

Figure 1. Wavelet decomposition and separation of stochastic and deterministic components  
 (a) original signal, (b) - (e) wavelet coefficients ( $m = 1, \dots, 4$ ),  
 (f) scaling function coefficients ( $L = 4$ ), (g) extracted deterministic component

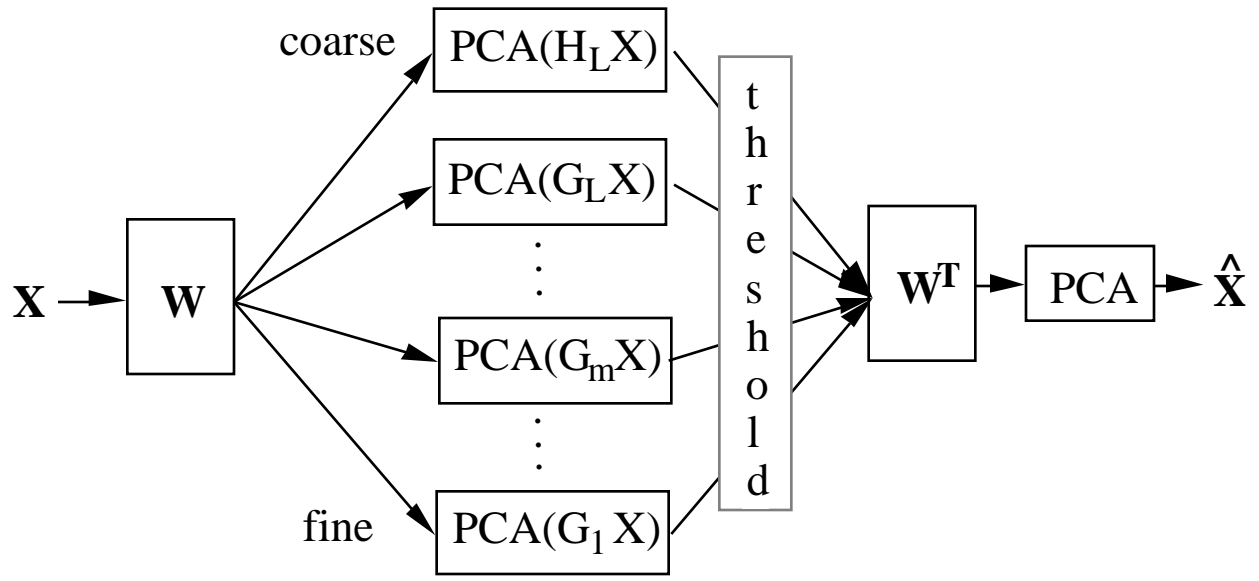


Figure 2. Methodology for multiscale principal component analysis

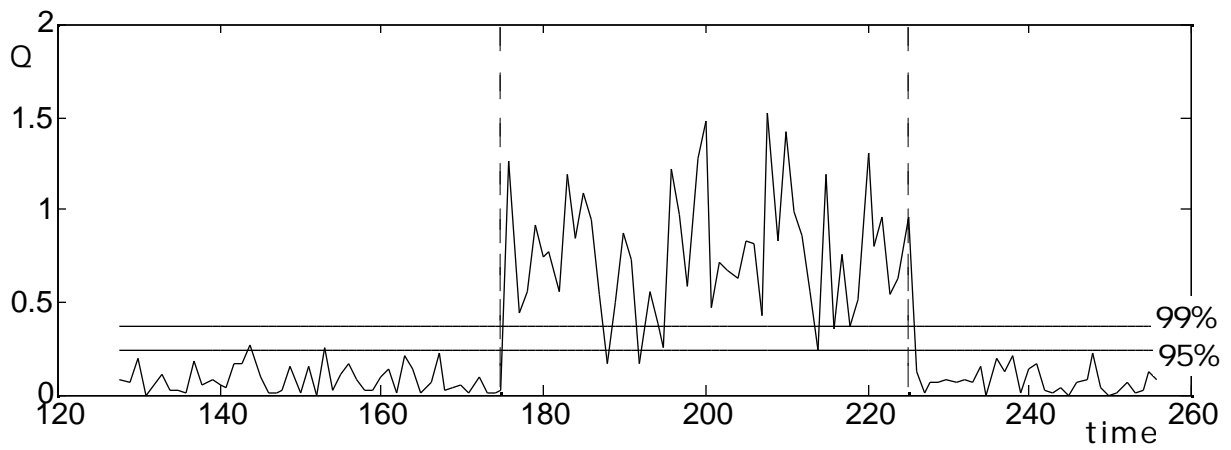
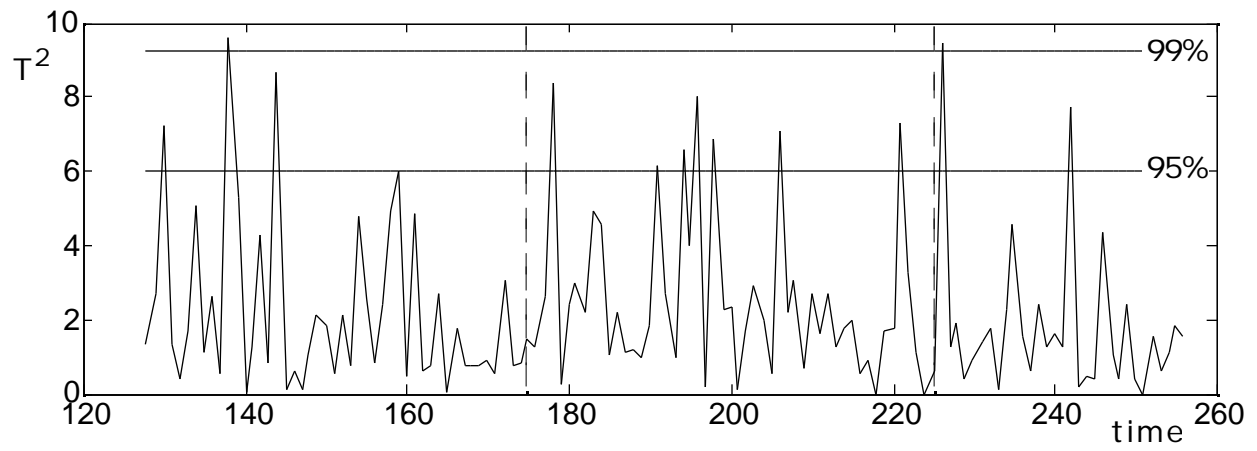


Figure 3. Performance of PCA for detecting mean shift of 1 between samples [176, 225] in uncorrelated measurements

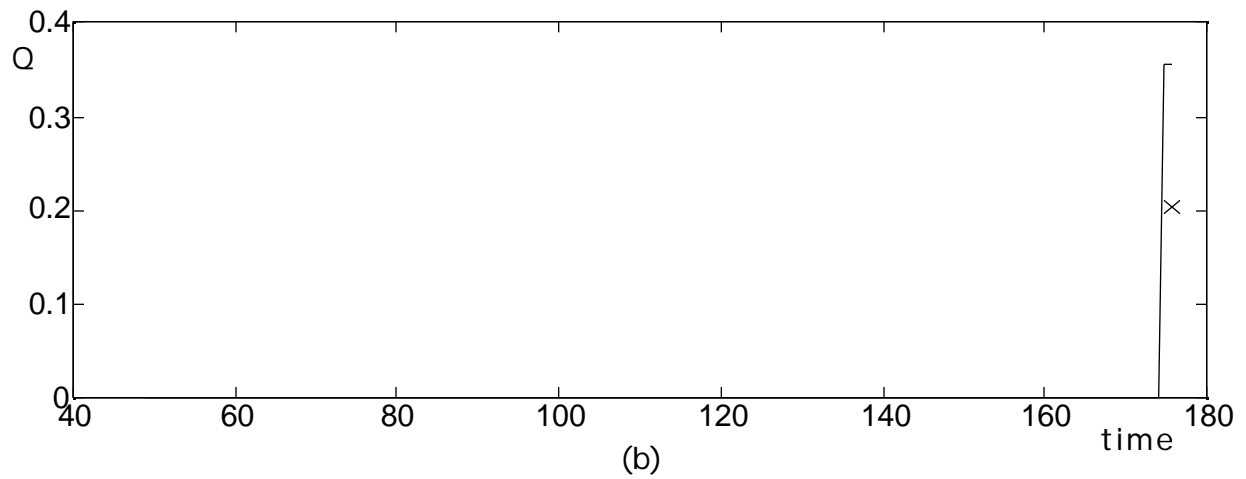
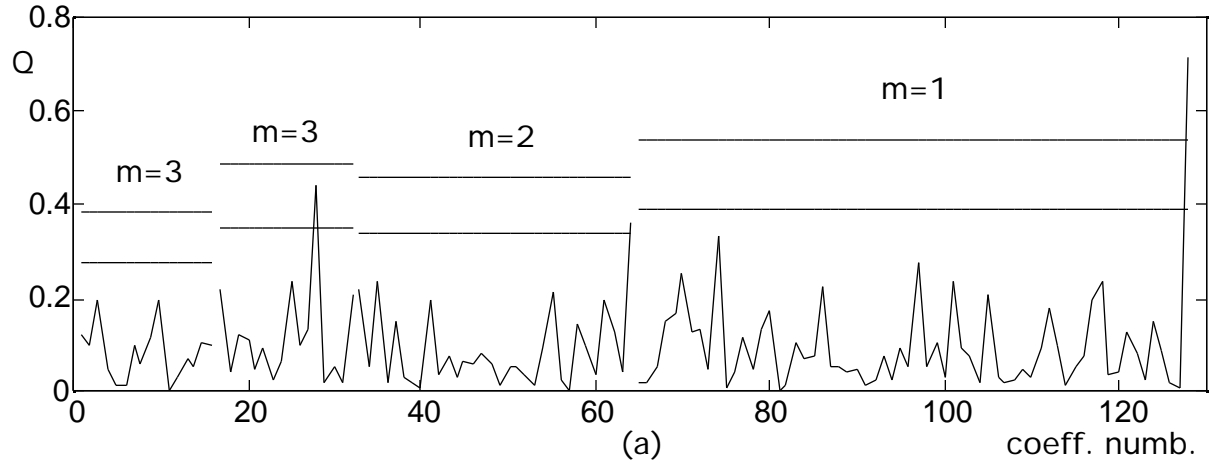


Figure 4. Multiscale detection of unit mean shift at 175 in uncorrelated measurements for data in window [49, 176] .

- a) Q chart for wavelet decomposition at each scale with 95 and 99% limits. Mean shift is detected with 99% confidence at finest scale,  $m=1$ .
- b) Q chart for reconstructed signal based on coefficients outside 99% limit in (a). 99% detection limit for current measurement is computed from variance of normal data at scale  $m=1$ , and indicated by  $\times$ . The value of the signal and detection limit at 176 contribute to Figure 8b.

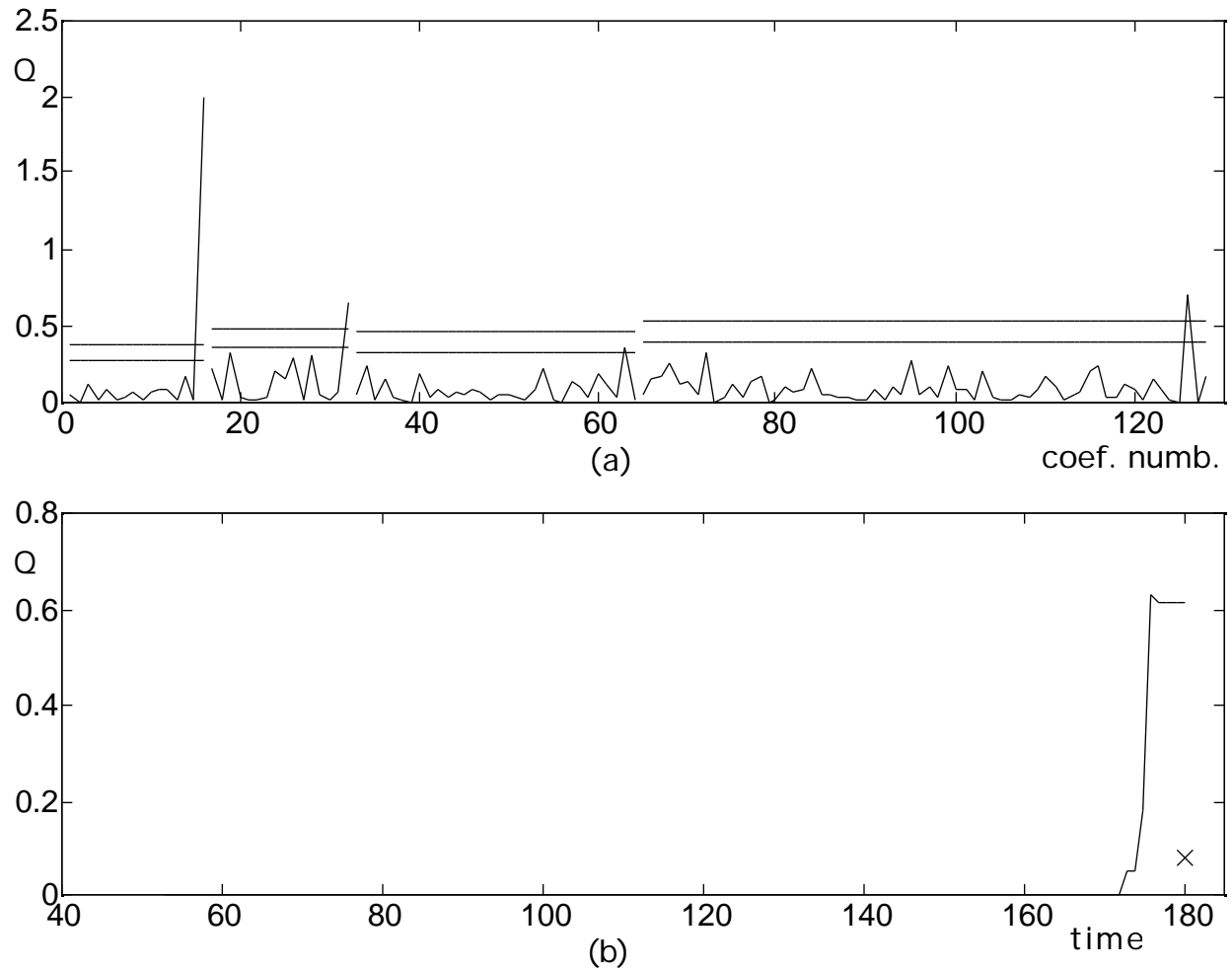


Figure 5. Detection of unit mean shift in uncorrelated measurements for data in window [53, 180].

- a) Q chart for wavelet decomposition at each scale with 95 and 99% limits. Mean shift is detected at coarser scales for wavelet and scaling function coefficients at  $m=3$ .
- b) Q chart for reconstructed signal based on coefficients outside 99% limit in (a). 99% detection limit for current measurement is computed from variance of scaling function and wavelet coefficients for normal data at scale  $m=3$ , and indicated by  $\times$ . The value of the signal and detection limit at 180 contribute to Figure 8b.

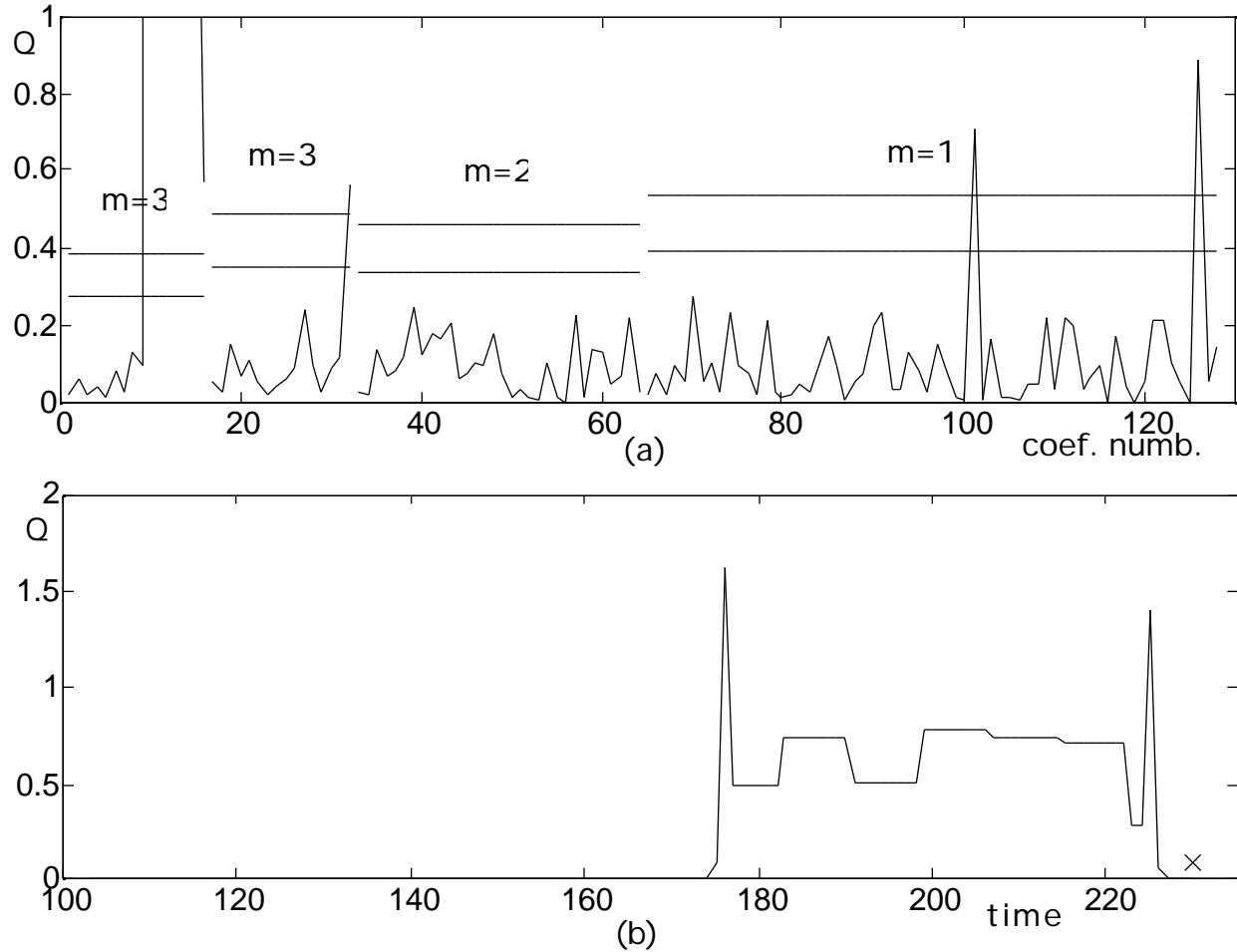


Figure 6. Detection of end of unit mean shift in uncorrelated measurements for data in window [103, 230]

- Q chart for wavelet decomposition at each scale with 95 and 99% limits. End of mean shift is detected at scale  $m=1$ , but coefficients at coarser scales continue to violate detection limit due to shift at 175.
- Q chart for reconstructed signal based on coefficients outside 99% limit in (a). 99% detection limit for current reconstructed measurement is computed from variance of normal data for wavelet coefficients and scaling function coefficients at scale  $m=3$ , and indicated by  $\times$ . Return of process to normal operation is clearly indicated by reconstructed signal and detection limit at 230.

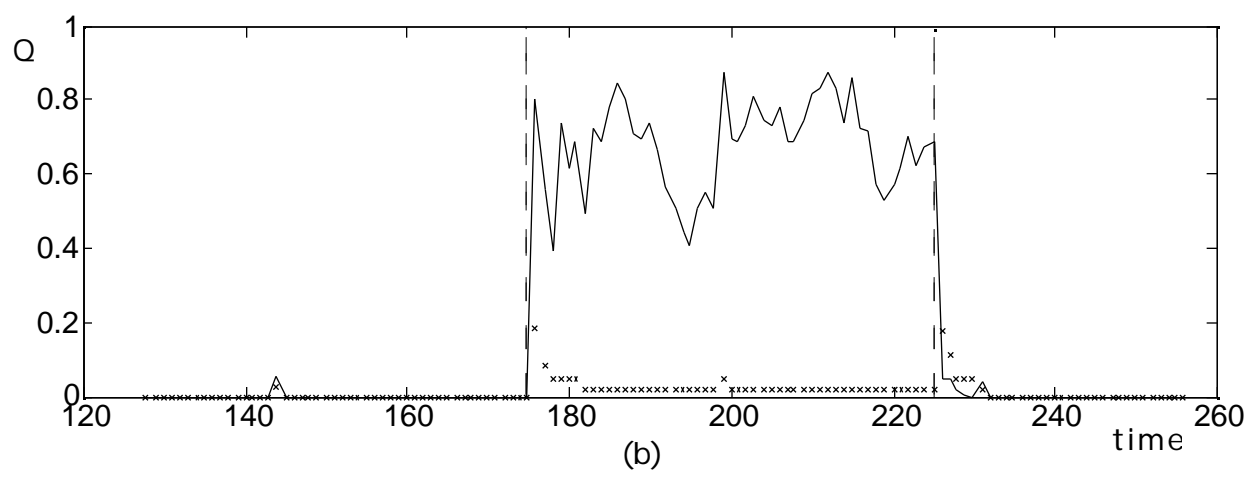
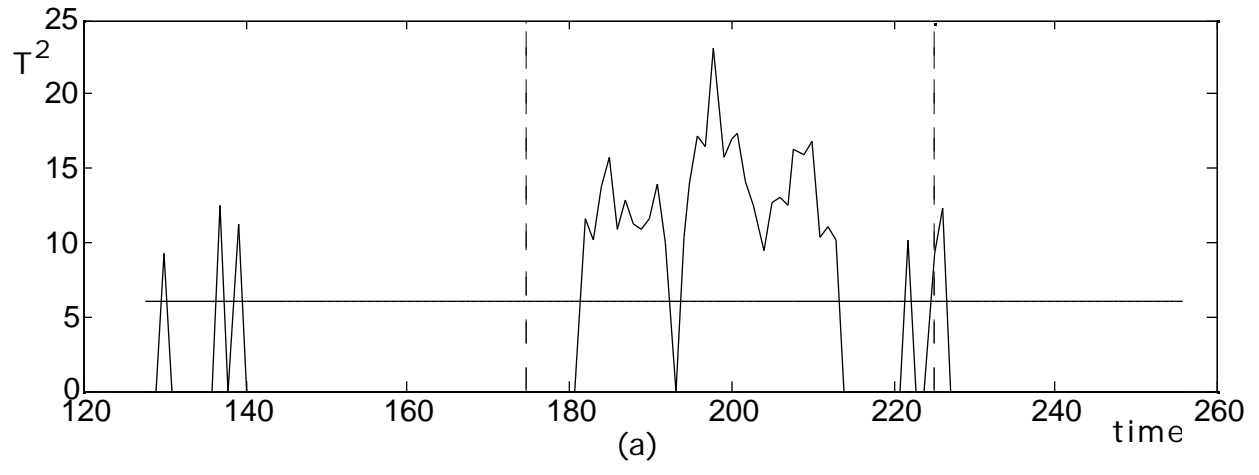


Figure 7. Monitoring by MSPCA of uncorrelated measurements for mean shift of 1.  
 (a)  $T^2$  plot with 95% confidence limit,  
 (b) Q plot with 95% confidence limit indicated by  $\times$ .

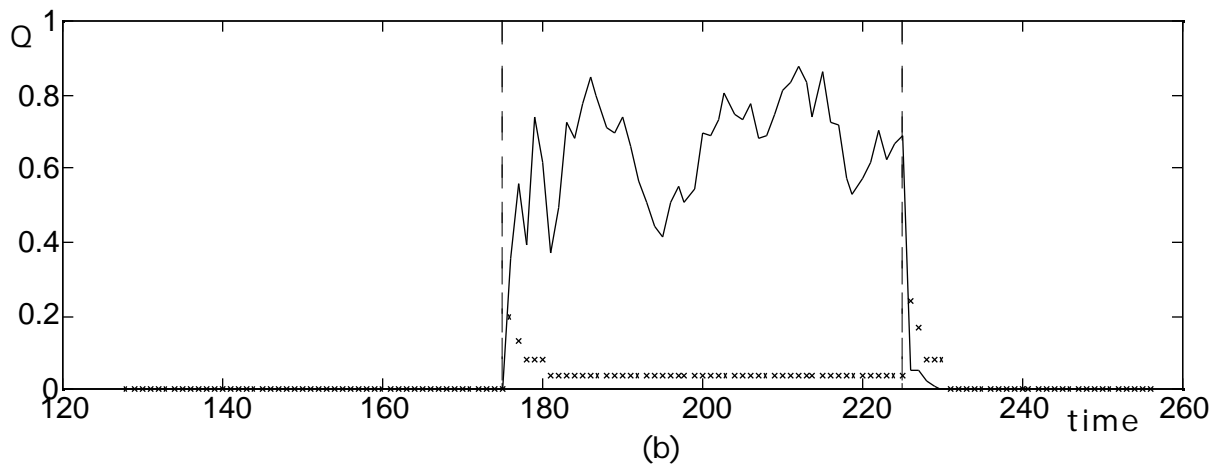
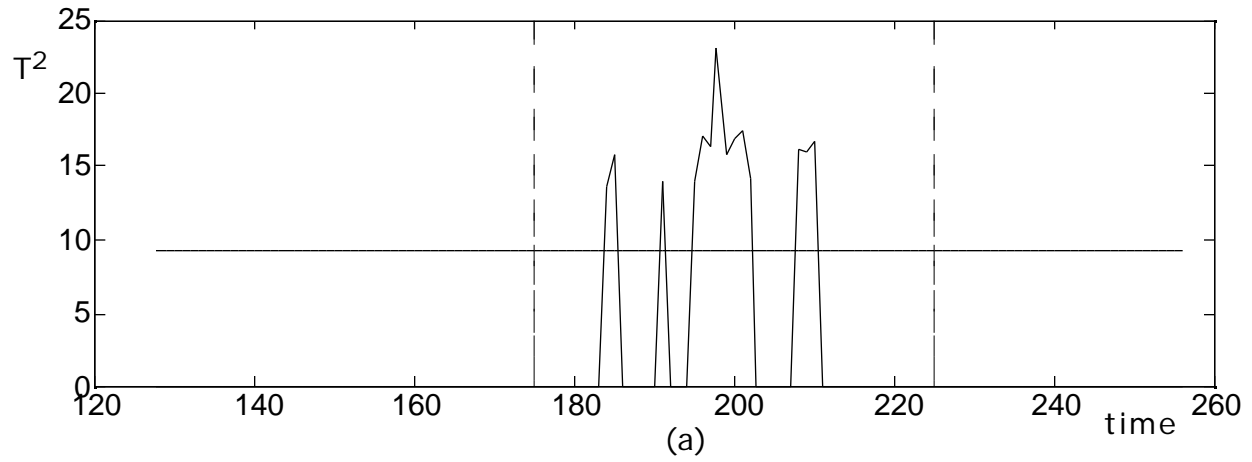


Figure 8. Monitoring by MSPCA of uncorrelated measurements for mean shift of 1.  
 (a)  $T^2$  plot with 99% confidence limit,  
 (b) Q plot with 99% confidence limit indicated by  $\times$ .

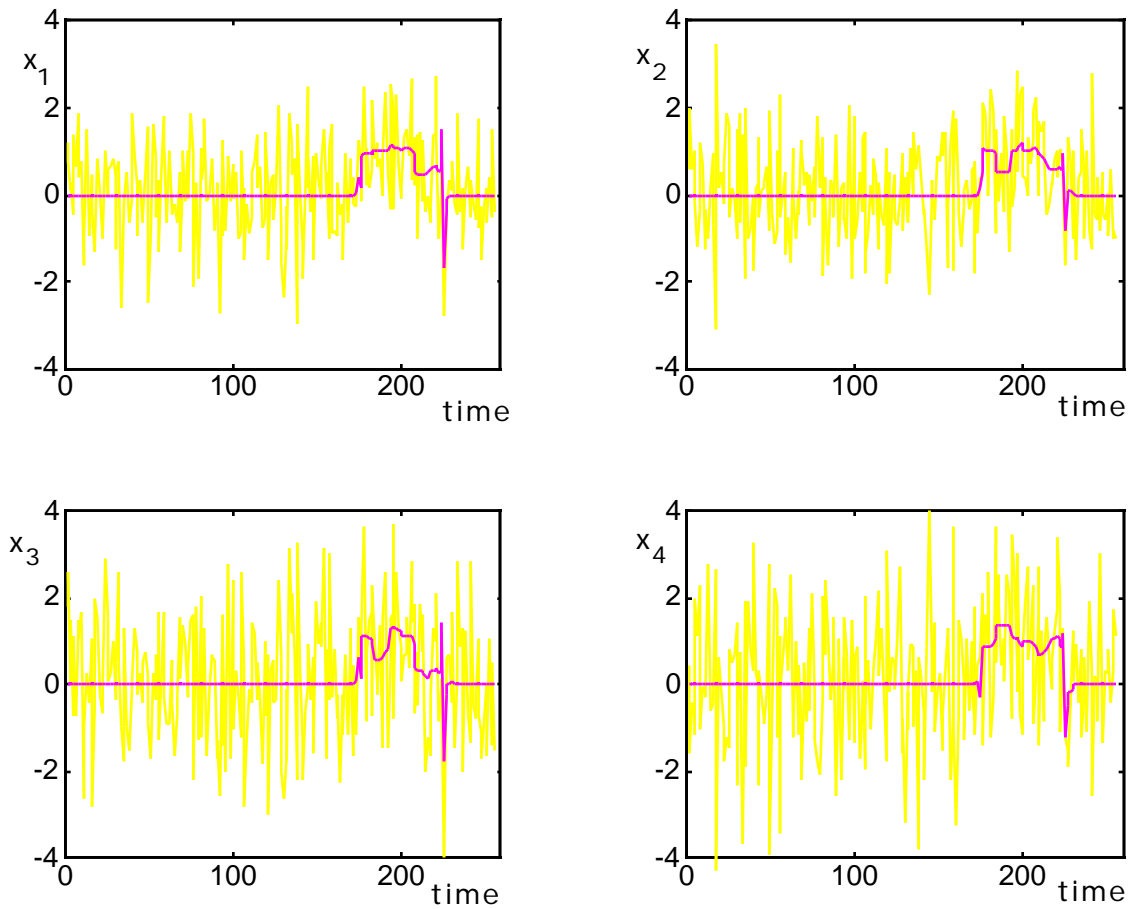


Figure 9. Features relevant to abnormal operation extracted from each variable by MSPCA residuals plot for 99% confidence shown in Figure 8. Plot in lighter shade is actual data, darker shade is extracted feature. True feature is a unit mean shift between samples 176 and 225.

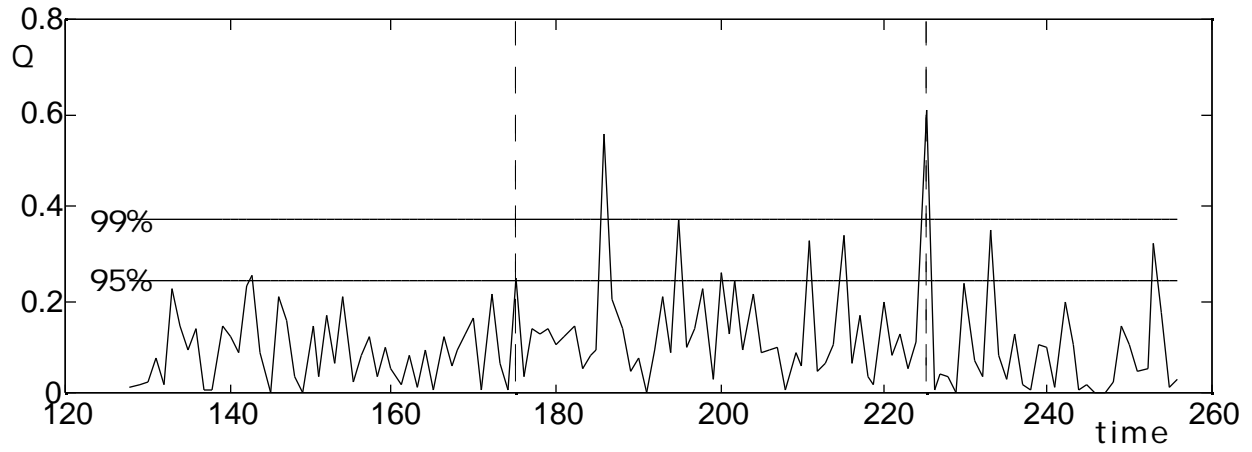
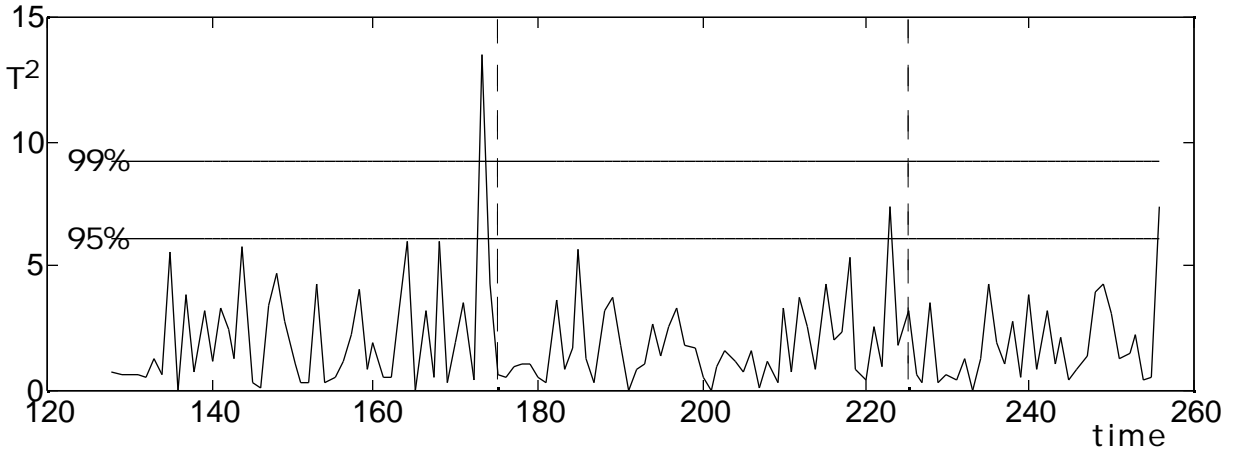


Figure 10. Performance of monitoring uncorrelated measurements with mean shift of 0.3 by PCA.

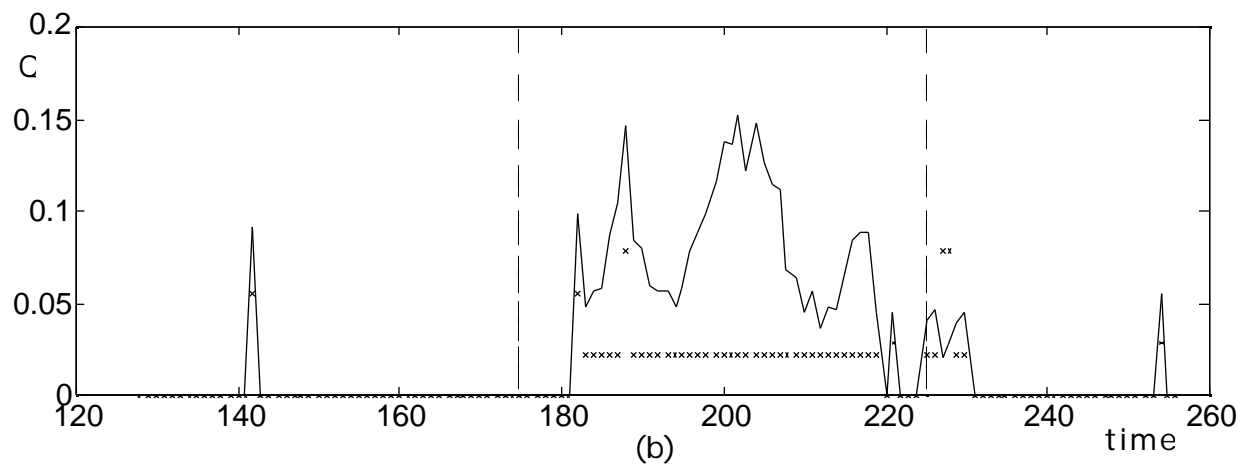
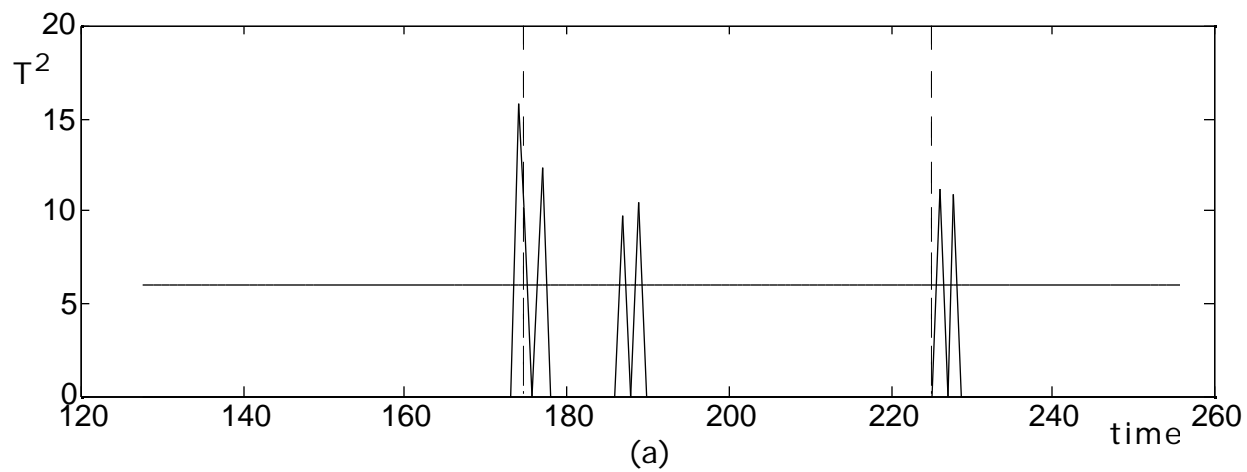


Figure 11. Monitoring uncorrelated measurements with mean shift of 0.3 by MSPCA.  
 (a)  $T^2$  plot with 95% confidence limit,  
 (b) Q plot with 95% confidence limit indicated by x.

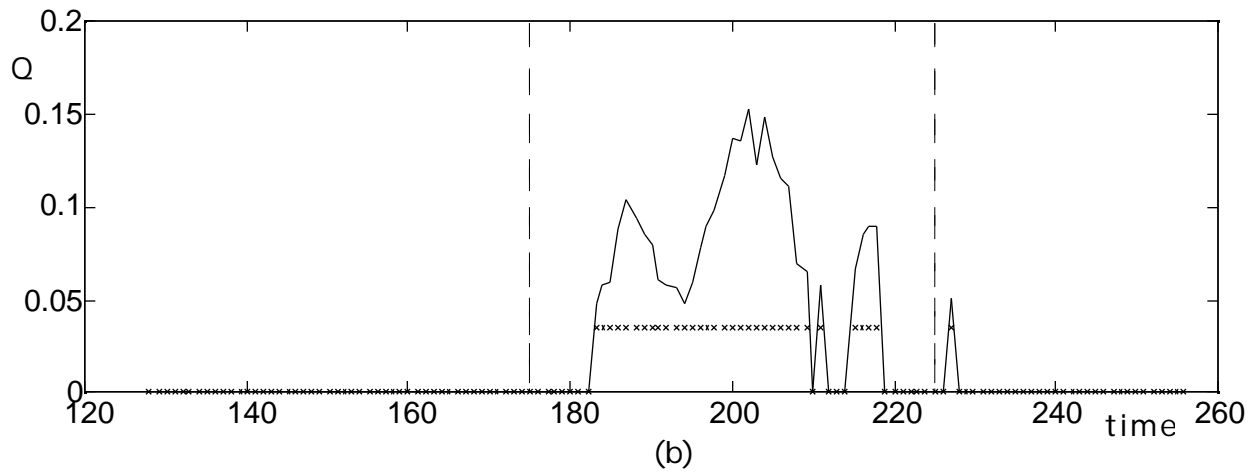
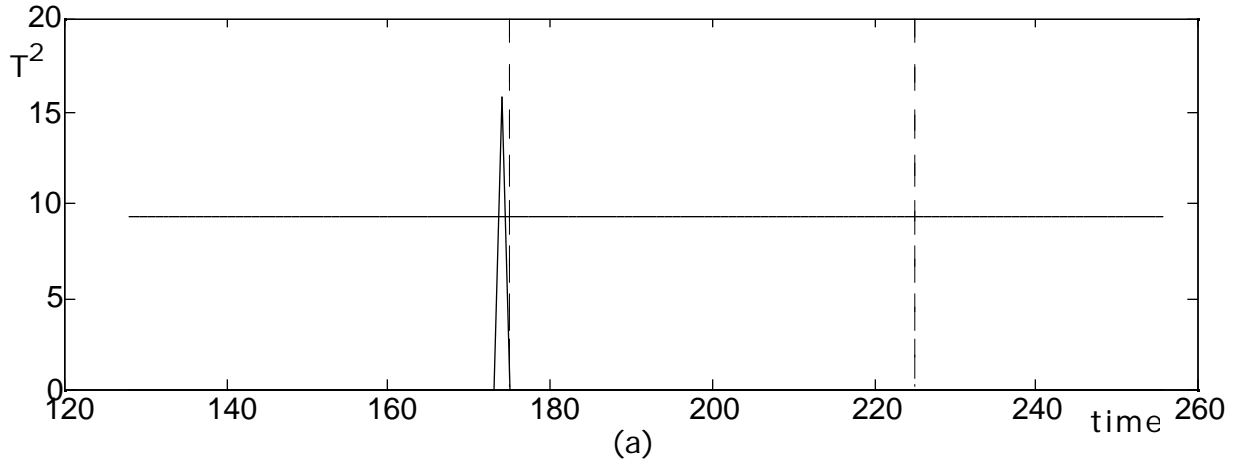


Figure 12. Monitoring uncorrelated measurements with mean shift of 0.3 by MSPCA.  
 (a)  $T^2$  plot with 99% confidence limit,  
 (b) Q plot with 99% confidence limit indicated by  $\times$ .

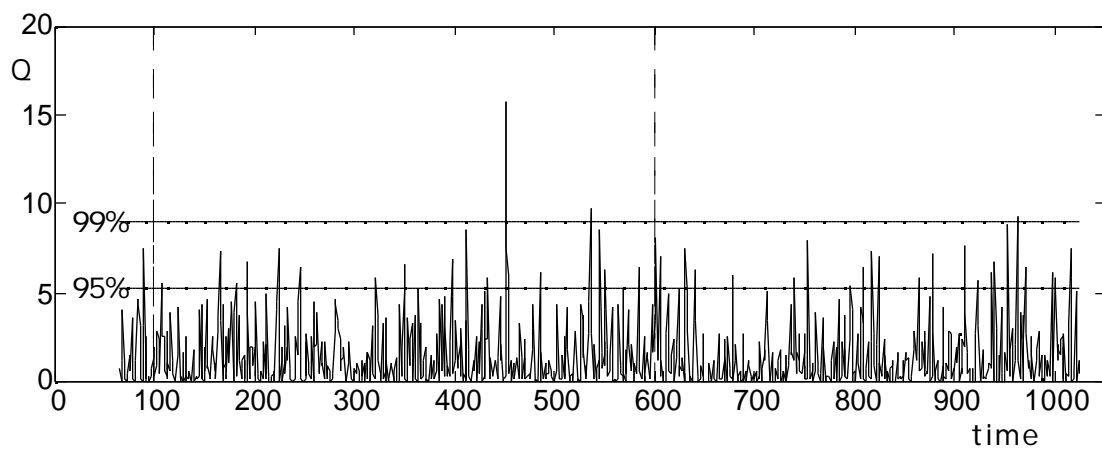
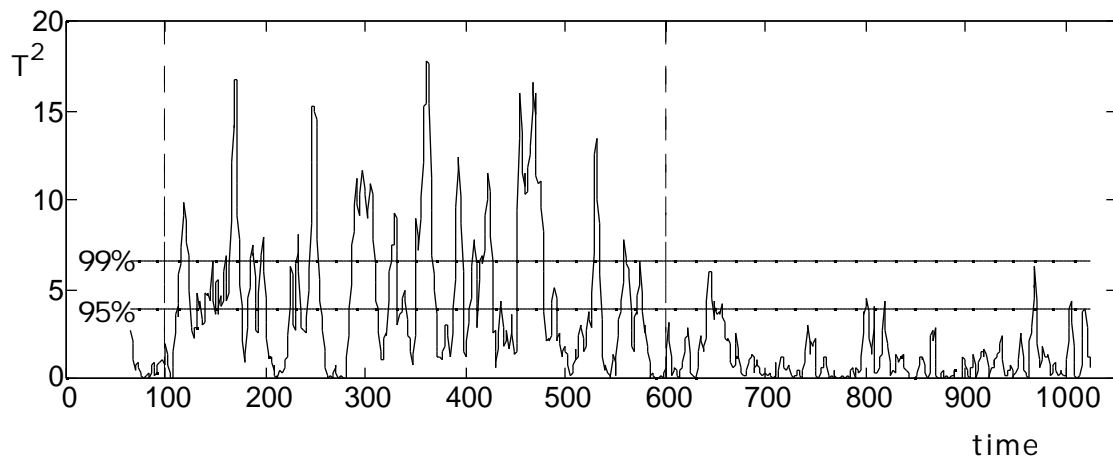


Figure 13. Monitoring of autocorrelated measurements with mean shift of 0.5 by steady-state PCA

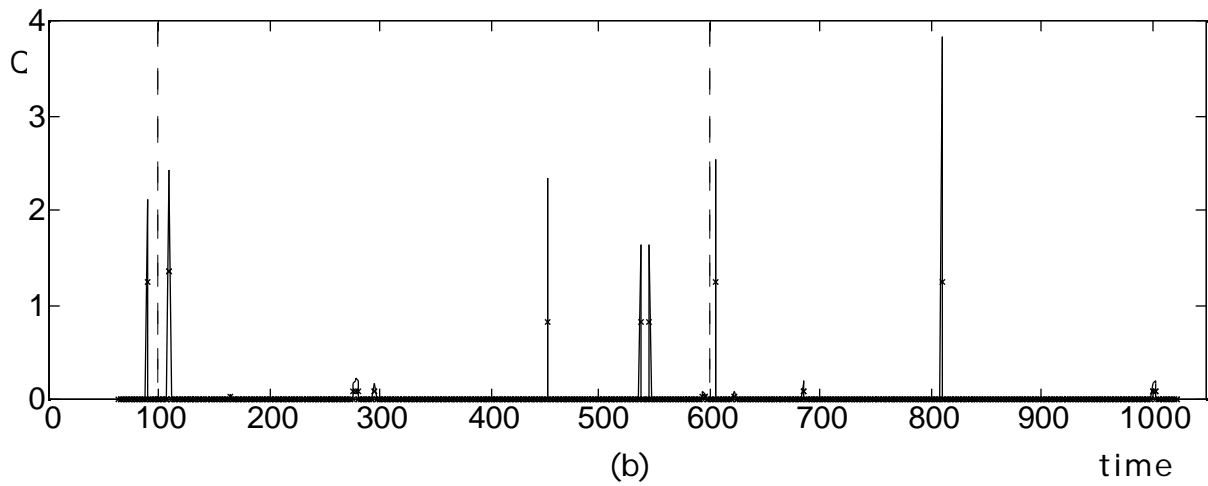
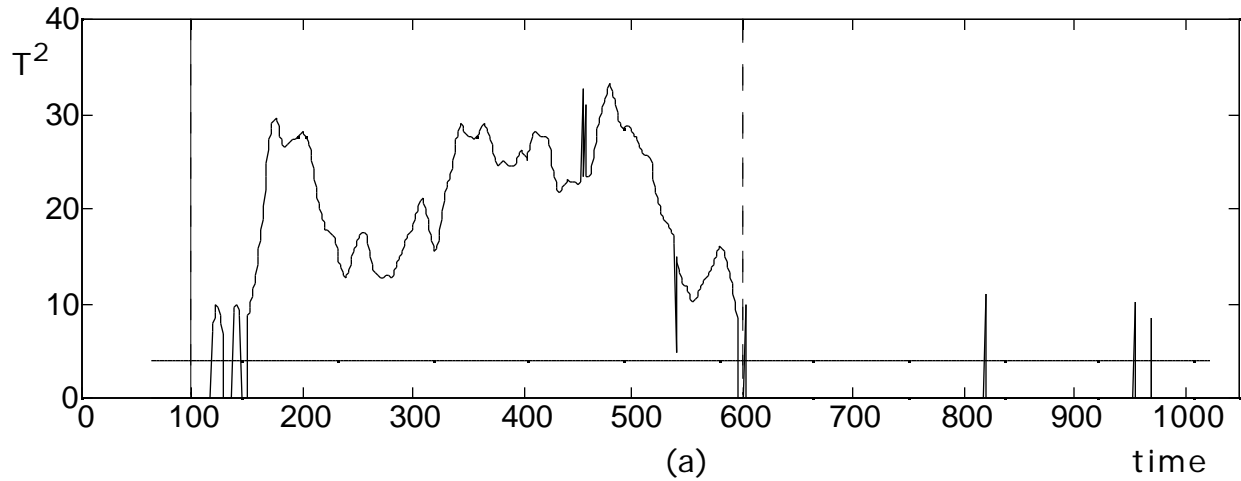


Figure 14. Monitoring of autocorrelated measurements by steady-state MSPCA  
 (a)  $T^2$  plot with 95% confidence,  
 (b) Q plot with 95% confidence limit indicated by  $\times$ .

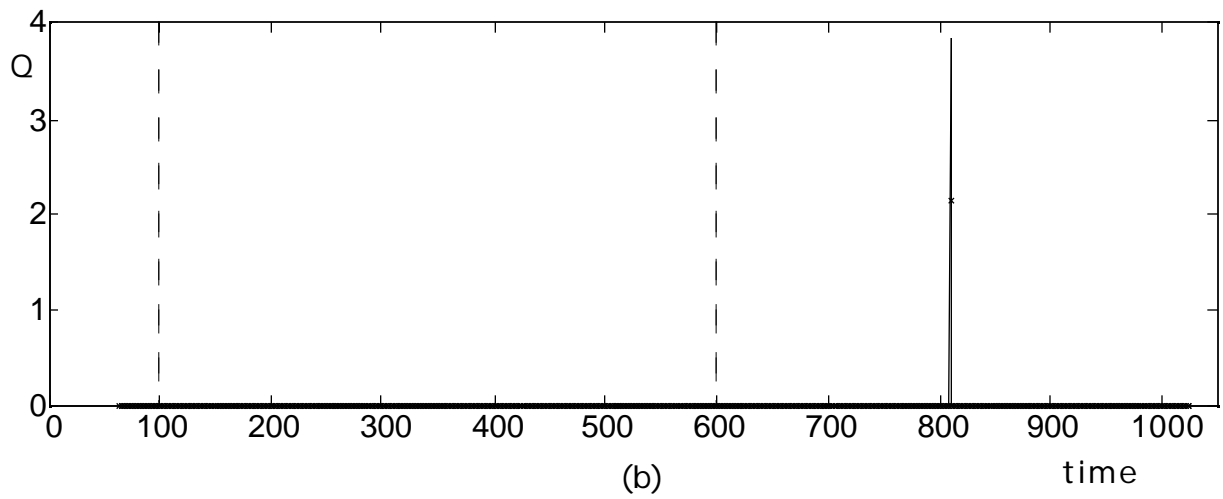
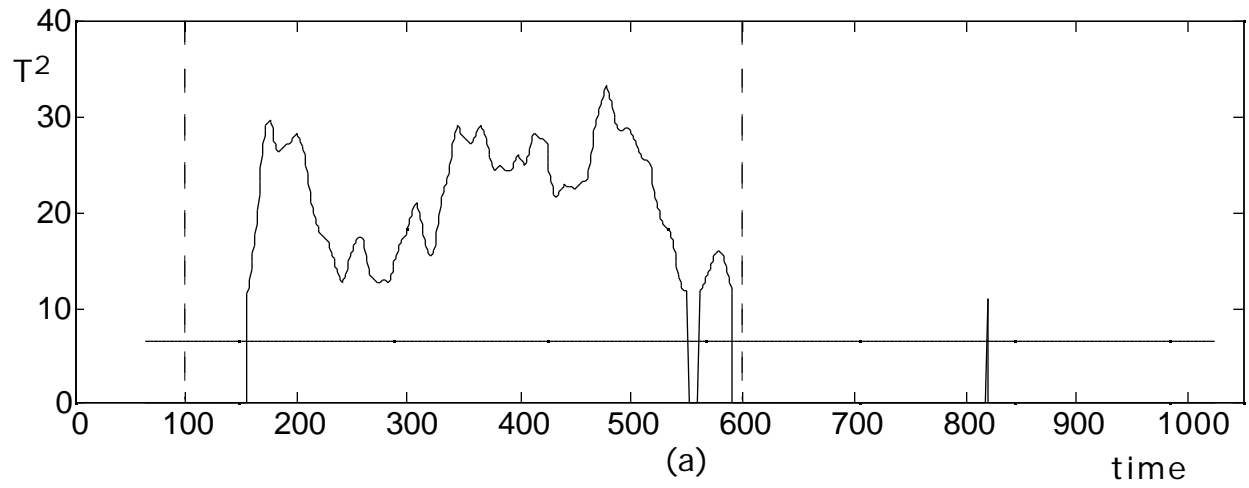


Figure 15. Monitoring of autocorrelated measurements by steady-state MSPCA.  
(a)  $T^2$  chart with 99% confidence limit,  
(b) Q chart with 99% confidence limit indicated by  $\times$ .

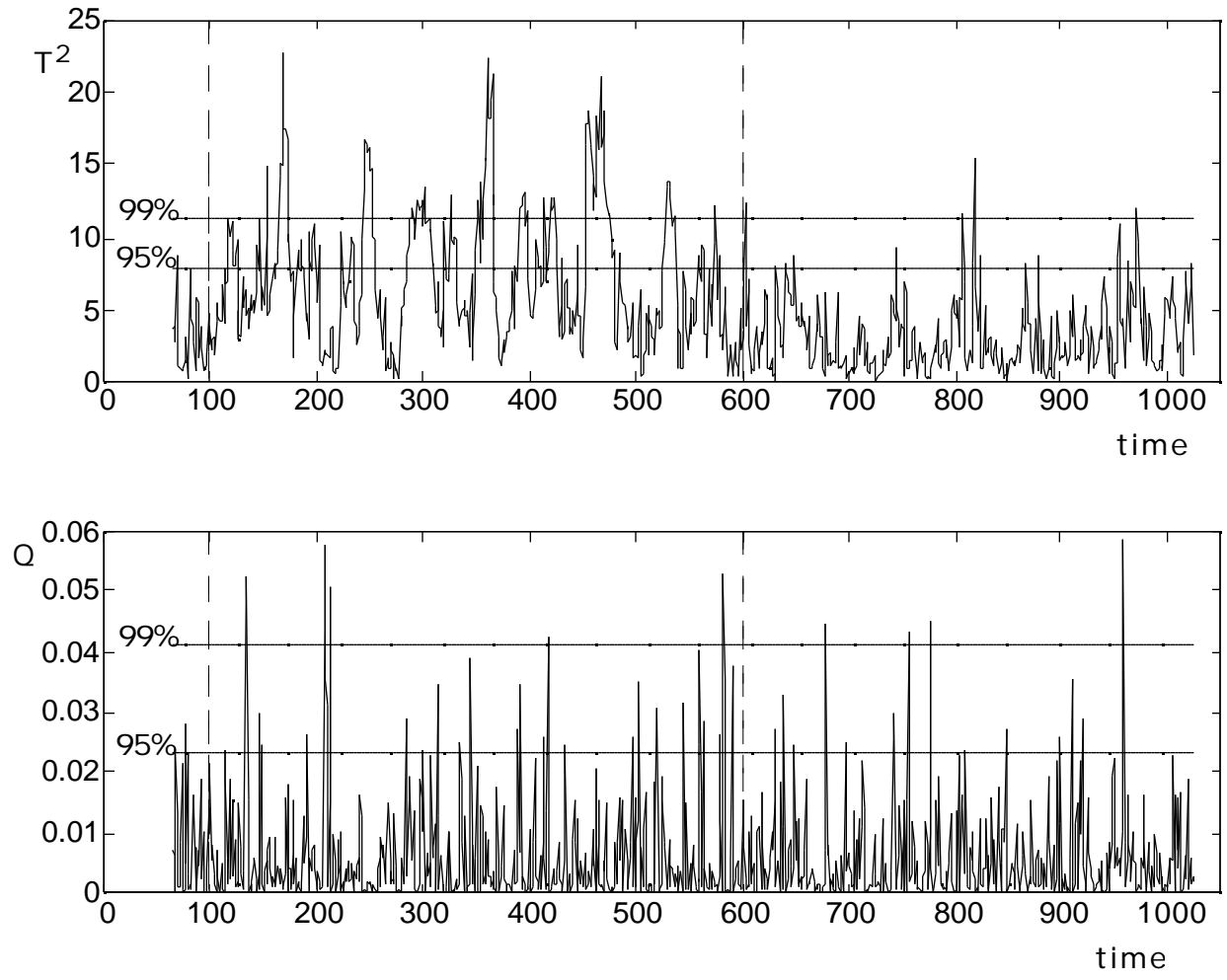


Figure 16. Monitoring of autocorrelated measurements with mean shift of 0.5 by dynamic PCA

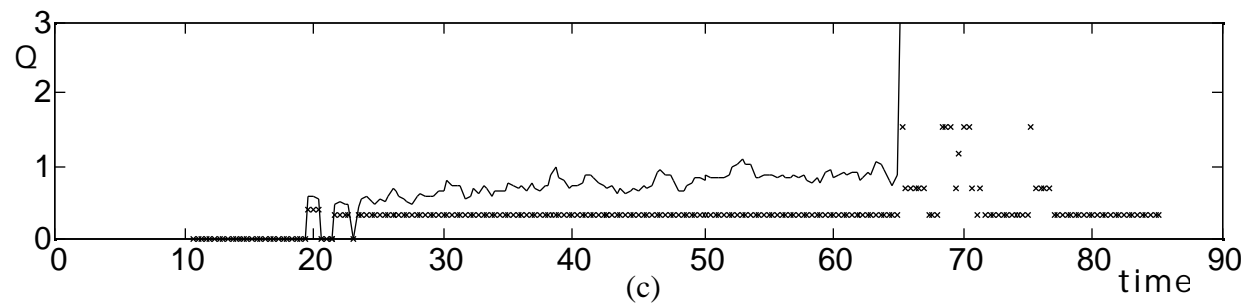
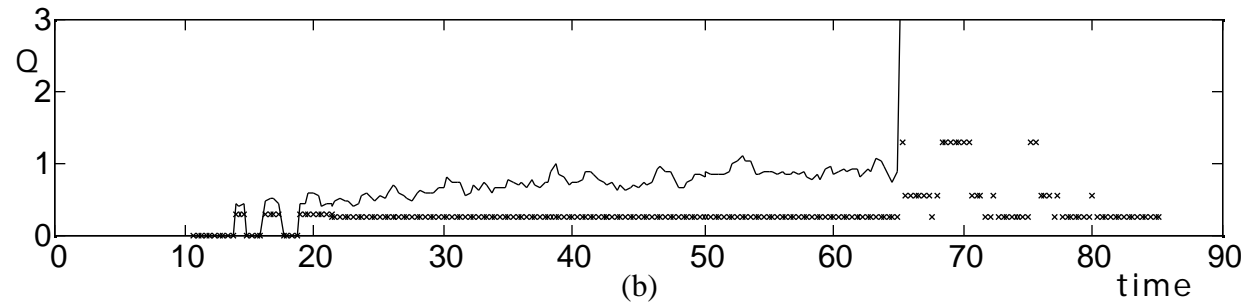
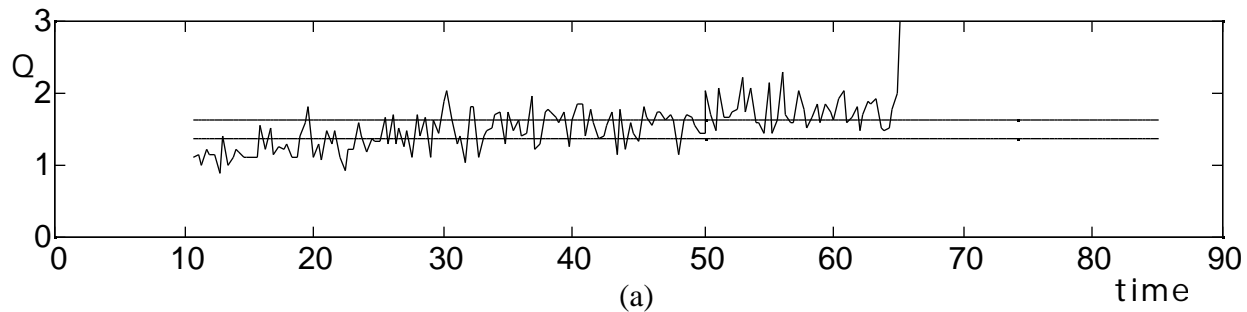


Figure 17. Q charts for slow ramp failure of slurry pump-around in FCCU.  
 (a) PCA with 95% and 99% confidence limits,  
 (b) MSPCA for 95% confidence,  
 (c) MSPCA for 99% confidence.