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On the subject of red tide predictions from temperature patterns[1]

Predictions of major natural disasters such as earthquakes, volcanic eruptions, droughts, tornadoes, or floods pose difficult technical as well as moral problems to scientists and engineers. A rather dramatic example is the potential for violent earthquakes in the region of the San Andreas fault. It is our view that researchers in other disciplines would do well to emulate the caution exhibited by most seismologists. On the other hand, researchers are the only ones capable of devising new predictive tools, and they should certainly publicize their results despite the obvious dangers.

During the past year, a predictive method for red tide occurrences along the Florida coast has been proposed (Baldridge 1975*a,b*). A widely publicized prediction of a red tide on the west Florida coast for fall 1975 has even been made (Feder 1975). The toxic blooms of the dinoflagellate *Gymnodinium breve* which discolor the water off the west coast of Florida certainly qualify as natural disasters, and this new claim of a predictive method deserves careful scrutiny.

According to this method, the probability of a red tide outbreak in Florida waters is related to (with no claim for causality) the normalcy of the surface water temperature during a critical period of 2.5 months in the preceding winter. A quantitative measure for this normalcy is given by the "temperature departure"

$$TD = \sum [(T - T_a)^2/(N-1)]^{1/2},$$

where T is the measured daily mean temperature, T_a is the long term average temperature for that day, and N is the number of days in the indicator period from 19 January to 2 April.

Figure 1 is copied from Baldridge (1975*b*). Two correlations are claimed as a basis for prediction:

1. As seen in curve A, the minima in TD correspond to major red tide outbreaks.

2. Large decreases in TD from one year to the next (>0.42°C) also correlate with red tide outbreaks in the second year. These are plotted as curve B in Fig. 1 as

$$\Delta TD = TD \text{ in previous year} - TD \text{ in study year.}$$

What should one think of these correlations? Detailed examination of the somewhat obtuse notions of TD and ΔTD has convinced us that these correlations are artifacts.

Red tide occurrences, if they are to be related to temperature departure minima, not only have to be related to low TD values in a given year but to comparatively high TD values in the preceding and following years as well. Such links to the system's past and *future* seem farfetched.

Since the final predictive tool is claimed to be ΔTD, let us concentrate on the precise meaning of that parameter. It is not a measure of temperature; cold or warm winters have not been correlated with subsequent red tide occurrences in any case. It is not a measure of the rate of temperature change during the late winter months. Although this idea is interesting, nobody has related the red tide occurrences with how fast or how slowly the water warms or cools in any time period. It is not a measure of how close a particular year is to the pattern of average temperatures. TD itself measures that, and as seen in Fig. 1, the absolute value of TD is not correlated with red tide occurrences (cf. 1959 with 1966).

ΔTD quantifies the difference between the temperature patterns of two consecutive years, but it is unrelated to the direction of that change and is not a simple measure of its magnitude. The square in the expression for TD masks the direction

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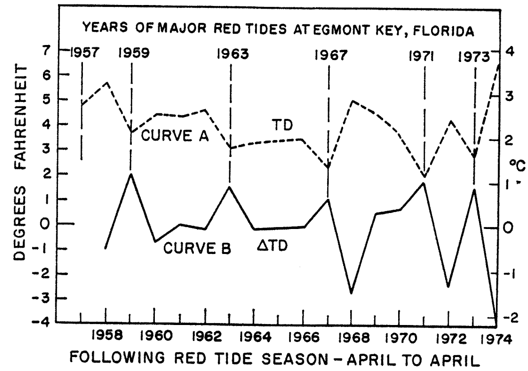

Fig. 1. Temperature departures (*TD*) and values of Δ*TD* (*TD* of previous year minus that of subject year) during indicator periods of 19 January–2 April and the strong empirical relationship to subsequent occurrence of major red tide in the area of Egmont Key, Florida. (Redrawn from Baldridge 1975*b*.)

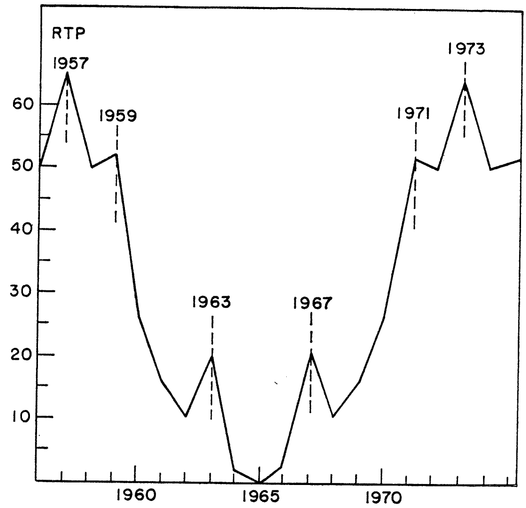

Fig. 2. Red tide predictor, *RTP*.

of the temperature deviation from the long term average. Warm and cold winters equally deviant from the long term average will appear identical when the *TD* parameter is used. In addition a large difference in the temperature patterns of two successive years could yield a large or a small Δ*TD* depending on the relative position of the long term temperature average. Δ*TD* is a measure of the change in the temperature pattern from one year to the next relative to the pattern of long term averages. This notion of a pattern of long term averages which is essential to this predictive method is purely a mathematical abstraction. Figure 1 shows that there are very wide temperature variations during that time of year and that the typical year is not average at all (average *TD* about 2.2°C). Thus the correlated events that lead to the red tide outbreaks and to the large decrease in *TD* values should not only have a memory of the preceding year's temperatures but should somehow have inherent knowledge of the long term average temperature for each specific day of the critical period. This is more than our common sense can accept.

For example, the movement of water masses which has been suggested as a possible common causative factor (Baldridge 1975*b*) could, at the limit, explain a correlation between red tides and variations in temperature patterns from one year to the next. However, in such a case, one would observe direct correlations between red tides and temperature patterns without any need for comparison with long term daily averages. Similarly, for all conceivable physical processes that might be invoked as causative mechanisms, a much simpler correlation with temperature patterns would be observed with no need for the mathematical abstraction of patterns of long term average temperatures.

What then accounts for the observed correlation in Fig. 1? One should bear in mind that finding correlation between temperature patterns and red tide events was the express purpose of the research. Given the great variety of parameters that can be defined for this purpose and the few instances of red tide events to be fitted (there are only five), several good correlations should be possible. In this respect, the arbitrary nature of the critical time period should be emphasized. To exemplify the danger of establishing correlations without regard for causalities, note that four out of five of the red tide events "predicted" by this method occurred during the year preceding a leap year. On a more mathematical note, under the tradition of unicorn studies (Cole 1957), the following red tide "predictor" parameter *RTP* can be defined:

$$RTP = [8 - Rem_{16}(x+7)]^2 + [2 - Rem_4(x+1)]^4,$$

where the function $Rem_n(y)$ gives the remainder of the division by n of the integer y, and x is the number formed by the last two digits of the calendar year.

A plot of *RTP* as a function of time is given in Fig. 2. A perfect correlation between peaks in *RTP* and red tide events is obtained.

Will there be a red tide along the Florida coast in 1975? ΔTD and *RTP* both say yes and 1976 is a leap year after all. In all seriousness, we hope that there is no red tide outbreak in fall 1975 along the Florida coast not only for the sake of the Florida residents, but also for the sake of those who might then believe that a reliable predictor has been formulated.

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References

Baldridge, H. E. 1975*a*. Temperature patterns as early indicators of impending red tide in Florida waters, p. 11. Proc. Florida Red Tide Conf. 10–12 Oct 1974, Sarasota. Fla. Dep. Nat. Resour. Mar. Res. Publ. 8.

———. 1975*b*. Temperature patterns in the long-range prediction of red tide in Florida waters, p. 66–79. Proc. Int. Conf. (1st) Toxic Dinoflagellate Blooms. Mass. Sci. Technol. Found., Wakefield.

Cole, L. C. 1957. Biological clock in the unicorn. Science **125**: 874.

Feder, B. 1975. Section 10, p. 1, 24 August 1975. *The New York Times*.