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Relationship between intermittency and stratification

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Summary. — A formal analogy exists between 2D turbulence and 3D turbulence with stratification and rotation. Although the effect of the rotation, to the scale typical of the turbulence, is negligible in the atmosphere, we have found a relationship between the behavior of the intermittency and that of the atmospheric stratification. In order to do that, the intermittency has been characterized through the flatness of the PDFs of velocity increments, for the smallest possible scale, present in our measurements.

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1. – Introduction

The deviation that turbulence presents [1, 2] with regard to the theory of Kolmogorov [3] is known as intermittency. This intermittency is associated with the presence of rare events; this is translated in the scale-dependent stretching of the tails presented by the PDFs of the velocity increments, compared to the Gaussian form and its approach by stretched exponentials [4-8].

2D turbulence is a special type of turbulence characterized by the conservation of the vorticity and the absence of intermittency [9, 10]. In conditions of homogeneity and isotropy, 2D turbulence is explained by the theory of Kraichnan [11, 12] according to which a direct cascade of enstrophy exists with a slope of -3, and other inverse cascade of energy, with a slope of $-5/3$.

An index that allows characterizing the form of the PDFs is $\log(F/3)$ [13], where F is the corresponding flatness. The number 3 alludes to the value of the Gaussian flatness, so that the larger this index, the bigger the deviation of the PDFs from the Gaussian distribution is found and, therefore, major will be the grade of existing intermittency (an example of the evolution of the flatness with the scale can be seen in [14]).

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In environmental flows, 2D turbulence does not properly exist. Nevertheless, 3D turbulence in conditions of stratification and rotation shows a formal analogy with 2D (the geostrophic approach of Charney [15]; see also [16,17]). With regard to the rotation in the atmosphere, to the turbulence typical scale, the effect of the rotation can be considered to be negligible, since it presents a very high Rossby number. Concerning the stratification, in 3D turbulence, the absence of rotation hinders the analogy with 2D turbulence. However, the stability produces, precisely, the inhibition of the vertical motions. And since 2D turbulence is characterized by the absence of intermittency, it is expected that the stable situations present a minor grade of intermittency, or even a type of intermittency in another sense, than the corresponding ones in situations of neutrality or of convective instability. Consequently, we could find a relationship between stratification and intermittency.

2. – Data

SABLES98 (Stable Atmospheric Boundary Layer Experiment in Spain 1998) data [18] from a sonic anemometer (20 Hz sampling rate) at 32 m have been used. This field campaign took place in September 1998 (from 10 to 28) at the Research Centre for the Lower Atmosphere (CIBA) which is situated on the Northern Spanish Plateau [19]. The surrounding terrain is fairly flat and homogeneous. In the experiment, different degrees of stable stratification were achieved during the night, from near-neutral to very stable conditions, while during the day, the stability ranged from neutral to convective situations.

The period of study will be between September 10, 2008 at 17:00 GMT and the 17th September at 23:30 GMT, with information taken at intervals of 30 minutes (in total, 350 samples to study). For each of these samples we will use intervals of 5 minutes (6000 data), which in the atmosphere constitute a suitable scale for the study of the turbulence. Anyway, due to the sampling rate frequency (20 Hz), we will be studying mainly the spectral interval between the integral length scale and the Taylor microscale, which can be denominated as macroturbulence [20].

3. – Relationship between intermittency and stratification

Among the numerous parameters existing to characterize the degree of stratification in the atmosphere we will use the difference of temperatures between two levels (50 and 0.22 m), which has showed to reflect enough the daily evolution of the stability. Also, the module of the vertical speed has been used, since for the greatest stabilities, such vertical velocity will be inhibited, although sometimes it can be perturbed by the presence of internal-gravity waves. Figures 1a and 1b show the temporal evolution of these variables for our period of study. In fig. 1b, in order to eliminate the irregular component of the series and to make the cyclical component more visible, we also have performed a moving average with a 6 hour window (12 points).

Figure 1a reflects the biggest stability that the night usually presents opposite to the day, since the night cooling makes the temperature of the air increase with the height. Also it is possible to observe that the last nights of the study (the 14th, 15th, 16th and 17th) had lower winds, presenting a major stability than the previous ones. An extended work on this stable period of SABLES98 can be found in [21].

With regard to intermittency, there exist several models that try to characterize it [22]. Some of these models look for an expression of the scaling exponents that appear in the

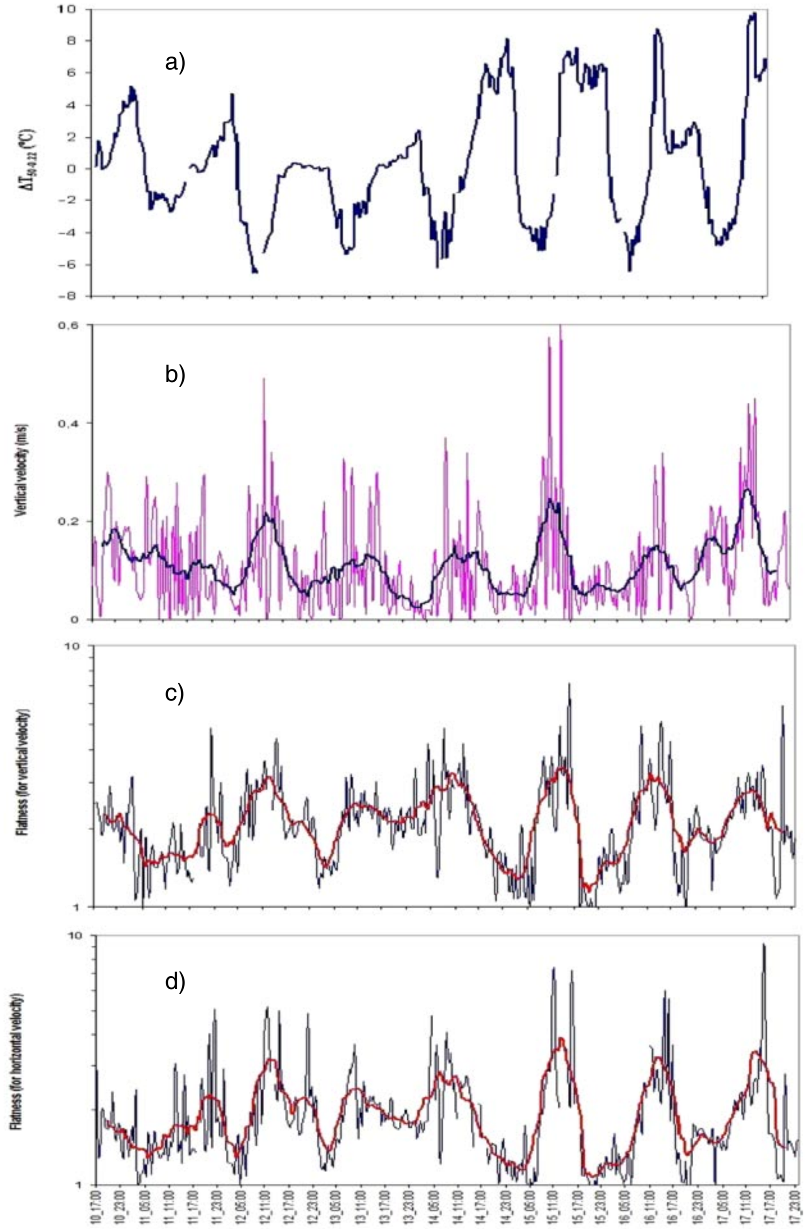

Fig. 1. – Temporal evolution along the studied period of a) temperature difference between 50 m and 0.22 m; b) vertical speed module, and moving average using a mean period of 6 h; c) $\log(F/3)$ and moving average with a 6 hour period for vertical velocity; d) $\log(F/3)$ and moving average with a 6 hour period for horizontal velocity.

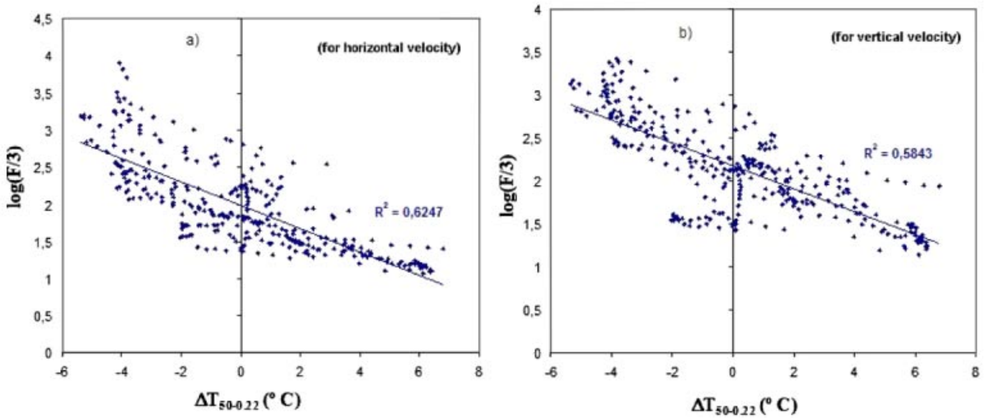

Fig. 2. – $\log(F/3)$ *vs.* $\Delta T_{50\text{-}0.22}$ for a) horizontal velocity; b) vertical velocity.

potential relation existing between the structure functions and the scales, for example, Kolmogorov [23] or Meneveau and Sreenivasan [24]. A previous study on the horizontal velocity, including a convergence study for the data, showed that it was adequate up to structure functions of order 2-3 [25]. Other models concentrate on the evolution with the scale that the PDFs of the velocity increments present. Hnat *et al.* [26] reported two important approaches in this sense: the model of diffusion, based on the equation of Fokker-Planck, and the model of Castaing. On the other hand, as we have already pointed out, the degree of intermittency can be represented from the $\log(F/3)$ of the PDFs, where F is the flatness of the PDF (figs. 1c and 1d). Concretely, we have used the PDF corresponding to the velocity increments to the smallest possible scale (1 s/20) since, when scale is diminished, the differences from Gaussian form are getting more evident (at least in terms of tendency).

As in the previous figures, in figs. 1c and 1d we observe a daily evolution that confirms the relationship between intermittency and stratification. It is noteworthy that this relation appears using both vertical (1c) and horizontal velocity increments (1d).

In order to quantify the grade of existing correlation between stratification and flatness, in fig. 2 we have represented $\log(F/3)$ *vs.* the difference of temperatures between the levels of 50 and 0.22 m (both for the horizontal speed and for the vertical one) for all the data. Although, as was expected when working with atmospheric data far from controlled laboratory experiments, the coefficient of determination that is obtained is not too high, even when a process of smoothed across a moving average is done, but nevertheless the obtained decreasing of flatness (for the minor possible scale) as the grade of stability is increased is clear.

In order to visualize the difference between the PDFs corresponding to situations with different grade of intermittency, we have represented in fig. 3 the PDFs corresponding to the scale 1 (the minor scale that we can represent, 1 s/20) for some moments of the period of study (in the same graph, a nocturnal situation and a diurnal of the next morning, are included) in which peaks (minima and maxima, respectively) are observed (in fig. 1).

It is observed how the PDFs corresponding to the diurnal situations present more stretched tails (major presence of rare events) than those corresponding to the situations at night, with minor intermittency, or even, an intermittency in an inverse sense.

It is interesting to show not only the PDFs corresponding to the minor scale for which we have resolution, but also the change that is taking place in the tails of the PDFs as the scale is diminishing. In figs. 4 and 5 this evolution has been represented.

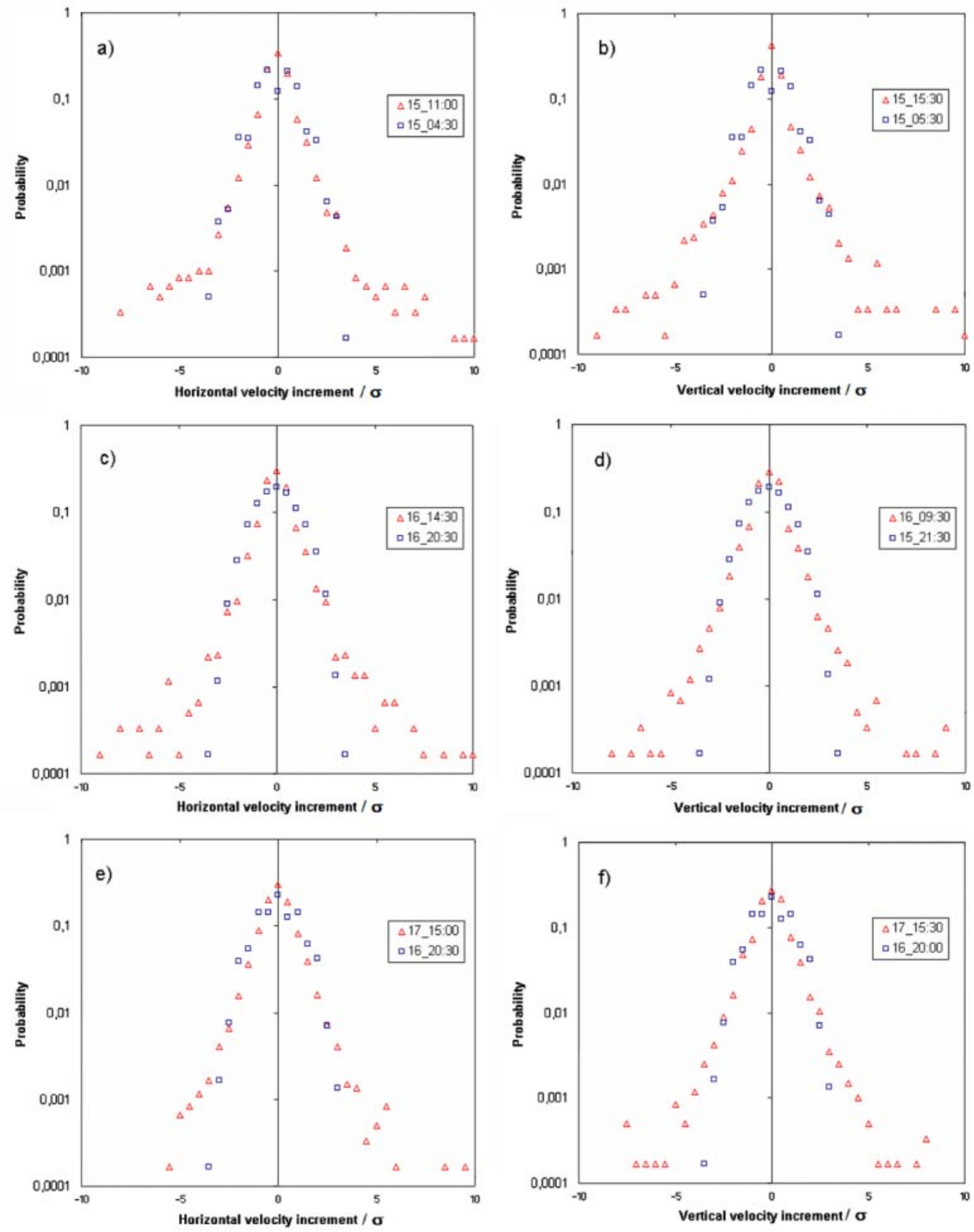

Fig. 3. – PDFs of the horizontal velocity (a, c, e) and the vertical velocity (b, d, f) for scale 1 s/20 for different study situations.

In these figures (4 and 5) it is observed that the most intermittent situations, related to diurnal convection (those of the left side) are more peaked, and that the PDF of the minor scale is wider than those of major scales. This change of the PDF with the scale is less pronounced in the situations of the right-hand side (nocturnal), compared to that they present in the situations of the left side (diurnal).

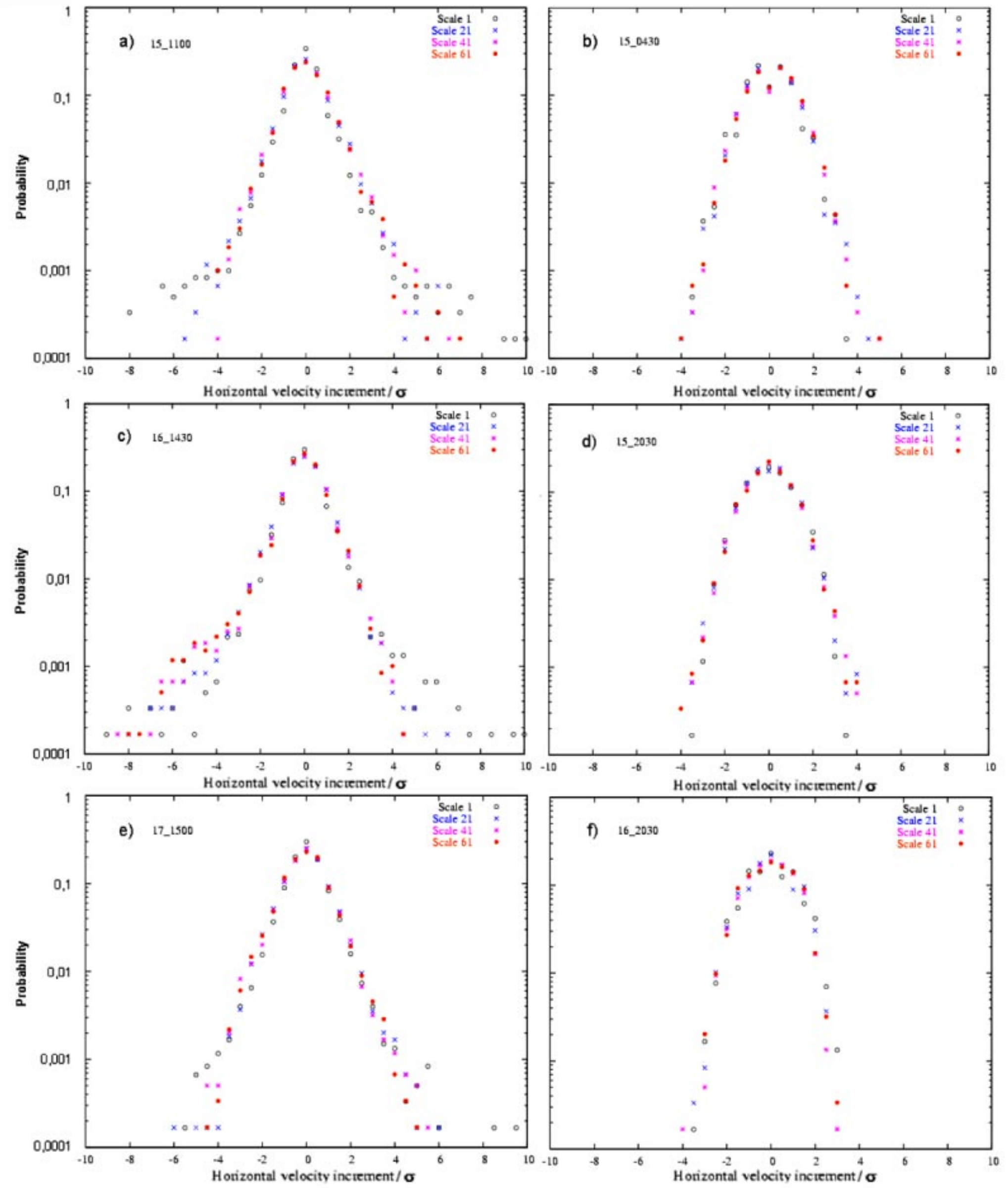

Fig. 4. – PDFs of the horizontal velocity increments for different scales (61, 41, 21, 1) and different studied situations.

To make more clear the evolution that the PDFs of figs. 4 and 5 experience, in fig. 6 we have represented the evolution of the flatness ($\log(F/3)$) with the scale. This figure puts in evidence clearly: a) the very top value of the flatness in the situations in the daytime opposite to the night situations and b) the increase, in general, of the flatness when the scale decreases for the diurnal situations (especially strong for the smallest scales) and the rough constancy, or even the decrease of the flatness for nocturnal stable

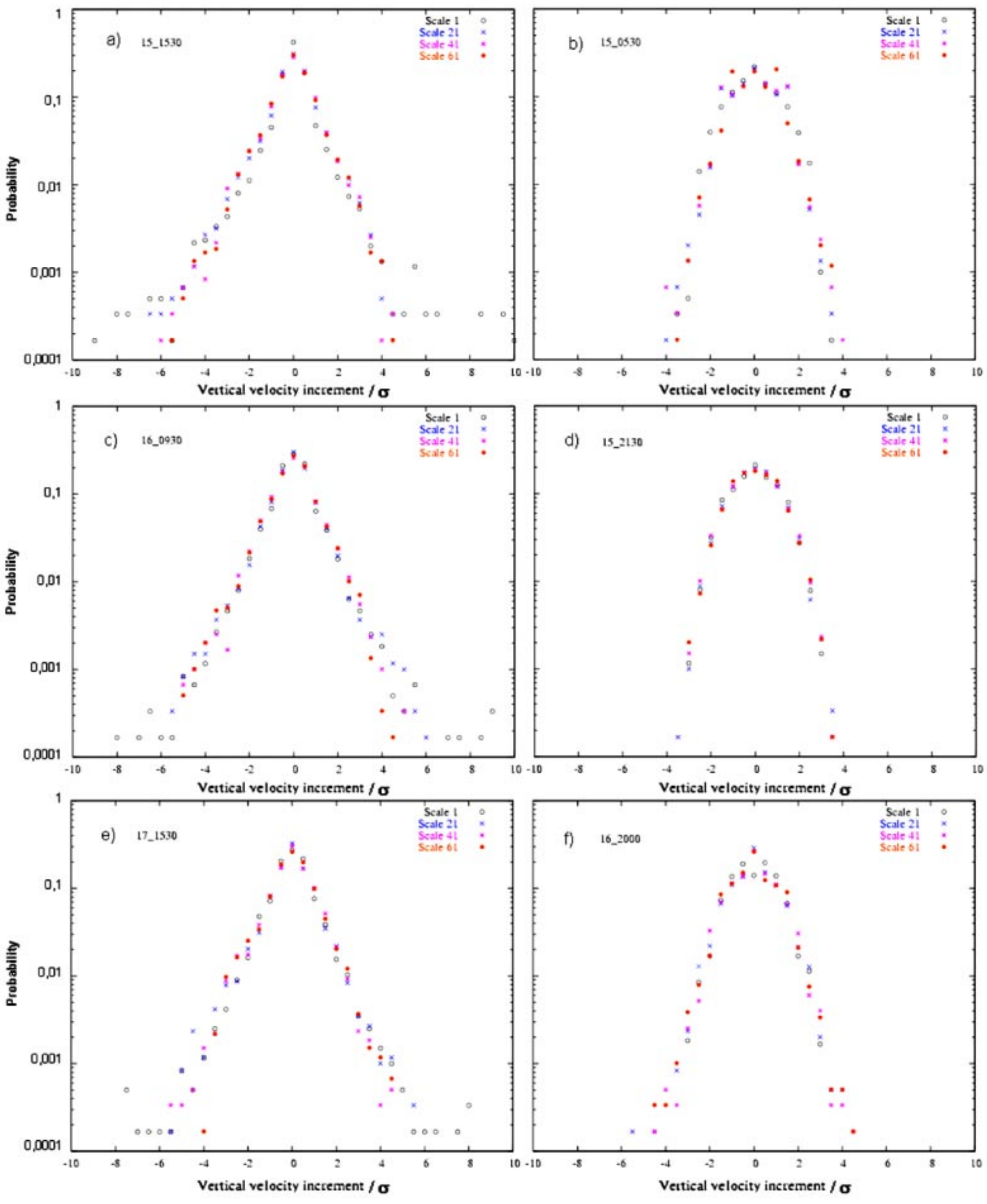

Fig. 5. – PDFs of the vertical velocity increments for different scales (61, 41, 21, 1) and different studied situations.

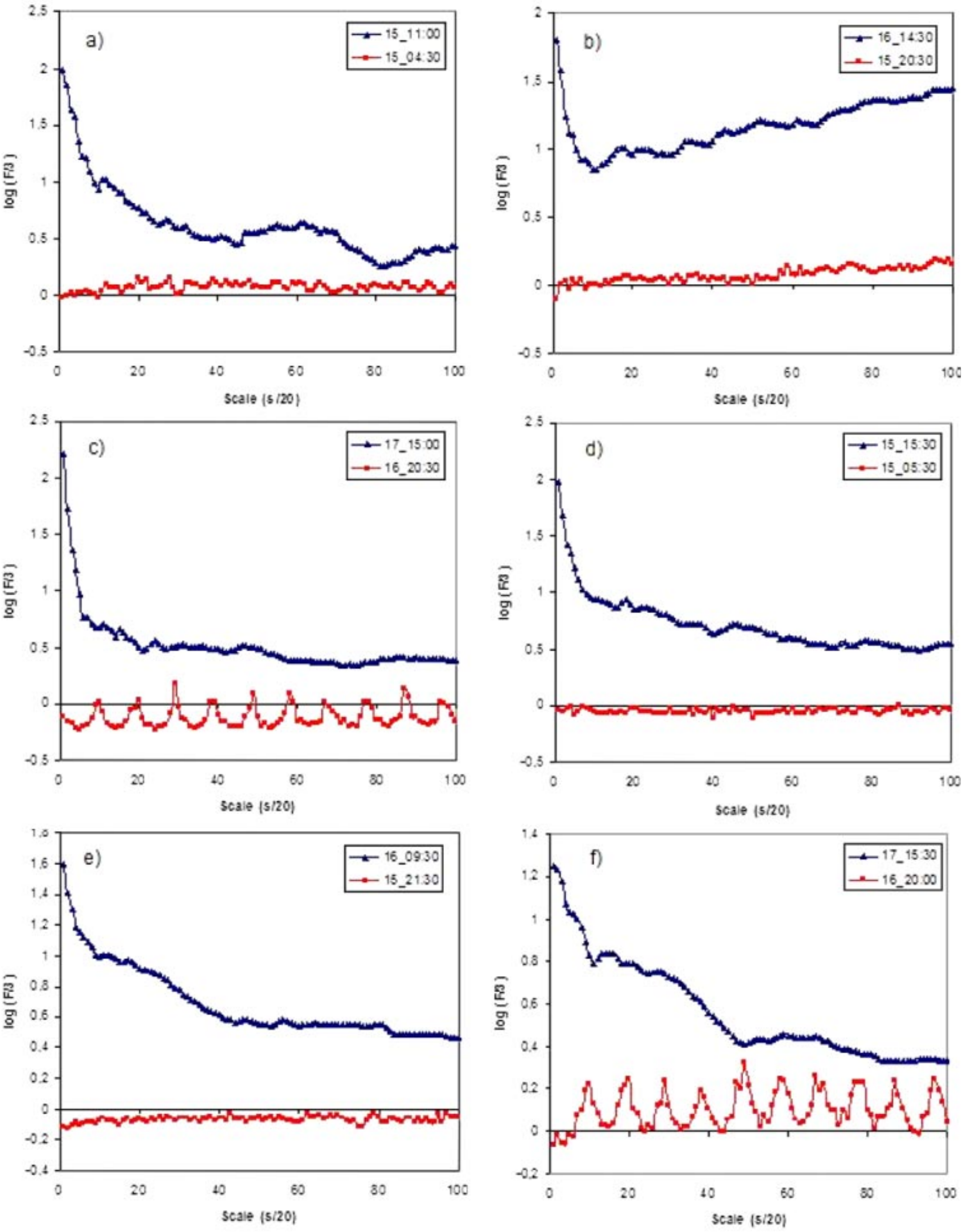

Fig. 6. – Evolution of log $(F/3)$ with scale for different situations for: a), b), and c) horizontal velocity; d), e) and f) vertical velocity.

situations.

4. – Conclusions

Although the reasons are not known exactly, the experiments in laboratory show that 2D turbulence is characterized by the absence of intermittency. It has been shown in this work that, in the atmosphere, also the situations of stability are characterized by a minor intermittency, or an intermittency in another sense. Consequently, the different degree of stratification along the day (normally major stability during the night than during the diurnal hours) will be reflected in a different behavior of the intermittency during the day (minor intermittency for the night, or even in strong stratification situations, an intermittency in an inverse sense). To show these relations data from 7 consecutive days have been used. For this period, the characteristic daily evolution of the stratification (and of the module of the vertical speed) also becomes clear for the case of the intermittency. To characterize this intermittency we have used as index the $\log(F/3)$ of the PDF of the velocity increments to the resolution scale ($1\,\mathrm{s}/20$). This index gives idea of the degree of stretching that can reach the tails of the PDFs in its evolution along the cascade. In the least intermittent cases, or with inverse intermittency, the PDFs turn out to be more closed (minor flatness), while in those presenting major direct intermittency (normally diurnal), the PDFs becomes more pointed and with more elongated tails. This is clearly shown in the evolution of the flatness with the scale (fig. 6).

It would be interesting to perform this type of analysis in much more stable atmospheric boundary layer datasets in extreme conditions, such as those in the Antarctic described by Yagüe and Redondo in [27].

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