Effect of the Free Core Resonance derived from tidal strain data

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1. INTRODUCTION.

The Free Core Nutation (FCN) is a rotational eigenmode arising from the dynamic influence of the rotating fluid outer core and the rotating, elastic and elliptical mantle. A wobble of the fluid core against the mantle appears in addition to the well-known Chandler wobble because the rotation axes of the mantle and of the core are slightly misaligned. In the Earth-fixed reference frame, the frequency of FCN can be expressed as $f_{FCR} = 1 + 1/T_{FCN}$ (T_{FCN} is the period of FCN) and is inside the diurnal tidal band. As a consequence, some diurnal tidal waves with frequencies close to f_{FCR} (mainly P1, K1, Ψ1 and Φ1) are modified, hence the acronymous FCR (Free Core Resonance).

To investigate the effect of the Free Core Resonance (FCR) we use the data from two European strain stations: Baksan (Russia), and Gran Sasso (Italy) (**Fig. 1**).

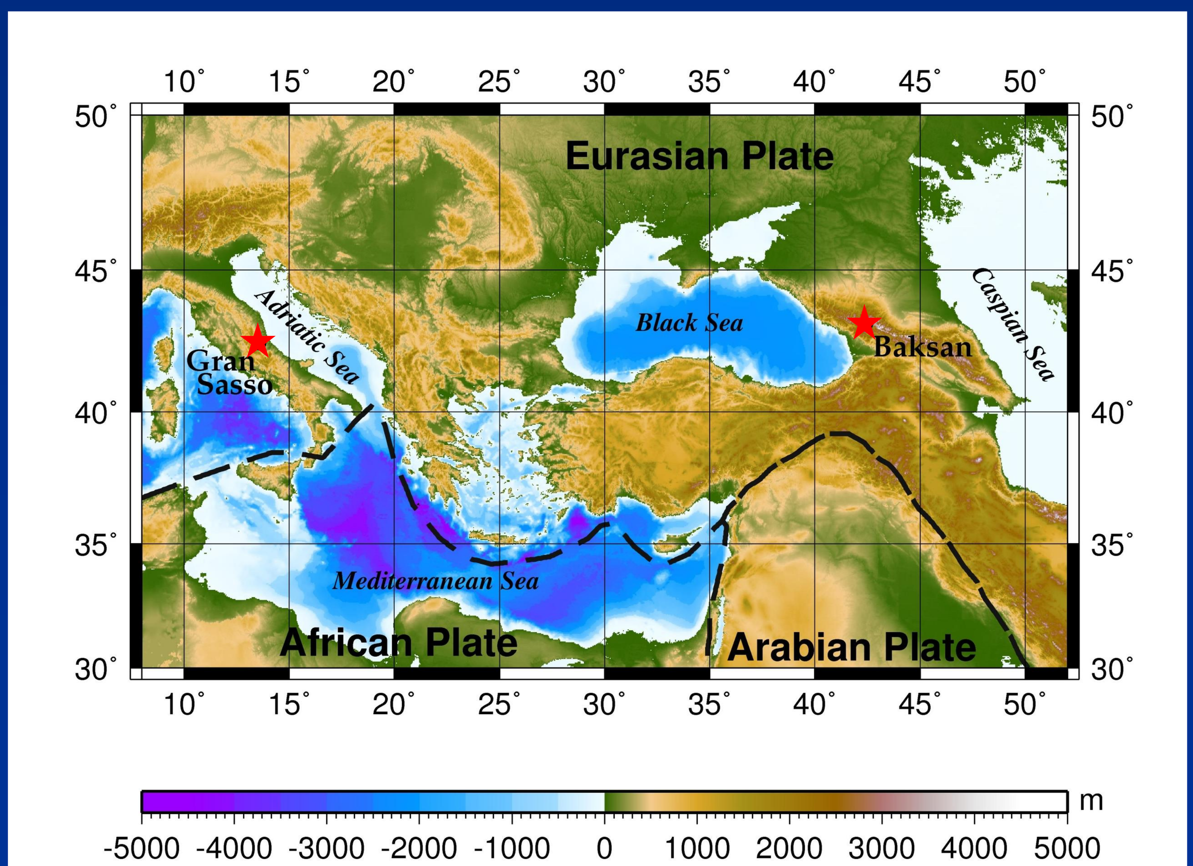

Fig. 1: Positions of the stationary deformation stations Baksan (Russia) and Gran Sasso (Italy).

Eight years of strain recorded by two crossed 90-m long laser interferometers (BA and BC) at Gran Sasso underground observatory, and six years of strain recorded by the 75-m long laser interferometer at Baksan underground observatory, have been analysed (**Fig. 2**).

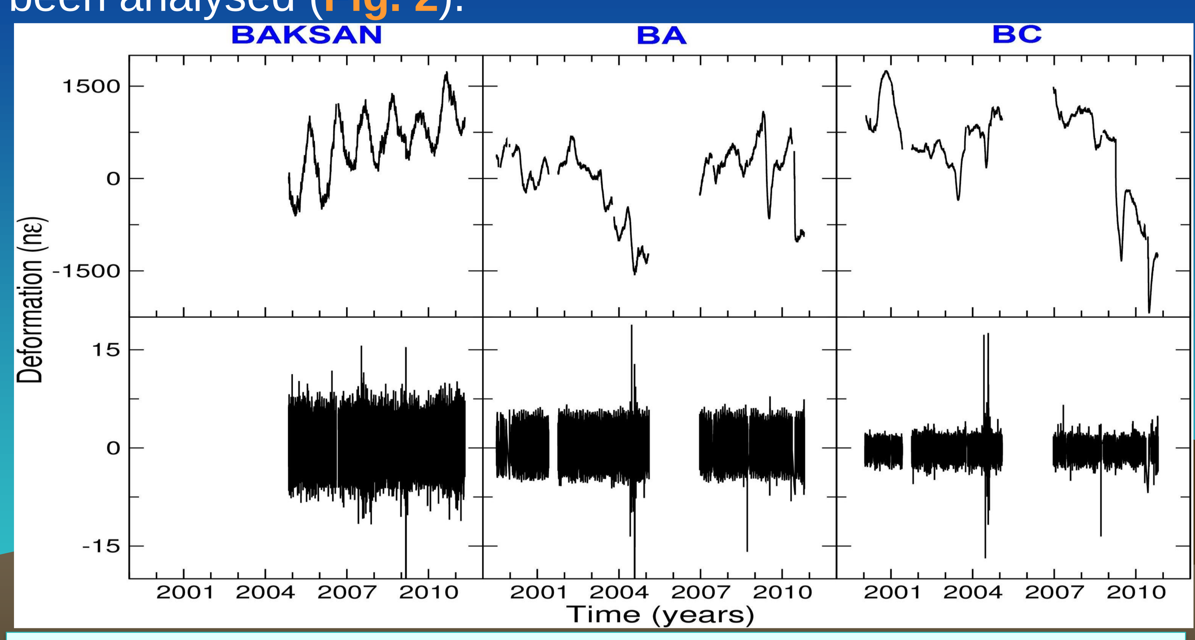

Fig. 2: Strain records used to estimate the FCR parameters. Upper plots: records decimated at 2 cycles per hour. Lower plots: first-differences (pre-whitened) sequences

2. DATA ANALISYS.

The overall analysed lenghts of the records are 2270, 3020, 2870 days for BAKSAN, BA, and BC respectively. Since deformation noise is red (i. e. its power spectral density increases as frequency decreases), in the following we always use pre-whitened sequences.

The power spectral density for BAKSAN, BA, and BC interferometers in the diurnal tidal band and the apparent power spectral density ($A^2T/2$, where A is the VAV03 amplitude and T is the actual record length) of the main diurnal tidal harmonics (O1, P1, S1, K1, Ψ1, Φ1, J1, OO1) is shown in **Fig. 3**. The strain series is as long as the related temperature sequence (about 2130, 500, and 480 days, for BAKSAN, BA and BC respectively).

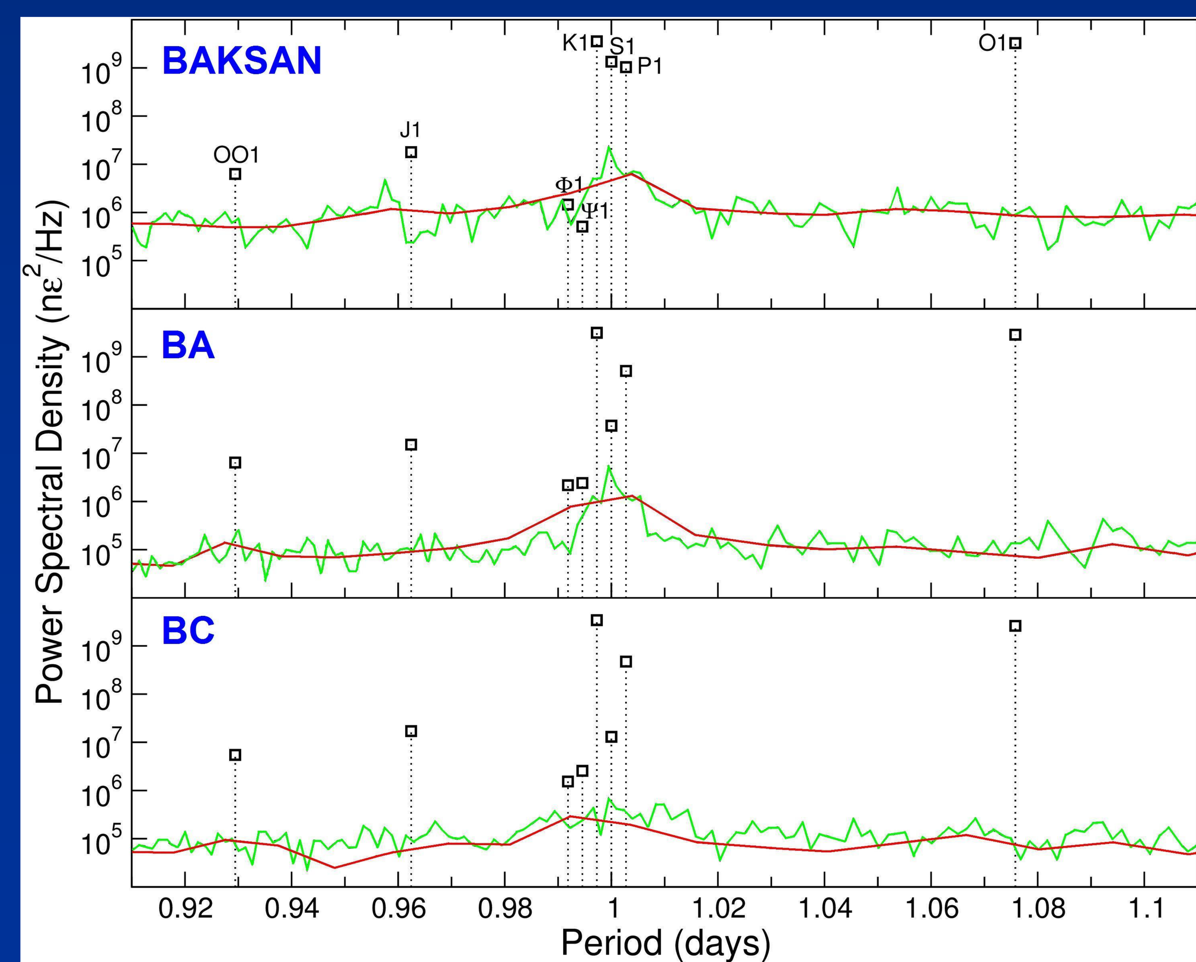

Fig. 3: PSD in the diurnal band, with and without temperature corrections.

Red lines are residuals of strain series obtained using VAV03 without correcting for temperature; green lines are residuals of strain series obtained using VAV03 and correcting for temperature; squares are apparent PSDs from VAV03 analysis on the whole strain data records; diamonds and crosses are apparent PSDs from VAV03 analysis on strain records as long as temperature ones, with and without temperature correction respectively.

3. RESONANCE PARAMETR ESTIMATION.

For the FCR parameter estimation we use 8 diurnal tidal constituents (namely Q1, O1, P1, K1, Ψ1, Φ1, J1, OO1) and compare measurements and model predictions through a joint fit on BAKSAN, BA, and BC tidal parameters minimizing the £¹ misfit function. As measurements we use the amplitudes of the sine and cosine terms of the observed tides, obtained from the output amplitudes and phases of the VAV03 code [*Venedikov et al., 2003*] applied on the pre-whitened strain series. Retrieved tidal parameters are corrected for ocean loading and local effects (**Table 1, Fig. 4**).

harmonic	BAKSAN		BA		BC	
	amplitude	phase	amplitude	phase	amplitude	phase
Q1	1.075	-26.346	0.872	-18.658	0.863	10.257
O1	5.807	-23.260	4.692	-18.833	4.588	11.747
P1	2.416	-46.823	1.977	-18.400	1.954	10.987
S1	0.951	90.349	0.534	-3.902	0.324	-58.430
K1	5.795	-31.245	4.918	-22.298	5.252	14.558
Ψ1	0.153	103.542	0.136	0.155	0.144	18.301
Φ1	0.172	-49.873	0.129	-41.156	0.112	-2.205
J1	0.405	-35.291	0.340	-18.322	0.372	10.124
OO1	0.250	-23.552	0.222	-15.555	0.210	5.842

Table 1: Amplitudes (nanostr) and phases (degrees) of observed tidal strain for BAKSAN, BA and BC obtained using VAV03 code.

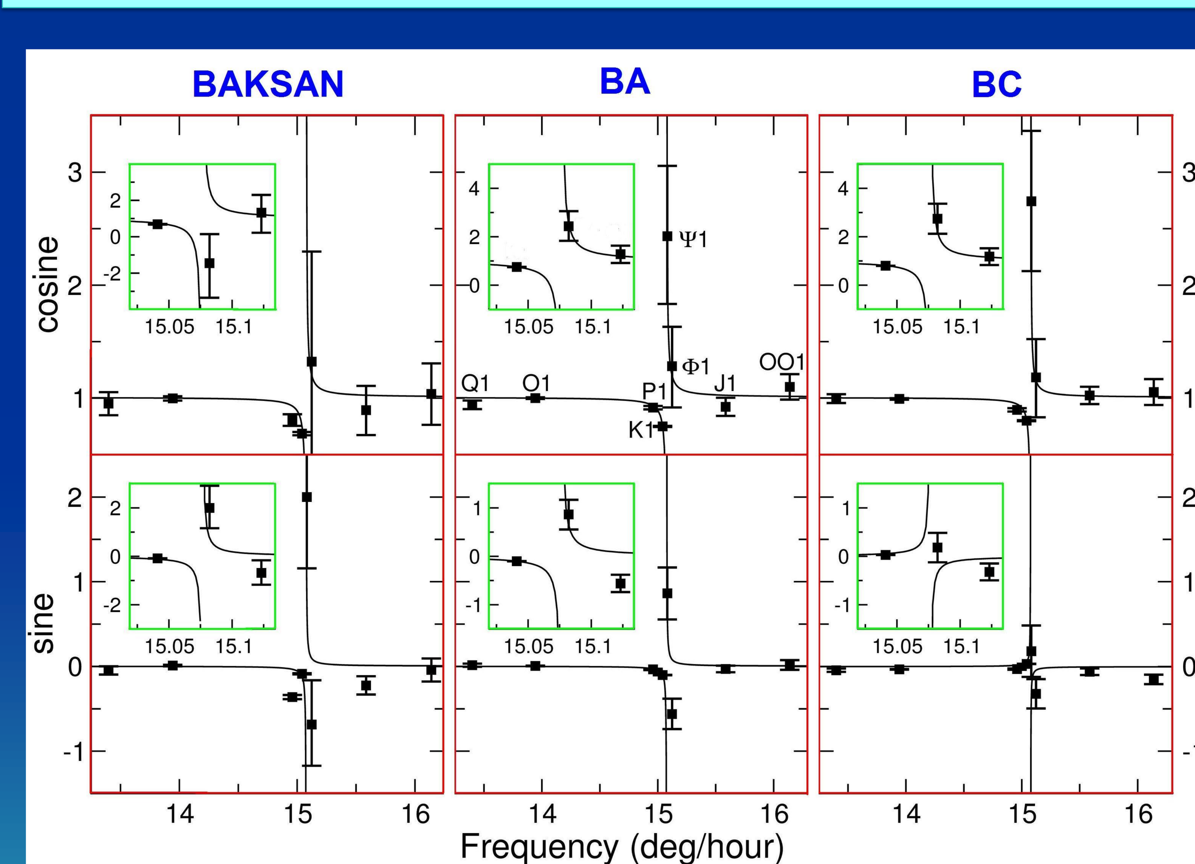

Fig. 4: Amplitudes of the in-phase and out-of-phase (with respect to SNRE tides) terms, normalized to the SNRE tidal amplitudes. Error bars give twice the uncertainties from VAV03 tidal analysis; predicted values (solid line). Insets represent an enlargement around the resonance.

4. RESULTS.

We consider $1/T_{FCN}$ and $\log Q$ as free parameters in the inversions. As regards the complex Love and Shida numbers, $Re(h_0 - 3l_0)$, $Re(h_1 - 3l_1)$, $Re(l_0)$ are free in all the inversions, but $Re(l_1)$, $Im(h_1 - 3l_1)$, $Im(h_0 - 3l_0)$, $Im(l_0)$, and $Im(l_1)$ can be free or fixed to their IERS 2003 values.

For each case as a first step we determine the best-fit FCR parameters using Adaptive Simulated Annealing [*ASA; Ingber, 1993*], then we generate 400000 synthetic tidal parameter sets (obtained from real one by adding a null-mean random noise). The retrieved distributions of T_{FCN} (**Fig. 5**) give its Probability Density Function (PDF). The PDF distributions, leaving all or 5 parameters free, are peaked around 428.5 and 426.5 sidereal days respectively; in the first case the result is consistent with those obtained from the analysis of VLBI and gravity data in [*Rosat and Lambert, 2009*].

Cumulative distributions show that at the 80% (50%) confidence level the T_{FCN} value is between 413.5 (421.2) and 436.8 (431.0) sidereal days leaving free all parameters, and 409.3 (417.1) and 440.2 (430.8) sidereal days fixing 5 parameters.

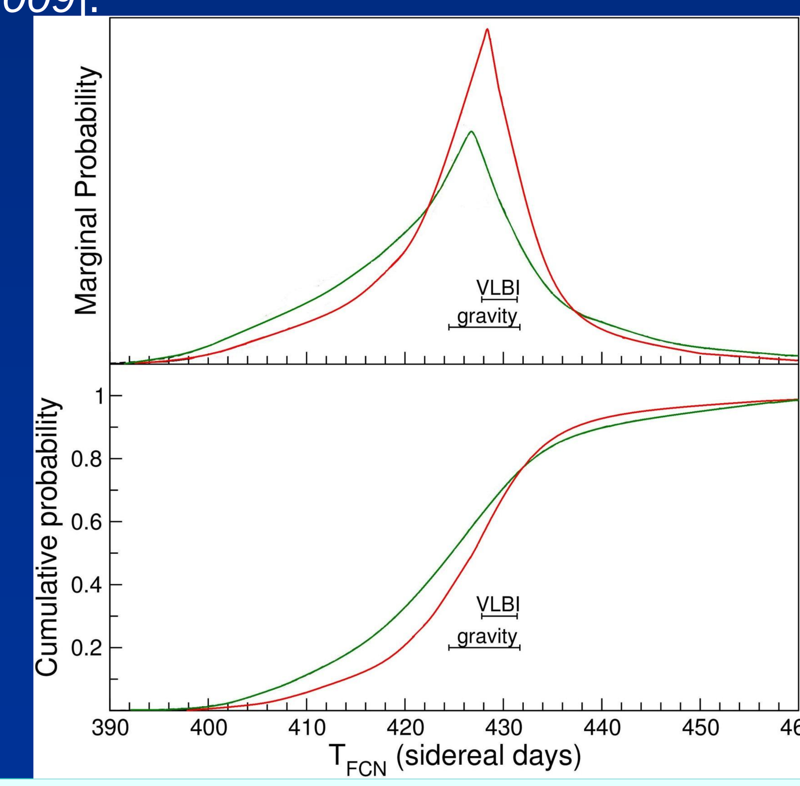

Fig. 5: PDF and cumulative probability of T_{FCN}. Red line, free all parameters; green line, fixed five parameters.

The Q factor is badly constrained because of the large uncertainty on the Ψ1 phase. PDF of Q-factor shows a peak around 18000 (5 fixed parameters). The joint analysis confirms the results obtained from the analysis of the Gran Sasso strain tides only [*Amoroso et al., 2012*] and are comparable to those from gravity tides (**Fig. 6**).

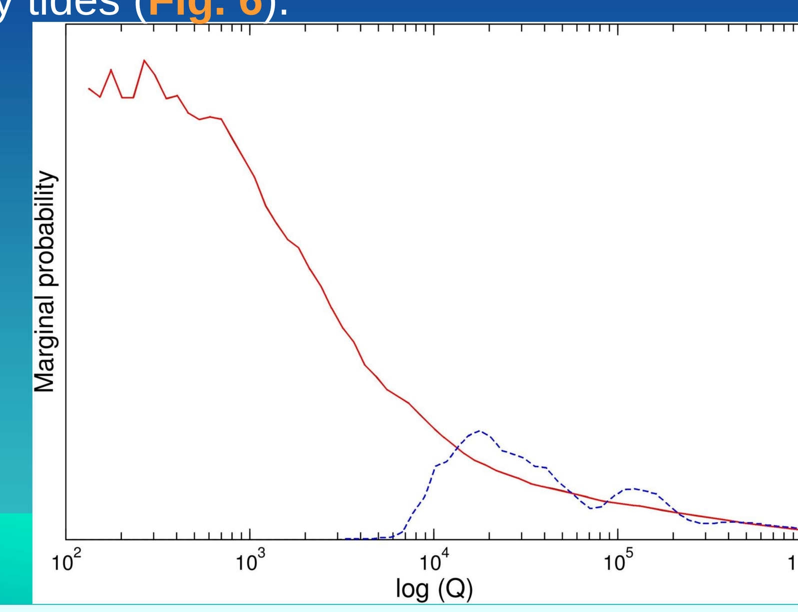

Fig. 6: Marginal probability of the quality factor Q obtained leaving all or 5 parameters free red and green lines respectively).

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