Parameterizations of dry deposition

A contribution to subproject CAPMAN

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Aims and Rationale

The overall aim of the work is to extend the theory for turbulent fluxes of momentum, heat, and gases, in order to extend parameterizations for conditions of quasi-homogeneous conditions.

Activities During the Year

During 1999, generalized equations for the flux profile relations were derived. For the momentum budget under quasi-homogeneous conditions, it was found that the vertical windspeed profile could be expressed as:

$$\partial U/\partial z = u^*/kz\ (\text{Ø}_m - R - S + W) \tag{1}$$

where $R = z/z_o\ \partial z_o/\partial z$; $S = ß\ (z/L)^2\ \partial L/\partial z$; and $W = kzU^2/2u^{*3}\ \partial U/\partial x$. The value of ß is typically 3 for unstable conditions; and approximately 5 for stable flow. The quantity Ø_m is the profile stability function, the quantities R, S, and W are respectively corrections to the windspeed profile caused by horizontal gradients of roughness, atmospheric stability, and windspeed. In (1), Ø_m may be considered to be the only "local" parameter, while all others are spatially varying. It was also found that, under most conditions, equation (1) reduces to a more practical form, i.e.:

$$\partial U/\partial z = u^*/kz\ (\text{Ø}_m - R + W) \tag{2}$$

It was also found that equation (2) could be integrated, in order to estimate the fetch dependent drag coefficient variability over the coastal ocean. The value of the drag coefficient then becomes a function of fetch and horizontally varying quantities, such as windspeed and roughness. The real drag coefficient for short fetch conditions is smaller than what is typically used in most modelling studies, i.e., caused by a flux divergence within the surface layer. For simplicity, one may say that the smaller value of the drag coefficient is associated with the deviation from the classical assumption that the surface layer is a constant flux layer.

Back in 1999, a similar equation was derived for chemical compounds, which applies to those which are reactive and those which are relatively nonreactive. A general expression was derived:

$$\partial c/\partial z = (\langle w'c'\rangle/u^*kz)(\phi_c(z/L) - W - V) - (S\Delta c/\langle w'c'\rangle) - \gamma\partial c_o/\partial x + (\Delta c/2UC_D)\partial U/\partial x \tag{3}$$

where:

$$W = \gamma z/z_c\ \partial z_c/\partial x \qquad V = (ku^*Uz(c-c_o))/\langle w'c'\rangle^2\ \partial c/\partial x \tag{4}$$

and S is a source or sink of the chemical during transport.

Note that if the conditions are horizontally homogeneous, and if the chemical is slowly reacting, equations (2) and (4) reduce to the more popular form, i.e.:

$$\partial g/\partial z = (\langle w'g' \rangle / u_* kz)\ \phi g(z/L) \quad (5)$$

where g represents either concentration c or windspeed U.

During 2000, the utility of these equations was explored in more detail. Comparison to data obtained from measurements carried out during the MEAD field campaigns in 2000 (in the Kattegat between Denmark and Sweden) showed that the coastal ocean exhibits far more windspeed variability than what has been generally assumed. Based on model calculations, the terms containing windspeed variability were observed to be substantially larger than terms containing roughness length variability. This led to a further simplification, such that roughness length gradients in the coastal zone could be assumed to be relatively unimportant as a control over the flux divergence. This, however, must not be confused with the value of the roughness length as a parameter as a control over the drag coefficient, during pseudo-constant flux layer conditions.

The vertical windspeed profile was explored during 2000, in terms of its variation in the offshore domain, with a view towards improved estimates of wind power production from offshore wind mills. Most models of offshore wind power potential are based on the use of a constant flux layer regardless of distance from the coastline. When one introduces a horizontal gradient of windspeed, the shape of the vertical wind profile will change, thus changing the mean windspeed as a function of height as well as the gradient across the blades. During 2000, only simple formulations of $\partial U/\partial z$ were constructed, and alterations of the windspeed profile were very sensitive to the strength of $\partial U/\partial x$ as a function of x. This implies that estimates of offshore wind power potential will rely strongly on the use of high resolution boundary layer models applied to the domain, and it will further require that the assumption of a constant flux layer (in the surface layer) is relaxed.

Plans for the next year

The terms of equations (1) and (3) will be examined in more detail, in reference to more realistic estimates of $\partial U/\partial x$ in domains controlled by complicated coastal geometries and variations in upwind roughness. Where possible, the model calculations will be compared to data gathered in the field campaigns carried out in the Kattegat Straits, under the MEAD project. Data from the MEAD project are already available from 2000, and additional data will be provided after the field campaigns in early summer 2001.

Summary

A general form of the flux profile equation was derived for both windspeed and chemicals, which considers quasi-homogensous conditions. During 2000, it was found that the integration of these equations for practical application rely on a careful and accurate treatment of the horizontal windspeed gradients. The use of these equations was also explored for the offshore energy sector, insofar that estimates of wind power potential rely on accurate estimates of the vertical windspeed gradient in the offshore region. These gradients, in turn, are sensitive to the flux divergence present within the surface layer.

Acknowledgements

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Publications

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