Detection of Thermal Plume Signature in and around the Younggwang coastal waters of Korea using LANDSAT & NOAA Thermal Infrared Data

Yu-Hwan Ahn, P. Shanmugam, Jae-Hak Lee and *Yong Q. Kang
Korea Ocean Research and Development Institute, Seoul, 425-600, Korea
*Pukyong National University, Pusan, 608-737, Korea
yhahn@kordi.re.kr

Abstract

The thermal contamination of the Younggwang coastal marine ecosystem has been investigated using space borne thermal infrared data acquired over the period 1985-2003 by the Landsat and NOAA satellites. The analysis of AVHRR data brought out the general pattern and extension of thermal plume while TM data yielded more accurate information about the plume shape, dimension, dispersion direction etc. The examination of sea surface temperature (SST) computed from these images clearly indicates that the thermal plume extends 70 to100km southward during summer and 50 to70km northwestward during winter monsoons. The maximum plume temperature was 29°C in summer and 12 °C in winter. The comparative analysis shows that the temperature retrieved from TM is slightly higher (1.8 °C, 3 °C and 2.2 °C for the images of 98/11/10, 99/05/05 and 99/05/21 respectively) than those derived from AVHRR data. The correlation coefficient between the TM-derived SST and AVHRR-derived SST was 0.72.

Keywords: AVHRR, Younggwang, Thermal plume

1. Introduction

In the recent years, thermal contamination of water is of major concern in many of coastal waters and estuaries around the world. The coastal marine ecosystems are potentially threatened by a large quantity of warmer water discharge from the nuclear power plants. For many years, it was never thought of a major problem as nothing was added to these waters. But the effect of sharp changes in water temperature due to warmer water discharge can significantly affect the aquatic lives in marine environment. Recently, it has been realized that only small changes in water temperature (even 1 or 2 °C) are sufficient to have considerable environmental impact. According to Huang et al. (1998), warmer water discharge from nuclear power plants could have significant consequences on the ecology of coastal bays. Hence, mapping and monitoring such thermal contaminated coastal waters are extremely necessary to protect the health of marine ecosystems. Sea surface temperature is one of the important parameter to be studied for mapping thermal structures in coastal waters. Although traditional shipboard sea surface temperature measurements provide accurate results, this method of observation is time consuming and very expensive. On the other hand, the high spatial and radiometric resolution, the regular sampling, and the synoptic perspective of space borne thermal sensors make them well suited to improving SST measurement capability (Donlon et al., 2002). In the present study, a special attempt is made to determine the spatial and temporal characteristics of thermal plume signature and its dynamics in and around the Yonggwang coastal waters of Korea using Landsat-TM, ETM+ and NOAA-AVHRR thermal infrared image data.

2. Study site

The Younggwang nuclear power plant is located on the southwest coastal track of Korea. It was started in 1986 with the capacity of 950MW. Owing to rapid advancement, it has 6 units comprising of 5.9×1000 MW. The total cooling water requirement estimated was about 173 - 190 x 10^5 tons/day with the temperature rise of recirculating water estimated was ΔT 6 - 9 degree Celsius. The marine region adjacent to power plant is well characterized by shallow shelf waters of highly oxidized condition. The seasonal plume temperature is found to be well pronounced with maximum in summer (30°C) and minimum in winter (12°C).

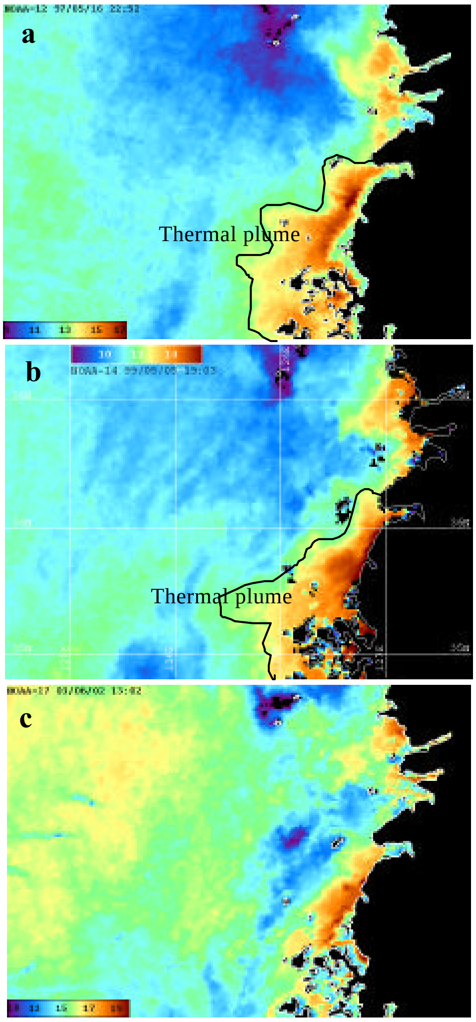
3. Data and Methods

The data used in the present study are from Landsat-5, Landsat-7 and NOAA-12, 14, 16 & 17 satellites. For computation of sea surface temperature from TM and ETM data, the thermal band was geo-referenced to a standard datum and projection and followed by radiometric calibration in which the actual DN values were converted to radiance at satellite temperature (K) using pre launch calibration coefficients. Finally, Kelvin temperature was rescaled to Celsius in degrees (°C = K - 273.15). Similarly, SST was computed from AVHRR data using MCSST algorithm.

4. Results and Discussion

1) SST from AVHRR data and comparison

Based on the analysis of wide range of AVHRR data, it was observed that the maximum plume temperature approaches 15°C in winter and 27°C in summer. It extends 60 to 100km southward direction during summer (Figs.1a-c). The high thermal dispersion in southern coastal waters is mainly due to the strong tide and wave-induced currents in the northern parts. These regions are relatively less dominated by thermal dispersion as estimated about 50-75km during summer. The reason is that the tide and wave induced currents generated in the southern parts are often diffused by number of islands located nearby. Thus, these currents become sluggish within the power plant site. The SSTs derived from AVHRR data are also compared with the SSTs estimated from TM data. For the purpose of comparison, the temperature values of 9 × 9 pixels of the TM-derived SST were averaged and then compared with the corresponding pixel temperature of the AVHRR-derived SST. Sea surface temperature of plume pixels of the AVHRR-derived SST image was found to be 14.2°C for the period 98/11/10. This temperature value is slightly lower (1.8°C) than the TM-derived sea surface temperature (16°C). The reduction of SST in AVHRR pixel is essentially due to the atmospheric absorption by the presence of both visible and sub-pixel level clouds in AVHRR images (60-70%). Moreover, the MCSST split window algorithm provides good STT estimates for daytime AVHRR image with improved bias but it has poor bias and high standard deviation when performing for nighttime AVHRR images (Li *et al.*, 2001). The measurements of sea surface temperature are also caused by other factors such as change of



Figs. 1a-c. Spatial and temporal representations of the thermal plume signature inferred from AVHRR thermal infrared data. The maximum plume temperature is (a) 17°C, (b) 16 °C and (c) 21 °C. (Note that only three images are shown here).

atmosphere over time, wind speed, air-sea temperature differences, humidity and other associated components. On the other hand, the pixel temperatures of the thermal plume in TM-derived SST were 19 °C and 21.7°C for the period 99/05/05 and 99/05/21 respectively. These temperature values are considerably higher than the AVHRR-derived SST (16 °C and 19.5 °C). The large temperature differences between the AVHRR- and TM- derived SSTs (3 °C and 2.2 °C for the periods 99/05/05 and 99/05/21 respectively) are mainly due to the atmospheric emission by the presence of aerosols, CO_2, ozone. Fig.2 shows the relationship between sea surface temperatures computed from the Landsat-TM and NOAA-AVHRR thermal infrared channels. The correlation coefficient for this relationship was 0.72. It is important to mention that the sea surface temperature computed from TM was always found to be higher than the SST derived from AVHRR. Only a few pixels of TM-derived SST were found to be lower than the same pixels of the AVHRR-derived SST. We suspect that the bias may arise from the uncorrected TM infrared data that would account for atmospheric absorption due to dense and sub-pixel level clouds along the atmospheric path between the sea surface and satellite sensor.

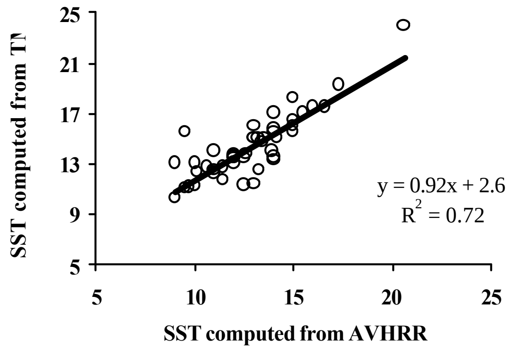
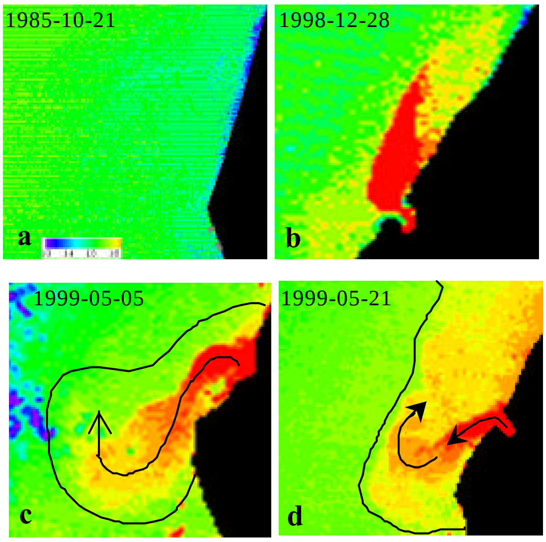


Fig. 2. Relationship between TM-derived SST and AVHRR-derived SST.

2) SST from TM-band6

The analysis of TM and ETM thermal infrared data provides detailed information about the plume shape, orientation, dispersion direction, and seasonal pattern in and around the Younggwang coastal waters (Figs. 3a-d). It is worth noting that there was no thermal plume signature before start of the Younggwang power plant. In winter, the thermal plume is found to be thick near the outlet canal while sharp end orienting north. This kind of signature infers the rate of current speed and winds,



Figs. 3a-d. Schematic representations of the thermal plume signature and its dynamics in and around the Younggwang coastal sea of Korea. The maximum plume temperature is (a) 15.3 °C, (b) 11 °C, (c) 24 °C and (d) 29 °C.

which were sluggish within the power plant regions. It is important to note that when the wind speed is diminished, the horizontal heat transfer becomes diminished, and instead, strong molecular and viscous heat transfer processes dominate beneath the water column. This temperature is rather difficult to retrieve from our TM and AVHRR infrared data but may be possible from SST measurements by a low frequency (6-10GHz) microwave radiometer (Donlon et al., 2002). The temperature observed was about 11°C during this period. In spring and summer, the thermal dispersion is found to be "significant" in southern coastal waters, where the plume temperature approaches maximum of 29 °C. Figs. 3c & d illustrate the thermal plume dispersion in the southern coastal waters with the temperature gradient from 24°C to 29 °C in plume dispersion waters and 15 °C ~ 10 °C in non-plume waters. It is interested to note that the "brush" like plume structure infers the direction of wind and current pattern that dominate in the opposite direction to the flowing pattern of the plume structure (Fig. 3d). The thermal dispersion is found "most significant" both in southern and northern coastal waters as seen in Fig. 4f. In contrast to Fig.3b, a strong horizontal dispersion is well evident during 1999/05/21.

5. Conclusion

Thermal contamination of the Younggwang coastal marine ecosystem has been investigated using a wide range of thermal infrared data assimilated from the Landsat and NOAA satellites. Sea surface temperature maps derived from these data provided good information about the spatial and temporal aspects of the thermal plume signature in and around the Younggwang coastal waters. In winter, the thermal plume is limited to a small area within the power plant region. In late spring and summer, it extends from 70 to 100km to the southern region and 50 to 80km to the northern coastal waters. The tidal currents and winds especially in the southern and northern regions greatly govern the thermal dispersion in these waters.

References

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