# Temporal and spatial Analysis of Sea Surface Temperature and Thermal Fronts in the Korean Seas by Satellite data

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**Abstract:** In the Korean seas, Sea Surface Temperature (SST) and Thermal Fronts (TF) were analyzed temporally and spatially during 8 years from 1993 to 2000 using NOAA/AVHRR MCSST. As the result of harmonic analysis, distributions of the mean SST were 10~25℃, and generally SST decreased as latitude increased. SST increased in the order as following; the South Sea (20~23℃), the East Sea (17~19℃), and the West Sea(13~16℃). Annual amplitudes and phases were 4~11℃, 210~240° and high values were shown as following; the West Sea (A1, 9~11℃), the Northern East Sea (A5, 8~9℃), the Southern East Sea (A4, 6~8℃), the South Sea (A3, 6~7℃), the East China Sea (A2, 4~7℃) and phases; A3 (238~242°), A4 (235~240°), A5 (225~235°), A1 (220~230°), A2 (210~235°), respectively. Both of them were related inversely except the area A2, therefore the rest areas were affected by seasonal variations.
TF were detected by Sobel Edge Detection Method using gradient of SST. Consequently, TF were divided into 4 fronts; the Subpolar Front (SPF) based on the Cold Water Mass (low SST and salinity Subartic Water), resulting from the North Korea Cold Current (NKCC) and the East Sea Proper Cold Water in the middle and low layer, and the Warm Water Mass (high SST and salinity Subtropical Water), resulting from the Tsushima Warm Current (TWC) in area A4 and 5, the Kuroshio Front (KF) based on the Kuroshio Current (KC) and shelf waters in the East China Sea (ESC) in A2, and the South Sea Coastal Front (SSCF) based on the South Sea Coastal Water (SSCW) and TWC in A3. Also, the Tidal Front was weakly appeared in A1. TF located in steep slope of submarine topography. Annual amplitudes and phases were bounded in the same place, and these results should be considered to influence of seasonal variations.
**Keywords:** NOAA/AVHRR, SST, Thermal Fronts, Harmonic Analysis, Sobel Edge Detection Method

## 1. Introduction

The research of SST (Sea Surface Temperature) variations is fundamental and crucial in the Ocean, atmosphere, fisheries and environment. There have been a lot of research about SST variations in the Korean seas and they contributed to represent conditions of natural environment in this region [1,2]. In this paper, SST and Thermal Fronts (TF) in the Korean Seas were analyzed temporally and spatially by long-time (8 years) NOAA/AVHRR (National Oceanic and Atmospheric Administration / Advanced Very High Resolution Radiometer) MCSST (Multi-channel Sea Surface Temperature) since satellite data is very useful in the research about long-time variations of SST. The oceanic fronts are the area where two water masses, having quite different properties, contact and then mix, and their forming process, shape, location vary. Thermal Fronts were revealed using SST gradient, and locations of Thermal Fronts (TF) concerning temporal and spatial characteristics of SST were analyzed.

## 2. Data and Method

### 1) Data and Study Area

The AVHRR MCSST data set contains weekly values of SST available in (approximately) 19 × 19km grids for the entire globe. A weekly period consists of 8 days so as to give a 1-day overlap between consecutive weekly files. The data containing mask values for areas of no data, sea ice, and land were provided by JPL PO.DAAC (Jet Propulsion Laboratory, Physical Oceanography Distributed Active Archive Center)[3]. The MCSST data set was chosen rather than the newer Pathfinder SST data set as it has a complete and continuous temporal coverage for this period. The study area is 25°~45°N, 117°~142°E (Fig. 1). The area covers the West Sea, the East China Sea, the South Sea and the East Sea influencing on the Korean seas. For the effectiveness of this research, the study area is divided into area A1~5, and each area range is designated as below;

The West Sea, Area1 (WS, A1): 32°N~40°N, 117°E~127°E

The East China Sea, Area2 (ESC, A2): 25°N~32°N, 117°E~127°E
The South Sea, Area3 (SS, A3): 32°N~36°N, 124°E~131°E
The Southern East Sea, Area4 (SEC, A4): 34°N~40°N, 127°E~140°E
The Northern Sea, Area5 (NS, A5): 40°N~45°N, 127°E~140°E

SST was validated using serial oceanographic data from the National Fisheries Research and Development Institute (NFRDI, Korea). Serial Oceanographic Data (SOD) of only 3 stations in the West Sea (WS), the South Sea (SS), the East Sea (ES) were compared with the most adjacent SST pixels, because NOAA/AVHRR MCSST by JPL PO.DAAC has been previously proved. The correlation coefficients were high above 0.8 (Table 1).

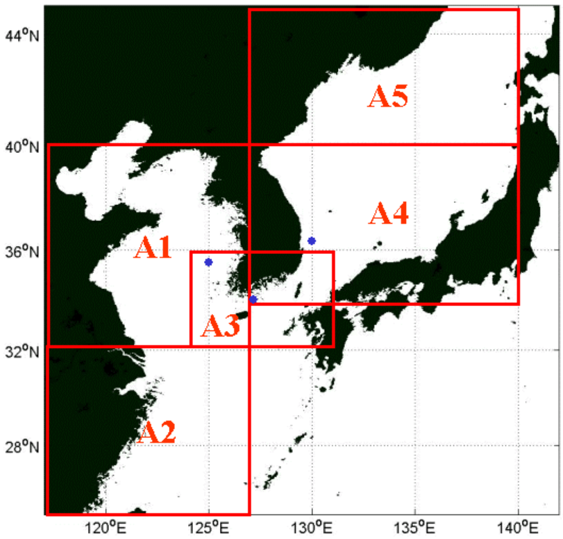


Fig. 1. Study Area (blue dot: serial oceanographic data station).

Table 1. Locations and correlations of validation data in Serial Oceanographic Data (SOD) and Satellite MCSST

| | | ES | WS | SS |
|---|---|---|---|---|
| SOD | Location | St. 103-7<br>36.30°N<br>130.00°E | St. 309-7<br>35.51°N<br>125.00E | St. 205-3<br>34.05°N<br>127.56°E |
| | Mean SST | 17.26□ | 15.31□ | 18.61□ |
| Sat. | Location | 36.29°N<br>129.99°E | 35.59°N<br>125.06°E | 34.01°N<br>127.52°N |
| | Mean SST | 18.61□ | 16.03□ | 19.25□ |
| Correlation coefficient | | 0.89 | 0.92 | 0.89 |

**2) Harmonic Analysis**

Harmonic Analysis was used to figure out spatial distributions and seasonal variations of SST in the Korean seas. Generally, Equation of harmonic analysis is written as Eq. 1;

$$T(t) = \overline{T} + A_1 \cos(\omega_1 t - p_1) + A_2 \cos(\omega_2 t - p_2) \quad (1)$$

In this equation, mean SST is $\overline{T}$, annual and semi-annual amplitudes are $A_1$, $A_2$, and annual and semi- annual phases are $p_1$, $p_2$, respectively, and $w_1$, $w_2$ are angular velocities.

### 3) Sobel Edge Detection Method

Thermal Fronts (TF) are regions, where isotherm is denser than other regions, i. e. steep gradient appears in SST pixels. Sobel Filtering, a method to detect edge (TF) using SST gradient, can obtain clean results in noisy parts of images because weight of filter is high [4]. Sobel Edge Detection Method used the linear differential equation.

$$\square f(x,y) = i\underset{Gx}{(\partial f/\partial x)} + j\underset{Gy}{(\partial f/\partial y)} \qquad (2)$$

$$\text{Gradient magnitude: } [Gx^2 + Gy^2]^{½}$$
$$\text{Gradient Orientation Angle: } \tan^{-1}(Gx/Gy)$$

| | | |
|---|---|---|
| -1 | 0 | 1 |
| -2 | 0 | -1 |
| -1 | 0 | 1 |

X direction Mask

| | | |
|---|---|---|
| -1 | -2 | -1 |
| 0 | 0 | 0 |
| 1 | 2 | 1 |

Y direction Mask

Applying Sobel Mask, gradient magnitude and orientation angle were calculated and determined edge when gradient magnitude exceeds threshold. Edge Detection Sobel Filtering in Matlab Image Processing Toolbox is used by 0.3□ threshold [5].

## 3. Results and Discussion

### 1) Temporal and spatial analysis of SST

As the result of harmonic analysis, the mean SST were 10~25□, and generally SST decreased as latitude increased. SST increased in the order as following; the South Sea (20~23□), the East Sea (17~19□), the West Sea (13~16□) (Fig. 2). In spite of the same latitude, ES was about 2□ higher than WS. The annual amplitudes were 4~11□ and high values were shown in the area as following; A1 (9~11□), A5 (8~9□), A4 (6~8□), A3 (6~7□), A2 (4~7□) (Fig. 3).

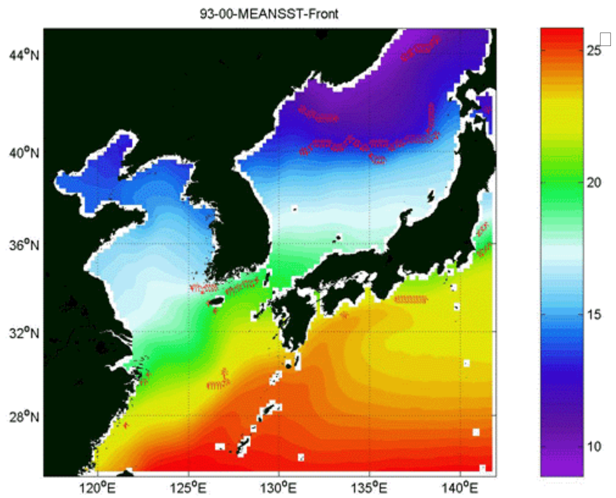


Fig. 2. Distributions of mean SST(℃) by harmonic analysis and Thermal Fronts (red dotted line).

A2, where the Kuroshio Current (KC) flows, showed lowest amplitudes in the whole areas, and A3, 4 also showed low values affected by the Tsushima Warm Current (TWC), a branch of KC. A1, 5 showed the closer to the continent locations the higher amplitudes. It can be supposed that heat exchange in the continent is larger than that in the ocean [6]. Though ES and WS located in the same latitude, the mean SST in ES were about 2℃ higher than those in WS, while amplitudes in ES were about 3℃ lower than those in WS. It can be supposed to heat transportation flowing into ES by TWC and heat volume difference by the depth of water difference between ES and WS. When heat supply through sea surface was compared with that through current, heat supply through current took up 60~70% in A4, but below 10% in A5 [7]. Namely, while in summer, both of A4, 5 were heated same, in winter, according to weakening of heat supply through current in A5, this area showed relatively low SST, and A4 showed higher SST than those of A5 due to heat supply through TWC.

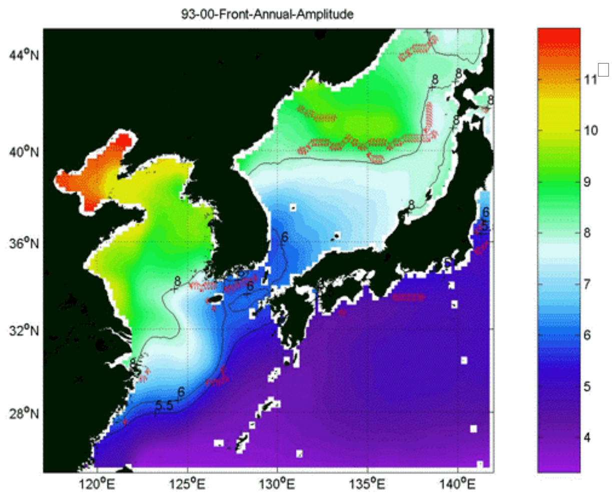


Fig. 3. Distribution of annual amplitude(℃) by harmonic analysis and Thermal Fronts (red dotted line).

Annual phases were 210~240° (August), and A2 was 210~235° due to influence of KC. The time of maximum SST in A2 was earliest as 201° (Aug. 1), and delayed till 235° (Aug. 25) in the northeast of this region. Also, A1 was 210~230°, Aug. 25 ~ Aug. 30 and A4, 5 was divided into north and south heading toward northeast from the stating point, Ulleung island, so the northern and southern part was 225~235° (Aug. 15 ~ Aug. 20), 235~240° (Aug. 25 ~ Aug. 30), respectively (Fig. 4). This location was similar to those of divided annual amplitude, and the Subpolar Front (SPF, 39°~40°N, 130°~140°E). This annual phase difference was related to annual amplitude difference in this region. SST in northern part is more quickly decrease than that in southern part because vertical stratification and mixed layer depth in the northern part were shallower than those in southern part [8]. These caused difference about 7 and 8 days. A3 was latest as 238~242° (Aug. 27 ~ Sep. 2). Table 2 shows that distribution of annual amplitude and phase are related inversely except the area A2 affected by KC. This means the rest areas are influenced by seasonal variations. Semi-annual amplitudes were small values, 0~1.8℃, It was considered that its influence was little (Fig. 5).

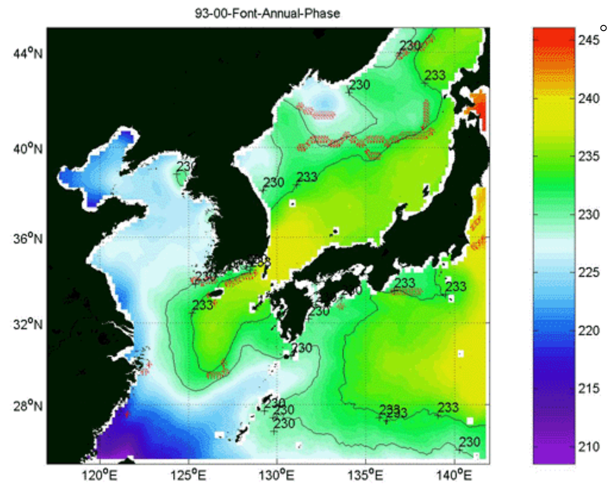


Fig. 4. Distributions of annual phase(°) by harmonic analysis and Thermal Fronts (red dotted line).

**2) Distributions of Thermal Fronts**

Thermal Fronts (TF) above 0.3℃ were figured out using SST gradient by Sobel Edge Detection Method. Only relatively distinctive TF were extracted using mean SST in wide area (Fig. 6). TF were divided into 4 fronts broadly. First, the Subpolar Front (SPF) was formed in 39°~40°N, 130°~140°E dividing A4 and 5. Second, the Kuroshio

Front (KF) was formed in 28°~32°N, 124°~126°E within A2. Third, the South Sea Coastal Front (SSCF) was formed near the south coast (34°N, 125°~129°E) within A3. Last, although there was not detected distinctive front in A1, tidal front resulting from strong tide appeared in In-Cheon coast. SPF based on the Cold Water Mass (low SST and salinity Subartic Water), owing to the North Korea Cold Current (NKCC) and the East Sea Proper Cold Water in the middle and low layer, and the Warm Water Mass (high SST and salinity Subtropical Water), owing to the Tsushima Warm Current (TWC). SPF was detected in all seasons except for summer and appeared most distinctively in winter (Fig. 6). This agreed with [9,10]. In summer, it was difficult to detect TF since SST of the whole area in ES increased equivalently owing to solar radiation. Thus, in this paper, forms and locations of TF were not detected in summer. However it has been studied that TF existed in summer according to [11].

Table. 2. Comparison between annual amplitude and phase

| | | | | | |
|---|---|---|---|---|---|
| Amp. | A1 | A5 | A4 | A3 | A2 |
| | 9~11□ | 8~9□ | 6~8□ | 6~7□ | 4~7□ |
| Pha. | A3 | A4 | A5 | A1 | A2 |
| | 238 ~242° | 225 ~235° | 235 ~240° | 220 ~230° | 210 ~235° |

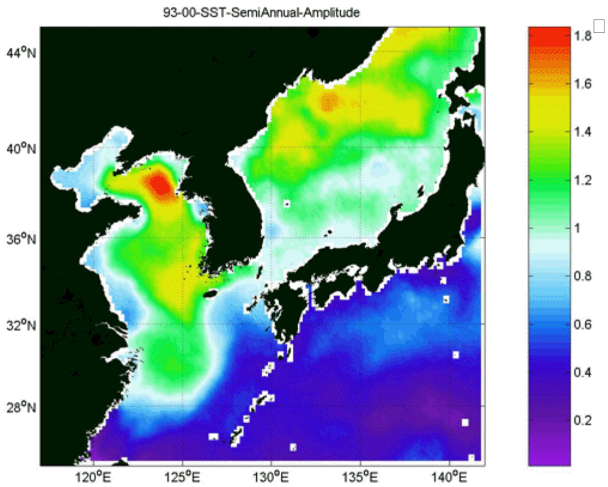


Fig. 5. Distributions of semi-annual amplitude (□) by harmonic analysis.

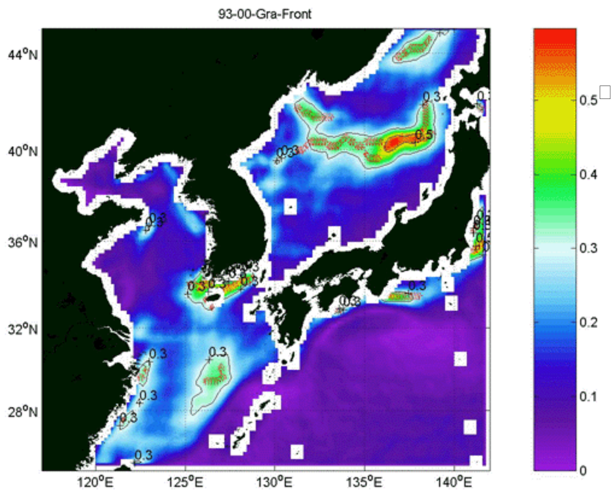


Fig. 6. Distributions of SST gradient value (□) and Thermal Fronts (red dotted line).

Commonly, the KF forms in the Japan South Sea, where it extends to 150°E. But KF in A2 based on the KC and shelf waters in the ESC can mention the KF in ESC according to previous research [12,13]. This front was detected in spring distinctively. SSCF based on the South Sea Coastal Waters (SSCW) and TWC in A3 was detected in all seasons.

### 3) Distribution Analysis of Thermal Fronts and SST

In addition to SPF, the locations of TF in the Korean seas were represented area dividing difference of annual amplitudes and phases. The locations of KF and SSCF were similar to location of the border dividing difference of annual amplitudes and phases (Fig. 3 and 4). TF were located in steep continental slope, SPF was in slope to southern 1000~2000m isobath from 3000m continent shelf, KF was in slope to 500~1000m isobath from 100m continent shelf, and the SSCF was in slope of 20~100m isobath (Fig. 7). The submarine topography affected locations of TF. Annual amplitudes and phases were bounded in the same place, and these results should be considered to influence of seasonal variations.

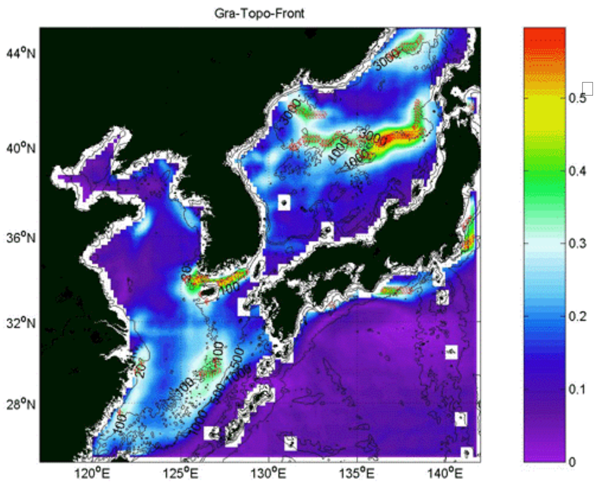


Fig. 7. Distributions of submarine topography and Thermal Fronts (red dotted line) in SST gradient image.

## 4. Conclusions

In the Korean seas, Sea Surface Temperature (SST) and Thermal Fronts (TF) were analyzed temporally and spatially during 8 years from 1993 to 2000 using NOAA/AVHRR MCSST. As the result of harmonic analysis, distributions of the mean SST were 10~25℃ and generally SST decreased as latitude increased. SST increased in the order as following; the South Sea (20~23℃), the East Sea (17~19℃), and the West Sea (13~16℃). Annual amplitudes and phases were 4~11℃, 210~240° and high values were shown as following; the West Sea (A1, 9~11℃), the Northern East Sea (A5, 8~9℃), the Southern East Sea (A4, 6~8℃), the South Sea (A3, 6~7℃), the East China Sea (A2, 4~7℃) and phase; the South Sea (A3, 238~242°), the Southern East Sea (A4, 235~240°), the Northern East Sea (A5, 225~235°), the West Sea (A1, 220~230°), the East China Sea (A2, 210~235°), respectively. Both of them were related inversely except the area A2 therefore the rest areas were affected by seasonal variations. Semi-annual amplitudes were small values, 0~1.8℃, that is its influence was little.

Thermal Fronts (TF) above 0.3℃ were figured out using SST gradient by Sobel Edge Detection Method. Consequently, TF were divided into 4 fronts broadly. First, the Subpolar Front (39°~40°N, 130°~140°E: Open Sea Front) based on the Cold Water Mass (low SST and salinity Subartic Water), owing to the North Korea Cold Current (NKCC) and the East Sea Proper Cold Water in the middle and low layer, and the Warm Water Mass (high SST and salinity Subtropical Water), owing to the Tsushima Warm Current (TWC) in area A4 and 5. Second, the Kuroshio Front (28°~32°N, 124°~126°E: Continental Shelf Front) based on the Kuroshio Current (KC) and shelf waters in the East China Sea(ESC) in A2. Third, the South Sea Coastal Front (34°N, 125°~129°E : Coastal Front) based on the South Sea Coastal Waters (SSCW) and TWC. And last, although there was not detected distinctive front in A1, tidal front resulting from strong tide appeared in In-Cheon coast. In conclusion, the locations of TF were border dividing differences of annual amplitudes and phases. Thus seasonal variations were related to TF. In addition, TF located in steep slope of the submarine topography, that showed the relation between TF and the submarine topography.

This paper represented temporal and spatial distributions of SST numerically with these parameters; mean SST, annual amplitude, annual phase by Harmonic analysis using satellite data, and then showed distributions of TF and figured out correlation of these. However, satellite data didn't show TF in summer, also it was so difficult to present objectively the threshold dividing TF. Therefore research about objective and correct distribution of TF [14] and correlation of TF and seasonal variations of SST are needed.

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