TAT NEW DATA FILTERING MODES

1 INTRODUCTION

After some time we returned to the various filtering modes present in TAT and included new modes in addition to modifying some of them. In TAT up to now the following modes were present:

For Tsunami Analysis (*analysis periods of some hours*)

- Moving Average
- 3 points Filters
- FFT

For Cyclones Analysis (*periods larger than 2-3 days*)

- Two points tide removal

Please refer to the Users Manual for a description of these methods.

We have realized that the modes above are not sufficient or not enough to have a good filtering modes and therefore the following have been included or modified:

- Moving median
- Moving Average
- Polynomial fitting
- Harmonics Analysis
- Harmonics Analysis with exclusion
- Power Spectrum*
- FFT*

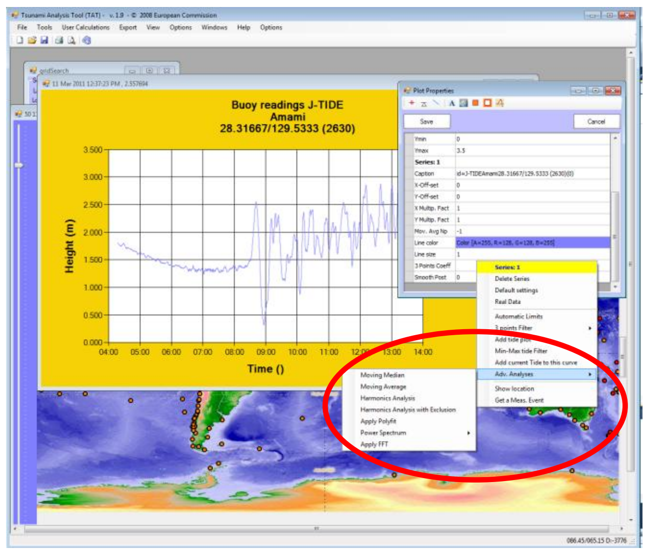


Figure 1 - Selection of the Analysis Modes

With * modified methods.

The various methods can be selected by right clicking on the quantities and selecting Advanced Analysis to invoke the new methods. In the future we would like to expose the possibility of adding additional methods so that every use can test his own method inside TAT.

In the following some specific and characteristic cases will be examined to show the effects of the various methods on the behavior, distinguishing the different situations:

- Post Tsunami Analysis (post event, with the curves already developed
- Ongoing Tsunami Analysis (during an event)
- Post Cyclone Analysis

- Ongoing Cyclone Analysis

The difference between Ongoing and Post event is very important because the oscillations around a baseline value helps to keep the prediction of the baseline values but during an ongoing event it may happens that some methods will fail because tend to be influenced by the last values while they are deviating from the baseline.

2 DESCRIPTION OF THE VARIOUS MODES

2.1 MOVING MEDIAN

The moving median is obtained by a moving sample of the data, ordered and taken the middle value. As an example, considering the following set of data: 4,5,**9,3,2,4,2,1,4,6**,7,8 the moving median with 5 points is obtained by assigning the middle value in a range of 5 values moving from the third point up to the last but 3 points. So for the third point the sample of numbers would be 4,5,9,3,2; when ordered the sample would appear as 2,3,4,5,9 so the middle number would be 4. Following the same approach the median series would be 4,4,3,2,2,4,4,6 and is defined for less number of points because at the borders there are not enough points to ge the sample.

This method tends to exclude the outlayers values from the fitted curve wich is very useful to exclude false values, missing values etc.

The series are reinterpolated linearly in order to have a constant interval of points. The time interval is the smallest in the series. This is done for all the methods described below.

The method proposes a number of points for the sample that is considered correct in order to filter out tidal components larger than 2 h: Np=2*3600/dtMinsec where dtMinsec is the minimum time interval in seconds between two different points in the original data.

2.2 MOVING AVERAGE

The moving average is obtained assigning at each point the average in a sample of Np points. In the example above of the series it would be 4.6,4.6,4,2.4,2.6,3.4,4,5.2 and is already evident that the first point is 4.6 as it “feels” the high peak of the point 9 whereas the moving median was showing 4. The moving average is therefore a good method to preserve the “average energy” of the series but suffers the presence of large outliers.

The series are reinterpolated linearly in order to have a constant interval of points. The time interval is the smallest in the series. The method proposes a number of points for the sample that is considered correct in order to filter out tidal components larger than 2 h: Np=2*3600/dtMinsec where dtMinsec is the minimum time interval in seconds between two different points in the original data.

2.3 POLYNMIAL FITTING

This method requests the degree of the polynomium and consists in establishing a number of nodes equal to the degree of the polynomium trhough which a spline curve is passing. The nodes are selected by considering the average value in the domain of interest of the node. A large value for the degree means a large number of points and thus the curve is better followed but the residual curve does not reflect the deviation from the average. In order to remove the tide the number of nodal points has to be calculated so that the interval between 2 points is larger than the tsunami maximum period. We propose a minimum of 2 h as period to filter out and therefore the number of points to use in the polynomial fiting (and thus the polynomial degree) will be

Degree=int((Tmax-Tmin)/ 2h)

With Tmax and Tmin the min and max time interval considered in the analysis.

2.4 HARMONICS ANALYSIS

The tidal sea level is the result of astronomical gravity interaction between the earth and the moon; some long term components are however caused also by the sun. According to the theory the descrtiption of any tidal behaviour could be performed by using 39 characteristic periods ranging from 6 h to about 19 years.

The sea level can therefore be expressed as:

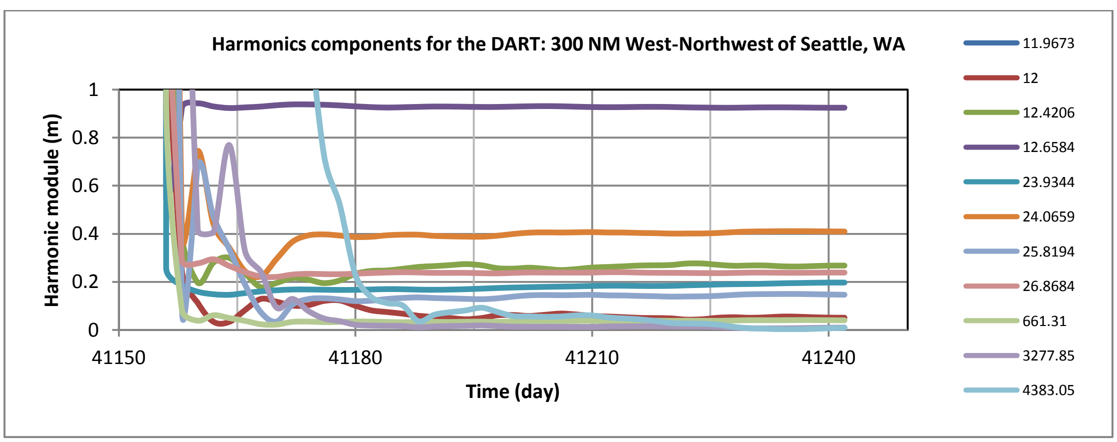
$$f(t) = a_0 + \sum_{n=1}^{39}\left(a_n \cos\frac{2\pi t}{T_n} + b_n \sin\frac{2\pi t}{T_n}\right)$$

The components of the tide a_n and b_n are obtained by a least square procedure on the available observations.

Considering the fact that we want to analyse relatively small periods, we will consider only 10 components ranging from about 12 hours to 4.55 months (see table below) which however is never obtaining his final value. Taking in consideration one location in the Pacific, represented by the DART 300 NM West-Northwest of Seattle, we consider the determination of the components for 3 months. The table below represents the module related to the various periods, or

$$M_n{}^2 = a_n{}^2 + b_n{}^2$$

It is possible to note that in order to reach a stable value (module lower than 5 cm) it is necessary to wait at least 1 month with exception of the slower components that in reality do not yet reach their final value even at 3 months.



\ Months									**27.51**	**4.55**
Days\Hours	**11.9673**	**12**	**12.4206**	**12.6584**	**23.9344**	**24.0659**	**25.8194**	**26.8684**	**661.31**	**3277.85**
0	2101.81	2450.471	718.7852	374.9632	504.0915	162.7371	1160.897	833.0948	2334.016	2444.739
2	1.72122	2.258528	0.561632	0.258485	7.767973	8.705125	2.0457	1.002312	125.2132	3049.495
4	0.247365	0.395736	0.926393	0.187345	0.393448	0.102515	0.289357	0.08313	3.289288	78.98909
6	0.113174	0.196656	0.942887	0.159305	0.745272	0.688531	0.277444	0.038622	0.417885	9.387546
8	0.034035	0.280393	0.929987	0.148739	0.440131	0.471025	0.294138	0.061273	0.405611	9.503729
10	0.033552	0.299936	0.923349	0.146329	0.342605	0.336457	0.26647	0.049533	0.769241	15.65942
12	0.082677	0.236148	0.925931	0.153559	0.244922	0.189034	0.24063	0.037871	0.32849	5.991761
14	0.129131	0.178144	0.929466	0.160499	0.222625	0.074029	0.222372	0.023805	0.242282	4.124073
16	0.117533	0.195669	0.93505	0.165329	0.295635	0.034886	0.220955	0.022309	0.092935	1.320613
18	0.101186	0.216087	0.938401	0.168232	0.366613	0.104959	0.230469	0.03356	0.12928	2.338077
20	0.103103	0.209459	0.938472	0.168402	0.39332	0.128424	0.233608	0.034776	0.079485	1.350694
22	0.120742	0.195007	0.937008	0.167432	0.397602	0.13176	0.232466	0.032679	0.04782	0.729869
24	0.122853	0.205843	0.934159	0.16658	0.393017	0.127021	0.231948	0.033456	0.036626	0.522636
26	0.100801	0.233805	0.930341	0.167069	0.386643	0.120208	0.234273	0.034934	0.021555	0.228793
28	0.081615	0.24568	0.927135	0.168422	0.387801	0.12189	0.236868	0.034679	0.018345	0.137402
30	0.074613	0.247668	0.925506	0.17002	0.394007	0.129058	0.239048	0.033395	0.017235	0.111962
32	0.067664	0.2546	0.926658	0.169501	0.396487	0.133377	0.240181	0.032166	0.016376	0.101654
34	0.058969	0.262289	0.928424	0.167836	0.396311	0.135489	0.239221	0.033521	0.011236	0.036142
36	0.053958	0.265798	0.929579	0.167197	0.39154	0.132868	0.237567	0.033774	0.014883	0.063431
38	0.049666	0.269816	0.929417	0.16819	0.389437	0.131309	0.23768	0.033242	0.016206	0.073958
40	0.044537	0.274125	0.928551	0.169653	0.388338	0.129493	0.237668	0.03426	0.017329	0.081476
42	0.049587	0.269066	0.927781	0.172105	0.388022	0.127965	0.236134	0.034611	0.019081	0.092482
44	0.06101	0.256985	0.927963	0.174593	0.392206	0.131697	0.235426	0.033512	0.016152	0.074838
46	0.062128	0.255235	0.929357	0.176529	0.399425	0.138882	0.237505	0.03552	0.013742	0.057956
48	0.058319	0.258968	0.930694	0.177956	0.404716	0.144064	0.239173	0.037114	0.013651	0.056576
50	0.063011	0.25481	0.93127	0.179347	0.406104	0.145361	0.23903	0.036929	0.013612	0.054945
52	0.06817	0.249377	0.930604	0.180345	0.405453	0.144714	0.238866	0.037151	0.013448	0.056116
54	0.064407	0.253382	0.928968	0.181582	0.406222	0.145475	0.238637	0.037592	0.012826	0.060837
56	0.058431	0.259608	0.927489	0.183046	0.407181	0.146267	0.239057	0.037947	0.012934	0.060435
58	0.055995	0.262142	0.92692	0.184042	0.4055	0.143979	0.240281	0.036316	0.014654	0.052195
60	0.053316	0.264845	0.927191	0.184035	0.405403	0.143533	0.240291	0.036265	0.015227	0.048319
62	0.050236	0.268061	0.928103	0.183164	0.403716	0.141578	0.238955	0.037799	0.015565	0.04415
64	0.049507	0.269009	0.928342	0.182978	0.402785	0.140454	0.237879	0.038481	0.015493	0.037464
66	0.048123	0.270234	0.927616	0.183561	0.400993	0.138576	0.237765	0.037944	0.014726	0.029159
68	0.042941	0.276408	0.926215	0.185734	0.401336	0.139377	0.23724	0.038403	0.014595	0.026935
70	0.044717	0.276503	0.925468	0.187308	0.401603	0.13994	0.236762	0.038238	0.01443	0.026117
72	0.050813	0.271124	0.924598	0.189223	0.403578	0.142163	0.236409	0.038121	0.012774	0.022028
74	0.0528	0.267029	0.924603	0.190462	0.407025	0.145942	0.237287	0.039342	0.009046	0.012854
76	0.050829	0.268359	0.925532	0.191199	0.409493	0.148616	0.238746	0.040645	0.007074	0.006955
78	0.052407	0.268261	0.926241	0.192441	0.41021	0.14928	0.23867	0.040487	0.006714	0.005333
80	0.055723	0.264901	0.926322	0.194149	0.410827	0.149735	0.23816	0.040689	0.006725	0.002999
82	0.055246	0.263967	0.92582	0.195279	0.411044	0.149725	0.237952	0.041124	0.00741	0.002815
84	0.052933	0.265787	0.925106	0.196317	0.410654	0.148852	0.238436	0.041152	0.008508	0.004804
86	0.05137	0.267603	0.924657	0.197123	0.410003	0.147572	0.238874	0.04049	0.009365	0.006985
88	0.050895	0.268009	0.924635	0.19718	0.40956	0.146602	0.238837	0.040235	0.010019	0.009
90	**0.050895**	**0.268009**	**0.924635**	**0.19718**	**0.40956**	**0.146602**	**0.238837**	**0.040235**	**0.010019**	**0.009**

Analysing a period lower than the stable period does not mean that the analysis cannot be performed but there is no possibility of extrapolating the results to future long periods, i.e.: having only 1 day of data I can extrapolate to 1 or 2 h of data and not more. For practical Tsunami analysis this is certainly sufficient while if one wants to predict the tide with sufficient precision, it is necessary to analyse several years of data.

While for cyclones analysis in which the important signal is the difference between the tide and the values being the effect of atmospheric pressurization or the effect of friction on the sea and therefore the determination of the astronomical constants can be done one for ever, in the tsunami analysis it is always necessary to reset the values and remove eventual differences due to amospheric effects and the correct determination of a shifting factor that probably do not change during the period of analysis of few hours.

2.5 HARMONICS ANALYSIS WITH EXCLUSION

This method is similar to the previous one. The difference is that it is performed in two steps. In the first step an initial calculation of the harmonics is performed and then the difference between the estimated value and the measured value is evaluated. If the difference exceed a threshold, at the moment arbitrarily fixed at 5 cm, that particular point is excluded from the following harmonics estimation. The second estimation is performed excluding the points in which the estimate was above 5 cm. This method allows to: a) eliminate spikes due to bd measurements from the harmonics estimation; b) tries not to take into account deviations from the pure tidal component due to atmspheric effects.

2.6 POWER SPECTRUM

The power spectrum is the presentation in a graph of the module of the fourier series expansion of the measured data. It is quite useful to perform first the power spectrum and then decide which small or large period to use in the following FFT analysis.

2.7 FFT

The FFT analysis did not change from the previous TAT but is performed with an improved performance routine that makes it faster. At the beginning the maximum period (h) for a low pass filter and the minimum period (h) for a high pass filter is requested to the user. The resulting curve is therefore the filtered curve. Using an infinite large period and a 0 small pass filter means no filtering and the original signal is replicated (and thus is useless).

3 ANALYSIS WITH DIFFERENT MODES

3.1 POST TSUNAMI ANALYSIS

Two typical cases are analysed: a very small DART event with a ratio signal over tidal component extremely small (Figure 2 and Figure 3) and to cases of large ratio, tidal gauge and DART, both related to 11.03.2011 Japan event (Figure 4). The selected tidal gauge is measured in Anami (28.3166/129.5333) measured between 4:00AM and 2:00PM of 11 Mar 2011.

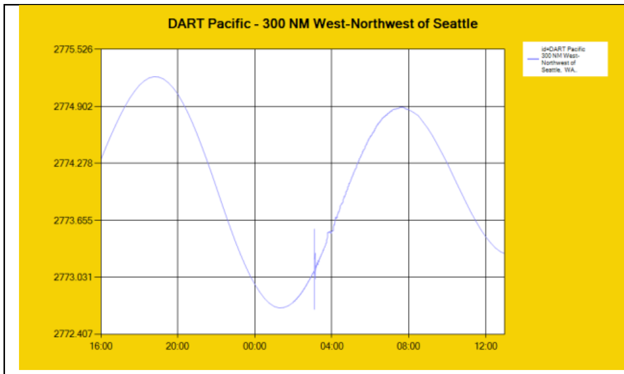


Figure 2 – 28 Oct 2012, Canada

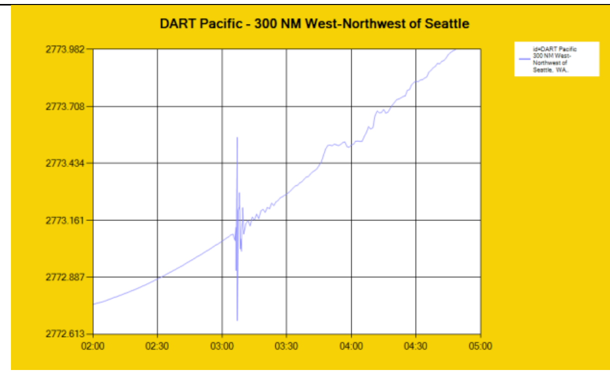


Figure 3 – 28 Oct 2012, Canada, detail

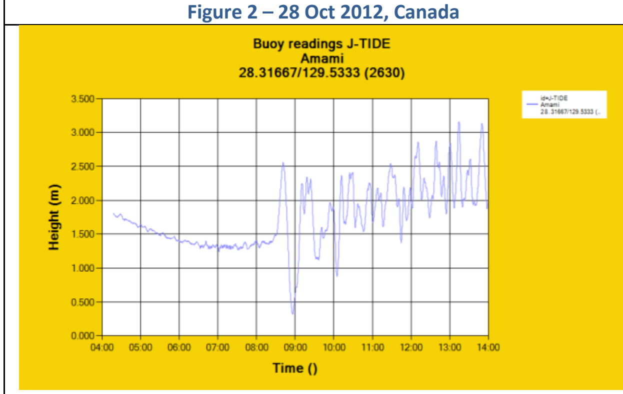


Figure 4 – 11 March 2011 case, Japan

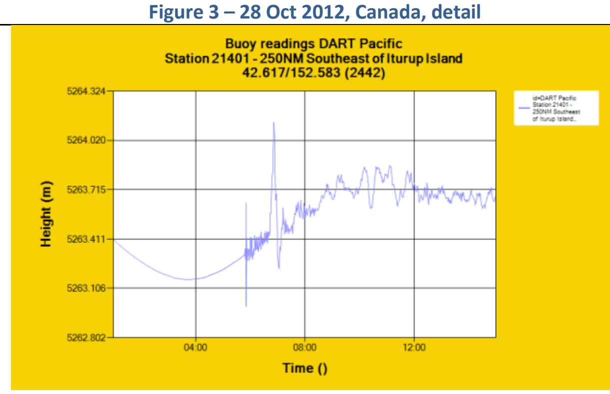


Figure 5 – March 2011 Japan event, DART

3.1.1 TIDAL GAUGE

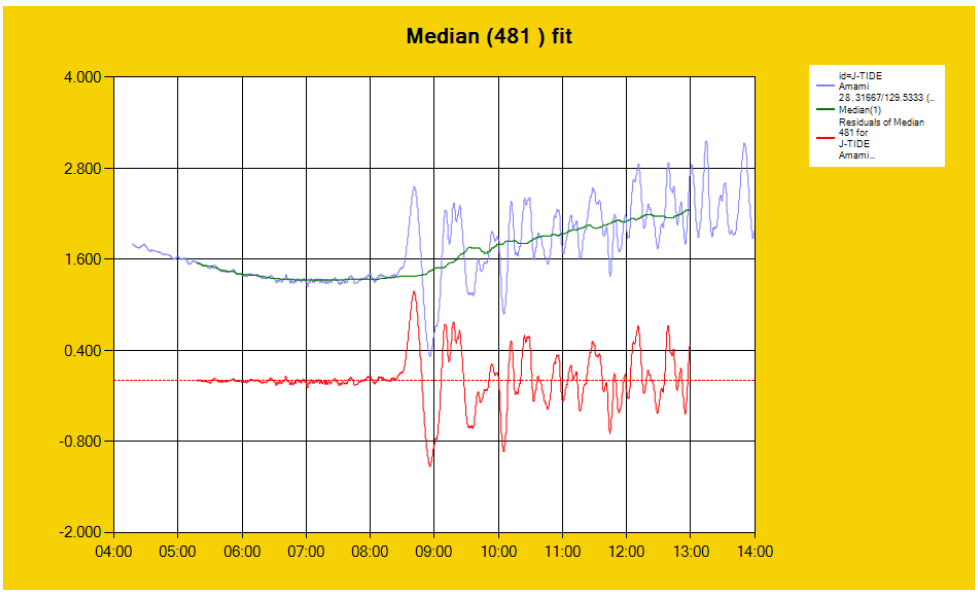
3.1.1.1 MOVING MEDIAN

In the Moving Median and in the Moving Average it is necessary to indicate the number of points to be used for the median. The proposed value is corresponding to a period of 2h divided by the minimum time interval among two points in the analysis period dt (in s):

Np=2*3600/dt

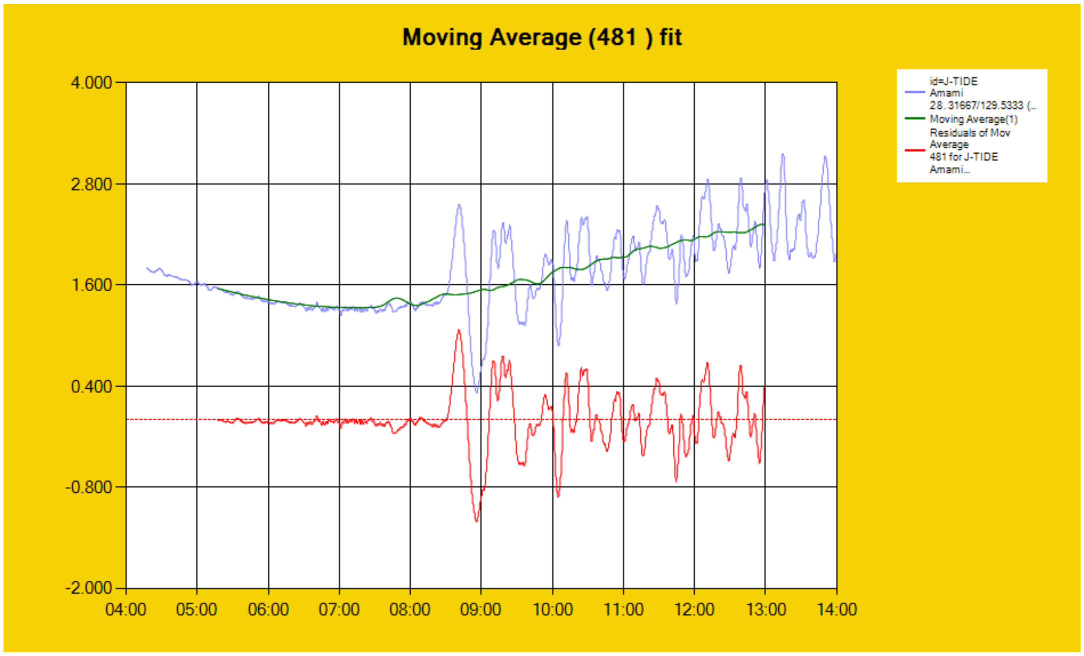
The value of 2 h is used in order to filter out tidal components. In the case of the tidal gauge this number of points is 480. It is possible to see however that at the border there is no estimation given the fact that the method takes the central point in the analysis period.

The result is quite good to identify the first peak but at the second peak there is a deviation from the expected baseline tide when the first peak becomes the middle value or in any case there are several points out of the average.



3.1.1.2 MOVING AVERAGE

Also the case of moving average suggests a minimum number of points to perform the analysis and is 48o as in the previous case. It is possible to see that in this case the deviation from the average occurs even before the arrival of the wave and disturbances continue also during the tsunami event. The Moving Median is therefore preferable respect to the moving average.

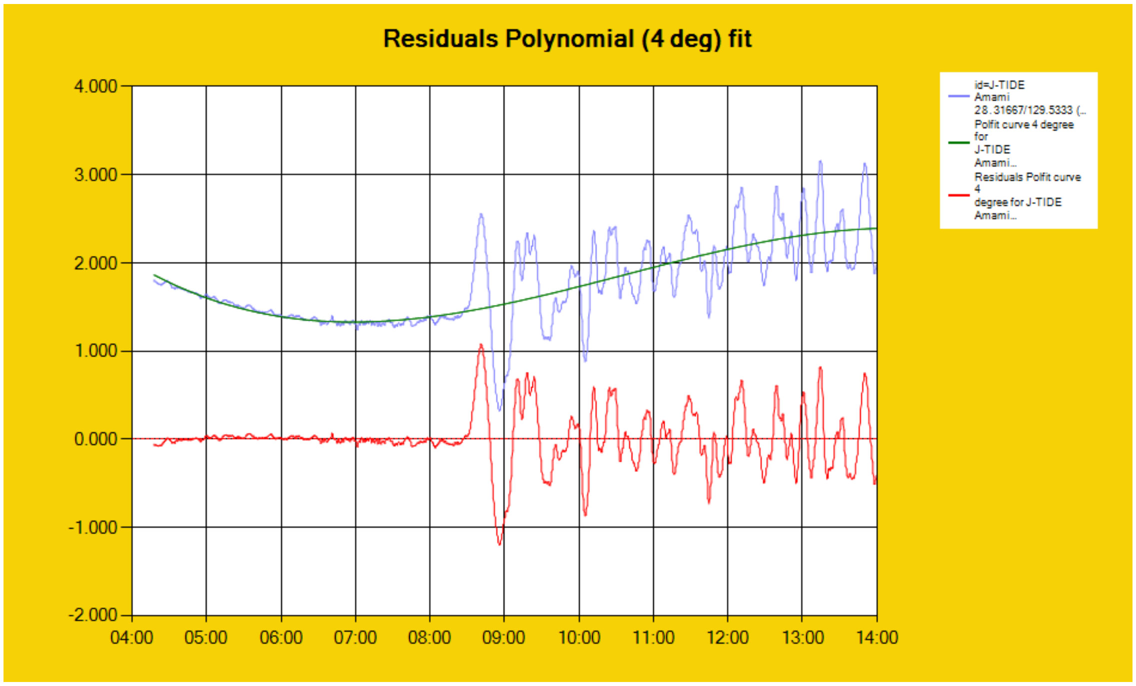


3.1.1.3 POLYNOMOMIAL FITTING

Polynomial fitting initially requests the degree of the polynomial. Since the method assumes an even number of points for the fitting in the analysis period that in this case is 9.6 h, the degree is chosen so that the time interval between two nodes is smaller than 2h to remove the tide. Therefore in this case the suggested degree of the polynomial fitting is

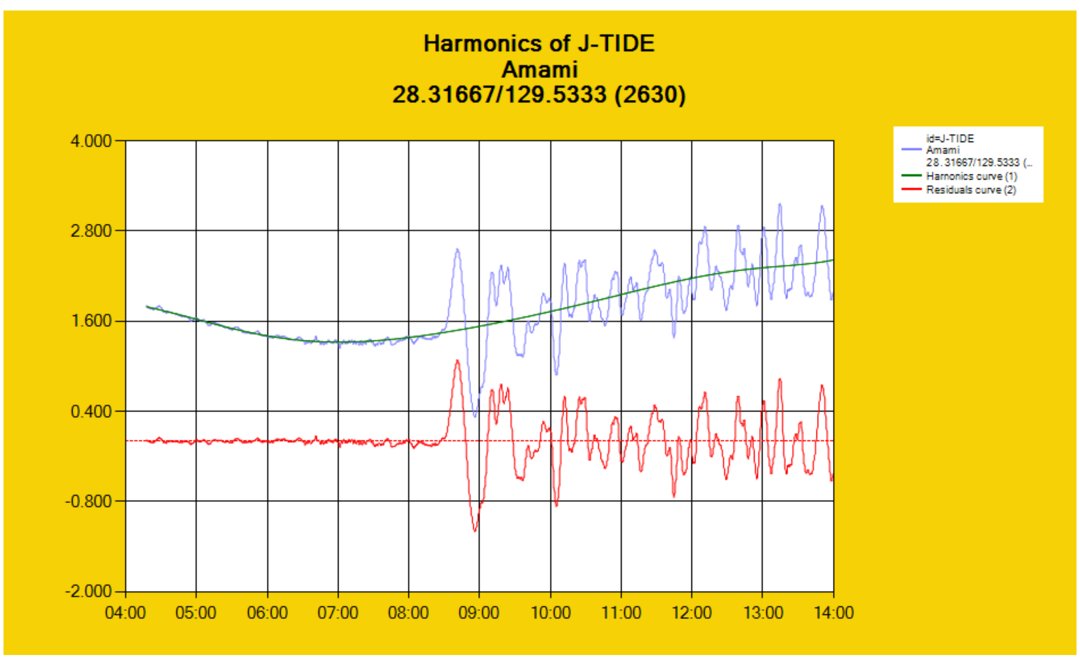
Degree=int((Tmax-Tmin)/ 2h) =int(9.6/2) =4

The fitting in this case is very good and the method is able to identify the peak and is not influenced after the peak.



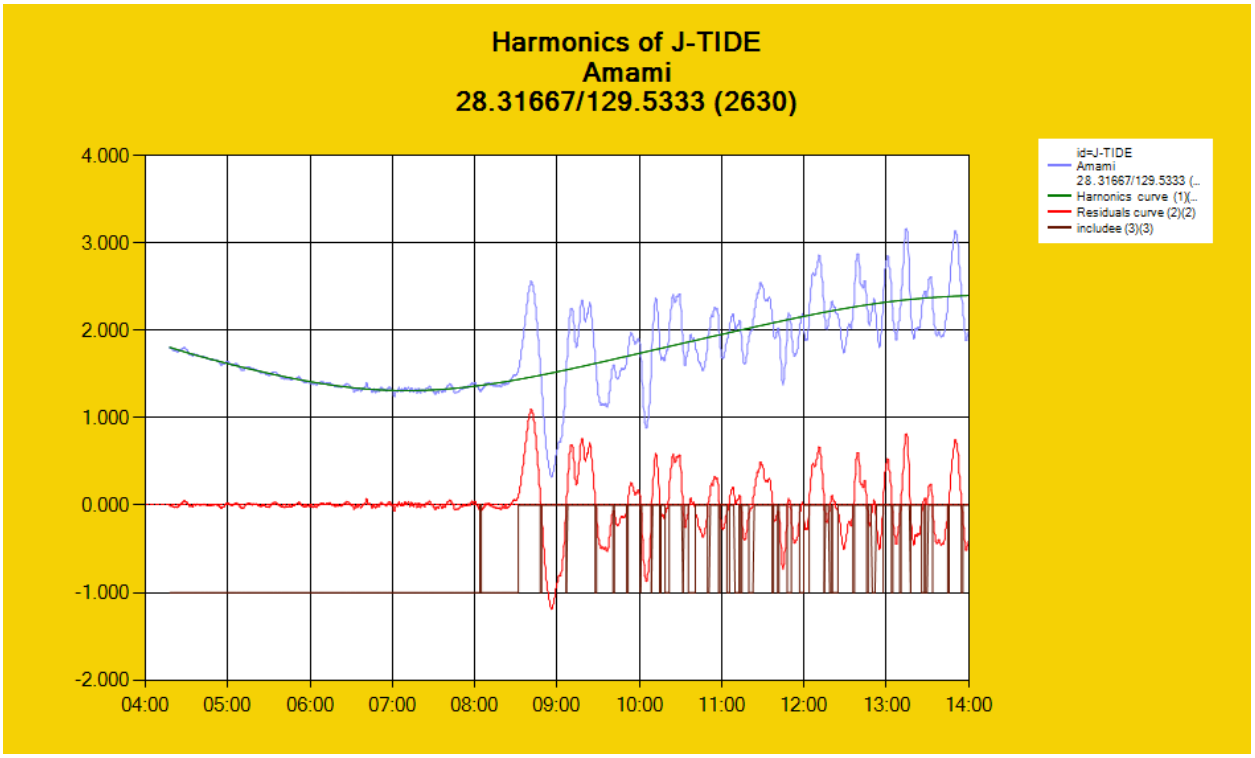
3.1.1.4 HARMONICS ANALYSIS

The harmonics analysis is quite good in identifying the tidal component and remove it from the global behavior. Even during the event there is no influence because only the tidal components are considered with periods larger than the oscillations.



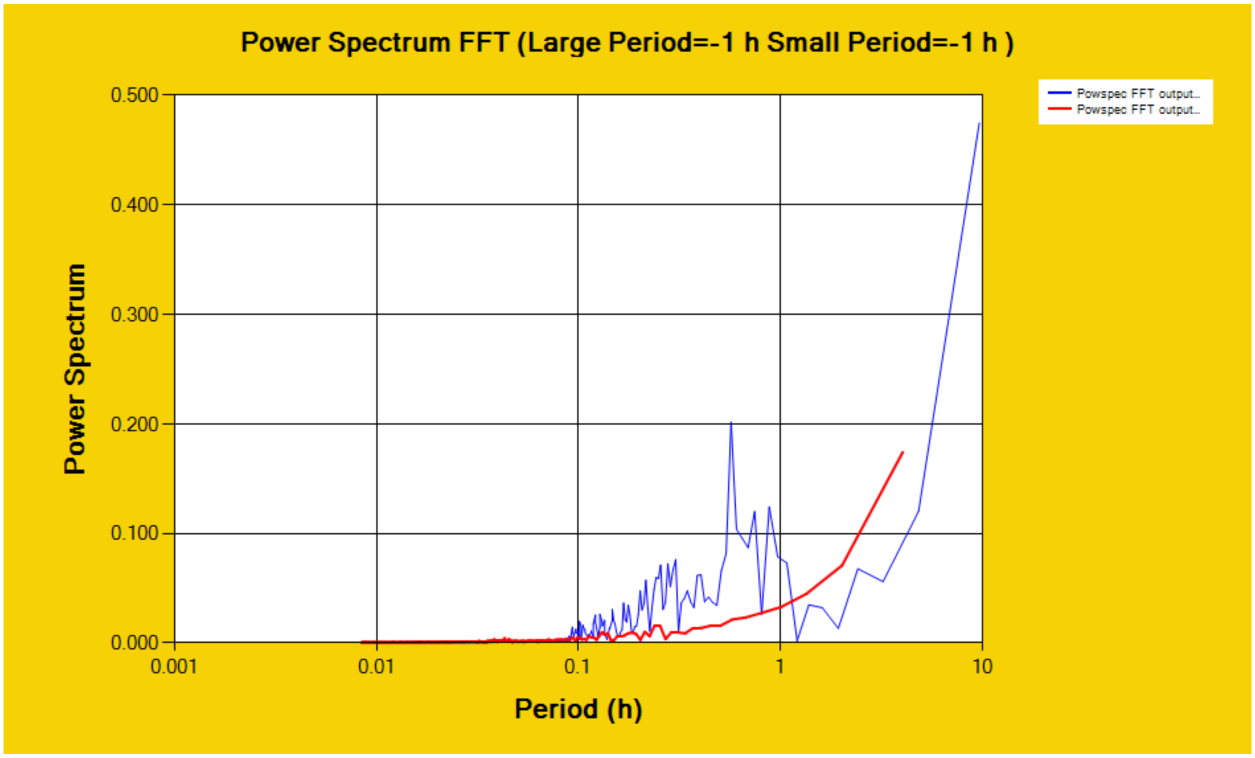
3.1.1.5 HARMONICS ANALYSIS WITH EXCLUSION

According to this method only the periods that keeps the average error within a limit are maintained.

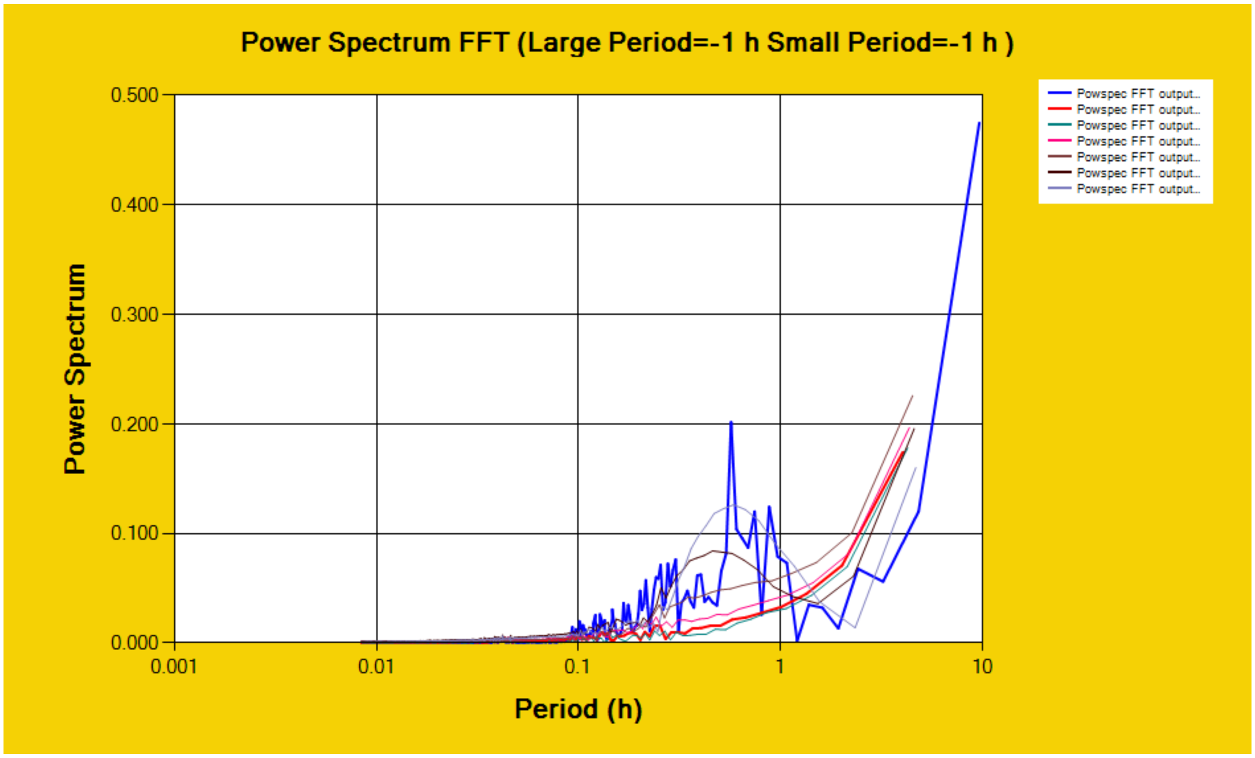


3.1.1.6 POWER SPECTRUM

The power spectrum is not a fitting but is used to understand which are the important periods of this event. It is possible to see (blue curve) that there are large components in the period range between 0.5 and 1h that were not present in the power spectrum in the initial part of the event (red curve). The presence of components in that range could be used to identify the presence of a Tsunami.



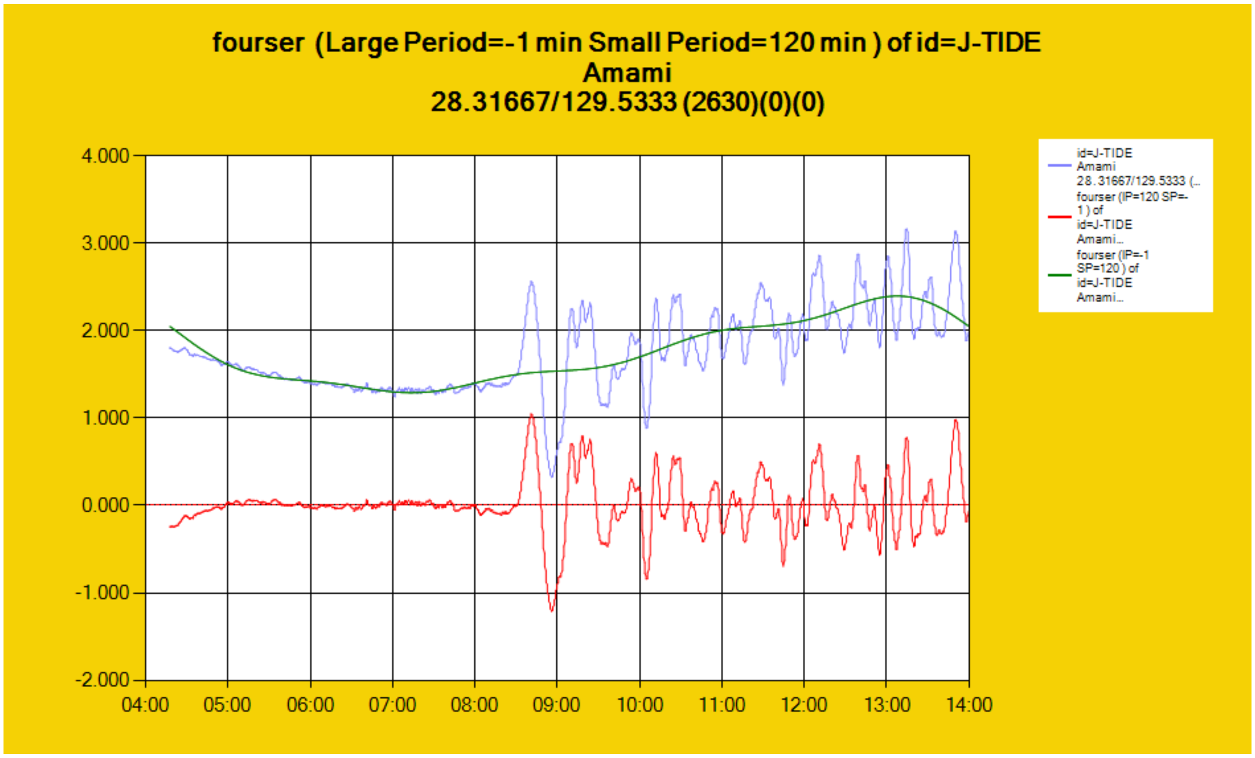
However the application of the power spectrum until various times is shown in the following figure at steps of 5 min. The red curve is until 8:30, then 8:35, 8:40 etc. The last curve, gray curve is a clear deviation of the power spectrum which occurs when the time considered is between 8:55 and 9:00 which indicates that **it is a too slow method for Tsunami detection**.



3.1.1.7 FFT

The FFT method foresees the indication of a Large and Small period cut. We will assume 2h for the large period cut and none for the small period cut[1].

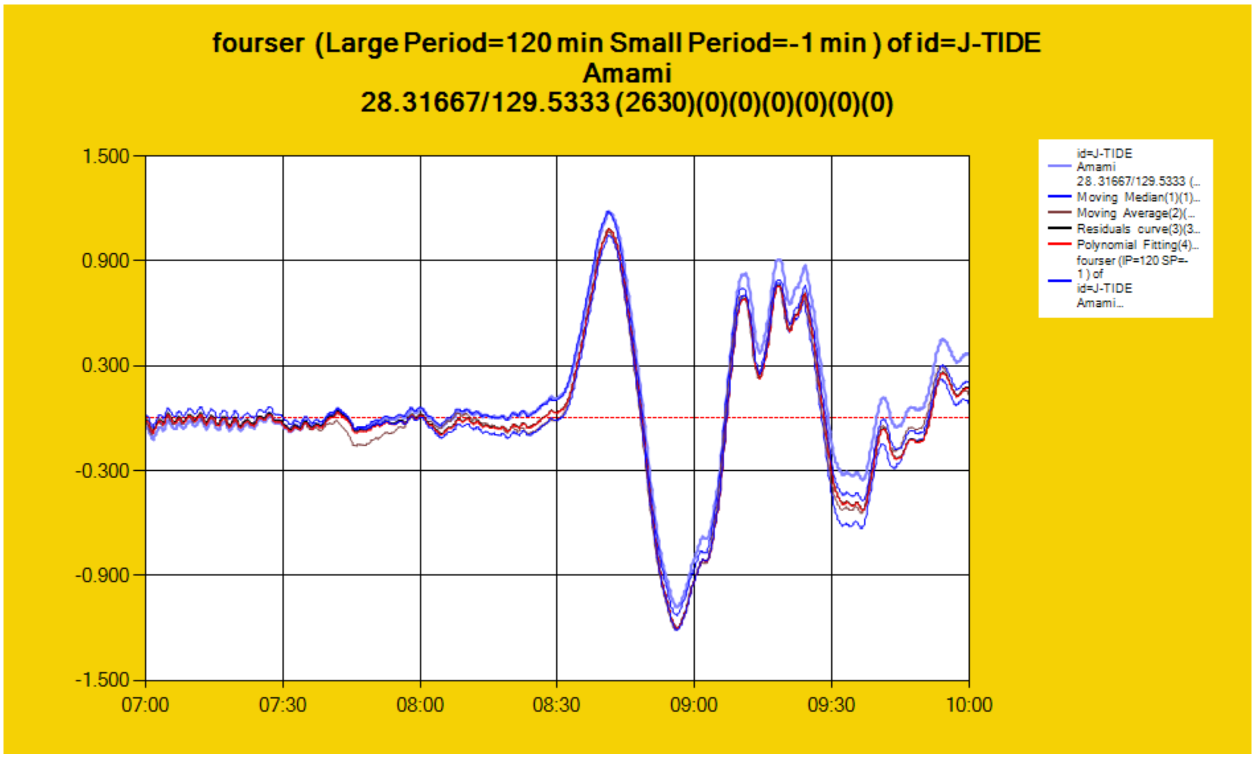
The method is quite general but in this case there are some problems at the border of the event and also there are some not physical oscillations in the baseline



[1] In order to obtain the baseline curve the 2h period is used as Small period cut and none for the large period cut

3.1.1.8 CONCLUSIONS ON THE TIDAL GAUGE ANALYSIS

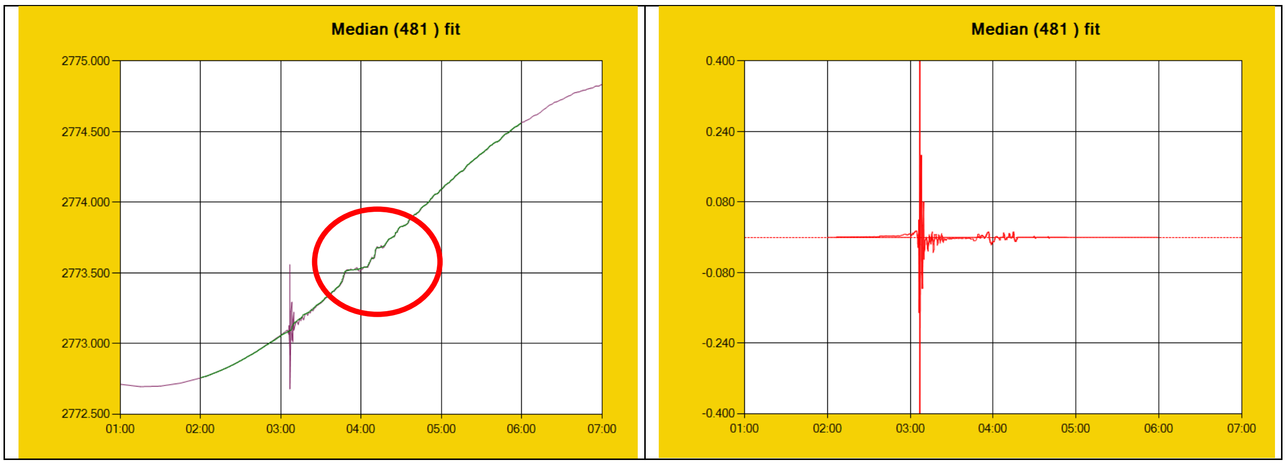
In conclusion, all the methods, excluding the Harmonics with exclusion, are able to identify the peak (in the comparison below all the methods are compared with the 3 points filtering, cyan curve). The best appears however the harmonics method and the polynomial fitting. The first being preferred to the other one because no parameter is given and the calculation is fast and precise.



3.1.2 ANALYSIS OF A SMALL EVENTS RECORDED BY DART

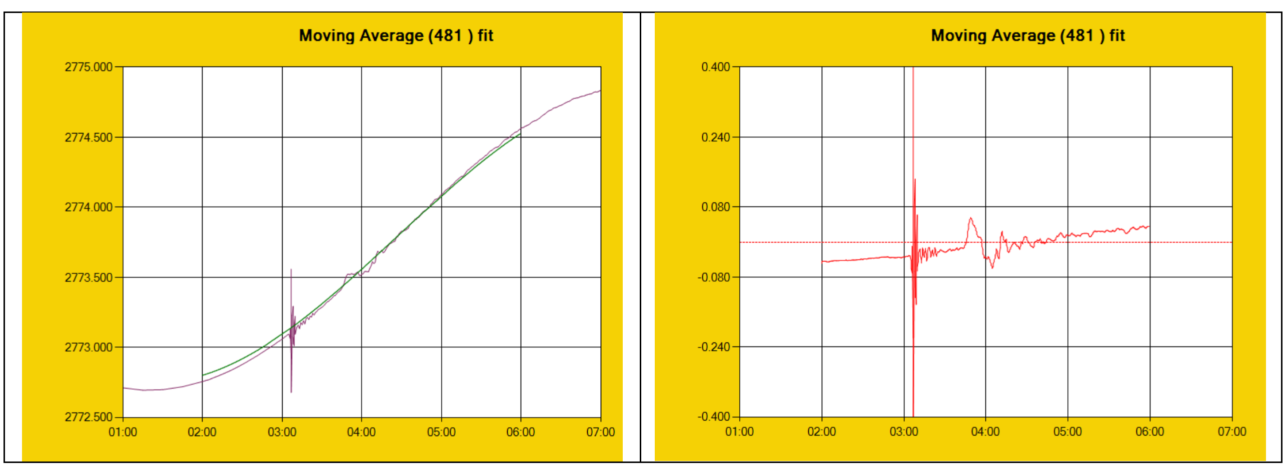
3.1.2.1 MOVING MEDIAN

In this case the moving median cannot work because the deviation from the tidal signal is smaller than the difference between the tidal component variation in the filtering period. The consequence is that the moving median is able to filter the initial spike due to the earthquake but is unable to filter out the tsunami and therefore no Tsunami signal is detected.



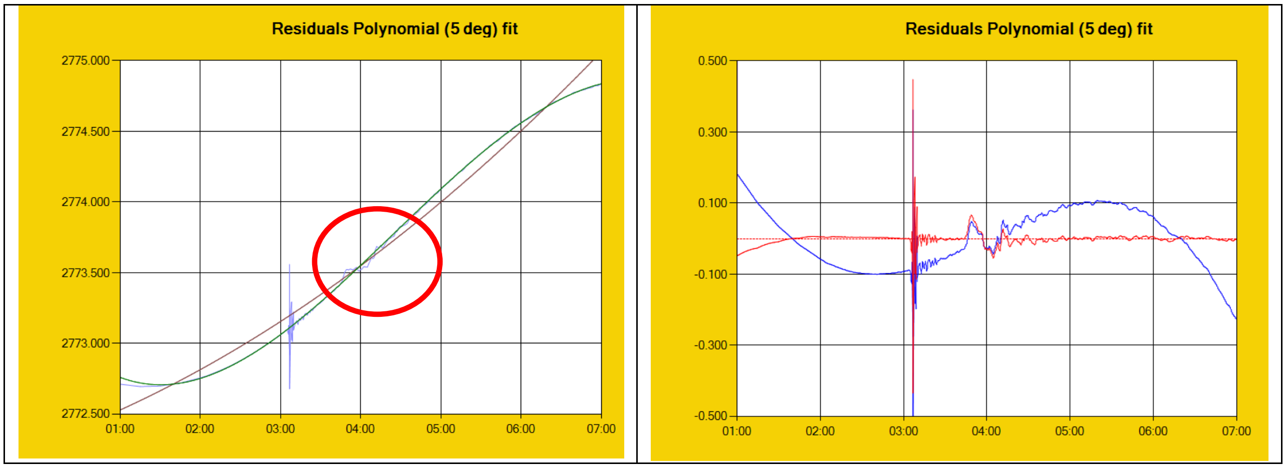
3.1.2.2 MOVING AVERAGE

Also the moving average has problem in this case because the average is influenced by the initial peak and as a consequence the residual curve (right plot) starts from a negative value which should not be the case. Nevertheless, contrary to the Moving median this methid is able to identify the tsunami signal even if the maximum value estimated is affected by the initial deviation.



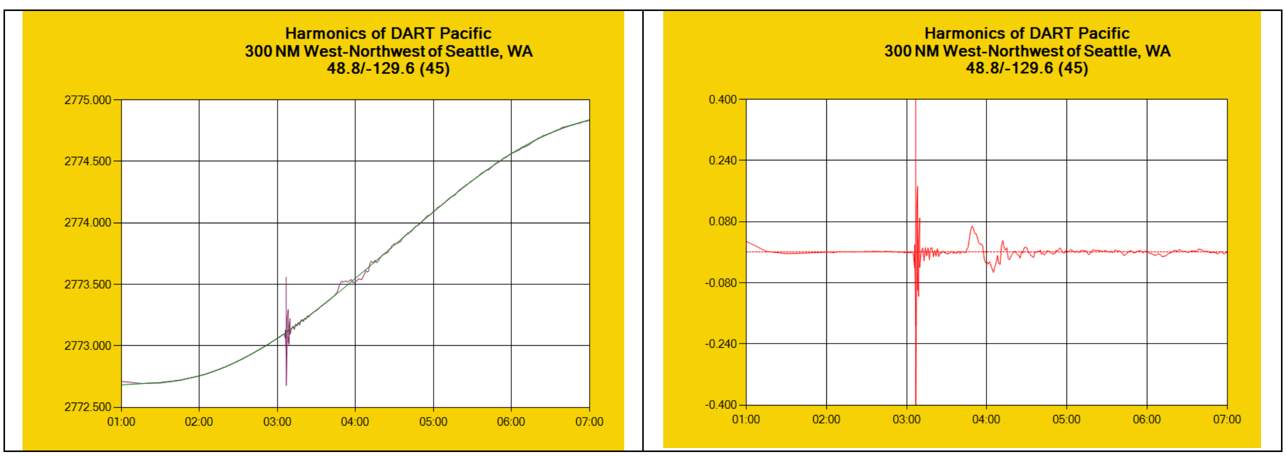
3.1.2.3 POLYNOMIAL FITTING

The use of the polynomial fitting according to the default condition for this period of analysis would suggest a 3 degrees polynomial. However using 3 degree the resulting residual is the brown curve on the left and the blue curve on the right which shows a very bad trend. Increasing the polynomial degree to 5 the agreement is better. The reason is that the analysis period here considered (6h) is not enough to create a good polynomial fitting. Increasing the period (Tmax-Tmin) the polinomium degree increases and the agreement improves.



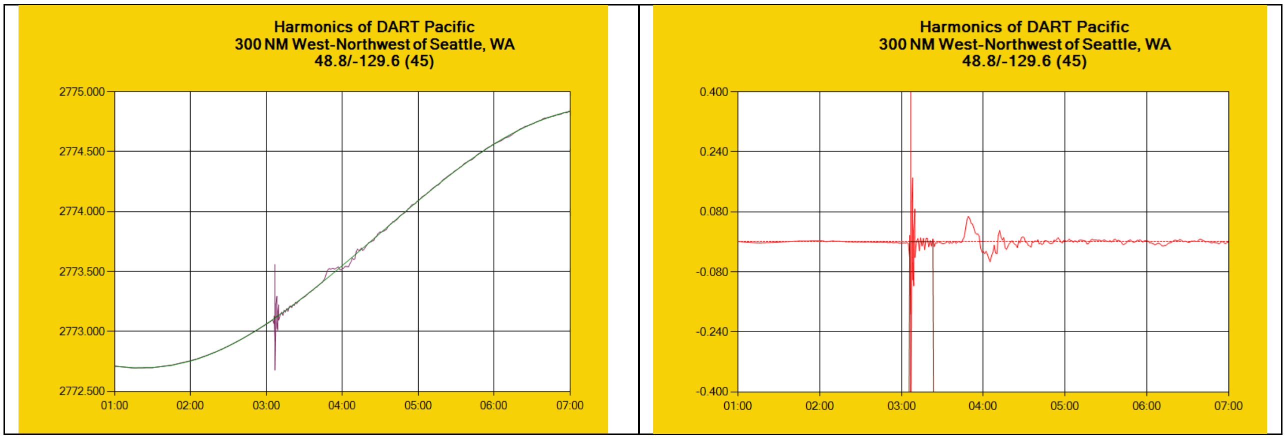
3.1.2.4 HARMONIC ANALYSIS

The harmonics analysis shows a perfect fitting with the data. Only a small deviation at the left border is present. With such a small period of analysis not all the harmonics are stabilized, as shown before, and therefore the smaller contributions from the large periods are failing. Nevertheless in the period of interest the agreement is pefect.



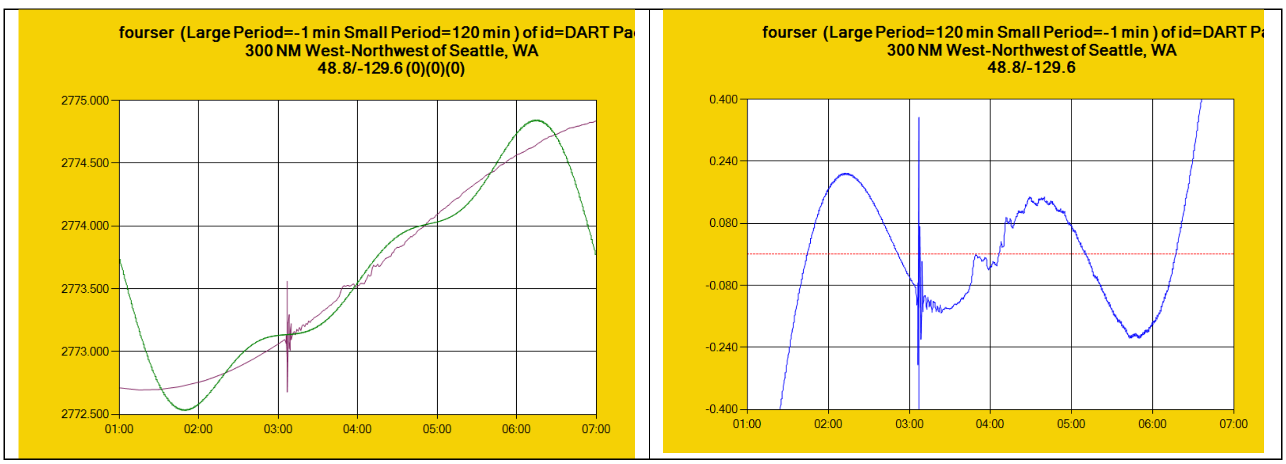
3.1.2.5 HARMONIC ANALYSIS WITH EXCLUSION

This method will exclude the period during the large excursion due to the earthquake but for the rest is very similar to the Harmonics method. The exclusion of the large deviation however improves also the behavior at the borders.



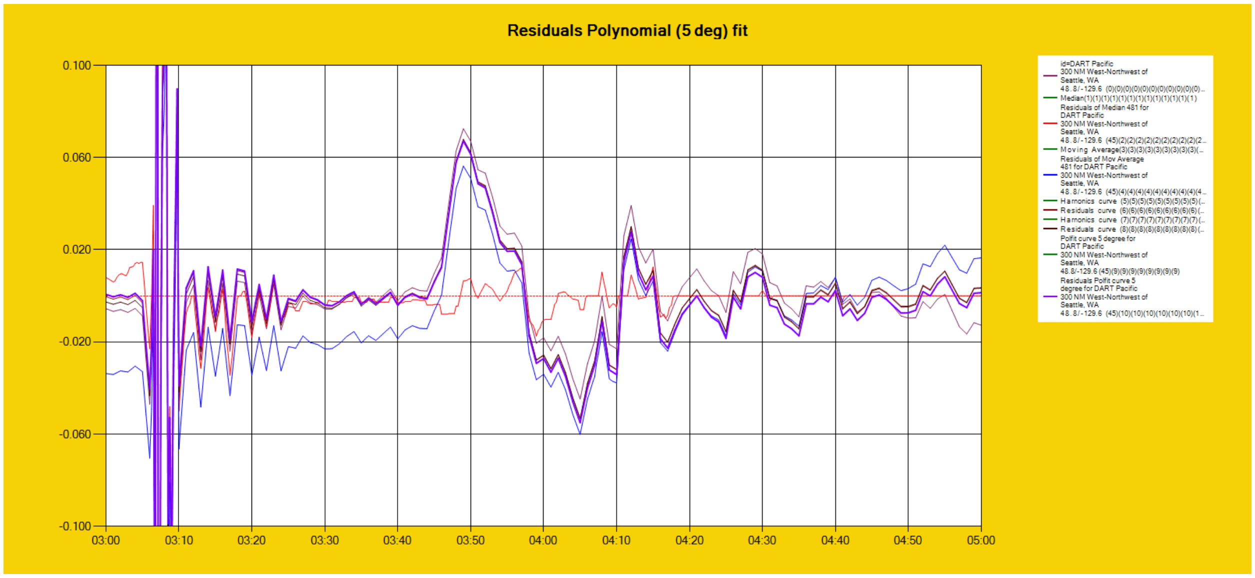
3.1.2.6 FFT

The use of 2 h for large period filtering and no filtering for the small period is unable to describe the curve which is infact very badly predicted.



3.1.2.7 CONCLUSION ON SMALL DART SIGNAL

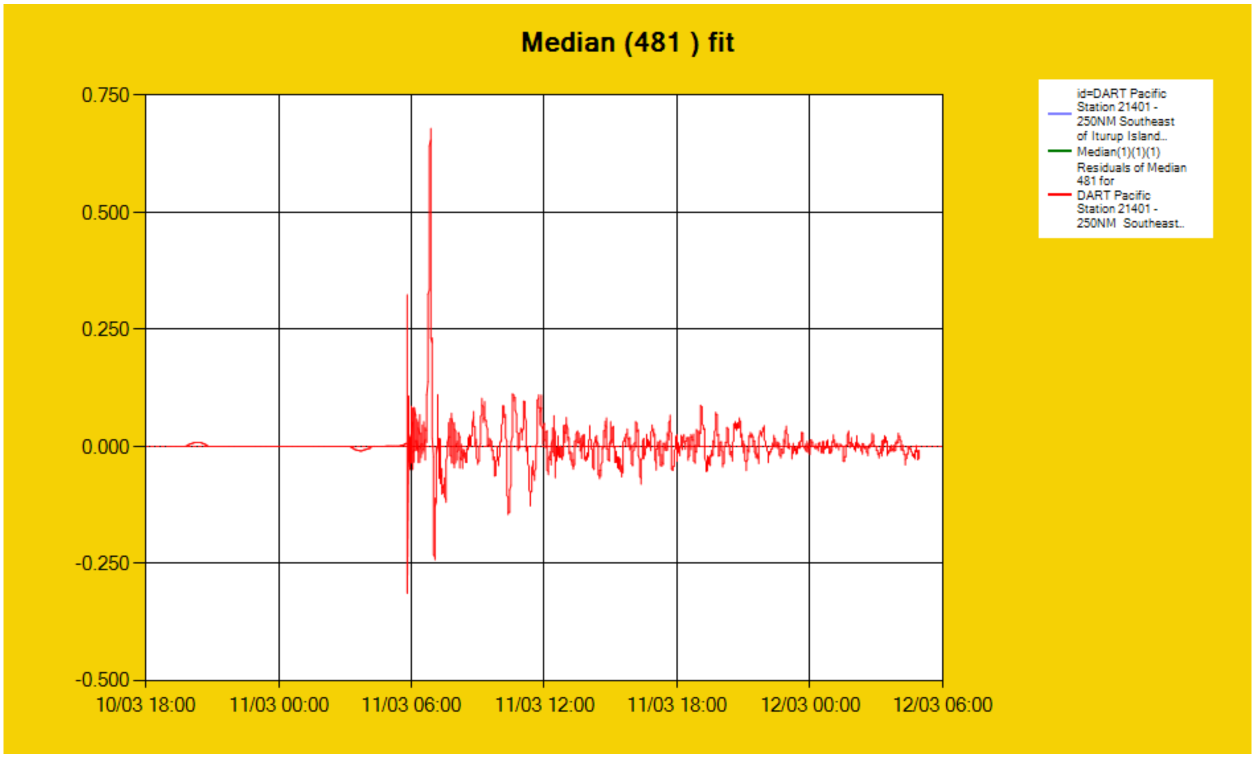
Excluding the moving average and moving median all the other methods successfully show the behavior of the DART signal. The harmonics with exclusion method is able to correctly predict the behavior over the whole long time span.



3.1.3 LARGE DART SIGNAL

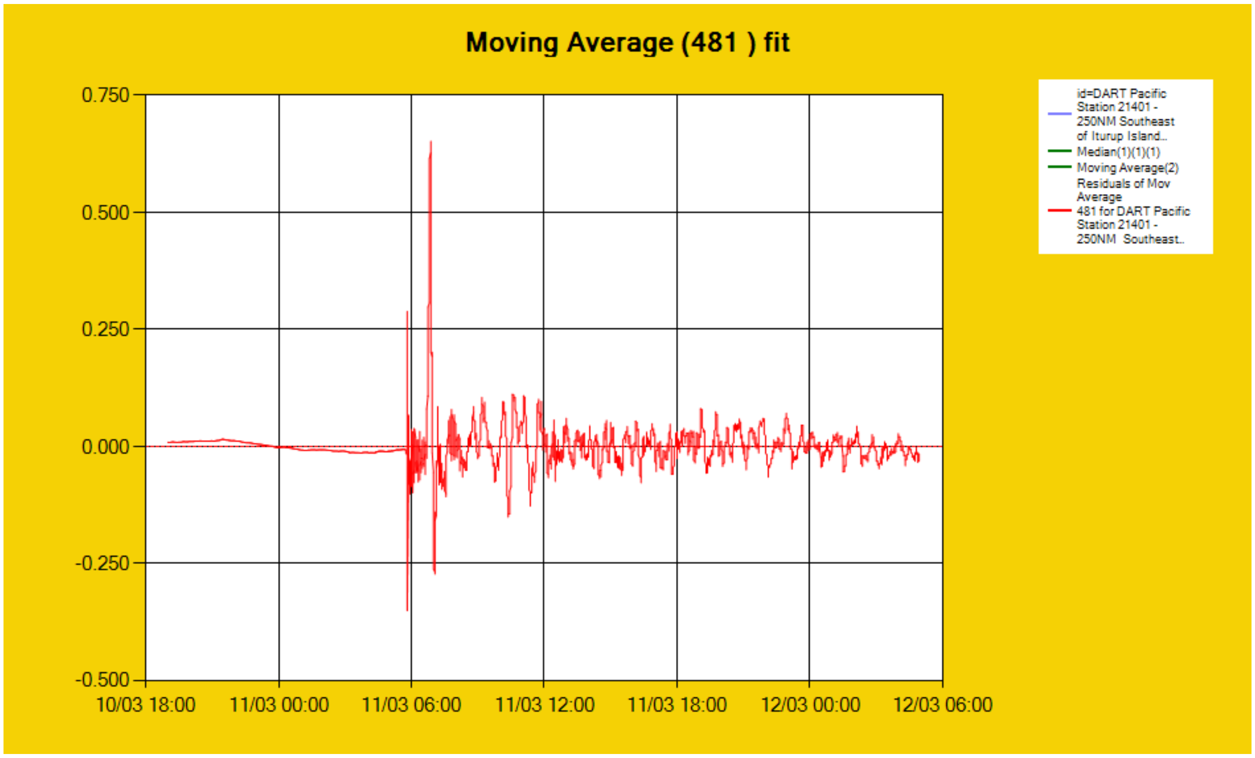
3.1.3.1 MOVING MEDIAN

For the large DART signal the moving median shows a very stable behavior before time 0 and is able to show the correct signal soon after the initial earthquake signal.



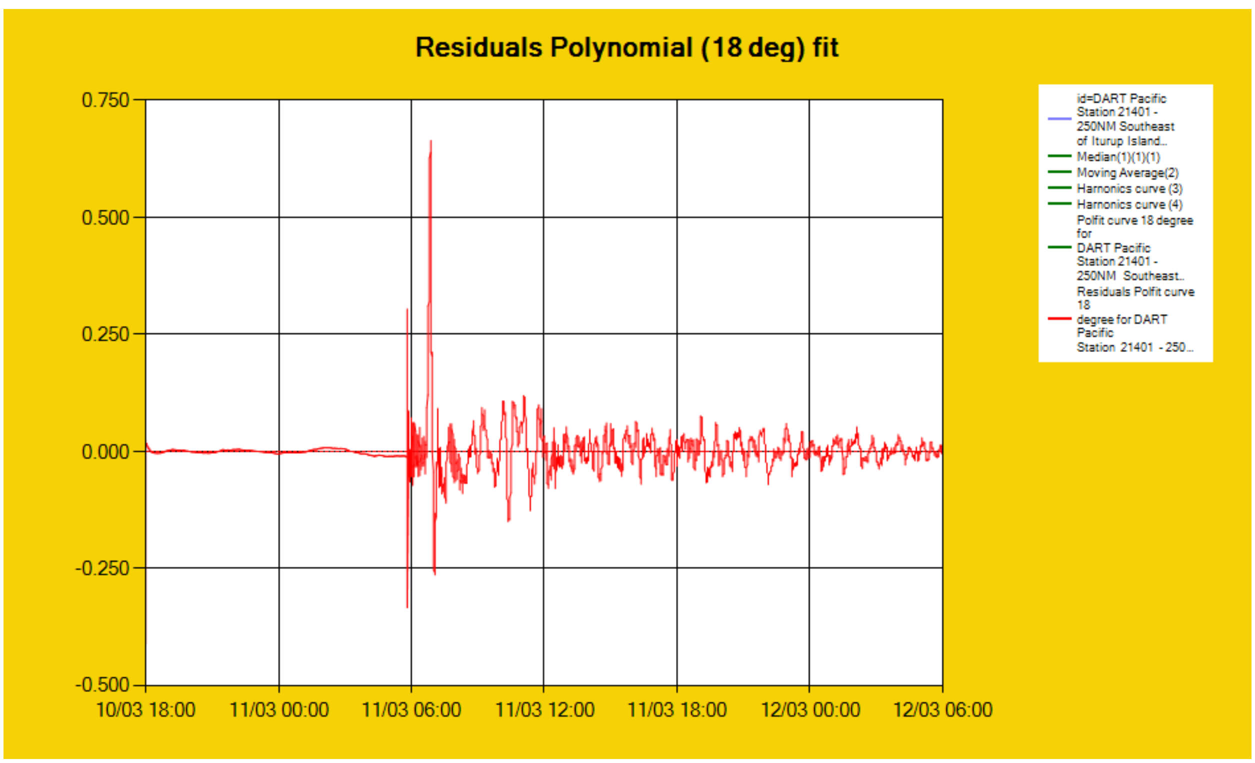
3.1.3.2 MOVING AVERAGE

The moving average shows a slightly oscillating signal before time 0 mostly due to the different time interval between the data. After time 0 the behavior is very similar to the moving median.



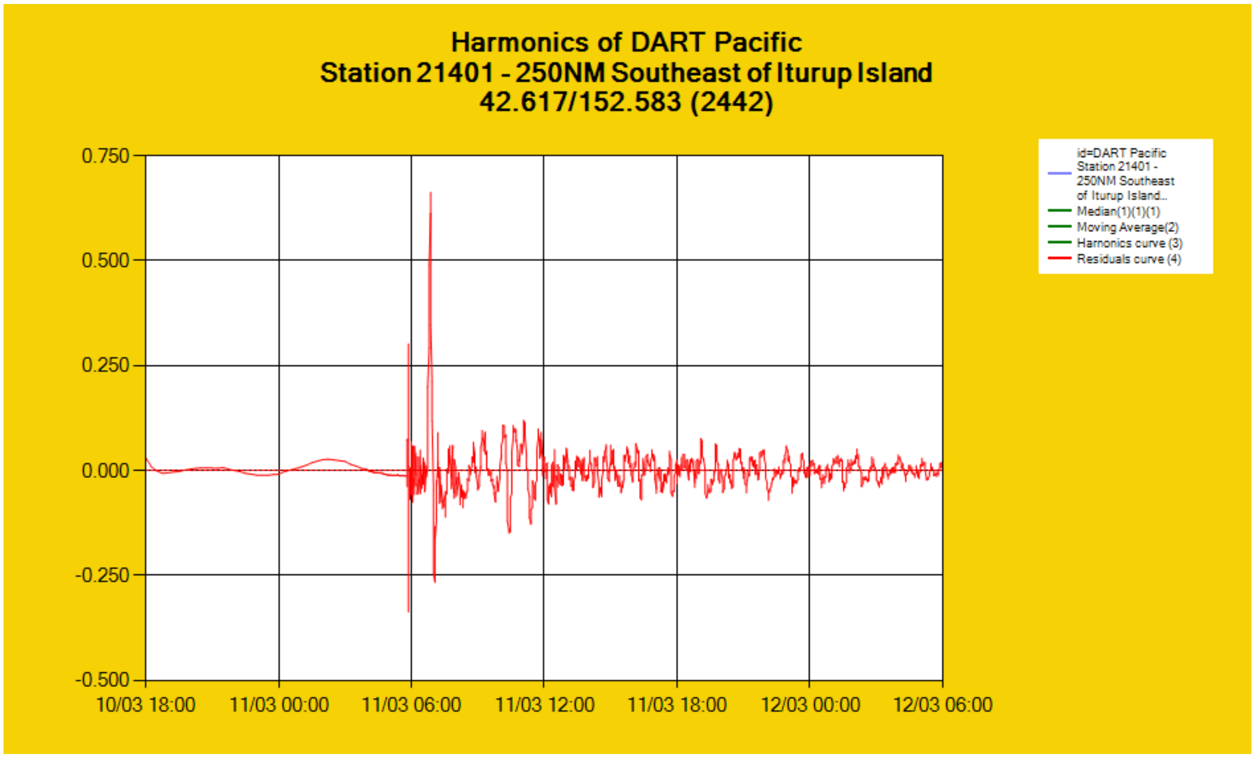
3.1.3.3 POLYNOMIAL FITTING

The polynomial fitting correctly shows the signal both before and after time 0.



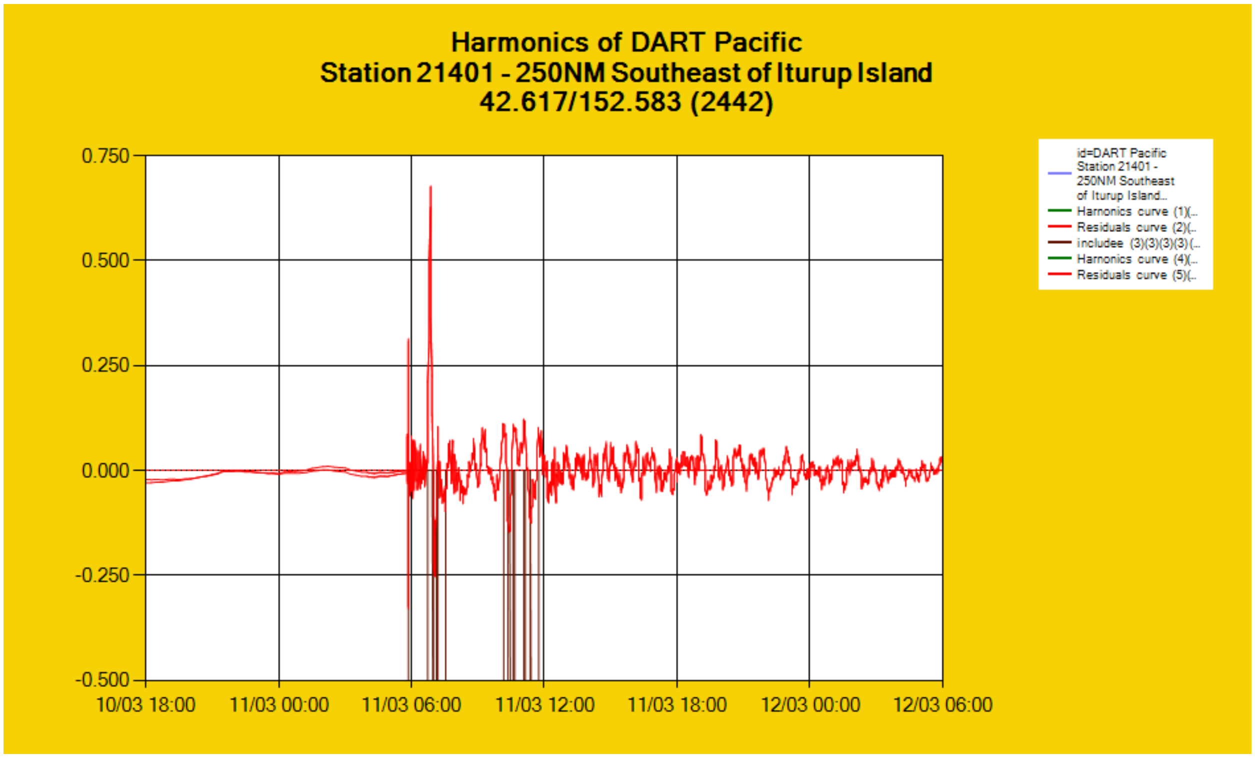
3.1.3.4 HARMONIC ANALYSIS

The harmonics analysis works well after time 0 while before it shows an oscillating signal, similar to the moving average.



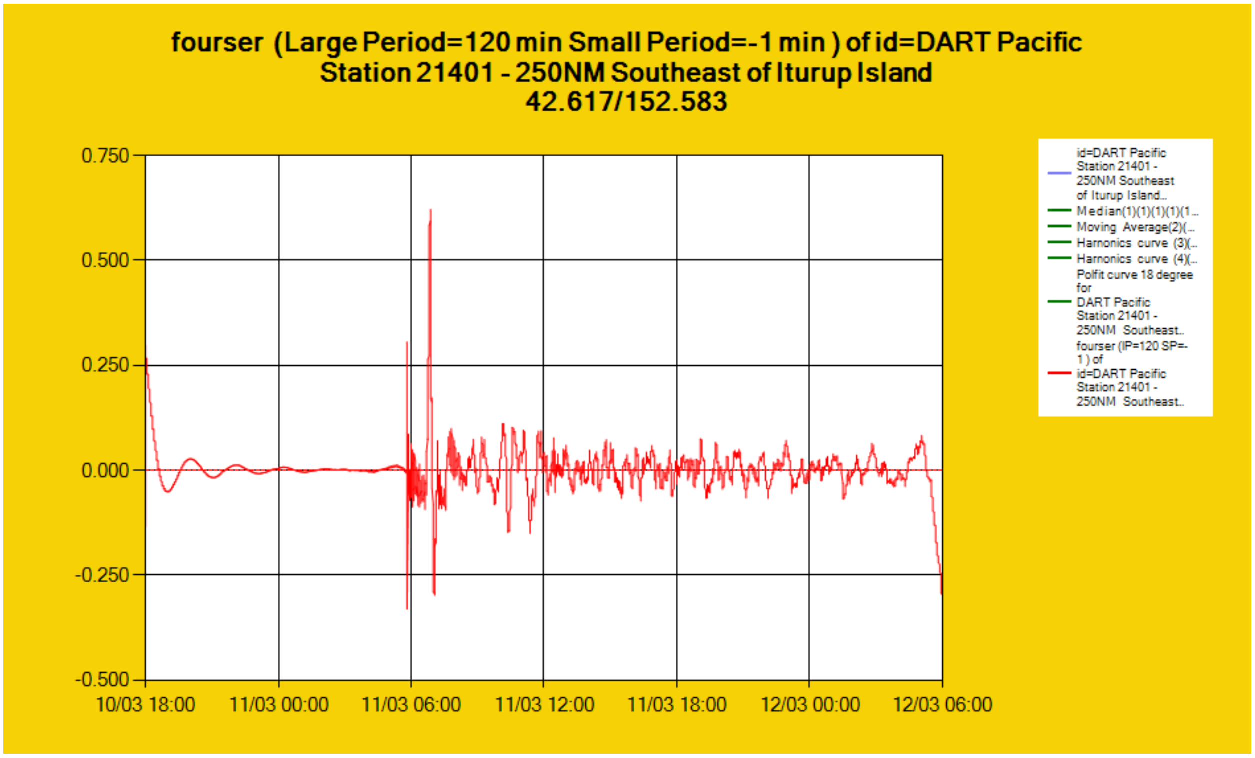
3.1.3.5 HARMONIC ANALYSIS WITH EXCLUSION

The exclusion of signals does not notably improve the behavior before time 0. After time 0 the trend is similar to the Harmonics method.



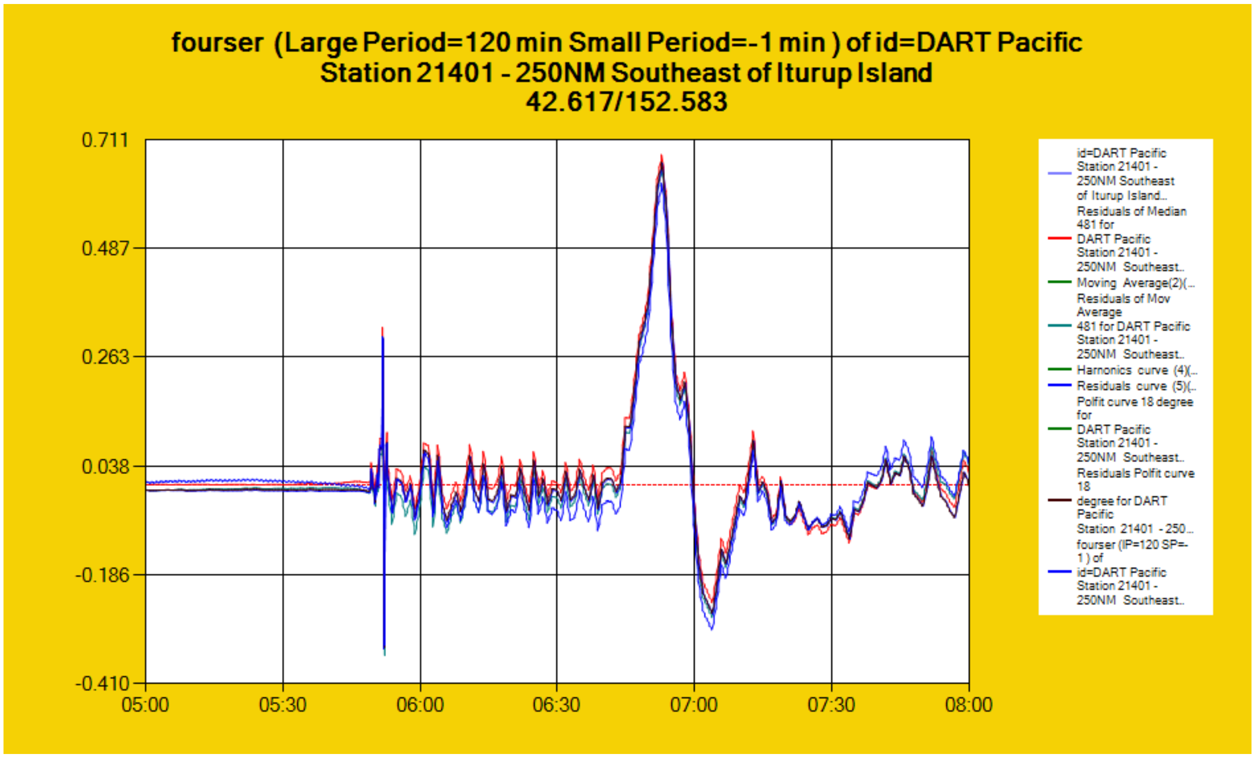
3.1.3.6 FFT

Excluding the borders where there is a large deviation the behavior is similar to the other methods. In this case the low pass filtering at 2h was used.


fourser (Large Period=120 min Small Period=-1 min) of id=DART Pacific Station 21401 - 250NM Southeast of Iturup Island 42.617/152.583
0.750
0.500
0.250
0.000
-0.250
-0.500
10/03 18:00
11/03 00:00
11/03 06:00
11/03 12:00
11/03 18:00
12/03 00:00
12/03 06:00
id=DART Pacific Station 21401 - 250NM Southeast of Iturup Island..
Median(1)(1)(1)(1)(1...
Moving Average(2)(...
Harmonics curve (3)(...
Harmonics curve (4)(...
Polfit curve 18 degree for DART Pacific Station 21401 - 250NM Southeast..
fourser (lP=120 SP=-1) of id=DART Pacific Station 21401 - 250NM Southeast..

3.1.3.7 CONCLUSION ON DART LARGE SIGNAL

There is not a large difference among the various methods. A large DART signal can well be represented by any of the methods.

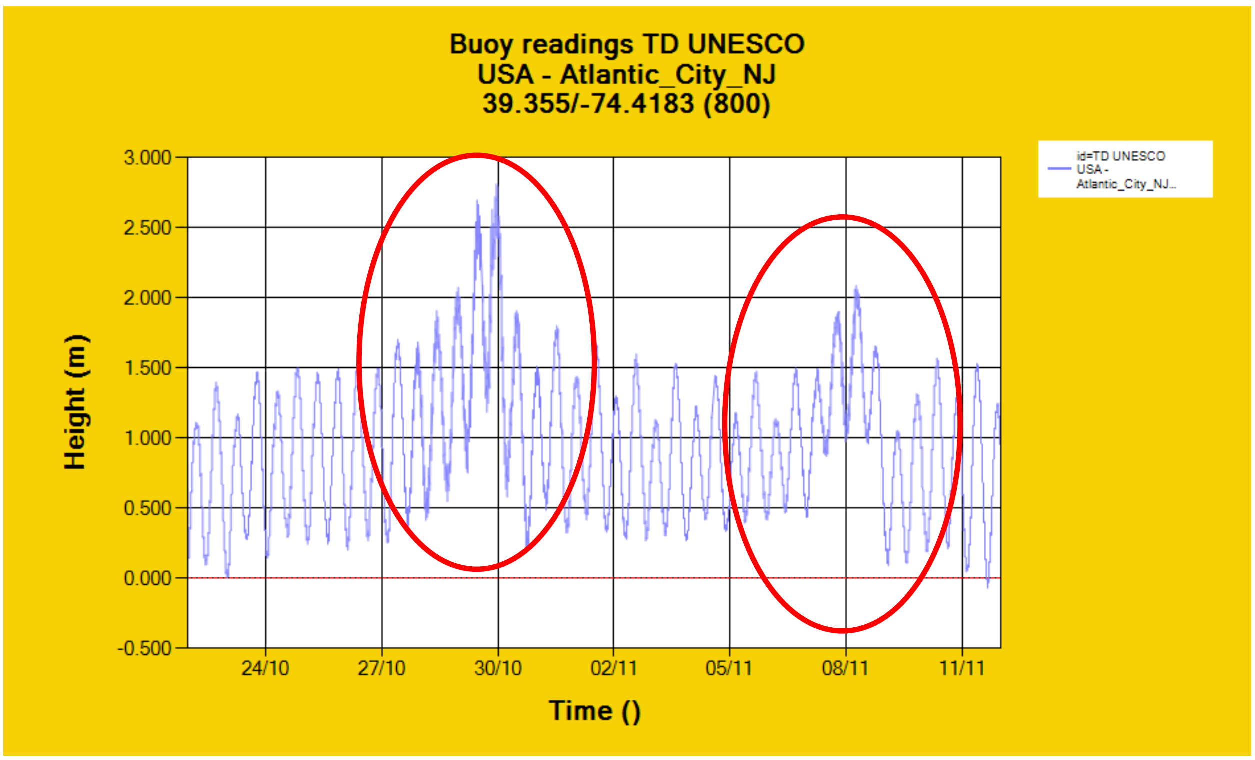


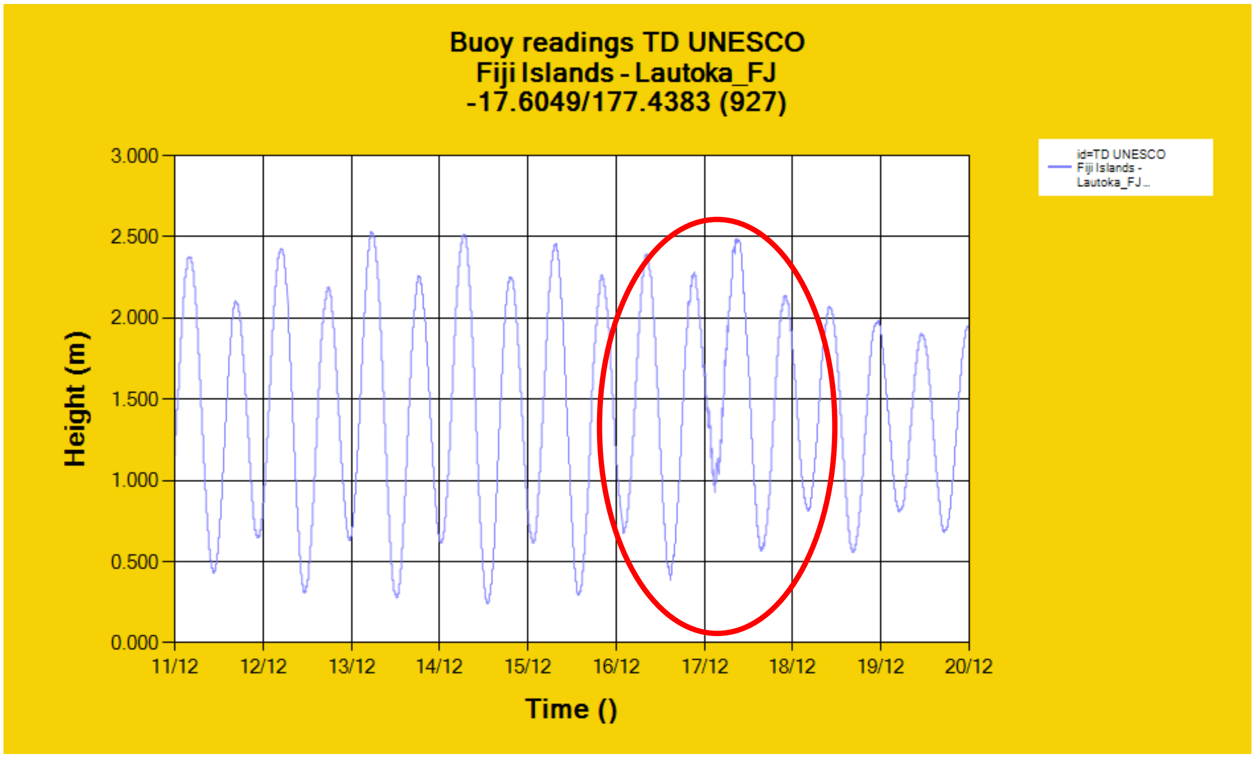
3.2 CYCLONE ANALYSIS

The analysis of cyclones is much more complicated than Tsunamis because the objective is the extraction of a deviation from the average lasting several days. If a moving average can work for Tsunamis because the signal oscillates around the theoretical tide with a period much smaller than the tide itself, in the case of cyclone the signal to extract is non-periodical and with a duration of days.

Therefore excluding Moving median, Moving Average and polynomial fitting the only remaining methods are: a) the already existing two points tide removal, that however does not work for DART signals because the harmonics are not defined there, and requires a manual intervention; b) the harmonics method with or without exclusion.

The selected test signals are the sea level in Atlantic City during the Sandy cyclone with 2 large events at distance of 3-4 days and in Lautoka, Fiji Islands in which a smaller event is shown.

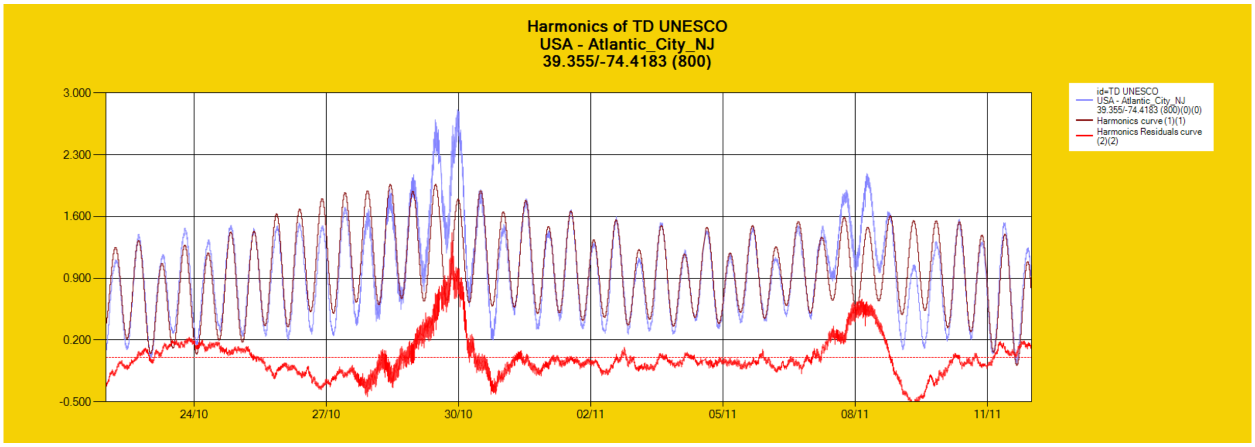




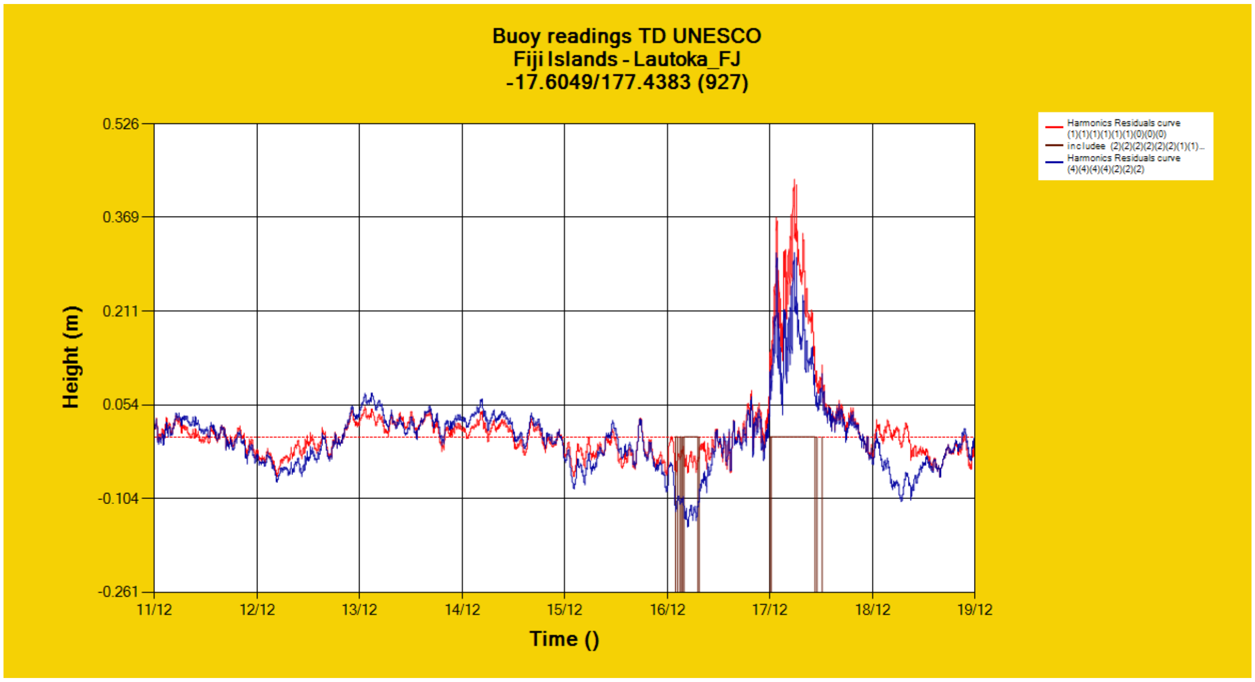
3.2.1 ATLANTIC CITY DATA

The analysis of Atlantic City shows that the method becomes correct only after 10 or 12 days but in the first 4-5 days a long term deviation is present. Nevertheless the two peaks are correctly identified without any big hassle. In particular the second peak is very well described with almost zero before and almost zero after the event.

The use of exclusion does not improve notably the data analysis



3.2.2 FIJI ISLAND CASE



In the case of Fiji Island the behavior is rather similar but the case with exclusion (red curve) is able to reduce the decrease before and after the large peak.

3.2.3 OVERALL CONCLUSION FOR POST EVENTS

	Tidal Gauge	DART small	DART large	Cyclone Large	Cyclone Small
Moving Median	Yes	No	**Yes** (BEST)	No	No
Moving Average	Yes	No	**Yes**	No	No
Harmonics	Yes (BEST)	**Yes**	**Yes**	Yes	Yes
Harmonics w/e	Yes	**Yes (BEST)**	Yes	Yes (BEST)	Yes (BEST)
Polynomial fit	Yes	**Yes**[1]	**Yes**	No	No
FFT	Yes	No	**Yes**	No	No

1 – with degree 5 instead of 3 as default

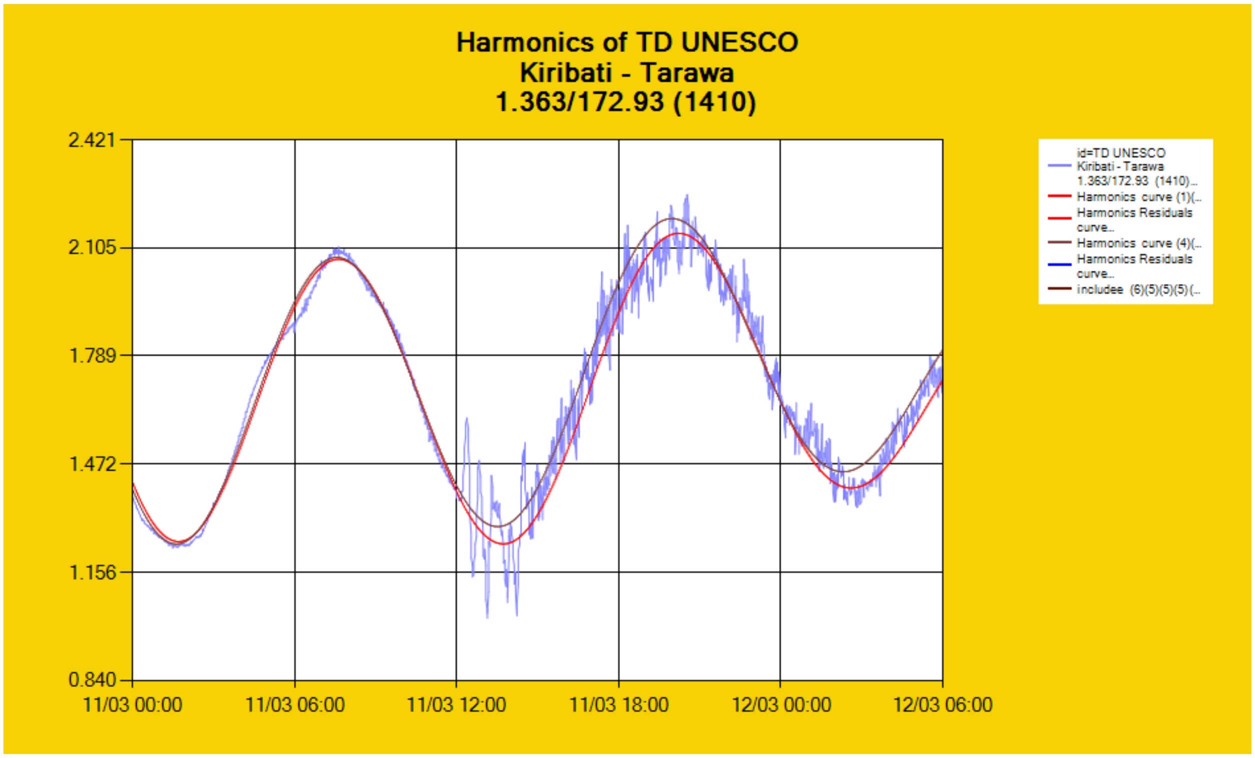
Taking into account the above analysis the following consideration can be made:

- The Harmonics analysis is certainly valid both for Tsunami as for Cyclone events and therefore is included as default analysis method for TAT. It will always possible to visualize the original data however
- The exclusion mode need to be refined but has certainly an important potential to perform even better.
- The other methods can be tested on a case by case but all require some input parameters while the harmonics methods not and thus are preferable.

4 SHORT TERM FORECAST OR ANALYSIS OF ONGOING EVENTS

During an ongoing event the evaluation of the residuals of the tidal gauge is not as easy as after an event. A part the psychological important reason that is due to the pressure to give an estimate of an event, a more technical reason is the fact that most of the methods shown before are much better in the central part of the analysis and much less in the border. During an ongoing event the future behavior in not known and therefore it is possible to rely only on the historic values (i.e. 1 month of previous data or less).

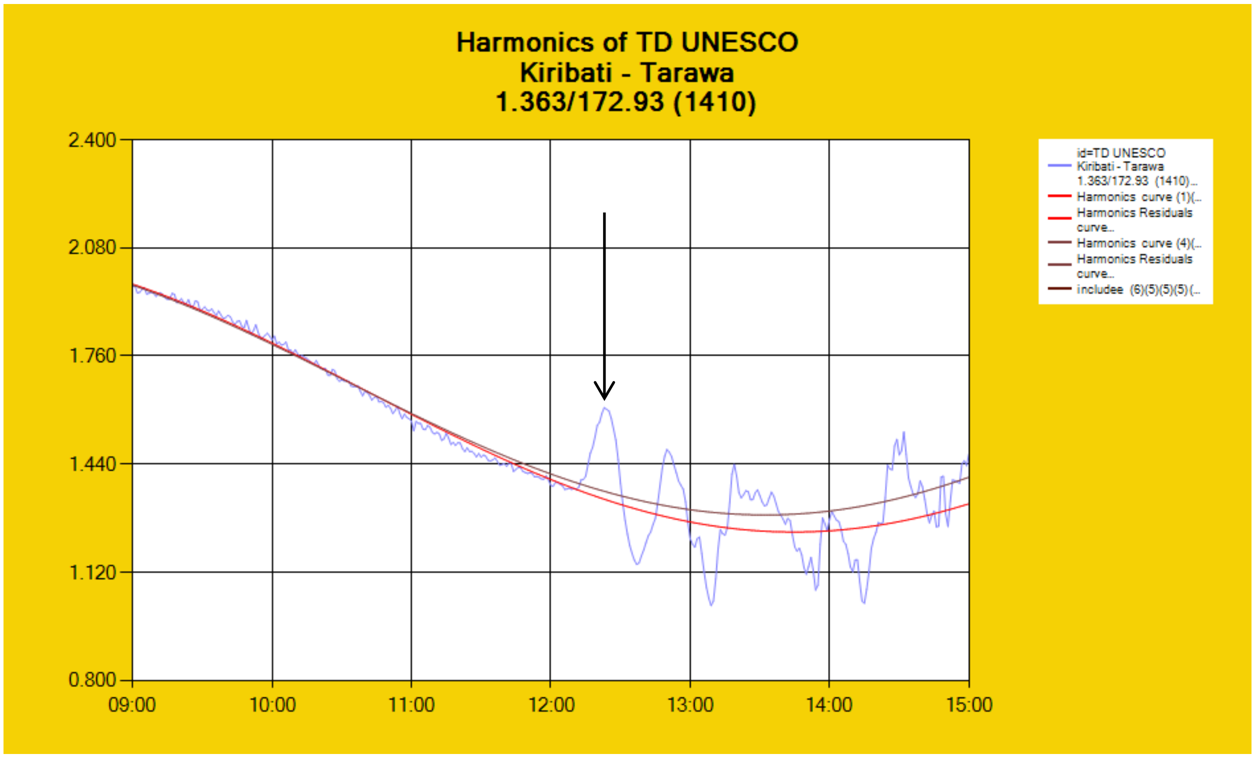
As an example the curve below shows the behavior in Kiribati, an island in the Pacific Ocean, during the 2011 Tsunami event. The wave arrives at this location at 12:11 PM. If we use the harmonic analysis over the whole period one would get the red curve as result of the tidal estimation.

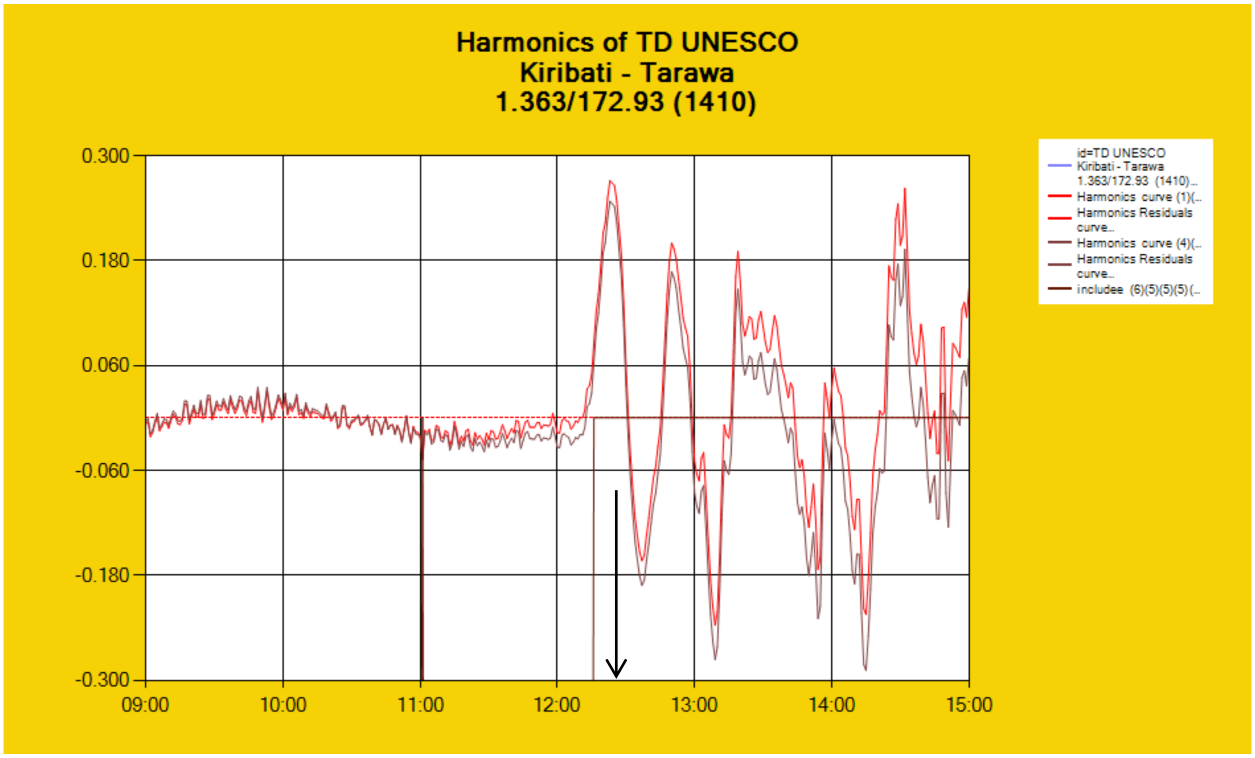


Limiting the period to determine the harmonics up to 12:20, i.e. the point indicated in the arrow, corresponding to the first maximum and determining the harmonics with exclusion, the resulting curve would be the brown one which is very close up to 12:00 and then deviates from the previous one. It should be noted that the exclusion would exclude also the period 10:11 to 10:20 because a larger deviation (more than 5 cm) from the curve is identified.

The resulting residuals are shown and it is possible to see that the 2 curves, the one determined with harmonics on the whole curve and the one obtained limiting the analysis to the beginning of the curve are very similar with a discrepancy that increases over time. However at the first maximum the difference being only 1 or 2 cm.

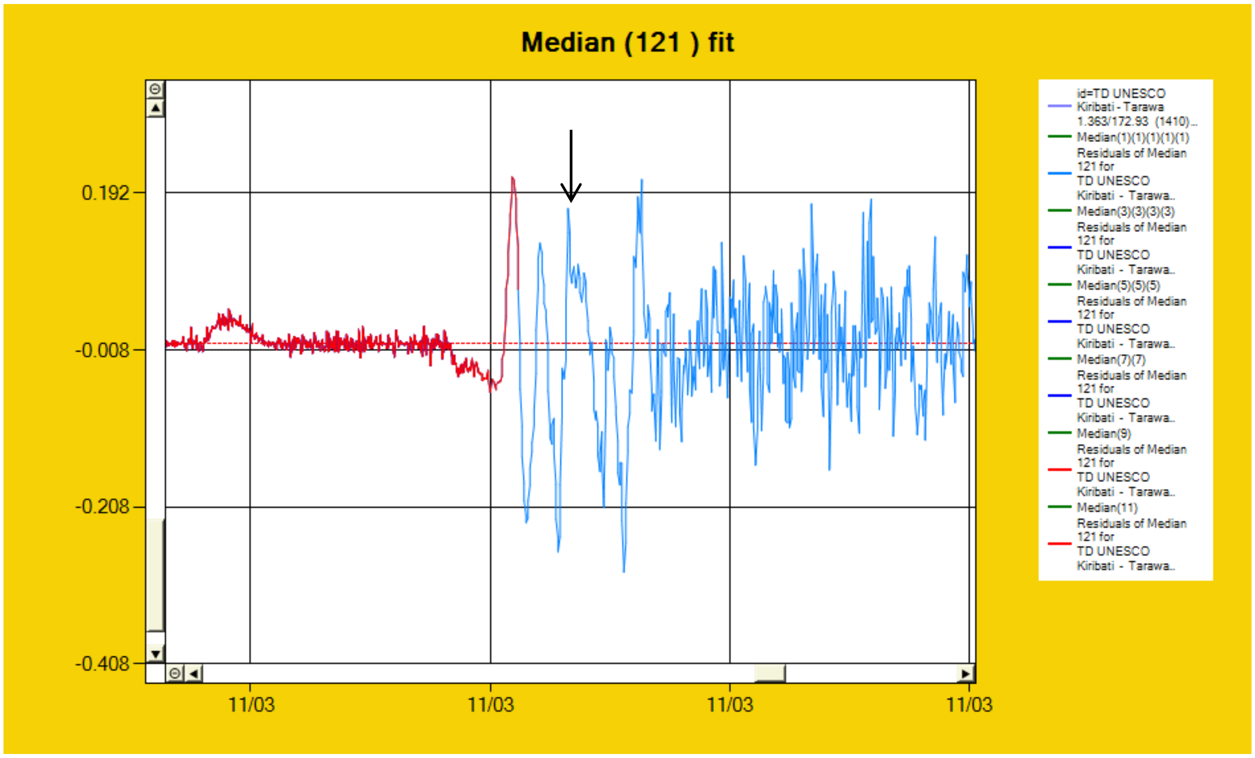
We will now examine if also the other methods are suitable for the ongoing analysis as it appears the Harmonics with exclusion.


Harmonics of TD UNESCO
Kiribati - Tarawa
1.363/172.93 (1410)
2.400
2.080
1.760
1.440
1.120
0.800
09:00
10:00
11:00
12:00
13:00
14:00
15:00
id=TD UNESCO
Kiribati - Tarawa
1.363/172.93 (1410)...
Harmonics curve (1)(...
Harmonics Residuals curve...
Harmonics curve (4)(...
Harmonics Residuals curve...
includee (6)(5)(5)(5)(...


Harmonics of TD UNESCO
Kiribati - Tarawa
1.363/172.93 (1410)
0.300
0.180
0.060
-0.060
-0.180
-0.300
09:00
10:00
11:00
12:00
13:00
14:00
15:00
id=TD UNESCO
Kiribati - Tarawa
1.363/172.93 (1410)...
Harmonics curve (1)(...
Harmonics Residuals curve...
Harmonics curve (4)(...
Harmonics Residuals curve...
includee (6)(5)(5)(5)(...

4.1.1 MOVING MEDIAN

The problem of the average median is that it needs a large sample in order to estimate the medium point. As we choose 120 points for the sample and in this case the points are stored every 1 min (in order to filter 2h components), it is necessary to wait 1h before having the point for the considered point. Once the point is calculated it is identical to the point calculated considering the whole interval, see below. The arrow shows the time at which the estimation is done. This is not acceptable for ongoing events.

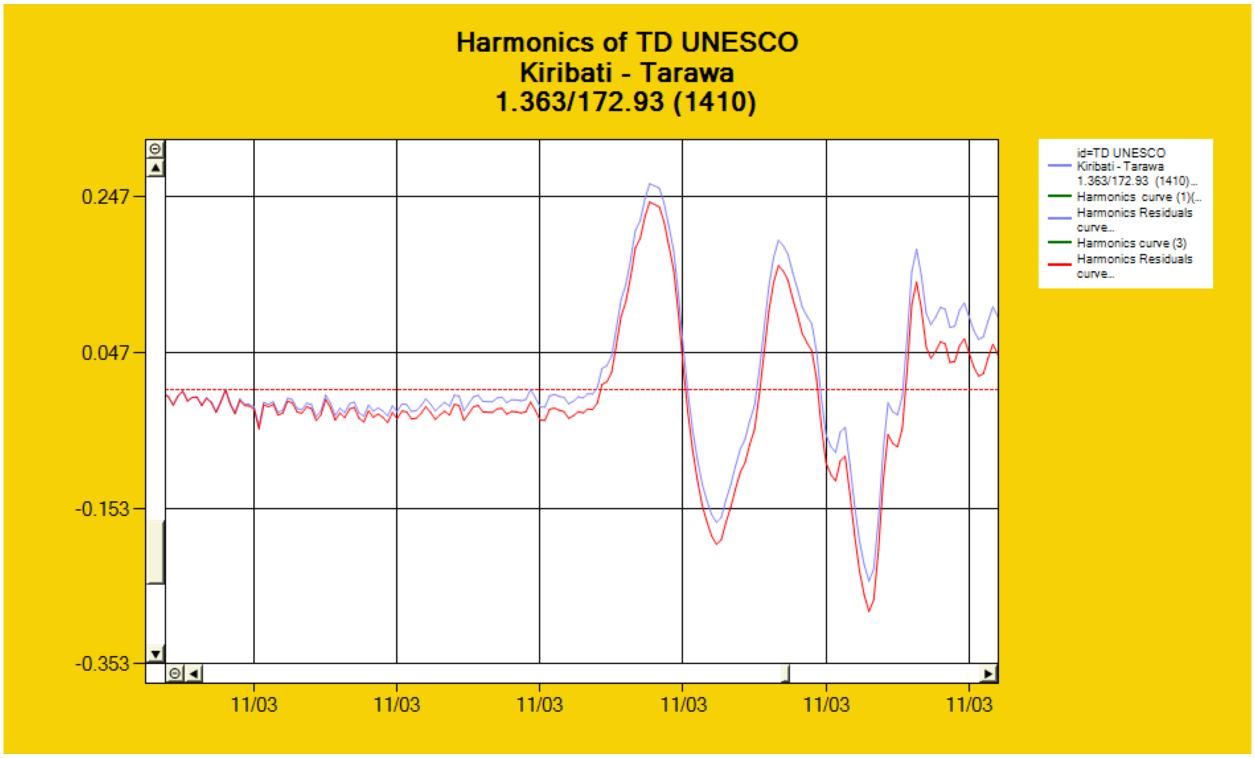


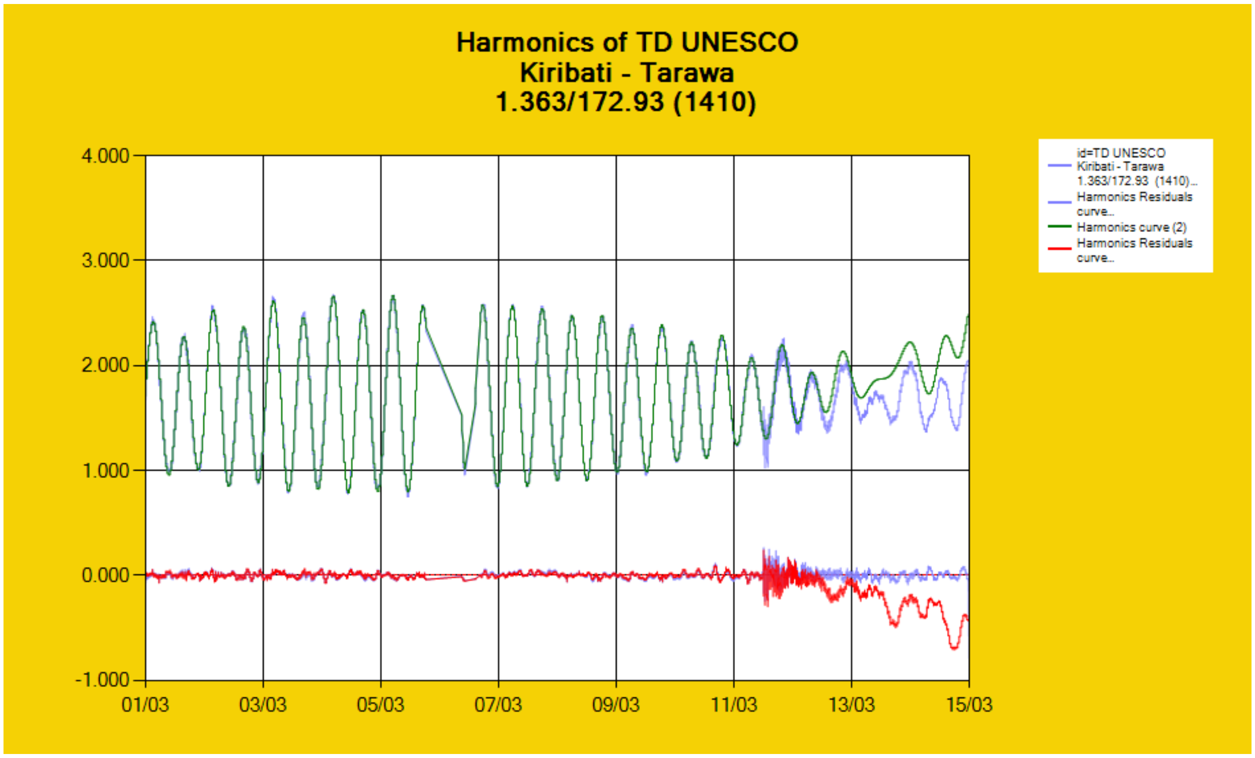
4.1.1.1 MOVING AVERAGE

The same as for moving median can be said for the moving average.

4.1.1.2 HARMONICS ANALYSIS

Even without the exclusion this method gives a perfect estimation of the behavior even considering only a partial set of data. Only after several hours the forecast becomes unacceptable.

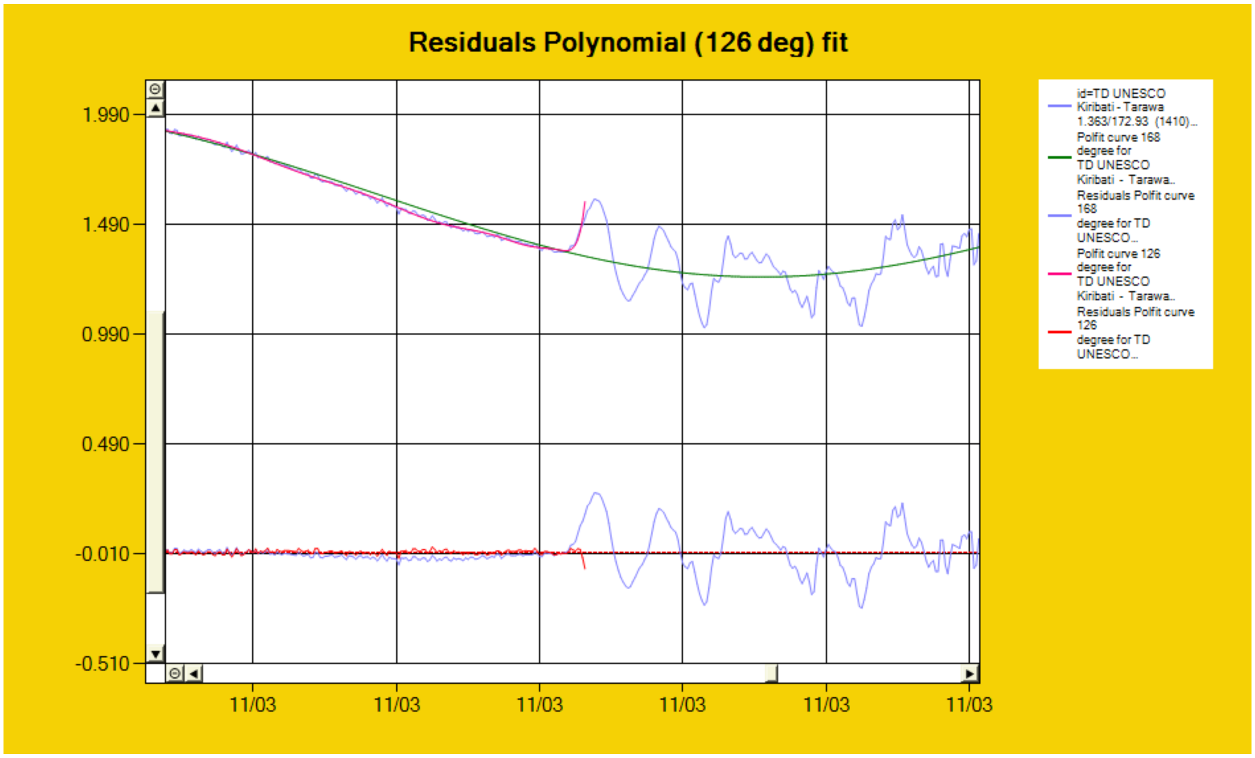




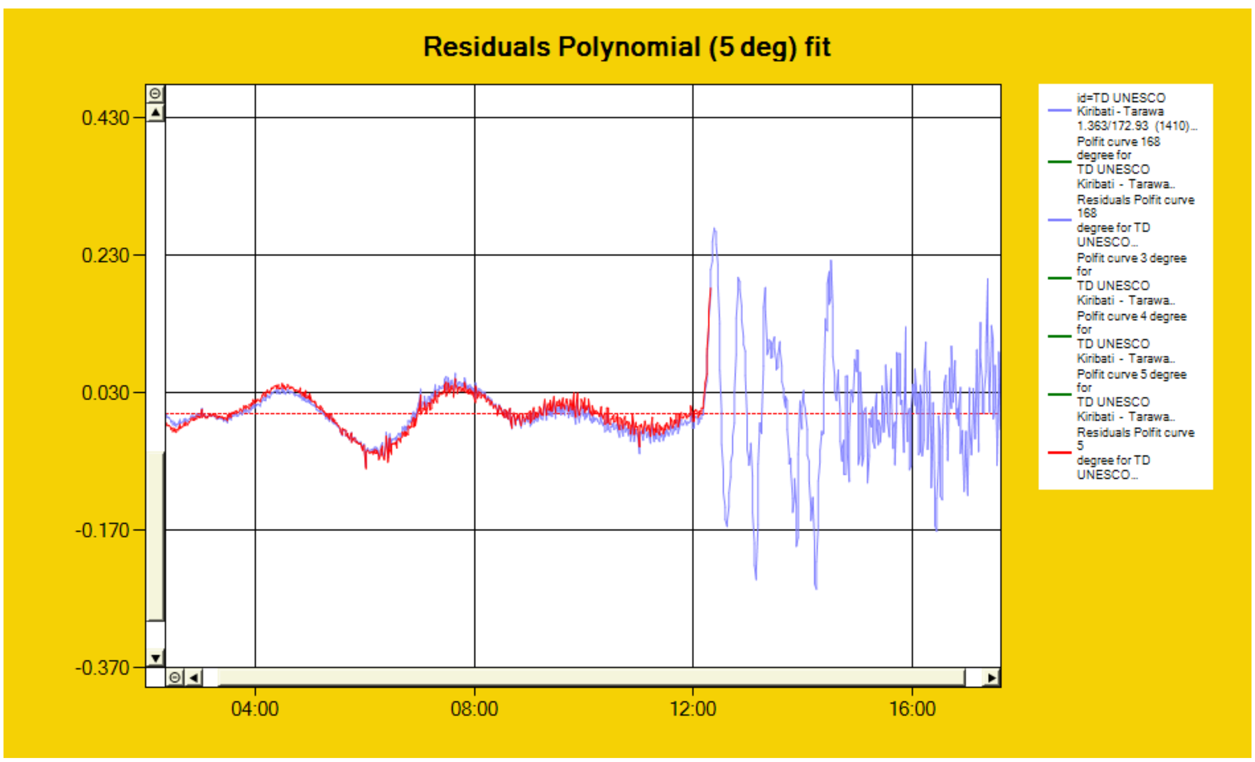
4.1.1.3 POLYNOMIAL FITTING

The method works well but it is necessary to choose carefully the time interval to be considered in order to have the estimating polynomial correct. As the method proposes a time interval so that the degree of the polynomial curve is the ratio between the time interval and 2 h, in order to have a maximum degree 4 in the polynomium it is necessary to have a maximum history of 8 h.

In the example below, using a degree 126 in the polynomial fitting because it is using several days of history, the curve follows too close the sea level curve and the residual curve does not represent the deviation from the tide.



Reducing the time considered for the fitting to 8 h, and using a degree 5, the system represents very well the rise of the first maximum.



4.1.1.4 CONCLUSIONS ON THE TSUNAMI ESTIMATE OF ONGOING EVENTS

Overall conclusion for short term forecast

	Tidal Gauge
Moving Median	No
Moving Average	No
Harmonics	Yes
Harmonics w/e	Yes (Best)
Polynomial fit	Yes
FFT	No

The Harmonics analysis with exclusion represents the best method to predict the data during an ongoing event because it can forecast the behavior for several hours. However in order to work well it needs several hours of data to correctly predict the harmonics. If the set of data is much smaller, it is possible to use the polynomial fitting keeping the degree of the polinomium between 3 and 6.

5 CONCLUSIONS

Some important improvements have been made in the TAT data analysis model. Several new models have been added and tested and the best is the harmonics analysis that is therefore included as a default method.

The method has been tested online during the ongoing event of Alaska of 5 January 2012 and proved to be very effective in allowing a good forecast. The old methods are however always ready to be used in case of doubts.

In the future the analysis will be exposed to the users so that everyone can try and implement his own method independently by the development.

In consequence of the conclusions JRC started to reanalyze all the available sea level data in order to compute harmonics coefficients continuously on the fly as the data are stored. This has already led to the creation of a database of harmonics based on a time period ranging from 6 months to 1.5 year, depending on the sensor. Once the stability of the coefficients will be achieved, it will represent another method for estimating the tide in a very stable condition and will allow long range forecast, which at the moment is limited to a fraction of the time of analysis considered.