THE AYSÉN FJORD TSUNAMI OF APRIL 2007: UNEXPECTED USES OF CIRCULATION MODELS

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1 INTRODUCTION

One characteristic of the Chilean territory is its high frequency of earthquakes. The responsibility for the coordination of responses and management in case of natural disasters in Chile rests with the National Emergency Office (ONEMI, `http://www.onemi.cl`). When dealing with specific disasters, ONEMI seeks advice from experts and scientists through Scientific Technical Committees (STC). On January 22nd, 2007 a seismic crisis started in the Aysén fjord area. A series of earthquakes, sometimes referred as earthquake's swarms, occurred during a period of approximately four months. Given the steepness of the fjord's topography and the possibility of landslides that could in turn generate tidal waves within the fjord, ECOMANAGE scientists were invited to join ONEMI's STC for Aysén. On April 21st, 2007 a major earthquake (6.2 on the Richter scale) affected the Aysén region. This earthquake triggered a $7\,x10^6$ m^3 landslide, mostly rocks, which, in turn, generated a 14 m tidal wave (SHOA 2007). Although the tsunami did not reach populated areas, it resulted in the dead of people which, at the moment of its triggering, were onboard small vessels within the fjord. Both national and local governments started a desperate search for the victims, in order to relief the pain of the affected families. At that point, ONEMI turned to ECOMANAGE posing a specific question: Was it possible to use the results of Aysén's circulation model as an aid in searching for the tsunami's victims? The remainder of this chapter is a summary our response.

2 MODELLING THE THREE-DIMENSIONAL CIRCULATION OF THE AYSÉN FJORD

The circulation of deep estuaries like fjords is highly three-dimensional (see Marín et al., this volume). In the specific case of the Aysén fjord, both data (Cáceres et al. 2002) and models show that there may be more than two layers which are influenced by the wind and the tidal cycle. Beyond this local complexity, the tidal signal that arrives in the fjord has to cross a singular seascape full of islands and small channels (Marín and Campuzano, in press). In order to model this complex signal a 3-level nested circulation model was implemented. Most details about the first level (FJORD), have been explained by Tironi et al. (this volume) and by Marín and Campuzano (in press). Since our main objective in ECOMANAGE was to understand and model the inner Chacabuco bay, we developed a second level nesting model which we termed AYSEN (Tironi et al., this volume). This second level would normally be 2D barotropic, since its only purpose would be to bring the tidal signal from the previous level (FJORD) into the target model (CHACABUCO). However, when ONEMI's request arrived it was clear that a three-dimensional model of the whole Aysén fjord was necessary. The reason for this was the processes that undergo a dead human body when falls in the water (explained to us by physicians from the Chilean Medical Legal Service), which makes them first sink all the way to the bottom, to re-surface again after a period of time that will depend on temperature to finally sink again permanently.

The modified AYSEN model was implemented with eleven Cartesian layers, seven of them in the first 50 m in order to accurately solve the circulation near the surface. Its grid size was 57x215, with a resolution close to 555 m. Its spatial extent and bathymetry are shown in Figure 1. Forcing for the AYSEN model corresponded mainly to the oceanic semidiurnal tidal signal and river discharges (see Tironi et al., this volume). The FJORD model (upper nesting level) was initialized for 15 days in order to stabilize the tidal signal. Then the AYSEN model was initialized for a month for the same reason. The potential advective patterns of the tsunami victims were modeled using MOHID's lagrangian module. The module was initialized for the three locations were victims fell into the fjord's waters (Fig. 1). For each location lagrangian drifters were continuously deploy for five minutes starting on April 21st at 14:00 hrs. Drifters were followed for 15 days, with hourly outputs.

The average circulation of the fjord, for the standard no-wind run used in this experiment, is shown in Figure 2. The model effectively resolves a two layer estuarine circulation, with maximum surface velocities on the order of 0.2 $\mathrm{m\,s^{-1}}$. This velocity is within the same order of magnitude of that reported by Cáceres et al. (2002).

3 LAGRANGIAN EXPERIMENTS

Considering the dynamics of bodies in the water (see 2. Above), we generated two experiments, both with the same initial conditions respect to the location of the lagrangian drifters: for the first experiments, objects stayed on the surface without sinking. This scenario would simulate human bodies that would get trapped on drifting objects such as tree trunks. For the second experiment, objects were allowed to sink at velocities close to that of a human body ($\approx$0.25 m/s). The results of both scenarios after 36 hours of simulation are shown on Figure 3. When objects stayed in the surface (Fig. 3 A) most of them had left the fjord after 36 hours or they anchored in the south shore. Conversely, if objects are allowed to sink, they would remain inside the fjord, in deep waters in the middle of the channel (Fig. 3B). In the last case, even if objects would re-surface again they would leave the system thorough its surface flow to disappear after 72 hours.

4 LANDSLIDE RISKS AND CIRCULATION MODELS

Contrary to what it is expect from tsunamis generated on open coastal oceans, landslide tsunamis occur so fast that there is hardly time for reaction. In the case of the Aysén tsunami it took only 6 minutes for the waves to arrive at populated areas (SHOA 2007). Given the location of the landslide and the distribution of populated areas, victims were reduced only to those standing on boats during the event. Although the Chilean government deployed a rather costly operation in search of victims, none were found. Our lagrangian model results suggest that the main reason for this is that just 36 hours after falling I the fjord's waters, victims were already far away from the main event sector.

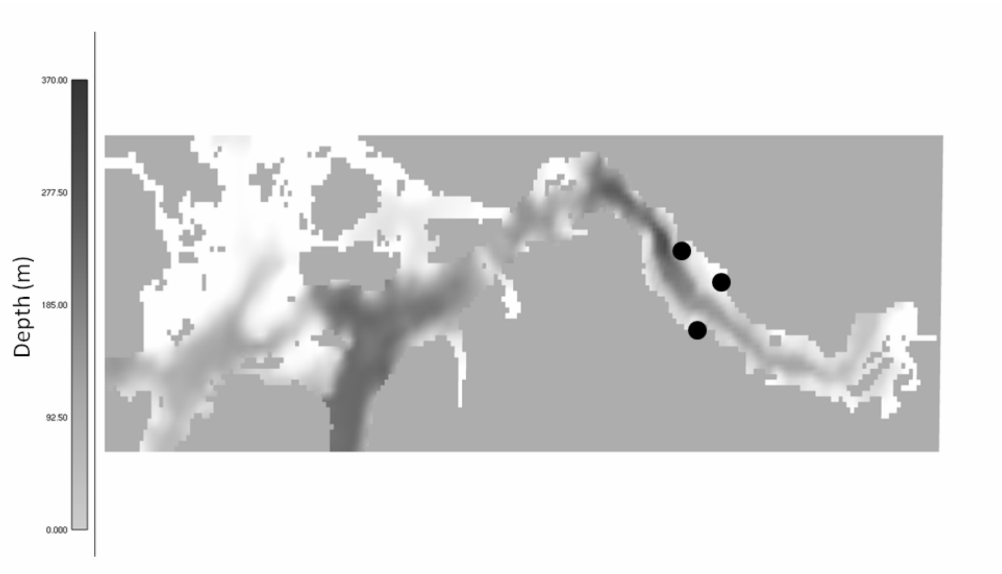

FIGURE 1: *Spatial extent and bathymetry of the AYSEN model. Please refer to the work by Tironi et al (this volume) for the geographic location and description of the study area. Black circles mark the approximate positions were victims fell into the water during the tsunami on April 21st, 2007.*

Risk prevention seems to be the only solution in the face of landslide tsunamis, given its fast dynamics. After the April event, the Chilean government organized a group of experts on numerical modelling, including ECOMANAGE scientists. The main task of this group was to generate a prediction model to assess risk potential and likely responses in other sectors of the Aysén fjord. The results of that work were delivered to the government on August 2007 (SHOA 2007). As a result of the studies conducted by ECOMANAGE and by other members of ONEMI's STC for Aysén, most parts of the inner fjord were declared as dangerous for aquaculture. However, although human lives and whole farming facilities were lost, salmon farmers soon started a lobby to reverse the decision of fjord closure for salmon farming.[1]

Thus, the main lesson from this experience is that numerical models, such as the ones developed by ECOMANAGE on the Aysén fjord, may be important tools for risk assessment and to suggest strategies for local governments. Specially when confronted to decisions that may affect human lives. However, in the end these tools will be only one component in a complex set of components related to the development and security of coastal areas. Final decisions will always be political!

[1] http://www.nuestromar.org/noticias/pesca_y_acuicultura10512_092007_chile_lobby_salmonero_

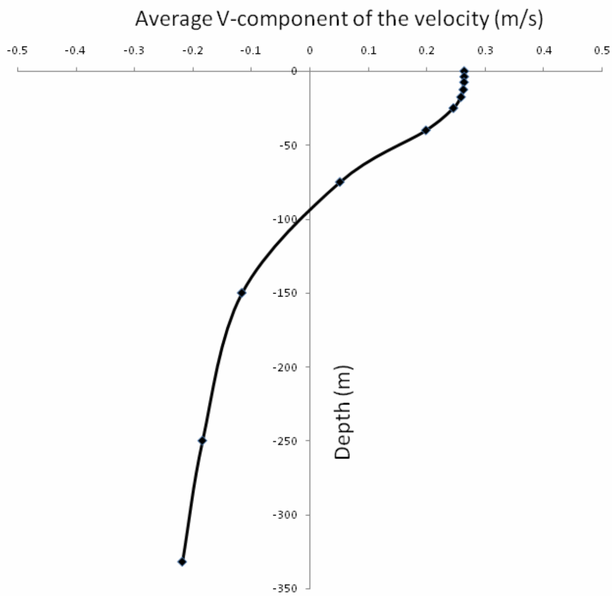

FIGURE 2: *Average along-fjord component of the velocity for the no-wind standard run used during the lagrangian experiments.*

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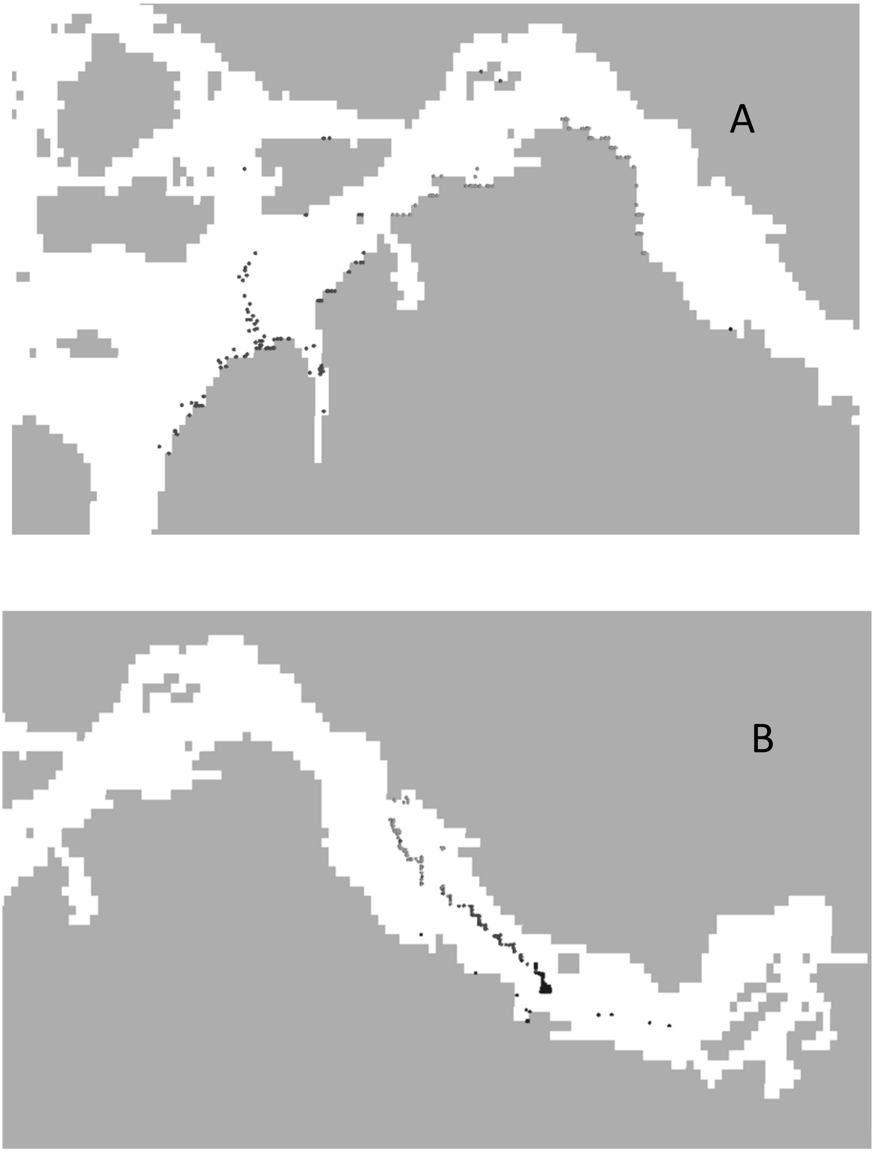

FIGURE 3: *Spatial distribution of lagrangian drifters for the first experiment, non-sinking drifters (A) and the second experiment (sinking drifters) after 36 hours of simulation.*