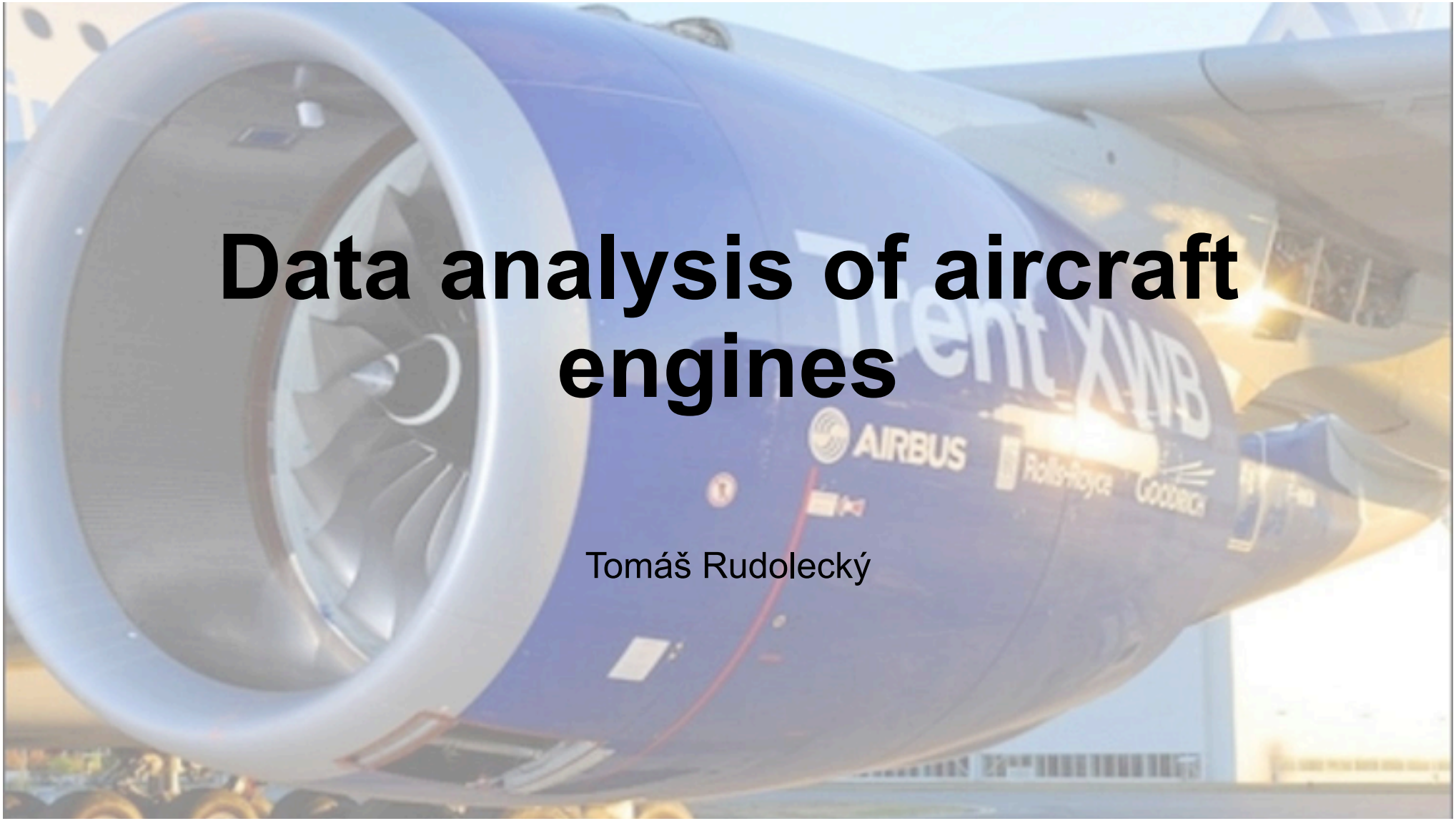


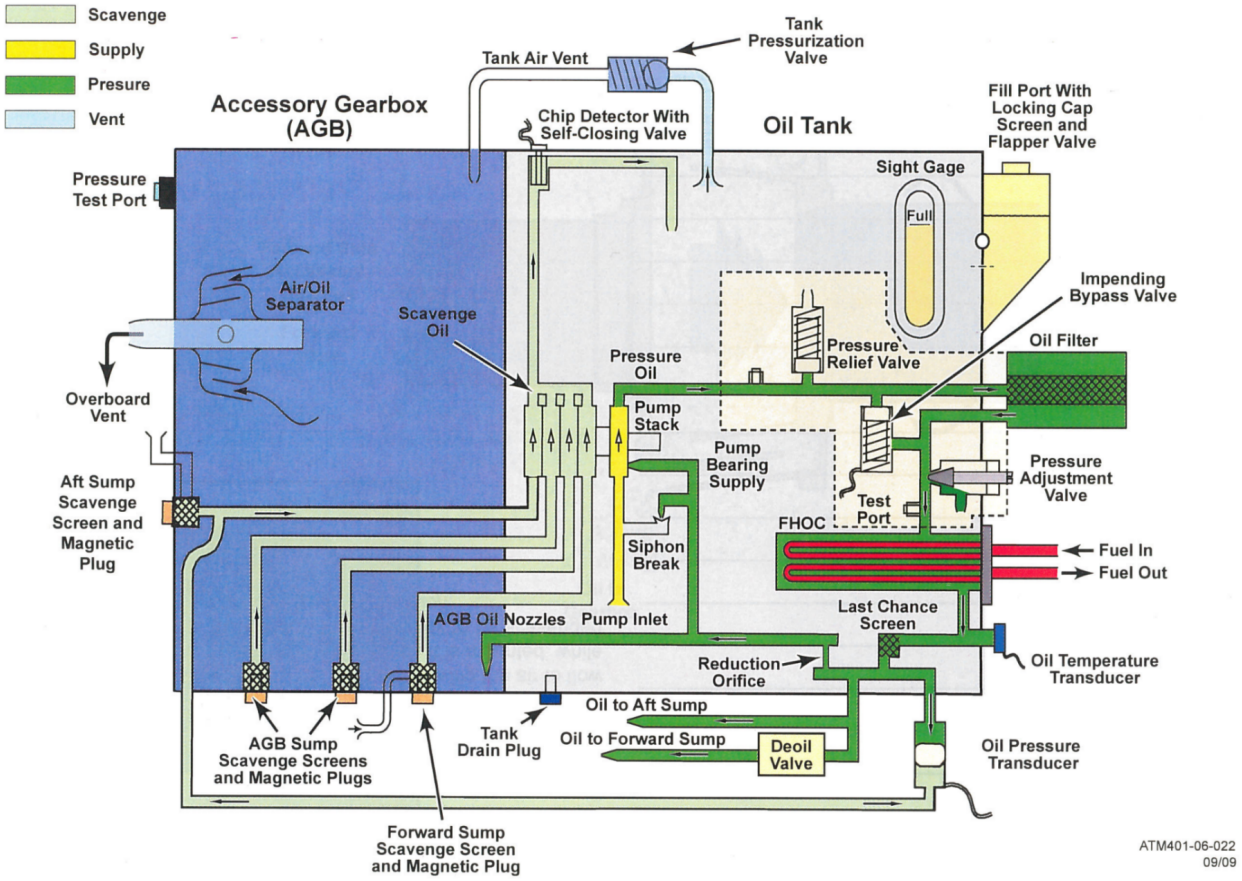
Data analysis of aircraft engines

Tomáš Rudolecký

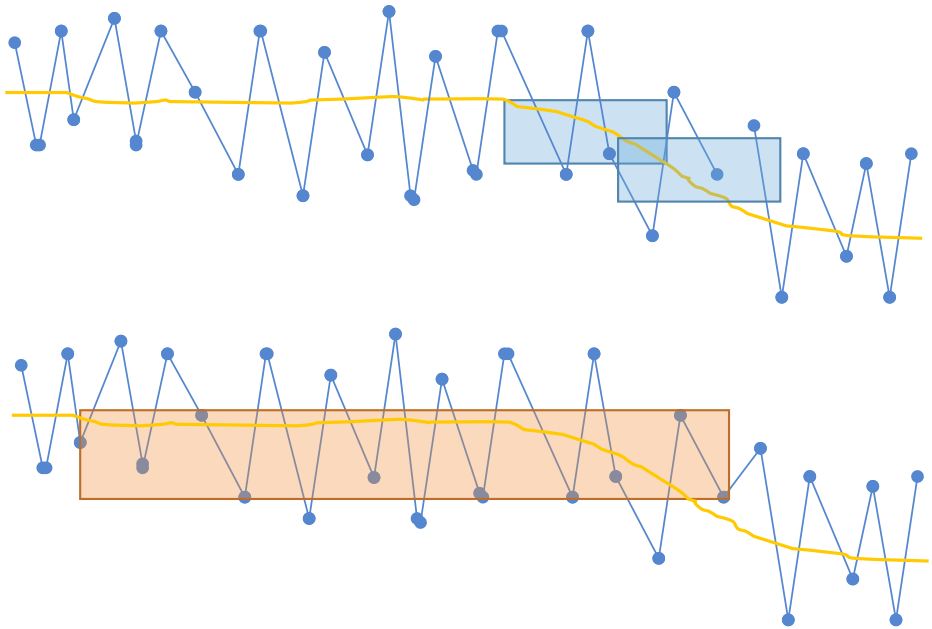
Outline

- Why we want to use Machine Learning techniques for engine fault prediction
- Characteristics of the data
- Possible approaches
- Examples

Engine critical systems



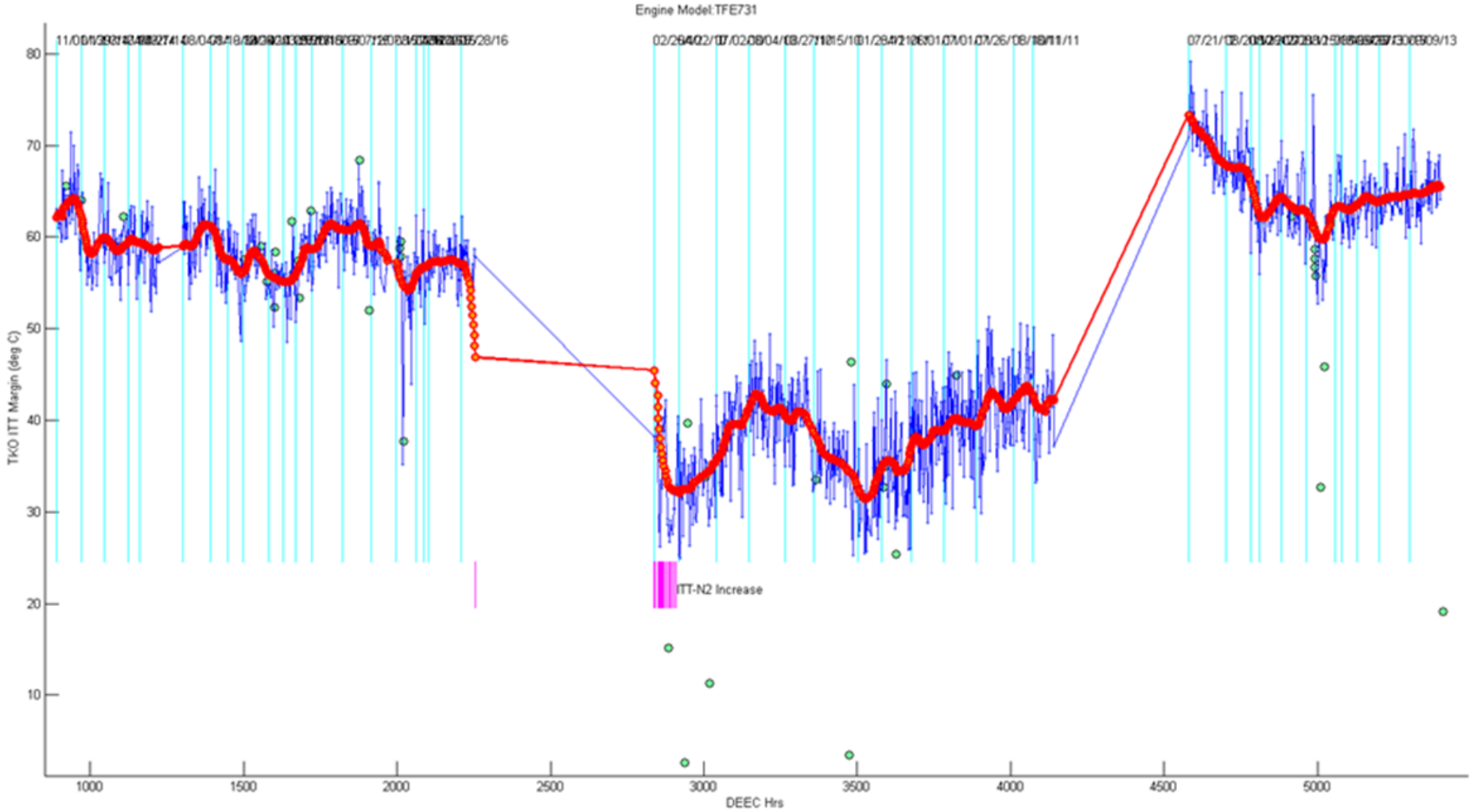
Change detection - trending

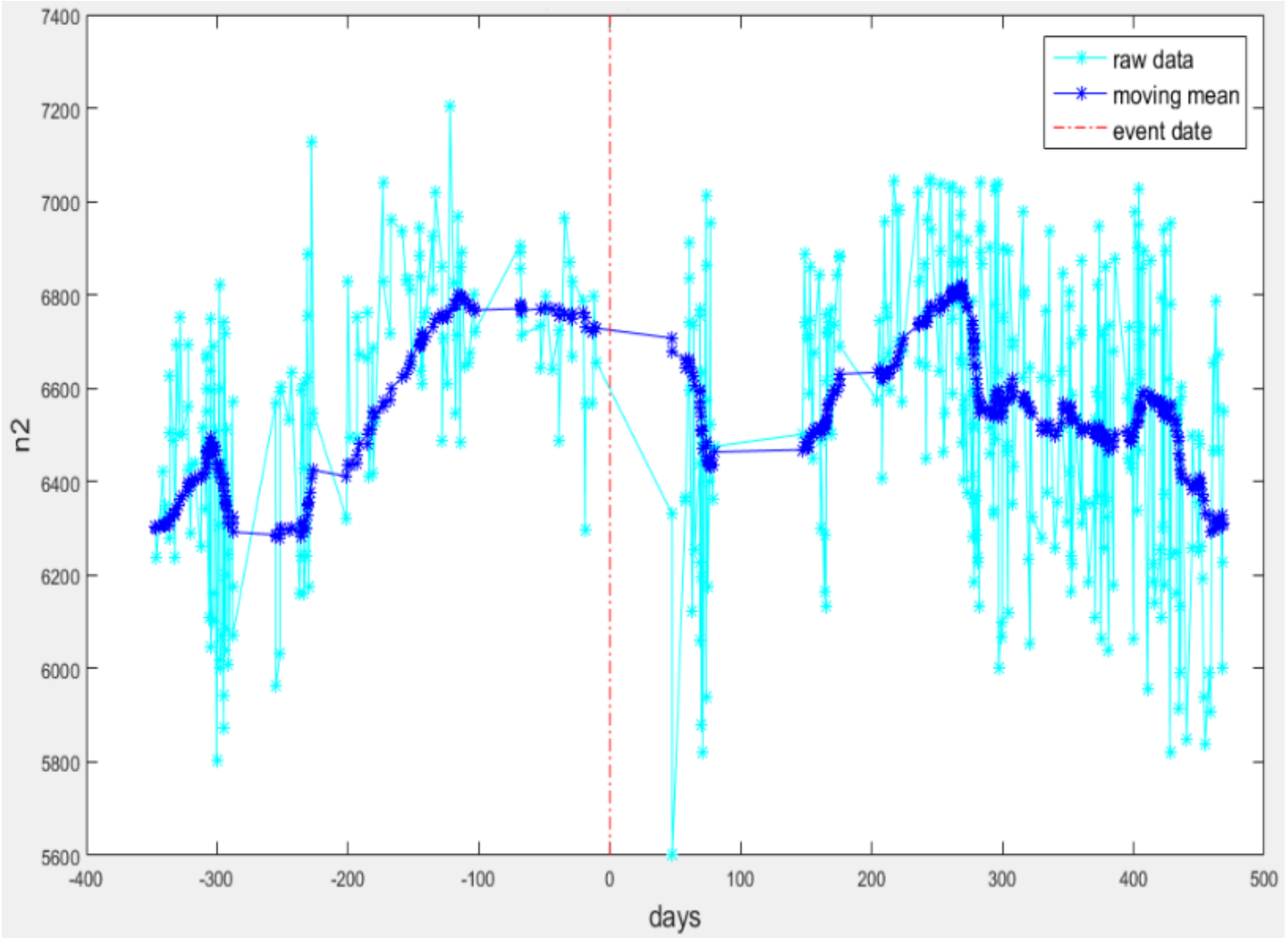


Short-term change is detected.

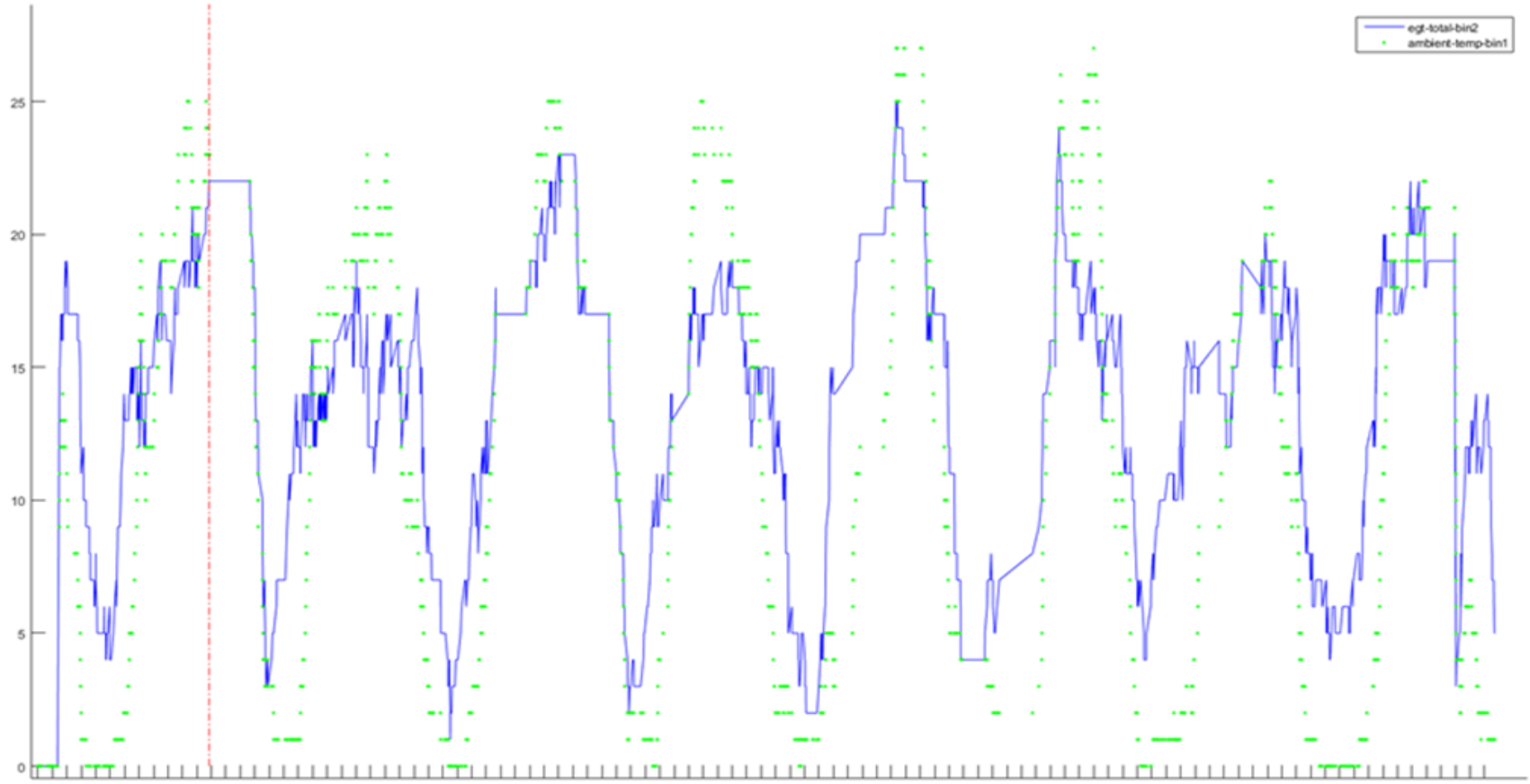
Long-term change is detected.

• The objective in change detection is to produce evidence for HI mapping. Short-term CD implements a WE-type rule to detect statistically significant shift in the smoothed signal.
• Long-term CD detects significant change within a pre-defined period that develops through smaller drops in the margin.

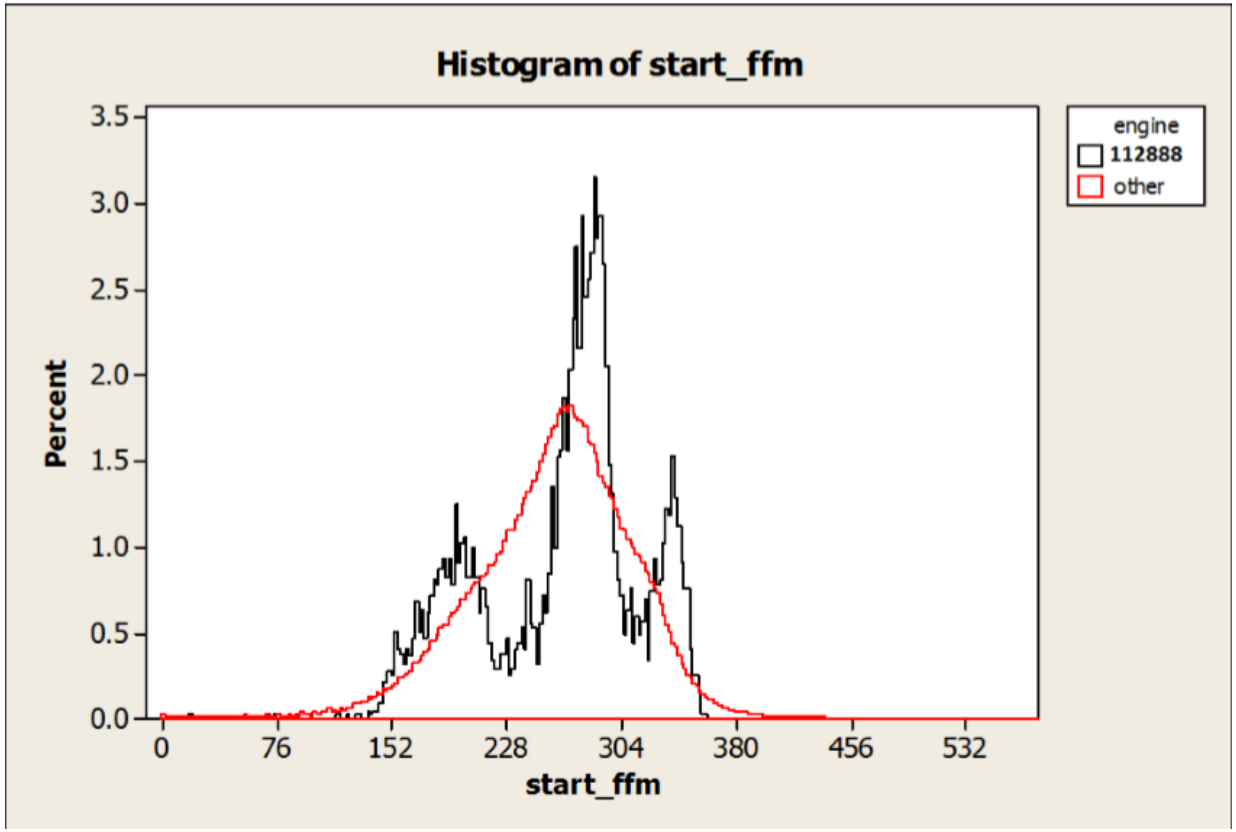

Engine Model:TFE731
TKO ITT Margin (deg C)
DEEC Hrs
ITT-N2 Increase
80
70
60
50
40
30
20
10
1000
1500
2000
2500
3000
3500
4000
4500
5000


raw data
moving mean
event date
n2
days
7400
7200
7000
6800
6600
6400
6200
6000
5800
5600
-400
-300
-200
-100
0
100
200
300
400
500

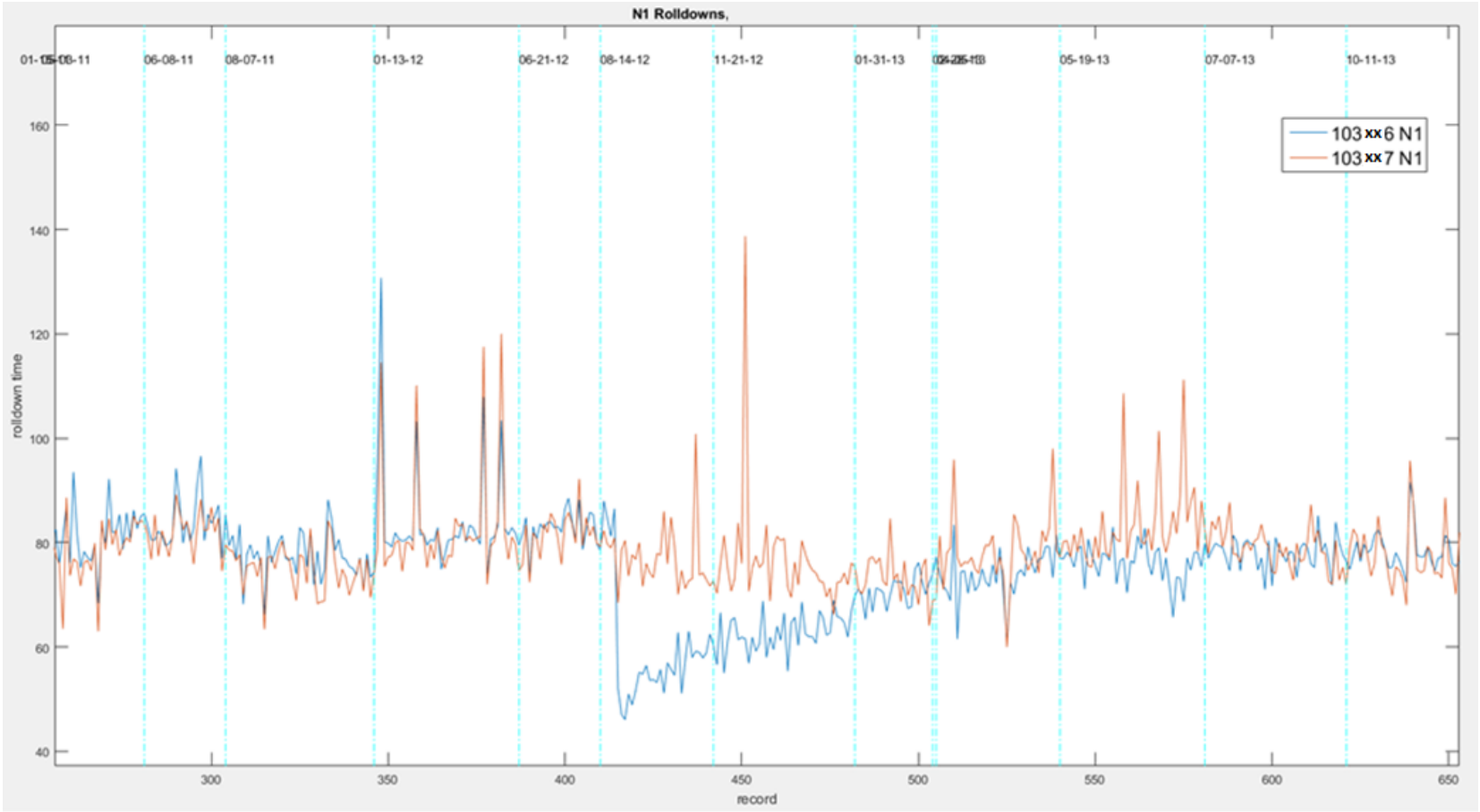
Ambient conditions



Different data distributions



Comparison of sister engines

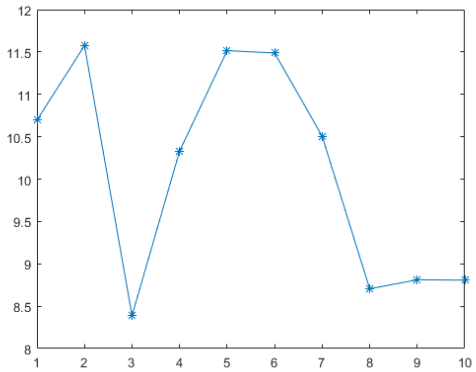


Time series – vector transpose

start_n2	start_egt
7560	209
8156	228
6858	102
8049	152
8396	208
8368	208
8031	165
6860	123
6982	122
6977	122

SVM

score
10.7
11.6
8.4
10.3
11.5
11.5
10.5
8.7
8.8
8.8



start_n2										start_egt									
7560	8156	6858	8049	8396	8368	8031	6860	6982	6977	209	228	102	152	208	208	165	123	122	122

SVM

score
14.5

Time series – vector transpose

Separate rows

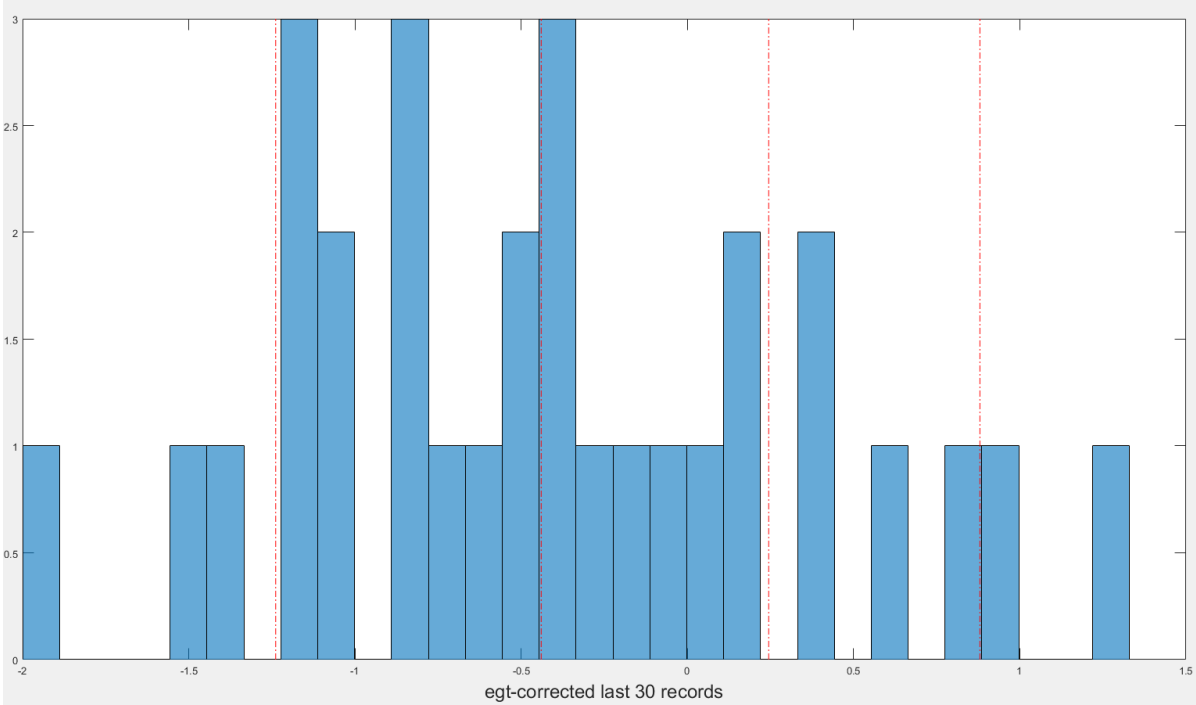
start_n2										start_egt									
7560	8156	6858	8049	8396	8368	8031	6860	6982	6977	209	228	102	152	208	208	165	123	122	122
6542	7053	7127	6981	6970	6985	7204	7126	8159	7954	188	206	223	169	154	183	209	212	143	158
6557	7245	8641	8022	7684	7540	6837	7021	7489	7124	187	164	116	202	198	178	168	220	185	182

Moving window

start_n2										start_egt									
7560	8156	6858	8049	8396	8368	8031	6860	6982	6977	209	228	102	152	208	208	165	123	122	122
8156	6858	8049	8396	8368	8031	6860	6982	6977	6542	228	102	152	208	208	165	123	122	122	188
6858	8049	8396	8368	8031	6860	6982	6977	6542	7053	102	152	208	208	165	123	122	122	188	206

Feature binning

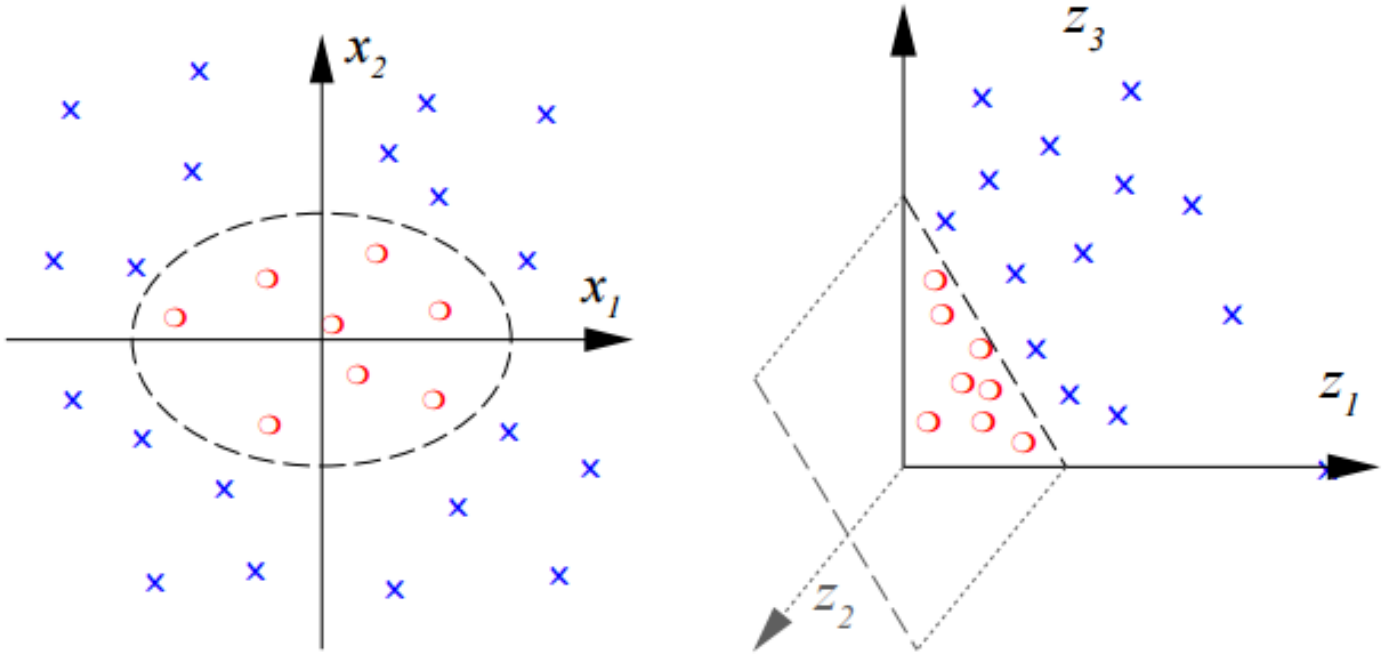
Moving window: 30 rec.			
egt_corrected & scaled			
1	-0.0603	16	0.9502
2	-1.0557	17	-0.4373
3	0.3771	18	-0.4524
4	-0.2262	19	-0.4976
5	-0.3619	20	-0.754
6	-1.1763	21	-0.8144
7	0.1207	22	-0.5881
8	-1.1763	23	-0.2111
9	-1.0557	24	-1.1311
10	-1.3724	25	0.0001
11	-0.8596	26	-0.3921
12	-1.5534	27	-1.9153
13	0.166	28	0.8296
14	-0.8898	29	0.3319
15	0.6486	30	1.3273



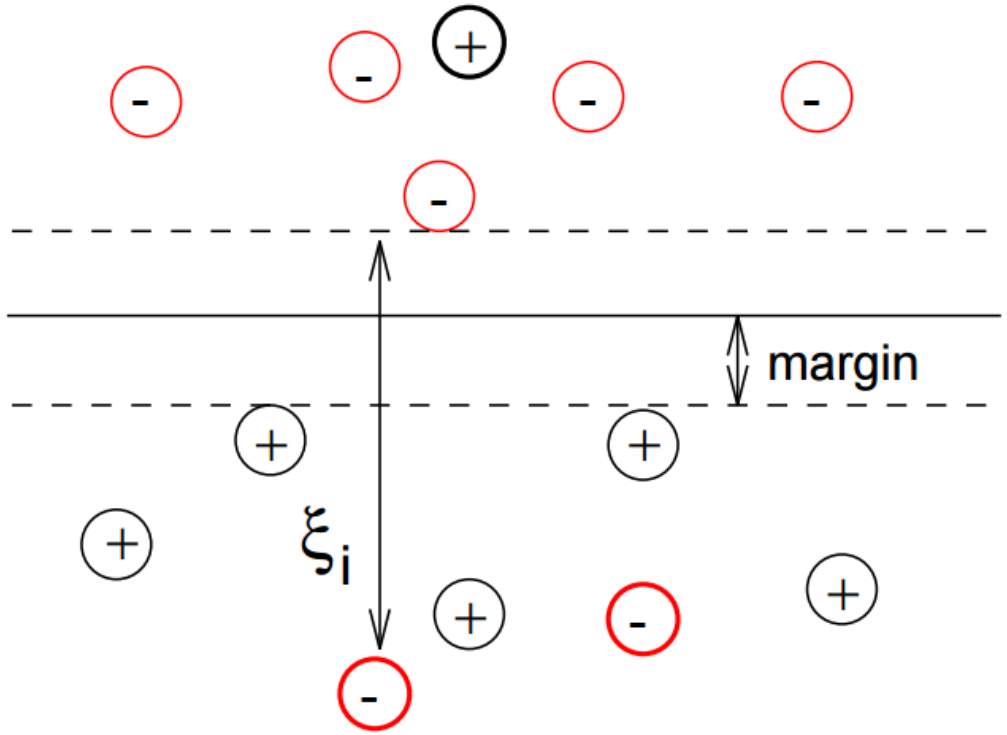
Output

Bin 1	Bin 2	Bin 3	Bin 4	Bin 5
3	12	9	4	2

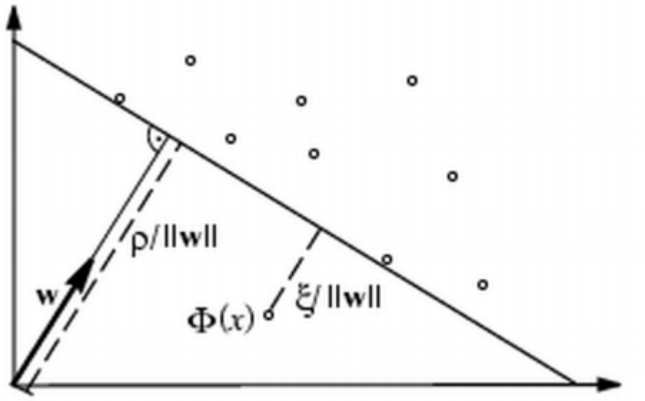
Support Vector Machine



Support Vector Machine



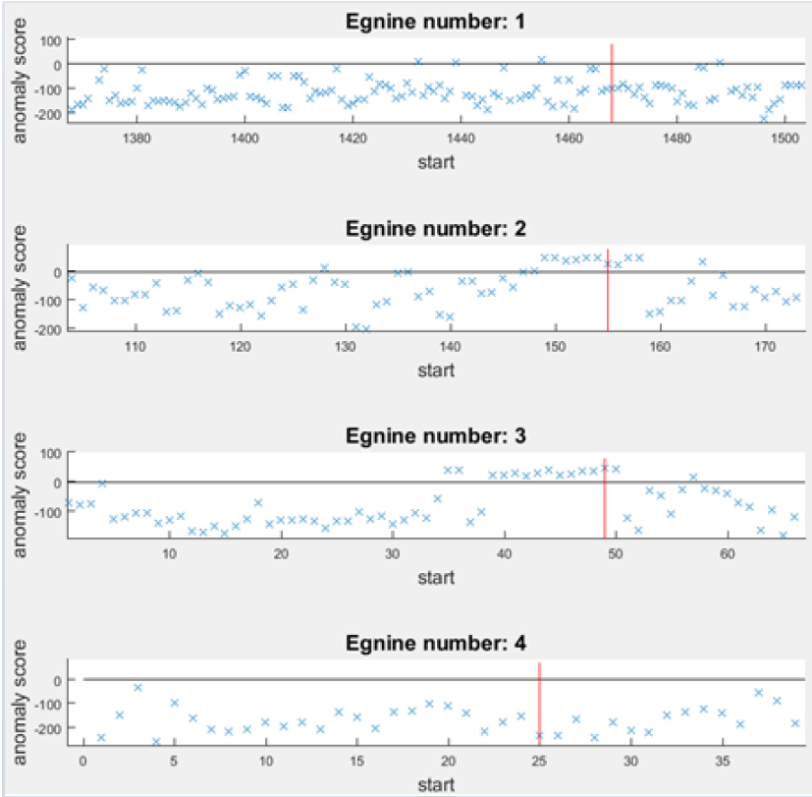
One Class SVM



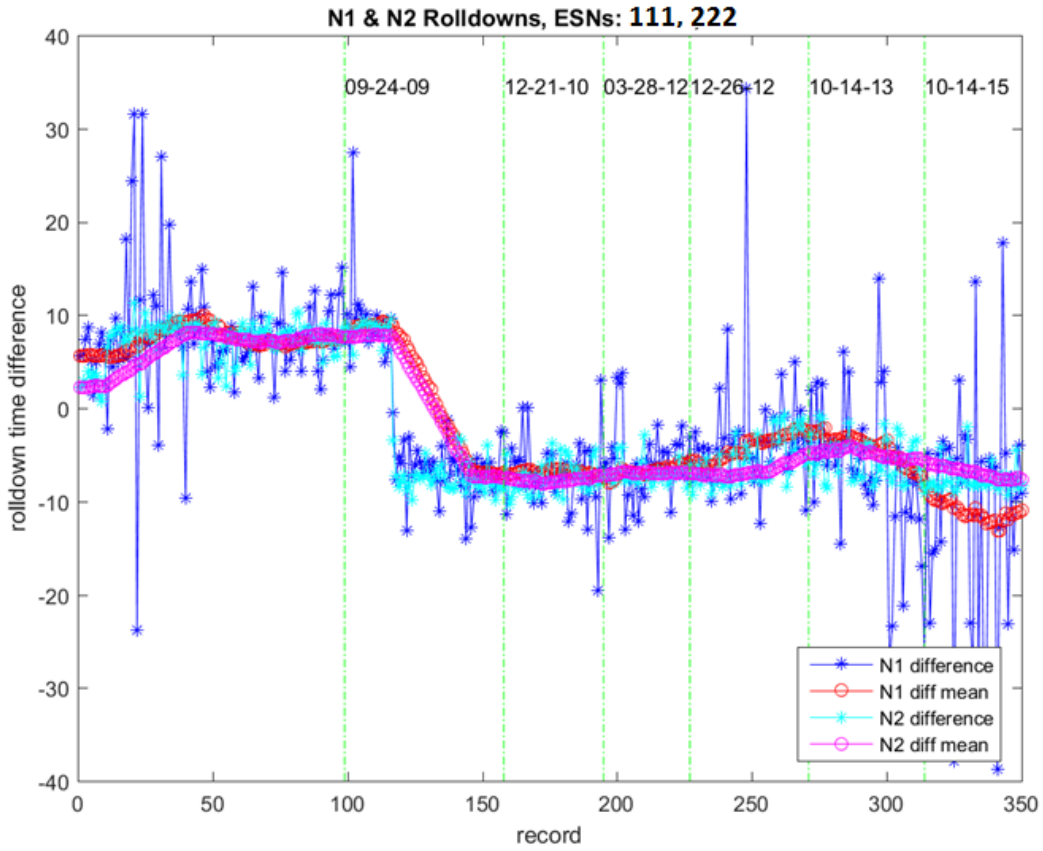
- The hyperplane $\langle \mathbf{x}, \mathbf{\Phi}(x) \rangle = \rho$ separates all but one of the points from the origin
- Small $||w||$ corresponds to a large margin of separation from the origin

- Map training data into the feature space $\mathcal{H}$ corresponding to the kernel
- Separate data from the origin in $\mathcal{H}$ with maximum margin using a hyperplane
- Penalize outliers by employing slack variables ξ in the objective function
- Carefully control the tradeoff between empirical risk and regularization penalty

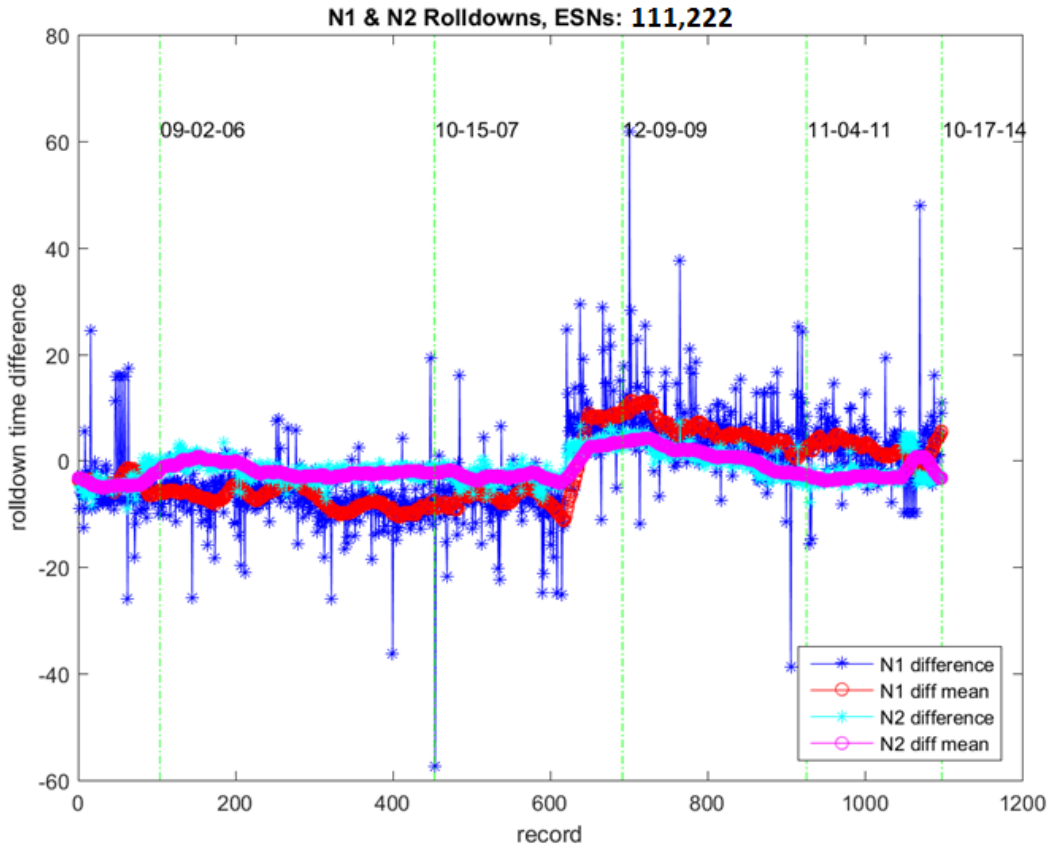
Results of Start Monitoring



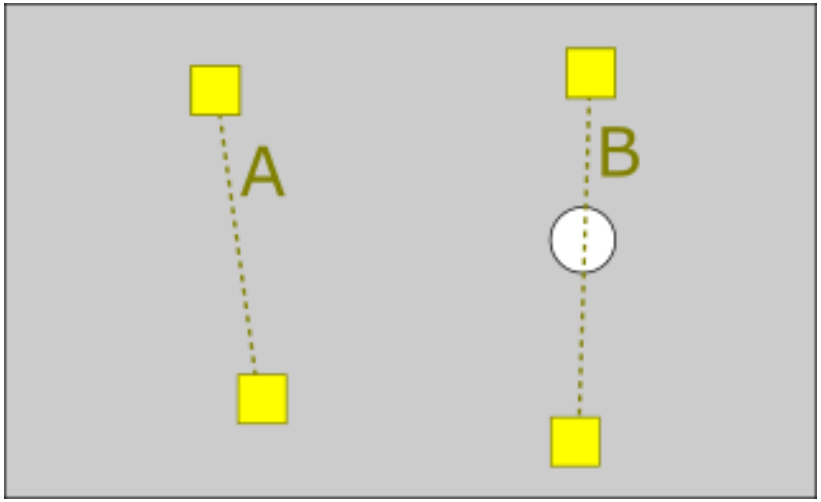
Rolldown differences: interesting cases

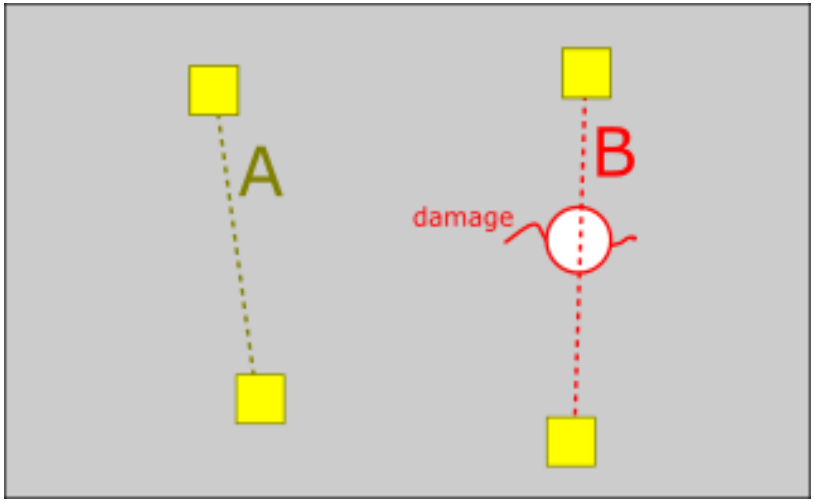


Rolldown differences: interesting cases

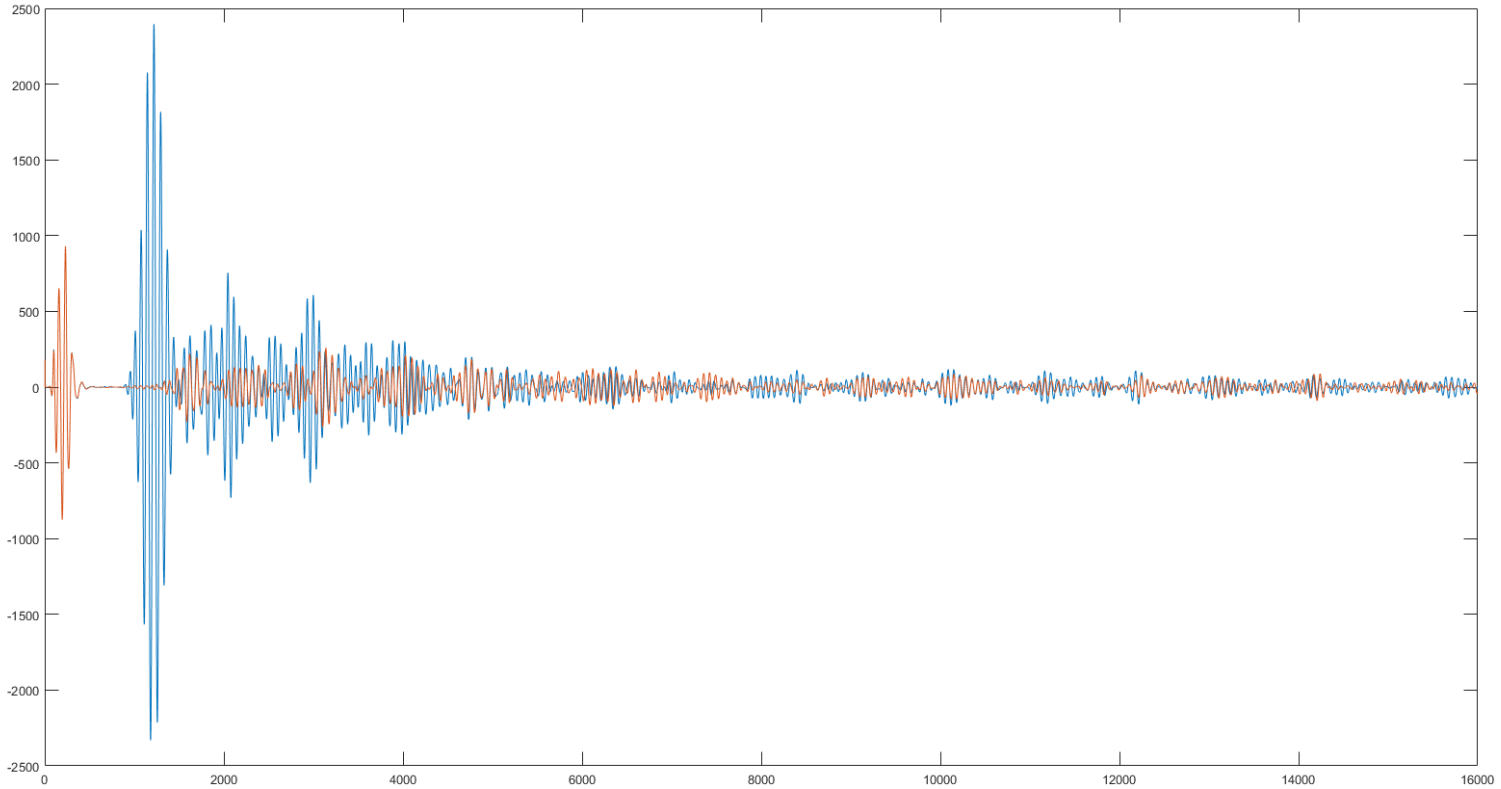


Damage detection

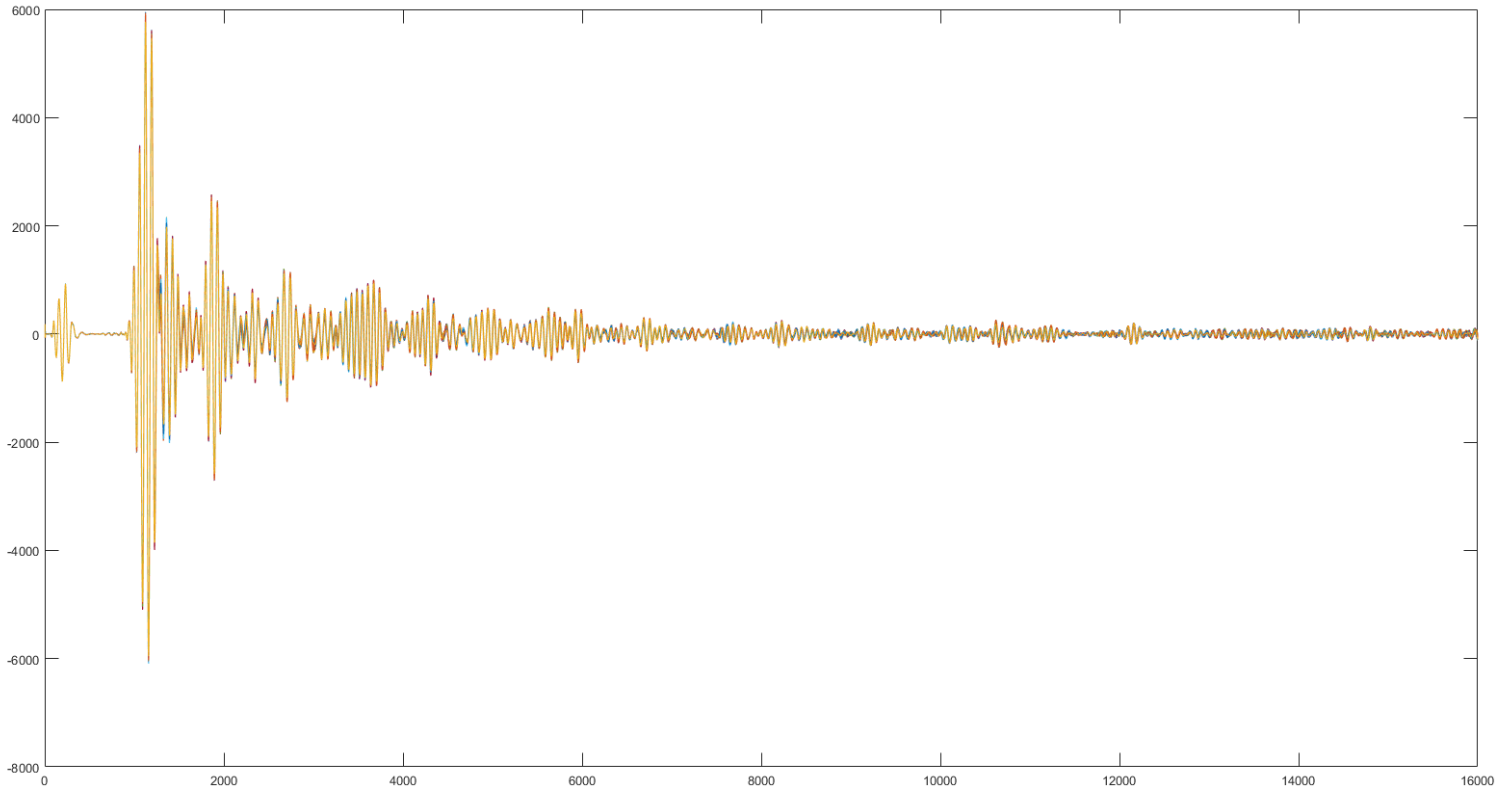




Difference between two signals



Difference between two signals



Difference between two signals