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Detecting changes in Bhavnagar city water through a water mass analysis of BCTS data

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ABSTRACT

A new water mass analysis technique is used to analyze the BCTS data set in the Bhavnagar city of ten years for changes in Water properties. The technique is based on a sequential quadratic programming method and requires careful definition of constraints to produce reliable results. Variations in water properties viz., temperature and salinity observed in the water are used to define the constraints. It is shown that to minimize the residuals while matching the observed temperature and salinity changes in the source region the nitrate concentration in the water has to be allowed to vary as well. It is concluded that during the period of investigation nitrate underwent significant variations in the city water properties.
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KEYWORDS

BCTS;
Water mass analysis technique;
Temperature;
Salinity;
Nitrate.

INTRODUCTION

The Bhavnagar city Time-series Study (BCTS), a project of the Department of Ocean Development (DOD), Govt. of India and Gujarat Science Foundation Chair (GSFC), Govt. of Gujarat, has been producing high quality hydrographic data and now represents one of the best long-term water time series available. The study was primarily set up to investigate the biogeochemistry of the Bhavnagar city and its relation to climate variations Work at the BCTS site has contributed greatly to our understanding of nutrient processes in the upper levels of the ocean. In particular, our understanding of nutrient behavior under different atmospheric conditions has been greatly improved. Interannual fluctuations in N_2 fixation might be linked to climate fluctuations, in particular to link with the direction of the prevailing winds over the Sea[5].

There has been some work performed on the BCTS data set looking at the deeper water properties and the hydrographic history. Cooling in the deep layers of the water properties data might be linked to earlier cooling in the city and oceanic properties, this scenario and gave a transit time[2,7].

In this paper we concentrate on the depth range and investigate the question whether it is possible to link variations in hydrographic properties observed at the BCTS location to variations of hydrographic properties in water mass formation regions at significant distance from the observation site in a quantitative manner. We use a new water mass analysis technique, called Time Resolving Optimum Multi-Parameter (TROMP) analysis, for that purpose. The method requires observations of temperature, salinity, oxygen and nutrients. Sample collection for nutrient analysis was only taken up at the BCTS site.

DATA AND METHOD

TROMP analysis was developed as an extension of classical OMP analysis[13] when a previous application of OMP analysis to the BCTS dataset[8] indicated the disappearance of water properties at the BCTS locations. The apparent disappearance was accompanied by a significant increase of the residual error. This led Leffanue and Tomczak to suggest that the disappearance of water properties was an artefact of the method, produced by changes of water properties source that cannot be accounted for in the OMP analysis. A detailed description of TROMP analysis is given in Henry-Edwards and Tomczak[4]. To apply TROMP analysis to the BCTS data, the data set had to be fitted to a uniform grid in space and time. Outliers in the BCTS time series were removed, and the measurements were averaged into five vertical bins of 100m thickness, starting from the uppermost layer to for the lowest layer. The time step was defined by the sampling interval (1 month). A five-month running mean was applied to the time series in order to filter short-term variations from the BCTS data. Tests of the TROMP analysis during its development and theoretical considerations with regard to the sequential programming technique used suggested that the method achieves the most reliable results if any changes of source water mass properties are small and evolve slowly in time. To meet that requirement the data sampling rate was increased from monthly to weekly by linear interpolation.

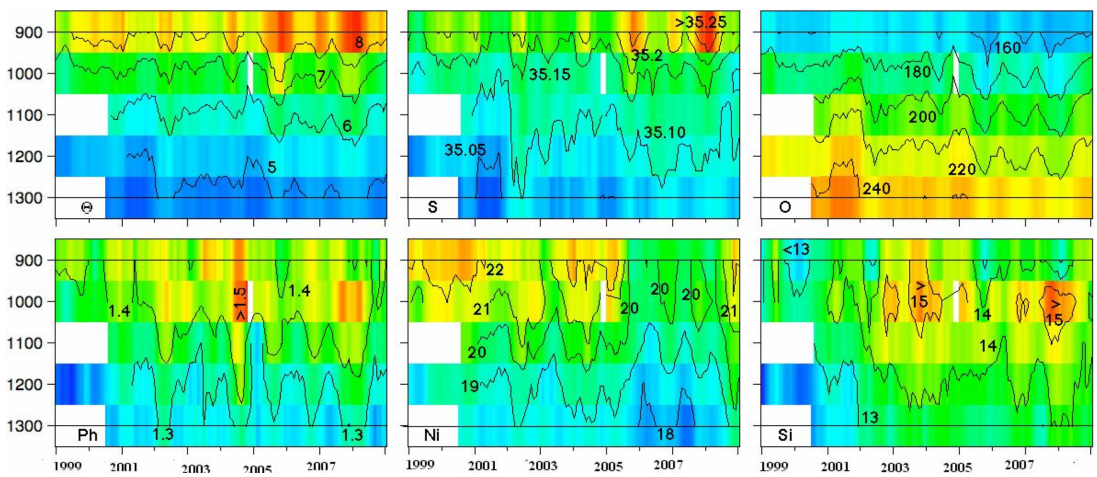

Figure 1

Figure 1 shows the resulting BCTS data as used in the TROMP analysis. It is worth noting the level of variation in the nutrient data; nitrate concentrations in particular decrease at all depths during the period 1999-2008 when water properties disappeared in the analysis of Leffanue and Tomczak[8]. At the same time, the salinity concentration is increasing,and similar though smaller variations in the other water properties are taking place. The investigation followed the conclusions of Henry-Edwards and Tomczak[4], who suggested the following sequence of steps:

Step 1: A series of TROMP analyses in which one source water property is allowed property is allowed to vary across all source water types simultaneously, while all other source water properties are kept constant.

Step 2: Inspecting of the resulting error fields and analysis output, to identify source water properties which may have varied during the analysis period.

Step 3: a targeted TROMP analysis in which variation are restricted to the source water properties and SWTs identified as likely to have varied.

The constrained minimized method that underlines TROMP analysis has an unlimited number of solutions, and additional sources of information are required to provide guidance towards the most acceptable scenario.

We used the temperature and salinity as a guide for the time evolutions of time series measurement. Water properties contributions of approximately 40% in the depth ranges 1100 to 1300m at time series[3,8]. Assuming water nutrient quality with different source water properties, it seems reasonable to except that volumetric contribution of water samples collected at the BCTS site should remain close to 40% throughout the entire time period. Any TROMP analysis result that did not satisfy this requirement was thus deemed unrealistic.

Four source water types were included in this analysis: (1) The Northwest-North-Northeast Zone [NW-N-NE], (2) The Northeast-East-Southeast Zone [NE-E-SE] (3) The Southeast-South-Southwest [SE-S-SW] (4) The Southwest-West-Northwest [SW-W-NW].

RESULT

A large number of TROMP analysis runs were performed for step 1 of the analysis. In each run a single source property was defined as a variable for the analysis and allowed to vary in all source water masses. The error fields generated in this way were not as clear as those generated for the simulated data sets in Henry-Edwards and Tomczak[4].

Through our experience with the TROMP analysis, we have found that if a water mass contributes less than a third of the measured sample, the results are usually unreliable. We therefore excluded data from the 900m and 1000m levels from further consideration in the analysis.

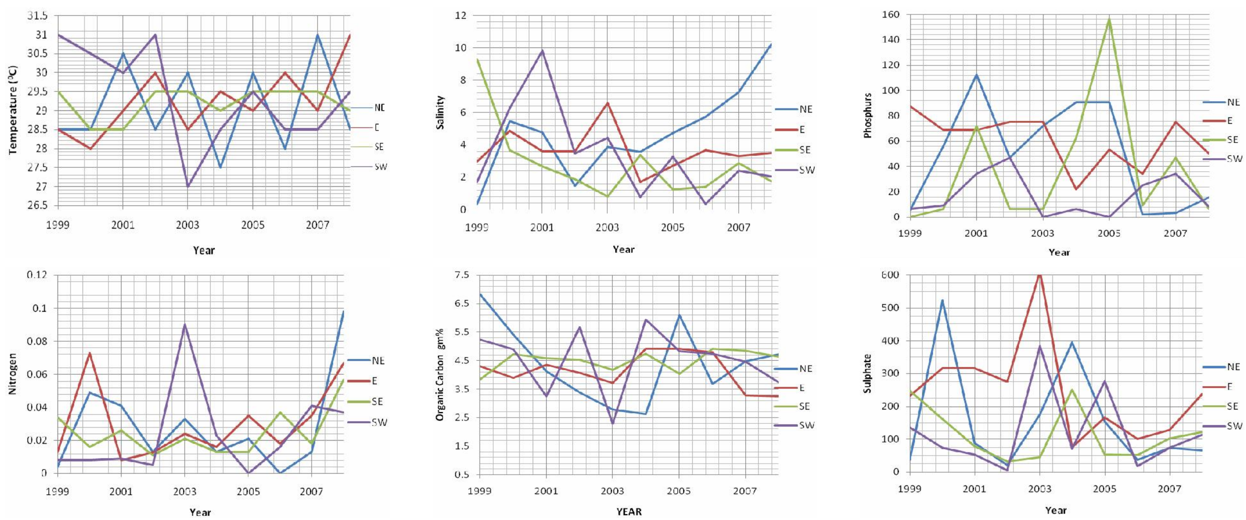

Figure 2 : Water properties potential temperature Θ (°C), salinity *S*, Organic *C* (gm%), phosphate *Ph* (μmol/L) and nitrate *Ni* (μmol/L) if one source water property is varied in all source water types.

The variations of LSW potential temperature and salinity are much larger than observed and are certainly unrealistic. Comparison of shows that the quantitative result is quite dependent on the weights used. Leffanue and Tomczak[8] derived their weights in the standard manner for OMP analysis to reflect the measurement accuracy and spread between water masses of each parameter. In a TROMP analysis weights play quite a different role; they influence the search direction of the line search procedure in the quadratic optimization[4], and there is no objective rule that determines their choice. We performed the analysis with numerous weightings, ranging from those of Leffane and Tomczak[8] to uniform weights.

The insight gained from the runs shown in as well as many other runs determined the conditions for step 3 of the analysis. LSW temperature and salinity were selected as variables, based on our knowledge from Dickson et al[3]. It was also noted that the nitrate concentration showed a consistent decrease over time in all runs regardless of the chosen weights, while the other nutrients and oxygen behaved erratically and did not show clear trends. Nitrate was therefore included as a variable in the analysis, while oxygen, phosphate and silicate concentrations were kept as constants. An interesting consequence of this is the implicit assumption that the Redfield ratio varied significantly in the Labrador Sea during the investigation period.

Transit times of the order of 6–10 years place the observed potential temperature in the range 27.5–31^{0}C, slightly higher than derived by TROMP analysis. Salinity in the range for the period is 0.35–10.23, somewhat lower than derived by TROMP analysis.

DISCUSSION

It is possible to achieve reasonable agreement between observed and calculated time changes of potential temperature and salinity by restricting the selection of variables to three properties, namely potential temperature, salinity and nitrate. This does of course not imply that the source properties of all other water masses remained unchanged during the period. But the analysis suggests that of all possible variations in source water mass properties, the ones that had the greatest impact at the BCTS location were the three properties identified through TROMP analysis. Many combinations of source water property changes can be imagined to explain the remaining difference between observed and calculated potential temperatures and salinities. Without additional information they would remain pure speculation. Identifying the most appropriate solution to a nonlinear underdetermined system of equations is a complex task, and more work will be required to develop TROMP analysis into a standard technique of water mass analysis. The present paper has to be seen as a pilot project in that process. Future efforts will probably have to concentrate on methods to find the best weighting procedure, since the weights determine the search direction in parameter space for the minimization scheme and therefore have a large influence on the solution.

TROMP analysis has several other potential applications. Tomczak and Liefrink[14] recently completed an OMP analysis of WOCE section SR03 between Tasmania and Antarctica, which produced five oceanographic sections across the Circumpolar Current between 1991 and 1996. They found a significant increase of the volume of Lower Circumpolar DeepWater at the expense of Upper Circumpolar Deep Water over the five year period and raised the question whether this could at least partly be an artefact produced by variations in the source water properties of the water masses found in the section. A repeat analysis using the TROMP technique indicates that for the data collected in 1999–2008 the residual error cannot be reduced any further by changing the source water type definitions, confirming the correct choice of source water types in the OMP analysis. Significant reductions of the residual error are possible for the years 1999 and 2008. TROMP analysis is currently being used to determine the most appropriate water type definitions for these years and to construct a time history of Antarctic water mass properties[14]. Another possible application of TROMP analysis is the determination of variations in the Redfield ratios. Historically it was assumed that these ratios are constant. During the last two decades it became evident that the ratios are functions of space[1,6,11,12]. There is now evidence to suggest that they can vary not only from region to region but also in time[9]. TROMP analysis could prove a useful tool for the identification of variations in Redfield ratios in space or time.

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