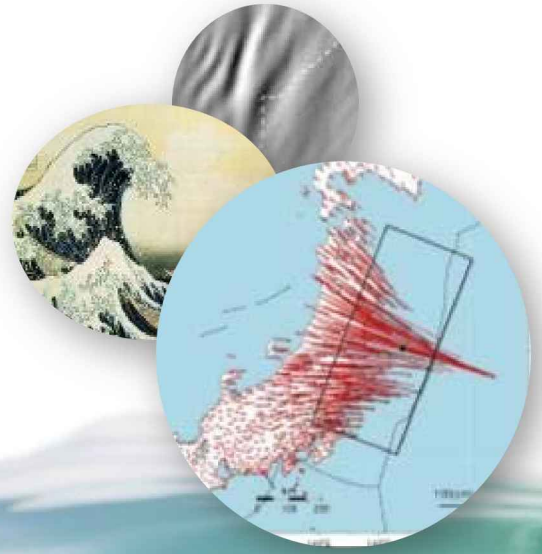
TO EOS / The **T**ohoku-**O**ki Earthquake from **E**arth, **O**cean and **S**pace

A ***critical case-study to improve earthquake and tsunami anticipation***



March 6-7, 2013

J-RAPID symposium

PI Japan : Shingo Watada (ERI)
PI France : Anthony Sladen (Geoazur)

TO EOS, an joint ANR-JST project

Anthony Sladen
Geoazur, Sophia-Ant.

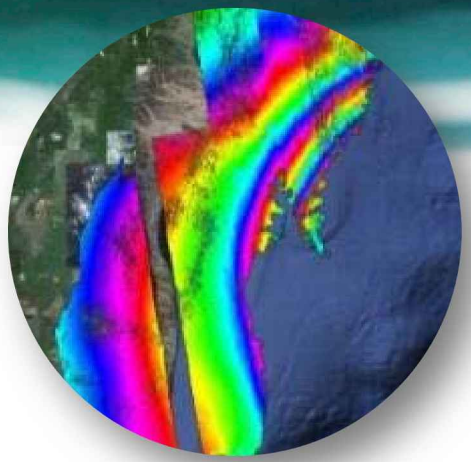
Shingo Watada
ERI, Tokyo

T.Yahagi, L.Rolland, E.Astafyeva, P.Bosser, B.Delouis, Ph.Lognonné, O.Cavalié, G.Occhipinti, A.Kherani, P. Coisson, M.Vallée, H.Hebert, M.Vergnolle,

Motivation

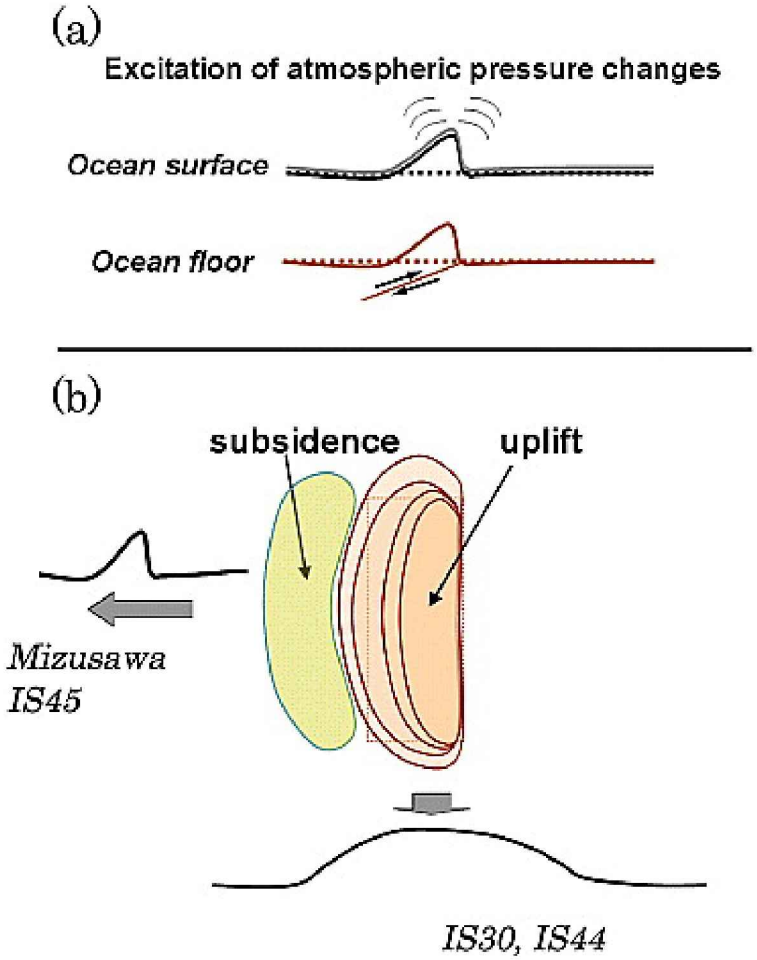
- Tsunami hit the Sanriku-coast 30 min after the earthquake,
- **Atmospheric** waves from the tsunami source region arrived on land 6 min after the earthquake,
- Same waves propagated upward marked a **ionospheric** disturbance signature 7 min after the earthquake.

➢ ***What is the potential of these signals for early-warning?***



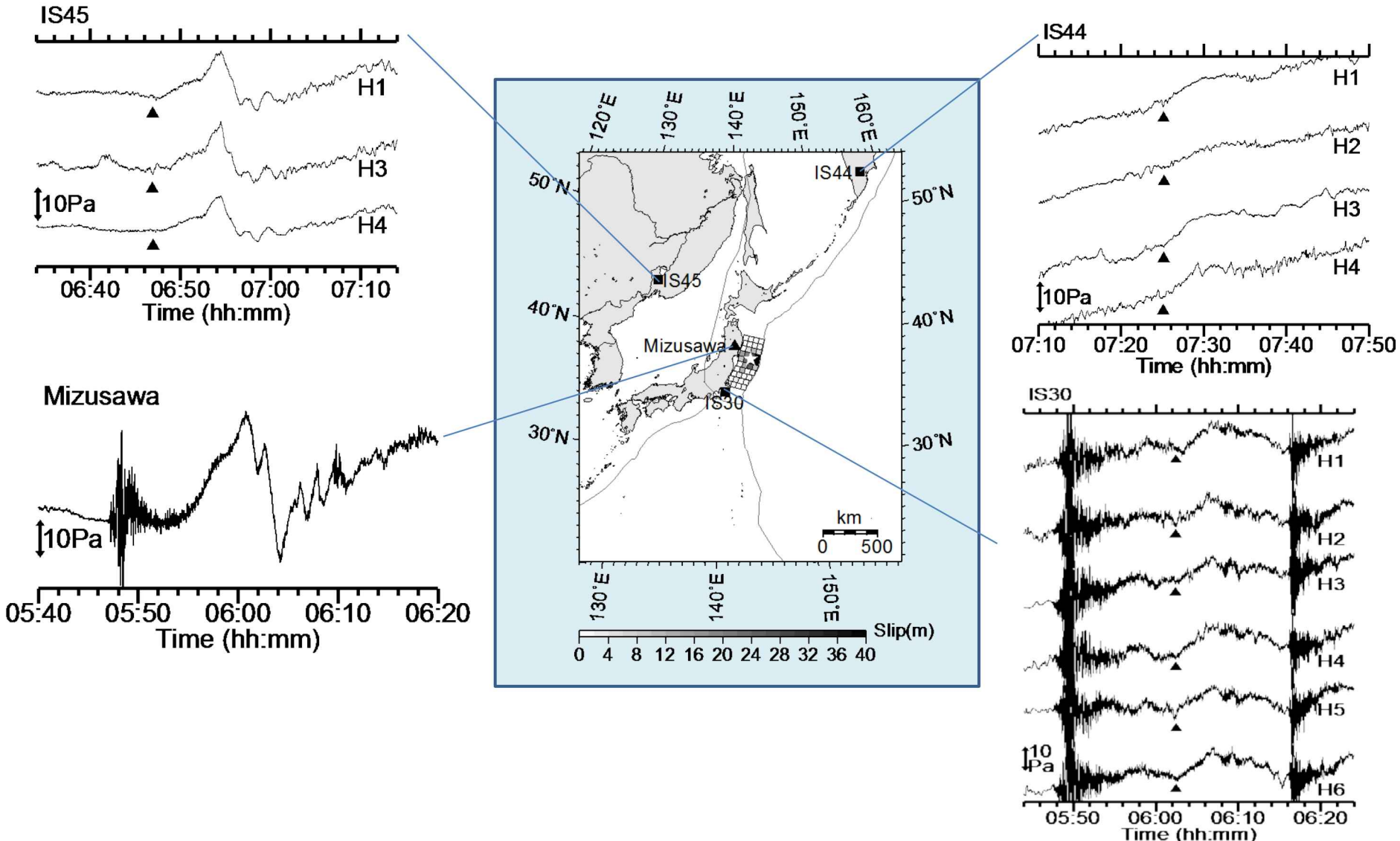
The atmospheric waves

Atmospheric boundary waves excited by the tsunami generation related to the 2011 great Tohoku - Oki earthquake

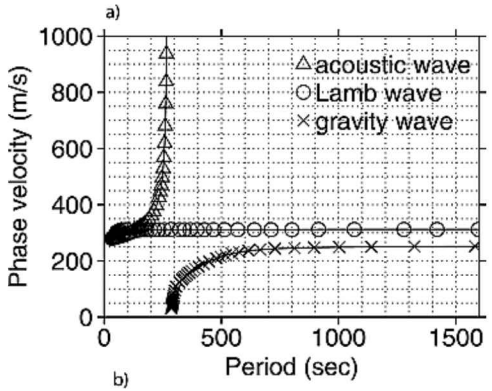


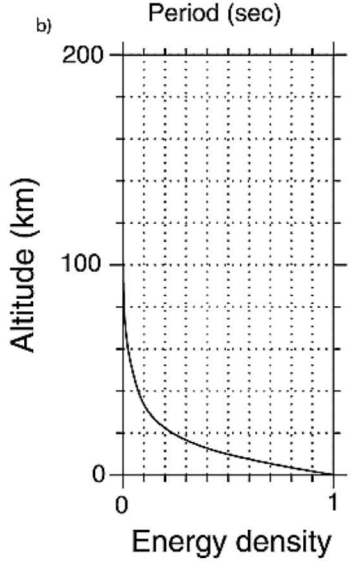
Geophysical Research Letters
Volume 38, Issue 7, L00G18, 1 NOV 2011 DOI: 10.1029/2011GL049146
http://onlinelibrary.wiley.com/doi/10.1029/2011GL049146/full#grl28542-fig-0006

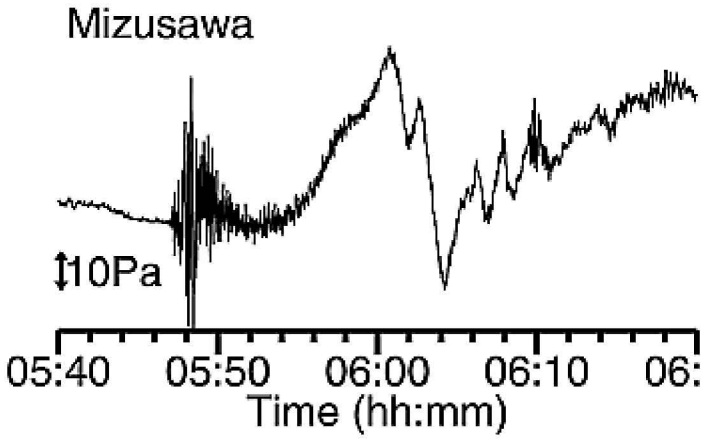
Waveform is preserved after a long distance of propagation with little dispersion.



Atmospheric boundary waves excited by the tsunami generation related to the 2011 great Tohoku - Oki earthquake







釜石沖海底ケーブル式地震計システムで観測された海面変動

東京大学地震研究所

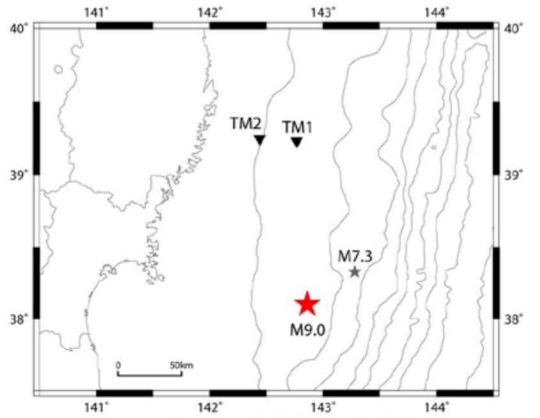


図１　釜石沖ケーブル式海底水圧計の位置

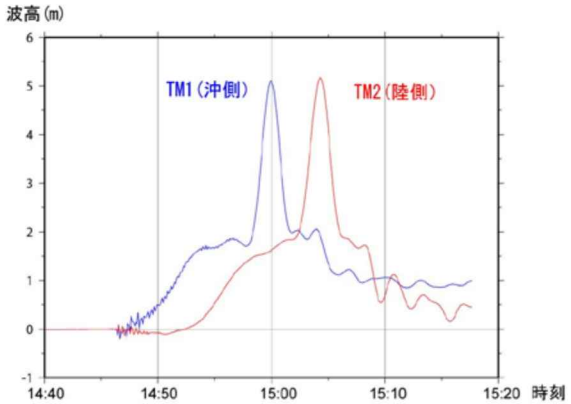
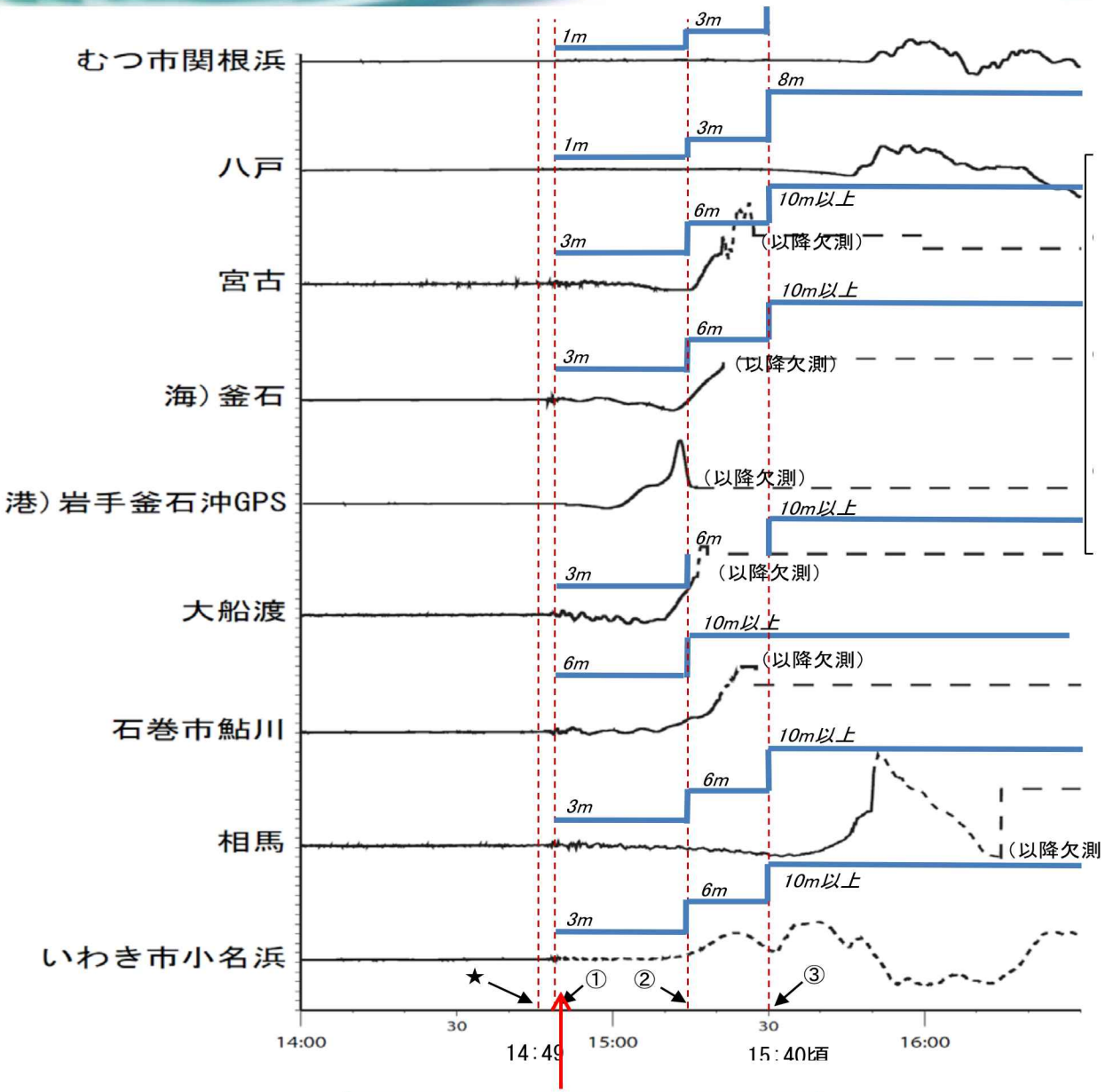


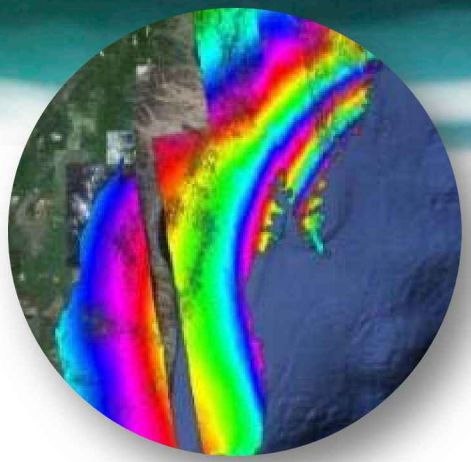
図２　海底水圧計の観測記録。14時46分頃、本震(M9.0)の振動が水圧計に伝わり、TM1（海寄り）では、その時から徐々に海面が上昇している。約２m上昇し、約11分後にはさらに約3m急激に上昇し、合計約5m海面が上昇した。約30km陸寄りに設置されているTM2では、TM1から約4分遅れて同様の海面上昇を記録した。

Geophysical Research Letters
Volume 38, Issue 7, L00G18, 1 NOV 2011 DOI: 10.1029/2011GL049146
http://onlinelibrary.wiley.com/doi/10.1029/2011GL049146/full#grl28542-fig-0005

Tsunami waveforms

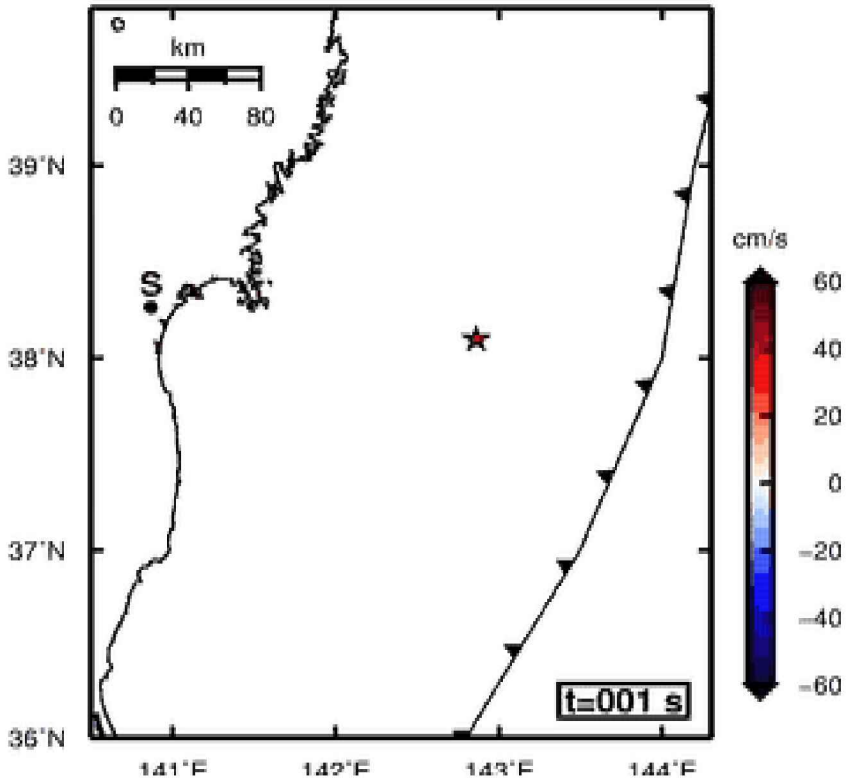


Air waves hit the coast



The ionospheric waves

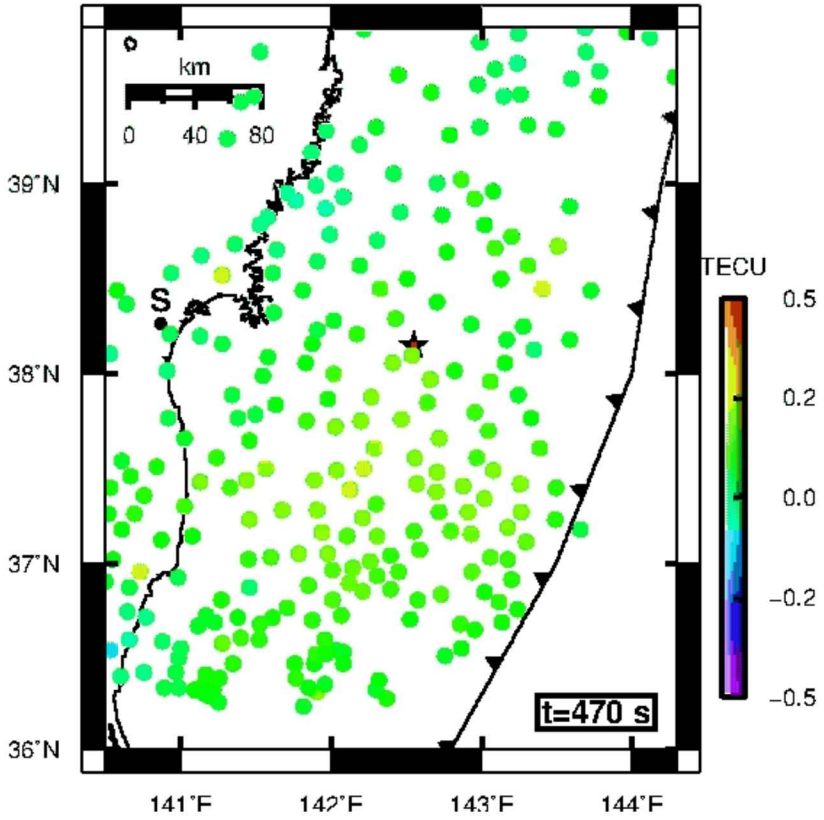
The ionosphere is sensitive to the details of the seismic source



TO_EOS source model

Based on the inversion of seismology, geodesy and tsunami data

(Bletery et al., in prep.)



Ionospheric observation

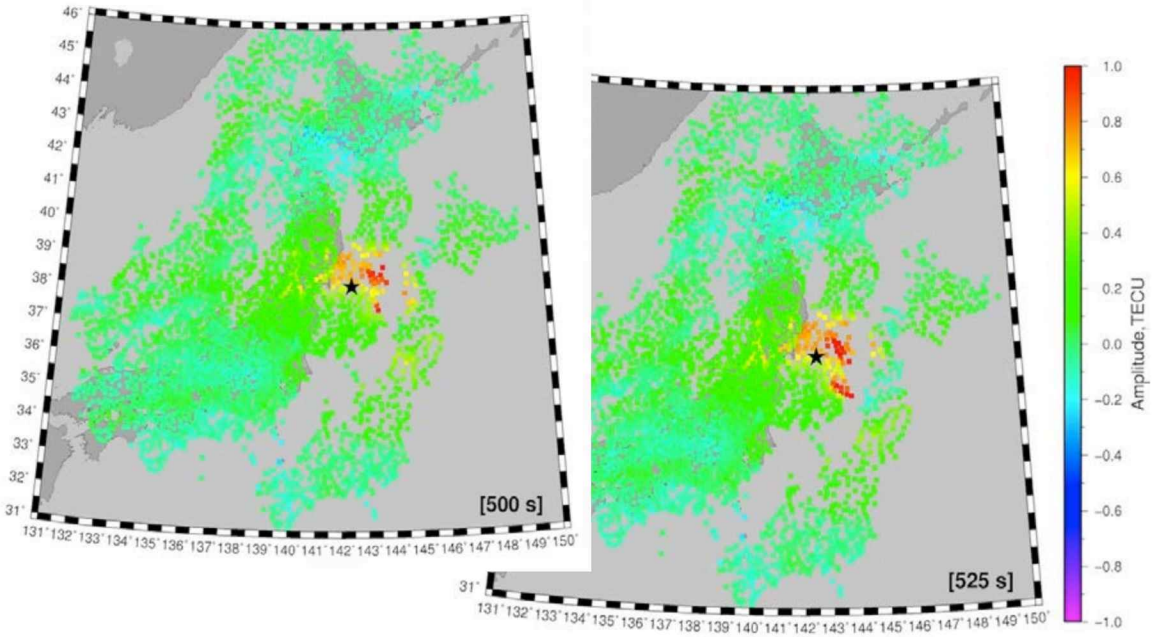
less 10min after T_0

Modeling in preparation

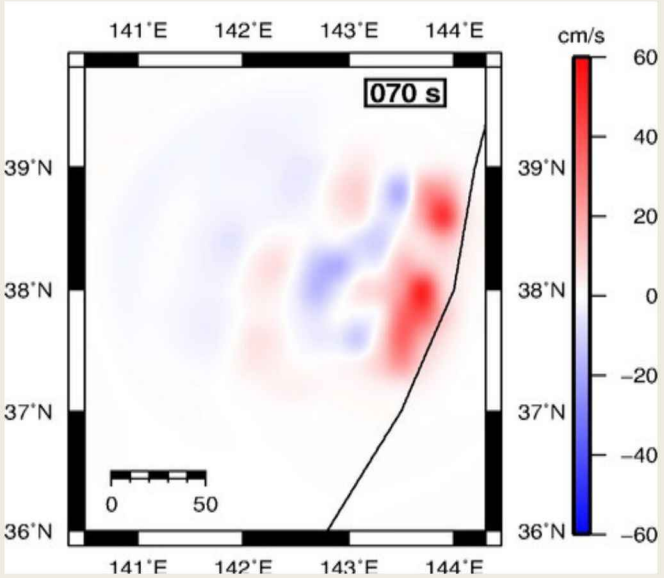
(*Rolland et al., in prep*)

The ionosphere is sensitive to the details of the seismic source

Complexity of slip distribution imaged from the ionosphere?
(from 500 to 570 s. after the earthquake initiation)



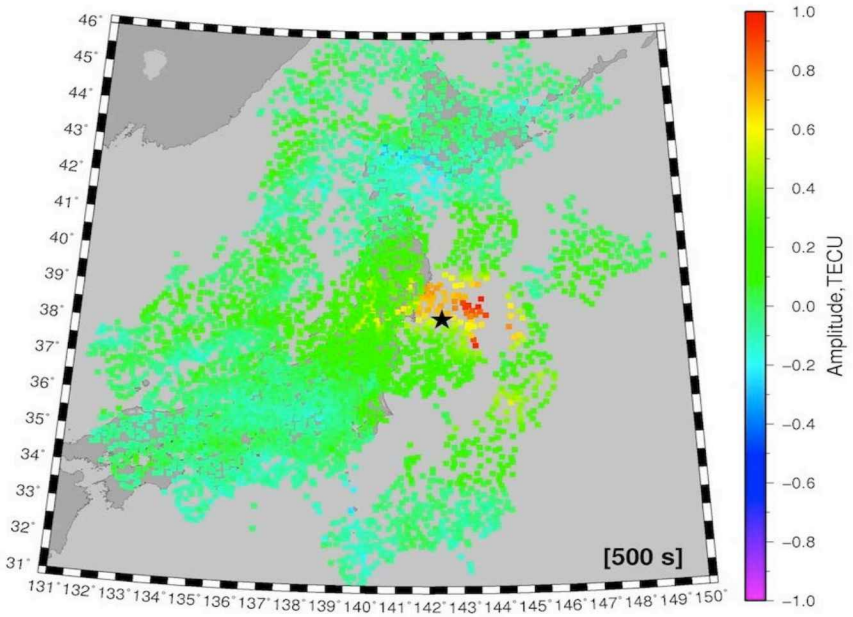
Correspondence with source models

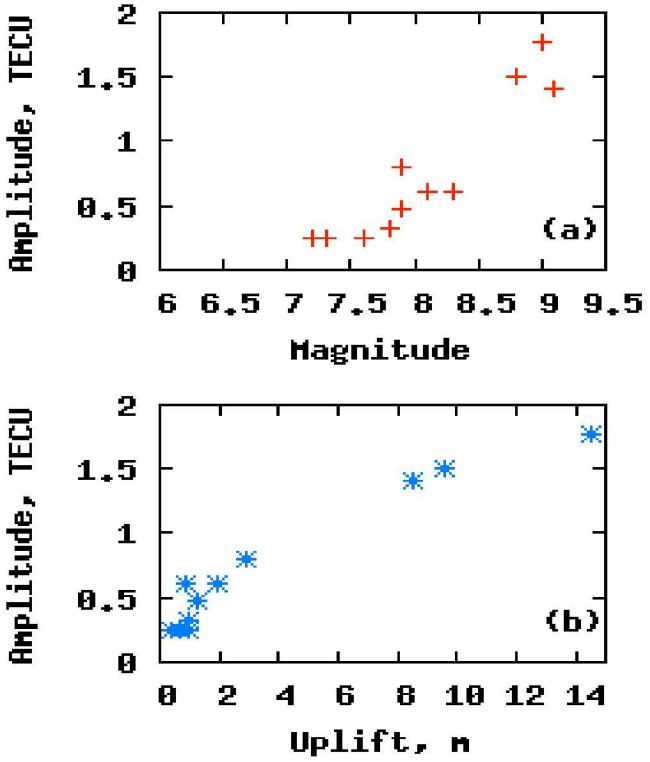


Astafyeva et al., ***Geophys. Res. Lett.***, 2011
Astafyeva et al. , ***JGR-Space Science,*** *in prep.*

The ionosphere is sensitive to the details of the seismic source

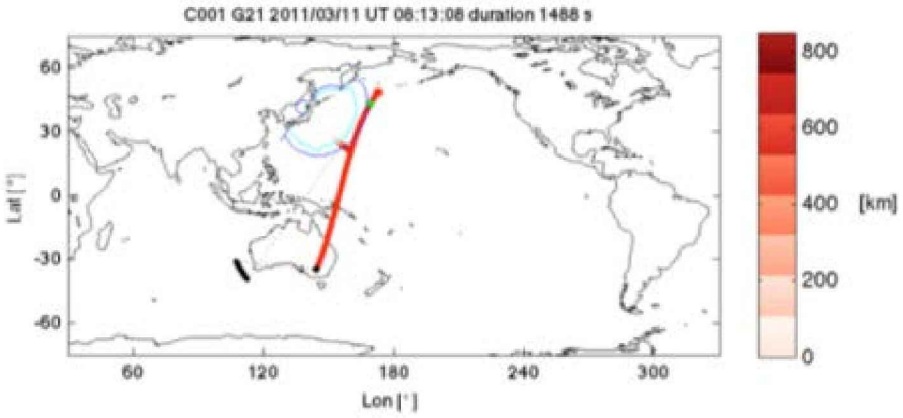
Ionospheric perturbations to estimate the magnitude or sea-floor deformation (even more critical for tsunami estimation)

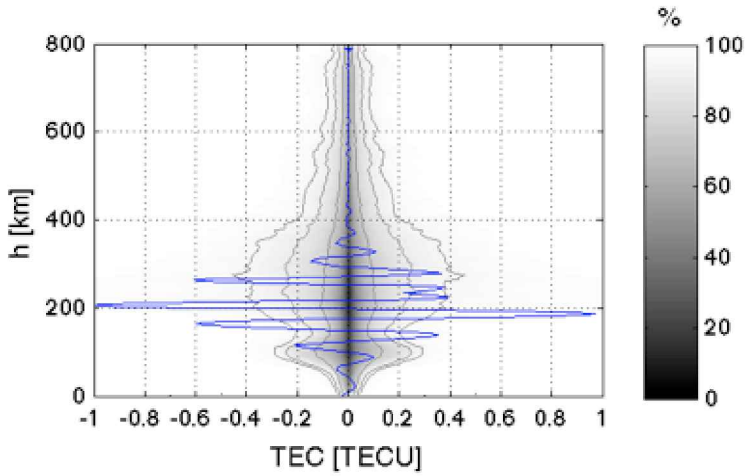




Astafyeva et al., ***Geophys. Res. Lett.***, *submitted*

Perspectives for the ionospheric observations





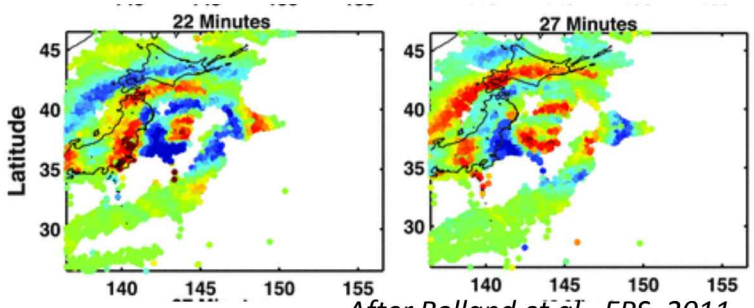
<u>Radio occultation:</u> GPS receiver on a satellite at low altitude (COSMIC satellites)

- First tsunami gravity wave detection in ionospheric radio occultation data,
- Provides vertical structure of ionosphere,

P.Coïsson et al. ***Geophys. Res. Lett.***, *in prep.*

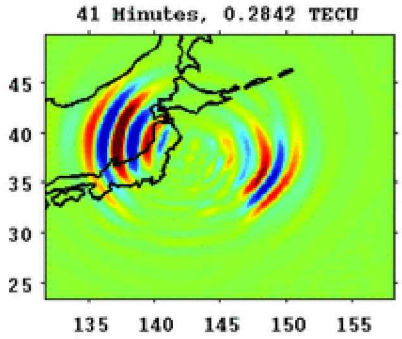
Modeling of ionospheric waves **and** magnetic field

Observed ionospheric waves

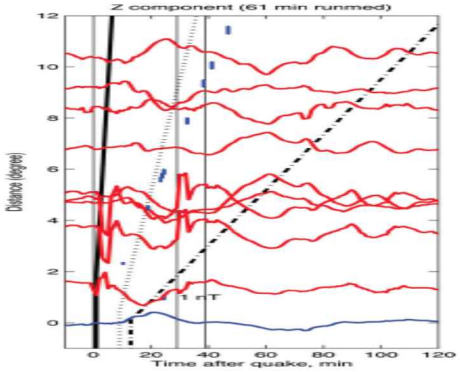


After Rolland et al., EPS, 2011

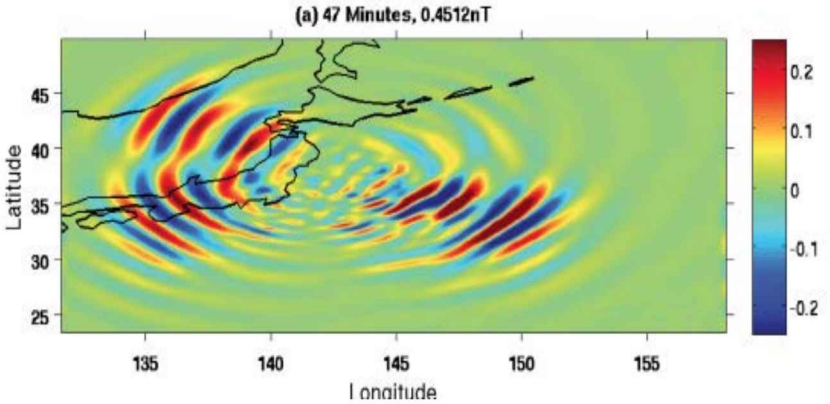
Simulation



Observed magnetic waves



Simulation

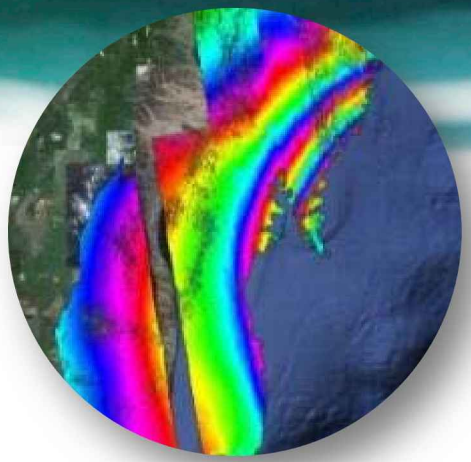


Development of new simulation codes with full-coupling and 3D propagation :

- better understand the origin of ionospheric waves,
- explore the potential of magnetic records

Kherani et al., ***Geophys. J. Int.***, 2012

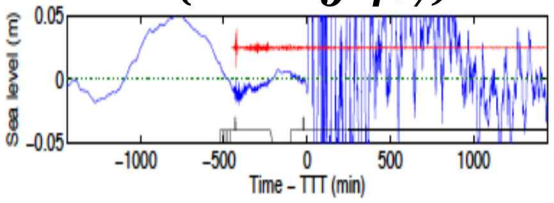
Occhipinti et al.,, *J. Geophys. Res.,* submitted

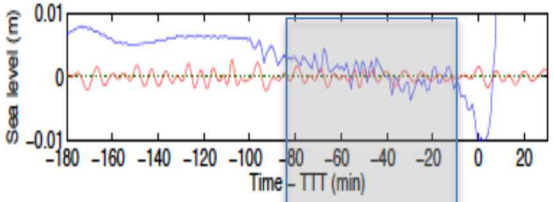


The precursor waves

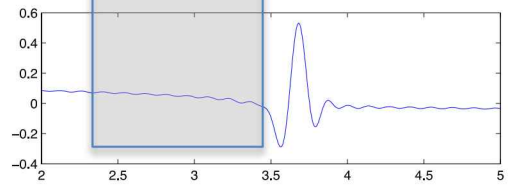
Precursor waves in Hawaii

In tsunami buoy
(DART 51407)





Synthetic at Sea-surface



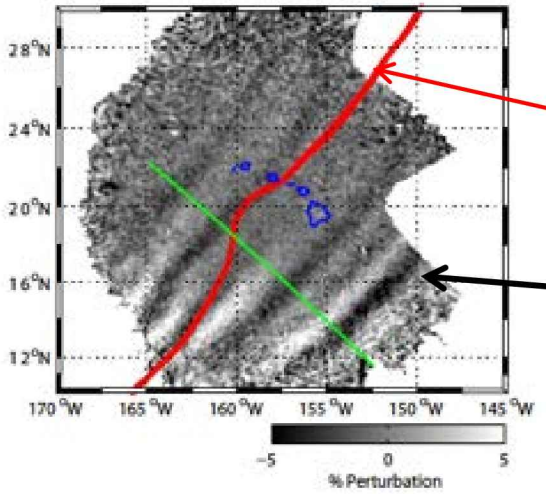
250km altitude (no precursor)

Amplitude m

ime, hr

- sea-level precursor visible across Pacific,
- related to elastic earth-ocean coupling,

In airglow video
(optical images of sky)



Tsunami wavefront

Precursor waves

Origin of atmosphere precursor still not understood:

- Conversion process?
- Quake precursor? 1sps GPS tells us that its magnitude Mw<6.7,
- Magnetic waves? No airglow precursor for Charlotte earthquake

- New codes in dvlpt for full modeling of the coupling effects

Conclusion

- Atmospheric pressure waves measured on land and ionospheric disturbance reflects the initial ocean surface deformation,

- A quick analysis of atmospheric pressure change near the coats and imaging of GPS-TEC ionosphere disturbances above the ocean can potentially serve as an element of a robust tsunami early warning system.

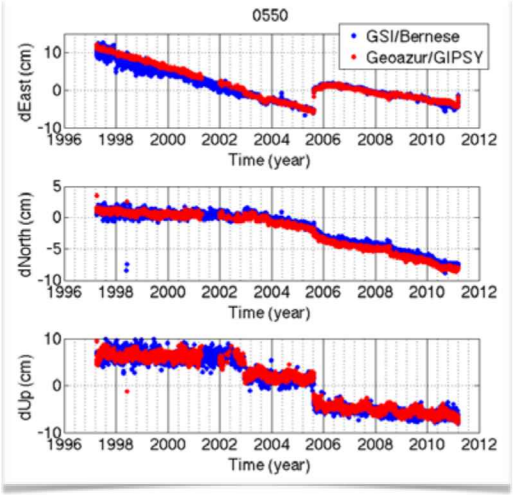
お気遣いありがとうございます

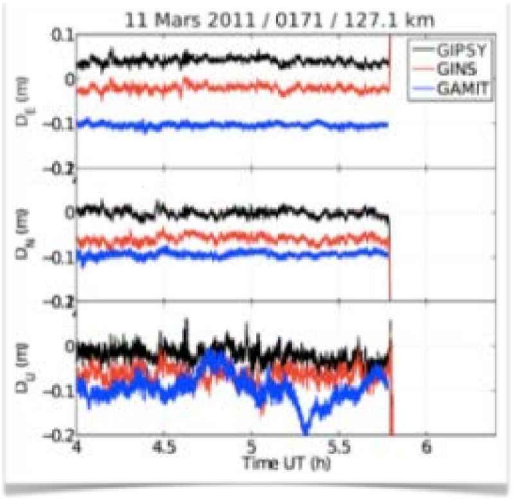
Thank you for your attention

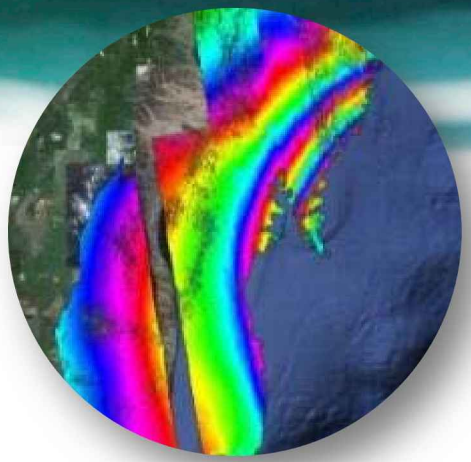
Special thank to GSI, Japan, for their support regarding the access to the GEONET GPS data

Other contributions of the **TO EOS** project

- 15 years of' the 30 sps GEONET data processed (strong collaboration with GSI):
  - Develop algorithm for automatic event detection,
  - Modeling of pre- and post- Tohoku strain evolution (on-going),
- Benchmark of GPS processing codes (GAMIT, GIPSY, GINS)
  - improve solutions (including 1sps),
  - e.g. bound largest possible precursor to Tohoku-Oki earthquake (Mw<6.7)
- Refine source models with more realistic physics and error models
  - Discrimination physical processes responsible for Tohoku-Oki,
  - Move towards real-time robust source models





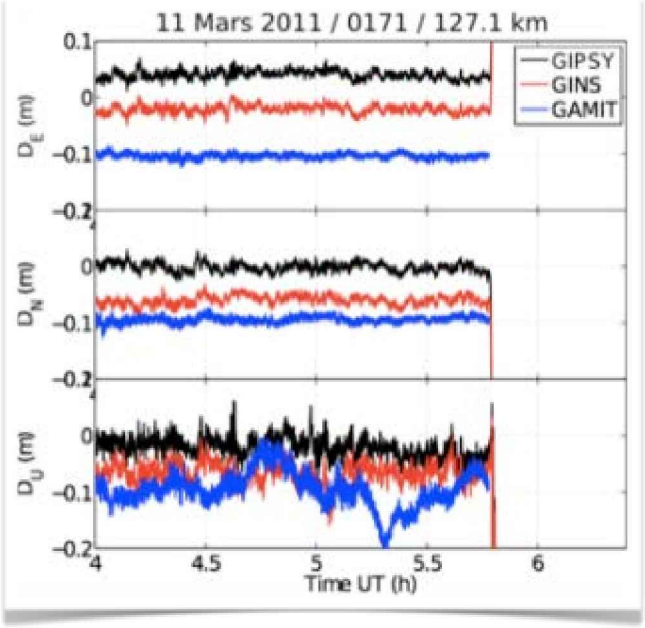


Extras

Analysis of the preseismic phase in 1-Hz GPS data

1-Hz kinematic solutions (8 days , 1250 receivers) with 3 methods:

- Differential pos. : GAMIT (JM Nocquet)
- PPP (absolute pos.)
  - GIPSY (P. Bosser, ENSG)
  - GINS (F. Fund, CNES)



Inversion of a synthetic short-term aseismic phase :

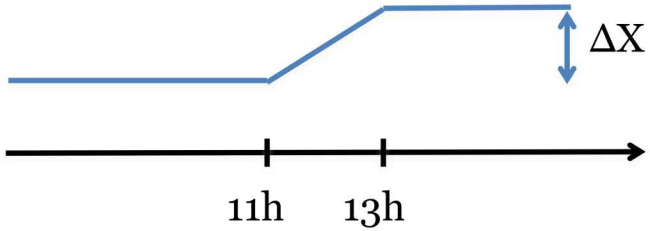
✓2 hours ramp on 8 March

✓Mechanism of the 9 March largest foreshock (point-source, CMT)

✓Different amplitudes (Mw 6 to 8)

1.GIPSY v2

2.GINS v1



ΔX : coseismic displacement (model)

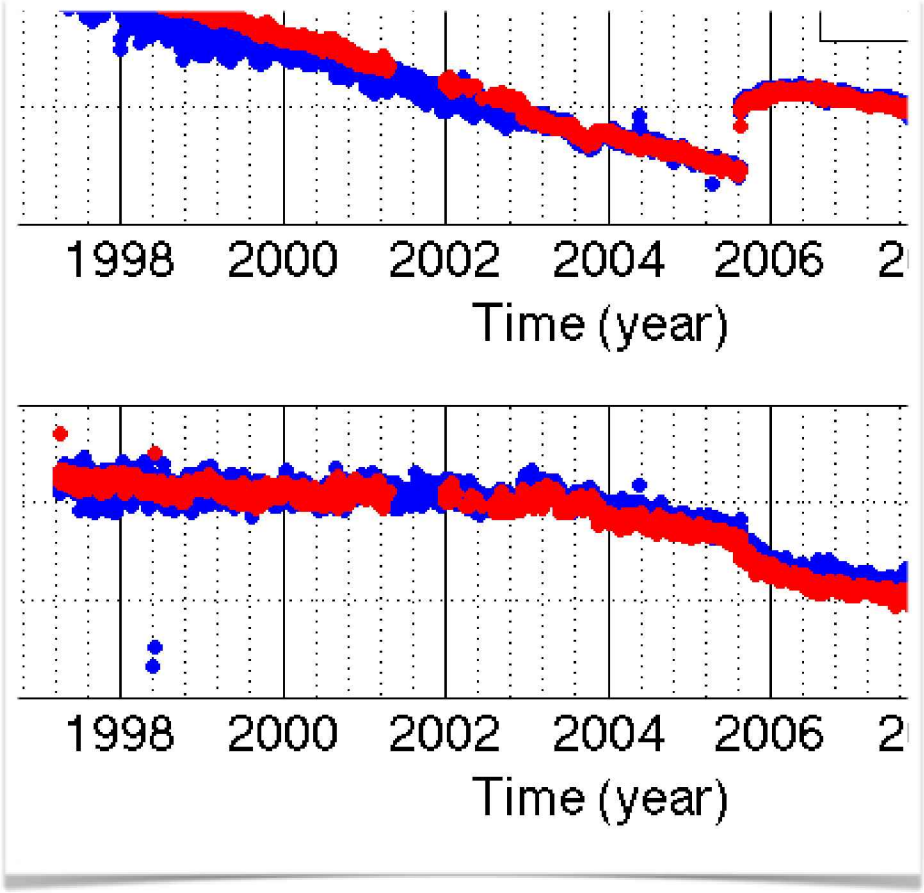
Detection threshold : Mw=6.7

Rolland, Nocquet, Bosser & Fund, in prep.
Poster at AGU Fall meeting 2012

Observation of the seismic cycle

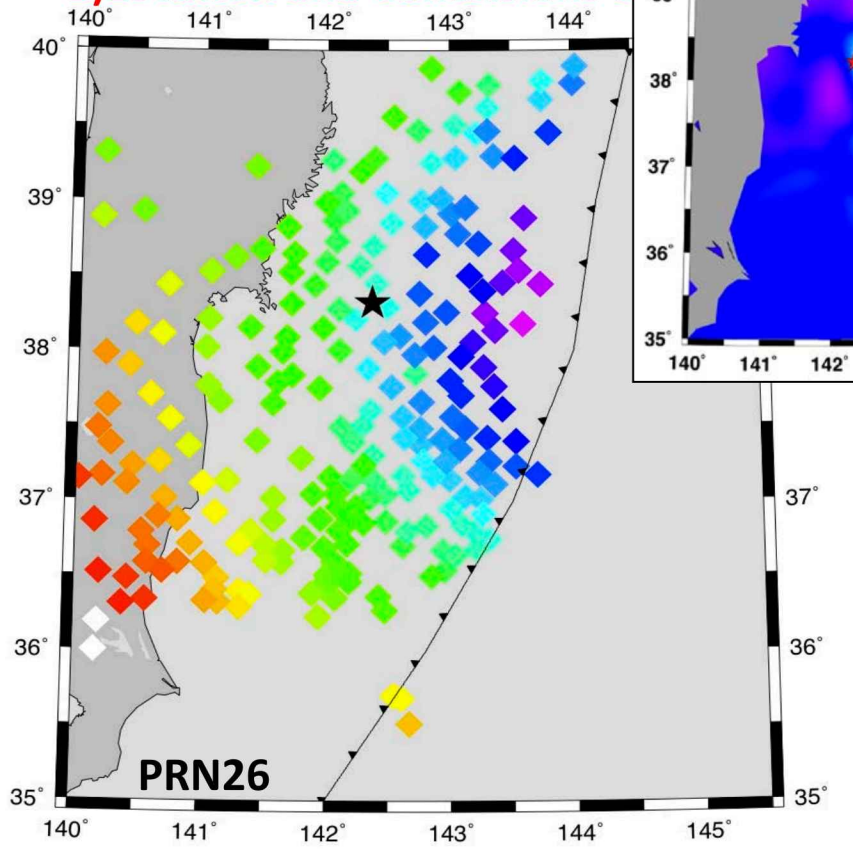
GPS network:~1200 stations

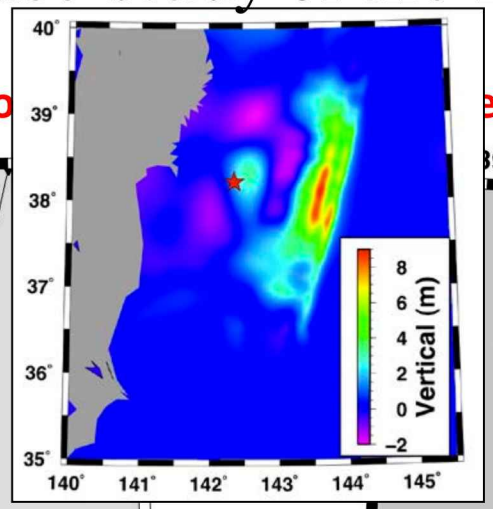
Daily solutions

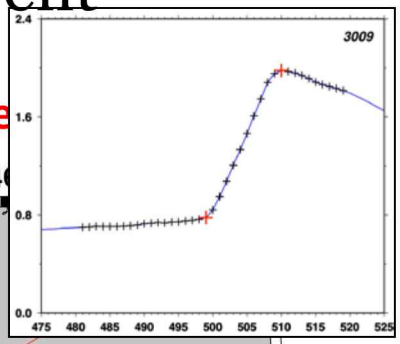


Parameters of seismic source as deduced from ionospheric data: case-study of the Tohoku-oki event

1)Location and dimensions o … en from the ionosphe







Ionospheric Radio Occultation

- First tsunami gravity wave detection in ionospheric radio occultation data (P. Coïsson et al., GRL, *in preparation*.

- Satellite GPS Radio Occultation provide details on vertical structure of ionosphere.

- 3 COSMIC satellites in orbit allowed a detection 2.5 hours after the earthquake, with 1 TECU amplitude at 200 km height.

- Geometry constrain the probability of detection, only 1 of 3 satellite sounded the region near the tsunami parallel to its wave front.