Article ID: 1006-8775(2001) 02-0175-12

KEY AREAS OF AIR-SEA INTERACTION IN GLOBAL OCEANS AND STUDY OF THE CLIMATOLOGICAL FEATURES

ZHANG Wei-qing (张卫青), QIAN Yong-fu (钱永甫)

(*Department of Atmospheric Sciences*, *Nanjing University*, *Nanjing*, 210093 *China*)

ABSTRACT: Seven key areas of air-sea interaction in the global oceans are determined by comprehensive analysis of the global data of monthly mean sea surface temperature (SST), surface wind, temperature, humidity, sea surface sensible heat and latent heat fluxes. The time-lag correlation between SST and each atmospheric element in each key area are focally analyzed to expose the same and the different features of air-sea interaction in different key areas. The results show that the air-sea thermal interaction is strong in each area, SST, temperature and humidity can be fairly replaced with one another, particularly in the central eastern Pacific and the south India Ocean. The dynamic effect on SST is different in different areas and in the central western Pacific such effect is more important. The correlation between sensible heat, latent heat and SST is more significant in the eastern Pacific, the western Pacific and the two major monsoon areas — the northwestern Pacific and the south India Ocean. By analyzing the sustainable correlation probability of SST and every atmospheric element in each key area, we further know that the anomalies of which element, in which area and in which period are well sustained or easily destroyed. This is beneficial not only to prediction, but also to discussion of the physical mechanism of air-sea interaction.

Key words: air-sea interaction; time-lag correlation; persistence of anomaly

CLC number: P732.6 **Document code:** A

1 INTRODUCTION

The interaction between the atmosphere and ocean is one of the essential compositions in the research of climatic changes. Meteorologists and oceanographers have spent a huge amount of effort in coping with mechanisms of air-sea interactions[1], characteristics of annual and seasonal variations of air-sea heat exchange[2, 3], in the tropics, effects of changes in SST in tropical ocean on the general circulation and interannual climatic variation[4, 5], and air-sea interactions on different time scales near the warm pool in the equatorial western Pacific. It is noted that much of the previous work focus on specific waters in the tropical ocean, leaving comprehensive and systematic study of air-sea interactions a much-needed topic for every parts of the global ocean. The ocean (atmosphere) affects the atmosphere (ocean) differently across the globe, and the air-sea interaction depends on both the ocean and atmosphere, with the atmosphere playing the dominant role in some parts of the ocean and the ocean in others. In view of it, key areas of global air-sea interaction are determined on the basis of integrated analysis of changes in SST and meteorological elements, after a statistic study of 40-year (1958-1997) global SST data and sea-surface meteorological element fields having an important role in the air-sea interaction.

To seek the magnitude of air-sea interactions, a usual way is to conduct an EOF decomposition

---

Received date: 2000-03-28; **revised date:** 2001-07-10
Foundation item: National Key Programme for Developing Basic Sciences: Part I (G1998040900); the NSFC Project (No.49735170)
Biography: ZHANG Wei-qing (1968 –), female, native from the Inner Mongolia Autonomous Region, lecturer, Ph.D. candidate, undertaking the study of climatic change and modeling.

of sea surface temperature anomaly (SSTA) with reference to the spatial distribution of characteristic vectors. For that matter, the waters of central and eastern Pacific Ocean are specially interested such that the SSTA there is used to define the El Niño and La Niña events. It is unfortunately incomplete. On the one hand, the air-sea interaction is mainly manifested in the magnitude and variation of fluxes between the two components. On the other hand, the air-sea interaction shows differently depending on different Nino regions, with no exception for the central and eastern Pacific waters. It is therefore necessary to have more study of the correlation between SSTA and meteorological elements. A traditional typical correlation method is used here to study the time-lag correlative relation between meteorological elements over each key waters and SST. In addition to determination of the dependent and mutual-substituting tendency among various element fields and understanding whether the air is interacting with the sea or one varies depending on the other, the treatment makes it easier to know more about the changes in the fluxes between air and sea on the basis of existing correlation. If the air and sea are well correlated, it is likely that the flux may be either small or change over a small range. It is then possible that areas with large values of SSTA may not necessarily be the ones playing the key role. On the contrary, lightly correlated waters may be the place where key interactions may be going on between the air and sea. Besides, the determination and study of key oceanic regions can also provide us with foundation for assessing the performance of oceanic or atmospheric models.

2 DATA AND METHODS OF TREATMENT

The data used in the work are 2° × 2° global monthly mean SST sets, 2.5° × 2.5° monthly mean sets of 1000-hPa zonal and longitudinal winds, air temperature and specific humidity, from 1958 to 1997, and pentad-by-pentad sea surface sensible and latent values from 1979 to 1995, by NECP / NCAR. For the convenience of comparison, the latter data are transformed into monthly mean ones.

To identify key oceanic waters, variability (root mean square) and amplitude of variation (difference between the highest and lowest values in the period of interest) are first used to study the interannual variation of SST and meteorological elements. Then, time-lag correlation and persistence correlations are used to discuss the influence mutually exerted by the SST and meteorological elements and persistence of anomaly in the atmosphere and ocean. In view of the possibility that the anomalies of individual months may be counteracted during the derivation of the amplitude of seasonal and annual mean variability, we first determine the interannual variability for the months and then seek averages of interannual variability in corresponding periods selected, compose interannual variability for the year and season, and take the maximum monthly amplitude of variation as the interannual amplitude of variation in the year and season selected.

3 SELECTION OF KEY OCEANIC WATERS

3.1 *Interannual variation of SST*

Fig.1 presents the interannual variability and variation amplitude of SST across the globe. The most significant display of annual root mean square (≥ 0.5°C) of SST is found in the following five regions: the equatorial central and eastern Pacific (CE-P, 160°E ~ 80°W, 10°S ~ 10°N), the northern Pacific (N-P, 120°E ~ 120°W, 25°N ~ 55°N), northwestern Atlantic (NW-A, 70°W ~ 20°w, 30°N ~ 60°N), southern Indian Ocean (S-IND, 20°E ~ 110°E, 40°S ~ 20°S), central Pacific in the Southern Hemisphere (C-P (s), 170°E ~ 100°W, 40°S ~ 20°S). The interannual amplitude of variation is also quite large in these waters (annual amplitude ≥ 4°C). The central and eastern

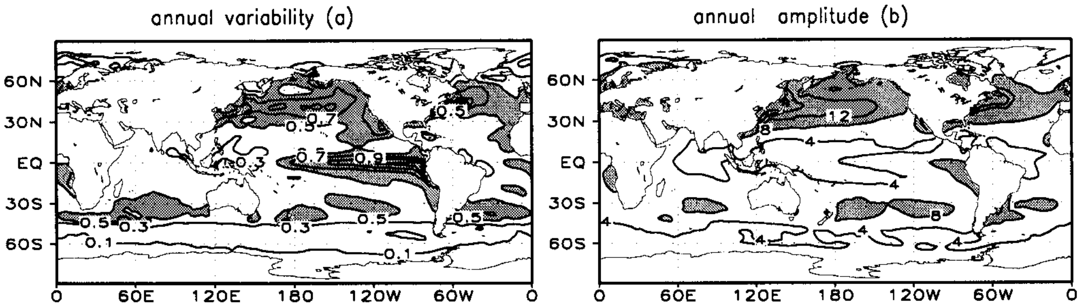

Fig.1 Interannual variability (a) and interannual amplitude (b) of global SST (unit: ℃). The shaded areas in (a) are regions with root mean error higher than 0.5 and those in (b) are regions with amplitude larger than 8.

Pacific is a key region of the El Niño event. Facing the eastern coast of China, the northwestern Pacific is a key region of monsoon in East Asia. It is easy to see large amplitude in the interannual variation and extreme events of SST.

Similar characteristics are found in the distribution of interannual variability of varying amplitude of SST when the season changes (in the Northern Hemisphere), though they differ in extent (omitting the figure for seasonal variability and amplitude). For instance, the interannual changes in the autumn-and-winter are more significant over the waters of the central and eastern Pacific in the hemisphere. It is consistent with the fact that temperature has dropped to the lowest point in a year in the cold water zone of the entire equatorial Pacific in the northern autumn while reaching the highest point in the warm water zone.

3.2 *Interannual variation of zonal and longitudinal winds*

Fig.2 shows three regions of the most significant interannual variability (with the root mean square ≥ 2.0 m/s) of the zonal wind, which are respectively located in the northern Pacific, northwestern Pacific and central Pacific in the Southern Hemisphere. The 2.0 m/s interannual variability is also recorded in the spring and summer of the southern Indian Ocean. By comprehensive examination, we find that the interannual variability of the zonal wind with varied years and seasons are generally consistent with waters of high interannual SST variations, with the exception of the equatorial eastern Pacific region. The distribution in the regions varies with the season. It deserves attention that the interannual variability of the zonal wind is larger in the equatorial central Pacific than in the equatorial eastern Pacific regarding the seasonal and annual scales. It is the largest in the north-northwestern part of the Pacific Ocean, especially in the winter and spring, with the maximum variability being 3.5 m/s in wintertime. Large-value areas of interannual zonal-wind variability tend to move in the north-south direction with the change of season in

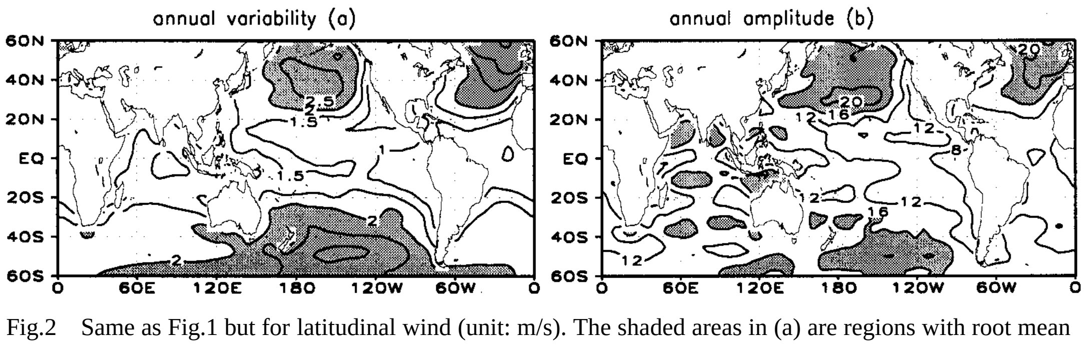

Fig.2 Same as Fig.1 but for latitudinal wind (unit: m/s). The shaded areas in (a) are regions with root mean error higher than 2.0 and those in (b) are regions with amplitude larger than 16.

southern Indian Ocean. They appear northward near the equator in the autumn and winter but southward near 40°S in the spring and summer. More efforts should be taken to probe into whether there is a triggering effect by the anomalous zonal wind over the equatorial central and western Pacific on the generation and evolution of El Niño, whether the anomaly of zonal wind in the north-northwestern Pacific is related with the monsoon climate in East Asia, and whether the seasonal geographic movement of large interannual variability of zonal wind is associated with the seasonal variation of Indian monsoon.

In Fig.3, the most pronounced region of interannual longitudinal-wind variability is in north-northeast Pacific and northwestern Pacific with much larger amplitude of variation in the spring, autumn and winter than in the summer. In addition, the longitudinal wind varies by large amplitude in the spring and autumn in the Bay of Bengal, Arabian Sea and South China Sea and so does it over waters off the eastern coast of China except in the summer. It demonstrates that anomalous events are likely to happen in these two monsoon regions.

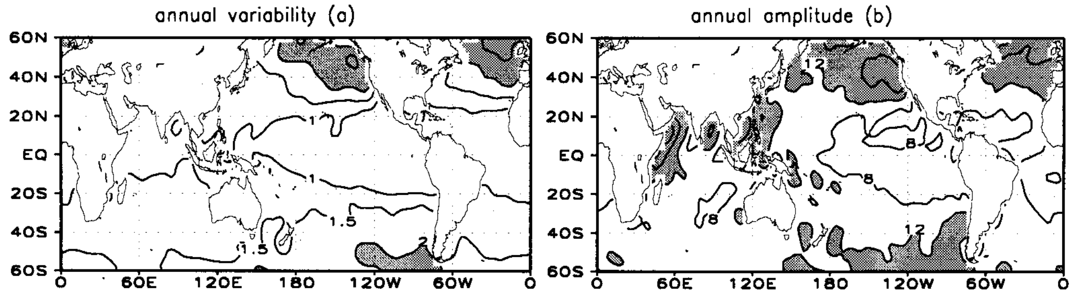

Fig.3 Same as Fig.1 but for longitudinal wind (unit: m/s). The shaded areas in (a) are regions with root mean error higher than 2.0 and those in (b) are regions with amplitude larger than 12.

3.3 *Interannual variation of air temperature and specific humidity at sea surface*

In Fig.4, the large-value zones of interannual variability and amplitude of sea-surface air temperature are generally consistent with those of SST. Such high values are also found in the winter and spring off the eastern China coast. The interannual variation of sea-surface air temperature is different depending up the season and oceanic waters. For the region of central and eastern Pacific, it is larger in the autumn and winter than in the spring and summer, which is consistent with that of seasonally averaged SST. Apart from it, the interannual variation of sea-surface air temperature is also quite high in the summer in the eastern Pacific waters.

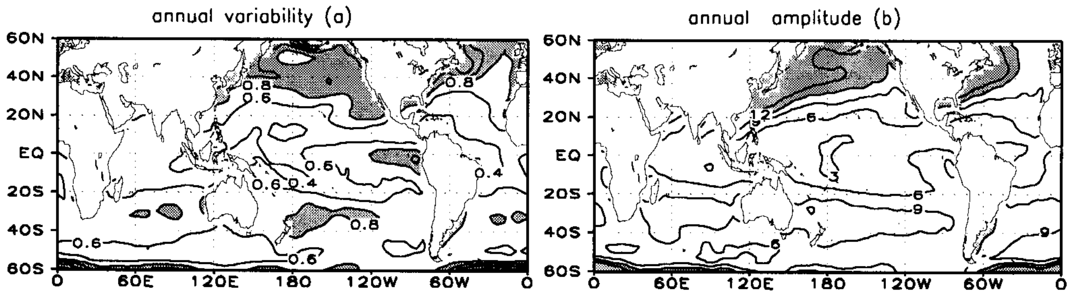

Fig.4 Same as Fig.1 but for sea surface temperature (unit: ℃). The shaded areas in (a) are regions with root mean error higher than 0.8 and those in (b) are regions with amplitude larger than 12.

In like manners, the large-value zones of interannual variability and amplitude of sea-surface air specific humidity (Fig.5) are generally consistent with those of SST. Besides, the interannual difference of annual and seasonal mean of specific humidity is also quite large in the South China Sea, waters off eastern China and beyond, Bay of Bengal, Arabian Sea and central Pacific in the Southern Hemisphere. The content of moisture over the equatorial Pacific is distributed in close association with SST, which is higher in the western than in the eastern part with significant interannual variation and smaller amplitude in the western warm waters than in the eastern cold waters. In the central and eastern Pacific, such larger interannual difference of specific humidity in the autumn and winter is consistent with that of SST and air temperature over sea surface. As shown in Fig.5, in contrast to mild performance in the southern Indian Ocean, specific humidity has significant interannual variability in the winter and spring and large amplitude of variation.

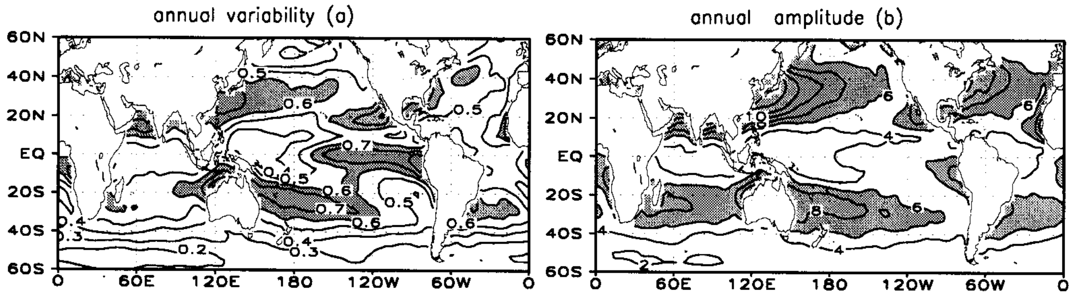

Fig.5 Same as Fig.1 but for specific humidity (unit: g/kg). The shaded areas in (a) are regions with root mean error higher than 0.6 and those in (b) are regions with amplitude larger than 6.

3.4 *Interannual variation of sensible and latent heat at sea surface*

The exchange of sensible heat is related with temperature difference between air and sea while that of latent heat with the vertical gradient of wind and specific humidity. The exchange of heat over the ocean surface is an important physical process during air-sea coupling.

From the interannual variability and amplitude of the sensible heat (Fig.6), we know that the sensible heat varies by a large amplitude in waters off the eastern China, northern Pacific, northwestern Pacific, southern Indian Ocean and high-latitude Pacific in the Southern Hemisphere but by a small amplitude in the equatorial Pacific. Although its variability of both SST and sea-surface air temperature are the highest among all other waters, the equatorial Pacific has relatively small variability of air-sea temperature difference and interannual variation of wind speed. As a result, the sensible heat varies little on the interannual scale in this part of the ocean and so does it with

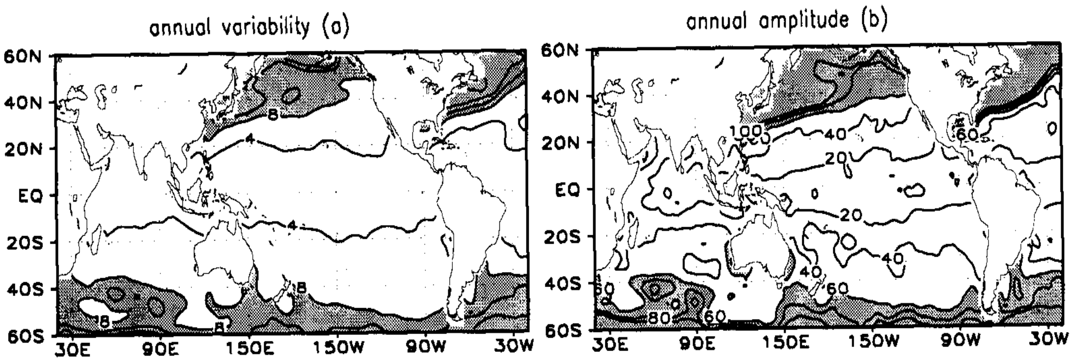

Fig.6 Same as Fig.1 but for sensible heat (unit: W/m^2). The shaded areas in (a) are regions with root mean error higher than 8 and those in (b) are regions with amplitude larger than 60.

the change of season. Being next to continental landforms, the regions of northwestern Pacific, south Indian Ocean and north Atlantic all have large land-sea thermal contrast and substantial interannual variation in zonal winds (Fig.3), resulting in relatively higher sensible heat and its interannual variation. In fact, the sensible heat varies off the eastern coast of China and in the northwestern Pacific in summertime on an interannual scale smaller than in the other three seasons, which is related with relatively small difference of air temperature and wind speed between the atmosphere and ocean. The variation of amplitude of the sensible heat on the annual and seasonal scales is generally consistent with that of variability.

There are 4 large-value zones of latent heat (Fig.7) as far as the interannual variation is concerned. They are respectively located in the waters off the eastern Chinese coast and the central Pacific farther away to the east, southern Indian Ocean, northwestern Atlantic and central Pacific in the Southern Hemisphere. Apart from them, relatively high values of interannual variability and amplitude are also found in the Bay of Bengal and northern waters of the South China Sea. The interannual difference of latent heat is smaller in summer than in the other three seasons. The region of equatorial Pacific is low in the flux of latent heat variability, with small interannual variation on the annual and seasonal scales. The interannual variation is generally the same as far as the amplitude of variation and the variability are concerned.

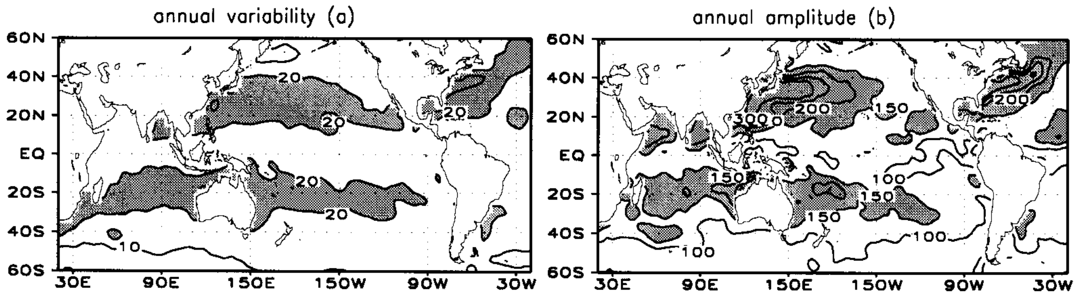

Fig.7 Same as Fig.1 but for latent heat (unit: W/m^2) The shaded areas in (a) are regions with root mean error higher than 20 and those in (b) are regions with amplitude larger than 150.

Key oceanic areas, as shown in Tab.1, are selected based on the analyses above and distribution of SST and variability / amplitude of various meteorological elements.

As indicated in the geographic location of the key zones, it is clear that the thermal factors for the central and eastern Pacific waters, the zonal winds for the western Pacific waters and the thermal / dynamic factors for the other waters are quite large in the interannual variation. It can be inferred that there is difference in the characteristics of the air-sea interaction as it changes from one part of the ocean to the other. In this work, further attempts will be made to study the correlation between the SST and individual meteorological elements for the characteristics of air-sea interaction over various parts of the ocean. In view of the inconsistency of key zones as defined by SST and meteorological elements, the work resets the domain of waters for the convenience of computation. The maximum domain, mean, mode and sensible and latent heat references are considered to divide respective domains of waters, with the discovery that the correlation between the sensible heat and SST is the most sensitive to key zones defined with different factors, especially for the northwestern Pacific, southern Indian Ocean and central Pacific in the Southern Hemisphere, and the correlation of other elements with the SST is less significant with the little change of zones. The coverage of key zones as defined with sensible and latent heat is then considered in the determination, though with possible effects on the representation value of some elements. To evaluate the independence of the key zones so selected and to make them more representative, the work has

Tab. 1 Key zones of air-sea interactions

element	C.E. Pacific	W. Pacific	NW. Pacific	C.N. Pacific	NW. Atlantic	S. Indian O.	C. Pacific(s)
SST	160°E～80°W 10°S～10°N		120°E～150°W 26～45°N	150°E～120°W 25～55°N	70～20°W 30～60°N	20～110°E 40～20°S	170°E～100°W 40～20°S
Lon. wind		130°E～180° 15～5°S		150°E～130°W 20～50°N	60～10°W 20～60°N	60～100°E 10°S～10°N	150°E～90°W 60～30°S
Lat. wind			100～140°E 0～30°N	160°E～120°W 25～55°N	60～10°W 30～60°N		
Air temp	160°E～80°W 10°S～10°N		120～150°E 20～40°N	150°E～120°W 25～60°N	70～20°W 30～60°N	20～110°E 40～20°S	170°E～100°W 40～20°S
S. H.	180°～80°W 10°S～10°N		120～150°E 10～35°N	150°E～120°W 18～40°N	70～20°W 20～50°N	30～120°E 40～10°S	150°E～120°W 35～10°S
Sen. heat			120～150°E 20～40°N	150°E～120°W 20～60°N	70～10°W 30～60°N	20～110°E 60～24°S	
Lat. heat			120～150°E 10～40°N	150°E～120°W 10～45°N	70～20°W 20～60°N	20～110°E 40～10°S	150°E～120°W 30～10°S
Sum	160°E～80°W 10°S～10°N	130°E～180° 15～5°S	110～150°E 10～40°N	150°E～120°W 20～55°N	70～20°W 30～60°N	20～110°E 40～15°S	160°E～110°W 40～10°S

made an analysis of autocorrelation (figure omitted) between the central point, the reference point, and the entire field, in the key zones and has adjusted them. As shown in the autocorrelation distribution of individual elements, the highly correlated zones, which take the central points for the key zones of waters as basic points, are generally within the domain as defined with this procedure. In other words, each selected individual zone of waters is independent of all others. With all principles of selection counted, a total of 7 key zones are given in the summary columns of the table and the distribution is seen in Fig.8.

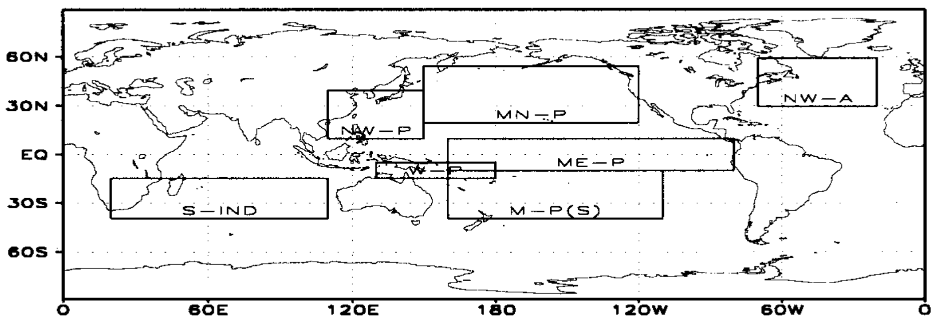

Fig.8 Distribution of key zones of waters.

4 TIME-LAG CORRELATION BETWEEN SST AND METEOROLOGICAL ELEMENTS IN KEY ZONES OF WATERS

Through the action of wind stress, wind-forced and up-turning currents are generated in the ocean to change the SST. In turn, the change in SST alters the ocean thermal forcing on the atmosphere. By means of vertical transport of sensible and latent heat at the air-sea interface and radiation exchange, the atmosphere is directly powered by the forcing for its motion. The atmospheric effect on the ocean is dynamic while the oceanic effect on the atmosphere is thermodynamic. The goal of this section is to discuss both the SST effect on the atmosphere and the atmospheric effect on the SST, by way of the time-lead correlation between various meteorological elements and SST in the key zones of waters. Tab.2 gives the significant lead/lag correlation between the elements in different seasons and the SST. The correlation coefficients are the maximum in respective periods of lead/lag correlation between the elements and SST. The symbols attached behind indicate simultaneous correlation by "0", SST leading by "–", and SST lagging by "+". The numerals are the number of season leading or lagging. The correlation coefficient for the level of 0.05 significance is 0.304.

Studying the magnitude of the correlation coefficients listed in Tab.2, we know that the air temperature and specific humidity have good overall correlation with the SST for all oceanic waters. It implies that individual key zones are affecting each other in terms of the thermal conditions of the air and sea, with the regions of central and eastern Pacific and south Indian Ocean having the most pronounced thermal interaction between air and sea. On the contrary, no significant inter-

Tab. 2 Significant correlation coefficients of lead and lag between individual elements and SST indifferent seasons and waters

Zones		C.E. Pacific	W. Pacific	C.N. Pacific	NW. Pacific	NW. Atlantic	S. Indian O.	C. Pacific(s)
Lon. wind *u*	win.	0.7 0	0.4 -2		-0.32 +1		0.35 +1	
	spr.	0.65 0		-0.32 0				
	sum.	0.5 +1	0.4 -2		-0.4 0			
	aut.	0.7 0,+1						-0.35 0
Lat.wind *v*	win.	-0.6 -1		0.35 +1				-0.5 -1
	spr.	-0.6 0					0.3 -2	-0.3 0
	sum.	-0.32 0	-0.55 0			0.42 -1,0		-0.41 0
	aut.		-0.48 -1		-0.3 -2			-0.4 0
Air temp. *t*	win.	0.9 -1	0.5 +1	0.55 +1	0.5 0		0.7 +1	0.4 +1
	spr.	0.8 0	0.55 0		0.5 0		0.7 0	0.42 0
	sum.	0.9 0	0.65 0	0.44 0	0.65 0	0.61 0	0.8 0	0.52 0
	aut.	0.9 0	0.55 0	0.41 0	0.62 0	0.55 0	0.75 0	0.52 0
S. H. *q*	win.	0.9 -1	0.4 +1	0.42 +1	0.5 0,+1	0.52 0	0.65 0	0.3 +1
	spr.	0.8 0	0.42 0			0.45 0	0.7 0	0.35 0
	sum.	0.9 0	0.6 0	0.4 0	0.6 0	0.7 0	0.8 0	0.42 -1
	aut.	0.9 0	0.55 0	0.4 0	0.6 0	0.7 0	0.7 0	0.6 +1
Sen. heat	win.	0.3 +2	-0.3 0	-0.6 -2	0.3 +1	-0.35 0	-0.6 -2	-0.4 -2
	spr.	0.5 +2	-0.35 0	0.35 0		0.32 +1		0.3 -2
	sum.		-0.4 -2,+2	-0.3 +1	0.3 -1		-0.42 0	
	aut.	-0.3 -1,0	-0.35 -2	-0.5 -2	-0.35 0	-0.54 +2	-0.58 -1,0	-0.6 -2
Lat. heat	win.	0.85 0	-0.6 +1	-0.3 +1	-0.5 -2	0.45 -2	-0.6 +2	-0.3 +1
	spr.	0.6 0	-0.3 0	0.4 0			-0.3 +2	-0.45 0
	sum.	0.5 +1	-0.5 0		-0.5 0			-0.4 0
	aut.	0.4 +1	-0.5 0	0.6 -2	0.6 0	-0.35 +1	-0.5 +2	

actions are found in the winter and spring of the northwestern Atlantic and the spring of the northwestern Pacific. Apart from the fact that in the winter of the central and eastern Pacific and the summer of the central Pacific in the Southern Hemisphere the atmospheric conditions are subject to thermal conditions of the ocean in the preceding period, the air-sea thermodynamic interaction is predominantly simultaneous in other zones of waters, with quite a number of them having the atmosphere affect the ocean. It is now obvious that the SST, sea-surface air temperature and specific humidity can be well replaced among themselves, especially in the central and eastern Pacific and southern Indian Ocean.

With the change in zones of waters and seasons, differences are large in the correlation between the longitudinal/latitudinal winds and the SST. The interannual variation of these winds is small but the correlation between them and the SST is significant in the central and eastern Pacific waters with the simultaneous and lagging SST correlation a main feature. Large correlation is also present between the longitude wind and SST for the central Pacific in the Southern Hemisphere and between the longitude/latitude winds and SST for the western Pacific. In conjunction with the fact that the interannual variability of the longitudinal/latitudinal winds is larger in the central and western Pacific than in the east Pacific, the dynamic effect of the central and western Pacific plays an essential role in the air-sea interaction while these winds in other zones of the ocean interact with the SST only in some of the seasons.

The correlation between the sensible heat and SST is the most significantly displayed in the northwestern Pacific and southern Indian Ocean as strong negative effect of preceding SST anomaly on the flux of sensible heat in the autumn and winter. In addition, the correlation of sensible heat with SST is also obvious in the western Pacific and northwestern Atlantic, though by different lead/lag features in different seasons. As shown in Tab.2, more periods of time are marked by negative correlation between the sensible heat and SST, showing that the rise or fall of SST over the time are accompanied by more outstanding rise or fall in air temperature. It is therefore natural that the SST in the preceding period affects the sensible heat in subsequent periods. As indicated in previous text of the work, the air temperature has strong positive correlation with SST, leading to decreased upward transport of heat from the surface of ocean or increased downward transport of heat towards the atmosphere.

Although the flux of latent heat has the minimum interannual variability, it is correlated the most with the SST, among the zones of waters, with the regions of central and north Pacific, south Indian Ocean and northwestern Pacific having quite remarkable correlation. The difference is that it is dominated by positive correlation in the central, eastern and northwestern Pacific but by negative correlation in the western Pacific and southern Indian Ocean. There is also significant seasonal difference in the lead/lag correlation for individual zones. For instance, the latent heat interacts with the SST simultaneously in the central and eastern Pacific in the winter and spring but the former affects the latter in subsequent periods. Opposite trends are found in the western Pacific. The latent heat affects the SST in subsequent periods in the winter while they affect each other in the other three seasons. It is then clear that the air-sea exchange are different in the two monsoon regions, namely the zone of central and eastern Pacific/western Pacific, and the zone of northwestern Pacific and southern Indian Ocean. For the thermal exchange between the ocean and atmosphere, these waters are all important.

5 INTERMONTHLY PERSISTENCE OF ATMOSPHERIC AND SST ANOMALIES IN KEY ZONES OF WATERS

The current section is involved in further study of the persistence of anomaly in the ocean and atmosphere so as to determine which elements have good anomalous persistence and in which zones and when or whether the persistence is likely to be destroyed. It provides basis for the physical mechanisms responsible for the air-sea interaction as well as some degree of reference to operational forecast. Fig.9 gives the annual cycles of probability of sustainable correlation in adjoining months regarding the SST, meteorological elements and heat fluxes in individual zones of waters. The abscissa denotes the adjoining months, with 0 and 12 representing the sustainable probability in December ~ January, 1 the one in January ~ February, etc. The ordinate stands for the probability of correlation with the mark on the left top corner for identification of zones of waters.

The correlation probability is obtained by subtracting the number of opposite sign from the number of same sign for the 40-year old dataset of subsequent months before dividing it by the total number. The low point of probability for sustainable correlation is in the period when the sustainability is easier to be destroyed for the anomaly of a particular element, or, when it is varying drastically. When the probability is larger than 0, the sustainability is thought to be good; when it is smaller than 0, the probability is said to be high for the sign to change; when it is equal to 0, the sustainability and probability for sign change are each having a 50% chance. To remove a minor waving of 2 ~ 3 months over the annual cycle, a 3-month weighted running mean is conducted for the correlation probability[9], e.g. R_{3-4} stands for the correlation probability for March ~ April and the running mean correlation probability R'_{3-4} is the correlation probability that has been through running mean treatment:

$$R'_{3-4} = (R_{2-3} + 2R_{3-4} + R_{4-5})/4$$

Studying the magnitude of sustainable correlation coefficient (Fig.9), we find that the SST is the best, followed by the air temperature and specific humidity and last by the longitudinal/latitudinal winds and sensible/latent heat, in terms of the sustainability of the correlation. It is shown much more obviously in the central and eastern Pacific. The SST, air temperature and specific humidity are selected as predictors for climatic anomalies, combining the analysis of correlation above.

Obvious stage characteristics are evident in the sustainability of the same element for various zones and the same zone for various elements, i.e. they can be more sustainable in some time than in the other. This stage-based performance must be exploited in forecasting to use periods with high sustainability but avoid those with low one, of the predictors. Attention should be drawn to the following points in addition to the consideration above.

(1) In the zone of western Pacific, the sustainability of the latitudinal wind exceeds that of the specific humidity in June ~ August and that of the SST in August ~ December. The probability of sustained correlation is as low as –0.4 for the longitudinal wind in January ~ February and nearly 0.0 for the latitudinal wind in February ~ March. It is apparent that the dynamic effects of the western Pacific zone are playing a vital role in the air-sea interaction. It also agrees well with the correlation analysis.

(2) As sensible heat is a flux between the ocean and atmosphere and subject to more than one factor, the probability is relatively large for the sign to change. In contrast, it is poorly sustainable in the central and eastern Pacific zones, reducing to specially low in June at –0.1. So is the sustainability of the latent heat in the summer and autumn of the northwestern Pacific waters where the probability has once reached –0.1 in August. The difference is not large in other zones of waters, generally between 0 and 0.2.

(3) Low points of sustainability in individual zones usually occur in the winter and spring,

though being different in concrete elements or months. Take the central and eastern Pacific zone for example. The SST and latitudinal wind have relatively low sustainability in January ~ February and air temperature and specific humidity in April ~ May. The lowest sustainability occurs in May for the SST in the western Pacific and in January ~ March for the longitudinal/latitudinal winds. It shows that it is not easy for the anomalies of the atmosphere and SST to maintain in the winter and spring, which may be one of the reasons for difficult operation of spring forecast.

With mainly the statistic approach, the work above reveals how the air and sea are interacting with each other over different zones of the ocean and how the atmosphere and SST sustain the anomalies. Questions like the ocean and atmosphere are having intense changes in some of the months and what is responsible for such interaction are dealt with in [9], which credits the fundamental cause to strong changes in the cold and hot sources, though being different with the zone. The current work has neither attempted to explain for the aspects of physics and dynamics. More

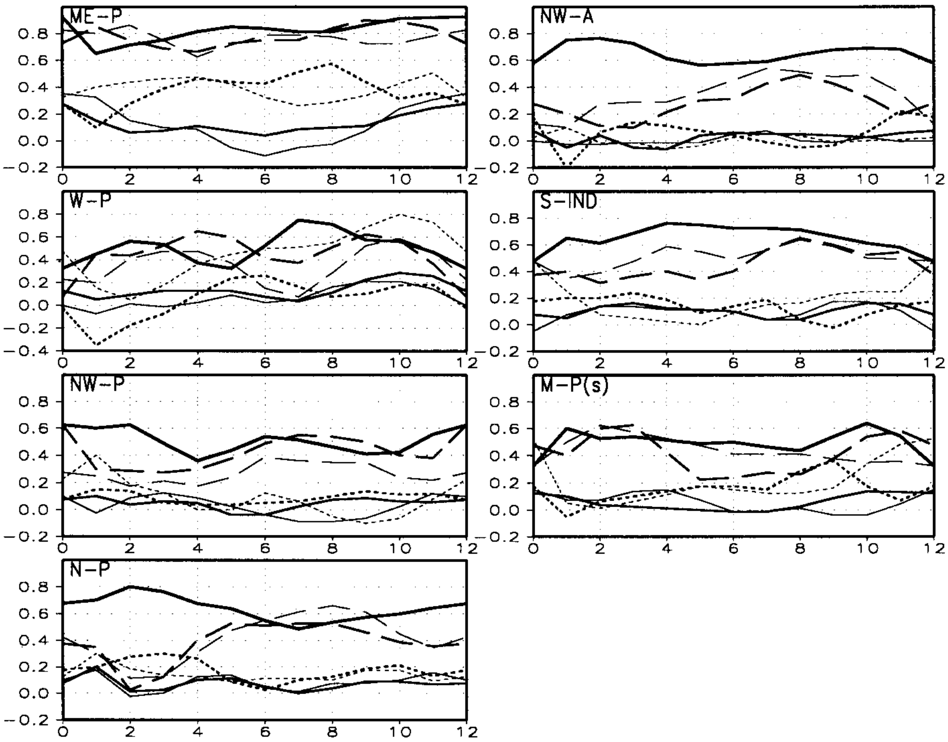

Fig.9 Annual cycle of probability of sustainable correlation in successive months for individual elements.

research and verification need to be done for these phenomena revealed.

6 CONCLUDING REMARKS

a. With a comprehensive analysis of the global SST and meteorological elements, 7 oceanic zones are identified that play a key role in the air-sea interaction. Conducting lag correlation for the meteorological elements and SST over these zones, we know that the air-sea interaction shows differently with the change of waters. In general, the correlation is the best between the air temperature/specific humidity and the SST, which can be replaced with each other, especially in the central and eastern Pacific and southern Indian Ocean. The correlation between the longitudinal/latitudinal winds and SST varies quite dramatically from zone to zone, with the dynamic effect more important for the waters of central and western Pacific. For the correlation between sensible heat and SST, the east and western Pacific zones and two monsoon region over the northwestern Pacific and south Indian Ocean seem to have an essential role.

b. Among all zones of waters, the sustainability is the best for the SST and sea-surface air temperature/specific humidity but poor for the longitudinal/latitudinal winds, sensible and latent heat. Based on this discovery, it is useful to take the SST or air temperature/specific humidity as predictors with awareness to its stage-based features. Obvious stage characteristics are evident in the sustainability of the same element for various zones and the same zone for various elements, i.e. they can be more sustainable in some time than in the other. This stage-based performance must be exploited in forecasting to use periods with high sustainability but avoid those with low ones, of the predictors. Attention should be drawn to the following points in addition to the consideration above, i.e. the sustainability of the atmospheric and oceanic anomalies is low in both winter and spring, which might be one of the causes forecasting barriers in spring.

Acknowledgements: Mr. CAO Chao-xiong, who works at the Guangzhou Institute of Tropical and Oceanic Meteorology, has translated the paper into English.

REFERENCES:

[1] MA Kai-yu, BAN Yi-nong, LI Qi. Mechanism study of El Niño and La Niña cycle in the coupled air-sea system [J]. *Acta Meteorologica Sinica*, 1995, **53**(4): 461-470.
[2] ZHOU Lin, SHA Wen-yu. Analysis of annual variation of heat exchange between the ocean and atmosphere in tropical Pacific [J]. *Acta Oceanologica Sinica,* 1996, **18**(2): 32-39.
[3] MA Kai-yu, YAO Hua-dong, JIANG Da-yong. Characteristics of seasonal variations in the influence of heat source over tropical Pacific and Indian Ocean upon atmosphere [J]. *Journal of Tropical Meteorology,* 1991, **7**(3): 218-225.
[4] WU Guo-xiong, WANG Jing-fang. Comparison of the correlations of lower tropospheric circulation with tropical and extratropical sea surface temperature anomalies [J]. *Acta Meteorologica Sinica*, 1996, **54**(4): 385-397.
[5] LONG Zhen-xia, LI Chong-yin. A numerical study of the summer climatic response in East Asia to position SSTA in equatorial eastern Pacific [J]. *Scientia Atmospherica Sinica*, 1999, **23** (2): 161-175.
[6] LONG Bao-seng, LI Bo-cheng, ZOU Er-mei. Anomalous eastward displacement of the western tropical Pacific warm pool and warming of the eastern tropical Pacific [J]. *Acta Oceanologica Sinica,* 1998, **20**(2): 33-41.
[7] GAO Shi-ying, WANG jing-shu, XU shen, et al. Variation of wind field in the equatorial central and eastern Pacific and El Niño [J]. *Scientia Atmospherica Sinica*, 1989, **13**(4): 410-416.
[8] PALMER T N, SUN Zhao-bo. A modeling and observational study of the relationship between sea surface temperature in the north-western Atlantic and the atmospheric general circulation [J]. *Quarterly Journal of Royal Meteorological Society*, 1985, **111**: 947-975.
[9] WANG Shao-wu, ZHAO Zong-ci, CHEN Zhen-hua. Persistence and rhythm of monthly mean circulation anomaly and air-sea interactions [J]. *Acta Meteorologica Sinica*, 1983, **41**(1): 33-41.