on both sides of SST=29.6°C, which implies that the occurrence of the peak value of *LH* is wind-induced. Fig.3 indicates the relation between *LH* and *u*.

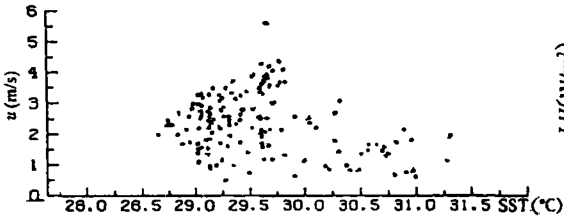

Fig.2. The relation between u and SST for Moana Wave during Nov.28~Dec.3.

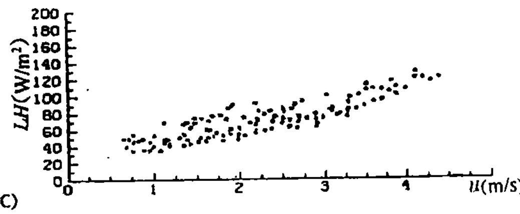

Fig.3. The relation between LH and u during Nov.28~Dec.3

The period for Dec.20-24 was the strong wind period when SST was usually less than 29.3°C. When SST increased, LH decreased monotonically, their correlation coefficient was –0.49, at this time, u and SST displayed negative correlation, having a coefficient of –0.47, suggesting that wind speed is still the main factor in the variation of LH with SST. More detailed analysis will be done later on. It is obviously seen that the relation between u and SST depends on the evolution of the mesoscale system during the high or low SST periods.

The latent heat flux formula may be written:

$$H_l = -\rho LC_E u(q - q_0) = -\rho LC_E u\Delta q \tag{11}$$

Comparing it with Zeng's formula, we can obtain:

$$C_E = \frac{-H_l}{\rho Lu\Delta q} = \frac{u_* q_*}{L\rho\Delta q} \tag{12}$$

Then we can compute C_E from Eq.(12) after u_*, q_* are made known. Differentiating Eq.(11) with respect to SST (T_s):

$$\frac{\partial H_l}{\partial T_s} = -\Delta qu\rho L\frac{\partial C_E}{\partial T_s} - C_E uL\rho\frac{\partial \Delta q}{\partial T_s} - C_E\Delta qL\rho\frac{\partial u}{\partial T_s} \tag{13}$$

and computing the magnitudes of the three terms on the r.h.s. of Eq.(13), we may know the roles of different factors in the variation of LH with SST. First, by computing the magnitudes of the partial derivatives on the r.h.s. of Eq.(13), the three derivatives, seen as the linear regression coefficients of C_E, Δq, u on T_s (Fig.4), may be derived. The l.h.s. of Eq.(13) represents the regression coefficient of H_l with respect to T_s.

Tab.1 shows that the summation of the 3 terms approaches the value of the l.h.s. of (13) from the regression of H_l with respect to T_s, meaning that the computation is convincible. From Tab. 1 we may see that during low wind and high temperature periods, the third term plays the most important role, which is in agreement with Zhang et al (1995)'s result. Its effect is the reverse to that of the first and second terms and larger than the sum of the two. As a result, the LH is decreased with the increase of SST. When the wind is low and SST is relatively cooler, Zhang argues that the second term is the most important in this case, or, the increase of LH is contributed mainly by that of $|\Delta q|$ due to the growth of T_s. Our result is that the increase of wind speed during the T increase plays the same role as the second term. In case of strong wind, as shown in the third row of Tab.1, the third term plays the most significant role, which is different from

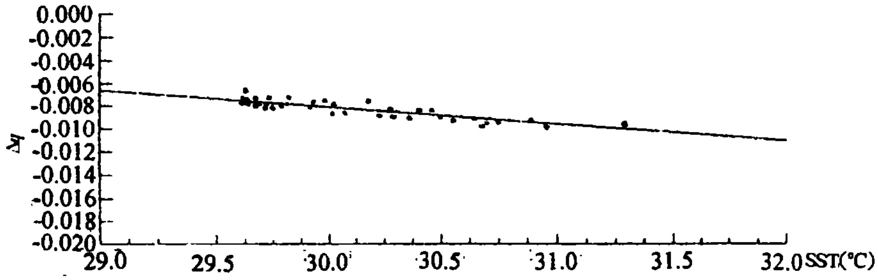

Fig.4 The regression of Δq with respect to T_s during Nov. 28–Dec.3 when SST>29.6°C

Zhang's results. Another difference from Zhang's is that Zhang shows that the first term is not important in the case of low wind and high temperature. Our result shows a different conclusion. This is because the domain and period for the data are different and so is the processing method. For our result, generally speaking, wind speed is the most important factor.

IV. THE CORRELATION ANALYSIS BETWEEN FLUXES AND METEOROLOGICAL ELEMENTS

Tab. 1 The components of $\partial H_l / \partial T_s$ (W/m^2 C)

	$(\partial H_l / \partial T_s)_1$	$(\partial H_l / \partial T_s)_2$	$(\partial H_l / \partial T_s)_3$	$\Sigma(\frac{\partial H_l}{\partial T_s})_i$	$\partial H_l / \partial T_s$
Nov.28-Dec.3, T_s >29.6C	23.20	16.06	-55.31	-16.05	-18.71
Nov.28-Dec.3, T_s <29.6 C	1.94	16.69	16.28	34.91	31.79
Dec.20-Dec.24	10.52	-12.75	-202.89	-205.12	-207.15

1. *Undisturbed period Nov.28-Dec.3*

The correlation coefficients for the fluxes computed from 157 data sets of the Moana Wave with u, Δq, $\Delta\theta$, SST are shown in Tab.2, where SH represents the sensible heat flux, τ the momentum flux. It is seen from the table that the best correlation occurs between LH and u (See Fig.3). The relation between LH and SST is not high because the peak value of LH appears at SST=29.6°C and neither is that between Δq and LH. It may be considered that wind is the most important factor for the formation of LH. We analyze the data of WHOI buoy during the low wind period on Nov.13-22 and find that LH has its peak value at SST=28.8°C, which is caused by the appearance of peak value of wind speed. However, the SST at which LH attained the peak value, being dependent on the wind speed, is lower than that for Moana Wave data because the maximum wind speed attained 5-6 m/s for the buoy, but 4-5 m/s for Moana Wave.

Tab.2 The correlation coefficients between fluxes and meteorological elements during Nov.28-Dec.3

	U	$\Delta\theta$	Δq	SST
LH	0.87	-0.23	-0.30	0.21
SH	0.39	-0.79	-0.47	0.46
τ	0.97	0.05	0.11	0.44
SST	-0.24	-0.74	-0.93	0.44

For SH, $\Delta\theta$ has the best correlation, the next being the wind speed, among meteorological elements. The correlation between SH and SST is caused by a rise in SST, which is accompanied by a rise in $|\Delta\theta|$, leading to eventual increases in SH. The correlation coefficients between SH and $\Delta\theta$ is much greater than that between LH and Δq which can be explained as follows: From the formula, $SH = -c_p \rho C_H u \Delta\theta$, we know that SH depends on $\Delta\theta$, u and C_H as well and the latter depends on stability in our scheme of computation. The greater the $|\Delta\theta|$, the stronger the instability, then the greater the C_H, i.e., C_H and $\Delta\theta$ affect SH in the same manner. This increases the correlation coefficient between SH and $\Delta\theta$. C_E is, however, not affected by Δq, hence, the coefficient between LH and Δq is much less than that between SH and $\Delta\theta$. For the momentum flux, the wind is an important physical factor. Fig.5 depicts the temporal variations of LH and u during this period, from which we can see the close correlation between them. The relation between LH and other elements is much looser than that between LH and u.

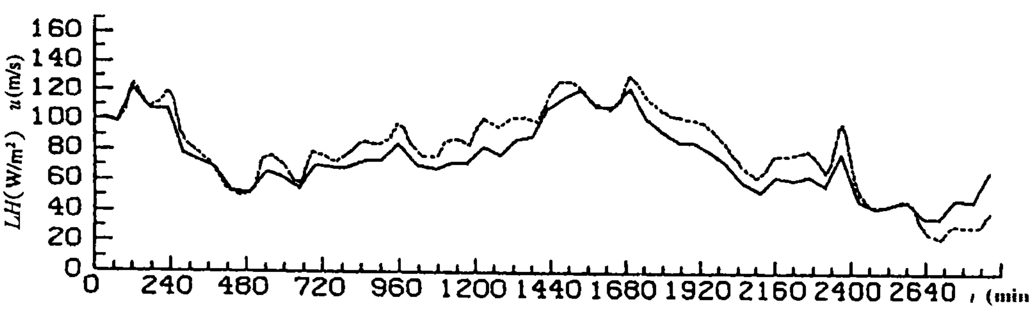

Fig.5. The temporal variations of u and LH, the solid line is for LH, the dashed line is for u(m/s)×30. the abscissa is time (min), and the period is Nov.30-Dec.1

2. *Westerly wind burst period*

As an example, we choose the data in Dec.20-24. For the period, there is more rainfall and stronger wind, and the convection is active. The correlation coefficients for 113 data sets of Moana Wave are shown in Tab.3, where T is the air temperature. We still can see that the best correlation occurs between LH and u, τ and u. For SH, the best correlation is with $\Delta\theta$, next is u. All of these are the same as in the case of low wind. The negative relation between u and SST still exists. Contrary to the situation in undisturbed periods, the correlation coefficient between LH

Tab.3 The correlation coefficients between fluxes and meteorological elements during Dec.20-24

	u	$\Delta\ \theta$	$\Delta\ q$	Rainfall	SST	T
LH	0.96	-0.45	-0.12	0.26	-0.49	
SH	0.63	-0.90	-0.13	0.52	-0.28	
τ	0.97	-0.32	0.14	0.23	-0.53	
SST	-0.26	0.06	0.13	-0.26		
Rainfall	0.21	-0.50	0.01			-0.53

and SST is larger because there is no peak value of LH at some points of SST. If the level of convection is expressed through rainfall, then rainfall affects SH as shown in Tab.3, which is explained by the fact that at this time, rainfall decreases $\Delta\theta$, i.e., increases $|\Delta\theta|$. From the relation between rainfall and T in Tab.3, we see that rainfall reduces the air temperature, increasing $|\Delta\theta|$ and SH. Fig.6 depicts the relation between rainfall and $\Delta\theta$ from the Moana Wave data and gives us a consistent variation.

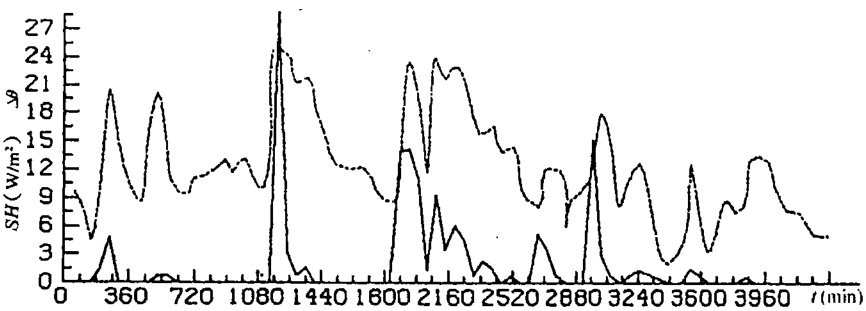

Fig.6. The temporal variations of rainfall and $\Delta\theta$, the solid line is for rainfall, the dashed line is for $|\Delta\theta| \times 6$(C), and the period is Dec.20-23

The period from Dec.25 to Jan.4 also witnesses the burst of westerly wind. An optimum correlation can still be obtained regarding LH and u, τ and u and SH and $\Delta\theta$ using the same data of Moana Wave. Being different in detail, the characteristics in the period are largely the same as that in Dec.20 ~ 24.

The WHOI buoy data during Dec.25~Jan.4 shows the similar characteristics as Moana Wave data except there exists a negative coefficient (–0.62) between LH and rainfall. The reason is that at this time the correlation coefficient between rainfall and wind is –0.58, i.e., wind reduces during the rain in reality. In other words, LH is mainly controlled by wind which is different from the case of SH. Similar to the previous example, rainfall increases SH and the coefficient between rainfall and $\Delta\theta$ is –0.58.

3.*Convectively disturbed period Dec.7-17*

During this period, wind speed is greater than that in the undisturbed period but lower than that in the strong wind period while convection develops and rainfall increases. We use the

WHOI buoy data to analyze due to the lack of Moana Wave data for this period. The correlation coefficients of 240 data sets are shown in Tab.4. The relation between *LH* and SST is less strong because *LH* attains its peak value at SST=29.3°C. Tab.4 shows that there is still the best correlation between *LH*, τ and *u*, *SH* and $\Delta\theta$, Similarly, rainfall increased fluxes because wind increased during the rain, being different from the example in section 2 for strong wind with a negative coefficient between rainfall and wind from the buoy data. As a conclusion, the relation between rainfall and wind shows different characteristics for different periods so that the relation between rainfall and fluxes shows different characteristics.

The fluxes during this period is greater than that in the undisturbed period but less than that in the westerly wind burst period, in agreement with the results of Qu et al (1996), Gao et al (1997) that the fluxes attains their maximum during westerly wind burst.

Tab. 4. The correlation coefficients between fluxes and meteorological elements during Dec.7-17.

	u	$\Delta\theta$	Δq	Rainfall	SST
LH	0.89	-0.15	-0.09	0.53	-0.21
SH	0.57	-0.70	-0.04	0.50	
τ	0.94	-0.03	0.23	0.53	
Rainfall	0.50	-0.20	0.09		-0.24

4. *Wind event during Jan.28-Feb.2*

Stronger wind exists with a shorter duration than that in a westerly wind burst, but the wind speed can be as strong as in the westerly wind burst, which in general attains 7-8 m/s, the maximum being 12 m/s, for wind speed, and the correlation coefficients are shown in Tab.5.

Tab. 5. The correlation coefficients between fluxes and meteorological elements during Jan.28-Feb.2.

	u	$\Delta\theta$	Δq	rainfall	SST
LH	0.95	-0.58	-0.72	0.11	
SH	0.66	-0.92	-0.55	0.34	
τ	0.95	0.50	-0.48	0.04	
Rainfall	-0.02	-0.41	-0.22		0.16

It is now obvious that *LH* peak value does not appear due to higher wind speed, so in general, the characteristics in the westerly wind burst period are shown. The best relations between *LH*, τ and *u*, *SH* and $\Delta\theta$ may be seen clearly. Rainfall also increases *SH*, due to the same reason that rainfall reduced air temperature, increasing $|\Delta\theta|$ because the relation between rainfall and SST is poor while the relation between rainfall and $\Delta\theta$ attains –0.41. In this period, no correlation exists between wind and rainfall so that rainfall does not affect the latent heat flux. A special situation is that there exists a close relation between *LH* and Δq, and the correlation coefficient is found to be –0.52 between wind and Δq, though with very low coefficients in other periods. Hence, the higher the coefficient between Δq and *LH* caused by wind, the closer the correlation between wind and Δq probably caused by the drier air brought in by wind at this stage (Weller et al ,1996).

V. CONCLUSION

We have analyzed the relation between fluxes over tropical ocean and meteorological elements by using hourly data collected at the vessel Moana Wave and WHOI buoy in the western Pacific during IOP of TOGA COARE . The use of hourly data is more appropriate for the physical basis of the formulas. This paper does not study the climatology of the exchange between air and sea, so we only analyze the characteristics of air-sea exchange in some specific periods and the main conclusions are:

a. During the undisturbed periods and when the wind is not strong, *LH* has peak value with respect to SST. The SST at which the peak value appears depends on the wind speed at the time— this critical temperature decreases when wind speed increases. The peak value occurs because the variation of wind speed with SST is out of phase on both sides of the peak value.

b. The cause for the variation of *LH* with SST is contributed mainly by the variation of the wind speed with SST and secondarily by the variation of $\Delta\theta$ with SST. The effect of C_E should also receive due attetion.

c. Regardless of the conditions of the wind speed and convection, *LH* is affected mainly by *u*, *SH* by $\Delta\theta$, τ by *u* and rainfall affects heat flux by affecting air temperature and its relation with wind. The wind speed may be strong or weak during the rain, depending on the mesoscale meteorological process , which needs to be studied further.

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