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Communication

Variations of SST around Korea Inferred from NOAA AVHRR Data

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Abstract : The NOAA AVHRR remotely sensed SST data, collected by the National Fisheries Research and Development Institute (NFRDI), are analyzed in order to understand the spatial and temporal distributions of SST in the sea near korea. Our study is based on 10-day SST images during last 7 years (1991-1997). For a time series analysis of multiple SST images, all of images must be consistent exactly at the same position by adjusting the scales and positions of each SST image. We devised an algorithm which automatically detects cloud pixels from multiple SST images. The cloud detection algorithm is based on a physical constraint that SST anomalies in the ocean do not exceed certain limits (we used ± 3°C as a criterion of SST anomalies). The remotely sensed SST data are tuned by comparing remotely sensed data with observed SST at coastal stations. Seasonal variations of SST are studied by harmonic fit of SST normals at each pixel and the SST anomalies are studied by statistical method. It was found that the SST anomalies are rather persistent for one or two months. Utilizing the persistency of SST anomalies, we devised an algorithm for a prediction of future SST. In the Markov process model of SST anomalies, autoregression coefficients of SST anomalies during a time elapse of 10 days are between 0.5 and 0.7. The developed algorithm with automatic cloud pixel detection and rediction of future SST is expected to be incorporated to the operational real time service of SST around Korea.

Key Words : SST, NOAA AVHRR, Markov process model, Time series analysis

1. Introduction

National Fisheries and Research Institute (NFRDI) of Korea has been operating NOAA satellite receiving station since 1989. We made time series analysis of the sea surface temperature (SST) using the satellite remote sense data archived by NFRDI. For a better real time service of SST, we devised an algorithm for an automatic detection of cloud pixels. This paper shows how to handle multiple satellite images for time series analysis. Some results on the variation of remotely

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sensed SST are presented in this paper.

2. Preparation of Data

We made 10-day SST image by choosing the maximum temperature at each pixel of SST images for the specified 10 days. The 10-day SST images from 1991 to 1997 are used as the basic data set. For time series analysis of SST, the SST images are scale-transformed and geometrically corrected such that each given pixel of multiple images represents the same geographic position. The 10-day SST images contain cloud pixels. The high altitude cloud pixels with very low temperature are easily identified, which are treated as missing data. The low altitude cloud or fog pixels with relatively warm temperature, are not immediately identified as cloud pixels which must be rejected form SST data. Those pixels are depicted as follows.

First, we computed SST normals or the averages in the same period of the year of each 10-day SST, and computed SST anomalies, deviation from SST normal, at each pixel of all images. Any pixel with magnitude of SST anomalies more than 15℃, which is physically unacceptable value, is treated as missing data.

Next, we compute SST normals and SST anomalies using only valid data and reject pixel with SST anomalies greater than 14℃. The Similar procedure with the successive decreasing threshold for SST anomalies, with 13℃, 12℃,⋯, etc., is repeated until the magnitude of SST anomalies are within ±3℃.

Fig. 1 shows an example of SST image in which black pixels represent missing data points. The missing data or cloud pixels are removed by linear interpolation of SST anomalies. Fig. 2 shows cloud free SST image at the same time as in Fig. 1.

3. Time Series Analysis of SST

The SST normals Tn(t) at each pixel are fitted to a harmonic function

$T_n(t)=T_0+A_1\cos(\omega t-\phi_1)+A_2\cos(2\omega t-\phi_2)$

where T_0 is average, A_1 and A_2 are annual and

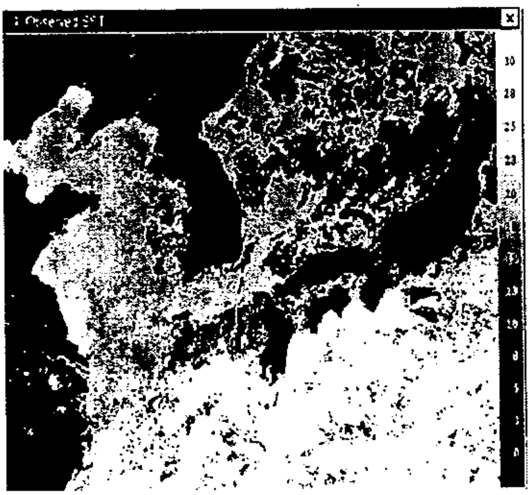

Fig. 1. SST image with cloud pixels (black) of the third 10 days in June, 1996.

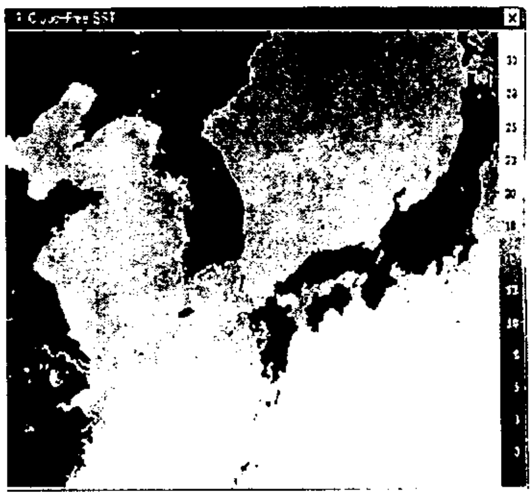

Fig. 2. Cloud-free SST image at the same time as in Fig. 1.

semi-annual amplitudes, respectively. ϕ_1 and ϕ_2 are annual and semi-annual phases, respectively, and ω is annual angular frequency (Kang and Jin, 1984). Fig. 3 shows distribution of annual average temperature $T_0(x, y)$. Annual averages of SST in the Kuroshio region are higher than 20℃ and those in the northern part of East Sea are less than 10℃. Fig. 4 shows the annual amplitude of SST. The annual amplitudes in the Kuroshio region are less than 5℃ but those in the northern part of the Yellow Sea are higher than 10℃. The distribution of annual phase of SST, shown in Fig. 5, indicates that the maximum temperatures in the region far away from the coast occurs at the end of August, but those in the coastal region of the Yellow Sea occur at the end of July.

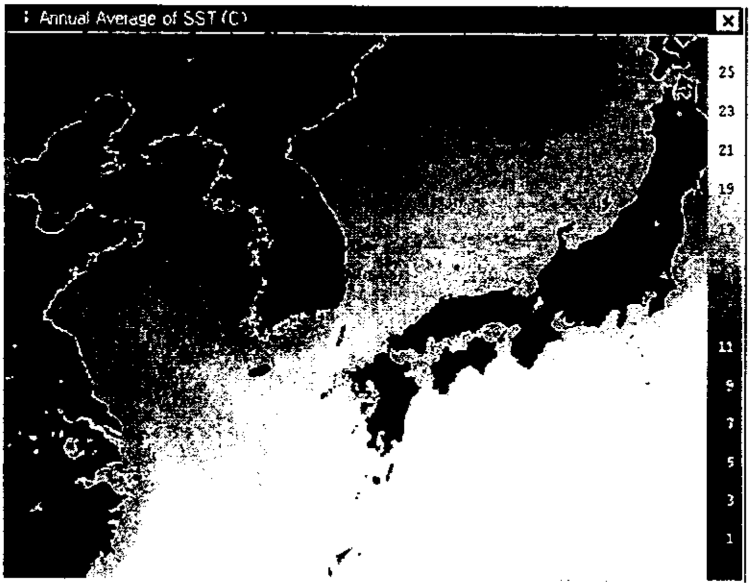

Fig. 3. Annual average of SST.

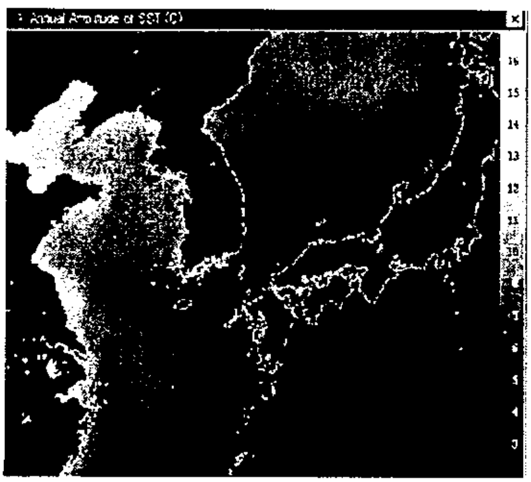
Fig. 4. Annual amplitude of SST.

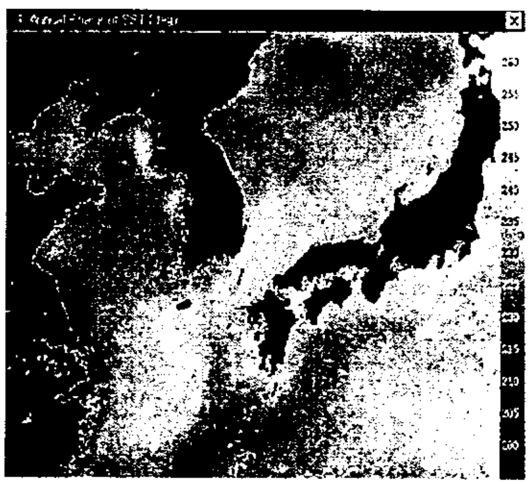
Fig. 5. Annual phase of SST.

The RMS (root mean square) amplitudes of SST anomalies are typically about 1℃ or less. In the frontal regions, however, they exceed more than 1℃ (its figure not shown). The time scales of SST anomalies estimated by time interval between the change of sign at each pixel are shown in Fig. 6. This shows that SST anomalies are rather persistent in time scales for one or two months.

We computed the gradient of SST in order to identify locations of oceanic thermal front. The spatial slope of SST at each pixel is estimated by the least square fit of the SST at nearby 3×3 pixels to a plane equation,

$$T(x,y) = ax+by+c.$$

In this equation, a and b are zonal and meridional slope of SST, respectively, and c is the average temperature at the center. The magnitude of SST gradient at the center of each 3×3 window, $|\nabla T|$, is computed by

$$|\nabla T| = \sqrt{a^2+b^2}.$$

Fig. 7 shows the distribution of the magnitude of SST gradient of the third 10 days in May, 1997. The numbers on the scale box on the right hand side of this figure are logarithm index of slope S_L defined by

$$S_L=100\times(2.5+\log|\nabla T|).$$

We applied Markov process model or autoregression of order 1 model AR(1) to the time series of SST anomalies at each pixel by the equation,

$$T_i=\phi T_{i-1}+a_i$$

where T_i and T_{i-1} are SSTs at time i and i–1, respectively and ai is random noise. The AR(1) coefficient ϕ_1 can be estimated by (Mardarkis and Wheelwright, 1979)

$$\phi_1=\frac{\sum_{i=2}^{n} T_i T_{i-1}}{\sum_{i=2}^{n} T_{i-1}^2}$$

The AR(1) coefficients of 10-day SST anomalies at most of pixels range between 0.5 and 0.7 (its figure not shown). The variance σ_a^2 of unpredictable random noise is given by

$$\alpha_a^2 = \frac{1}{N-1}\sum_{i=2}^{n}(T_i-\phi_i T_{i-1})^2$$

Fig. 8 shows the observed SST and predicted

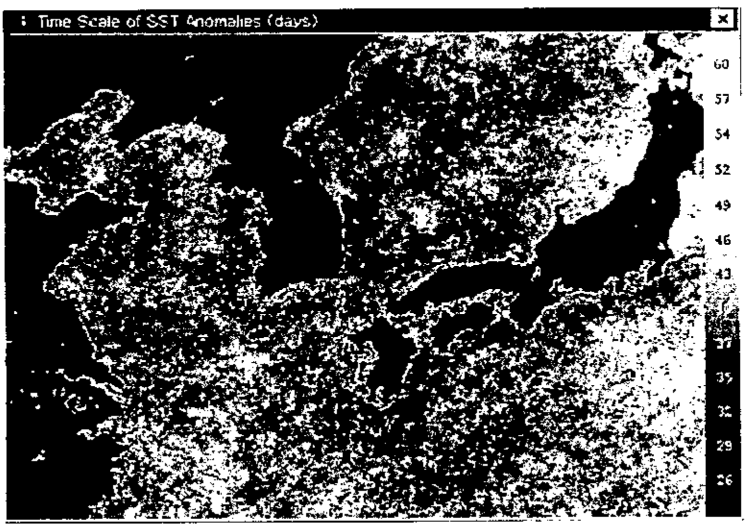

Fig. 6. Time scales of SST anomalies (in days).

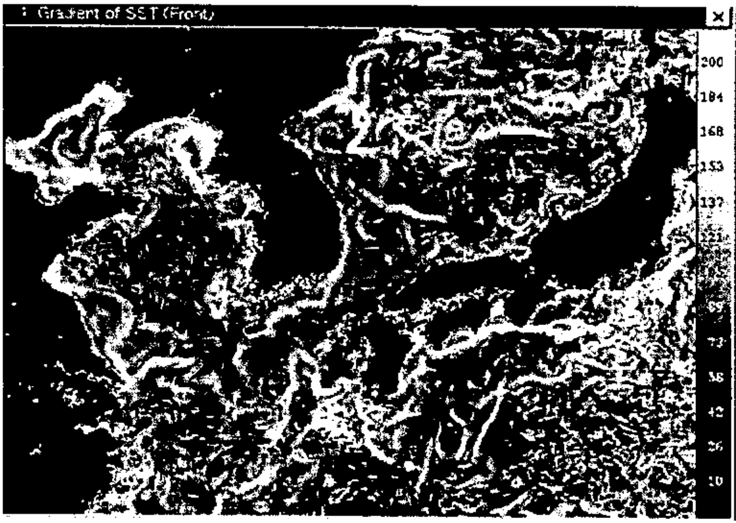

Fig. 7. Time scales of SST anomalies (in days).

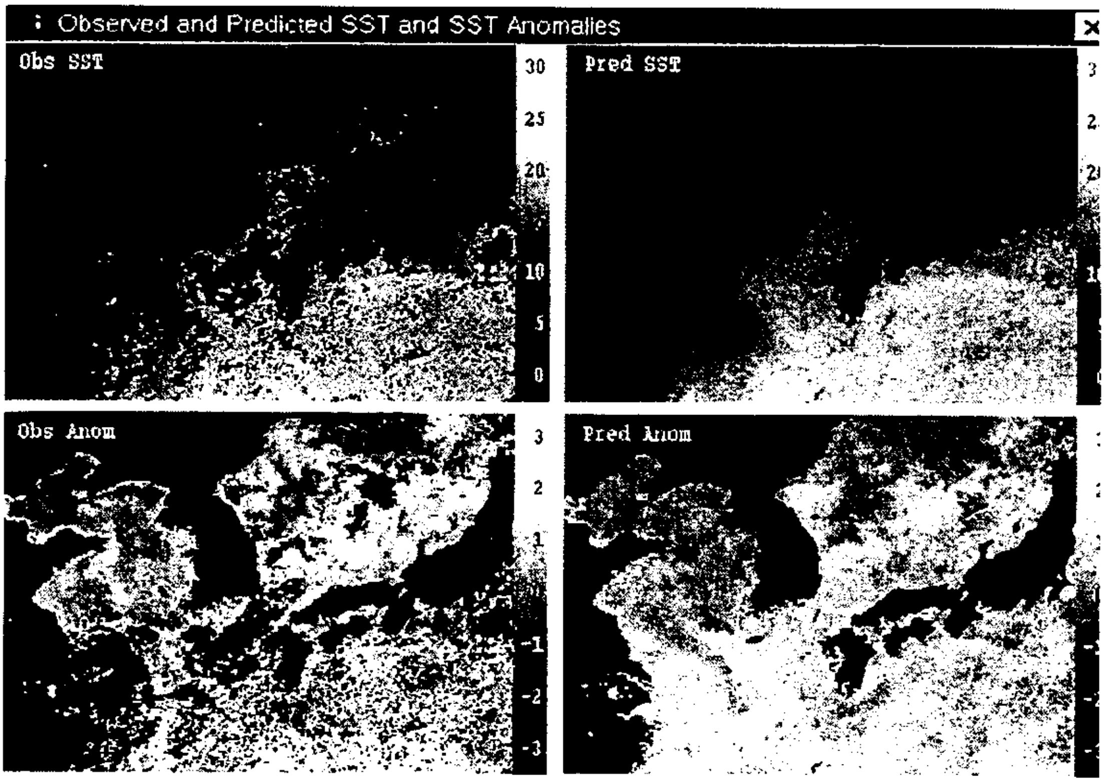

Fig. 8. Observed and predicted SST of the second 10 days in March, 1997. Lower figures are observed and predicted SST anomalies.

SST in the second 10 days in March, 1997.

Using the data base of SST normals, we can easily compute the SST anomalies of 'today' at each pixel. By combining the SST anomalies in the SST images of the previous few days and SST normal of today, we can infer the SST values at cloud pixels. In Fig. 8, the observed SST and the corresponding predicted SST are compared. It also shows the observed and predicted SST anomalies. This indicates that our methods of cloud removal and computation of SST anomalies are very useful for real time service of SST information to fishermen.

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