TIDAL ANALYSIS & PREDICTION: IS THERE ROOM FOR NEW PHYSICS?

Eduardo Marone[1,2] & Renzo Mosetti[2]

[1] Centro de Estudos do Mar, Paraná, Brasil

[2] Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Trieste, Italia

Background

Many years ago, in the pages of this Newsletter, we proposed a challenge for the scientific community dealing with tidal analysis and prediction. We called the proposal TAP Competition (Tidal Analysis and Prediction) (Marone et al., 1995). The idea was not just to determine which methods squeeze better the physics of tides and their constituents, or which others, using these constituents, are able to predict more accurately the sea level variation in tidal frequencies, but to revisit the fundamental of the methods and the physics of the phenomenon, considering that there is a lot of uncertainties regarding tidal physics as non linear processes (Marone & Mesquita, 1995) and other phenomena which are linked to tidal propagation.

We did not succeed in convincing some of the old “popes” of tidal analysis and predictions who argued, as Lord Kelvin in the Nineteen Century, that almost “nothing new was to be revealed in physics” or, in other words, that it was nothing new to be discovered regarding tides and, as predictions work pretty well in spite the methods for analysis and forecast, such exercise would be worthless.

In our proposal we argued also, that the propagating use of numerical models, which for instance use the tides as initial and/or border conditions, will require more physically accurate acknowledge of tides and their constituents and physics. Today, the numerical modeling of coastal and open sea dynamics is widely used and has advanced a lot compared to fifteen years ago, while tidal analysis and prediction methods remained almost unchanged for more than half a century.

Many recent works (D’Onofrio et al., 2009; Falkenberg, 2009; Lopes, 2010) in the numerical modeling of coastal circulation have shown strong limitations when using tidal constituents, getting improved results, on the other hand, when time series of real sea level data are used instead (which force the modelers to have available long time series data). More often than not, this better behavior of the model’s outputs occurs when shallow water non linear tidal constituents are not relevant in the studied area, suggesting that the use of the real time series would introduce less “noise” than the tidal constituents into the model.

Nonetheless, we are not yet able to say if this characteristic is due to a misinterpretation of the non linear dynamics in most of the tidal analysis methodologies or because the numerical modeling, in spite of its great improvements in recent years, are still lacking a better fit to the real world. To make the challenge more stimulating, we cannot disregard a combination of both problems at the same time, being the less output quality a result of methodological misreadings in both, the analytical and the numerical ones.

Classical tidal analysis methodologies use the well known astronomical tidal potential, in combination with observations at a given place, in order to decompose the sea level signal in as much as possible already known tidal frequencies. The minimum square method, for instance, does it solving the corresponding *n* equations in the time domain to obtain *n* tidal constituents. Harmonic methods work with a superabundant equation system, i.e. having more equations -
than unknowns (the tidal constituents), while the solution is obtained in the time domain, usually getting the spectral peaks via Fast Fourier Transform or other algorithms (Watts, Direct Fourier Transform, etc.) (Marone, 1991).

It has to be expected that whatever the method we apply over the same dataset, the results have to be very close, which is uncommon to happen. To complicate the situation, taking individual pieces of a long tidal record of a same place and analyzing each one even with the same methods, the results use to show variability higher than the expected ones for a so called "tidal constants".

Examples

To better show this anomaly in the results of different tidal analysis methodologies, we can go back and compare the outputs of the analysis of the same sea level data set (Marone, 1991), reproduced in Table 1.

Method->	MHF	MHF	MHW	MHW	MMQ	MMQ	MR	MR
Constituent	Amplitude	Phase	Amplitude	Phase	Amplitude	Phase	Amplitude	Phase
O1	14	2	14	2	15	7	14	304
K1	19	46	19	46	22	58	18	293
N2	25	73	25	73	25	96	25	58
M2	153	172	153	172	157	182	153	176
L2	27	251	27	235	22	252	6	255
S2	16	299	16	299	19	316	18	158
M3	3	110	3	110	3	123	4	286
SK3	5	283	5	283	4	293	n.e.	n.e.
M4	16	160	16	160	18	176	n.e.	n.e.
MN4	5	53	5	52	5	91	n.e.	n.e.

TABLE 1 – Main tidal constituents for Ingeniero White, Argentina (Marone, 1991), where MHF means Harmonic Methods by Franco's and MHW the same but using the Watts algorithm instead of FFT; MMQ states constituens obtained with the Minimum Square Method and, finally, MR is for the Response Method (amplitudes are in cm and phases in degrees).

In the case of the MHF and MHW results, both using the same principle but differing only on the spectral algorithm, results fit exactly for amplitudes and pretty well for the phases, except in few cases (see L2, for instance). Those few cases indicate that even the used spectral algorithm is capable to introduce difference in the results. However, the worst cases are evident when comparing different methods as MH, MMQ or MR. Note that on these cases, even the estimated amplitudes present small but not unimportant differences (say on K1, M2, L2 or S2), while phases differ with pretty great values (in practically all the frequencies except for M2).

Or, just to give a more recent example, the astronomical components calculated for the Gulf of Trieste, Italy, with the Minimum Square Method (Raicich, 2007) and the Harmonic Method using the Franco's software (Franco, 2009), presented differences of up to 60% for M1 amplitudes, and 46% on the estimated phases or 260 vs 69 degrees for 2MSK4 (Marone et al., 2011).

It is possible to see that the tidal constants are not so “constants” but, mainly, that depending on the used method, the capability of them of getting a constant “set” of components is not present as one could be expect if all the methodologies are equally representing the physic and stochasticity of the problem. While for the more important tidal components the methods do not present great differences in amplitudes, phases show less agreement and, when we go to compare shallow water constituents obtained by one or other method, when obtained, we see greater anomalies and fewer coincidences.

The search for answers

There are still enough uncertainties on tidal analysis results to deserve deeper investigation. Apart of the accuracy and representativeness of the outputs of classical tidal analysis, it has been found that other physics has to be considered as the perturbation due semi-diurnal atmospheric tide S2p, disturbing the sea constituent S2, as well as other frequencies, probably, in the diurnal specie (Marone et al., 2011).

These results are in agreement with the theoretical development of Chapman and Lindzen (1970) and the numerical simulations due to Arbic (2005). It is concluded that a better stochastic model for tidal analysis and forecast needs to be formulated in order to better represent the physics of sea level: while tidal forecast with the usual methods seems to work well in many practical cases, the high dependence of numerical models on initial and contour conditions suggests that sea level harmonic constituents estimation has to be improved.

The harmonic contribution of the atmosphere to the sea level could also explain, at least partially, the discrepancies obtained when comparing field data analysis with numerical models (D’Onofrio et al., 2009). Also, considering the wide use of tidal induced numerical models, it would be wise if a better representation of the oscillating sea level is used instead of the purely astronomic one.

As we cannot disregard the evidences that non tidal oscillating signals are clearly present in the sea level, we suggest reformulating the analysis and forecasting methodologies considering a better stochastic model for the sea level.

Acknowledgments

The authors want to acknowledge the support of CAPES (BEX 1186/10-8) to E. Marone as post-doctoral fellow at INOGS, Trieste, Italy.

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