DETECTION OF VORTEX MOTION BY SATELLITE (AVHRR/NOAA-6) AND REGIONAL UPWELLING OFF IZU-OSHIMA ISLAND

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人工衛星（AVHRR/NOAAー6）による伊豆大島沖の渦の計測と局地性渦昇

概要：海洋の沿岸域において、海流や吹送流が海底・海岸地形と作用し、渦昇（局地性渦昇）を発生させることは、海洋物理学的に古くから予測されてきた。本研究は、沿岸域で観測された渦昇を人工衛星（AVHRR/NOAA-6）を用いて観測し、その特徴を明らかにすることを目的とした。

研究の方法は、人工衛星データを用いた渦昇の検出方法を開発し、その検出結果を評価する方法を提案した。人工衛星データは、渦昇の発生を捕らえるのに有効であるが、その解析には課題が残されていた。そこで本研究では、人工衛星データを用いた渦昇の検出方法を開発し、その効果を評価する方法を提案した。人工衛星データを用いた渦昇の検出方法は、渦昇の発生を捕らえるのに有効であるが、その解析には課題が残されていた。したがって、人工衛星データを用いた渦昇の検出方法を開発し、その効果を評価する方法を提案した。
Abstract: The advanced very high resolution radiometer (AVHRR) mounted on the NOAA-6 satellite has a temperature sensitivity of 0.1°C and area scale of about 1km. It was found to be capable for the detection of regional upwelling plumes around Izu-Oshima Island which have a thermal contrast of 3 to 5°C and a size of 1 to 30km. It is suggested that the large coverage area (3000 km) and repeat measurement capabilities of the satellite will be extremely useful for the future study of geographical distribution of regional upwellings and their variations in time.

Introduction

Recent developments in remote sensing techniques have aided science and technology in many fields. In oceanography, observations are normally made using research vessels. However, some oceanographic phenomena, particularly those of small size and fast time scales, are often missed by vessel experiments because of the limited cruising speed of vessels.

Upwelling in the ocean is one of the most important but rather newly recognized phenomenon and is now the subject of increased research interest. Some upwelling features have fast time scales (hours to days), and size scales of those are often small (1 to 10's of kilometers). This is particularly true for upwelling that occurs regionally due to topography and currents. Takahashi et al. (1980a, 1981a, 1981b, 1981c) have detected upwelling plumes off Izu-Oshima Island from the surface temperature patterns taken by aircraft supported multispectral scanner measurements and they noticed clear vortex motion in those temperature patterns. Such a vortex motion has never been detected by ordinary vessel observations.

The size of regional upwelling such as occurs off Izu-Oshima Island covers a few hundreds of square kilometers, and is too large for observation by small airplane. Also repeated measurements are impractical. Thus preferable to use a satellite which covers a larger area. Also repeated measurements for a given fixed area can be easily made if satellite stays at a fixed location or passes the area at a certain time intervals. For the application of a satellite, it is critical whether the sensor has enough detection capability to sense the thermal variations as well as achieve the areal coverage of the target upwelling. Temperature is a most probable parameter for the detection of upwelling plume because temperature difference are up to 3 to 5°C lower in an upwelled water mass compared with the surrounding water (Takahashi et al. 1980b).

In the present paper, we will present a thermal image taken by the AVHRR/NOAA-6 satellite and demonstrate its usefulness in detecting regional upwelling plumes around Izu-Oshima Island. Surface water temperatures predicted by the AVHRR/NOAA-6 were evaluated by sea truth data collected by ship observations.

Methods

Satellite NOAA-6 passes over Japan once in the morning and again in the evening. The orbit shifts regularly with each passing causing the satellite to be over a given location at 4-5 day intervals. A thermal image taken by the advanced very high resolution radiometer (AVHRR) of the NOAA-6 satellite at 8 am on 19 November 1980 was obtained from the Meteorological Satellite Center. The desired image was recorded in computer compatible tapes (CCT). According to the procedure developed by Koga(1982), a part of image which included the target area was picked up from the CCTs. We
analyzed channel 4 of the AVHRR (detection wavelength, 10.3-11.3nm) which indicating ocean surface temperature and then the desired image was displayed with 16 color codes corresponding to different temperatures.

Sea truth measurements of surface water temperature were made on water pumped continuously through an intake hole at the bottom of a ferry boat (approximately 4m below the surface). There was no major difference in temperature and salinity between surface bucket samples and the water pumped from 4m below the surface (unpublished data). Measurements were made continuously along the cruise track.

Results

A satellite thermal image taken by AVHRR/NOAA-6 on 19 November 1980 was analyzed. The area of approximately 200×200 km² covering Izu-Oshima Island and its surrounding area were the focussed our attention. Temperature was calculated from the brightness temperature detected by the AVHRR after correction for loss due to atmospheric effects. Temperature slicing was first done using a 1°C increment between 10 and 25°C (Plate 1A). Surface temperature varied from 13 to 20°C in the entire area, and the pattern of temperature distribution was complicated nearshore and in bays, but rather smooth in offshore region. Temperatures below 17°C were found along the north-western side of Sagami Bay and the north-eastern shore of Boso Peninsula. Even colder water (13 and 14°C) was seen in Tokyo Bay and along the north-eastern Boso Peninsula and Kashima. In the next step, color slicing was done at a temperature increment of 0.6°C between 16 and 19°C (Plate 1B). Details of dynamic temperature change occurring nearshore in Plate 1A partly disappeared because of lower temperatures than 16°C of the lowest temperature setting, but temperature fine structure appeared in the offshore region, particularly around the islands. Warm water (19°C) which seems to be a part of the Kuroshio current, impinges Izu-Oshima Island at the western side, then appeared to go around the island. According to the oceanographic report (Hydrographical Agency, 1980), the Kuroshio was flowing towards the east-south-east and the current speed varied approximately between 0.3 and 1.9 knots around Izu-Oshima Island between 18 November and 3 December (Fig. 1). Obvious vortex motions were observed north-east and south-east of Izu-Oshima Island. This vortex motion became obvious with a fine temperature slicing of 0.1°C between 16 and 19°C (Plate 1C). The vortex motion showed clockwise pattern off the north-eastern side and counter clockwise off the south-eastern side. The vortices which were connected in series were obvious off the south-eastern side of the island. The size of vortex motion off the north-eastern side was about two to three times larger than the island (approximately 15 km in the longest axis) and that of the south-eastern side was about the same size as the island.

![Fig.1. Current field around Izu-Oshima Island. Redrawn from the report of the Hydrographical Agency, Japan(1980).](image-url)
Surface water temperature was determined along the cruise track in the study area two times on 19 November, 1980 (Fig. 2); one in the early morning between 0:19 and 4:39 (south bound) and the other in the afternoon between 13:28 and 17:29 (north bound). Two patterns showed a similar general feature which indicated low and changeable temperatures nearshore and was high and less changeable offshore, although both patterns did not show a clear matching (Fig. 3). The AVHRR/NOAA-6 image taken around 08:00 also gave a similar pattern as those of sea truth profiles (Fig. 3) which showed low temperature nearshore and high and nearly constant temperatures offshore. However there was a consistent difference in the absolute temperature between sea truth and satellite temperatures. AVHRR/NOAA-6 temperatures were about 3°C lower than sea truth temperatures. This difference was due to possible atmospheric effects. Tanaka et al (1981) pointed out that the AVHRR/NOAA-6 temperatures were about 3°C lower than sea surface temperature at 15°C due to the atmospheric effects over the sea area of Enshunada in May and December. The dotted curve in Fig. 3 indicates the AVHRR/NOAA-6 temperature pattern which was shifted up 3°C.

Detail thermal patterns from the AVHRR along longitudes were analyzed around Izu-Oshima Island (Figs. 4 and 5). According to Fig. 3, actual sea surface temperatures were about 3°C higher than those of the AVHRR/NOAA-6. The surface temperature difference around the island was 0.8°C ranging between 19.0 and 19.8°C (approximately 22.0 to 22.8°C for the corrected temperature), although there occurred low temperatures (Cl) below 19°C along the #1 line which was a possible effect of low
Fig. 4. Geographical locations of longitude lines for detail analysis of surface brightness temperature profiles. Results are shown in Fig. 5.

Fig. 5. Detail brightness temperature profiles along longitudes detected by the AVHRR/NOAA-6 on 19 November 1980.
temperature water occurring nearshore. The lowest water temperature at the upper stream side of the island, lines # 1 and # 2, was 19.2-19.3°C (22.2-22.3°C for the corrected temperature) when the nearshore low temperatures were excluded. Colder water spots (C2, C3, C4, C5 and C6) (19.0 to 19.1°C and 22.0-22.1°C for the corrected temperature) were found in several locations at the down stream side of the island.

Discussion
Small scale differences in sea surface water temperature in a size of 1 km or larger can be detected by the advanced very high resolution radiometer (AVHRR) mounted on the NOAA-6 satellite around Izu-Oshima Island (Tanaka et al. 1981). Relative temperature differences of 0.1°C were clearly separated and gave a good relative pattern. Because the brightness temperature detected by the AVHRR was lowered by 3°C due to energy loss of atmospheric effects (Tanaka et al. 1981), absolute measurements are less accurate. However both of those characters, detecting an approximate size of 1 km and approximate temperature difference of 0.1°C, are obviously sufficient in order to detect most of regional upwelling water masses which generally have temperature difference of up to 3-5°C and are 1 km or larger (Takahashi et al. 1980).

The AVHRR/NOAA-6 covers a large area at a surface width of 3000 km along each orbit. This is extremely advantageous for the evaluation of geographical distribution of regional upwelling. Furthermore the NOAA-6 satellite comes back over a given location at least every 4-5 days, so the time course change of a given upwelling plume can be followed at that time interval. By mounting the AVHRR on a satellite which stays over a fixed location or comes around more frequently, time course change of regional upwellings will be analyzed at shorter time intervals. Such repeating measurements and a large coverage area are better than ordinary airplane remote-sensing.

Takahashi et al. (1980b) found upwelled cold water masses at the down stream side of Izu-Oshima Island and that they apparently are caused by vortex shedding as the Kuroshio passes Izu-Oshima. These observations were made with a multi-spectral scanner (MSS) from an airplane (Takahashi et al. 1980a, 1981a, 1981b, 1981c). The coverage area was approximately 30 x 40 km which was made by 7 different passes of 5-7 km width. Similar vortex motion was clearly detected in a single image by the AVHRR/NOAA-6 in the present study, and the motion pattern was more obvious in the AVHRR/NOAA-6 image compared with the synthesized airplane MSS image.

Temperature detected around Izu-Oshima Island ranged between 19.0 and 19.8°C except for low temperature water of 18.7°C occurring nearshore. This small temperature difference was probably the effects of winter cooling. Therefore temperature differences observed in the present study around Izu-Oshima Island was only 0.8°C which was extremely small compared to 3-5°C in summer time. Low temperature waters were found at several locations off the east and south sides of Izu-Oshima Island. They were obviously associated with vortices as was recognized previously by airplane MSS measurements (Takahashi et al. 1980a, 1981a, 1981b, 1981c).

In conclusion the AVHRR/NOAA-6 is capable of distinguishing regional upwelling plumes of 1 km or larger in size from the temperature pattern. It is highly recommended that an areal study around the Japan Island and a time course study of those upwelled water plumes be made in the future using the AVHRR/NOAA-6 or any other suitable satellite sensor.

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References
Plate 1. Brightness temperature pattern taken by the AVHRR/NOAA-6 on 19 November 1980. A, temperature slicing at a temperature increment of 1°C between 10 and 25°C. B, temperature slicing at 0.6°C interval between 16 and 25°C. C, temperature slicing at 0.2°C interval between 16 and 19°C.