Multi-scale Analysis of Turbulence Dissipation in the South China Sea

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***Abstract*—Measurements for long-term ocean turbulence observation are obtained from a mooring line deployed in the South China Sea. The measurements were made at a single level of 250m depth in the water column for about 3 month duty cycle. These time-extended measurements of TKE have yielded a valuable database. Based on advanced spectral methods for dissipation time series, the evolution processes of ocean turbulence in the South China Sea are illustrated. The distribution patterns of dissipation in different time-scales reveal the multiscale evolution and time dependence over tidal cycle. The extended observations of dissipation will contribute to improving our understanding of the ocean evolution processes of multiple time scales in the South China Sea.**

Keywords—Turbulence; Extended; Observations; Multiscale analysis; Reconstruction

I. INTRODUCTION

A key factor that regulates water properties and drives ocean circulations is turbulent dissipation [1]. However, because of limitations of surveys instruments and methods, the measurements of turbulence and mixing in the open ocean are typically under-sampled and sparse both in time and space. Measurements for longer-term finer-scale observation are necessary to resolve the critical role of ocean turbulence. The extended observations in time series can contribute significantly to improve understanding of the ocean evolution processes of multiple time scales.

Using sea ice as a stable platform, oceanic turbulent flux measurements were made by eddy correlation methods in the under-ice boundary layer [2]. More recently, extended mixing measurements were made from a mooring by using a string of temperature microstructure recorders, sampling at several levels [3]. Being a region of several water masses existing and converging, spatial structure of turbulent mixing in the northwestern Pacific Ocean is also observed [4] Koch-Larrouy et al [5] examined the effect of internal tidal mixing on the transformation of the Pacific Water into the Indonesian through flow water. Norwegian continental shelf covers periods of two storms, and for 2 weeks in the turbulent dense gravity current plume of the Faroe Bank Channel overflow [6]. However, the South China Sea is poorly understood in terms of its ocean turbulence dissipation and evolution process. Limited research has been undertaken on the South China Sea and the available sources of data are also in great need.

In this paper, a moored autonomous turbulence system was deployed in the South China Sea from 19 October 2013 to 11 February 2014 at 21 09.900'N 117 42.031'E in about 250-m-deep water. Shear signal and other necessary data of 110 days were measured and analyzed using multi-scale spectral methods.

II. EXPERENMENT DEPLOYMENT

The instrument, Moored Autonomous Turbulence System had been deployed in the South China Sea (Fig. 1) from 19 October 2013 to 11 February 2014 at 21°09.900′ N 117°42.031′ E in about 250-m-deep water. In this experiment, this instrument has already sampled 28.5GB of turbulence data for about 110 days and they include shear voltage signal, platform vibration data and time series of attitude data. These data laid the foundation for further analysis of the turbulence characteristics of the South China Sea and the time evolution mechanism.

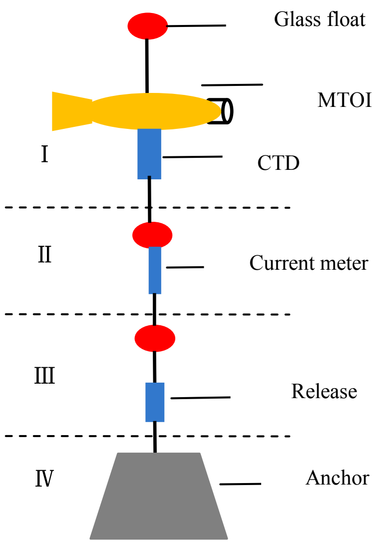

Fig. 1. Sketch of the mooring system arrangement.us scales.

The instrument (Fig.1) can collect copious hydrologic data of deep-sea for a long time at a constant level. The system consists of five parts. The Mooring Turbulence Measuring

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Instrument is mounted at part I. It is designed and developed by Ocean University of China. The assembled instrument weighs about 254.9kg, with a net buoyancy of 12kg in seawater. It has a total length of 3.0m, and the maximum diameter of the main body is 50cm. Two shear probes and two FP07 thermistors are located in MTOI's nose. Three orthogonal accelerometers are positioned inside the pressure case and monitor body vibrations. Body vibrations can serve to quantify the level of signal contamination at the shear probes. Ideally, the accelerometers should be installed as close as possible to the shear probes, but space limitations dictate a mounting point 0.5m aft of the probes. The CTD (SBE 37-SM MicroCAT) is installed in part Ⅰ, it mainly records the water temperature, conductivity and the pressure under the sea. Being rigidly attached to the main body, this sensor also points into the flow for good flushing of the conductivity cells and minimal flow disturbance. The speed of the ambient current is measured by Aanderaa Current Meter RCM11 which is deployed at part Ⅱ. An acoustic release transponder in part Ⅲ is used for recycling the instrument. The last Part is the anchor block, providing gravity for the whole system. There are groups of glass floats to provide buoyancy, which is custom modified to fit the turbulence instruments and the battery packs. The floats can be used as the upper buoyancy element or can be integrated at the desired depth in a mooring line.

III. RESULT

Since turbulence dissipation is a chaotic system, which is nonstationary and nonlinearity, special methods are needed to analysis. Three methods are involved in this paper, Singular Spectrum Analysis, periodogram method and Reconstruction.

A. *Some Common Mistakes*

SSA is based on calculating the principal directions of extension of the sequence of augmented vectors $\{\tilde{X}(t): t = 1, ..., N'\}$ in phase space [7]. In practice, SSA establish a vector space of dimension M (embedding dimension).

This method was utilized to signal decomposition and reconstruction. In brief lag-covariance matrix C_x is computed by

$$C_x = \frac{1}{N'} D' D \tag{1}$$

Where (1) D is trajectory matrix, basing on it, E_k is eigenvectors of C_x Furthermore, principal components (PCs) A_k is defined by

$$A_k(t) = \sum_{j=1}^{M} x(t+j-1) E_k(j)$$

(2)

Finally, reconstructed components (R_k) could calculated by

$$R_k(t) = \frac{1}{M_t} \sum_{k \in K} \sum_{j=L_t}^{U_t} A_k(t+j-1) E_k(j)$$

(3)

As embedding dimension (parameter M) increases, scale of reconstructed components (RCs) expands. Thus various reconstructed components offer multi-scale view of time series.

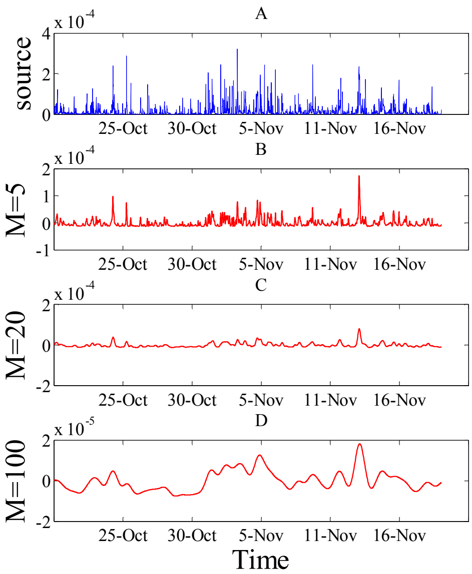

Fig. 2. Series in one month duration from 20 October 2013 to 20 November 2013 . (a) is raw dissipation data. (b),(c),(d) is robust skeleton that processed by SSA with various embedding dimension (parameter M). That three red lines show various scales of dissipation. In (d), there is a bulge every ten days.

In this paper Singular Spectrum Analysis (SSA) will be used to process the dissipation series, and dissipation will be presented in different scales (Fig.2).Since the platform is mooring at depth of 250-meter, without influence from wind and wave tide becomes the most likely factor impacting on dissipation. Take an instance, ocean tides and atmospheric tides due to the luni-solar tide-generating force [8]. There is a bulge appears in tide every ten days at this place. Parallelly, a view in similar scale (about ten days) of dissipation indicates the necessary of analyzing the relationship between tide and dissipation. Reconstructing the dissipation, selecting a proper embedding dimension (M = 100), will give a view of dissipation in appropriate scale (about ten days). After reconstructing, a ten-day-bulge is presented from arrhythmic, (Fig.2 d). Thereupon macroscopic phenomena contact with the microcosmic level.

When taking a small embedding dimension (M = 5), some detailed information of high frequency remain. In that way, small scale (shorter than one day) of dissipation appears.

B. *Periodogram method*

Power spectral density (PSD) is obtained by periodogram, which provides a perspective of frequency field instead of time field. This mathematical tool makes quantitative analysis possible.

Before the transformation, calculating the spectral resolution F is necessary. Only when spectral resolution cover the significant frequency spectrum, this transformation makes sense. The spectral resolution F defined by

$$F = \frac{1}{NT} \tag{4}$$

In the Equation (1), N is sampling number, T is sampling interval.

By using the periodogram method, dissipation is transformed into frequency field. In frequency field, every point (Fig.3) stands for a certain time-scale. Hence, the power strength of every time-scale is visualized. Thus, the distribution of dissipation in every time-scale is vivid and available to quantification.

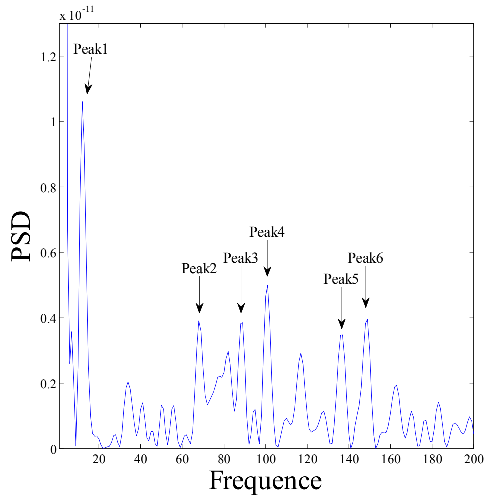

Fig. 3. Power spectral density (PSD) of dissipation. The length of PSD series is 12000, but there are only 250 points in this figure. There are two reasons, firstly, all high peaks are consisted in this field. Secondly, when studying dissipation in large time-scale, only low frequence field makes sense. The period (in days) of Peak1 to Peak6 are T1 = 10.0 T2 = 1.76 T3 = 1.34 T4 = 1.18 T5 = 1.02 T6 = 0.80.

Peak1 is the highest peak except DC component (Fig.3). Analog frequency of this point could be calculated by,

$$f_k = \frac{k}{NT} \tag{5}$$

Where N is sampling number, T is sampling interval and f_k is the analog frequency of point k. For that matter, k = 12, N = 12000 and T = 0.01 (day), period (in days) of Peak1 is 10. That means existence ten-day regularity in dissipation series as well as tide. Thus tide is a considerable source of dissipation.

C. Periodogram method

Every point in the frequency field represents a sinusoid in time field. Reconstruction is based on

$$\in_k = a_k \cos(2\pi\omega_k t - \varphi_k)$$

(6)

where a_k represents amplitude of point k in frequency field, and ω_k and φ_k are the frequency and phase lag.

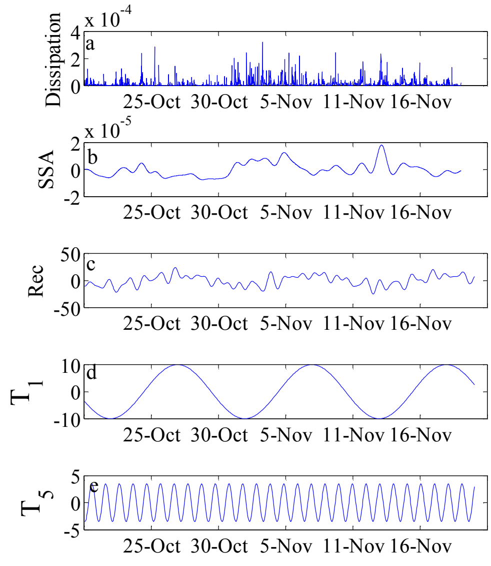

Fig. 4. Time field. (a) is raw dissipation data from 19 October 2013 to 11 February. (b) is evolution process of dissipation by SSA. (c) is reconstruction with six peaks. (d) is reconstruction with peak1. (e) is reconstruction with peak5.

After analysis in frequency field (Fig.3), reconstructions in time field show different sizes of time scale, such as quaterdiurnal constituent, daily cycle, and ten-day cycle. The six patterns (based on six major peaks) are added up to reflect profile of dissipation (Fig.4 c). Two reconstructing series (based on Peak1 and Peak5) are presented separately (Fig4 d e) in order to compare with tide in time field.

Comparing with raw dissipation data (Fig.5 a), series processed by SSA (Fig.5 b) and Reconstructing series (Fig.5 c), having different appearance that make these methods be applied in different situation. The evolution process of dissipation has the similar time depended variation of tidal cycle (daily cycle and ten-day cycle).

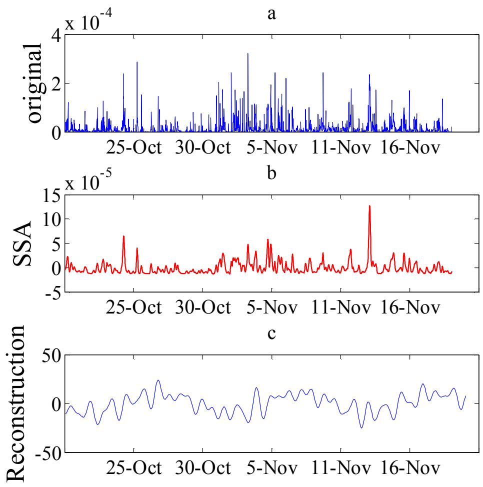

Fig. 5. Time field. (a) is raw dissipation data from 19 October 2013 to 11 February. (b) is evolution process of dissipation by SSA. (c) is reconstruction with six peaks. (d) is reconstruction with peak1. (e) is reconstruction with peak5.

In time field, (a) raw dissipation data. (b) is series processed by SSA, (c) is reconstrucing series from frequency field (Peak1 to Peak6).

IV. CONCLUSIONS

Reconstruction will offer an intuitionistic view of dissipation in time field. Furthermore, it may clarify some information hidden in frequency field.

This paper recommends two methods to choose the points used to reconstruction. Firstly, taking high points then the reconstructing series reveal the robust skeleton of dissipation in the view of power. Secondly, taking special points that are interested in.

The evolution process of dissipation has the similar time depended variation of tidal cycle (daily cycle and ten-day cycle). These measurements of turbulence dissipation have yielded a valuable database and revealed the multi-scale evolution and time dependence over tidal cycle. The extended observations of dissipation will contribute to improving our understanding of the ocean evolution processes in The South China Sea.

Furthermore, there are researches manifest that mixing has strong relevance with tide [9] from surface to mixing layer [10]. Dissipation is also influenced by other factors [11] that may illuminate the other Peaks (except Peak1 and Peak5) in PSD (Fig.2). Above conclusions provide clues as to the relationship between Marine microstructure and macroscopic natural phenomenon.

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