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CHILE

TIDE-TSUNAMI INTERACTION

IN A HIGHLY ENERGETIC CHANNEL

ICCE 2018
36TH INTERNATIONAL CONFERENCE ON COASTAL ENGINEERING 2018
Baltimore, Maryland | July 30 – August 3, 2018
The State of the Art and Science of Coastal Engineering

WHO WE ARE...

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Mathematician, MSc.

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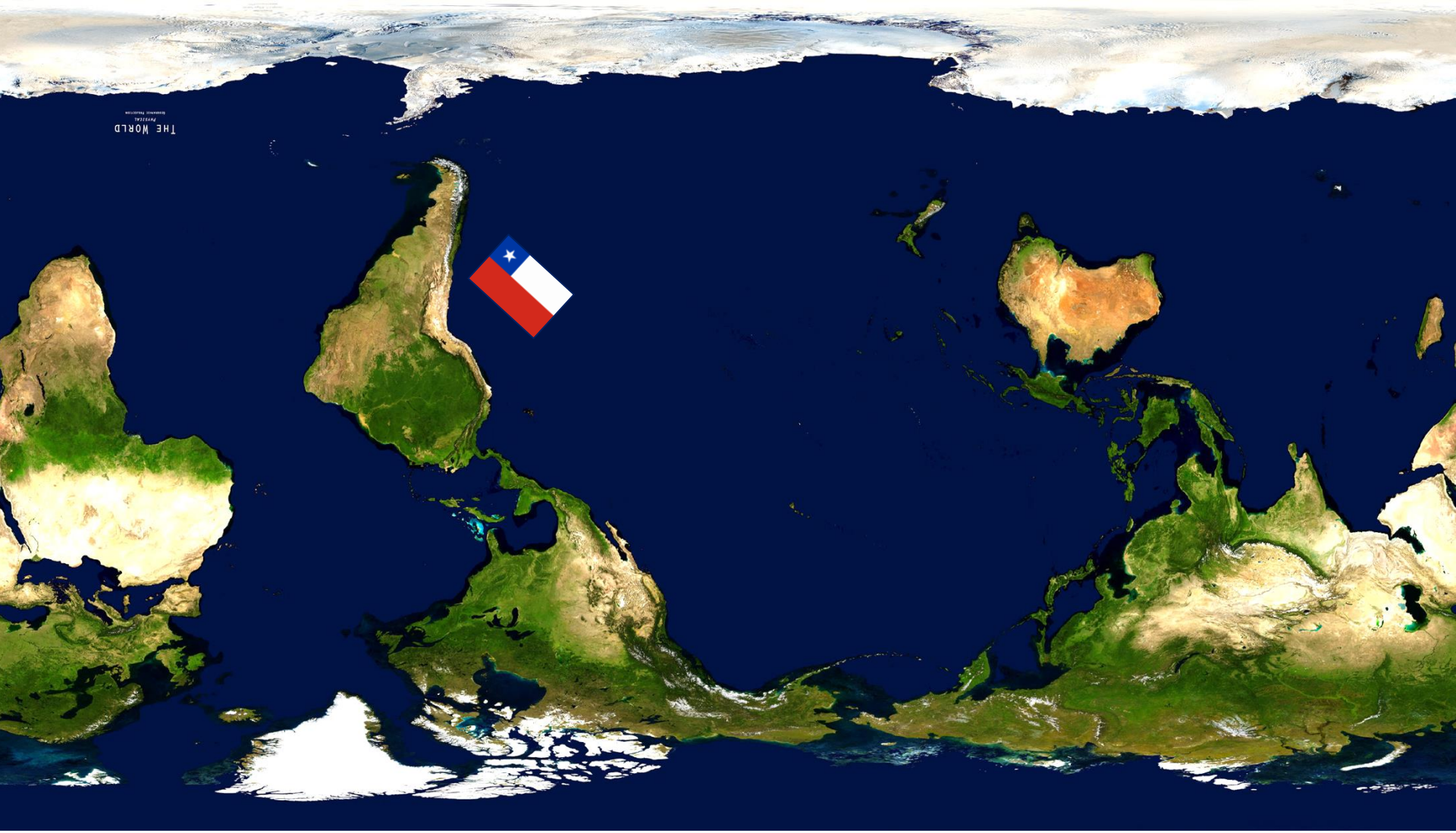

http://www.worldmapsonline.com/

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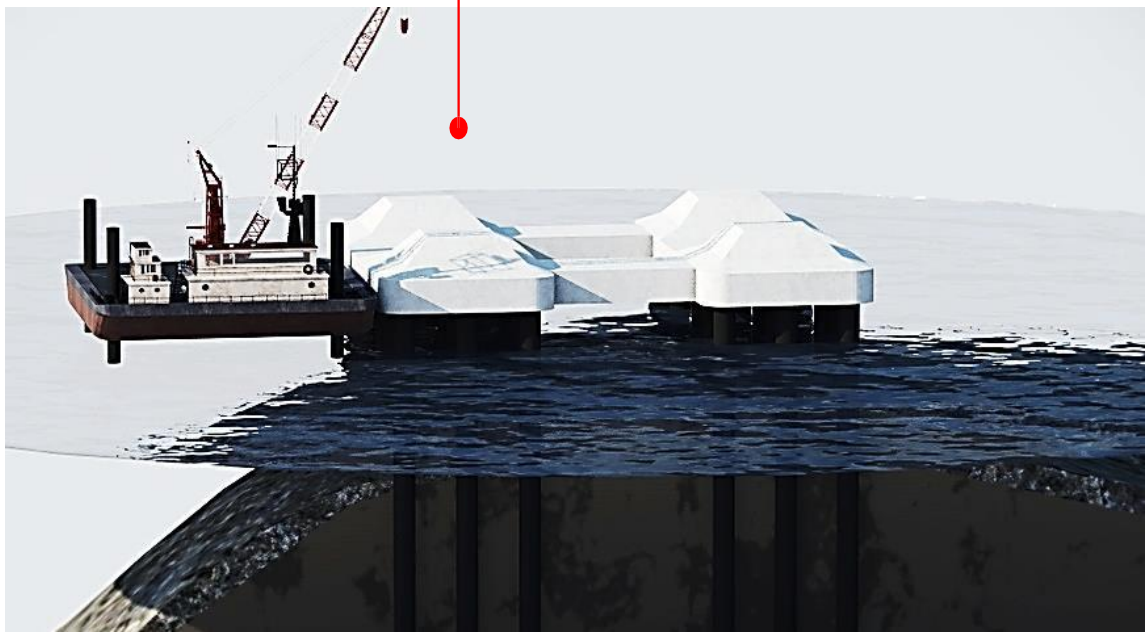
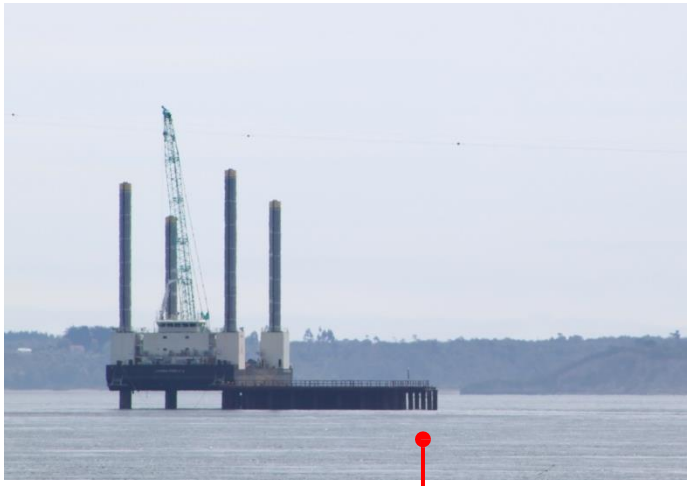
MOTIVATION

MOTIVATION

CHACAO BRIDGE PROJECT

U$ 800 millions

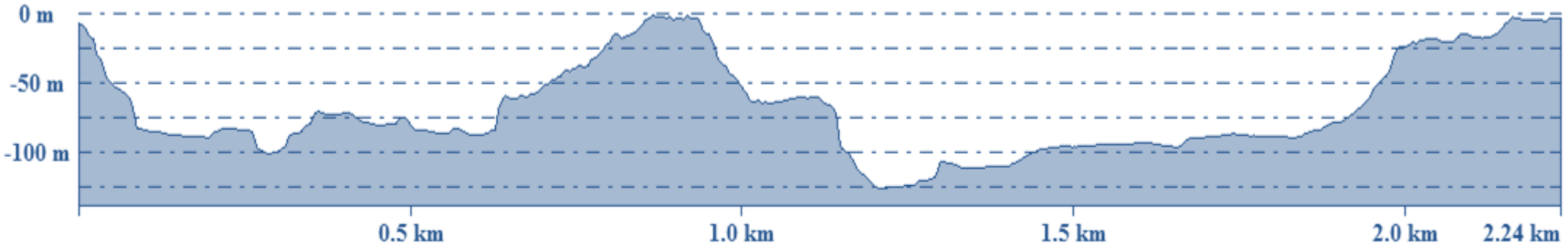


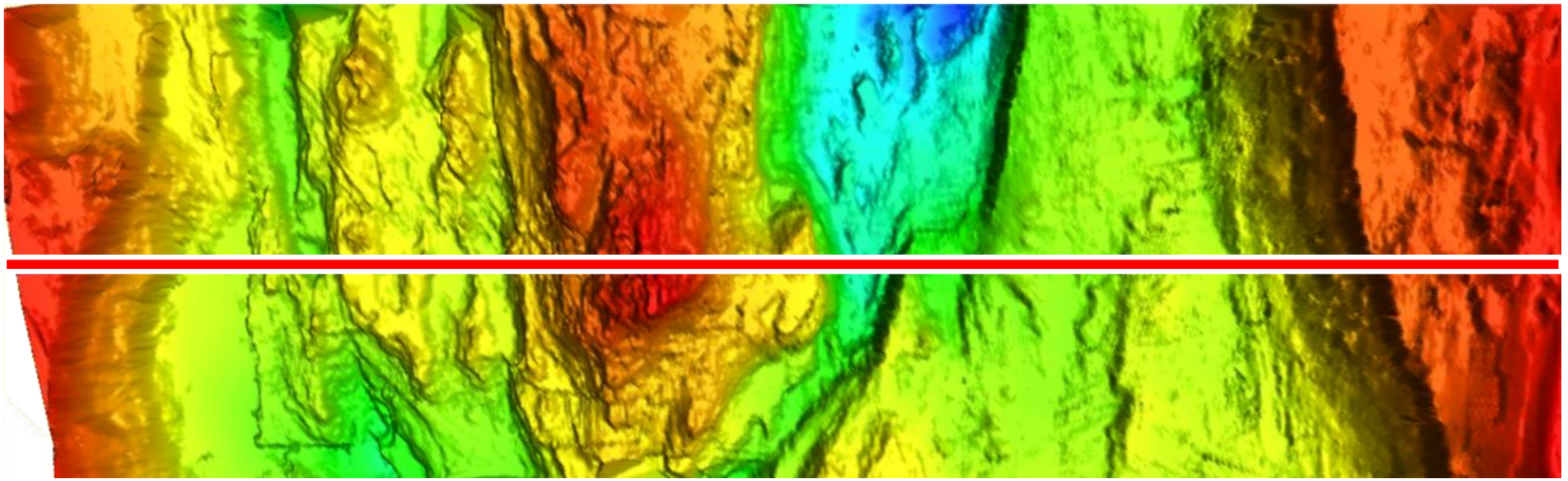


JACK-UP
AT ROCA REMOLINOS

VIDEO FROM A FIXED POSITION !

Source: Horacio Parragué



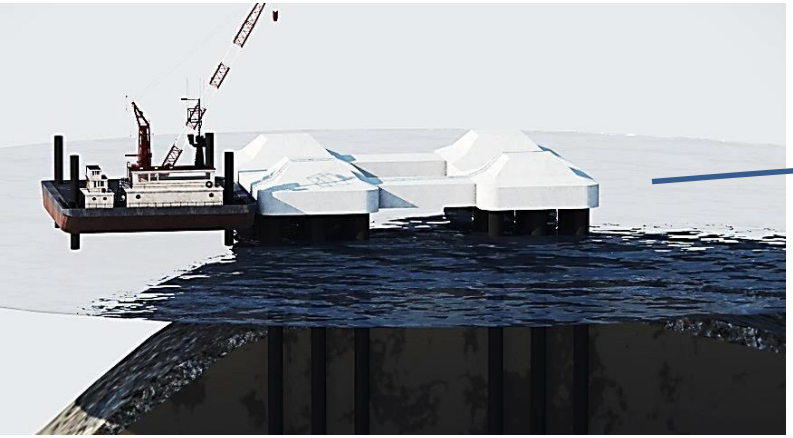


SOUTH

NORTH

MOTIVATION

CHACAO BRIDGE PROJECT

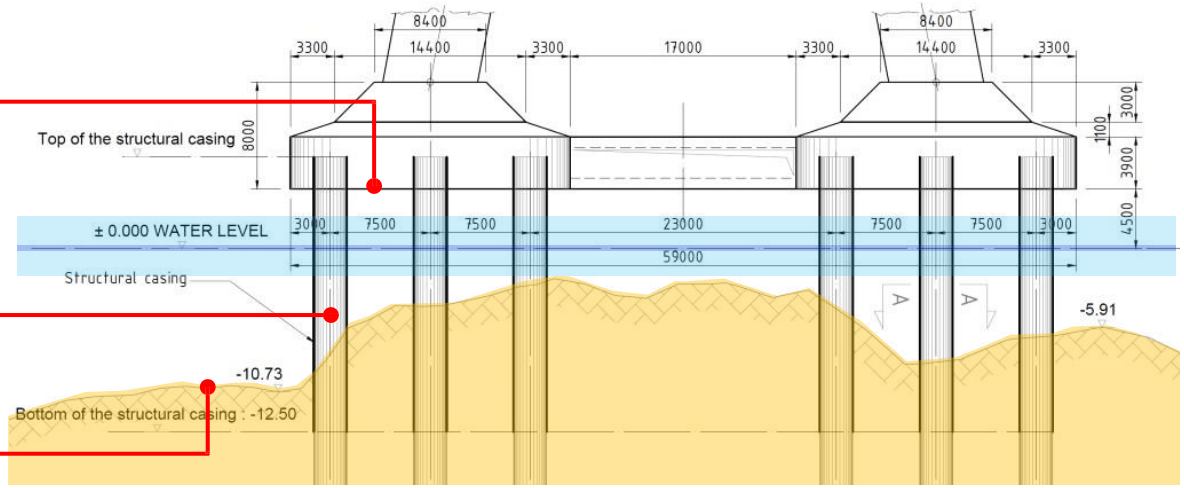


IMPACT

FORCES

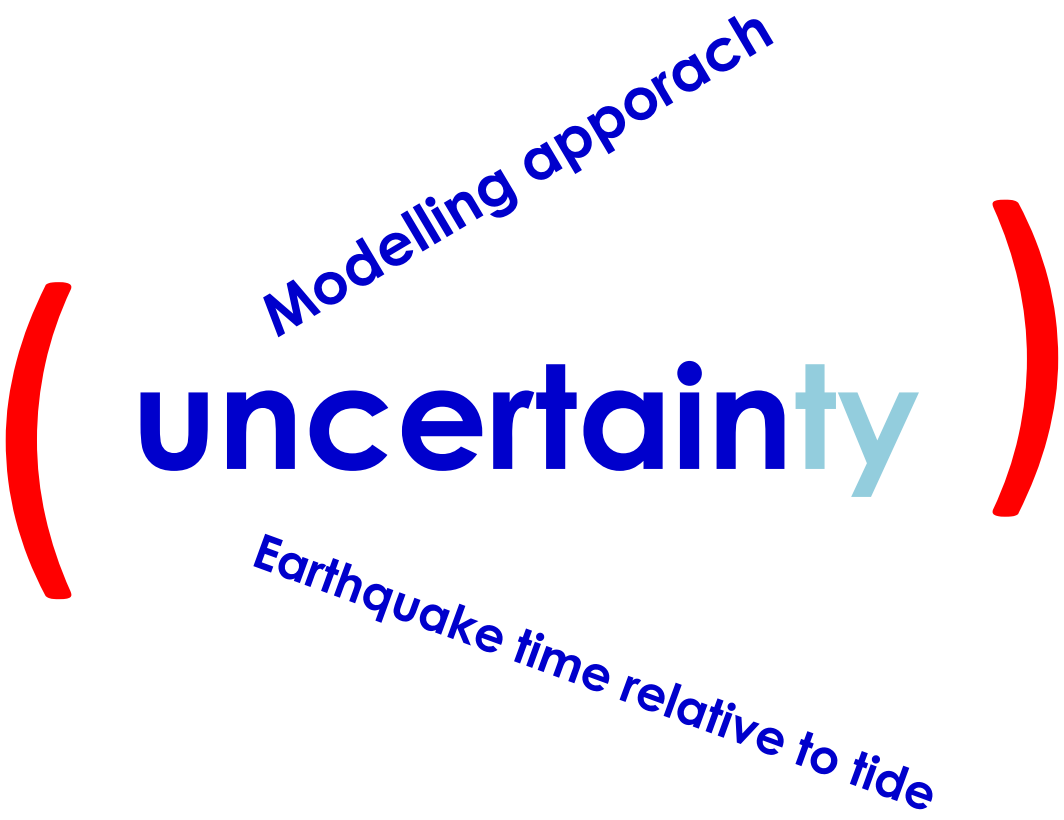
ABRASION

SCOUR



MOTIVATION

CHACAO BRIDGE PROJECT



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CONCEPTS

CONCEPTS

NUMERICAL MODELING OF TIDE - TSUNAMI

- **Tsunami**

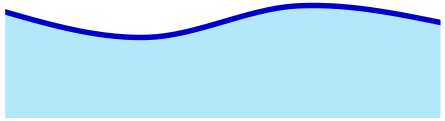
  (constant tide)

- **Linear superposition tide – tsunami** (composite)

  (both are independent)

- **Coupling tide – tsunami** (full)

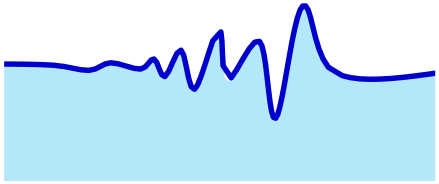
TIDE (CONSTANT)



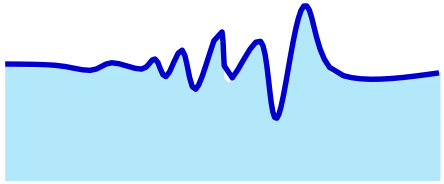
TIDE

TIDE

+



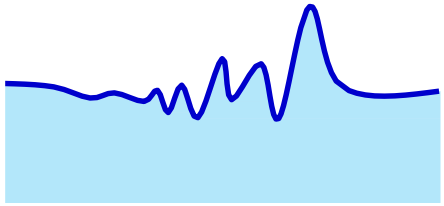
TSUNAMI MODEL



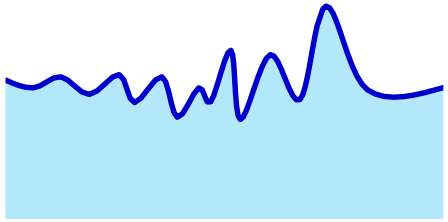
TSUNAMI

TSUNAMI

=



COMPOSITE MODEL



FULL MODEL

MORE PHYSICS & COSTS

CONCEPTS

NUMERICAL MODELING OF TIDE - TSUNAMI

LOCAL VOLUME CHANGES

ADVECTIVE FLUXES OF MASS

$$\frac{\partial \eta}{\partial t}+\frac{\partial h\bar{u}}{\partial x}+\frac{\partial h\bar{v}}{\partial y}=0$$

NONLINEAR TERMS

$$\frac{\partial}{\partial t}(h\bar{u})+\frac{\partial}{\partial x}(h\bar{u}^2)+\frac{\partial}{\partial y}(h\bar{u}\bar{v})=fh\bar{v}-gh\frac{\partial \eta}{\partial x}-\frac{g\bar{u}\sqrt{\bar{u}^2+\bar{v}^2}}{M^2h^{1/3}}+\frac{\partial}{\partial x}(hT_{xx})+\frac{\partial}{\partial y}(hT_{xy})-h\frac{\partial \Omega}{\partial x}=0$$

$$\frac{\partial}{\partial t}(h\bar{v})+\frac{\partial}{\partial x}(h\bar{u}\bar{v})+\frac{\partial}{\partial y}(h\bar{v}^2)=fh\bar{u}-gh\frac{\partial \eta}{\partial y}-\frac{g\bar{v}\sqrt{\bar{u}^2+\bar{v}^2}}{M^2h^{1/3}}+\frac{\partial}{\partial x}(hT_{yx})+\frac{\partial}{\partial y}(hT_{yy})-h\frac{\partial \Omega}{\partial y}=0$$

LOCAL MOMENTUM CHANGES

ADVECTIVE FLUXES OF MOMENTUM

CORIOLIS

GRAVITY & PRESSURE

BOTTOM FRICTION

TURBULENT STRESSES

TIDAL POTENTIAL

CONCEPTS

NUMERICAL MODELING OF TIDE - TSUNAMI

$$\bar{u}_t = U_t cos(\theta_t)$$

$$\bar{u}_m = U_m cos(\theta_m)$$

$$\frac{\partial}{\partial x}(h\bar{u}^2) = \frac{1}{2}\frac{\partial}{\partial x}\left(hU_t{}^2[cos(2\theta_t) - 1]\right) \quad \text{TSUNAMI TSUNAMI}$$

$$+ 2\frac{\partial}{\partial x}\left(hU_tU_m cos(\theta_t)cos(\theta_m)\right) \quad \text{TSUNAMI TIDE}$$

$$+ \frac{1}{2}\frac{\partial}{\partial x}\left(hU_m{}^2[cos(2\theta_m) - 1]\right) \quad \text{TIDE TIDE}$$

$$\frac{\partial}{\partial t}(h\bar{u}) + \frac{\partial}{\partial x}(h\bar{u}^2) + \frac{\partial}{\partial y}(h\bar{u}\bar{v}) = fh\bar{v} - gh\frac{\partial \eta}{\partial x} - \frac{g\bar{u}\sqrt{\bar{u}^2 + \bar{v}^2}}{M^2h^{1/3}} + \frac{\partial}{\partial x}(hT_{xx}) + \frac{\partial}{\partial y}(hT_{xy}) - h\frac{\partial \Omega}{\partial x} = 0$$

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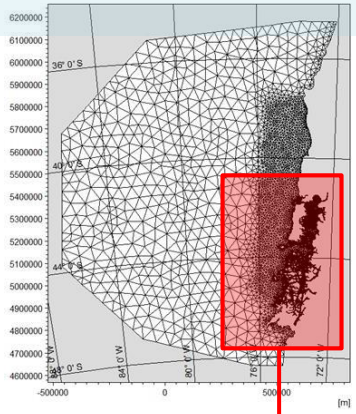
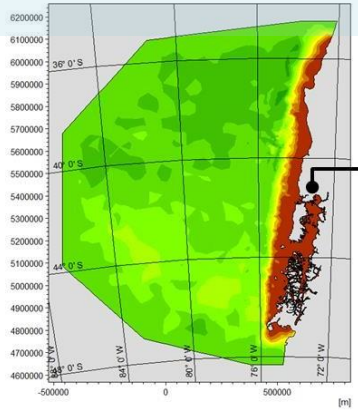
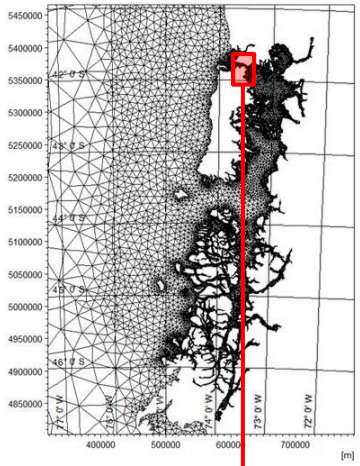
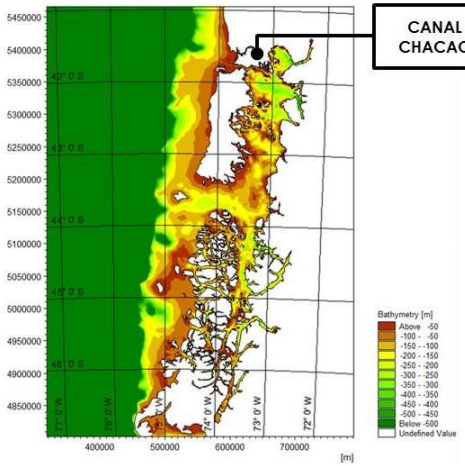
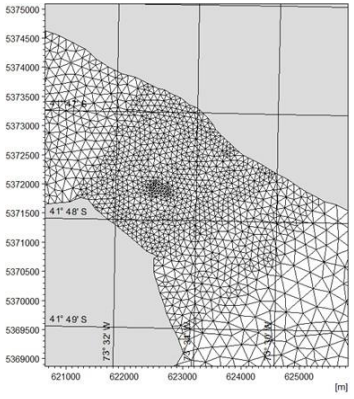
TIDE MODEL

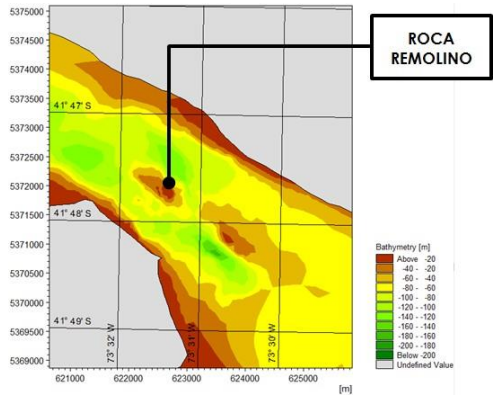



CANAL
CHACAO




CANAL
CHACAO




ROCA
REMOLINO

TIDE MODEL

GLOBAL TIDE MODEL

Table 2: Data sources used in calibration of the tide model in 2000.

Type	Station	Latitude Longitude	Location	Availability (days)
Elevation (1)	Puerto Montt	41°29'06" S 72°57'39" W	Open coasts	Since 1999
Elevation (2)	Tique	41°48' S 73°24' W	Canal Chacao	23/07/2000 06/09/2000
Elevation (2)	Eje-1	41°48' S 73°32' W	Canal Chacao	03/12/1999 24/01/2001
Elevation (2)	Carelmapu	41°49' S 73°43' W	Canal Chacao	15/01/2000 22/01/2001

(1) Measurements by SHOA, available at www.sealevelmonitoring.com
(2) Measurements by ICUATRO-COWI (2000)

Table 1: Tidal constituents

Constituent	Amplitude [m]	Period [hr]
M2	0.2423	12.421
O1	0.1005	25.819
S2	0.1128	12.000
K2	0.0307	11.967
N2	0.0464	12.658
K1	0.1416	23.934
P1	0.0468	24.066
Q1	0.0193	26.868
Mf	0.0417	13.661
Mm	0.0220	27.555
Ssa	0.0194	182.621

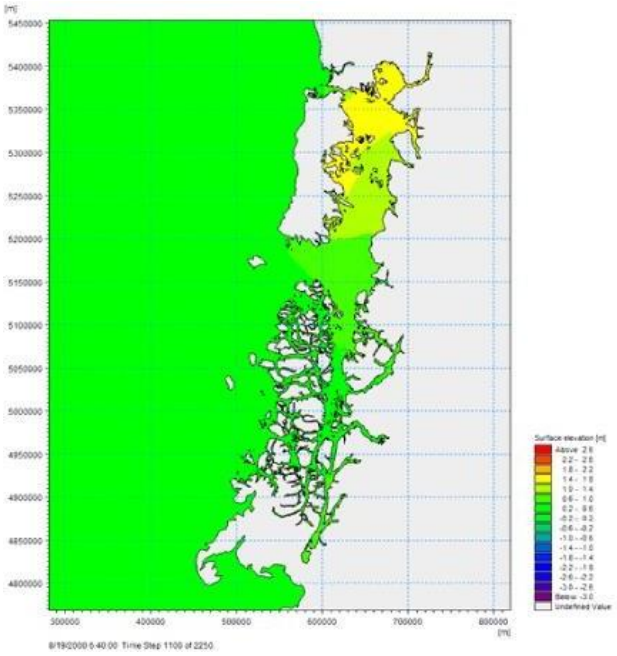
$$\frac{\partial \eta}{\partial t} + \frac{\partial h\bar{u}}{\partial x} + \frac{\partial h\bar{v}}{\partial y} = 0$$

$$\frac{\partial}{\partial t}(h\bar{u}) + \frac{\partial}{\partial x}(h\bar{u}^2) + \frac{\partial}{\partial y}(h\bar{u}\bar{v}) = fh\bar{v} - gh\frac{\partial \eta}{\partial x} - \frac{g\bar{u}\sqrt{\bar{u}^2 + \bar{v}^2}}{M^2 h^{1/3}} + \frac{\partial}{\partial x}(hT_{xx}) + \frac{\partial}{\partial y}(hT_{xy}) - h\frac{\partial \Omega}{\partial x} = 0$$

$$\frac{\partial}{\partial t}(h\bar{v}) + \frac{\partial}{\partial x}(h\bar{u}\bar{v}) + \frac{\partial}{\partial y}(h\bar{v}^2) = fh\bar{u} - gh\frac{\partial \eta}{\partial y} - \frac{g\bar{v}\sqrt{\bar{u}^2 + \bar{v}^2}}{M^2 h^{1/3}} + \frac{\partial}{\partial x}(hT_{yx}) + \frac{\partial}{\partial y}(hT_{yy}) - h\frac{\partial \Omega}{\partial y} = 0$$

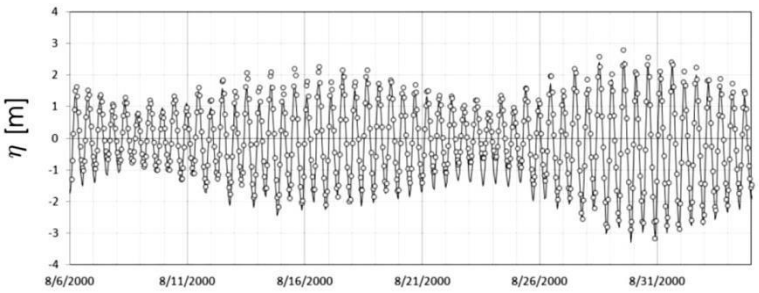
TIDE MODEL

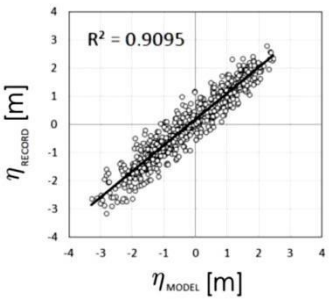
CALIBRATION



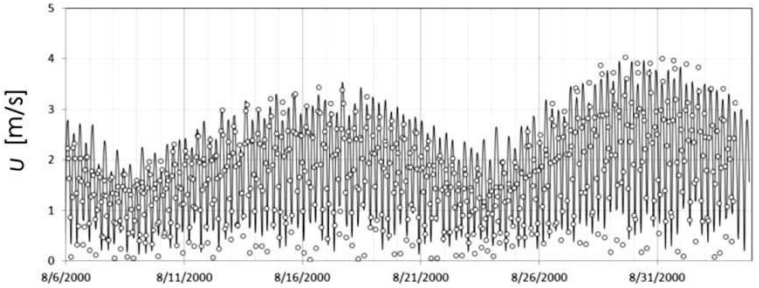
ELEVATION

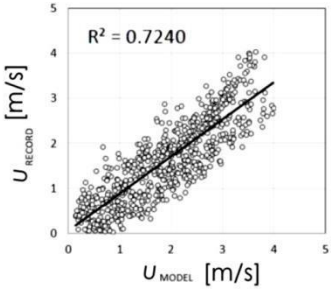
ELEVATION EJE 1





VELOCITY ROCA REMOLINO





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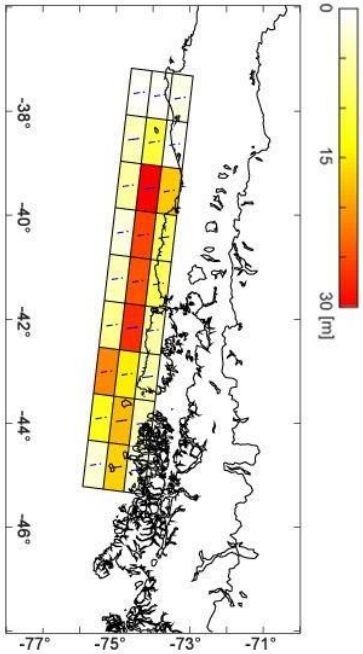
RUPTURE MODEL

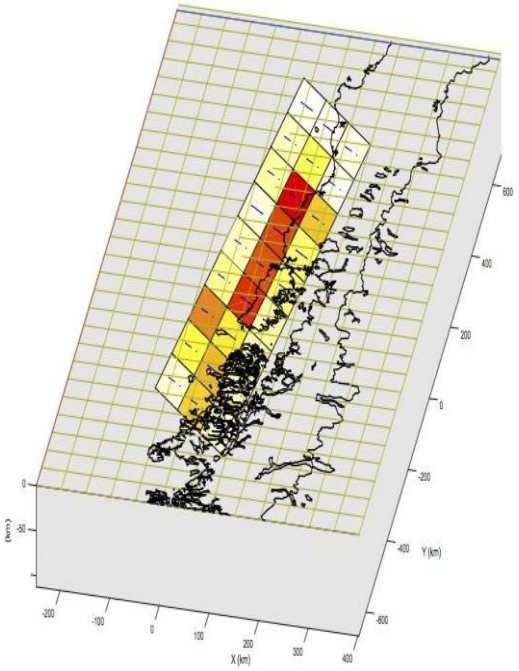
RUPTURE MODEL

1960 – TYPE EVENT



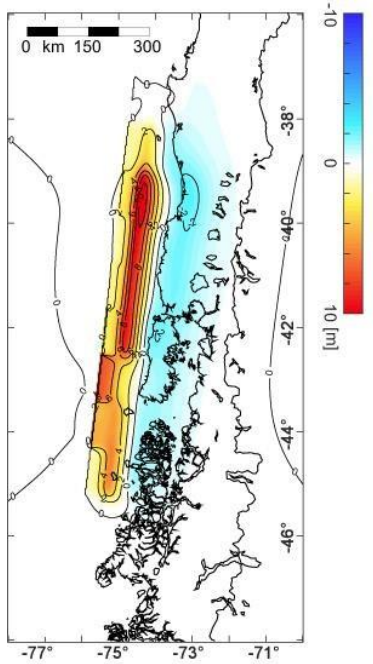
1960

SLIP MODEL



1960

SLIP MODEL ON FAULT PLANE



1960

SURFACE ELEVATION

Fuente: Fujii & Satake (2012)

Kenji Satake

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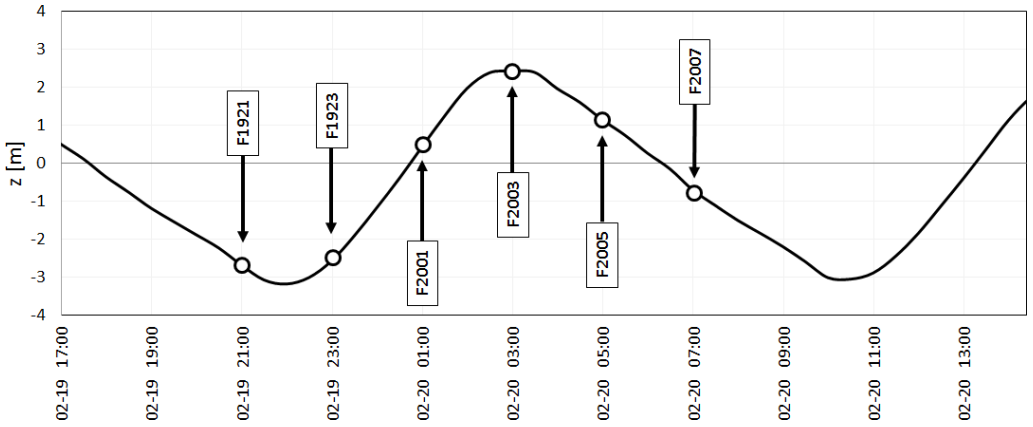
TIDE-TSUNAMI

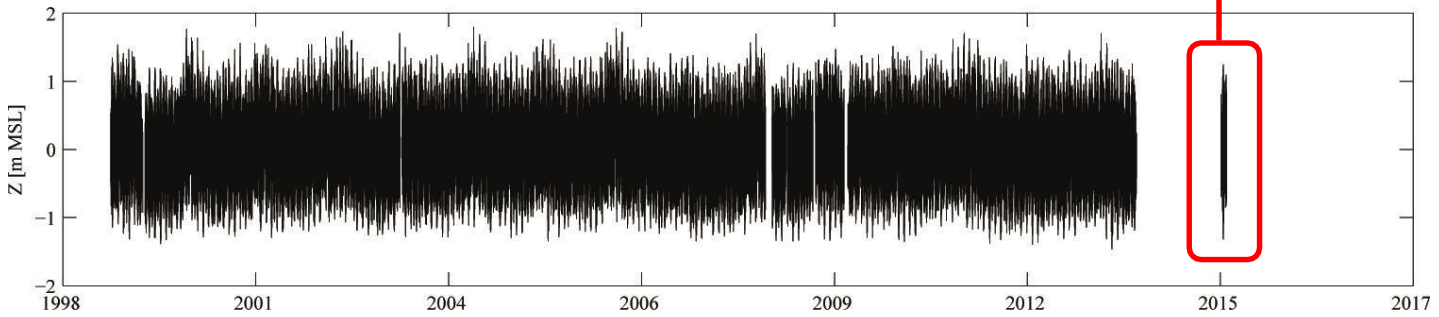
INTERACTION

TIDE – TSUNAMI INTERACTION

TIDE LEVEL



TIDE LEVEL IN ANCUD



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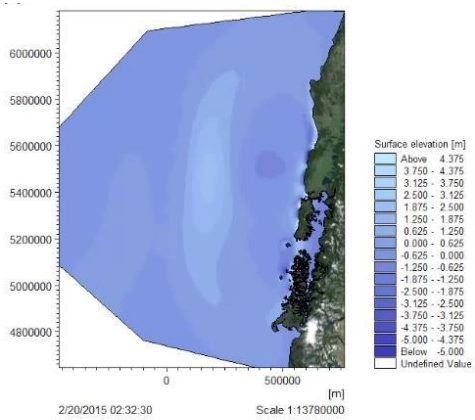
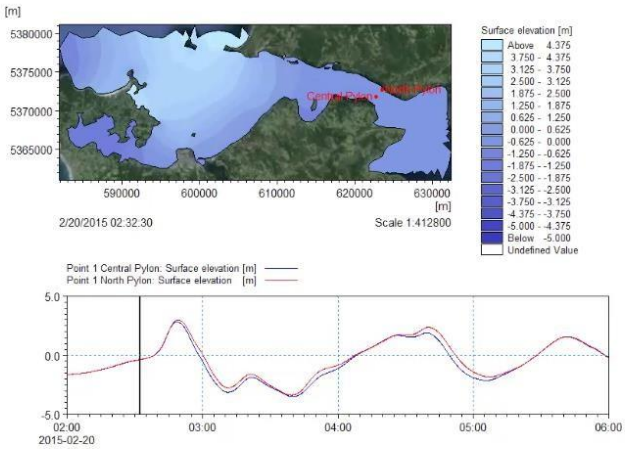
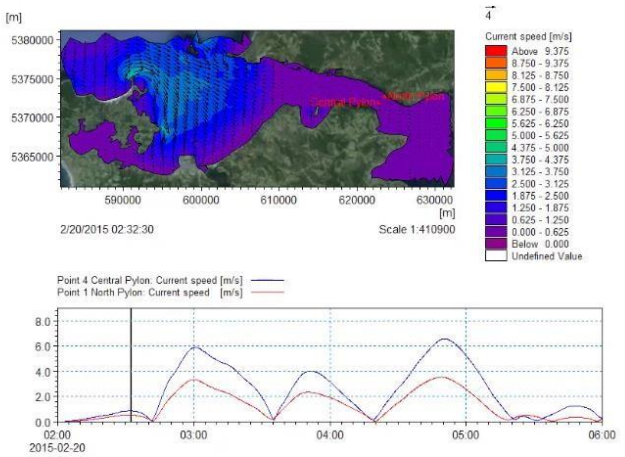
TSUNAMI MODEL



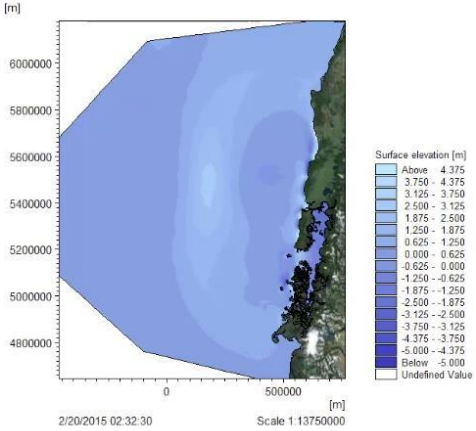
ELEVATION

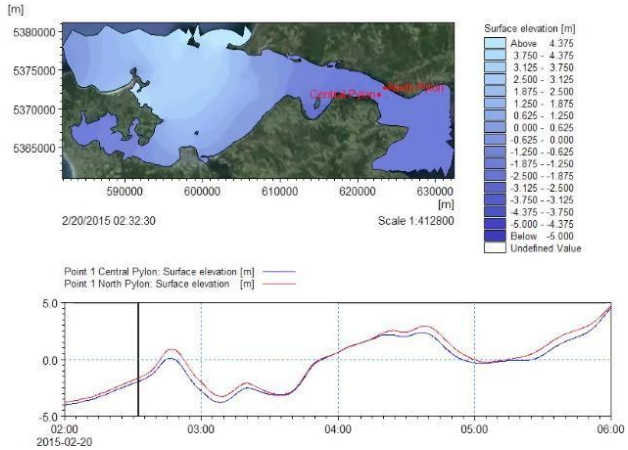


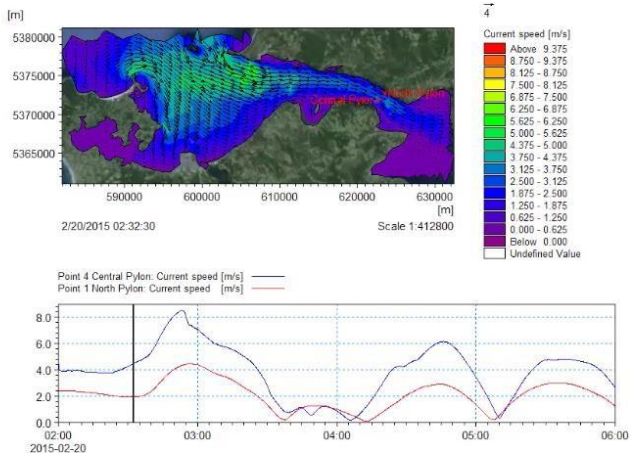
SPEED



FULL MODEL







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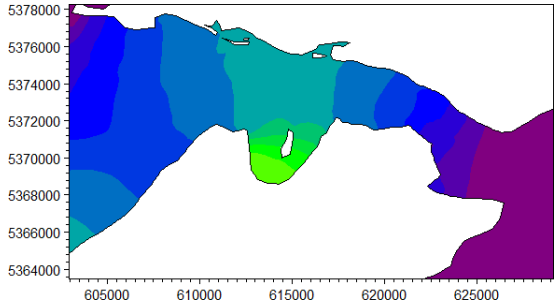
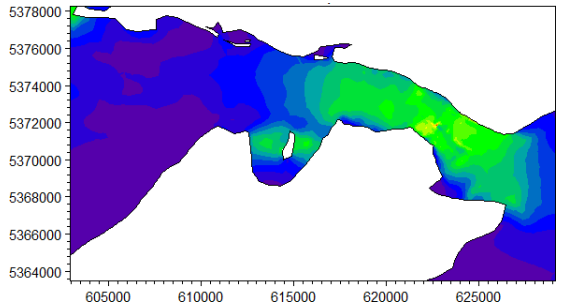
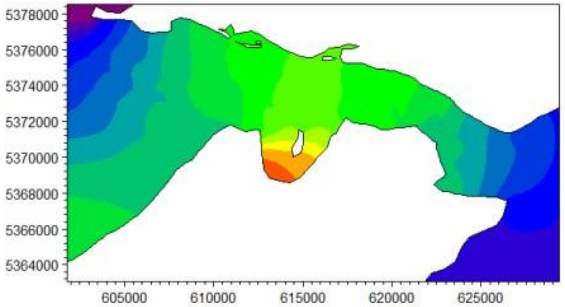
TSUNAMI MODEL



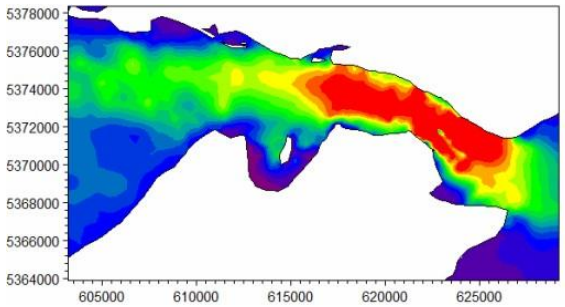
TSUNAMI MODEL



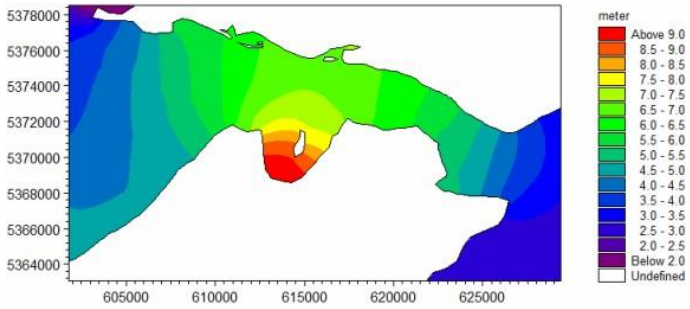
COMPOSITE MODEL (WORST)



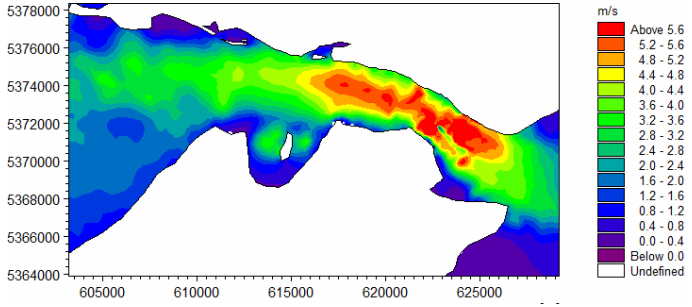
COMPOSITE MODEL (WORST)



FULL MODEL (WORST)



FULL MODEL (WORST)



MAXIMUM ELEVATION

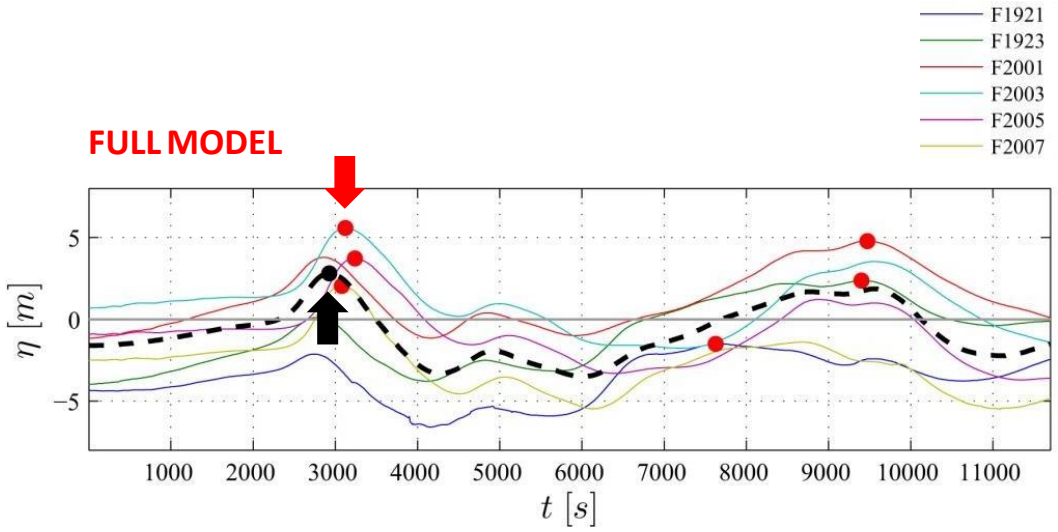
MAXIMUM SPEED

TIDE – TSUNAMI INTERACTION

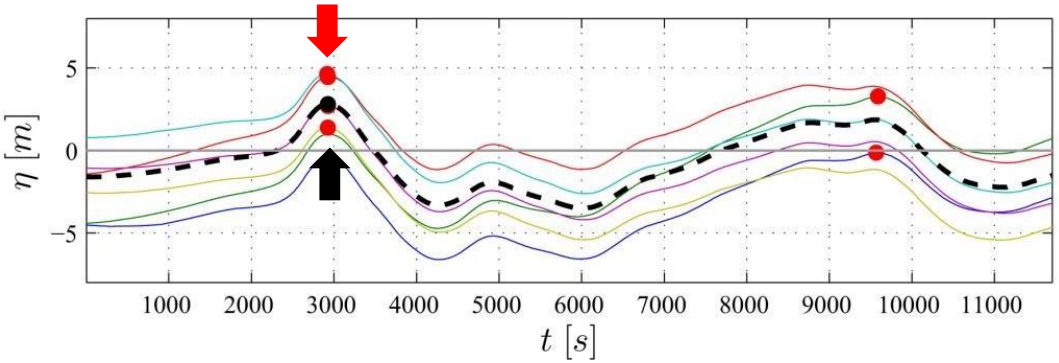
SURFACE ELEVATION

Surface elevation is sensitive to tide level

FULL MODEL



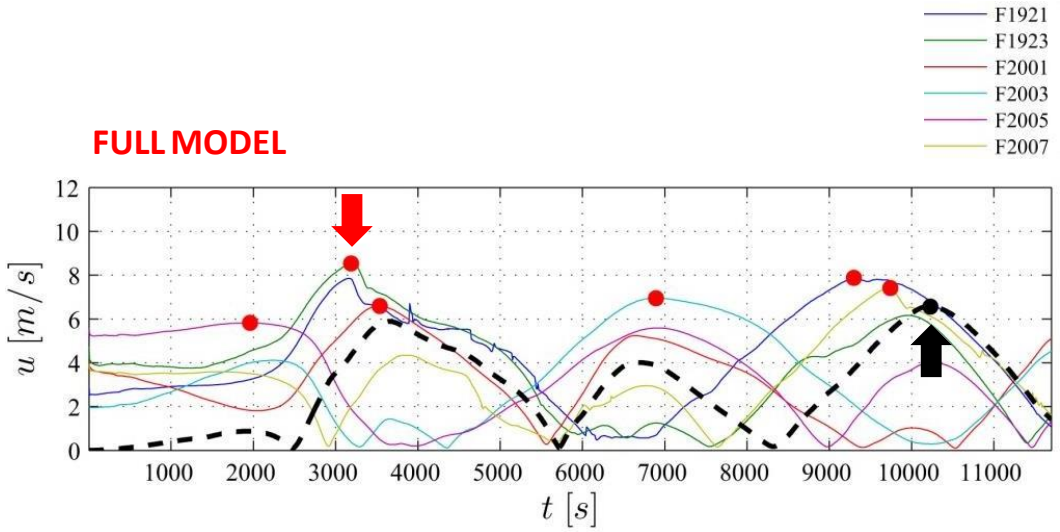
COMPOSITE MODEL



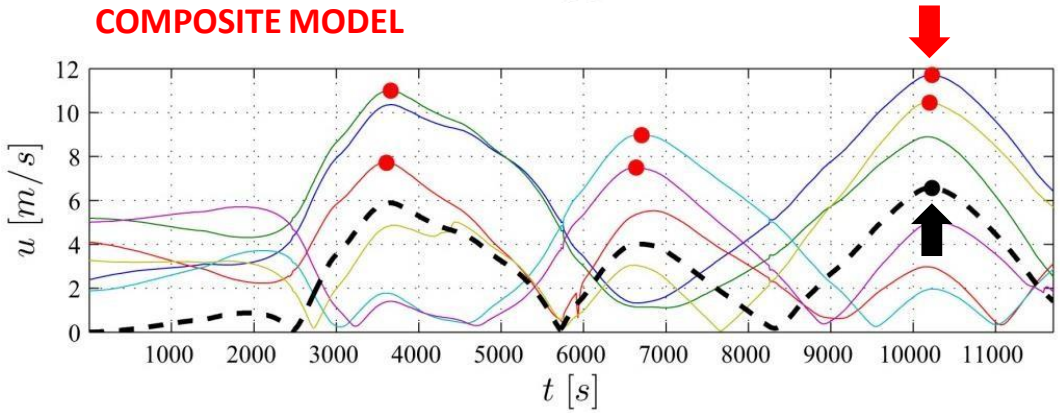
TIDE – TSUNAMI INTERACTION

CURRENT SPEED

FULL MODEL



COMPOSITE MODEL

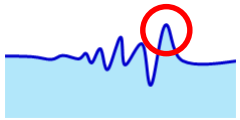


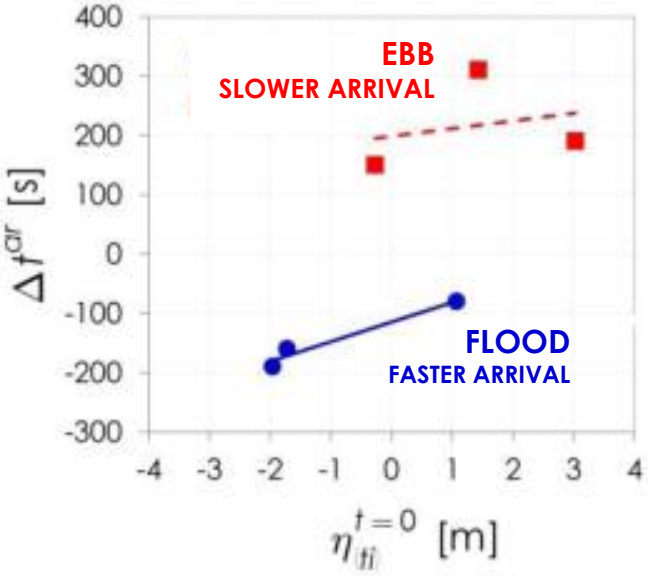
Drag forces generated by tsunami are duplicated !

TIDE – TSUNAMI INTERACTION

ARRIVAL TIME

- Very sensisitve to **tidal flow direction**
- Not sensitive to **tidal level**





EBB
Delay: 1~3 minutes

FLOOD
Anticipation: 2~6 minutes

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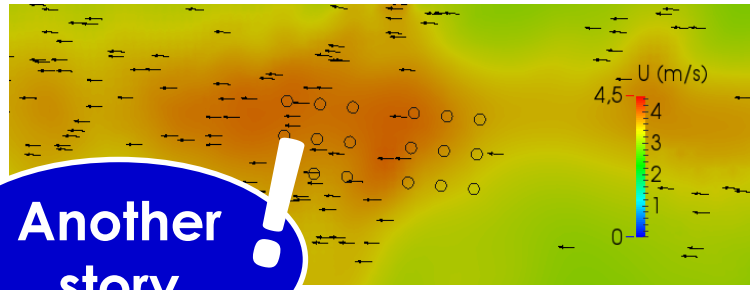
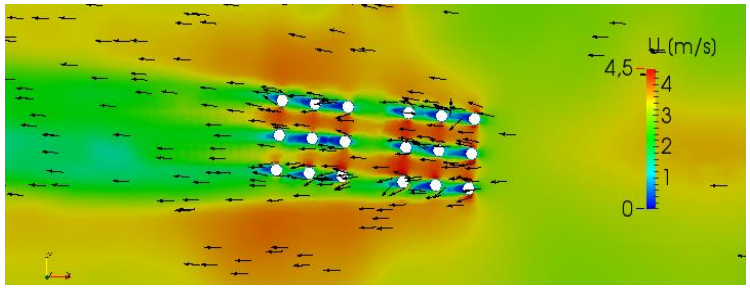
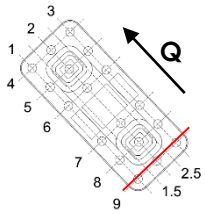
VISTA EN PLANTA NIVEL DE FONDO

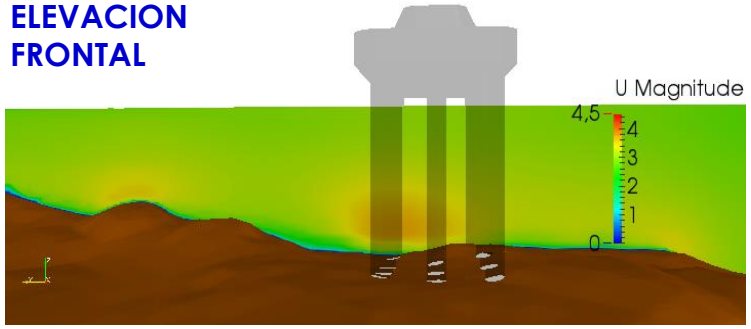
Another story !

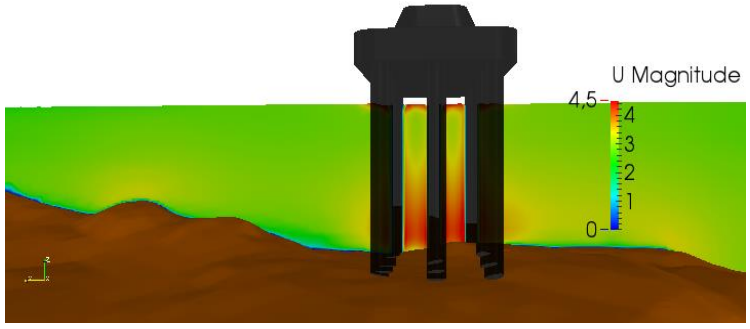




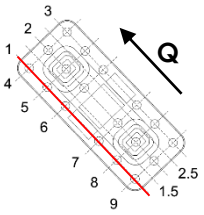
ELEVACION FRONTAL

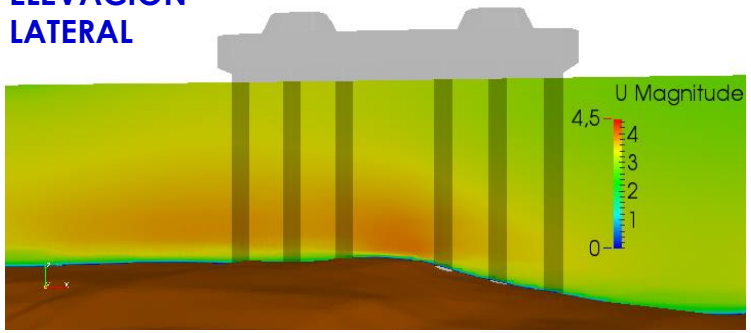


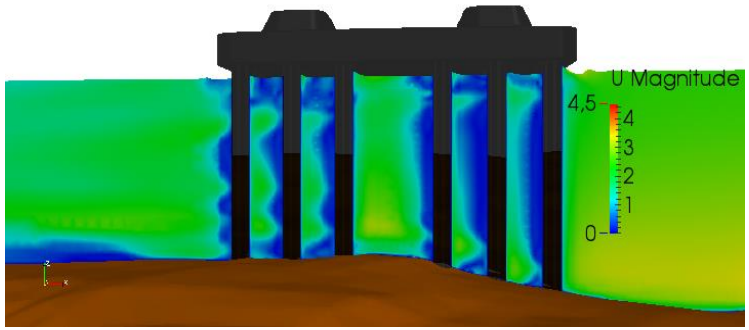




ELEVACION LATERAL







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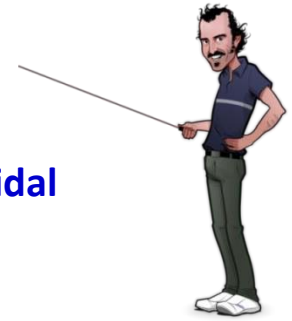
FINDINGS

FINDINGS

MOST RELEVANT…

- To well studied uncertainties (e.g. source, bathymetry, model), we add **uncertainty** associated with **earthquake time** (and its relation with the tide) and **modelling approach**.
- **Tides** play a significant role in tsunami propagation in highly energetic channels.
- **Hydrodynamic patterns** differ significantly among approaches:
  - **Tsunami model** is less conservative in both velocities and amplitudes
  - **Composite model** provides larger velocities
  - **Full model** yields higher amplitudes, specially in shallow areas
- Time of arrival of the **leading wave is sensitive to the direction of the tidal current** and less sensitive to tidal level and speed



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FUTURE WORK...

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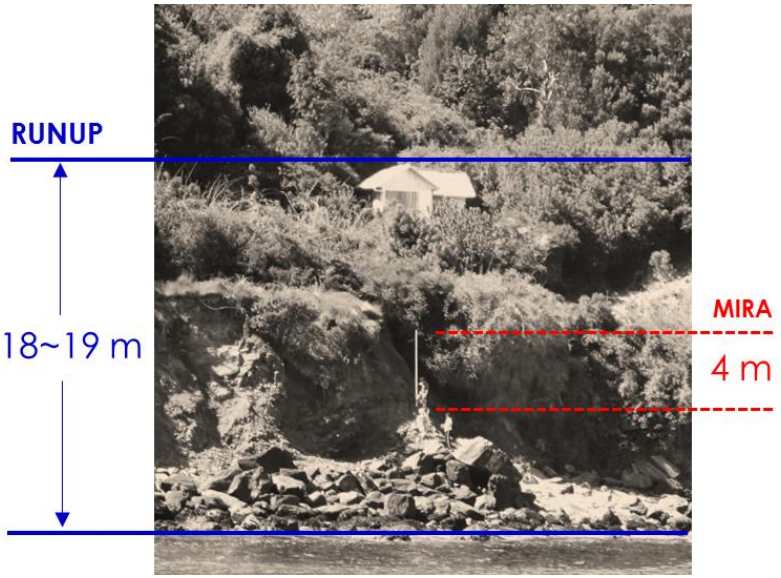
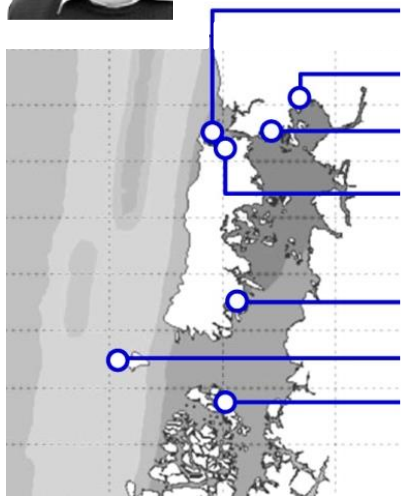
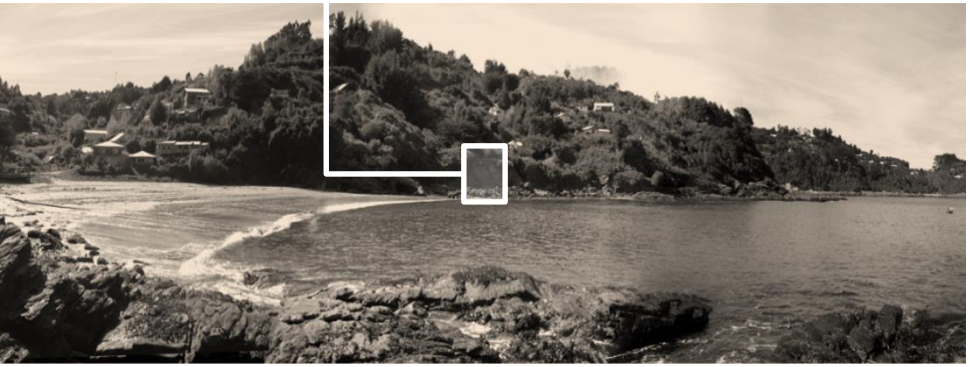
1960!

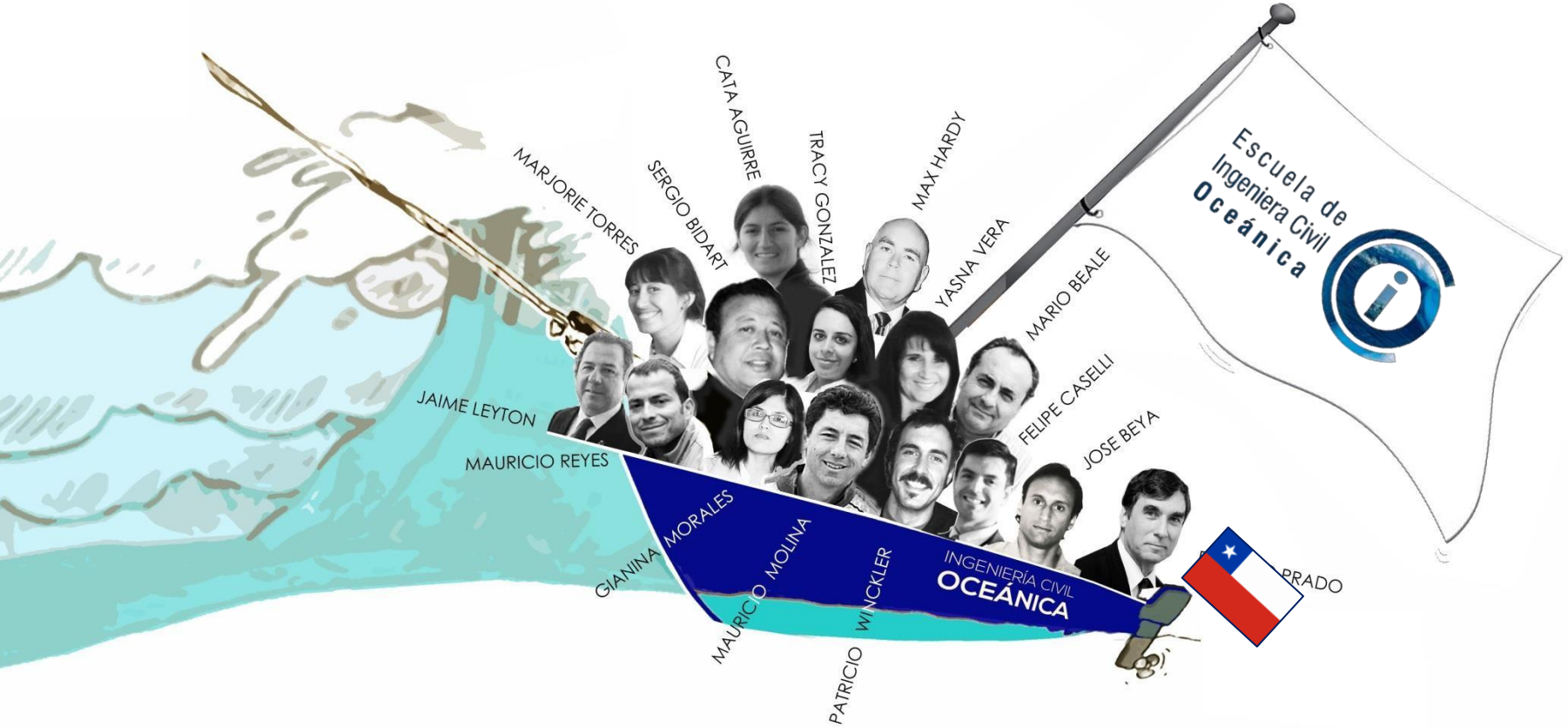






1960!

Runup (m)
30
25
20
15
10
5
74°W
73°W
72°W
75°W
36°S
37°S
38°S
39°S
40°S
41°S
42°S
43°S
44°S
Concepción
Mehuín
Quellón


MARJORIE TORRES
SERGIO BIDART
CATA AGUIRRE
TRACY GONZALEZ
MAX HARDY
YASNA VERA
MARIO BEALE
FELIPE CASELLI
JOSE BEYA
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