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EARTH TIDE OBSERVATIONS AND ANALYSIS METHODS

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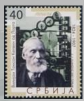
INTRODUCTION

Because the Earth tides are so small in comparison with ocean tides, building instruments to detect them has long been a challenge, though an easier one over time, as sensitive transducers and digital recording have become more readily available.



Kelvin's tide predictor (an analog computer) of 1876, is also featured in the background of 2007 Serbian stamp showing Kelvin.

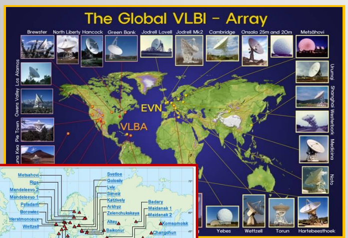
INSTRUMENTS

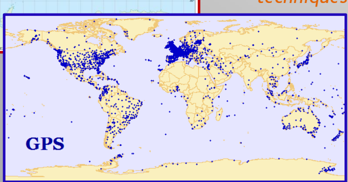
The earliest measurements were of tidal tilts, and over the years a wide variety of tiltmeters has been designed and is used. Different types of strainmeters sensitive to tidal deformations are also widely used.

The second type of Earth tide detection was changes in gravity, and many such measurements have been made with a variety of types of gravimeters.

Long base watertube tiltmeter (top) and superconducting gravimeter (bottom) at the Walferdange Underground Laboratory for Geodynamics, Luxembourg

The newest procedures for measuring Earth tides are the techniques of space geodesy: Very Long Baseline Interferometry (VLBI), Global Navigation Satellite Systems (GNSS), as well as Satellite Laser Ranging (SLR).





Global networks of the space geodetic techniques

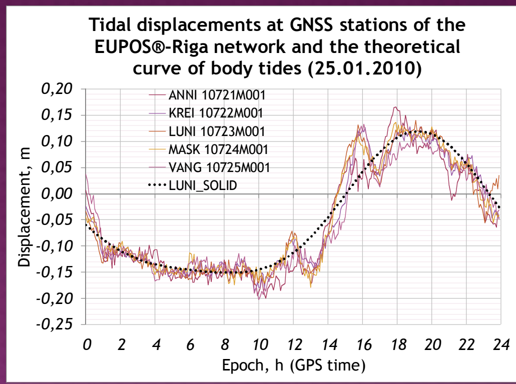
"Tides are motions of water on the earth, due to the attractions of the sun and of the moon, but its exact behaviour on any spot on the coast is strongly affected by the shape of the coastline and the profile of the seabed. So, although the forces that cause and influence tides were well understood, one needed to collect data regarding the tides at a certain spot over a certain period of time and then use that data to calculate and predict future rise and fall of tides at that spot. Using a method, called "harmonic analysis", the complex curve of the tidal gauge measurements was broken down into the separate curves representing the effect of time, moon, sun, etc... The exceedingly complicated motion that we have in the tides is analysed into a series of simple harmonic motions in different periods and with different amplitudes or ranges; and these simple harmonic constituents added together give the complicated tides."

William Thomson a.k.a. Lord Kelvin

TIDAL ANALYSIS

The goal of the tidal analysis is mainly to determine the amplitude ratio between the observed tidal amplitude and the modelled one (body tides) as well as the phase difference between the observed tidal vector and the theoretical one. Moreover, the tidal loading due to the corresponding oceanic tidal waves cannot be separated from the body tides as they have practically the same spectrum, as the result the superposition of both effects is observed. The only way to determine the true body tides is to compute the tidal loading vector by integrating the oceanic tidal vector over the whole ocean.

The tidal analysis demand careful data preparation and precise calibration of the instruments, as well as the detection of the anomalous parts of the records.

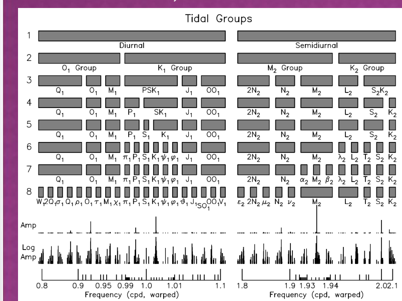


One of the main algorithms is tidal analysis according to the Method of the Least Squares (MLS). The application of MLS is based on a model of the tidal signal. Every tidal phenomena has a corresponding theoretical tidal signal whose expression *s(t)* at time *t* is $s(t)=\sum_{\omega} h_{\omega}\cos(\varphi_{\omega}(t))=\sum_{\omega} h_{\omega}\cos(\varphi_{\omega}(0)+\omega t)$, ω is frequency of a tide or tidal wave, taking *m* known discrete values $\omega=\omega_1,\omega_2,...,\omega_n$. In this expression *ω* is in radians per unit of time. In practice, frequencies are in deg/hr (degrees of arc per hour), in cpd (cycles per day) and in cph (cycles per hour). For example, one can use *s(t)* provided by the development of Tamura (1987) of the tide-generating potential with m=1198 tides with $\omega>0$ and 2 constant terms with $\omega=0$. The quantities h_ω and $\varphi_\omega(t)$ are called theoretical amplitude and phase at time *t* of the tide with frequency *ω*. All parameters are precisely known quantities.

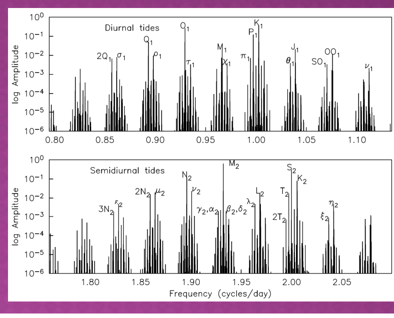
In the observed data of the tidal phenomena we have an observed tidal signal whose expression at time *t* is $S(t)=\sum_{\omega} H_{\omega}\cos\Phi_{\omega}(t)=\sum_{\omega} H_{\omega}\cos(\Phi_{\omega}(0)+\omega t)$

The quantities H_ω and $\Phi_\omega(t)$ are called observed amplitude and observed phase at time *t*. Unlike the theoretical, the observed H_ω and $\Phi_\omega(t)$ are unknown quantities, which are subject to estimation by the tidal analysis. The relation can be described by using the so-called amplitude factor $\delta_\omega=H_\omega/h_\omega$ and phase shift (lag) $\kappa_\omega=\Phi_\omega(t)-\varphi_\omega(t)=\Phi_\omega(0)-\varphi_\omega(0)$, namely $S(t)=\mathrm{Re}\sum_{\omega} x(\omega)h_{\omega}\,\mathrm{Exp}(i\varphi_{\omega}(t))$ $x(\omega)=\delta_{\omega}\,\mathrm{Exp}(i\kappa_{\omega})$

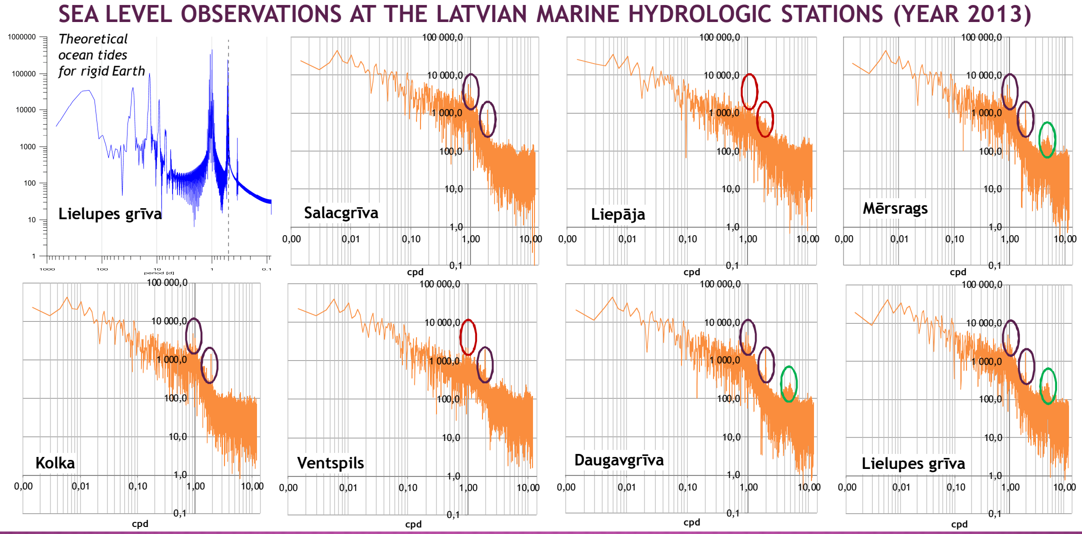
In the classical methods of analysis in the Earth tide domain the directly estimated unknowns used to be a set of the observed, but this kind of unknowns does not allow a correct application of MLS.



Diurnal and semidiurnal tidal groups shown with the frequency axis warped to make each of the groups equal in size; the ticks at the bottom are for 0.1, 0.01, and 0.001 cycles/day, chosen to avoid crowding. The two lines below the groups show the amplitude spectrum of tidal harmonics in both linear and log amplitude (on the right - the amplitude spectrum with named diurnal and semidiurnal harmonics).



SEA LEVEL OBSERVATIONS AT THE LATVIAN MARINE HYDROLOGIC STATIONS (YEAR 2013)



The global tidal models do not include the Baltic Sea, where the tidal variation is of the order of centimetres only. For example at the Helsinki tide gauge the amplitudes of the largest waves K1 and O1 are 1.7 and 1.8 cm, respectively, and the tidal range is about 10 cm. However, the range of non-tidal variation is up to 2-3 m on the coasts of the Gulf of Bothnia and Gulf of Finland. At short periods, the variations are primarily driven by wind stress, at longer - by water exchange through the Danish straits.

The spectral analysis of sea level data for Latvian hydrologic stations (spectral density function diagrams) have shown diurnal and semidiurnal tide occurrence concerning stations of Gulf of Riga, and the power at the frequency of 5 cpd (marked with green colour) in the case of three stations: Mērsrags, Lielupes grīva and Daugavgrīva. This frequency doesn't correspond to the tidal frequency. Mentioned stations are located relatively close together, and the power could represent some local effect.

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