Rupture process of the September 25, 2003 Tokachi-Oki (Hokkaido, Japan) Mw 8.3 earthquake from joint inversion of tsunami waveform and GPS data

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Abstract

The aim of this work is to infer the slip distribution along the rupture zone of the 25 September 2003 Tokachi-Oki earthquake from GPS records of the coseismic displacement and tide-gauge records of the tsunami. We subdivide the fault plane into several subfaults (both along strike and downdip) and compute the corresponding Green's functions both for the tsunami and for the coseismic displacement. The slip distribution is determined by means of an inverse method based on simulated annealing algorithm.

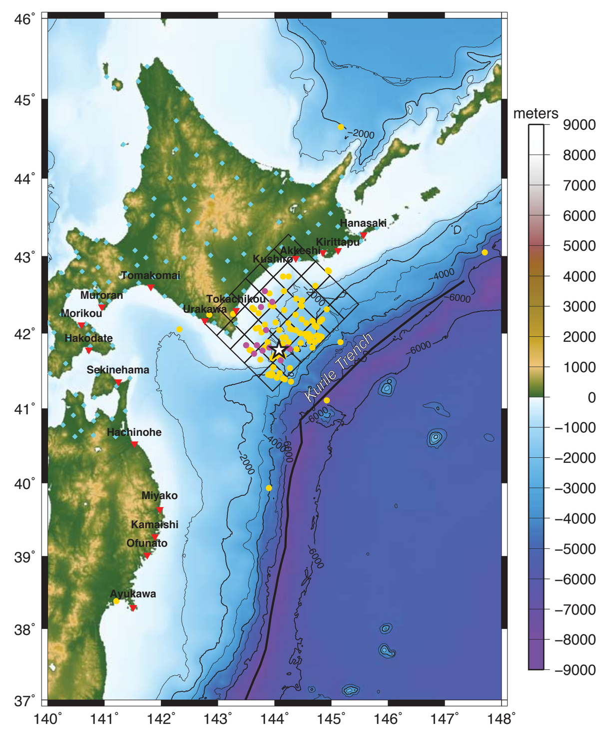

FIGURE 1

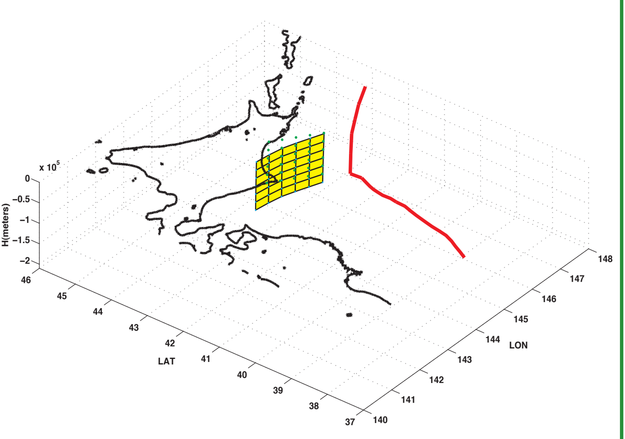

FIGURE 2

Data

We use 16 tidegauge records from stations distributed along the east coast of the Hokkaido island and the north-east coast of the Honshu island, provided by JMA, HRDB and HOD (*Hirata et al., 2004*).

Furthermore we use about 140 GPS records from stations of GEONET located mainly in Hokkaido (*Geographical Survey Institute, Crustal deformation of Japan detected, GEONET http://mekira.gsi.go.jp/ENGLISH/index.html*).

Fault parameterization

We assume the fault plane to be consistent with the geometry of the subducting plate (*Katsumata et al.,2003*) and the slip direction with both the focal mechanism solutions and previous inversions of teleseismic body waves (*Yamanaka et al., 2003*).

After preliminary tests to evaluate the minimum size of the subfaults, we split the fault area into 6x5 subfaults of 30x30 km of size:

1) 6 subfaults along strike direction, corresponding to a total length of 180 km
2) 5 subfaults along dip direction, corresponding to a total length of 150 km

The strike angle is 225° roughly paralell to the Kurile trench, the dip angle varies from 7.5° (shallowest subfaults) to 24.6° (deepest subfaults) and the rake angle is 109° (Fig.1, Fig.2).

Green's Functions

We compute the tsunami waveform by numerically solving the non-linear shallow water equations through a finite-difference technique in a staggered grid. The bathymetric dataset is provided by HOD (*Hydrographic and Oceanographic Department*). In this preliminary study we use a spatial resolution of 30 arc-seconds.

Furthermore we compute the coseismic surface displacements by means of the Okada's formula (homogeneous halfspace) (*Okada, 1992*).

Inversion

We use a inverse method based on a simulated annealing algorithm to infer the slip distribution (*Piatanesi et al., 2007; Lorito et al., 2008*).

The resolving power of the inversion setup (azimuthal coverage, fault parameterization, etc.) is tested by means of a checkerboard experiment, with target slip values of alternatively 1 and 3 meters on adjacent subfaults. The synthetic data generated with the checkerboard slip distribution are corrupted with gaussian noise.

Checkerboard test

Waveform

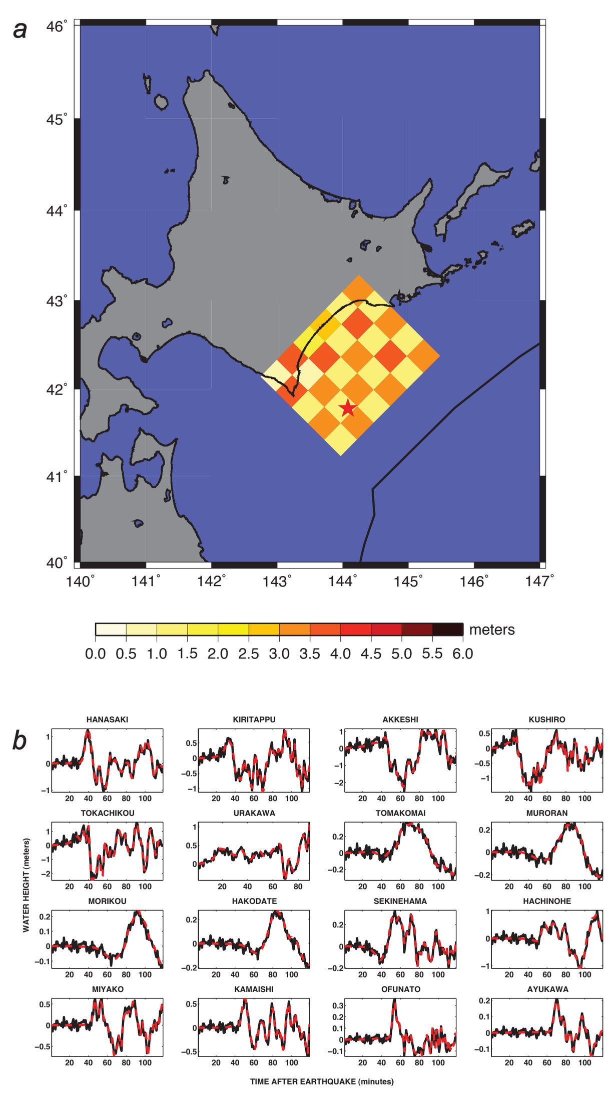

FIGURE 3

Using subfaults of 30x30 km of size, the checkerboard pattern (Fig.3a) is reproduced fairly well and the inverted waveforms fit very well the synthetic data corrupted with noise (Fig.3b). We observe that the checkerboard pattern is better in the offshore part of the fault than in the onshore one.

GPS

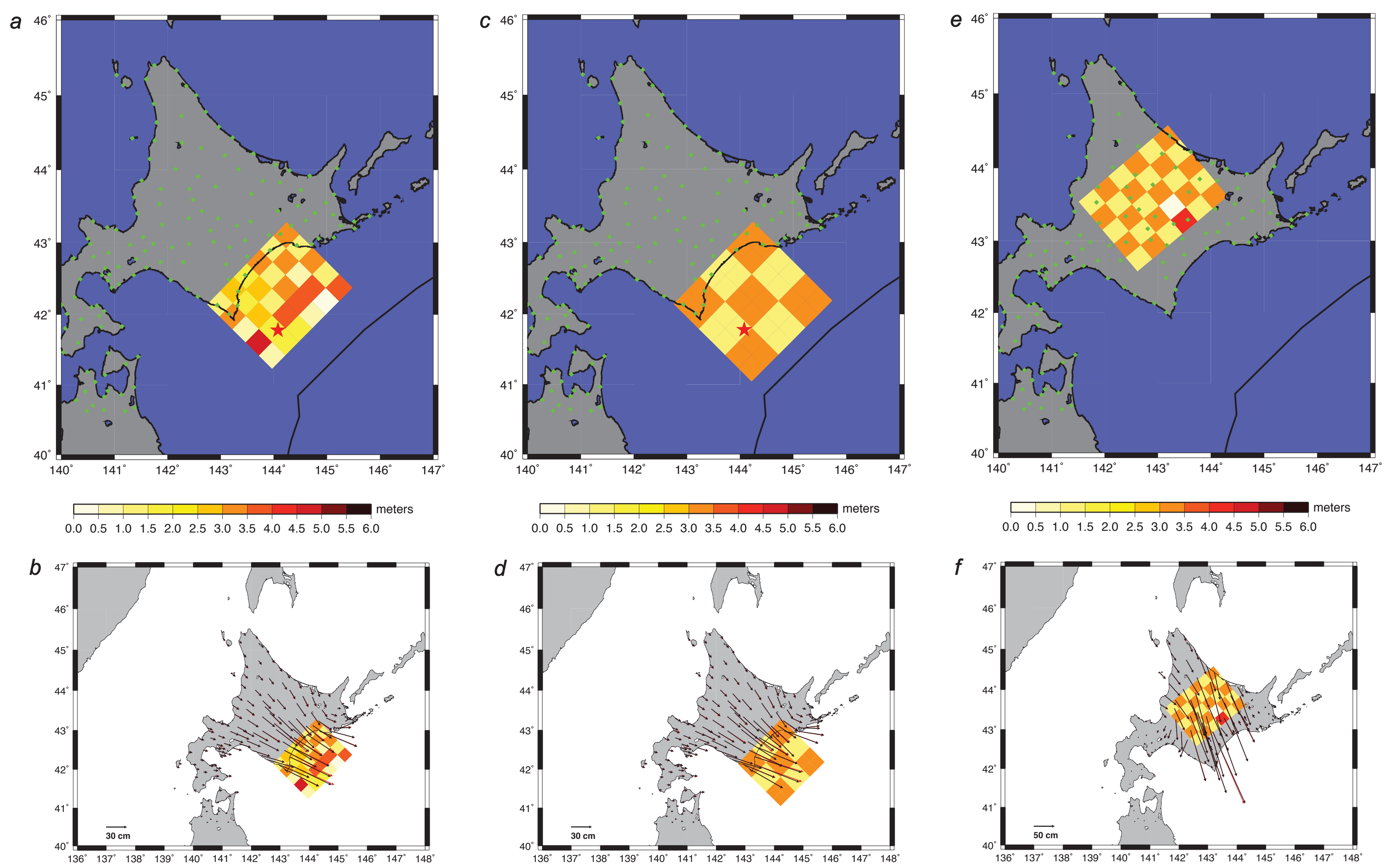

FIGURE 4

Using a configuration with 30x30 km subfaults we observe that, in comparison to the tsunami waveform inversion, the checkerboard pattern is fairly well reproduced only for subfaults that are close to the land (Fig.4a), whilst the match between data and synthetics is very good (Fig.4b). Actually, when we use a configuration with a coarser spatial resolution of the subfaults (60x60 km), we find that the checkerboard pattern is perfectly retrieved (Fig.4c). Also, if we place the fault area completely below the Hokkaido region, and if we use a configuration with 30x30 km subfaults, we observe that the target model is well reproduced (Fig.4e). Therefore the resolution of the slip distribution depends on the relative positions of subfaults and GPS stations. Tsunami waveforms and GPS data are able to resolve the slip on the offshore and onshore portion of the fault, respectively; then a joint inversion of these data could be useful to infer the slip distribution on the whole fault area.

Joint

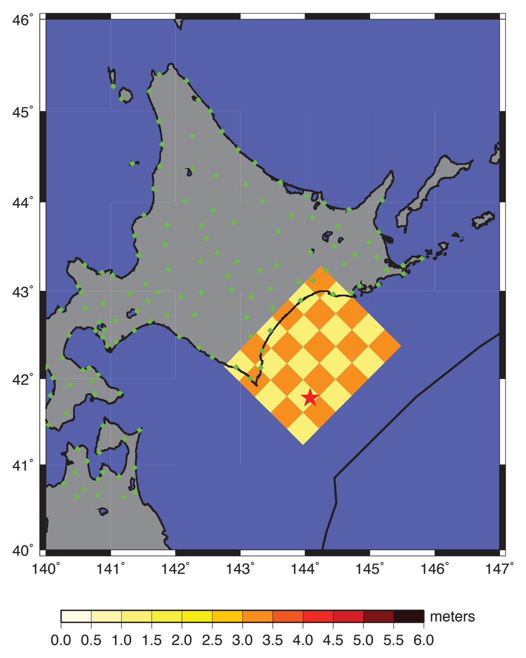

FIGURE 5

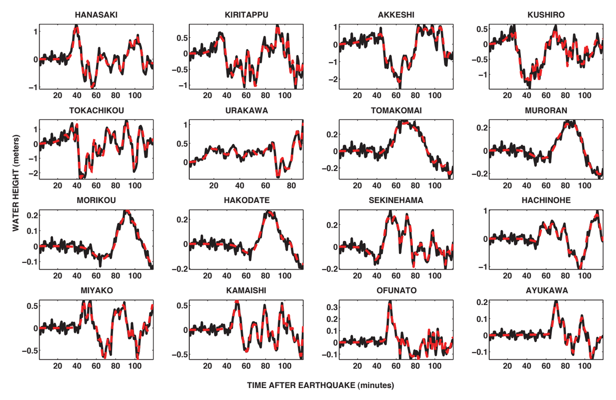

FIGURE 6

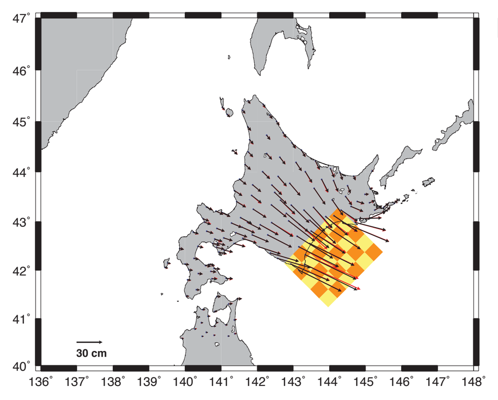

FIGURE 7

Performing a joint inversion we observe that the checkerboard pattern is very perfectly reproduced (Fig.5) and the fit of the waveforms (Fig.6) and of the horizontal coseismic displacements are very good (Fig.7).

Application to the Tokachi-Oki earthquake

Waveform / GPS

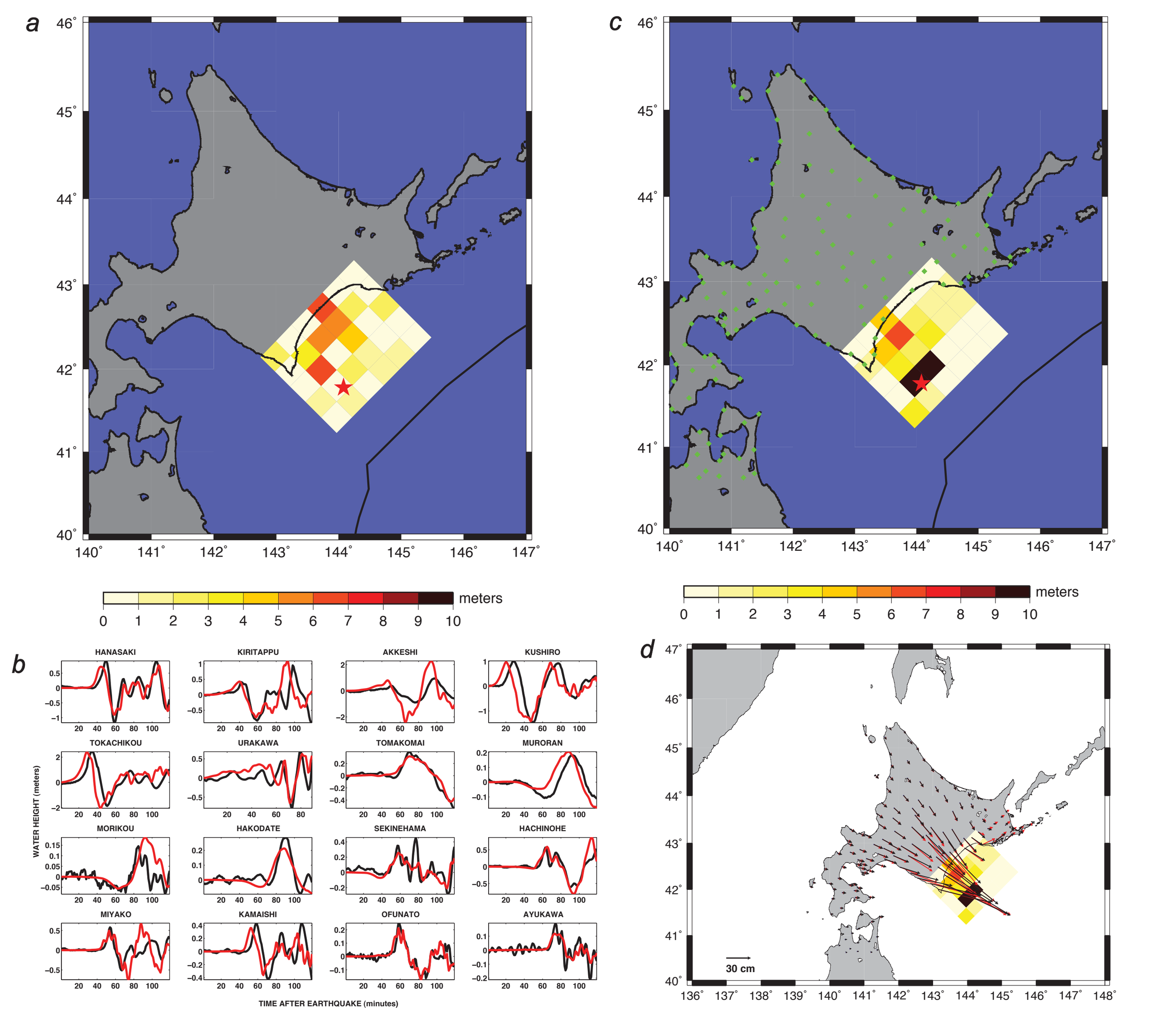

FIGURE 8

Joint

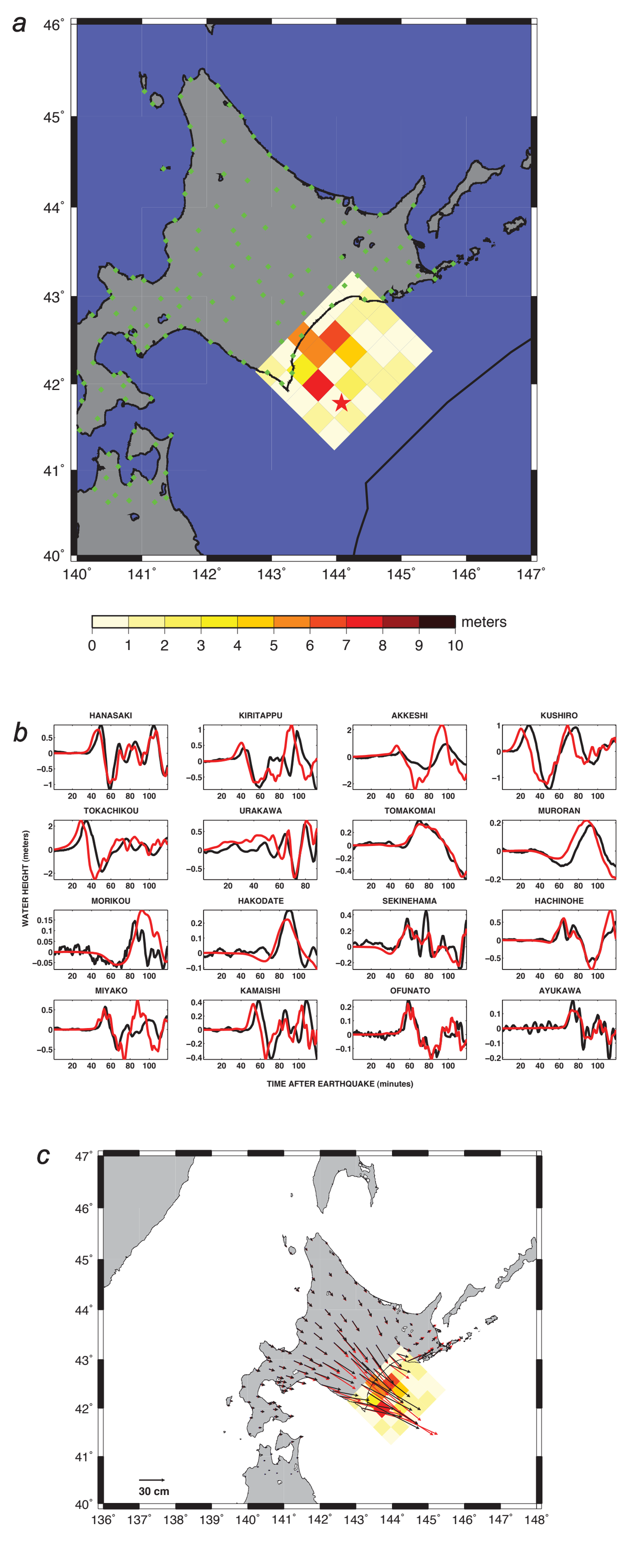

FIGURE 9

Discussion

When we invert only for the tsunami waveforms, the largest slip patches (5-6m) are located well below the hypocenter (Fig.8a); the match between the inverted and the observed waveforms is fairly good, except for the phases (Fig.8b). The inversion of GPS data alone shows large amount of slip around the hypocenter (9-10m) (Fig.8c) and the inverted horizontal coseismic displacements fit well the observed displacements (Fig.8d). Finally, from the joint inversion, we observe that the distribution of slip offshore is in agreement with that from waveforms inversion; furthermore the distribution of slip onshore is in agreement with that from GPS inversion (Fig.9a). The fit of the waveforms is good except for the phases (Fig.9b), probably due to the low bathymetric resolution.The fit of the horizontal coseismic displacements is fairly good (Fig.9c).

Conclusions and future developments

GPS data are limited to land and therefore the slip distribution is poorly resolved offshore.

We have found that a joint inversion of tsunami waveform and GPS data constrains better the slip distribution on the entire fault area in comparison with the single inversions.

To improve our results we will compute the tsunami waveforms in nested grids with high-resolution bathymetric dataset (HOD). Also, we will compute the coseismic offsets considering a layered Earth's model implemented in a Finite-Element code.

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