Observations of rapid large-scale slip/deformation of the slab before some large subduction earthquakes

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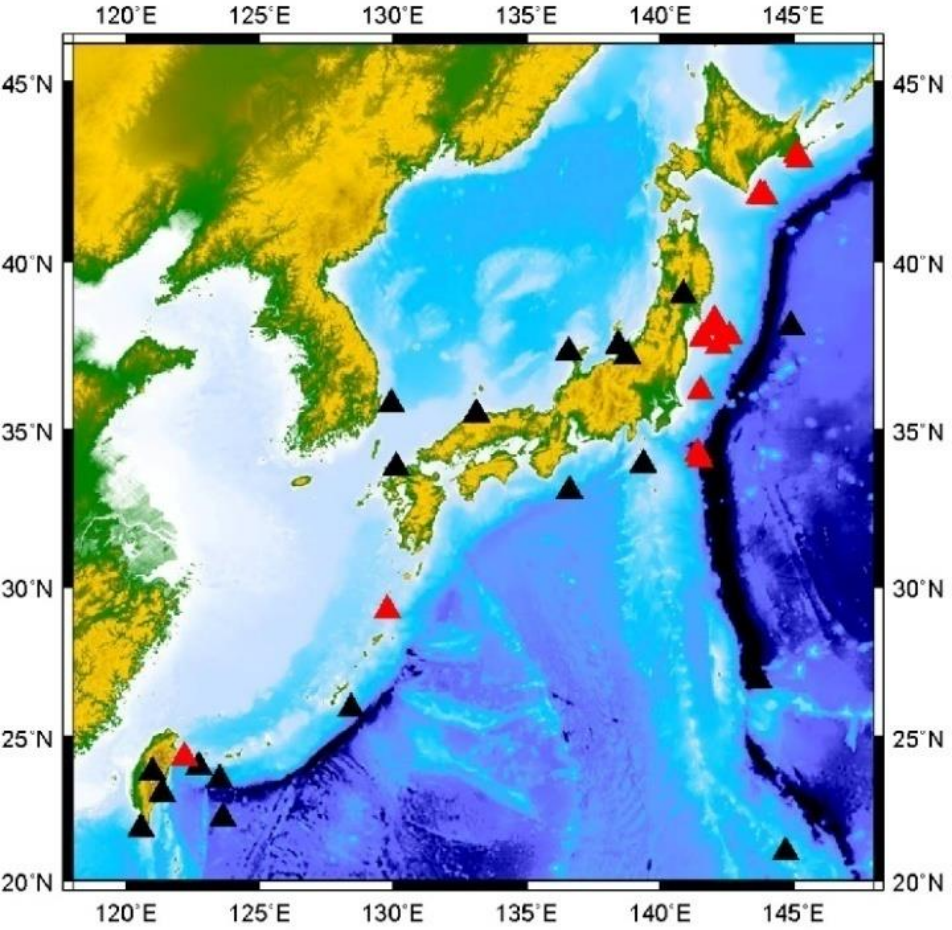
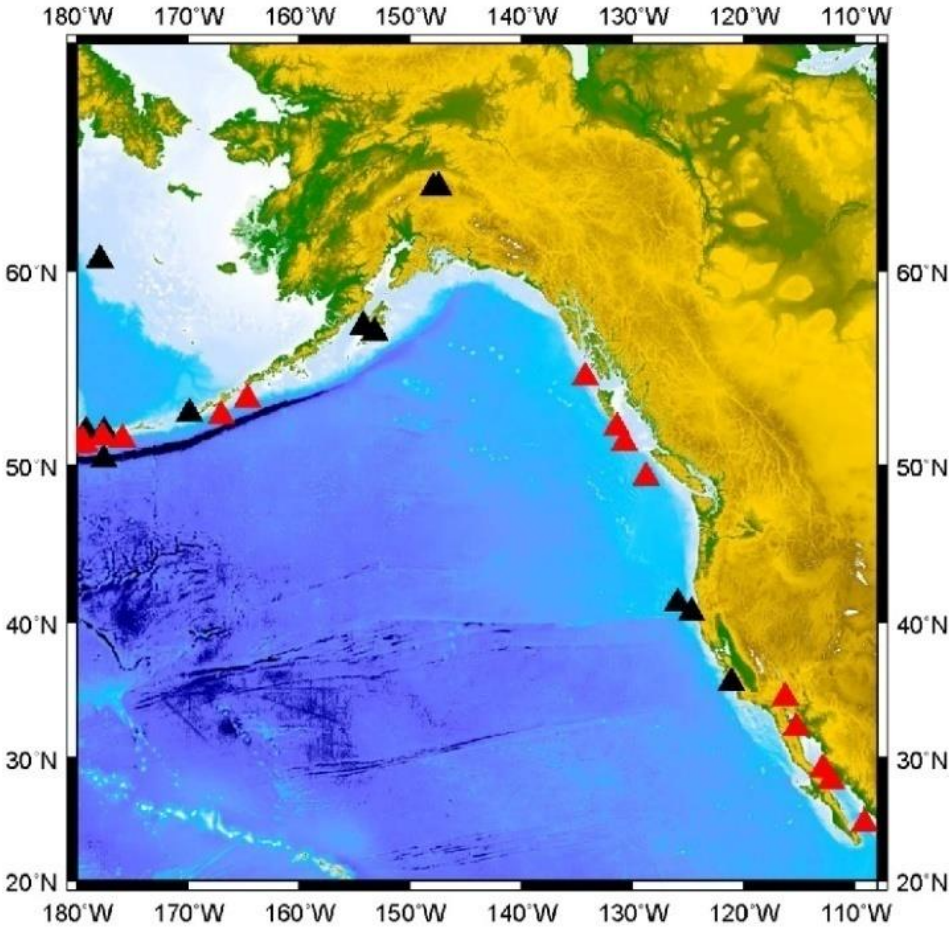
All the M≥6.5 (interplate and intraplate) earthquakes which occurred in these two densely instrumented zones between 01/01/1999 and 01/01/2011





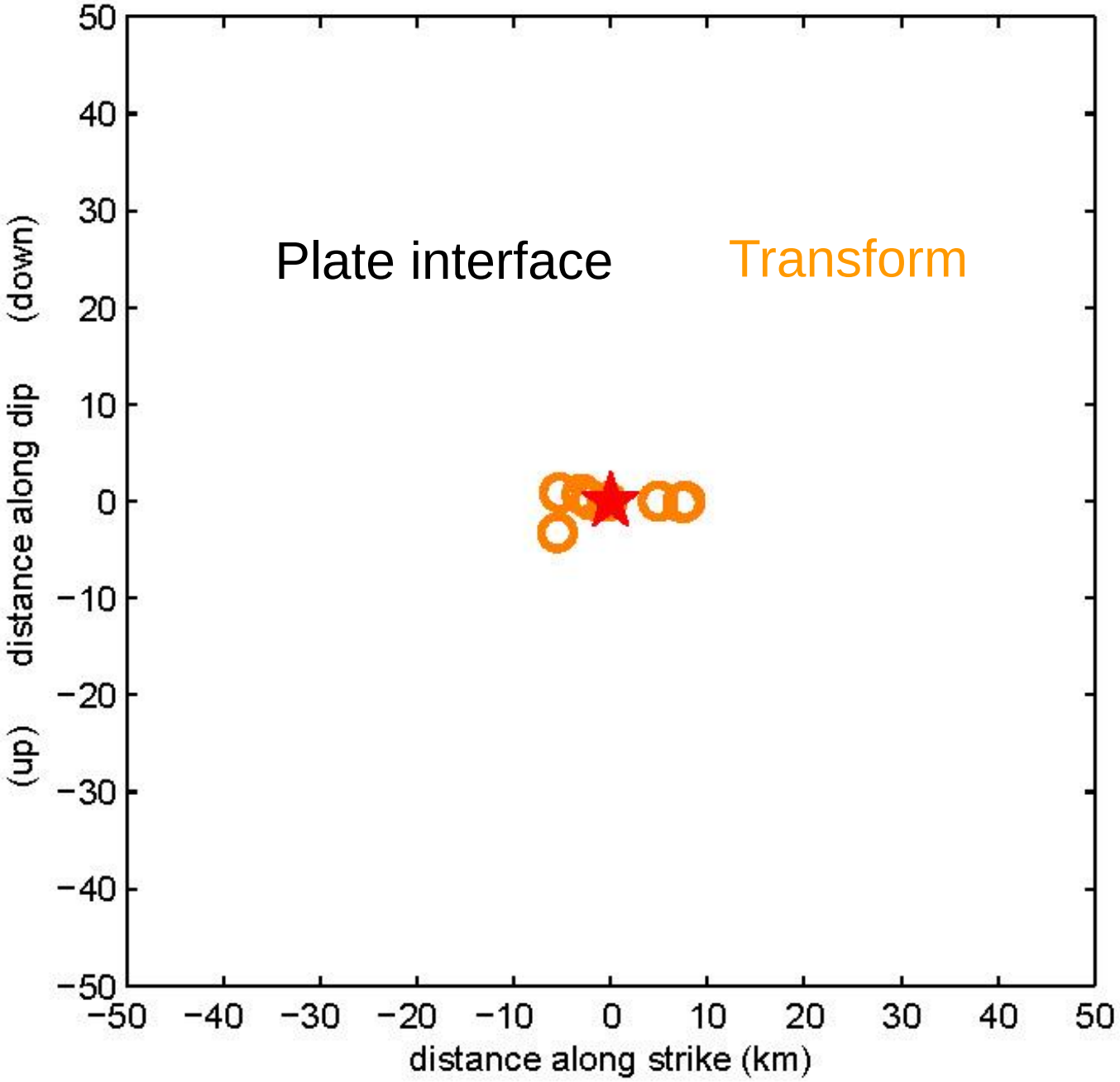


Plate interface
Transform
50
40
30
20
10
0
−10
−20
−30
−40
−50
(up) distance along dip (down)
−50 −40 −30 −20 −10 0 10 20 30 40 50
distance along strike (km)

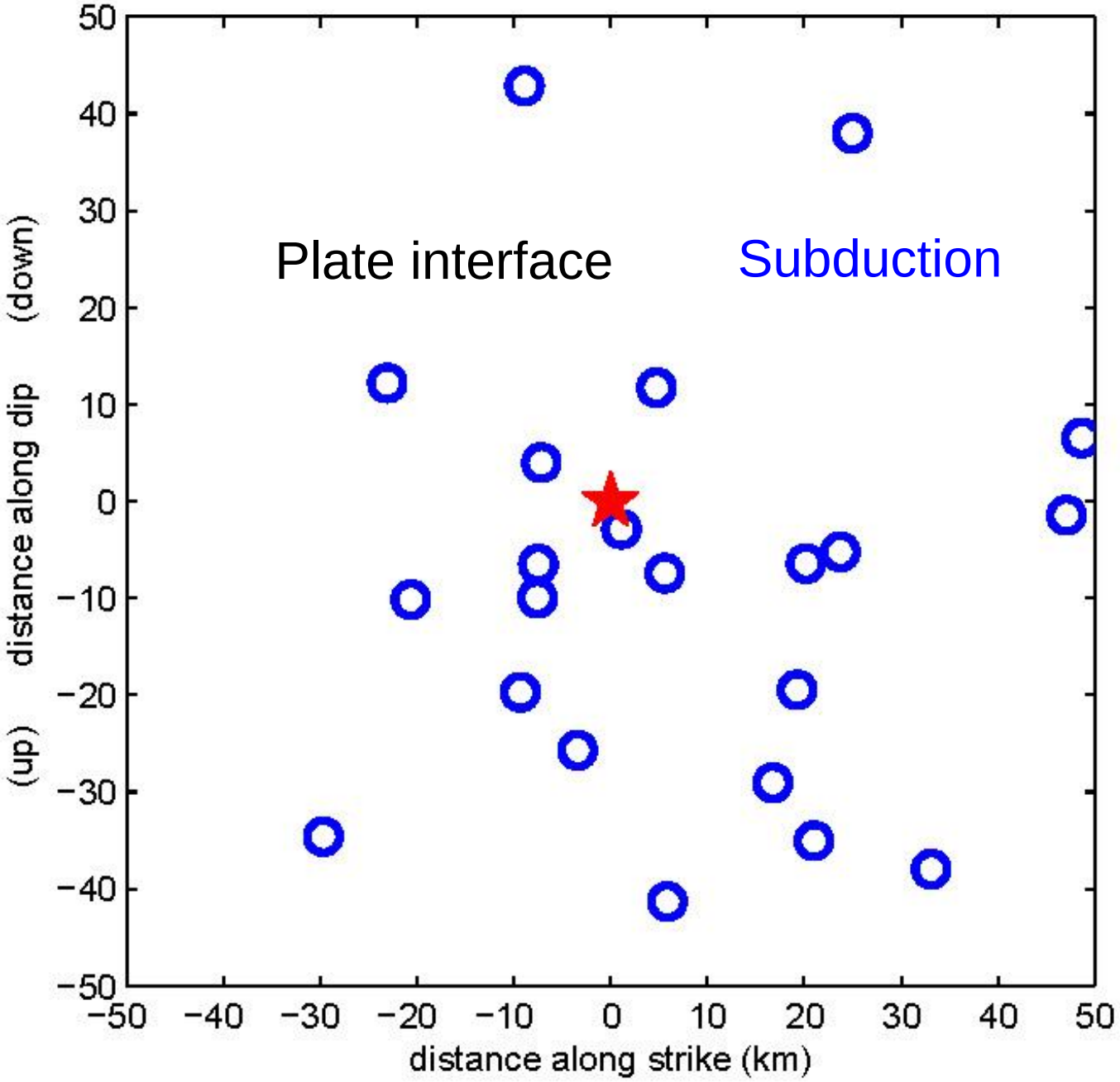


Plate interface
Subduction
distance along dip (down)
(up)
distance along strike (km)
50
40
30
20
10
0
−10
−20
−30
−40
−50
−50
−40
−30
−20
−10
0
10
20
30
40
50

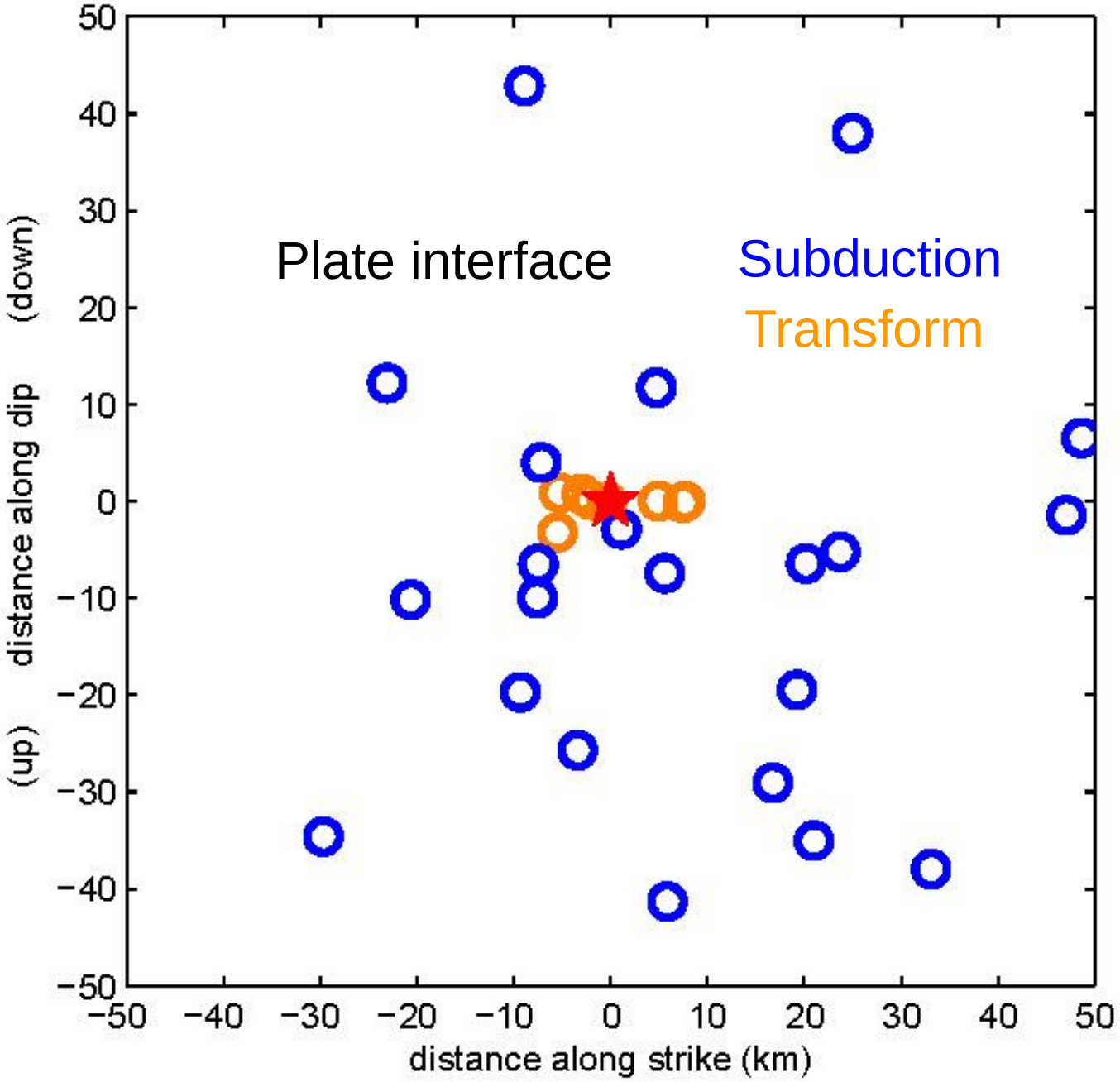
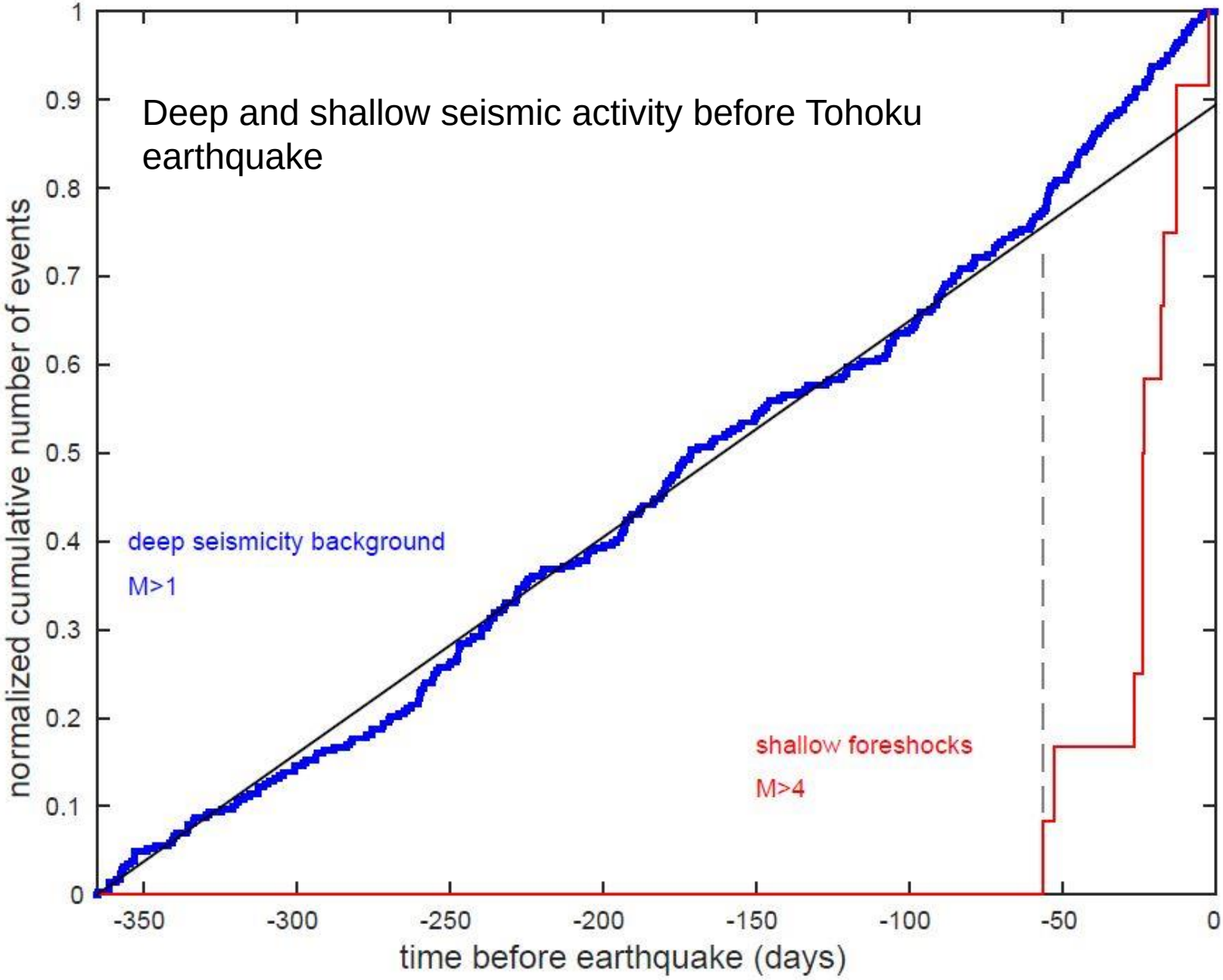
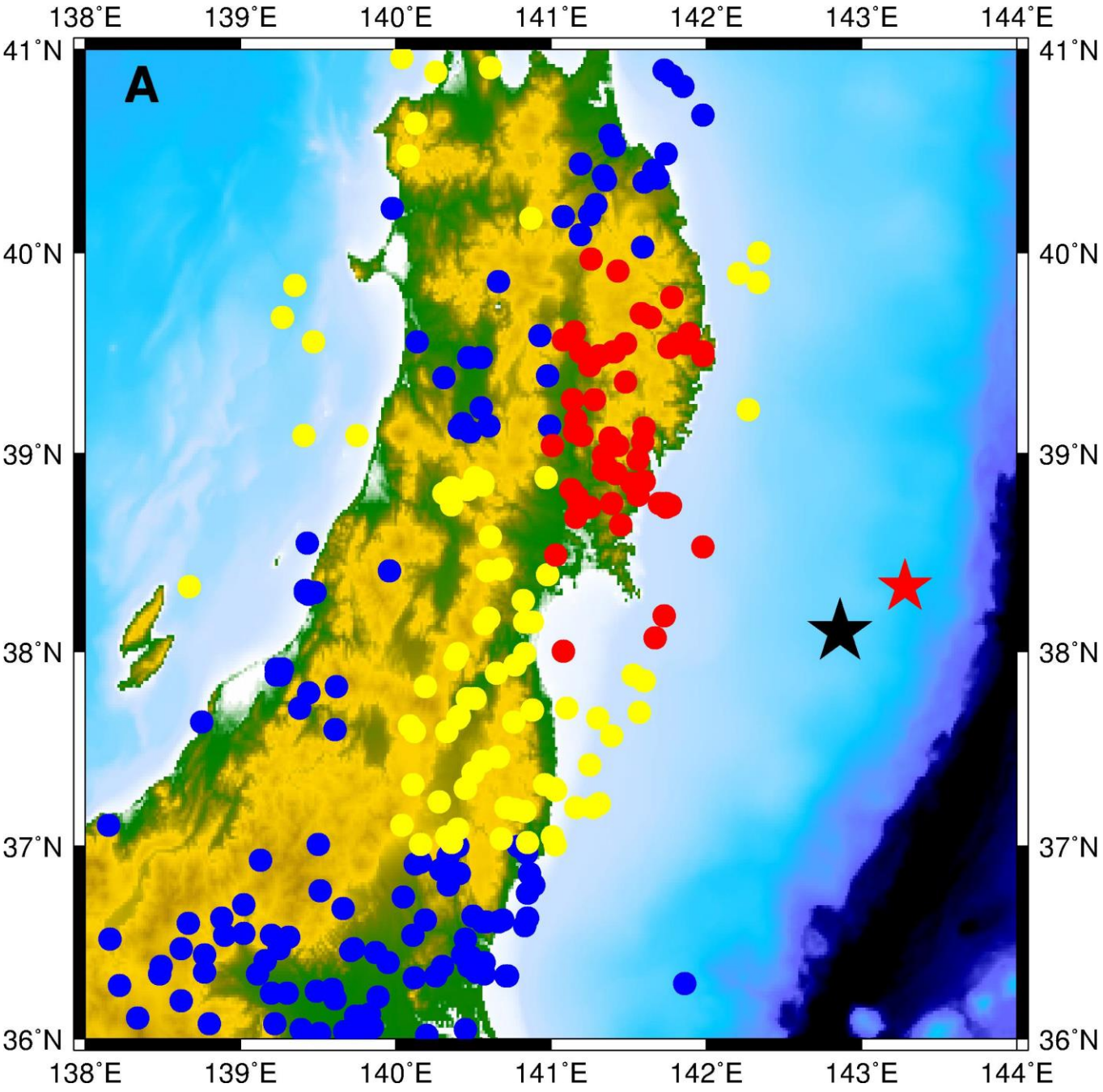
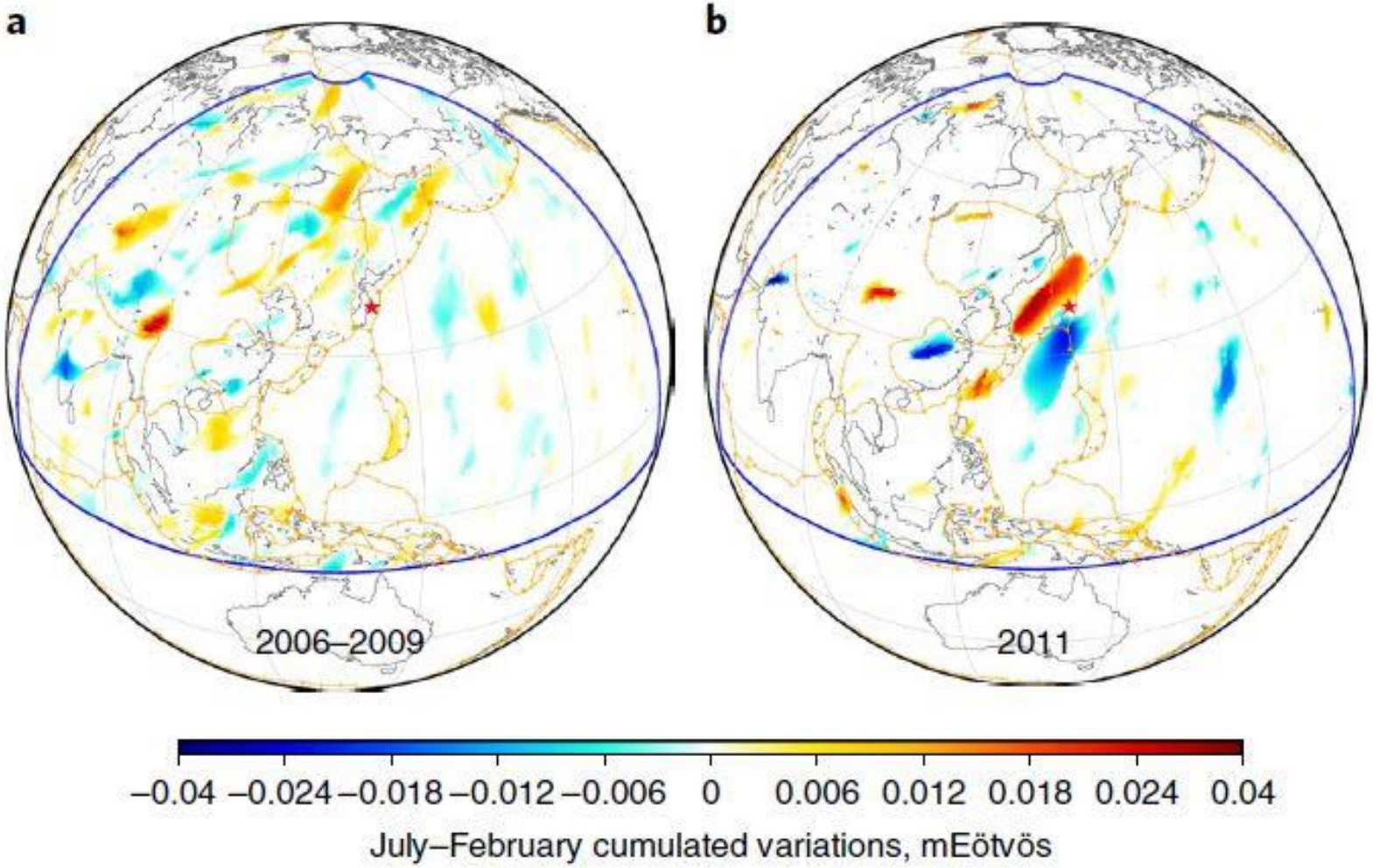


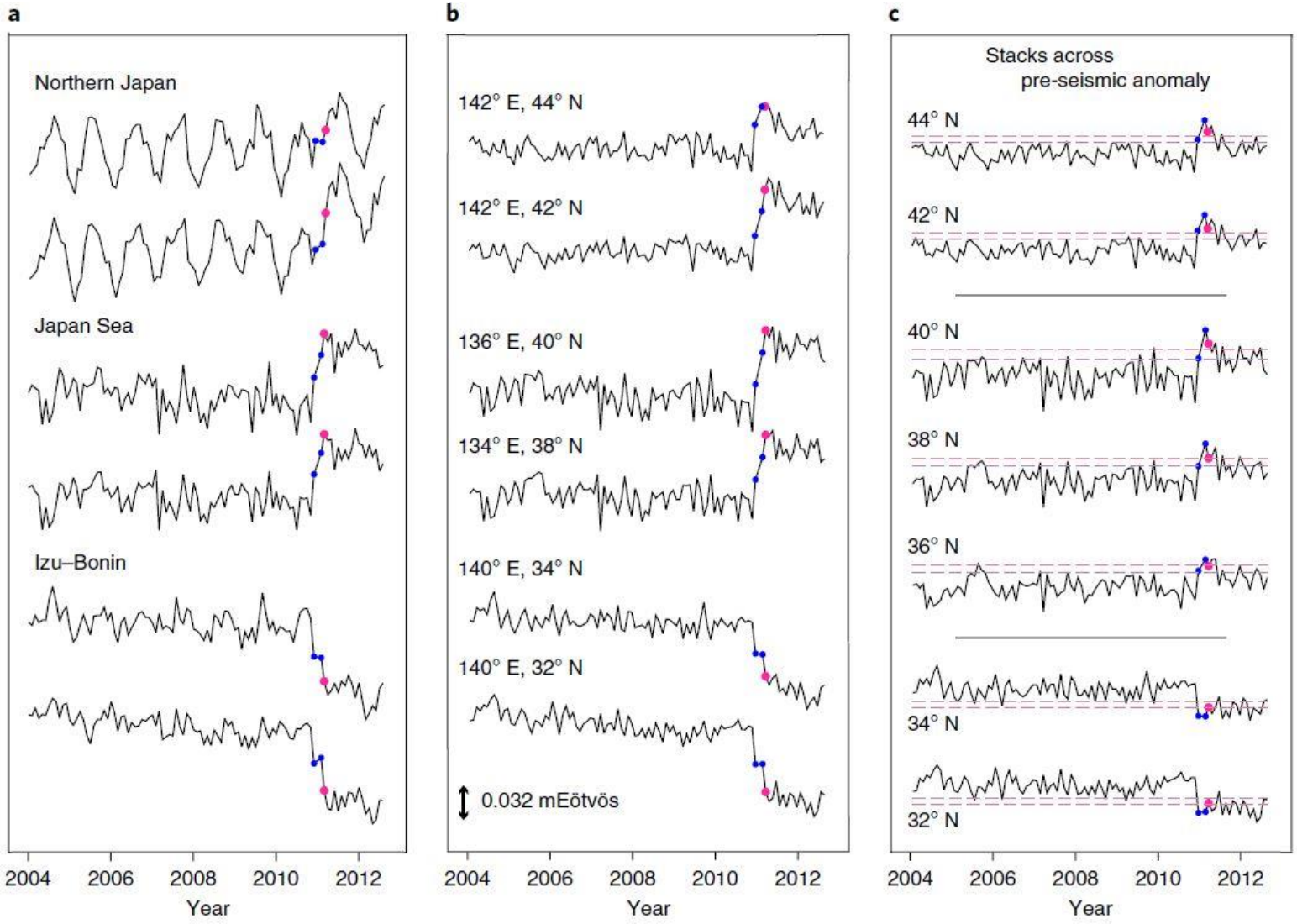
Plate interface
Subduction
Transform
distance along dip
(up)
(down)
distance along strike (km)
50
40
30
20
10
0
−10
−20
−30
−40
−50
−50
−40
−30
−20
−10
0
10
20
30
40
50


Deep and shallow seismic activity before Tohoku earthquake
normalized cumulative number of events
time before earthquake (days)
deep seismicity background
M>1
shallow foreshocks
M>4
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
-350
-300
-250
-200
-150
-100
-50
0


A
138°E
139°E
140°E
141°E
142°E
143°E
144°E
41°N
40°N
39°N
38°N
37°N
36°N



Panet et al. 2018



Time series of the gravity signals at different stages of their analysis. Blue dots: December 2010 and February 2011 values; pink dots: March 2011 value.

Panet et al. 2018

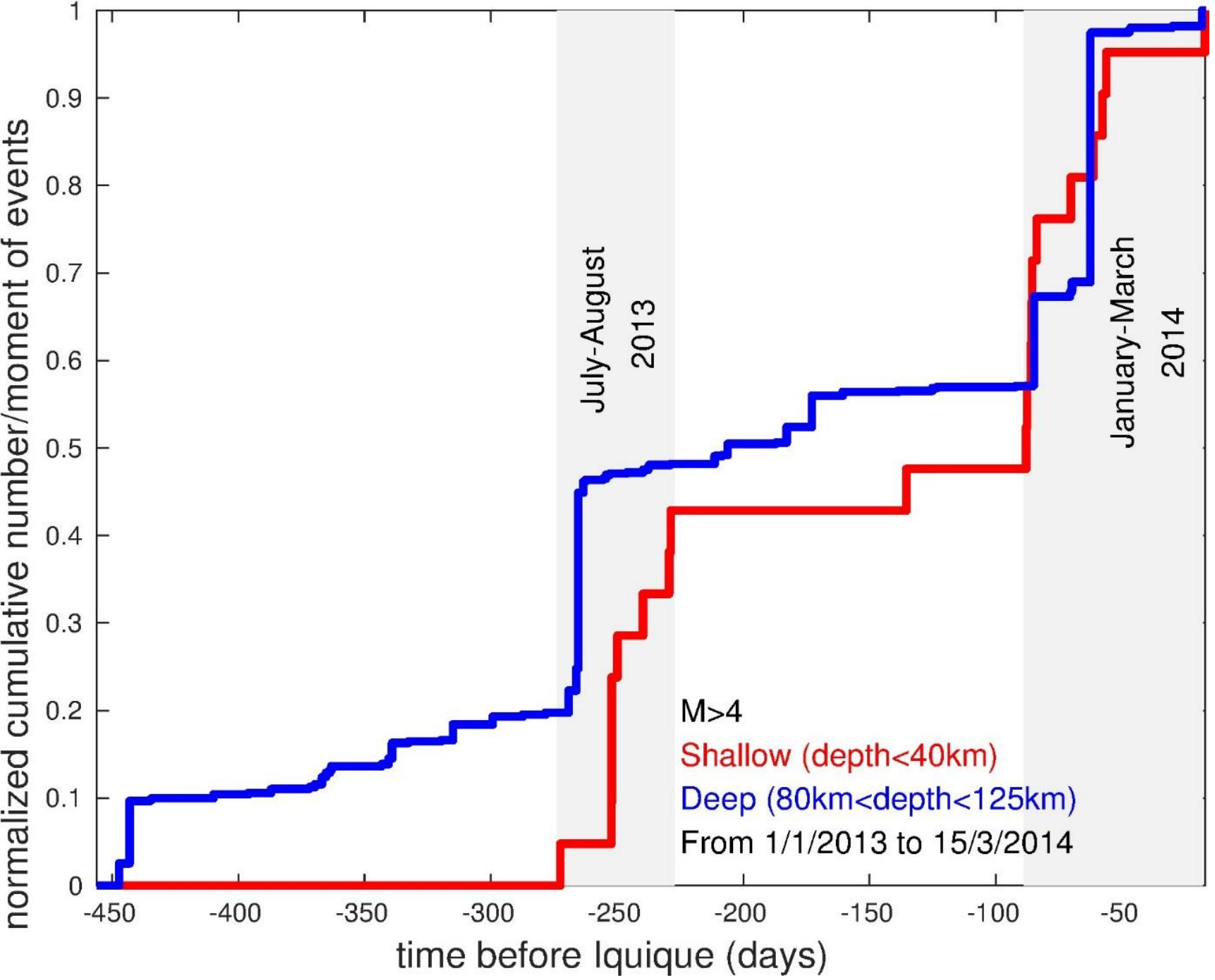
“ We show that this earthquake is the extreme expression of initially silent deformation migrating from depth to the surface [ ] starting a few months before March 2011.”

Panet et al. 2018

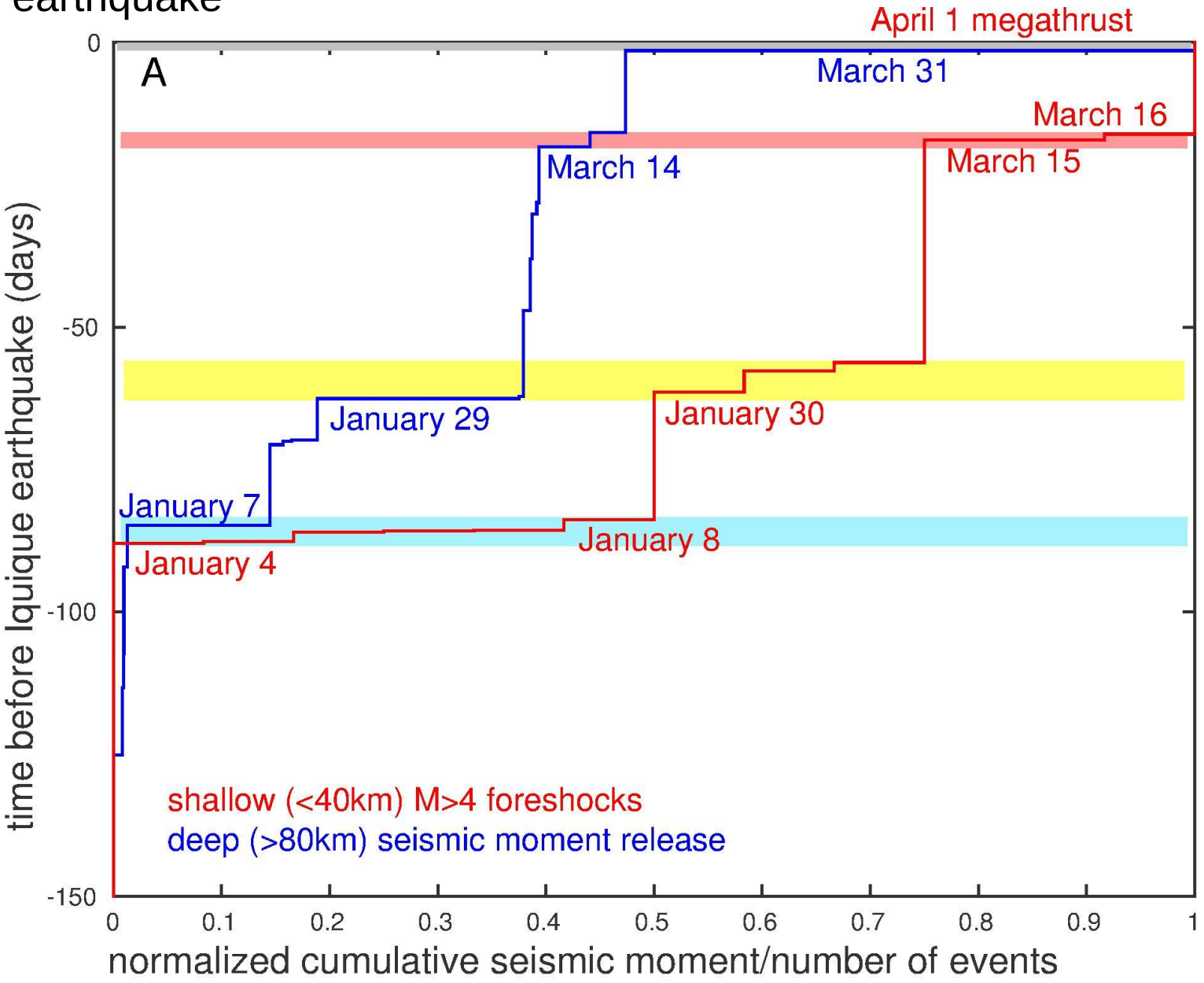
The 2014 M8.2 Iquique, Chile, earthquake

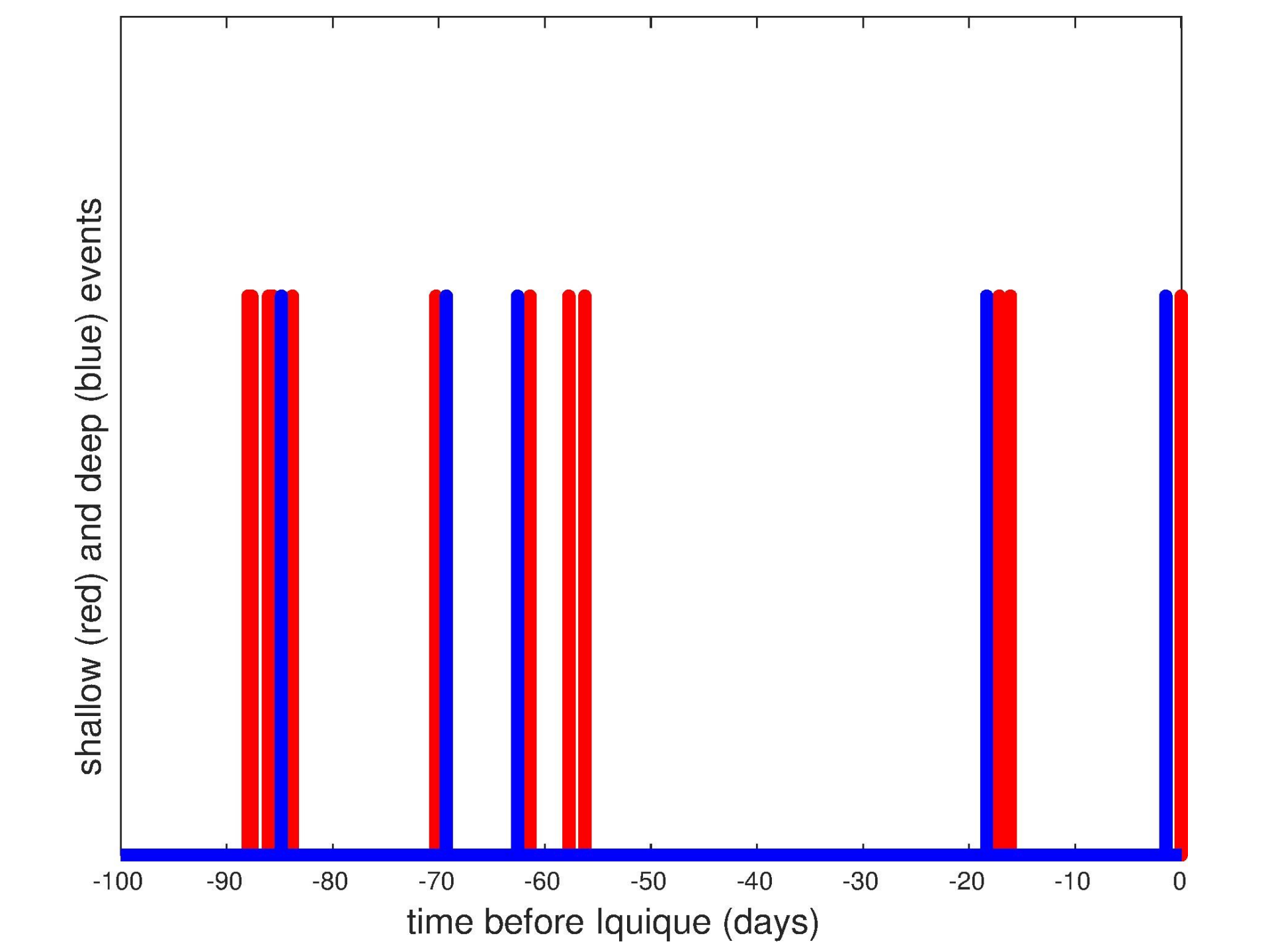
“Accelerations in seismicity started around 270 days before the mainshock”

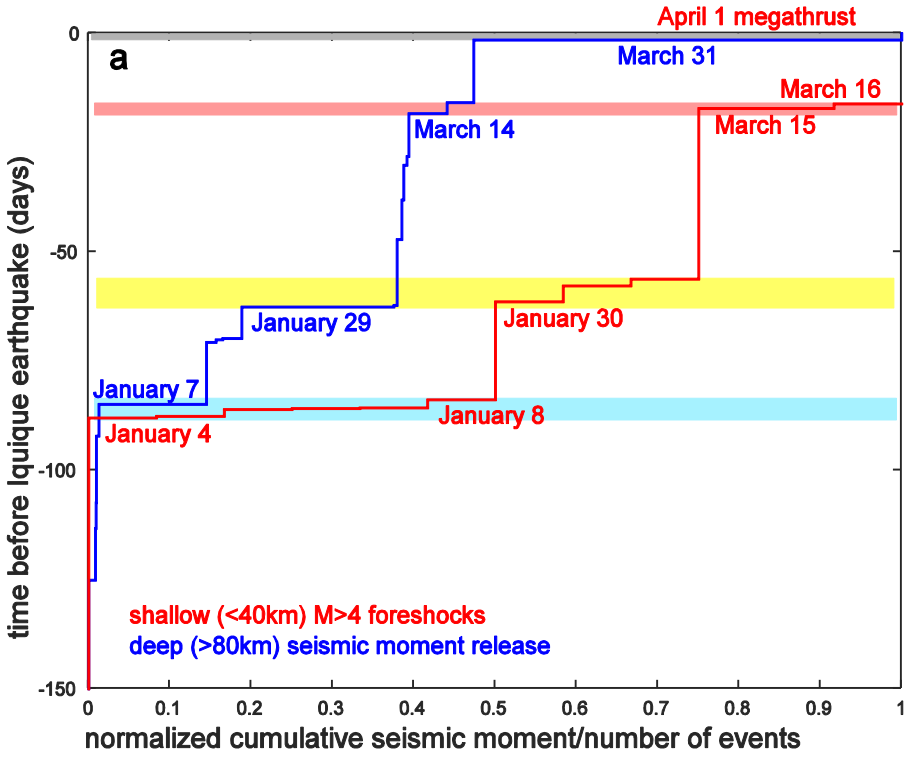
Kato et al., 2016

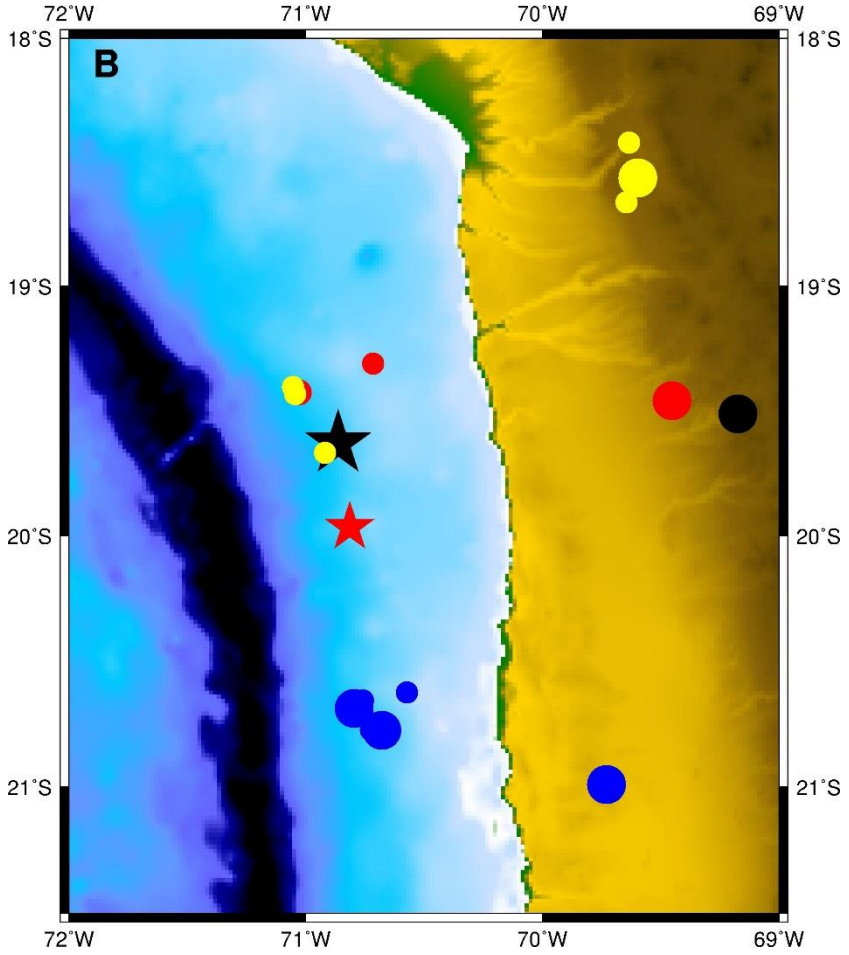

normalized cumulative number/moment of events
time before Iquique (days)
July-August 2013
January-March 2014
M>4
Shallow (depth<40km)
Deep (80km<depth<125km)
From 1/1/2013 to 15/3/2014
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
-450
-400
-350
-300
-250
-200
-150
-100
-50

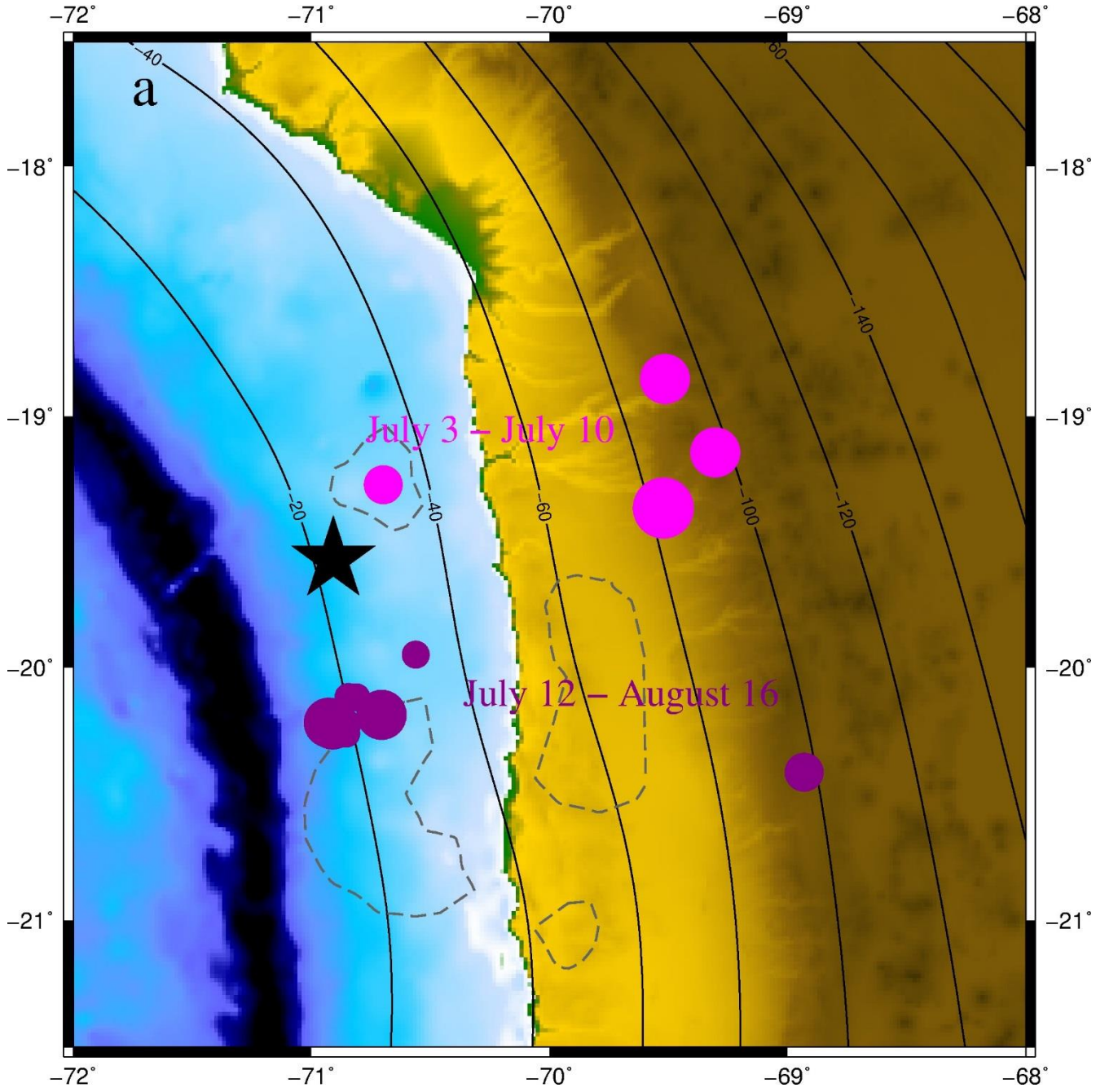
Deep and shallow seismic activity before 2014 *M8.2* Iquique earthquake

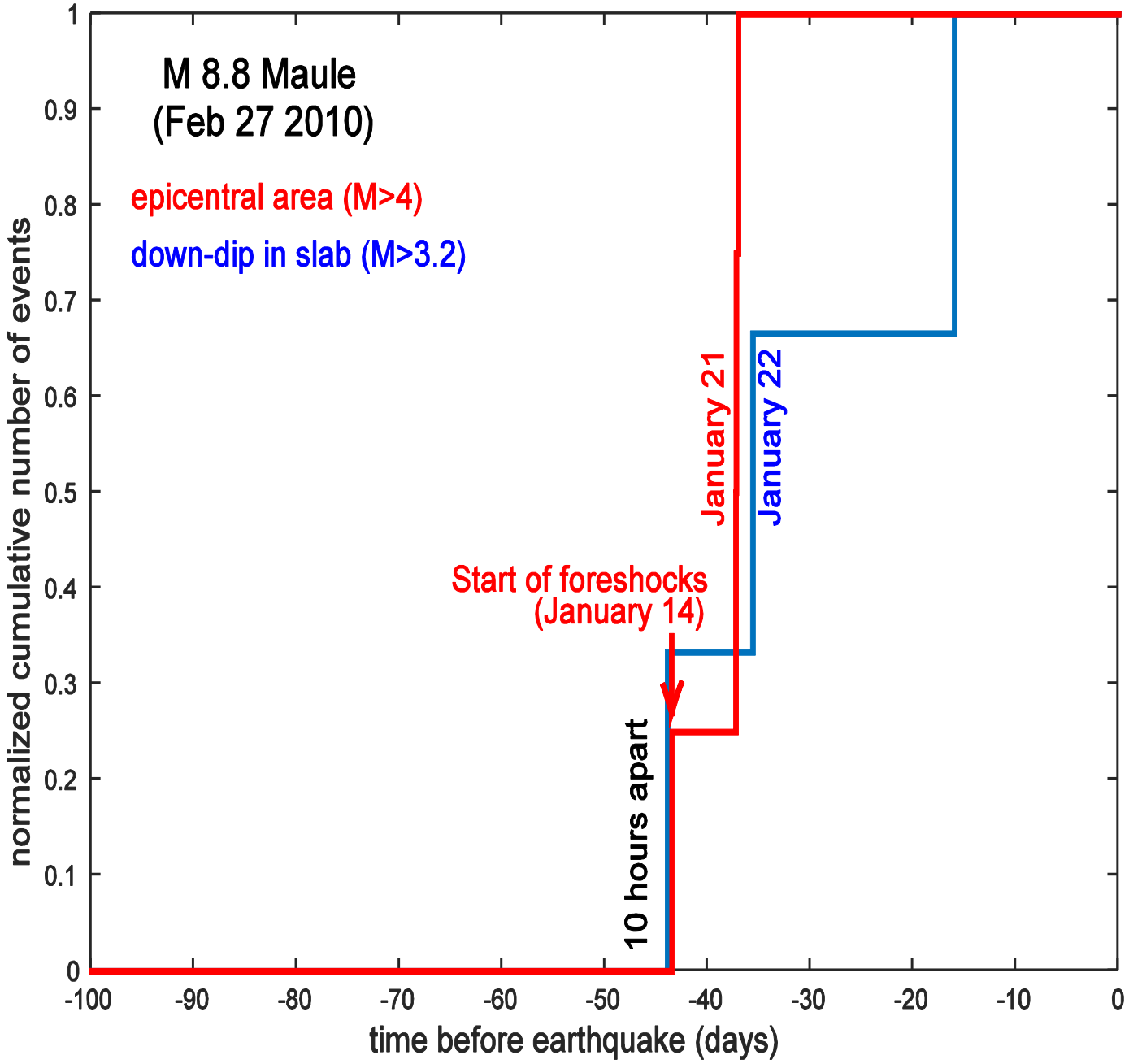


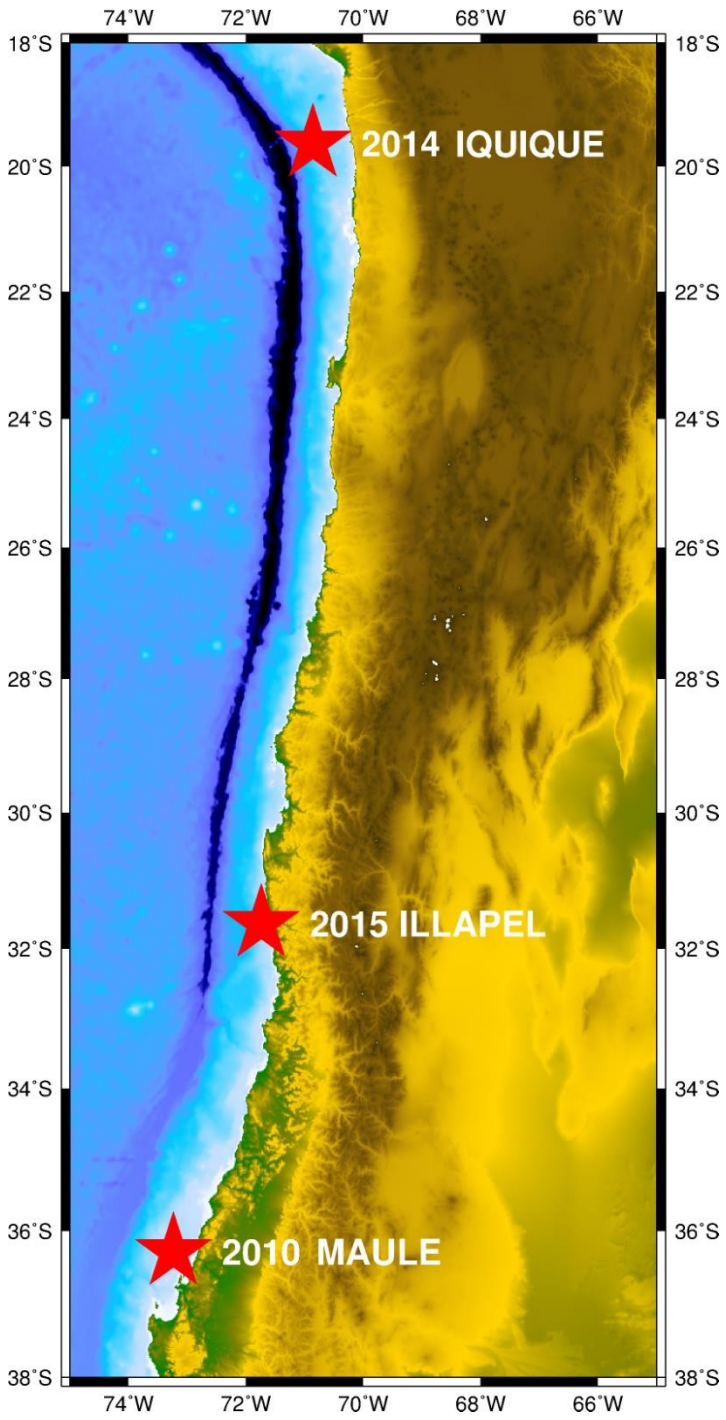

shallow (red) and deep (blue) events
-100
-90
-80
-70
-60
-50
-40
-30
-20
-10
0
time before Iquique (days)

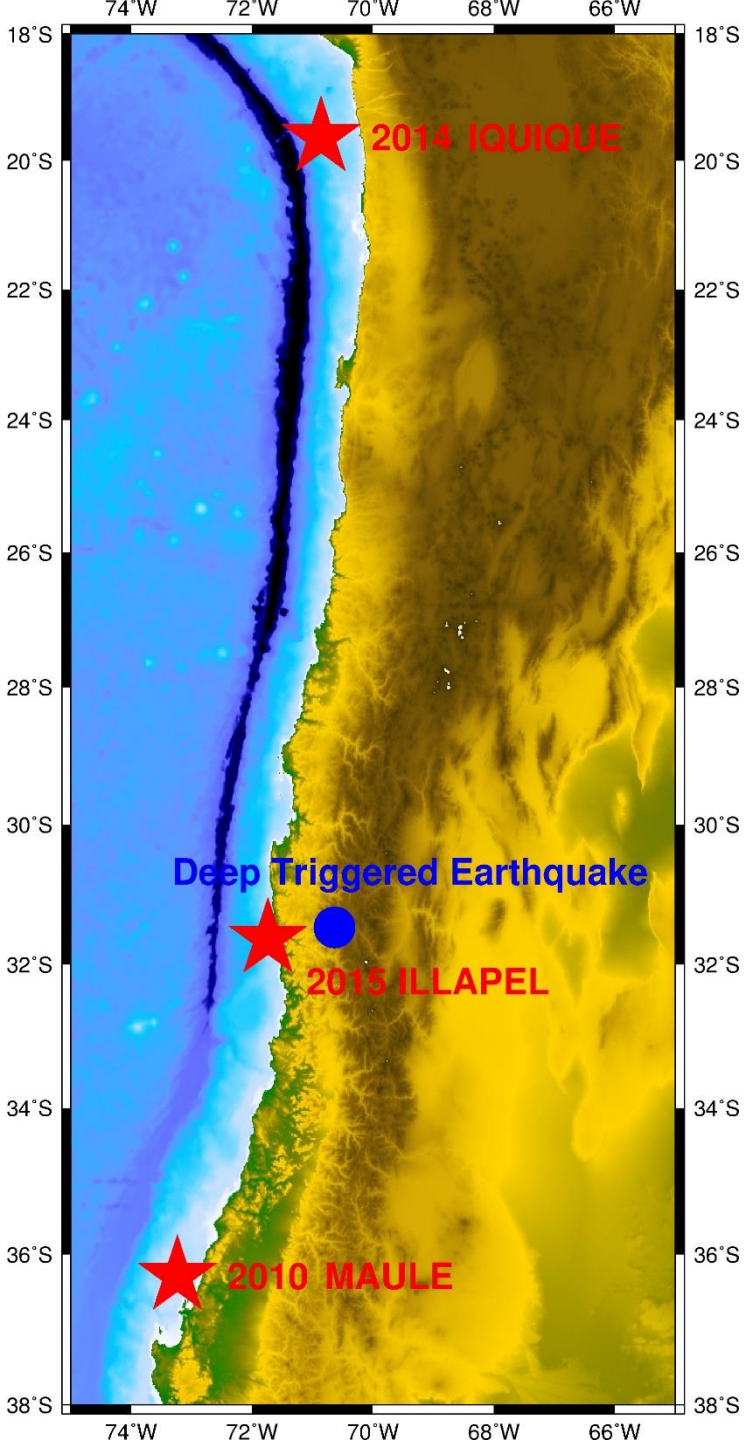

a
April 1 megathrust
March 31
March 16
March 14
March 15
January 29
January 30
January 7
January 8
January 4
shallow (<40km) M>4 foreshocks
deep (>80km) seismic moment release
time before Iquique earthquake (days)
normalized cumulative seismic moment/number of events
0
-50
-100
-150
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

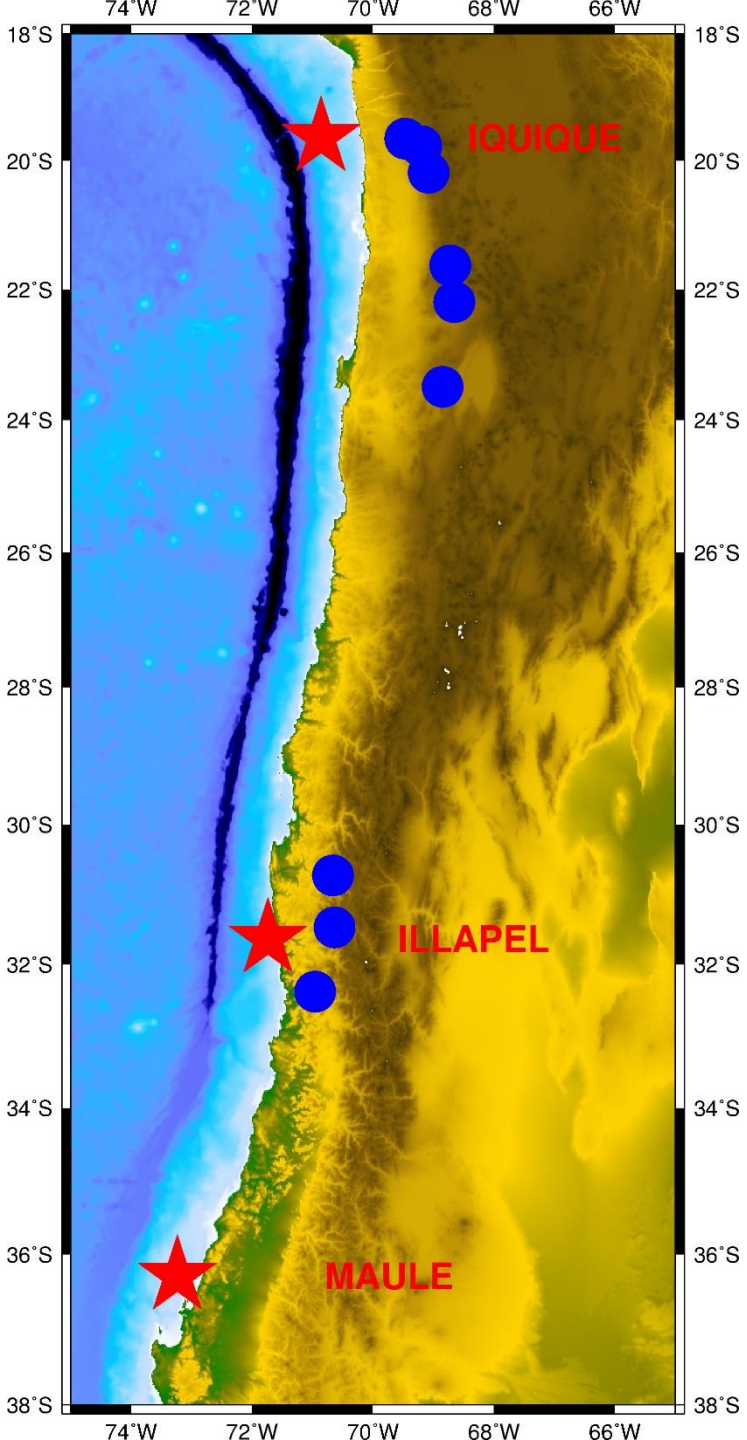

B
72°W
71°W
70°W
69°W
18°S
19°S
20°S
21°S

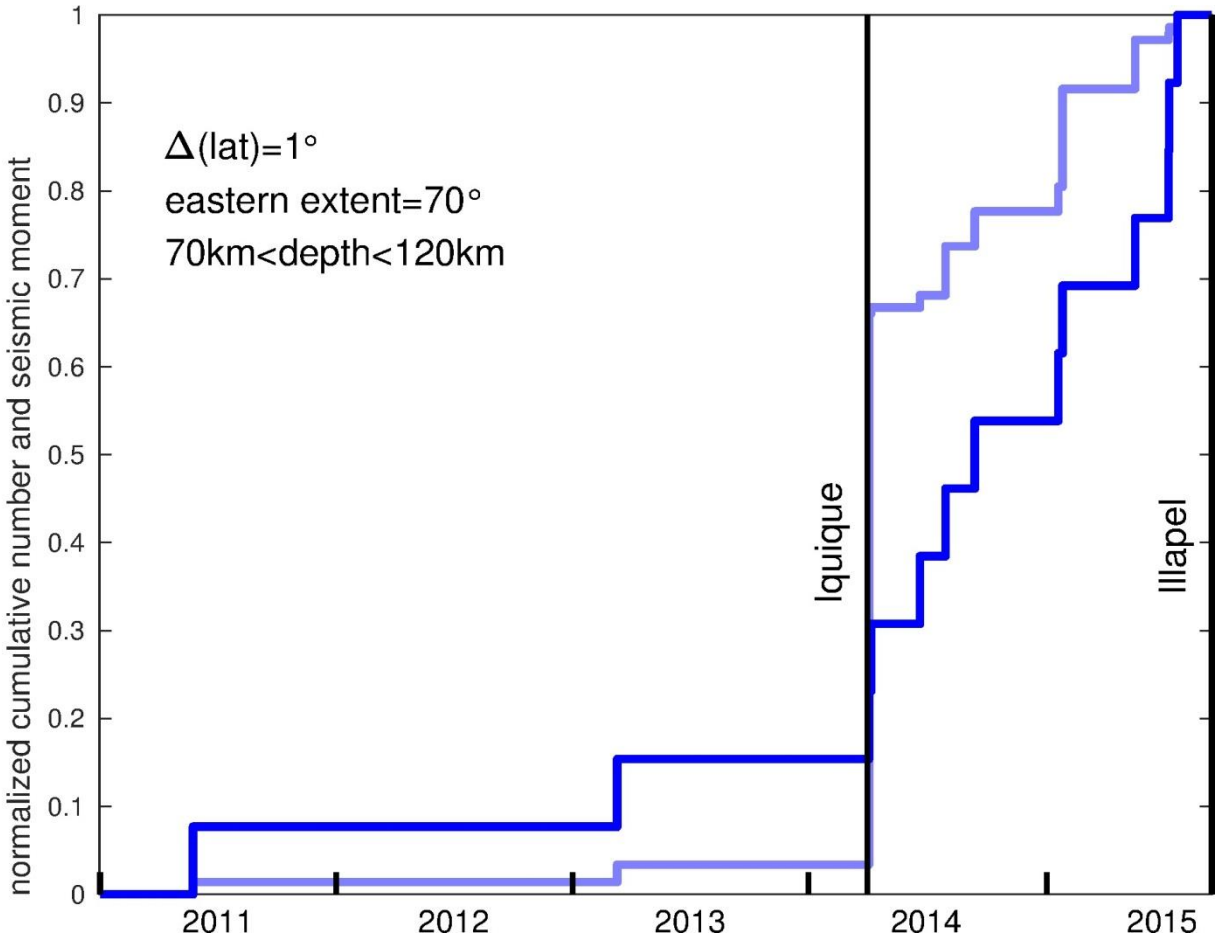

a
−72°
−71°
−70°
−69°
−68°
−18°
−19°
−20°
−21°
40
60
140
20
40
60
100
120
July 3 – July 10
July 12 – August 16

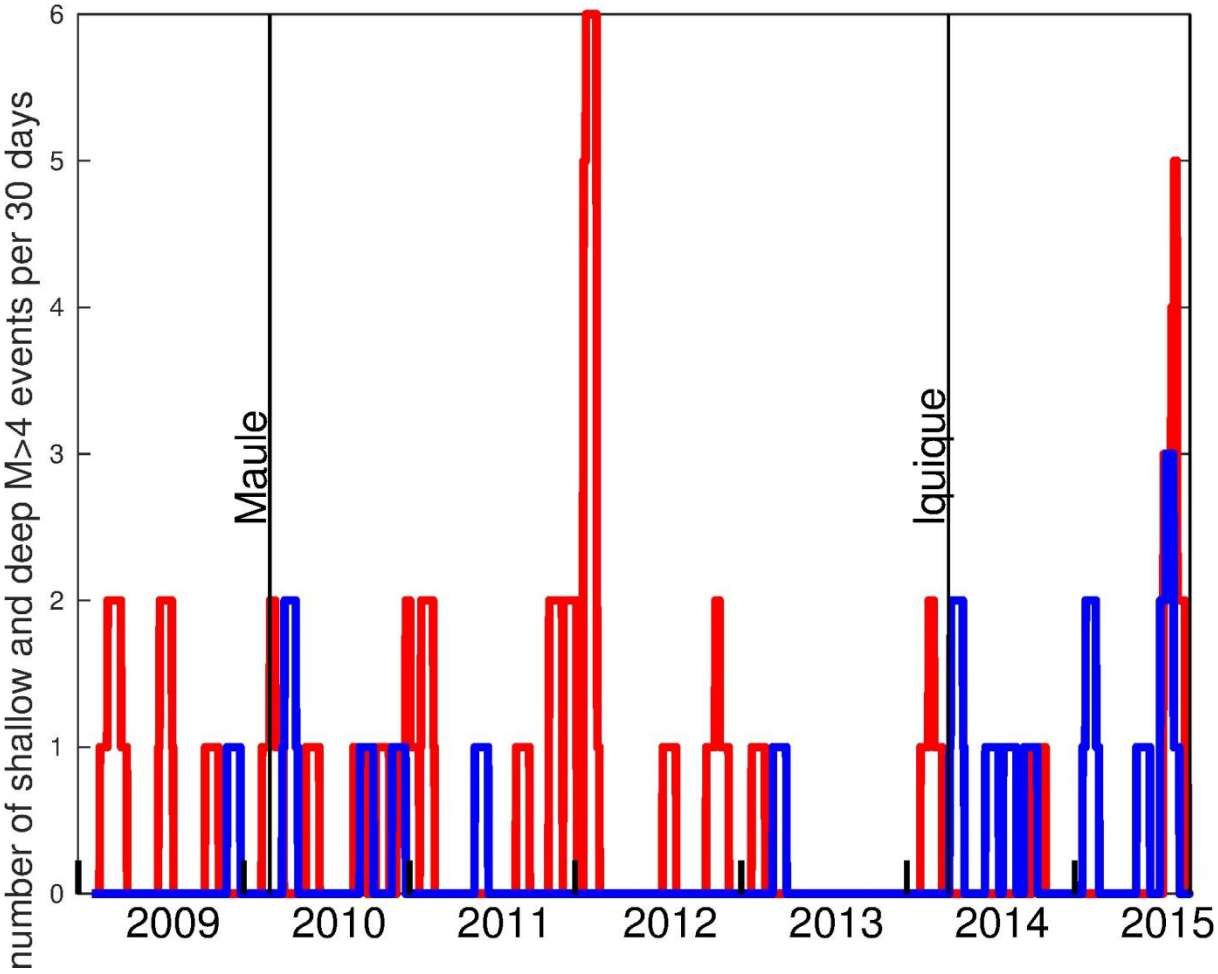

M 8.8 Maule
(Feb 27 2010)
epicentral area (M>4)
down-dip in slab (M>3.2)
January 21
January 22
Start of foreshocks
(January 14)
10 hours apart
normalized cumulative number of events
time before earthquake (days)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
-100
-90
-80
-70
-60
-50
-40
-30
-20
-10
0

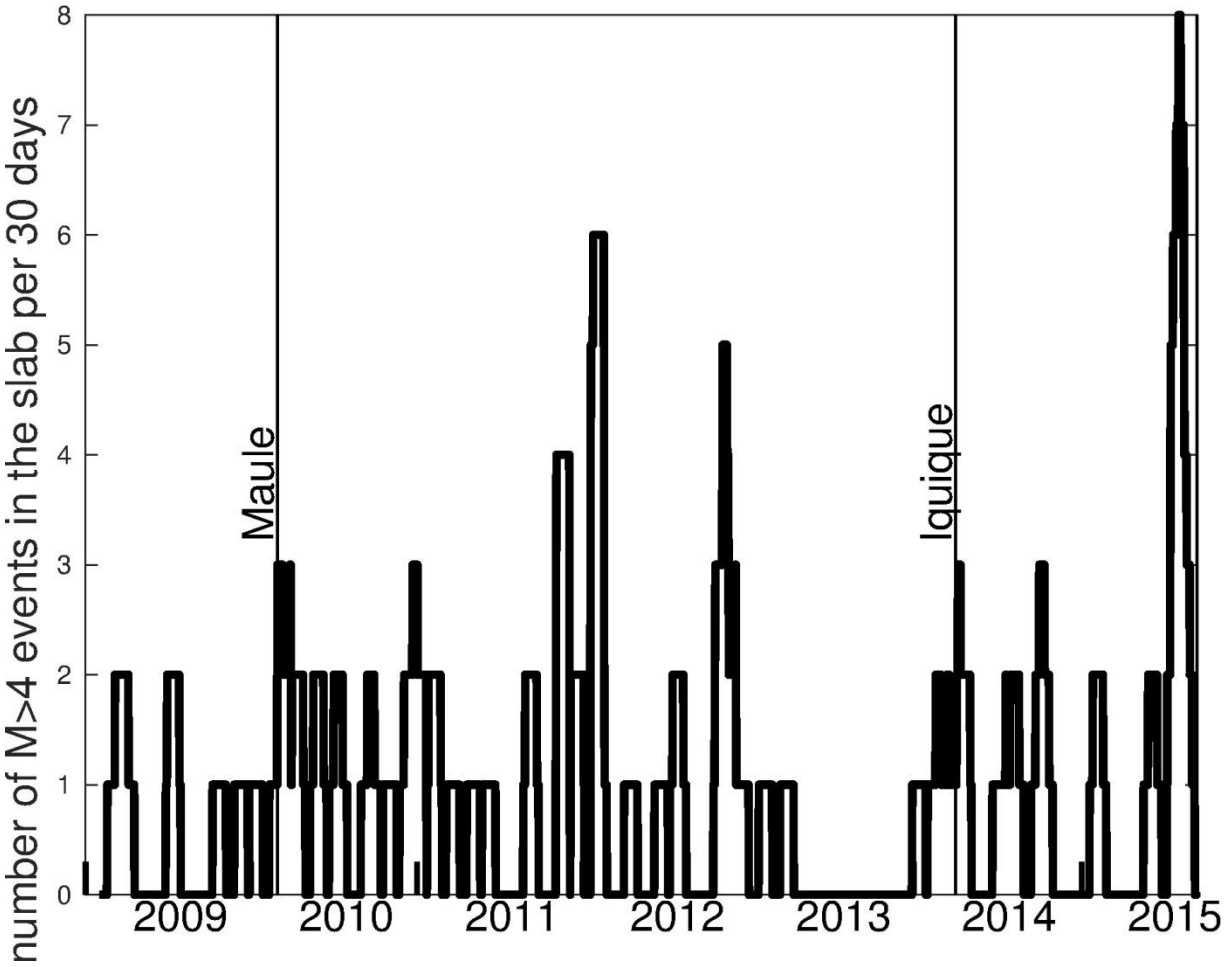

74°W
72°W
70°W
68°W
66°W
18°S
20°S
22°S
24°S
26°S
28°S
30°S
32°S
34°S
36°S
38°S
2014 IQUIQUE
2015 ILLAPEL
2010 MAULE

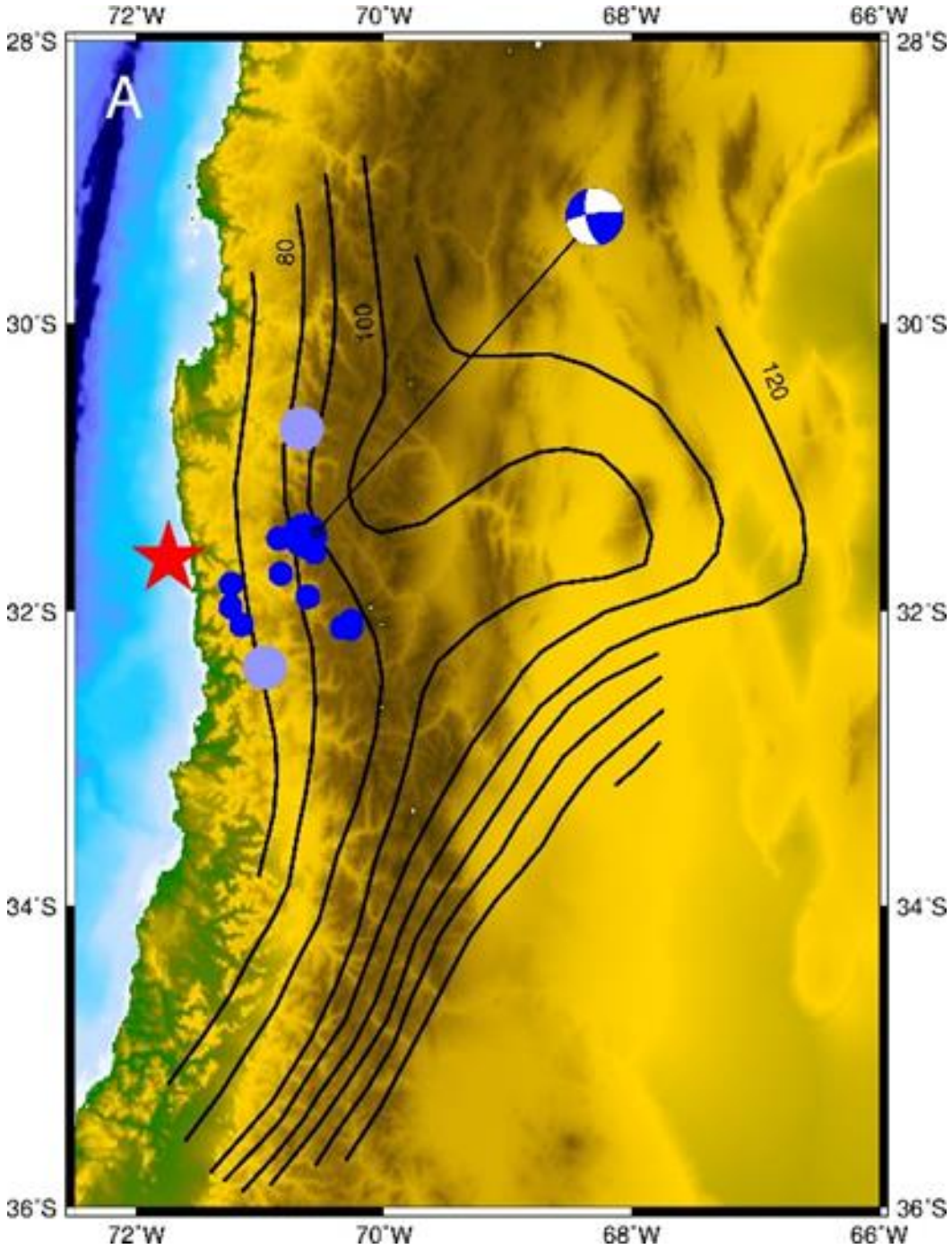

74°W
72°W
70°W
68°W
66°W
18°S
20°S
22°S
24°S
26°S
28°S
30°S
32°S
34°S
36°S
38°S
2014 IQUIQUE
Deep Triggered Earthquake
2015 ILLAPEL
2010 MAULE

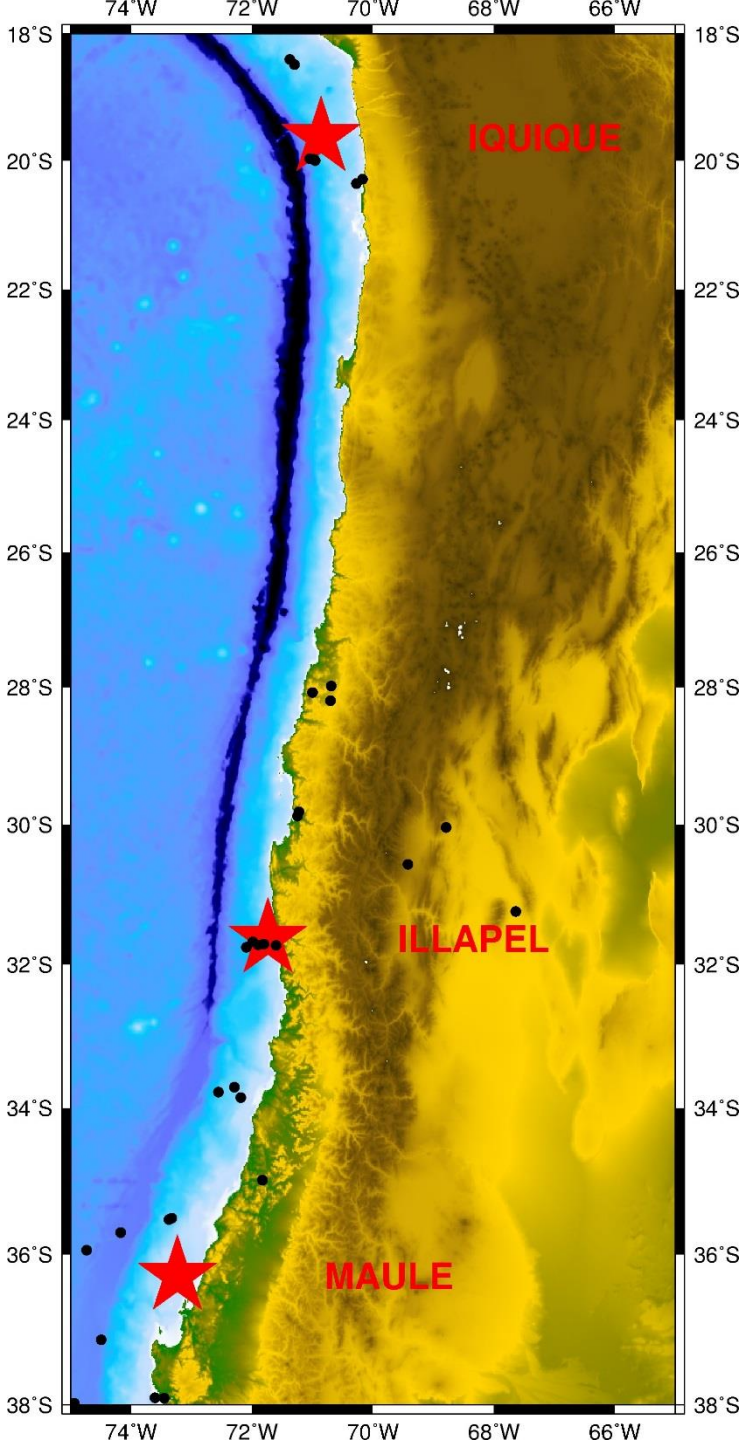

74°W
72°W
70°W
68°W
66°W
18°S
20°S
22°S
24°S
26°S
28°S
30°S
32°S
34°S
36°S
38°S
IQUIQUE
ILLAPEL
MAULE

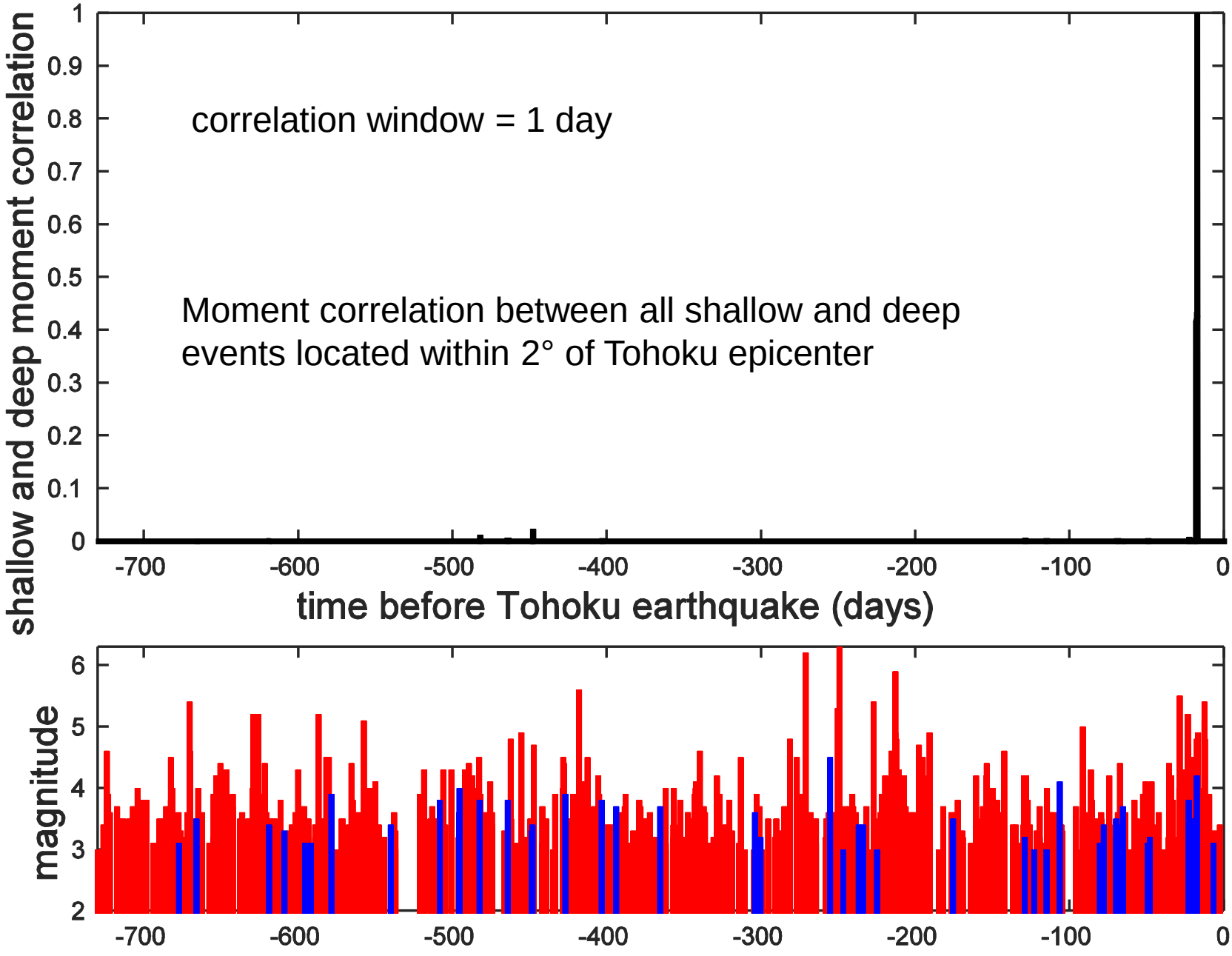

normalized cumulative number and seismic moment
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2011
2012
2013
2014
2015
Δ(lat)=1°
eastern extent=70°
70km<depth<120km
Iquique
Illapel

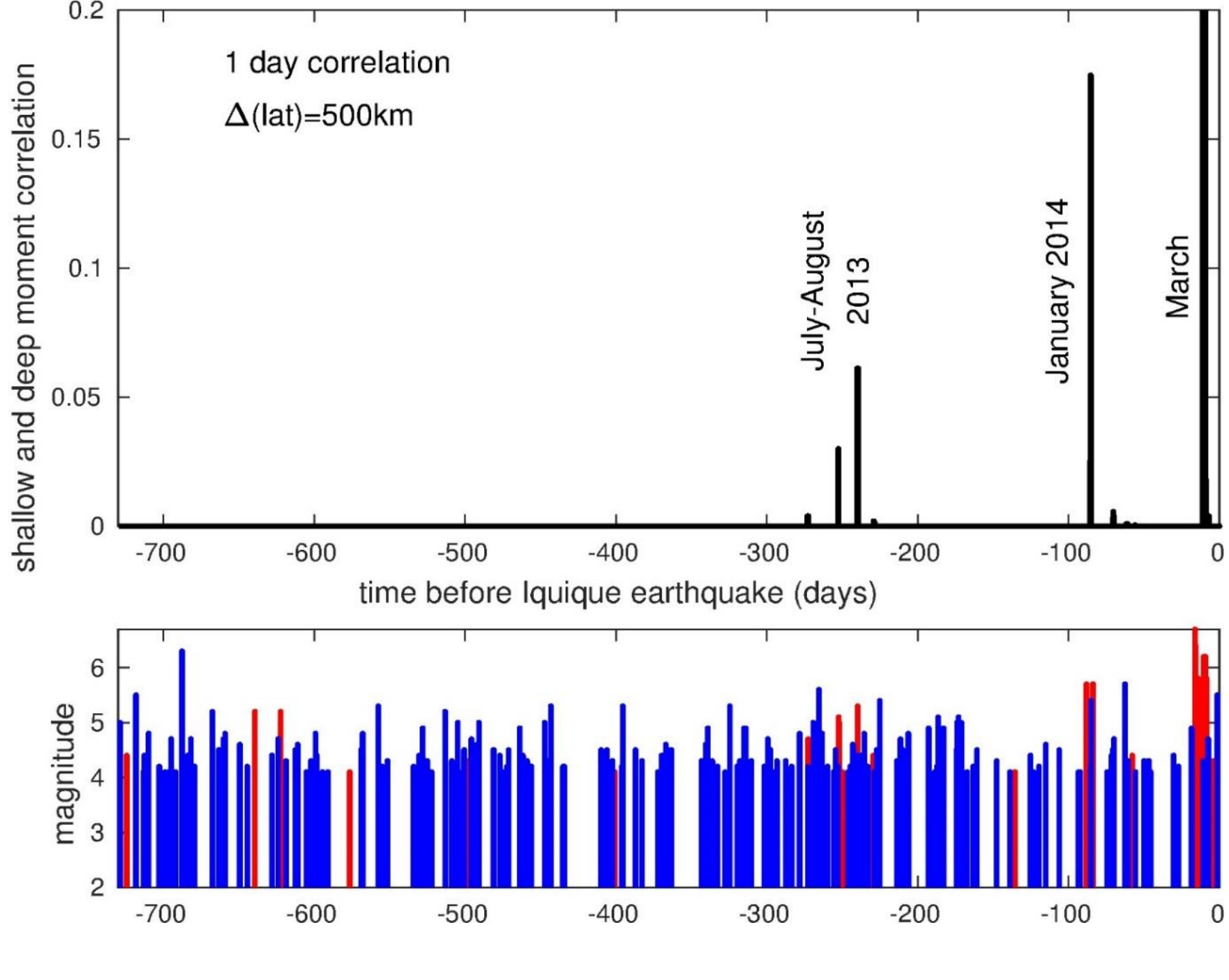

number of shallow and deep M>4 events per 30 days
0
1
2
3
4
5
6
Maule
Iquique
2009
2010
2011
2012
2013
2014
2015

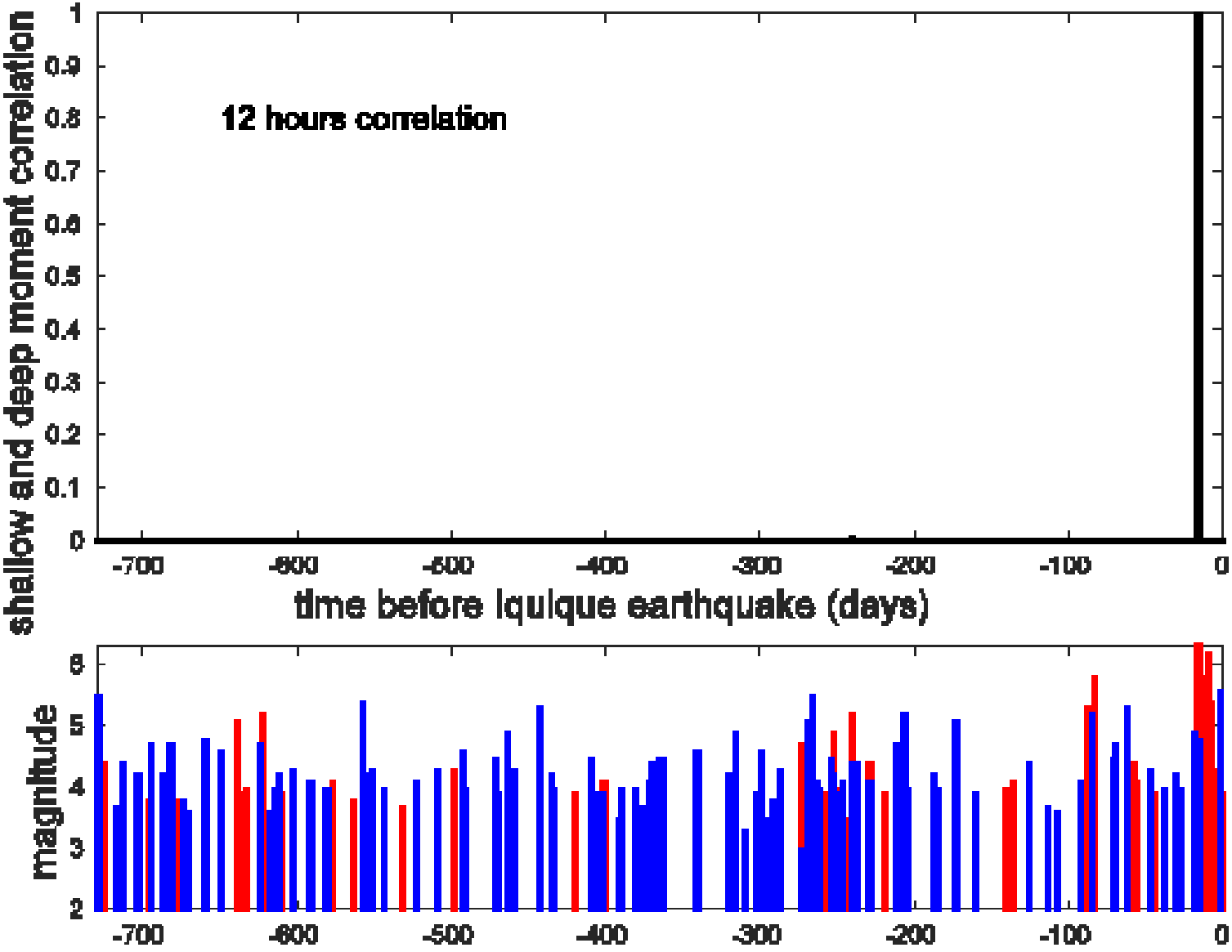

number of M>4 events in the slab per 30 days
0
1
2
3
4
5
6
7
8
Maule
Iquique
2009
2010
2011
2012
2013
2014
2015

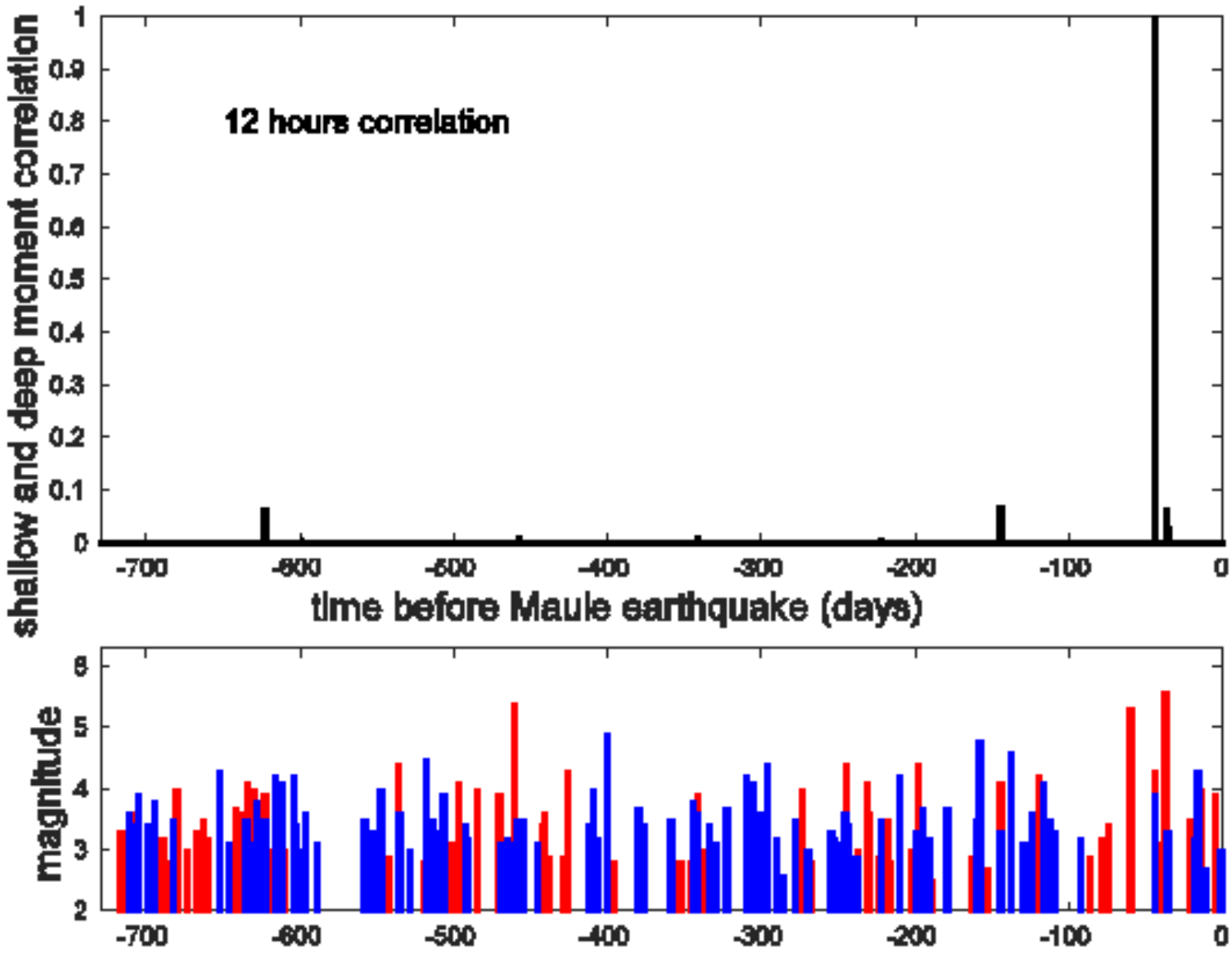

A
72°W
70°W
68°W
66°W
28°S
30°S
32°S
34°S
36°S
80
100
120


74°W
72°W
70°W
68°W
66°W
18°S
20°S
22°S
24°S
26°S
28°S
30°S
32°S
34°S
36°S
38°S
IQUIQUE
ILLAPEL
MAULE


shallow and deep moment correlation
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
correlation window = 1 day
Moment correlation between all shallow and deep events located within 2° of Tohoku epicenter
-700
-600
-500
-400
-300
-200
-100
0
time before Tohoku earthquake (days)
magnitude
6
5
4
3
2
-700
-600
-500
-400
-300
-200
-100
0


1 day correlation
Δ(lat)=500km
shallow and deep moment correlation
0.2
0.15
0.1
0.05
0
July-August
2013
January 2014
March
-700
-600
-500
-400
-300
-200
-100
0
time before Iquique earthquake (days)
magnitude
6
5
4
3
2


12 hours correlation
shallow and deep moment correlation
time before Iquique earthquake (days)
magnitude
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-700
-600
-500
-400
-300
-200
-100
0
8
5
4
3
2

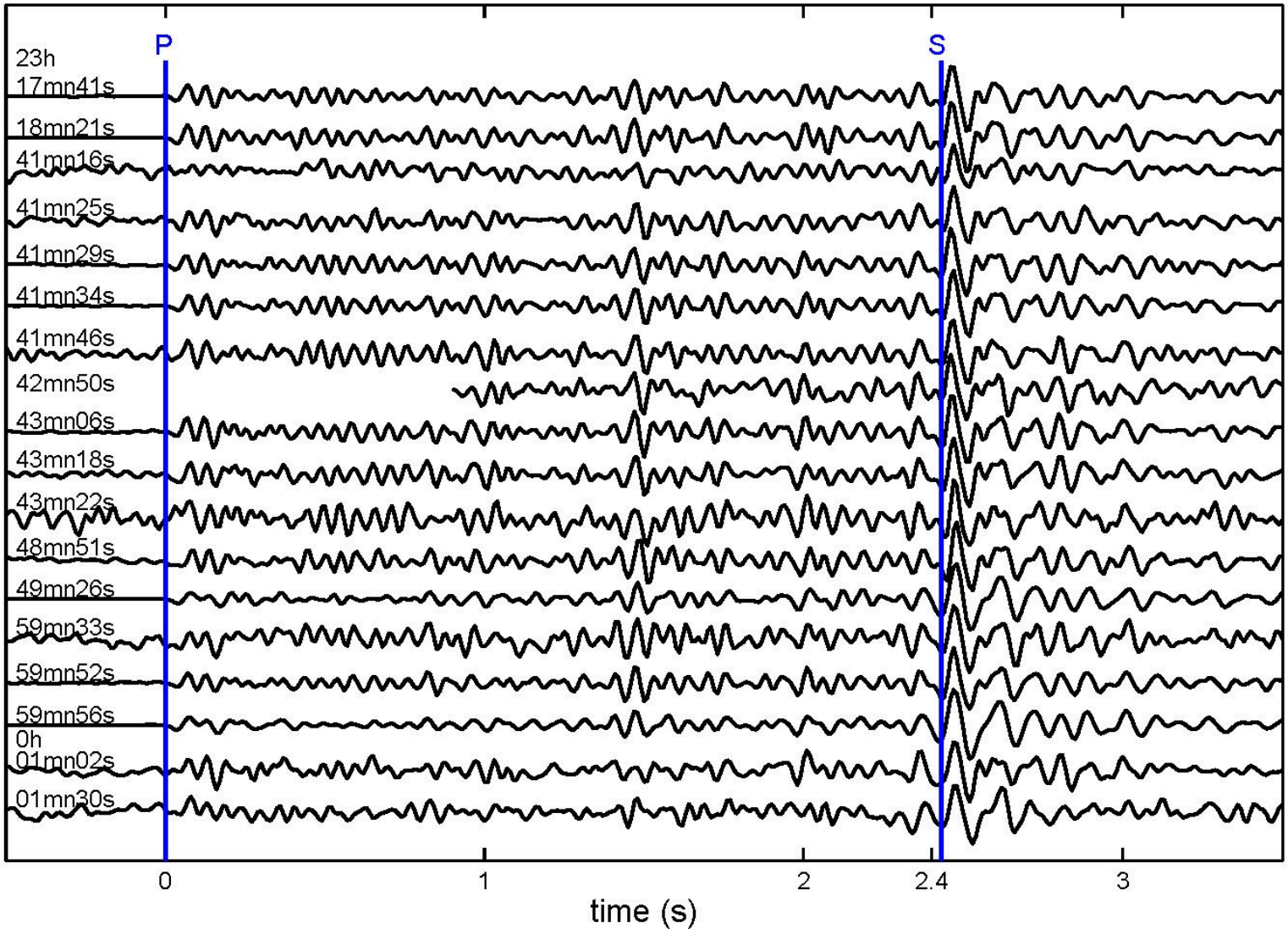

shallow and deep moment correlation
12 hours correlation
time before Maule earthquake (days)
magnitude
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-700
-600
-500
-400
-300
-200
-100
0
6
5
4
3
2

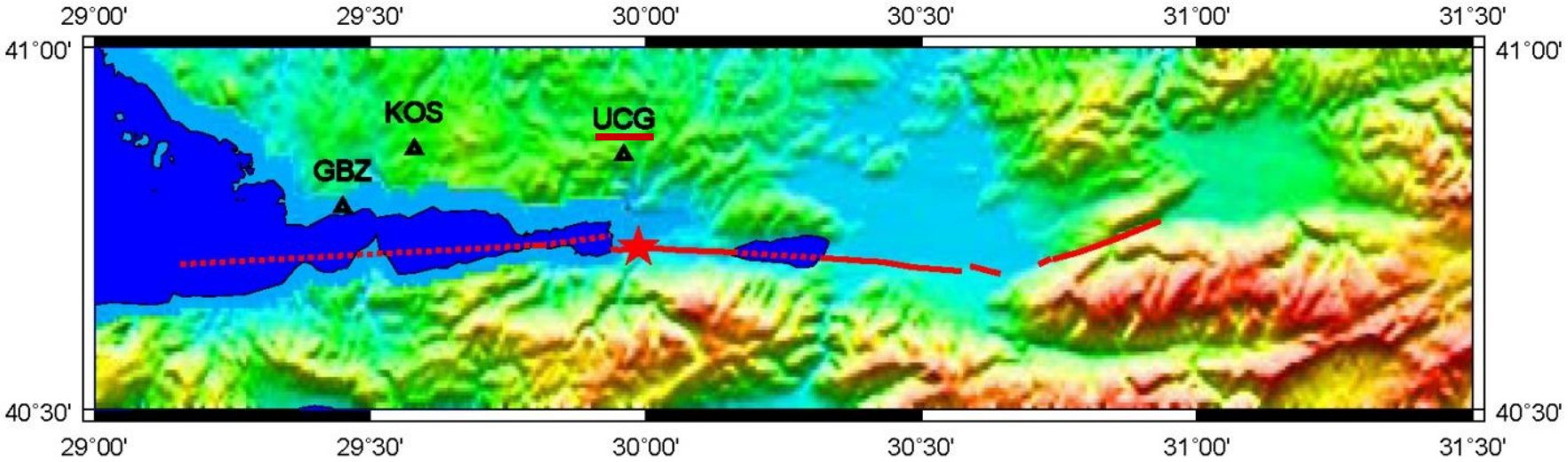
Seismic activity increases deep (~100km) in the slab before several giant subduction earthquakes.

This moderate activity is spread over a broad range of the slab and is synchronized with bursts of activity in the seismogenic zone.

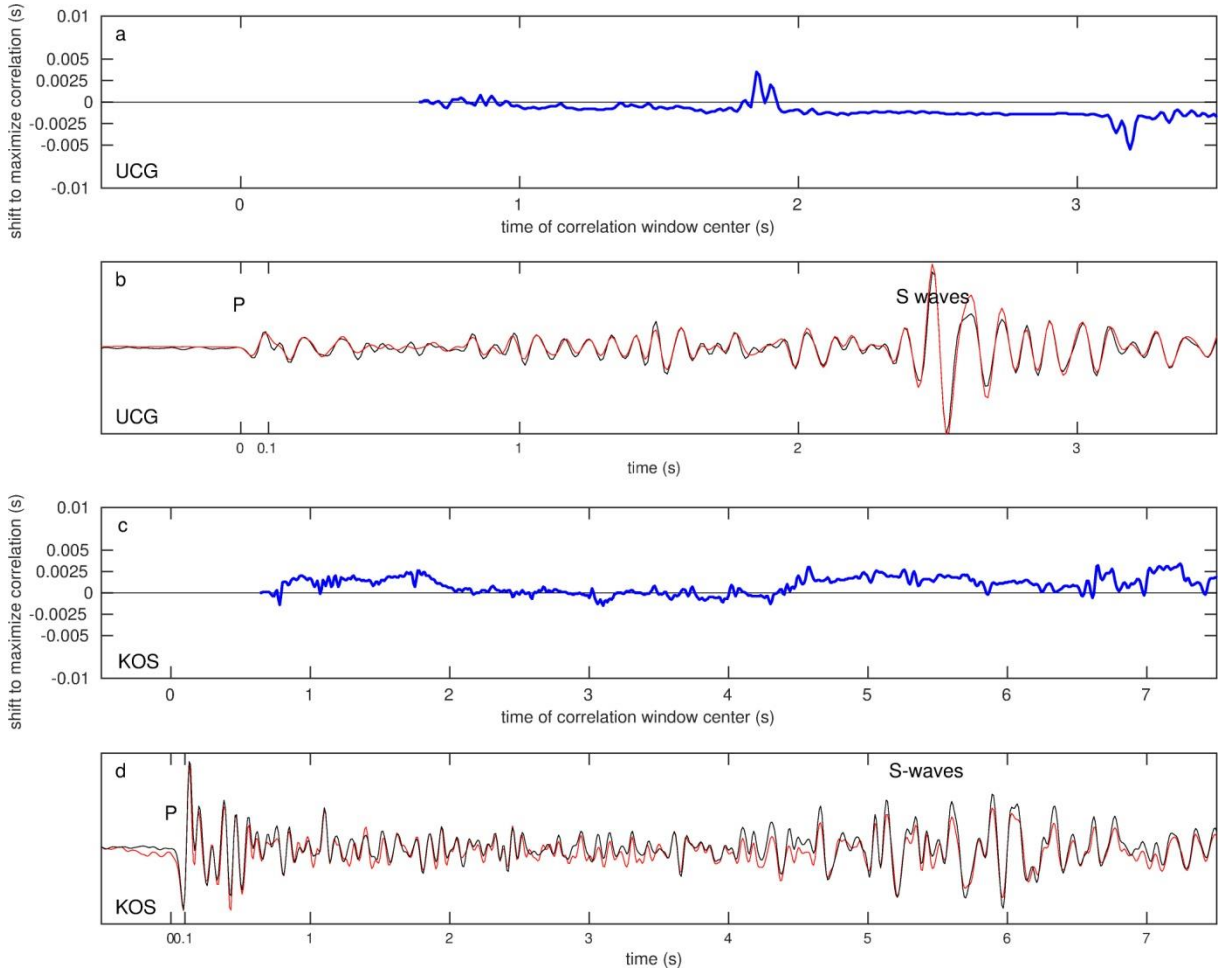
Some characteristics of this activity are reminiscent of those of SSE's: Small deformation/slip occurring over a broad spatial range over a period of a few months.

18 shocks are visible in the 6 triggerred windows:





The 150km-long Izmit rupture and the closest stations to the epicenter


a
UCG
shift to maximize correlation (s)
0.01
0.005
0.0025
0
-0.0025
-0.005
-0.01
0
1
2
3
time of correlation window center (s)
b
P
S waves
UCG
0
0.1
1
2
3
time (s)
c
KOS
shift to maximize correlation (s)
0.01
0.005
0.0025
0
-0.0025
-0.005
-0.01
0
1
2
3
4
5
6
7
time of correlation window center (s)
d
P
S-waves
KOS
0
0.1
1
2
3
4
5
6
7
time (s)