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RICHARDSON'S NUMBER AND ITS RELATION TO THE CURVATURE OF THE WIND PROFILE BASED ON PANTANAL MICROMETEOROLOGICAL DATA.

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1 - INTRODUCTION

Several experimental and theoretical studies have been carried out to study the problem of atmospheric turbulence since the forties, e.g. those by Monin and Obhukov (see Monin and Yaglom, 1977), Viswanadham (1982), Kaimal and Wyngaard (1990) and Kaimal and Finnigan (1994). A convenient way of testing the theories is the relationship between kinematic and thermal forces producing turbulence, and the relative curvature of the wind profile (β). The aim of this work is to determine β and its relation with Richardson's number (R_i) for different stability conditions for the Brazilian Pantanal wetland based on data obtained in the IPE-1 experiment.

2 – THEORETICAL RELATIONSHIPS

Turbulence can be generated either thermally or mechanically and a convenient stability parameter is R_i, whose gradient form is

$$R_i = \left(\frac{g}{T}\right)\left(\frac{\partial \theta}{\partial z}\right) \Big/ \left(\frac{\partial u}{\partial z}\right)^2 \quad (1)$$

where g is the acceleration of gravity (9.8 ms^{-2}), θ is the potential temperature and u is the velocity at height z, and T is the mean temperature of the layer.

The similarity theory of Monin and Obukhov (see Monin and Yaglom, 1977) is based on the assumptions that the flow is plane-homogeneous and that the vertical fluxes of momentum (τ), sensible heat (H) and latent heat (LE) are constant.

Thus, the average surface layer wind and temperature fields should depend only on the vertical heat flux H, the height from the ground z, the buoyancy parameter g/T and the surface shearing stress τ_0. These define the following velocity, temperature and length scales:

Scaling velocity (m s-1), $$u_* = \left(|\tau_o / \rho|\right)^{1/2} \quad (2)$$

Scaling temperature (K), $$\theta_* = -H/(\rho\, C_p\, u_*), \quad (3)$$

Monin and Obukhov's lenght (m),

$$L = -\left(u_*^3\, \rho\, C_p\, \theta\right)/(k\, g\, H) \quad (4)$$

and the dimensionless forms:

wind shear, $$\phi_m = \frac{k z}{u_*}\frac{\partial u}{\partial z} \quad (5)$$

temperature gradient, $$\phi_h = \frac{k z}{\theta_*}\frac{\partial \theta}{\partial z} \quad (6)$$

height, $$\zeta = z/L \quad (7)$$

ratio of the eddy diffusivities $$\gamma = \frac{K_h}{K_m} = \frac{\phi_m}{\phi_h} \quad (8)$$

where k is von Kármán's constant. Thus,

$$R_i = \phi_h / \phi_m^2 \quad (9)$$

From profile analysis, Businger et al. (1971) have presented the following formulas for unstable conditions (i.e., $\zeta < 0$):

$$\phi_m = (1 - 15\,\zeta)^{-1/4} \quad (10)$$

$$\phi_h = 0.74\,(1 - 9\,\zeta)^{-1/2} \quad (11)$$

Equations (8), (10) e (11), together with Eq. (9) give

$$R_i = \frac{0.74\,\zeta\,(1 - 15\,\zeta)^{1/2}}{(1 - 9\,\zeta)^{1/2}} \quad (12)$$

and for stable conditions (i.e., $\zeta > 0$)

$$\phi_m = (1 + 4.7\,\zeta) \quad (13)$$

$$\phi_h = (0.74 + 4.7\,\zeta) \quad (14)$$

Equations (8), (13), (16) together with Eq. (9) give

$$R_i = \frac{\zeta\,(0.74 + 4.7\,\zeta)}{(1 - 4.7\,\zeta)^2} \quad (15)$$

The testing of profile theories is most conclusively based on second order derivatives or profile curvature characteristics. The change in profile curvature and change of average profile steepness (wind gradient, or shear) are know to be produced by boundary heating. The simplest mathematical form which expresses curvature is:

$$\beta = -\left(z\,\frac{\partial^2 u}{\partial z^2}\right) \Big/ \frac{\partial u}{\partial z} = 1 - d(\log \phi_m) \Big/ d(\log \zeta) \quad (16)$$

The theoretical β - R_i curve can be compared with experimental data. Lettau (1956) has transformed Eqs. (1) and (15) to compute R_i and β from the experimental data as (heights 1, 2, and 3):

$$R_{i_2} = g z_2 (\theta_3 - \theta_1) T^{-1} (u_3 - u_1)^{-2} \ln(z_3/z_1) \quad (17)$$

and $$\beta_2 = 1 - \alpha_2 - 2[\log(\alpha_{2,3}/\alpha_{1,2})]/\log(z_3/z_1) \quad (18)$$

where: $\alpha = d(\log u)/d(\log z) \equiv \left(z\,\frac{\partial u}{\partial z}\right)/u$

so that $\alpha_{2,3} = [\log(u_3/u_2)]/\log(z_3/z_2)$

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$$\alpha_{1,2} = [\log(u_2/u_1)]/\log(z_2/z_1)$$

and $\alpha_2 = (1/2)\,(\alpha_{2,3} + \alpha_{1,2})$

On the basis of preceding considerations, it is possible to obtain the β - R_i curve theoretically and also from the experimental data. Using Eqs. 10 and 13, respectively, in the defining Eq. (16), Viswanadham (1979) obtained:

for unstable conditions $\beta = (5 - \phi_m^4)/4$ (19)

for stable conditions $\beta = 1/\phi_m$ (20)

3. EXPERIMENTAL DATA

The data used in the present study were collected during IPE-1 campaign, conducted in May 1998, during the transition period at the Pantanal wetland. IPE is a broad experimental program to study the weather and climate of the central region of Brazil. The data collection campaign was carried out in the southern region of Pantanal wetland of Mato Grosso do Sul State (MS). Measurements were made using a 21 m aluminum tower located near to the Base site of Pantanal Studies (19°33' S; 57°01' W) in Passo do Lontra. Data comprise measurements acquired by a fast response three dimensional sonic anemometer (10 Hz) installed at 25 m, as well as slow (10 min averages - 143 points per day) response instruments for measurements of wind speed and temperature and humidity at heights 3.8 m, 8.1 m and 15.7 m. Data from the sonic anemometer were obtained by microcomputer, while data from all the other instruments were recorded in a data logger.

4. RESULTS AND DISCUSSION

As shown in the figure for typical clear and cloudy days, for 10 minute average data, the experimental curvature β, for all stability conditions ($-20 < R_i < 20$) found in each day, has a near constant dependency on R_i, with a slight linear decrease as R_i, increases. This decrease is somewhat steeper in cloudy days.

These results agree, for unstable conditions, with Eq. 19 (via Eq. 9) and other equations for β analyzed by Viswanadham (1982) for the range $-0.50 < R_i < 0.20$. This is not the case for neutral and stable conditions, showing the inadequacy of Eq. 20 and said equations for these conditions.

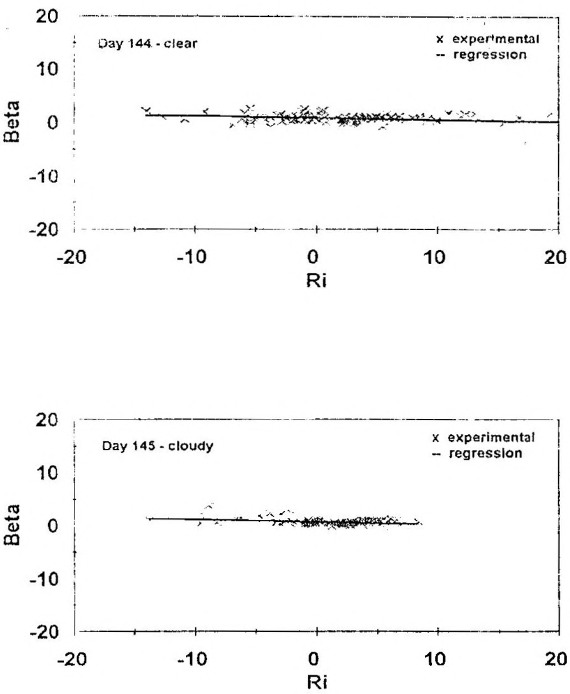

Fig. 1. Experimental curves β versus R_i, for clear and cloudy days at Pantanal wetland.

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