

Risk assessment of tsunami impact on an oil refinery

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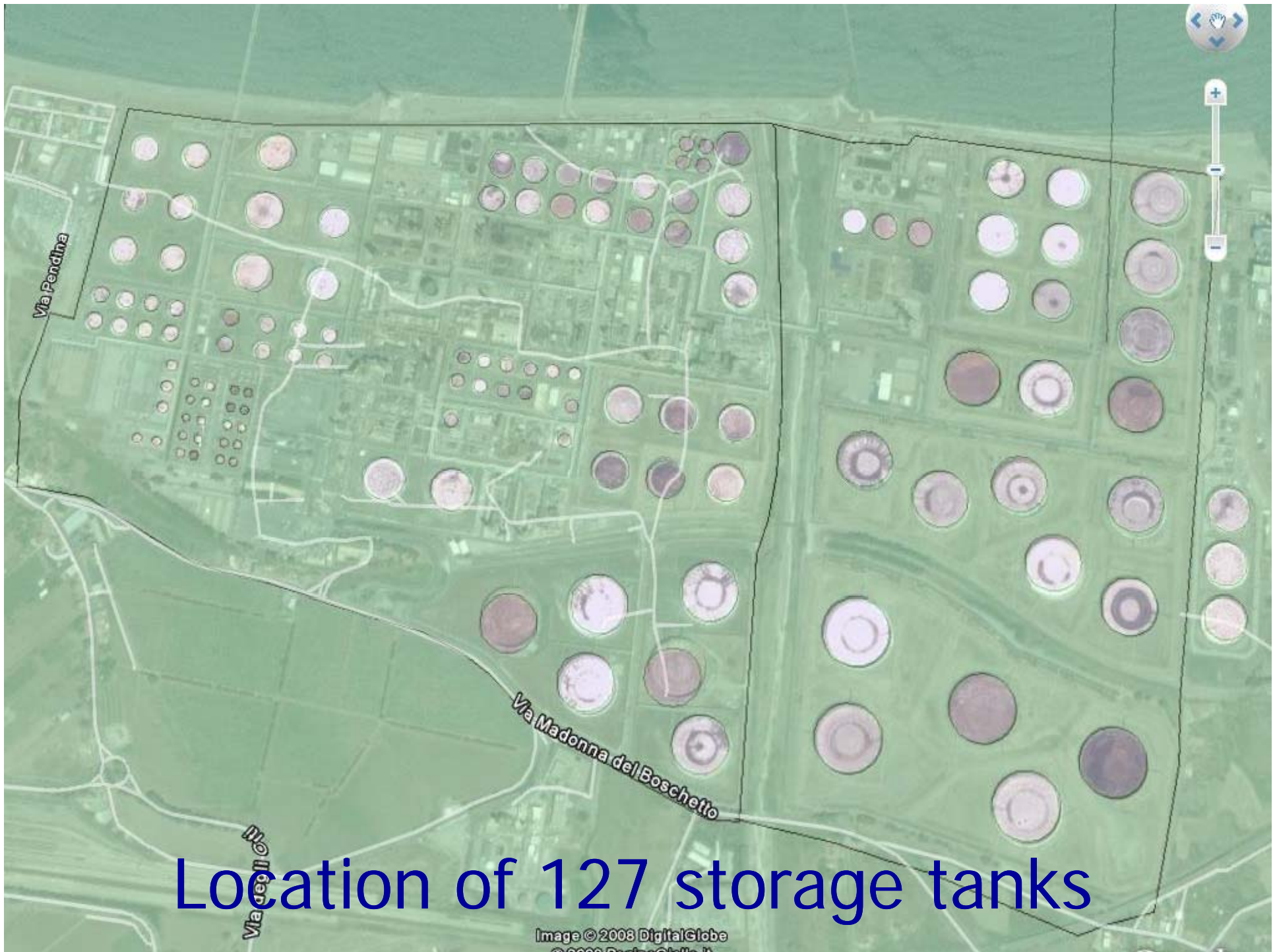
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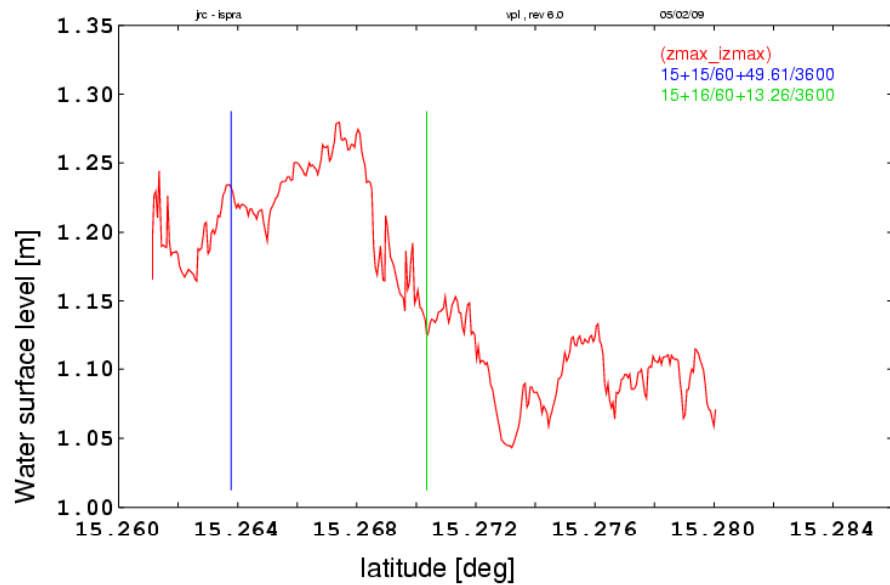
- Two tsunami scenario impacts at refinery in north-eastern Sicily :
 - a) Tsunami triggered by M_w 7.0 earthquake along Capo Vaticano fault
 - b) Tsunami triggered by landslide at Stromboli
- Modeling with HyFlux2 using nested grid system (400mx400m to 100mx100m to 20mx20m to 5mx5m)



Location of 127 storage tanks

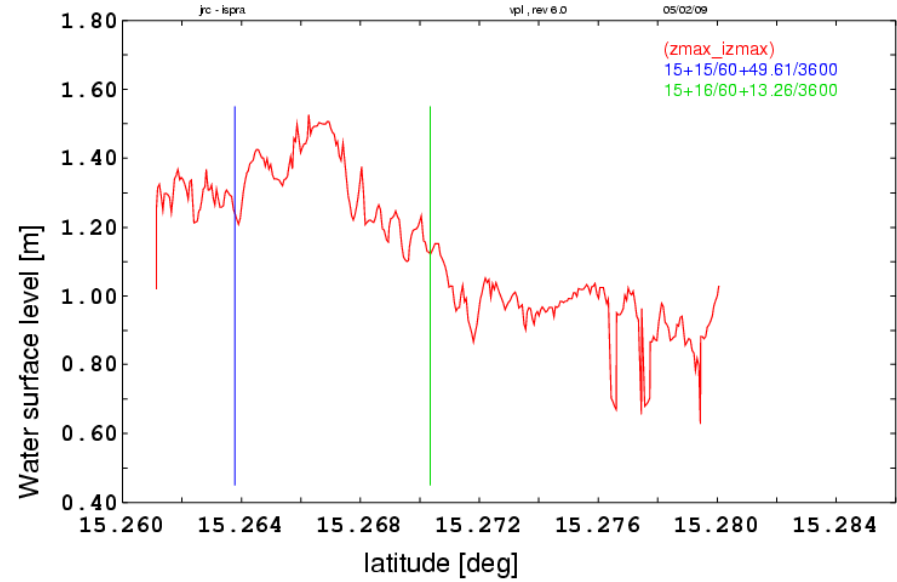
Tsunami impacts

- Flow velocities generally low (<1 m/s) for Capo Vaticano (a), with some peaks at 3-4 m/s
- Flow velocities 1- 2.8 m/s for Stromboli (b), with peaks over 3.5 m/s
- Max runup heights 1.3 m and 1.6 m, at inland distances of 140 m and 160 m for a) and b) respectively.



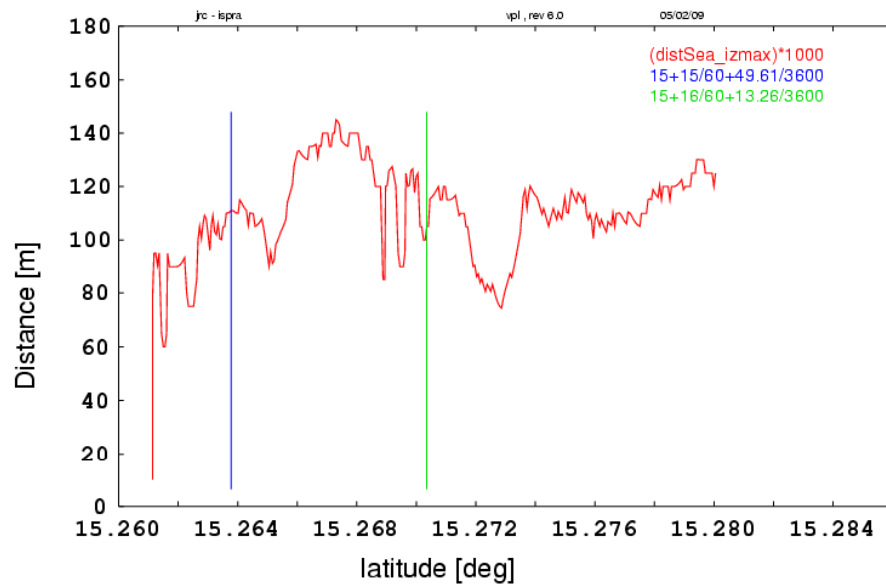
Maximum water runup

a. Maximum water run-up for
Capo Vaticano



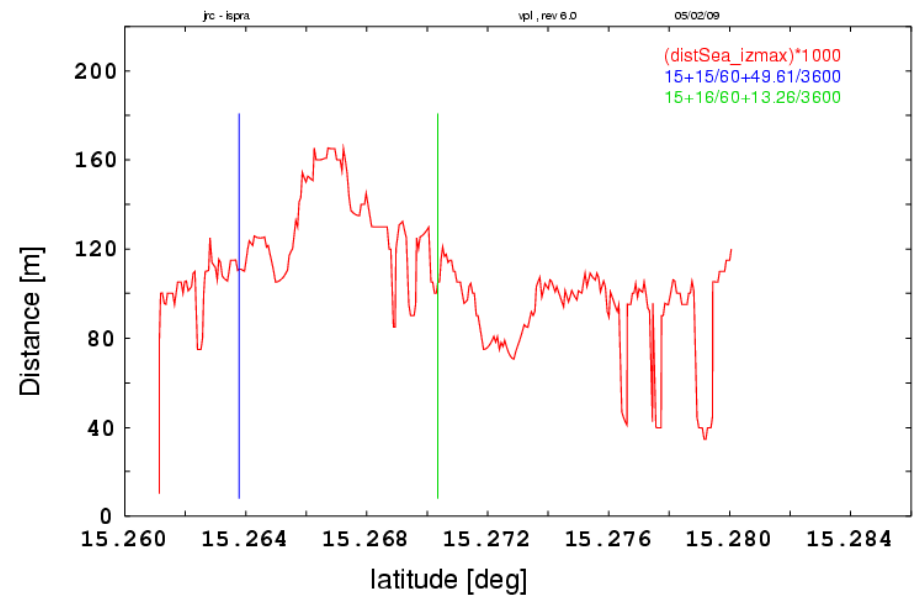
Maximum water runup

b. Maximum water run-up for
Stromboli



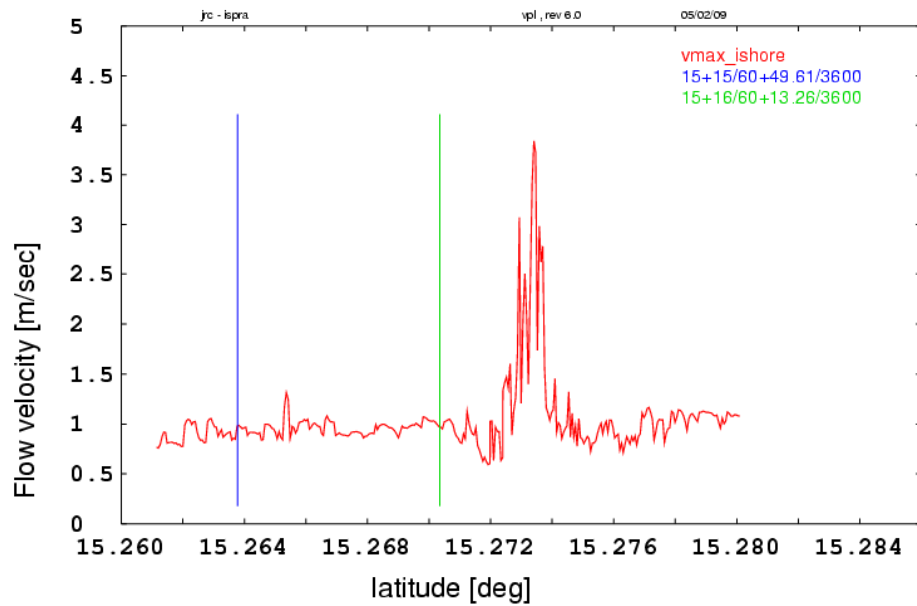
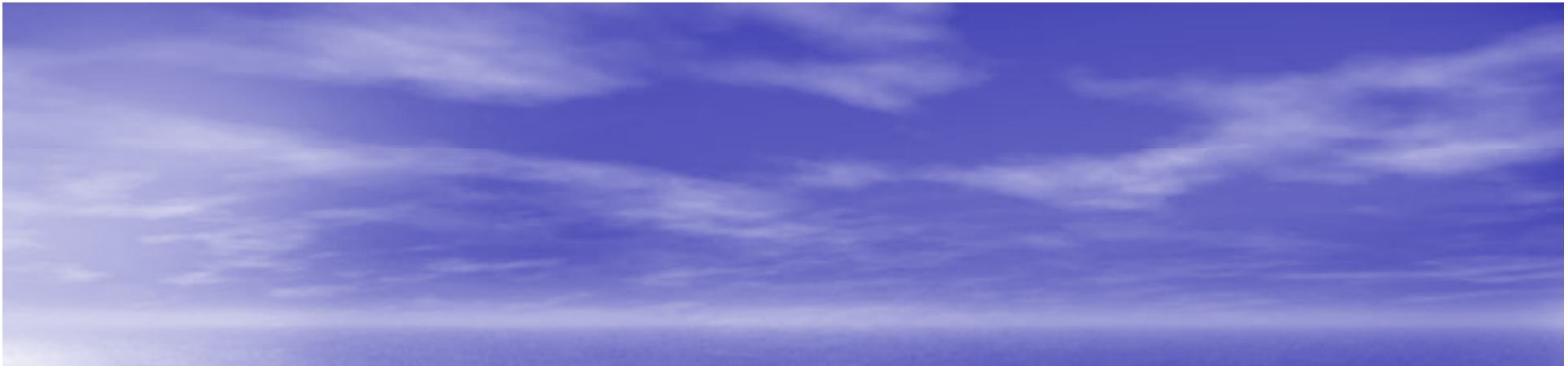
Distance to the sea of the maximum water runup

a. Distance to the sea of the maximum water run-up for Capo Vaticano

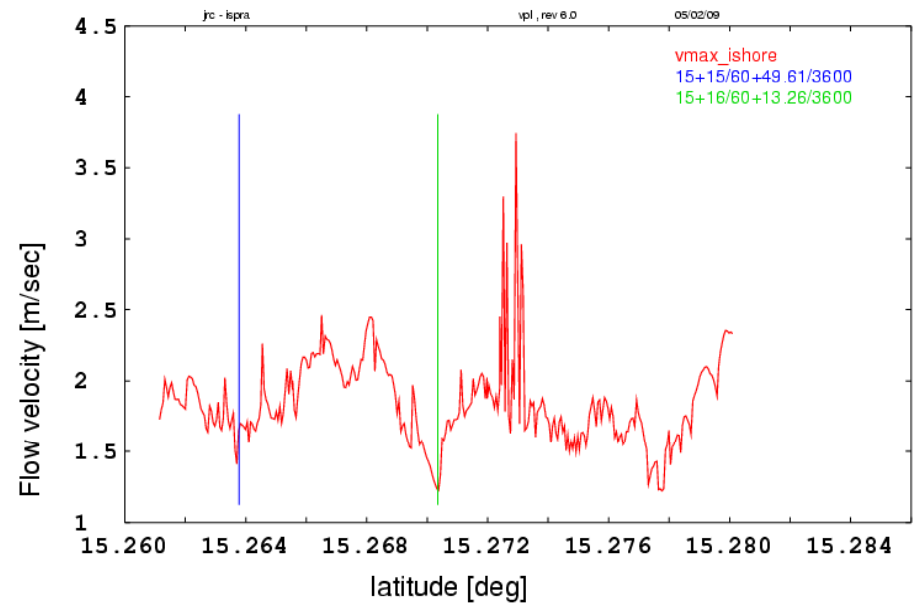


Distance to the sea of the maximum water runup

b. Distance to the sea of the maximum water run-up for Stromboli



Maximum water velocity in the shoreline



Maximum water velocity in the shoreline

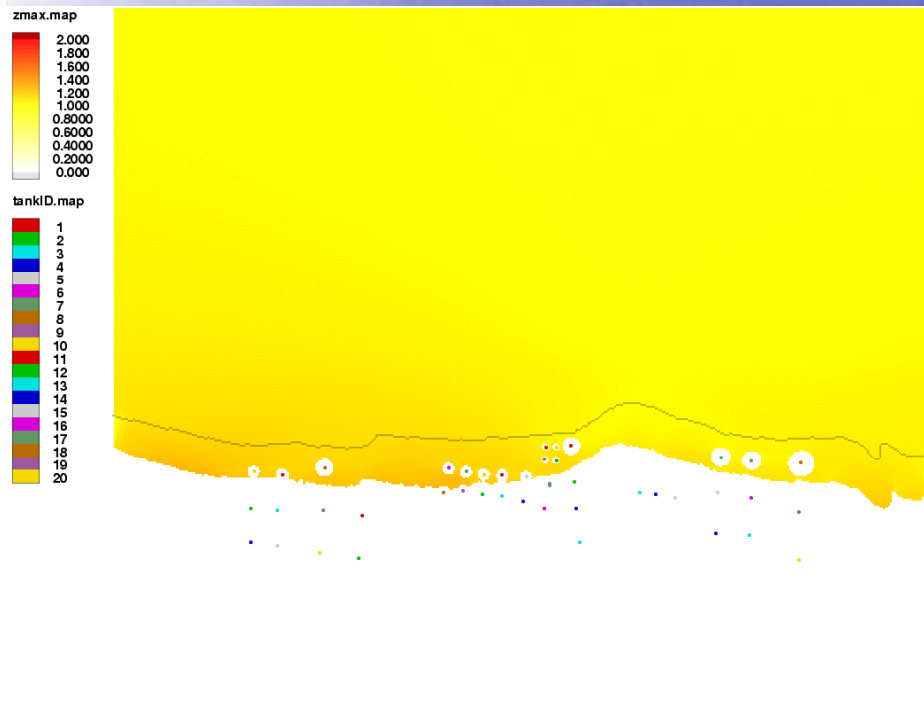
a) Maximum water velocity in the shoreline for Capo Vaticano

b) Maximum water velocity in the shoreline for Stromboli

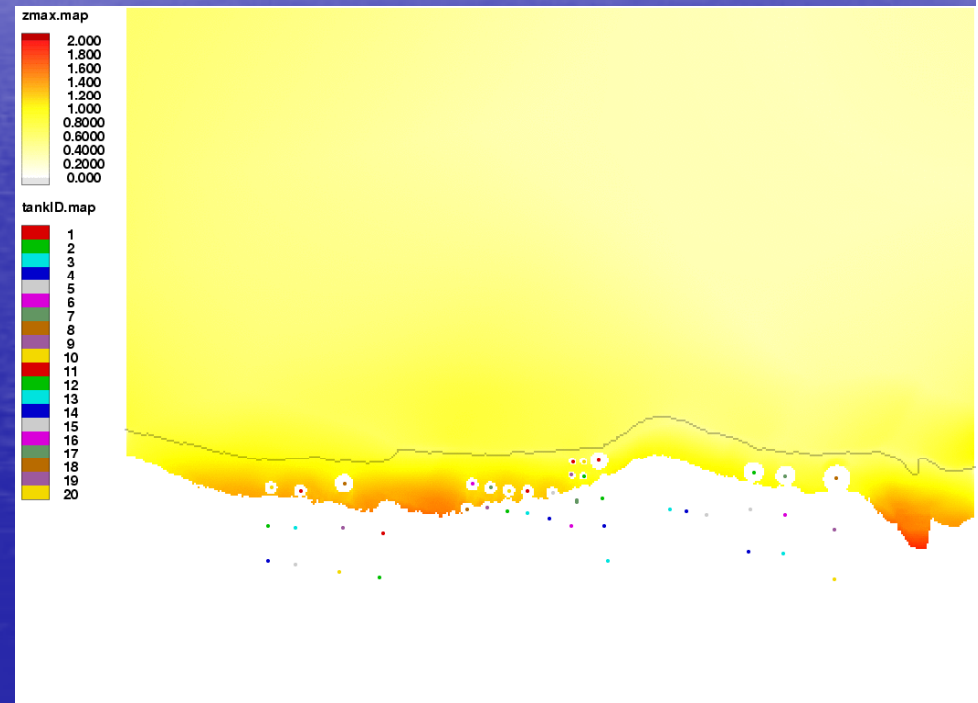
Tsunami impacts

- Refinery port terminals subject to 2 m height differential
- 18 storage tanks at refinery subject to flooding; tanks near shore subject to 0.8 m inundation
- Western section of refinery subject to higher flood depths
- Central section of refinery subject to higher water flow velocities (v)

Storage tanks (dots) and maximum water surface level



a. Maximum water surface level (zmax) for Capo Vaticano



b. Maximum water surface level (zmax) for Stromboli

Vulnerability Assessment

- For low water flow velocities, damage to tanks likely due to buoyancy loads
- Low likelihood (< 5%) of hazmat release from pipes and flange connections due to floating off of partially full or almost empty pipelines and storage tanks/containers
- High likelihood of salt water intrusion on low lying equipment such as motors, pumps, electrical equipment and control panels

Vulnerability analysis

Excerpt from table showing storage tank data, tsunami forces (f_{max}), and ratio of buoyancy force to dead weight of tank (W_v).

ID	TANK_TYPE	D [m]	H [m]	t	Wv	Capo Vaticano			Stromboli		
						fmaxXY [N]	fmaxZ [N]	r	fmaxXY [N]	fmaxZ [N]	r
0	FLOATING ROOF	40	15	4.79	2334601	37961	2134885	0.9	37691	2348407	1.0
1	FLOATING ROOF	40	15	4.79	2334601	18388	1457025	0.6	31427	2042664	0.9
2	FLOATING ROOF	40	15	4.79	2334601	0	12	0.0	0	12	0.0
3	FLOATING ROOF	40	15	4.79	2334601	0	12	0.0	0	12	0.0
4	FLOATING ROOF	40	15	4.79	2334601	0	12	0.0	0	12	0.0
5	FLOATING ROOF	40	15	4.79	2334601	0	12	0.0	0	12	0.0
6	FLOATING ROOF	40	15	4.79	2334601	125331	5404784	2.3	86860	4263878	1.8
7	FLOATING ROOF	40	15	4.79	2334601	81537	4246295	1.8	71628	3756736	1.6
8	FLOATING ROOF	40	15	4.79	2334601	635	169146	0.1	4589	415376	0.2
9	FLOATING ROOF	40	15	4.79	2334601	1585	278309	0.1	2133	287791	0.1
10	FLOATING ROOF	40	15	4.79	2334601	33919	2302747	1.0	37153	2526443	1.1
11	FLOATING ROOF	40	15	4.79	2334601	29229	2039980	0.9	27165	2047403	0.9
12	FLOATING ROOF	40	15	4.79	2334601	0	12	0.0	0	12	0.0
13	FLOATING ROOF	40	15	4.79	2334601	0	12	0.0	0	12	0.0
14	FLOATING ROOF	40	15	4.79	2334601	0	12	0.0	0	12	0.0
15	FLOATING ROOF	40	15	4.79	2334601	6520	735296	0.3	8531	925306	0.4
16	FLOATING ROOF	40	15	4.79	2334601	0	12	0.0	0	12	0.0
17	FLOATING ROOF	40	15	4.79	2334601	0	12	0.0	0	12	0.0
18	FLOATING ROOF	55	16	7.03	6010356	255356	11726238	2.0	180164	9396131	1.6
19	FLOATING ROOF	55	16	7.03	6010356	0	23	0.0	0	23	0.0
20	FLOATING ROOF	55	16	7.03	6010356	0	23	0.0	0	23	0.0

Estimated flood vulnerability index (index) of storage tanks*

*Based on damage curves by Campedel *et al.* 2008

ID	Capo Vaticano				Stromboli			
	hmax [m]	vmax [m/s]	vmax2	index	hmax [m]	vmax [m/s]	vmax2	index
0	0.17	0.22	0.05	0.00	0.19	0.30	0.09	0.00
1	0.12	0.13	0.02	0.00	0.17	0.25	0.06	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.44	0.58	0.34	0.00	0.35	0.96	0.92	0.00
7	0.34	0.68	0.47	0.00	0.30	0.95	0.90	0.00
8	0.01	0.10	0.01	0.00	0.03	0.20	0.06	0.00
9	0.02	0.08	0.01	0.00	0.02	0.16	0.03	0.00
10	0.19	0.51	0.26	0.00	0.21	0.51	0.26	0.00
11	0.17	0.25	0.06	0.00	0.17	0.46	0.21	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	0.06	0.14	0.02	0.00	0.08	0.17	0.03	0.00
16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	0.50	0.40	0.16	0.00	0.40	1.02	1.03	0.00
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31	0.63	0.50	0.25	0.00	0.33	0.78	0.60	0.00
32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
52	0.38	0.32	0.10	0.00	0.18	0.36	0.13	0.00
53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
57	0.40	0.31	0.10	0.00	0.16	0.36	0.13	0.00
58	0.44	0.28	0.08	0.00	0.19	0.42	0.18	0.00
59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
119	0.44	0.60	0.36	0.00	0.27	0.78	0.60	0.00
120	0.75	0.69	0.48	1.00	0.41	1.27	1.62	0.00
121	0.78	0.71	0.50	1.00	0.46	1.20	1.43	0.00
122	0.39	0.56	0.31	0.00	0.17	0.69	0.48	0.00

Vulnerability Assessment (cont.)

- Some damage to pipelines, warehouse and pumps possible from impact of floating debris in central area of refinery near the shoreline where $v > 3 \text{ m/s}$
- Possible erosion and scour in this area could undermine equipment foundations and pier piles
- At port terminals differential between wave crest and trough (almost 2 m) could result in breaking off of connected loading arms and possible spills

Conclusions and recommendations

- Low likelihood of damage to large storage tanks under the two tsunami scenarios
- Some likelihood of small oil and other chemical spills from broken flanges and pipe connections
- Possible oil spills from loading/ unloading arms at port terminals due to high wave differential
- Salt water intrusion on sensitive equipment may cause extensive damage and cause complete shutdown of plant

Conclusions and recommendations

- Risk reduction measures to reduce exposure and vulnerability of people and property at the refinery during a tsunami:
 - construction of breakwalls or other external barriers
 - elevation of sensitive equipment above max flood height
 - Insure that all equipment is properly anchored to resist possible buoyant forces
 - as much as possible secure free standing equipment to insure they do not become water borne during a tsunami
 - Establish a tsunami monitoring and warning system accompanied with proper emergency procedures, drills and training

Acknowledgments

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A blue-tinted photograph of a vast ocean under a cloudy sky. The text "Thank you!" is centered in white.

Thank you!