# Direct Measurement of Recirculation in the Alaskan Stream[1]

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ABSTRACT

Three drifting buoys were deployed off Kodiak Island and tracked by satellite in summer 1978; all three veered out of the southwestward flowing Alaskan Stream and moved to the east and northeast around the Gulf of Alaska gyre. This is the first direct measurement of recirculation around the gyre, but the pattern is strikingly similar to what was inferred two to three decades ago from property distributions, and it has been predicted theoretically.

## 1. Introduction

The arcuate Gulf of Alaska coastline forces the northern boundary of the Pacific subarctic gyre into a westward outflow of water from the Gulf of Alaska. This narrow, deep, intense flow (the Alaskan Stream) appears to be continuous from the head of the Gulf to the western Aleutian Islands, but losses or gains of water across its southern boundary seem to occur (Favorite *et al.*, 1976). A loss of Stream water to the southeast is indicated frequently in the vicinity of 160°W (Favorite *et al.*, 1976); this water is presumably entrained into the eastward flowing Subarctic Current and recirculates around the Gulf of Alaska gyre. Most of the evidence for this type of circulation is based on physical property distributions, but theoretical studies also support such a pattern. Munk's (1950) pioneering study, for example, suggested southward outflows from the northern boundary of the subarctic gyre, and Thomson's (1972) model of the Alaskan Stream indicated one or more zones of eastward recirculation well east of the western portion of the subarctic gyre.

The salinity pattern in Fig. 1 (summer 1959; Dodimead *et al.*, 1963) is suggestive of a southeastward recirculation of dilute Stream water near 160°W, but the data do not provide conclusive evidence that a significant part of the water column was actually flowing to the east in a quasi-steady manner. This note presents data from drogued drifting buoys, however, which do indicate the existence of a large-scale recirculation around the Gulf of Alaska gyre that supports the classical concept of the flow regime.

## 2. Data and methods

Three drogued buoys were deployed off Kodiak Island in July 1978 as part of NOAA's Seasat-A verification project. The buoys were manufactured by the Polar Research Laboratories; they consisted of cylindrical aluminum spars with a flotation collar and ballast and "windowshade" drogues (~2 m × 10 m) centered at a depth of about 20 m. The buoy locations were determined by the Random Access Measurements System of the Nimbus 6 satellite, and they were provided by Sperry Support Services at NOAA's Data Buoy Office. Additional details on this system are given by Royer *et al.* (1979). For about the first six weeks after deployment, several locations were obtained each day, but the number of fixes thereafter rapidly declined, mainly because the receiving stations were being used with a new satellite system. The drifters were equipped with tension devices to determine if the windowshade drogues were intact; the data received by the satellite could not be used unambiguously for this purpose, but it seems likely that the drogues remained intact during the trajectories and that the paths were not strongly affected by windage as indicated by the results of Kirwan *et al.* (1978). The location data were subjectively evaluated, and the resulting positions probably have reliabilities comparable to the rms position error (~4 km).

## 3. Drifter paths and circulation

Reed (1979) analyzed the July–August 1978 data from two of these drifters; mean daily positions were used, and some evidence was found for changes in speed associated with inshore-offshore migrations near the Stream edge. The drifter paths, from deployment until the last positions were received, are shown in Fig. 2. Representative positions are given rather than locations at fixed intervals; this was necessitated by the very irregular nature of the data received after August. All three drogued buoys moved southwest in the Alaskan Stream, all turned southeast, and they all moved northeast toward the Gulf of Alaska. Drifter numbers 400 and 561 moved in very similar paths until both buoys approached the head of the Gulf of Alaska, when number 561 became entrained in the coastal Kenai Current

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(Schumacher and Reed, 1980) but number 400 did not. Drifter number 753 was deployed between numbers 400 and 561; after early August, however, it moved inshore of the other two buoys and did not turn offshore until almost 500 km west of where they departed the continental slope. The eastward movement of number 753 was subsequently to the south of the other two drifters. Its more easterly course may have been affected by the smaller northward total wind-stress transport at this latitude than to the north near the other two drifters [wind-stress data provided by A. Bakun, National Marine Fisheries Service, private communication; see, also, Reed *et al.* (1980)].

Table 1 compares the net speeds determined for various positions along the drifter tracks. (Southeast flow is the initial part of the recirculation, and northeast flow is presumably the movement of the Subarctic Current.) Speeds within the Alaskan Stream were greatest, except for the one drifter in the Kenai Current, and the southeast flow was slightly less than the northeast flow toward the Gulf. The net speed in the Kenai Current is similar to values given by Royer *et al.* (1979). Although flow perturbations are present, the large-scale movement during the period is quite orderly.

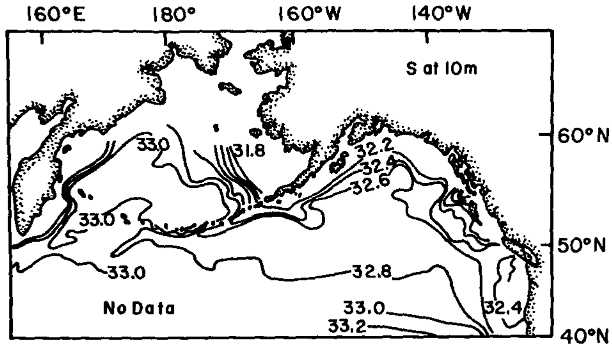


FIG. 1. Horizontal distribution of salinity (‰) at 10 m during summer 1959. After Dodimead *et al.* (1963).

## 4. Discussion

Maximum velocities in the Alaskan Stream (Favorite *et al.*, 1976) are generally at least twice as great as the larger values here, so it is likely that the peak Stream speeds were inshore of where the drifters were deployed. We expect recirculation to occur on the southern side of the Stream, of course, as these data would suggest; the offshore movement, though, occurred in at least two distinct locations (near 158 and 166°W). Eastward velocities in the Subarctic Current are roughly twice those obtained from the geostrophic relation, as was found by Kirwan *et al.* (1978) who attributed the differences largely to an Ekman component from the westerly winds. Unfortunately, there are not adequate data during these observations to map the large-scale geopotential topography for comparison with the observed flow.

Perhaps the most striking impression from Fig. 2 is that the large-scale flow is quite smooth. The flow does not seem chaotic or disorganized, although there is evidence for some "events" (little movement during 22–30 September for example). These results provide additional evidence that Lagrangian

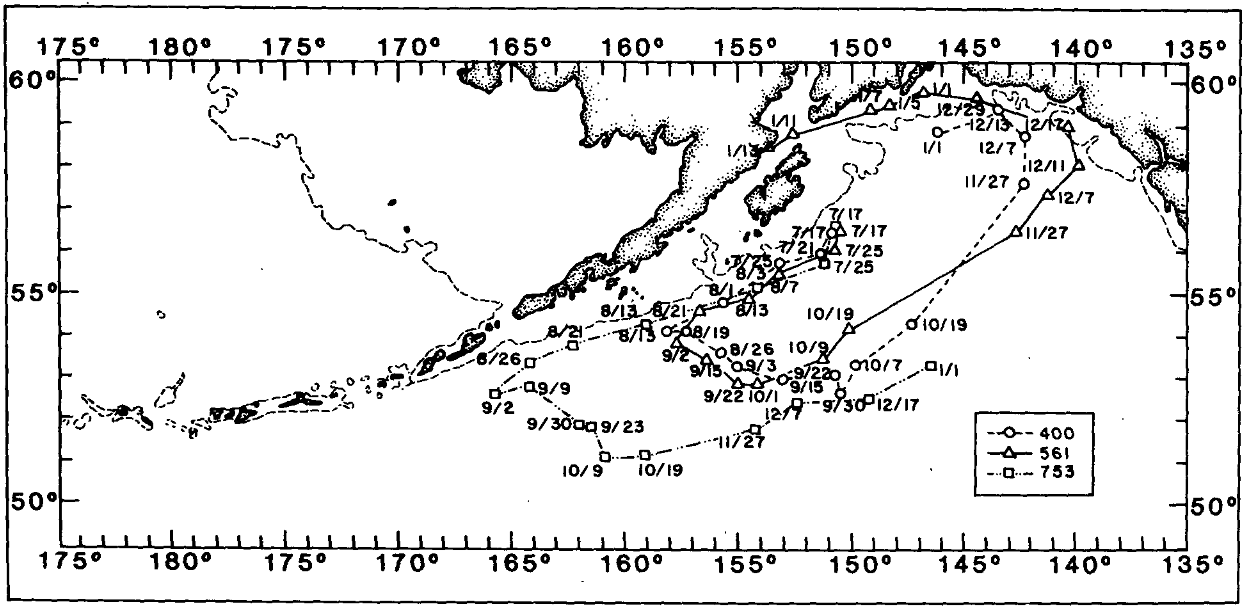


FIG. 2. Paths of drogued drifting buoys (numbers 400, 561 and 753), 17 July 1978–13 January 1979. The dashed line on the map is the 100 fathom (183 m) isobath.

TABLE 1. Net speeds (cm $s^{-1}$) during various portions of the drifter tracks, July 1978–January 1979.

| Drifter No. | Alaskan stream | Southeast flow | Northeast flow | Coastal (Kenai) current |
|---|---|---|---|---|
| 400 | 29 | 13 | 15 | — |
| 561 | 15 | 10 | 17 | 43 |
| 753 | 27 | 11 | 14 | — |

methods can yield very useful descriptions of the flow field [see also Kirwan *et al.* (1978) and Grundlingh (1978)]. It is difficult to envision how a large-scale feature such as recirculation in the Alaskan Stream could have been so unambiguously and easily determined from Eulerian data.

These are the first data to demonstrate conclusively recirculation around the Gulf of Alaska gyre. This modern method substantiates the early inferences about circulation based on property distributions (Dodimead *et al.*, 1963), and it is heartening to see that these classical interpretations appear to be essentially correct.

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