Electrostatics Probes
Gomtraic 2013 final report – Remote part

by Marco Martínez[1], and Miguel Gomez[2]

[1]Universidad Nacional Autónoma de México (UNAM), Mexico City, Mexico
[2]Instituto Superior Técnico, Lisbon, Portugal

Experimental Set-up

In order to study the temporal and spatial evolution of the floating potential (U_{fl}) of the plasma in the tokamak GOLEM, we used a rake probe with 12 tips, which are made of Molybdenum wire of the diameter 0.7 mm, spaced by 2.5 mm and length of individual tips is about 2 mm. The rake probe is inserted in the tokamak vessel from bottom, as schematically shown in Figure 1.

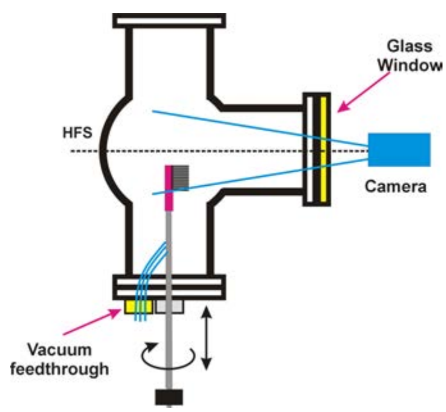

Figure 1. Lay-out of the experiment.

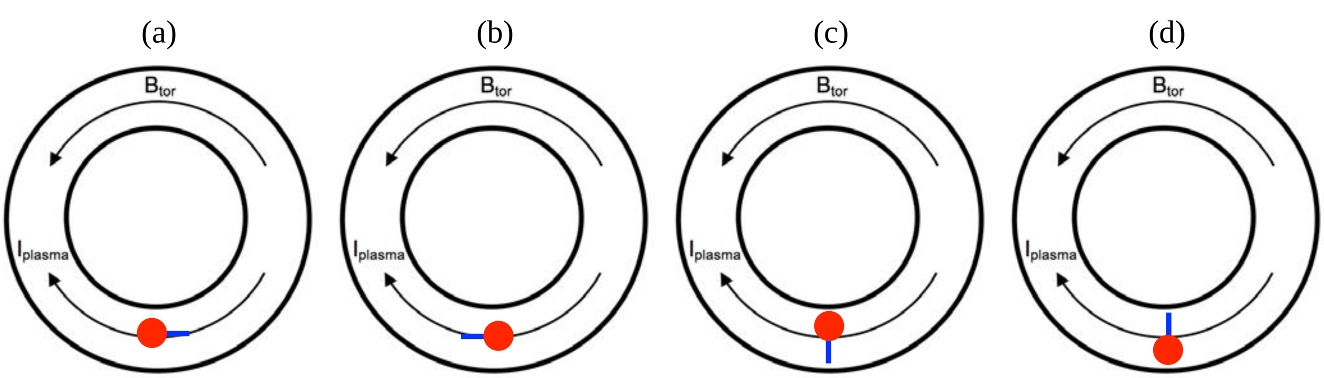

Figure 2. Orientations of the rake probe with respect to the toroidal magnetic field direction as seen from the top of the GOLEM. (a) Downstream orientation, (b) Upstream orientation, (c) Low-Field side (LFS) orientation, (d) High-Field side (HFS) orientation.

The first tip of the rake probe was placed at the radius position r = 60 mm from the centre of the tokamak chamber. The rake probe is installed on the rotatable shaft; therefore, it was possible to change orientation of the tips with respect to the direction of the toroidal magnetic field and the plasma current as depicted in Figure 2.

Measurements were performed for two different series of shots by charging voltage of the capacitor bank for the toroidal magnetic field U_B = 600 V, and changing voltage of the capacitor bank for the primary winding of the GOLEM transformer U_{CD} = 400 V and U_{CD} = 350 V. The time delay between triggers of these capacitor banks are T_{CD} = 2000 μs and T_{CD} = 10000 μs, respectively for each value of U_{CD}. The pressure of the working gas (Hydrogen) is P_{H2} = 10 mPa, and pre-ionization was switched ON. All the parameters are shown in the Table 1 and Figure 3 shows the basic parameters.

Table 1. Parameters of the discharges.

# Shot	Orientation	U_B [V]	U_{CD} [V]	T_{CD} [μs]	P_{H2} [mPa]	Pre-ionization	Plasma [s]
11754	Downstream	600	350	2000	10	on	0.01226
11749	Upstream	600	350	2000	10	on	0.01202
11743	LFS	600	350	2000	10	on	0.01238
11748	HFS	600	350	2000	10	on	0.01226
11781	Downstream	600	400	10000	10	on	0.01222
11784	Upstream	600	400	10000	10	on	0.01178
11788	LFS	600	400	10000	10	on	0.01198
11790	HFS	600	400	10000	10	on	0.01118

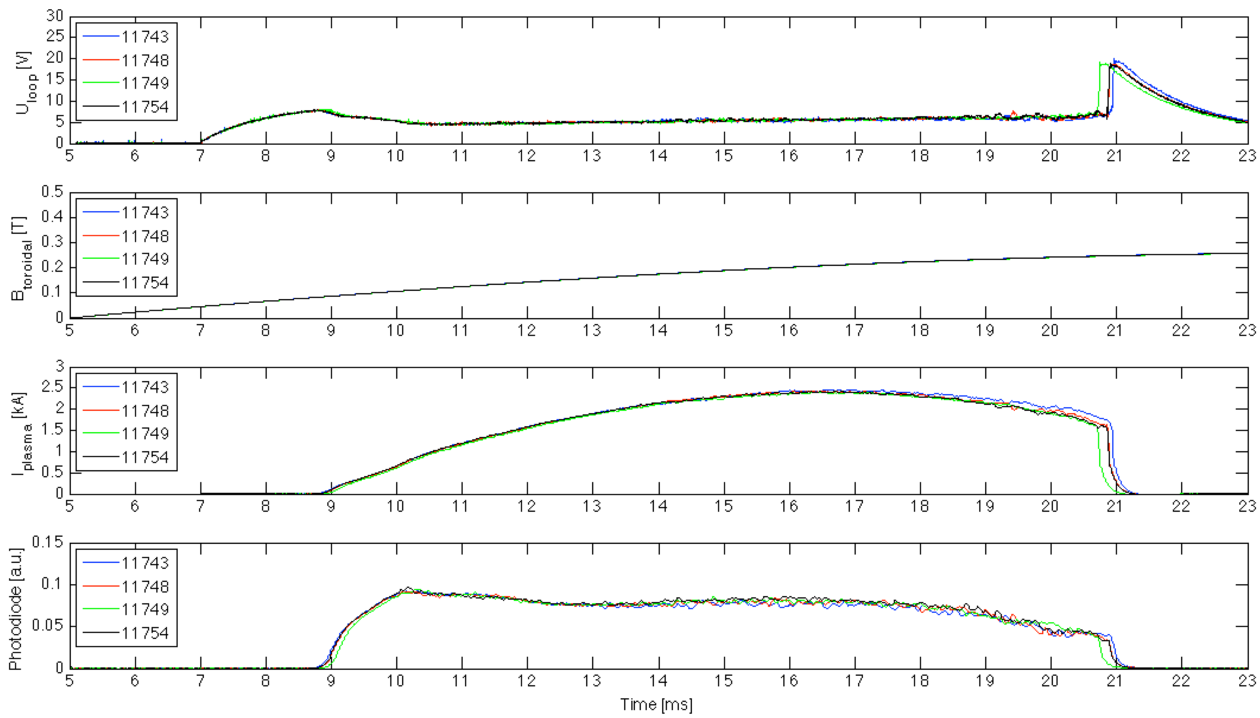

Figure 3. Basic parameters

Results

The shots #11754, #11749, #11743, and #11748 (downstream, upstream, LFS and HFS, respectively), are shown in following figures. Figure 4 shows the floating potential in each direction, Figure 5 shows 3D plot and its contour of the floating potential, Figure 6 shows smoothing of floating potential with a degree of 100, Figure 7 shows the floating potential integrated over different intervals of time, Figure 8 shows the fluctuations of the floating potential, Figure 9 shows 3D plot and its contour of the smoothing of FFT, Figure 10 shows the cross correlations for the probe 6, Figure 11 shows 3D plot and its contour of the cross correlations for the probe 6, Figure 12 radial velocity between probes, and Figure 13 skewness and kurtosis for the four position of the rake.

Figure 4 shows raw data of the floating potential of individual tips. For further analysis, it is important to check the raw data out as there may be errors in electronics, arcing in the case of ion saturation regime and other defects. Figure 5 puts the data to 3D plots. In both the figures, we can observe that the floating potential is higher in downstream direction, then the LFS direction, after the HFS direction and finally upstream direction. Also, the value of floating potential is bigger in the probe No.1 and this value decreases for the other probes.

There are two main ways to characterize the plasma from the probe measurements: the mean values and the fluctuations. First, we will focus on the mean values. The signal is smoothed in a suitable time window of 1 ms, as shown in figure 6. The most practical way is usually the radial profile of the measured parameter, as shown in Figure 7, which shows how the floating potential is changing, over different intervals of time and between probes.

The fluctuation analysis is shown in following figures. Figure 8 shows the raw data fluctuations, e.g. the raw signal (Figure 4) subscribed from the smoothed signal (Figure 6). We can see that the fluctuations are bigger in LFS direction and upstream direction than HFS direction, and it is lower for downstream direction. But, from Figure 9 it can see that FFT is bigger in downstream direction, then the LFS direction, after the HFS direction and finally upstream direction. Also, Figure 9 shows that there are dominant frequencies between 3 kHz and 5 kHz and 8 kHz and 10 kHz.

Cross-correlation analysis can help us to get an idea about structures in the investigated region and to estimate the radial velocity from the fluctuations. First, we need to calculate the cross-correlations of the adjacent probes as shown in Figure 10. Figures 10 and 11 show that the cross correlation (from 9ms to 21ms) between probe 6 and the other probes is lower for HFS direction, then increase for downstream direction, then for LFS direction and finally for upstream direction. For HFS, downstream and LFS directions the cross correlation between probes 6-5 and 6-7 is higher than 0.5, while the cross correlation in upstream direction between probes 6-4, 6-5, 6-7, 6-8 and 6-9 is higher than 0.5. The peak in correlation around the probe 6 suggest that there is a big structure sitting in this area. The velocity can be estimated from the lag of the cross-correlation maxima. This lag shows how fast the structures moved from one tip to another. Thus, the radial velocity is the ratio of the time lag to the distance of the probes. The resulting radial velocities between probes (in three time windows: 9ms to 10ms, 14ms to 15ms and 20ms to 21ms) are in the Figure 12.

For statistical analysis, the most important moments are the first four: mean value μ, variance σ^2, skewness ***S*** and kurtosis ***K***. Where σ^2 (it's square root is the *standard deviation*) indicates the variability of the distribution. Skewness shows the dominating part of the data: the negative value of skewness indicates that the left tail of respective PDF (probability distribution function) is longer that the right one. The skewness for a normal distribution is equal to zero. Kurtosis indicates how “peaked” the distribution is, “peaked” distributions have positive kurtosis while “flat” ones have negative values of kurtosis.

In this work the skewness and the kurtosis were calculated for each position (downstream, upstream, LFS and HFS), with a time window of 2 ms, see Figure 13. This analysis shows the following results:

- For downstream position: the skewness shows predominant negative values, which it means that left tail of its respective PDF is longer that the right one. On the other hand, the behaviour of kurtosis is predominant positive, which means that PDF is peaked, and this behaviour is more remarkable between 16ms and 20ms.

- For upstream position: the skewness shows negative values like downstream position, but between 16 ms and 20 ms the skewness becomes positive, which means that right tail of its respective PDF is longer that the left one. On the other hand, the behaviour of kurtosis is predominant positive, which means that PDF is peaked, but it is less positive that in downstream position.

- For LFS position: the skewness shows predominant negative values, like in downstream behaviour, but it is less negative. The behaviour of kurtosis is predominant positive like downstream position, but there is not a remarkable behaviour between 16ms and 20ms.

For HFS position: the skewness shows the same behaviour as upstream position. And the behaviour of kurtosis is the same as upstream position.

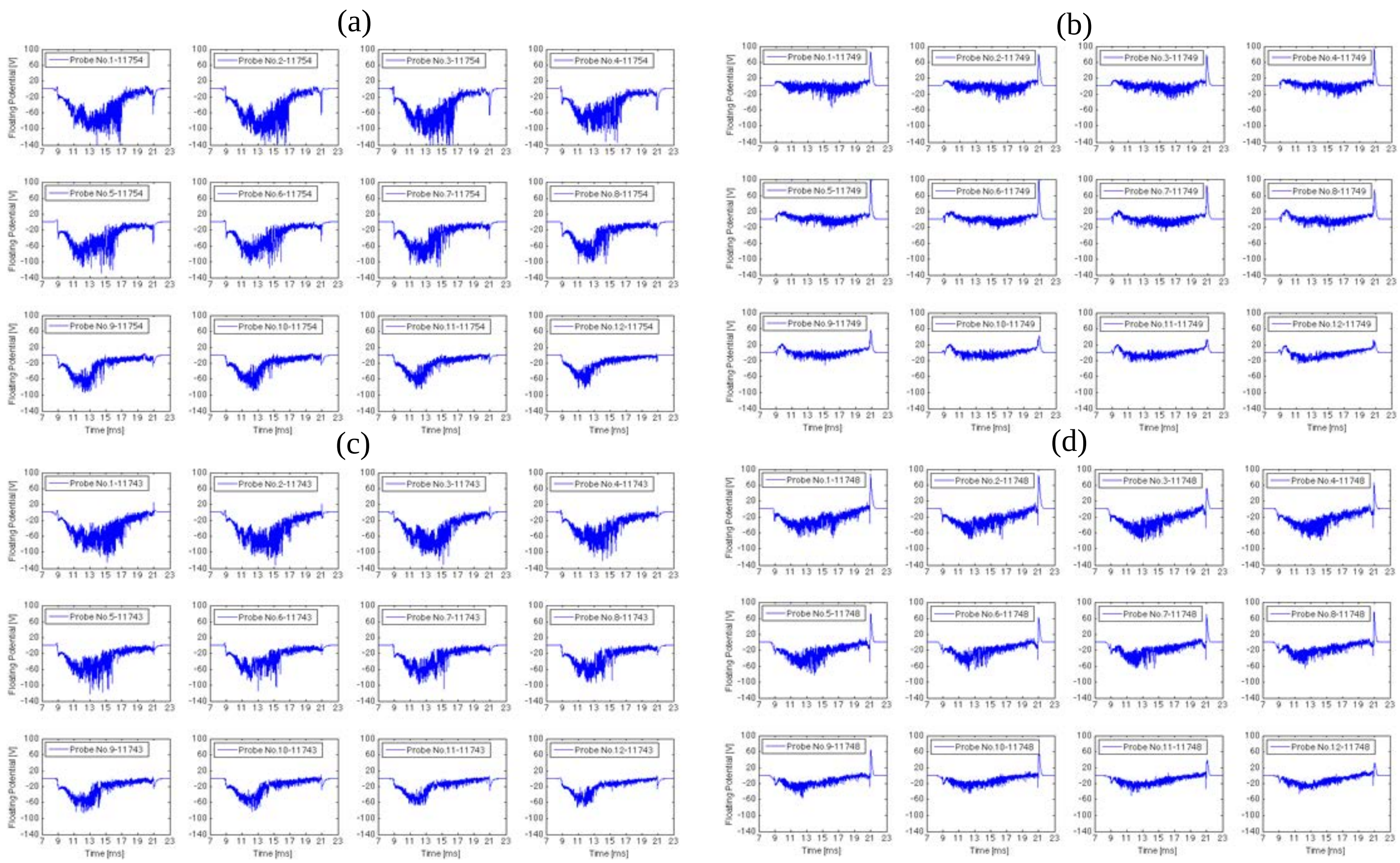

Figure 4. Floating potential in each direction: (a) downstream, (b) upstream, (c) LFS and (d) HFS.

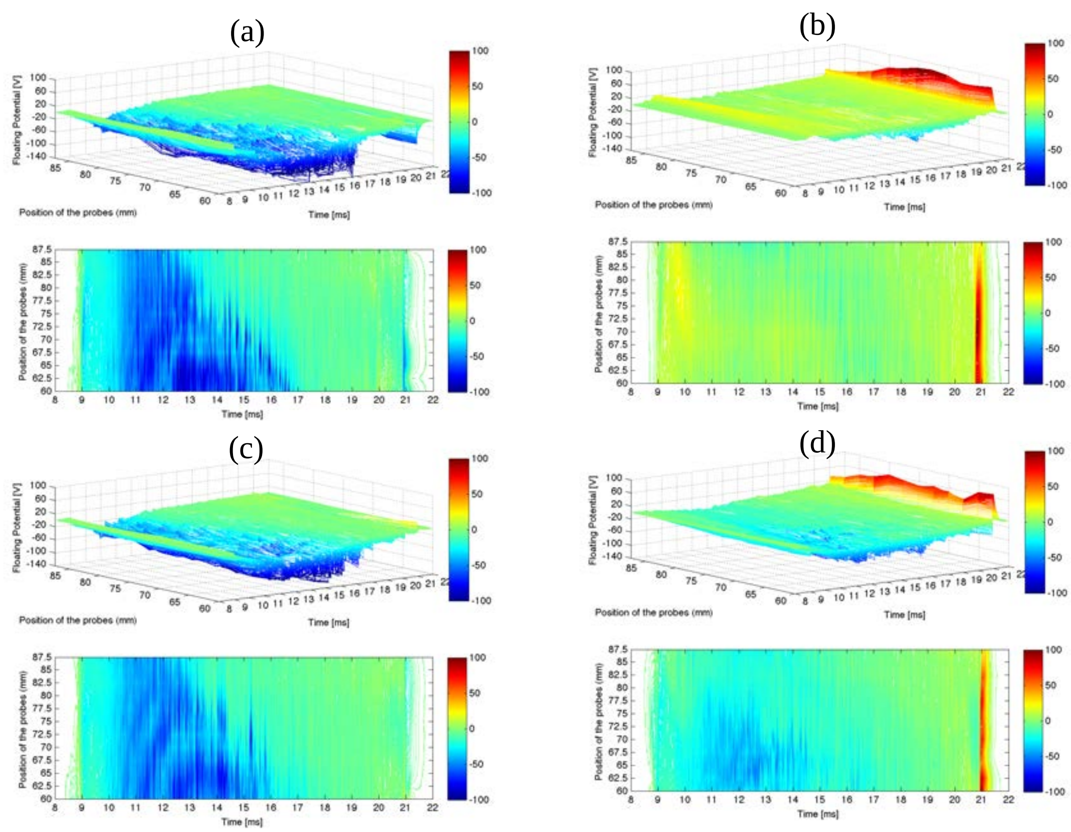

Figure 5. Floating potential. (a) downstream, (b) upstream, (c) LFS and (d) HFS.

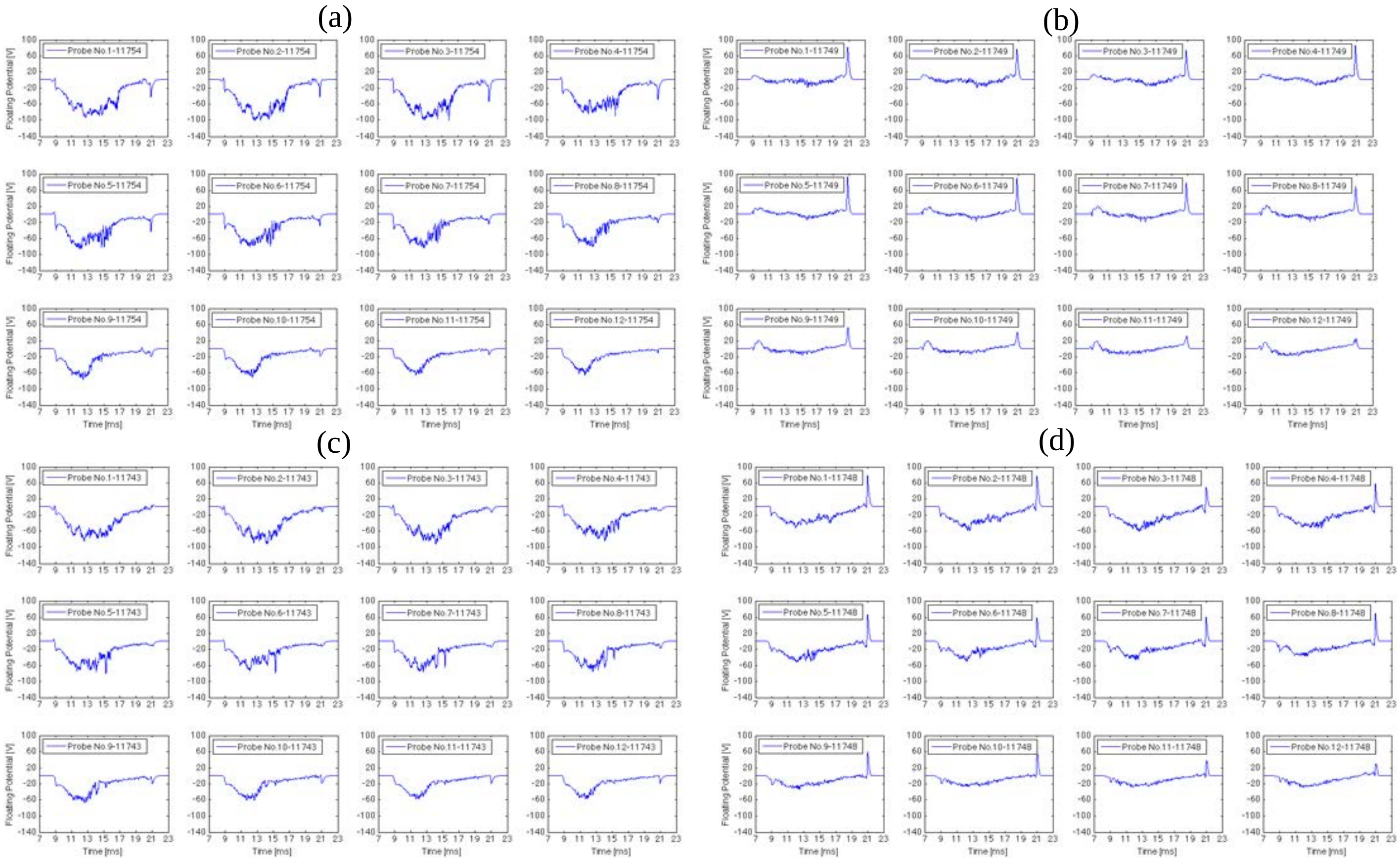

Figure 6. Smoothing of floating potential with a degree of 100. (a) downstream, (b) upstream, (c) LFS and (d) HFS.

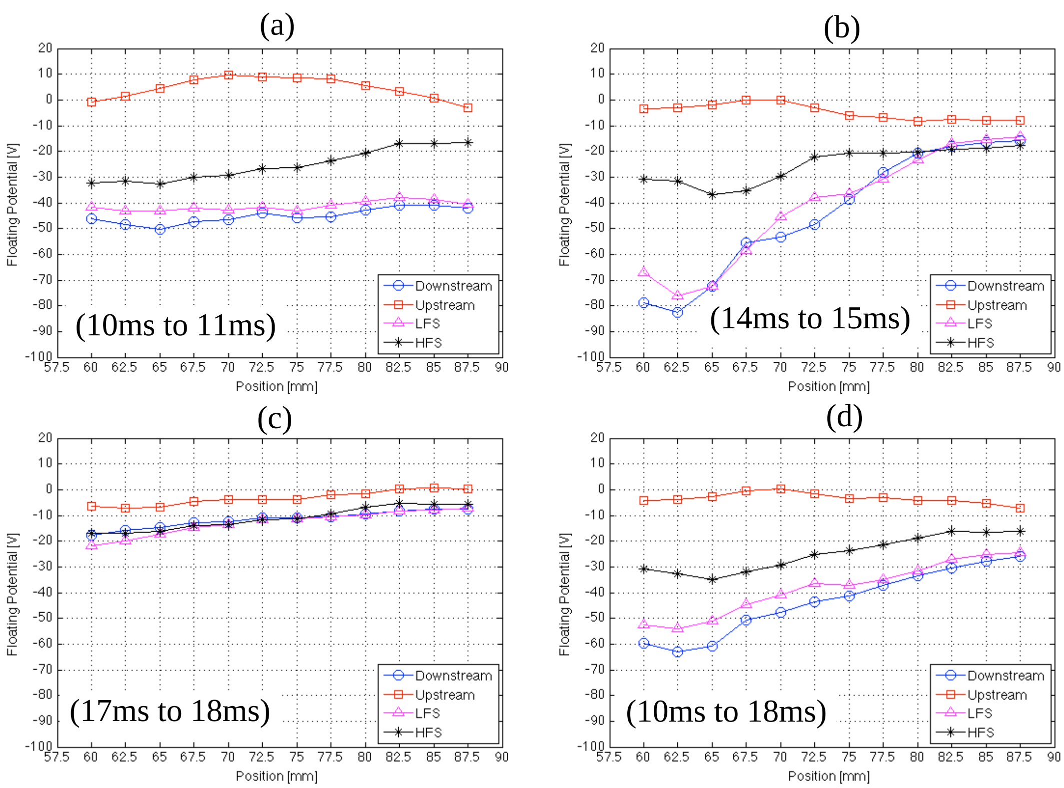

Figure 7. Floating potential integrated, for all orientations of the rake: downstream, upstream, LFS and HFS. Intervals of integration (a) from 10ms to 11ms, (b) from 14ms to 15ms, (c) from 17ms to 18ms, (d) from 10ms to 18ms

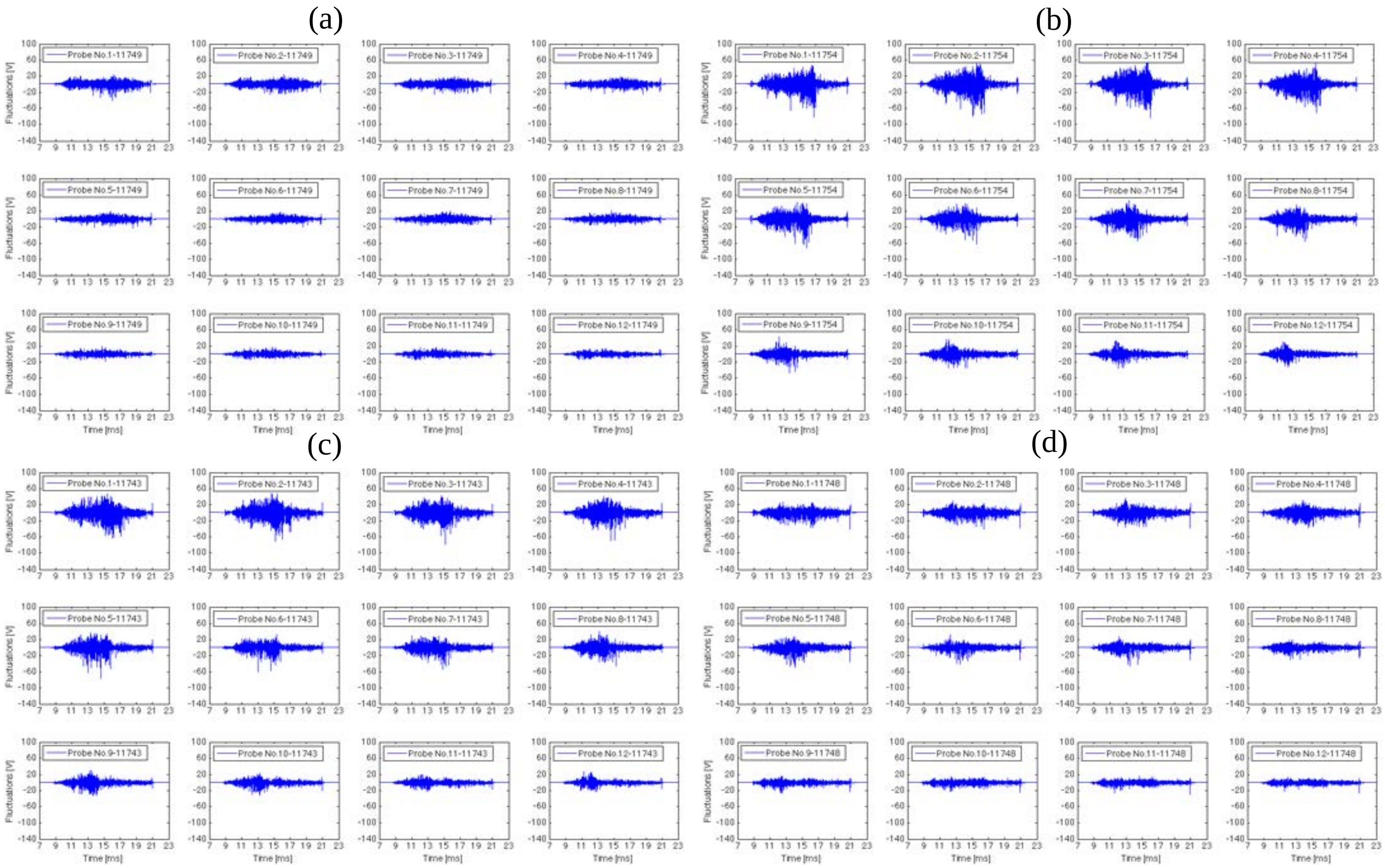

Figure 8. Fluctuations of the floating potential. (a) downstream, (b) , (c) LFS and (d) HFS.

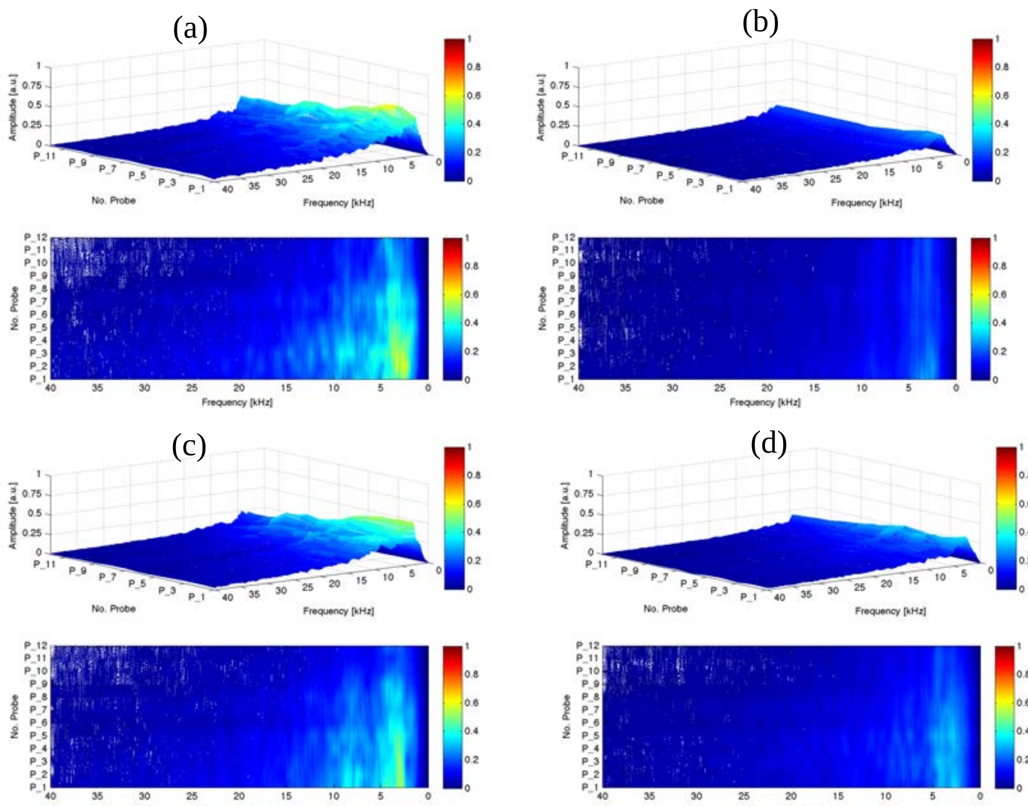

Figure 9. 3D plot and its contour of the smoothing of FFT. (a) downstream, (b) upstream, (c) LFS and (d) HFS.

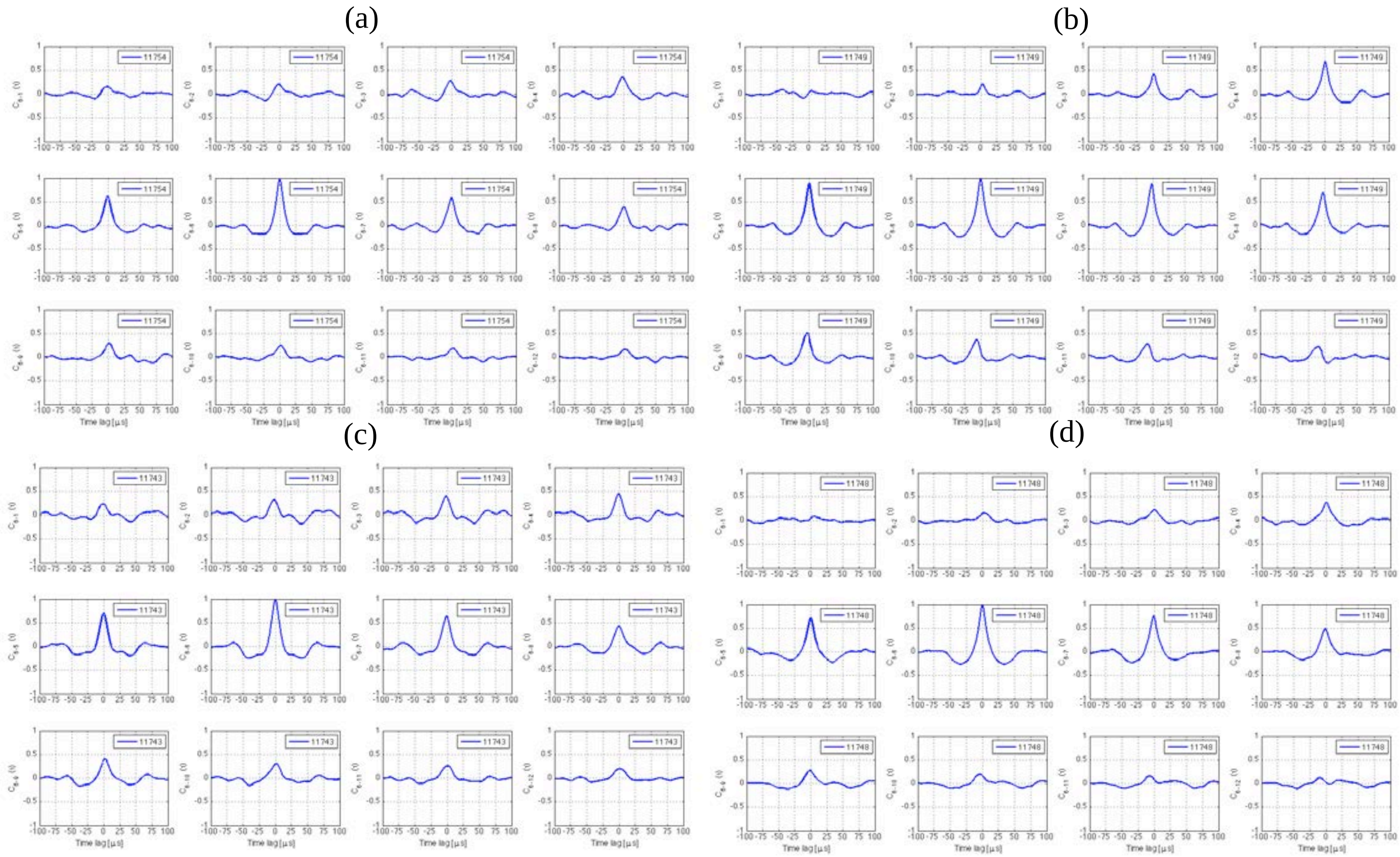

Figure 10. Cross correlations for the probe 6. (a) downstream, (b) upstream, (c) LFS and (d) HFS.

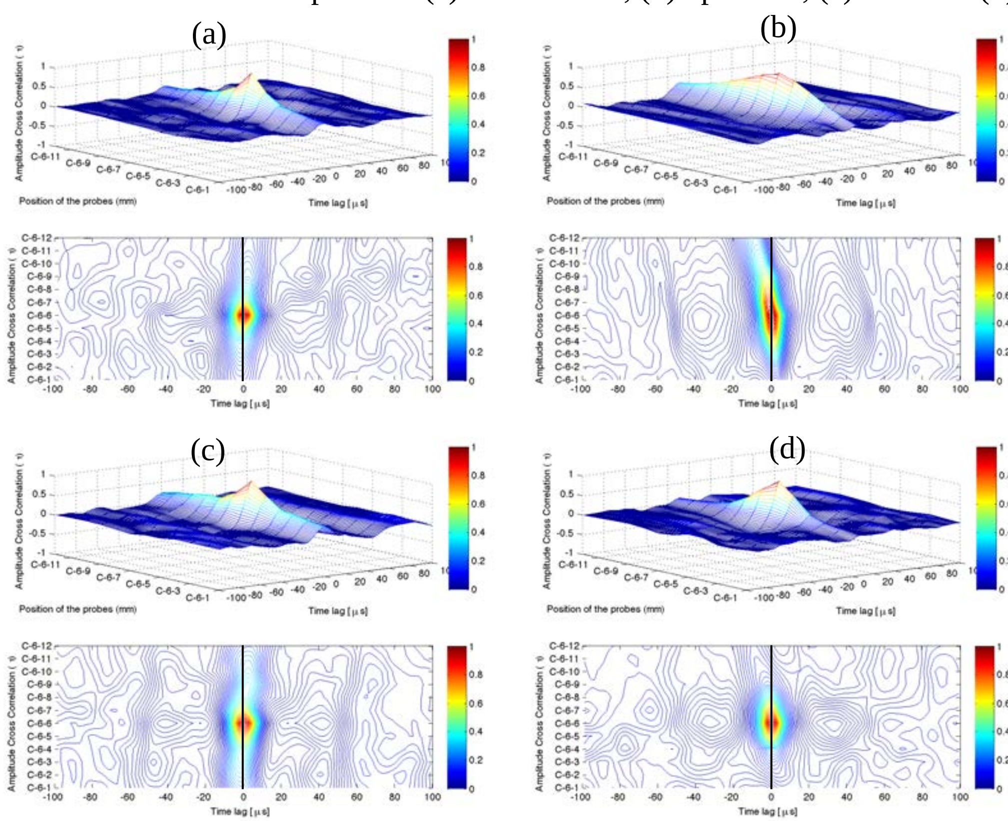

Figure 11. 3D plot and its contour of the cross correlations for the probe 6. (a) downstream, (b) upstream, (c) LFS and (d) HFS.

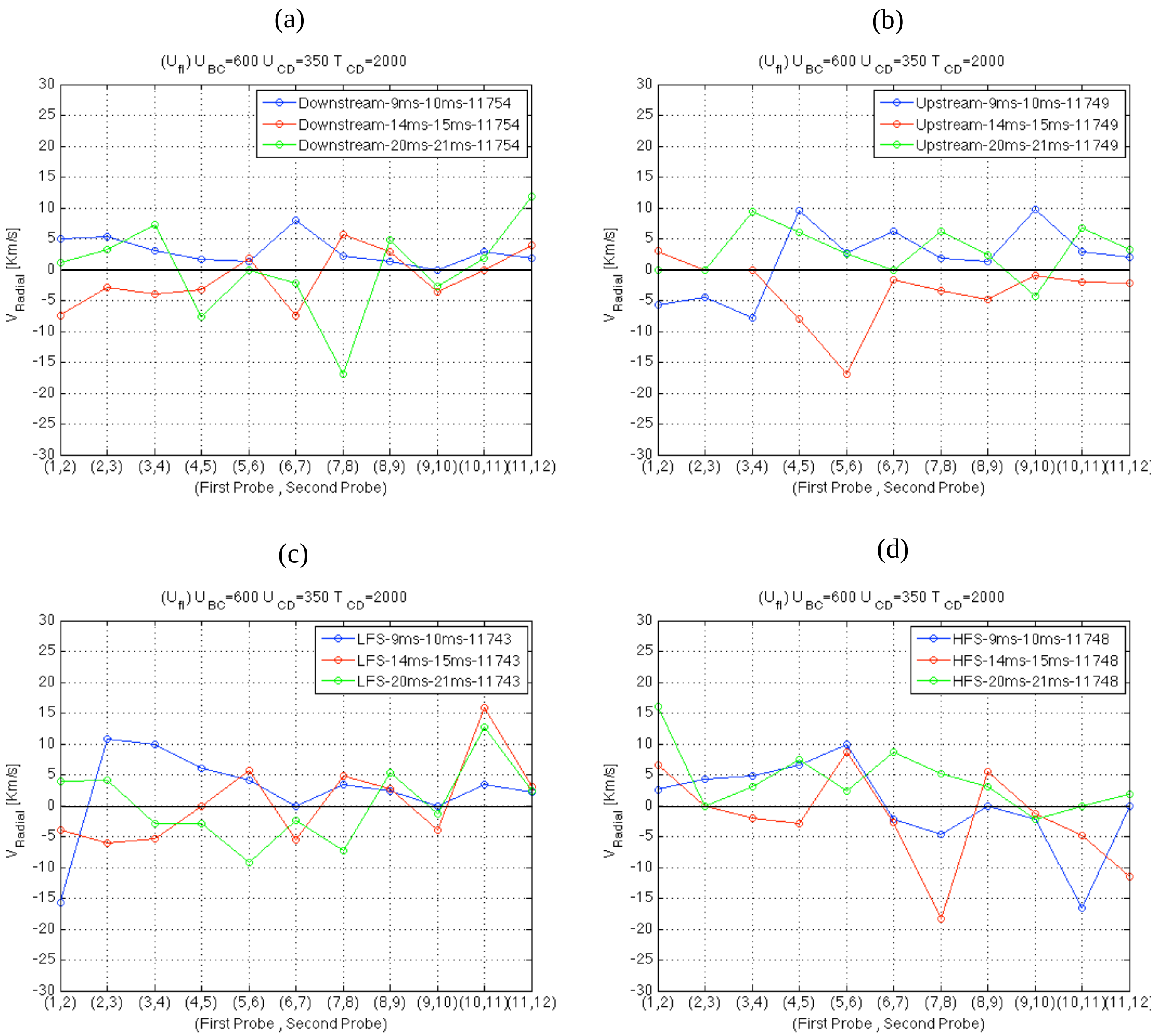

Figure 12. Radial velocity between probes in three time windows: 9ms to 10ms, 14ms to 15ms and 20ms to 21ms. (a) downstream, (b) upstream, (c) LFS and (d) HFS.

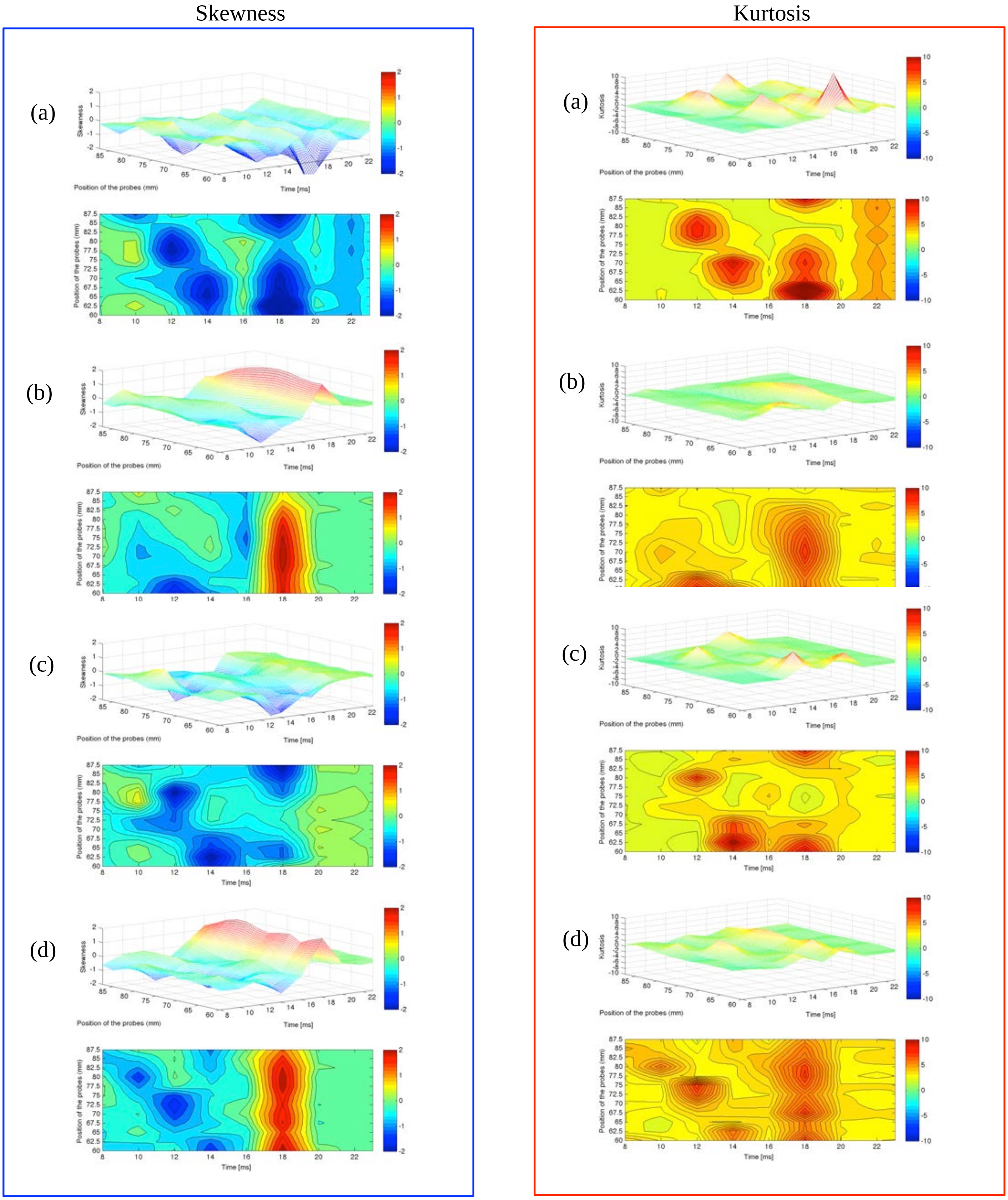

Figure 13. (Left column) Skewness for (a) downstream, (b) upstream, (c) LFS and (d) HFS. (right column) Kurtosis for (a) downstream, (b) upstream, (c) LFS and (d) HFS.