STUDY OF THE MARINE CLOUD STRUCTURE WITH AQUA AMSR-E

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This study investigates the spatial structure of the total cloud liquid water content Q fields over the Northwest Pacific Ocean during winter monsoon. The distributions of Q have been estimated from the brightness temperatures of the ocean - atmosphere system $T_B(f)$, where f is frequency, measured by AQUA AMSR-E in January – March 2003. Marine strati (St) and stratocumuli (Sc) are typical for winter monsoon season. They were analysed using mainly high-frequency channel at f = 36.5 GHz, vertical polarisation. T_B data were accompanied by the data on near surface wind speed, air temperature and humidity from the nearest meteorological stations. Tow one-dimensional spectra were computed for downwind and crosswind sections of Q fields. The AMSR-E antenna field of view (14-8 km) and the cloud field sizes (100-1000 km) restricted the spatial scales. The results of case study Jan 31 2003 are presented. Scale-invariant spectrum is typical. In the cases of extended St levels a spectral slope equals about –1.7, conforming to classical –5/3 of turbulence theory. For Sc cases the absolute magnitude of spectral slope is rather higher, as a rule. The value is about -2. In the case when cloud streets are presented, a strait line form of spectrum is less reliable with a slope being rather lower (about –1.4).

KEY WORDS: Microwave remote sensing, Total liquid water content, Brightness temperature, Spatial structure, Energy spectrum

1. INTRODUCTION

Knowledge of spatial structure of clouds is required for a task of calculation of the Earth's radiative budget and for many other applications, such as the advancement of the processing and interpretation of satellite passive microwave measurements, improvement of detectability of weak space sources of emission in radio astronomy, etc.

A spatial distribution of vertically integrated liquid water content *Q* reflects inhomogeneities of cloud structure both in the horizontal and vertical planes. Microwave radiometry is essentially the only technique, which permits the *Q* values to be determined. There are very few experimental data about *Q* fields especially for marine clouds. Spectral analysis of Q variations was completed for experimental data of Q, obtained during coastal experiments (Cahalan and Snider, 1989; Feijt and Jonker , 2000; Shoom et al., 2000; Shoom et al, 2002)

Equipment of the modern satellites with microwave radiometer complexes permits new feasibility for global investigations of the ocean-atmosphere system. This study investigates the spatial structure of the total cloud liquid water content Q fields over the Northwest Pacific Ocean estimated from the brightness temperatures of the ocean - atmosphere system *TB*(f), measured by AQUA AMSR-E.

2. ENERGY SPECTRUM OF Q FIELD

2.1 Data

This study is based on the AMSR-E data, channel at f = 36.5 GHz, vertical polarisation. Space sampling of data is 10x10 km, IFOV(36.5 GGz) is 14x8 km, incidence angle is 55° (Lobl, 2001). The received data in hdf-format were visualised and proceeded with the program of NOESYS Research System.

Microwave data were accompanied by R/Z Soundings data on near surface wind V_s, sea surface temperature T_s and integrated water vapour content W of the atmosphere from nearest meteorology stations. This data were received in Internet.

2.2 Computation of Q variations

Obtaining of the Q variations field is based on the knowledge of increments of brightness temperatures of cloud atmosphere over ocean with respect to clear one .

The brightness temperature of the ocean-cloud atmosphere system observed from satellite is given by

$$T_B^V = \kappa^V(\varphi,V_s)T_s\exp(-\tau_\Sigma\sec\varphi) + T_{eff}^{\uparrow}[1-\exp(-\tau_\Sigma\sec\varphi)] + \left\{T_{eff}^{\downarrow}[1-\exp(-\tau_\Sigma\sec\varphi)] + T_B^c\exp(-\tau_\Sigma\sec\varphi)\right\}\cdot \cdot[1-\kappa^V(\varphi,V_s)]\exp(-\tau_\Sigma\sec\varphi) \tag{1}$$

where $\kappa^V(\varphi,V_s)$ is emissivity of sea surface at vertical polarization depending on an incidence angle φ and sea surface wind speed V_S, T_S is sea surface temperature, τ_Σ is total atmospheric absorption, T_B^c is brightness temperature of cosmic radiation (2.7 K), $T_{eff}^{\uparrow}$ and $T_{eff}^{\downarrow}$ are effective temperatures for upwelling and downwelling radiation of the atmosphere, τ_Σ is total absorption by the atmosphere. $\tau_\Sigma = \tau_0 + \tau_{cl}$, τ_{cl} is total cloud absorption, $\tau_0 = \tau_{OX} + \tau_{WV}$ is total absorption by the clear atmosphere (the sum of the total absorptions by oxygen and by water vapor).

This is the main expression . Primarily a calibration of digital information was completed: The brightness temperatures for some points were calculated with (1). Such calibration point was choised in the non-cloud marine part of the hole image and in the vicinity of the meteorology station. Than we calculated T_B value for all poins.

The variations of the total cloud liquid water content were found from the measured increments of T_B of the cloud atmosphere with respect to the clear one.

Writing expression (1) for cloud atmosphere and for clear one, than residing one expression from another and accomplishing necessary changing for simplicity and neglecting the terms of second order of value we obtain the expression for $\Delta T_B(\varphi) = T_B^{cl}(\varphi) - T_B^0(\varphi)$,

where T_B^{cl} and T_B^0 are the brightness temperatures of cloud and clear atmosphere respectively. Following it we obtain:

$$\tau_{cl} = -\cos\varphi \cdot$$
$$\cdot \ln\left[1 - \frac{\Delta T_B(\varphi)}{\kappa(\phi)(T_{eff} - T_s)\exp(-\tau_0 \sec\phi)}\right] \qquad (2)$$

T_{eff} is effective temperature of the atmosphere. It is suggested that the effective temperatures of the cloud and clear atmospheres are equal.

The oxygen absorption varies only slightly and is essentially the constant. For total absorption by cloud and by water vapor we have the following forms:

$$\tau_{vp} = \gamma_{WV} W \ ,$$

$$\tau_{cl} = \gamma_{cl}(t_{cl})Q \qquad (3)$$

where γ_{WV} and γ_{cl} are the mass absorption coefficients by water vapor and by liquid water; respectively, and t_{cl} is the effective temperature of cloud.

We calculate the values of τ_{OX}, γ_{WV} and γ_{cl} using relationships by Liebe (Liebe, 89).

The values of Q can be found from (2) and (3).

2.3 Spectral analisys

To investigate spatial structure of cloud fields tow one-dimensional spectra were computed for downwind and crosswind sections of Q fields.

We follow a common way of turbulence research and apply one-dimensional spectral analysis to the retrieved Q variations to investigate the spatial structure of marine strati.

Let $q(k)$, $-\infty < k < \infty$, is the Fourier transform of a stochastic process $Q(x)$, $0 \le x \le L$. The the wavenumber spectrum $E(k)$ of $Q(x)$ is defined as

$$E(k) = \frac{1}{L}\langle q(k)q^*(k)\rangle ,$$

where symbol * denotes a complex conjugate value and symbol $\langle . \rangle$ denotes an ensemble averaging.

Spectral analysis allow us to locate the dominant frequencies of the stochastic process and also to specify the lower and upper limits of the wavenumber spectrum $E(k)$ which bound scale invariant regime. Between these limits the wavenumber spectrum follows a power law:

$$E(k) \propto k^{-\beta}$$

For the real experiment it is difficult if not impossible to perform the ensemble averaging (1) in rigorous sense. We simulate the ensemble averaging following approach.

Let's suppose that selected for analysis part of image (and correspond part of digital 2-dimension matrix of data) has a dimensions n x m. Then one of these values (n) is a sample number of profile (n/2 is the number of calculated point of energy spectrum), and m is the number of averaging.

3. RESULTS

The results of case study Jan 31 2003 are presented. Five circuits contain the ranges of our interest.
An example of $T_B^V(36.5)$ image of Japan sea (file name P1AME030131111MD_P011B0000000) is presented in

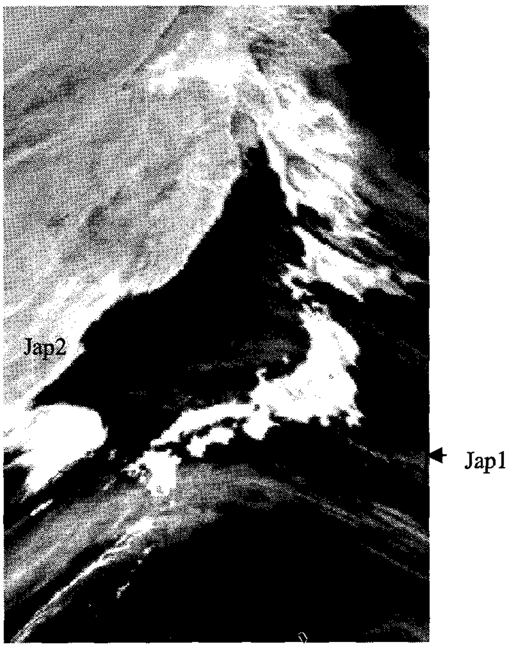
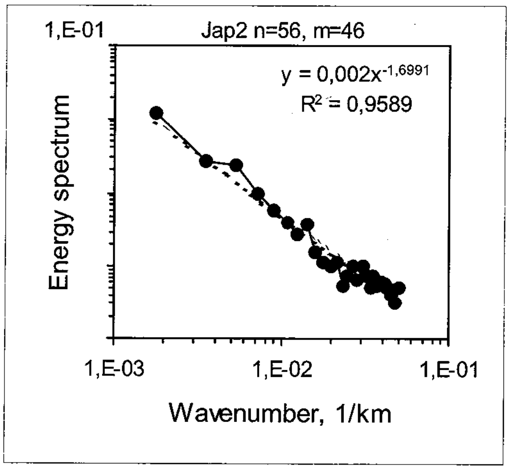
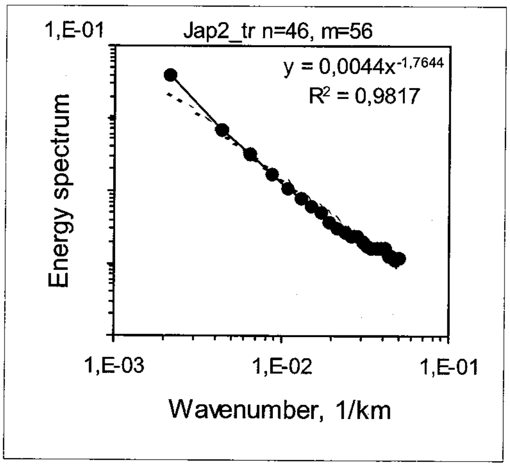


Fig.1. Fragment of $T_B^V(36.5)$ image Jan 31 2003 P1AME030131111MD_

Tow fragments were selected for analysis (Fig.1) They are named Jap1 and Jap2, corresponding to 1) extended St cloud field under Japan Sea and 2) cloud field with distinct cloud sheets at the east from Japan islands. The fragments has a form of parallelogram with a sides n x m: n is a number of points in a profile along which one-dimensional spectrum is calculated and m is a number of averaged profiles. Atmospheric sounding data from stations 31977 (Sag Gorod, Vladivostok) and 47600 (Wajima) accompanied microwaave data.



a)

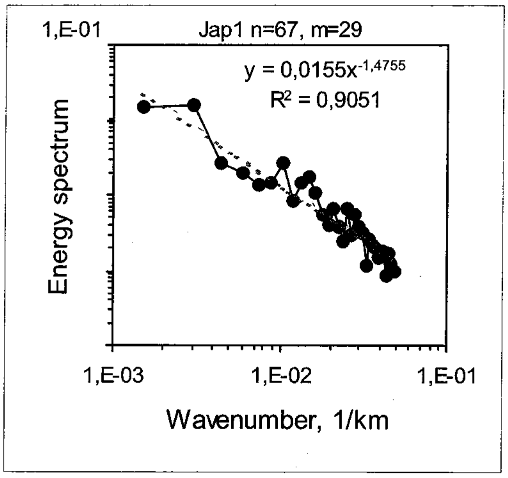


b)

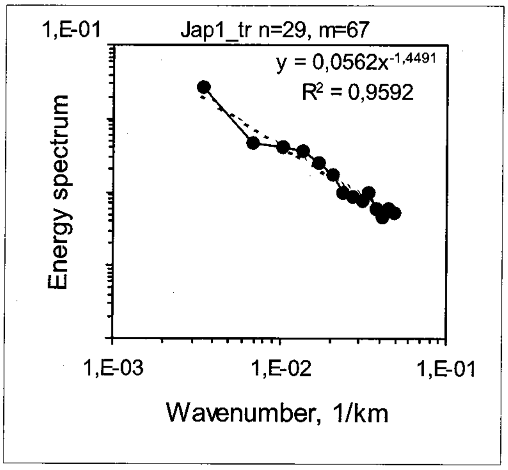
Fig.2. Energy spectrum of Q variations at Jap2 fragment
a) Jap2, profile direct from NE to SW, n=56, m=46;
b) Jap2_tr, profile direct from west to east, n=46, m=56.

The both model one-dimension spectra, calculated for cross directions reveal scale invariant regime extended to the hole wave number range (spatial scales) investigated. The strait line approximation of spectrum in log-log axis is high reliable. Value of the spectral slope $-\beta$ is equal -1.70 for Jap2 case and –1.76 cross-directed spectrum, the result is in good agreement with slope value –5/3 of Kolmogorov theory of developed turbulence.

Results of spectral calculations for Jap1 fragment are presented in fig.3. We used meteorological data from stations 47420 (Nemuro) and 47678 (Hachijyojima) for these calculations.



a)



b)

Fig.3. Energy spectrum of Q variations at Jap1 fragment
a) Jap1, profile vertically direct n=67, m=29;
b) Jap2_tr, profile direct along cloud sheets, n=29, m=67.

For Jap1 case study calculated model spectra may be approximated by strait line too. But in this case the reliability of approximation is rather smaller. The $-\beta$ value is –1.47 for Jap1 and –1.44 for Jap1_tr.

The $T_B^V(36.5)$ image of region to North from Taiwan and to South from Japan (file name P1AME030131216MA_P011B0000000) is presented in fig.4.

Sounding data from stations 47909 (Naze) and 47936 (Naha) were used as accompanying data for Q field calculation in this case study.

We calculated tow cross-directed energy spectra of Q variations for Taiw fragment and obtained following results:

a) Taiw, profile vertically direct n=40, m=74;
   $-\beta = -2.02$ with reliability of approximation $R^2 = 0.97$;
b) Taiw_tr, profile horizontally direct, n=74, m=40;
   $-\beta = -2.01$, $R^2 = 0.98$.

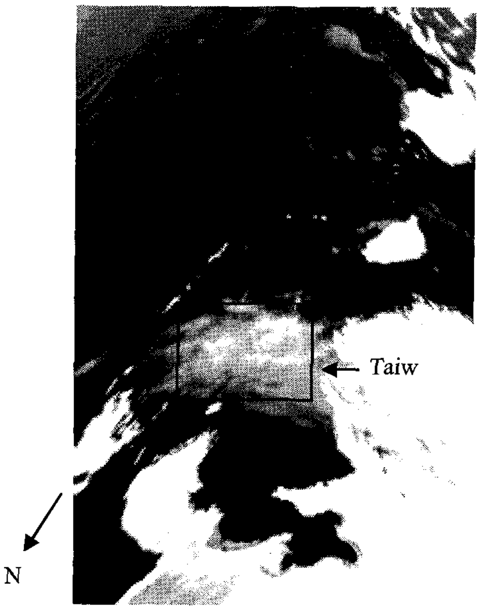


Fig.4. Fragment of $T_B^V(36.5)$ image Jan 31 2003 P1AME030131216MA_

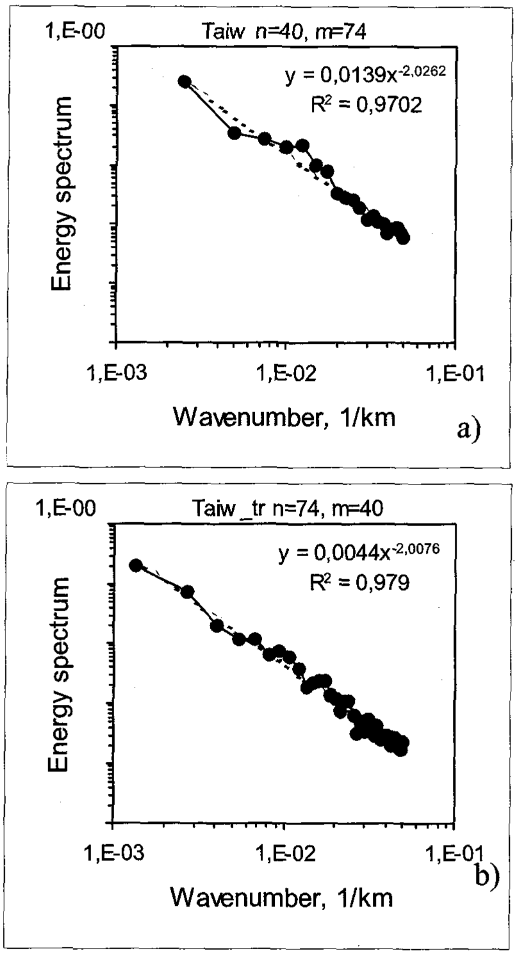


Fig.5. Energy spectrum of Q variations at Taiw fragment:
a) Taiw, profile vertically directed n=40, m=74;
b) Taiw_tr, profile horizontally direct, n=74, m=40;

4. DISCUSSION

Three examples of processing AMSR-E data following suggested algorithm of calculation of model spatial energy spectrum of Q field are presented. In all this cases scale invariant regime were reviled with magnitude of spectral slope rather close to classical value –5/3 of developed turbulence theory. But it is necessary to complete a lot of data processing for different image patterns of microwave remote sensing data, different meteorology situations and different stages of physical processes in the ocean-atmosphere system to improve our understanding of the connection of spatial structure of Q field with the atmospheric turbulence.

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