RICHARDSON NUMBER AS AN INDICATOR OF TURBULENT STRATIFICATION IN NEAR NEUTRAL AND FREE CONVECTION REGIMES OF THE SURFACE LAYER.

K. P. R. Vittal Murty*, Edson P. Marques Filho*, Gannabathula S. S. D. Prasad*, Leonardo Deane de Abreu Sá
Divisão de Ciências Meteorológicas/INPE (murty@met.inpe.br)
Amaury de Souza
Departamento de Física/Universidade Federal do Mato Grosso do Sul (fax: (067)787.3093)
Yadvinder Malhi
Institute of Ecology and Resource Management /University of Edinburgh

Resumo

O número de Richardson é um indicador da turbulência na camada limite superficial e tem atraido a atenção de muitos trabalhos científicos no campo da turbulência. Neste artigo, é feita uma tentativa de estudar as varias funções do número de Richardson para a camada limite superficial, baseado em observações gradientes obtidas durante o Experimento Interdisciplinar do Pantanal (IPE-1). Os resultados mostram um padrão esperado. A função de Priestley para o regime de turbulência dinâmica variou linearmente com o número de Richardson gradiente e para o regime de convecção livre apresentou-se constante.

Keywords

Micrometeorology, Richardson numbers, Pantanal.

1 - Introduction

Richardson number is well know as an indicator of surface layer turbulence. It is the ratio between thermal forces and kinematic forces and closely associated with turbulence production terms in the turbulent balance equation. This fact make Richardson number very important, eventhough its variation with hight is still uncertain. In this article an attempt is made to study the turbulent state of the surface layer as a function of Richardson number.

Number of experimental meterial including the gradient observations of the vertical variation of wind velocity, temperature and humidity of the air and their pulsations were obtained and analysed in the last few decades by Swinbank and Taylor (1960), Gurvich (1961), Paripelkina (1959) and Chrichmeyer (Vittal Murty, 1971; Murty and Vittal Murty, 1993). The data of Swinbank and Taylor was analysed by Pristley (Tsvang, 1960), who suggested a function of Ri $[f(\mathrm{Ri})]$ for free convection. Later Gurvich (1961) suggested alternative forms for $f(\mathrm{Ri})$.

In this article the $f(\mathrm{Ri})$ as envisaged by Pristley, Pasquill, Gurvich and Rider were estimated using IPE-1 gradient observation data.

2 - Methodology

The IPE-1 is a part of broad experimental programe to study the weather and climate of central region of Brazil. The data collection campaign was carried out in South Mato Grosso Pantanal in the

(*) The authors are grateful to CNPq for providing finantial grant.

experimental site in the farm São Bento (19^o33S and 53^o8W), 1.5km from the Pantanal studies base of UFMS in Passo do Lontra, Miranda, MS. A micro meteorological tower 21m height was installed and a fast response three dimentional sonic anemometer was installed at 25m. The slow response instruments for measurements of wind speed and temperature and humidity were provided at heights 2m, 3.8m, 8.1m, 9.8m, 15.7m, 21.5m.

The thermal flux $\frac{Qo}{\rho c_p}$ at the ground can be written as

$$\frac{\mathrm{Qo}}{\rho \mathrm{c_p}} = \mathrm{K_h}\frac{\mathrm{d}\theta}{\mathrm{dz}} = \frac{\chi \mathrm{v_*}(\mathrm{z})}{\phi(\eta)}\left(\frac{\mathrm{d}\theta}{\mathrm{dz}}\right) \tag{1}$$

and the frictional velocity $\mathrm{v_*}$ can be written as

$$\mathrm{v_*} = \chi^{1/3}\left(\frac{\mathrm{g}}{\theta}\right)^{1/3}\left(\frac{\mathrm{Qo}}{\rho \mathrm{c_p}}\right)^{1/3}(\mathrm{L})^{1/3} \tag{2}$$

Substituting (2) in (1) and rearranging we get

$$\frac{\mathrm{Qo}}{\rho \mathrm{c_p}} = \frac{\chi^2}{(\eta)^{1/2}\phi(\eta)^{3/2}}\left(\frac{\mathrm{g}}{\theta}\right)^{1/2}\left(\frac{\mathrm{d}\theta}{\mathrm{dz}}\right)^{3/2}\mathrm{z}^2 \tag{3}$$

when $\eta = \mathrm{z/L}$.

Ri is related to η

$$\mathrm{Ri} = \eta\phi(\eta) \tag{4}$$

so

$$\mathrm{f}(\mathrm{Ri}) = \frac{\chi^2}{(\eta)^{1/2}\phi(\eta)^{3/2}}$$

where $\mathrm{f}(\mathrm{Ri})$ is a function of Ri, therefore

$$\mathrm{f}(\mathrm{Ri}) = \frac{\left(\frac{\mathrm{Qo}}{\rho \mathrm{c_p}}\right)}{\left(\frac{\mathrm{g}}{\theta}\right)^{1/2}\left(\frac{\mathrm{d}\theta}{\mathrm{dz}}\right)^{3/2}\mathrm{z}^2} \tag{5}$$

All the parameters in the r.h.s of Eq. (5) as well as Ri can be calculated by gradient observations. If $\eta = \frac{z}{L}$ is small the $\phi(\eta)$ is very nearly equal to unity and in which case

$$\mathrm{f}(\mathrm{Ri}) = \chi^2(\eta)^{-1/2} = \chi^2(\mathrm{Ri})^{-1/2} \tag{6}$$

This shows that $\lg|\mathrm{Ri}|$ and $\lg|\mathrm{f}(\mathrm{Ri})|$ has linear relation. On the other hand for strong unstable stratification

$$\mathrm{f}(\mathrm{Ri}) = \frac{\chi^2}{\mathrm{c}^{3/2}} = \mathrm{f}* = \text{constant} \tag{7}$$

Pasquill (Pasquill, 1974) has constructed nondimentional functions in the form

$$\mathrm{f_2}(\mathrm{Ri}) = -\frac{\mathrm{Qo}}{\rho \mathrm{c_p}\frac{\mathrm{du}}{\mathrm{dz}}\frac{\mathrm{d}\theta}{\mathrm{dz}}\mathrm{z}^2} = \frac{\chi^2}{\phi^2(\eta)} \tag{8}$$

Rider (Taylor, 1960) has suggested

$$\mathrm{f_3}(\mathrm{Ri}) = -\frac{\mathrm{v_*}^2}{\mathrm{z}^2\left(\frac{\mathrm{du}}{\mathrm{dz}}\right)^2} = \frac{\chi^2}{\phi(\eta)} \tag{9}$$

it can be shown easily that

$$f(Ri)=\frac{f_2(Ri)}{(Ri)^{1/2}}=\frac{f_3(Ri)}{(Ri)^{1/2}} \tag{10}$$

Gurvich (1961) suggested

$$f_4(Ri)=\frac{v_*}{z\frac{du}{dz}}=(f_3(Ri))^{1/2} \tag{11}$$

and therefore

$$f(Ri)=\frac{f_4{}^2(Ri)}{(Ri)^{1/2}} \tag{12}$$

The variation of $f(Ri)$ with Ri as suggested by various work's was tested with the IPE-1 gradient observation data.

3 - Results and discussion

In Fig.1 we here estimated various $f(Ri)$ suggested by different workers which was discussed for the julian day 141. Figure 1 consist of 8 small graphics showing the variation of different $f(Ri)$ with Ri_{g1} (3.8m and 15.7m) and Ri_{g2} (8.1m and 21.5m).

The interesting graphic is I which is $f(Ri)$ otherwise known as Pristley function. This clearly shows a linear decrease upto approximate $-Ri_{g1}$ value of 0.3 and then on is a constant. The linear portion is termed as dynamic turbulence and the constant one is free convection. However data is not sufficient in graphic II to show there two regimes .

Graphics III and IV represent $f_2(Ri)$ which is positive always (which corresponds to unstable conditions). Here $f_2(Ri)$ is plotted against $\frac{Ri_g}{(Ri_g)^{1/2}}$. These values are more for higher height which was shown in graphic IV. Graphics V and VI are for $f_3(Ri)$ and graphics VII and VIII are for $f_4(Ri)$. The pattern is similar in both the plots as $f_3(Ri)$and $f_4(Ri)$ are closely related $\left(f_4(Ri)=(f_3(Ri))^{1/2}\right)$ and the values are always positive.

Over all observation point out that for day 141 the variation $f_2(Ri)$, $f_3(Ri)$ and $f_4(Ri)$ is positive.

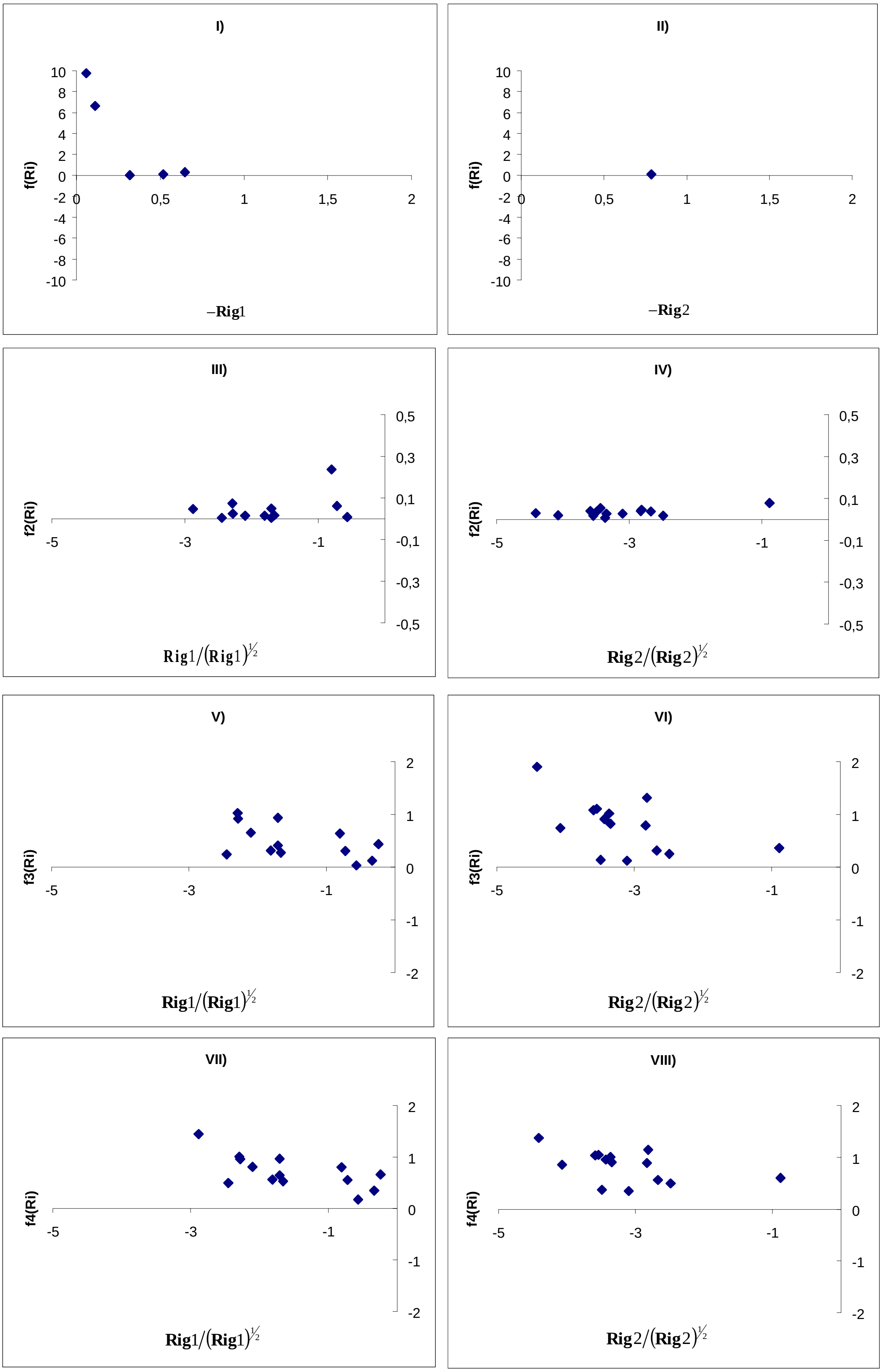

Fig. 1 - Variation of functions of Richardson number for the julian day 141.

4 - Conclusions

(1) All the functions of Richardson number described in the literature, when tested with IPE-1 data have given expected variations;
(2) $f_2(Ri)$, $f_3(Ri)$ and $f_4(Ri)$ always were positive and show linear variation with large scatter;
(3) Pristley function of Richardson number for the day 141 shows clearly the dynamic turbulence and free convection regimes.

5 - Acknowledgement

The authors give thanks for the support received from the Fundação de Amparo à Pesquisa do Estado de São Paulo, FAPESP (proc. n^{o} 98/00105-5) and from the Conselho Nacional de Desenvolvimento Científico e Tecnológico, CNPq (procs. n^{os} 381.699/97-8, 381.690/97-0, 139.164/96-0).

Acknowledgement is also given to all the people involved in the IPE-1 Project organization and data collecting: Drs. Antônio Ocimar Manzi, Regina Célia dos Santos Alvalá, Clóvis Angeli Sansigolo, Ralf Gielow, Plínio Carlos Alvalá, Clóvis M. do Espirito Santo and Mrs. Paulo Rogério Aquino Arlino, Luis Eduardo Rosa, Celso von Randow, Jorge Martins de Melo, Sabrina B. Monteiro Sambatti, Elizabete Cária Moraes of INPE, Drs. Edson Kassar, Hamilton Germano Pavão, Masao Uetanabaro and Mrs. Carla Muller, Jorge Gonçalves and Waldeir Moreshi Dias of Universidade Federal do Mato Grosso do Sul, Dr. Bart Kruijt of University of Edinburgh, Dr. Maria Lúcia Meirelles of EMBRAPA/CPAC, Dr. Romísio Geraldo Bouhid André of UNESP/Jaboticabal.

Special thanks are due also to Dr. Nelson L. Dias of SIMEPAR and Dr. Paulo Henrique Caramori of IAPAR who provided kindly a sonic anemometer and a hygrometer to be used during the IPE-1 campaign.

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