Developing Best Practices in Tidal Analysis

Andrew Matthews and the IAPSO Tidal Analysis Study Group

National Oceanography Centre, Liverpool, United Kingdom antt@noc.ac.uk

Sharing is encouraged

Introduction

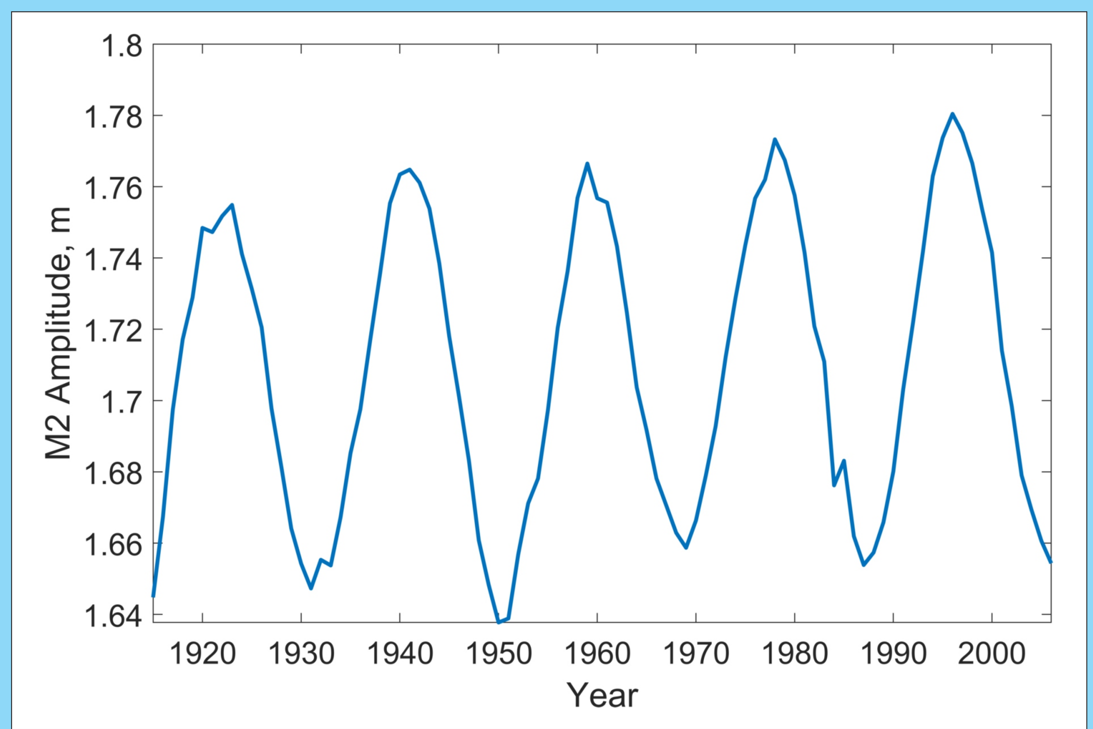
The tide is generally the dominant component of a sea level record in many parts of the world and its analysis has therefore been a central part of oceanography for hundreds of years. A variety of techniques exist to analyse the tide, using astronomical variables related to position of the moon and sun as predictors, the most well-known of which is classical harmonic analysis.

Whichever technique is used, performing the analysis involves making a number of choices about the predictors used, the data used, the method of solution and how results are interpreted. Often these are more art than science, relying on rules-of-thumb established within institutions over the years based on analysts' experience, and so isn't accessible to others.

There's a need for clearer guidance on how to analyse tides, so thanks to funding from IAPSO (International Association for the Physical Sciences of the Oceans) we have a Best Practice Study Group on Tidal Analysis. We held a workshop last November to discuss the issues involved, and are currently in the process of creating a document that will be submitted to the IOC's (Intergovernmental Oceanographic Commission) oceanbestpractices.org web portal.

We aren't aiming to produce a single prescriptive guide on how to analyse the tide - given the complexity of tides this isn't realistic. Instead we'll suggest suitable software, techniques and working patterns, and provide some worked examples using different kinds of data. We'll touch on some more advanced subjects (such as analysing currents), but not in detail.

Long term cycles



Many lunar constituents are affected by the 18.61 lunar nodal cycle, representing the change in the inclination of the Moon's orbit with respect to the ecliptic.

Good tidal software packages will account for the effect of this nodal cycle by adding extra terms to modulate the phase and amplitude of lunar constituents over the course of this cycle.

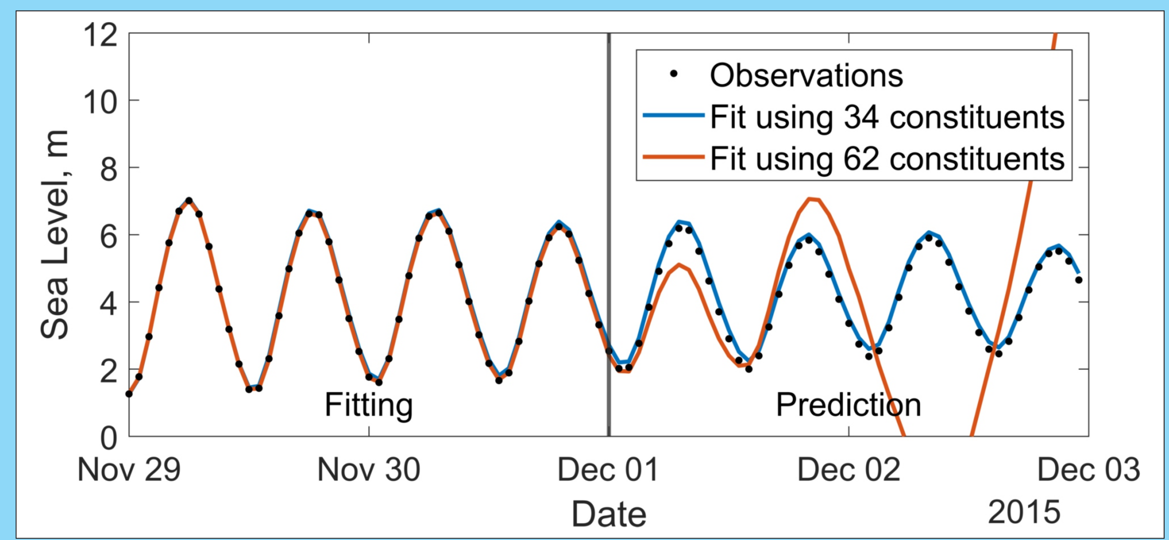
This plot shows the M2 amplitude of fits made to one year of data at a time from Newlyn, UK over the period 1915 to 2006 without accounting for this cycle. Without these corrections, our estimate of M2 from one year of data will vary from the mean by up to 3.7%, depending on which point of the nodal cycle our observations are from.

Selecting Input Variables

Whatever method used, we must take care when selecting predictor variables to avoid overfitting. For example, in classical harmonic analysis, we must make sure our selected tidal constituents can be properly separated given the length of the record we are analysing.

The rule-of-thumb typically used is the Rayleigh criterion, adapted from optics, which states that in order to separate two constituents, our data records needs to be at least as long as the inverse of the difference between their frequencies.

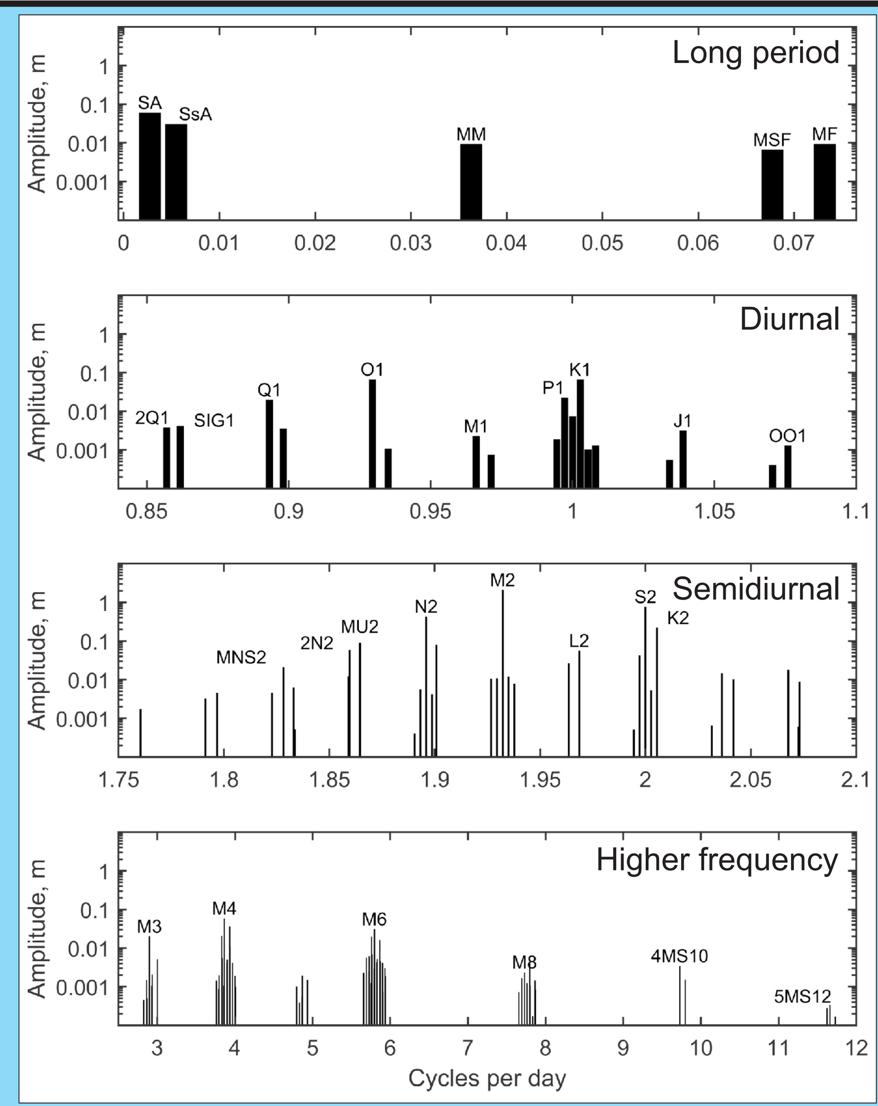
In practice this tends to be over conservative, and a shorter record can be used if the signal to noise ratio of the record is strong enough.



An example of the effect of selecting too many constituents. Two harmonic analyses were performed on 1 month of data (November 2015) from Brest, France.

The analysis in blue uses a '1 month' set of 34 constituents and predicts the early data in December well.

The analysis in orange uses a set of 62 constituents typically used to analyse 1 year of data, and the fit rapidly degenerates in early December, showing clear overfitting.



A visualisation of the amplitudes and speeds of 115 constituents fitted to data from Brest, France over the years 1991 to 2010. This long period allows a large number of constituents to be fitted.

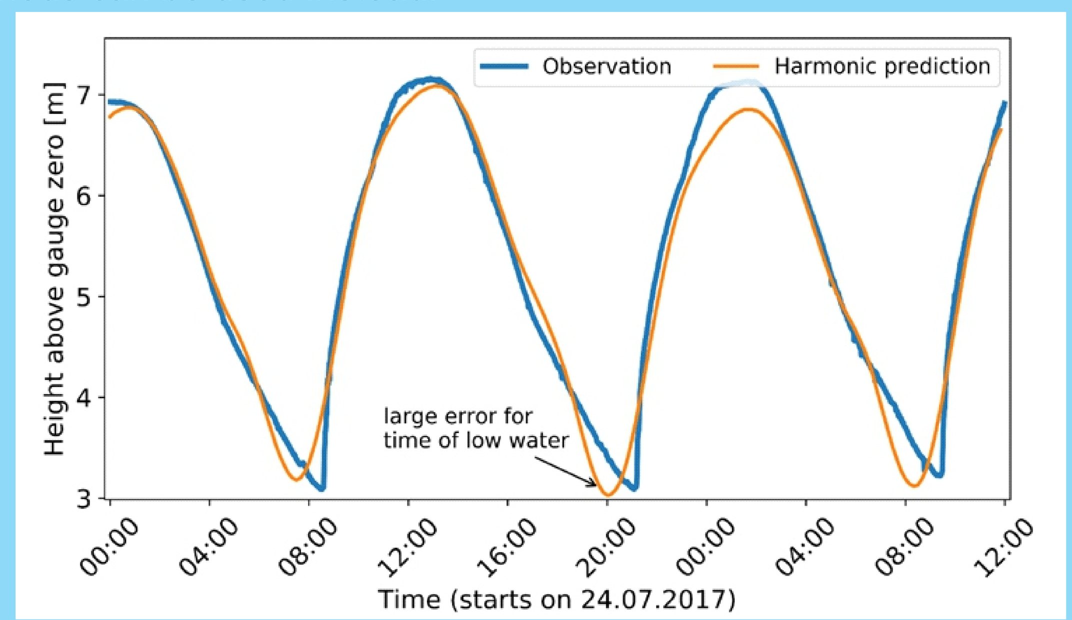
Note the logarithmic scales on the y-axes. Results are dominated by a small number of constituents, showing only a small number are required for a reasonable fit. However, a large number of constituents, particularly of higher frequencies, may be required for a more precise result.

Duration of data (not inc. gaps)	Number of Constituents	Comments
1 –10 days	1	M2 only
15 days	4	M2, S2, O1, K1 only can potentially generate more however it would involve missing out some of the key constituents (such as N2 and K2) and therefore probably of little value. May be of value in quality controlling data but not for future tide table production.
15 days	15 14 if Msf excluded	Msf, 2Q1, O1, K1, OO1, Mu2, M2, S2, M3, M4, MS4, S4, M6, 2MS6, 2SM6 Use with caution for tidal prediction as N2 can't be separated from M2 with only 15 days of data.
30 days	26 24 if Mm and Msf excluded.	Mm, Msf, Q1, O1, M1, K1, J1, OO1, Mu2, N2, M2, L2, S2, 2SM2, MO3, M3, MK3, MN4, M4, SN4, MS4, 2MN6, M6, MSN6, 2MS6, 2SM6 Use with caution for tidal predictions as K2 is not included. It is better to infer K2 from S2, than leave it out altogether.
30 days	26 standard, 8 inferred (related)	As above but with 8 additional harmonics which are inferred from another close in frequency. The 8 inferred constituents are: Pi1, P1, Psi1, Phi1, 2N2, Nu2, T2, K2. For predictions this set should be used over the set without the inferred terms.
6 months	54	Reasonably predictions can be made as all the constituents generally accepted to be the most significant are now included with the exception of long-period terms such as the Sa annual constituent.
12 months	102	Sa and Ssa can be derived but should be used with extreme caution.
4.5 years	114 +	Most harmonics can be extracted –at this point, it is usually the limitations of the software that are significant.
10+ years	114 +	As for 4.5 years, however the long period terms such as Sa can be used with more confidence as the observation record gets longer.

Constituent sets recommended by NOC's Marine Data Products Group (supplied by Colin Bell)

Special Cases

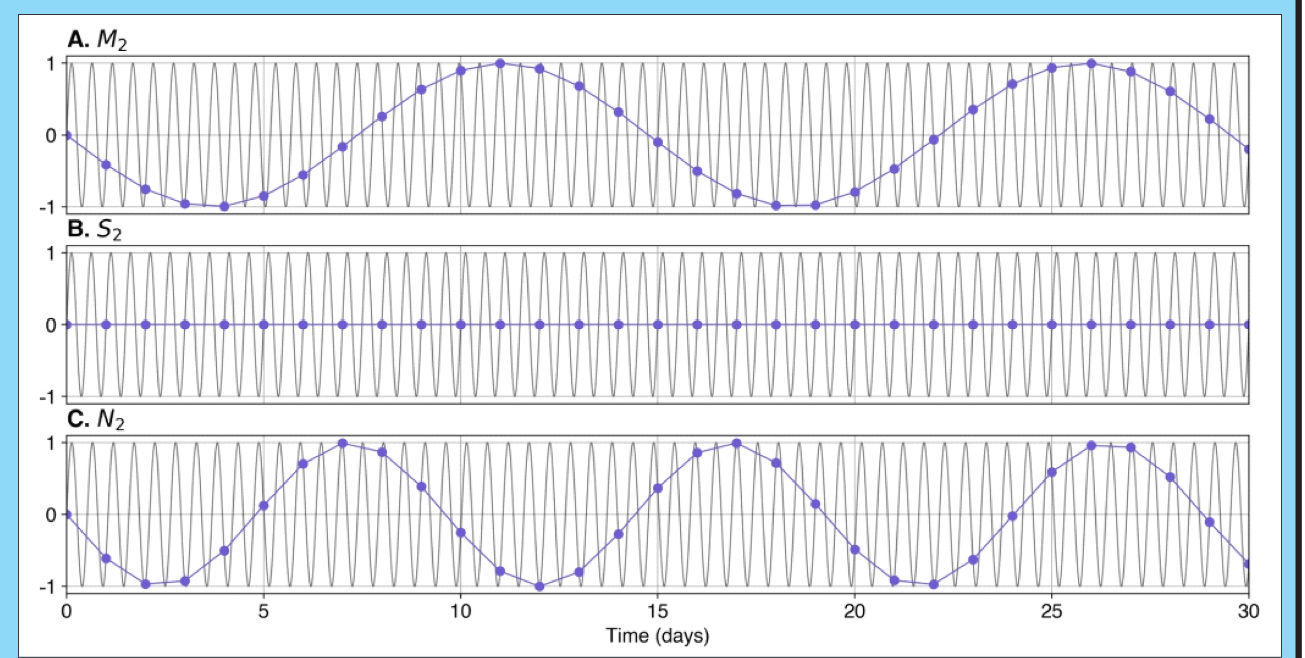
In some cases, classical harmonic analysis will not work or we are forced to adapt our methods due to peculiarities of the input data. Our best practice document will include examples of these cases, and suggestions of what methods can be used instead.



An illustration of how classical harmonic analysis fails to predict asymmetric tides - this example is taken from Papenburg on the Ems river in Germany, the site of a large shipyard.

Here a different approach needs to be taken. BSH use the Harmonic Representation of Inequalities method, also see Joanne Williams's poster in this session for an alternative approach (EGU24-9923).

Image from Boesch, A. and Jandt-Scheelke, S.: A comparison study of tidal prediction techniques for applications in the German Bight, EGU General Assembly 2020, Online, 4–8 May 2020, EGU2020-1640, https://doi.org/10.5194/egusphere-egu2020-1640, 2019



When analysing satellite altimetry data, the orbital repeat period of the satellite must be considered. This period will be greater than the frequency of tidal constituents, meaning the signal will be aliased. As a result, a much longer record will be required to estimate a given constituent.

In the example above, the satellite is in a sun-synchronous orbit, giving one observation per day at a site. For example, the are only 2 cycles of the aliased M_2 constituent in a month, whereas S_2 cannot be analysed at all as the two signals are perfectly in phase.

Image courtesy of Michael Hart-Davis

How you can help

Please let us know if you'd like to contribute to the Best Practice document. In particular, you can help in the following ways

If you do tidal predictions from data can you let us know:

- What software do you use to carry out analyses?
- What mistakes have you made in the past, and how do you avoid making them now?
- Do you have examples of difficult locations where you need to employ more complex techniques?

If you use tidal analysis and want to understand it better

- If you've tried to understand tidal analysis in the past struggled, what did you struggle with?
- What do you think our document should focus on?
- Do you have particular examples of series that you have had difficulties analysing?
- Do you have example of series where standard methods don't work for other reasons?

Contributors:

Bernardo Aliaga (UNESCO Intergovernmental Oceanographic Commission)
Colin Bell (NOC, UK)
Andreas Boesch (BSH, Germany)
Hilde Sande Borck, (Norwegian Mapping Authority, Norway)
Elizabeth Bradshaw (NOC, UK)
Andy Broderick (NOC, UK)
Adam Devlin (University of Hawai'i at Manoa, USA)
Catia Domingues, (NOC, UK)
Greg Dusek (NOAA, USA)
Lisa Eastwood (NOC, UK)
Ayesha Genz (NOAA, USA)
Pieter Gurdebeke (AMDK, Belgium)
Michael Hart-Davis (DGFI-TUM, Germany)
Angela Hibbert (NOC, UK)
Zarina Jayaswal (Australian Hydrographic Office, Australia)
Christopher Jones (UKHO, UK)
Chanmi Kim (NOC, UK)
Jue Lin-Ye (Nologin Ocean Weather Systems, Spain)
Phillip Macaulay (Canadian Hydrographic Service, Department of Fisheries and Oceans, Canada)
Gerard McCarthy (Maynooth University, Ireland)
Constantinos Matsoukis (NOC, UK)
George Mungov (NOAA, USA)
Fernando Oreiro (Servicio de Hidrografía Naval / Universidad de Buenos Aires, Argentina)
Begoña Pérez Gómez (Puertos del Estado, Spain)
Jeff Polton (NOC, UK)
Tom Prime (NOC, UK)
Layton Quinton, (NOC, UK)
Fabio Raicich (CNR, Italy)
Richard Ray (NASA Goddard Space Flight Center, USA)
Linta Rose (UHSLC, USA)
Colin Shepherd (UKHO, UK)
Peter Stone (NOAA, USA)
Laurent Testut (LIENSs, France)
Matthew Widlansky (UHSLC, USA)
Joanne Williams (NOC, UK)
Simon Williams (NOC, UK)
Philip Woodworth (NOC, UK)

National Oceanography Centre

Permanent Service for Mean Sea Level

IUGG

IAPSO

International Association for the Physical Sciences of the Oceans