Intermittency and non-Gaussian statistics in canopy turbulence

and their role in turbulent trace-gas exchange

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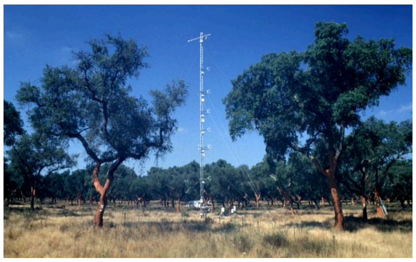
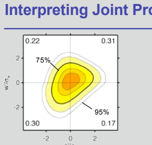


Large parts of the roughness sublayer, and in particular the canopy layer, are characterized by highly non-Gaussian and intermittent turbulence which are distinctly different from characteristics in the surface layer [1]. For subcanopy scale flux measurements, but also for ecosystem scale estimations close to canopies, it is of interest how the non-Gaussian nature of turbulence and its related intermittency drive and affect turbulent trace-gas exchange, and which key parameters appropriately describe these flows.

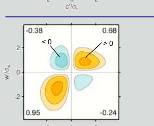
For this purpose, turbulence data were sampled within and above a sparse tree plantation. The extensively instrumented tower at Rio Frio in Portugal was operated for 12 days in Summer 2003 in a cork oak plantation with 76 trees ha^{-1} and a canopy height *h* of 10 m [2]. The tower supported 9 levels with ultrasonic anemometer-thermometers (8 CSI CSAT-3, 1 Gill HS) and 5 levels with infrared open path gas analysers (IRGA Licor 7500). The sensors were vertically arrayed between trunk space and 2.06 *h*. This setup allowed not only to measure a highly resolved profile of turbulent fluctuations of wind components *u', v', w'* and acoustic temperature θ' but also a profile of concentration fluctuations of water vapour *q'* and carbon dioxide *c'*.

Interpreting Joint Probability Densities



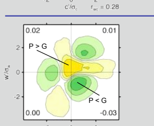
The **joint probability density (JPD)** *P(c,w)* displays the probability of cooccurence of two turbulent fluctuations (here CO_2-concentration *c'* and vertical wind *w'* in a nocturnal run). By definition, its area-integral is equal one.

Numbers denote *time fractions* of the four quadrants. The total of all four time fractions is equal one.



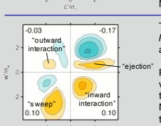
The **weighted JPD** *W(c,w)* is a JPD multiplied by local *c'* and *w'*. It is a measure of the local flux contribution, and its area-integral is equal the covariance *w'c'*.

Regions in blue colors contribute to a negative flux, red colors to a positive one. Numbers denote the *flux fractions* of the quadrants. The total of all flux fractions is equal one and corresponds to the covariance.



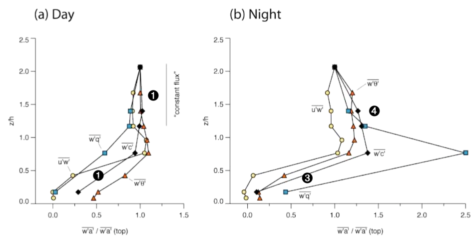
A **non-Gaussian JPD fraction** *N(c,w)* - only shown on the laptop - displays the difference between *P(c,w)* and a Gaussian JPD *G(c,w)* [3] with same correlation coefficient as the actual distribution.

Green colors denote regions which are actually underrepresented compared to *G(c,w)*, regions in yellow colors are of higher probability compared to *G(c,w)*. The area-integral of *N(c,w)* is equal zero. Numbers denote the *non-Gaussian time fractions*.



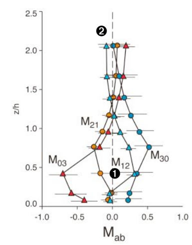
The **weighted non-Gaussian JPD contribution** is *N(c,w)* multiplied by local *c'* and *w'*. Therefore, it is a measure for non-Gaussian flux contributions.

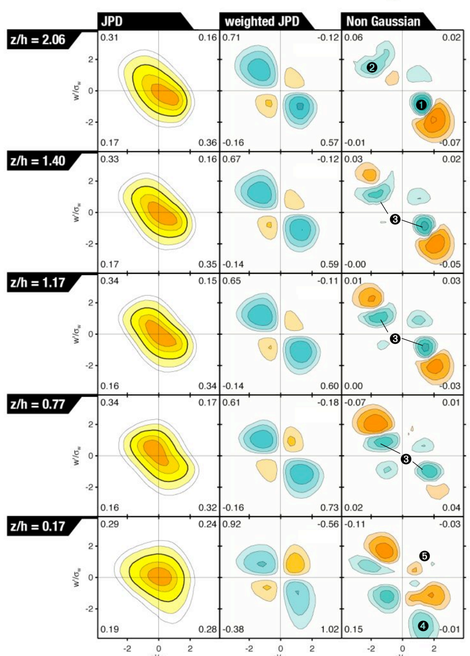
Regions in blue colors are non-Gaussian parts which contribute negatively, red colors positively to the overall flux. The area-integral is equal zero. Numbers denote the *non-Gaussian flux fractions* of the quadrants. The total of all non-Gaussian flux fractions is zero.



▲ **Vertical profiles of flux densities.** Ensemble average of flux densities normalized by corresponding flux densities at tower top. Daytime turbulent fluxes of sensible heat, H_2O and CO_2 are all characterized by a constant flux layer above 1.2 *h* (❶). Within the sparse canopy, the different offsets of the decay (❷) imply different 'active surfaces' (highest for H_2O, lowest for sensible heat). In the nocturnal runs, we encounter a different order in the canopy (❸) and a small flux divergence above (❹).

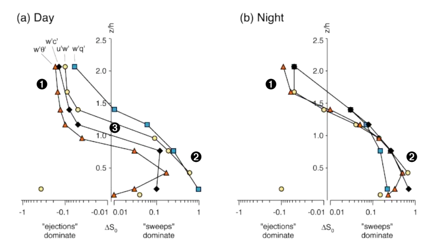
▶ **3rd order velocity joint moments** ($M_{ab} = \overline{u'^a w'^b} / (\sigma_u^a \sigma_w^b)$) in the canopy are distinctly different from zero (❶). This is in contrast to values at tower top (❷) and to assumptions in the surface layer where M_{ab} are close to zero. As a consequence of these profiles, turbulent transport of TKE is an important process. TKE is removed from the crown space and the region above the canopy (z/h > 0.8) and transported down into the mid canopy and trunk space.

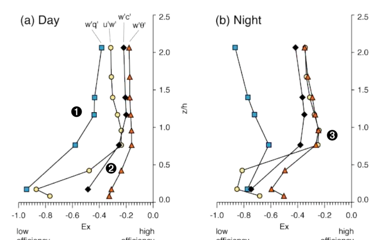




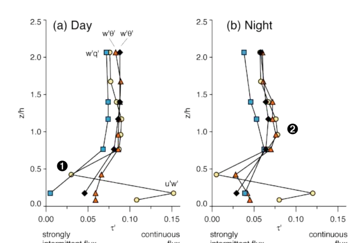
▲ **Daytime CO_2 joint probability density analysis.** The ensemble JPDs (left column), the weighted JPDs (middle column) and the weighted non-Gaussian JPD contributions (right column) summarize many detailed features and point out the non-Gaussian nature of the exchange in the vertical profile: Well above the canopy, large 'ejections' (❶) and small scale 'sweeps' (❷) dominate the flow. Around canopy top, a small-scale and efficient exchange is observed (small scale 'sweeps' and small scale 'ejections', ❸). Down in the trunk space, large 'sweeps' dominate the CO_2-exchange in the canopy (❹). Here, also outward and inward interactions are not equally contributing (lowering) to the flux: outward interactions (upward motions with high CO_2) are much more common (❺).

▼ **Ejections and Sweeps.** ΔS_0 is defined as the difference between direct upward motions ('ejections') and direct downward motions ('sweeps'). Generally, the vertical profiles show a domination of 'ejections' (❶) above and 'sweeps' (❷) below *h* for all scalars and momentum. The height of the daytime crossover is different for the various scalars (❸), and depends mainly on the height of the 'active surfaces'. These can be attributed to the crown space in the case of $\overline{u'w'}$ and $\overline{w'q'}$, to the upper canopy for $\overline{w'c'}$. The lowest 'active surface' is interpreted from $\Delta S_0(w'\theta')$. This sparse canopy allows large parts of the direct irradiance to penetrate down to ground level, and to induce significant sensible heat fluxes already in the trunk space. Nocturnal ΔS_0-values show a higher similarity between the different scalars.





▲ **Exchange efficiency.** Vertical profiles of exuberance *Ex* [4] are reflecting dissimilarities in the exchange efficiency of the various flux densities. Again, the least efficient H_2O exchange starts already higher up to decrease in efficiency (❶), while daytime CO_2 and sensible heat exchange are still well correlated in the canopy (❷). Nocturnal data show most efficient exchange close to canopy top (❸).



▲ **Intermittency.** By defining a hyperbolic hole of size *H'* above which half of the flux occurs we have a conditional measure for the size of structures contributing to the exchange [5]. Analogously, intermittency can be quantified using the total time fraction τ' above which half of the flux occurs. With decreasing height in the canopy, τ' indicates a more intermittent regime (❶). During night, fluxes are least intermittent at canopy top (❷) where simultaneously highest efficiency was observed.

Data source

All values are calculated from ensemble JPDs (the average JPD from all runs at given height and in the selection). The selection criteria result in 224 daytime (u > 2 m s^{-1}) and 149 nocturnal runs (u > 1 m s^{-1}). Runs were processed over 30-min without detrending.

References

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[2] see also poster by R. Vogt, et al., this workshop.
[3] J. C. Wyngaard , C. H. Moeng, 1992, *Bound.-Lay. Meteorol.*, 60, 1-13
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