A NUMERICAL MODEL FOR THE STUDY OF THE LOAD EFFECT OF THE WATER IN THE AREA OF THE RIVER PLATE.

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Abstract.

We present a simplified geophysical model to evaluate the deformation field of the local lithosphere during a marked swell of the River Plate. The influence of this phenomenon on the displacement field is analyzed. The differential equations of elastic equilibrium were solved by means of a three dimensional finite element method with appropiate boundary conditions. The results obtained indicate that very high precision measurements would be neccesary to quantify these effects. This, in turn, would allow us to improve the estimation of the elastic parameters of the area.

Introduction.

The study of the deformation of the Earth by surface tractions is a classic problem of geophysical interest as a tool for the study of its mechanical behaviour. As it is well known, large masses of water produce important loading tilts in the crust which extent their effect far from the loads. In some cases this effect may also cause temporal fluctuations of the absolute gravity which can be registered in continental areas with high precision gravimeters.

The River Plate, one of the widest in the world, frequently shows an important increase of its volume due to strong south easterly winds and other meteorological effects. These phenomena present particular characteristics such as very high levels of water (on the order

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of the oceanic tide) and temporal aperiodicity, which are observed by a continuous network of tide gauges around the river.

The aim of this work is to evaluate the load effect of water during the forementioned swells. Using the available geological information, we developed a simplified numerical model to compute the deformation of the lithosphere in the area of the River Plate under the hypothesis of linear elastic behaviour. The differential equations of static equilibrium for the displacement field were solved by using a finite element method. Unlike the classic convolutional method, valid for uniform halfspaces (Farrell 1972), this approach allowed us to consider geological strata of variable thickness. It should be mentioned that finite element modelling was previously used in this context for instance, by Beaumont and Lambert (1972) and Sato and Harrison (1990).

Definition of the three-dimensional model.

In order to build up our simplified three-dimensional model of the local lithosphere, the first step was to define a plane two-dimensional domain extending from 29° 45' S to 39° 45' S and from 51° 29' W to 61° 29' W, according to Figure 1. The dimensions of the area were chosen so as to contain the whole surface of the river and to include points sufficiently far from it as well. This was necessary to ensure (as much as possible) the validity of the boundary conditions applied for the numerical solution of the problem.

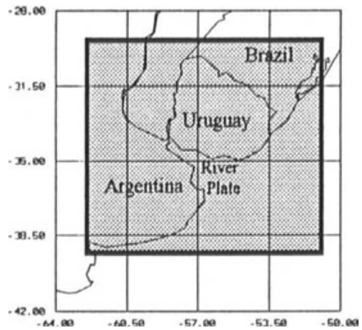


Figure 1. Location of the model (geographical coordinates)

To include the main geological features of the region in our model, we looked for information in the geological and geophysical literature on the subject (Urien 1981; Sprechmann et al. 1981; Bracaccini 1972). From that analysis we can briefly say that the crust in the area consists of a wide variety of Cretaceous-Cenozoic sedimentary fill with seismic p-wave velocities lower than 5 km/sec, lying on a basement composed of Precambrian and Paleozoic methamorphic and Upper Jurassic volcanic rocks with seismic velocities higher than 5 km/sec. Then, for the local crust we adopted the simple scheme of a *sedimentary layer* of variable thickness (from approximately 0.025 to 6 km) over a *basement* extended up to 33 km depth (Barrio 1993). To delineate the top of the basement (see Figure 2) we also used some borehole information taken from Barrio (1993). For simplicity, the effects of the curvature and topography were not taken into account. Also, we considered a plane bottom for the basement (i.e. a plane Mohorovicic discontinuity). The *lower lithosphere* was included as a third layer, extending from 33 to 115 km depth, according to PREM model (Dziewonski and Anderson 1981). In Figure 3a we show a scheme of the three-layer model.

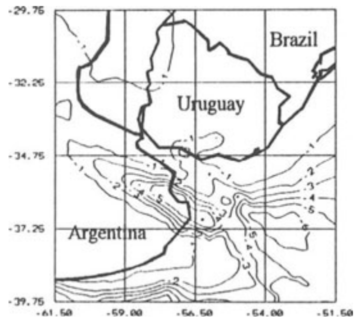


Figure 2. Contour map showing basement depth in km measured from top surface of the model (geographical coordinates)

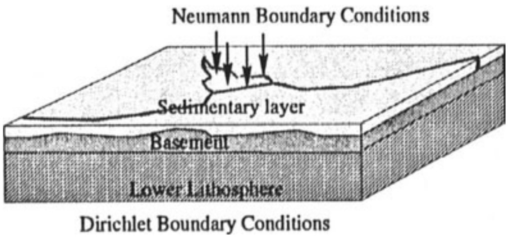
To assign the elastic parameters to sediments and basement we used the forementioned p-wave velocities measured by Bracaccini (1972) in seismic refraction surveys. From that data and using Nafe-Drake relations (Ludwig et al. 1970) to estimate the corresponding s-wave velocities, we established the following range for the elastic parameters λ and μ (Lamé constants) for the sedimentary layer: $\lambda^S_{min} = 6.15$ GPa, $\mu^S_{min} = 0.824$ GPa and $\lambda^S_{max} = 18.33$ GPa, $\mu^S_{max} = 21.44$ GPa. Using the same procedure, we obtained $\lambda^B \cong \mu^B = 34$ GPa for the basement, but for the numerical tests we also used $\lambda^B_{low} = \mu^B_{low} = 10$ GPa, according to one of the values given by Melchior (1983) for the crust. The mean elastic properties adopted for the lower lithosphere are $\lambda^L = 85.12$ GPa and $\mu^L = 67.26$ GPa and were calculated from PREM model. Finally, we must mention that for the shallow water of the Argentine sea in the area of study, we considered the same elastic properties of the sediments.

Resolution of the numerical problem and analysis of results.

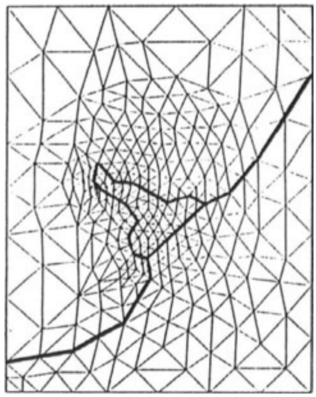
To evaluate the load effect of water during an important swell of the river we computed the static deformation of an elastic non-gravitating three-dimensional bounded domain[1] subjected to the action of surface forces. The equilibrium equations for the displacement field were solved using a finite element method. To do this, we first constructed a plane

[1] It should be pointed out that due to the large horizontal extension of the domain compared to its vertical size, a plate model would probably be more efficient to solve this problem.

two dimensional mesh of triangular elements with the least possible distortion (Figure 3b). In some cases the location of the nodes was chosen to coincide with the position of the tide gauges situated around the river. Next, we generated three-dimensional mesh with three layers (subdomains), as described in the previous section. The total number of elements was equal to 5076 with 1192 nodes.



a



b

Figure 3a,b. a Schematic representation of the three dimensional model. **b** Surface two-dimensional mesh

The load effect of water was simulated by means of a Neumann type boundary condition on the top, representing a distribution of surface forces with the real shape of the river (Figure 3a). The pressure at each point was computed using water height data measured during an ordinary swell due to meteorological causes. On the bottom boundary (i.e. the lithosphere-astenosphere contact), we used a Dirichlet boundary condition (zero displacement) and on the lateral faces we tested the algorithm with both types of condition (zero displacement and zero tractions).

In Figures 4a, b, c we plot the vertical component of the displacement field at the surface for different combinations of the above mentioned elastic parameters. The contours in Figure 4d display the same magnitude as in Figure 4a calculated for a lower water height. From these results we observe that the area of significant deformation is located immediately under the loads and extends up to approximately 20 km from the coast line. Within this area the shape of the contours is mainly controlled by the volume distribution of the loads and the elasticity of the basement (lower values of λ^B, μ^B result in greater displacements). In the remainder, the deformation pattern depends only on the elastic modulus of the basament. The greatest value of displacement (approx. 1.56 cm) is controlled by the elastic properties of the sediments. As can be seen in Figures 2 and 4 this occurs at points within the Salado basin, where the sedimentary thickness and the water heights reach their maximum values simultaneously.

Similarly, at the top of basement and at Mohorovicic discontinuity we observe that the pattern of the displacement field is related to the volume distribution of the loads and the elasticity of the basement. In Figure 5 we show the amplitude decrease of the vertical displacement with depth along a representative cross-section.

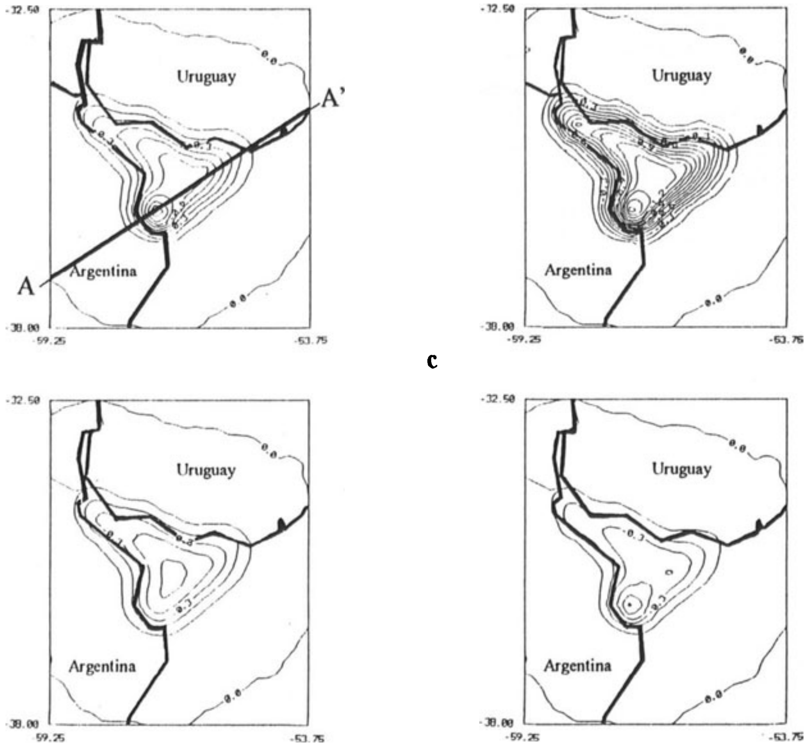


Figure 4a-d. Numerical model estimates of the vertical component of the displacement field at the surface measured in cm, **a** for λ^{S}_{min}, μ^{S}_{min} and λ^{B}, μ^{B}, **b** for λ^{S}_{max}, μ^{S}_{max} and λ^{B}, μ^{B}, **c** for λ^{S}_{min}, μ^{S}_{min} and λ^{B}_{low}, μ^{B}_{low}, **d** for λ^{S}_{min}, μ^{S}_{min} and λ^{B}, μ^{B} and for a lower water height. The graph was restricted to the area where there exist significant values of displacement

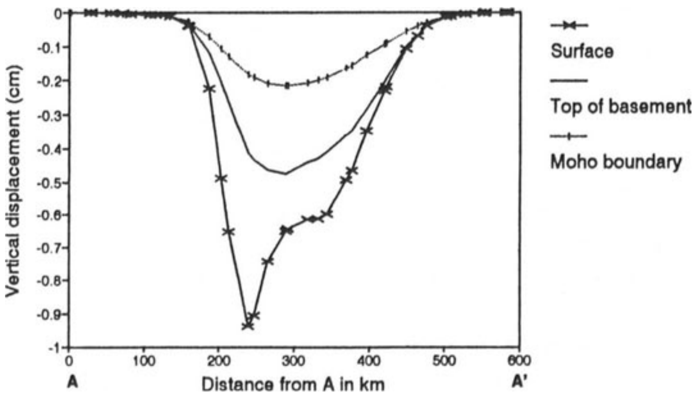


Figure 5. Vertical displacements at different depths along the A-A'profile (indicated in Figure 4a)

As expected, the results obtained using Dirichlet and Neumann boundary conditions on the lateral sides of the domain do not show meaningful differences in the neighborhood of the loads.

As a conclusion we may state that, despite of its simplicity, the numerical model presented here gives a reasonable approximation of the static deformation of the local lithosphere during an important swell of the River Plate. Thus we consider that the combination of this model with high precision GPS and tidal gravity measurements could help not only to achieve a better understanding of the deformation mechanisms but to improve the estimation of the elastic properties in the surrounding of the river as well.

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