Variations of SST around Korea inferred from NOAA AVHRR data

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The NOAA AVHRR remote sense 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 seas adjacent to 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 aligned exactly at the same position by adjusting the scales and positions of each SST image. We devised an algorithm which yields automatic detections of 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℃ as a criterion of SST anomalies). The remote sense SST data are tuned by comparing remote sense data with observed SST at coastal stations. Seasonal variations of SST are studied by harmonic fit of SST normals at each pixel. The SST anomalies are studied by statistical method. We found that the SST anomalies are rather persistent with time scales between 1 and 2 months. Utilizing the persistency of SST anomalies, we devised an algorithm for a prediction of future SST. Model fit of SST anomalies to the Markov process model yields that autoregression coefficients of SST anomalies during a time elapse of 10 days are between 0.5 and 0.7. We plan to improve our algorithms of automatic cloud pixel detection and prediction of future SST. Our algorithm is expected to be incorporated to the operational real time service of SST around Korea.

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. In this paper we show how to handle multiple satellite images for time series analysis. Some results on the variation of remote sense SST are presented in this paper.

Preparation of data

We made 10-day SST image by choosing the maximum temperature at each pixel of SST images within specified 10 days. The 10-day SST images from 1991 to 1997 are used as our basic data set. For time series analysis of SST, the SST images are scale-transformed and aligned such that each given pixel of multiple images represents the same geographic position. The 10-day SST images contain cloud pixels. High altitude cloud pixels with very low temperature are easily identified, and we treat those pixels as missing data. Low altitude cloud or fog pixels with relatively warm temperature, are not immediately identified as cloud pixels, but they must be rejected from SST data. Those pixels are depicted as follows. First, we computed SST normals or the averages at the same period of the year of each 10-days, and computed SST anomalies, deviation of observed SST 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 valid data only and reject pixel with SST anomalies greater than 14℃. Similar procedure with successive decreasing threshold of SST anomalies, with 13℃, 12℃, ⋯, etc., are repeated until the magnitude of SST anomalies are within ±3℃. Fig. 1 shows an example of SST image in which black pixels represent data missing 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.

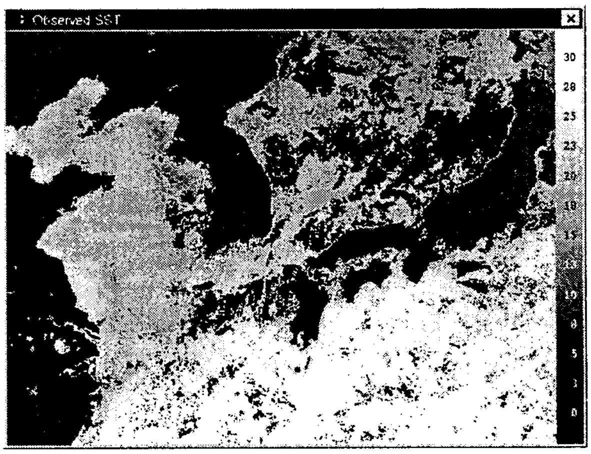

Fig. 1. SST image with cloud pixels (black) in 3rd 10 days, June 1996

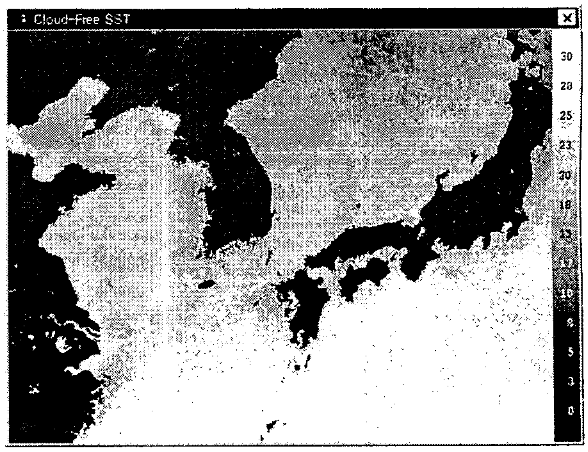

Fig. 2. Cloud-free SST image at the same time as in Fig. 1.

Time series analysis of SST

The SST normals $T_n(t)$ 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 semi-annual amplitudes, respectively, ϕ_1 and ϕ_2 are annual and semi-annual phases, respectively, and ω is annual angular frequency (Kang and Jim, 1984). Fig. 3 shows distribution of annual average temperature $T_0(x, y)$. Annual averages of SST in the Kuroshio region are higher then 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 larger than 10℃. The distribution of annual phase of SST, shown in Fig. 5, indicates that the maximum temperatures in the regions 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.

The RMS (root mean square) amplitudes of SST anomalies are typically about 1℃ or less. In the frontal region, however, they exceed more than 1℃ (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 figure shows that the SST anomalies are rather persitant with time scales between 1 and 2 months.

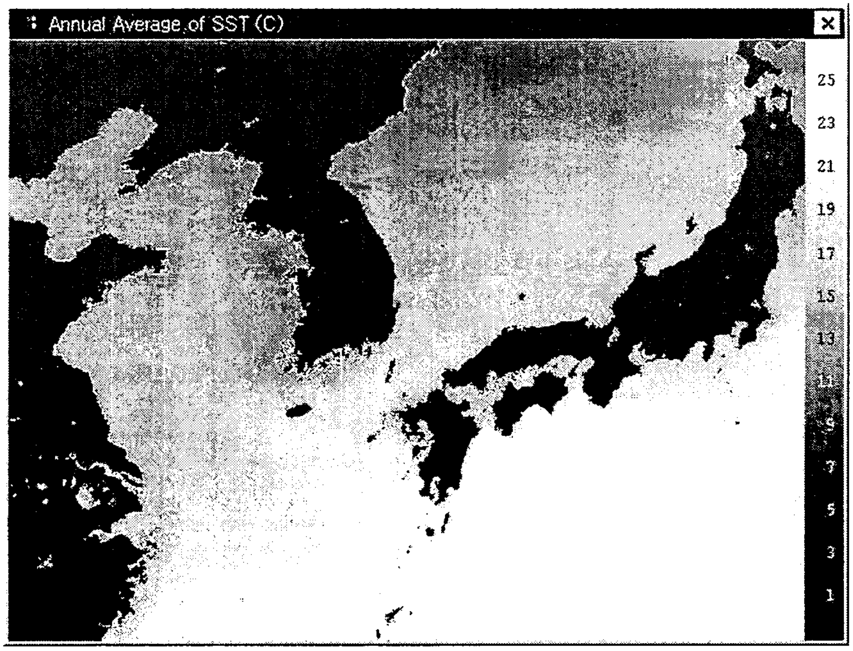

Fig. 3. Annual average of SST

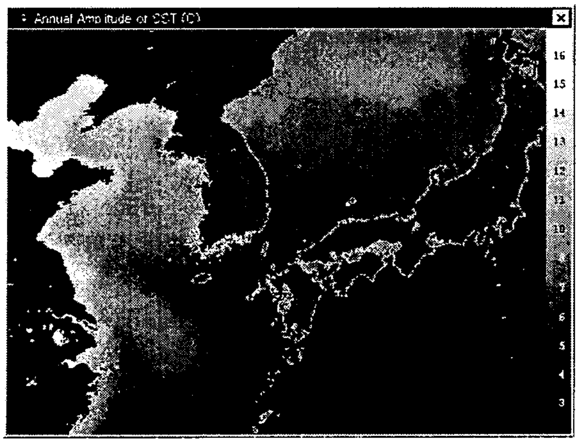

Fig. 4. Annual amplitude of SST

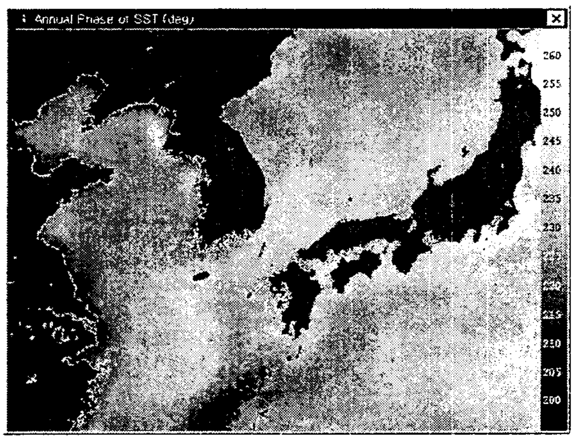

Fig. 5. Annual phase of SST

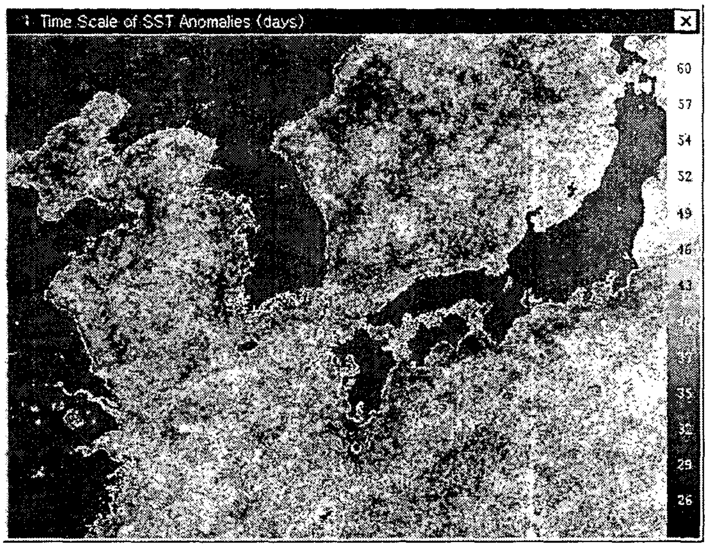

Fig. 6. Time scales of SST anomalies (in days)

We computed gradient of SST in order to identify locations of oceanic thermal front. The spatial slope of SST at each pixel is estimated by a least squares 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 $|\nabla T|$ at the center of each 3×3 pixels is computed by

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

Fig. 7 shows the distribution of the magnitude of SST gradient in 3rd 10 days, 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

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

where T_i and T_{i-1} are SST's at time i and $i-1$, respectively and a_i is a random noise. The AR(1) coefficient ϕ_1 can be estimated by (Mardakis and Wheelwright, 1979)

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

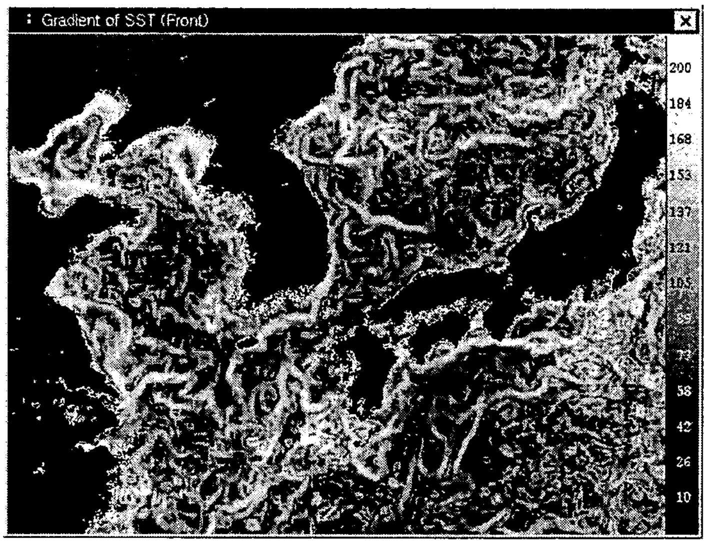

Fig. 7. Gradient of SST in 3rd 10 days, May 1997

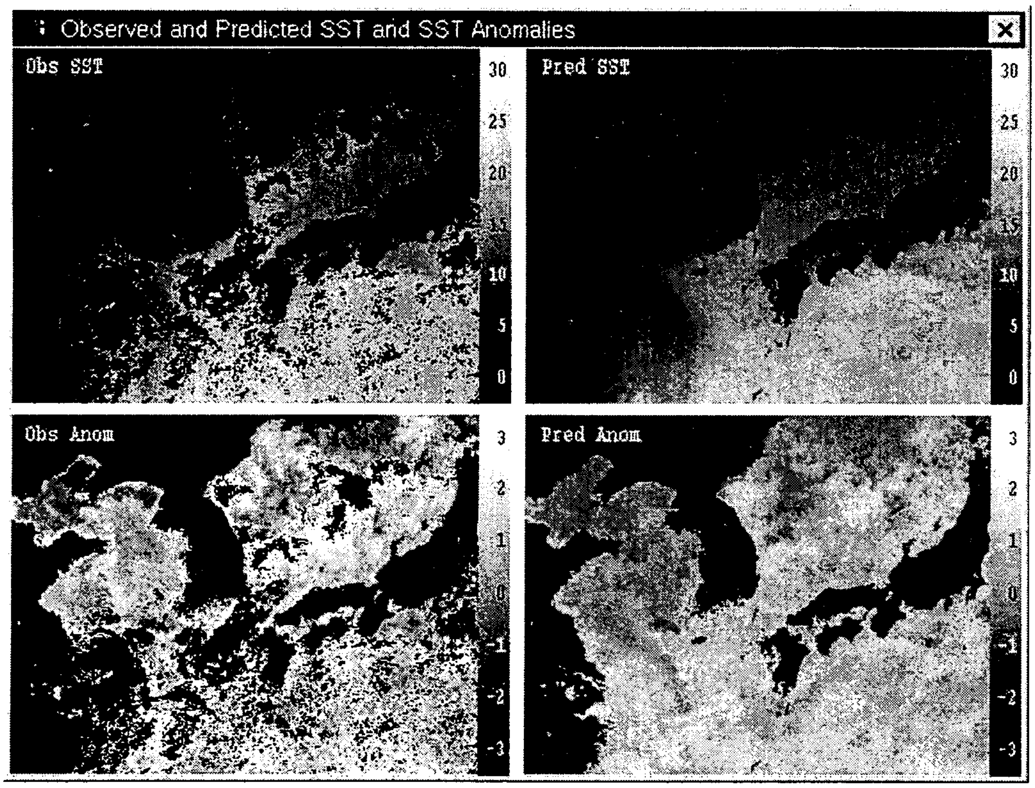

Fig. 8. Observed and predicted SST in 2rd 10 days, March 1997.
Lower figures are observed and predicted SST anomalies.

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

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

Fig. 8 shows the observed SST and predicted SST in 2rd 10 days, 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 previous few days and SST normal of today we can infer the SST values at cloud pixels. In Fig. 8, the observed SST and predicted SST are compared. It also shows the observed and predicted SST anomalies. Our methods of cloud removal and computation of SST anomalies are very useful for real time service of SST information to fishermen.

References

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