TRADITIONAL NORMALIZED TOTAL ALKALINITY AS A TRACER OF THE SURFACE SEAWATER MASSES OF THE NORTH SEA

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Abstract

The North Sea is a semi enclosed epicontinental sea located on the North Western European continental shelf, where the different water masses result from the mixing of the North Atlantic Ocean, the Baltic Sea, the English Channel and fresh water run-off inputs. Total alkalinity is known to be a conservative parameter of water masses, and was measured with a strong spatial and temporal coverage during the CANOBA project (**Ca**rbon and nutrient cycling in the **No**rth Sea and the **Ba**ltic Sea), covering four seasons campaigns (08/01; 11/01; 02/02 and 05/02).

Regressions of traditional Normalized Total Alkalinity TA (35) versus salinity allow to distinguish five hydrologic provinces: the North Atlantic water, the Skagerrak and Norwegian coastal waters, the English Channel water, the Continental Coastal water (from the Belgium to the Danish coasts) and the Central North Sea water. Excellent regressions were obtained for the Continental Coastal water, the Norwegian and Skagerrak waters as well as the English Channel water. This suggests that TA (35) as a conservative parameter, is a useful tracer of water masses for the North Sea Eastern coasts. Also, it follows the pattern of the residual current with a single water mass resulting from the mixing of the water coming from the English Channel with waters coming from the Eastern continental coasts. Results are less conspicuous for the "Central North Sea water" and this could be explained by the restricted salinity range (from 34 to 34.5) but also by a more complex pattern of residual circulation. In the case of the North Atlantic water, the regression gives good results depending on the extension of this water type into the North Sea.

Introduction

The North Sea is a semi enclosed epicontinental sea located on the Northwestern European Continental shelf and is probably one of the best studied area in term of hydrology and its dynamism. Works starting in the early seventies based on the surface salinity/temperature data and currents, were also performed with the use of radioactive tracers, which brought to the fore major hydrological provinces and the general circulation of the North Sea (Lee A. 1970, Oceanogr. Mar. Biol. Ann. Rev. 8: 33-71; Dalhgaard H. 1995, J.of Mar. Syst. 6: 381-389; Turrell *et al*. 2002, Cont. Shelf Res. 12: 257-286). Total Alkalinity is known to be a useful conservative parameter of water masses and have been widely employed to characterize oceanic water (Frankignoulle *et al*. 1990, Bull. De la Sct. Royale des Sc. de Liège 2: 105-111; Millero F.J. *et al*. 1998, Mar. Chem. 60: 111-130). Nevertheless, it has not been used yet for the North Sea, where the different water masses result from the mixing of the North Atlantic Ocean, the Baltic Sea, the English Channel and freshwater run-off inputs. In the present study, we propose to use the traditional normalization of Total Alkalinity to distinguish between the different seawater masses of the North Sea, their distribution and mixing.

Methods

During CANOBA I samples for the determination of Total Alkalinity (TA) were filtered through GF/F filters and stored at 4°C for the final determination in the laboratory using the classical Gran electro-titration method. During CANOBA II-IV TA was determined onboard using the classical Gran electro-titration method, on 100ml GF/F filtered samples. The reproducibility of TA measurements performed on board is ±4µmol/l.

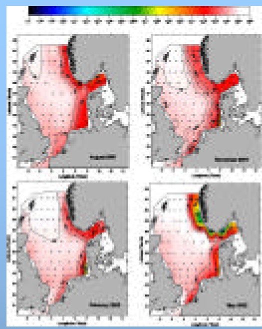
Results and Discussion

Map 1 shows the **seasonal distribution of surface salinity of the North Sea** including the Skagerrak and English Channel. Seasonal variability is mainly **reflected by freshwater discharges** along the coasts bordering the study area, **with two distinctive phases**. First, during autumn and winter, with higher rainfall events and so runoff on the Western European land (*e.g.* Belgium, the Netherlands, Germany and Denmark). Second, with spring thaw in Norway and Sweden. Freshwater inputs increase during these two phases, bringing down to the North Sea, via estuaries and fjords, high inorganic carbon freshwater content which result in an increase of Total Alkalinity (TA) of seawater. Nevertheless, this increase of TA is not so obvious because of a dilution effect with strong freshwater inputs, as it was observed along the Norwegian and Swedish coasts (Distribution of surface TA not shown). Because, salinity represents the major charges of seawater, particularly inorganic carbon species, this effect can be suppressed by the traditional salinity normalization of Total Alkalinity: TA (35), *e.g.* map 2. The use of this method (Millero *et al*. 1998, Mar. Chem. 60: 111-130), instead of the recent formula proposed by Friis *et al*. 2003 (Geo. Res. Let. 30 (2): 57/1-57/4) $TA^{eS} = ((TA^{meas} - TA^{S=0})/S^{meas}).S^{ref} + TA^{S=0}$ is that in the latter the employ of a non-zero freshwater endmember ($TA^{S=0}$) is not possible in the present study. Actually, the North Sea is bordered by numerous freshwater inputs (as estuaries and fjords) where some previous campaigns realized in some of them, Scheldt, Rhine, Ems, Elbe, showed that $TA^{S=0}$ is different from an estuary to another one, respectively 4000, 2700, 2400 and 2050µmol.kg^{-1}. Then the use of a non zero $TA^{S=0}$ appear to be inconsistent here because of the high variability of this one. From map 2, it is obvious that higher TA (35)values are observed along the coasts. A tongue of high TA(35) follows the residual coastal current affecting the Western European coasts, from Belgium to the Northern Norway.

Figure 1 and Table 1 show the TA(35) as a function of salinity and equation of regression obtained for month of November 2001. 6 seawater masses appear from the results: the **English Channel** (**r^2=0.97**), the **Southern Bight** (including Belgium and Dutch coastal waters, but excluding English stations) **r^2=0.99**, the **German Bight associated with Jutland waters** (**r^2=0.98**), the **Skagerrak and Norwegian coastal waters** (**r^2=0.92**), the North Atlantic inflow and the Central North Sea (including the Scottish and British coasts). Total Alkalinity range for the Southern Bight and the German Bight, as well as the intercept in the regression equation, show the maximum values because of estuaries discharges. In the case for the North Atlantic inflow and the Central North Sea, distinction between these domains was based on salinities values measured on stations, according to literature (*cf.* next citations): all stations with salinity$35 where considered influenced by North Atlantic inflow. But regression coefficient were weaker than the other seawater masses, r^2=0.49 and 0.73 for North Atlantic inflow and Central North Sea water respectively. Whereas previous studies based on the salinity and temperatures values, as well as the general circulation, showed others seawater provinces like the British and Scottish waters, the North North Sea water, the Central North Sea water and the South North Sea water (Lee A. 1970, Oceanogr. Mar. Biol. Ann. Rev. 8: 33-71; Otto *et al*. 1990, Netherlands J. of Sea Res. 26 (2-4): 161-238; Turrell W.R. 1992, ICES J. Mar. Sci. 49: 107-123), it was not possible from our TA values to find those water types. An explanation for that could be that as shown on the salinities distribution (*e.g.* map 1), all these regions have salinity between 34-35, with various TA values. Salinity's range was then too restricted to get good regressions probably because the stations closed to England and Scotland were too far from outer estuaries and because of the complex current pattern and the various seawater masses (water originating from the Celtic Sea via the Fair Islands current, North Atlantic Ocean water, estuaries discharges). But, when excluding from Central North Sea data, stations closed to the English coasts and stations where the water column is well-mixed trough the year (stations under 54°North latitude), then it was observed a better relation between salinity and TA(35), but regression coefficient still under 0.9. Another kind of seawater masses found in the literature is the "**Continental Coastal Water**", bordering the North Sea Eastern Coasts, *e.g.* coastal water from English Channel to the Baltic. Regression of TA(35) versus salinity gave excellent results for the four campaigns, taken as an example November 2001, TA(35)= -79.95.Salinity+ 5100, **r^2=0.98**. This suggests that, and in agreement with literature, water from English Channel follows the Northeasterly-bound Western European coastal current and mixes with the major estuarine discharges, such as the Scheldt, Rhine, Ems and Elbe.

Conclusion

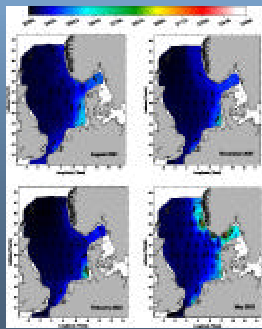
Results show that Traditional salinity normalization of Total Alkalinity TA (35) appears to be a good tracer to distinguish between coastal seawater masses of the North Sea. Along the Eastern continental coast of the North Sea, water originating from the English Channel mixes secondary water masses (Southern Bight and the German Bight associated to the Jutland water) to form a primary water mass: Continental Coastal water, and according to the northeasterly residual coastal current. Complex currents pattern in the Central North Sea and along the British coasts avoid in our present study the use of TA(35) as a tracer. It could be resolved by getting a higher spatial distribution of the stations along the British and Scottish coasts, in order to follow any change due to the currents and mixing.



Map1: Seasonal distribution of surface salinity

Western European coasts are under influence of freshwater discharges. Seasonal trends result in high freshwater discharges along the North Sea Eastern coasts (Belgium, the Netherlands, Germany and Denmark) during autumn and winter when rainfall and runoff increase, whereas this pattern is reversed during late spring (may 2002) along the Scandinavian coast as a consequence of the thaw.

Dots on the maps correspond to the stations sampled during the CANOBA cruises.



Map 2: Seasonal distribution of Traditional normalized Total Alkalinity (µmol/kg)

High inputs of inorganic carbon are brought to the North Sea via estuaries and mainly in the eastern part of the studied area, where it is expressed by a tongue of high TA(35) bordering the Western European coasts. These higher values correspond to the freshwater inputs of high inorganic carbon content. This is obvious when run-off is dominant along the coast, as it is the case for the Scandinavian coasts in late spring and German Bight during winter.

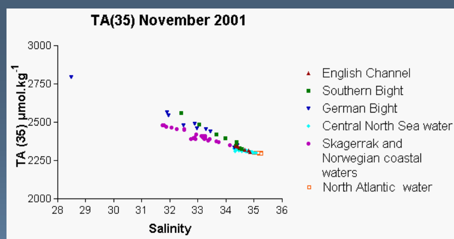


Figure 1: TA(35) as a function of salinity

6 water masses are found, with good regression coefficient for the English Channel water, Southern Bight water, German Bight water with the Jutland water and Skagerrak with Norwegian coastal water.

Water masse	Salinity range	Total Alkalinity range (µoml.kg^{-1})	Regression TA(35) versus salinity	r^2
English Channel	34.7-35.1	2294-2302	TA(35)=-75.3 Sal + 4931	0.97
Southern Bight	33.5-34.6	2293-2368	TA(35)= -104.6 Sal + 5946	0.99
German Bight	25.6-34.4	2274-2339	TA(35)= -76.0 Sal + 4969	0.98
Skagerrak and Norwegian Coastal water	32-34.9	2235-2300	TA(35)= -55.5 Sal + 4206	0.92
Central North Sea water	33.9-34.9	2265-2303	TA(35)= -29.5 Sal + 3333	0.73
North Atlantic water	35-35.4	2300-2315	TA(35)= -13.3 Sal + 2765	0.49

Table 1: Characteristics of the Water masses in the North Sea for November 2001

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