Available online at www.sciencedirect.com

ScienceDirect

Procedia IUTAM 26 (2018) 124–131

Procedia IUTAM

www.elsevier.com/locate/procedia

IUTAM Symposium Wind Waves, 4–8 September 2017, London, UK

Wind modulation by variable roughness of ocean surface

Lev Ostrovsky[a,b]

[a]*University of Colorado, Boulder, USA*
[b]*Institute of Applied Physics, Russian Acad. Sci., Nizhny Novgorod, Russia*

Abstract

Recent results concerning transient effects of variation of short sea-surface wave roughness on near-surface turbulent wind are briefly outlined. This variation can be caused by oil, surfactants, inhomogeneous currents, internal waves, ship wakes, etc. To describe the wind parameters including surface stress and turbulent energy density, we use a direct solution of the Reynolds-type equations in the boundary-layer approximation. The solutions include a sharp and smooth roughness variation, 2-D surface variation, and a moving slick. The applicability of the theory was verified by comparison with laboratory data. Further on, the theory was applied to a problem related to the devastating tsunami near Fukushima Daichi in 2011.

Keywords: Wind modulation; Sea surface roughness; Reynolds equations;

---

1. Introduction

The interaction between wind and sea surface is a classic problem of ocean/atmosphere dynamics. The parameters of the wind flow, such as momentum flux and wind drag, are being thoroughly studied, mainly in terms of values averaged over the considered area. Wind variations over curved surfaces (hills, long waves) were also studied in detail, see, e.g., [1]. Transient problems considered in meteorology are generally focused on sharp changes in the underlying terrain; for example, a transition from water surface to shore or from field to forested land (e.g., [2]). Less studied are near-surface wind variations over horizontally varying sea roughness which are of importance in many practical cases, e.g., for evaluation of wind drift of oil spills and tsunami-caused debris, remote sensing of marine slicks, and others.

Methodically, most of the studies of horizontal wind variations were based on the two-layer approach (see [1–3] and references therein). Here we briefly outline the results based on direct solutions of the Reynolds-type equations for wind velocity and turbulent kinetic energy (TKE) simplified for the low boundary layer conditions. This theory, partially described in [3], allows to significantly extend the applications of the model, for example, to consider a smooth variation of roughness, moving inhomogeneities, two-dimensional “spots”, etc. In some cases the theoretical

10.1016/j.piutam.2018.03.012

results are applied to the data of a laboratory experiment and to modeling of wind over the debris floating from the Fukushima tsunami.

2. Basic equations

The general configuration of the considered process is shown in figure 1.

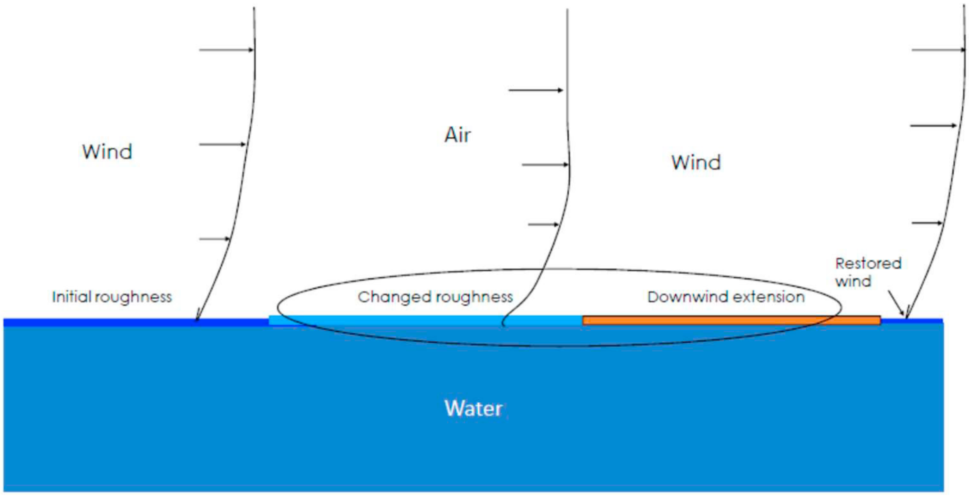

Fig. 1. Schematic of the wind variation over a finite area (spot) of changed roughness. The near-surface air flow changes over the spot and this variation can extend beyond the spot.

The starting point is Reynolds equations for an incompressible turbulent flow with neutral stratification [4, 5]:

$$\frac{\partial u_i}{\partial t}+(\mathbf{u}\cdot\nabla)u_i=-\frac{\partial p}{\partial x_i}-\frac{\partial \tau_{ij}}{\partial x_j},\ \tau_{ij}=-K\left(\frac{\partial u_i}{\partial x_k}+\frac{\partial u_k}{\partial x_i}\right),$$
$$\frac{\partial b}{\partial t}+(\mathbf{u}\cdot\nabla)b=\frac{\partial}{\partial x_i}\left[\kappa_b K\frac{\partial b}{\partial x_i}\right]+K\left(\frac{\partial u_i}{\partial x_k}+\frac{\partial u_k}{\partial x_i}\right)\frac{\partial u_i}{\partial x_k}-K\frac{\gamma b}{l_z^2}, \qquad (1)$$
$$\nabla\cdot\mathbf{u}=0.$$

Here **u** is the average air velocity vector, p is pressure, b is the turbulent energy density (TKE), and τ_{ij} is the turbulent stress tensor. The parameters are: K is the turbulent exchange (viscosity) coefficient. In the framework of the Kolmogorov's eddy-viscosity closure hypothesis, $K=l_z\sqrt{b}$, l_z being the vertical turbulence scale, and the empirical coefficients are taken as $\kappa_b=0.7$ and γ= 0.05 to 0.09 in different realizations. In what follows we use the boundary-layer approximation, letting $\partial/\partial x << \partial/\partial z$ and $w << u$, where u and w are the horizontal and vertical velocity components, respectively. Thus, the equations to be studied here are reduced to