EGU General Assembly 2020

Quasi-real-time on-fault heterogeneous slip distributions for tsunami early warning purposes

Enrico Baglione, Alberto Armigliato, Stefano Tinti

Alma Mater Studiorum – Università di Bologna

Dipartimento di Fisica e Astronomia (DIFA), Bologna, ITALY

OUTLINE

Slip distribution on earthquake faults is **heterogeneous** and, in the case of tsunamigenic earthquakes, slip heterogeneity influences significantly the distribution of **tsunami run-ups**, especially for **near-field areas**.

Unfortunately, when an earthquake occurs, the so-called finite-fault model (FFM) describing the co-seismic on-fault slip pattern becomes available over time scales which are incompatible with early warning purposes, particularly in the near-field.

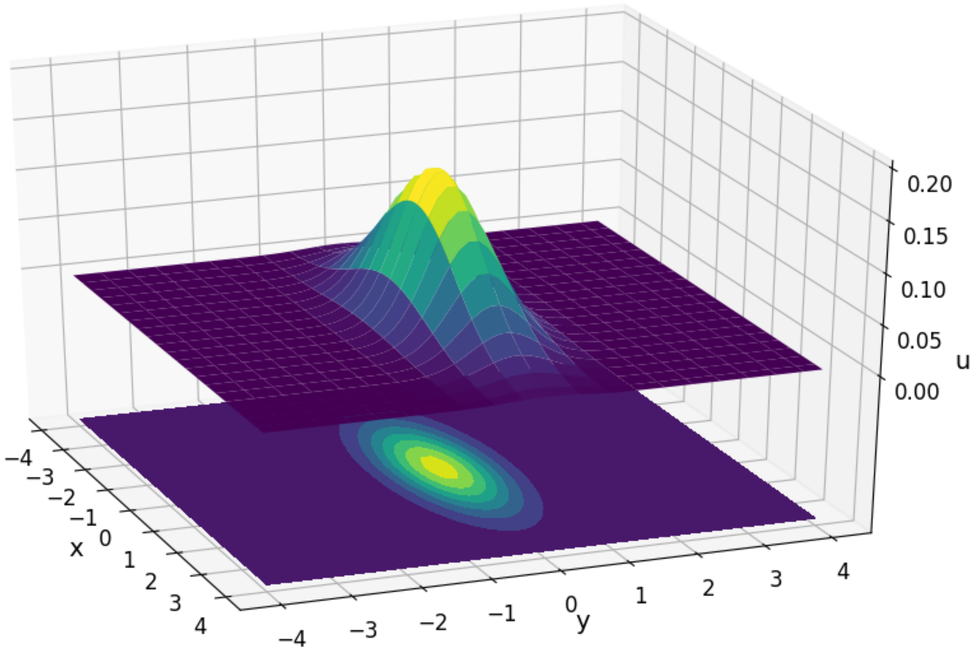
In the perspective of **tsunami early warning**, a crucial issue is to obtain a reasonable slip distribution within a time significantly shorter than the time taken by the waves to impact the nearest coastlines.

STRATEGY

When an earthquake occurs, the only information that becomes available after a few minutes concerns the **location of the earthquake** and its **magnitude**.

Assuming that, the main objective of this study is to provide a strategy for obtaining a **seismic source model** that:

- can be derived in a **very short time** after an earthquake occurs;
- considers the **heterogeneity of slip** on the fault plane;
- is not overly complicated, in order to be treated with simplicity and speed.



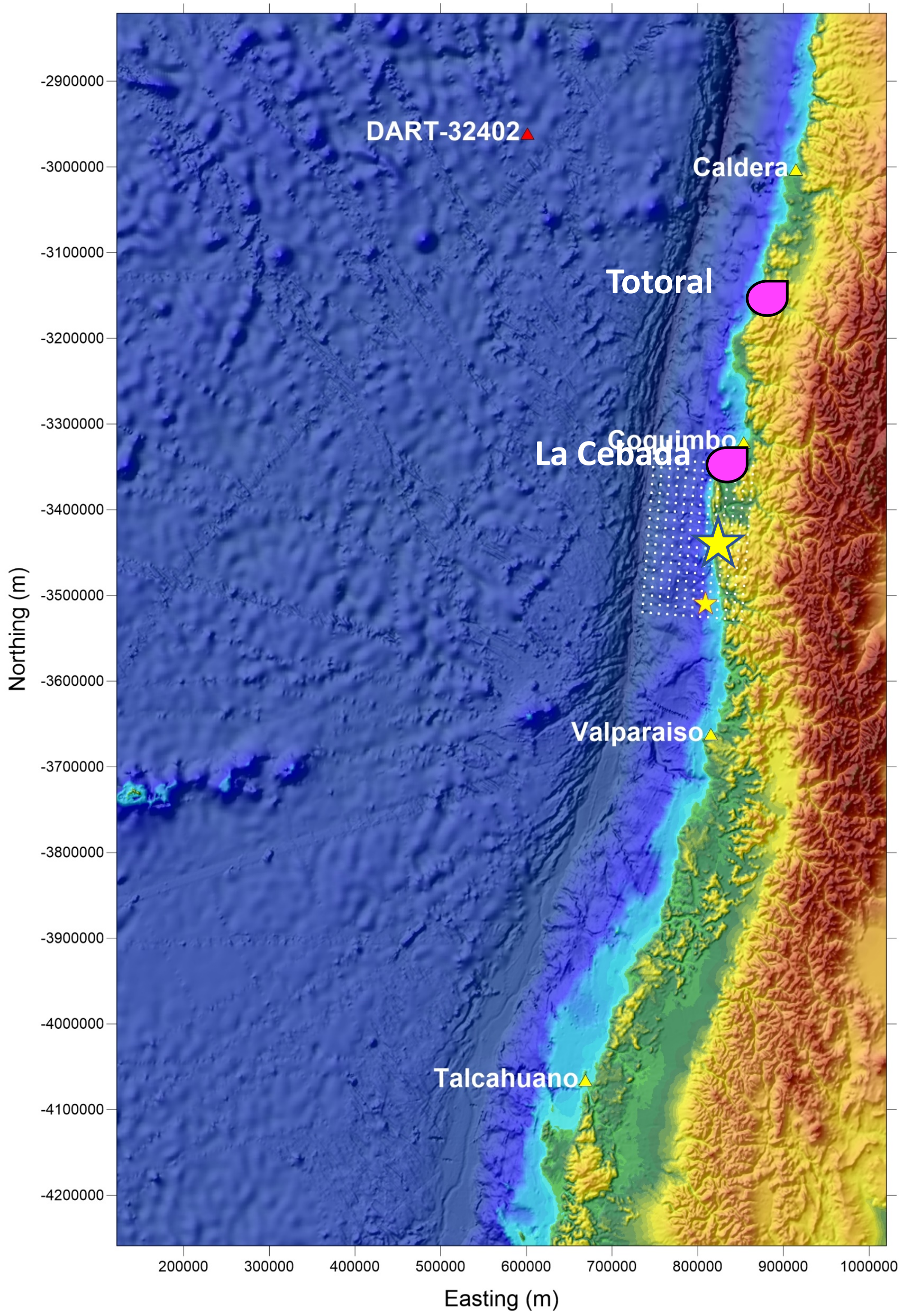
We opted for a:

2D Gaussian Distribution

The parameters characterising the 2D-GD are directly derived from the magnitude through **scaling laws**.

EGU General Assembly 2020

APPLICATION



The 16 September 2015
Illapel (Chile) earthquake
Mw = 8.3

Tsunami heights on the Chilean coast were measured by several post-tsunami surveys:

- maximum of **13.6 m** in La Cebada (Contreras-Lopez et al., 2016) and of **10.8 m** in Totoral (Aranguiz et al., 2016);
- up to 9 m in the latitude interval 29°S-32°S.

Reason of the choice:

- ❑ it generated a tsunami.
- ❑ there is a FFM in the database.
- ❑ being a recent event, a lot of data from observations and studies are available.

Tsunami simulations

- performed by solving the **linear shallow water (LSW) equations** on a coarse (900 m) resolution grid (GEBCO_2014 data), by means of the UBO-TSUFD code (Tinti and Tonini, 2013).
- The coastal boundary is treated as a vertical wall, at which pure reflection occurs (**no inundation**).

EGU General Assembly 2020

SIMULATIONS FROM SOURCE MODELS DERIVED FROM MAGNITUDE AND HYPOCENTRE LOCATION

Earthquake information

Lat (°S)	Lon (°W)	Depth (m)	Mw	Strike (°)	Dip (°)	Rake (°)
31.573	71.674	22400	8.3	353	19	83

Characteristics of the slip distributions

	Length (km)	Width (km)	u_{mean} (m)
T	260	80	3.87
G	240	120	2.32
UNI_A	320	120	1.88
UNI_R	380	160	1.20

Uniform slip distributions

T: Thingbaijam et al. (2017)

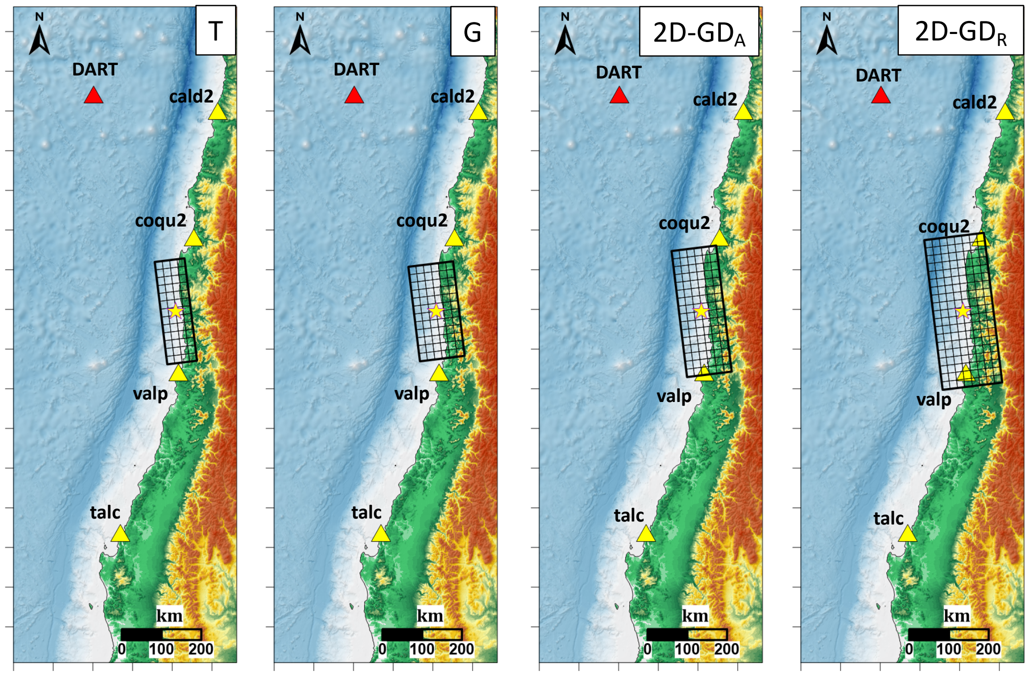
G: Goda et al. (2016)

A: "All"

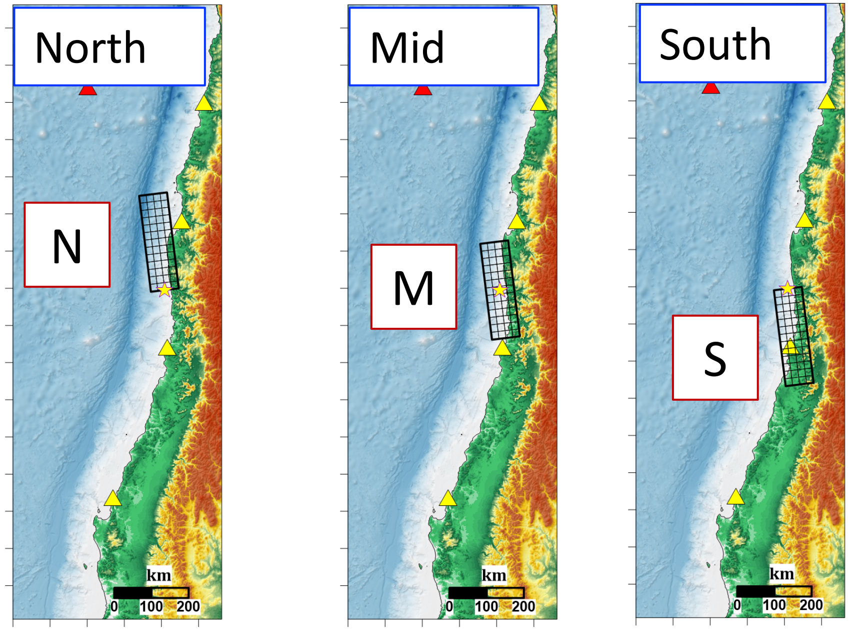
R: "Reverse"

	Length (km)	Width (km)	u_{max} (m)	σ_1 (km)	σ_2 (km)
$2D\text{-}GD_A$	320	120	7.89	48.97	26.06
$2D\text{-}GD_R$	380	160	5.19	61.80	35.56

2D-GD slip distributions

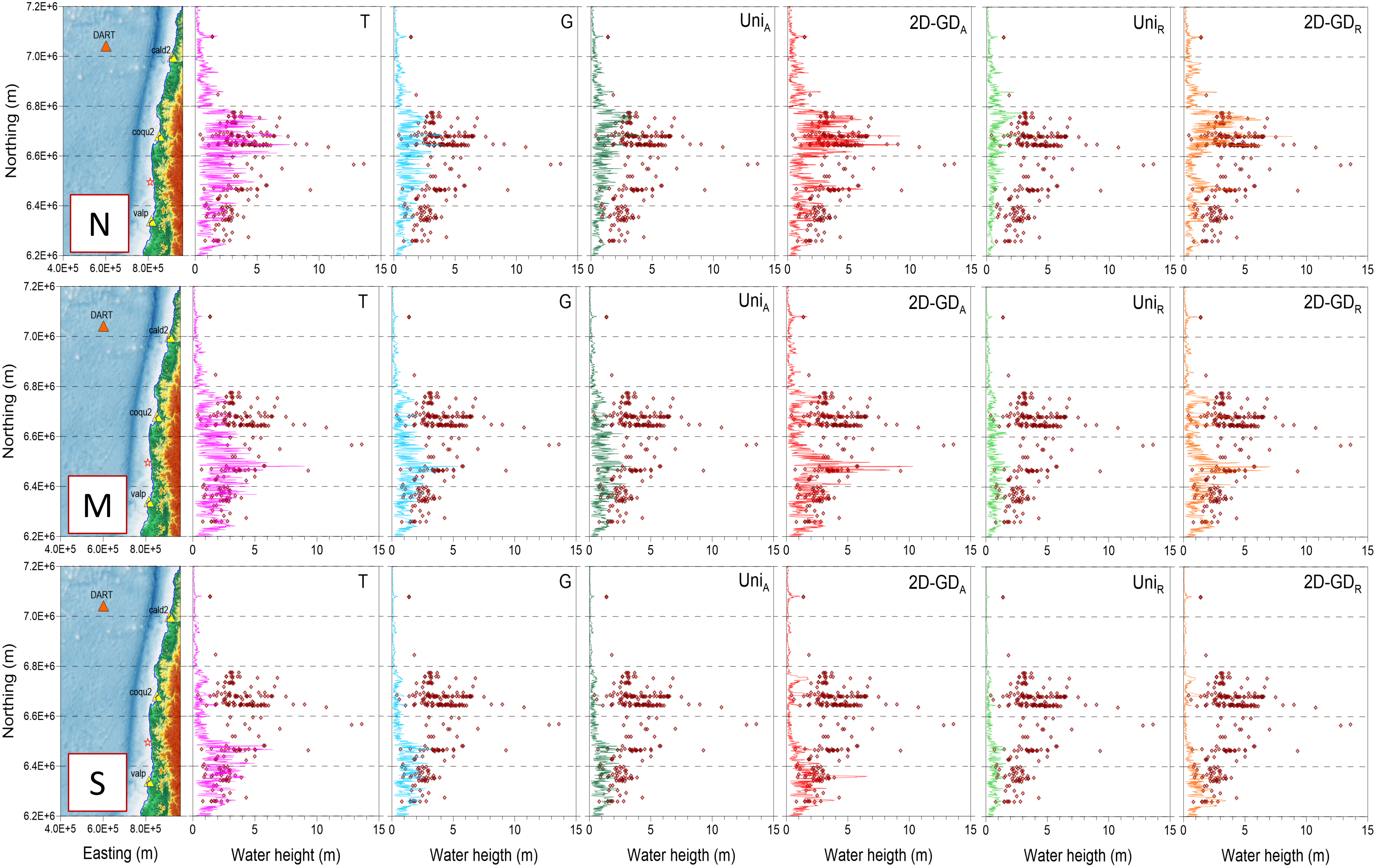


Uncertainty in the fault plane location



EGU General Assembly 2020

Maximum water elevations along the 10-m isobath



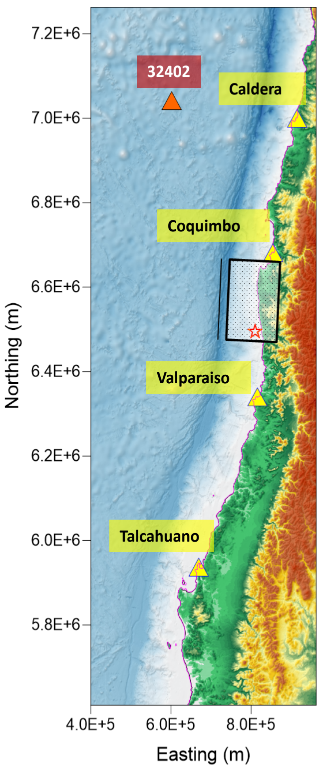
It is immediate to notice how the fault location with respect to the nucleation point brings with it inevitable and important consequences on the distribution of the coast run-ups. The uncertainty in this relative position is the really important.

EGU General Assembly 2020

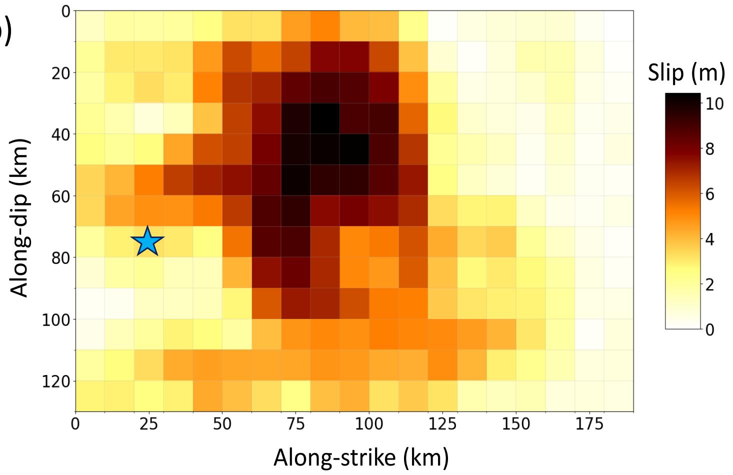
COMPARISON WITH TWO SLIP MODELS OBTAINED FROM INVERSION TECHNIQUES

O slip model (Okuwaki et al. 2016)

a)



b)

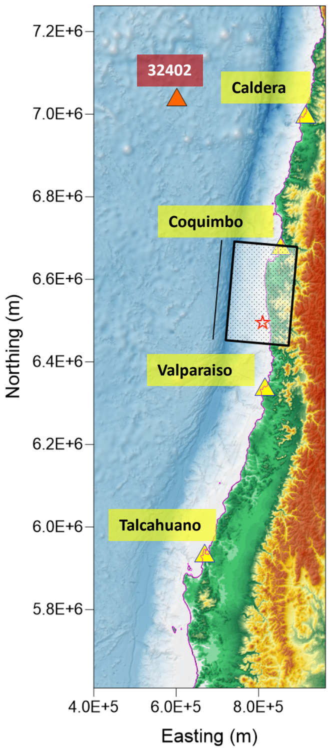


Obtained by a hybrid inversion of teleseismic waveforms and backprojection data.

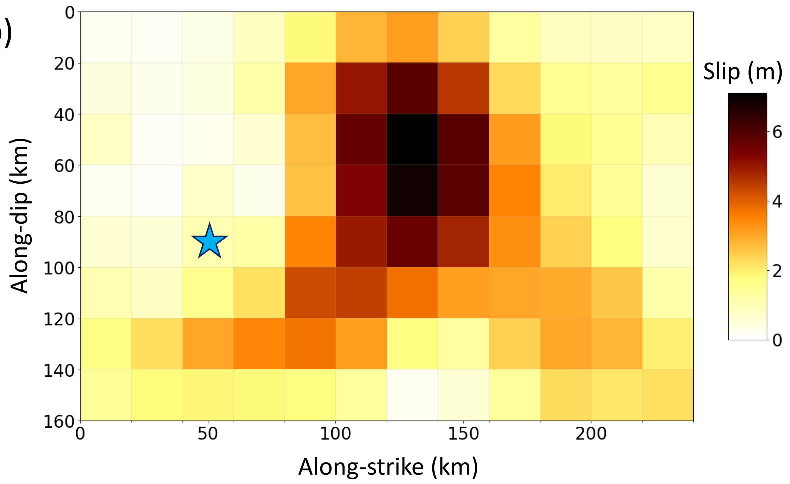
hypocentre

H slip model (Heidarzadeh et al. 2016)

a)



b)



Obtained by a **joint inversion** technique (teleseismic and tsunami data).

For each of them a 2D-GD distribution has been calculated by a least-square procedure.

EGU General Assembly 2020

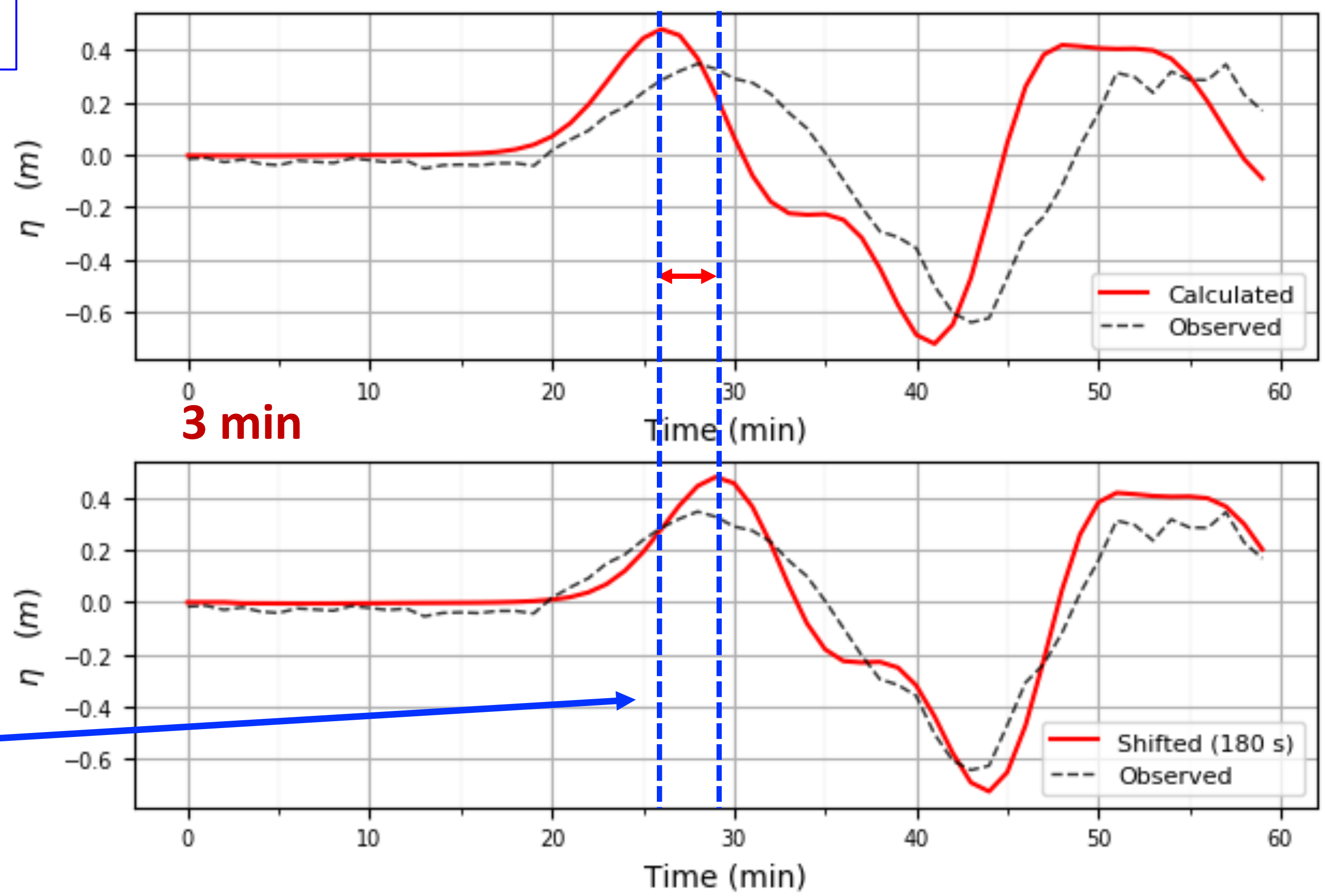
Waveforms Comparison

These analyses aim at quantifying the degree of similarity between the synthetic signals and the observed ones.

Being interested in reproducing the main waveforms rather than finding the exact time of the first arrival, the synthetic signal has been time shifted by a time τ such that the **cross-correlation**:

$$(f * g)[\tau] = \sum_t f[t]g[t+\tau]$$

assumed its maximum value.



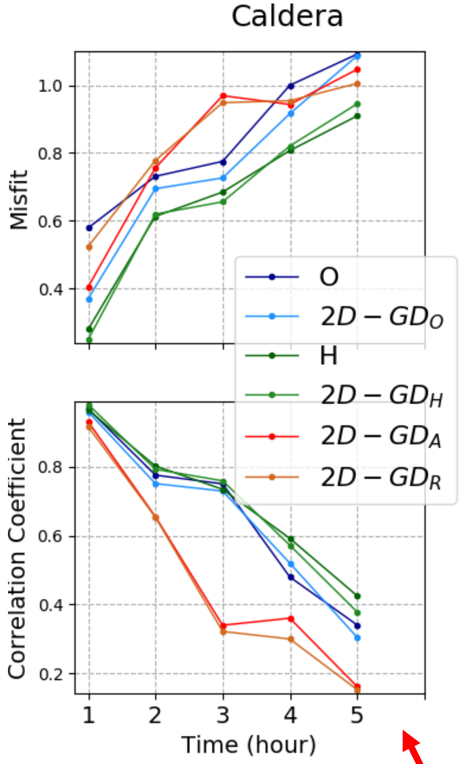
The indices used to evaluate the similarity between waveforms are:

$$misfit = \sqrt{\frac{\sum_n (w[n] - w_0[n])^2}{\sum_n (w_0[n])^2}}$$

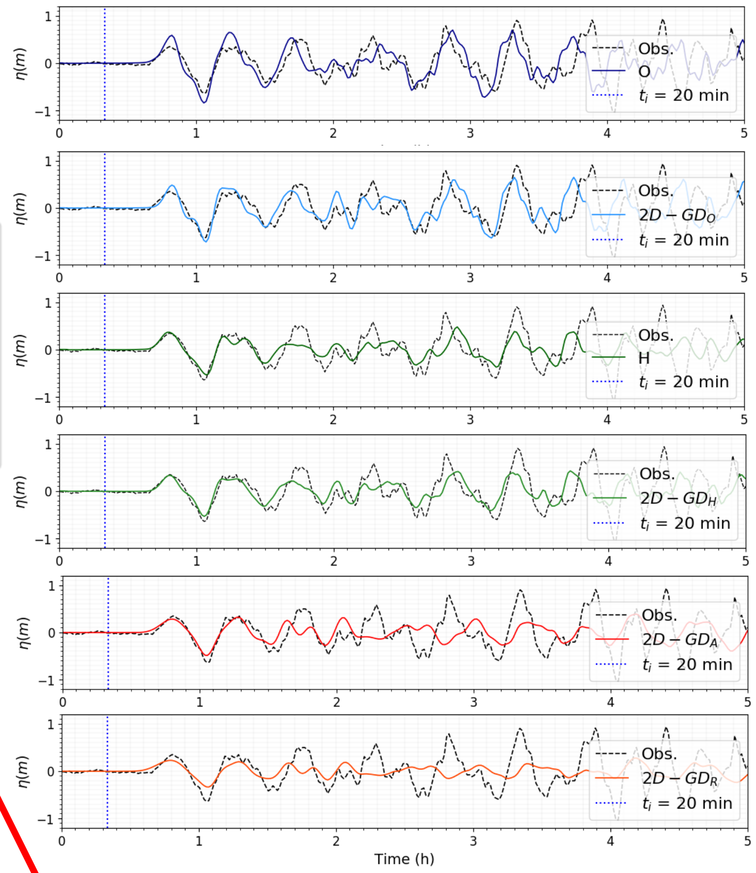
$$R = \frac{\sum_n (w[n] - \overline{w})\,(w_0[n] - \overline{w_0})}{\sqrt{\sum_n (w[n] - \overline{w})^2 \sum_n (w_0[n] - \overline{w_0})^2}}$$

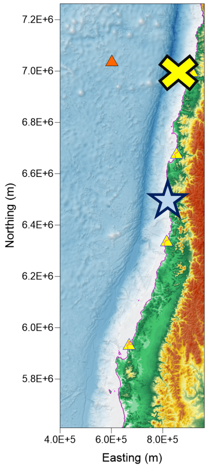
$-1 \leq R \leq 1$

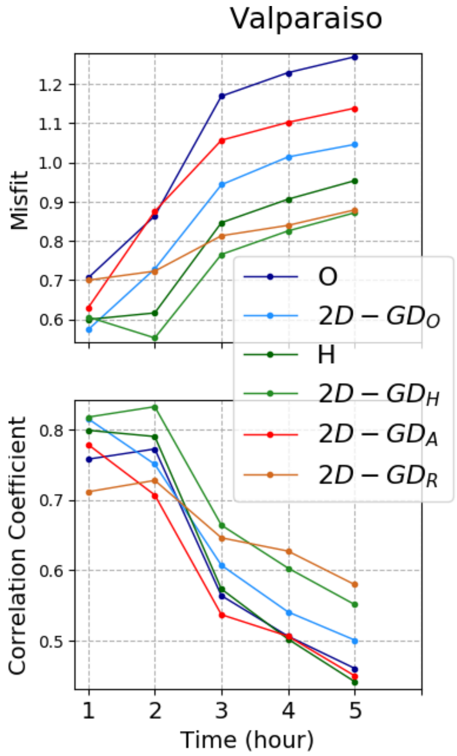
- w: synthetic
- w_0: observed



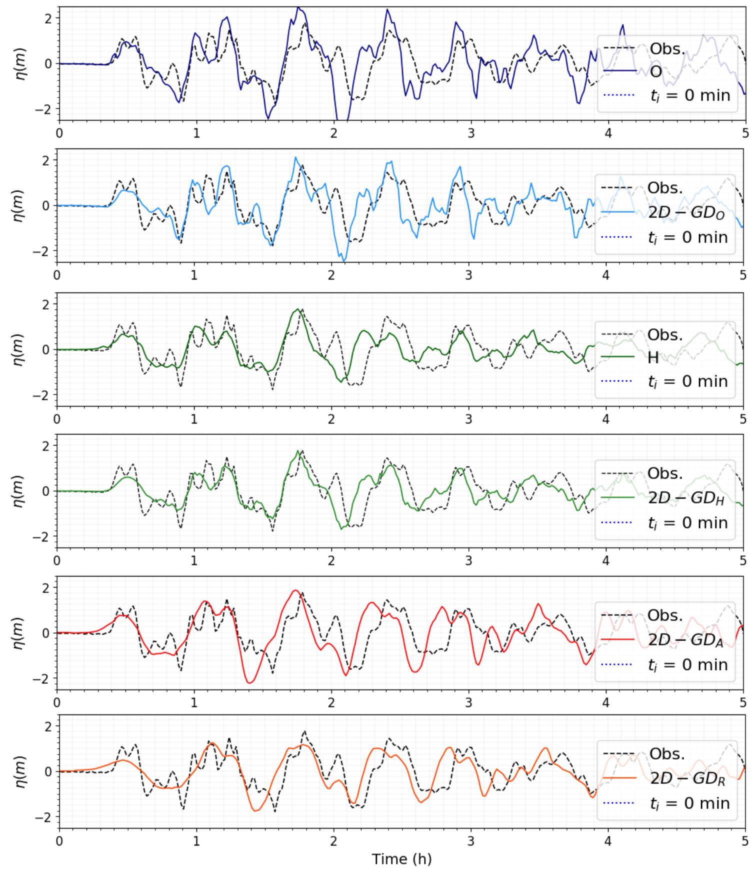
Tsunami waveforms

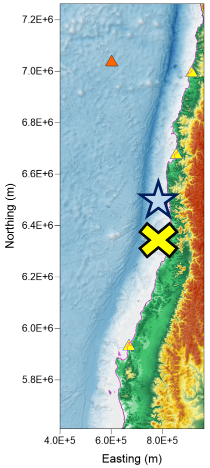






Tsunami waveforms





The misfit and correlation coefficients are reported for each stations for the first 5 hours of tsunami propagation.

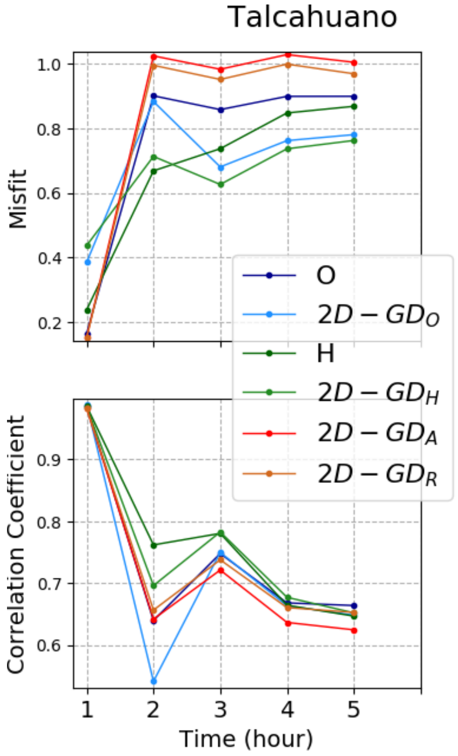
The tsunami waveforms are plotted too.

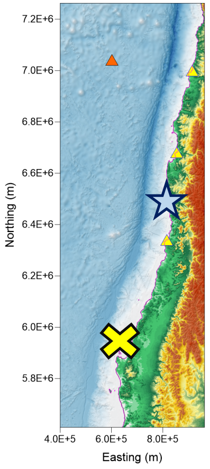
✖ : location of the considered station

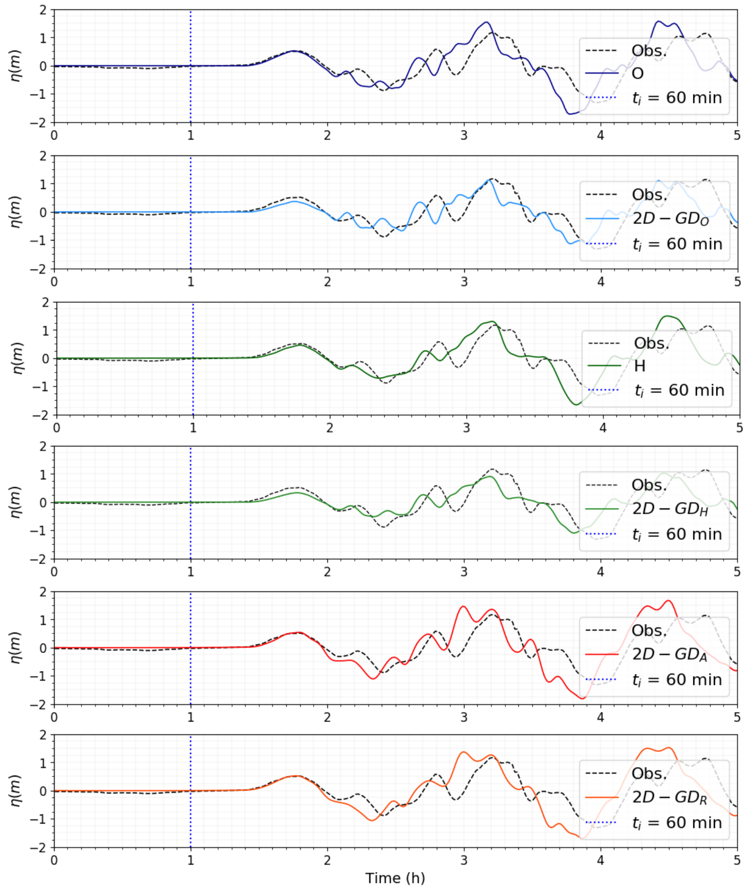
☆ : hypocentre

EGU General Assembly 2020

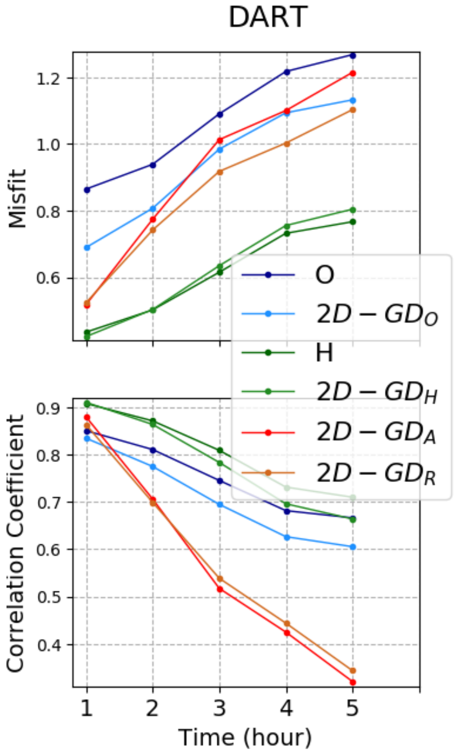
Tsunami waveforms

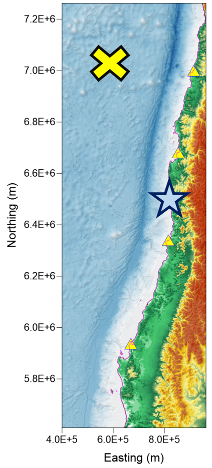


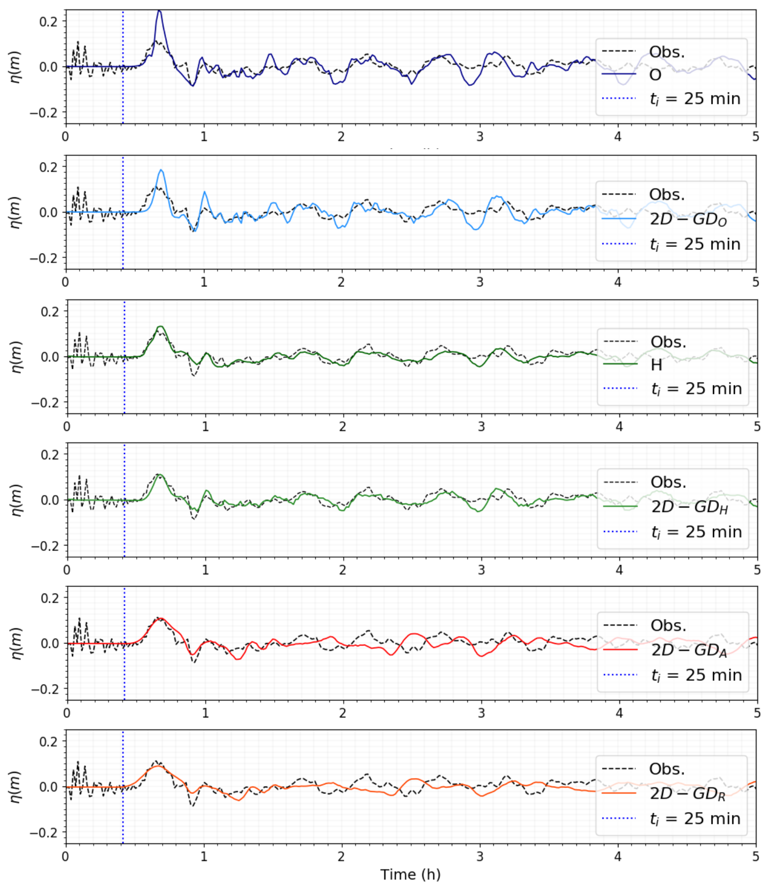




Tsunami waveforms







Timing consideration and early warning implications

The marigrams listed above show a good agreement both by the FFM H and by the Gaussians derived from the hypocentre location and magnitude. However, as quantified by the misfit and the correlation coefficients, the faithfulness of the model H model to the observed data is greater.
Nevertheless, there is an important and fundamental distinction between the two distributions.

The H model was obtained **a posteriori**, by inversion of seismic data and tsunami waveforms. Therefore, potentially, it is available several hours after the tsunami hits the coasts.

The 2D $GD_{A/R}$ are obtained directly from the magnitude and location of the earthquake, which is a much simpler and quicker procedure.

As an example, let's consider the bulletins launched by the Pacific Tsunami Warning Centre (PTWC).

The first tsunami threat message was issued from the PTWC **7 min** after the main shock. The message contained the following earthquake information:

- **MAGNITUDE**: 7.9;
- **ORIGIN TIME**: 22:55 UTC SEP 16 2015;
- **COORDINATES**: 31.5 SOUTH, 71.9 WEST;
- **DEPTH**: 33 KM / 20 MILES;
- **LOCATION**: NEAR THE COAST OF CENTRAL CHILE.

National Weather Service
Pacific Tsunami Warning Center

Few minutes after the main shock of a dangerous earthquake it is possible to get a **first asperity model** of the event.

This makes the 2D Gaussian models extremely interesting for early warning.

CONCLUSIONS

We propose a method to represent the real, often complex coseismic **on-fault slip distribution** of large (possibly tsunamigenic) earthquakes by means of simple, yet realistic 2D Gaussian distributions (2D-GD) depending exclusively on the parent earthquake's magnitude.

We applied the method to the 16 September 2015 Illapel (Chile) tsunamigenic earthquake (Mw=8.3).
We derive slip models only knowing the **magnitude** and the **location of the hypocentre**.
Among these models, the best behaviour, in terms of tsunami waveforms and maximum elevations is represented by **the 2D-GDs**.

The **FFM** by Heidarzadeh et al. 2016 remains the best one. But it has been obtained by **tsunami waveforms inversions**, hence can be potentially derived after several hours the tsunami hits the coasts.

We can conclude that the 2D-Gaussian distribution is a **simple** representation of the seismic source, that however takes into account the **slip heterogeneity**, effectively replacing the main asperity, and takes **very short time to be derived**.