Observations of Upwelling around the
Izu Peninsula, Japan: May 1982*. **

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Abstract: Hydrographic observations between the Izu Peninsula and Oshima Island, Japan, in May 1982, showed upwelling around the tip of the Peninsula and possibly also in the lee of Oshima Island. The upwelling introduced water as cold as 18 °C with nitrate concentrations of 3 µM to the surface. Temperature/salinity analyses indicated that the upwelled water was of Kuroshio characteristics. Slightly fresher water was advected out of Sagami Bay in a coastal counter current.

1. Introduction
As part of a Joint U.S./Japan study of the physics and biology of the interaction of western boundary currents with topographic features we made observations in the Izu Peninsula region of Japan where the Kuroshio often flows past peninsulas, islands and seamounts. Wind driven upwelling has been observed along the east coast of the Izu Peninsula (Kishi, 1976, 1977) and upwelling has been reported in the lee of Oshima Island when the Kuroshio impinges on it (Takahashi et al., 1980), Niijima Island (Takahashi and Kishi, 1984) and along the Kuroshio front (Nakao, 1977). In this paper we will present observations made between the Izu Peninsula and Oshima Island during a time when the Kuroshio was flowing through the area (Fig. 1). We will show that in this case upwelling occurred downstream from Tumeki Point at the tip of the Izu Peninsula.

The area sampled was between Tumeki Point on the Izu Peninsula and Oshima Island (Fig. 1). The 200 m isobath is indicated on Fig. 1. Maximum depths between Oshima Island and the Peninsula are 500 m while depths reach 1,500 m at points more distant from land such as in Sagami Bay and south of the Izu Peninsula. The mountains on Oshima Island and the Izu Peninsula are ca. 1,000 m high and thus can affect the local wind field.

During our observations in late May the Kuroshio was in its B and C modes (Shoji, 1972) looping far offshore in the south of Honshu Island then flowing north towards the Izu Peninsula where it flowed northeastward along the coast (Fig. 2). The arrows near the Izu Peninsula in the left panels of Fig. 2 are from the original charts and indicate strong northeastward currents past the Izu Peninsula during our study. The general flow inferred from these charts and our observations are shown schematically in Fig. 1.

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Fig. 1. Location chart of the study area around the Izu Peninsula. CTD lines that were repeated are indicated. Large arrows indicate general flow pattern inferred from hydrographic and GEK data.

Fig. 2. The Kuroshio path and sea surface temperature (°C) averaged over 2 two-week periods during the cruise. Data from the Maritime Safety Agency, Japan.
2. Methods
The cruise was conducted on board the R/V Tansei Maru of the Ocean Research Institute of the University of Tokyo between 22 and 26 May 1982. The cruise originated in Tokyo harbor and the main observations were made between Oshima Island and the Izu Peninsula. Hydrographic stations were usually spaced at two nautical-mile intervals in lines orthogonal to the coast and the main current flow. Two lines were sampled one east from Tumeki Point and a second between Oshima Island and the Izu Peninsula. At each station a CTD/Rosette was lowered to approximately 200 m or the bottom. Some spacing adjustments were made based on observations and navigational considerations. Surface temperature, salinity, chlorophyll and nitrate were measured continuously along the cruise track. Surface temperature data were also obtained from passenger ferries that ply a route between Tokyo and Oshima Island and others farther south.

Phosphate, silicate, and nitrate + nitrite were measured using standard automated techniques.

Geomagnetic Electrokinetograph (GEK) current measurements were made at selected locations using a standard box pattern in a manner suitable for shallow water (Nagata, et al. 1981). This technique is effective in shallow waters in regions of thick sedimentary layers. Since sediment in the area was not thick the accuracy of the GEK method is not known although there was good agreement with concurrent ship drift measurements.

Satellite derived sea surface temperature maps were obtained on 21 and 22 May from the AVHRR-II (Advanced Very High Resolution Radiometer) sensor on the NOAA-7 satellite and color enhanced.

Weather observations were made on board the ship by the bridge officers. Tidal heights were obtained from Ito and Minami-Izu on the Izu Peninsula (Fig. 1) and Hachijo Island (the southernmost island in the satellite image). The data were uncorrected for barometric pressure, but since the stations are close to each other the effect on the height differences is assumed to be minimal.

3. Results

3.1. Winds
A stick plot of the shipboard winds is shown in Fig. 3. Winds from coastal stations are available but orographic effects rendered them invalid for estimation of offshore winds in the study area. Prior to 22 May, winds were variable but had some strength from the north. However, on 23-26 May winds became consistently northward to northeastward with velocities as high as 10 m sec⁻¹. Thus during the first two days of the cruise winds may have caused some downwelling or advection of water southward from Sagami Bay, but after the 23rd the northward winds may have caused coastal upwelling around the eastern side of the Izu Peninsula. In either case winds were relatively

![Fig. 3. Shipboard winds, m sec⁻¹. Arrows point in direction of flow.](image_url)
weak.

3.2. Sea surface temperatures from satellite
Two clear nighttime (am) images on 21 and 22 May were processed for SST using the 2-channels (11 and 12 microns) algorithm discussed in Barbieri et al. (1983). The 3.7 micron channel was too noisy to use for SST estimation. The images were remapped to a transverse Mercator projection having common latitude and longitude boundaries and were coregistered to each other. In the images land is masked black and clouds are white. Some cloud fringing effects which result in erroneously low temperatures are present, especially in the 22 May scene.

It is clear that the Kuroshio was very close to the coast on the first day (21 May) and was branching into the embayments on both sides of the Izu Peninsula. Cold water masses were present behind five of the northernmost islands. On 22 May the temperature front had migrated offshore and temperatures within the survey area had decreased. The cloud cover on the 22nd indicates that a atmospheric front may have passed through the area. The winds shown in Fig. 3 indicate a shift from northward to southwestward direction during the one day interval, which would explain the formation of the cloud bank over the Kuroshio. The ship track in Fig. 7 provides temperatures in the wake area east of Oshima Island. To check the AVHRR SST values a 31×31 pixel box was sampled from that region. One pixel is 0.56 km so the box was 17.5 km × 17.5 km. On 21 May \( T_{av} = 18.55 \, ^\circ C \), \( T_{min} = 17.25 \, ^\circ C \), \( T_{max} = 21.0 \, ^\circ C \) and the standard deviation was 0.51 \(^\circ C\), respectively. The values on 22 May compare quite favorably with the ship data. Note also that the range of values obtained from the ferry (Fig. 7) agrees quite well with the values in the 21 May image even though the time separation is several hours.

3.3. Sea level fluctuations
Sea level fluctuations can indicate the presence or absence of the Kuroshio. Sea level varies approximately one meter across the Kuroshio so lower than average sea level indicates the gauge is located on the northern (cyclonic) side of the axis of strong eastward flow. During the 100 day period between 1 March and 30 June sea level on the Izu Peninsula was about 0.2 m lower than the level at Hachijo, as would be expected since the Kuroshio front normally lies between those locations.

We spectrally analyzed a 114-day period of sea level data for Ito, Minami-Izu and Hachijo for the period of 5 March–26 June. The mean was extracted from each series and a linear trend was removed. The resulting energy spectra were averaged in the frequency domain using each five adjacent frequency estimates resulting in ten degrees of freedom.

The results of the spectral analysis (Fig. 5) show that the principal fluctuations occurred at periodicities of 3–4, 7–10 and 30 days (Fig. 5). The variances along the Izu Peninsula were similar at these three periodicities, but variances at Hachijo were much greater at 30-day periods, and the 10-day fluctuation was not as prominent in the spectra.

Time-series of demeaned sea level (Fig. 6) were plotted over a 20-day period that includes the cruise. Three fluctuations occurred over
that record, which was consistent with the 7–10 day period in the spectra (Fig. 5). During 10–19 May sea level was about 0.15 m higher at Hachijo Island, suggesting that before the cruise geostrophic flow was eastward between Hachijo Island and Izu. At the beginning of the cruise sea level rose at all three locations and became nearly equal implying that the geostrophic component of eastward flow diminished or practically ceased. Following that rise, sea level at all three locations dropped by about 0.2 m, indicating that the Kuroshio was meandering southward. During the cruise sea level at Hachijo Island decreased and was less than that at the Izu Peninsula sites. This could result from the possibility that Hachijo Island was in an area of the cold water mass associated with the large meander of the Kuroshio.

3.4. Sea surface temperature from ferry

A commercial ferry runs between Tokyo and Miyake Island with occasional stops at Oshima and other islands. Data from 20 and 21 May, when the ferry was going straight between Tokyo and Miyake Island, clearly show the cold surface water associated with either upwelling in the lee of Oshima Island or the front (Fig. 7). Between 20 and 21 May the surface temperatures decreased both in the lee of Oshima Island and to the south, confirming the satellite data.
3.5. Sea surface temperature from shipboard measurements

The temperature maps are shown in Fig. 8. The first surface temperature map was obtained on 21-22 May starting in the northwest and proceeding towards the Izu Peninsula. The Kuroshio front (the 20 °C isotherm) was lying in a NE/SW direction southeast of Tumeki Point and a band of cold water (≤19 °C) extended from Tumeki Point northeasterward on the western side of the front. Surface temperatures east of Oshima Island indicated a minimum of less than 18 °C, also agreeing with satellite and ferry data. From these data the actual Kuroshio path cannot be determined but the satellite data suggest substantial flow between the Izu Peninsula and Oshima Island. On 22 May a temperature minimum (≤19 °C) was evident along the coast and in the front between Oshima Island and Izu Peninsula. On 23 May surface temperatures east of the front increased suggesting northwestern movement of the front. On 24 May isotherms were farther to the northwest, suggesting a continued northwestern movement of the Kuroshio. There was a small patch of water colder than 19 °C off Tumeki Point. On 25 May the front, as evidenced by the 21 °C isotherm, moved southeast.
On 26 May surface temperatures increased on the warm side of the front and 21°C water apparently extended northward between Oshima Island and Izu Peninsula. In contrast to the situation on 25 May, surface temperatures decreased to 19°C near Izu Peninsula and in a small patch 10 km east southeast of Tumeki Point, suggesting renewed upwelling.

3.6. Currents measured by GEK

Currents measured by GEK were superimposed on surface temperature charts (Fig. 8). On 21–22 May velocities along the Kuroshio front were nearly 150 cm sec⁻¹ and flow appeared to be toward Oshima Island. At stations within 5 km of the Izu Peninsula currents were counter to the main flow at about 50 cm sec⁻¹. Later on 22 May flow was northerly at nearly 100 cm sec⁻¹. At the station nearest the Izu Peninsula currents were offshore at 70 cm sec⁻¹. On 23 May flow was directed northeastward between Oshima Island and Izu Peninsula with a weak counter current between the front and Izu Peninsula. Currents between Oshima Island and Izu Peninsula were weaker on 24 May but still nearly 100 cm sec⁻¹. Weak counter flow was observed near Izu Peninsula. The currents were again strong to the northeast and east of the front with offshore flow at stations near the Izu Peninsula on 25 May. A single GEK measurement on 26 May indicated continued northeastward flow in the front. The general pattern was northeastward flow reaching

Fig. 9. Surface nitrate concentrations on 22–26 May 1982. Areas > 2μM are hatched.
150 cm sec\(^{-1}\) in the Kuroshio front with a counter flow at the locations between the front and Izu Peninsula.

3.7. Surface nitrate concentration

Surface nitrate concentrations were greater than 3 \(\mu\)M south of Tumeki Point and 2 \(\mu\)M in the band of cold water trailing northeastward from Tumeki Point on 22 May (Fig. 9). Between 23 and 25 May concentrations generally decreased to less than 0.5 \(\mu\)M although higher values were found along near the coast. On 26 May surface concentrations again increased coincident with decreasing surface temperatures. Highest concentrations were in the colder water adjacent to Tumeki Point and 10 km off Tumeki Point. The patch of water with concentrations around 1.5 \(\mu\)M was in an area where offshore flow was observed on 25 May, suggesting that nitrate enrichment resulted from offshore flow of recently upwelled water.

3.8. Temperature, salinity and density vertical sections

Hydrographic stations were occupied on lines off Tumeki Point and between the Izu Peninsula and Oshima Island (Fig. 1). Both sections were repeated three times. The frequency of sampling was scarcely adequate to resolve the upwelling but when combined with other observations a reasonably clear scenario develops.

On the Oshima Island section (Fig. 10) iso-
therms above 120 m generally sloped upward toward the peninsula. On 22-23 May surface temperatures were at a minimum both near the coast and in mid-channel in agreement with the surface mapping measurements. On 23-25 May the 20-21 °C isotherms moved shoreward, erasing the mid-channel minimum. During the observations the deeper isotherms (14-16 °C) ascended about 50 m or about 17 m day⁻¹.

At Tumeki Point the front (21 °C isotherm) was closer to the coast than on the Oshima line. Between 23 and 24 May isotherms in the upper 100 m steepened and ascended about 40 m. By 26 May the isotherms lifted further and a surface temperature minimum was present about four nautical miles offshore. It appears that the front moved onshore and upwelling occurred between the front and the coast.

Salinity variations on the Oshima Island section show high salinity water indicated by the 34.70 to 34.75 % salinity, moved onshore between 22 and 23 May with the onshore movement of surface fronts (Fig. 11). Between 23 and 25 May the same isolines suggest an offshore movement of the front and the high salinity mode water was absent.

Salinity distributions at Tumeki Point suggest a similar scenario with high salinity water approaching the coast on 24 May and retreating offshore by 26 May with the offshore movement of the front (Fig. 11).

The vertical distribution of density at Oshima Island (Fig. 12) suggests a general northward flow with possible counter currents in the upper 100 m and in deeper waters near the slope. By 25 May, when the front had moved offshore, there was little evidence of a counter current.

Density structures off Tumeki Point were more complicated, possibly because of the presence of the headland.

Temperature/Salinity pairs from all CTD data are plotted in Fig. 13. The T/S relationship, similar to other T/S plots from the same area (Iwata, 1979), shows a rather tight envelope at all temperatures but above 15 °C some mixing with fresher coastal waters was indicated.

Data from the 22 May Oshima Islands section (Fig. 13) shows that surface waters at Stations

Fig. 13. Temperature vs. Salinity plot of data from one CTD section 22 May 1982. Stations on the first Oshima Island line. Inset shows envelope of all data.
1 and 2 were slightly fresher while offshore the surface waters were essentially undiluted. The largest reduction in salinity was 0.4‰, suggesting that the total dilution of water in the Kuroshio front by freshwater runoff (0‰) was less than 1‰.

3.9. Nitrate, phosphate and silicate sections

Vertical sections at Tumeki Point (Fig. 14) demonstrates an uplifting of the isopleths during the study period. By 26 May the 1 and 2 μM nitrate isopleths surfaced on the inner part of the section indicating upwelling. Occasional high

![Diagram of nitrate, phosphate, and silicate sections](image-url)
silica concentrations at the inner station (Stations 8, 17 and 28) suggest possible interaction with coastal waters, although the effect was minimal.

At the Oshima Island section (Fig. 15) doming near Station 4 was evident in all plots and appeared to extend to depths greater than 100 m. The isopleths generally sloped up toward the coast although not as steeply as at Tumek Point. Silica concentrations at nearshore stations suggested little addition of coastal waters.

4. Discussion
4.1. The sequence of events

Combining various observations we conclude that the following sequence of events occurred during our study:

**21-22 May 1982** The Kuroshio moves offshore; upwelling occurs along Izu, particularly in the vicinity of Tumek Point upwelling plume extends from Tumek Point; towards Oshima Island; upwelling may occur in the lee of Oshima Island.

**22-25 May 1982** Onshore movement of Kuroshio; cold upwelled water restricted to coastal region; on 23 May wind shifted to northward (upwelling favorable) at 10 m sec⁻¹.

Fig. 15. Vertical distribution of nitrate, phosphate and silicate at the Oshima Island section. pM.
25–26 May 1982 Kuroshio remains in position but upwelling occurs along the Izu coast and at Tumeki Point.

With these limited observations it is not possible to test any hypothesis concerning the cause of upwelling. It should be noted that upwelling related to mesoscale winds have been observed in July and August in Sagami Bay (Unoki, 1983).

4.2. Source of upwelled waters

The coldest waters were observed in the vicinity and downstream of Tumeki Point and very nearshore along the Izu Peninsula. The cold waters at Tumeki Point exhibited high salinities and relatively high nutrient concentrations and were no doubt upwelled water from offshore. The cold waters observed along the Izu Peninsula northeast of Tumeki Point exhibited slightly lower salinity and no doubt originated from Sagami Bay. However, the water had similar characteristics, especially with respect to nutrients. This is because water from Sagami Bay is just Kuroshio water that has recirculated through the Bay where surface salinities may be slightly reduced.

An interesting aspect of these studies is to compare the Kuroshio and Gulf Stream for analogous processes. The area of this study is analogous to the Gulf Stream south of Cape Hatteras. The situation of the Kuroshio flowing past the Izu Peninsula, around islands and circulating through Sagami Bay of course has little analogy since the adjacent embayments in the South Atlantic Bight such as Onslow Bay and Raleigh are very shallow but nevertheless receive frequent intrusions of Gulf Stream water. The headlands, such as Cape Canaveral, do seem to induce upwelling in a manner analogous to the Izu Peninsula (Blanton, et al., 1981).

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References


Fig. 4. Sea surface temperature derived from NOAA-7 infrared image. Color temperature code: white, cloud mask; black, land mask; dark blue, <17 °C; blue, 17-18 °C; light purple, 18-19 °C; purple, 19-20 °C; orange, 20-21 °C; yellow, 21-22 °C; red, 22-23 °C.
1982年5月の伊豆半島周辺での湧昇の観測

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要旨: 1982年5月の伊豆半島と大島の間での調査で、半島尖端のまわりと、大島の島陰で湧昇がみられた。湧昇

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は、18℃の低温で3ρMの硝酸塩を含んだ水を、海表面にもたらした。T/S解析から、湧昇水が黑潮の特性をもつことが明らかとなった。やや淡水の混じった水が相模湾から沿岸反流域に流出していた。