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Continuous Harmonics Analysis of Sea Level Measurements

Description of a new method to determine sea level measurement tidal component

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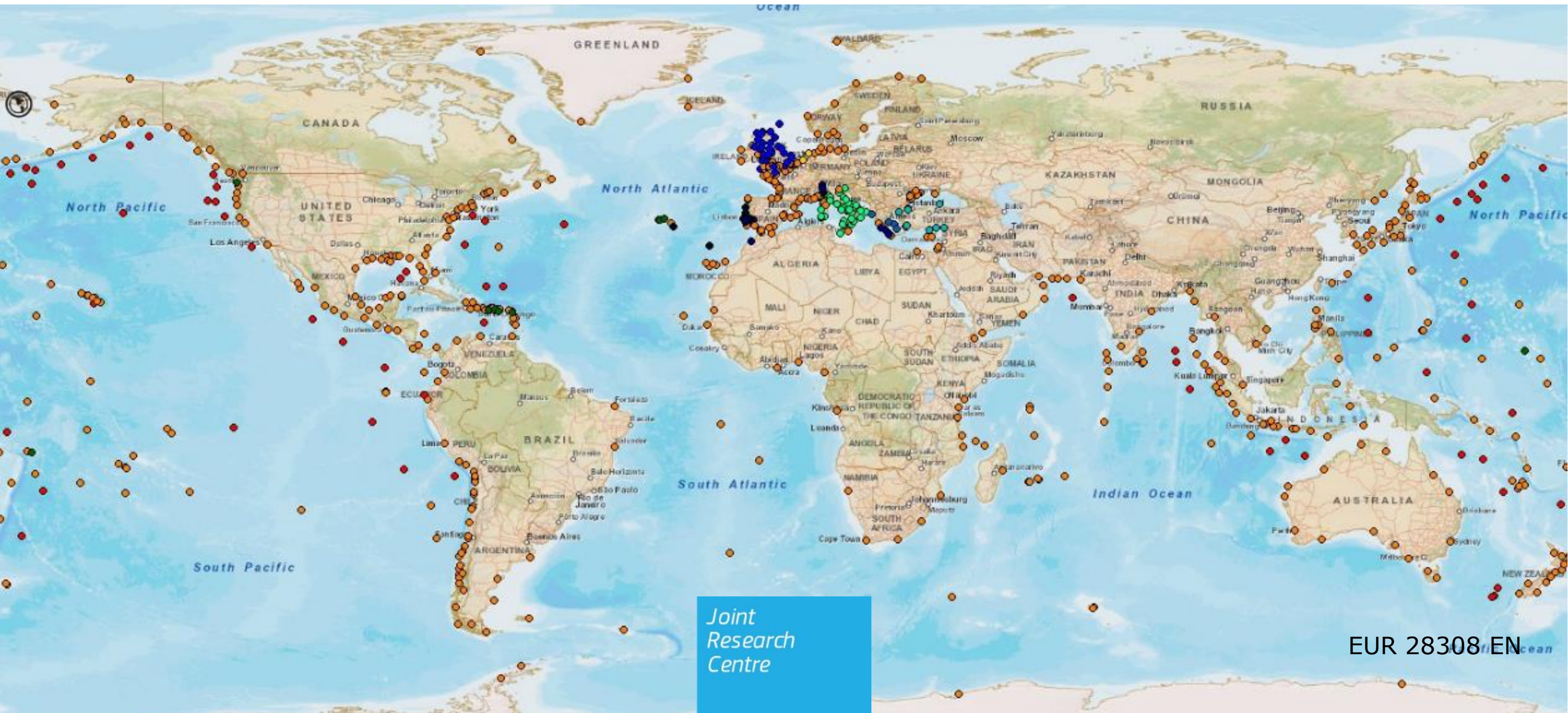

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Contents

Abstract

Removing the tidal component from sea level measurement in the case of Tropical Cyclones or Tsunami is very important to distinguish the tide contribution from the one of the Natural events. The report describes the methodology used by JRC in the de-tiding process and that is used for thousands of sea level measurement signals collected in the JRC Sea Level Database.

1 Introduction

Detiding mechanism is very important for the analysis of sea level behavior in the case of Tropical Cyclones or Tsunami as it is necessary to distinguish the tide contribution from the one of the Natural events. The situation is even more exacerbated when real-time analysis is to be performed and the need to compare detied signals with calculated values, such as online publication of storm surge data.

The interest of JRC is in the frame of the Global Disasters Alerts and Coordination System (GDACS, http://www.gdacs.org), a system developed in the frame of a cooperation between JRC and the United Nations. It includes disaster managers and disaster information systems worldwide and aims at filling the information and coordination gap in the first phase after major disasters. GDACS provides real-time access to web-based disaster information systems and related coordination tools. The Natural Disasters considered in GDACS are Earthquakes, Tsunamis, Tropical Cyclones and Floods.

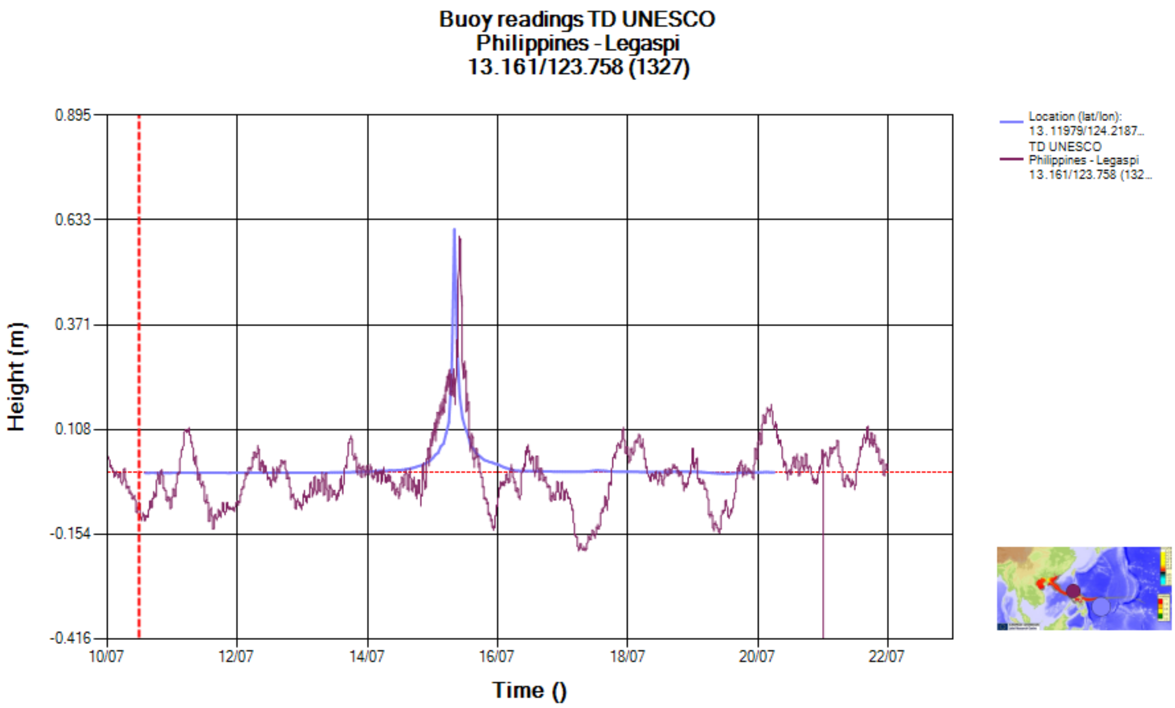

Figure 1 - Comparison of measured and calculated storm surge in Philippines, during the Tropical Cyclone RAMASSUN (July 2014)

An example is shown in the **Figure 1** in which the calculated storm surge is compared with the estimated one from the sea level measurement for the RAMASSUN Tropical Cyclone that hit Philippines in July 2014. In order to perform this comparison it is necessary to de-tide the measured value (***ML***, brown curve in **Figure 2** and **Figure 3**) from the estimated tide (***TD***) in that location, green curve. The difference between those two is the storm surge ***SS***, compared in **Figure 1** with the calculated value:

$$SS = ML - TD$$

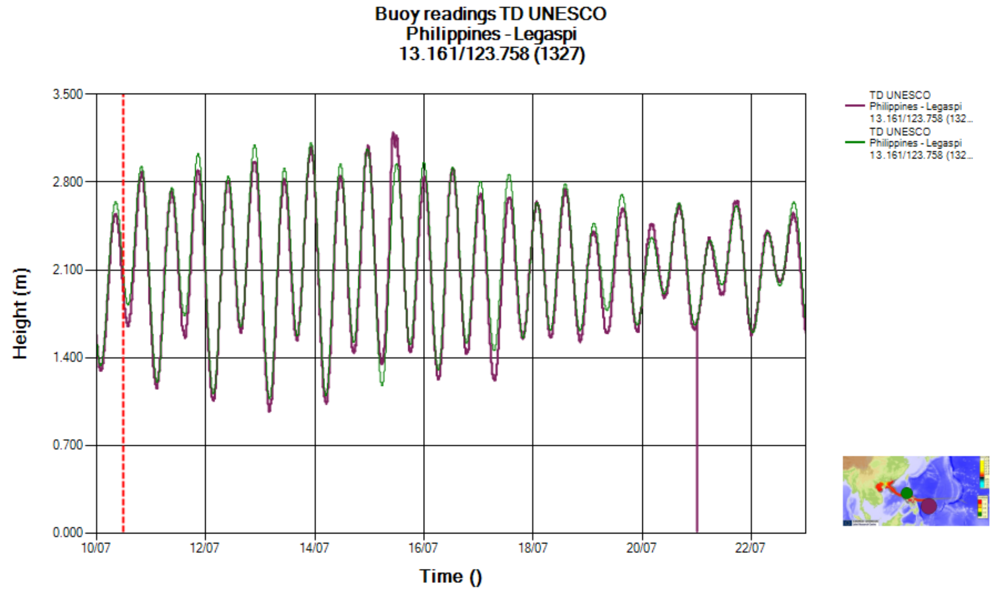

Figure 2 – Measured (brown curve) sea level and estimated tide from Harmonics

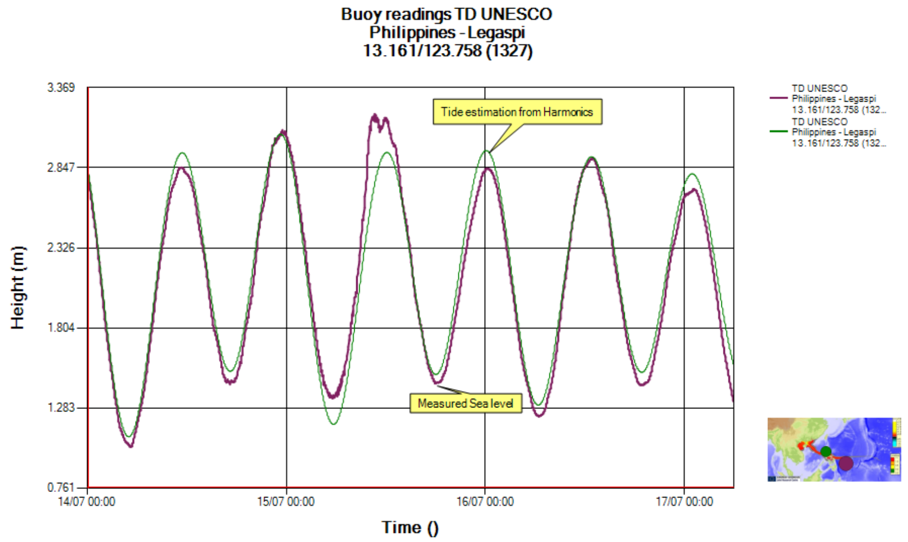

Figure 3 – Measured (brown curve) sea level and estimated tide from Harmonics during the storm surge

At the same time it is also possible to add the estimated tide to the sea level calculated by the codes that do not calculate tide (see **Figure 3**) to compare the measured level with the estimated sea level. In this case, **Figure 1** is much more representative of the deviation from the normal conditions due to the passage of the tropical cyclone.

It could also be possible to use global tide models to obtain the tide behavior at the location of the measurements, such as DTU10[1] . These models are valid worldwide but for specific locations where the tide gauge are installed (ports, small habours etc) it is better to derive the harmonics of the tide gauge and use these for tediting process. In these locations, the global models are not so accurate because the local characteristics can influence the tide estimation.

The determination of the harmonics coefficients from the measured data is a known method, based on least square approximation of the first order in the coefficients. However the computational requirements when several years of data are considered may be a limiting factor for a routine and frequent update of the coefficients; several centres determine the constants once a year or less frequent. This paper describes a new method, named Continuous Harmonics Determination (CHD), that is used at JRC in order to continuously compute the harmonics with a rather limited computing time; this allows to repeat the harmonics identification procedure once per hour for thousands of different sensors worldwide.

[1] Yongcun Cheng, Ole Baltazar Andersen, (2010). Improvement in global ocean tide model in shallow water regions. Poster, SV.1-68 45, OSTST, Lisbon, Oct.18-22.

2 Methodology

2.1 Harmonics constituents

The objective is the estimation of the tide harmonics constants which constitutes the coefficients of a series of periodic terms. The definition of the terms varies from organization to organization.

For instance the National Oceanographic Center in UK uses the following formulation[2]:

$$L=Ho+\sum H_n \cos(\sigma_n t - g_n)$$

Where

t is the time since 1976

$\boldsymbol{\sigma_n}$ is the speed expressed in rad/s, so that the period in h would be: $T_h=1/3600\ 2\pi/\boldsymbol{\sigma_n}$

$\boldsymbol{g_n}$ is the phase expressed in rad but the published data are in Degrees

NOAA[3] uses another similar but not identical formulation of the terms

$$L=Ho+\sum H_n \cos(s_n t_h \pi/180 - g_n)$$

The difference is the speed definition that in their case is

t_h is the time in hours since 1976

s_n rate change in the phase of a constituent, expressed in degrees per hour. The speed is equal to 360 degrees divided by the constituent period expressed in hours. The period in this case is $Th=360/s_n$

$\boldsymbol{g_n}$ is the phase expressed in rad and the published data are in degrees

The third example is the Italian Institute for the Environmental Research, responsible for the mareographic network, who uses another formulation[4]

$$L=Ho+\sum H_n \cos(f_n t - g_n)$$

Where

Fn is expressed in cycles per cycles per hour

2 http://www.ntslf.org/tides/constants
3 http://tidesandcurrents.noaa.gov/harcon.html?id=8730667
4 http://www.mareografico.it/?session=0S15912498696789906 8A838074&syslng=ita&sysmen=-1&sysind=-1&syssub=-1&sysfnt=0&code=ARCH

At JRC we always used yet another method to express the constituents, based on a sum of sinus and cosines terms:

$$L=Ho+\sum A_n \cos(\boldsymbol{\sigma}_n t^*) + B_n \sin(\boldsymbol{\sigma}_n t^*)$$

Where

t^* is the time in s since 1900

$\boldsymbol{\sigma}_n$ is the speed expressed in rad/s, so that the period in h would be: $T_h=1/3600\ 2\pi/\boldsymbol{\sigma}_n$

As all the formulation need to provide the same component for the same constituent, the following equality is always valid:

$H_{nocs} \cos(\sigma_{nocs} t - g_{nocs}) = H_{NOAA} \cos(s_{NOAA}\, t_h\, \pi/180 - g_{noaa}) = H_{ISPRA} \cos(f_{ISPRA}\, t - g_{ISPRA}) = A_{JRC} \cos(\boldsymbol{\sigma}_{JRC}\, t^*) + B_n \sin(\boldsymbol{\sigma}_{JRC}\, t^*)$

To change from one to another formulation requires some trigonometric functions involving the coefficients A, Bn, and some change in the input independent variable time or in the period in days or hours (See appendix A for an example).

Also the number of published components data varies a lot. NOAA publishes 37 components of the harmonics, NOCS 4 and ISPRA 60.

#	Name	Period(h)	NOAA	NOCS	ISPRA	Description
1	M8	3.10515031	X			Shallow water eighth diurnal constituent
2	S6	4.00000000	X			Shallow water overtides of principal solar constituent
3	M6	4.14020040	X			Shallow water overtides of principal lunar constituent
4	2SK5	4.79737334			X	
5	2MK5	4.93087894			X	
6	SK4	5.99179843			X	
7	S4	5.99999880	X		X	Shallow water overtides of principal solar constituent
8	MK4	6.09485174			X	
9	MS4	6.10334054	X		X	Shallow water quarter diurnal constituent
10	SN4	6.16019210			X	
11	M4	6.21030065	X		X	Shallow water overtides of principal lunar constituent
12	MN4	6.26917584	X		X	Shallow water quarter diurnal constituent

13	SK3	7.99270426			X	
14	MK3	8.17714309	X		X	Shallow water terdiurnal
15	SO3	8.19242365			X	
16	M3	8.28040087	X		X	Lunar terdiurnal constituent
17	2MK3	8.38629981	X		X	Shallow water terdiurnal constituent
18	2SM2	11.60695156	X			Shallow water semidiurnal constituent
19	ETA2	11.75452232			X	
20	MSN2	11.78613168			X	
21	K2	11.96723515	X		X	Lunisolar semidiurnal constituent
22	R2	11.98359685	X		X	Smaller solar elliptic constituent
23	S2	11.99999904	X		X	Principal solar semidiurnal constituent
24	T2	12.01644908	X		X	Larger solar elliptic constituent
25	L2	12.19162058	X		X	Smaller lunar elliptic semidiurnal constituent
26	LAM2	12.22177436	X		X	Smaller lunar evectional constituent
27	MKS2	12.38550069			X	
28	H2	12.40302847			X	
29	M2	12.42060131	X	X	X	Principal lunar semidiurnal constituent
30	H1	12.43822401			X	
31	NU2	12.62600437	X		X	Larger lunar evectional constituent
32	N2	12.65834802	X		X	Larger lunar elliptic semidiurnal constituent
33	MU2	12.87175727	X		X	Variational constituent
34	2N2	12.90537393	X		X	Lunar elliptical semidiurnal second-order constituent
35	EPS2	13.12726847			X	
36	OQ2	13.16223481			X	
37	UPS1	21.57823654			X	
38	OO1	22.30607323	X		X	Lunar diurnal
39	SO1	22.42017744			X	

40	J1	23.09847573	X		X	Smaller lunar elliptic diurnal constituent
41	THE1	23.20695522			X	
42	PHI1	23.80447386			X	
43	PSI1	23.86929935			X	
44	K1	23.93446743	X	X	X	Lunar diurnal constituent
45	S1	23.99999808	X	X	X	Solar diurnal constituent
46	P1	24.06588855	X		X	Solar diurnal constituent
47	PI1	24.13214182			X	
48	CHI1	24.70906924			X	
49	M1	24.83324836	X			Smaller lunar elliptic diurnal constituent
50	NO1	24.83325093			X	
51	BET1	24.97475676			X	
52	TAU1	25.66813514			X	
53	O1	25.81934463	X	X	X	Lunar diurnal constituent
54	RHO	26.72305330	X			Larger lunar evectional diurnal constituent
55	RHO1	26.72305588			X	
56	Q1	26.86835848	X		X	Larger lunar elliptic diurnal constituent
57	SIG1	27.84838892			X	
58	2Q1	28.00622298	X		X	Larger elliptic diurnal
59	ALP1	29.07266626			X	
60	MF	327.85917793	X		X	Lunisolar fortnightly constituent
61	MSF	354.36740103	X		X	Lunisolar synodic fortnightly constituent
62	MM	661.31005522	X		X	Lunar monthly constituent
63	MSM	763.48699782			X	
64	SSA	4382.88920056	X		X	Solar semiannual constituent
65	SA	8766.54685719	X		X	Solar annual constituent

Table 1 - Components of the harmonics of NOAA, NOCS and ISPRA

Some of the methods establish the tides components each year (ISPRA) or use corrective functions in order to take into account slow components variations and use the same formulation per each year (NOAA). Most of the systems determine the new components once a year and then use the estimated components for another year.

At JRC we use all 69 harmonics components and all the available data (3 years for most of the data with few exceptions in which we have 10 years or more of data) and have established a procedure (Continuous Harmonics Determination - CHD) that allows easily to take into account all the data despite the number of years. The estimation is performed every hour and requires, for some 1000 signals, about 30-40 min in total. The estimated values considered are related to the whole amount of data available.

It is clear that the method is valid if the data are valid and if the reference point of the measurement is kept constant over the years, which sometimes is not the case. It is therefore necessary from time to time, to check the consistency of the collected data.

3 The Continuous Harmonics Determination method

3.1 Least square method

The method consists in obtaining a least square approximation of the harmonics constituents using as data a large number of measurements over a number of years. The discussion is here conducted considering the two components An, Bn of sin/cos but a similar analysis could be determined using the other formulations. In any case it is easy to convert the constants obtained with one method into the other ones.

Each measurement $Y_i(t_0)$ can be expressed as a linear combination of the harmonics terms plus an error:

$$Y_i(t_0) = c_o + cc_1 \cos(f_1\ t_0) + cs_1 \sin(f_1\ t_0) + cc_2 \cos(f_2\ t_0) + cs_2 \sin(f_2\ t_0) \ldots + cc_n \cos(f_n\ t_0) + cs_n \sin(f_n\ t_0) + \varepsilon$$

Where ε is the error and n is the number of harmonics considered in the expansion.

The objective is to minimize the overall error over the N points assumed:

$$totErr^2 = \varepsilon^2 = \Sigma_{j=1,N} \left(Y_j - c_o - \Sigma_i\ cc_i \cos(f_i\, t_j) + cs_i \sin(f_i\, t_j) \right)^2$$

This can be rewritten as a series of coefficients

$$totErr^2 = \varepsilon^2 = \Sigma_{j=1,N} \left(Y_j - a_o - \Sigma_{i=1,2n}\ a_i\ X_i^j \right)^2$$

with

$a_o = c_o$

$a_i = cc_i$ for i=1,n

$a_i = cs_i$ for i=n+1,2n

$X_i^j = \cos(f_i\ t_j)$ for i=1,n

$X_i^j = \sin(f_i\ t_j)$ for i=n+1,2n

the derivation of the total error for each coefficient produces a matrix C of order (2n+1)x(2n+1) in which each term can expressed as a linear combination of the various sums.

The coefficients are obtained differentiating the quantity ε with respect to the various coefficients a_i.

$$\partial\varepsilon/\partial a_o = 2 N a_o - 2 \Sigma Y_j + 2 a_1 \Sigma X_1^j + 2 a_2 \Sigma X_2^j + \ldots + 2 a_n \Sigma X_n^j$$

$$\partial\varepsilon/\partial a_1 = 2 a_1 \Sigma (X_1^j)^2 - 2 \Sigma (Y_i^j X_1^j) + 2 a_o \Sigma X_1^j + 2 a_2 \Sigma (X_1^j X_2^j) + \ldots + 2 a_n \Sigma (X_1^j X_n^j)$$

$$\partial\varepsilon/\partial a_2 = 2 a_2 \Sigma (X_2^j)^2 - 2 \Sigma (Y_i^j X_2^j) + 2 a_o \Sigma X_2^j + 2 a_1 \Sigma (X_1^j X_2^j) + \ldots + 2 a_n \Sigma (X_2^j X_n^j)$$

…

$$\partial\varepsilon/\partial a_n = 2 a_n \Sigma (X_n^j)^2 - 2 \Sigma (Y_i^j X_n^j) + 2 a_o \Sigma X_n^j + 2 a_1 \Sigma (X_1^j X_n^j) + \ldots + 2 a_{n-1} \Sigma (X_{n-1}^j X_n^j)$$

Setting all those derivatives to zero, it is possible to determines the coefficients

a_o , a_1, a_2, … a_n

by solving the corresponding system of equations, whose matrix representation is the following:

$$
\begin{bmatrix}
N & \Sigma X_1^j & \Sigma X_2^j & \cdots & \Sigma X_n^j \\
\Sigma X_1^j & \Sigma (X_1^j)^2 & \Sigma (X_1^j X_2^j) & \cdots & \Sigma (X_1^j X_n^j) \\
\Sigma X_2^j & \Sigma (X_1^j X_2^j) & \Sigma (X_2^j)^2 & & \Sigma (X_2^j X_n^j) \\
\cdots & \cdots & & & \\
\Sigma X_n^j & \Sigma (X_1^j X_n^j) & \Sigma (X_2^j X_n^j) & \cdots & \Sigma (X_n^j)^2
\end{bmatrix}
*
\begin{bmatrix}
a_o \\ a_1 \\ a_2 \\ \\ a_n
\end{bmatrix}
=
\begin{vmatrix}
\Sigma Y_i^j \\ \Sigma (X_1^j Y_i^j) \\ \Sigma (X_2^j Y_i^j) \\ \\ \Sigma (X_n^j Y_i^j)
\end{vmatrix}
$$

This solution system can be symbolically expressed as

$$[C]\ [x]=[Tn]$$

The unknown vector is obtained by inverting the C matrix

$$[x]= C^{-1}\ Tn$$

Once the coefficients a0, a1… have been obtained it is possible to back obtain the original harmonics coefficients c0, cc1, cs1, cc2, cs2 etc.

Although the inversion of the matrix does not depend on the number of points considered but only by the number of harmonics, the estimation of the matrix for a large number of points can still be quite time consuming because it is necessary to sum all the terms for all the available data points in order to compose the coefficients for C and Tn. Therefore we identified a method, that we call CHD (Continuous Harmonics Determination) that allows to progressively calculate the harmonics without the need to compute them since the beginning.

This means that having the harmonics calculated at a certain time and the original matrix C, obtained using a set of data N, and having an additional set of data N1, the objective is to find a method to avoid to compute the harmonics using all the data N+N1 but rather using only the additional data N1.

If one needs to analyse the least square method for the large sample N+N1, each term in the matrix C will be something like

$$\Sigma_{N+N1} (X_2^j X_m^j)$$

That can be expressed as

$$\Sigma_N (X_2^j X_m^j) + \Sigma_{N1} (X_2^j X_m^j)$$

And the same for the know terms

$$\Sigma_{N+N1} (X_m^j Y_i^j) = \Sigma_N (X_m^j Y_i^j) + \Sigma_{N1} (X_m^j Y_i^j)$$

Using the properties of the matrices this means that the solution of the system

$$[C_{N+N1}] [x]=[Tn_{N+N1}]$$

Is equivalent to solve the system

$$([C_N]+ [C_{N1}]) [x]=[Tn_N]+ [T_{N1}]$$

This means that keeping the individual elements of the matrix at the previous calculation C_N and known term Tn_N, it is possible to estimate the new matrix and known terms $[C_{N+N1}]$ and $[Tn_{N+N1}]$ adding to each element of the matrix the terms corresponding to the additional points. Once inverted the matrix the resulting solution is corresponding to the overall number of points N+N1.

This method is extremely efficient because to obtain the solution vector for a series of 10 years of data may require also 10-12 min of computing time while storing the previous matrix and just adding the new available data to the old base matrix will take only few seconds.

Using this procedure it is possible to perform the harmonics estimation very frequently. At JRC we estimate the harmonics for more than 1000 signals once every hour.

4 Harmonics estimation using previous computations

4.1 Computations using overall harmonics over a period

The method described above is quite effective but it requires the estimation of the components of the harmonics using all the data. Once these have been obtained the following steps is easier as it involves only the additional points N1.

Assuming that it is possible to convert the harmonic constants by other organizations it would be quite useful to use those values in order to estimate the new period without the need to reprocess all the data with which the harmonics were obtained.

In other terms it is necessary to reproduce all the terms of the matrix C and of the known terms Tn so that in the following step they can be used with the method described above.

This can be done by recreating each individual term of the matrix C by recreating an equivalent set of data corresponding to the number of points N with which the "foreign" harmonics were obtained and estimating the corresponding known terms by the equation. Given Tmin and Tmax the time range, it is possible to generate a series x1,x2,…xN at equally spaced interval

$$DT=(Tmax-Tmin)/N$$

and estimating the corresponding y1,y2,…yN

using the series

$$Y_i = a_o + a_1 \cos(f_1 x_i) + b_1 \sin(f_1 x_i) + a_2 \cos(f_2 x_i) + b_2 \sin(f_2 x_i)\ldots + a_n \cos(f_n x_i) + b_n \sin(f_n x_i)$$

The resulting matrix C will be equivalent to the one that could be obtained using the original data x,y. It is necessary however to follow the following important conditions:

- The maximum time between two consecutive points has to be a fraction of the minimum period to analyse. For example if the minimum period is 3h it should be 10% of this, i.e. 18 min
- The minimum time interval to analyse has to be at least 3 times the larger period considered. So if the maximum period is 1 year, it should be 3 year.
- As the time interval and the time difference has been fixed, also the number of points is fixed. In order to make this period representative of the whole period analysed, every points considered in this learning harmonics estimation should have a weight corresponding to the ratio: Np/Real Number of points.

At this point the coefficients of C can be stored and from that moment on the same method outlined above can be used.

4.2 Computations performed using only yearly periods

Another case is when it is the case that yearly harmonics have been determined. In that case it could be useful to use the individual previous years harmonics to estimate the overall period estimates.

Suppose that you have N sets of harmonics, one for each year.

SET1={z0,a1,b1,a2,b2…an,bn}$_1$,SET2={z0,a1,b1,a2,b2…an,bn}$_{2…}$SETN={z0,a1,b1,a2,b2…an,bn}$_N$

It is possible to perform a similar strategy as in the previous case.

Using SET1, build a series of data points, using the constants present in SET 1 and obtain a first matrix C; repeat the same with a series of data points corresponding to SET2 and so on. The final matrix that will be obtained and its solution, will be equivalent to the whole set of data points.

5 Progression of the Harmonics over the time

5.1 When the harmonics are representative?

It is sometimes interesting understand after how many cycles the harmonics become representative of the real tide. This depends on the period of the harmonic that is considered but in general it is necessary to wait several months for most of the harmonics constituents and many years for the longest components.

In order to monitor the progression of the harmonics the data from an Italian tide gauge (San Benedetto del Tronto) has been analysed for 10 years, kindly provided by ISPRA. The modulus of the largest coefficients of the harmonics (square root of the sum of the squares of the sinus and cosinus components) are presented in the following table as obtained by each additional year considered. The periods in hours or days are indicated at the first and second line.

Hours		11.96723443	11.9999996	12.4206015	12.6583479	23.9344691	24.0658897	25.8193413	763.486415	4382.90841	8766.23946
Days	Z0	0.49863	0.50000	0.51753	0.52743	0.99727	1.00275	1.07581	31.81193	182.62118	365.25998
10/03/2000	21.31535	0.048977	0.086069	0.511912	0.015567	623.1244	383.9314	0.011554	0.098936	7.709654	28.7035
21/02/2001	0.196814	0.015236	0.05907	0.096424	0.01643	0.048406	0.016731	0.015795	0.031872	0.031966	0.061857
25/02/2002	0.19594	0.01625	0.059253	0.096808	0.016394	0.050042	0.017029	0.017071	0.02176	0.022042	0.038163
08/02/2003	0.180554	0.01748	0.059413	0.096709	0.016431	0.051075	0.01673	0.017783	0.020938	0.011126	0.05355
01/01/2004	0.184339	0.017722	0.059458	0.096488	0.016273	0.051554	0.016686	0.017971	0.019944	0.011824	0.060085
21/02/2005	0.182593	0.018868	0.059666	0.096132	0.015942	0.052393	0.016785	0.019013	0.010153	0.015437	0.059113
04/02/2006	0.183871	0.019543	0.059715	0.095761	0.015799	0.053188	0.016634	0.01935	0.008157	0.012353	0.056748
18/01/2007	0.18409	0.019903	0.059742	0.095562	0.015662	0.053707	0.016805	0.01964	0.008327	0.009073	0.053376
07/01/2008	0.182792	0.020248	0.05986	0.095491	0.015678	0.054019	0.01677	0.019808	0.006333	0.007816	0.050176
27/02/2009	0.178955	0.020253	0.060034	0.095446	0.015825	0.054176	0.016572	0.019957	0.007264	0.005799	0.046597
05/01/2010	0.169274	0.019939	0.060347	0.095775	0.016062	0.054286	0.016753	0.019816	0.000671	0.009971	0.05025
06/01/2011	0.123383	0.019567	0.060863	0.096946	0.016372	0.053181	0.016684	0.019575	0.014218	0.024666	0.077229
03/01/2012	0.122064	0.019057	0.061275	0.097487	0.016492	0.052894	0.01687	0.019469	0.019772	0.02451	0.057702
05/01/2013	0.125478	0.018165	0.061244	0.097944	0.01629	0.051979	0.01691	0.019126	0.016443	0.024661	0.060541
01/01/2014	0.117213	0.017591	0.061161	0.098722	0.016339	0.050801	0.016802	0.01854	0.01251	0.014237	0.050137

Table 2 - Modules of the largest coefficients of the harmonics as obtained by each additional year considered for the Italian tide gauge of San Benedetto del Tronto.

In the table above the cells are colored in red if the changes respect to the final value (2014) is larger than 5%. It is possible to note that some of the shorter period harmonics stabilize quite fast while the longest periods harmonics are not yet stabilized. The constant term was almost stabilized in 2009 but then between 2009 and 2010 an important drop is present.

It is therefore important to follow the development over the years in order to be sure that the data are consistent and the harmonics meaningful. Changes in the hardware or in the reference points can invalidate the quality of the harmonics obtained and should be checked regularly. For this reason we established a number or tools that allow to monitor the evolution of the harmonics over long periods of time.

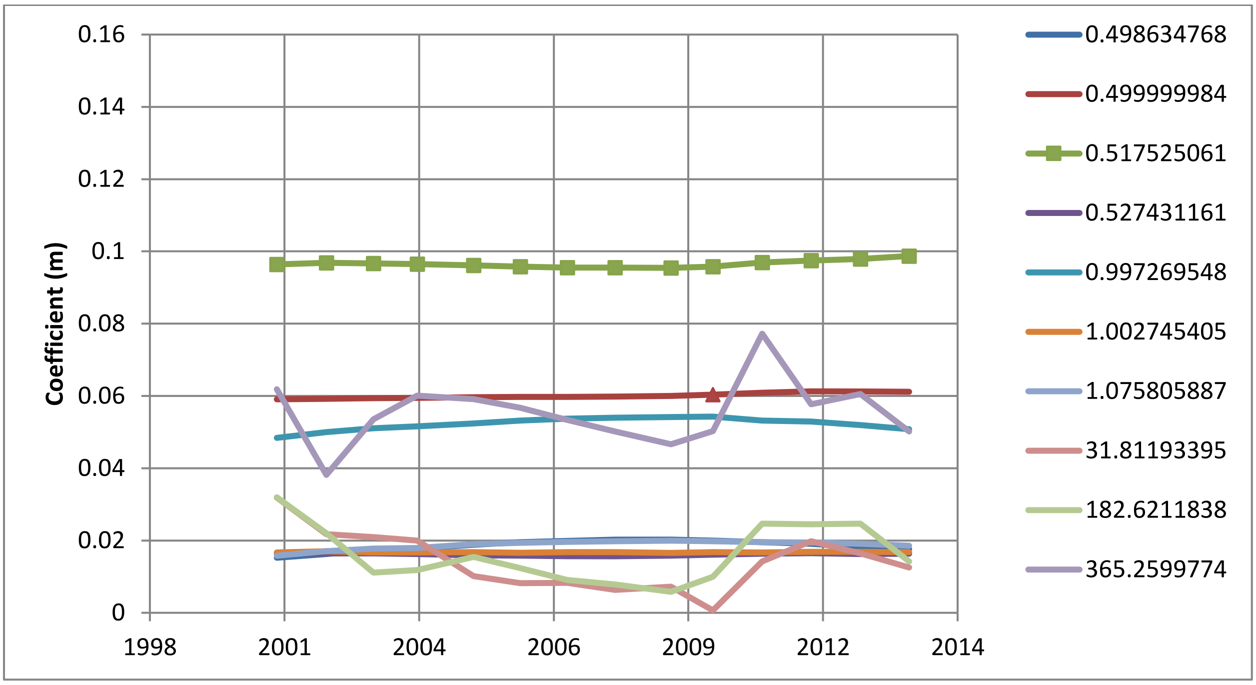

Figure 4 – Behaviour of the main components of the harmonics of San Benedetto del Tronto, over the years

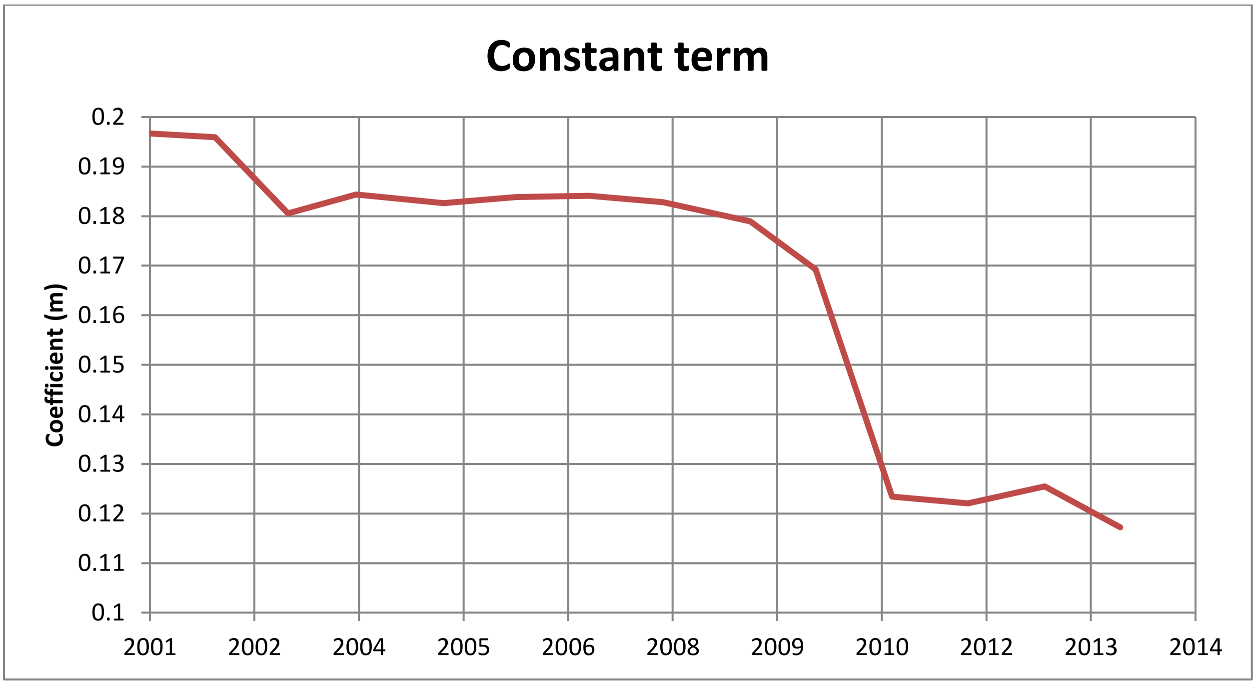

Figure 5 – Constant term variation over the years for San Benedetto del Tronto Signal

6 Realtime detiding

The worldwide data for which we at JRC perform detiding is shown in the figure below. Those are about 1000 signals for which it is possible to obtain current values of the measured sea level and the constants that allow to detide these signals.

The procedure has been written in VB.net and consists in calculating for a period starting from the last time the procedure was run to the current time, the harmonics according to the method described earlier and storing in a SQL database all the data of the matrix C and of the known terms Tn for each of the sensor.

Dedicated internet URL is available to retrieve the list of sensors and for each sensor the sea level in a specified time interval and the harmonics constants.

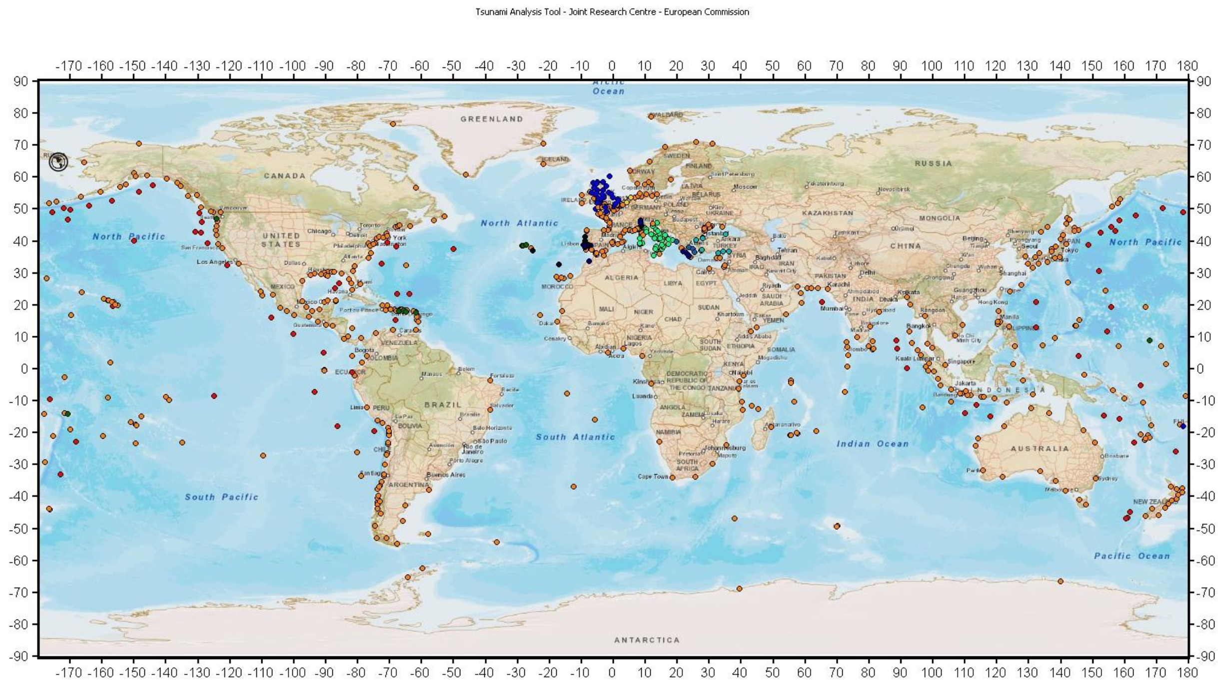

Figure 6 – Geographical distribution of the signals for which the harmonics are computed

The procedure is continuously running and we hope that, if the measurement devices reference are not changed, to have more and more refinement in the estimation of the harmonics constituents. At the moment we offer the sea level with this page

http://webcritech.jrc.ec.europa.eu/worldsealevelinterface/?list=true

and if you enter in one of the sea levels indicating its ID, i.e. Setubal, SET-01, ID=2033

http://webcritech.jrc.ec.europa.eu/worldsealevelinterface/?id=2033

the harmonics are present in the reply, in the 11th row.

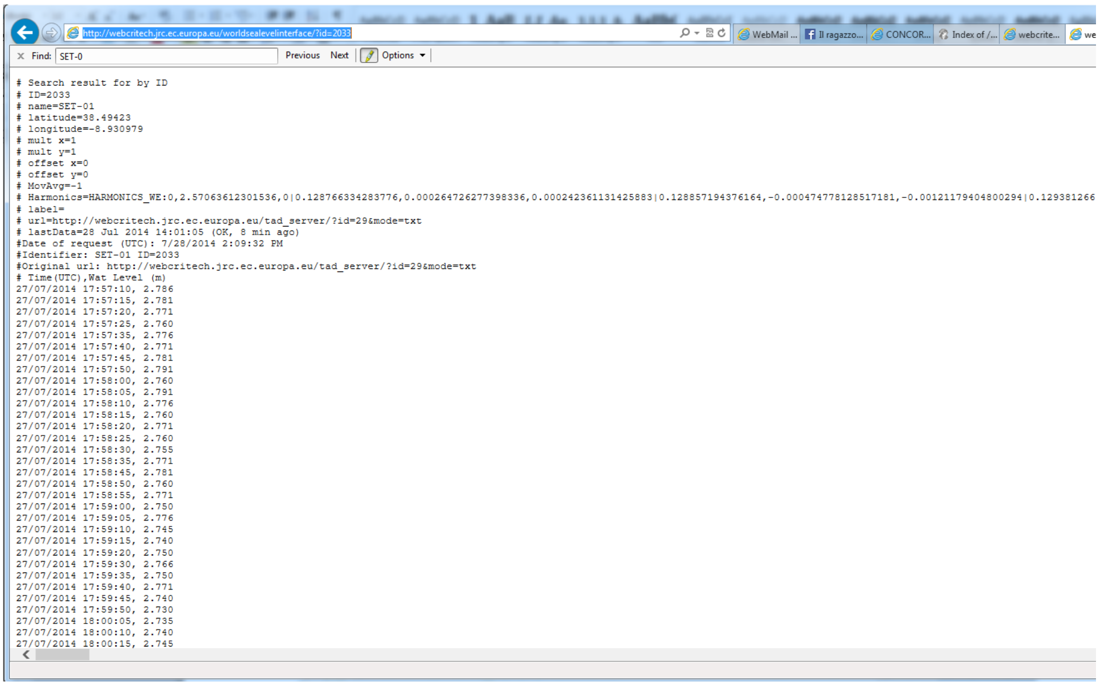

Figure 7 – Harmonics for Setubal station created by JRC
Source: JRC - http://webcritech.jrc.ec.europa.eu/worldsealevelinterface/?id=2033

They are 69 terms separated by "|" signal

In each block there are 3 terms:

Period (days)| cos coefficient (m) | sin coefficient (m)

Summing up all these terms you can get the tide. An example of signal and its harmonics forecast is shown in the following figure for Setubal tidal gauge (Portugal). The blue curve is the measurement, the red curve is the estimated tide while the green dotted curve is the tide forecast.

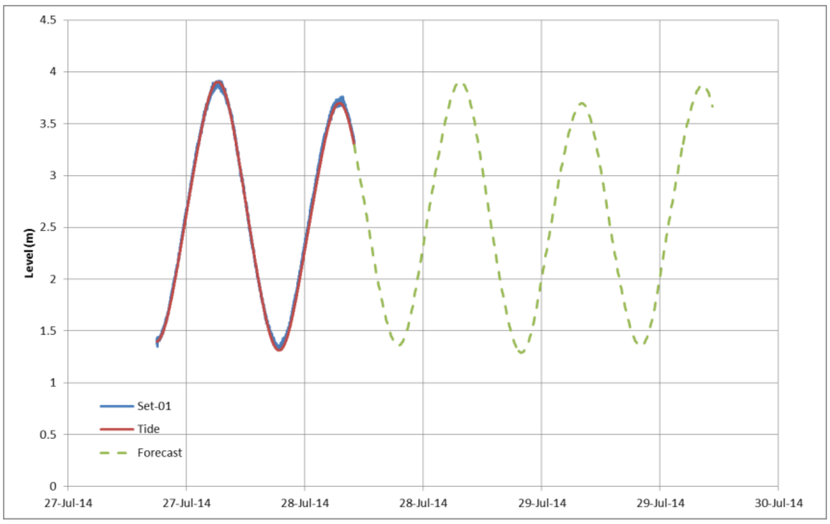

Figure 8 – Sea level signal in Setubal with the tide forecast for the next 4 days

7 Conclusions

The detiding process is important in the analysis of Natural events. The determination of tidal components using the harmonics evaluation is a rather known method; at JRC we established a novel procedure that allows to continuously calculating the harmonics coefficients taking into account all the points acquired over the years.

It is shown that some years are necessary in order to stabilize also the yearly components of the tide but the merit of the implemented method is the fast estimation so that at JRC the calculations are performed every 1 h since several years.

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List of abbreviations and definitions

CHD	Continuous Harmonics Determination
DTU	*Danmarks Tekniske Universiet* - Technical University of Denmark
EC	European Commission
GDACS	Global Disasters Alert and Coordination System
GLOSS	Global Sea Level Observing System
IPMA	Portuguese Institute for Sea and Atmosphere
ISPRA	Istituto Superiore per la Protezione e la Ricerca Ambientale
JRC	Joint Research Centre
ML	Measured value
NOC	UK National Oceanography Centre
NTSLF	National Tidal and Sea Level Facility
SS	Storm surge
TD	Estimated Tide

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Annexes

Annex 1. Function to convert sin/cos into speed/phase

NOCS=NOAA=ISPRA=JRC

H_{nocs} cos ($\sigma_{nocs} t - g_{nocs}$)=$H_{NOAA}$ cos ($s_{NOAA}\, t_h\, \pi/180 - g_{noaa}$) = H_{ISPRA} cos ($f_{ISPRA}\, t - g_{ISPRA}$) = A_{JRC} cos ($\boldsymbol{\sigma}_{JRC}\, t^*$) + B_n sin($\boldsymbol{\sigma}_{JRC}$ t*)

```
function convertCoeff(ccos, csin, TauDays,  byref h, byref teta)

   Dim a1, b1, h, al, teta, t0, pi, taugiorni As Double

   t0 = CDate("1/1/1976")
   pi = 3.14159265358979

   a1 = ccos
   b1 = csin

   h = (a1 ^ 2 + b1 ^ 2) ^ 0.5
   al = acos(a1 / h) * pi / 180

   If Sgn(sin(al)) <> Sgn(b1) Then
      al = -al
   End If

   teta = (al - 2 * pi * t0 / TauDays) * 180 / pi
   teta = modReal(teta)

End Function

Function modReal(fase)

        n = Int(fase / 360)
        fase1 = fase - n * 360
        modReal = fase1

End Function
```

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