On the Seasonal Transition and the Interannual Variability in Global Kinetic Energy at 500 hPa, Accompanied with Anomalies of Energy during the 1982 / 83 ENSO①

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ABSTRACT

Utilizing the material of monthly means of the three primary kinetic energy modes over the whole globe at 500 hPa during the nine years of 1980–1988, both the rapid seasonal changes and the interannual variability in the general circulation in terms of the energy modes have been investigated, with special attention paid to the unusual year 1983. Two main results are obtained. One, there are remarkable seasonal rapid changes over the Northern Hemisphere, occurring generally in April and October. The other, among the nine years of 1980–1988, 1983 is the only one with unusual energy modes and remarkably abnormal seasonal changes.

I. INTRODUCTION

Seasonal variation in the general circulation is one of the fundamental problems of the general circulation. This problem has been studied from different points of view, in which one important view is to study the sudden change of seasonal transition in the general circulation in the Northern Hemisphere. The idea of the seasonal sudden change was first put forward by Yeh et al. (1959). We also ever studied the seasonal transition in terms of energy parameter (Qiu et al., 1985). But little work has been done, to the author's knowledge, on the subject of the rapid (sudden) change during the seasonal transition through systematical studies from the whole range of the globe and by means of quantitative criteria. The atmospheric kinetic energy is a fundamental physical property of atmospheric motion, and it can be divided into two parts: in zonal mean flow and in eddies. Owing to this, it will be taken as a fundamental property to study the seasonal transition of general circulation over various latitudinal belts of the whole globe. On the basis of the monthly means of various kinetic energy modes calculated from ECMWF's data set during the nine years of 1980–1988, the timing of occurrence of rapid seasonal change will be determined by means of quantitative criteria.

The other part of this paper is to study the interannual variability in the general circulation. It will be investigated by using the 9–year monthly means of various kinetic energy modes to inspect the anomalies of kinetic energy over the whole range of the globe, especially the anomalies during 1982 / 83 ENSO event. Finally, the lag–cross correlation analysis is used to study the relationship between various kind of energy modes and the sea surface temperature anomaly (SSTA) over the equatorial eastern Pacific, with special attention paid to the linkage of the unusual kinetic energy during the year 1983 to the SSTA.

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II. DATA

Utilizing the 500 hPa wind data set gridded in 2.5° × 2.5°, provided by ECMWF during the 9−year period of 1980−1988, daily values of three primary kinetic energy modes, i.e., the kinetic energy in zonal mean flow (KZ), the kinetic energy in eddies (KE), and the zonally averaged total kinetic energy (K) (K = KZ+KE), along with the values of the kinetic energy modes of wavenumbers 1−10 (K1, K2, ……K10), have been calculated at intervals of 2.5°lat. from the north pole to the south pole. The values of each energy mode are then integrated over seven belts with different latitudinal intervals. They are integrated over the whole globe (90°N−90°S), over the Northern (0°−90°N) and the Southern (0°−90°S) Hemispheres, and over the middle (30°−60°N or S) and the low (0°−30°N or S) latitudes in either hemisphere, and averaged over the areas of corresponding belts. The integrated energy modes are all measured in $J/(m^2 \cdot hPa)$. The seven belts are denoted by GG, NH, SH, NM, NL, SM and SL, respectively, and in the present article will be referred to as seven latitudinal belts tentatively.

Monthly mean values of the three primary energy modes are taken as primary materials in this study. The 9−year averaged monthly means are temporarily referred to as climatological monthly means.

III. SEASONAL TRANSITION OF THE PRIMARY KINETIC ENERGY MODES

It is shown from the annual cycles (Fig.1) of the three primary kinetic energy modes, which are made up of the climatological monthly means, that whichever hemispheres they are and whatever energy modes they are of, the values in winter months are higher, the values in summer months are lower, and the intermonthly changes either in winter or in summer are very small, so they may be considered as two equilibrium states. However, the values of intermonthly changes in the seasonal transition both from winter to summer and from summer to winter are very large. In spite of the large changes, there are two visible different states —slower changes and rapid changes. It is seen that the seasonal transitions of the three energy modes in the SH are much slower than those in the NH. Obviously this difference is attributed to the ocean−land distribution and the topography. In order to determine quantitatively the rapid seasonal changes in the energy modes, the following two criteria are adopted.

(i) The absolute values of intermonthly change in any of the energy modes, $|\Delta K|$, must be equal to or greater than $R/4$, where R denotes its annual range; and

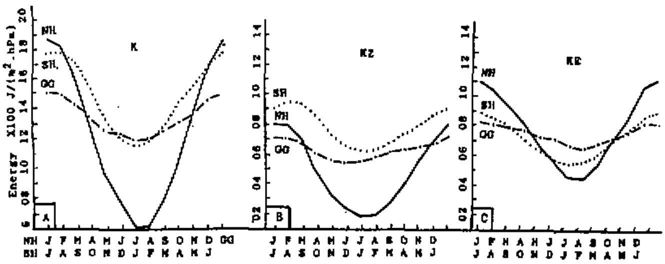

Fig.1. The annual cycles of the total kinetic energy (K) (A) the kinetic energy for zonal mean flow (KZ) (B) and of eddies (KE) (C) over the whole globe, the Northern and the Southern Hemispheres respectively.

(ii) The relative intermonthly change in the energy mode, $\Delta K / K$, must be greater than 40% for the kinetic energy growth period during the transition from summer to winter and lower than −25% for the energy decay period during the transition from winter to summer.

According to Fig.1, in general the value of annual range of an energy mode is determined by 4 intermonthly changes in succession during the transition season, so Criterion (i) is taken as a basic criterion for determining the rapid seasonal change. But on the other hand, the annual ranges of some energy modes are rather small, such as those in the midlatitudes of the SH. The $|\Delta K|$ of the energy modes there may easily attain the threshold of Criterion (i), $R / 4$, or even $R / 3$. Yet, even so, there does not always occur the rapid seasonal change in the energy mode. Hence Criterion (ii) is taken as supplementary one. Because the relative intermonthly changes in an energy mode during the stage of its decay are much smaller than those during the stage of its growth, two different percentages in Criterion (ii) are taken to signify the two different stages.

To prevent subjectivity, the thresholds of the both Criteria are to be modified so as to make the conclusion reliable. Then the two Criteria mentioned above would become the following eight Schemes, which are adopted for the following analyses.

Scheme	$\|\Delta K\|$	$\Delta K / K$ Growth period	Decay period
A1	>R / 4	40%	−25%
A2	>R / 4	40%	−20%
A3	>R / 4	40%	−30%
A4	>R / 4	30%	−30%
B1	>R / 3	40%	−25%
B2	>R / 3	40%	−20%
B3	>R / 3	40%	−30%
B4	>R / 3	30%	−30%

Using the eight Schemes, the climatological monthly means and the monthly means of each of the nine years for three primary energy modes over the seven belts are analyzed. The results of the analyses of the climatological monthly means by Scheme A1 and Scheme B1 are given in Table 1. The results of the analyses of the nine years derived from the four cases of Scheme A's are given in Table 2, where the figures on the left of A1, or A2, ··· or A denote the accumulated frequency for the nine years. It is shown in Table 1, Table 2, and the other tables (omitted) that the number of months with rapid seasonal changes based on the analyses of the four cases of Scheme B's are obviously less than that based on the four cases of Scheme A's. In the following are results shown from the tables.

(1) There is no rapid seasonal change in kinetic energy, taking the globe as a whole.

(2) There is no rapid seasonal change in energy in the whole SH except in the low latitudinal belt. In this belt, in spite of short transitional season, there is remarkably rapid seasonal change, mainly expressed by the zonal mean motion and occurred in the period of April−May corresponding to the summer−winter transition and in the period of September−October corresponding to the winter−summer transition.

(3) Either in the whole NH or in the middle or low latitudinal belt, there exist rapid seasonal changes in atmospheric kinetic energy, especially in the kinetic energy in zonal mean flow. The summer−winter transition often occurs in October, but the winter−summer transition often occurs in April, rather than in June (Yeh et al., 1959).

Table 1. *Months in Which the Rapid Seasonal Changes Occur, Analyzed by Scheme A1 and Scheme B1*

Month	J	F	M	A	M	J	J	A	S	O	N	D
Global	No occurrence of rapid changes for KZ, KE and K											
NH KZ			A1 B1	A1						A1		
KE												
K				A1								
SH	No occurrence of rapid changes for KZ, KE and K											
NM KZ			A1 B1						A1	A1 B1		
KE												
K									A1			
SM	No occurrence of rapid changes for KZ, KE and K											
NL KZ			A1 B1								A1	A1 B1
KE			A1							A1	A1 B1	
K			A1 B1								A1 B1	
SL KZ				A1	A1 B1				A1 B1	A1		
KE												
K				A1						A1		

Table 2. *Monthly Frequence of Rapid Seasonal Changes for the Peroid of 1980–1988 Based on the Analysis of* Scheme A

Item Month	J	F	M	A	M	J	J	A	S	O	N	D
Global	only one time											
NH, KZ			5A1	4A					5A	2A4		
KE				4A2				1A	4A4	3A		
K			5A2	4A1					2A	5A4		
SH	only one time											
NM, KZ			5A1					4A	5A	6A		
KE				2A1				3A	5A			
K				2A1				2A	6A	4A4		
SM	only one time											
NL, KZ		3A	7A	5A							6A	6A
KE			6A1	2A						4A	5A	1A
K		4A1	8A1	2A						2A	8A	2A
SL, KZ			2A	5A	6A				2A	3A	4A	
KE			3A4	5A4								
K				5A	7A					3A	4A	

From the tables one can find that months in which rapid seasonal changes occur in the period of 1980–1988 are rather scattered as compared with the climatological status. As far as season is concerned, months in which in the NH the summer–winter transition occurs are

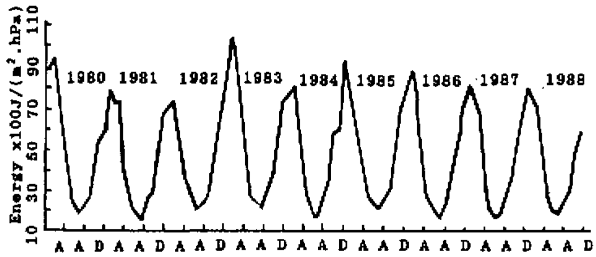

Fig.2. The annual cycles of the NH / KZ for 9 years of 1980–1988, in J / (m^2 • hPa) (constructed by Mr Sun Jisong).

more scattered than the winter–summer transition. As far as latitudinal belt is concerned, months in which rapid seasonal changes in the low latitudes of either hemisphere occur are more scattered than in the middle latitudes. However, months in which rapid change often occurs are in agreement with the climatological results. And, the results here obtained from monthly means are mainly in agreement with those obtained from daily data in Sun et al. (1993). By the way, the rapid seasonal changes in KZ over the NH represent the rapid contraction and the rapid stretching of the polar vortex. The months of the rapid changes, April and October, are near to the equinoxes and supported by the energy sources of the earth surface layer (Kubato, 1970).

IV. INTERANNUAL VARIABILITY IN THE GLOBAL KINETIC ENERGY

By analyzing the annual cycles of each of the nine years and anomaly curves of the three primary kinetic energy modes in the globe and both hemispheres we found that their interannual variability is quite large. Fig.2 illustrates the annual cycles of each year of the kinetic energy in zonal mean flow in the Northern Hemisphere, in which the variability is clearly shown, especially the 1983 ENSO.

By the way, we will incorporate any of the seven latitudinal belts with any of the three primary energy modes to discuss some problems in the following. For simplicity, the format of "latitudinal belt / energy mode" will be used to express the meaning of "certain energy in certain latitudinal belt", henceforth referred to as an item of kinetic energy. For example, GG / KZ denotes the kinetic energy in the whole globe. The incorporation of seven belts with three energy modes results in 21 items of kinetic energy.

1. *Harmonic Analysis*

Using climatological monthly mean values, the 21 energy items are investigated by the harmonic analysis. The amplitude, phase angle and relative amplitude, which are denoted by An, Qn and Rn respectively, of the first four harmonic waves were estimated. Harmonic analysis is also applied to the monthly mean of each year in the 9–year period. Using yearly amplitudes of each of the first four harmonic waves, the standard deviation of the amplitude for each harmonic during the 9–year period is calculated, and denoted by Sn. Parameters A1, R1 and S1 of the year waves of the 21 energy items are given in Table 3. It is first shown that, except for the middle latitudes of the SH, the majorities of the relative amplitudes of the year wave for these energy items are more than 90%, some R1 even attain 99%. Even when the R1 of some items such as GG / KZ, GG / KE, NL / KZ, NL / K etc are less than 90%, the sum of their R1 and R2 is over 90%. So, for all these energy items except for the mid-latitudes of the SH, seasonal variation can be expressed by the sum of the year wave and the half-year wave.

Table 3. Year Wave Parameters for 21 Kinetic Energy Items

	KZ			KE			K		
	A1	R1	S1	A1	R1	S1	A1	R1	S1
GG	74	79	11	74	82	12	146	94	12
NH	298	96	18	300	96	11	598	99	15
SH	159	92	13	153	90	20	309	97	17
NM	472	93	35	499	95	26	968	97	43
SM	103	31	56	197	84	25	274	78	46
NL	255	82	46	167	90	14	422	88	46
SL	216	91	21	113	89	15	330	93	27

Note: A1–amplitude of year wave (in $J / (m^2 \cdot hPa)$), R1–relative amplitude (in %), S1–standard deviation of the amplitude of year wave for the period of 1980–1988.

2. *Interannual Variability of Harmonic Parameters of the Energy Items—Unusual Year 1983*

Using harmonic components to fit seasonal variation, there are two ways of composition: one is to fit the first two harmonic components, i.e., the year wave and the half year wave, into a seasonal variation (Guo et al., 1979), the other is to fit the first four harmonic components (Trenberth et al., 1983). Adding the annual mean either to the first two harmonics or to the first four harmonics, the annual cycle will be composed. From the discussion above, the former composition will be adopted here. But if the relative amplitude of year wave is over 95%, the seasonal variation will be expressed by year wave, instead of the sum of the first two waves. Either the year wave amplitude anomaly or the composition of the year wave amplitude anomaly and half year wave amplitude anomaly, is used to investigate interannual variability. As usual, if the n–th wave amplitude anomaly for a given year is equal to or greater than twice the n–th wave standard deviation Sn for the 9–year period, the n–th wave in that year is referred to as unusual wave. And, if there is a year during the 9 years in which the year wave amplitudes or the year wave and half–year wave amplitudes, of any four or more of the 21 energy items are unusual, this year will be defined as unusual. In the light of this definition, the year of 1983 was the only one unusual year. The unusual energy items of the year wave and the half–year wave in 1983 are given as follows.

Year wave: GG / K (94%), NH / KZ (96%),
NH / K (99%), NL / KZ (82%), NL / K (88%);
Half–year wave: GG / K (3%), GG / KE,
SH / KE, NL / KZ (11%), NL / K (8%).

Here percentages in the parentheses denote relative amplitude. Hence the seasonal variation in 1983 was unusual, mainly expressed in the total kinetic energy in the whole globe, or in the total kinetic energy, especially in the kinetic energy in zonal mean flow in the whole NH.

Table 4. Yearly Mean and Anomaly Values of the Total Kinetic Energy at 500 hPa over the Whole Globe. Unit: $J/(m^2 \cdot hPa)$

Year	1980	1981	1982	1983	1984	1985	1986	1987	1988
Ann.mean	1299	1291	1304	1328	1295	1299	1303	1287	1299
Anomaly	−1	−9	4	28	−5	−1	3	−13	−1

Now let us inspect the annual means of the 21 energy items for finding the unusual year and the unusual item of annual mean. It is found that just in 1983 during the 9−year period, annual means for five items were unusual and the five items, GG / K, NH / KZ, NH / K, HL / KZ and NL / K, were just the same as the items of which the year wave amplitudes were unusual. Taking GG / K as an example, the annual means and the annual anomalies for this energy item are given in Table 4. The 9−year annual mean for the total kinetic energy in the whole globe is 1300 units, the standard deviation is 12 units, but anomaly for 1983 is 28 units, which exceeds twice the standard deviation. It is worth noting that the annual mean for the total kinetic energy in the whole globe is conservative in general, but in 1983 it increased by 2.2 percent. That is a significant figure.

Table 5. Anomalous Years and Anomalous Months of Kinetic Energy Modes according to the Anomaly Analysis

ITEM	YEAR \ MON	J	F	M	A	M	J	J	A	S	O	N	D
GG / K	1983	+	+						+				
NL / KZ	1983		+	+	+			+				+	+
SM / KE	1984					+	−						+
SL / KZ	1980				+	−				−	−		
(NH / K)	1983	(+)	+					(+)					

3. *Analysis of Monthly Anomaly Number*

The year when three or more monthly anomalies occur in a given energy item, is considered as an unusual year in view of the monthly anomaly number. The result is given in Table 5. For convenience of discussion, the NH / K item in 1983 did not attain the standard of unusual year of month anomaly number, yet it is contained in the table, given in parentheses. It is shown that the year 1983 was not only an unusual year of month anomaly for two energy items, GG / K and NL / KZ, but also as viewed from NL / KZ, was a year with 6 unusual months. So this year was the most unusual year in the 9 years in terms of month anomaly number. Besides the GG / K and NL / KZ items, the NH / K in 1983 was near the standard of unusual year of month anomaly number. From these it can be seen that the result is in agreement with the harmonic analysis as mentioned in the last subsection. This further verifies the result that the year 1983 was the most unusual year in the 9 years.

4. *Linking to the SST over the Equatorial Eastern Pacific (SSTA)*

It was shown from the discussion of the above two subsections that the kinetic energy over the whole globe in 1983 was unusual, and it was the most unusual year in the nine years. It is easy to remind us of the effect of the anomalous SST over the equator in 1983 on the atmospheric motion over vast area, or even over the whole globe, because in the period of

1982 / 83 occurred the most outstanding ENSO in the past decade. In this paper a lag-cross correlation analysis will be adopted to investigate the interrelation between the SSTA and the energy modes from two different views. One is to discuss the influence of the ENSO on the energy modes, and the other is to find the effect of an energy mode on the SSTA before the onset of the 1982 / 83 ENSO event. Utilizing the data of the 91 kinetic energy items, which are obtained by multiplying the seven latitudinal belts by the 13 kinetic energy modes, as mentioned in Section 2, and the data of monthly SSTA averaged over 0°–10°S, 180°–90°W, the author has investigated the lag-cross correlation among them, the time sequence of them each being 108 months. The anticipatory confidence is taken to be 0.01. The maximum lag number is 10 months. So the critical correlation coefficient for 99% significant level is nearly 0.256, we take it as 0.26, or 26 in terms of percentage. All the energy items of which the correlation coefficients are equal to and greater than 26 are given in Table 6.

Table 6. Significant Lag-Cross Correlation Coefficients among SSTA and Various Kinetic Energy Modes, in %

Lag Month Number	0	1	2	3	4	5	6	7	8
Sequence of SSTA lags									
SL / K1				26	32	35	32	28	
SM / K1						27	26		
Sequence of SSTA ahead									
GG / KZ	42	44	45	41	41	29			
NM / K3	−36	−34	−31	−30	−26				
NH / K3	−35	−34	−32	−29	−26				
NH / KZ	33	33	35	34	30				

It can be seen from Table 6 that between SSTA and GG / KZ (or NH / KZ or SH / KZ), which lagged behind SSTA (the time lag being up to four months), there is high positive correlation coefficient. In other words, after the SST over the equatorial eastern Pacific is much higher than its average, then within about four months over the whole globe, especially over the NH, the zonal mean flow is strengthened. During the nine years there were two ENSO events, one in 1982 / 83 and the other in 1986 / 88, but the former is much stronger than the latter (Zhao et al., 1989). It was shown from the last two subsections' discussion that in 1983 the total kinetic energy over the whole globe was unusual. From the correlation analysis it is likely that the unusuality in the kinetic energy in 1983 was primarily due to the influence of the 1982 / 83 event.

In Table 6 there is another interesting fact, i.e., the SSTA is positively correlated with the K1 over the low-latitudes of the SH which is about 5 months ahead of SSTA. In other words, after K1 over the low-latitudes of the SH has been strengthened about five months, the SSTA over the equatorial eastern Pacific is remarkably raised. The curve of change of K1 with time (omitted) verifies this point and it is also shown that in July of 1982 the anomaly of K1 attained the threshold of unusuality. Therefore, the unusual growth of K1 over the low-latitudes of the SH may be considered as a precursor for monitoring the major ENSO event.

V. CONCLUSION

The results obtained are as follows.

(1) Over the whole area of the Southern Hemisphere except in the low latitudes there is

no occurrence of the rapid seasonal changes in the three energy modes. However, referring to the southern low latitudes, there are the rapid seasonal changes.

(2) Over the area of the whole Northern Hemisphere including the limited area of both the northern middle and low latitudes there are remarkably rapid seasonal changes in the energy modes especially in the kinetic energy in the zonal mean flow, and, in general, the summer–winter transition occurs in October and the winter–summer transition in April, rather than in June.

(3) Among the nine years of 1980–1988, 1983 was the only one year with unusual energy modes and remarkably abnormal seasonal changes. In this year, not only the year wave and the half-year wave amplitude anomalies of the total kinetic energy over the whole globe, the kinetic energy in zonal mean flow and even the total kinetic energy over the Northern Hemisphere were unusual (anomaly is equal to or greater than twice the standard deviation), but also the annual means of these energy modes were unusual. Furthermore the number of occurrences of the unusual months in 1983 was the largest in these nine years.

(4) By means of the lag–cross correlation between each of the 91 kinetic energy items and the monthly anomalies of SST averaged over the equatorial eastern Pacific, it may be considered that the unusuality of the kinetic energy modes over the whole globe in 1983 was closely correlated with the 1982 / 83 event, and that the unusual strength of the kinetic energy of wavenumber one over the southern low latitudes could be considered as a precursor for monitoring the major ENSO event.

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