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Premonitory phenomenon of El Niño event reflected in the observations of *LOD* and sea level

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Abstract Data sets of the changes of the length of day, the sea surface temperature in the eastern Pacific and of the sea level in Hong Long from tide gauge observations are used to analyze and reveal the reflections in the observations of the length of day and the sea level changes concerned with the premonitory phenomenon of next El Niño event. The results from this study indicate that a new El Niño event has been brewing with the ending of the strong La Niña event that started in early summer of 1998. The estimated formation period of the new El Niño event will begin before the end of 2000, and the peak period may be reached at around the end of 2001.

Keywords: change of the length of day, sea level change, El Niño event.

Since the successful detection of the strong El Niño event that occurred in 1982—1983 from the changes in the length of day (ΔLOD) that characterize the variations in the rate of Earth rotation and are observed by space geodetic techniques[1], scientists in the field of geodynamics have been interested in the study of the relationship between the rotation of the Earth and El Niño events. Investigations of both scientific and practical significance in this area have been carried out[2—9]. Results from these studies have indicated that the relationship between the rotation of the Earth and El Niño events can basically be described as a dynamics process between the atmosphere, the oceans and the rotation of the solid Earth. During an El Niño event, the equatorial westward trade wind and the tropical surface ocean current in the Pacific collapse, causing the sea level to rise in the eastern Pacific and resulting in the increase in the atmospheric and oceanic angular momentum. The rate of Earth rotation is then decelerated (increase in *LOD*) as a result of the exchanges of angular momentum among the atmosphere, the ocean and the solid Earth and the conservation of the total angular momentum. On the other hand, during a La Niña event, the equatorial trade wind and the tropical ocean current strengthen, causing the sea level to rise in the western Pacific and resulting in the decrease in the atmospheric and oceanic angular momentum and the acceleration of the rate of Earth rotation (decrease in *LOD*).

In this note, the premonitory phenomena of the next El Niño event as reflected in the observations of ΔLOD and the sea level change (*SLC*) will be analyzed by using the latest data sets of ΔLOD and the sea surface temperature (*SST*) in the eastern Pacific since 1962 provided by the International Earth Rotation Service (IERS, Paris, France) and by the National Center for Environment Prediction (NCEP, USA), as well as the sea level data from two tide gauge stations in Hong Kong. Based on this analysis, preliminary assessment of the timing of the new El Niño event will be carried out.

1 Processing of observational data

The highly accurate and systematically stabile daily *LOD* data of "EOP97C04" spanning the period from January 1962 to April 2000 obtained by the recent space geodetic and astronomical optical measurements[10] are adopted in this study. Tidal variations of periods of up to 35 d in the daily *LOD* data have been removed by the theoretical formula of Yoder et al.[11]. The *LOD* data have been further reduced, corresponding to the data of the atmospheric angular momentum in the same period, by the method of Multi-Stage Filter (MSF)[12] to eliminate the fluctuations on the "decadal time scale" induced by the coupling effect between the mantle and the core of the Earth. The monthly *LOD* series is then derived by simple monthly averaging of the daily data. After the linear and seasonal terms in the monthly *LOD* series are removed by the least-squares method of Householder Transform, the residual series, referred to as "interannual variations" of *LOD*, are obtained and drawn in fig. 1(a). In addition, the residual series of *LOD* is filtered again by the MSF to eliminate the high frequency variation in the *LOD* data of periods of up to two years. The interannual series of *LOD* is generated practically by band-pass filtering and is given in fig. 1(b). Fig. 1(c) shows the interannual variations of sea surface temperature in the eastern equatorial Pacific (El Niño3+4 area) characterizing the El Niño events. They can be derived by the least-squares method of Householder Transform to remove the linear and seasonal terms from the monthly data of sea surface temperature during January 1962—April 2000 presented by NCEP.

Comparing (a), (b) and (c) in fig. 1, we found that the signals of all the eleven ENSO events that have occurred since 1960 appear clearly in the interannual *LOD* variations. The interannual *LOD* increases (i.e. the rate of Earth rotation decelerates) when the *SST* in the eastern Pacific is going up (the formation period of an El Niño event), while the interannual *LOD* decreases (i.e. the rate of Earth rotation accelerates) when the *SST* is dropping down (the formation period of a La Niña event). It can be seen from the result that nearly all the El Niño events have occurred after a 'turning point', when the interannual *LOD* changes from going down to going up had occurred. It is interesting to note from the interannual *LOD* variations derived by using the band-pass filtering (fig. 1(b)) that a new minimal value of interannual *LOD* was found in August 1999. It is a sign indicating that the strong La Niña event occurred since the early summer of 1998 has ended and a new El Niño event is being brewed.

Since Hong Kong is geographically located at almost the southern part of China and close to the edge of the western tropical Pacific, the sea level data from the tide gauge stations in Hong Kong are useful for the study of ENSO events. The tide gauge data have been collected since 1954 and have very good continuity and stability. Ding et al. have used the data to study the relationships between sea level changes in the area and Southern Oscillation[13]. Fig. 1(d) shows the interannual changes of the sea level since 1962. The interannual data has been obtained by removing the linear, seasonal and 18.6-year tidal terms from the monthly sea level data by the least squares method and then by

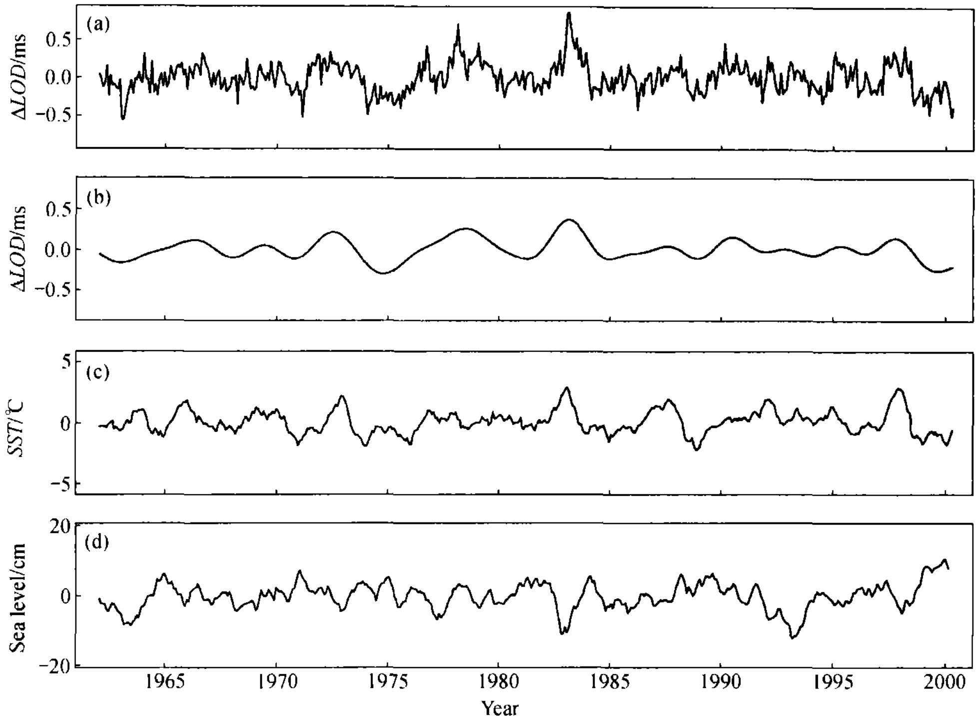

Fig. 1. (a) and (b) are the interannual changes of *LOD* derived from the least-squares method and band-pass filtering of 2—10 a, respectively; (c) is the interannual changes in the *SST* in the eastern equatorial Pacific (El Niño3+4 area); (d) is the interannual changes in the sea level in the Hong Kong area.

calculating a half-year moving average. Comparing the interannual sea level changes in Hong Kong with the *SST* in the eastern equatorial Pacific in fig. 1(c), we can see that the signs of changes in the two time series are opposite with each other. The interannual sea level drops during an El Niño event while the sea level rises during a La Niña event. The opposite relationship is mainly a result of the changes in the sea surface pressures and wind fields between the eastern and the western Pacific accompanied by the occurrences of El Niño and La Niña events[14, 15]. It is worth noting here that a turning point has occurred in the interannual sea level changes in Hong Kong after the see level has risen for over 10 cm as a result of the strong La Niña event that began in the summer of 1998 and have lasted for about two years. This is another evidence to confirm that a new El Niño event has been in its brewing period.

2 Pre-assessment of the new El Niño event

The cross-correlation function in the time domain and the squared coherence spectrum in the frequency domain of the interannual variations of *LOD* and the sea level (shown in fig. 1(a), (d)) with the *SST* series (fig. 1(c)) are analyzed, respectively, to assess the coming El Niño event. Cross-correlation function $\rho(\tau)$ and squared coherence spectrum $\gamma^2(f)$ between the two time series can be estimated by[16]

$$\rho(\tau)=\frac{\sigma_{12}(\tau)}{\sqrt{\sigma_{11}\sigma_{22}}}, \tag{1}$$

$$\gamma^2(f)=|R(f)|^2, \tag{2}$$

and

$$R(f)=\frac{S_{12}(f)}{\sqrt{S_{11}(f)S_{22}(f)}}. \tag{3}$$

σ_{12} in eq. (1) is the cross-covariance function of phase lag τ. σ_{11} and σ_{22} are the variances of the two time series, respectively. f in (2) and (3) is the frequency. $S_{12}(f)$ is the cross-power spectrum between the two time series. $S_{11}(f)$ and $S_{22}(f)$ are the auto-power spectra of the two series, respectively. In this study, the multi-window spectral technique[17] is introduced when the power spectrum is calculated with Fourier transform. The estimated cross-correlation functions and squared coherence spectra between the interannual *LOD* and the *SST* in the eastern equatorial Pacific as well as those between the interannual sea level in Hong Kong and the SST are given in fig. 2(a), (b), (c) and (d), respectively.

It can be seen from the estimated squared coherence spectra shown in fig. 2(c), (d) that the variations of the *LOD* and the sea level in Hong Kong have stronger coherence with the sea surface temperature changes in the eastern equatorial Pacific mainly on the interannual frequency bands of 0.21—0.39 cycles per year (cpy) and 0.26—0.47 cpy, respectively. The coherence spectral estimates of the bulks of the frequency points on these bands have exceeded the significance level of 95%[18]. It can be seen from the cross-correlation estimations on the time domain shown in fig. 2(a), (b) that the changes of the *SST* have positive correlation with the interannual *LOD*, while negative correlation with the interannual sea level changes in Hong Kong. The maximal correlation values (0.52 and −0.50, respectively) occur with the phases of the *SST* leading by one month. Based on the statistical test, the values have obviously exceeded the significance level of 95%[19].

When examining estimated cross-correlation (fig. 2(a)), we can see that the maximal value of

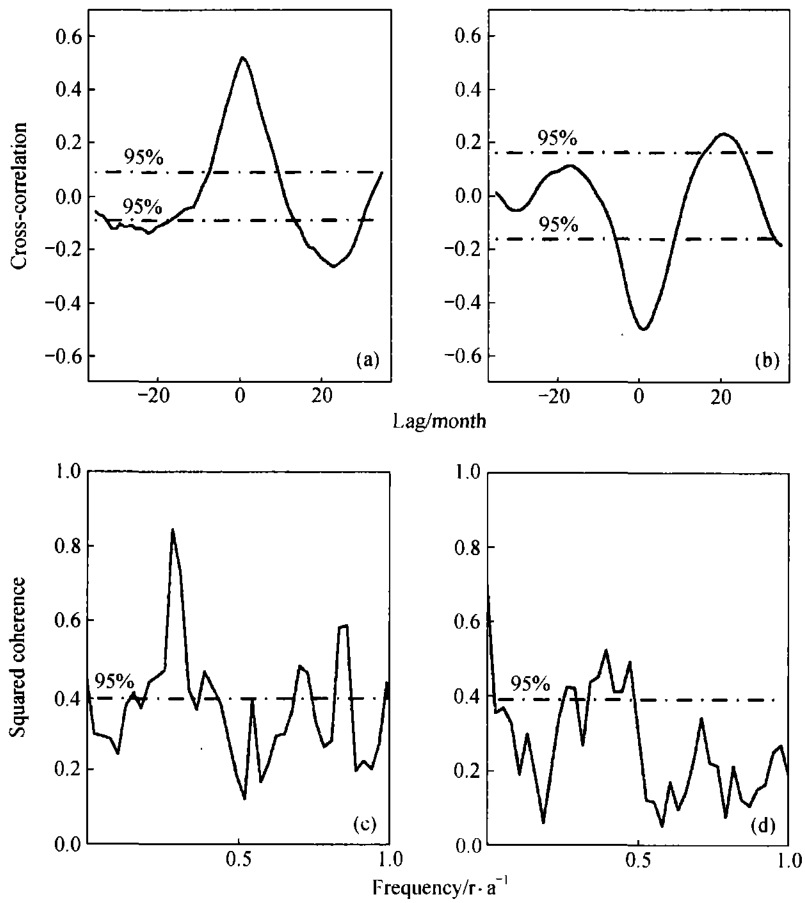

Fig. 2. (a) and (b) are respectively the estimates of cross-correlation functions in time domain between the interannaul changes of *LOD* and the *SST* in the eastern equatorial Pacific as well as those between the sea level in Hong Kong and the *SST*. (c) and (d) are the corresponding squared coherence spectra in frequency domain. The dashed lines are the threshold values of significance tests for the estimated values.

negative correlation of – 0.14 occurs with the phase of the interannual *LOD* leading by 23 months and the value has also exceeded 95% confidence level in the statistical test. According to ref. [15], the atmospheric and the oceanic movements in the eastern and western directions in the tropical Pacific accompanied by El Niño and La Niña events induce interannual variations in the rate of rotation of the Earth. The variations in the interannual rate of rotation of the Earth can then in reaction also influence the latitudeward movements of the oceanic currents and affect the formation duration of El Niño events. This result of study on the interactions of the tropical atmosphere and ocean with the solid Earth rotation mentioned above has been proved by monitoring the processes of occurrence and development of the 1997—1998 El Niño event with the technique of satellite altimeter[20]. This has formed the theoretical foundation to study an assess signals preceding El Niño events that are contained in the *LOD* data obtained from astronomical and space geodetic observations. The *LOD* data can be used to reduce and monitor the minimal value of interannual *LOD* and then to pre-assess the situation of the new El Niño event by means of the ahead of interannual *LOD* with 23 months.

The analysis results presented above have revealed a new minimal value that occurred in August 1999 in the interannual *LOD* changes. This indicates evidently that the strong La Niña event that started in the early summer of 1998 has ended after lasting for about two years and that a new El Niño event is in the process of brewage. The recent measurements of the interannual sea level changes in Hong Kong have also provided additional evidence to confirm the above conclusions. According to the existing findings on the interactions between the tropical Pacific Ocean, the atmosphere and the rotation of the Earth and the estimated time-lags between correlations of these physical processes presented in this work, it can be further inferred based on the results of the above analysis that the formation period of the next El Niño event, when the interannual changes of *SST* maintain their positive values, will occur before the end of 2000. The peak period of the El Niño event may be reached in the winter of 2001. This will be the first El Niño event in the 21th century.

In this note, the signals preceding the coming El Niño event as reflected in the astronomical and geodetic measurements have been studied. Preliminary assessment of the occurrence and features such as the peak period of the El Niño has been made based on the study. The results of the study may be presented to the meteorological and oceanic departments as referable information to further monitor and forecast the El Niño event.

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In situ time-resolved FTIR investigation on the reaction mechanism of partial oxidation of methane to syngas over supported Rh and Ru catalysts

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Abstract *In situ* time-resolved FTIR spectroscopy was used to study the reaction mechanism of partial oxidation of methane (POM) to synthesis gas and the reaction of $CH_4/O_2/He$ (2/1/45, molar ratio) gas mixture with adsorbed CO species over Rh/SiO_2, $Ru/\gamma\text{-}Al_2O_3$ and Ru/SiO_2 catalysts at 500—600℃. It was found that CO is the primary product of POM reaction over reduced and working state Rh/SiO_2 catalysts. Direct oxidation of CH_4 is the main pathway of synthesis gas formation over Rh/SiO_2 catalyst. CO_2 is the primary product of POM over $Ru/\gamma\text{-}Al_2O_3$ and Ru/SiO_2 catalysts. The dominant reaction pathway for synthesis gas formation over $Ru/\gamma\text{-}Al_2O_3$ catalyst is via the reforming reactions of CH_4 with CO_2 and H_2O. For the POM reaction over Rh/SiO_2 and $Ru/\gamma\text{-}Al_2O_3$ catalysts, consecutive oxidation of surface CO species is an important pathway of CO_2 formation.

Keywords: partial oxidation of methane, synthesis gas, reaction mechanism, *in situ* time-resolved FTIR, ruthenium, rhodium, supported metal catalyst.

A unified mechanism of partial oxidation of methane (POM) to synthesis gas over metal catalysts has not been reached so far, especially for the reaction pathway over noble metals. Several studies show that the direct oxidation of CH_4 to CO and H_2 is the main pathway of synthesis gas formation over supported Ru[1], Rh[2—4], Pd[5] and Pt[6] catalysts. In contrast, some other experiments come to the conclusion that the formation of synthesis gas over the same or similar metal catalysts mainly proceeded via an indirect route[7—9], i.e. complete oxidation of CH_4 to CO_2 and H_2O (combustion), followed by reforming of unconverted CH_4 with CO_2 and H_2O. Obviously, for the direct oxidation mechanism, CO is the primary product of CH_4 oxidation, while for the combustion-reforming mechanism, CO_2 should be formed before the formation of CO. In this note, *in situ* time-resolved FTIR spectroscopy (*in situ* TR-FTIR) with time resolution better than 0.3 s was used to study the POM reaction and the reaction of $CH_4/O_2/He$ (2/1/45, molar ratio) gas mixture with adsorbed CO species over Rh/SiO_2, $Ru/\gamma\text{-}Al_2O_3$ and Ru/SiO_2 catalysts. The advantage of using FTIR spectroscopy to study the POM reaction is that both gas phase and surface species formed during the reaction can be followed at the same time. Therefore, the experiments can provide useful information for the understanding to