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THE EXCITING MECHANISM OF TROPICAL INTRASEASONAL OSCILLATION TO *EL NINO* EVENT[1]

Li Chongyin (李崇银) and Liao Qinghai (廖清海)

LASG, Institute of Atmospheric Physics, CAS, Beijing 100080

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ABSTRACT

The data analyses indicated that the occurrence of *El Nino* event is closely related to intraseasonal oscillation (ISO) in the tropical atmosphere: The intraseasonal oscillation is very strong in the tropics (particularly over the equatorial western Pacific) prior to the occurrence of *El Nino*; But the ISO is evidently reduced and the quasi-stationary system is enhanced after the outbreak of *El Nino*. A simple air-sea coupled model study shows that the periodical self-excited oscillation can be produced in the air-sea-coupled system, but the pattern is different from the observed ENSO mode. When there is external (atmospheric) forcing with interannual time scale, a coupled mode, which looks like the ENSO mode, will be excited in the air-sea system. Synthesizing the results in data analyses and the theoretical investigation, the mechanism of ISO in the tropical atmosphere exciting the *El Nino* event can be suggested: The interannual anomalies (variations) of the tropical ISO play an important role in the exciting *El Nino* event through the air-sea interaction.

Key words: Intraseasonal oscillation (ISO) in the tropical atmosphere, interannual anomalies, *El Nino* (ENSO)

I. INTRODUCTION

More attention has been paid to the *El Nino* event since the 1980s, because the occurrence of *El Nino* is always closely related to the climate anomalies (especially the drought and flood) in great scopes in the world. As a frontier scientific problem, a series of studies have been completed and great success achieved on *El Nino* event and its impacts (Philander, 1985; Barnet, Latif and Roeckner, 1991; Barnet, Latif and Cane et al., 1994 and Battistic and Sarackik. 1995). However, the occurring mechanism of *El Nino* has not been understood very well until now. In general, the *El Nino* event is resulted from air-sea coupled interaction in the tropics.

It has been inferred that the tropical ISO is probably an exciting factor of ENSO through the coupled ocean-atmospheric interaction (Lau and Peng, 1986). It is thought that the reducing frequency and enhancing amplitude of tropical ISO can excite *El Nino* under the air-sea-coupled interaction. Our data analyses show that the tropical ISO is abnormally strong, particularly in the equatorial western Pacific region, prior to the occurrence of *El Nino* (Li and Zhou. 1994). This proves the importance of tropical ISO to exciting *El Nino* event, but the exciting mechanism has not been addressed.

As we know, the ISO always exists in the tropical atmosphere, and there is similarity in intensity between winter and summer. Nevertheless, the *El Nino* event does not occur year after year, having a 2-7 year quasi-periodical feature. It is obvious that the exciting effect of the tropical ISO to the *El Nino* event is not the ISO itself but rather its interannual anomalies, which has

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been proved in data analyses that the occurrence of *El Nino* event is closely related to interannual anomalies of the tropical ISO. Based on the data analysis results and the dynamical study, the exciting mechanism of tropical ISO to the *El Nino* event will be addressed in the present paper.

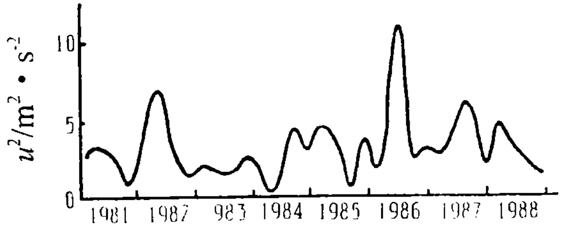


Fig.1. Temporal variation of the u^2 at 200hPa for intraseasonal oscillation in the equatorial central-western Pacific region (10°S–10°N, 110°–180°E).

II. KINETIC ENERGY CONVEYANCE OF TROPICAL LOW-FREQUENCY SYSTEM

The kinetic energy analysis shows that the kinetic energy of tropical ISO is abnormally enhanced prior to the occurrence of *El Nino* event, particularly in the equatorial western Pacific. For example, the temporal variation of monthly u^2 at 200 hPa (it is same to kinetic energy because the v component is very small) for the tropical ISO in the equatorial western Pacific, completed in the ECMWF data, is shown in Fig.1. It is clear that there is abnormal strong ISO in spring in both 1982 and 1986 prior to the outbreak of *El Nino* events. This means that the occurrence of *El Nino* event is closely related to the abnormal activities of tropical ISO. The origin of anomalous ISO in the equatorial western Pacific has been indicated: It is closely related to strong convection activities in the equatorial western Pacific region caused by the continued strong winter monsoon in East Asia (Li and Li, 1995). It needs, however, to investigate how the strong tropical ISO (with more energy of the ISO than normal) can excite the *El Nino* event.

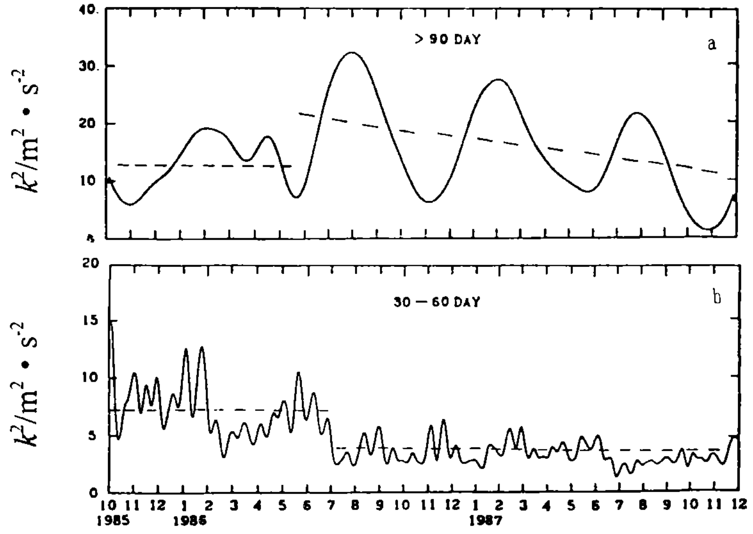


Fig.2. Temporal variation of zonal mean kinetic energy k (m^2s^{-2}) at 200 hPa for intraseasonal oscillation (b) and the quasi-stationary system (a) in the equatorial atmosphere (10°S-10°N) associated with the occurrence of *El Nino* in 1986.

Fig.2 gives the temporal evolutions of atmospheric kinetic energy associated with the occurrence of *El Nino* in 1986 in view of the importance of the problem presented below and necessity to assist in the following discussion. It was known that the *El Nino* can be regarded as a long term variation with a 2-7 year period in the air-sea coupled interaction system. In order to understand the effect of tropical ISO on the occurrence of *El Nino* event, to counteract with the 1982-83 and 1986-87 *El Nino* events, the temporal variations of the kinetic energy are computed and compared for tropical ISO and the quasi-stationary system (the period T>90 days, including the ENSO mode). The result is very interesting that the kinetic energy of tropical ISO decreases abruptly in association with the outbreak of *El Nino* event while that of the quasi-stationary system increases. This phenomenon has been thoroughly analyzed (Li, 1995).

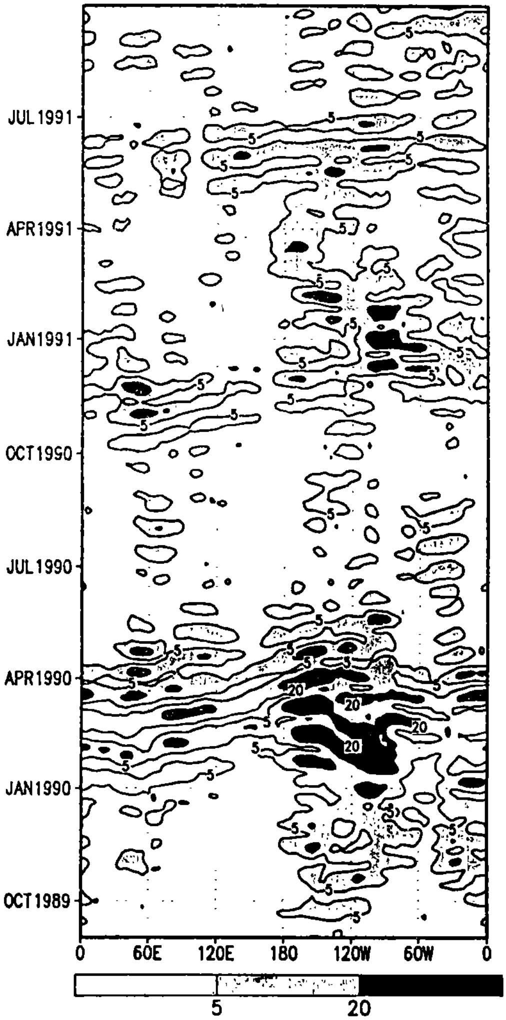


Fig.3. Time-longitude section of the kinetic energy for intraseasonal oscillation at 00hPa in the tropics (10oS-10oN) during October 1989 - October 1991.

The *El Nino* event in 1991 can be regarded as a special case to discuss, because there has been obvious positive SSTA in Nino3 and Nino4 regions since spring 1990 (figure omitted). Corresponding to the variation of SSTA in the equatorial eastern Pacific, the time evolution of kinetic energy of tropical ISO is also a special pattern. The time-longitude section of kinetic energy of tropical ISO at 200 hPa during October 1989 - October 1991 is shown in Fig.3, the seasonal variation feature of tropical ISO is clear and the interannual anomaly is also shown through yearly comparison. From May 1990 on, the kinetic energy decreased, but not clearly in November 1990, and went so far as to increase slightly in the spring of 1991. The kinetic energy of tropical ISO decreased clearly again in the summer of 1991. This means that the kinetic energy of tropical ISO was also reduced in association with the outbreak of *El Nino* event in 1991. To the contrary, the kinetic energy of the quasi-stationary system increased in the summer in 1990, but it even took on a trend of increase in the spring and summer in 1991, which was followed by gradual decrease (figure omitted).

The data analyses have clearly shown that kinetic energy of tropical ISO is particularly strengthened prior to the occurrence of *El Nino*, but it abruptly decreases corresponding to the outbreak of *El Nino* event and the kinetic energy of the quasi-stationary system will increase abruptly. This disappearance and rise of kinetic energy indicate the energy conveyance feature of tropical atmospheric systems with different time scale. It can be suggested that the "surplus" energy of tropical ISO after its abnormal enhancement will be transferred to the quasi-stationary system through the scale interaction and leads to strong development of the quasi-stationary system before the occurrence of *El Nino* event under the air-sea interaction. Obviously, the interannual anomaly of tropical ISO plays a key role in the exciting of *El Nino* event, and the quasi-stationary system, as the intermediary system, plays an important role in the energy conveyance of different scale systems.

In order to expose important role of interannual anomaly of tropical ISO in exciting *El Nino*, a simple theoretical analysis with air-sea coupled model will be done next. To catch up with the heating effect of the ocean and the wind stress effect of the atmosphere in the air-sea coupled system, the interannual anomaly of tropical ISO can be regarded as an external forcing.

III. NONLINEAR COUPLED OSCILLATION IN TROPICAL AIR-SEA SYSTEM

According to the quasi-periodic feature of tropical air-sea system which is shown in the ENSO cycle, the ENSO dynamics can be reflected by using nonlinear coupled oscillation of tropical air-sea system, for the first-order approximation. Based on the Gill's and Philander's studies (1980, 1984), the atmospheric equations can be simply written as

$$\frac{\partial U}{\partial t}+g\frac{\partial H}{\partial x}=-r_a U \tag{1}$$

$$\frac{\partial H}{\partial t}+D\frac{\partial U}{\partial x}=-\alpha_a H-Q \tag{2}$$

and the oceanic equations can be simply written as

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+\frac{\partial h}{\partial x}=-r_0 u+\tau_x \tag{3}$$

$$\frac{\partial h}{\partial t}+u\frac{\partial h}{\partial x}+(d+h)\frac{\partial u}{\partial x}=-\alpha_0 h \tag{4}$$

where U is the horizontal wind velocity in the x direction, D is the equivalent atmospheric depth, H is the deviation from D, Q is the heating from the ocean, r_a and α_a are the coefficients of Rayleigh friction and Newtonian cooling in the atmosphere; τ_x is wind stress in the x direction, u is oceanic flow velocity in the x direction, d is the equivalent depth of the oceanic mixed layer, h is the deviation from d, r_0 and α_0 are the coefficients of Rayleigh friction and Newtonian cooling in the ocean.

Based on the previous studies (Battisti and Hirst, 1989), the air-sea interaction can be respectively written as

$$Q=\eta(h-\kappa h^3) \tag{5}$$

$$\tau_x=\gamma U \tag{6}$$

where η is heating function.

The Rayleigh friction and Newtonian cooling both in the atmosphere and ocean can be ignored in order to solve the problem more conveniently. Thus, the air-sea coupled equations can be written as follows

$$D\frac{\partial U}{\partial x}=-\eta(h-\kappa h^3)-F \tag{7}$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+g\frac{\partial h}{\partial x}=\gamma U \tag{8}$$

$$\frac{\partial h}{\partial t}+u\frac{\partial h}{\partial x}+(d+h)\frac{\partial u}{\partial x}=0 \tag{9}$$

where the F in Eq. (7) is an external forcing to the air-sea system.

Taking the time scale $T=L/c_0^2$, where L and c_0 are the oceanic basin width and the Kelvin wave speed in the ocean, respectively.

Let $t'=t/T$, $x'=x/Tc_0$, $(U',u')=(U,u)/c_0$, $(H',h')=g(H,h)/c_0^2$, the dimensionless form of Eqs.(7)-(9) is

$$\frac{\partial U}{\partial x}+\eta_c h=\eta_c\kappa h^3-\eta_2 F \tag{10}$$

$$\frac{\partial u}{\partial t}-\gamma_c U+u\frac{\partial u}{\partial x}+\frac{\partial h}{\partial x}=0 \tag{11}$$

$$\frac{\partial h}{\partial t}+\frac{\partial u}{\partial x}+\frac{\partial}{\partial x}(uh)=0 \tag{12}$$

where η_c, γ_c and η_2 are some characteristic parameters, F is non-dimensional forcing.

The motion in the air-sea coupled system has multiple-time-scale feature, or simply, it can be assumed that $\tau=t$ for the fast process and $T=\varepsilon t$ for the slow process. Thus, we can have the formula

$$\frac{\partial}{\partial t}=\left(\frac{\partial}{\partial \tau}+\varepsilon\frac{\partial}{\partial T}\right) \tag{13}$$

and Eqs.(10)–(12) becomes:

$$\frac{\partial U}{\partial x}+\eta_c h=\eta_c\kappa h^3-\eta_2\mu F(T)\cos kx \tag{14}$$

$$\left(\frac{\partial}{\partial t}+\varepsilon\frac{\partial}{\partial T}\right)u+\frac{\partial h}{\partial x}-\gamma_c U+u\frac{\partial u}{\partial x}=0 \tag{15}$$

$$\left(\frac{\partial}{\partial t}+\varepsilon\frac{\partial}{\partial T}\right)h+\frac{\partial u}{\partial x}+\frac{\partial}{\partial x}(uh)=0 \tag{16}$$

where the external forcing has been assumed as

$$F=\mu F(T)\cos kx\,.$$

Finally, the equation of amplitude (A_0) evolution can be obtained from Eqs.(14)–(16) by performing mathematical calculations:

$$\frac{d^2A_0}{dT^2}-k^2A_0+\frac{3}{4}\kappa k^2A_0^3-\mu F(T)=0 \tag{17}$$

This is a forced Duffing equation, and when there is no external forcing, the equilibrium solution of the amplitude is

$$\bar{A}_0 = \left(\frac{3}{4}\kappa\right)^{-\frac{1}{2}} .$$

Let $A_0 = \bar{A}_0 A$, Eq.(17) can be written as

$$\frac{d^2A}{dT^2} - k^2A + k^2A^3 = \mu F(T) = \mu\cos\left(\frac{2\pi}{\omega}\right)t \qquad (18)$$

where ω is external forcing period, such as 1 year, 2 years and 3 years. Based on Eq.(18), we can understand the temporal variation of air-sea coupled waves.

For the no external forcing, $\mu = 0$, the air-sea interaction system is a self-organized system, which has the periodic oscillation solution and the period depends on the coupling strength. For example, the temporal variations of the amplitudes of coupled waves with different coupling strength are shown in Fig.4. When the coupling strength is stronger ($\gamma_c \eta \approx 1\times10^{-10}s^{-2}$), the period is about 3 years; If the coupling strength is weaker ($\gamma_c \eta \approx 1\times10^{-11}s^{-2}$), the period is about 8 years. The reason why the period is decreasing with coupling strength is that the critical wavenumber k_c becomes larger as the coupling strength increases and the recovering term ($\eta\kappa h^3$) becomes more dominant, which leads to shorter period.

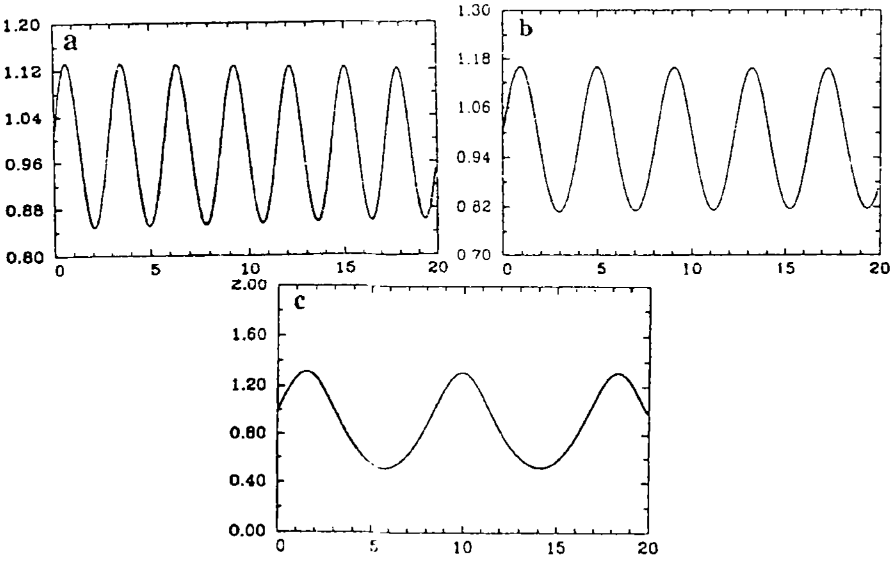


Fig.4. The self-excited oscillation of air-sea coupled system without atmospheric external forcing. a. b and c represent coupling intensity in $1\times10^{-10}s^{-2}$, $5\times10^{-11}s^{-2}$ and $1\times10^{-11}s^{-2}$, respectively.

Obviously, under the nonlinear air-sea coupled interaction, the variation feature of the coupled wave amplitude for general parameters is consistent with the mean period of the ENSO cycle. If the coupling strength is stronger, the period of coupled wave is more consistent with the mean period of the ENSO. Therefore, as previous studies, the result means that the air-sea coupled interaction is a basic reason to produce ENSO. However, this periodic regular oscillation is still different from the observational ENSO cycle, because the observational ENSO is quasi-periodic (no same and fixed period) and has a different evolution pattern. In other words, the air-sea coupled interaction provides the background to produce ENSO, but the coupled oscillation is unable to explain the ENSO cycle satisfactorily.

IV. FORCED NONLINEAR AIR-SEA COUPLED MODE

The preceding discussion shows that ENSO is produced due to the air-sea coupled interaction, but the self-excited oscillation, caused by air-sea interaction alone, is difficult to explain the features of ENSO cycle satisfactorily. How about the air-sea coupled system with the external forcing?

When there is external forcing on the air-sea coupled system, the feature of the coupled mode will be changed, concerning not only the pattern (wave shape) but also the period to be quasi-periodic. These changes are more obvious if the forcing is stronger (μ is larger). For example, in Fig.5, the temporal variations of the coupled modes caused by external forcing with 2-year period are respectively shown for different forcing intensity. It can be seen that comparing with periodic oscillations shown in Fig.4, the patterns of the coupled mode under the effect of external forcing with a 2-year period are variations and the period of the coupled mode is unfixed. These coupled modes are more similar to the evolution shapes of observational SSTA in the equatorial eastern Pacific. In other words, the air-sea coupled system, in which the atmospheric external forcing with interannual time-scale exists, can produce a kind of coupled mode which is similar to the ENSO mode.

Comparing Fig.4 with Fig.5 it has been shown clearly that when there is external forcing, the

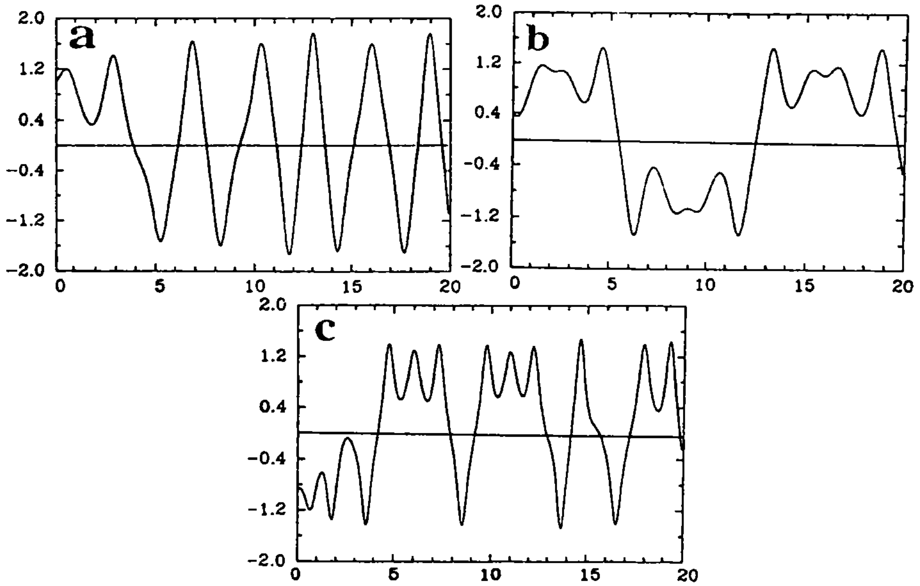


Fig.5. The coupled modes in the air-sea coupled system with atmospheric external forcing, which has a 2-year period, for the same coupling intensity but different forcing intensities.

periodic self-excited oscillation caused by the nonlinear air-sea interaction will be changed and the quasi-periodic mode with different variation patterns can be excited. It can also be put this way that the coupled mode being similar to observational ENSO cycle can be excited in the air-sea coupled system for the existence of external forcing. In Fig.5, an example is just shown in which for other forcing with different interannual time-scales (such as 1-year or 3-year period). the coupled mode is mainly similar to but slightly different from that shown in Fig.5, especially the quasi-periodic feature and the unfixed shape. Therefore, the results above, which are based on a simple tropical air-sea coupled model, show that the atmospheric external forcing (particularly the forcing with interannual time-scale) also plays an important role in exciting ENSO cycle in addition to the air-sea coupled interaction. These results still indicate a dynamical basis for the interannual anomaly of tropical ISO exciting *El Nino* event.

V. CONCLUSIONS

As we know, there are always ISO in the tropical atmosphere and some studies have indicated the tropical ISO activities are closely related to ENSO. However, the time-scale of ENSO is 2-7 years, the *El Nino* event is not evident every year. How does the activity of tropical ISO excite the *El Nino* event? Through the data analyses and theoretical study, the preliminary explanation has been given in the present paper.

a. The interannual variation of kinetic energy of tropical ISO is very strong and it is closely related to *El Nino*. There is abnormal enhancement of tropical ISO prior to the occurrence of *El Nino* event, especially over the equatorial western Pacific. This interannual time-scale anomaly of tropical ISO means that there is an interannual time-scale forcing (comparing to averaged value over long periods) in the air-sea coupled system.

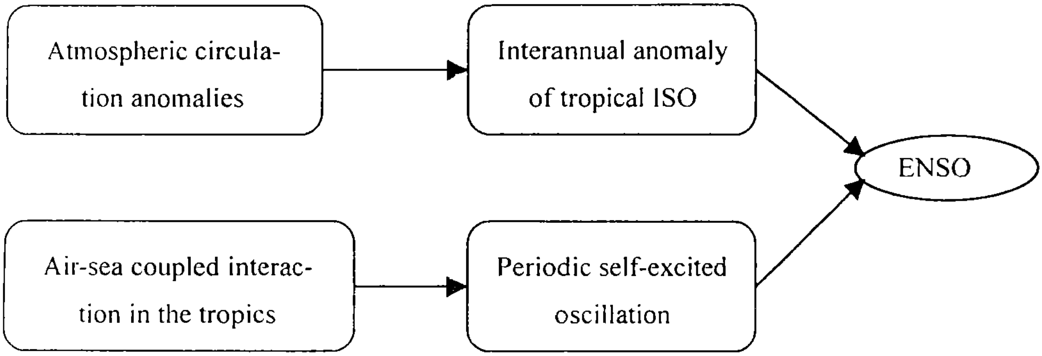
b. Corresponding to the outbreak of *El Nino* event, the kinetic energy of tropical ISO decreases abruptly and kinetic energy of quasi-stationary wave increases abruptly. This means that not only the energy conveyance between the climate systems with different time-scale, but also the exciting effect of tropical ISO to *El Nino* event. For the exciting of *El Nino* event, the interannual anomaly of tropical ISO plays a key role; the quasi-stationary wave is an intermediary system.

c. The air-sea-coupled interaction is a basic reason to produce ENSO. However, the air-sea interaction alone is unable to explain the ENSO cycle satisfactorily.

d. The air-sea-coupled system with the atmospheric external forcing can produce the coupled mode which is similar to the observational ENSO phase. Therefore, the atmospheric external forcing also plays an important role in exciting ENSO cycle.

e. Joining the data analyses and the air-sea coupled model results, the mechanism of tropical ISO exciting *El Nino* can be as follows: The abnormal enhancement of tropical ISO, caused the atmospheric circulation anomalies, will transfer its surplus energy to the quasi-stationary system. so that the coupled mode can be excited by this interannual anomaly of tropical ISO as an external forcing to the air-sea coupled system, through the air-sea interaction. This mechanism is shown next.

Finally, we would like to indicate that the abnormal development (kinetic energy increase) of tropical quasi-stationary system associated to the outbreak of *El Nino* means that the quasi-stationary system receives the energy from the ISO. We named this system as the intermediary system, and its development will be advantageous to the air-sea-coupled interaction. It will be studied in another paper.



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