Estimating the Absolute Salinity of China Sea Using Nutrients and Inorganic Carbon Data

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Abstract. In June 2009, the Intergovernmental Oceanographic Commission of UNESCO released the international thermodynamic equation of seawater – 2010 (TEOS-10 for short) to define, describe and calculate the thermodynamic properties of seawater. Compared to the Equation of State-1980 (EOS-80 for short), the most obvious change with TEOS-10 is the use of Absolute Salinity as salinity argument, replacing the Practical Salinity used in the oceanographic community for 30 years. Due to the lack of observational data, the applicability of the potentially increased accuracy in Absolute Salinity algorithms for coastal and semi-enclosed seas is not very clear to date. Here, we discuss the magnitude, distribution characteristics and formation mechanism of Absolute Salinity and Salinity Anomaly in Chinese shelf waters, based on the Marine Integrated Investigation and Evaluation Project of China Offshore and other relevant data. The Absolute Salinity S_A ranges from 0.1 to 34.66 g·kg^{-1}. Instead of silicate, CaCO$_3$ originating from terrestrial input and re-dissolution of shelf sediment is most likely the main composition anomaly relative to SSW and the primary contributor to the Absolute Salinity Anomaly δS_A. Finally, relevant suggestions are proposed for the accurate measurement and expression of Absolute Salinity of the China offshore.

1 Introduction

An absolute salinity, which is traditionally defined as the mass fraction of dissolved material in seawater, replaces Practical Salinity as the salinity argument in the TEOS-10(IOC et al, 2010)seawater standard for the thermodynamic properties of seawater. This is because these thermodynamic properties are directly influenced by the mass of dissolved

25 constituents whereas Practical Salinity depends only on their conductivity. Since the relative amounts of different

constituents change from place to place and from time to time, accounting for the biases that are introduced by these

changes may be important. However, appropriate methods for frequent and regular measurements of the dissolved

content directly in ocean studies are still a topic of research.

At present, the TEOS-10 Absolute Salinity of a seawater sample is obtained by adding Absolute Salinity Anomaly δS_A

30 to Reference Salinity S_R, in which S_R is the mass fraction of dissolved material in a stoichiometric composition model

(the Reference Composition or RC) of seawater, defined by Millero (2008), for which the reference material known as

IAPSO Standard Sea Water (SSW for short), is a good approximation, of the same conductivity as that of the sample.

δS_A is the mass fraction change caused by composition variations relative to RC. Three algorithms for calculating

Absolute Salinity in the open ocean are provided in TEOS-10. The two that avoid a direct measurement either make

35 assumptions about the dominant biogeochemical processes in the ocean that affect the Absolute Salinity Anomaly or

rely on empirically-determined correlations.

However, the applicability and accuracy of the TEOS-10 algorithms are still not very clear for estuaries and semi-

enclosed oceanic basins where the relative compositions of the seawater may be different from that of the open ocean.

Although there have only been very few direct measurements of conductivity and density in such areas (Millero 1984,

40 Feistel et al., 2010a), Pawlowicz (2015) used chemical composition/conductivity/density modelling and climatological

data to estimate the Absolute Salinity Anomaly near many rivers around the world, finding values of up to one order of

magnitude higher than those extrapolated from the open ocean.

The coastal areas of China comprise one of the widest shallow seas in the world, with a large north-south span,

numerous estuaries and bays, and a large amount of fresh water input from rivers. The relative composition of this

45 coastal seawater may not only differ from that of the open ocean but also vary from place to place. However, the

influence of relative composition variation on the Absolute Salinity in this area has never been systematically studied,

although salinity measurement has played an important role in Chinese national ocean survey projects since 1957

(CSTPRC,1964) and for metrological purposes a Chinese primary seawater standard has been developed (Li et al.,

2016). Moreover, in any efforts to detect salinity variations associated with climate change variability in Bohai and

50   northern Yellow Sea(Wu et al., 2004a; Wu et al., 2004b; Xu, 2007; Lv, 2008; Song, 2009) , Practical Salinity S_P is still

used as the simplicity of Absolute Salinity and its change caused by the relative composition variation is ignored. That

will raise obvious problems in the correct presentation of time series and/or transects that begin near the coast and end

well offshore (Wright, 2011).

Therefore, in this paper we first clarify the definition, status and application of TEOS-10 Absolute Salinity. Second,

55   based on the measured data and related research results, we estimate the magnitude, temporal and spatial distribution

characteristics and formation mechanisms giving rise to Salinity Anomalies in Chinese coastal seawaters. Finally, based

on the above results, we put forward relevant suggestions and future research directions for the accurate measurement

and expression of absolute salinity of Chinese offshore seawaters.

2   Methods and data

2.1   Calculation of Absolute Salinity

The TEOS-10 Solution Absolute Salinity of seawater is essentially based on adding up the mass of solute in a sea water

sample,

$$S_A^{soln} = \sum_{i=1}^{N_c} M_i c_i \qquad (1)$$

Where, c_i is the molar concentration of component i in seawater per kilogram, M_i is the molar mass of the component,

65   and N_c is the number of species of component in seawater. However, it is impractical to carry out a full chemical

analysis for the seawater to get the S_A^{soln} regularly. The primary and most demanding purpose of oceanographic

salinity measurements is the calculation of seawater density to estimate significant ocean currents driven by sometimes

tiny horizontal pressure gradients. In TEOS-10, Absolute Salinity is instead defined so that the density of seawater can

be accurately calculated by the following equation.

70                        $$\rho = f_{TEOS-10}(S_A, t, p) \qquad (2)$$

where f_$_{TEOS-10}$ is a specified function. Therefore, S_A is also called a density salinity.

Unfortunately, although for many purposes we can treat S_A and S_A^{soln} interchangeably, at highest precisions $S_A \neq S_A^{soln}$ due to small changes in the relative composition of sea salt. In order to get S_A at this highest precision, Millero (2008) first defines a stoichiometric composition model (the Reference Composition or RC), based on a reference material (IAPSO Standard Seawater), and specifies an algorithm to determine a consistent estimate of the mass fraction of dissolved material in a sample of arbitrary salinity with the RC. This estimate is based on the widely-used Practical Salinity S_P (UNESCO, 1981):

$$S_R = u_{PS} \cdot S_P, \qquad 2 < S_P < 42 \tag{3}$$

In Eq. (3), the factor u_{PS} between the reference salinity of standard seawater and the practical salinity is (35.16504/35) g·kg⁻¹, and is not equal to one mainly because an evaporative technique used by Sørensen in 1900 (Forch et al., 1902) led to the loss of some volatile components of dissolved material.

General seawater can be considered as the mixture of standard seawater concentrated/diluted with pure water and a small amount of other components. The calculation formula of Absolute Salinity from Reference Salinity requires the addition of a correction, the Absolute Salinity Anomaly δS_A:

$$S_A = S_R + \delta S_A \tag{4}$$

At present there are three methods for determining Absolute Salinity Anomaly δS_A. First, to obtain it by comparisons with direct density measurements performed in the laboratory (Millero et al., 2008; Wright et al., 2011). According to the density difference $\rho = \rho^{lab} - \rho(S_R, 25°C, 0 \text{ dbar})$ and the haline contraction coefficient which is 0.7519 for SSW, δS_A is determined by

$$\frac{\partial \rho}{\partial S_A}\big|_{t=25°C, p=0 \text{ dbar}} \approx 0.7519 \, \text{kg} \cdot \text{m}^{-3}/(\text{g} \cdot \text{kg}^{-1}) \tag{5}$$

This procedure is useful for laboratory studies or in situations where ocean water can be obtained from sampling bottles retrieved from certain depths for subsequent laboratory measurements of density.

Second, it can be estimated using a correlation equation, if chemical measurements of the most variable seawater constituents in the open ocean (carbonate system and macro-nutrients) are also available (Pawlowicz et al., 2011, IOC et al., 2010).

$$\delta S_A^{dens}/(\text{mg} \cdot \text{kg}^{-1}) = 55.6 \times \Delta[\text{NTA}] + 4.7 \times \Delta[\text{NDIC}] + 38.9 \times [\text{NO}_3^-] + 50.7 \times [\text{S}_i(\text{OH})_4] \tag{6}$$

The units of each component on the right are all mmol·kg⁻¹, $\Delta[\text{NTA}] = \text{TA} - 2.3 \times \frac{S_P}{35}$ is the standardized change in

Total Alkalinity ΔTA, and $\Delta[\text{NDIC}] = \text{DIC} - 2.08 \times \frac{S_P}{35}$ is the standardized change in Total Dissolved Inorganic

Carbon, ΔDIC. Note that the coefficients of this model are calculated using a numerical model for chemical

100   interactions (Pawlowicz, 2008, Pawlowicz et al., 2010, Pawlowicz et al., 2011), which performed well against lab

studies, and were shown to have reasonable accuracy for seawater samples by Ryan (2014). An important aspect of

this modelling is that, in order to maintain a charge balance in the dissolved constituents, it was assumed that calcium

concentrations also changed according to:

$$\Delta[\text{NTA}] = 2\Delta\text{N}[\text{Ca}^{2+}] - \Delta[\text{NO}_3^-] \tag{7}$$

105   Calcium was chosen to balance charge since it is a) not usually measured, but b) it is known to vary in its relative

composition by a few percent in the open ocean. However, the accuracy of this relationship is not known.

Third, it can be found from a global δS_A climatology created by McDougall et al., (2012). Due to the lack of seawater

component data, McDougall et al. carried out regression calculation on the practical salinity, density and silicate

concentration data of 811 seawater samples worldwide, and found that δS_A can be directly related to $S_i(\text{OH})_4$

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$$\delta S_A/(\text{g} \cdot \text{kg}^{-1}) = (S_A - S_R)/(\text{g} \cdot \text{kg}^{-1}) = 98.24(S_i(\text{OH})_4/(\text{mol} \cdot \text{kg}^{-1})) \tag{8}$$

although for further work the numerical coefficient was tuned for specific ocean basins. Taking the effects of

evaporation and rainfall on ocean salinity into consideration, Eq.(8) can be simplified as:

$$\delta S_A = R^\delta S_R \quad \text{(except the Baltic sea)} \tag{9}$$

in which, $R^\delta = \delta S_A^{\text{atlas}}/S_R^{\text{atlas}}$, both the S_R^{atlas} and $\delta S_A^{\text{atlas}}$ are from the Mcdougall et al (2012) hydrographic atlas.

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$$S_A = u_{ps}S_P(1 + R^\delta) = \frac{35.16504/(\text{g} \cdot \text{kg}^{-1})}{35}S_P(1 + R^\delta) \tag{10}$$

Eq.(10) is adopted in the official GSW software toolbox (available from www.teos-10.org) to calculate δS_A with

uncertainty in the ocean is less than 0.0047g·kg⁻¹. For the semi-enclosed Baltic sea, Feistel (2011) has fitted an

empirical formula for calculating δS_A which is mainly due to rivers bringing material of anomalous composition into the

Baltic, and this formula has also been incorporated into GSW algorithm library.

120   In the work described here we compare the latter two methods.

2.2   Observation data

The near-synchronous oceanographic and ocean chemical data used here are from 1,480 stations covering Chinese offshore waters that were set up for the Marine Integrated Investigation and Evaluation Project of China offshore conducted by the State Oceanic Administration of China (Xiong, 2012; Ji, 2016), as shown in Fig. 1. At these sites,

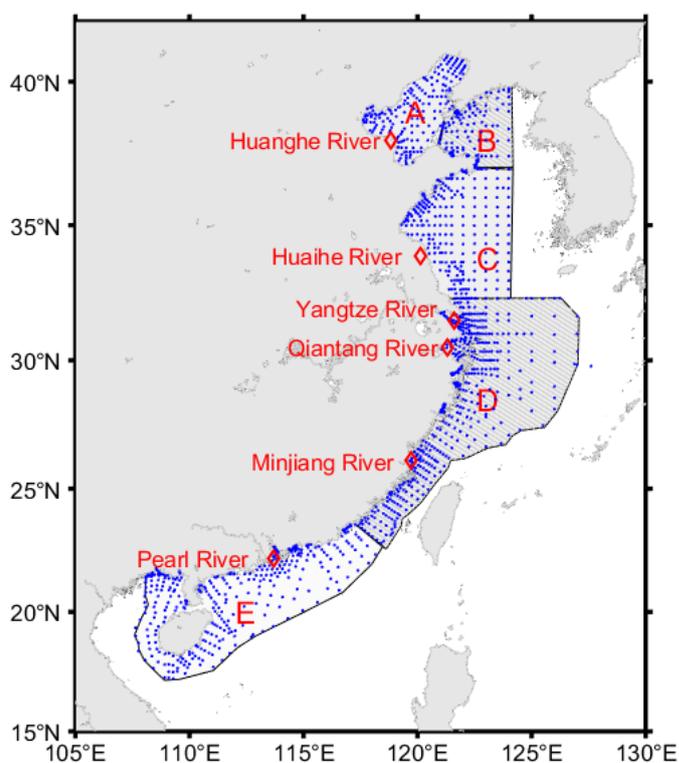
125   surface, 10m, 30m and bottom values for nutrients, as well as TA and pH, are available in four seasons of spring (April - June), summer (July - September), autumn (October - December) and winter(January - March)of 2006 to 2007. Since in-situ observation of DIC is missing in this project, it is derived from pH and TA data using CO2SYS software released by the department of ecology of Washington State based on the carbonate equilibrium (Lewis, et al. 1998).

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Fig. 1 The geographical distribution map of sampling stations

The blue dots are the observation stations of the Marine Integrated Investigation and Evaluation Project of China Sea. "A" is the Bohai Sea, 'B' is the North Yellow Sea, 'C' is the South Yellow Sea,'D' is the East China Sea, and 'E' is the South China Sea.

3 Results

3.1 Reference Salinity S_R of the China offshore seawater

The first step in determining salinity anomalies is to estimate the Reference Salinity based on the Practical Salinity.
Because the standard PSS-78 algorithm for Practical Salinity is only valid in the range $2 < S_P < 42$, values for samples
135 in the mouth of Yangtze River, Qiantang River and Pearl River (labelled in Fig.1) whose S_P less than 2 are recalculated
with a modified form of the Hill et al. (1986) formula based on the in-situ conductivity, temperature and pressure. Then
Eq. (3) is used to get S_R.

Based on our observations (Fig. 1), the Reference Salinity S_R of Chinese offshore seawater diluted by low salinity river
runoff ranges from 0.01 to 34.66 g·kg^{-1}. The extreme minimum S_R of 0.01 appears in the south branch of Yangtze
140 River in the summer of 2006 and the maximum of 34.66 appears in the path of the Kuroshio current (Fig. 2). Low
salinities are also seen in the Pearl River estuary and to a lesser degree in shallow areas of the South Yellow Sea, as
well as near a few other river mouths.

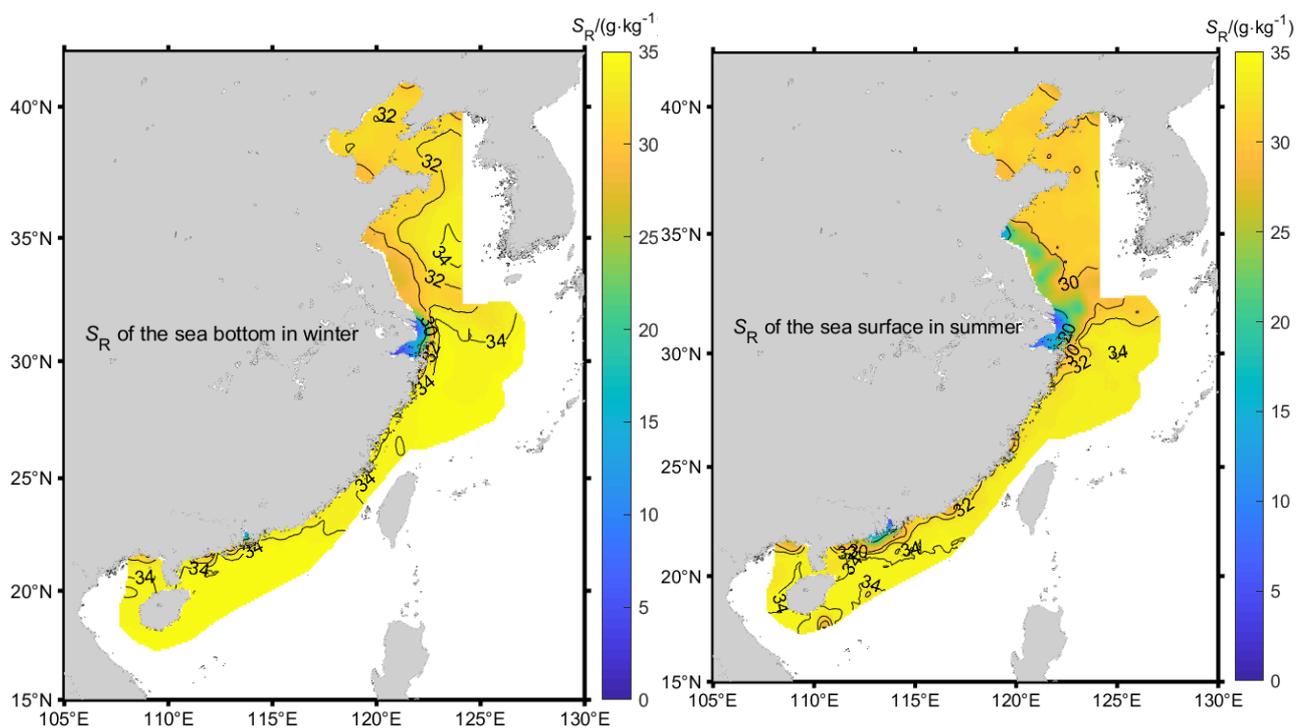



Fig. 2 S_R isoclines of China offshore seawater

3.2   Absolute salinity Anomaly δS_A of Chinese offshore waters

145   Using Eq. (6), the estimated δS_A of Chinese offshore waters ranges from 0 to 0.30 g·kg⁻¹ (Fig. 3). The largest Salinity Anomalies are one order higher than those of the open ocean. As much as 90% of the calculated δS_A arises from $\Delta[NTA]$ term in Eq. (6), so that areas with high δS_A also have high $\Delta[NTA]$ (Fig. 4). The largest δS_A values appear in Yangtze River estuary, Hangzhou Bay, Laizhou Bay, Bohai Bay, North Jiangsu Shoals and Pearl River estuary. Hangzhou Bay, which is adjacent to the Yangtze River estuary, has continuously transported water from the Yangtze

150   River estuary due to its current and tidal characteristics (Yuan, 2009) and has almost same water composition with Yangtze River estuary. Thus, in this paper, the waters in Yangtze River estuary and Hangzhou Bay are analyzed as a single water mass. The δS_A in the above coastal regions, which are often in excess of 0.05 g·kg⁻¹, are given in Table 1.

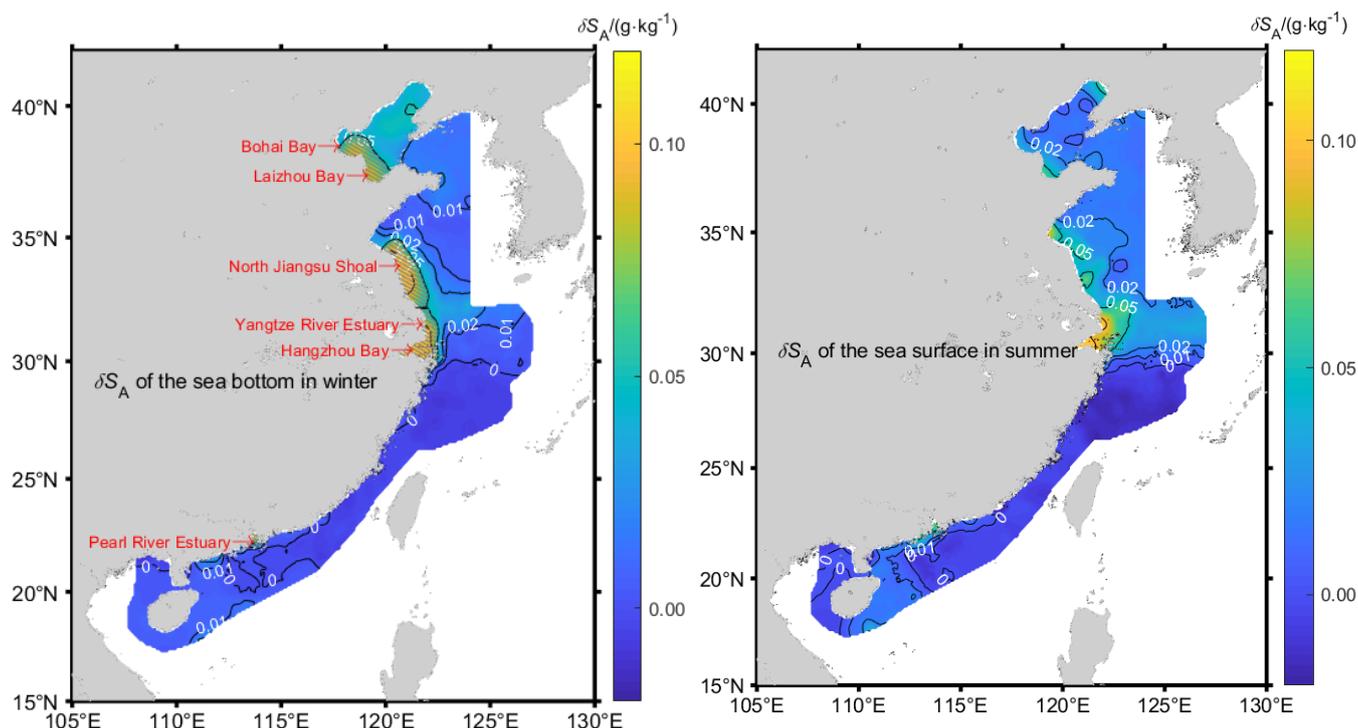



Fig.3 δS_A isoclines of Chinese offshore seawater. Hatched areas at left represent Salinity Anomalies more than 0.05 g·kg⁻¹.

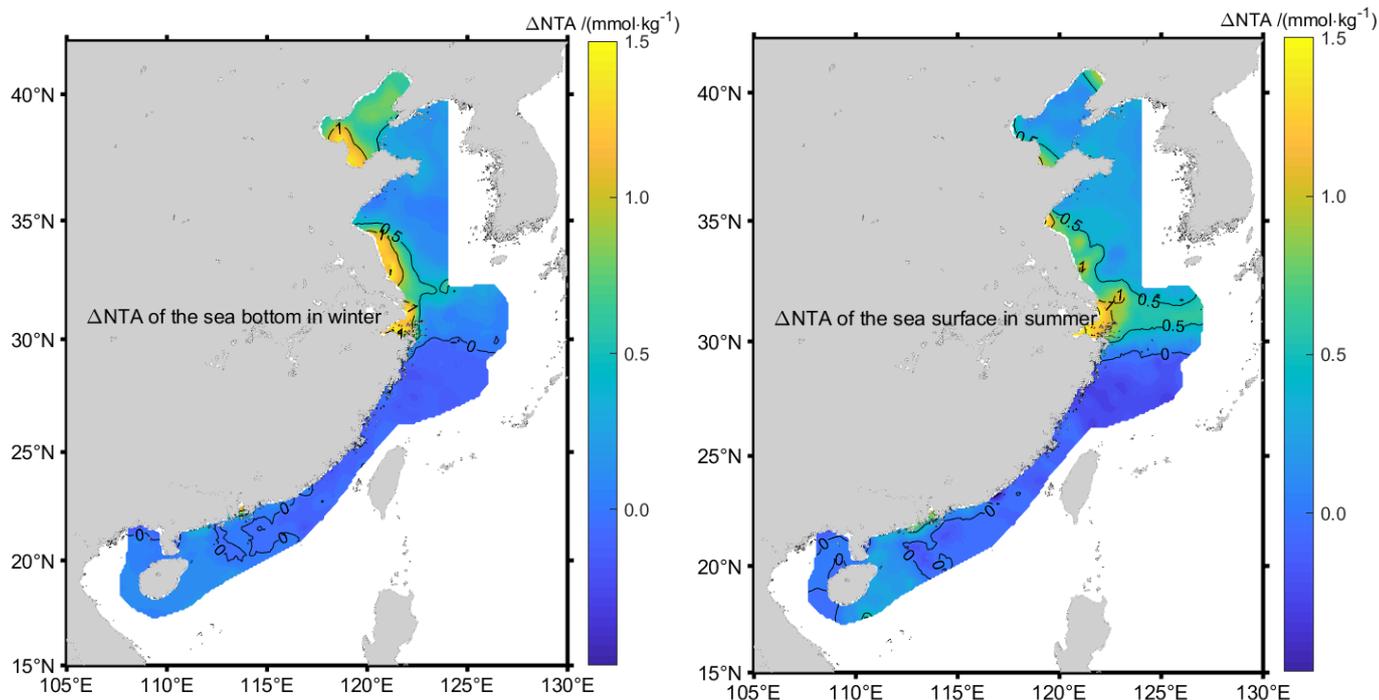



Fig.4 Δ[NTA] isoclines of China offshore seawater

Table 1. δS_A in different coastal regions hatched in Fig.3. Units are mg·kg^{-1}.

Region	Min	Max	Mean±Std
Laizhou Bay and Bohai Bay	0	132	54±23
North Jiangsu Shoal	0	228	46±32
Yangtze River Esturary and Hangzhou Bay	-50	279	86±63
Pearl River Esturary	0	125	52±32

The maximum δS_A of 0.30 g·kg^{-1} appears at the sea surface of the Yangtze River Estuary and in Hangzhou Bay in
summer. As China's largest runoff into the sea, the Yangtze River is rich in nutrients from land. At its entrance to the
sea, the silicate concentration exceeds 100 umol·kg^{-1}, Δ[NTA] is larger than 1 mmol·kg^{-1} and the δS_A is greater than 0.1
g·kg^{-1} all year round, but these nutrient concentrations decrease rapidly away from the entrance. Δ[NTA] is the primary
contributor to δS_A. The surface coverage of the 0.05 g·kg^{-1} isocline varies with seasons and depths, reaches to the
maximum in summer but with little variation in other seasons.

In the northern North Jiangsu Shoal, the maximum δS_A of 0.23 g·kg^{-1} appears on the bottom layer in winter. Centered at
33.4°N and 121°E, many points have δS_A greater than 0.05 g·kg^{-1} all the year round and gradually decreases from the

coast to the offshore. The δS_A of the bottom layer is higher than that of the surface layer in dry season (spring and winter), while smaller in flood (summer and autumn) season in which more terrestrial input is brought by Huaihe River system.

170   The largest δS_A of 0.20 g·kg^{-1} in the Bohai Sea appears on the bottom of the Laizhou Bay in winter and seasonal characteristics are basically the same as the North Jiangsu Shoal although in summer more terrestrial materials are input by the Yellow River. As a semi-enclosed shallow sea with lower exchange with the open ocean, the δS_A in the whole Bohai Sea is always larger than 0.02 g·kg^{-1} and the δS_A difference between of the bottom and that of the surface within the same season is not as significant as its seasonal variation in the area.

175   A δS_A of greater than 0.05g·kg^{-1} also occurs at the mouth of the Pearl River and Minjiang River in summer, but values are less than 0.02g·kg^{-1} in other seasons. However, these values are seen within the estuary with very little presence on the shelf. In the remaining areas, the magnitude of δS_A is below 0.005g·kg^{-1}, which is about the same as the magnitude of the statistical uncertainty of the Absolute Salinity Anomaly in the open ocean, and so is essentially zero.

Although we have used eqn. (6), which is meant for seawater of relatively high salinity, to estimate the Salinity
180   Anomaly near river mouths where the salinity is far smaller, a more complex calculation of the Salinity Anomaly, based on a full chemical analysis of river water composition, was plotted for some of these rivers (the Yangtze, the Pearl and Minjiang Rivers) in Pawlowicz (2015). The values calculated in that work are consistent with those found here (Table 2).

Table 2. δS_A in some rivers as estimated in this paper, compared with values estimated using a more complete theory
185   in Pawlowicz (2015). Units are mg·kg^{-1}.

Rivers	Mean±Std (our data)	Values from Pawlowicz (2015)
Yellow River	-	200-239
Yangtze River	90±23	105~116
Minjiang	26±15	30
Pearl River	80±26	95~96

3.3   Parameterisation of the Absolute Salinity of the China offshore waters

Although Salinity Anomalies within rivers are always non-zero, the Salinity Anomaly is significantly nonzero in only four areas along the Chinese coast and river mouths (hatched areas in Fig.3). They are occupied by different coastal water masses (Xiong, 2012) and Salinities Anomalies in each can be parameterized separately.

190   The seawater of China offshore is a mixture of the Kuroshio water originating from the North Equatorial Current and

the runoff into the sea. The Salinity Anomaly in Pacific surface waters in any case is generally small; it is the deeper

waters that have (relatively) large Salinity Anomalies arising from remineralization in the subsurface branch of the

ocean's overturning circulation. In this paper, we ignore the relative composition difference between the Kuroshio and

SSW for now. Following Feistel et al. (2010), these four water masses are considered as the mixture of Standard

195   Seawater that has standard-ocean salinity, with the local coastal water which contains unknown amounts of unknown

solute. The related regression lines of the four water mass between Absolute Salinity Anomaly and the Reference

Salinity can be computed from the samples with salinity $S_R > 2$ g·kg^{-1}, in which the seawater endpoints are chosen to be

SSW with a δS_A of zero, as shown in Eq. (11) and Fig.5

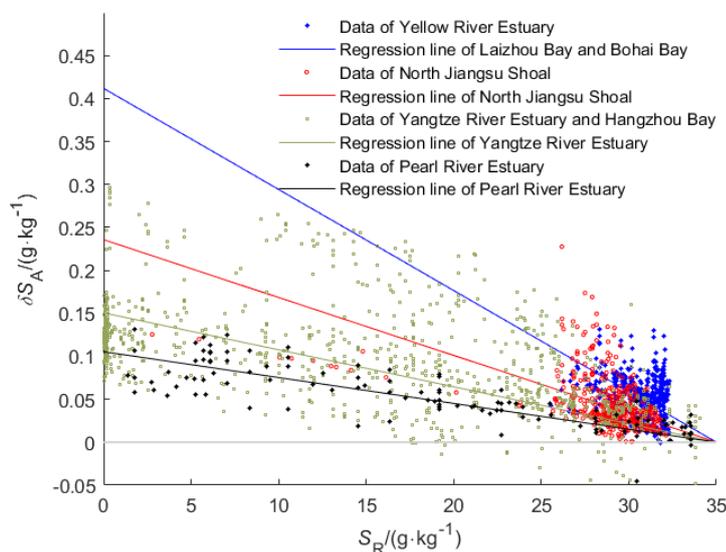
$$S_A - S_R = \begin{bmatrix} 412 \\ 236 \\ 150 \\ 107 \end{bmatrix} / (\mathrm{mg \cdot kg^{-1}}) \cdot \left(1 - \frac{S_R}{S_{SO}}\right), \begin{bmatrix} \text{Laizhou Bay and Bohai Bay} \\ \text{North Jiangsu Shoal} \\ \text{Yangtze River Esturary and Hangzhou Bay} \\ \text{Pearl River Esturary} \end{bmatrix} \quad (11)$$

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Fig.5 The Absolute Salinity Anomaly of the four regions of China offshore as a function of their Reference Salinity

The linear correlation between Absolute Salinity Anomaly and S_R in the Pearl River Estuary is the strongest among the

four regions, which shows that the mixture between the coastal seawater and that of open ocean is relatively

conservative. There are many measurements over all salinities for the Yangtze River water. The strong scatter visible in

205   Fig.5 at low salinities is likely due to the rich (and highly variable) nutrient loading brought by Yangtze River draining

from land.

The regressions for the two northernmost areas are less precise, as the oceanographic sampling pattern does not enter into the rivers and measured salinities are larger than 25 g·kg^{-1}. The fitted curves are somewhat steeper. Note that Pawlowicz (2015) also finds that Salinity Anomalies in the Yellow River of about 0.2 g·kg^{-1} are also higher than in the
210 other rivers (Table 2), although not as high as our fits in Fig. 5 suggest. The fit for the North Jiangsu Shoal region is heavily influences by many high values when salinities are between 20 and 25 g·kg^{-1}, and lies somewhat above a smaller number of values spread over lower salinities.

It can be seen from Fig.5 that the relative composition anomalies decrease from north to south. The exchange of coastal waters with the open ocean waters increases gradually from the northernmost (and somewhat enclosed) Bohai Sea
215 Estuary to the southernmost Pearl River area, which is open to the South China Sea.

3.4 Relative composition anomaly of China offshore seawater

In Eq. (6), the coefficients are determined by fitting to the results of a more complete calculations that assume changes to Ca^{2+} to maintain a charge balance according to Eq. (7). We cannot directly check the accuracy of this assumption. However, Ca^{2+} was directly measured from samples in 13 cruises from April 2011 to February 2012 (Qi Di, 2013).
220 Although these measurements do not occur at the same time as our larger dataset, we can group these measurements in the same regions (labelled in Fig.1) in which we find large Salinity Anomalies. Then, we find the $\Delta N[Ca^{2+}]$ ($\Delta N[Ca^{2+}] = Ca^{2+} - 10656.6 * S_P/35/(\mu mol \cdot kg^{-1})$), in which Ca^{2+} and S_P are the measured value of Ca^{2+} and Practical Salinity of sea water respectively and $\Delta[NO_3^-]$ and $\Delta[NTA]$ (first column) values from our dataset (Table 3) , are approximately consistent with Eq. (7).

225 **Table 3**. The mean value of $\Delta[NTA]$, $\Delta[NO_3^-]$, $\Delta[NTA]^*$, and $\Delta N[Ca^{2+}]^*$ are given in different areas (marked in Fig.1).

Values obtained from Qi Di (2013) are labelled with '*'. Units are $\mu mol \cdot kg^{-1}$.

Region	$\Delta[NTA]$	$\Delta[NO_3^-]$	$\Delta[NTA]^*$ (Qi Di, 2013)	$\Delta N[Ca^{2+}]^*$ (Qi Di, 2013)
Bohai	620±339	13.6±11.3	-	364±115
South Yellow Sea	318±330	6.8±10.1	-	136±46
East China Sea	170±540	16.4±23.0	-	90±54
South branch of Yangtze River (S_P<1)	1727±301 in Feb. and Apr. 1770±150 in Jul. 1977±304 in Oct.	112.06±18.84 101.45±4.67 81.42±9.62	1845 1696~1869 1900	981~1014 925~936 992
North branch of			245~480	132~250

Yangtze River Estuary

($8 < S_P < 20$)

The other nutrient of phosphate is not considered in the calculation for their concentrations range from 0 to 0.01

mmol·kg^{-1} in the existing observation which is much smaller than those items in Eq. (7) above and its effect is

230   negligible. In this case, $\Delta[NO_3^-]$ is mostly negligible and $\Delta N[Ca^{2+}]$ is about 43%~58% of $\Delta[NTA]$, in Bohai, South

Yellow Sea, East China Sea and Yangtze River.

The importation of Ca^{2+} and the carbon system suggests that the major source of Salinity Anomalies in shelf areas is the

high $CaCO_3$ content of rivers. This is consistent with Salinity Anomalies in the Baltic Sea, which were found to be

mostly related to the calcium carbonate input from rivers (Feistel et al., 2010a). These rivers would be the Yangtze,

235   Yellow River, and Huaihe Rivers. The importation fluxes of Ca^{2+} into the sea of Yellow River and Yangtze River are

3.6×10^{10} and 6.5×10^{11} mol·yr^{-1} respectively in 2011(Qi Di, 2013). In addition, there may be re-dissolution of sediments

in the Yellow River Estuary and North Jiangsu Shoal. Due to the accumulation of materials entering the sea from the

old Yellow River and the ancient Yangtze River, the $CaCO_3$ concentration of surface sediments on the seafloor of the

North Jiangsu Shoal ranges from 2.8% to 10.5% (Qin, et al, 1989; Yang and Youn, 2007). The $\Delta NDIC$ of the south

240   Yellow Sea near China has always been high, even when strong biological activity in spring reduces the surface

$\Delta[NTA]$, the sediment of PIC will resuspend and maintain the high dissolved $CaCO_3$ of seawater through the solid-

liquid balance (Hong, 2012; Zhang, et al, 1995).

3.5   Contrast to the δS_A calculated by GSW

Using the GSW function library and the corresponding climatological silicate and practical salinity data, the calculated

245   δS_A of China offshore ranges from 0 to 0.002 g·kg^{-1}. This is two orders of magnitude less than values calculated in

Section 3.2. The spatial distribution characteristics are also significantly different. These differences mainly come from

the following aspects:

(1) Instead of silicate, $CaCO_3$ is most likely the main relative composition anomaly of China offshore seawater and the

primary contributor to the δS_A where it is greater than 0.05 g·kg^{-1}.

250   (2) High silicate concentrations (up to 100μmol·kg^{-1}) do appear in Chinese coastal seawaters from the effects of river

(Fig 6), but these do not appear in the global silicate climatology used for the GSW calculations. However, even if they

did, in these places NTA is even larger, so that the effects of this coastal silicate on the Salinity Anomaly is small.

In the remaining areas, the silicate concentration is less than 20μmol·kg⁻¹, as shown in Fig.6. At 95 % degree of
confidence, the difference between the observation and the GSW climatological dataset is [5.46, 6.21] μmol·kg⁻¹ which

255 does not change much with the seasons. It can be indicated the GSW climatological dataset basically reflects the

distribution characteristics of silicate in these areas.
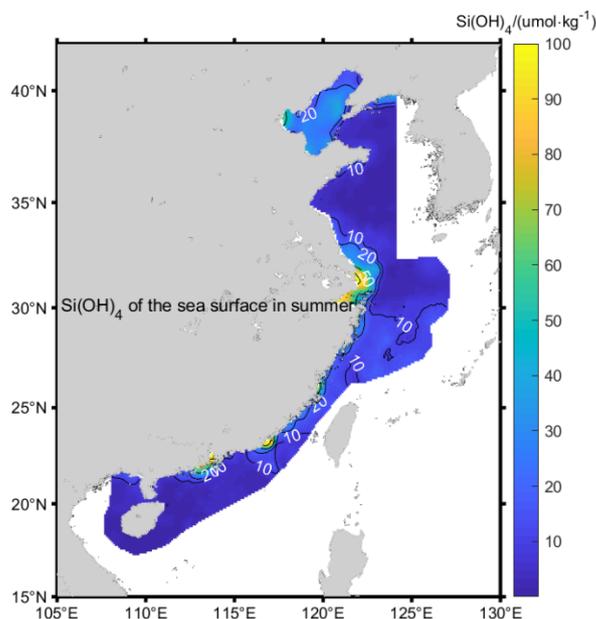
Fig.6   Si(OH)₄ isoclines of sea surface in summer

4   Conclusion and analysis

260 The proposal and implementation of the concept of S_A in TEOS-10 is meant to accurately quantify the total mass of

inorganic substance dissolved in sea water, to ensure that the density and related quantities are accurately represented

by the Gibbs function for seawater and correct errors caused by the measuring the properties of seawater such as

chloride and conductivity to get the salinity. In this paper, based on observations and calculations, the magnitude,

distribution characteristics of Absolute Salinity in China offshore are described:

265 1) The Absolute Salinity S_A ranges from 0.1 to 34.66 g·kg⁻¹, in which S_R ranges from 0.01 to 34.66 g·kg⁻¹ and the

Absolute Salinity Anomaly δS_A ranges from 0 to 0.30g·kg⁻¹, this is an order of magnitude larger than the largest values

in the open ocean.

2) The largest δS_A are located in four distinct regions: the Yangtze River mouth/Hangzhou Bay, North Jiangsu Shoal, Bohai Sea, and the Pearl River mouth, all of which are areas where the $\Delta[NTA]$ is high;

270 3) Instead of silicate, $CaCO_3$ is most likely the main composition anomaly relative to SSW and the primary contributor to the δS_A in the above four areas;

4) Under the combined effects of different water system dynamics, terrestrial input, marine biological activities, and re-dissolution of marine sediments, the δS_A in China offshore seasonal variations are obvious, and the maximum can be as high as $0.05\text{g}\cdot\text{kg}^{-1}$; the difference between the surface layer and the bottom layer is also up to $0.1\text{g}\cdot\text{kg}^{-1}$;

275 With the observations available, this paper only lists the magnitude and distribution characteristics of δS_A in China offshore from 2006 to 2007, although it is likely that similar features will occur in other years. At present, we have collated the long-term series of seawater composition data to continue the study on δS_A changes and get an empirical formula to calculate it.

The current researches are only based on the existing seawater composition data, and the exact influence of other

280 changes to composition is still not very clear. To verify these findings, a complete chemical analysis and/or direct measurements of seawater density would be useful in the estuaries of the Yangtze River, Qiantang River, Pearl River, Minjiang River, and the semi-enclosed Bohai Sea.

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