THE TSUNAMI ASSESSMENT MODELLING SYSTEM BY THE JOINT RESEARCH CENTRE

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ABSTRACT

The Tsunami Assessment Modeling System was developed by the European Commission, Joint Research Centre, in order to serve Tsunami early warning systems such as the Global Disaster Alerts and Coordination System (GDACS) in the evaluation of possible consequences by a Tsunami of seismic nature. The Tsunami Assessment Modeling System is currently operational and is calculating in real time all the events occurring in the world, calculating the expected Tsunami wave height and identifying the locations where the wave height should be too high. The first part of the paper describes the structure of the system, the underlying analytical models and the informatics arrangement; the second part shows the activation of the system and the results of the calculated analyses. The final part shows future development of this modeling tool.

1. INTRODUCTION

The Joint Research Centre of the European Commission is operating the Global Disasters Alerts and Coordination System (GDACS, http://www.gdacs.org) since 2003. This System, jointly developed by the European Commission and the United Nations, combines existing web-based disaster information management systems with the aim to alert the international community in case of major sudden-onset disasters and to facilitate the coordination of international response during the relief phase of the disaster. When new natural disasters events occur automatic analysis reports are created and sent to the users by mail, fax or sms.

As a consequence of the 26th December Tsunami JRC included Tsunami modeling in the GDACS system in order to improve and complete the automatic reporting system. At the beginning of 2005 a travel time wave propagation model was included (Annunziato 2005). This model calculates the wave arrival time independently on the initial tsunami wave height. In 2006 a new analytical tool has been developed in order to be able to provide also the height and identify the locations with higher risk of tsunami damage.

This report describes the JRC Tsunami Assessment Tool, which is a complex computer arrangement whose objective is to calculate the prediction of the tsunami behaviour when minimal parameters are known, that is the condition when an earthquake is firstly identified. Therefore knowing the position of the earthquake (lat/long) and the Magnitude of the event, the programme will calculate the fault characteristics, the Tsunami generation and displacement, the identification of the location on the coast, which will be mostly affected. As such, although it was developed for the GDACS system, it can serve any Early Warning System.

2. TSUNAMI GENERATION

When an earthquake is occurring and generates a Tsunami the following mechanisms occur:

- subsidence faults movements can result in rising part of the earth and lowering the opposite section (a seismic horizontal movement does not generally determines a Tsunami)
- the water above the fault rises of the same quantity (slip)
- a pulse wave is generated
- the wave travels even thousands of km in the ocean reducing its height due to energy distribution on a larger surface. Focusing mechanisms, due to reflections of the bathymetry or of the coasts may influence the wave height.
- an increase of the height (shoaling effect) and a reduction in width and speed occurs as the tsunami approaches the shore

A Tsunami modeling tool need to take into account the above mechanisms to proper describe the phenomenon. The wave behaviour prediction can be performed according to the following task list:

- evaluate the earth deformation caused by the earthquake and impose an initial water displacement as initial condition of the calculation

- calculate water wave propagation
- evaluate the run-up and estimate the impact to the coast

3. THE JRC TSUNAMI ASSESSMENT SYSTEM

The JRC Tsunami Assessment System integrates in a single programme several components that are needed in order to fully evaluate the Tsunami as a consequence of an earthquake event. When a new event is detected by the seismic networks the following parameters are known few minutes (15-30) after an event:

- Epicenter Latitude
- Epicenter Longitude
- Magnitude
- Earthquake Depth

The fault form and the fault movement are not known other than hours after the event due to the need to analyze seismic waves far from the epicenter. The JRC-SWAN programme estimates the fault length, height and direction (which will influence the initial water displacement), initializes the calculation space, performs the travel time propagation calculation, verify at each step if there are locations reached by the wave, update the visualization and animation files. The programme can run in manual interactive mode or in automatic mode.

3.1 Fault length

The analysis of past earthquakes indicates that it is possible to recognize a relation between the fault length and the magnitude of the earthquake, as shown in Figures 1 and 2 (Ambrasseys and Jackson 1998).

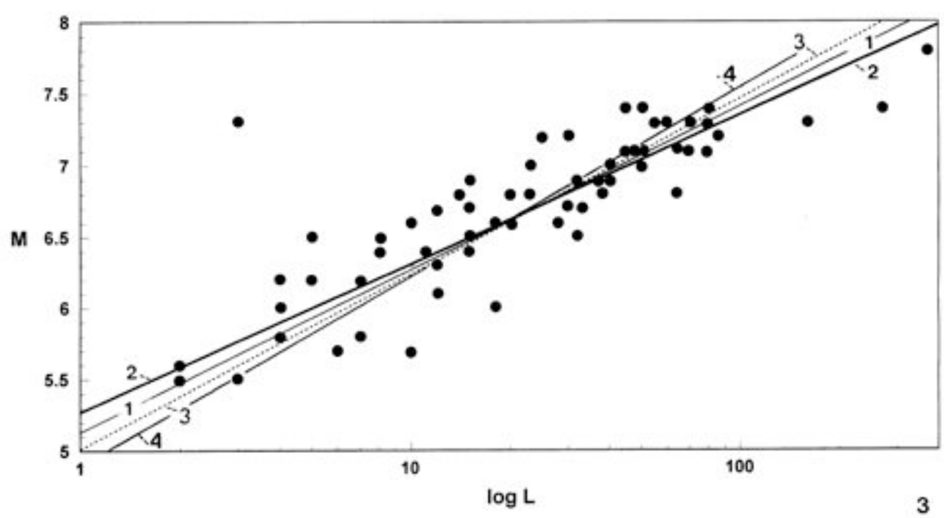


Fig. 1 – Ambrasseys et al: relation between fault length and magnitude

Several interpolation models exist for the evaluation of the fault length. Most of these models are of the following form:

Log (L) = A Mw + B

With L length in km, Mw is the earthquake magnitude and A and B two constants which determine the length of the fault. These constants are extremely sensitive because solving the above equation; the length has the expression on the right as an exponent of 10.

Taking, as an example (Ambrasseys and Jackson 1998) A=0.82 and B=-4.09, it is possible to see that

Mw=9.1, L=2355 km

Reducing the Magnitude to 8.5 the length becomes 758 km. In the following section we will adopt the formulation by Ward (2001), with A=0.5 and B=-1.8, which gives a value of 501 with a magnitude of 9. The two models become equal for a magnitude about 7. In the Sumatra case (9.1), the Length of the fault was about 1000 km, so the above equation can be a good starting point for the evaluation of the fault length, (Fig. 2).

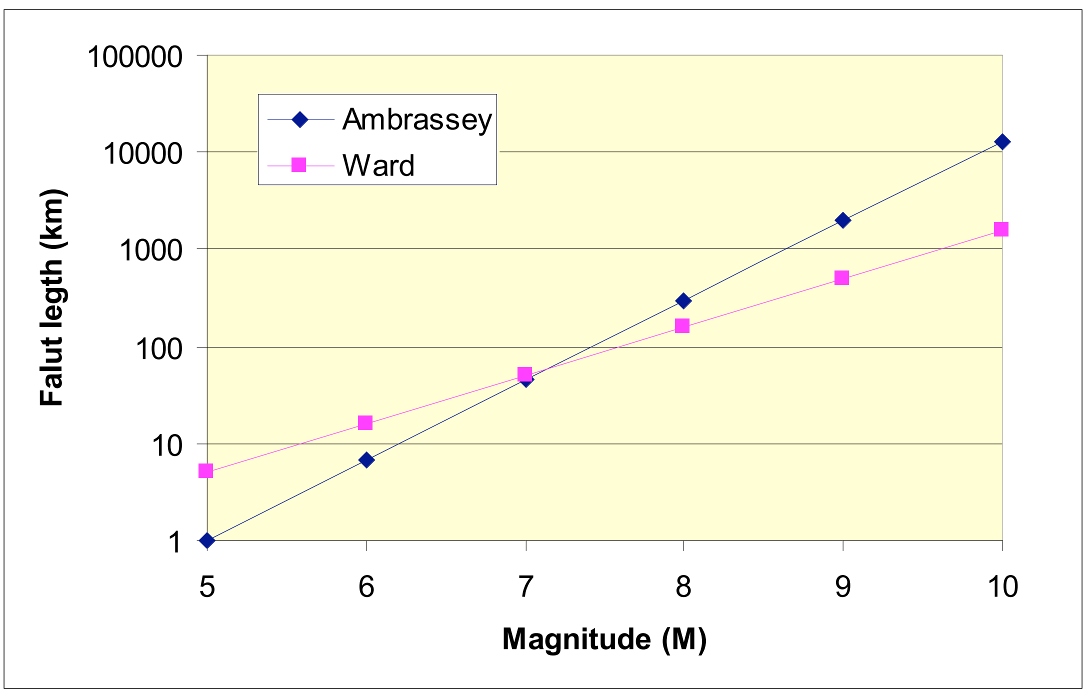


Fig. 2 - Relation between magnitude and fault length: comparison of two models

3.2 Water level increase at epicenter

As the earth is moving by L, determined at the previous subchapter, an increase of the water level occurs. The level increase is proportional to the fault length. Ward proposes a simple expression for the water level increase (slip) as $Du=2\ 10^{-5}\ L$, with Du in km, multiplied by 1000 to have it in m.

Mw	L (km)	W (km)	Du (m)
6.5	28	8	0.56
7	50	14	1.00
7.5	89	25	1.78
8	158	44	3.17
8.5	282	79	5.64
9	501	140	10.02
9.5	891	250	17.83
10	1585	444	31.70

This means that a magnitude 9 earthquake determines an increase of 10 m in the water level.

When the water rises, it is possible to have different patterns (Fig. 3):

- part of the water rises and part decreases
- the water increases in all directions of the same quantity (full rise)
- The longitudinal water distribution can be
- follows a regular pattern (cosinus)
- have a flat pattern

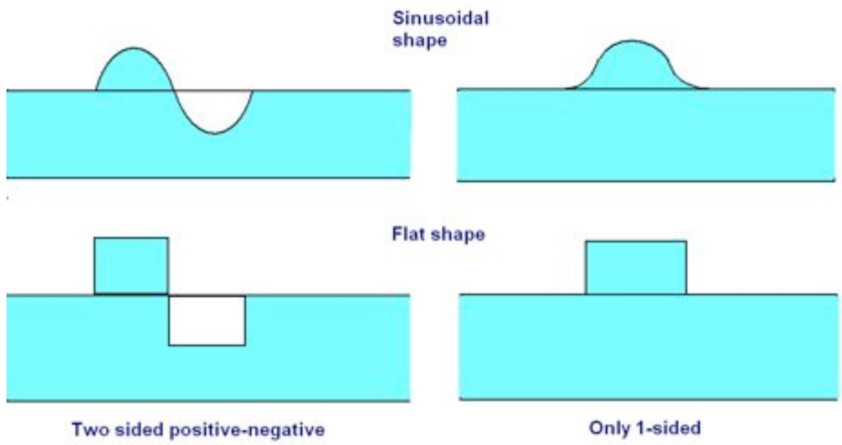


Fig. 3 – Water initial conditions

Any of this type of initial condition will create a different wave pattern in terms of form of the wave. In absence of information on the type of movement of the earth crust, the sinusoidal all positive shape is normally assumed for automatic calculations. It is however possible manually to test any of the other possible solutions.

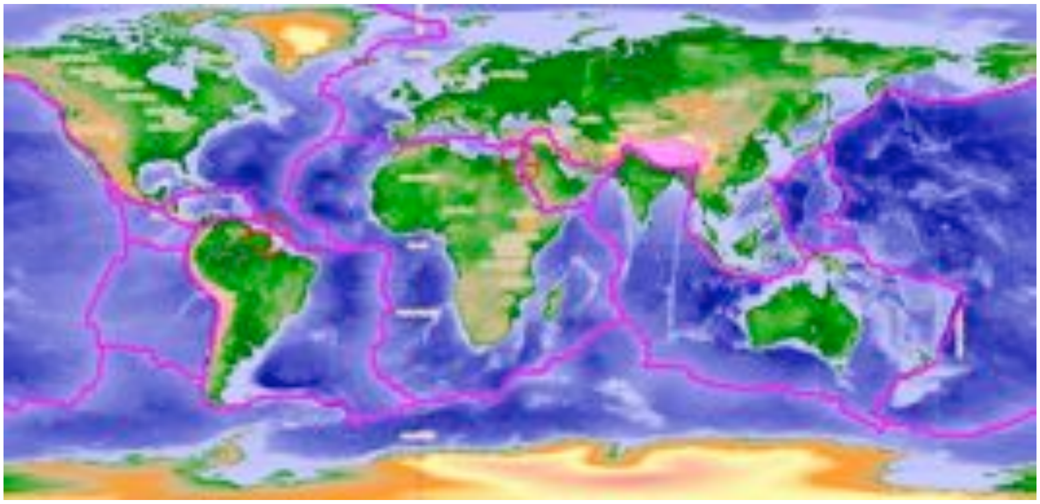


Fig. 4 - Tectonic plates and major fault lines

3.3 Fault direction

The earthquake faults generally occur following existing faults directions, which identify the Tectonic Plates. The known faults lines are indicated in Fig. 4. When an earthquake occurs at a generic location X, Y the programme searches the closer fault line and assigns the fault direction as parallel to that fault line.

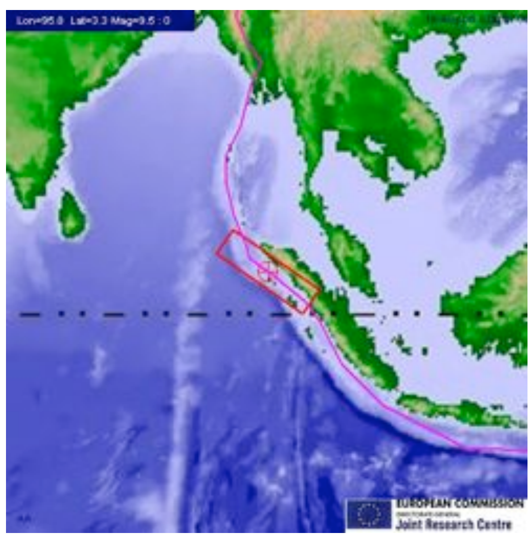


Fig. 5 - Creation of the fault direction and width

In some cases this choice may lead to errors in the correct identification of the fault location. In the case of the Tsunami in the Indian Ocean for instance, the epicenter was in the lower part of the fault and the fault was extending about 1000 km in the north, due to a progressive rupture. This method would instead position the fault symmetrically respect to the epicenter (Figure 5). Few minutes after the event there are no other information to judge the correct position of the fault, therefore this first approximation is the only possible.

3.4 Calculation space initialization

Typically an open ocean Tsunami propagation analysis is performed with a bathymetry grid of 20 min (36 km at the equator); local analyses are calculated with 2 min (1.8 km). Run-up calculations, to evaluate the flooding extent, need to be performed with even higher resolutions (i.e. 150-200 m, or 4.5 to 6 sec). The base bathymetry is the 2 min dataset, known as ETOPO-2. In some areas however the bathymetry has been improved, as in the Caspian Sea, where very coarse data were present.

The programme redefines the bathymetry according to the required cell size. The new bathymetry is obtained interpolating each point using the four adjacent data points. In case an automatic calculation is performed, the programme selects a bathymetry size according to the following logic:

- determination of the fault width and length, as indicated in 0
- evaluation of the maximum cell size, considering that the minimum size (width) has to be represented at least by 10 cells. The width of the calculation as 5 times the fault length but limited to have a maximum grid of 600x600 and thus accordingly determined
- evaluation of the depth at the epicenter and calculation of the wave velocity
- determination of the maximum calculation time considering the wave velocity and the assumed width size

Example: M 7.5 earthquake

Fault length=89 km
Fault width=24 km

$$\text{Max cell size} = \frac{24 \cdot 180 \cdot 60}{10 \cdot \pi \cdot 6340} = 1.30 \text{ min}$$

(Earth radius=6340 km)

WidthMax = 7.26 min = 800 km

Assuming a depth of 1460 m, the wave velocity is 431 km/h, thus the maximum problem time is

T= 800/431=1.9 = 1 h 54 min

If the depth is lower, 500 m, the velocity is lower, 252 km/h and thus the problem time longer, 3h 18 min.

Therefore the cell size depends strongly on the magnitude of the earthquake. Greater is the magnitude and greater is the cell size and the calculation domain size.

3.5 Tsunami propagation in the Ocean

It is now interesting to evaluate how the initial height of the Tsunami reduces as it propagates in the ocean. If a Tsunami of initial height H_o propagates from a point source and a constant water depth is considered, the wave amplitude at distance R is proportional to the inverse of the distance and proportional to the initial height (Figure 6).

$$H \propto H_o R^{-1}$$

This means that the height cannot be higher that the initial height and reduces along the distance.

Taking into account the motion equations it is possible to see that the height is initially proportional to a value between 0.5 and 1 (Ward).

In theory using the above correlations to express the wave height reduction as the Tsunami propagates in the ocean.

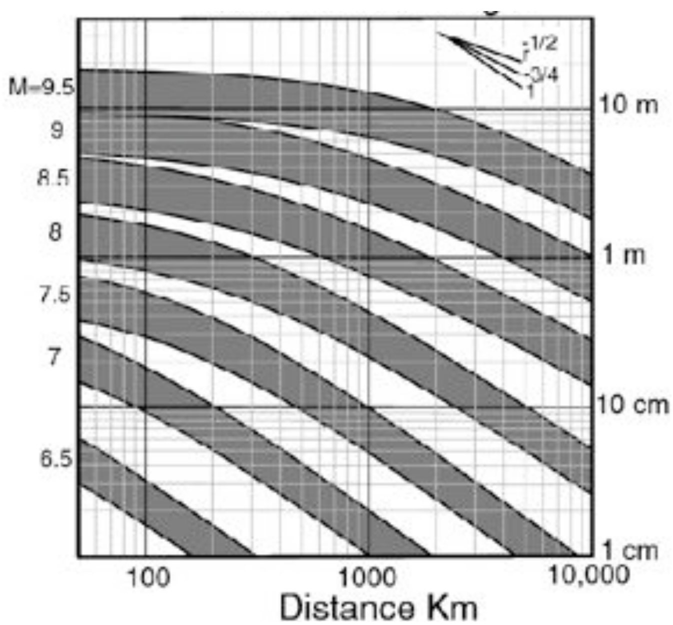


Fig. 6 – Relation between magnitude and height at various distances

However after some attempts to use easy relations as the one above as connected with the wave propagation model, it has been decided to use the complete shallow water equations because there are so many different situations that it is not possible to consider all the variations. A typical example is an isle around which the wave is propagating and in which the term “distance from the epicenter” looses its meaning because is it the distance in straight line or the distance along the path?

3.5.1 Shallow water propagation model

In order to express the Tsunami propagation it is possible to use the shallow water equations in the form proposed by C. Mader coded into the SWAN code (Mader 2004).

The model uses the mass and momentum conservation equations in 2 dimensions, with the approximation of constant velocity along the height. This theory is valid when the ration wave length over the water depth is low. Therefore for Tsunami calculations, considering about 4000 m as maximum depth, when the wave length is several times the depth (i.e. 10 times) so when the wave length is greater than 40 km.

Mass conservation equation

$$\frac{\partial H}{\partial t} + \frac{\partial\left[(D+H)U_x\right]}{\partial x} + \frac{\partial\left[(D+H)U_y\right]}{\partial y} = 0 \qquad (1)$$

Momentum conservation

$$\frac{\partial U_x}{\partial t} + U_x\frac{\partial U_x}{\partial x} + U_y\frac{\partial U_y}{\partial y} - FU_y + g\frac{\partial H}{\partial x} = -\frac{1}{\rho}\frac{\partial P}{\partial x} + A^{(x)}$$
$$\frac{\partial U_y}{\partial t} + U_x\frac{\partial U_x}{\partial x} + U_y\frac{\partial U_y}{\partial y} + FU_x + g\frac{\partial H}{\partial y} = -\frac{1}{\rho}\frac{\partial P}{\partial y} + A^{(y)} \qquad (2)$$

Where D is the water depth (under water is positive depth, mountains are negative depths), H is the local water level, U_x and U_y are the velocities in the two directions, P is the pressure derivative, which is express as water level difference, and A contain tide generating forces.

The above equations are integrated over control volumes and finite difference equations are obtained. The original code by Mader in Fortran Language has been rewritten in C and connected with a Visual Basic driver into the SWAN-JRC code.

3.6 Identification of relevant locations

In order to identify if a location is hit or not and with which height the following procedure is adopted. At each calculation time step a check of every point of the calculation grid is performed. If the height of the wave is greater than 80% of the depth (h/d>0.8) or if the height is positive and the depth positive (water on the earth), a check is performed of all the locations at a distance of 5 km from the grid center (Fig. 7). These locations are assigned the wave height calculated for that cell. The procedure is repeated for each calculation cell. The database for identifying the locations includes about 700 thousands cities around the world.

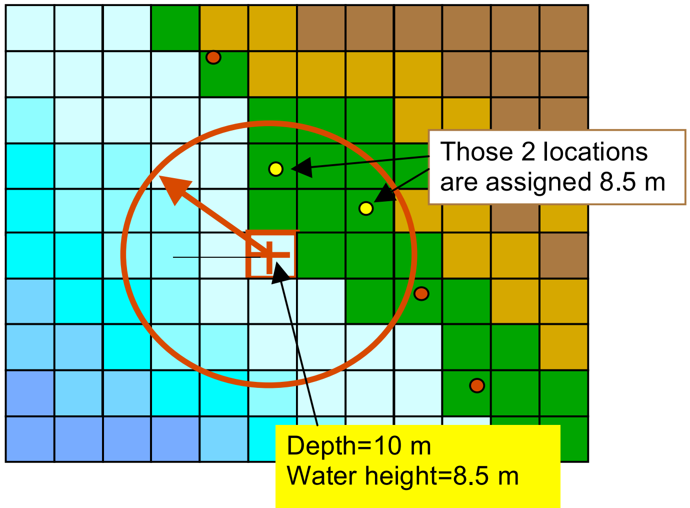


Fig. 7 – Identification of locations

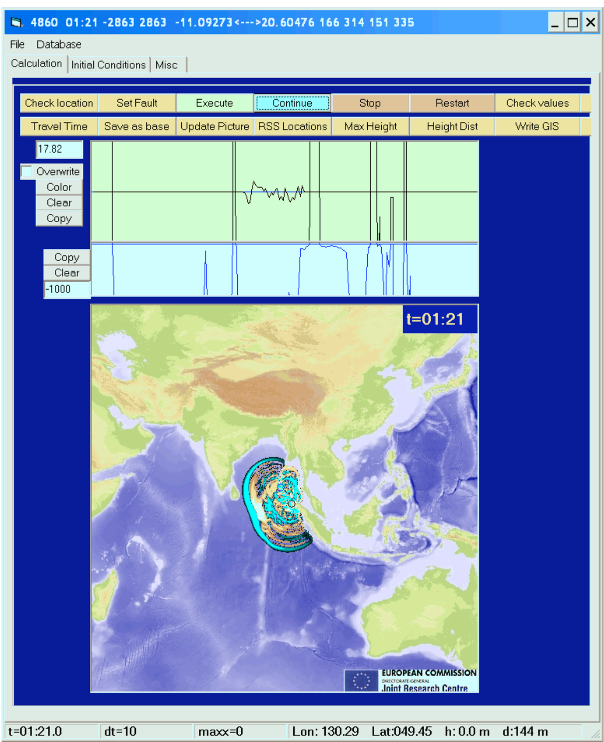


Fig. 8– Calculation output window

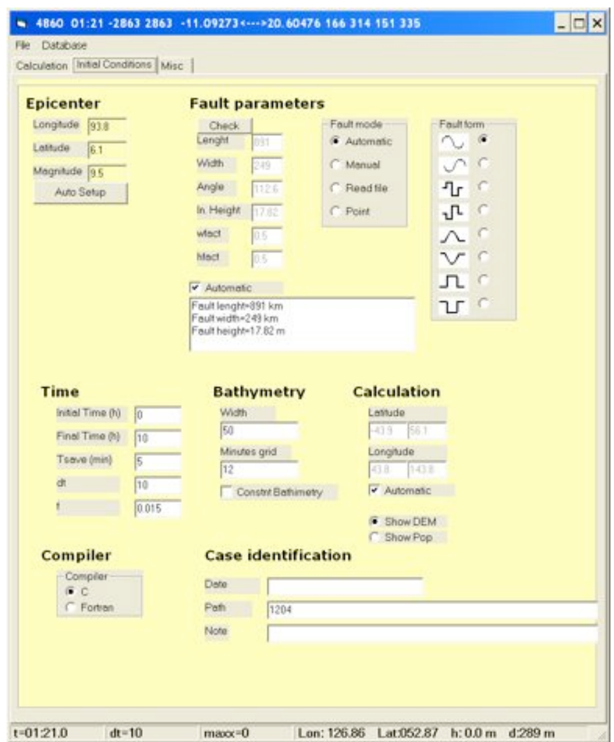


Fig. 9 -User interface to establish the initial conditions of the calculations

3.7 The JRC-SWAN interface

Very often the difficulty to use some computer programmes is represented by the user interface which is difficult to use and not easy to perform several sensitivity analyses. In order to make the programme user friendly a user interface has been developed. This is in the form of a Windows programme which allows establishing and changing all the initial conditions. It is also possible to change the form of the fault and its shape (Fig. 8 and 9 above).

4. JRC TSUNAMI ASSESSMENT TOOL WORKING MODE

The JRC Tsunami assessment tool is part of the Global Disasters Alerts and Coordination System (GDACS), a joint United Nations (OCHA) and Commission (ECHO, ENV, and JRC) system. GDACS does not make physical observation (like deep see observations or seismographs). Instead, it picks up such information though web protocols and performs additional processing such as overlaying information with population density. GDACS aims at controlling the information flow after the disaster, including fast alerts, updated news, satellite maps and needs and relief related information.

When a new event is detected by the seismological sources (USGS, EMSC), an evaluation of the event is performed to estimate the importance of the event from humanitarian point of view. If the event is relevant the system automatically sends out alerts (email, SMS, fax) to the registered users. The information is published on the GDACS web site in real time (Fig 10).

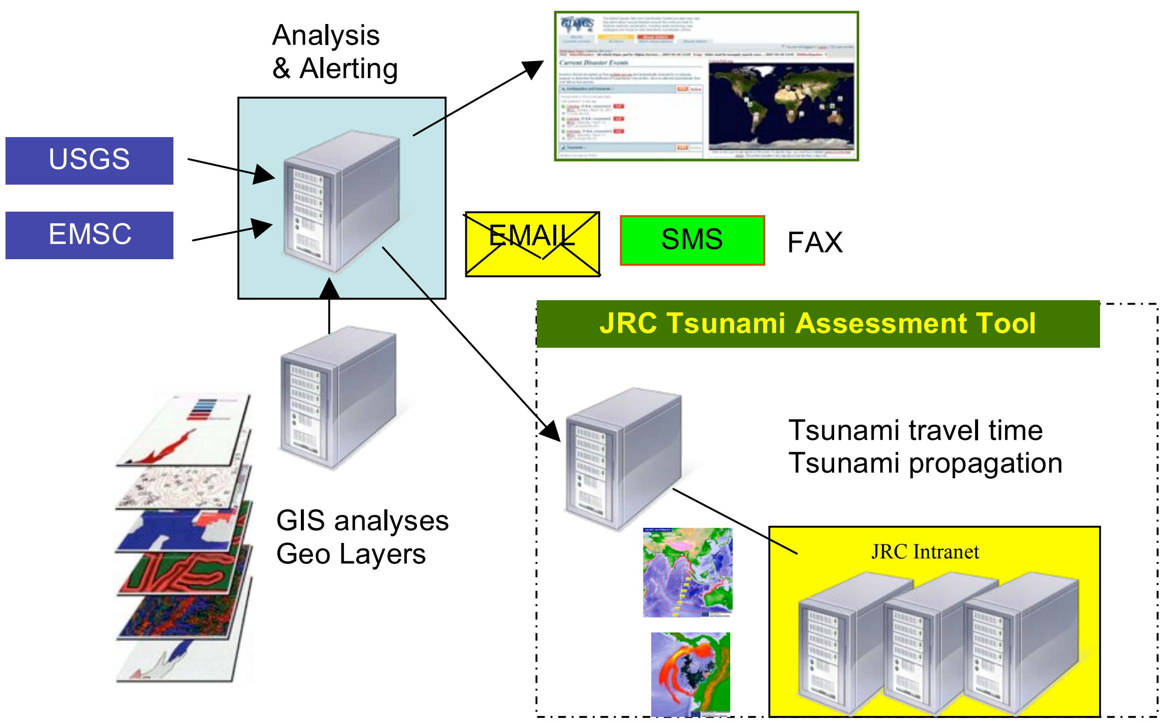


Fig. 8 – Architecture of the Global Disasters Alerts and Coordination System and relation with the Tsunami Assessment

In case of an earthquake event occurring under water and of magnitude greater than 6.5, the JRC

Tsunami Assessment Tool is invoked and a new calculation is requested. The current arrangement foresees 1 collection server and 3 execution server. When a new calculation is to be performed one of the three servers picks up the required initial conditions and begins the calculation. In the meantime the other two servers are in standby, waiting for additional requests. The reasons for multiple execution servers are the following: a) possibility that two events occurs at very short time interval each other and a new calculation is required (on 25/3/2007 two earthquakes in Vanuatu and Japan occurred at 1 min each other); b) events are redefined in terms of position or magnitude and therefore a new calculation should be performed; c) possibility to perform systematic calculations within a range

The calculations are all stored in a database and a file system. This means that if a new calculation is requested with the same parameters of one already present in the database this calculation is offered by the system as result of the analysis. The current settings is that a new calculation is performed if the difference in latitude or longitude or magnitude is greater than 0.1 (degrees or Richer scale value). This is a quite stringent requirement but it allows having exactly the right calculation for the requested case.

The system works with the method of the web service. It means that if a system (GDACS or any other client) needs a calculation for a certain location (ex latitude/longitude 28.86/-19.73, magnitude 8.2), it has to perform a call to a specific Internet address such as:

http://...cmd.asp?CMD=SET_CALC&eqid=LP001&evDate=01/12/2007&**mag=8.2&lat=28.86&lon=-19.73**&location=off-shore Canary Islands&Client=Manual

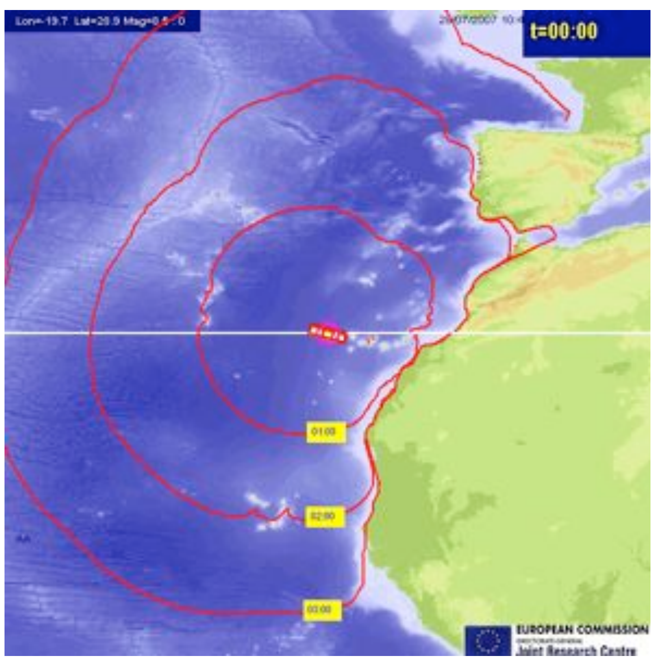


Fig. 9 – Travel time image calculated for the Canary Island case

The system will respond with an xml file containing several information including:
- the initial conditions of the fault (length, width, orientation, height)
- the output parameters:
    - travel time image (Fig. 11)
    - locations where to find the output images and files
    - list of locations affected

If the required calculation is already present in the database because similar to a previous case or already requested by another system, the stored calculation is offered to the user; if not a new calculation is initiated.

Soon after the receipt of the request one of the execution server will start the job and the calculation initiated. About every 5 minutes updates of the running calculation are published at the internet location indicated in the xml response file. Fig. 12 represents the update after 11 min of calculation time. It is possible to note the indication of the locations with the predicted height at each location and the time of the maximum height and the height distribution.

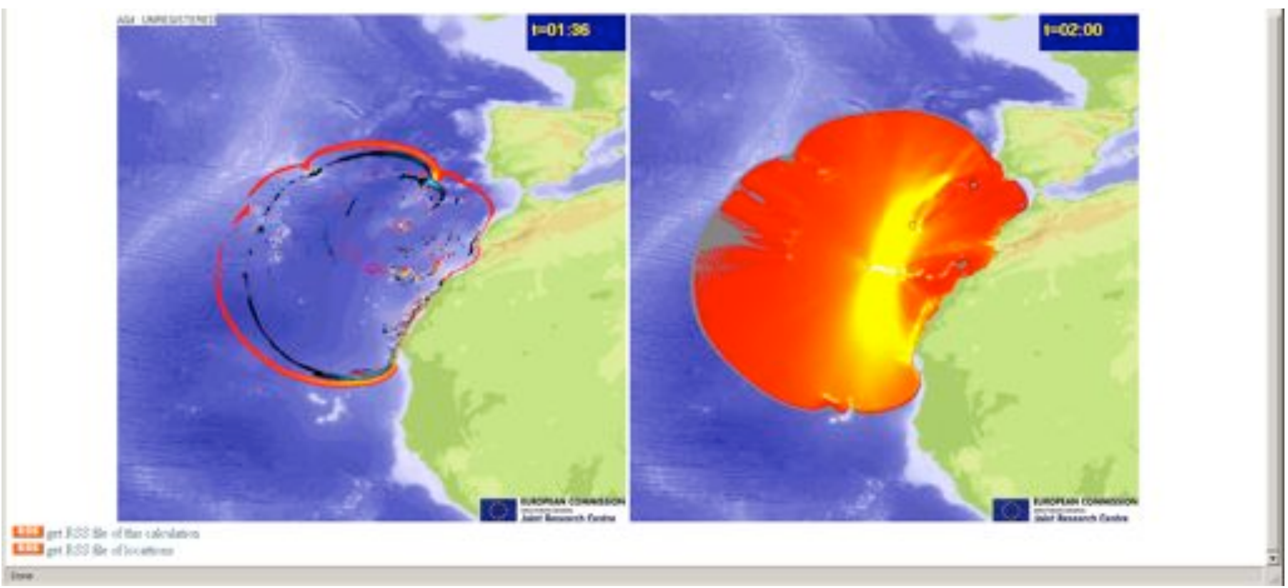
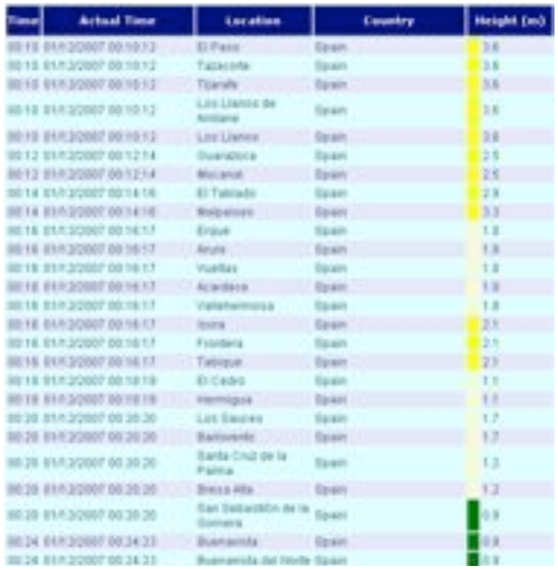


Fig. 10 –Overall output of the JRC Tsunami Assessment System

A typical calculation takes about 30 minutes to be completed. However the closer the location, the quicker it appears in the update page. So, for instance in the case considered above, the location San Sebastian de a Gomera, which is reached in 20 minutes the evaluation takes less than 1 minute; San Pedro da Cadeira (Portugal), reached at 2h 36’, is shown after 10 minutes of calculation.

The list of locations with the time after the event and the actual time, the height and the population estimate is updated as soon as the calculation progresses in the model result page (Fig. 13).

The final form of the calculation is indicated in Fig. 14 which shows the maximum height in any location.



Time	Actual Time	Location	Country	Height (m)
00:10	01/12/2007 00:10:12	El Paso	Spain	3.6
00:10	01/12/2007 00:10:12	Tazacorte	Spain	3.6
00:10	01/12/2007 00:10:12	Tijarafe	Spain	3.6
00:10	01/12/2007 00:10:12	Los Llanos de Aridane	Spain	3.6
00:10	01/12/2007 00:10:12	Los Llanos	Spain	3.6
00:12	01/12/2007 00:12:14	Guarazoca	Spain	2.5
00:12	01/12/2007 00:12:14	Mocanal	Spain	2.5
00:14	01/12/2007 00:14:16	El Tablado	Spain	2.9
00:14	01/12/2007 00:14:16	Malpaises	Spain	3.3
00:16	01/12/2007 00:16:17	Erque	Spain	1.8
00:16	01/12/2007 00:16:17	Arure	Spain	1.8
00:16	01/12/2007 00:16:17	Vueltas	Spain	1.8
00:16	01/12/2007 00:16:17	Acardece	Spain	1.9
00:16	01/12/2007 00:16:17	Vallehermosa	Spain	1.8
00:16	01/12/2007 00:16:17	Isora	Spain	2.1
00:16	01/12/2007 00:16:17	Frontera	Spain	2.1
00:16	01/12/2007 00:16:17	Tabique	Spain	2.1
00:18	01/12/2007 00:18:19	El Cedro	Spain	1.1
00:18	01/12/2007 00:18:19	Hermigua	Spain	1.1
00:20	01/12/2007 00:20:20	Los Sauces	Spain	1.7
00:20	01/12/2007 00:20:20	Barlovento	Spain	1.7
00:20	01/12/2007 00:20:20	Santa Cruz de la Palma	Spain	1.2
00:20	01/12/2007 00:20:20	Breña Alta	Spain	1.2
00:20	01/12/2007 00:20:20	San Sebastián de la Gomera	Spain	0.9
00:24	01/12/2007 00:24:23	Buenavista	Spain	0.8
00:24	01/12/2007 00:24:23	Buenavista del Norte	Spain	0.9

Fig. 11 – Detail on the list of locations with indication of locations and population estimates

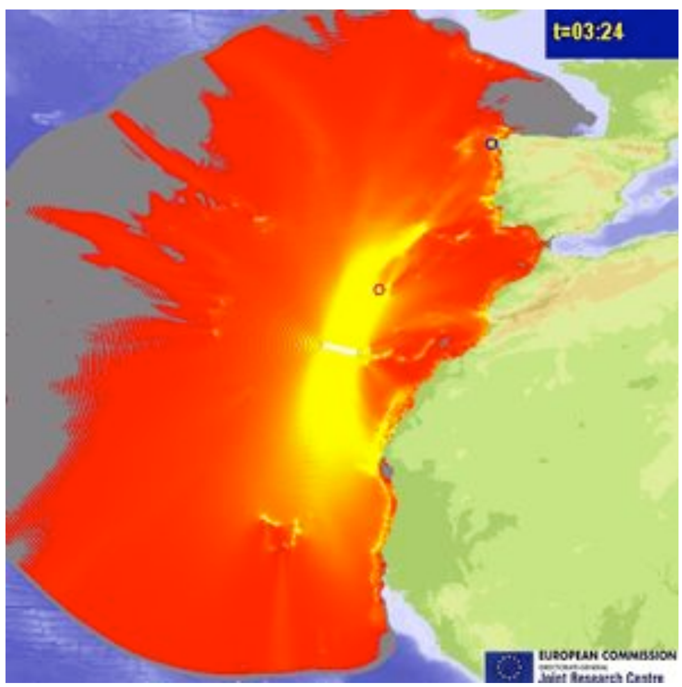


Fig. 12 – Final height distribution for a M 8.2 earthquake occurring off-shore Canary Islands

5. ACTUATIONS OF THE JRC TSUNAMI ASSESSMENT SYSTEM

The Tsunami Assessment Tool is operational since November 2005. Since the start of the operations the actuation of the system was requested 13 times (as 8/8/2007). In 8 cases real Tsunamis were generated, in 3 cases the earthquake depth was too high to generate a Tsunami (>100 km), in 1 case the initial magnitude of 6.9 was then lowered to 5.7, in 1 case there was no tsunami even if the depth was very low (2 km).

#	Location	Magnitude	Depth (km)	Date	CPU time min	Note
1	Kuril Islands	M 8.3	30	15/11/06	22	**0.4 m Tsunami** reached Japan, Hawaii and California
2	China	M 7.2	2	26/12/06	28	No Tsunami generated
3	Kuril Islands	M 8.2	10	13/01/07	40	**Small Tsunami generated**
4	Indonesia	M 7.2	10	21/01/07	22	**Small Tsunami generated**
5	Vanuatu	M 6.9	35	25/03/07	23	**Small Tsunami generated**
6	Japan	M 7.3	50		48	Small Tsunami generated
7	Solomon Island	M 8.1	10	01/04/07	22	**10 m Tsunami**, about 200 persons dead
8	Papua New Guinea	M 6.9[1]	20	01/07/07	25	No Tsunami generated[3]
9	Honshu	M 6.6	55	16/07/07	34	**0.5 m Tsunami** on Japanese coasts, damages from the earthquake
10	Honshu	M 6.8	314	16/07/07	38	No Tsunami generated
11	Vanuatu	M 7.3	144	01/08/07	35	No Tsunami generated
12	Sakhalin	M 6.9	39	02/08/07	30	**0.3 m Tsunami generated**
13	Indonesia	M 7.5	289	08/08/07	60	No Tsunami generated

(Situation as 8/8/2007. New cases occurred after that, as Peru' earthquake, which was correctly calculated)

[1] This earthquake was initially classified 6.9 by GEOFON, finally reduced to 5.7

Therefore assuming no Tsunami below 100 km (a modification done in the last release of the system), and excluding the case of wrong initial magnitude, on 12 cases 11 would have been correctly calculated, which is extremely good result.

An analysis has been done on the time of issuing of the various PTWS bulletins and the execution of the calculations for two events: Kuril Island (15/11/2007) and Solomon Island event (01/04/2007). The reason for choosing these two events is that the first one can be identified as a long distance Tsunami, since traveled up to Japan, Hawaii and California. The second one is instead a more localized event.

5.1 Kuril Island event, 15/11/2006

On 11/15/2006 11:14:01 AM UTC an earthquake of magnitude 8.3 struck the unpopulated Kuril Islands between Russia and Japan (Lon: 153.22 Lat: 46.68). The earthquake triggered a relatively small tsunami (with wave heights up to 50cm), which reached mainly Japan, Russia but it was detected also in Hawaii, California coasts and South America. No casualties were reported.

Calculations of tsunami wave height were automatically initiated with the JRC SWAN model. Results were updated on the dedicated web site every 10 minutes. The model predicted a maximum height of 40 cm in Japan arriving at 1h 30 min; in effect a wave of about 30 cm arrived at 1h 22 min, according to Japanese measurements (Fig. 15).

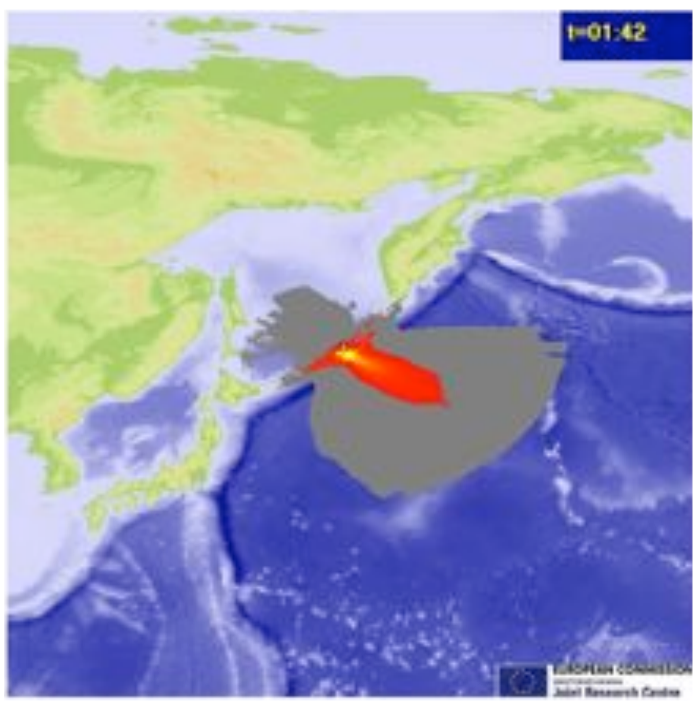


Fig. 13 – Height Distribution for the Kuril Island event of 15/11/2006

The highest predicted height was 6.6 m to occur on the inhabited Islands (Fig 16).

The calculation, initiated when the notification occurred, 17 min after the event, and was completed in 30 min thus, related to Japan, there were still 43 minutes available for early warning.

This is the timeline of the events actuation

0	11:14:15 UTC M7.7 earthquake Kuril Islands
16’	1st PTWS message generated (“**it is not known if a Tsunami was generated**”, arrival times indicated)
17’	JRC-SWAN calculation starts
47’	JRC-SWAN calculation ends, locations identified with 0.4-0.5 m height maximum
1h	Magnitude revised to M 8.1 2nd PTWS message generated (“**it is not known if a Tsunami was generated**”)
1h 1’	New JRC-SWAN calculation started
1h 16’	JRC-SWAN predicts Hokkaido, Japan reached 0.1 m at 1:30
1h 22’	JRC-SWAN predicts Oishi, Japan, reached at 2 h, 0.12 m
1h 30’	Hasahi Hokkaido reached by the wave, 0.3 m
2h 3’	3rd PTWS bulletin, indicating that “**a Tsunami was generated**” and that two locations in Japan were reached by the wave
3h 44’	4th PTWS bulletin, indicating that also Alaska was reached by the wave, 0.2 m

The image below was produced at the end of the first calculation, when the known magnitude was 7.7. Already this image was showing very clearly that the direction of the energy distribution was such that a major wave on Japan had not to be expected.

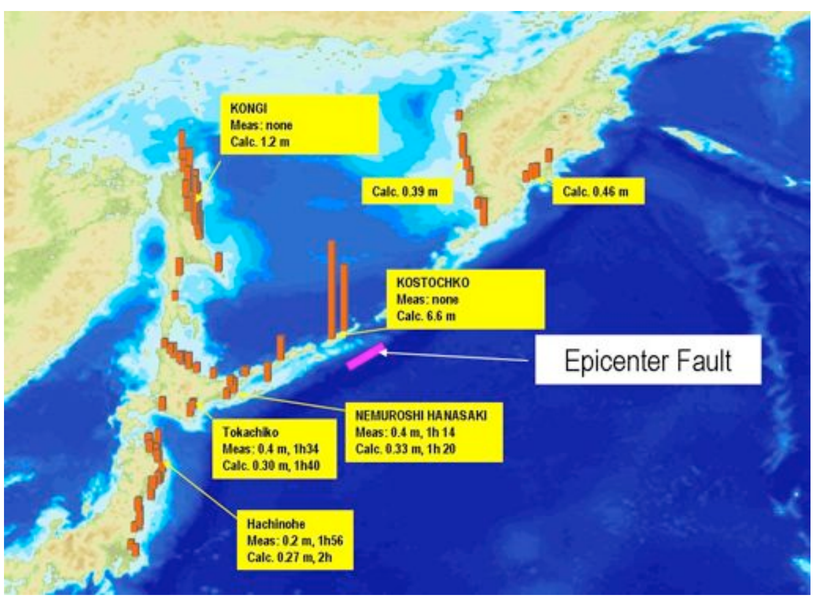


Fig. 14 – Distribution of the predicted and measured after the Kuril Island event of 15/11/2006

Also the image indicates that great amount of energy is directed towards Hawaii, which indeed were reached several hours after by waves up to 1 m.

The results of the revised calculation are indicated in the figure below, which shows the various locations reached by the wave. It is interesting that one remote location (Kostochko) was reached by a 6.6 m wave. Analysis of the satellite images in the area allowed concluding that indeed an important wave reached those coasts (Fig 17).

The analysis of this event indicates that in this case of long distance Tsunami the information was produced rather quick, well in advance respect to the time the wave reached the first populated areas (Japan). The timings are comparable with the ones of PTWS. The use of these calculations could have allowed issuing bulletins indicating that no major problems were expected on Japanese coasts.

Fig. 15 - Satellite image on the coast on Kuril Islands showing that a section of the vegetation was taken out as a result

5.2 Solomon Island Event

On Sunday 1 April 2007 at 20:39 UTC, an underwater earthquake of magnitude 8.1 caused a tsunami of several meters to hit the Solomon Islands. More than 10 people have been reported killed and thousands affected or injured. The international community was put on standby and offered help through OCHA. Australian beaches were evacuated.

JRC systems detected the event 16 minutes after the event, i.e. as soon as it was published by the

United States Geological Survey. The event was calculated to be a Red Alert and over 3000 alerts were sent out.

0	20:40:00 UTC M7.7 earthquake Solomon Islands
15’	1st PTWS message generated (“**it is not known if a Tsunami was generated**”, arrival times indicated)
16’	JRC-SWAN calculation starts with 7.7 magnitude
17’	JRC-SWAN identified the following locations in less than 1 minute of calculation: Hofovo, 3.2 m, Harai 3.1 m, Vanikuva 3.1 m, Judaea 3.1 m, Au 3.1 m, Kunji 3.3 m, Pienuna 1.5 m, etc. All these locations are calculated to be hit in less than 5 min.
41’	JRC-SWAN calculation completed, calculated values: Harsi 1.9 m, Vanikuva 2.2 m, Kunji 1.5 m, Honiara 0.1 m (predicted to be hit at 54’) etc
52’	2nd PTWS message generated (“**it is not known if a Tsunami was generated**”, arrival times indicated), revised magnitude to **8.1**
53’	Second JRC-SWAN calculation initiated
54’	JRC-SWAN new estimates of locations in less than 1 min: Ganongga 3.5 m, Pienuna 3.5 m, Mundimundi 1.8 m, Paramata 1.8 m, Iringgila 1.4 m, Lunga 1.6 m, Vella Lavella I 1.5 m, Eghelo 3.7 m, Mburuku 3.7m etc.
57’	Honiara reached by 0.15 m wave (measurement)
1h 5’	Second JRC-SWAN calculation (with higher magnitude) completed (Honiara predicted to be reached at 48’ with 0.3 m)
1h 59’	3rd PTWS message, confirmation of the Tsunami, measurements in Honiara reported (0.15 m, at 57’)

Other 5 PTWS messages follow with additional locations measurements, but none of these indicate high wave values (Manus 9 cm, Vanuatu 15 cm, Cape Ferguson 11 cm) because the measurement locations were not close to the epicenter and not in line with the greater energy track (see the orange dots in Fig. 18).

The JRC-SWAN calculations were available already at least at the time of the second PTWS message, indicating about 3.3 m in Kunji. Thus the availability of this calculation tool could have been useful in identifying the extent of the possible affected areas, once the tsunami would have been confirmed by the far measurement points.

It is interesting to note that, although the first PTWS message was issued 15’ after the event, the email was received at JRC only after 2h 31’. At least one media source reported that the GDACS alert arrived while the Pacific Tsunami Warning Centre did not issue any alert message[2].

[2] MICHAEL FIELD - Fairfax Media, initially wrote: “The Pacific Tsunami Warning Center in Hawaii has not issued any warnings but the European Union/United Nations Global Disaster Alert and Coordination System says a tsunami is a high risk.”. The text of the article was then modified.

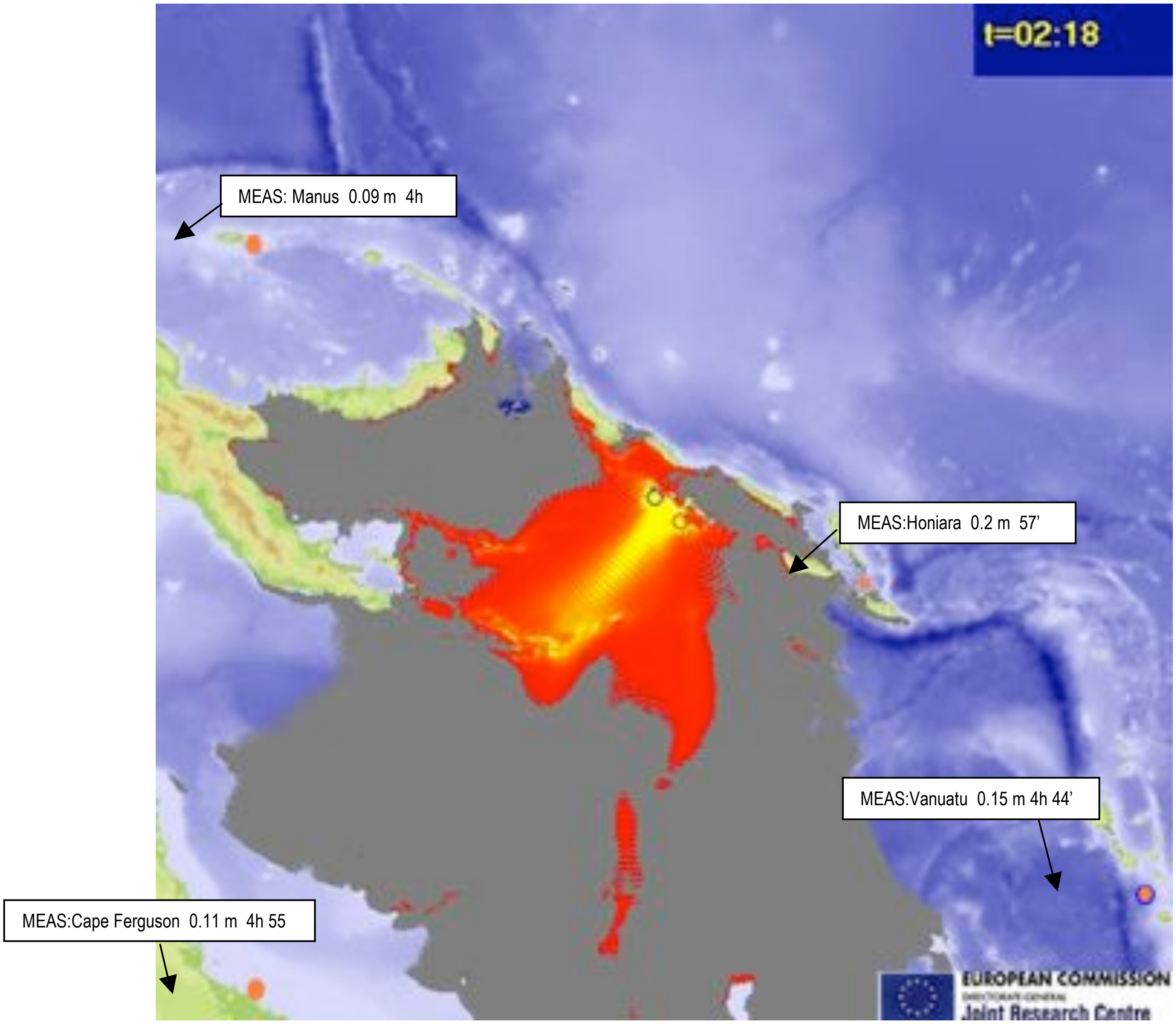


Fig. 16 – Solomon Island Event. In orange the positions of the water height measurements indicated in the PTWS messages

6. FUTURE ACTIVTIES

Is it better to use on-line calculations performed when an event occurs or pre-calculate all the possible conditions?

On-line calculations have the advantage that it is possible to specify the exact conditions (lat/long and magnitude; then it is possible to upgrade the model without the need to re-run all the thousands of calculations.

Another argument in support to the on-line calculation is the fact that the computer speed increases constantly over the years. In the last 5 years the computing power increased by a factor greater than 10 (Fig. 19). This means that in 5 years from now it could be possible to perform in 3 minutes the same calculation that now is performed in 30 minutes!

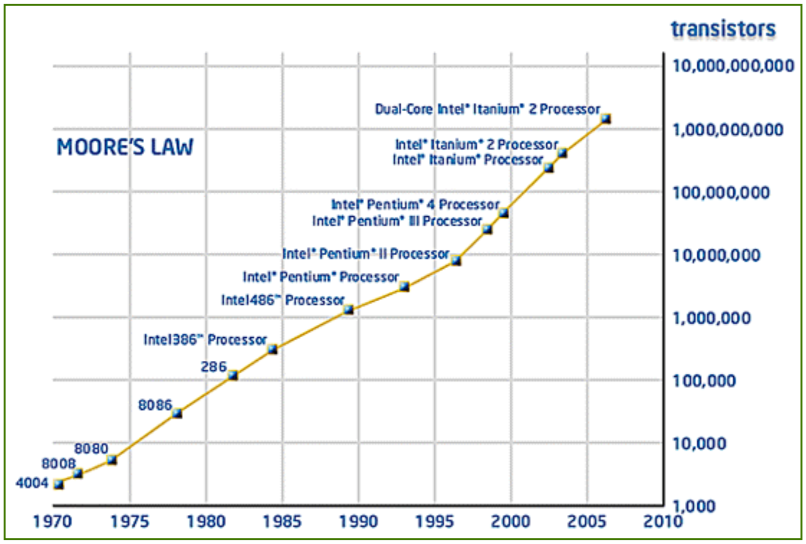


Fig. 17 – Calculation speed over the years

A disadvantage of the on-line calculation is that the system must be ready to execute the calculations at any time. The failure probability should be reduced as low as possible by adopting a number of execution servers. At the moment we are using three servers but we intend to increase them to five.

The pre-calculation has the advantage to have already all the calculations performed thus allowing more time for the alerting. However it is not possible to make any possible calculation for the whole world. In order to reduce the amount of needed calculations to the areas really potentially tsunami prone, a reduced calculation grid has been defined. For every historical Tsunamis source (each square in Fig. 21), the bounding 5x5 grid points have been determined using a 0.5 degrees grid.

This produces an overall not-uniform grid of 10185 data points as initial earthquake location. Considering that each calculation imply 30 minutes CPU time and 8 Mbytes storage space, means to spend 1 month on 7 computers and occupy 80 Gbytes per set of magnitude calculation. Calculating from M 6.5 to M 9.5 every 0.25, that means 12 sets of magnitude calculations (1 year using 7 computers). We started these grid calculation and when completed will be used in the normal routine operations.

Therefore the solution that we find more adequate is, at the moment of the event to provide an initial estimate based on the grid calculations we are creating, using the closer initial point on the 0.5 grid database and in the meantime launch a more precise calculation based on the actual location and magnitude, which will be ready, as it is currently, within 30 minutes.

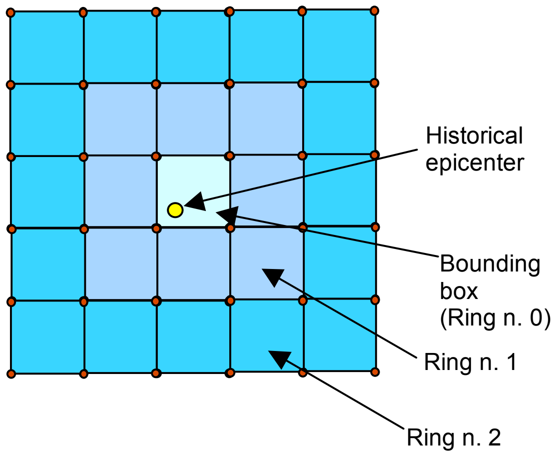


Fig. 18 – Definition of the grid boundary for historical Tsunamis

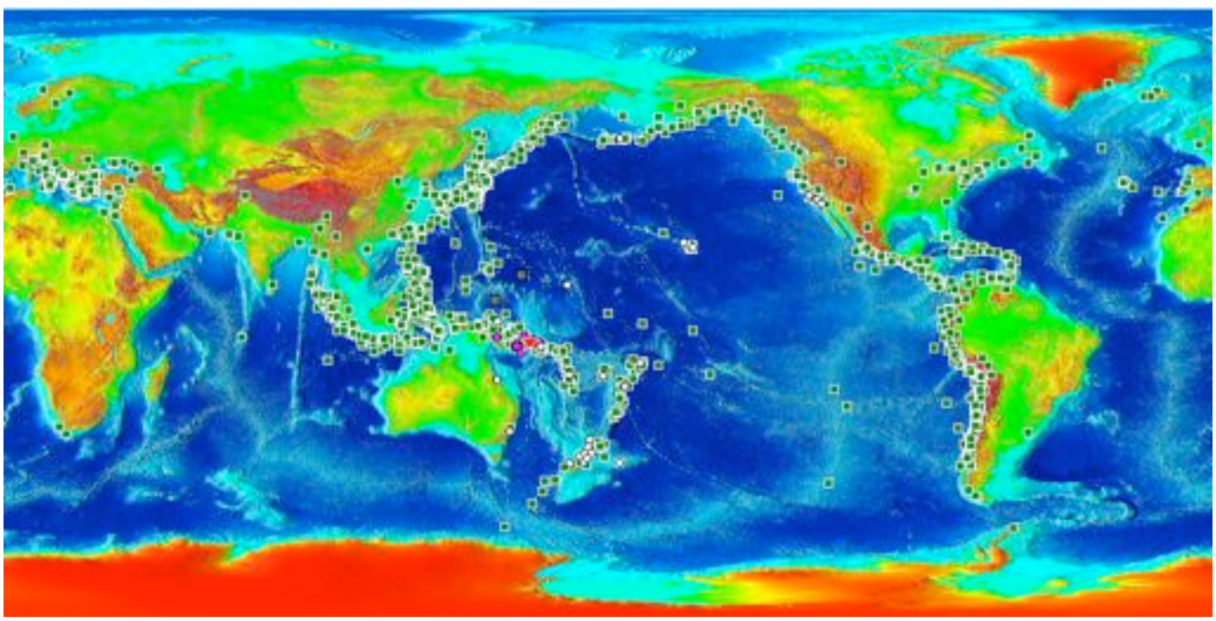


Fig. 19 - Historical database of Tsunami in the world (source NOAA, NGDC database)

7. CONCLUSIONS

Several computer codes for simulating the Tsunami behavior have been developed worldwide. None of them however has been designed in order to respond automatically with the only available information known few minutes after an earthquake event which may cause a Tsunami and publish, while it is running, the results on the web.

The JRC Tsunami Assessment Modeling System is a complex series of computer codes, procedures and computers set-up to respond in about 30 minutes to any request coming from Early Warning Systems, such as the Global Disaster Alerts and Coordination System (GDACS) or the LiveMon[3], both developed and operated by JRC.

The Tsunami Assessment System is now fully operational and performs automatic calculations whenever receives requests from the early warning systems.

In the future the system will be powered with a pre-calculated set of grid calculations to reduce the response time. The calculation time to produce such a database is quite large (1 year) but it will allow saving important time during the real events.

8. REFERENCES

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