Application of Wavelet Spectrum Analysis to Horizontal Structure of Sea Surface Temperature

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Abstract

Two-dimensional wavelet spectrum analysis is applied to Advanced Very High Resolution Radiometer (AVHRR) images from the NOAA meteorological satellites in the area around Japan to unfold the horizontal structure of SST into space and scale (wavenumber), which can yield localized space-wavenumber information. The results reveal significantly new and previously unexplored insights on horizontal structure of sea surface temperature, which cannot be revealed using a traditional Fourier transform approach.

Introduction

There have been some wavenumber spectral studies of sea surface temperature (SST) derived from aircraft or satellite data using Fourier transform approach. McLeish (1970) presented an estimate of the SST spectra, and demonstrated an overall slope of $k^{-5/3}$ (k is the wavenumber) for a scale range smaller than 20 km, which agreed with -5/3 law for the power spectrum predicted for the inertial subrange of 3-D isotropic turbulence suggested by Kolmogorov (1941). Saunders (1972) and Deschamps et al. (1981) found the density of temperature variance exhibited a k^{-p} (p is around 2.0) power law over the range of scales 3-100 km. Holladay and O'Brien (1975) indicated that over the range of scales from 4-20 km the isotropic part of the temperature variance spectrum obeyed a -3 power law.

While avelet analysis has been widly recognized as a revolutionary approach applicable to many fields of studies, the application of wavelet transform to oceanography is still in its infancy. The present study presents the attempt to understand SST wavenumber spectra applying 2-D wavelet spectrum analysis (which can yield localized time-frequency information) to NOAA IR images for the area around Japan.

Wavelet Spectrum

The Wavelet transform of a function x is defined as the integral transform with a family of functions ψ and is given as

$$WT_k(j) = a^{-1/2} \sum_m x(m) \psi^* \{(m-b)/a\}, \tag{1}$$

where the functions ψ are called mother wavelet, **a** is a scale dilation, **b** is a position translation and an asterisk superscript indicates the complex conjugate (ex. Katul et al., 1994). As mother wavelet, we choose the Haar wavelet basis that is the simplest orthonomal wavelet basis and given by

$$\psi(x) = \begin{cases} 1 & for\ 0 < x < 1/2 \\ -1 & for\ 1/2 < x < 1 \\ 0 & elsewhere. \end{cases} \tag{2}$$

For the Haar wavelet basis, the wavelet component and the coarse grained signal can be determined using the Haar wavelet function (1, -1) and the Haar scaling function (1, 1), respectively. The wavelet component is a high-pass filtered function using the Haar wavelet function, while, the coarse grained signal is a low-pass filtered function using the Haar scaling function. In analogy with Fourier energy density spectrum, a wavelet spectrum can be readily defined for a data series **x(t)** as

$$W_X(s,\tau) = \widetilde{X}(s,\tau)\widetilde{X}^*(s,\tau) = \left|\widetilde{X}(s,\tau)\right|^2. \tag{3}$$

In the present study, a two-dimensional wavelet spectrum for each scale (wavenumber) was computed at each position using the Haar wavelet basis, and then a spacially-averaged wavelet spectrum was calculated for each scale.

Data

The data used in the present study were collected in the four area (Perturbed area between the Kuroshio and Oyashio, Japan Sea, East China Sea and the Kuroshio area). The resolution of these images is reduced to half the resolution, so 1 pixel corresponds to about 2.2 km. Two images of the perturbed area were collected by NOAA-5 in 1980 and the others were collected by NOAA-9 in 1988. We chose several 128x128 pixels or 64x64 pixels cloud-free sub-images from every IR images.The total number of the small sub-images is 18 (Table 1).

Table 1. Information of each image

Region	Date	Time	Sat.	# of Sub-Images
Perturbed Area	5/23/80	07:09	5	4 (128 x 128)
Perturbed Area	5/27/80	18:40	5	4 (128 x 128)
Perturbed Area	4/10/88	03:24	9	3 (64 x 64)
Japan Sea	4/09/88	03:34	9	2 (128 x 128)
East China Sea	4/24/88	04:13	9	3 (128 x 128)
Kuroshio	5/06/88	03:43	9	2 (128 x 128)
				total 18

Results

The spacially-averaged wavelet spectrum along each scale (wavenumber) for the four areas are shown in Fig. 1. The wavelet spectral slope is about -2.0 in the wavelength range between 4 and 280 km (scale: -1 to -7) both in the Kuroshio area and the East China Sea, while in the Japan Sea and the Perturbed area (between the Kuroshio and the Oyashio), the slope is about -5/3. The north-south and east-west components of the spacially-averaged wavelet spectrum indicate that each of N-S and E-W components of wavelet spectrum also has a -5/3 power law respectively although horizontal turbulence is not isotropic motion in the wavelength range between 4 and 280 km.

However, the calculation of the slope at every position (Fig. 2) indicates the values of the slope are randomly distributed, and in the Japan Sea and the Perturbed area, the number of positions where the slope is -5/3 is about 10% (even the number of positions where the slope is between -3 and zero is only about 30 %).

In addition, the distribution of the wavelet spectra at each scale is nearly Gaussian distribution at the lower wavelengths, while at the higher wavelengths, it largely shifts from the normal distribution near the center of the distribution (Fig. 3).

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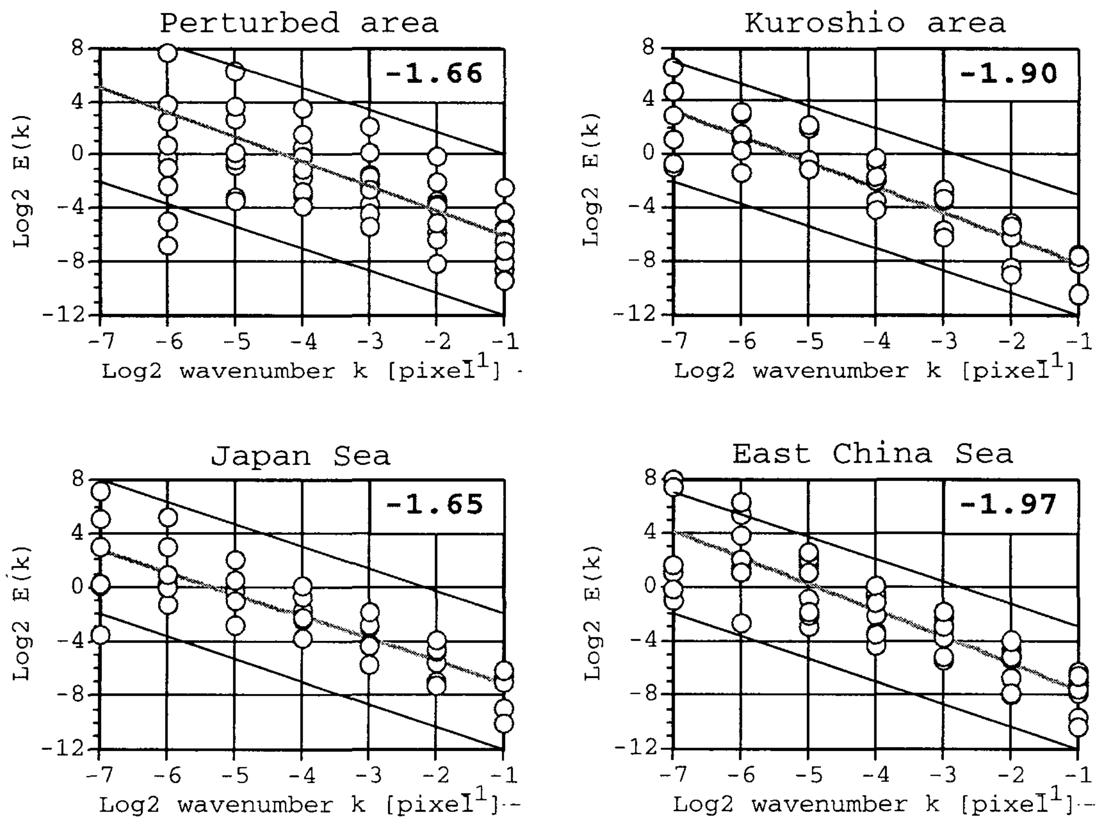

Fig. 1. Wavenumber spectra of SST from data listed in Table 1.

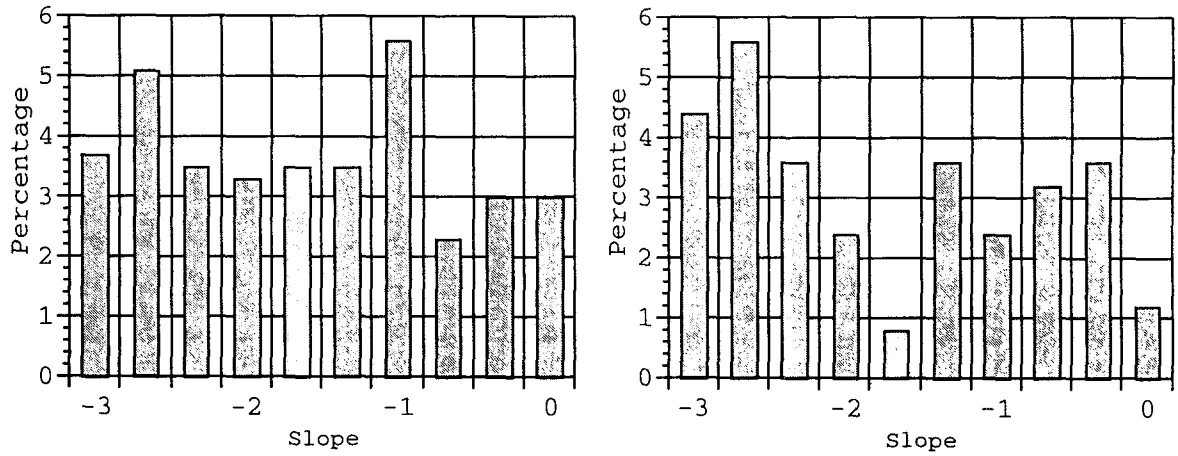

Fig. 2. The number of positions (%) versus slope; Scale 2-3 (left); Scale 3-4 (right).

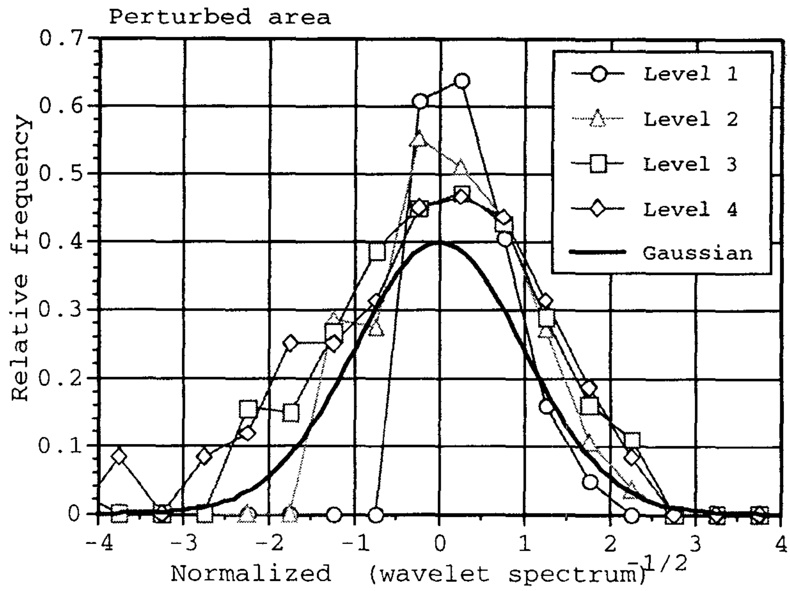

Fig. 3. Distribution of the wavelet spectra at each scale