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ANALYSIS OF LOW-FREQUENCY OSCILLATIONS FOR THE SOUTH CHINA SEA SUMMER MONSOON IN 1998

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ABSTRACT: With NCEP/NCAR reanalysis daily data and SST for 1998, the paper investigates the features of summer monsoon low-frequency oscillation (LFO) over the South China Sea (SCS). Results show that SCS summer monsoon onset is enhanced because of its LFO. Low-frequency (LF) low-level convergence (divergence) region of SCS is in the LF positive (negative) rainfall area. LFO of the SCS region migrates from south to north in the meridian and from west to east in zonal direction. LF divergence of SCS is vertically compensating to each other between high and low level.

Key words: SCS summer monsoon; low-frequency oscillation; transportation

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1 INTRODUCTION

Locating at the southeastern part of Asia, the South China Sea (SCS) links the Indian Ocean and western Pacific and immediately borders with the South Asia monsoon region. It is an important location in which the East Asia monsoon system interacts with the Indian Ocean one and a most direct source of moisture for the subtropical monsoon system in East Asia. The SCS monsoon anomalies can directly affect on the temporal-spatial distribution of precipitation in the south of China and the Changjiang River valley so that serious floods/droughts are caused. Comprehensive understanding of the SCS summer monsoon, therefore, is essential for correct recognition of the monsoon systems in South Asia and East Asia.

Since the 1980's, Chinese meteorologists[1, 2] have pointed out that the Asian summer monsoon consists of interrelated and yet independent regimes in South Asia (India) and East Asia; the monsoon has its earliest onset in the SCS region, which then expands to the northwest and north, leading to eventual establishment over South Asia and East Asia. From the 1990's onwards, closer attention has been paid to the summer monsoon in the SCS and the onset and mechanism have been studied from various points of view and useful conclusions obtained[3-7]. Much work has done in the aspect of low-frequency oscillations (LFO) of the SCS summer monsoon and summer season in China. Chen et al[10]. discover that there is significant difference in the allocation of low-frequency (LF) flow fields and transportation direction of LF waves for typical drought and flood years in the Changjiang River valley. Zhou et al[10]. suggest that LF oscillations have longer periods in drought years than in flood years. Lin et al[10]. find that the LFO is specially short in periodicity in April – September of 1991, a wet year, which lasts between 20 and 40 days. Huang et al[11]. report that the variance taken by LF latitudinal and longitudinal winds in most of the valley can be as high as 50%; precipitation in wet years form as northern

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and southern LF vortexes converge over the valley; precipitation in dry years is resulted from northwestward movement of minor LF vortexes from the tropical Pacific Ocean to the valley.

The study of LFO of the summer monsoon in the SCS region has been high on the agenda of meteorologists and is one of the key issues in the South China Sea Monsoon Experiment in 1998. With the global daily mean analysis fields made at NCEP / NCAR for 1998, weekly and monthly mean SST data, the current work addresses the LF periodicity of the SCS summer monsoon, the effect of atmospheric LFO on the monsoon and LF coupling process of SST and monsoon precipitation, with an emphasized viewpoint of low frequency. These discussions are followed by a study on the transportation and vertical structure of LFO in the SCS.

2 WAVELET ANALYSIS OF OSCILLATION PERIODS OF SCS SUMMER MONSOON

For the determination of individual elements, the work first studies the periodic variations of wind, precipitation and convection fields in the SCS region (5°N – 20°N, 110°E – 120°E) using the Morlet wavelet, which is good at analyzing periods.

Fig.1 (a & b) gives a wavelet analysis of the latitudinal and longitudinal winds at 850 hPa over the region described above, with the time lag taken at 60 days. From Fig.1a, we know that the wavelet coefficients show that the energy mainly concentrates on the frequency domain 0 – 60 days; LFO is quasi-45 and quasi-23 days in May – August. In addition, there is also a

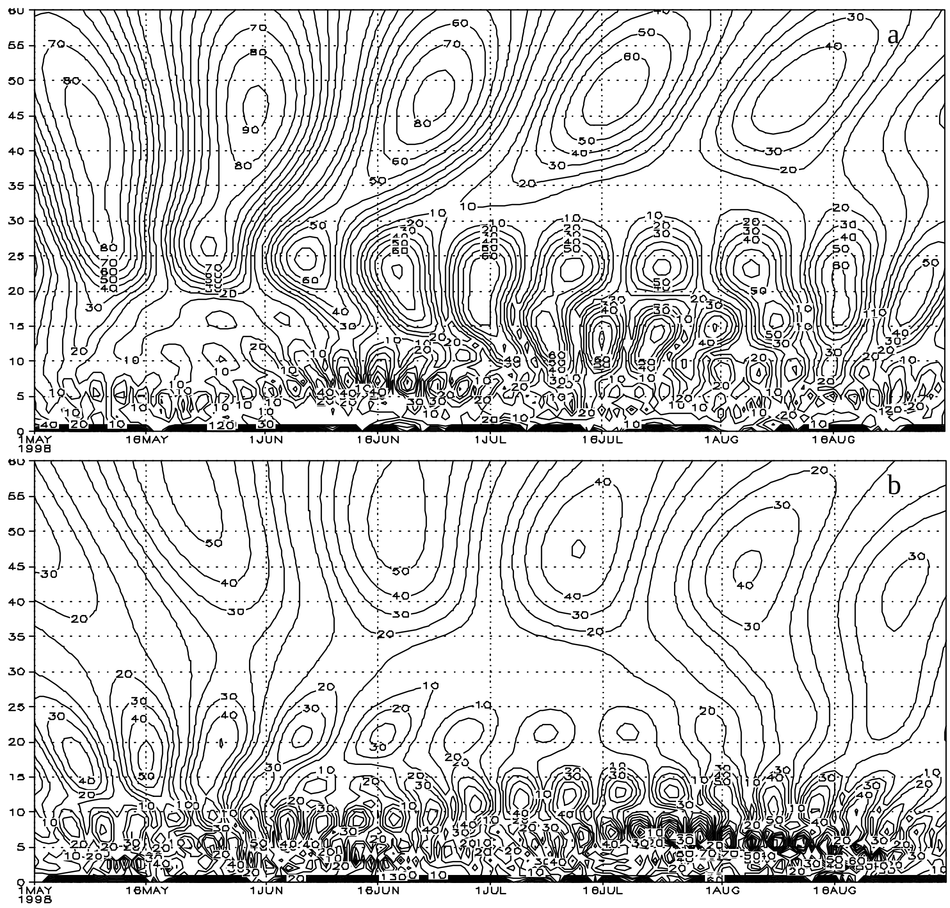

Fig.1 Morlet wavelet analyses of latitudinal wind (a) and longitudinal wind (b) at 850 hPa in the SCS. Abscissa: time; ordinate: time period; unit: day.

quasi-biweekly oscillation from the end of June to early August. The quasi-45-day oscillation is strong in May and June, when the SCS summer monsoon is around the set-off. The period reduces a little in July and August when the SCS summer monsoon prevails. The quasi-23-day oscillation virtually remains unchanged over the time from May to August. For the wavelet analysis of longitudinal wind (Fig.1b), the LFO is quasi-45-day in May – August, quasi-20-day in May and June and quasi-biweekly in June – August. Additionally, there is also a LF period of quasi-8-days. In general, the quasi-45-day period is common in both the latitudinal and longitudinal winds in the SCS while they have different LF periods in other domains.

In most of the other work, it has been pointed out that 30- to 60- day oscillations have been shown to exist in tropical atmosphere, which is also confirmed in our analysis of periods. Next we will filter elements of interest using a 32- to 63- day band-pass filter to study the quasi-45-day LFO in the summer monsoon of the SCS.

3 ROLE OF ATMOSPHERIC LFO IN THE ONSET OF SCS SUMMER MONSOON

Abrupt changes in wind direction with strengthening of the westerly speed are the most important indicators for the onset of summer monsoon in the SCS. It has been determined that it had a full onset in the 5th pentad of May, 1998. It is known that kinetic energy resulted from disturbance is an important quantity in physics. The kinetic energy of LFO in the atmosphere is readily available by exploiting LF latitudinal and longititudinal winds. To study the effect of atmospheric LFO on the onset of summer monsoon in SCS, a chart (Fig.2) is made combining the curves of 850-hPa latitudinal wind, LF latitudinal wind and LF kinetic energy for the SCS region (5°N – 20°N, 110°E – 120°E).

From Fig.2, we know that the LF latitudinal wind is in the same phase with observed latitudinal wind around the onset of the summer monsoon. The onset is right at the time when the ascending phase reaches the maximum and the LF variation is in phase with seasonal change. It is then seen that the LFO of the latitudinal wind can enhance the onset. The figure also shows that LF kinetic energy is the strongest, being 7.8 m^2/s^2. It indicates that the kinetic energy is the strongest around the onset but rapidly reduces after it, all below 3 m^2/s^2. When the monsoon is during the onset, the LF kinetic energy is also in phase with the westerlies in the SCS, which enhances the onset of SCS monsoon. After the onset, the LF kinetic energy, with relatively small values, is out of phase with the latitudinal wind in the SCS. It is then concluded that LF kinetic energy has a relatively small contribution to the summer monsoon during its maintenance.

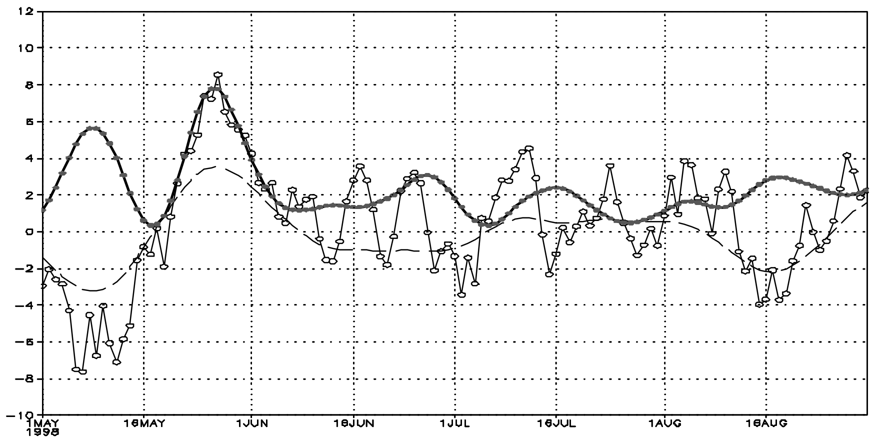

Fig.2 Variations features of zonal wind (thin lines), LF zonal wind (dashed lines) and LF kinetic energy (heavy solid lines) at 850 hPa in the SCS (units: zonal wind and LF zonal wind: m/s; LF kinetic energy: m^2/s^2).

4 LF COUPLING OF SCS SUMMER MONSOON PRECIPITATION WITH SST

As the SST varies mainly on long-term scales, its LF change is too small to reflect low frequency processes as they are. For the reason, the current work subtracts a running mean for 7 weeks from the temporal series of the SST to obtain those of the SST anomalies. Then, the band-pass filter is applied in the series for a temporal series of LF SST anomalies. It is based on the latter series that coupling oscillation is sought of LF SST, LF precipitation rate and 850 hPa LF divergence (Fig.3). As shown in the figure, there are roughly three LFOs for the 850-hPa diversity, precipitation and SST in the SCS region, in each of which LF diversity is generally out of phase with LF precipitation. It shows that the LF convergence zones correspond to where positive LF precipitation is while the LF divergence zones to where negative LF precipitation is.

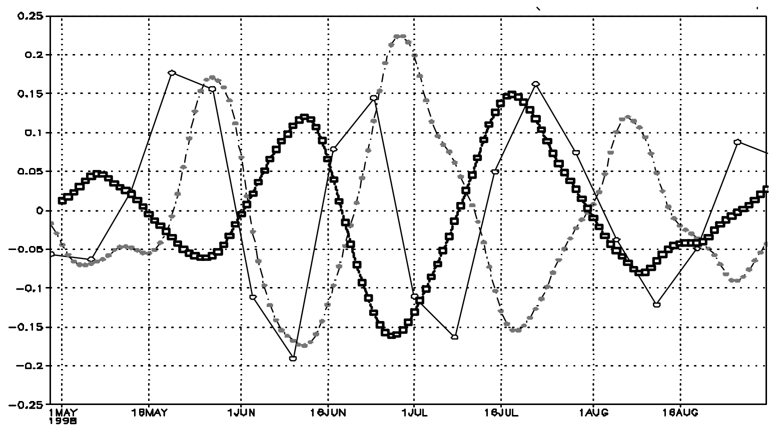

Fig.3 Coupling oscillation of LF SST (blank circle), LF precipitation rate (solid circle) and 850 hPa LF divergence (blank pane) from May to August in SCS in 1998. Units: SST (℃); precipitation-rate ($4\ E^{-4}kg/m^2s$); divergence ($4E^{-6}/s$).

It is also shown in the figure that for May – June, a time leading up to the monsoon onset, the LF oscillations of the SST are ahead of the LF oscillations of the precipitation by about 1/4 phase. It shows that as the SST rises and begins a positive phase, it helps strengthening the LF convergence at 850 hPa so that LF precipitation increases; as the precipitation increases and begins a positive phase, the SST starts to fall; as the SST falls and begins a negative phase, the LF divergence strengthens at 850 hPa and the LF precipitation starts to decrease; as the precipitation decreases and begins a negative phase, the SST begins to rise again; as the SST rises and a positive phase begins, the LF convergence begins to strengthen again and LF precipitation begins to increase again. Such mutual feedback processes will inevitably affect the maintenance of LFO for other meteorological convergence. The coupling oscillations are less evident when it comes to July and August. The cause for the phenomenon may be very complicated, which needs further discussion based on more evidence.

5 CHARACTERISTICS ANALYSIS OF TRANSPORTATION AND VERTICAL STRUCTURE OF ATMOSPHERIC LFO OVER THE SCS

5.1 *Transportation of atmospheric LFO in the SCS*

. To study the transportation of atmospheric LFO in the SCS region in 1998, a longitude-time cross-section has been made for the domain 5°N – 20°N to study the latitudinal transportation of the LFO in the SCS and a latitude-time cross-section constructed for the domain 110°E – 120°E to study the longitudinal transportation.

5.1.1 LONGITUDINAL TRANSPORTATION

Fig.4 is a time-latitude cross-section of 850-hPa LF longitudinal wind averaged over the area 110°E – 120°E. It shows that there are 3 pairs of LF belts of southerly and northerly from May to August 1998. They are all formed over central SCS before moving northward to be near 35°N. For the LF longitudinal wind in May – July, it keeps increasing over the course of movement, acquiring the highest intensity near 30°N; in the meantime, the LF longitudinal wind is almost opposite in direction in low and mid- and high- latitudes, for the same longitude. It shows that the onset of summer monsoon in May – July over the SCS has made it possible for tropical systems to travel northward more pronouncedly and for weather to change more dramatically; humid air from the tropics meets mild cold air mass near 30°N so that the synoptic systems are strengthened there and more violent changes in weather are resulted. It was over the region that serious flooding destruction occurred in the summer of 1998. It is another evidence that variation of LF summer monsoon over the SCS does have important effect on the heavy rain in the Changjiang River valley. In August, however, with the weakening of tropical systems, the LF longitudinal winds in both low and mid- and high- latitudes for the same longitude are generally the same, suggesting reduced interactions of synoptic systems between the two latitude zones.

5.1.2 LONGITUDINAL TRANSPORTATION

On the longitude-time cross-section (Fig.5) for LF 850-hPa vorticity averaged over the region 5°N – 20°N, there are three dominant pairs of positive and negative LF vorticity belts in May – August, 1998. They are alternatively appearing and transporting eastward. They change in intensity with longitude and the SCS region is largely where positive and negative centers of vorticity are found, suggesting strong LFO in the area.

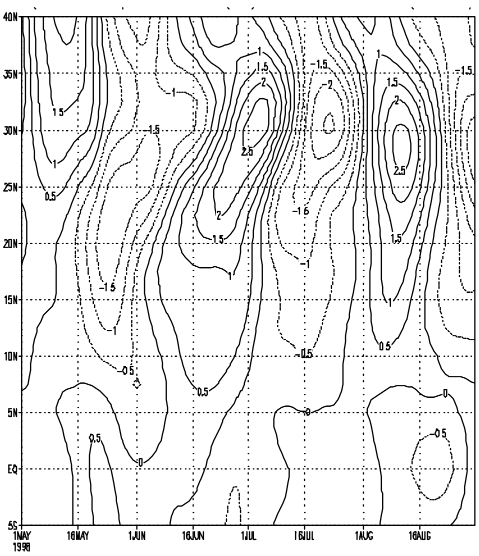

Fig.4 The time-latitude cross-section of 850-hPa LF longitudinal wind in 110°E - 120°E region (unit: m/s)

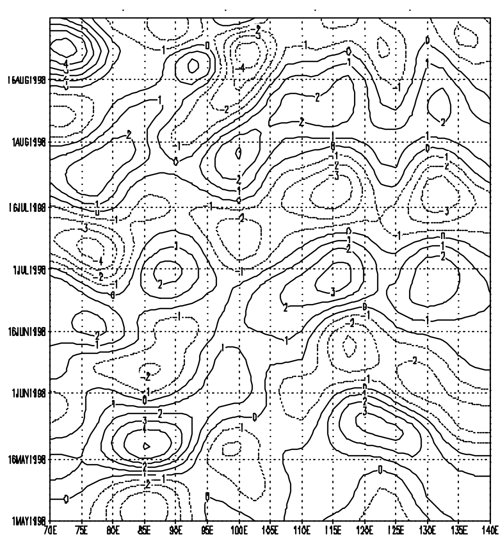

Fig.5 The longitude-time cross-section of 850-hPa LF vorticity in 5°N - 20°N region(unit: $1E^{-6}$/s)

On the longitude-time cross-section (Fig.5) for LF 850-hPa vorticity averaged over the region 5°N-20°N (figure omitted), however, there are three LF easterly and westerly zones that are transporting slowly eastward. Analytic study of the figure also shows that the east-going LF latitudinal wind tends to accelerate with time.

Summing up what has been discussed above, we know that for the summer of 1998, the atmospheric LFO is transporting northward longitudinally and eastward latitudinally, with changes taking place over the course of transportation.

5.2 *Vertical structure of atmospheric LFO in the SCS*

To study the vertical structure for the SCS region, coefficients are established that correlate 850-hPa grid points with the 100-hPa ones for unfiltered geopotential height fields versus those treated with 45-day low-pass filter (Fig.6).

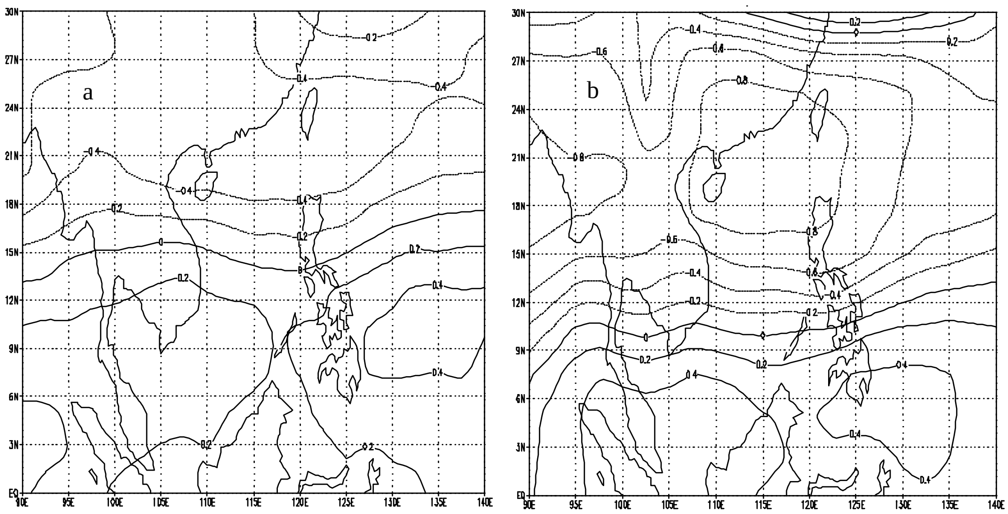

Fig.6 Correlation between 850 hPa and 100 hPa height. a. real height; b. LF height.

On the correlation panel for unfiltered upper and lower levels (Fig.6a), we see that the area 15°N - 30°N is negatively correlated, with the maximum negative correlation zone in the northern part of the SCS and southern part of the Changjiang River valley and the coefficient above –0.4. It shows that the region is of baroclinic structure that is out of phase between upper and lower levels, i.e. high (low) pressure at lower levels are corresponding to low (high) pressure at upper levels. The region from the equator to 14°N is positively correlated with the maximum positive correlation found over the western Pacific to the east of the Philippines. Its structure is equivalent to barotropic structure.

On the correlation panel for 45-day low-pass filter (figure omitted), the area 10°N - 29°N is a highly positively correlated, with the center of negative correlation center within the extensive area between central-southern parts of the SCS and southern part of China and a negative correlation coefficient over –0.8. The baroclinic structure is much stronger than it is before the filter. It shows the presence of significant baroclinic distribution in both upper and lower levels so that the LF synoptic systems have opposing characteristics on the two levels, i.e. a high (low) LF pressure zone at the lower level is corresponding to a low (high) pressure zone at the upper level, which is favorable for the formation of LF divergence (convergence) at the upper level and convergence (divergence) at the lower level. It then forms LF ascending (descending) air flows. A positive correlation zone is between the equator and southern SCS with the maximum in the area between the equator and 7°N and a positive correlation coefficient more than 0.4. The structure is equivalent of a barotropic one. The figure also shows that the isolines of correlation coefficients generally go parallel with the latitude, indicating variations of upper- and lower-level vertical structures with latitude. The cause for the significant baroclinic and barotropic structures remains to be determined with analytic and numerical simulations in the future.

In this work, vertical distribution of LF divergence field (Fig.7) is constructed for the SCS region (5°N - 20°N, 110°E - 120°E). It shows an out-of-phase distribution of LF divergence at high and low levels from May to August in the SCS region, i.e. upper-level divergence (convergence) versus lower-level convergence (divergence). The strongest LF divergence / convergence happens on the levels between 250 hPa and 100 hPa, followed by a less strong zone at the lower troposphere (levels below 850 hPa) while the LF divergence / convergence is relatively small at the middle layer of the troposphere, showing signs of mutual vertical compensation of LF divergence in the SCS region.

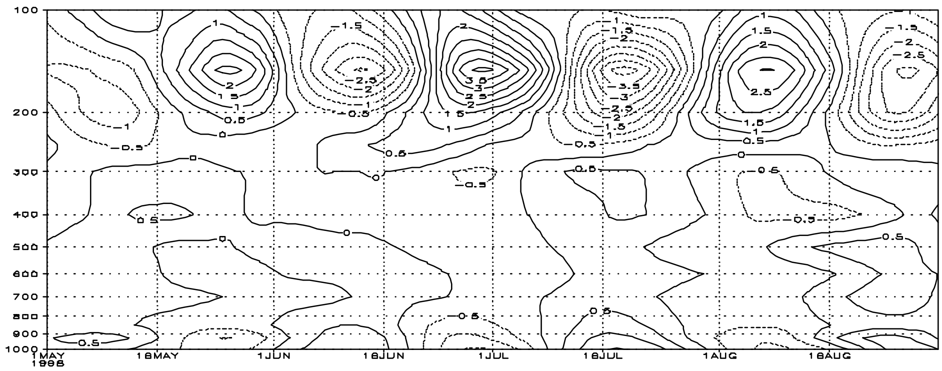

Fig.7 The vertical section of LF divergence in SCS (5～20 °N,110～120 °E) in 1998(Units: $1E^{-6}$/s).

In summary, the vertical structure of atmospheric LFO in the SCS is significantly different from that without the filter treatment for the course May to August, 1998. The regional LFO shows that its structure varies with latitude, with the baroclinity the main distribution for the area from northern SCS to southern China and the barotropy the main distribution for the area from southern SCS to the equator. The LF divergence in the SCS region shows inter-compensating feature vertically.

6 CONCLUDING REMARKS

a. For the atmospheric LFOs existing in the SCS region, the quasi-45-day oscillation is the most significant period.

b. The LFO of the latitudinal wind can enhance the onset of the summer monsoon in the SCS and so can the LF kinetic energy.

c. In the SCS, a low-level LF convergence (divergence) corresponds to a positive (negative) LF precipitation area. In May – June, i.e. around the onset of the SCS summer monsoon, the LFO of the SST leads the LFO of the precipitation by about 1/4 phase and there may be LF couplings between the them.

d. The atmospheric LFO in the SCS is propagating northward longitudinally but eastward latitudinally. The LFO vertical structure varies with latitude and the LF divergence inter-compensates vertically.

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