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Long-term Trends of SST in the Seas adjacent to Japan

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1. Introduction

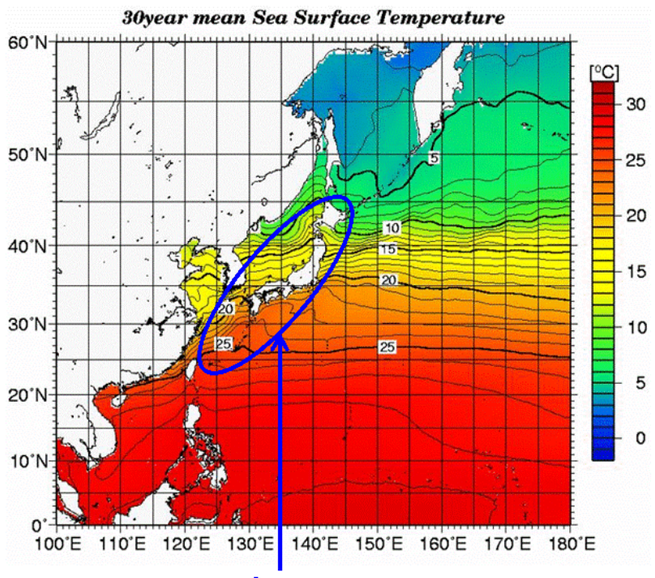

Fig.1. Location of Japan and the distribution of climatological SST (1971-2000 average) in the western North Pacific

There has been increasing global concern over the issue of global warming. For the assessment of the impact of climate change on the environment, it is important to clarify differences in regional rates of surface ocean warming. However, as for around Japan (Fig.1), the spatial distributions of the SST long-term trend over the past 100 years obtained from various objective analyses (e.g., COBE-SST, ERSST, and HadISST) are different with each other. This suggests that such objective analyses cannot reproduce small-scale phenomena sufficiently due to large-scale interpolation. The Japan Meteorological Agency (JMA) has investigated SST long-term trends in the seas adjacent to Japan without using large-scale interpolation.

2. Data and Method

- **In situ SST data**: ICOADS, Kobe Collection, JMA dataset (collected through the GTS and domestic communication lines in Japan). Instrumental bias correction (bucket correction) of Folland and Parker (1995) was applied to these historical SST data set.
- **Number of SST observations in 20-50° N, 110-160° E** : more than 4,000 and 8,000 per month before and after the World War II, respectively. Most of the data are located along major shipping routes, and data are sparse in other seas (Fig.2).
- **Analysis area**: 13 seas adjacent to Japan (Fig.3)
- **Method of division of the analysis area**: Cluster analysis (Ward method) using monthly (12-month running mean) 1° X 1° SST data obtained from COBE-SST
- **Analysis method**:
  SST deviation from COBE-SST on each observation location at the observation time
  → Monthly mean SST deviation averaged over each area
  → Monthly mean SSTs (by adding the deviations to the COBE-SST values)
  → Monthly mean SST climatological values (1971-2000 average)
  → Monthly mean SST anomalies
  → Annual (seasonal) mean SST anomalies (if the number of monthly data is not less than 5(2) in the year (season))
- **Statistical trend testing**:
  t-test and Mann-Kendall test
  (confidence level=95% for both tests)

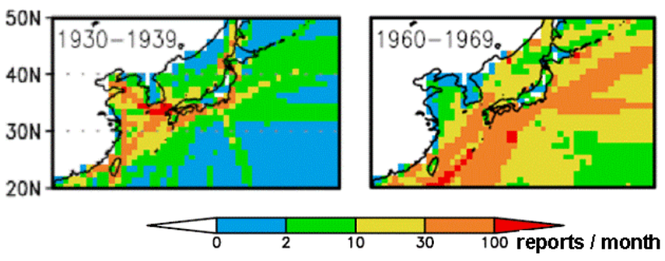

Fig.2. Distributions of the monthly number of SST observations on each 1° X 1° grid averaged over 1930-1939 (left panel) and 1960-1969 (right panel).

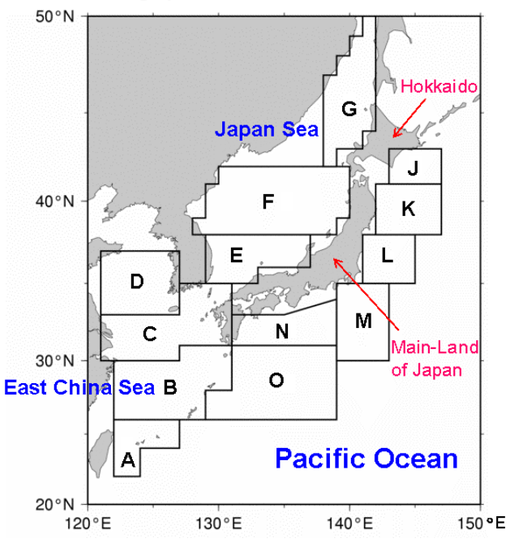

Fig.3. Analysis area (divided into 13 seas)

3. Results

3.1 Long-term trends of annual mean SST anomalies

- Warming trends in most seas are at a rate of +0.7 to +1.7℃ per 100 years with a statistical significance of 95% confidence level. The warming rates are larger than that of global SST (+0.50℃ per 100 years, calculated from COBE-SST).
- Warming trends are at a rate of +1.0 to +1.3℃ per 100 years in many seas such as the southern Japan Sea (E), the East China Sea (B, C, D) and south of Japan (M, N). The rate is almost the same as that of annual mean land-surface air temperature in Japan (+1.1℃ per 100 years).
- The warming trend is the largest (+1.7℃ per 100 years) in the central Japan Sea (F).
- Due to large decadal variability, no statistically significant trends are shown in the northern part of the Japan Sea (G), the seas adjacent to Hokkaido and east of Japan (J, K, L).

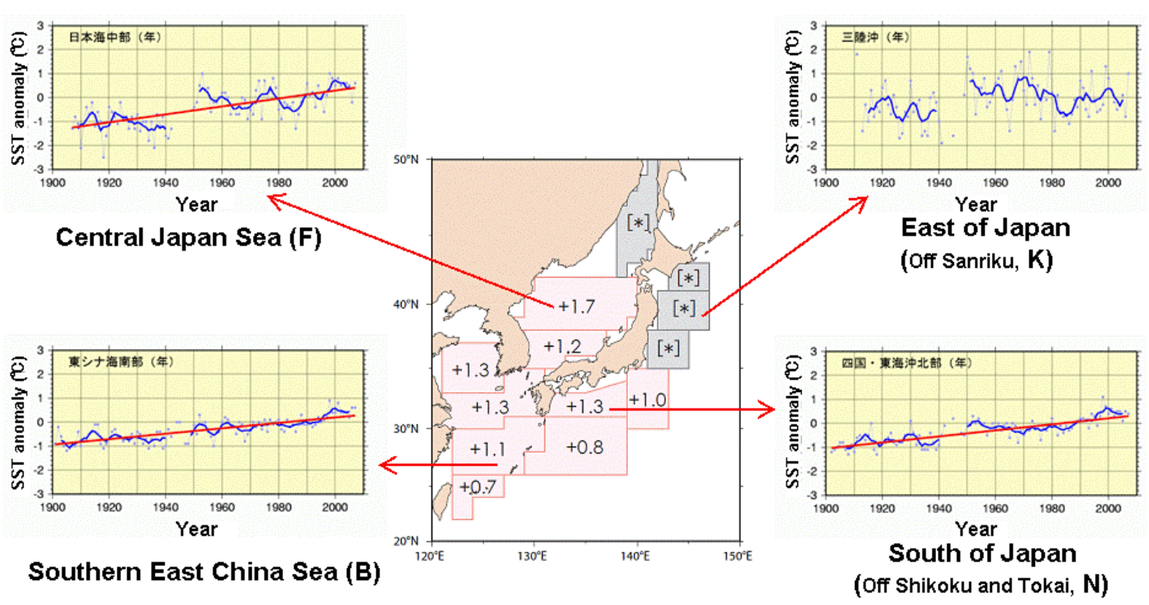

Fig.4. Linear trends of annual SST anomalies from the early 20th century to 2007 (℃ per 100 years) (center panel) and time series of annual SST anomaly in each area (left and right panels). Data missing years exist due to insufficient in-situ data in each sea. In particular, there are almost no data for the years during World War II.

3.2 Long-term trends of seasonal mean SST anomalies

- Warming trends are most prominent in autumn (October–December) and winter (January–March), whereas those of land-surface air temperature in Japan are most prominent in spring (March–May).
- Seasonal difference in warming trends is greater than that of land-surface air temperature in Japan.

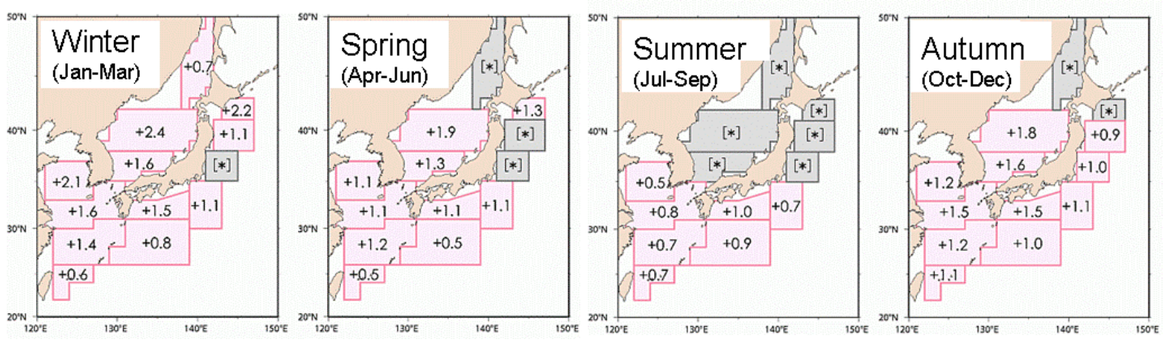

Fig.5. Linear trends of seasonal SST anomalies from the early 20th century to 2007 (℃ per 100 years) Areas with [*] indicate that the trend is not significant at the 95% confidence level.

4. Discussion

4.1 Similarity and difference between the distribution of SST trends of our analysis and those of the objective analyses (COBE-SST, ERSST, and HadISST)(Fig.4 and Fig.6)

- **Similarity**
  SST trends are larger in the seas adjacent to Japan than in the surrounding seas.
  SST trends are larger in the southern and central parts of the Japan Sea than in the northern Japan Sea.
- **Difference**
  There is a tendency that the SST trend increases with latitude (except for the northern Japan Sea, the seas adjacent to Hokkaido and east of Japan) in our analysis, while the SST trend is larger in the southern East China Sea than in the northern East China Sea, and larger in the southern Japan Sea than in the central Japan Sea in COBE-SST and HadISST.

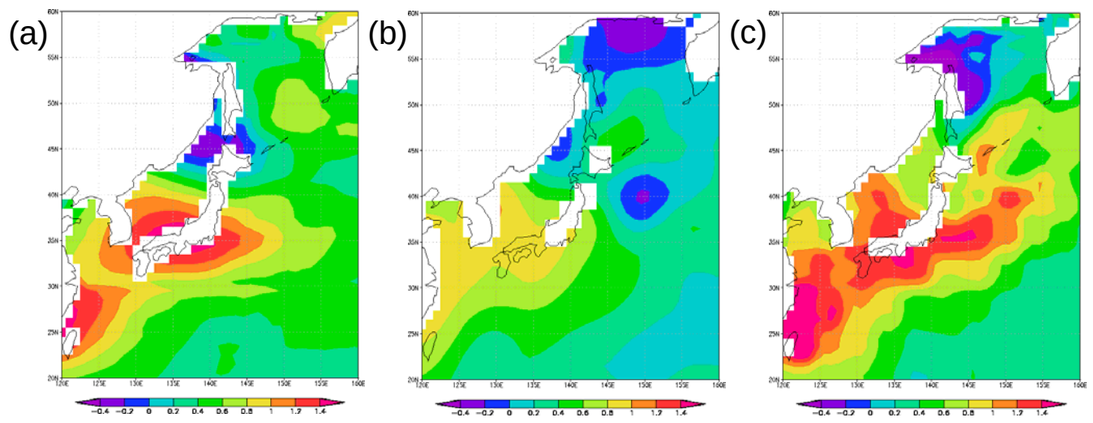

Fig.6. Distributions of SST long-term trend (℃ per 100 years) over the past about 100 years (1891-2003) around Japan obtained from (a) COBE-SST, (b) ERSST-Ver.2, and (c) HadISST.

4.2 Why is the SST trend in the central Japan Sea large?

- The land-surface air temperature in the mid-latitude of the Eurasian Continent has been fast warmed, especially in winter (Fig.7)
- Winter time surface winds over the Japan Sea (blowing from north-west to south-east) are strongly affected by upstream topography of the coastal region of the Eurasian Continent. There is a strong wind area off Vladivostok (Fig.8). The surface winds exit through the valley near Vladivostok.
- Long-term sea-level pressure data set (Trenberth and Paolino, 1980: Mon. Wea. Rev.) suggests no long-term change of the winter time surface winds over the Japan Sea (not shown).
- The SST trends in many of seas adjacent to Japan, including the central Japan Sea, are also the largest in winter (Fig.5).

⇒The larger SST trends in the seas adjacent to Japan (especially in the central Japan Sea) than global average are probably affected by the fast warming in the mid-latitude of the Eurasian Continent.

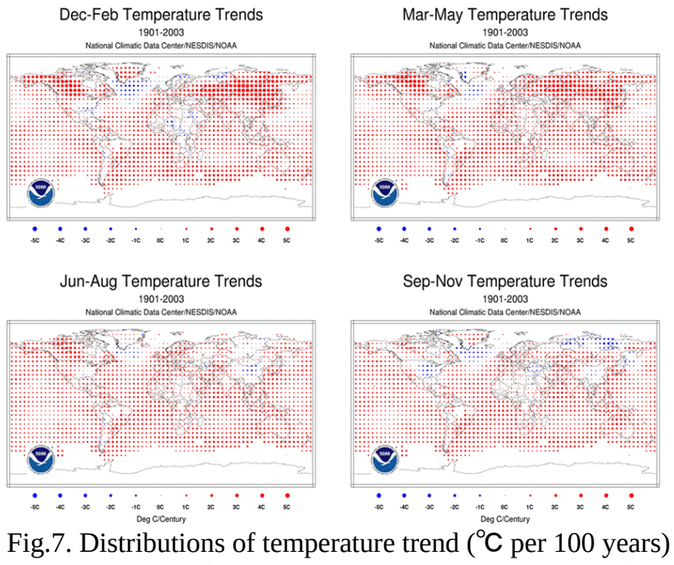

Fig.7. Distributions of temperature trend (℃ per 100 years) in winter (Dec-Feb), spring (Mar-May), summer (Jun-Aug) and autumn (Sep-Nov) over the past 100 years (1901-2003) (http://www.ncdc.noaa.gov/oa/climate/research/trends.html).

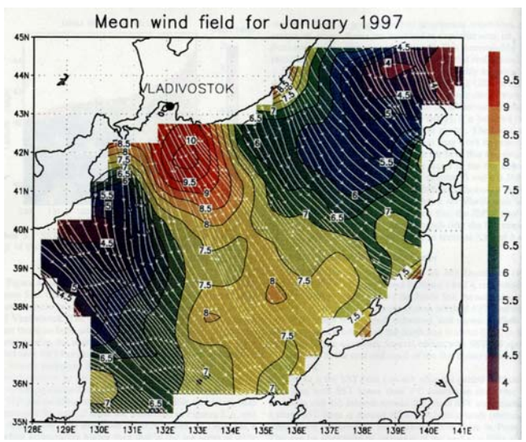

Fig.8. Monthly mean wind field over the Japan Sea in January 1997 (in meters per second) observed by NSCAT (Kawamura and Wu, 1998: JGR). Wind speeds are illustrated by color, and white stream lines are superimposed with arrows.

4.3 Are the SST trends in the seas adjacent to Japan related to global warming?

- The larger trend of SSTs than the global average is not entirely attributed to global warming due to human activities, because the investigated areas are limited around Japan and year-to-year variability is not negligible there.
- For example, faster temperature rise after the mid-20th century than before the mid-20th century can be found in both continental- and global-scale observations and results simulated by climate models using natural and anthropogenic forcings (IPCC 2007: WG1-AR4). On the other hand, it is difficult to find such fast rise since the mid-20th century in the SST time series around Japan (Fig.4).

5. Summary

- The SST warming trend around Japan is larger than the global average.
- The SST warming trend is the largest in the central Japan Sea.
- The SST warming trend around Japan is most prominent in autumn and winter.
- The larger trends in the seas adjacent to Japan (especially in the central Japan Sea) than the global average are probably affected by the fast warming in the mid-latitude of the Eurasian Continent.
- The larger trend of SST around Japan than global average is not entirely attributed to global warming due to human activities.