Diffusive and Convective parts of the turbulent flux in the SOL of tokamaks

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Introduction

Recently, the description of the turbulent transport in the SOL has made some improvement and in particular, the importance of the convective local events for the transport has been experimentally assessed[1]. A large fraction of the transport occurs through the convection of "blobs" or "avaloids" which are cells of over densities with a small poloidal extent (in the cm range) propagating with the help of their internal polarization, at velocities which are of a fraction of the sound speed. They are expected to travel radially over several cm in the SOL much beyond the e-folding lengths of the profiles, thus carrying some density and energy towards the wall components. However, they are included in a background turbulence and it is not easy to extract them properly to study in details their dynamics. It would be worthwhile to quantify their importance in the transport and to understand how they couple to the rest of the turbulence. We propose here a method for their extraction based on non linear filtering using orthogonal wavelets, which has already been used extensively to extract coherent events from numerical fluid turbulence[2].

Principle of the de-noising program

The de-noising program assumes that the turbulence is composed of a Gaussian white noise superposed on a background of events labeled as "coherent events". The program extracts the Gaussian white noise from the signal and by subtraction allows to recover the coherent part of the signal. To fulfill this task, the de-noising is performed on a basis of orthogonal discrete wavelets which allows to preserve the local information (in opposition to Fourier analysis). The mother wavelets which are being used are the Coifman 12 which in addition have 4 null moments. By definition, a Gaussian white noise is evenly distributed among all modes and amplitudes of the coefficients are given by their r.m.s. Since we do not know the r.m.s. of the noise a priori, we use an iterative procedure which assumes that it is equal to the r.m.s. of the raw signal as a first guess.

We project the signal on the wavelet basis to obtain the coefficients f and compute the threshold : $T_n = \left(2 \left\langle \tilde{fi} \right\rangle^2 \ln N \right)^{\frac{1}{2}}$

The incoherent coefficients are those for which: $\left|\tilde{f}\right| < T_n$, the threshold is then re-calculated with this reduced set of coefficients and the procedure is iterated as many times until the threshold becomes invariant. The coherent events are reconstructed from $\left|\tilde{f}\right| > T_n$. The incoherent noise is reconstructed from $\left|\tilde{f}\right| < T_n$.

Experimental data:

The data is measured on a poloidal ring of Langmuir probes in the CASTOR tokamak in Prague[3] (*R=40 cm, a = 6 cm)*. The ring is composed of 124 probes poloidally separated by 3 mm. The data presented here are measured on a quadrant of 32 probes located in the SOL. The probes operate alternatively in the floating potential and ion saturation current mode. This allows to calculate the turbulent particle flux at 15 poloidal positions. We use the fluctuating floating potential difference $\delta E_\theta = (V_n - V_{n-1})/d$ between 2 probes spaced poloidally by distance d, to calculate the turbulent radial velocity

$$\delta V_r = \frac{\delta \vec{E}_\theta \times \vec{B}}{B^2}$$

The fluctuating ion saturation current δj measured by the tip located in between the floating tips, allows to calculate the density fluctuations $\delta n = \delta j / c_s$, where c_s is the ion sound speed. The radial velocity and density fluctuations are decomposed in:

$$n_t(x,t) = n_c(x,t) + n_i(x,t)$$

$$v_t(x,t) = v_c(x,t) + v_i(x,t)$$

where c stands for “coherent” and i for “incoherent” part of the signal. The total flux is decomposed as: $\Gamma_t(x,t) = \Gamma_{cc}(x,t) + \Gamma_{ci}(x,t) + \Gamma_{ic}(x,t) + \Gamma_{ii}(x,t)$ where

$\Gamma_{cc} = v_c n_c$ v-coherent n-coherent flux,

$\Gamma_{ci} = v_c n_i$ v coherent n-incoherent flux,

$\Gamma_{ic} = v_i n_c$ v incoherent n-coherent flux,

$\Gamma_{ii} = v_i n_i$ v-incoherent n-incoherent flux.

Results:

Temporal evolutions of all the contributions to the total flux obtained from a set of 3 probes are shown in fig. 1. The two main components of the flux are Γcc which accounts for 54% and Γic which accounts for 32% of the total flux. As a consequence, 86 % of the total flux

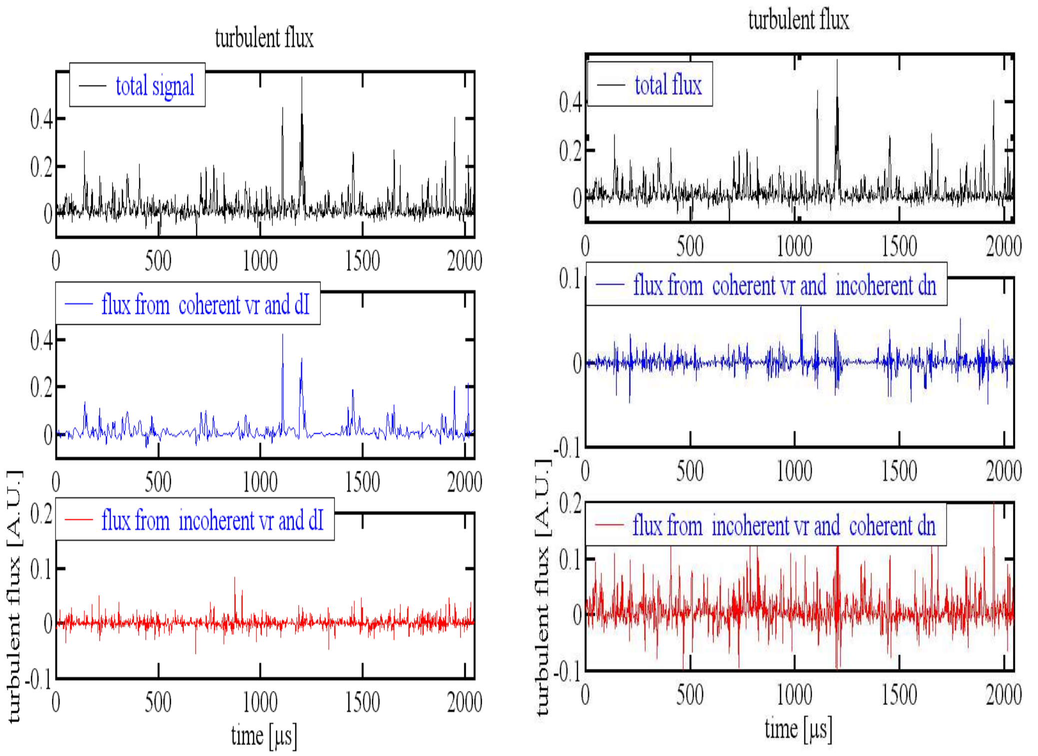

Fig 1: *Temporal evolution of the components of the turbulent flux calculated by the de-noising program. The first column corresponds to diagonal terms (Γcc Γii), the second column to the cross-terms (Γci and Γic).*

is produced by the transport of the coherent density peaks by the coherent and incoherent velocity terms. The fact that the incoherent term (the velocity), which should be a Gaussian white noise is able to transport the coherent density events is a posteriori a surprise.

In fact it can be shown that the program cannot extract a white noise over all the frequencies. This is shown in figure 2 where the frequency spectrum of the fluctuating radial velocity components are shown. Figure 2 shows that the de-noising program is unable to extract a white noise from the signal above 100 kHz. As a consequence, the incoherent part of the signal remains correlated above 100 kHz and the slope of its PSD is identical to that one of the total signal in this frequency range.

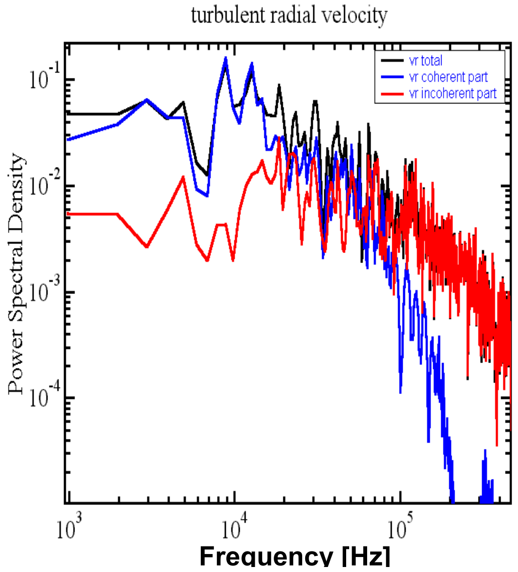

Fig. 2 *Power Spectral Density of the turbulent radial velocity*

It is this feature combined with the strong skewness of the coherent density peaks which is responsible for the amplitude of the transport of coherent peaks by incoherent velocity. Finally we observe that the coherent and incoherent density have different poloidal velocities. This is observed in figure 3 by plotting the time correlation function of one probe of the array with all the other probes of the same quadrant.

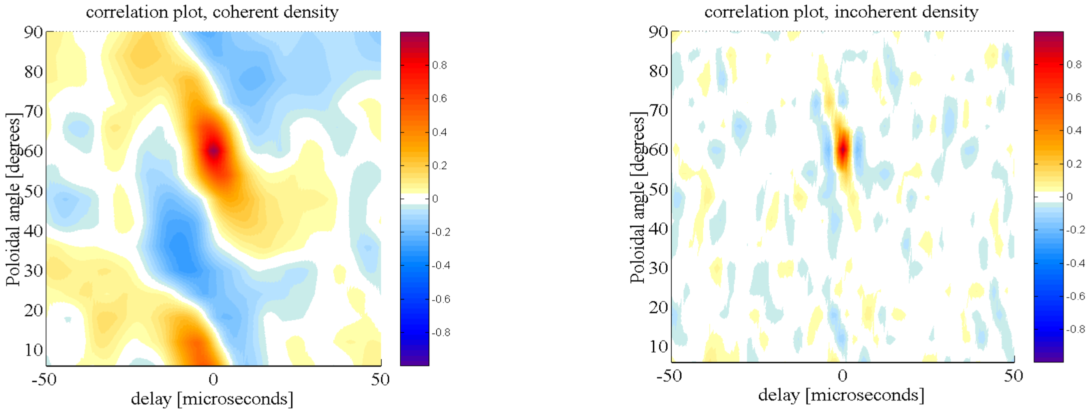

Fig 3: *Correlation plot for coherent and inherent part of density fluctuations on a quadrant of the poloidal ring.*

The coherent "blobs" have a poloidal velocity of 1.4 km/s with a maximum correlation time of 70 µs, while the incoherent part of the density has a velocity of 3.5 km/s with a maximum correlation time of 10 µs.

Conclusions

A non linear filtering program is used to extract the coherent events from the SOL turbulence of Castor. The bursts (blobs) are very efficiently extracted and the program performs cleanly the separation of the 2 scales (the bursts and the rest) which are involved in the signal. This separation allows to obtain the time series without any phase distortion (through the use of orthogonal wavelets) and the contribution of each of them to the turbulent transport can be evaluated. It is found that the coherent density bursts are transported both by the coherent and incoherent parts of the turbulent radial velocity and this accounts for 86 % of the total flux. The 2 different scales which are observed (the bursts and the rest) are found to have different poloidal velocities. However, the de-noising program fails to extract a Gaussian white noise from the turbulence over all the frequencies because the high frequency part (>100 kHz) remains correlated.

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References:

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