The Performances of CSR GRACE Mascon Solutions on Earthquakes

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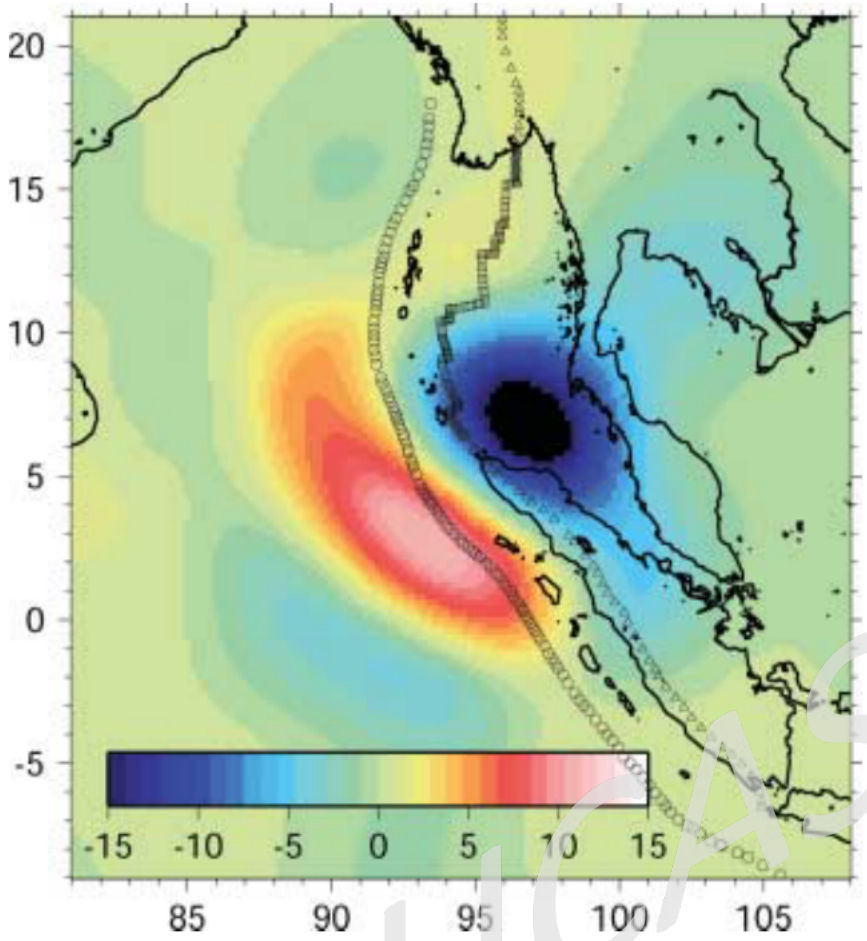
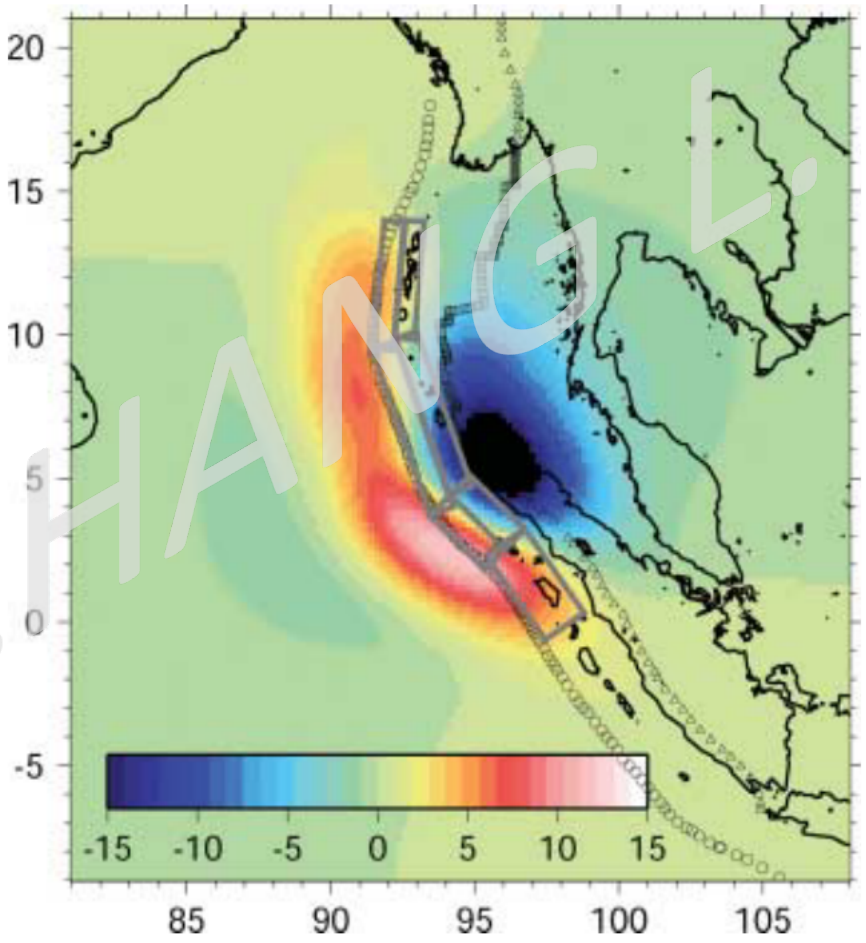
Motivation

First observe (Sumatra Earthquake Mw 9.2):



Gravity changes (in mGal) after the Sumatra Andaman earthquake computed from GRACE dara

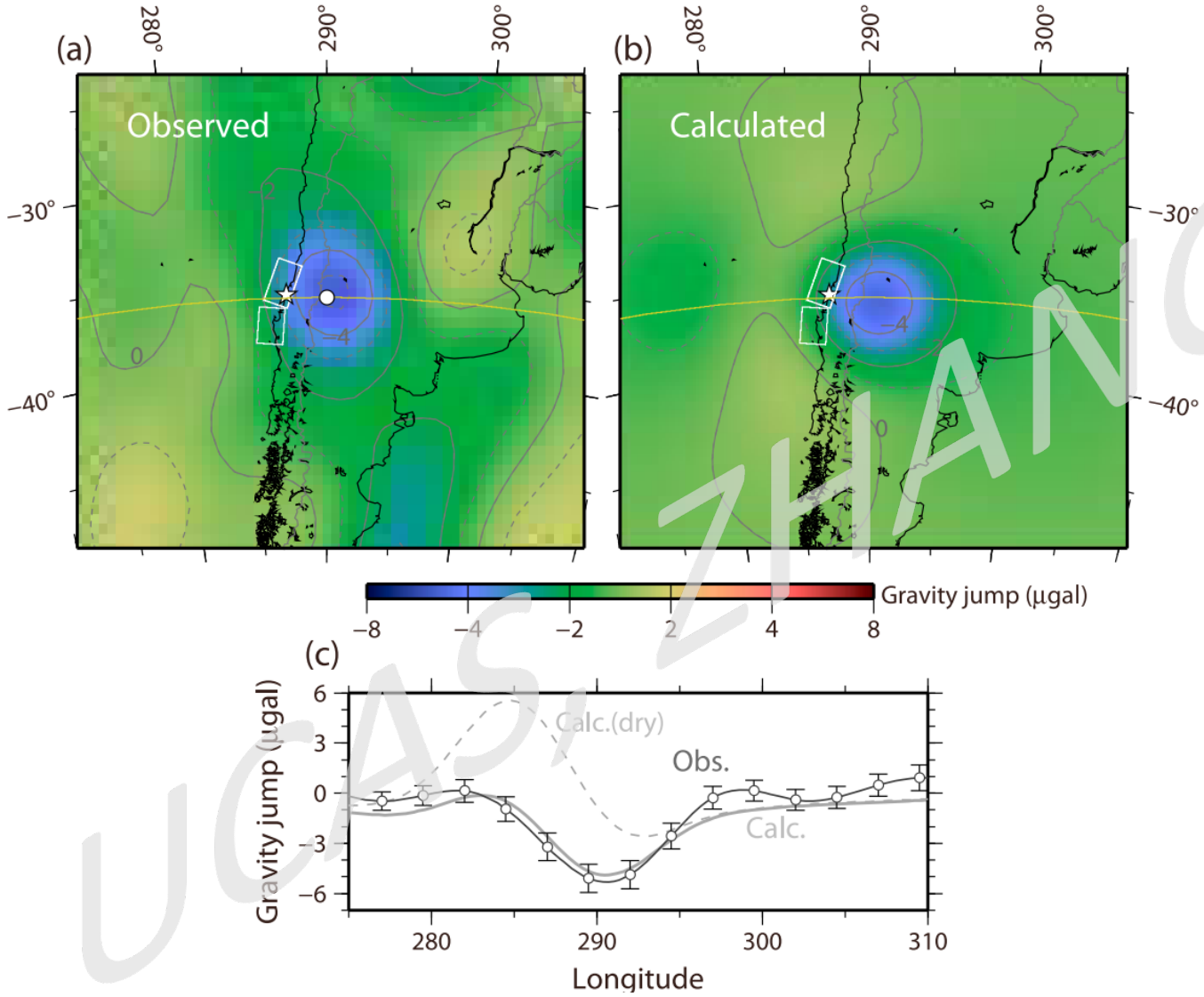


Predicted coseismic gravity changes (in mGal) from the seismic model

(Han et al., 2006)

Motivation

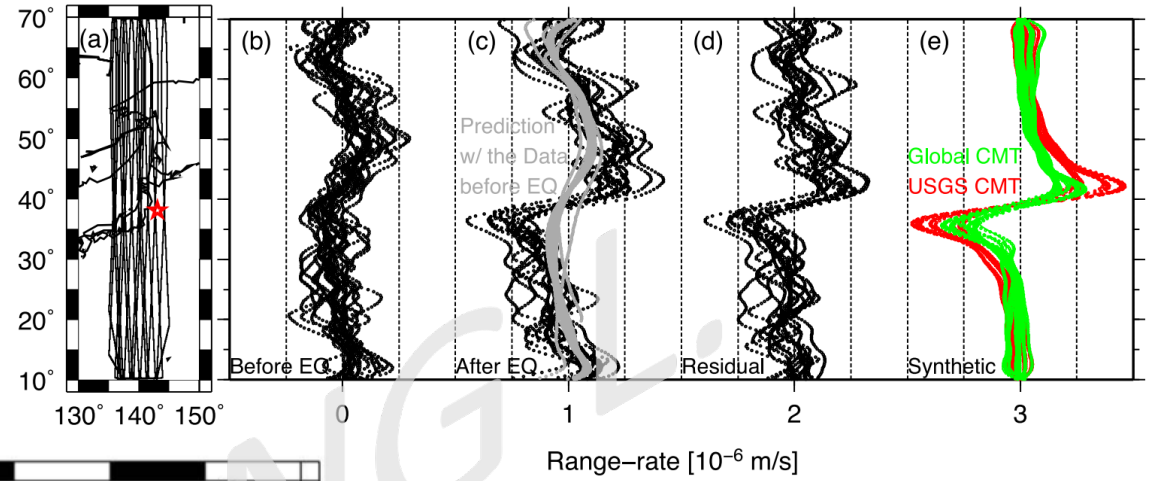
Observations after Chile earthquake (Mw 8.8):

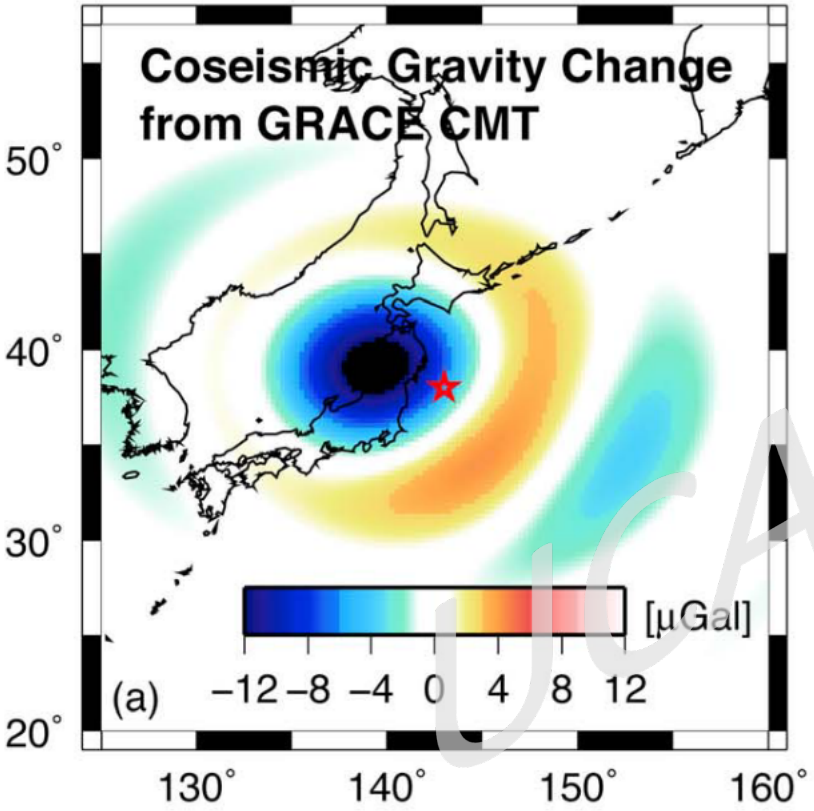


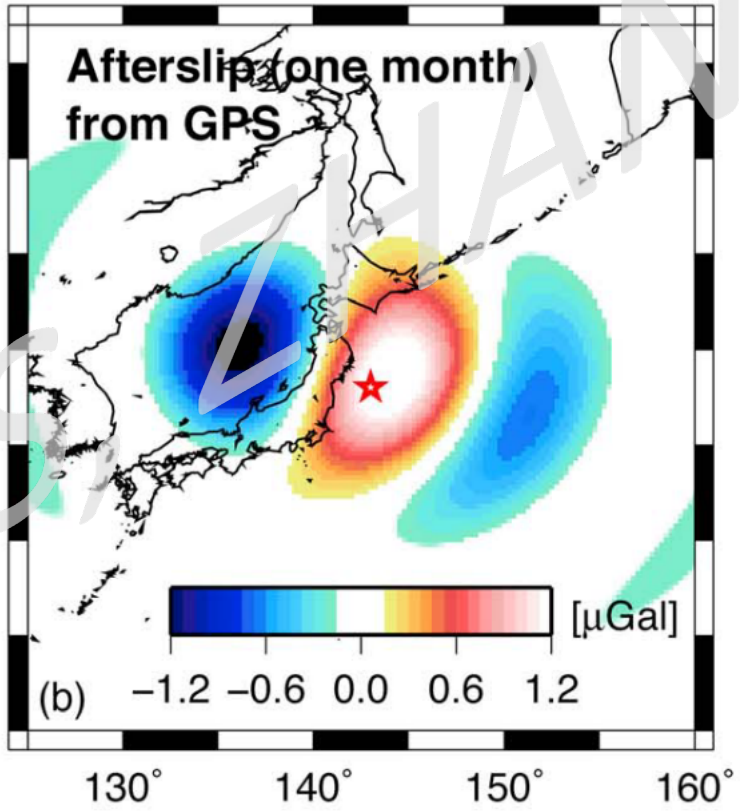
(Heki et al., 2010)

Motivation

Observations after Tohoku-Oki earthquake (Mw 9.0):

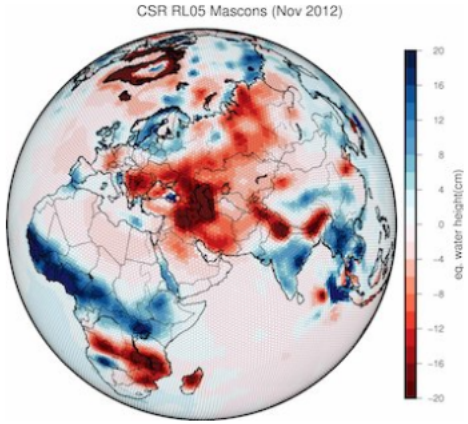






(Han et al., 2011)

Motivation



GRACE Monthly Mass Grids - UT-CSR Global Mascons

Global surface mass (land + ocean) from GRACE is updated monthly. Please visit the UT-CSR mascon site for further details.

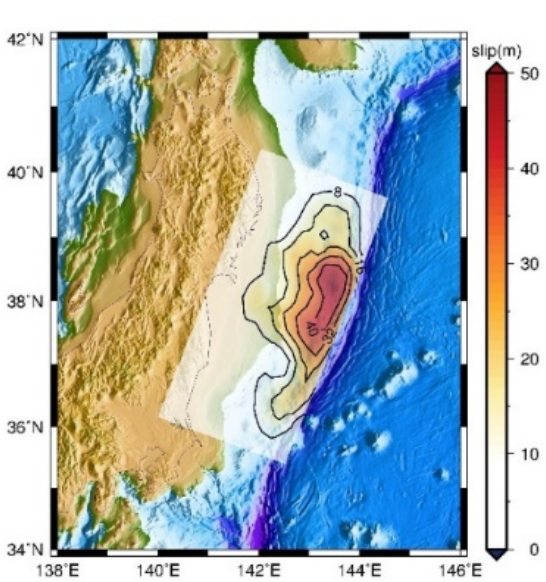
Few researchers have applied the mascon solutions on earthquake analysis, and few studies have investigate the performances of the mascon solutions on huge earthquakes systematically.

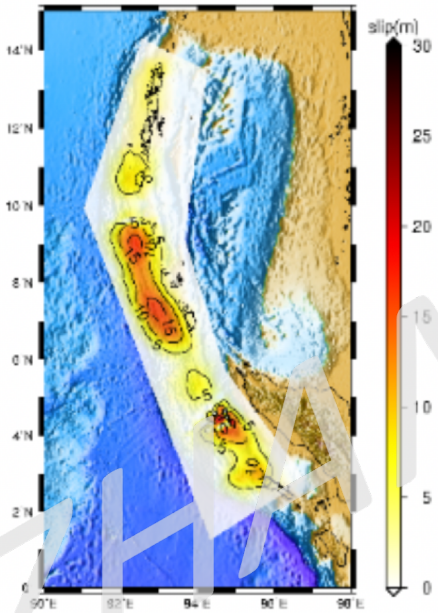
Examine the performances of the mascon solutions for three huge earthquakes-induced transient gravity signals: the Tohoku-Oki, Sumatra and Chile earthquakes.

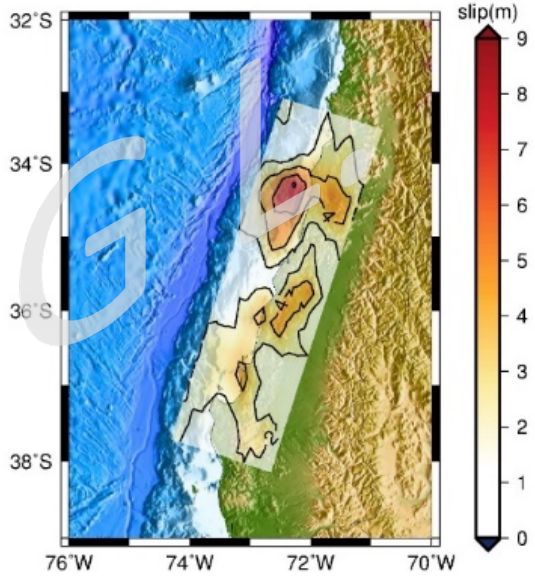
Motivation

Surface co-seismic gravity changes:

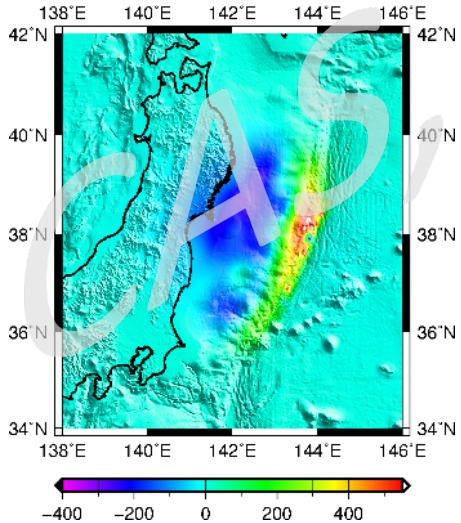
Co-seismic slip fault
(data from Wei et al., 2012, Chlieh et al., 2007)

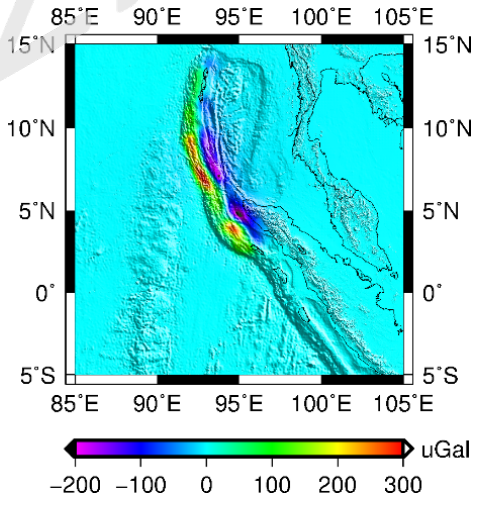


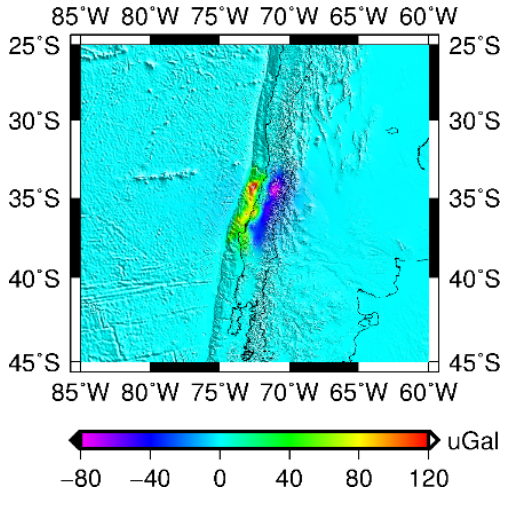




Theory gravity change modeled by dislocation theory







Methods

Data:

CSR RL05 Spherical Harmonic (SH) and mascon products;

a Gaussian +P4M6 filter;

Fit method:

$$y(t) = \begin{cases} A + Bt + C\sin(\omega t + \theta_1) + Dsin(2\omega t + \theta_2)\ t_0 \le t < t_e \\ A + Bt + C\sin(\omega t + \theta_1) + Dsin(2\omega t + \theta_2) + E + F\left\{1 - \exp(\frac{t - t_e}{\tau})\right\}\ t_e < t \le t_1 \end{cases}$$

Dislocation gravity change:

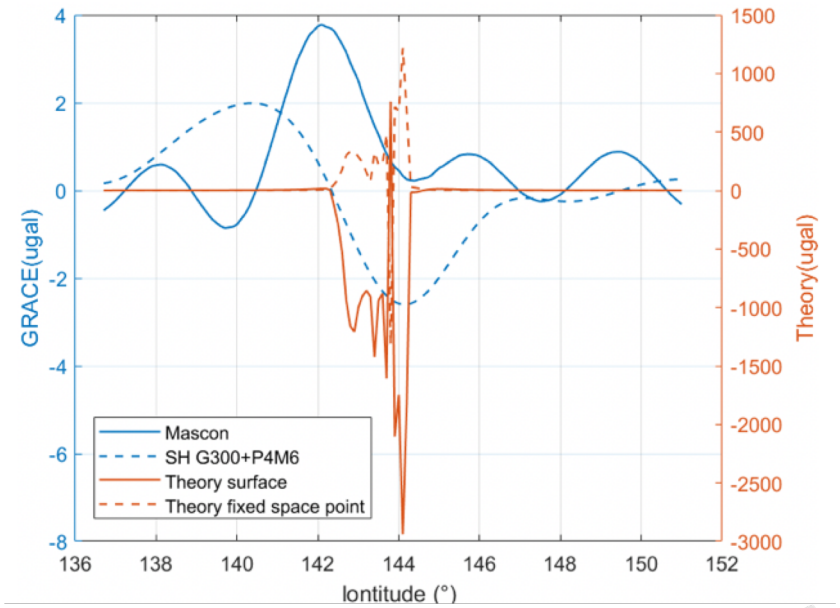
Finite faults (Wei et al., 2012; Chlieh et al., 2007);

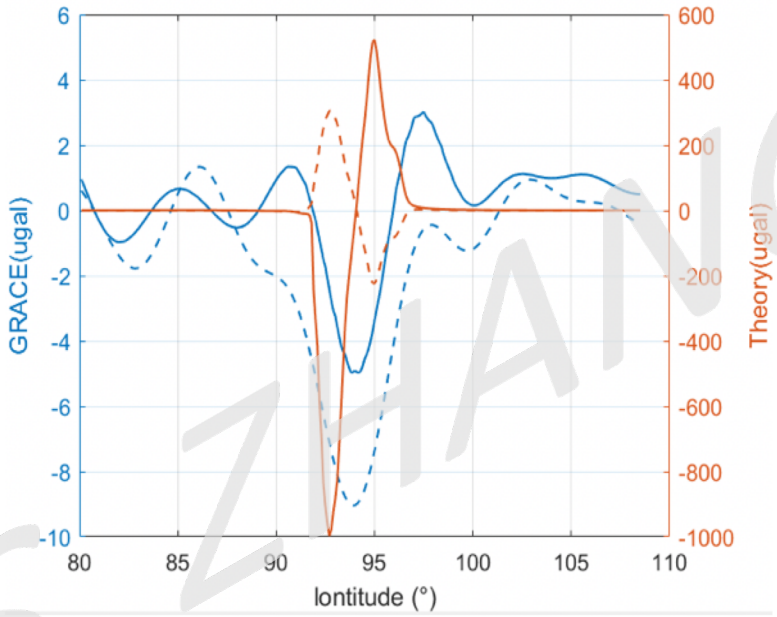
co-ordinate transformation;

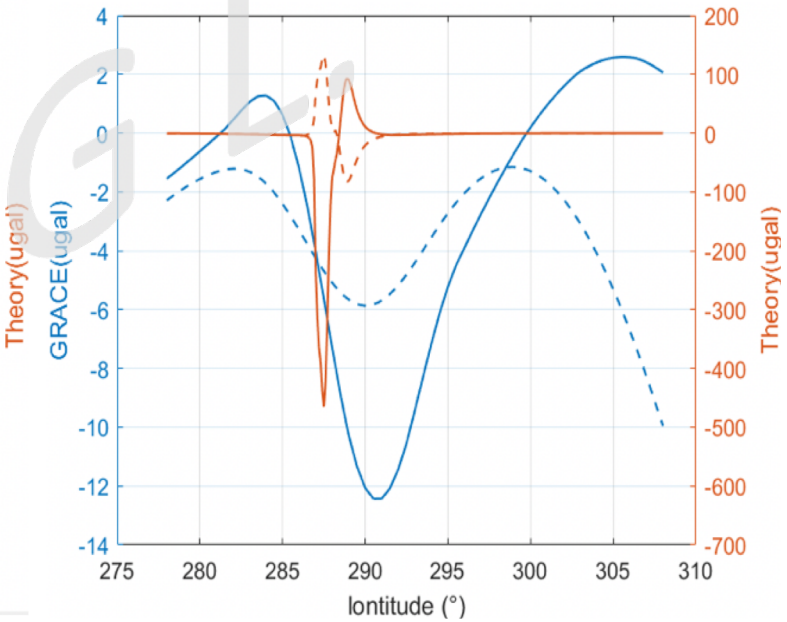
Seawater correction.

Methods

Way use Gaussian filter on the mascon solutions:





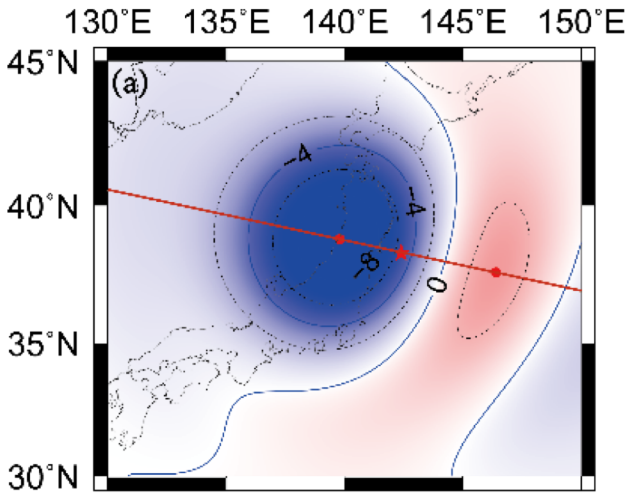


GRACE-observed and theoretical calculated profiles of co-seismic gravity changes of the three earthquakes across the maximum and minimum spatial points.

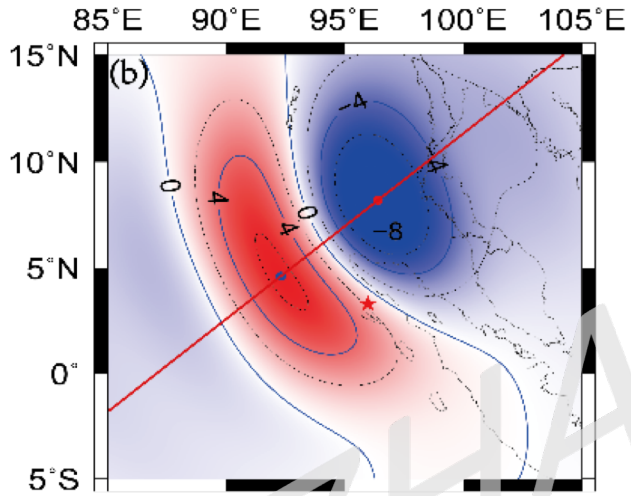
Results

Theory gravity changes with a Gaussian filter of 300 km radius (G300):

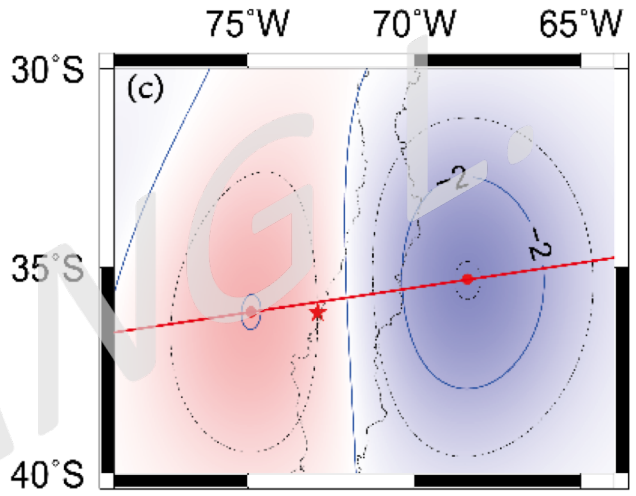
Tohoku

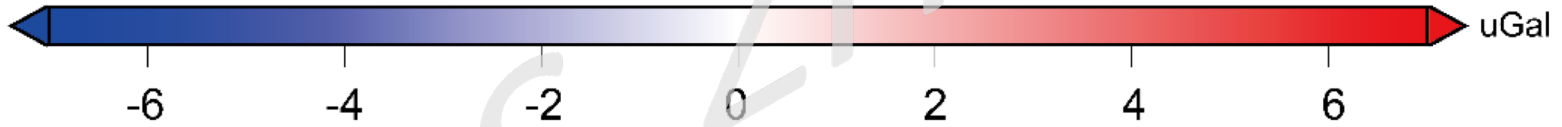


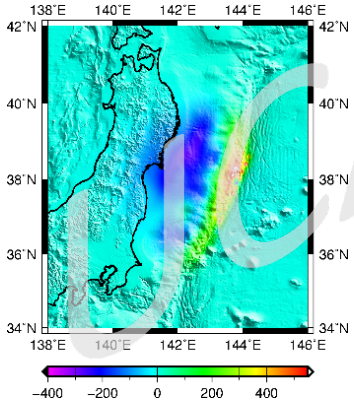
Sumatra

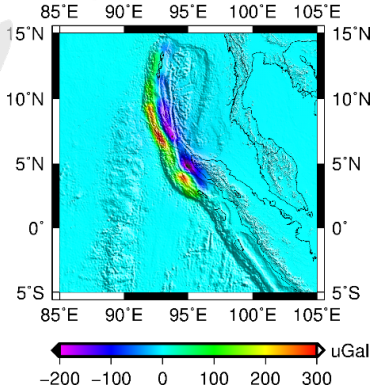


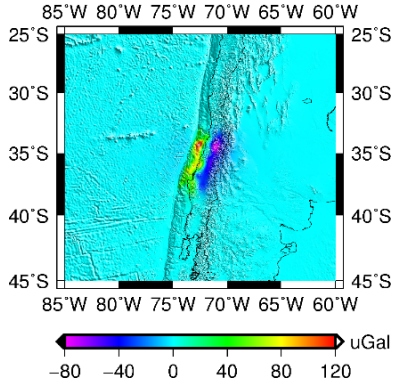
Chile





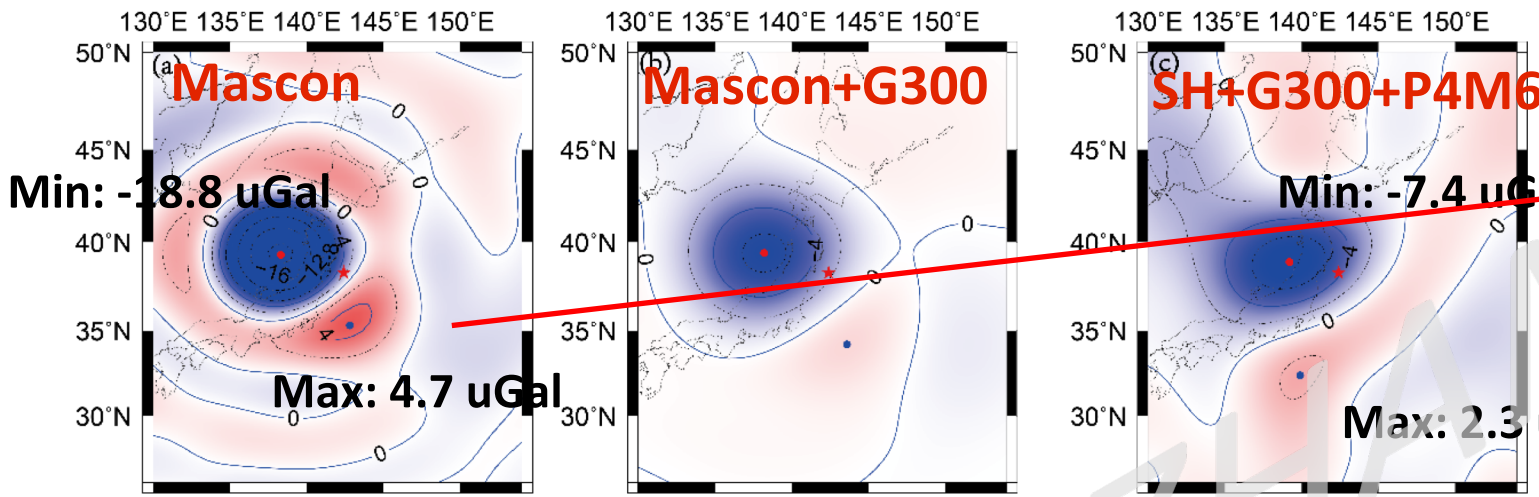


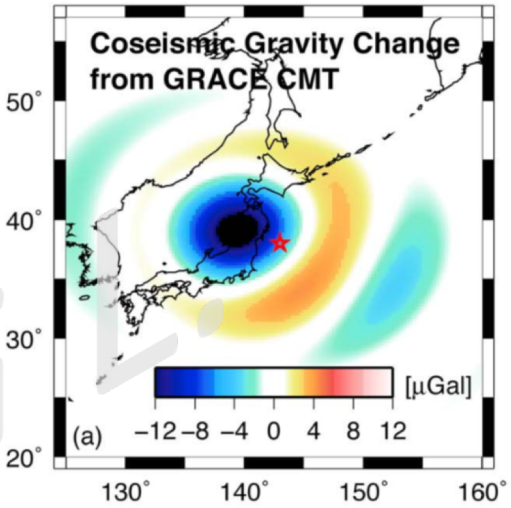




Results

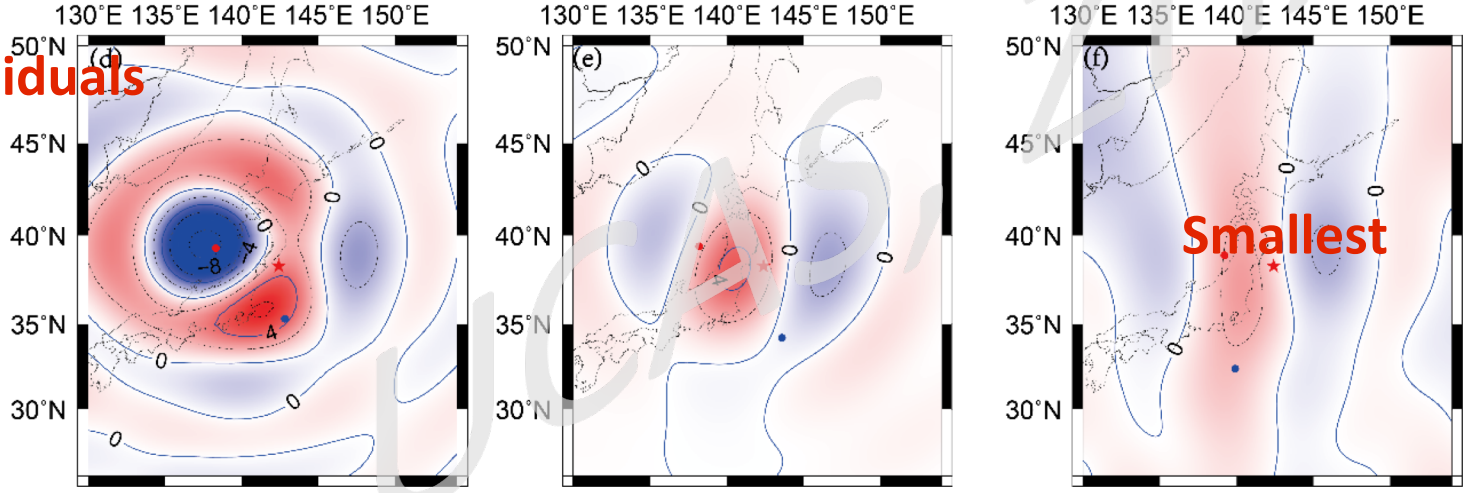
Co-seismic gravity change of Tohoku earthquake and their residuals differ from theory result:



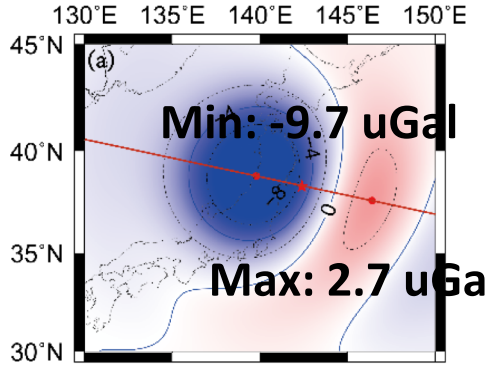


(*Han et al., 2011*)

Residuals

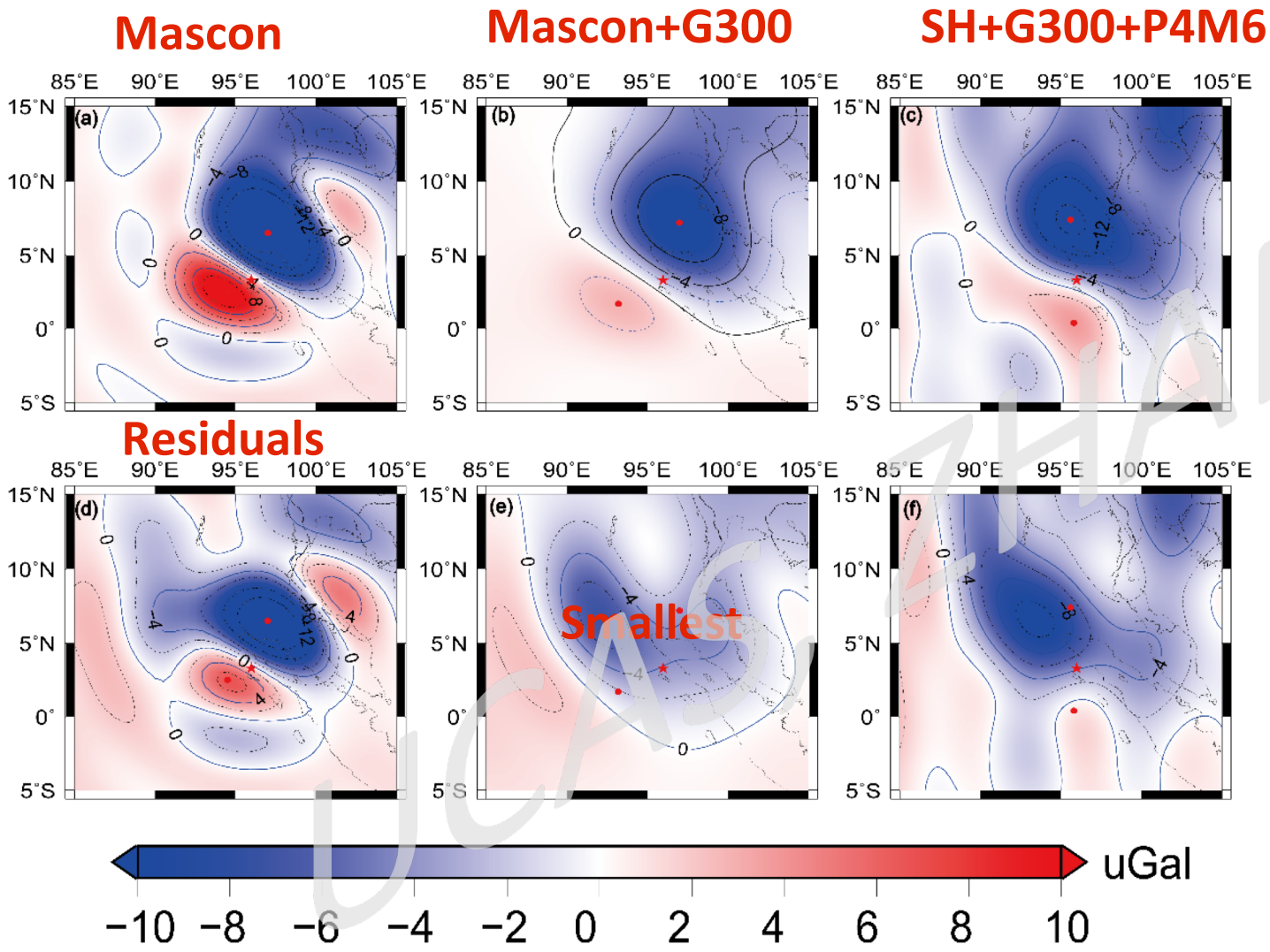


Theory:

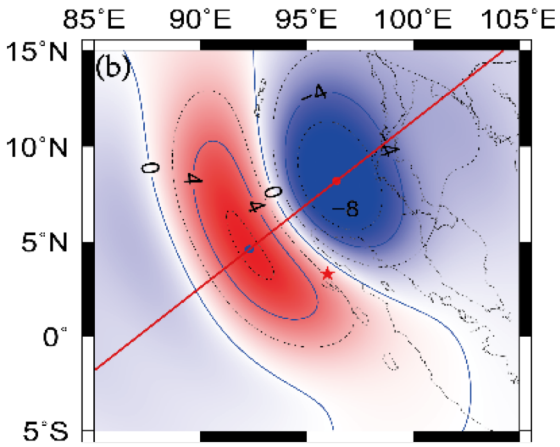


Results

Co-seismic gravity change of Sumatra earthquake and their residuals differ from theory result:

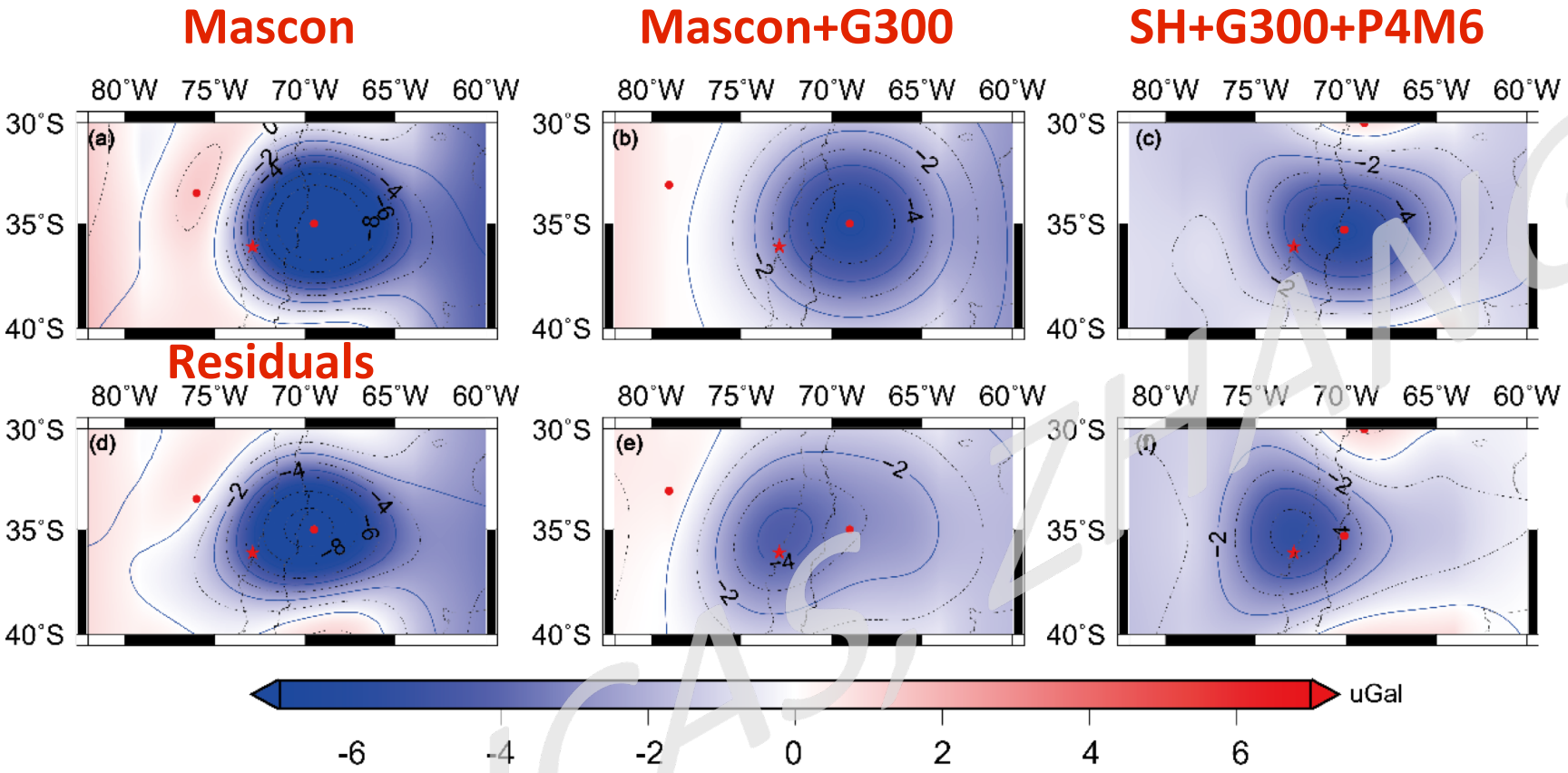


Theory:

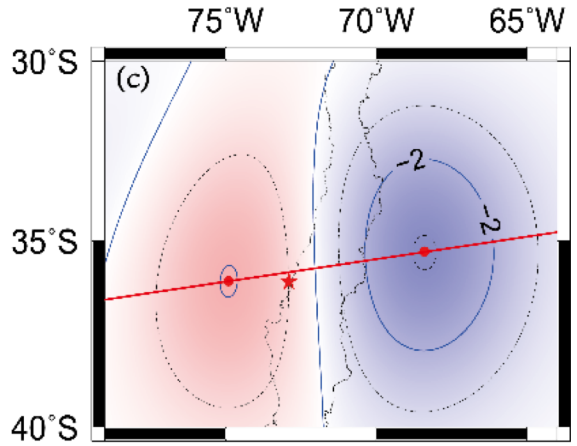


Results

Co-seismic gravity change of Chile earthquake and their residuals differ from theory result:

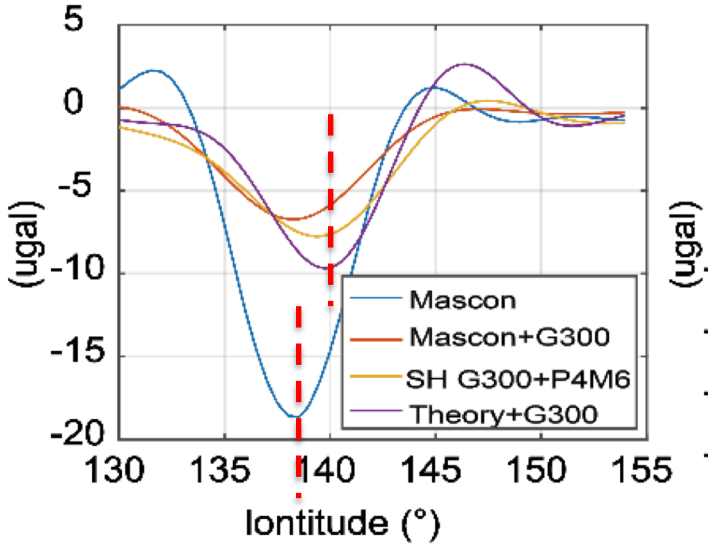


Theory:

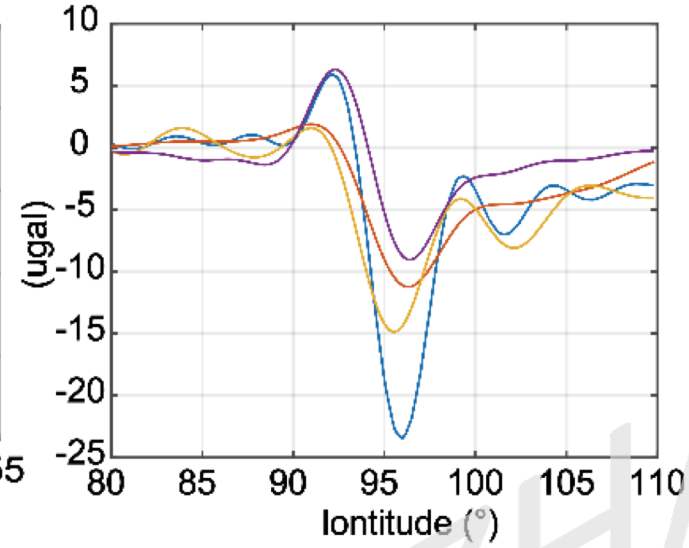


Results

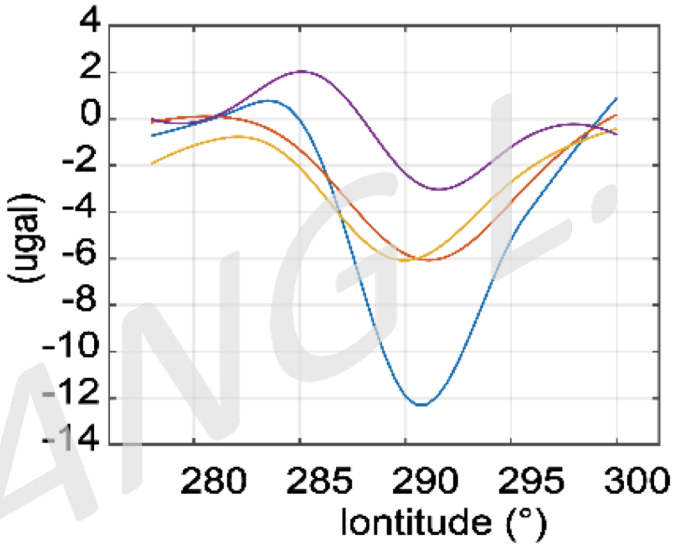
Profiles of co-seismic gravity change in three earthquakes:



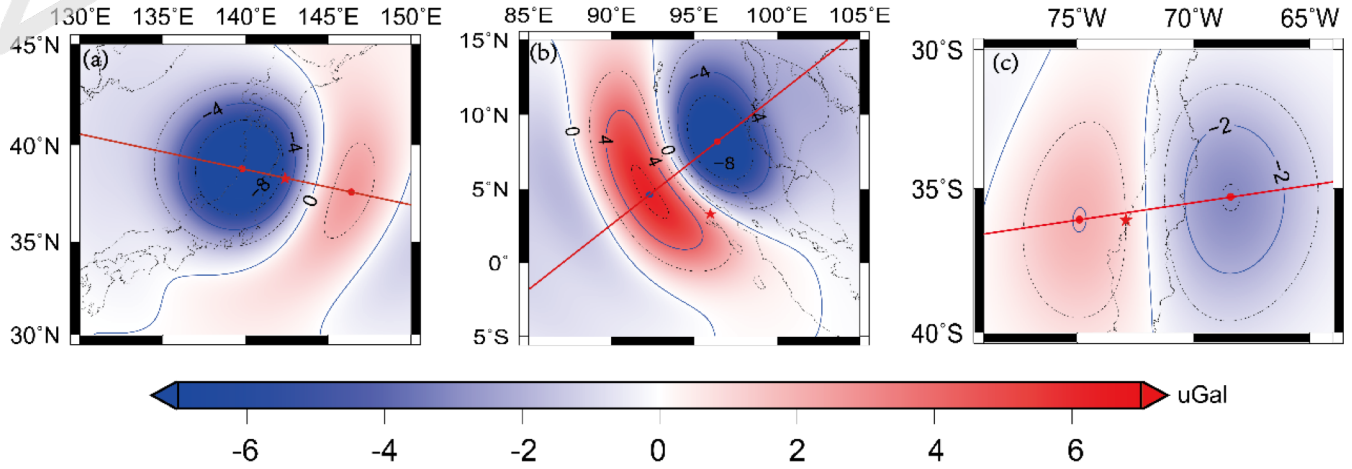
Tohoku-Oki



Sumatra

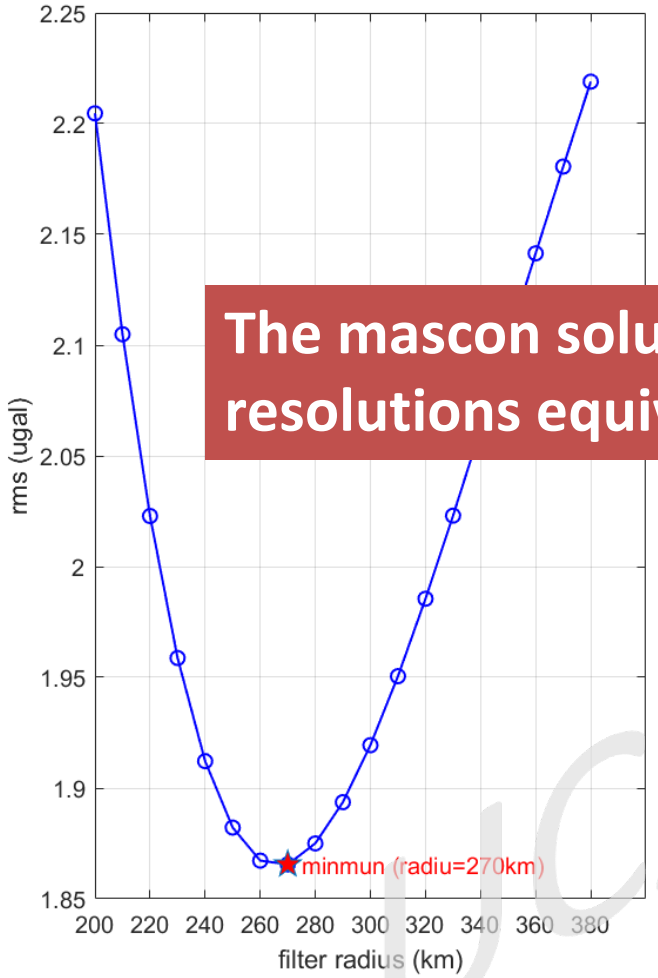


Chile

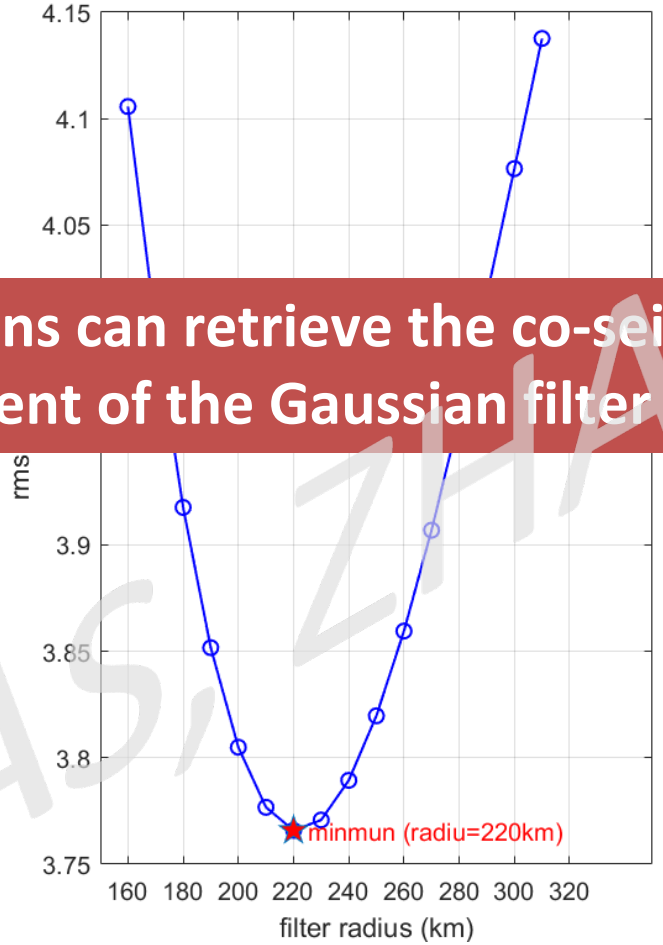


Further comparisons

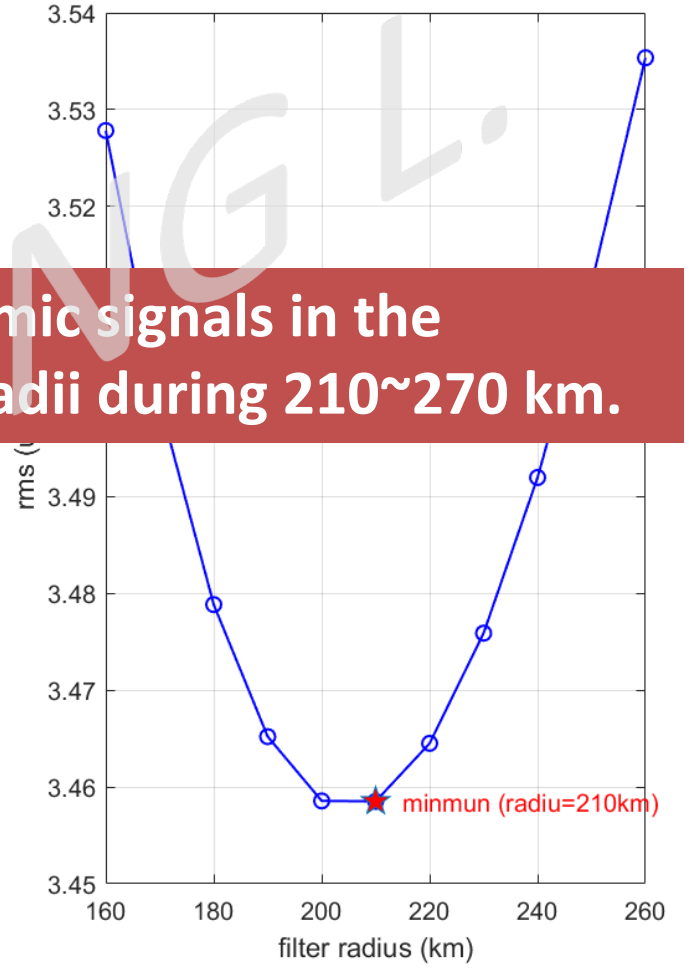
RMS of the residuals between Mascon solutions and theory results with Gaussian filter of different radius:



Tohoku-Oki



Sumatra

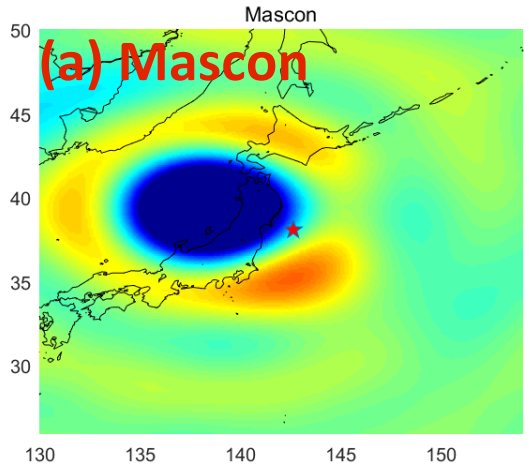


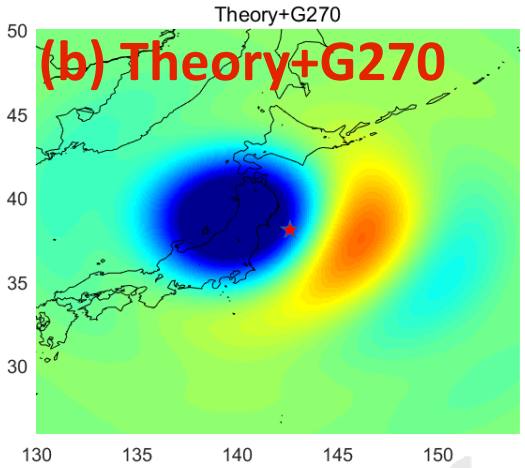
Chile

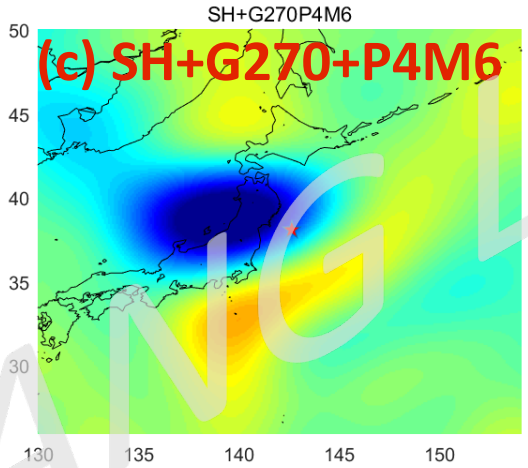
The mascon solutions can retrieve the co-seismic signals in the resolutions equivalent of the Gaussian filter radii during 210~270 km.

Further comparisons

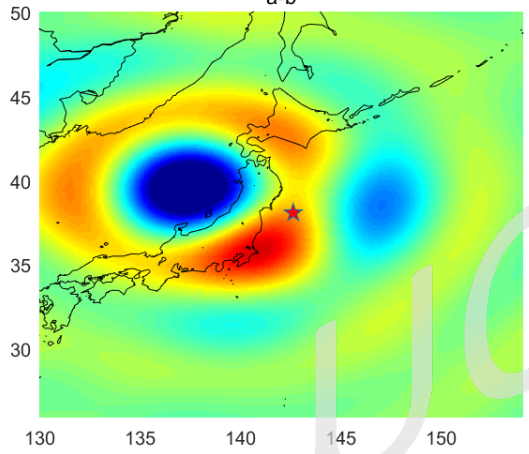
In best filter radius situation (Tohoku-Oki):



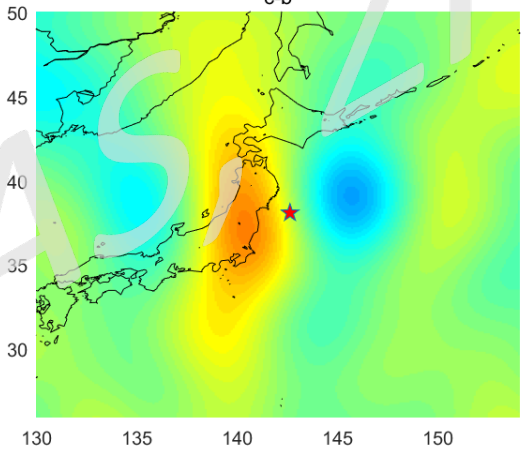




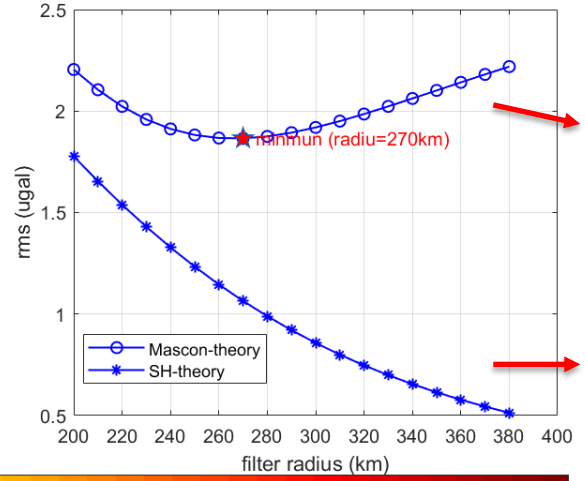
(a)-(b)



(c)-(b)

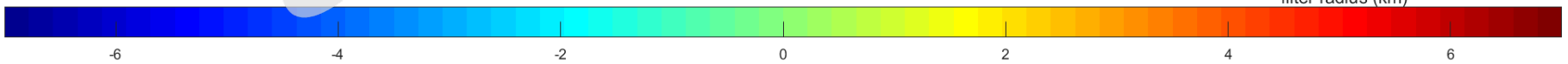


RMS for different filter radii



Mascon-Theory

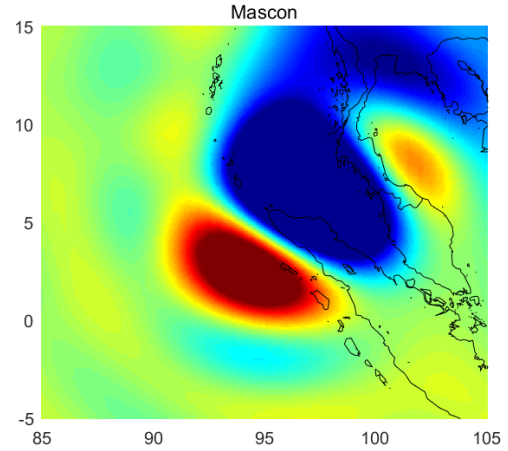
SH-Theory



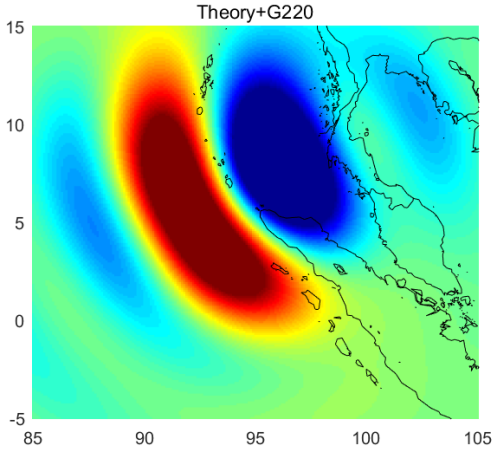
Further comparisons

In best filter radius situation (Sumatra):

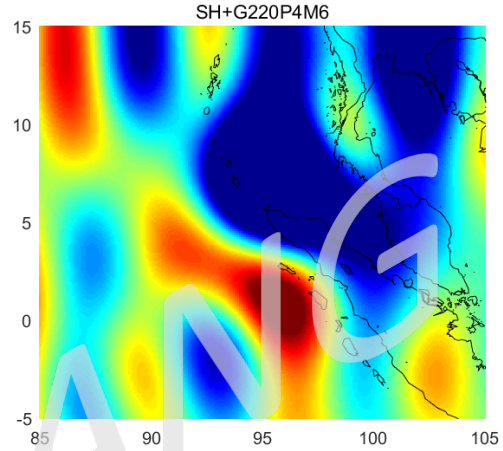
(a) Mascon



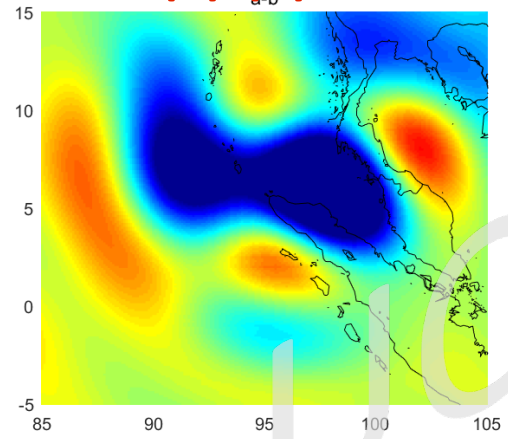
(b) Theory+G220



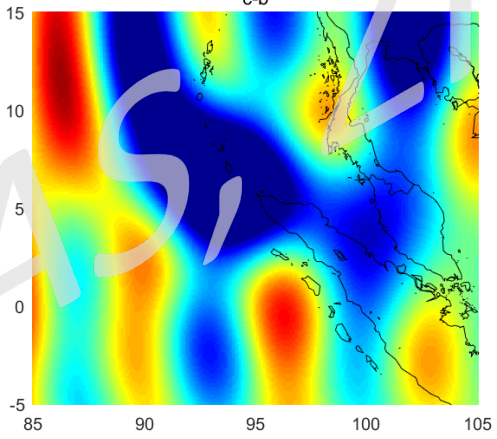
(c) SH+G220+P4M6



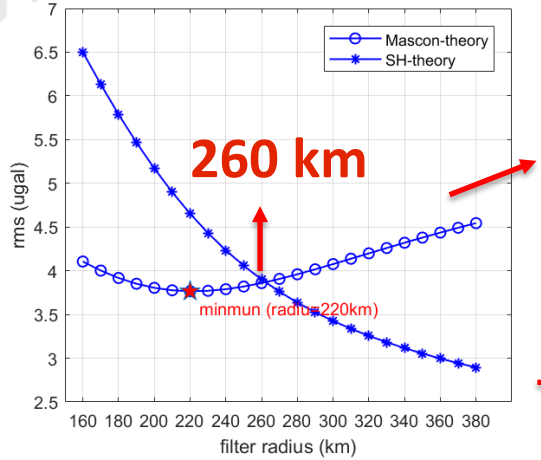
(a)-(b)



(c)-(b)

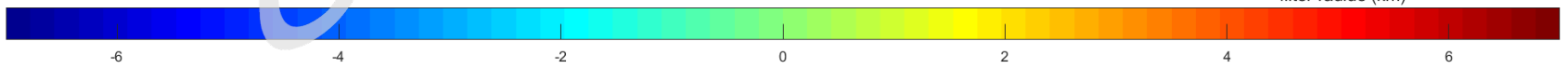


RMS for different filter radii



Mascon-Theory

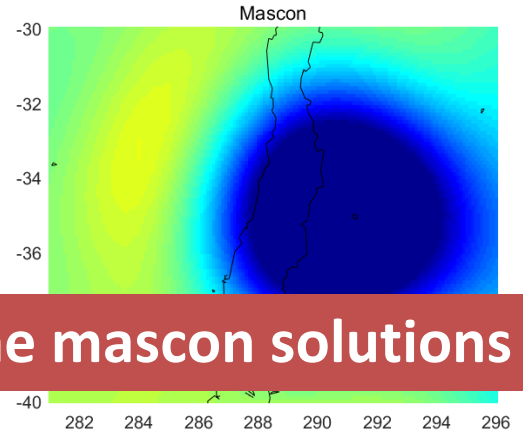
SH-Theory



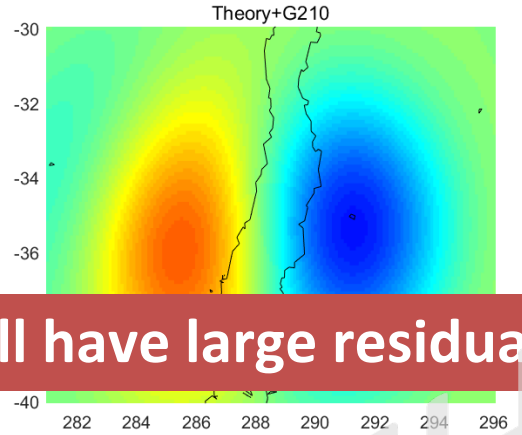
Further comparisons

In best filter radii situation (Chile):

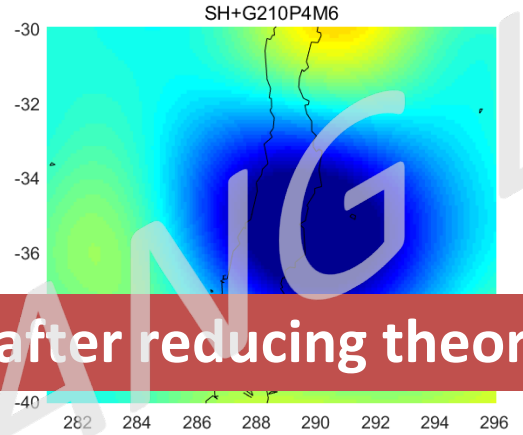
(a) Mascon



(b) Theory+G220

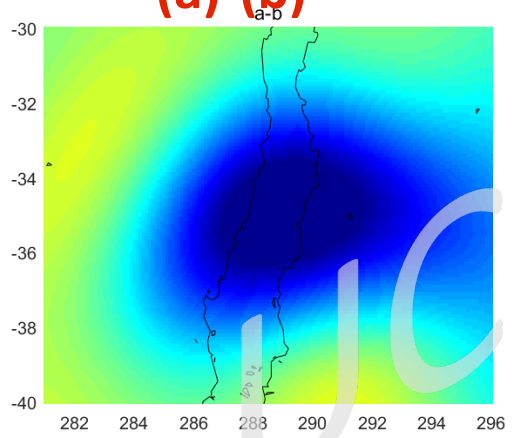


(c) SH+G220+P4M6

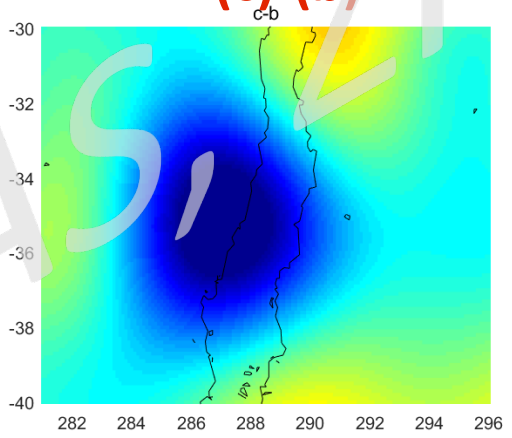


The mascon solutions still have large residuals after reducing theory results;

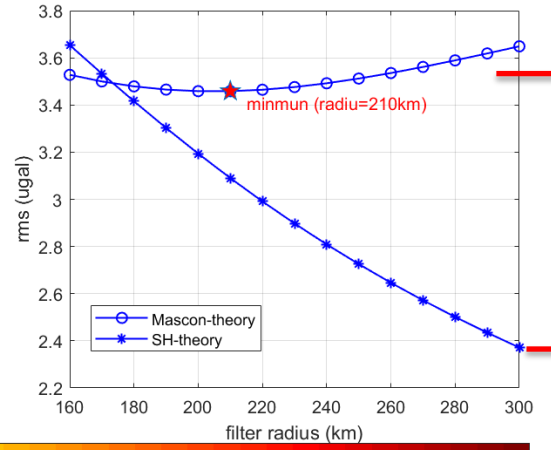
(a)-(b)



(c)-(b)

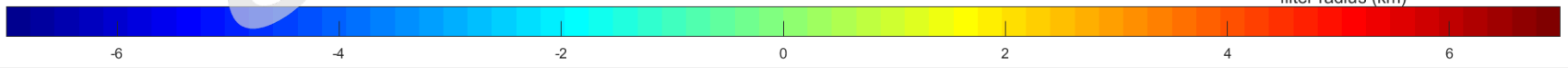


RMS for different filter radii

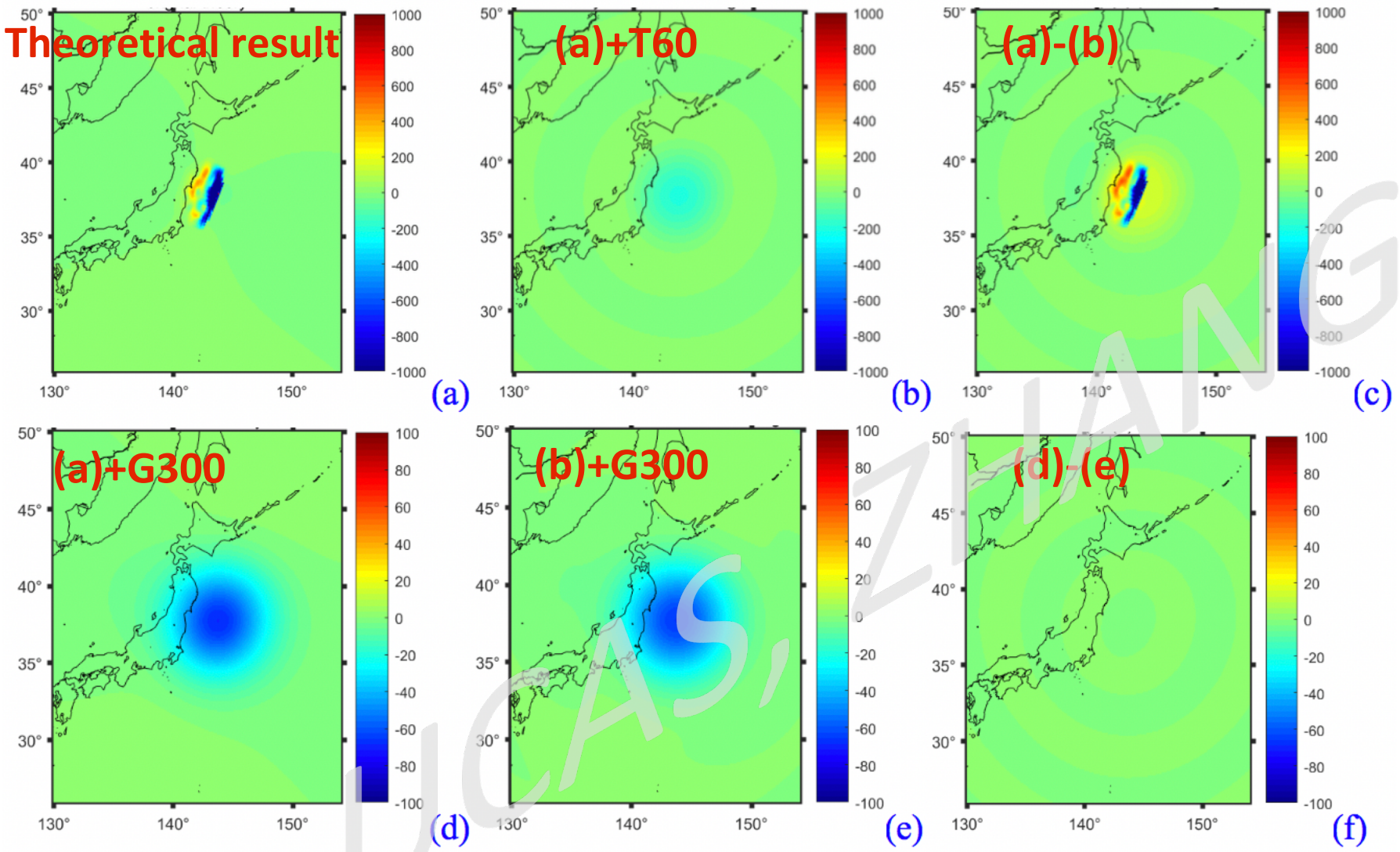


Mascon-Theory

SH-Theory



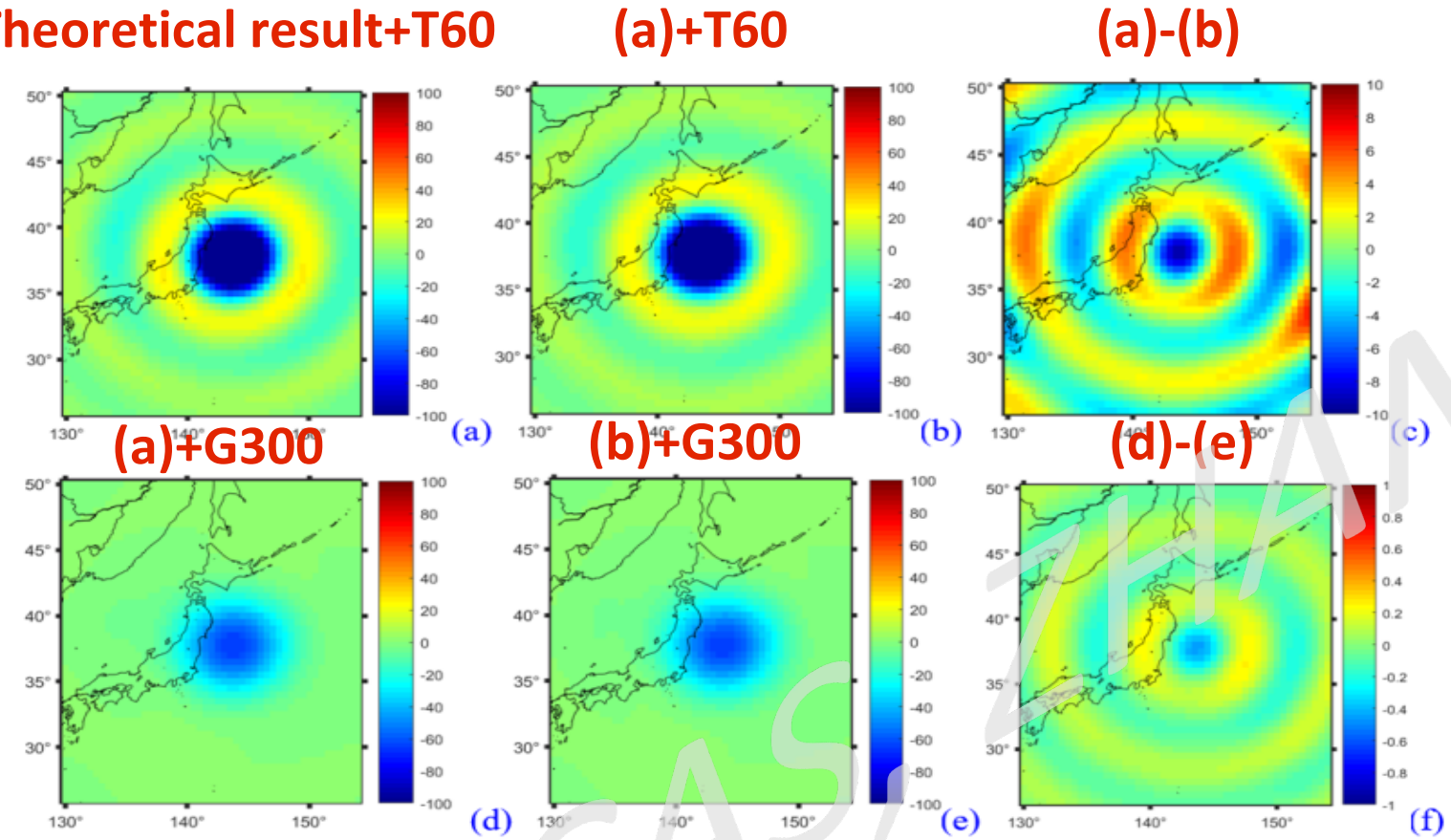
Theoretical simulation on high degree signals of Mascon solutions



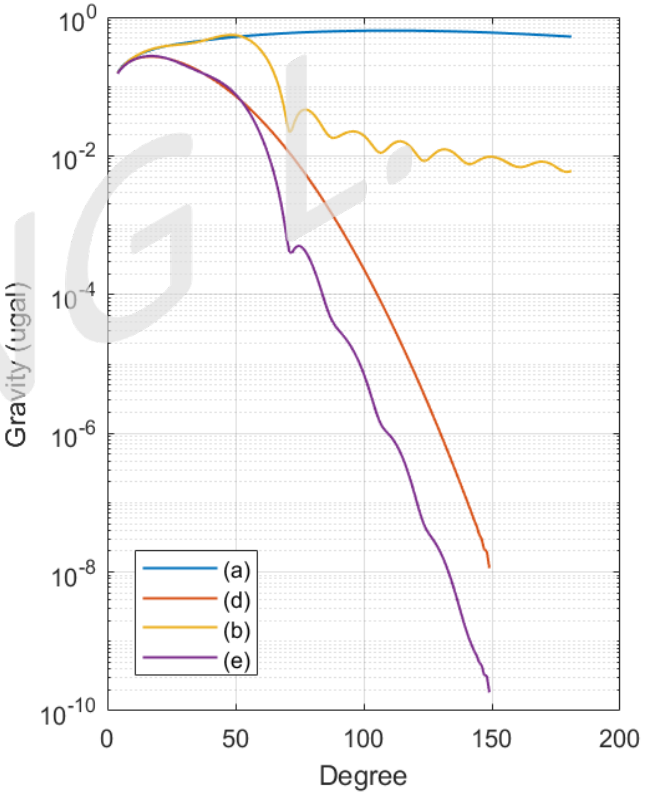
T60: truncated at degree 60

Simulations of theoretical co-seismic gravity changes of the Tohoku earthquake.

Theoretical simulation on high degree signals of Mascon solutions

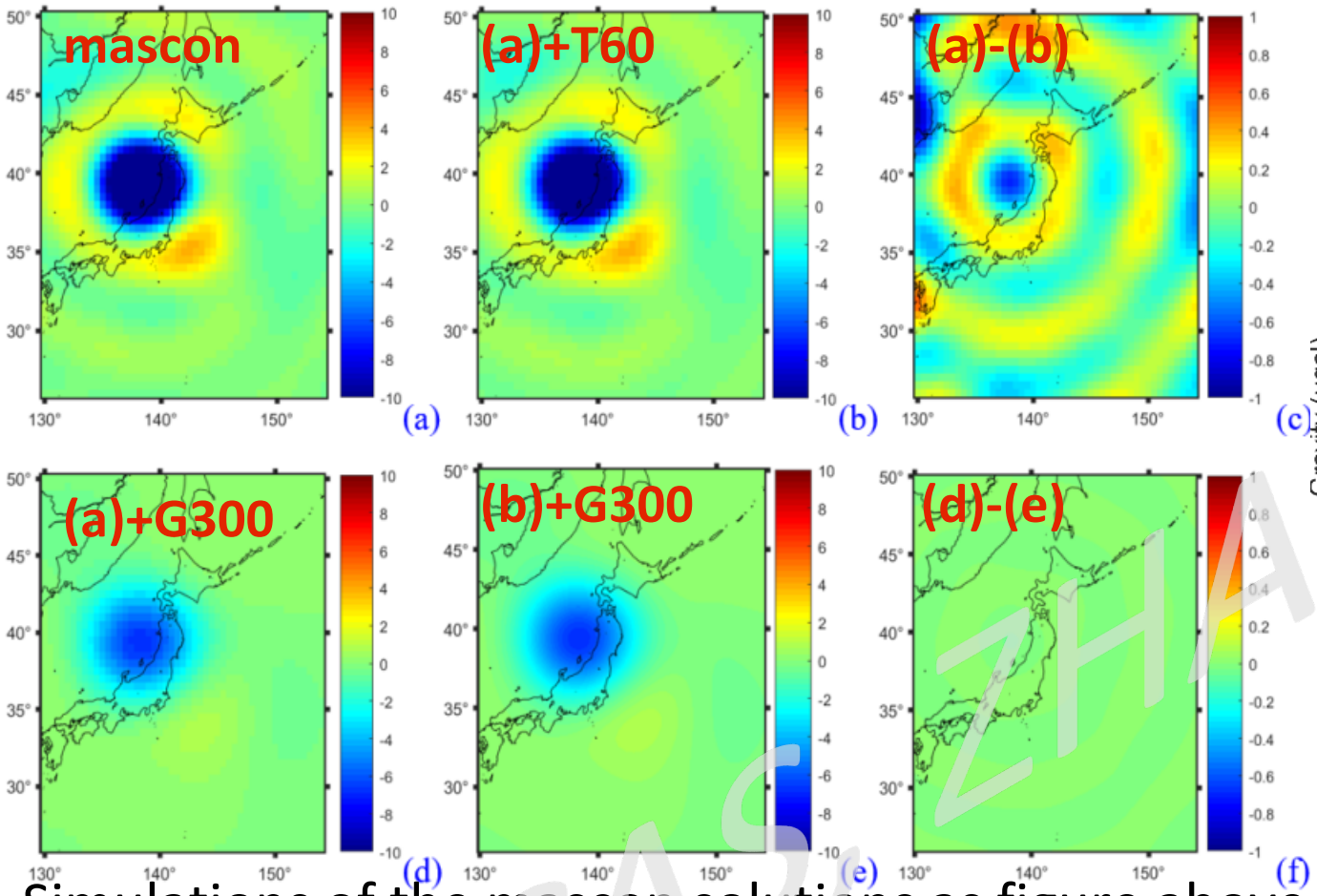


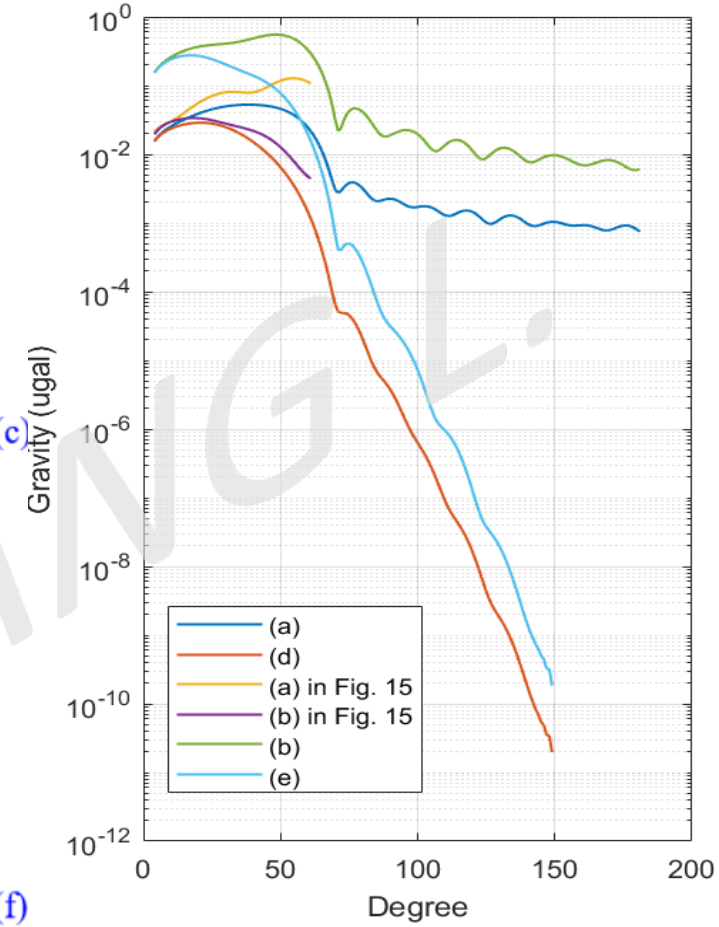
Degree amplitudes of the SHc of the co-seismic gravity change



Simulations of theoretical co-seismic gravity changes of the Tohoku earthquake in low degrees.

Theoretical simulation on high degree signals of Mascon solutions



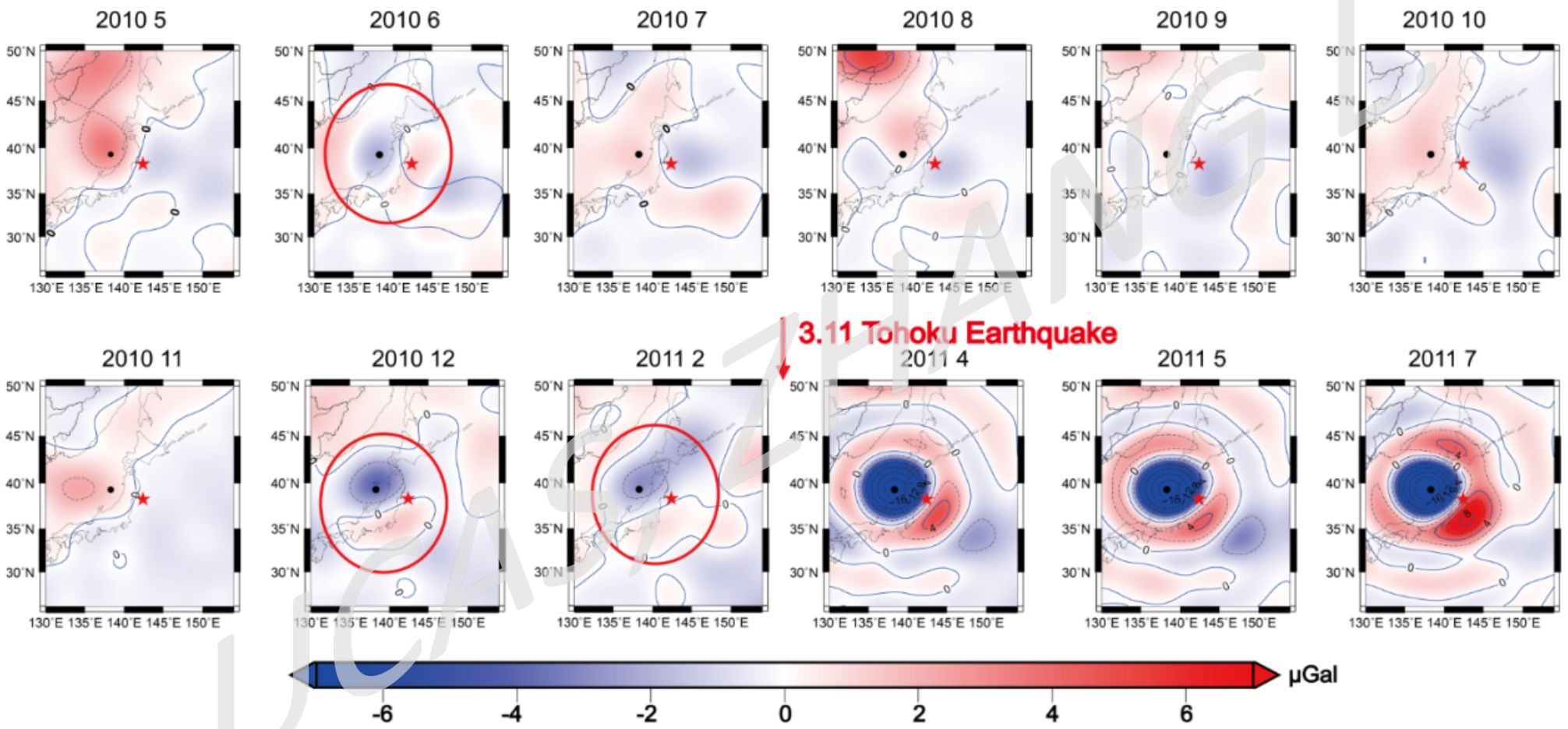


Simulations of the mascon solutions as figure above.

The performances the mascon solutions with the grids of 0.5°×0.5° are very similar to those of theoretical simulation. The signals with interpolated low resolutions or the mascon solutions contain non-negligible spurious signals at high degrees, accounting for about 7% of the magnitudes of total signals.

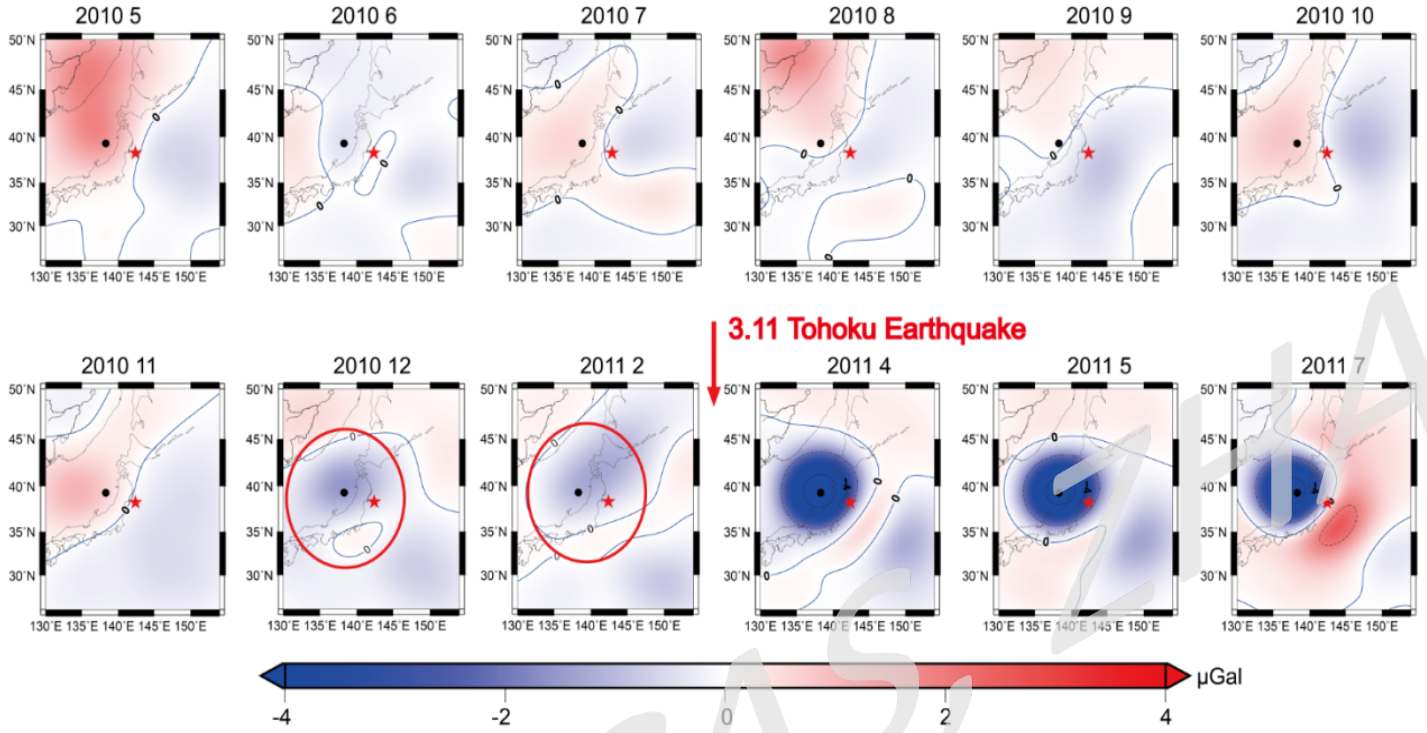
Pre-seismic signals

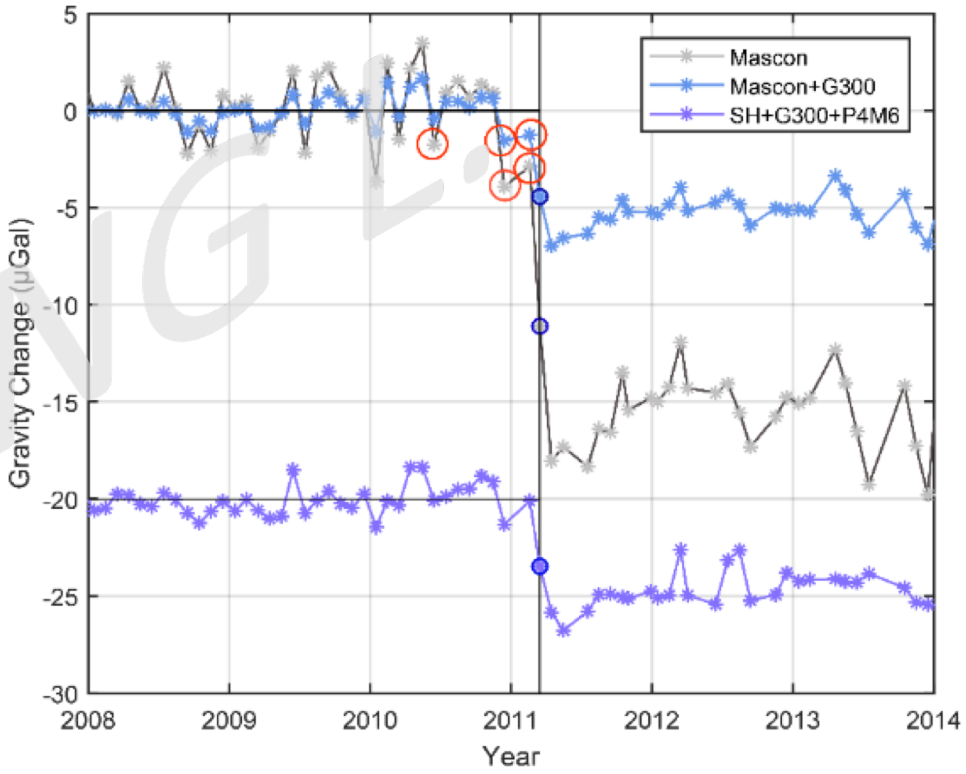
The mascon solutions in Tohoku earthquake:



Pre-seismic signals

The mascon solutions with a G300 filter:





Time series of gravity changes at red point

Discussion

Error of theoretical gravity signals

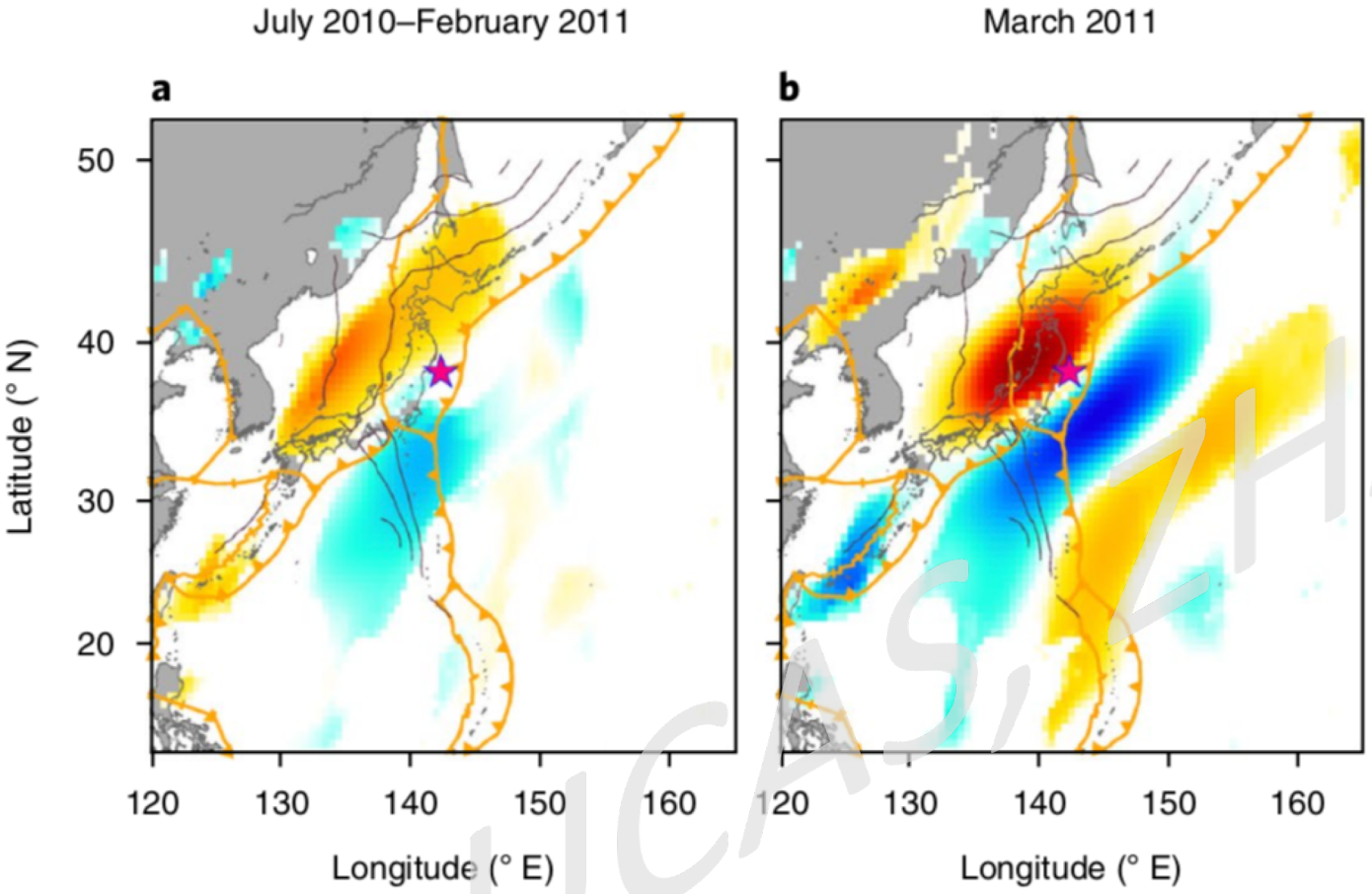
- Earth model -- SNREI model doesn't include the:
  lateral heterogeneity, vertical irregular interface, and the topographic effects;
- Fault slip models –differ from one to other:
  seismic waveforms, strong ground motions, displacements, and tsunami wave height;
- The discrepancies of the Earth model used in the dislocation theory and the fault slip model.

Error of GRACE observation

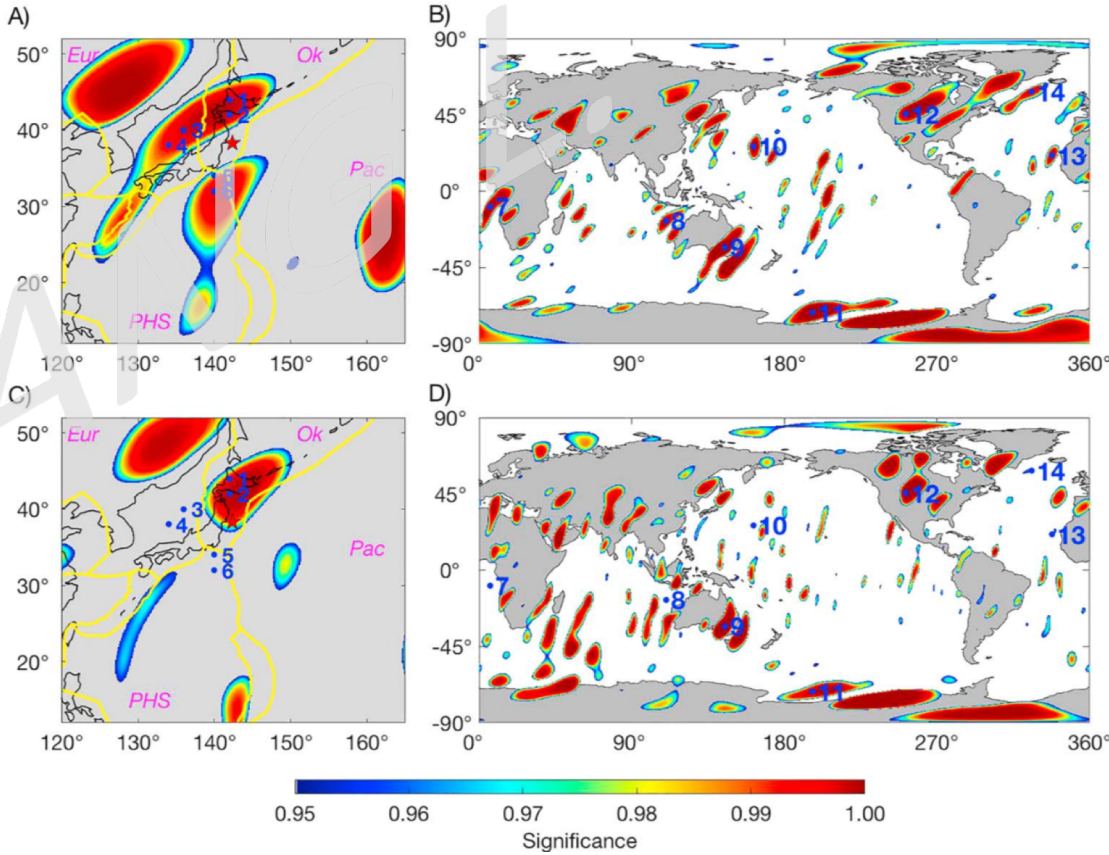
- Attenuation, leakage, truncation, and smoothing errors;
- hard to accurately remove all the post-seismic effects;
- not be sensitive to the negative-positive signals in the east-west direction;
- the regularization matrix designed in the mascon solutions can avoiding weak signals but cannot capture the entire earthquake signal.

Discussion

‘Pre-seismic’ signals of the Tohoku earthquake



(Panet et al., 2018)



(Wang et al., 2020)

Conclusion

- The mascon solutions facilitate the recovery of co-seismic gravity changes induced by the three M9 class earthquakes and contain almost the same information as the SH solutions but have other strengthening gravity change signals;

- The mascon solutions can retrieve the co-seismic gravity change signals at resolutions equivalent to the Gaussian filter radii within 210–270 km.

- The large residuals between the mascon and theoretical solutions contain non-negligible spurious signals at high degrees of the mascon solutions.

Thanks for your attention！