JAPAN'S DEEP MIXED LAYER TROUGH: KUROSHIO?

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ABSTRACT
A deep mixed layer trough off Japan is described from the BT Atlas of the North Pacific by means of centerline curves that connect the greatest depths of the troughs present in all 12 monthly mean charts. Curvatures are mainly clockwise, but the sign changes in a few cases, such as April, where the centerline curve meanders at mid-latitudes. Independent XBT data confirm the possibility of meanders in April. Though similar to the mixed layer trough off California, Japan's trough is roughly a factor of two shorter in length. Presumably the vertically uniform temperature water in the trough flows northeast at mid-latitudes, and surface cooling plus penetrative convection produce the deep mixed layer. It is concluded that Japan's deep mixed layer trough is a signature characteristic of the Kuroshio.

Keywords: Kuroshio, Japan's mixed layer trough

1. Introduction

In the 1970s a wide warm surface current off California was predicted on the basis of a very large ship-injection SST data set, covering most of the North Pacific for 30 years [1]. Being both real and permanent, this current flows northeast at mid-latitudes with an east/west width of 4,000 km at the surface along 35 N and maximum depths of a bit over 100 m in the middle. Mean flow speeds are slow: 10-20 cm/sec. Wide, warm, shallow and slow is the poleward flow.

One important function of the "new" current was conjectured to be transporting poleward some of the excess absorbed solar radiation in the ocean's surface layer away from the lower latitudes, where it is most abundant all the time [1]. That concept sets a ball rolling that has been trying to roll further for a long time. Recently the origin for the drifting wide warm water off California was hypothesized to be the western tropics of the North Pacific, because that is where a deep mixed layer trough exists which directly connects to the relatively warm sea surface region that comes close to California, and it then ends up in the Gulf of Alaska[2].

Data behind the hypothesized origin come from very many BT (bathythermograph) traces assembled into an atlas of the whole North Pacific [3]. BTs measured temperature continuously as a function of depth from the surface to about 100 m. In the Atlas 28 years of data were combined into monthly mean charts showing contours of constant temperatures at five different fixed equally spaced depths as well as charts with contours of constant mixed layer depth. All 12 mixed layer depth charts show a trough of deep mixed layers continuously connecting the western tropics with the offshore waters of California. Filled with warm water nearly uniform vertically the trough is believed to be a conduit for conducting heat northeastward.

A wonder as this permanent warm water drift off California is at any time of the year, yet there is virtually no possibility that it could adjust to the increased input of solar radiation absorbed in summer, because it is not readily believable, based on the available data, that such a current could significantly increase its mean speed, or get any deeper or wider in summer [4]. Observations provide another solution to this aspect of the ocean's heat budget problem. In the western tropics of the North Pacific the SSTs have an unusual property: they are always the warmest anywhere in that ocean but they are not significantly warmer in summer than in winter in spite of the self-evident fact of the increase in absorbed solar energy in summer. Consequently a very efficient heat balance mechanism in the region must be operating in the surface layer that just keeps pace with the sun.

Northward advection in the surface layer over a wide range of longitudes is suggested by the available SSTs. Two independent atlases agree that the surface isotherms in the western tropics begin to bulge northward in spring to the extent that the size of the surface area between the equator and the 80 F contour, for example, doubles in summer compared to the winter value [5]. This observation is consistent with northward advection in the surface layer. The driving force for the northward flow is thought to be a downward slope to the north in the sea level, set up by thermal expansion in the deep mixed layer trough during spring and summer.

Permanent and seasonal (summer) northward flows in the surface layer both originate in the western tropics and they both serve to help balance the heat budget within the top 100 m of the sea surface of the North Pacific. That much poleward transport might be sufficient to complete the heat balance if it can be assumed, for one thing, that there is no substantial cross-equatorial flow that would result in a net heat exchange between North and South Pacific. Such an assumption needs to be evaluated in the future.

Nevertheless, since there are many conceivable patterns of flow available for solving the heat budget problem, one should just double check the observations to see if any other warm poleward surfaces flows, permanent or seasonal, wide or narrow, long or short, fast or slow exist within the North Pacific proper. That is the goal of the present study, and as it turns out, the signal of an additional poleward flow is found in the west, in the mixed layer depth data, which may or may not be a surprise depending on the point of view adopted. It is of the permanent type. There are similarities and differences between it and the wide warm current off California.

2. Mixed Layer Depth Data

Positional information regarding the deep mixed layer trough off Japan is contained in Figures 1-3. There are three groups of four lines each. A line roughly represents the center of a trough, and twelve lines are presented, one per monthly mean. Immediately it can be seen that the trough exists in every month. By free-hand drawings, smooth continuous curves connect the deepest parts of the mixed layer troughs as far as they could be identified. These are called centerline curves for convenience.

A similar set of centerline curves were made earlier for the deep monthly mean mixed layer troughs off California [2]. By contrast those were considerably longer, at least by a factor of two, and steadier in position. However, in both cases the origin appears to be the same: the deep mixed layer trough of the western tropics.

In the present Figures 1-3 the centerline curves all have a curvature that varies in magnitude, but in a few cases the curvature can even change sign. April's centerline curve (Figure 1) is one of those, which exhibits a meandering pattern at mid-latitudes. Such a characteristic might be suspected of being unreal, but qualitative confirmation exists as explained next.

First, the mixed layer depth chart for April, copied from the Atlas [3], is presented in Figure 4. (Two other similar charts, for February and July, were republished elsewhere recently and used in a somewhat different context [5].) In Figure 5 is reproduced a vertical section of temperature in the upper 500 m obtained as part of a complete hydrographic section made from California to Japan along 35 N in March and April, 1976 [6]. BTs were used in the Atlas, XBTs in the vertical section. All the April BTs used in the Atlas were taken earlier than 1969, seven years before the April XBTs were made in the western North Pacific along 35 N.

After Figure 5 was completed, my attention was totally absorbed by the upper layer of the eastern half of the vertical section; interpretation of the temperature structure in the western half was postponed indefinitely. Now, in view of Figure 4 it appears very likely that the oceanographic ship sliced right through a meandering current while approaching Japan along 35 N.

By analogy with the wide warm current off California the deep mixed layer trough off Japan contains warm water that is presumed to flow northeast at mid-latitudes. As it moves along the cooling at the surface creates the deep mixed layer by penetrative convection.

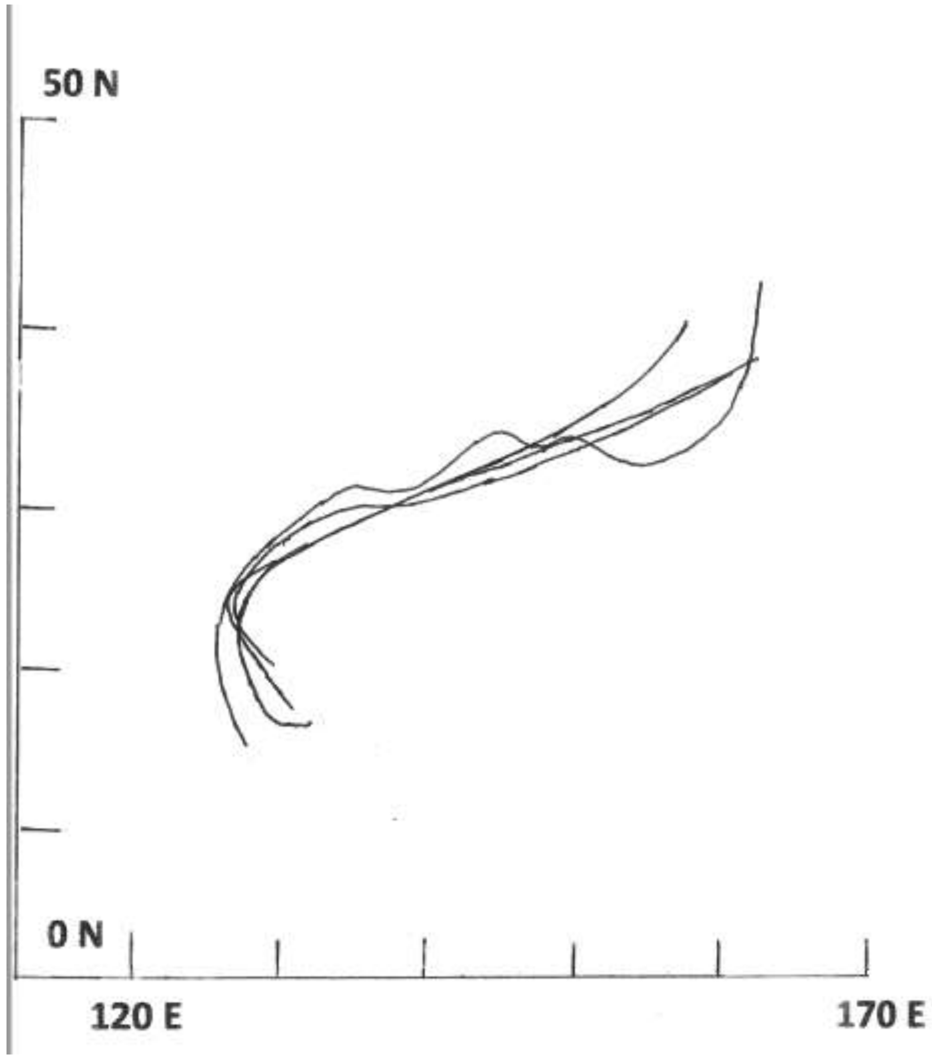

Figure 1 Centerline curves of troughs in deep monthly mean mixed layer depths obtained from Reference [3]. Longitude range of the horizontal axis is from 120 E on the left to 170 E on the right. Latitude range is from 0 N at the bottom to 50 N at the top. From most north to most south the western ends of the curves are for March, February, January and April.

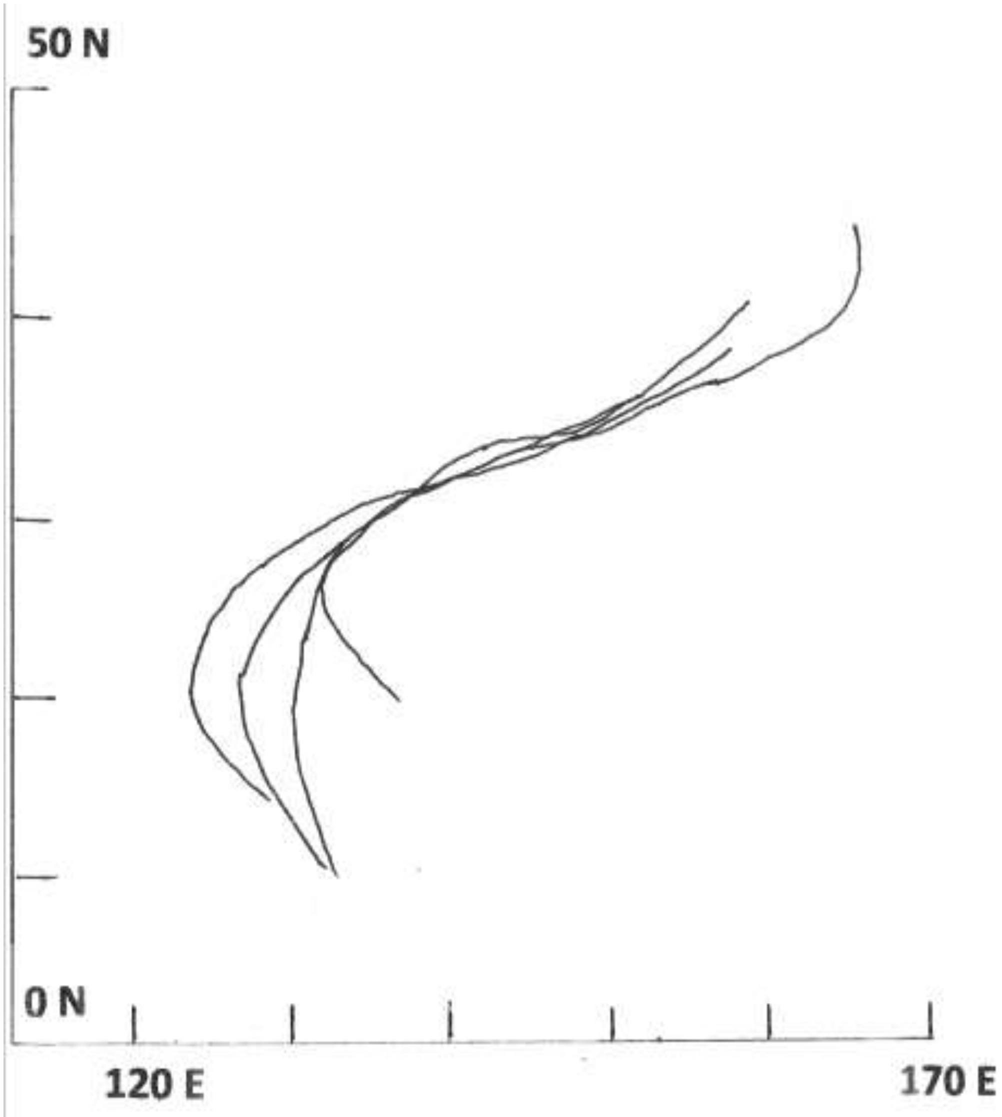

Figure 2 Same as Figure 1 except from most north to most south the western ends of the curves are for June, May, July and August.

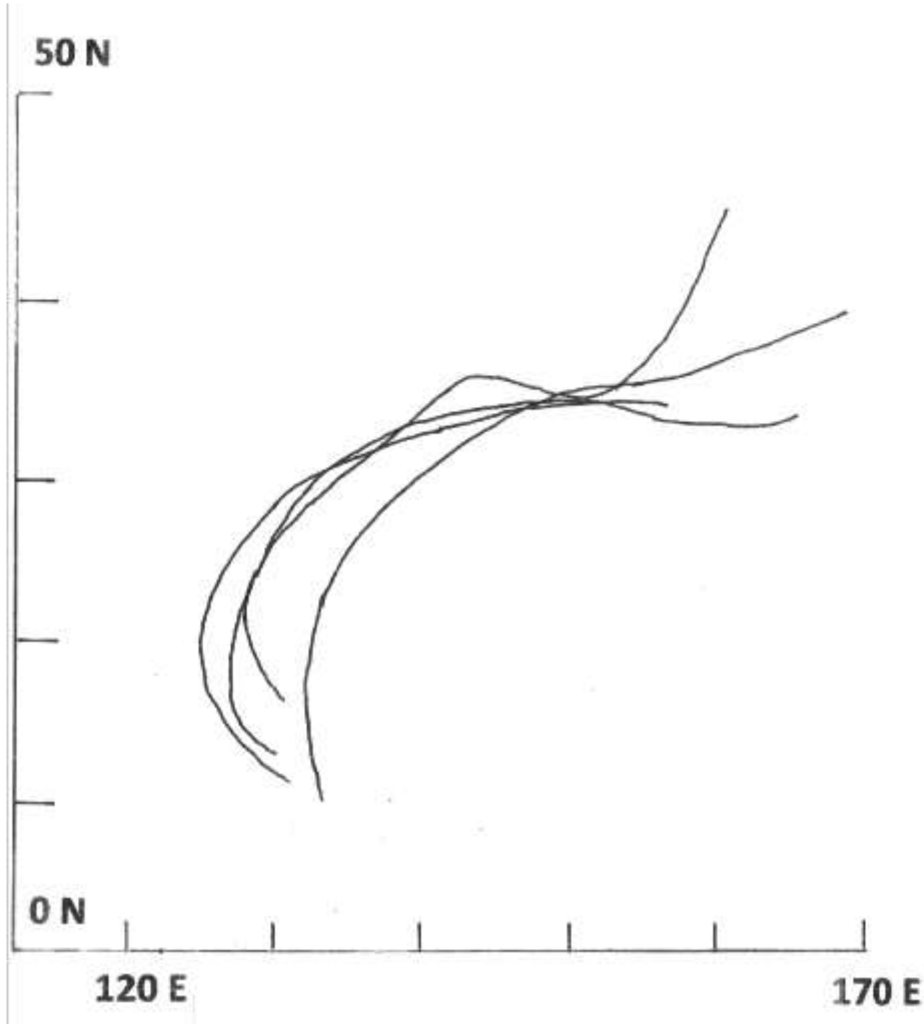

Figure 3 Same as Figures 1 and 2 except from most north to most south the western ends of the curves are for December, November, October and September.

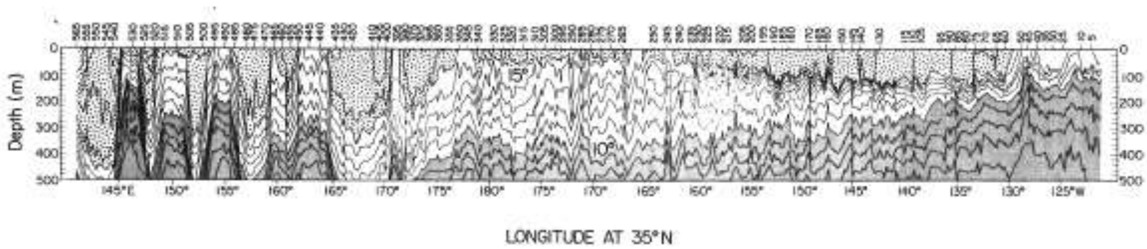

Figure 4 Monthly mean mixed layer depth contours for the North Pacific for April scanned from Reference [3]. Contour intervals are 50 ft.

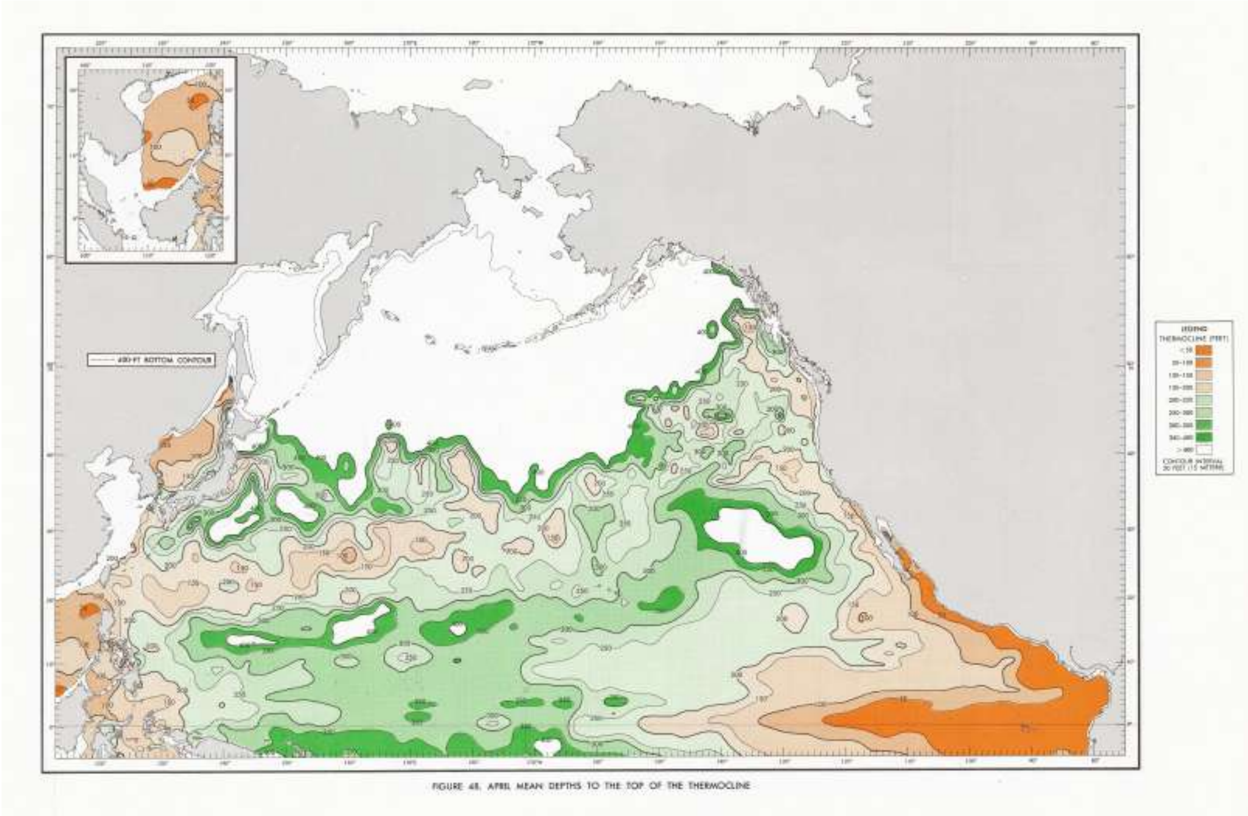

Figure 5 Transpacific temperature section at 35 N for the upper 500 m based on about 500 XBTs taken every 20 km between California and Japan. Isotherms are for each whole degree C.

3. Discussion

Logically Kuroshio is the name of the warm current flowing in the deep mixed layer trough off Japan. But when that name comes up, some readers will think of a narrow stream, perhaps about 100 km wide (or further marginalized to a thin western boundary current), in other words a current very similar to the Gulf Stream. On the other hand, by way of expansion, what should be said to people who grew up in Vancouver and heard from their grade school teachers that the reason the winters are milder there than expected for the latitude is because of the Kuroshio's influence?And it is too late to help those explorers in the Bering Sea who waited in vain for the warm waters of the Kuroshio to melt the ice and set their ships free.

Apparently the Kuroshio completes the heat balance of the North Pacific's surface layer, depending on whether or not there turns out to be any significant heat exchange between the North and South Pacific. But in so doing, by means of physical ideas, it tends to conceptually undermine the superficial coherence of the traditional gyre circulation that has existed for many years in the minds of oceanographers as well as the public. In the standard gyre it is only the Kuroshio that can transport warm water poleward.

Another way to put it is that what the observations are indicating is that there are two semi-loops (not closed gyres): the motion of warm surface water in the westernsemi-loop is clockwise, that in the eastern one is counter-clockwise (as viewed from above). They are both permanent but the one in the east dominates in horizontal scale. Then between these two semi-loops is the very wide seasonal summer surge of warm surface water moving almost straight north. Unification of all three sub-circulations comprises the net poleward transport of heat.

4. Conclusion

A Permanent deep mixed layer trough in the western North Pacific starts in the tropics and with concave curvature comes close to Japan, after which it heads generally northeast at mid-latitudes. This trough appears in 12 monthly mean charts in a classic BT Atlas showing contours of constant mixed layer depts. It is based on 28 years of bathythermograph (BT) data beginning in 1942. Meanders of the April trough are confirmed to be a likely possibility through independent XBT data taken on a hydrographic section at 35 N made in April of 1976. Presumably relatively warm and vertically uniform water moves poleward in the trough, which is formed by cooling at the sea surface and penetrative convection. It is concluded that the deep mixed layer trough is a characteristic feature of the Kuroshio.

References

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