Tidal and residual currents in the inner shelf of East China Sea detected from underway ADCP observations

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① Introduction

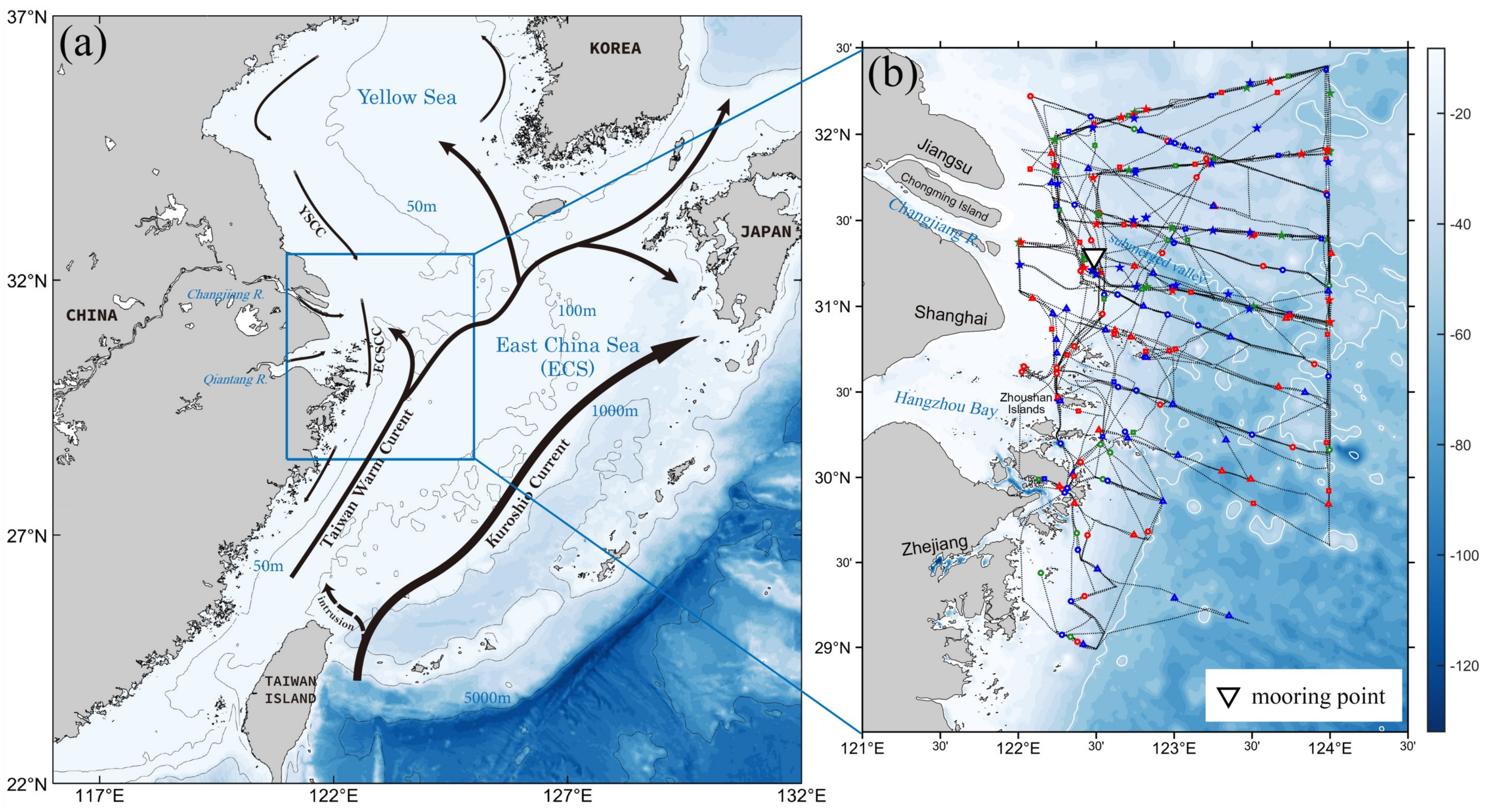

Fig.1 (a) A schematic regional circulation in the East China Sea

(b) The composite cruise tracks of the ADCP observations from 2019 to 2022

Main Current In Research Region

ECSCC (East China Sea Coastal Current) Only exists in winter season (Fig. 1a)

TWC(Taiwan Warm Current) Exists all year round, but its strength is affected by the monsoon

Tidal current is dominated by M2 tide component (>50%) (Fig. 3)

Characterizing the spatial variability of net flow transport in a tide-dominated area like the East China Sea (ECS) is key to understanding the material and heat budget as well as their impacts on local ecosystem. However, the residual circulation in the ECS was much less confirmed by observation as it can only be deduced from very sparse mooring data.

Given the strong tidal current in this area, the traditional underway ADCP observation is characterized by periodic signals, which is often less helpful to obtain the net transport or even the key tidal parameters. Here for the first time we derive the spatial patterns of tidal and residual currents in the inner ECS shelf from ADCP underway measurements conducted in 12 cruises using a spatial least squares (SLS) fitting technique.

② Data and Method

SLS: The extension of traditional tidal harmonic analysis with spatial interpretation

$$u(t) = u_m + \sum_{i=1}^{N} [b_i \cos(\omega_i t) + c_i \sin(\omega_i t)]$$

Tidal harmonic analysis, can be used at a **fixed** point , e.g. current velocity data collected from moored ADCP

Replace parameters with arbitrary space interpolation function: polynomial (what we used), biharmonic, or Gaussian function

$$u(x,y,t) = u_m(x,y) + \sum_{i=1}^{N} [b_i(x,y)\cos(\omega_i t) + c_i(x,y)\sin(\omega_i t)]$$

$$= u_m(x,y) + u_{semi-diurnal}(x,y,t) + u_{diurnal}(x,y,t) + \cdots$$

Additional consideration for the spatial variation, practical for dataset which **varies both in time and space**

e.g. velocity data collected from underway ADCP

Solved in a matrix format

From Rayleigh separation criterion we know distinguish between M2 and K1 is 1.08 days, 14.77 days for (M2, S2, K1, O1), and 182.62 days for (M2, S2, N2, K2, K1, O1, P1, Q1), here we choose N=4 (M2, S2, K1, O1)

$$\begin{cases} \sum_{j=0}^{J}\sum_{k=0}^{j} \alpha_{jk} x_1^{j-k} y_1^k + \sum_{n=1}^{N}\sum_{j=0}^{J}\sum_{k=0}^{j} \beta_{jk} x_1^{j-k} y_1^k \sin(\omega_n t_1) + \sum_{n=1}^{N}\sum_{j=0}^{J}\sum_{k=0}^{j} \gamma_{jk} x_1^{j-k} y_1^k \cos(\omega_n t_1) = u_1 \\ \sum_{j=0}^{J}\sum_{k=0}^{j} \alpha_{jk} x_2^{j-k} y_2^k + \sum_{n=1}^{N}\sum_{j=0}^{J}\sum_{k=0}^{j} \beta_{jk} x_2^{j-k} y_2^k \sin(\omega_n t_2) + \sum_{n=1}^{N}\sum_{j=0}^{J}\sum_{k=0}^{j} \gamma_{jk} x_2^{j-k} y_2^k \cos(\omega_n t_2) = u_2 \\ \cdots \\ \sum_{j=0}^{J}\sum_{k=0}^{j} \alpha_{jk} x_p^{j-k} y_p^k + \sum_{n=1}^{N}\sum_{j=0}^{J}\sum_{k=0}^{j} \beta_{jk} x_p^{j-k} y_p^k \sin(\omega_n t_p) + \sum_{n=1}^{N}\sum_{j=0}^{J}\sum_{k=0}^{j} \gamma_{jk} x_p^{j-k} y_p^k \cos(\omega_n t_p) = u_p \end{cases}$$

$$Ac = d$$

A: can be calculated with x, y, ω

c: the vector of coefficients to be determined

d: velocity vector known from ADCP datasets

Goal: Minimize $|Ac - d|^2$ for the least square solution!

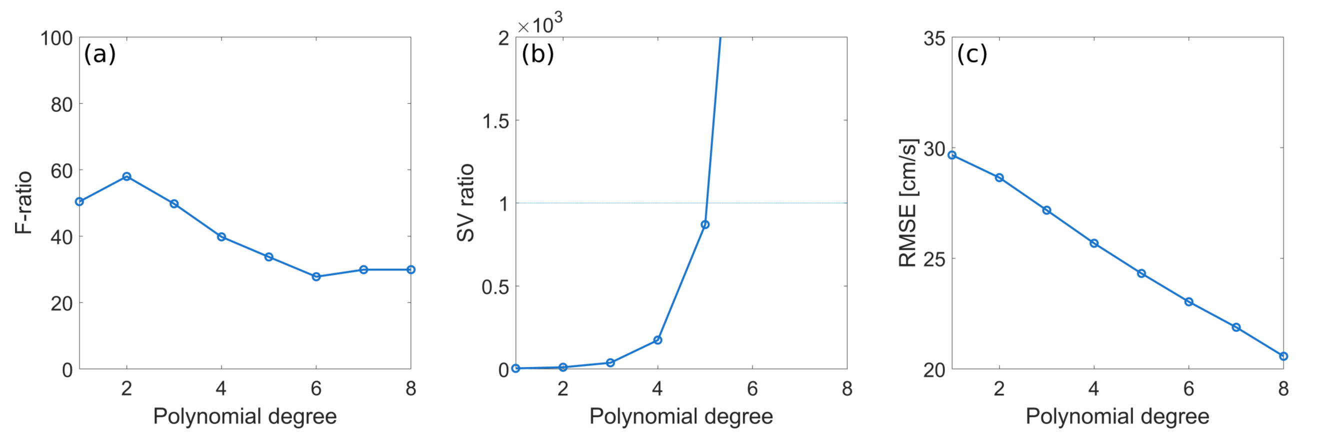

Fig.2 The variations of F-ratio (a),SV ratio (b) and RMSE (c) with the polynomial degree.

Even though we know how to solve the equation, it is still a question to select the degree or we cannot use SLS method. The variations of these three variables are monitored simultaneously to determine the optimal order 5.

There are over **18000 sampling data points** in all cruises combined, equivalent to a **80-day-long space-time data sequence.**

Once we solve the overdetermined equation set with 18000 equations, the current field function can be determined, which means we can deduce the tidal and residual current everywhere!

③ Result

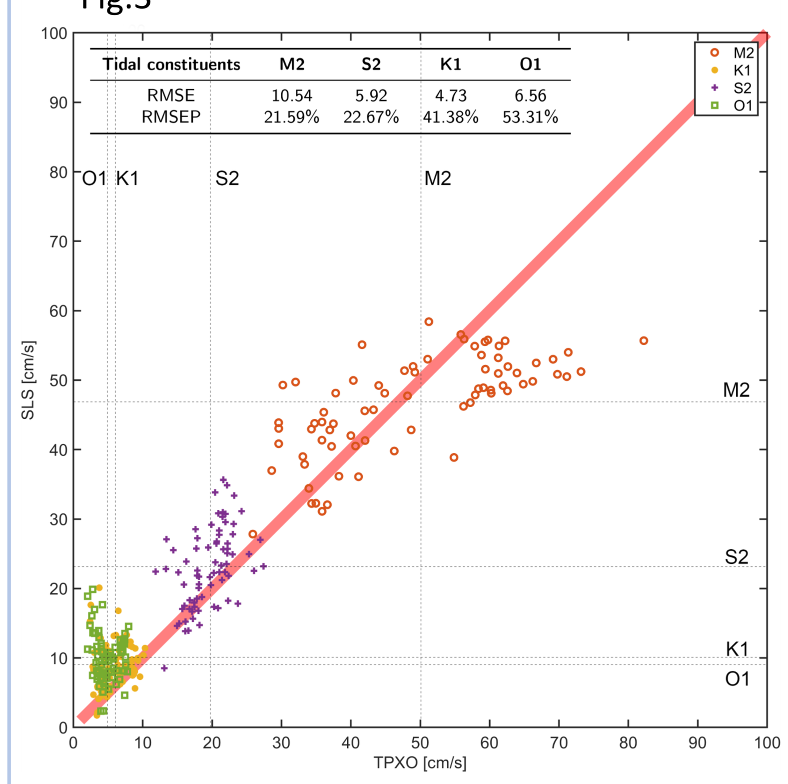

Fig.3

Tidal constituents	M2	S2	K1	O1
RMSE	10.54	5.92	4.73	6.56
RMSEP	21.59%	22.67%	41.38%	53.31%

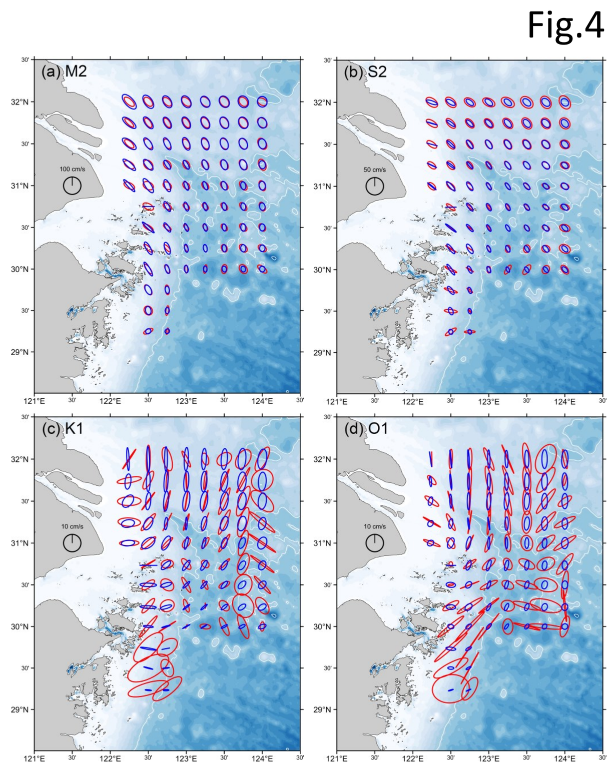

Fig.4

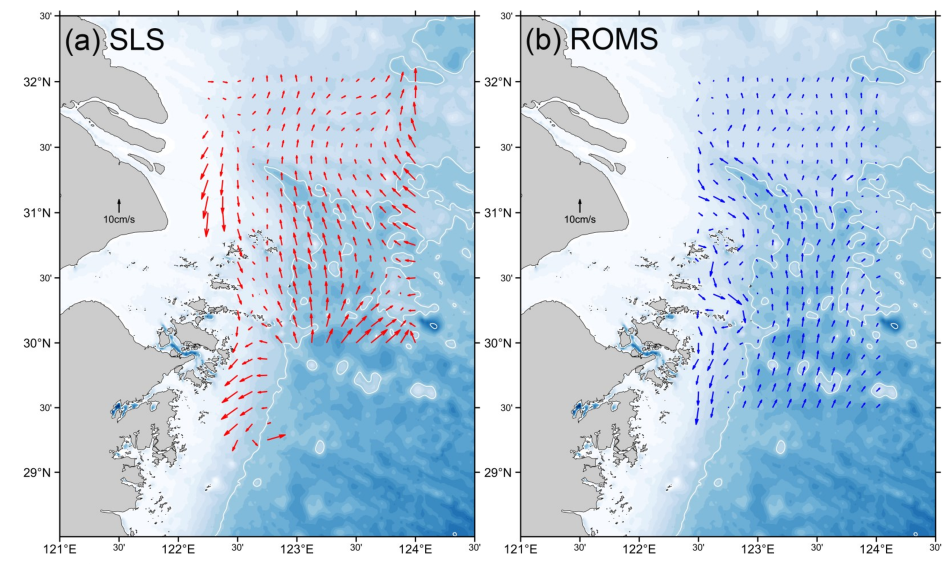

Fig.5

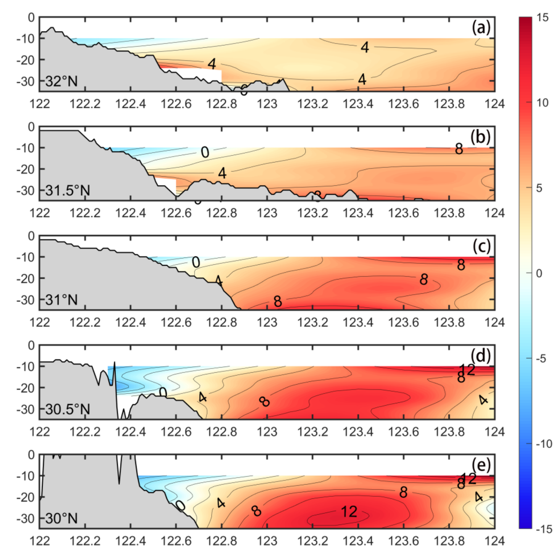

Fig.6

Scatter Plot of The Normalized Velocities (Fig.3)

Defined as the root mean square of maximal and minimal tidal current velocities of each tidal constituent, whose square is proportional to the tidal kinetic energy and indicates the relative importance of the four tidal constituents.

Tidal Ellipses Extracted from SLS (In Red) and TPXO (In Blue) (Fig.4)

The tidal current component:

· relatively good in semi-diurnal tide current, bad in diurnal tide current

Possible reason:

· the dominant position of the semi-diurnal tide's amplitude

· the influence of inertial frequency (very similar to the diurnal tide frequency, ~23.2356 hours in 31°N).

· the total data length cannot satisfy the Rayleigh criterion

Residual Currents Extracted from SLS (In Red) and ROMS Experiment (In Blue) (Fig.5)

The residual current field:

· maintain the principal circulation features · can not perform well in border

Possible reason:

· without constraint from fluid mechanics equation

· lack message input of bathymetry · the relatively simple form of polynomials

Some Features of Alongshore Residual Transects (Fig.6) :

· the residual circulation is characterized by a southward flow near the coast and a northward flow on the shelf.

· the north border that Taiwan Warm Current can reach is about 31.5°N

· the wedge-shaped vertical residual current structure in inner shelf of ECS

④ Conclusion and Discussion

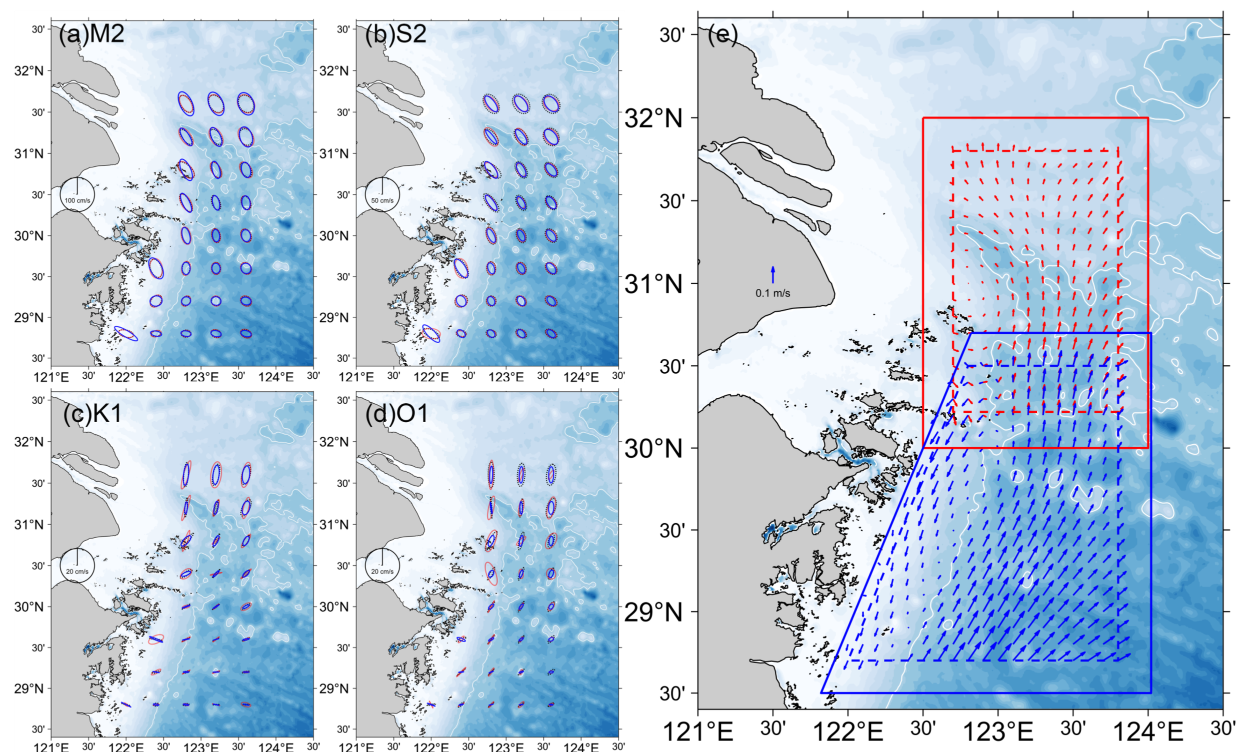

Fig.7 the fitting result by sub-regions of a 320-day-long virtual cruise from ROMS outputs

The SLS fitting with a polynomial function is shown here as a powerful tool to extract the major tidal constituents and residual current. Polynomial does not have any physical intuition but it is simple and easy to use with reasonably good accuracy given proper parameter selection.

With a fixed data length, the polynomial degree must be selected carefully, so that the results would neither be too smooth due to underfitting by a lower order polynomial nor overfitted by a polynomial of too higher order. In addition, there is a trade-off of performance in fitting the tidal and residual currents depending on the fitting strategy. Implementing the SLS fitting over sub-regions may capture more variability in residual current pattern at the expense of tidal current accuracy.

Reference: Wang, Y., Y. Zhong, S. Li, W. Chen, M. Zhou, Tidal and residual currents in the inner shelf of East China Sea detected from underway ADCP observations. Estuarine, Coastal and Shelf Science, 2024, 306, 108877.*

Space interpolation function:

replace polynomials with a neural network for a better result