MOVEMENTS OF FLOATING DEBRIS IN THE NORTH PACIFIC

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ABSTRACT

A net fragments tracking experiment and numerical simulations using surface current data set (SCUDS) data were conducted to estimate movements of floating debris in the North Pacific.

Six driftnet sets (40 tans each) were placed in the area lat. 39°N, long. 155°E. Locations of the net sets and sea surface temperatures were collected and transmitted every day using the Argos system. Data were taken about six times a day for 4 months. At termination of the net drifting experiment, the net sets with buoys were retrieved and new Argos buoys with curtain drogues were released at the points of retrieval to continue the surface current tracking.

The buoys moved predominantly eastward, although each track line was complicated, particularly in areas near the Oyashio Front. It is considered that the movements of the nets were mainly due to surface currents and that direct influence from wind was negligible, because the underwater portion was very large (a driftnet 2,000 m long although it had formed a mass) compared with the above-water portion of the buoy. Average speed was estimated based on the buoy movements and ranged from 10 km/day to 20 km/day. Movements of floating debris in the North Pacific were simulated using a computer model based on SCUDS.

Results showed the existence of two large-scale eddies in the eastern and western parts of the mid-Pacific, and floating debris are through to accumulate in these areas.

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INTRODUCTION

North Pacific currents are found in a great circle ranging from the Kuroshio through the Kuroshio Extension and the North Pacific Current to the California Current and the North Equatorial Current in the south. In the vicinity of these currents are the Oyashio, Alaska, Aleutian, and other currents.

Floating debris (excluding Styrofoam, which is mostly above the surface) moves along these currents. Movements change depending on large and small vortexes in the water and are difficult to generalize, but we can estimate average movements on the basis of surface currents.

Marine features of the North Pacific are outlined by Favorite et al. (1976). The northwestern part of the North Pacific is characterized by the Kuroshio Extension and the Oyashio. The distribution of water masses in summer is greatly affected by the southerly intrusion of cold water masses and the strength of the Aleutian Current, both of which vary from year to year, as reported by Hiramatsu (1987, 1988).

Tests using driftnets were conducted to estimate movements of floating of floating debris. Driftnets were set in the Oyashio waters in May 1988 and were recovered after about 4 months of drifting. The Argos system was used for tracking the nets and analyzing their drift routes. We have also illustrated overall currents on a computer display using the surface current data sets (SCUDS), which covers ship drift data from about 4 million ship observations over the past 40 years.

CURRENT OBSERVATIONS USING ARGOS BUOYS

Method

Six driftnets were set by the first survey ship in order to observe changes in net shapes and movements in the northwestern part of the North Pacific. Each net was equipped with an Argos buoy at one tip and a radio buoy at the other. Nets were set in waters at lat. 39°N, long. 155°E and were arranged in the shape of a star, with five nets set in a 37-km (20-mi) radius from a key net.

Each net was 2,000 m (40 tans) long. Their fluid resistance in the water was so large that the early movements of each net were presumed to indicate an average current over a distance of 2,000 m. Ten days later, the shapes of several nets had changed greatly. Some nets were either folded or "balled up." They became masses with a maximum length of roughly 50 m (Mio et al. 1990).

They were still large enough to resist winds, and buoy tracks accurately indicated the movements of nets in the sea currents. There was a thermometer inside each buoy case. The buoy was metallic and had no heat-resistant structure. Therefore, each thermometer was able to indicate surface water temperatures. Styrofoam was used as a floater at the upper part of each buoy. It reduced heat flow from sunlight. Even if the buoy was exposed to strong sunlight, the thermometer's deviation from surface water temperature would have been very small.

Argos buoys were set on 5 and 6 May 1988. Three of the six buoys suspended transmission during drifting because of mechanical troubles, but the second survey ship recovered three of the four trouble-hit Argos buoys 4 months later by tracking radio buoys. The second survey ship recovered the nets and released three Argos buoys with curtain drogues for further observation of currents.

Results and Analysis

Tracks of buoys from May to September are illustrated in Figure 1.

Buoy 4783, which moved the greatest distance eastward in the 4 months, reach long. 180°. The slowest-moving buoy (4782) came as far as long. 162°E. An average speed of the maximum eastward movement was about 20 km/day. Any buoy movement was not straight but very complex depending on inertial forces and tides. The theoretically calculated inertial cycle at lat. 40°N is about 19 h, and it matched these observations. Figures 2-4 indicate the track of buoy 4789, which is zoomed gradually. Figure 4, where vertical and horizontal scales are almost the same, shows that the floating debris moved north to northeast at an average speed of 7 cm/sec while making a clockwise motion. The radius of the circular motion was about 1.6 km, and the flow speed was 10-50 cm/sec. Driftnets, which were set at roughly the same place, followed very different tracks, hinting at a large diffusion coefficient in the waters. One hundred days after setting, the maximum east-west distance between tracks was 1,637 km and the maximum

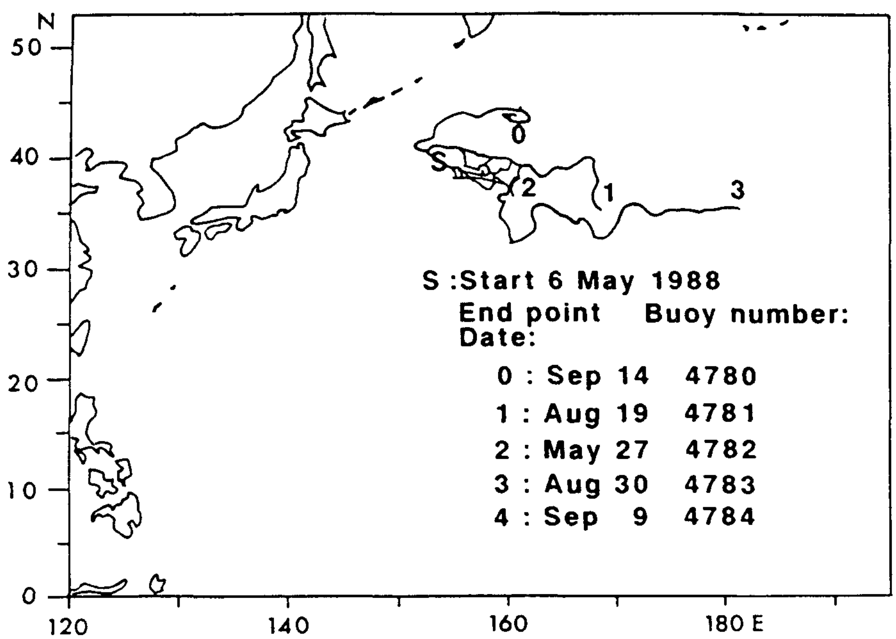

Figure 1.--Trajectories of drifting buoys.

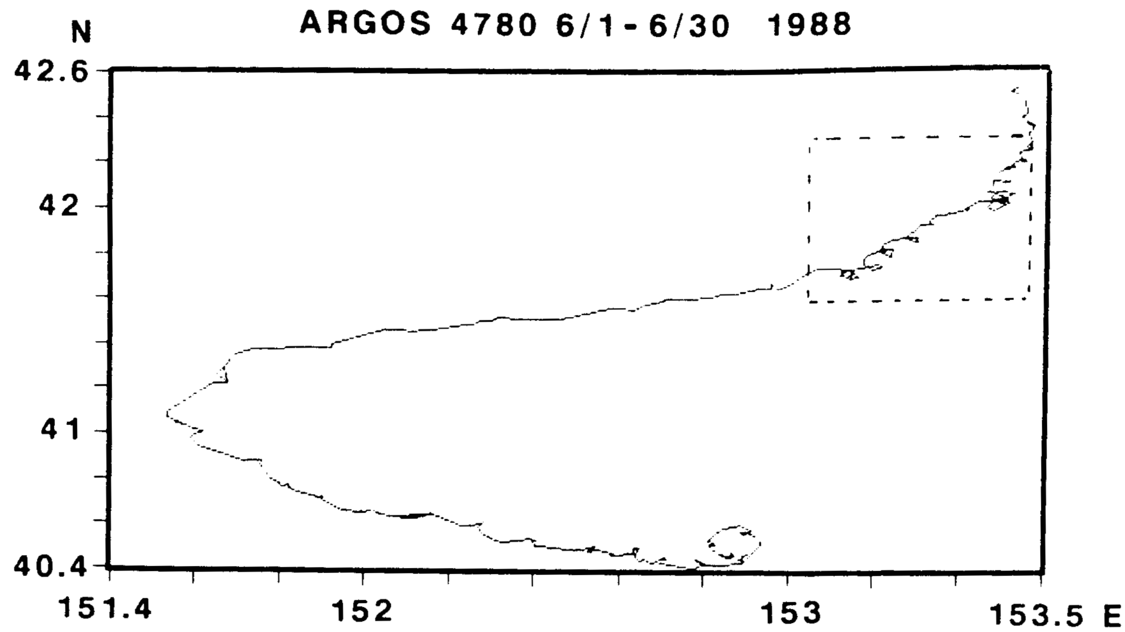

Figure 2.--Western part of buoy 4780 trajectory.

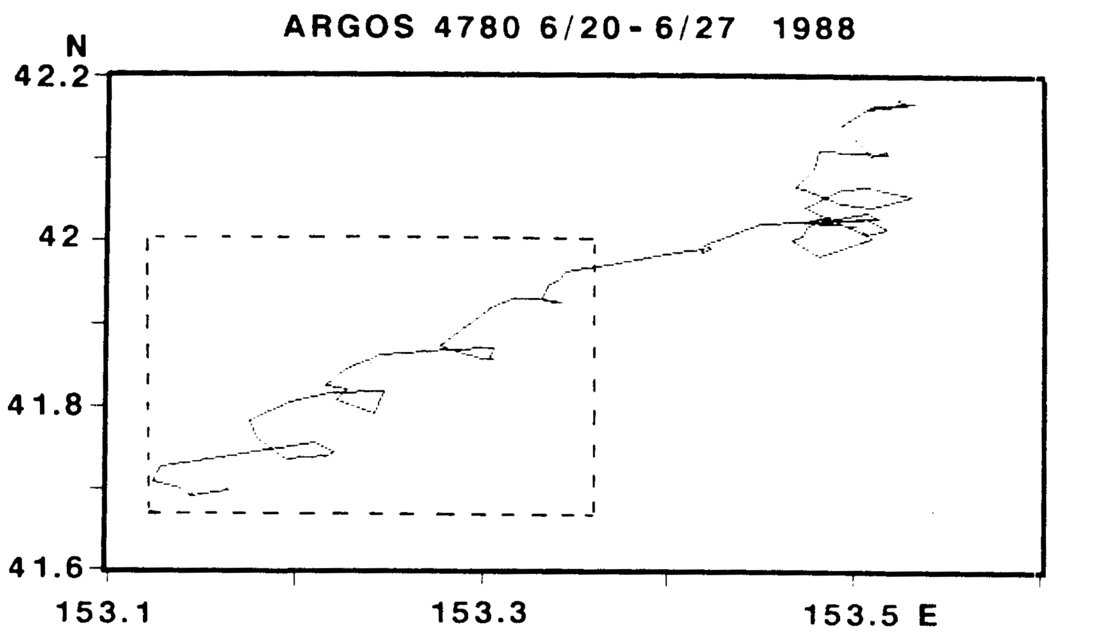

Figure 3.--Part of buoy 4780 trajectory, enlarged from Figure 2.

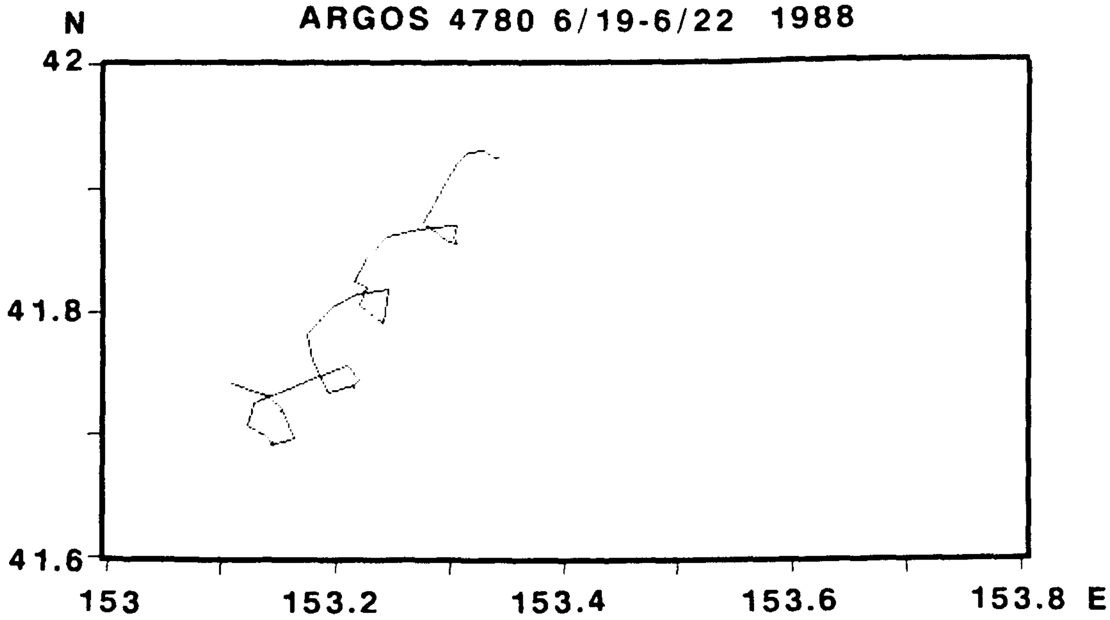

Figure 4.--Inertia circle of buoy 4780, enlarged from Figure 3.

north-south distance was 1,021 km. The large diffusion indicates a need to incorporate a large plus or minus deviation in forecasting the movement of any object in the water on the basis of the generally known currents. The large diffusion coefficient gives evidence of great turbulence in the waters.

Data from thermometers on the buoys are shown in Figure 5. Any buoy with a large net cannot be expected to go through a water mass or across the front of a mass. Short-term changes in the water temperature, especially sudden declines, may be attributable to vertical mixing of waters.

The water temperature rose gradually during the observation period between May and September. Any sudden rise in the temperature may be attributed to a combination of strong sunlight and calm water, which can cause an increase in just the surface water temperature. It may also be ascribed to surface water which was heated by the sun and flowed into the vicinity of a buoy.

Driftnets remained at a depth of 10 m. Warm surface waters which are frequently seen in the northern part of the North Pacific in summer are usually limited to 1 or 2 m in depth.

The surface water temperature changes are seen frequently in infrared heat pictures taken by satellites and have some adverse effect on analysis of water masses, which depends on surface temperature.

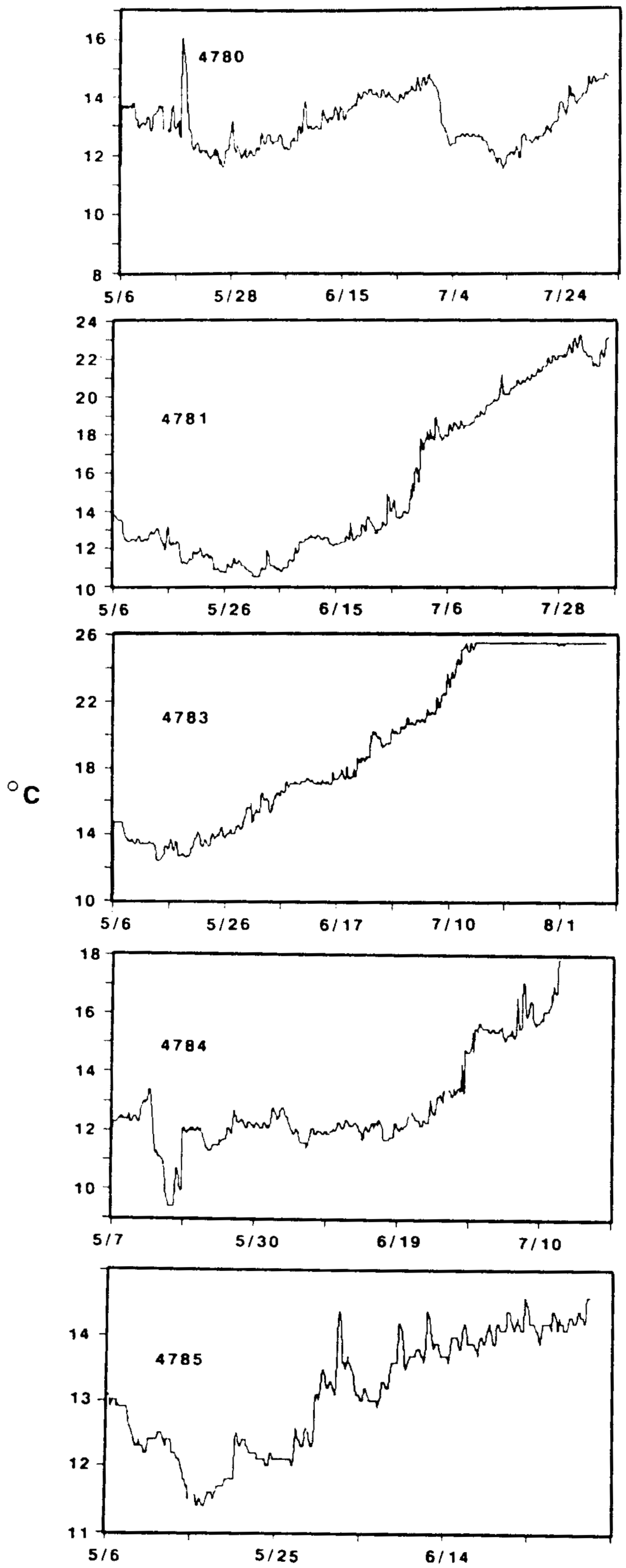

Figure 5.--Daily changes in buoy temperatures (May-August 1988).

SIMULATION OF FLOATING DEBRIS MOVEMENT AND DEBRIS DENSITY USING SHIP DRIFT DATA

If the speeds of all sea currents in time and space are available, the track of floating debris like the buoy on currents such as those discussed in the previous section can be simulated. Based on a specific speed at an initial point, we can determine a point debris would reach within a given period of time. Another current speed at the arrival point can be used to estimate how fast and where the debris would move further. Repeating such estimates can lead to a possible track which floating debris would follow.

In this section, we try to solve the Lagrangean equation and simulate a buoy track on the basis of given sea current speeds. We have used the ship drift data released by Meehl (1982). The currents in any time and space can be obtained by interpolating these data. We have compared the simulated results with findings from buoy drift observations by Kirwan et al. (1978) and sightings of floating debris observed by the Fisheries Agency, the Government of Japan (Mio et al. 1990) in order to analyze the mechanism for the gathering of objects.

Our simulation results successfully matched the findings from Kirwan's observation in both time and space. The model may be available for the simulation of buoy movement.

Thus, in the following, we will discuss where buoys set in waters around Japan move and where a number of buoys set all over the Earth would gather.

Drifting in the Western North Pacific

Assume that buoys are initially dropped at lat. 30°N, long. 140°W near Torishima Island in the western part of the North Pacific. The results show how the buoy track changes depending on the season.

Spring

Figure 6(a) shows the track of a buoy set on 1 April. The buoy immediately begins to move eastward and reaches the international dateline in 6 months. However, the buoy remains around lat. 30°N, long. 150°W for nearly 2 years while its track loops. This is because it is dragged into a vortex in the eastern part of the North Pacific (Meehl 1982, fig. 2). Floating debris can remain in the water for a long time. If floating debris such as waste were dumped evenly all over the Pacific, it would tend to gather in the vortex waters.

Summer

Figure 6(b) shows the track of a buoy set on 1 July. It also moves eastward, but its speed is far faster than that of the spring buoy. It reaches the international dateline in about 4 months. Since the speed of currents at long. 140°E is fastest in autumn, the buoy set in summer is eventually moved by these fast currents. Later, it is dragged into the vortex in the eastern Pacific and remains just north of Hawaii.

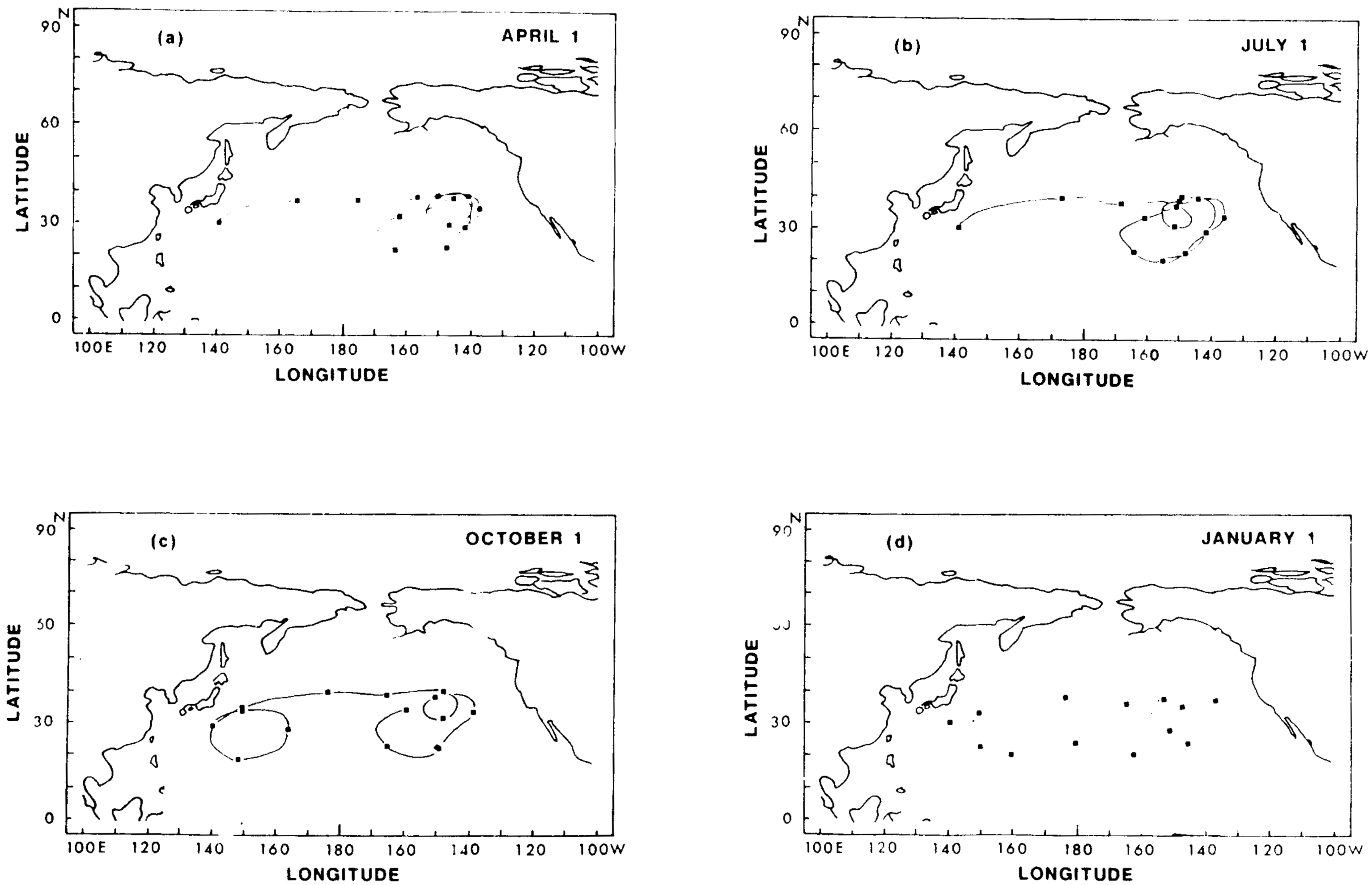

Figure 6.--Simulated tracks of buoys which were set at lat. 30°N, long. 140°E in the western North Pacific in (a) spring (1 April), (b) summer (1 July), (c) autumn (1 October), and (d) winter (1 January). Each buoy took 3 months to move from one mark to another.

Autumn

The track in Figure 6(c) is for a buoy set 1 October. Unlike the above tracks, this one loops around lat. 30°N, long. 150°E before extending eastward. The Kuroshio Extension weakens, and a vortex and a southward current around lat. 30°N, long. 150°E appear in winter. A buoy dropped in autumn is dragged into this winter current. The loop indicates that floating debris stays in the water for a long time.

Winter

Figure 6(d) shows the track of a buoy put into the water on 1 January. Like the track of a buoy set in autumn, the winter buoy track includes a small loop in the western Pacific.

All of the above tracks loop in the eastern part of the North Pacific. This indicates that floating debris remains in the water for a long time and tends to gather there.

Drifting in the Eastern North Pacific

Figure 7(a,b,c) shows the tracks of buoys put into the water on 1 May. The three drop sites are lat. 50°N, long. 140°W; lat. 40°N, long. 130°W; and lat. 30°N, long. 120°W, respectively. The buoy in Figure 7(a) is set in the region of the Alaskan current system. It moves westward, traveling south of the Aleutian Islands around the Alaskan gyre and western subarctic gyre. After turning south it is picked up by the North Pacific current system and moves eastward as in Figure 6.

The buoy which is set at lat. 40°N (Fig. 7b) is carried westward by the North Equatorial Current system after remaining in the vicinity of lat. 30°N for nearly 2 years. The buoy set at lat. 30°N (Fig. 7c) immediately begins to move westward.

Debris Density

We calculated many tracks in the Pacific from starting points evenly distributed in space and time to find where buoys would gather. We tried to find not the place where a buoy dropped at a certain point would go, but the place where buoys would gather intrinsically due to currents, irrespective of setting points or time.

We simulated tracks for 7,755 buoys. Dropping points were chosen randomly so that the number of initial buoys would be the same for every unit area. The setting density was five buoys for every 3.09×10^{11} m^2 of ocean; buoy setting continued for 4 years. To scatter drop times evenly, they were chosen on the basis of random numbers. Presuming a lifespan of 2 years, we simulated a track for each buoy for 2 years.

Figure 8 indicates the debris density in January after 4 years of setting. In the sea, you see some points to which buoys were carried by currents. In the North Pacific, which is our area of concern, debris is

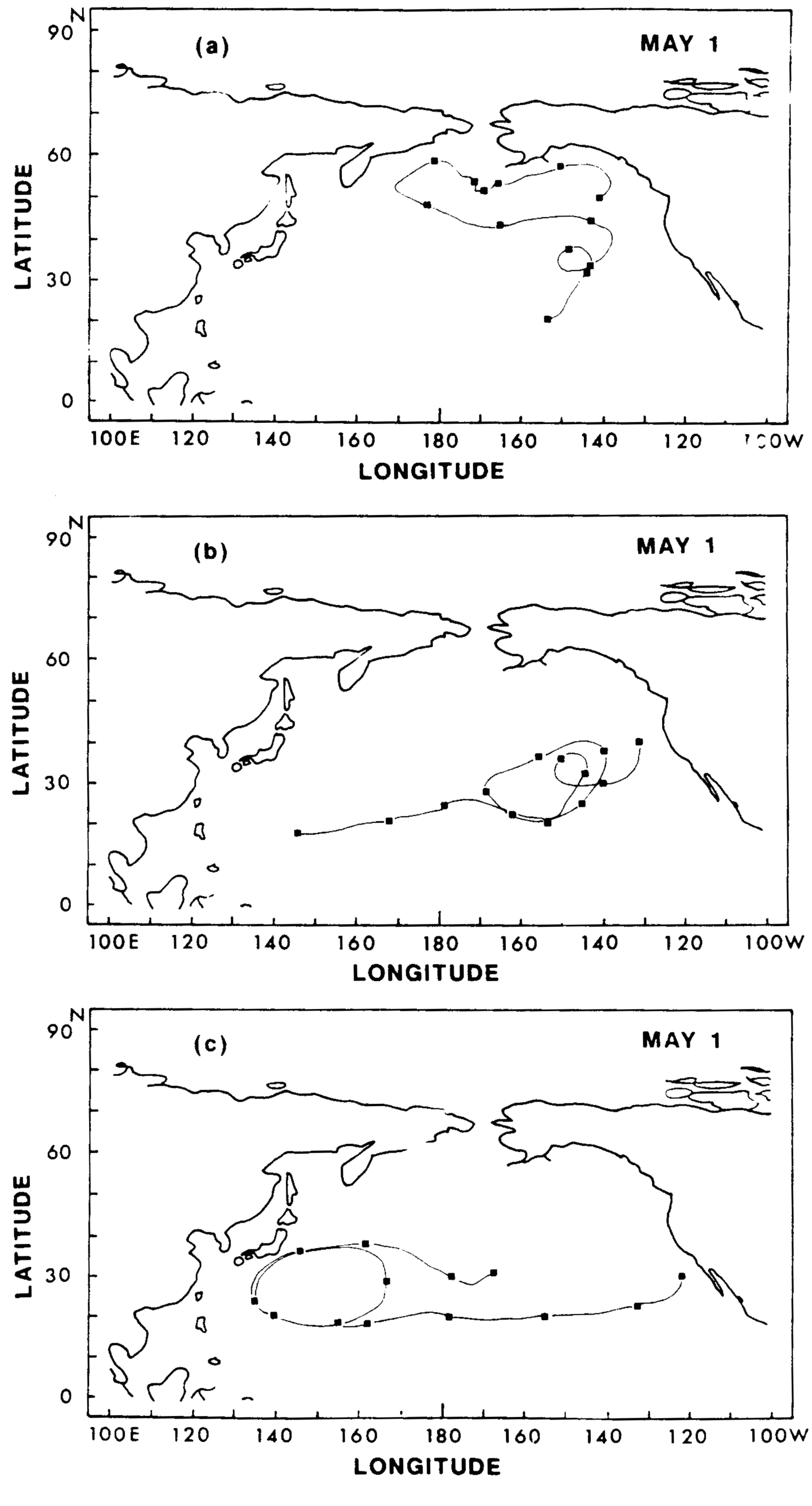

Figure 7.--Simulated tracks of buoys which were set at (a) lat. 50°N, long. 140°W; (b) lat. 40°N, long. 130°W, and (c) lat. 30°N, long. 120°W in the eastern part of the North Pacific on 1 May.

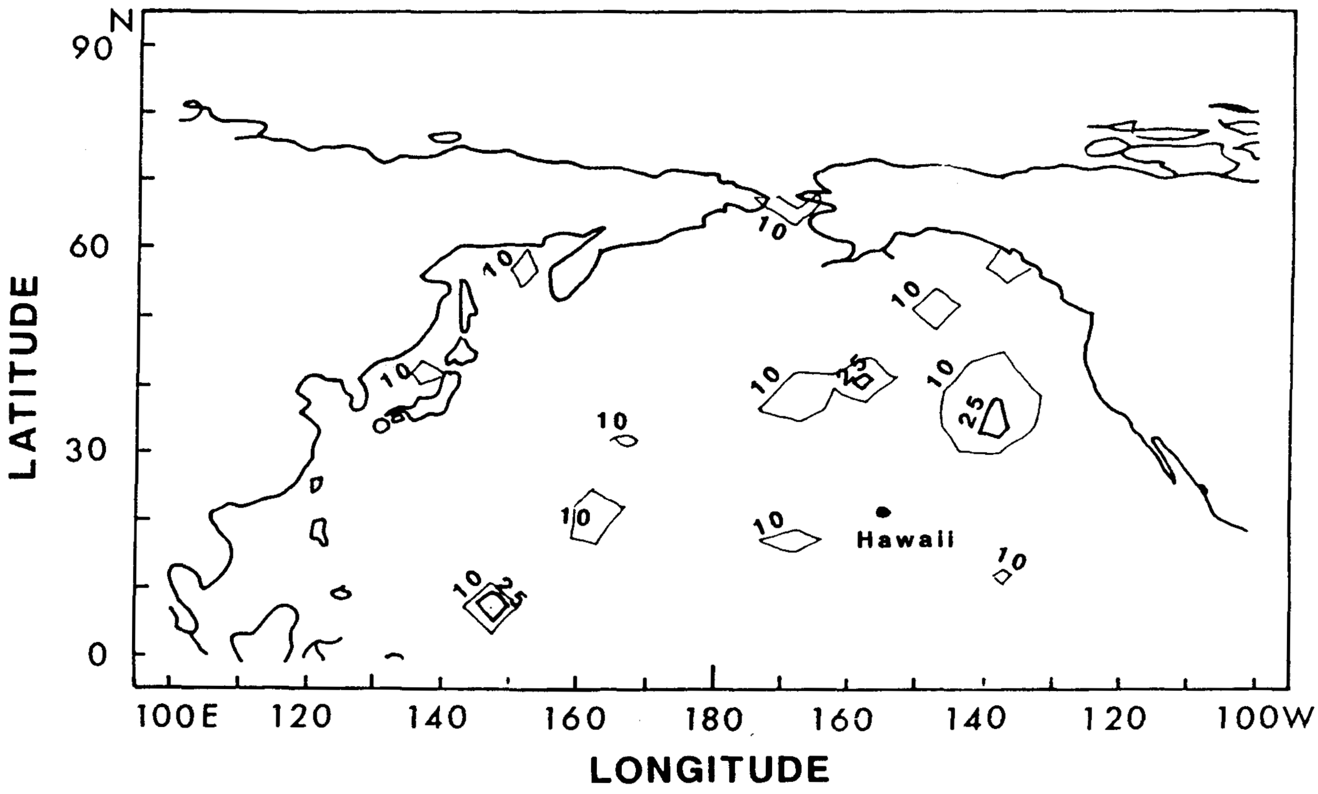

Figure 8.--Floating debris density in the North Pacific on 15 January. Contour line shows the number of buoys in unit area. Original density was give at every place.

seen to gather in the eastern part. The gathering points are to the north of Hawaii, which agrees with sighting observations of Mio et al. (1990). However, note that the gathering points shift seasonally. In the Northern Hemisphere, winds in areas of high atmospheric pressure circle to the right and sea surface currents deviate from the wind direction by 20° to 30°, as pointed out by McNally (1981). So we know that a high concentration of debris could be seen in the center of the North Pacific area of high atmospheric pressure.

CONCLUSION

The results of drift buoy observations matched fairly well those of the simulation based on ship drift data in waters like the Kuroshio Extension where the current is strong. Debris getting into the currents may cross the North Pacific in about 1 year.

There are no marked currents in waters around the Ogasawara Islands and northwest of Hawaii in any season. Figures for drift tracks and for distribution of floating debris point to those waters as locations where floating debris can gather.

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