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Northwest Indian Ocean's Spring Cooling

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Abstract

A major cooling down of the northwestern Indian Ocean's surface, including the Arabian Sea, starts in May, according to a well-known world atlas of SSTs. This is before the southwest monsoon which usually begins in June. Also within one year, there are two surface temperature maxima and two minima, which is not typical for the northern hemisphere. A surface current, cooler than the surrounding water, crosses the equator in April and May heading north and east on the western side of the ocean. That proposal is consistent with the given SST information. The warmer surrounding water is then moved to east and south as a consequence. Since wind driving is not available for initiation, the relatively cool northeastward current is thought to be caused by a thermohaline force related to the unstable northward temperature gradient in the west, which is of constant sign right across the equator beginning in May: cool in the south monotonically increasing to warm in the north.

Keywords

Indian Ocean, Spring Cooling

1. Introduction

A classical atlas of sea surface temperatures of the world [1] contains an amazing piece of information about the Indian Ocean: maximum surface temperatures of the year, in the western and northern open ocean waters, occur in April and May! How can that be? How can the sea surface begin cooling off in the northern hemisphere spring? April and May are before the southwest monsoon which usually begins in June [2] [3], which is known to carry some heat away from the sea. Also these maximum temperatures occur before June 21, when the greatest amount of excess solar radiation, per horizontal area and per unit time, is being absorbed in the top 100 m of the northern equatorial waters, *i.e.* when the sun is farthest north.

For comparison, in the thirty year average of the sea surface temperatures of the North Pacific the highest values occur in August and September over large areas of the middle of the ocean above 20 N, and there is even a smaller pocket near the US west coast where the highest surface temperatures of the year are to be found in October! Millions of compiled ship-injection temperatures have been used to establish these conclusions [4]. The significant time delay of August and September from June 21 has been explained by the seasonal variation, mainly in position, of a very wide warm and sluggish surface current permanently flowing northeast off California [5].

Although the data in the South Pacific are far fewer in number, two detailed hydrographic sections suggest strongly that there is an analogous wide warm surface current flowing southeast from the middle of the ocean at low latitudes diagonally toward the coast of South America [6].

Maury may have been the first to point out, in the late 1800s, that such a wide surface current exists in the North Atlantic when he used the following title for a subsection of a chapter of his famous and controversial book: "The large body of warm water outside the Gulf Stream" [7].

But in the northern Indian Ocean a similar wide surface current, carrying excess heat northward, is not expected. One very good reason is that the Indian Ocean is landlocked to the north. The main physical function of the wide warm surface current in the North Pacific, and presumably elsewhere too, has been proposed to be to transport some of the excess solar radiation absorbed in the surface layers of the tropical ocean to higher latitudes, in order to help maintain the earth's overall heat balance [8]. In the northern Indian Ocean, such a heat transport mechanism is not possible. Then the northern Indian Ocean has basically two choices. Give up the excess heat to the atmosphere and let the winds finish the job, or transport the extra heat southward, across the equator, by means of ocean currents. A mixture of both methods is also a possibility. The existence of the southwest monsoon of warm air, coupled with the returning northeast monsoon of cool air, indicate that the atmosphere is apparently attempting to move at least some net amount of oceanic heat northward over the time-scale of a year.

Interest in the lines of constant temperature in the oceans, and their deflection or curvature, has quite a long history in the field of climate going back several centuries in the North Atlantic [9]. If it were up to the sun alone, one anticipates the ocean surface temperature contours will be nearly parallel to lines of constant latitude far away from land. When that is not the case, the suspicion is that surface currents are a likely reason. There are a few months (see for example **Figure 4**) in the northwestern Indian Ocean in which some temperature contours are almost parallel to longitude lines over a significant band of latitudes! Surely currents must be responsible for that?

What follows is an analysis of the sea surface temperatures of the northwest Indian Ocean (**Figure 2**) which clearly demonstrates the startling spring cooling down of this region. May and June pages from the well-known world SST atlas (**Figure 3** and **Figure 4**) are used to interpret the cooling in terms of a newly proposed northeast surface current in the west that crosses the equator beginning in May. Since the southwest monsoon cannot be the initial cause of the northeast current, because it starts too late (in June), a thermal driving force within the surface layer, related to the positive northward surface temperature gradient, is conjectured to be responsible.

2. Temperature Features

What follows comes directly from the classical atlas [1] after one or two steps. Actually, all the present conclusions can be found by flipping back and forth the individual twelve sheets for the Indian Ocean, although that is a bit inconvenient. Summaries in graph form are a little easier to comprehend. Also the summaries are a type of average and therefore not sensitive to some small-scale deflections and curvatures of individual isotherms that might be distracting in the atlas. The latitude/longitude grid of one degree squares provided in the atlas facilitates the calculation of the averages.

Another reason for displaying the graphs is that the old atlas may be hard to get hold of now. My copy was handed down to me forty years ago by a retiring physical oceanographer at Scripps. In addition, I do not know of a more recent world atlas of sea surface temperatures to consult or I certainly would have done so by now.

It is interesting in these days of modern technology that there can be a qualitative phenomenon that is strong enough to emerge from a data base founded on thermometers that could not be read to the nearest 0.01 C. In fact, ship-injection temperature measurements included in the old atlas are known to be only good to the nearest 1 F!

In the southern Indian Ocean the open water isotherms on any given chart in the atlas are more or less parallel to each other and approximately parallel to latitude lines. Therefore, a sensible thing to do is to plot the average latitude of a particular isotherm as a function of month. That is what is done in **Figure 1** for the 80 F isotherm.

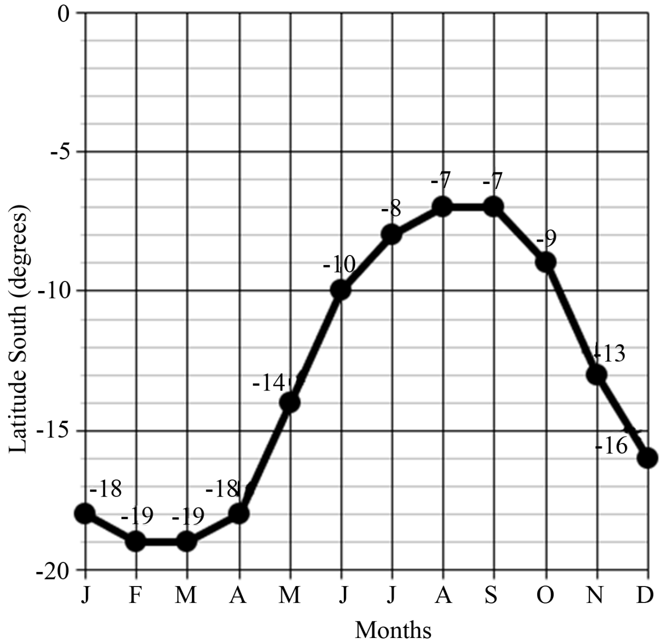

Figure 1. Average latitude of the 80 F isotherm in the southern Indian Ocean as a function of month. South latitudes are negative.

The smooth sinusoidal seasonal progression from the most southern latitude in February and March to the most northern latitude in August and September is what one might expect for the southern hemisphere, if allowances are made for the time lags between when the sun is farthest south and the warmest temperatures, and when the sun is farthest north and the coldest temperatures. No eyebrows should be raised at this point.

It is instructive next to plot the following graph (**Figure 2**), based on the western north Indian Ocean's SSTs from the classical atlas, in which the months of the year occupy the horizontal axis and on the vertical axis is the percentage of the total surface area where the temperature equals or exceeds 80 F. It is convenient here to define the northwestern Indian Ocean as that body of water north of the equator and west of 80 E, which includes the Arabian Sea. There are seen in the Figure two distinct maxima and two distinct minima in the period of one year! I am not aware that such a characteristic double "seasonal" variation of surface temperature exists in any other ocean. In **Figure 2**, the first minimum in the graph occurs in January, as would be normal for the northern hemisphere winter. But the second more marked minimum is centered about August, just when many of the SSTs of the North Pacific are at a maximum value. That August minimum must be real, and it can shock a person into going back to the atlas to see what might be going on to produce such a distinctive feature.

3. Interpretation

What the atlas shows by the isotherms is that cooling of the sea surface starts in the far west near the equator in May and then advances and intensifies to the north and to the east in June, July and August (see **Figure 3** and **Figure 4**). There is no indication of a cool down in April or before that. It is unlikely that the southwest monsoon winds can initiate this cooling because the cooling starts between May and June and the monsoon begins in June. After initiation the monsoon can and probably does make a contribution to the ocean's cooling.

Another mechanism must be found to start up the cooling then. An ocean surface current coming from the south and crossing the equator could accomplish the cooling. Are there any objections that can be raised to such a conjecture? Is this a new current that is being proposed here? If so, is this a seasonal phenomenon rather than a piece of the steady or permanent circulation?

First, consider some of the consequences. If cooler surface water than the surroundings is pushing north and east across the equator in the west, then the warmer water there must get out of the way by moving east and then south, in order to conserve mass. Since wind driving is not available for the start up, then a thermohaline force is the likely cause. When two separated water bodies of differing temperatures are constrained to lie at the same

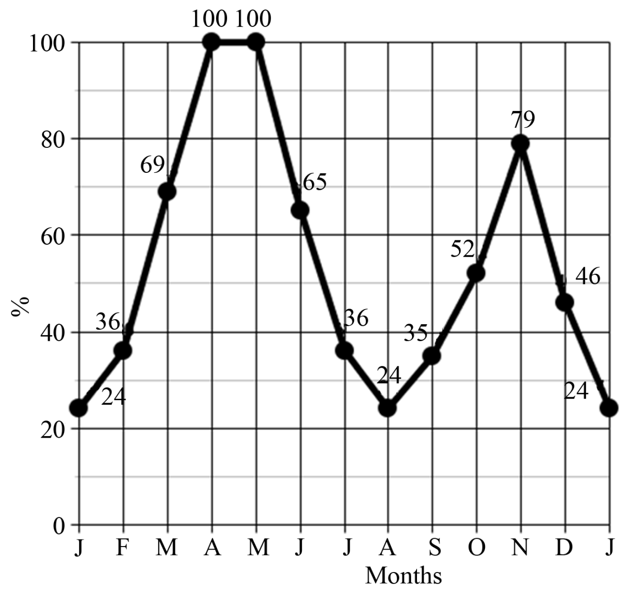

Figure 2. Percentage of surface area equal to or warmer than 80 F in the northwestern Indian Ocean as a function of month.

level (sea surface), by buoyancy, the situation is unstable: the cooler body, being heavier, tries to move the warmer body aside. Almost anywhere in the ocean the temperature decreases with increasing depth (the thermocline), so there is a buoyant force holding the surface layer up. If there is a mixed layer or not at the top of the thermocline, the argument is not materially altered. Also normally the density of sea water is controlled by the temperature, so salinity can usually be ignored. Therefore, the "haline" part of thermohaline can be disregarded in this particular case.

Consistent with the thermal driving mechanism is the fact that beginning in May (**Figure 3**) the north/south temperature gradient of surface temperature, west of about 60 E, maintains the same sign right across the equator: the temperature monotonically increases northward. Strictly speaking, for northward instability at and near the surface, the "horizontal surface" needs to have a finite "vertical thickness", say 100 m.

Where the northeast surface current crosses the equator in the spring is on the far western side of the Indian Ocean, as suggested by the temperature atlas. What is the reason for that? A qualitative answer is as follows. Since the thermal driving force is oriented to the north, because the sea surface temperature gradient points to the north in the southern hemisphere at all times of the year, initially the surface layer will move north. But as soon as that happens the Coriolis force will act to the left of the velocity, facing in the direction of flow, which will produce a diagonal northwest flow headed for Africa. It must be assumed that the northward flow starts far enough south that the Coriolis effect is significant, *i.e.* not too close to the equator.

To try to substantiate the hypothesis of a northward surface current crossing the equator on the western side of the Indian Ocean new measurements may be needed. One example would be to place floats in the surface layer (within the top 100 m) in May in the west and south of the equator and have them tracked by satellites for one to a few months as they cross into the northern hemisphere. Exposure of the floats to the wind should be minimized to make the results easier to interpret.

There exist vertical hydrographic sections throughout the Indian Ocean [10], including a more or less north/south one along the western side of both oceans and in the month of May. Also of interest are two east/west hydrographic lines from Australia to Africa, both along 30S but occupied in different seasons, which show remarkably contrasting temperature structures of the upper waters.

4. Conclusion

A significant cool down of the surface of the northwestern Indian Ocean starts in May and continues through June to August, according to a classic atlas of sea surface temperatures of the world. Since the southwest monsoon usually begins in June, the cool down cannot be initiated by the wind. Isotherms in the atlas suggest that a

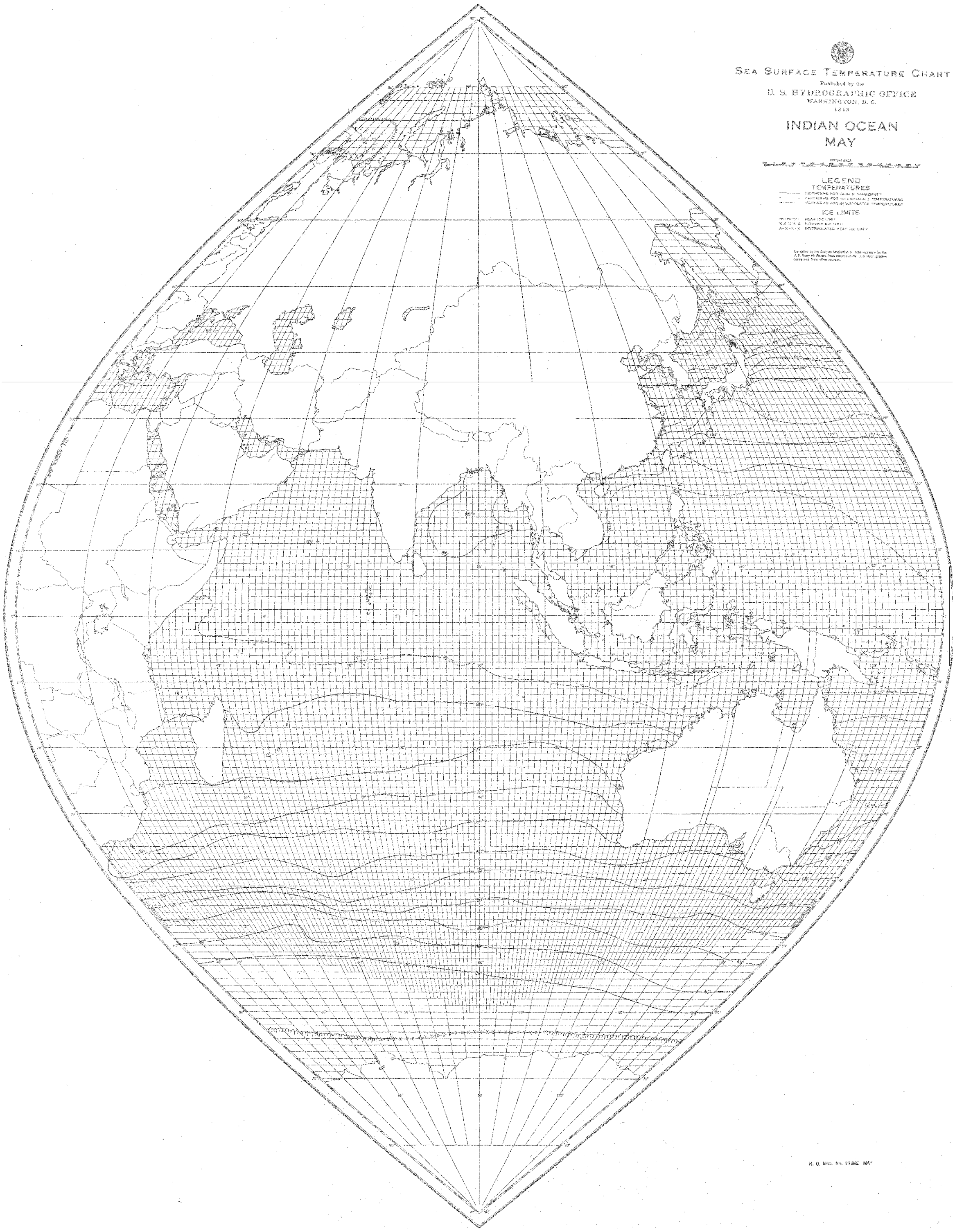

Figure 3. May isotherms of surface temperature in the Indian Ocean (from H. O. 225 atlas). And the distance scale on the atlas map goes from −100 to 1500 statute miles.

northward surface current crosses the equator in the west bringing cooler water to the region. Consistent with this hypothesis is the fact that the northward surface temperature gradient maintains a constant sign across the equator west of 60E starting in May: surface temperatures monotonically increase from south to north. Such a temperature

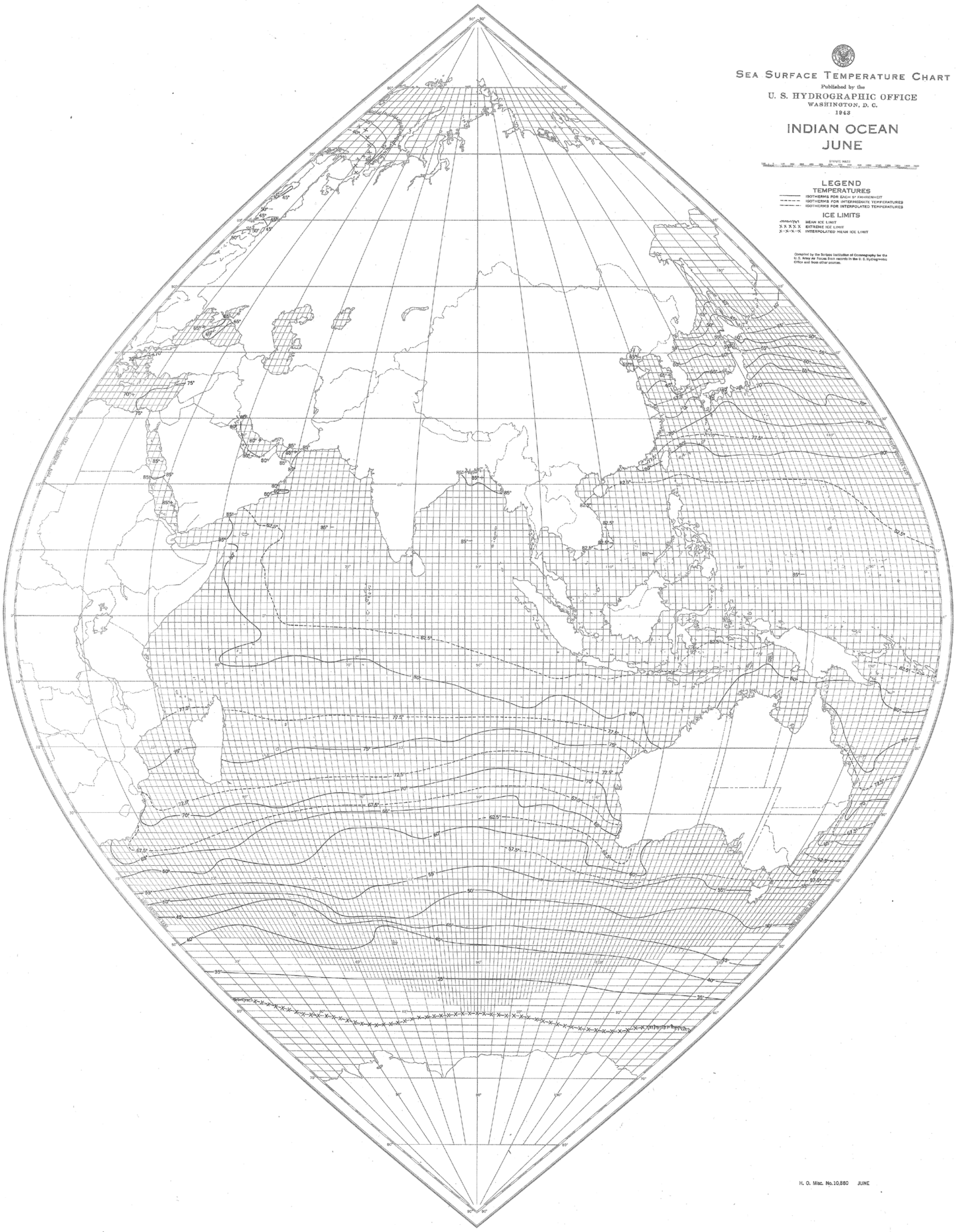

Figure 4. June isotherms of surface temperature in the Indian Ocean (from H. O. 225 atlas). And the distance scale on the atlas map goes from −100 to 1500 statute miles.

gradient is an unstable feature which results in a thermal northward driving force for waters of the surface layer.

5. Acknowledgements

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