

WIDE WARM SURFACE CURRENTS IN MOST OCEANS

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Abstract

Since a wide warm surface current, permanently flowing northeast off California, has been documented with all the available data that could be found plus helping to organize the collection of a new set of observations has happened, a search was carried out for a similar circulation feature in other oceans. Very likely there exists a wide warm surface current in the South Pacific moving southeast from the middle of the ocean and impinging on the coast of South America. In the South Atlantic a wide warm surface current appears to go south in the western half of the basin. Contained in the North Atlantic is “the large volume of warm water outside the Gulf Stream drifting north”, which was first described by Maury and confirmed recently by newer measurements. A puzzling SST observation in the northwest Indian Ocean, that in a given year two summers and two winters occur, is explained by a hypothesis that is a bit more complicated than shown by the surface currents in the other oceans. For confirmation more surface and near surface measurements are needed.

1. INTRODUCTION

According to the requirement of the Earth’s heat balance, both the atmosphere and the oceans must transport heat poleward (roughly tangentially to the earth’s surface), because there is an excess of absorbed incoming solar radiation at lower latitudes compared to that at higher latitudes whereas the outward long-wave radiation of heat is nearly independent of latitude. Exchange of heat between oceans and atmosphere does occur, but the main focus here is the heat balances of the oceans. Over the interior of continents it is only the atmosphere that can adjust the heat balance, of course.

A very remarkable feature of the world’s oceans is that five out of six of them have a broad open pathway of water connecting the low and high latitudes. Therefore, the possibility exists that poleward warm streams and equatorward cold streams could maintain the heat balance of those oceans individually, assuming little or no flows cross the equator. North and South Pacific, North and South Atlantic and the South Indian Ocean are those five oceans (obviously the seventh sea, the Arctic Ocean, does not belong in this list). An exception is the North Indian Ocean since it is land-locked to the north at mid-latitudes. Something different and very unusual must take place in that ocean, as will be explained below.

There is some uncertainty about the shortest time scales over which the ocean's heat balances are accomplished. Certainly the variations over the seasons appear to be readily accommodated, and the much more gradual changes in climate should be no problem even if the ocean currents involved are rather sluggish, which they are for the most part as it turns out. In the atmosphere, on the other hand, evidence exists that suggests that heat adjustments can occasionally take place on a time scale as short as one day.

Beyond maintaining the heat balance of the oceans, the poleward flowing wide warm surface currents have another important job that they can do: affect the weather above them as well as some of the weather that crosses the continents. By being rather slow moving the current allows time for the warm water to impart heat to the atmosphere, producing vertical convection in the air, one result of which is to create higher pressure at sea level.

For example, it has been proposed that a portion of the heat being transported northward leaks out of the wide warm surface current of the North Pacific at mid-latitudes and causes and maintains the North Pacific High pressure cell on the eastern side of the ocean, on top of the current. Then once in place the high pressure can affect the low pressure storms that come within its sphere of influence and then pass over the U. S.

Two more balances are taken care of by the wide warm surface currents and the colder return flows beside and underneath them: water and salt [1]. There should be as much water returning to the equator as that going toward the pole or the sea level will systematically either rise or fall, and that is not observed to happen. Since evaporation usually exceeds precipitation at low latitudes and it is the other way around at high latitudes, low latitude waters generally have greater salinity than high latitude waters. Consequently, salt is conserved by the convection system.

One step more complicated from the physics point of view, perhaps, and certainly further removed from what can be found in the oceanographic literature, is the balance of eastward angular momentum of the surface currents. Trade winds steadily blow the equatorial surface waters westward, and the westward winds urge the currents eastward at mid-latitudes. With respect to the Earth's axis of rotation, eastward currents have positive eastward angular momentum, and westward currents have negative eastward angular momentum. When these currents run into land, which they both will do in the North Pacific, for example, their angular moment are destroyed on contact and need to be restored. The diagonal northeastward warm current satisfies both these needs.

All of the conservation mechanisms occur at and within about 100 m of the surface, by reason of the fact that the circulation is driven by the absorption of solar radiation, and 90 % of the sun light that penetrates the sea surface has been absorbed when the depth of about 100 m is reached.

A wide warm surface current is expected to be found in the South Indian Ocean also, but it will not be reported on here because no really detailed studies of the data in that ocean, relevant to the present cause, have been made up to this point.

2. NORTH PACIFIC

Of the five oceans under consideration here, the North Pacific has the most data available for the purpose at hand: depicting the wide warm surface flows diagonally crossing mid-ocean from low to high latitudes. Unfortunately, the largest body of water, the South Pacific, has the least amount of data for several reasons but mainly because fewer (merchant) ships cross that ocean per unit time. Also the oldest ocean studied scientifically is the North Atlantic.

First, consider making an imaginary boat trip off the coast of California. Take along a thermometer for measuring the temperature of the water's surface (or a few inches below the surface).

Interpretation of the results is made easier if the boat sails straight west. It does not matter which latitude is selected, and the time of year is unimportant. For a constant speed of the boat, one temperature measurement per hour would be sufficient. A distance of at least 4,000 km from the coast should be traveled.

What will be found is that the temperature gradually rises to a maximum and then gradually tapers off again. Very many available data exist to establish the truth of this prediction. For example, ship-injection temperatures in my possession extend over a 30 year period and cover most of the North Pacific above 20 N. Each merchant ship crossing the ocean cools its engine with sea water that enters the hull through a pipe. In the pipe is a thermometer, near where the water enters, and the temperature is read every hour and recorded. All the individual data are collected by a government agency and averaged into 5 degree latitude/longitude squares and one month intervals. It has been estimated that over a 20 year span 8 million individual data points exist in this collection, which is sometimes referred to as the Namias-Scripps temperature set, or SSTs (sea surface temperatures).

When the five degree square/one month SST data are plotted against longitude at latitudes 35 and 40 N, for example, starting at the coast and going west, the large-scale longitudinal SST maximum exists for every month over the 30 year period at both latitudes. Where permanent means at least 30 years, the longitudinal SST maximum in the eastern North Pacific at mid-latitudes can now be considered to be a permanent feature. How far into the past the feature can be extrapolated to have existed is not known, but my guess is the order of thousands of years, and if it is extended even further, into the last glacial period, then some evidence of seeds and spores of tropical plants found on a few of the Aleutian Islands could be more easily explained.

That the SST maximum, based on averaged data, is also real has been verified as many times as possible against independent more closely spaced temperatures taken by more accurate thermometers on individual oceanographic cruises.

Evidently millions of SST data show that the longitudinal maximum is not only large in horizontal scale but they also indicate that there is a coherent structure involved. Even before any subsurface observations have been made, a hypothesis can be started as to what is happening. Since the water to the west, east and underneath the maximum is colder, and the air above is colder too (from separate measurements), in order to maintain the maximum as a permanent feature, warm water must constantly be brought to the region from the south, where the water is warmer still because part of the northward moving heat will undoubtedly escape into the air.

Then along came an opportunity of a lifetime: to take an oceanographic ship from Scripps all the way across the ocean to Japan collecting a vast quantity of mainly physical and chemical observations in a classical hydrographic vertical section from the surface to the bottom. Timing could not have been better. There had never been a hydrographic section done in the North Pacific before. I was involved with some of the planning, so I chose 35 N as the course to take and I picked the constant spacing of the stations: one degree of longitude totaling 98 stations. Since the ship would be gone for over a year, the time for "my" cruise was determined to be about 35 days during March and April of 1976, but that turned out to be an excellent choice (a summer cruise might have complicated the interpretation, as will become clear). Funding was provided by the National Science Foundation.

What I wanted to know was the depth structure to be associated with the longitudinal SST maximum, and the cruise data provided a full picture of it. There was a lens of relatively and uniformly warm water, convex side pointing down, extending about 4,000 km east/west at the surface with a maximum depth near the middle of a little over 100 m.

Immediately the earlier rather hesitant interpretation was confirmed and expanded. There is a wide warm surface flow heading northward and being cooled from above causing, in the spring, a mixed layer of nearly constant temperature. Since the maximum depth of this current appeared to be about 100 m, that is consistent with the penetration and absorption of the sun's rays, especially at lower latitudes. So the sun is ultimately the main reason for the existence of the current.

Back to the SSTs for further inspiration. Here is what I could have noticed in the mid-1970s, but did not. In one of the earliest graphs of the Namias-Scripps SSTs plotted against longitude, I used the twenty year means that Namias had previously computed. For example, at 40 N I nested twelve curves, one for each month, on one graph with a relative temperature scale. The longitudinal maximum appears on every curve, but its location had a puzzling seasonal variation: significantly further west in summer than in winter. Sometimes averaging can smear out features over a considerable time span such as twenty years. A possible explanation for that east/west seasonal shifting never occurred to me then. I made a similar graph of nested curves for 35 N at the same time, and in the publication containing these two graphs they just happened to appear on different pages in the journal, making comparisons somewhat difficult.

Here is some pure reasoning which could have taken place in the 1970s, but did not. One of the main jobs the wide warm surface current is proposed to carry out is to transport excess heat from low to high latitudes at all times of the year in order to help keep the ocean's heat budget balanced. But in summer there is more heat to transport than in winter because of the sun's northward movement. How is the wide warm surface current, a permanent feature, supposed to do this? It can't get any deeper because its depth scale is tied to the depth within which sunlight is absorbed (100 m). It is also very unlikely that it could speed up in summer, since the sluggishness of the current is due to the large horizontal separation between hot and cold sources at sea level. There is one possibility left: it could widen to the west (to the east the current bumps up against the continental boundary).

Alternatively, a separate surge of warm surface water might take place to the west of the permanent current only in summer but in every summer. That possibility appears to be what actually happens according to the available SST data. Twenty years of averaging the SST data may have smeared two separate longitudinal maxima into a single one during the summer months, but a clue was still left behind. The maximum along 35 N moves west at least one month before the maximum along 40 N does. For individual years the data show that the westward maximum can be distinctly separate from the eastern one and at other times closer together, almost adjoining. Potentially this is why a hydrographic section at mid-latitudes during the summer might have been a bit confusing to understand.

For still more stimulation from ship-injection temperatures, since the Namias-Scripps compilation exists only for latitudes north of 20 N, a classical atlas of world sea surface temperatures is consulted (H. O. 225) [2]. It is also based on ship-injection data. There a quite amazing fact is waiting to be studied. In the western equatorial waters of the North Pacific the highest SSTs are always found, but they are not significantly higher in summer than in winter! In conclusion: a very efficient heat transport mechanism must be in place such that more excess heat is expelled from the tropics in summer than in winter, just in phase with the sun's input. By eliminating the various options, the logical one left is northward transport by advection.

According to the H. O. 225 atlas, the area between the equator and the 80 F contour in the western tropical North Pacific doubles in size between winter and spring/summer. This area can be turned into a volume by multiplying it by the characteristic depth scale of 100 m for the absorption of solar

radiation. Then in the fall and winter, when the volume is cut in half again, where has all the inferred heat in the surface layer gone? Presumably it went north.

Northward movement of the 80 F isotherm in the western tropics is thought to occur as follows. After December 21 the sun begins its trip back north, and the surface layer starts warming up again, mostly at the equator and less and less with increasing distance north from the equator due to the curvature of the Earth. Consequently, sea level will begin to rise by thermal expansion, also mostly at the equator and less and less so with distance north. Thus, a sea level slope, downward to the north, is created. If there is no force to oppose it, the warm surface water will go downhill to the north.

At some point cold northern water will become unstable and rush south causing the summer warm surge to go north on top of it. Timing of the instability might vary from one summer to another by a few days or so and perhaps the exact longitudinal positioning might change from year to year as well.

3. SOUTH PACIFIC

Given the existence of such a large scale current system as the wide warm surface current of the North Pacific is, with the return flow of cold water underneath and beside it, both real and permanent according to the available data, it would be surprising if something similar were not to be found in other oceans. Even though there may not exist extensive data sets, by comparison with those of the North Pacific, it still makes sense to try to find evidence for wide warm surface currents in other oceans. At the very least lists can be made of the types of observation to be made in the future that would be useful for delineating analogous convective circulations. On the other hand, since the North Pacific documentation of the wide warm surface current is pretty well in hand, perhaps a similar current system can be identified elsewhere with fewer observations.

Subsurface measurements in the open ocean are difficult and expensive to obtain. However, SSTs are available at a moderate cost due to the ship-injection technique, and they are what sparked this whole investigation in the first place. H. O. 225 is a world atlas of ocean SSTs based on ship-injection temperatures. All six oceans are included. This classic atlas has been very inspirational, and it would be beneficial to update it at some stage. One point in favor of the old atlas, in my view, is that it was made before the dynamical theories of wind driven currents came into existence which got a firm hold on the minds of many oceanographers.

Years before the 35 N hydrographic section was run in the North Pacific (1976), two very long and thorough hydrographic sections had already been made in the South Pacific, both at mid-latitudes and both in the southern winter season of the same year (1967). If just the surface temperatures from June and July are plotted along the section at 28 S, there will be found a very large scale temperature maximum centered at about 130 W with an "amplitude" of at least 5 C and an east/west width of 60 degrees of longitude. How did all that warm water get to the middle of the ocean in the middle of winter [3]?

Very near the SST maximum at 28 S, 130 W sits Henderson Island, an uninhabited Heritage Site, one of the few existing raised coral atolls. In a recent KPBS news story it was pointed out that this once pristine island is being constantly inundated by vast amounts of plastic trash washing up on the beaches. Likely as not the trash came in with the warm water passing by the island.

Below the SST maximum subsurface hydrographic data show that there was a broad (30-40 degrees of longitude) relatively deep (100 m) mixed layer of nearly constant warm water, consistent with a southward flow being cooled from above.

Return now to the H. O. 225 SST atlas [2] for additional information which cannot be obtained from a couple of hydrographic sections. First, the highest surface temperatures of the whole ocean are always

to be found in the western tropics, just like in the North Pacific. Also similar is the feature that the SSTs are not significantly higher in the southern summer than in the southern winter. Therefore, the same logic applies: there must be an efficient heat adjustment mechanics operating, such as advective export of excess warm surface water southward. There is a 180 degree phase shift going on independently between the two hemispheres. Probably essentially no cross-equatorial flow takes place in the surface layer.

Between winter and summer the area of highest SSTs more than doubles as indicated by the 80 F and 82.5 F contours moving south. When the areas decrease again, between summer and winter, it is proposed that a surge of warm surface water has exited the tropics and heads south to the west of the permanent wide warm surface current. More observations are needed to confirm these predictions, which are created by analogy with those of the North Pacific.

Now, the seasonal migrations of the isotherms, moving poleward in the spring and summer, moving equatorward in the fall and winter, had been noticed a long time ago in the North Atlantic by Matthew Fontaine Maury, just before the Civil War broke out. Under his direction the first charts showing the lines of constant temperature at different times of the year were made, and this “springing” back and forth of the isotherms greatly stimulated his imagination. In fact, he came very close to an explanation of this phenomenon as he also did when describing “the large volume of warm water outside the Gulf Stream”, discussed below.

In his book, *The Physical Geography of the Sea*, Maury comes tantalizingly near the “truth”, but there is a mix of topics that can distract the reader. This book was famous and controversial from the start, so that one hesitates to recommend it for reading all the way through. But finding the little sparks of wisdom is not very easy to do either.

He lost his position at the start of the war leaving behind, or in the custody of friends, unfinished charts of the Pacific, which have not surfaced to my knowledge. I made a search for the Pacific charts years ago in Washington, D. C. at the National Archives, but could not read his handwriting well enough in the time available.

4. SOUTH ATLANTIC

It appears that when the ocean bodies get smaller, some features of the surface currents get a bit more cramped. The same physical principles must still be operating, of course. Excess solar heat absorbed at low latitudes has to be shipped poleward. On the one hand, the North and South Atlantic are not large enough to have wide warm currents the size of those found in the North and South Pacific plus similarly sized summer warm surges to the west of them. Also the Pacific wide warm surface currents have diagonal paths indicating that those bodies of water are wide enough that the deflecting operation of the Coriolis force becomes evident.

On the other hand, the Gulf Stream now would not appear to be big enough by itself to accommodate the heat balance of the whole North Atlantic. Then when the Northern Indian Ocean presents itself, there are puzzles enough to confound the mind and stall it from figuring out what is going on there.

What configuration of surface currents to expect in the South Atlantic is not known a priori [4]. Useful sources of data for the South Atlantic are two east/west coast to coast BT vertical sections, at 24 and 32 S, showing detailed surface layer temperatures from Fuglister’s *Atlantic Ocean Atlas*[5], and of course the H. O. 225.

Right away on the first chart of H. O. 225 atlas (January) the SST lines of constant temperature have a peculiar look to them in the middle of the South Atlantic, middle east/west as well as north/south. Look at the 75 F isotherm. For 18 degrees of latitude, starting at 11 S and going south, the isotherm

hugs a line of constant longitude, being essentially vertical. That is totally unexpected. Also two different isotherms west of the 75 F isotherm and two east of it have vertical stretches just as prominent. February has a similar region where the isotherms are more nearly north/south, but in all months there are marked sloping segments of the isotherms in mid-ocean.

If it were up to the sun alone, the isotherms should be parallel to latitude lines. Surely the cause is due to surface currents. If warm surface water goes south to the west of the vertical isotherms, and cold water goes north east of it, that would be a good explanation, and it would be consistent with what the vertical sections of temperature show: colder water in the eastern half of the ocean and warmer water in the western half at mid-latitudes. Thus warm water going poleward and cold water going equatorward exist side by side, rather than one flowing over the top of the other as in the Pacific (North and South).

Another perhaps unexpected aspect of the surface circulation of the South Atlantic, by comparison with the Pacific, is that the data indicate that some water crosses the equator into the North Atlantic, usually on the eastern side of the oceans. Evidence for flow crossing the equator is suggested by one of the two 80 F isotherms, which starts the year mostly in the South Atlantic, but it crosses the equator in more than half of the months. The northern 80 F isotherm is in the North Atlantic in all months.

Since the Pacific is not like that, the northern 80 F isotherm stays north of the equator but the southern 80 F isotherm also stays south of the equator, the overall result is that the smaller Atlantic tropics are significantly colder than the larger Pacific tropics are.

Whether or not any warm water from the North Atlantic exits through the South Atlantic is not known at this point. SST data do not make a strong suggestion either way (and the vertical sections do not help in this case).

5. NORTH ATLANTIC

“Let us return to this great expanse of warm water which, coming from the torrid zone on the southwestern side of the Atlantic, drifts along to the north on the outside of the Gulf Stream. Its velocity is slow, not sufficient to give it the name of current; it is a drift, or what sailors call a “set.” By the time this water reaches the parallel of 35 or 40 it has parted with a ‘good deal’ of its intertropical heat...”

An illuminating partial quote from Maury’s book [6], which, however, then turns confusing in such a way that the reader is distracted from what looked to be a very promising start, because several alternative (almost contradictory) propositions are all thrown into the same paragraph. Without any evidence to back it up the words “good deal” in the last sentence are already an exaggeration would be my guess. But to call out Maury as being crazy, and then to have nothing further to do with him, like a colleague did years ago, is not a constructive approach.

Essentially what Maury said next is that the large volume of warm water drifting north loses heat, gets heavy and stops, and that it can’t or at least does not cross the Gulf Stream. My position is just the opposite: the wide warm surface current continues on north and the Gulf Stream cannot cross it. One reason for that is the inherent instability of the Gulf Stream when it breaks down to form eddies, which never go any further north (in fact they drift south). Being at least ten times wider and driven by the equator to pole temperature difference at the surface, the large volume of warm water should certainly keep marching forward and dominate over the skinny Gulf Stream.

In support of that notion are three vertical sections of temperature in the surface layer of the North Atlantic, yielding important subsurface information (i.e. mixed layer depths) which Maury could not have had. During February, 1959, 250 BTs (bathythermograph) measurements were made along 30 N

starting at Africa and moving west over a 40 degree longitude band. They all show a distinct mixed layer depth greater than or equal to 85 m. By comparing this east/west vertical temperature section with two other BT sections, one along 16 N and the other along 40 N taken one year earlier, but also in the cooling season (October, November), it is proposed that there was a wide warm northward drift in the surface layer between 16 and 40 N, and probably extending beyond 40 N as well, and that the deep mixed layers were made by cooling from above. All three vertical sections are in Fuglister's atlas, but the one at 30 N is in the form of raw data which needed to be read with magnification to get out the mixed layer depths.

In addition, the H. O. 225 SST atlas shows that the southwestern tropical North Atlantic, excluding the Gulf of Mexico, exhibits the same remarkable feature already found in the North and South Pacific: the highest SSTs always occur there but they are not significantly higher in summer than in winter, in spite of the self-evident fact that more solar energy per unit time and per unit surface area is absorbed in summer than in winter. For a heat balance of the surface layer, excess heat must be exported at all times out of the tropics, but more in summer than in winter, and a broad northward advection is the most reasonable method of doing this. It is not believable that the narrow Gulf Stream could do this job on its own. No systematic seasonal variation in the width or speed of the Gulf Stream has come to my attention that could accommodate summer's increased accumulation of solar energy in the surface layer.

In May of a year in the early 2000s I got the chance to walk on one of the Isles of Scilly, just southwest of Land's End. It has the warmest climate of the U. K. at latitude 50, because it is bathed in warm water most of the year. There are tropical plants growing there. To suggest that the Gulf Stream keeps this island warm would be to stretch the imagination unduly I believe. More natural would be to assume that the large warm volume outside the Gulf Stream, which the vertical sections suggest heads north from 40 N, brushes by these islands.

6. NORTH INDIAN OCEAN

Investigating the Indian Ocean above the equator began with a question: what happens to the excess solar radiation absorbed in the low to mid-latitudes, especially that beginning in spring and continuing through the summer, since the ocean is landlocked to the north at mid-latitudes? Restrictions are thereby placed on what the ocean currents can do in order to solve this heat budget problem, compared to what exists in the other oceans. It did not seem plausible that all the excess oceanic heat could be given up to the atmosphere and carried to higher latitudes by the winds. For one thing the highest mountains on earth could stand in the way of the winds doing that. Monsoon activity undoubtedly does carry some heat away from the sea to the land.

Next, I supposed that somehow excess heat must cross the equator and exit to higher latitudes through the South Indian Ocean, but what evidence there was did not suggest such an alternative. So I started digging into the data for clues. In the northwestern Indian Ocean surprises were sitting there. For example, sea surface temperatures begin warming up in spring as expected. But in May the temperatures start cooling off and continue doing so right through August. What can be the reason for that happening? A spring cool down, which starts before the monsoon does, keeps on going all through the summer.

As if the spring cool down were not enough of a puzzle, after August the SSTs of the northwest Indian Ocean begin warming again and reach a new high in October/November! In other words, there are basically two summers and two winters in one year in this part of the ocean. Both the spring cool down and the double seasonal cycle of SST are substantiated by two independent sources of data in

two separate atlases: the H. O. 225 atlas contains all the ship-injection data available up to the date of publication (1944), while the Indian Ocean atlas [8] has monthly SST maps for the whole Indian Ocean that includes all the ship-injection data for the one year 1963, almost twenty years later. Therefore it can be accepted that the spring cool down and the so called second summer are real features [9].

When the spring cool down begins in the northwest Indian Ocean, SSTs show that the first temperatures to drop are at the coast of Africa (Somalia), and then the cooling spreads east and north across the basin's surface from there. What must be happening is that the colder water crosses the equator from the South Indian Ocean and begins pushing the warm surface layer out of the way in the North Indian Ocean. Resulting from the spring cooling is the second winter of the year, which peaks in August!

Apparently, the warm water pushed eastward by the entering cold water gets bunched up vertically and temporarily stored on and near the equator. This suggestion comes from a vertical hydrographic section along the equator that was carried out in July, 1962 [8]. It shows a deep mixed layer (100 m) in a large longitude band centered around 80 E. Assuming that the sun alone could not produce such a deep mixed layer in July on the equator without help from some sort of stirring mechanism, especially since 90 % of the sun's rays that penetrate the sea surface are absorbed within the top 100 m and the absorption rate decreases with increasing depth, the idea of a bunching up of the uniform warm water comes to mind.

A little more hypothesizing is needed before arriving at an explanation of the second summer in October/November. Beyond the reach of available data, suppose the depth of the mixed layer in the north latitude direction and within the northwest Indian Ocean is bowl shaped where the bottom of the bowl is at the equator (actually half a bowl would be a better image). If the hypothesis turns out to be true, logic can build an argument by incorporating thermal expansion: sea level will be highest at the equator and slope down to the north. In that case warm water will flow northward downhill, floating on the colder water, assuming no counteractive force exists that can stop it.

7. CONCLUSION

Of the five oceans examined in some detail four of them (North and South Pacific, North and South Atlantic) have permanent arrangements by which wide warm surface currents flow poleward and cold currents return equatorward, either below and/or to the side of the warm ones. It is thought that these currents are involved with maintaining the balance of heat of the individual oceans. Water and salt are also presumed to be conserved, and in the largest oceans of the North and South Pacific eastward angular momentum is balanced as well. It has been proposed that the wide warm current of the North Pacific can affect the weather immediately above it by causing the North Pacific High pressure cell, and to some extent the weather that passes over the United States. The northwest Indian Ocean has a unique solution to the heat balance problem exhibited by two summers and two winters in a given year, and the hypothesis to explain that observation is more complicated. Particularly newer data are needed for verification in this ocean, but there is considerable room for the accumulation of new observations to further elucidate the large-scale surface circulations in the other oceans as well.

References

- [1] Kenyon, K. E. (1981), A shallow northeastward current in the North Pacific. *J. Geophys. Res.*, 86, 6529-6536.
- [2] World Atlas of Sea Surface Temperatures (1944) 2nd Ed., H. O. 225, U. S. Navy, Washington, D. C.
- [3] Kenyon, K. E. (2012), Southward surface flow in the central South Pacific. *Natural Science*, 4, No. 11.
- [4] Kenyon, K. E. (2017), Pacific tropics are warmer than Atlantic. *Natural Science*, 9, No. 2.
- [5] Fuglister, F. C. (1960). *Atlantic Ocean Atlas*, Woods Hole Oceanographic Institution, Woods Hole, MA.
- [6] Maury, M. F. (1963). *The Physical Geography of the Sea and its Meteorology*. Belknap Press of Harvard University Press, MA.
- [7] Kenyon, K. E. (2017), Large volume of warm water outside the Gulf Stream, *Natural Science*, 9, No. 3.
- [8] Wyrtki, K. (1971). *Oceanographic Atlas of the International Indian Ocean Expedition*. National Science Foundation, Washington, D. C.
- [9] Kenyon, K. E. (2017), Second summer in NW Indian Ocean, *Natural Science*, 9, No. 8.