

ATLANTIDA3.1_2014 FOR WINDOWS: A SOFTWARE FOR TIDAL PREDICTION

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In this paper, we describe the possibilities of the ATLANTIDA3.1_2014 software, which was recently developed for predicting tidal parameters on the Earth. These possibilities include the calculation of the gravimetric oceanic effect, the amplitude delta-factors for oceanless Earth, as well as the modeled amplitude factors and phase shifts for the Earth with ocean. The program also calculates the tidal series. We present the highlights of the program and discuss the underlying theoretical and methodical ideas. The detailed installation guidelines and user manual are presented. The results of the calculations are compared with the observations.

INTRODUCTION

At present, there are about ten programs for calculating the prognostic delta-factors and phase shifts of the tides as well as oceanic gravimetric effect. Among the first group of the software, the most popular are the *PREDICT* program of the *ETERNA* package developed by Wenzel [Wenzel G., 1996], *T-soft* [Van Camp & Vanterin, 2005], and *MT80w* programs [ICET]. The calculations of the oceanic effect are conducted by the *LOAD97 (ETERNA 3.3)* [Francis O. and Mazzega P., 1990], **GOTIC2** [Matsumoto et al., 2001], **OLFG** [Scherneck, 1991], and **SPOTL** programs [Agnew, 1996, 1997].

The detailed intercomparison of these programs and the analysis of their performance against the ATLANTIDA3.1_2014 program fall beyond the scope of the present work. However, we briefly outline the main features of our program, which distinguish it from the previous programs.

First, for calculating the Love numbers and delta-factors of the body tides, we applied the latitudinal dependences of these parameters obtained in [Spiridonov E.A., 2014]. These dependences differ from those calculated by Dehant V. et al. [1999] for the DDW/NH model. Our curves have a somewhat steeper latitudinal gradient, which is particularly important in the prediction of tidal data at high latitudes (see Fig. 6). The latitudinal dependence used in our work does not depend on the form of the tidal or loading potential. Besides, we also calculated the

latitudinal variations of the loading Love numbers and delta-factors. This is the first distinction of our program from the other programs.

The calculations of the loading Love numbers take into account dissipation of tidal energy in the mantle according to the logarithmic creep function. Dissipation is allowed for by some but not all programs. For instance, LOAD97 does not consider this dependence despite the fact that nothing prevents this program from specifying the loading Green's functions calculated with the allowance for the dissipation.

In *ATLANTIDA3.1_2014*, calculations can be conducted in two models of the Earth's structure: *PREM* [Dzeiwonski, A.M.&Anderson, D.L., 1981] and a later IASP91 model [Kennett B.L.N., Engdahl E.R., 1991]. Although some authors in their calculations use, in fact, several Earth's models (e.g., besides *PREM*, the 1066A model, which is obsolete) or modified versions of *PREM*, this approach has not yet become common, and still less is it popular when designing the programs for tidal computations.

In each and every program calculating the oceanic loading effect, this effect is determined by the convolution of the tidal height with the Green's functions. In these calculations, it is common to separate the near zone (2–5 degrees), within which the data are subjected to the procedure of interpolation. Thus, the high spatial frequencies of tidal height are taken from the near zone, whereas the data falling beyond this area are coarsely described by the values at the grid nodes of the oceanic model. In our opinion, this approach is not quite reasonable because, first, the high-frequency components affect the entire Earth and, therefore, they should be calculated over the entire surface. Second, instead of the near zone, it is the far zone that provides the largest contribution to the modeled oceanic gravimetric effect, and the calculations for the far zone are less accurate. Therefore, when designing our program, we implemented a different approach, which is based on the spherical harmonic decomposition of tidal height after the preliminary interpolation of all the data of the oceanic models with the degree of detail that is not worse than in the near zone in the calculations of the other authors. Thus, the near zone covers the entire Earth. Strictly speaking, the approaches that are based on the application of the Green's functions and spherical harmonic decomposition of the tidal height are fully identical from the mathematical standpoint. At the same time, the attempt to specify the near zone (e.g. in the LOAD97 model) with a size of a few tens of degrees infinitely increases the time of the computations and the obtained result tends to our estimates obtained without the allowance for the dissipation.

In addition, our program also provides the possibility of calculating the oceanic effect at the grid nodes. However, in the case of the calculations at a point, the program separately yields the

loading and Newtonian (direct attraction) components of the oceanic effect as well as their sum. By no means all programs provide this option.

In contrast to almost all the other programs of this kind, ATLANTIDA3.1_2014 has a intuitively transparent user-friendly interface, which enables the user to run the program straightforwardly, without referencing to the manual.

In the first section of this work, we discuss the general principles of the program and the physical sense of the corresponding computational procedures. The second section, in fact, presents the user's manual. Finally, in the third part, we show some results of our calculations and compare the output of our program to the observations.

1. MAIN COMPUTATIONAL PROCEDURES

The general flow-chart of the calculations that are carried out when preparing the initial data for the ATLANTIDA3.1_2014 program and the calculations that are carried out directly by our program are illustrated by Fig. 1.

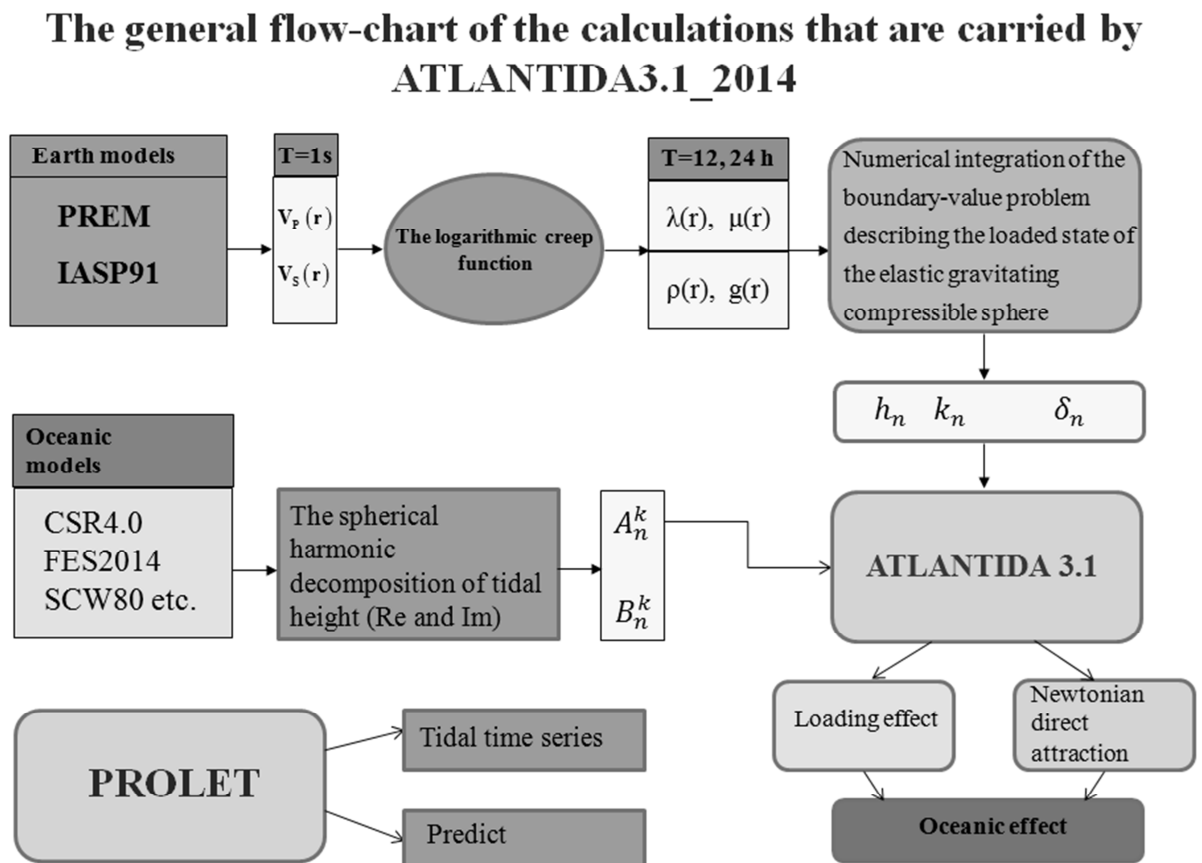


Fig 1. The general flow-chart of the calculations

In the calculations of the oceanic loading effect, Love numbers, and delta-factors of the body tide, we applied, as was mentioned above, two models of the interior structure of the Earth,

namely, PREM and IASP91 [Vinogradova, Spiridonov, 2012; Spiridonov, 2014]. The second model, for example, more adequately describes the structure of the crust and upper mantle of Europe and is more advanced. For the both models, the velocity curves of the seismic compressional and shear waves were recalculated from the reference period of 1 s to the periods of the tidal waves using the logarithmic creep function. Then, with the use of the obtained values, the Love parameters, density curves, and the curves of gravitational acceleration were calculated. These four dependences as well as the curves of compression and its derivative, served as the main input data required for numerical integration of the boundary-value problem describing the loaded state of the elastic gravitating compressible sphere with the allowance for the latitudinal variations in the elastic parameters and potential.

The problem is described by the set of the six ordinary first-order differential equations with three boundary conditions on the Earth's surface and three conditions on the mantle-core boundary [Spiridonov, 2014]. The method of numerical integration of the boundary problem is most thoroughly expanded in [Spiridonov E. and Vinogradova O., 2013; Vinogradova, Spiridonov, 2013b]. Integration was carried out with a 0.1-km step along the depth.

When determining the delta-factors of the M2 wave, the corresponding corrections for the effects of inertia forces presented in [Molodenskiy S.M., 1984] were added to the Love numbers k_2 and h_2 .

For the diurnal waves, we applied the resonance curve (24) from [Dehant V. et al., 1999]. We constructed this curve for the amplitude delta-factors of the waves in the near-diurnal period range for the DDW/H and DDW/NH models. After this, for the same models we calculated the ratios of the obtained delta-factors of diurnal waves to the delta-factor of the M2 wave and the average values of these ratios over two models. The need for calculating the average over two models was motivated by the fact that the latitudinal average delta-factor for the M2 wave obtained for the PREM model fell, within 0.004% accuracy, between the delta-factors of this wave in the DDW/H and DDW/NH models. At the same time, the averages for IASP91 have practically coincided with the averages for DDW/NH (see section 3).

Based on the values of the ordinary and loading Love numbers, the corresponding amplitude delta-factors are calculated. In contrast to the loading delta factors up to order 10000 and their latitudinal dependence (with a step of 0.1 degree), which were calculated a priori and, in fact, served as the input data for the program, the second-order delta-factors of the body tide are calculated every time the program is run.

The load was specified by the tidal masses of the six tidal models: CSR3.0, FES95.2, the Schwiderski model (SCW80), NAO99b, CSR4.1, and FES2012. The tidal heights were

expanded into the spherical harmonic series up to order 720 (up to order 1120 for FES2012). For doing this, we used the system of recurrent formulas for the integrals of the Legendre polynomials and associated polynomials [Spiridonov, Afanasyeva, 2014; Spiridonov 2013].

The obtained coefficients of the expansion together with the loading delta-factors composed the input data for the ATLANTIDA3.1_2014 program. Based on the obtained expansions and loading delta-factors, the program calculates the value of the loading effect, direct Newtonian attraction by the mass of water, and their sum.

The amplitudes and phases of the oceanic gravimetric effect as well as the delta factors of the body tide calculated by the program for 63 groups of the waves are inputted to the PROLET program developed by E.A. Boyarsky and L.V. Afanasyeva. Being the part of the ATLANTIDA3.1_2014 package, PROLET calculates the prognostic values of delta-factors and phase shifts for the Earth with ocean as well as the tidal series for the time interval of interest. The prognostic amplitude delta factors are only calculated for those waves for which the oceanic effect is known. The time series are separately calculated for the oceanic and body tide as well as for their sum. The computational scheme of PROLET largely follows the PREDICT program from the Wenzel's ETERNA 3.3 package. The expansion of tidal potential into 1200 Tamura's waves (1987) is applied. The corrections for the conversion from UTC to TDT time are taken from the USNO website <http://maia.usno.navy.mil/ser7/deltat.data> and decimated in such a way that for the time after 1973, the error of the correction does not exceed 1 s (the error of the tidal effect is less than $1 \text{ nm} / \text{s}^2$).

2. HOW TO WORK WITH THE PROGRAM

2.1 Downloading and installation

To download the program, please follow the link:

<https://yadi.sk/d/hszRKInqcrDSC>

or

https://drive.google.com/open?id=0B_PQJhBLmMBrWnpfanpYT01qeEE&authuser=0

and download the ATLANTIDA.EXE file to your computer. This a self-extracting archive, which should be installed to the root directory on any desired disc.

Attention! Unless installed to a root directory, the program won't run.

To run the program, hit **/ATLANTIDA31/ATLANTIDA31.EXE**. Select the desired options (see Fig.2 below) in the dropdown menu.

Warning! In the work with this menu, the separator between the integer part and fractional part of the entered numbers is a dot. However, by default, the WINDOWS settings prescribe this separator to be a comma. In order to correctly run the program, one should either replace the

separator in the form of a comma in the WINDOWS settings by the separator in the form of a dot, or to fill the menu prompts using the separator in the form of a comma. In the next versions of the program, we intend to make it independent on this OS setting.

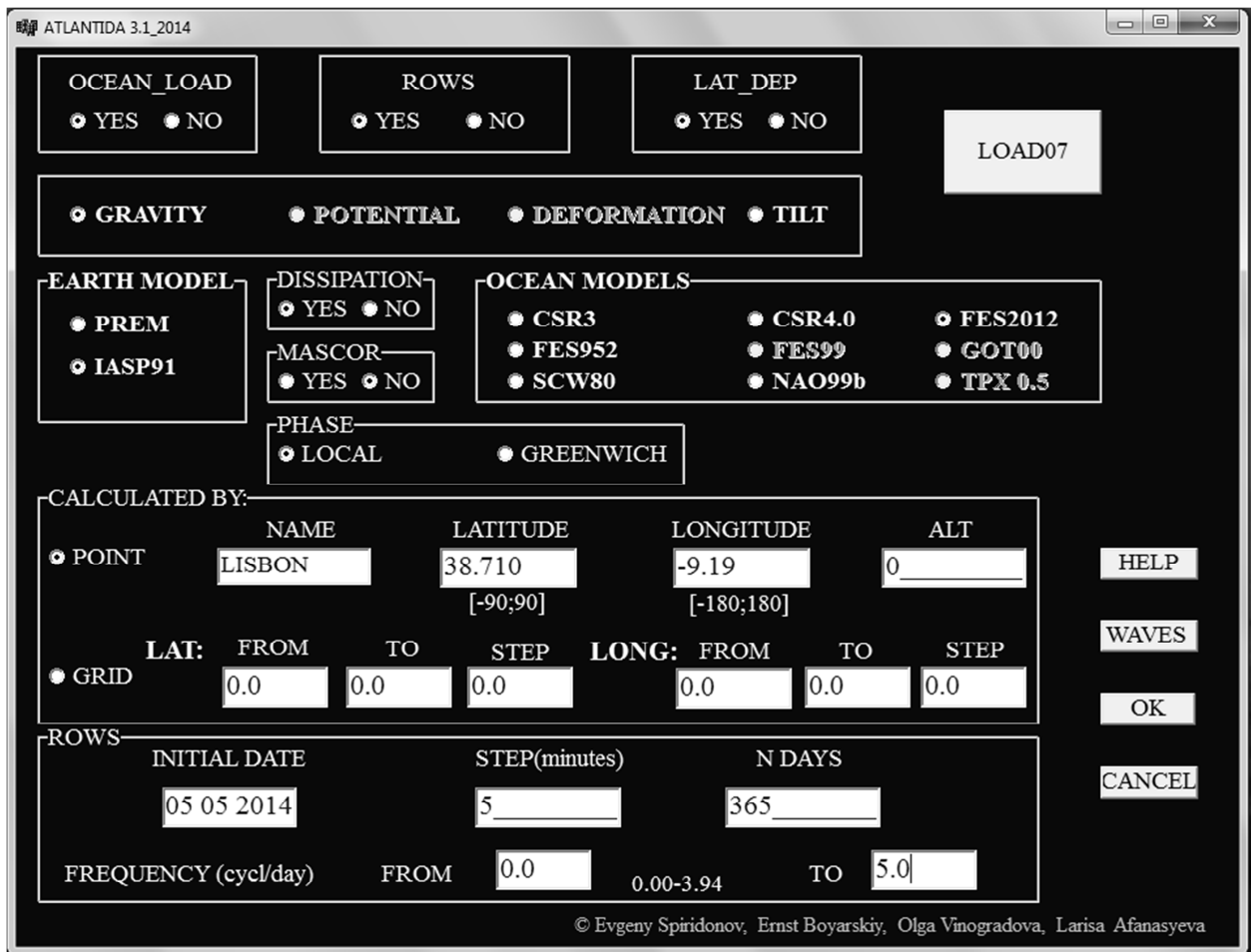


Fig 2. The *ATLANTIDA 3.1_2014* interface

2.2 Selecting the options

2.2.1. General options

OCEAN_LOAD YES or ***NO***: Calculate or not calculate the oceanic effect;

ROWS YES or ***NO***: Calculate or not calculate the tidal time series;

LAT_DEP: To take or not to take into account the latitudinal dependence of the ordinary and loading delta-factors.

After the desired options are selected, this version of the program can be used in either of the two possible modes: ***GRAVITY*** or ***TILT***. For tilt it is only possible now to compute ocean tide loading in the NS and EW directions.

EARTH_MODEL – Selecting the Earth model (PREM or IASP91);

2.2.2. Selecting the parameters of calculations of the oceanic gravimetric effect

OCEAN_MODELS - Selecting the tidal ocean model (**YES** if **OCEAN_LOAD** is selected).

The calculations for the selected oceanic model can be conducted with the allowance for dissipation (**DISSIPATION**) and mass correction (**MASCOR**). The **DISSIPATION** option only applies to the loading delta factors. By default, the delta factors of the body tides are calculated with dissipation.

You can select the phase: **LOCAL** or **GREENWICH**. (If the **ROWS** option is enabled, the **GREENWICH** option is unavailable.)

When calculating the oceanic effect (**OCEAN_LOAD: YES**), you should also specify the set of the waves for the selected oceanic model. For doing this, click on the **WAVES** bottom, select the desired waves in the popup window and be sure to hit the **SAVE** button (Fig. 3).

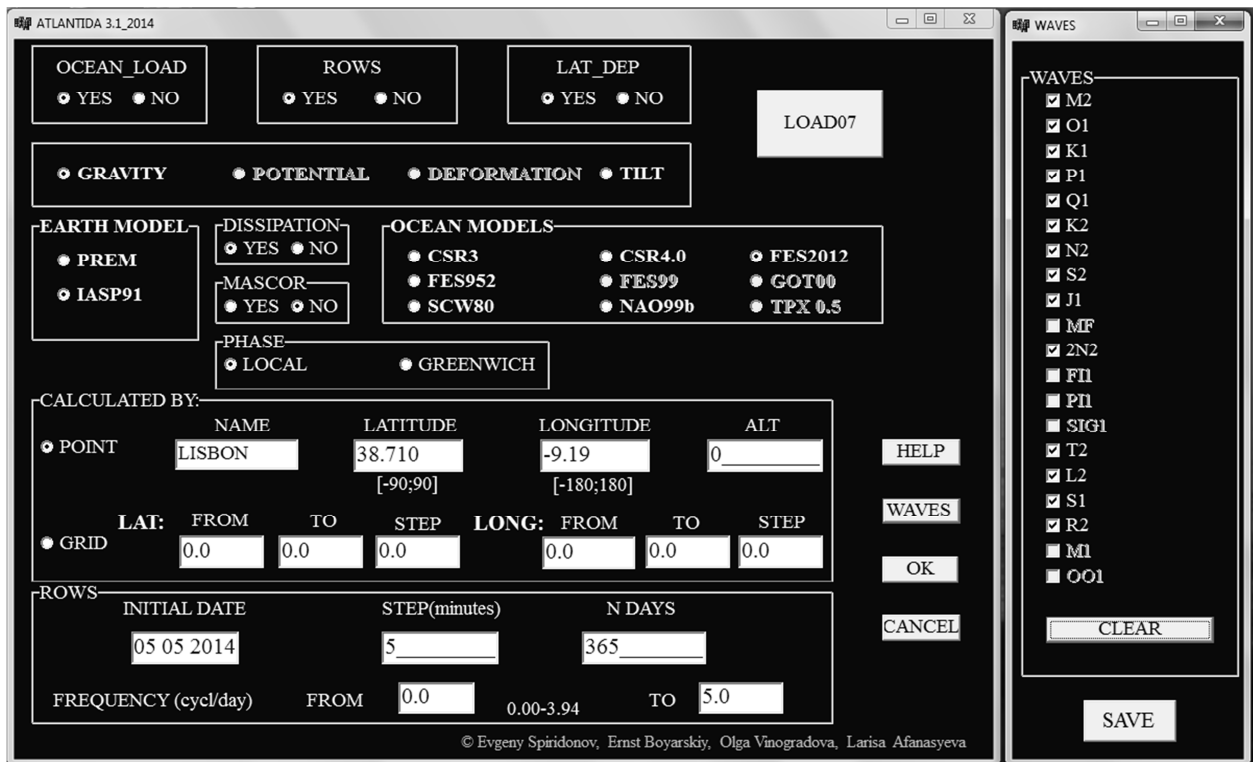


Fig.3. The ATLANTIDA 3.1_2014 program interface with the pop-up window to select the waves.

2.2.3. The name and location of the site

By default, all the options listed above (except for the selection of the waves and tidal time series parameters) are set optimal by the program. To get started, you should only specify the name of the station (**NAME**), the site latitude (**LATITUDE**) in degrees, longitude (**LONGITUDE**) in degrees, and altitude (**ALT**) in meters and tidal time series parameters.

2.2.4. The parameters of calculation of the time series

Then, in order to construct the time series in the **ROWS** mode, you should specify the start date (**INITIAL DATE**), the time step in minutes (**STEP (min)**), the number of the days (**N DAYS**), and the frequency band (**FREQUENCY**) in cycles per day. The entire tidal frequency band is subdivided into 63 groups of waves (Table 1). If the user specifies a limited frequency band, the group of the waves that contains the boundaries of this band is selected as a whole for the further calculations. If some of the waves that were previously selected for calculating the oceanic effect do not fall in the last frequency band, the program automatically removes them and issues the warning message.

NOTE: The additional **GRID** mode (creation of the gridded ocean loading data) only works in the **GRAVITY** mode with **ROWS NO**. Here, you may only select a single wave from **WAVES**. The additional **TILT** mode only works for **POINT** and ignores **ROWS** mode by default.

WARNING! In this version of the program, the **ALT**, **N DAYS** and **STEP** fields are integers.

In case of a wrong choice of the parameters, the program displays the error message (see section 2.4).

The interface has also a button that runs the **LOAD07** program. This program is completely identical to the **LOAD89 (97)** program of the Wenzel's **ETERNA3.3** package. At the same time, **LOAD07** has a convenient user-friendly interface, which makes it possible to conduct calculations both at a single point and on a grid and to select the waves of interest for the user. This interface was designed by Ernst Aronovich Boyarskiy in 2011. Later, two updates were introduced into the program. They provided the possibility to account for the effect of the **M2** wave of **FES95.2** model, which was previously impossible, and fixed the bugs associated with introducing the station height corrections and mass correction in the **FES95** and **SCW80** models. The **LOAD07** program has its own **HELP** (only available in Russian in this version of the program).

2.3. Running and operation of the program

After specifying all the required settings, click **OK**. The names of the results files are generated automatically.

If the **OCEAN_LOAD YES** option (calculation of the oceanic gravimetric effect) is selected, immediately after the start of the program, a popup window will appear (Fig. 4). This window displays the number of the wave for which the calculations are being conducted and the total number of the waves specified for calculating the oceanic effect.



Fig. 4. The popup window of calculations of the oceanic effect

Immediately upon the completion of the calculations of the oceanic effect, ATLANTIDA3.1 passes the control to the PROLET program. This only occurs if the ROWS YES option is selected. The PROLET program calculates the tidal series as well as the prognostic values of delta-factors and phase shifts for those waves for which the oceanic effect has been calculated previously. After the termination, the program displays the popup window shown in Fig. 5:

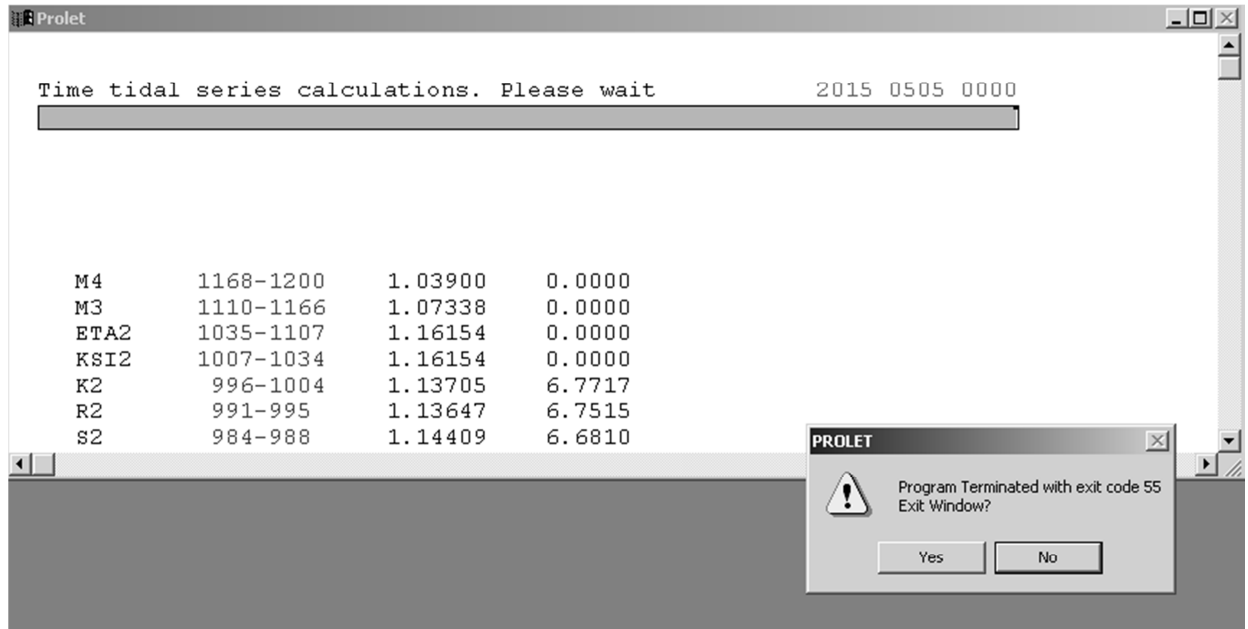


Fig. 5. The popup window of program termination

If the program was successfully terminated with exit code 55, press YES. Otherwise (exit code 0) press NO and reinstall the whole program package or contact the author of the program. Program termination with exit code 55 informs the user that failures were absent at all the steps of the calculations.

2.4. Program messages

The program issues more than thirty different messages overall. Below, we present short comments on each message. The messages are listed in the alphabetical order. By checking the messages, the user can also obtain the information on some limitations assumed in a given version of the program.

0<N_DAYS<=9800! The number of the days used for constructing the tidal series should be at most 9800 (26.8 years)

Access violation in CC3260MT.DLL. This system message appears if the program is installed in other than a root directory.

ALTITUDE is not valid! The height of the observation site specified for the program should range within -9000 to +9000 m.

DAY is not valid! The day of the month starting from which the user would like to calculate the tidal time series should be specified in the range from 1 to 31.

FILE [FILE_NAME] already exist! Replace it? (Y or N) This message may only appear in the case of repeated computations for the same site if the calculation is fully identical to the previous one or if a different set of the waves is selected for this oceanic model. By pressing Y and Enter, you can rewrite the new file over the old one (replace the old file by the new one). If you press No and Enter, the program terminates. The file can be copied from the RESULTS directory to any other directory.

The following three messages are concerned with specifying the frequency band in the calculations of the tidal time series. They appear if the lower specified frequency is higher than the higher frequency or if the specified frequencies are negative.

Frequency2 must be greater then frequency1.

Frequency1 is not valid!

Frequency2 is not valid!

GREENWICH PHASE does not work with ROWS option. The option of selecting the Greenwich phase in our program is only available for calculating the amplitudes and phases of the oceanic effect. This option does not work with the mode of constructing the tidal series (ROWS).

Latitude for this model must be >= -78 deg. This message only concerns the CSR3.0 and Schwiderski tidal oceanic models.

Latitude for this model must be >= -85 deg. This message only concerns the FES95 tidal oceanic model.

Latitude for this model must be from -89.75 to 89.75 deg. This message only concerns the NAO99b tidal oceanic model.

One of the following seven messages appears if the latitude specified for a site or for a grid node falls beyond the interval from -90 to +90 degrees, or if the longitude is lower than -180 degrees or higher than +180 degrees, or if the value of the lower latitude (longitude) in the grid calculations is greater than or equal to the larger latitude.

LatFin is not valid! (-90 90)

LATITUDE is not valid! (-90 90)

LATITUDE: LatStart>=LatFin!

LONGITUDE is not valid! (-180 180)

LONGITUDE: LongStart>=LongFin!

LongFin is not valid! (-180 180 for GRID)

LongStart is not valid! (-180 180 for GRID)

MONTH is not valid! (1 12) The number of the month specified in the initial date in the calculations of the time series should range from 1 to 12.

NO sp.exe! The program warns that the installation package lacks the sp.exe program, which checks the completeness of the whole package. This check is executed every time the ATLANTIDA3.1 program is run.

NO subject computing. OCEAN_LOAD or ROWS must be YES. The both **OCEAN_LOAD** and **ROWS** options are set to **NO**.

NO WAVES! This is the most frequent message warning that the waves for calculating the oceanic effect in the selected tidal model are not specified. To specify the waves, click on the **WAVES** button, select the desired waves in the popup menu and press **SAVE**. This message often appears if the user had selected the waves but changed some other settings afterwards.

Option ROWS for TILT does not work in this version. The tidal series of the tilts are not calculated in this version.

ROWS option: latitude must be from -89 to 89 degrees. In the calculations of the tidal time series, the latitudes should range within -89 and 89 degrees.

STEP>NDAYS*24*60! The time step in minutes indicated for the calculations of the time series cannot be longer than the length of the series.

The following three messages appear if in the calculations of the oceanic effect on the numerical grid, the selected step of calculations along the latitude (longitude) is larger than the entire range of calculations or if it is negative.

Step by latitude is too large! (the step along the latitude exceeds the entire latitudinal range of the calculations).

Step by longitude is too large!

Step by latitude or longitude is not valid! (the specified step is negative).

TILT GRID is not possible in this version. The grid calculations of the amplitude and phase of the oceanic effect for the tilts are not possible in this version of the program.

The ocean model wave [WAVE_NAME] is outside the rows frequency band. These waves will exclude from the list of the ocean model! This is a purely informational message. The waves of the oceanic effect that were not included in the frequency band selected for calculating the tidal series are excluded from the further calculations.

YEAR is not valid! The first year of calculations of the tidal series should fall in the interval from 1000 to 9999.

You can calculate only one wave for GRID! The calculations of the amplitudes and phases of the oceanic effect at the grid nodes are only possible for a single wave of the selected tidal oceanic model. This message appears if the user specifies many waves.

2.5. The Results Files

The files of the results are located in \ **ATLANTIDA31** \ **RESULTS**.

For the example shown in the Fig. 2, the program displays the following three files in the **RESULTS** directory:

LISBON_FES12_IASP_L_DY_MN_LAT_DEP_YES_GRAV.dat
LISBON_FES12_IASP_L_DY_MN_LAT_DEP_YES_GRAV.prn
LISBON_FES12_IASP_L_DY_MN_LAT_DEP_YES_GRAV.grw

The first file (**.DAT**) contains the tidal time series, the second file (**.PRN**) contains the constants used in the calculations, the amplitude delta-factors, and phase shifts for the Earth without and with the ocean for the groups of the waves. The amplitude factors and phase shifts for the Earth with ocean are only calculated for the waves for which the oceanic effect is calculated. These waves can easily be distinguished in the list of the waves by the non-zero phase shifts (Table 1).

The third file (**.GRW**) contains the amplitudes and phases of the gravity oceanic effect (the Newtonian attraction of water masses, the loading effect, and their sum). In the **TILT** mode, the **NS** and **EW** components are provided.

Table 1.

MAIN WAVE theoretical parameters								
Delta-factors and phase lags for the Earth with ocean								
N	Wave Group	<----- Cycle/Day	From...To	-----> Numbers	AMPL. nm/s**2	FREQUENCY Cycle/Day	Amplitude Factor	Phase Lag. Deg.
1	M4	2.935321	3.937897	1168-1200	0.91451	2.97161	1.03900	0.00000
2	M3	2.753244	2.935174	1110-1166	7.01912	2.89841	1.07338	0.00000
3	ETA2	2.039339	2.182843	1035-1107	3.23297	2.04177	1.16154	0.00000
4	KS12	2.005623	2.039177	1007-1034	1.87187	2.00577	1.16154	0.00000
5	K2	2.003032	2.005622	996-1004	57.82324	2.00548	1.13705	6.77168
6	R2	2.000619	2.003031	991-995	1.77965	2.00274	1.13647	6.75150
7	S2	1.998287	2.000456	984-988	212.74914	2.00000	1.14409	6.68103
8	T2	1.997115	1.997493	980-982	12.43269	1.99726	1.11181	6.44535
9	TL2	1.968876	1.997114	956-979	3.23189	1.96918	1.16154	0.00000
10	L2	1.968271	1.968875	950-955	12.92498	1.96857	1.10354	6.82502
11	LM2	1.932421	1.968270	904-949	3.37194	1.96371	1.16154	0.00000
12	M2	1.931817	1.932420	895-901	457.27659	1.93227	1.06495	7.96007
13	MNI	1.901459	1.931816	871-894	1.57185	1.92954	1.16154	0.00000
14	NI2	1.900545	1.901458	865-870	16.62923	1.90084	1.16154	0.00000
15	NIN	1.896602	1.900544	855-863	0.81804	1.89872	1.16154	0.00000
16	N2	1.895363	1.896601	843-854	87.55012	1.89598	1.00349	7.12819
17	NMI	1.865167	1.895362	818-842	0.94334	1.86729	1.16154	0.00000
18	MI2	1.864253	1.865166	813-816	13.98132	1.86455	1.16154	0.00000
19	MIN	1.861663	1.864252	804-812	0.35759	1.86424	1.16154	0.00000
20	2N2	1.859071	1.861662	795-802	11.58524	1.85969	0.94940	4.57114
21	NEP	1.830685	1.859070	779-794	0.65254	1.83311	1.16154	0.00000
22	EPS2	1.827342	1.830684	771-777	3.37798	1.82826	1.16154	0.00000
23	3N2	1.822633	1.826136	763-769	1.30356	1.82340	1.16154	0.00000
24	222	1.719381	1.822486	733-761	0.55939	1.79196	1.16000	0.00000
25	V1	1.111613	1.216397	686-731	2.49611	1.11223	1.15605	0.00000
26	OV	1.080797	1.109950	663-683	0.62659	1.10676	1.15605	0.00000
27	OO1	1.073202	1.078825	644-662	13.03706	1.07594	1.15610	0.00000
28	OJ	1.039193	1.073201	613-643	3.95301	1.07046	1.15631	0.00000
29	J1	1.036910	1.039192	606-612	23.83138	1.03903	1.15894	0.75464
30	THE1	1.010333	1.036748	584-604	4.55719	1.03417	1.15685	0.00000
31	FI1	1.007904	1.008655	576-581	6.06752	1.00821	1.17011	0.00000
32	PSI1	1.003651	1.007903	569-575	3.33251	1.00548	1.26954	0.00000
33	K1	1.002575	1.003650	557-568	426.17775	1.00274	1.12803	0.74981
34	KS	1.001826	1.002574	553-556	0.23882	1.00243	1.13841	0.00000
35	S1	0.997734	1.001825	546-552	3.33228	1.00000	1.08476	-4.46744
36	P1	0.995143	0.997733	537-544	140.99789	0.99726	1.14204	0.69984
37	PI1	0.989049	0.995142	532-536	8.24189	0.99452	1.15054	0.00000
38	PIC	0.971598	0.989048	525-530	0.19465	0.97404	1.15272	0.00000
39	CH1	0.970994	0.971597	521-523	4.55788	0.97130	1.15351	0.00000
40	CHM	0.968566	0.970993	515-519	0.14720	0.96918	1.15360	0.00000
41	M1	0.963399	0.968565	494-512	23.83207	0.96645	1.15366	0.00000
42	MTU	0.940017	0.963398	482-492	2.23608	0.96097	1.15376	0.00000

43	TAU1	0.932583	0.940016	463-481	3.95233	0.93501	1.15405	0.00000
44	TO	0.929684	0.932582	450-461	1.95353	0.93015	1.15406	0.00000
45	O1	0.928932	0.929683	439-449	303.02724	0.92954	1.14443	-0.62527
46	OR	0.898264	0.928931	412-438	1.04220	0.92680	1.15408	0.00000
47	RO1	0.896129	0.898263	406-410	11.02046	0.89810	1.15408	0.00000
48	RQ	0.893407	0.896128	394-405	0.54121	0.89598	1.15408	0.00000
49	Q1	0.892934	0.893406	387-392	58.01826	0.89324	1.16337	-1.39957
50	QSIG	0.866977	0.892933	369-386	0.55459	0.89279	1.15404	0.00000
51	SIG1	0.859381	0.866976	352-368	9.26549	0.86181	1.15399	0.00000
52	2Q1	0.721500	0.859380	283-349	7.67667	0.85695	1.15397	0.00000
53	MSQM	0.132715	0.249951	206-281	0.33202	0.14093	1.34442	0.00000
54	MTM	0.106756	0.130596	174-204	2.07906	0.10949	1.15753	0.00000
55	MSTM	0.075321	0.106446	140-171	0.39489	0.10464	1.15754	0.00000
56	MF	0.070317	0.073806	118-139	10.85895	0.07320	1.15767	0.00000
57	MSF	0.062103	0.070155	92-117	0.95163	0.06773	1.15770	0.00000
58	MM	0.033716	0.060132	53-91	5.73751	0.03629	1.15794	0.00000
59	MSM	0.028844	0.033701	40-52	1.09728	0.03143	1.15800	0.00000
60	SSA	0.004710	0.028697	21-39	5.05292	0.00548	1.15884	0.00000
61	SA	0.002428	0.003425	11-18	0.80223	0.00274	1.15924	0.00000
62	186	0.000141	0.000913	3-9	4.55421	0.00015	1.16144	0.00000
63	MOS0	0.000000	0.000140	1-2	51.30260	0.00000	1.00000	0.00000

The names of these files only differ by their extensions. The filename consists of the following parts:

- **LISBON** – site name (In the **GRID** mode, instead of the site name, this part of the filename is composed of the wave name and a flag that is indicative of the **GRID** mode, for example: **M2_GR_**);
- **FES12** – oceanic model **FES2012**;
- **L** – local phase (**G** – Greenwich);
- **DY** – dissipation **YES** (or **DN** - dissipation **NO**);
- **MN** – mass correction **NO** (or **MY** - mass correction **YES**);
- **LAT_DEP_YES** – dependence from latitude **YES** (or **LAT_DEP_NO**);
- **GRAV** – gravimetric effect (or **TILT**).

If only the oceanic effect is calculated (**ROWS NO**), a single file with **.GRW** extension is yielded.

The content of the Results file for the parameters shown in Figure 1 can be found in the **ATLANTIDA31 \ EXAMPLE** directory.

The theoretical and practical results that were used when designing the program are described in some of our papers. All these publications are available in the **\ ATLANTIDA31 \ PAPERS** directory.

3. SOME NUMERICAL ESTIMATES OBTAINED DURING THE DEVELOPMENT OF THE ATLANTIDA3.1_2014 PROGRAM

In this section, we briefly discuss some numerical results that we obtained when developing and testing our program. These results are provided by the different variants of calculations of the oceanic gravimetric effect and amplitude delta-factors for the oceanless Earth.

3.1. Oceanic Effect in Europe

3.1.1. Earth models PREM and IASP

The differences in the amplitudes of ocean loading effect calculated for the PREM and IASP91 models in Europe reach 0.1 μgal (M2 wave) near the Moroccan coast and increase to 0.3 μgal at the western coasts of Portugal and France [Vinogradova, Spiridonov, 2012]. Here, the maximum discrepancies in phases do not exceed 0.1°. However, near the tip of Cape Cornwall and close to the Irish seaboard, in the region of Le Havre and Calais, the differences in the amplitudes and phases reach 0.35–0.4 μgal and 3–5°, respectively. The maximum differences in amplitude for sums of semidiurnal and all (semidiurnal and diurnal) waves were observed near Cape Lands-End (Cornwall) and reach to 0.5–0.55 μgal . In Britany these values reach to 0.35 μgal and up to 0.2 μgal near southern coasts of Europe and Morocco. The difference for the sum of diurnal waves is negligible and it do not exceeds as rule 0.01 μgal .

3.1.2. Dissipation

Dissipation induces variations in the amplitude of M2 wave, which do not typically exceed 0.1 μgal in the immediate proximity of the coastline [Vinogradova, 2012; Vinogradova, Spiridonov, 2013a]. Somewhat higher values (up to 0.2–0.3 μgal) are only observed near the mentioned St. Matthew and Land's End Capes, which sharply project into the ocean. Again, the specific structure of the isolines in the Irish Sea and English Channel is remarkable. The phase differences do not normally exceed a few hundredths of a degree and can reach several degrees only in the specific knotty zones mentioned above. At more than 100 km distance from coastline the influence of dissipation is smaller than 0.01 μgal . The geographical distribution of considered differences derived for sums semidiurnal and all waves practically repeat the scheme of M2. In fact, in the transition from M2 to the sum of all semidiurnal waves the amplitude of differences increases upon the average to 0.05 μgal and considering the sum of eight waves it reaches 0.15–0.2 μgal . Almost half the discussed difference is obtained already even upon the transition from a reference period of 1 s to 200 s. The transition from 12 h to 24 h yields the corrections below 0.005 μgal to the amplitude and 0.1 degree to the phase.

So, the dissipation contributes 0.1-0.2 μgal to the amplitude and, typically, with a few hundredths of a degree to the phase of the total oceanic gravimetric effect near the coast of Europe

3.1.3. Spherical harmonic expansion of the oceanic tidal heights.

The comparison between the methods of calculating the oceanic load effect through Green's functions and by spherical harmonic expansion of the oceanic tidal heights up to $n = 720$ have revealed minimal discrepancies in the results at distances exceeding 50–100 km off the coast [Vinogradova, Spiridonov, 2013a]. The differences in the amplitudes of the effect are on the order of a few tenths of microgal, and the phase differences are hundredths and thousandths of a degree. In the immediate neighborhood of the coast in the zones of moderate gradients, these discrepancies do not typically exceed 0.2–0.3 μgal and a few tenths of a degree, respectively. In the very narrow zones, the amplitude differences may reach 0.5–0.8 μgal , and this situation certainly requires further analysis. In any case, the discrepancies make up at most 2–2.5% of the studied values.

The expansion of the tidal heights in the higher order spherical harmonics does not change this pattern significantly.

3.1.4. The latitudinal dependence of the oceanic gravimetric effect

The calculations by the ATLANTIDA3.1_2014 program have shown that the latitudinal dependence of the loading Love numbers only slightly affects the calculated oceanic loading effect. Significant contribution was only revealed for the islands in the open ocean and for the zones with high gradient of the amplitudes of the oceanic effect. For example, in the Canary Islands, the difference between the amplitudes of the oceanic effect for the M2 wave calculated with and without the allowance for the latitudinal variations reaches 0.15 μgal , which makes up 0.2–0.25% of the amplitude of the body tide for this wave.

3.1.5. Comparison of oceanic effect with observations

The comparative analysis of the oceanic gravitational effect calculated in this study with the observations is based on the results obtained by different authors at 21 stations using 22 instruments. Two stations are located on the Canary Islands; two, on Svalbard; five stations carried out measurements with SLR instruments in Europe; 12 stations with superconducting gravimeters are part of the GGP network. The instruments included 12 superconducting gravimeters, eight LaCoste_Romberg gravimeters, and two Askania gravimeters. Besides comparing our calculations with the observations, we also compared them with the model predictions by other authors using the programs based, inter alia, on the regional oceanic models.

The number of cases (in%), in which the results of ATLANTIDA 3.1 are closer to those observed than calculations performed by other programs are: Canary Islands - 62%; Spitsbergen - 69%; European LCR stations - 64%; GGP network - 59%. In 77% of the cases obtained in this study the results are closer to the observations than those computed using the package Load97 from ETERNA3.30. More results of this analysis refers to the article [Spiridonov E.A. Vinogradova O.Yu, 2014].

Low-frequency sea level T/P non-tidal perturbations give the magnitude of the gravimetric load effect of order 1 mgal. [Vinogradova, Spiridonov, 2013b].

3.2. The delta-factors for the oceanless Earth

We compared the amplitude factors for oceanless Earth obtained in [Spiridonov, 2014] and applied in ATLANTIDA3.1_2014 with the observations using the results presented in [Ducarme B. et al., 2009]. In the quoted study, the authors analyzed the measurements by seven modern instruments of the GGP network in Europe (the CT and CD series). The effect of the ocean was considered as the average over nine oceanic models. The results are presented for the M2, O1, and K1 waves.

In more than half cases, the empirical values differed from the model predictions by about 0.01% for PREM and by about 0.1% in the other cases. In this respect, it is worth noting that the standard deviation of the amplitudes for nine oceanic models used in [Ducarme B. et al., 2009] mainly corresponded to the error of 0.1%. Nevertheless, the slightly closer agreement between the observations and model predictions in our calculations was obtained for the *IASP91* model. The discrepancies between the theory and observations in most cases do not exceed a few hundredths percent [Spiridonov, 2014, Tables 3 and 4].

It was also found that the standard deviation of the differences between the delta-factors estimated with the use of the model of [Spiridonov, 2014] and the observations at all the seven stations and for the three waves is almost 8.4% lower than the estimation based on the DDW/NH model ($8.794 \cdot 10^{-4}$ against $9.600 \cdot 10^{-4}$). However, this discrepancy is small since all the seven analyzed stations are located in the middle latitudes, where the values predicted by our model for IASP and DDW/NH barely differ (Fig. 6).

In order to compare the results derived for these two models, we carried out detailed additional processing of the gravimetric data obtained at the Syowa Antarctic station operated by Japan [Kim et al., 2011]. These data are mainly interesting by the fact that they are acquired at very high latitude (69.007 S). At the same time, this station is marked with rather wide scatter of the amplitudes and phases of the oceanic tidal models. Nevertheless, it was shown that, irrespective of the oceanic tidal model used, almost in 70% cases (for 14 oceanic models and

eight waves), the application of the theoretical delta-factors of DDW/NH model for calculating the oceanic effect observed at the Syowa station leads to poorer results in comparison with the application of the modeled amplitude factors used in the ATLANTIDA3.1_2014 program.

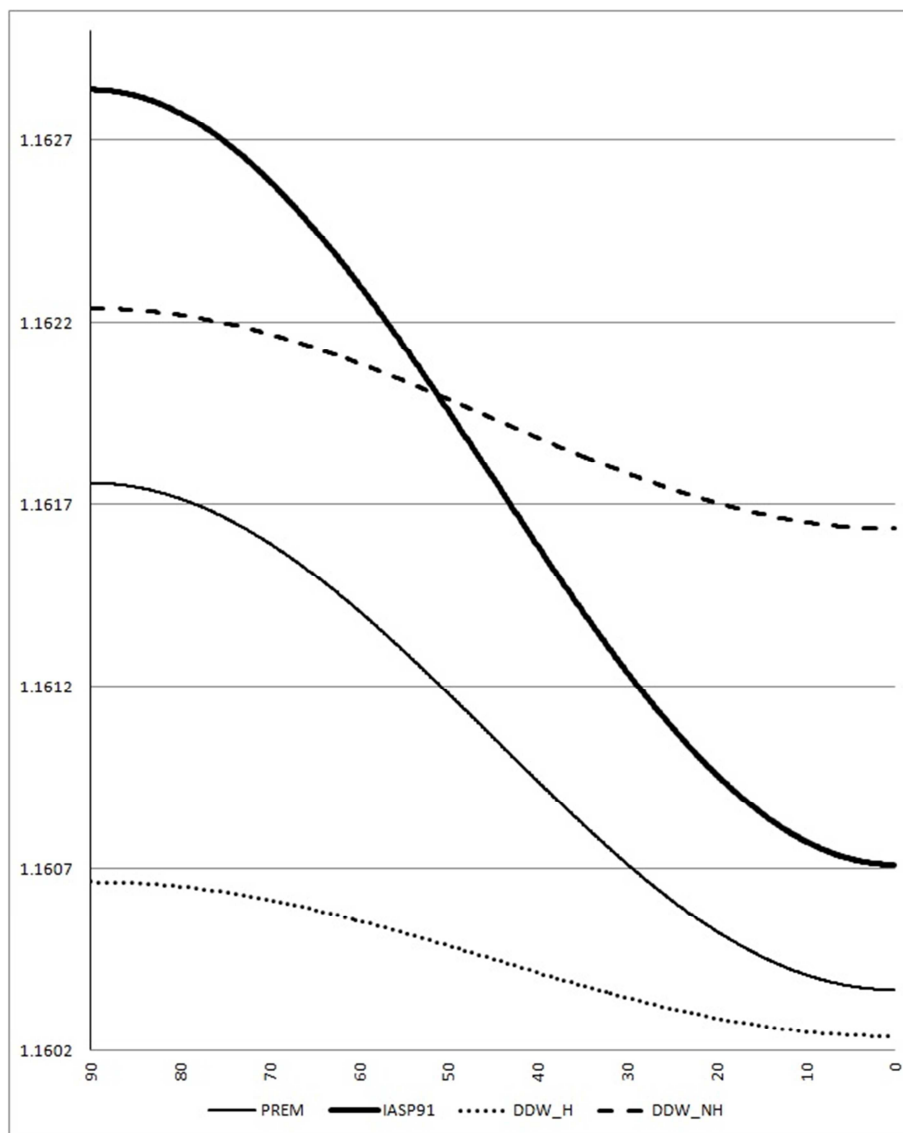


Fig. 6. Latitude dependence of M2 amplitude delta-factor calculated Spiridonov [2014] for Earth's structure models PREM and IASP91 in comparison with DDW/H and DDW/NH models of Dehant et. al. [1999].

CONCLUSIONS

We have considered the main characteristics and possibilities of ATLANTIDA_3.1_2014 --- the new program for tidal prediction, and described the internal structure of the methods that were applied for its design. We briefly described the comparison of the output of ATLANTIDA_3.1_2014 program with the observations. Of course, the further testing will significantly expand the comparative analysis

Even in the next version (ATLANTIDA_3.1_2015) whose release is expected in the fall 2015, it is planned to increase the number of the oceanic models and to include the program for calculating the observed delta-factors and phase shifts.

After this, we will take into account the latitudinal variations of delta-factors for the waves of the zero, third, and fourth order and expand the program package by the calculations of the potential, deformations, and displacements; we will also update the computations of the tilts (the present version of our program only calculates the tilts for the oceanic effect).

The comments on the operation of the program and the suggestions for the further improvements are greatly appreciated.

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