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Roughness parameter in WAM model : Application to the Japan Sea

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Synopsis

The so-called "HEXMAX" relation is used to describe the roughness parameter at the air-sea interface in the wave prediction model, WAM. In this paper we examined the variation of the roughness parameter with the wave age of the wind-wave, expressed as the ratio of the phase speed of the wind-wave at the peak frequency to the friction velocity. The wind fields given hourly for two storms in January 1995 and February 1994, are selected to apply the model to the Japan Sea.

Numerical results were compared to field data recorded at two locations : Rumoi and Ishikari in Hokkaido. The adjustement of the coefficients in the HEXMAX relation and the interpolated wind field improved the agreement between the numerical results and the observed data. We also compared our results with those obtained by using roughness parameter computed with Janssen's theory or Charnock's relation.

Keywords : wind-wave; WAM model; roughness parameter; HEXMAX relation; surface stress; wave age.

1. Introduction

The sea state is very complex due to the processes induced by the interaction between the atmosphere and the sea. The last version of WAM model (the third generation ocean wave prediction model) improved the prediction of the wind-wave parameters by including more accurate computations of the non-linear transfer between the wave components and the effect of the waves on the surface stress (Janssen, 1991). Janssen's theory assumes that Charnock's constant depends upon the ratio of the stress induced by the waves and the total stress. In this paper we rather consider the dependence of the roughness parameter on the wave age by introducing the HEXMAX relation into WAM model.

2. Roughness Parameters

The total stress (τ) at the sea surface is described by the combination of three components : the turbulent stress, the viscous stress and the stress induced by the waves. The viscous stress is generally neglected. The wind profile near the free surface is taken as a logarithmic profile and depends on the friction velocity U_* nd the roughness of the sea surface Z_0. It is expressed as follows :

$$U(Z) = \frac{U_*}{\kappa} \log\left(\frac{Z}{Z_0}\right) \quad (1)$$

Where κ is the Von-Karman constant, and Z is the reference height taken generally equal to 10 m. By analyzing laboratory data, Charnock (1955) showed that the roughness of the sea surface is proportional to the square of the friction velocity. He obtained the following relation :

$$Z_0 = \alpha \frac{U_*^2}{g} \quad (2)$$

Where α is a constant (0.0144) and g the acceleration of the gravity. Many authors showed that the coefficient a ranges between 0.01 and 0.03. Janssen (1988) introduced the effect of the waves on the wind profile by using a variable constant α' in Charnock's relation Eq. (2), which depends on the ratio of the stress induced by the waves τ_w and the total stress τ. Then the constant α' is related to α as :

$$\alpha' = \frac{\alpha}{\sqrt{1 - \frac{\tau_w}{\tau}}} \quad (3)$$

Recently many researchers (Smith et al., 1992) analysed field data (HEXMAX) and showed that the roughness parameter depends on the wave age (C_p/U_*), which is expressed as the ratio of the phase speed of the wind-wave at the peak frequency C_p to the friction velocity U_*. They derived the following relation which we called HEXMAX relation :

$$\frac{Z_0 g}{U_*^2} = \mu \left(\frac{C_p}{U_*}\right)^n \quad (4)$$

Where μ and n are constant coefficients.
In order to improve the prediction of wind-wave parameters, we introduce this parametrization of the roughness parameter in WAM model.

3. Computational Conditions and Results

The hourly wind field estimated by the planetary boundary layer model and the bottom topography are used in the computation of WAM in the Japan Sea, of which computational domain ranges between 127.5° and 142.25° in longitude and 34° to 47° in latitude. The input wind field and the bottom topography are interpolated on the grid points of 0.25°. The source time step is taken equal to 2 minutes while the propagation time step is equal to 4 minutes. The fetch used in the computations is of 300 kilometers.

We investigated the case of the storm starting on February 19, until February 23, 1994. Two values of 0.48 and 0.8 are considered for the coefficient μ in the HEXMAX relation while n is taken to be constant at -1. **Fig 1** shows the variation of the wind speed at 10 m above the sea surface at 04:00 on February 22, 1994. The highest wind speed 25 m/s is observed offshore Hokkaido. **Fig. 2** shows the variation of the significant wind-wave height in Japan Sea at 04:00 on February 22, 1994. The maximum wind-wave height 10 m is observed off shore south of Hokkaiddo. The wind-waves propagate toward the East and South-East direction in the east part of the Japan Sea, while they are oriented toward the south direction in the west part, as illustrated in **Fig. 2**.
The observed data used in this study are provided

from planetary boundary layer wind field data analized by the Japanese Institute of Technology on Fishery Ports and Communities. Two locations Rumoi and Ishikari in Hokkaido indicated in **Fig. 1**, are concerned. **Fig. 3** and **4** show the time histories of computed significant wind-wave heights and the observed data at Rumoi and Ishikari. For the starting two days we observed a quite good agreement between the numerical results and the observed data, while after 60 hours the numerical results shift and the significant wave heights computed by using the hexmax relation underestimate the observed values. For the second storm starting on January 29, 1995 until February 1, 1995, the coefficient μ is taken 0.8, while two values of $n = -1$ and $n = -1/2$ are considered. At $n = -1/2$, the numerical results give better approximation regarding to the observed data as illustrated in **Figs. 5** and **6**.

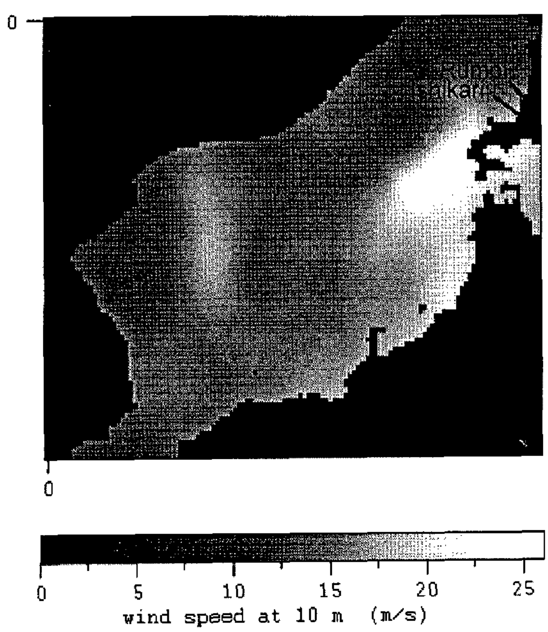

Fig. 1 Wind speed at 10 m height in Japan Sea at 04:00 on February 22, 1994.

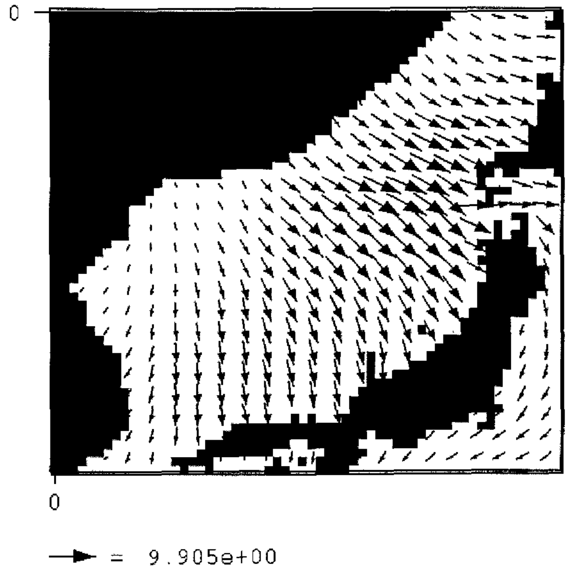

Fig. 2 Significant wave height and wave direction in Japan Sea at 04:00 on February 22, 1994.

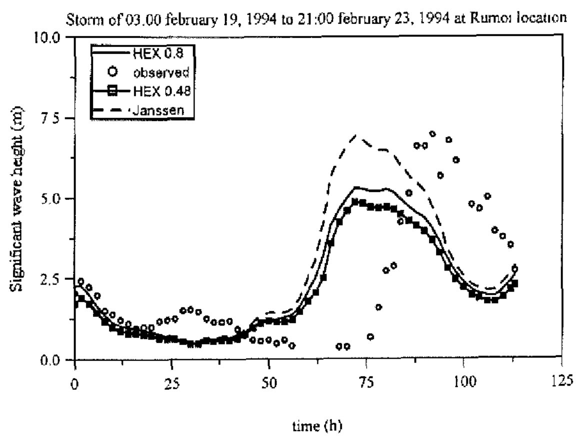

Fig. 3 Time histories of the significant wave heights in the storm of February 1994 at Rumoi.

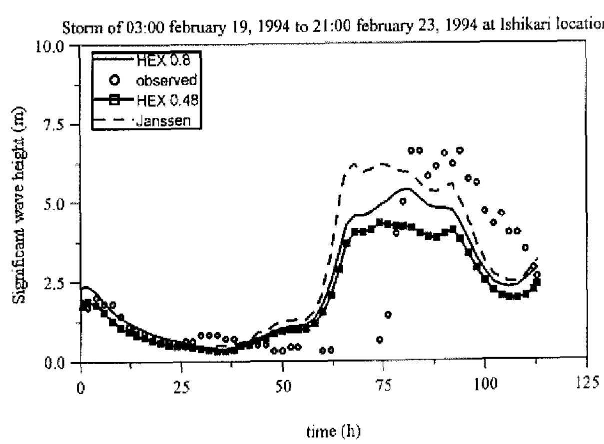

Fig. 4 Time histories of the significant wave heights in the storm of February 1994 at Ishikari.

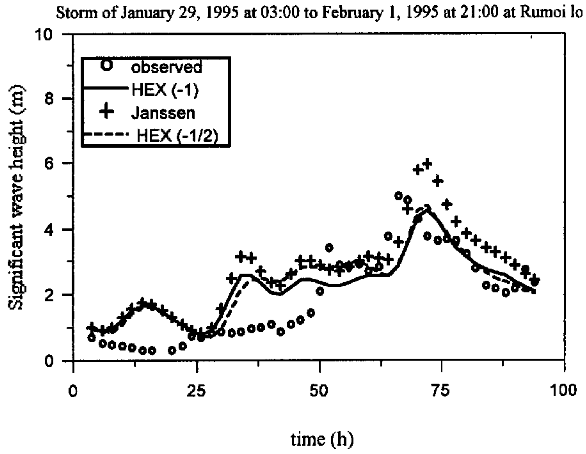

Fig. 5 Time histories of the significant wave heights in the storm of January 1995 at Rumoi.

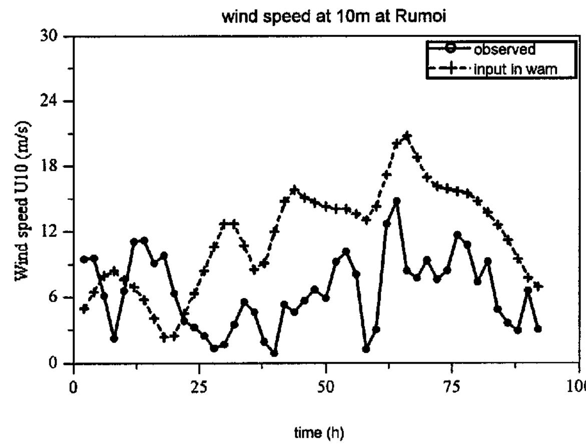

Fig. 7 Time histories of the wind speeds at 10 m above the sea surface during the storm of January 1995 at Rumoi.

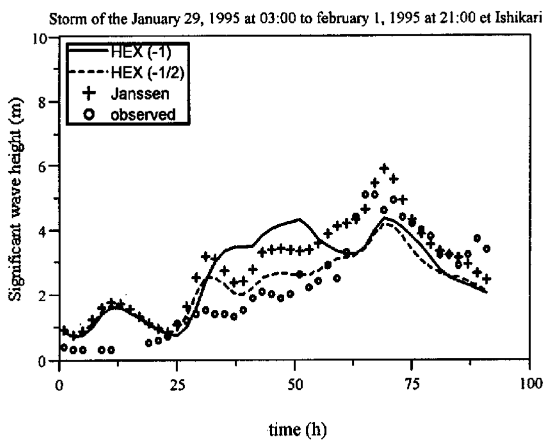

Fig. 6 Time histories of the significant wave height in the storm of January 1995 at Ishikari.

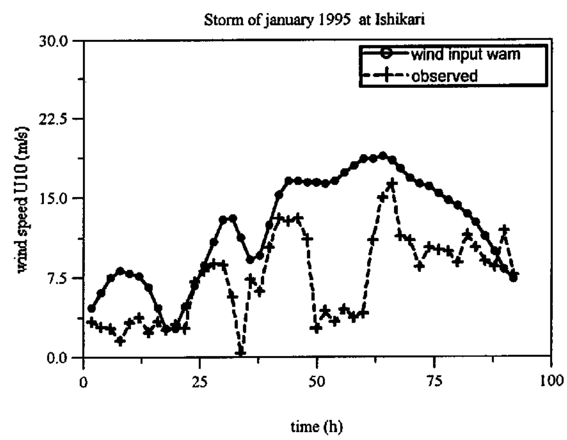

Fig. 8 Time histories of the wind speeds at 10 m above the sea surface during the storm of January 1995 at Ishikari.

However, the computations using the Janssen's theory overestimate the significant wind-wave heights for the last two days of the storm. During the first two days of the storm, the predicted significant wave heights do not agree with the observed data. An error more than 1.5 m is observed because the interpolated wind input used in the computations may not be accurate. This can be easely seen in **Fig. 7** and **8** which show the time histories of the wind input and the observed wind data at Rumoi and Ishikari.

The variations of the waves and the wind directions during the storm of January at Rumoi and Ishikari are plotted in **Fig. 9** and **10**, respectively. We point out that at the begining of the storm, the wave direction is not in the same direction as the wind, therefore small wave heights are expected. While in the last days of the storm (after 50 hours), the wave direction changes and follows the wind direction, then the energy transfer from wind to waves is maximum and high waves heights can be predicted well (see **Figs. 5** and **6**).

We are interested in the variation of the drag coefficient with the wave age at Rumoi, which is shown in **Fig. 11** for the storm of January 1995. The wind drag decreases with the increase in the wave age, in other words the young waves are rougher than the old waves. We can observe that the highest values of the drag coefficient are obtained for the case of the HEXMAX relation n = -1/2 and μ = 0.8.

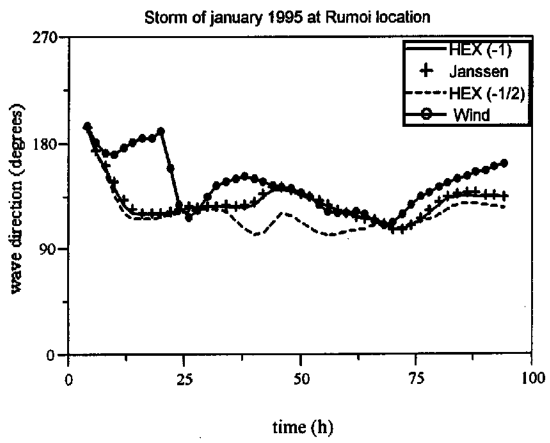

Fig. 9 Time histories of the wave and the wind direction in the storm of January 1995 at Rumoi.

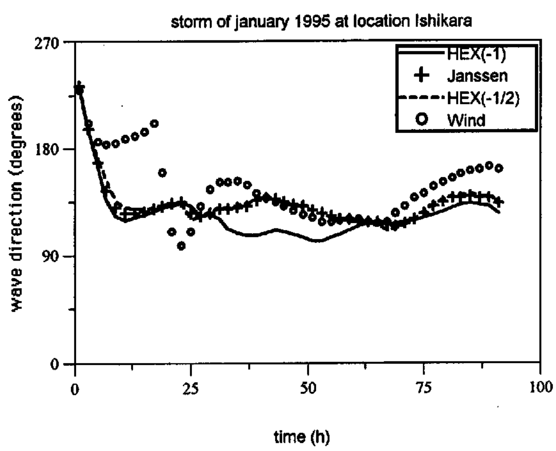

Fig. 10 Time histories of the wave and the wind direction in the storm of January 1995 at Ishikari.

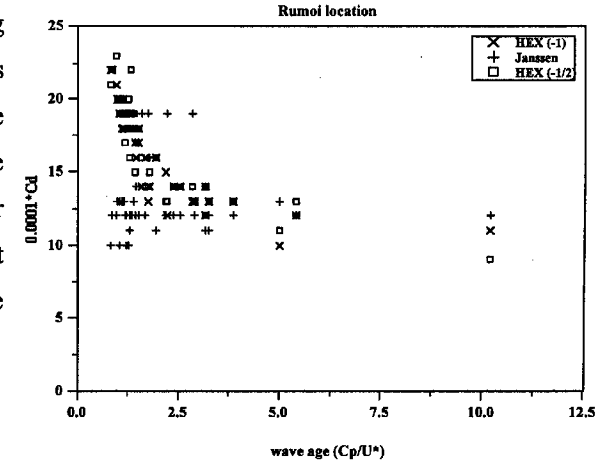

Fig. 11 Variation of the drag coefficient with the wave age in the storm of january 1995 at Rumoi.

4. Concluding Remarks

The WAM model modified in the roughness parameters has been successfully applied to the Japan Sea. For high wind speed Janssen's theory used to describe the roughness parameter gives good estimates of the wind-wave heights compared to field data, while the use of HEXMAX relation underestimates the significant wave height. However, in the storm of January 1995 the use of the HEXMAX relation with coefficients n = -1/2 and μ = 0.8 obtained the better approximation compared to field data. Further tests with different values of the parameter n should be conducted together with wind field accuracy investigation.

In this study it is well shown that the quality of the prediction of the wave model is controlled by the quality of the wind input. We point out that the WAM model is sensitive to abrupt variation of the bottom topography, which induce in some cases wrong values of the wind-wave height. Better approximation of the interpolated wind field and the bottom topography data at specified grid points should be used to improve the numerical results.

The modelling of the wind field data is proposed to seek accurate parametric descriptions of wind seas with view toward a systematic calculation of the momentum transfer between air and sea for arbitrary conditions.

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References

Charnock, H. (1955) : Wind stress on a water surface. Quart. J. Roy. Meteor. Soc., 81, 639-640

Janssen, P. A. E. M. (1991) : Quasi-linear theory of wind-wave generation applied to wave forecasting, J. Phys. Oceanogr. 21, 1631-1642.

Smith, S. D., Anderson, R. J.,Oost, W. A., Kraan, C., Maat, N., DeCosmo,J., Katsaros, K. B., Davidson, K. L., Bumke, K., Hasse, L., and Chadwick, H. M., (1992) : Sea surface wind stress and Drag coefficients. The HEXOS Results, Boundary Layer Meterol. 60, 109-142.

WAMDI Group, (1988) : The WAM model- A third generation ocean wave prediction model, J. Phys. Oceanogr. 18, 1775-1810.

波浪推算モデルWAMの粗度パラメター応答について
— 冬季日本海の波浪推算への適用 —

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要　旨

波浪推算モデルWAMにおける粗度パラメターに波齢の影響を考慮するため、HEXMAXの関係式を適用した。これは、粗度パラメターをピーク周波数の波速と海面での摩擦速度比で表される波齢で表示したものである。本研究では、この関係式の係数およびべき数を変化させて波浪推算結果に及ぼす影響を検討した。検証データとして、1995年1月および1994年2月の冬季日本海の波浪観測データおよび境界層モデルで推定された1時間毎の風域場を用いた。数値シミュレーション結果を留萌および石狩での観測結果と比較した結果、HEXMAX 関係式によるパラメター調整と海上風の推算精度を向上させることで、波浪推算の改良が可能なことが確認できた。さらに、粗度パラメターに波齢の関係を入れない Charnock 公式や波浪の影響を海面せん断応力に入れた Janssen の方法を用いた計算も行った。

キーワード：風波、WAMモデル、粗度パラメター、HEXMAX関係式、海面せん断応力、波齢