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On the Contribution of Swell to Sea Surface Phenomena

Hisashi Mitsuyasu
Department of Environmental Design, Hiroshima Institute of Technology, Hirosima, Japan

ABSTRACT

On the basis of our recent studies, various important phenomena relating to swell are discussed. First, the change in swell by turbulent winds is considered. It is shown that the magnitude of the decay rate of swell by adverse wind is almost the same as that of the growth rate of swell by following wind. Second, the effects of swell on various sea surface phenomena are discussed. As expected, the effects of swell are negligible unless the swell steepness is large. However, with the increase in swell steepness, swell shows an interesting effect on sea surface phenomena. Swell propagating against the wind intensifies the growth of wind waves, if the swell steepness is large. This is quite contradictory to the well-known phenomenon that steep swell propagating in the direction of the wind suppresses wind waves. The former phenomenon cannot be explained by the mechanism proposed by Phillips and Banner (1974); it explains only the latter case, even though the mechanism should be applicable to both phenomena. The similarly contradictory effect of swell is seen in the effect of the swell upon wind-induced drift current. Swell propagating against the wind intensifies the drift current, while swell propagating in the direction of the wind shows little effect upon the drift current. In spite of the drastic changes of wind waves by swell, the microwave intensity backscattered from the sea surface is not much affected by swell. This is probably due to the fact that swell changes only the dominant part of the wind wave spectrum and does not affect the high-frequency region of the spectrum, which mainly governs the Bragg scattering mechanism of the microwaves at the wavy surface.

INTRODUCTION

It is a ubiquitous phenomenon in the ocean that wind waves in some particular wind areas coexist with swell. Fig. 1 is an example of the wave spectra observed in the North Atlantic Ocean, which shows the transition of the spectrum from coexistent system of swell (low-frequency peak) and wind waves (high-frequency peak) in an initial stage to wind waves dominating over the swell in a later stage. Such swell is generated in other wind areas and not necessarily propagating in the direction of the local wind (Fig. 2). However, there are few systematic studies on the interactions among wind, wind waves and swell, except for several pioneering studies (Mitsuyasu, 1966; Phillips and Banner, 1974; Hatori et al., 1981; Donelan, 1987; Masson, 1993). Reflecting on such situations, many numerical wave models do not consider the interactions between swell and wind waves.

Recently we made a series of laboratory experiments concerned, in a wide sense, with the interaction between wind waves and swell (Mitsuyasu and Honda, 1982; Mitsuyasu and Yoshida, 1989, 1991; Cheng and Mitsuyasu, 1992; Mitsuyasu and Kusaba, 1992). The results of these studies are combined in the present paper to show the important contribution of swell to sea surface phenomena.

EXPERIMENTAL DATA

Wind and wave data from four sources are used in the present study: (1) The first data are from Mitsuyasu and Honda (1982), who studied the wind-induced growth of mechanically generated waves in a laboratory tank; (2) the second data are from Mitsuyasu and Yoshida (1989), who studied the attenuation of swell by adverse wind and the change of wind waves by opposing swell; (3) the third data are from Cheng and Mitsuyasu (1992), who studied the surface drift current induced by the wind and swell; and (4) the fourth data are from Mitsuyasu and Kusaba (1992), who studied the effect of swell on the microwave backscatter from wind wave surface.

The first three studies were done in the same wind-wave flume — 0.8 m high, 0.6 m wide — and with a commonly used 15-m-long test section; the experimental arrangements are different from one another, however. The water depth was kept at 0.335 m for the first study and 0.353 m for the second and third. The detailed experimental arrangements and procedures for these three studies are referred to in the individual papers. A large wind-wave flume — 2 m high, 1.5 m wide and 54 m long — (Kusaba and Masuda, 1988) was used in the fourth experiment. In this, microwave backscatter from the wavy water surface was measured at the fetch 20 m in the flume. Waves and the wind profile over water surface were also measured at the same fetch. The measurements were taken with the following water surface condition: Swell without wind, swell under the action of wind, and pure wind waves without swell. Various fundamental parameters of the experiment are as follows: Swell period T: 1.0, 1.5 (s); initial swell steepness H_0/L_0: 0.04; reference wind speed U_R: 3.0, 6.0 and 10.0 (m/s). Microwave scatterometer used in the experiment had 9.6 GHz and HH polarization, and the range of incident angles of the microwave was θ: -35° ~ +35°.

CHANGES OF SWELL BY WIND

When swell comes into a wind area, wind-induced growth or decay of the swell appears depending on whether or not the wind direction is the same as the propagation direction of the swell. In comparison with many studies on the growth of water waves (swell) by a following wind, studies are relatively few on the attenuation of the water waves (swell) by an adverse wind.

Fig. 3 shows a comparison of the normalized growth rate of swell β/f by a following wind (the broken line) and the normalized decay rate of swell β/f by an adverse wind (the solid line and

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