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Technical Communication

Comment on 'Marine GIS: Identification of mesoscale oceanic thermal fronts'

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In this paper, we aim to clear up a significant conceptual error in the use of the 'sink method' as presented by Valavanis et al. (2005) for oceanic thermal front detection. We argue that the features identified by the authors in their paper are mostly cyclonic or cold ring eddies in the Aegean Sea.

Keywords: coastal applications; ocean processes; remote sensing; geographic information systems

1. Introduction

In volume 19(10) of the *International Journal of Geographical Information Science*, Valavanis *et al.* (2005) proposed a new method – 'sink method' for identifying oceanic thermal fronts. Although it is encouraging to see the authors apply geographic information system (GIS) in an oceanographic study, we argue that this proposed method for front detection in the oceans is flawed as it is based on an erroneous definition of an oceanic thermal front.

2. The sink method and its application to Istrian front, Adriatic Sea

Valavanis *et al.* (2005) use AVHRR sea surface temperature (SST) grid as a lattice of elevation values. Using the ArcGIS implementation of the D8 algorithm, sink cells are identified and flagged. SeaWiFS chlorophyll concentration (Chl) data are then combined with the SST data. When the relationship between SST and Chl inside and outside the flagged sink cells fall within the necessary parameters they are mapped as oceanic thermal fronts.

We tested their method on the Istrian front in the northern Adriatic Sea (Figure 1), clearly identifiable by the SST images on both 2 and 7 February 2002 (Figure 2). The front was located south of the Istrian peninsula stretching from the southern tip of Istria across the northern basin with a temperature gradient of approximately $0.5^{\circ}\mathrm{C\,km^{-1}}$. According to Lee *et al.* (2005), the Istrian front is a mesoscale density-compensated temperature-salinity front, characterized by warmer, more dense water on the southern side of the front and fresher, colder water to the north of the front. The front exists at the boundary between two counter-rotating gyres, a cyclonic gyre to the south and a smaller anticyclonic gyre to the north in the northern Adriatic

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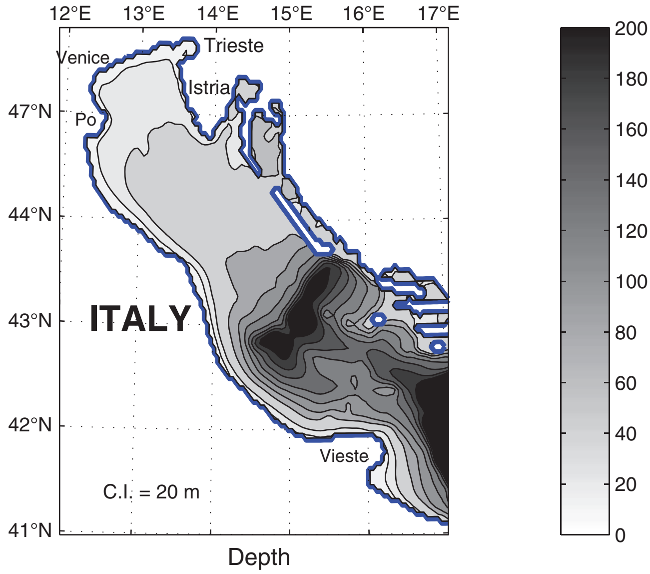

Figure 1. The location map of the northern Adriatic Sea.

Sea. These gyres are primarily driven by the Bora jets, formed as the cold and dry winds move across the Dinaric Alps from Euro-Asian continent.

It became apparent that neither the Istrian front nor any of the other fronts distinct in the SST images were being located or identified. In order to demonstrate that this method is not locating the thermal front features in the images and that the fronts do exist, an alternative gradient method using the ArcMap 'Slope' function was applied to the same images. The slope function is designed to identify slopes and the degree of slope or gradient on a digital terrain model. It identifies the maximum rate of change in value from each cell to its neighbours. The function determines the slope using the basic 'rise over run' function of a right-angled triangle. In our situation where the height values of a digital terrain model are substituted with SST values the 'rise' refers to units of temperature while the 'run' value refers to units of distance. The results of applying the gradient method contrast with the results gained from the sink method. A well-defined Istrian front was identified by the gradient method, with the front location and strength similar to those observed by previous researchers (e.g., Wang 2005, Pullen *et al.* 2007).

3. What went wrong with the sink method?

The D8 algorithm identifies sinks as areas of topography that do not drain. They are localized depressions. When SST is used as the data type, the temperature values are treated as height values creating a terrain picture such that areas of higher SST are treated as higher 'ground' and lower SST values represent lower 'ground'. The sink method is based on a method for identifying local depressions in the digital terrain model (DTM), which are not analogous phenomena to that of a front.

In oceanographic terms a thermal front is a zone of temperature change between two water masses of different temperatures. Areas where fronts commonly occur include the boundary between warm and cold currents, the boundary between coastal and oceanic waters, off estuaries, along the margins of areas of upwelling and

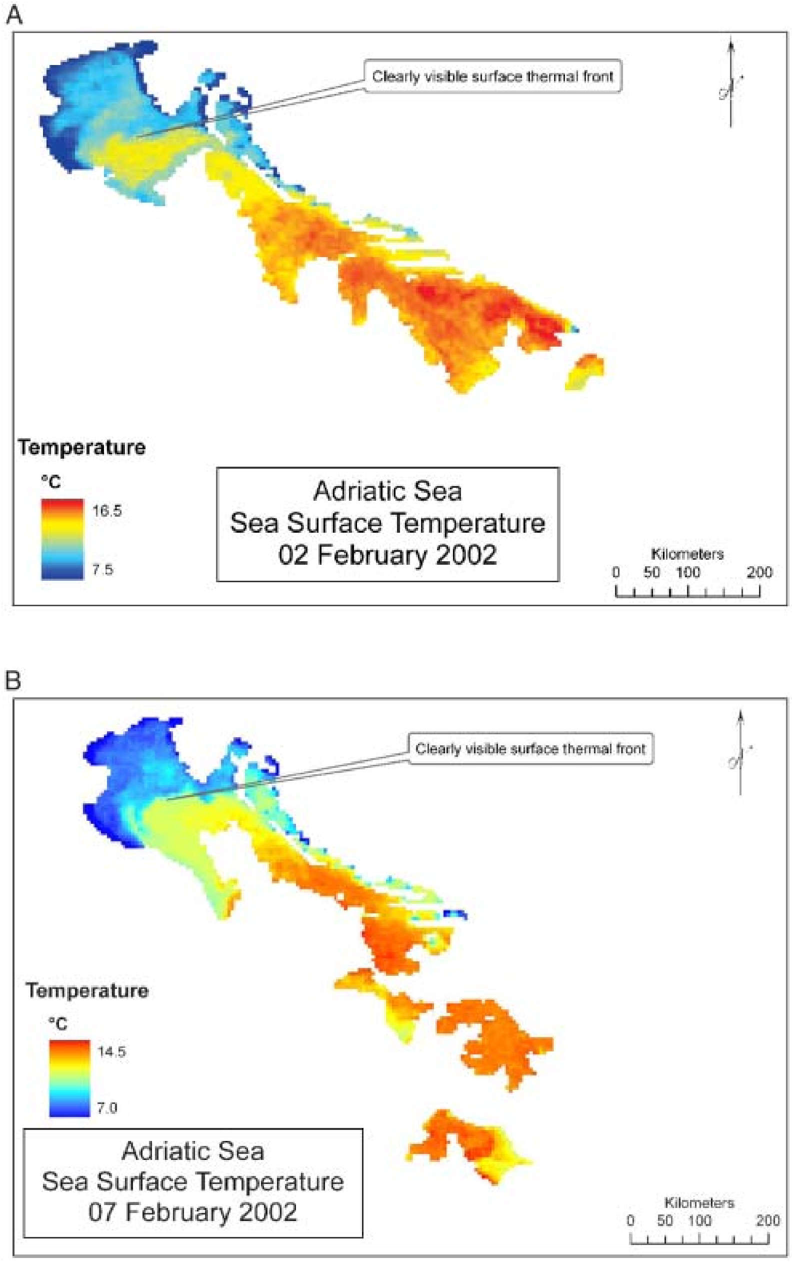

Figure 2. The sea surface temperature of the Adriatic Sea for (A) 2 February 2002 and (B) 7 February 2002.

around banks, reefs, shoals, island edges and shelf edges (Fearnhead 1975). What will be formed between these two different water masses will therefore be a gradient where the temperature changes from the temperature of one water mass to the other. Given the limitations this definition imposes it follows that throughout the area of the front the water temperature at any given position will match either that of the warmer water mass, the colder water mass or lie somewhere between the

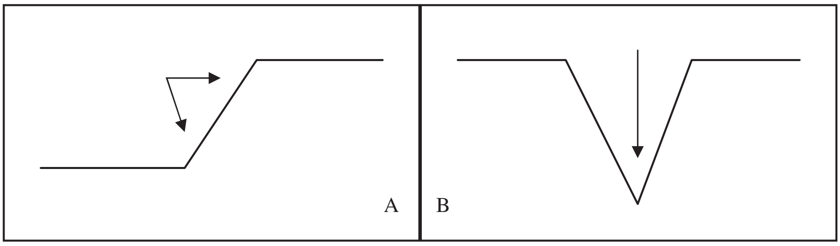

Figure 3. (A) Shows a simplified diagram of how a front should appear on a DTM cross section. The arrows indicate the area of interest when identifying fronts. (B) Shows a simplified diagram of what the sink method is finding. The arrow indicates the specific feature being identified.

temperatures of these two masses, thus creating a slope as opposed to a depression in the temperature range. There is little scope in this definition for the water temperature at any point within the front to fall outside the range dictated by the two water masses involved. Although it may be possible for spot temperatures outside of this range to exist, these would be anomalies and not reliable or sufficiently distinct upon which to base a front location technique. Figure 3 illustrates this in simplified terms. It is clear that the two features being described above are separate, unrelated phenomena.

4. What does the sink method actually find?

This Valavanis *et al.* (2005) method locates an area or patch of water with lower surface temperatures than the areas immediately surrounding it (Figure 1); according to the definition of a thermal front given previously this does not constitute a front. The explanation given above of what the method actually finds describes an area of cold water.

The additional testing of chlorophyll in the proposed method allows for a more specific definition of what the features actually are. The method states that the surface chl must be higher within the identified feature than in the surrounding areas. If both SST is lower and Chl is higher within the identified feature then that feature is considered to be of interest, however, incorrectly defined as a ‘front’ by this method. The higher Chl requirement implies that the area has increased biological activity, indicating that the identified area experiences higher organic productivity than surrounding areas. This, combined with the localized cold water, characterizes an area of upwelling.

Upwelling is the vertical movement of water by which deep, cold, nutrient-laden water is brought to the surface. On the basis of this information an area of upwelling would appear in an SST image as an area of water with surface temperatures lower than that of the surrounding water. Furthermore, high productivity of the nutrient-laden water results in higher Chl values than those of the surrounding water. This is consistent with the Chl requirements stipulated in the sink method where Chl within the identified feature must be greater than those in the surrounding area.

We believe that the features identified by Valavanis *et al.* (2005) in their paper are mostly cyclonic or cold ring eddies in the Aegean Sea. Cold eddies produce upwelling, whereas warm (anticyclonic) eddies produce downwelling in the oceans (http://www.geol.sc.edu/cbnelson/eddy/eddy.htm). In the Aegean Sea, a complex system of cyclonic and anticyclonic features of smaller scale has been observed in the various sub-basins owing to a very complex topography of the region (Sofianos *et al.* 2006). One example of such eddies is so-called 'Sporades cyclone', which forms in Sporades Basin (Kourafalou and Tsiaras 2007). Indeed, Valavanis *et al.* (2005) found high correlations between the bottom topography and the locations of the features found by the sink method. This provides further support that the features identified may be cyclonic or cold ring eddies generated by the complex topography such as islands, seamounts, shelf breaks and basins.

5. Conclusion

It has been our aim in this comment to clear up a significant conceptual error in the use of the 'sink method' as presented by Valavanis *et al.* (2005) for oceanic thermal front detection. It has not been our intention to diminish the significance of their work. In contrast, we see the emergence of GIS/remote sensing technology as having great potential for oceanographic research.

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