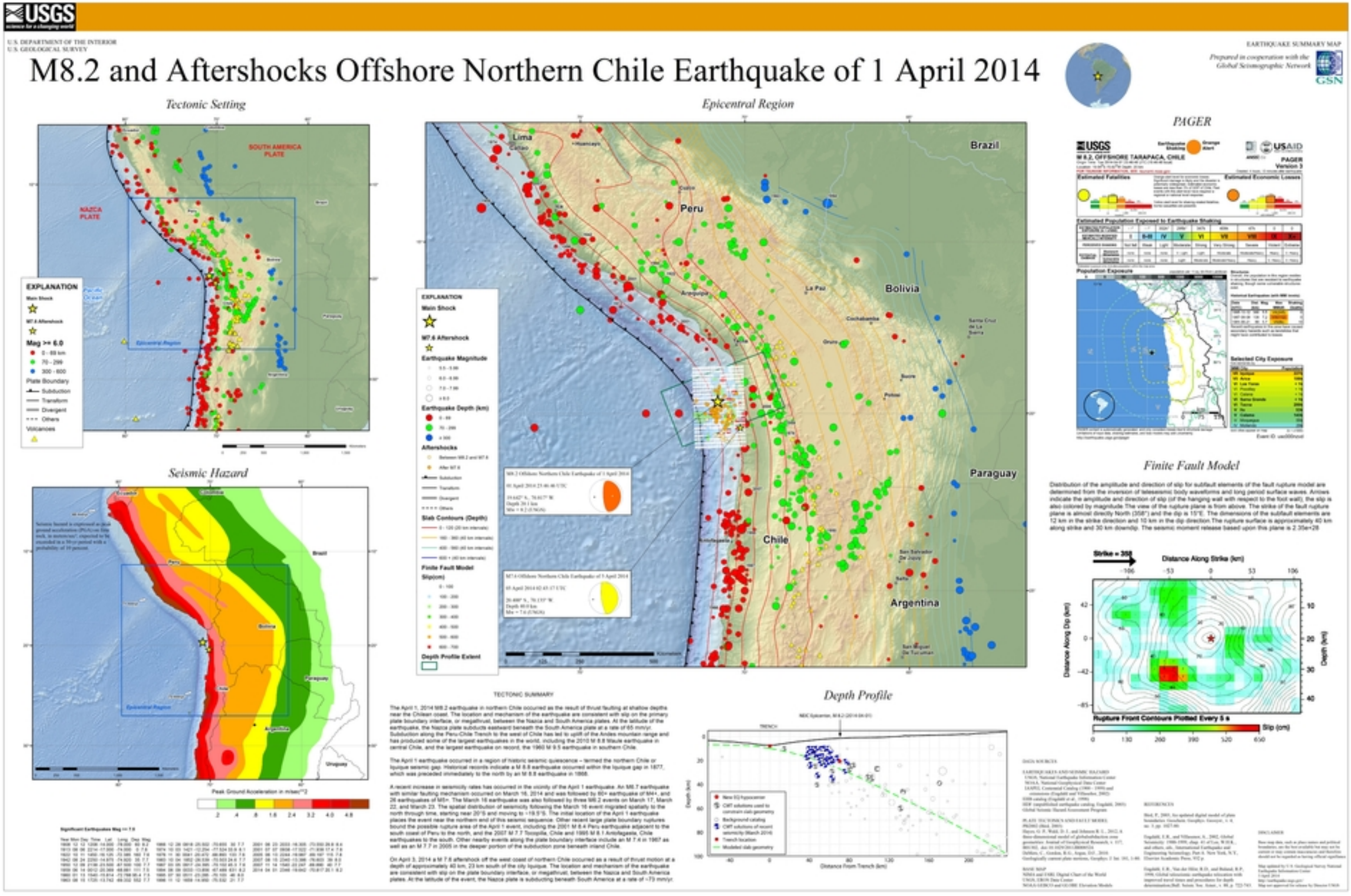
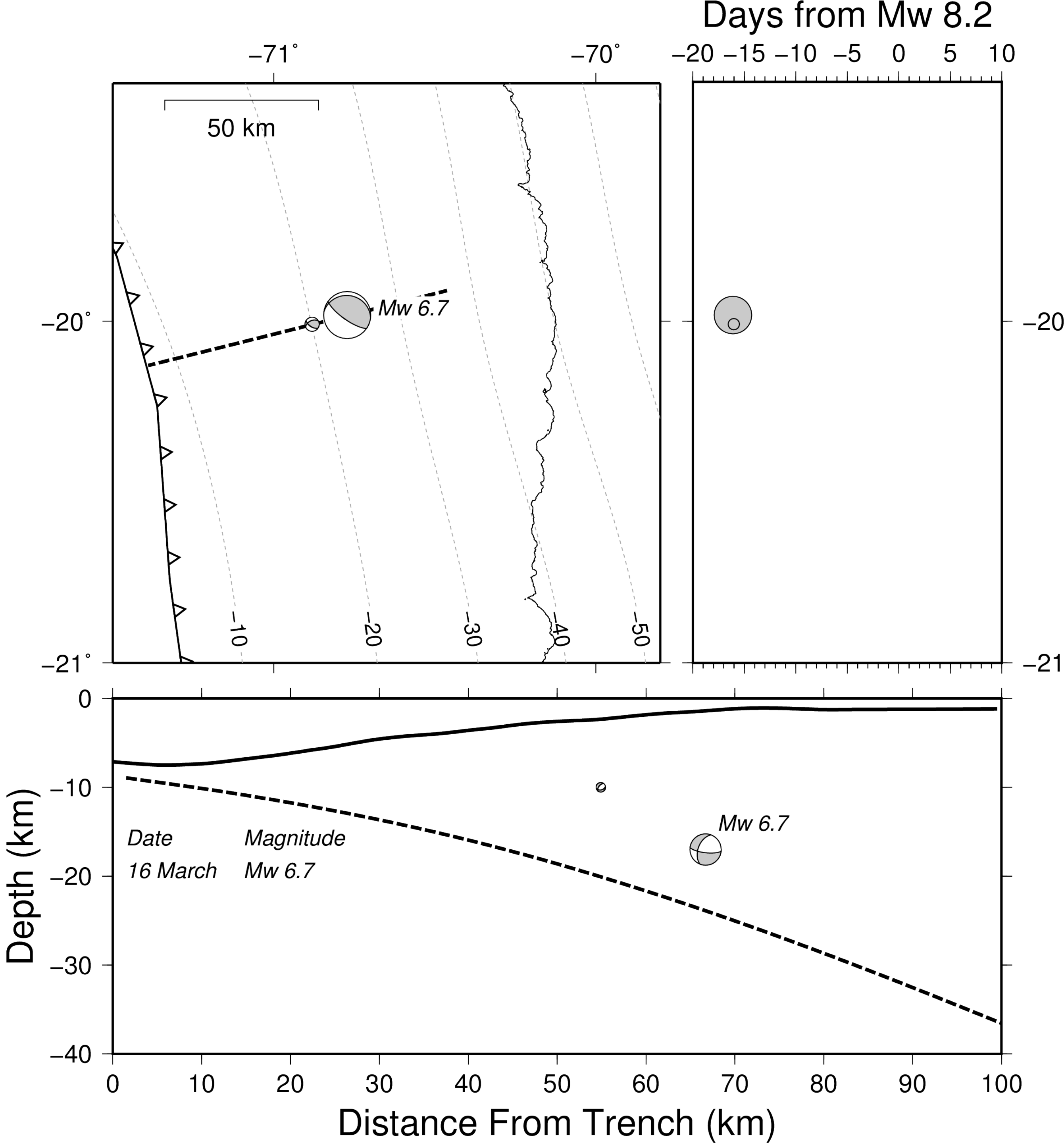
Case Study 2:
2014 Iquique Sequence



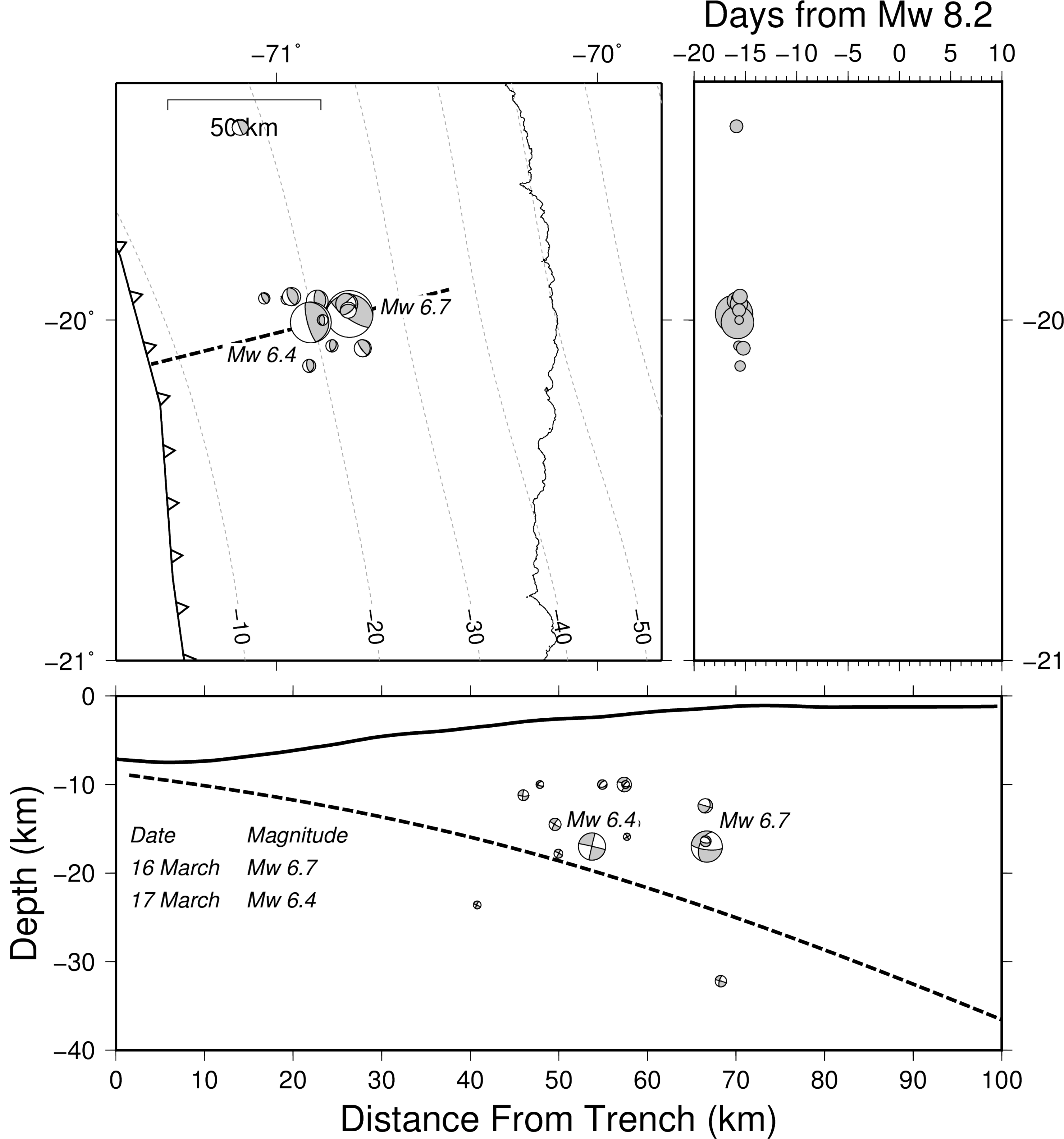
1 April 2014 11:08:43 UTC, Mw 8.2 earthquake

Santiago, Chile

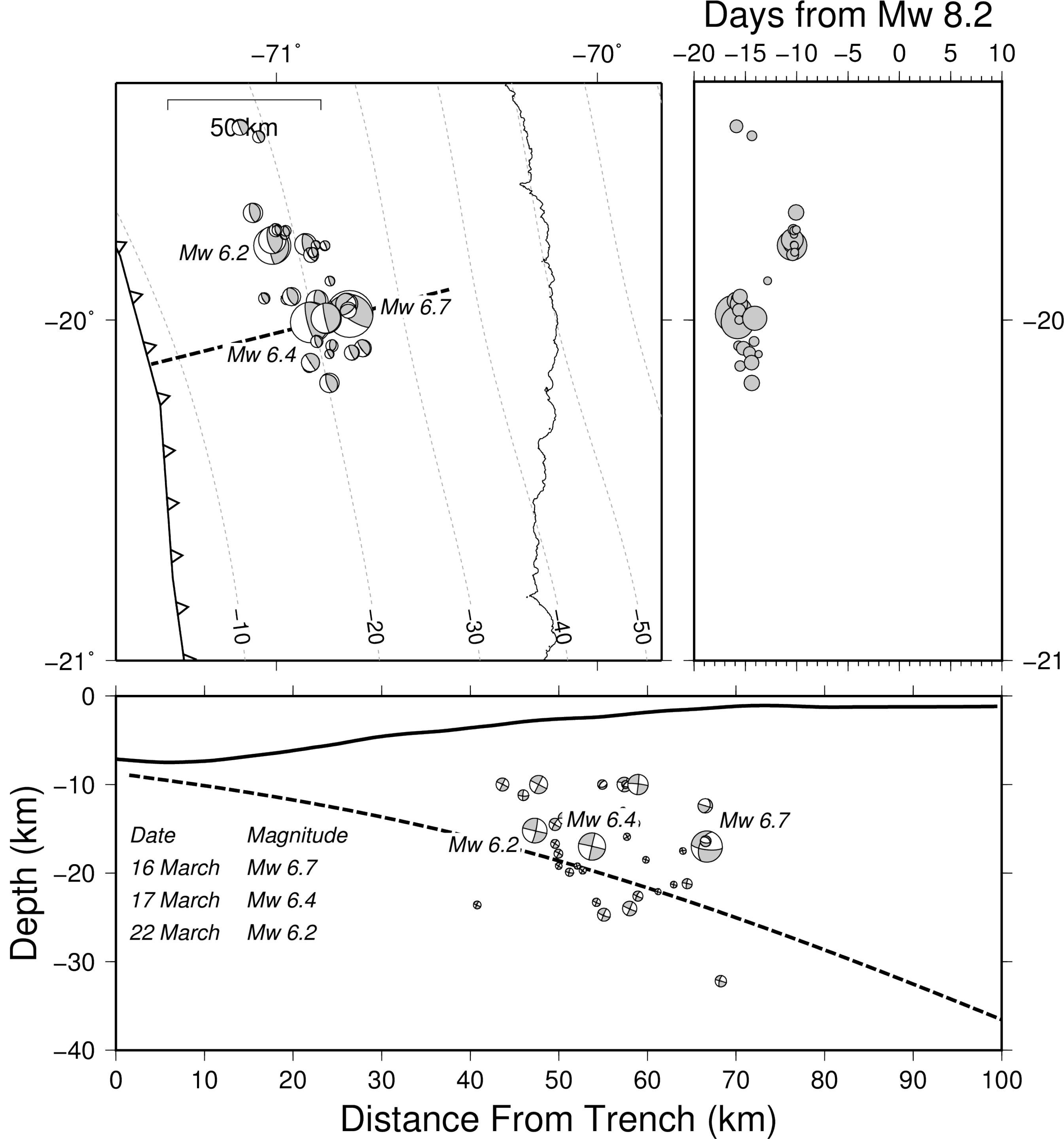
- 16 March


Days from Mw 8.2
−20 −15 −10 −5 0 5 10
−71˚
−70˚
50 km
Mw 6.7
−20˚
−21˚
−10
−20
−30
−40
−50
Depth (km)
0
−10
−20
−30
−40
Date
16 March
Magnitude
Mw 6.7
Distance From Trench (km)
0 10 20 30 40 50 60 70 80 90 100

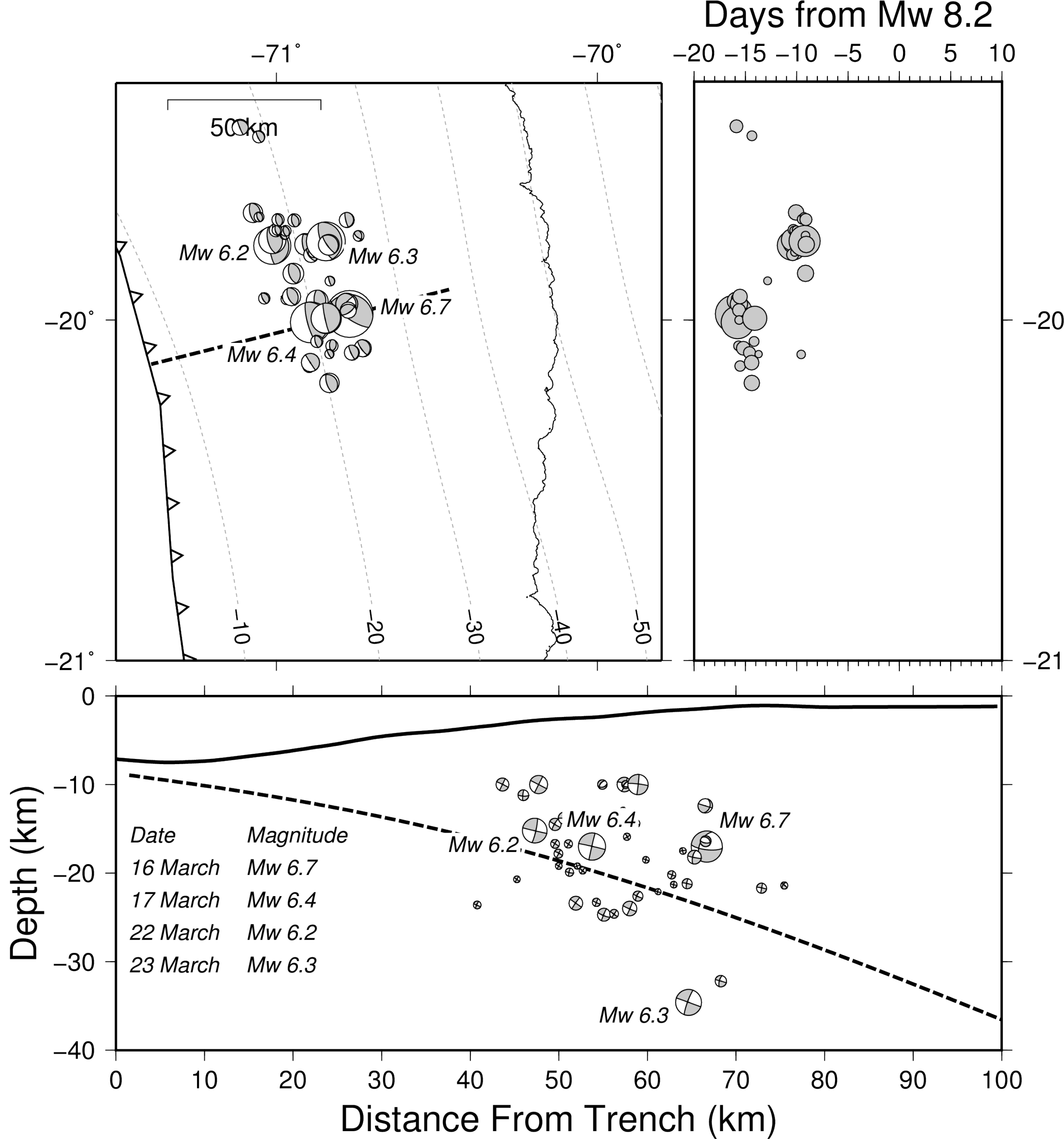
- 16 March
- 17 March



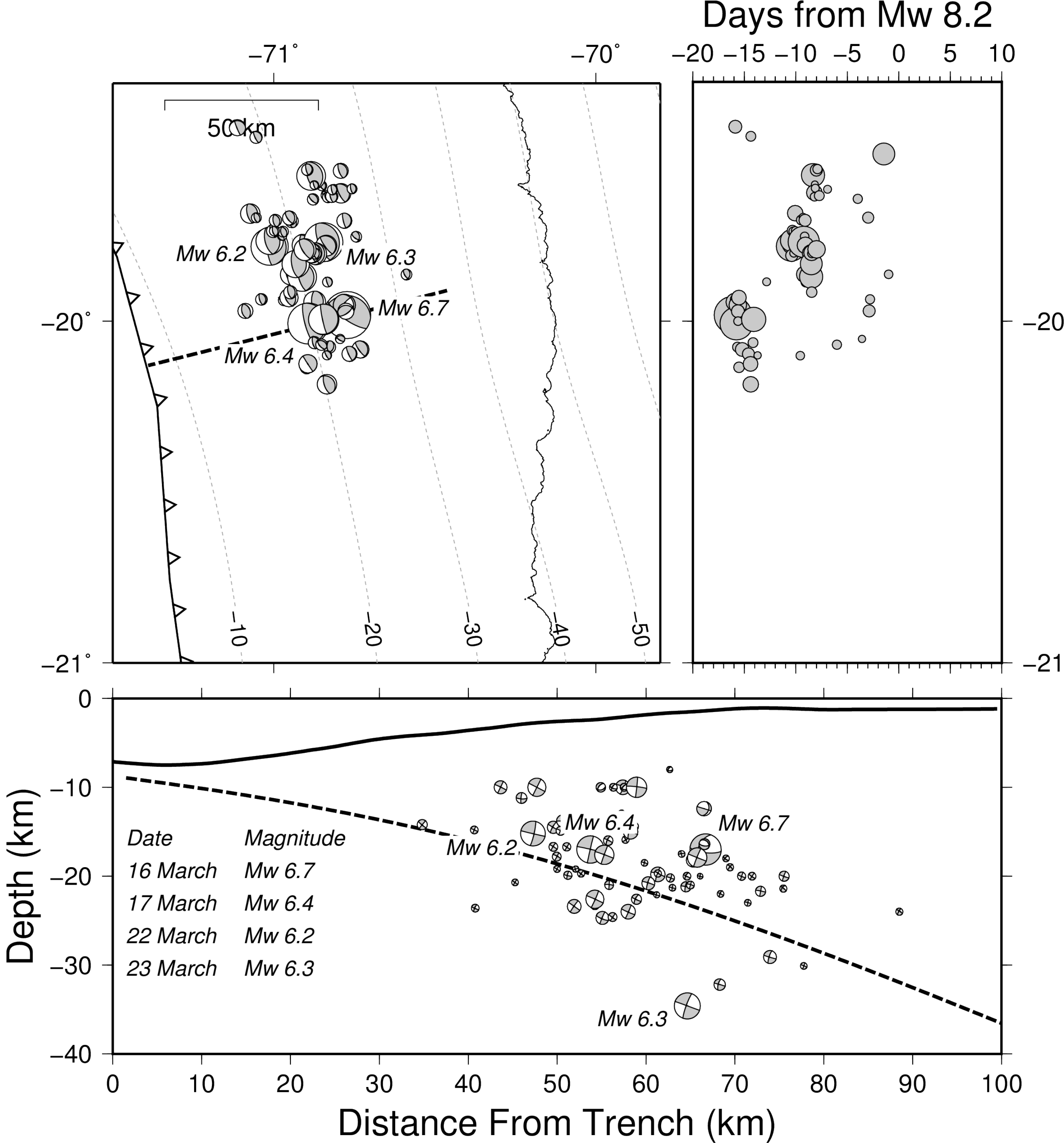
- 16 March
- 17 March
- 22 March



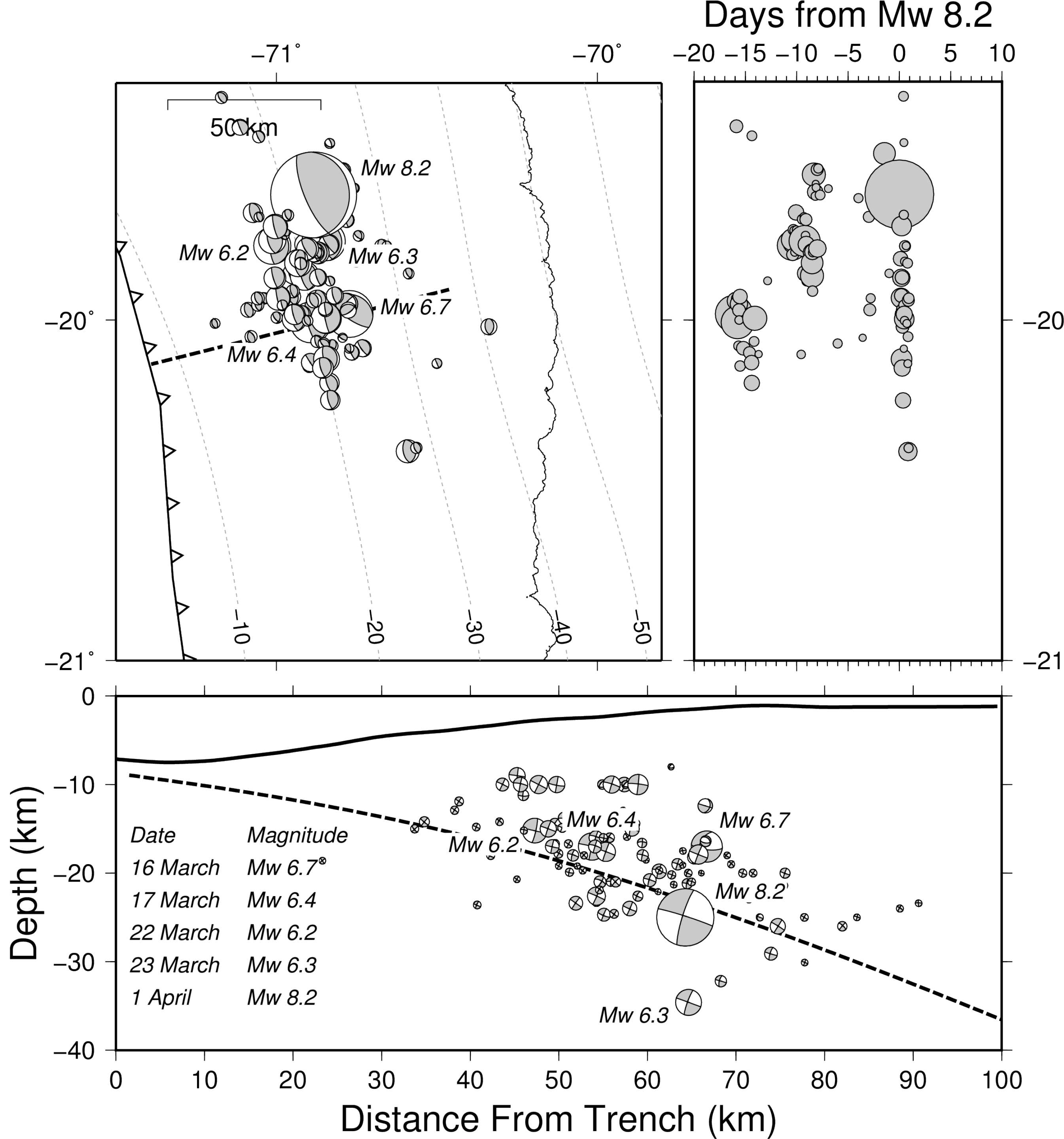
- 16 March
- 17 March
- 22 March
- 23 March



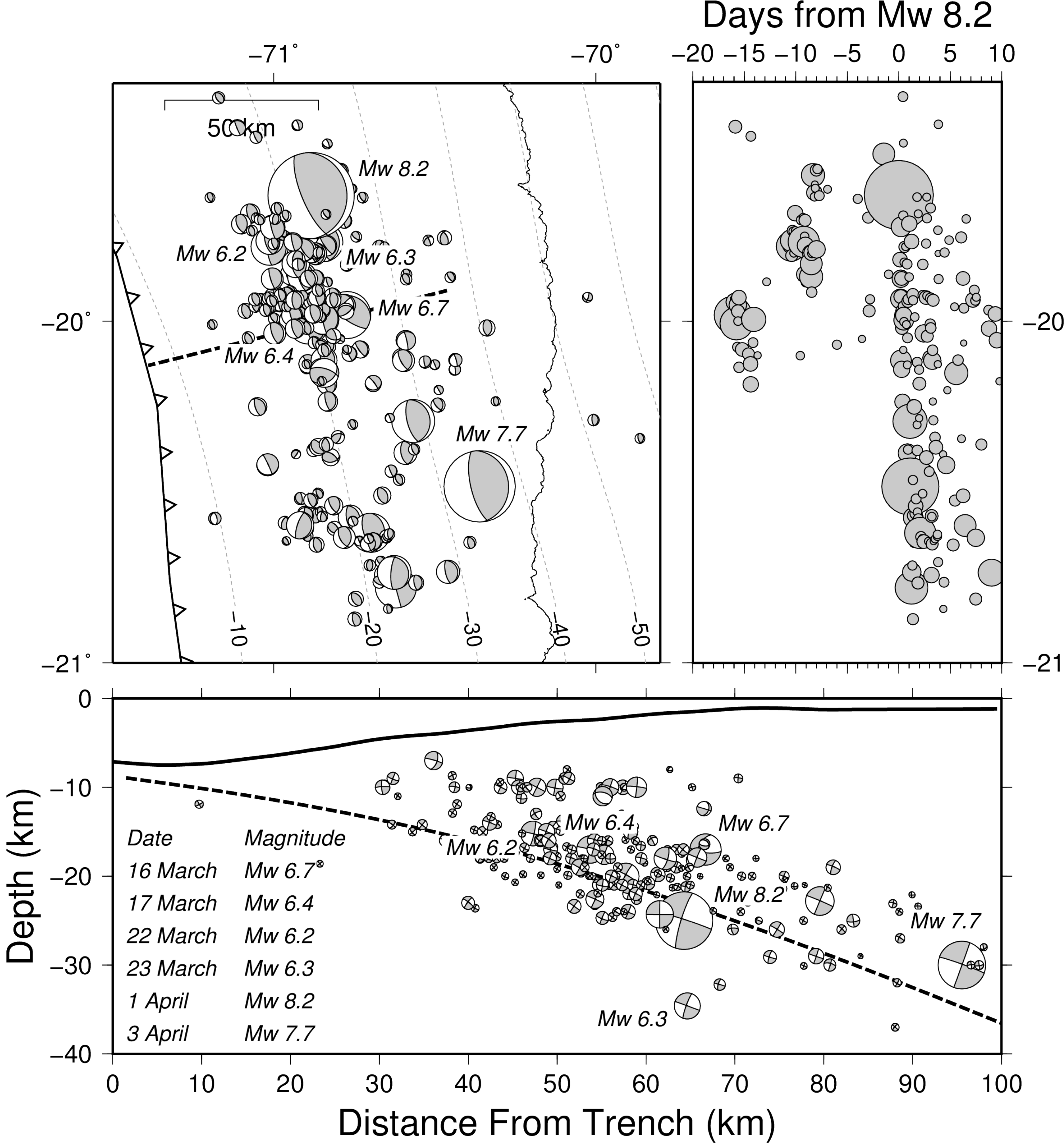
- 16 March
- 17 March
- 22 March
- 23 March
- Prior to main shock



- 16 March
- 17 March
- 22 March
- 23 March
- Prior to main shock
- 1 April



- 16 March
- 17 March
- 22 March
- 23 March
- Prior to main shock
- 1 April
- 10 April



Foreshock Displacements

- *Exercise: using the foreshocks Mw 6.0 and larger, predict the evolution of displacements at GPS stations along the Chile coast. Compare the total predicted horizontal displacements from all these foreshocks with the observed GPS displacements immediately prior to the 1 April Mw 8.2 main shock.*

Foreshock Displacements

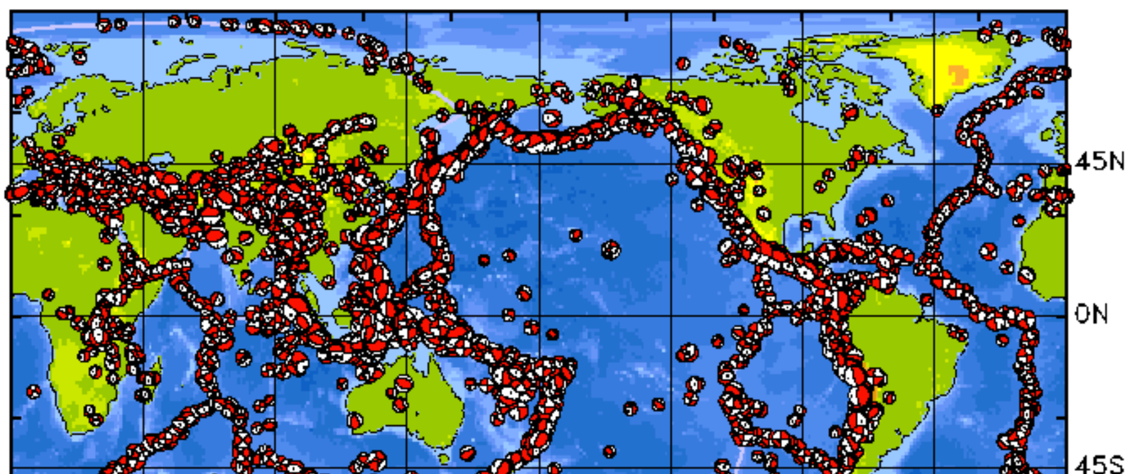
- Search the Global Centroid Moment Tensor catalog for the earthquake parameters you need
- www.globalcmt.org

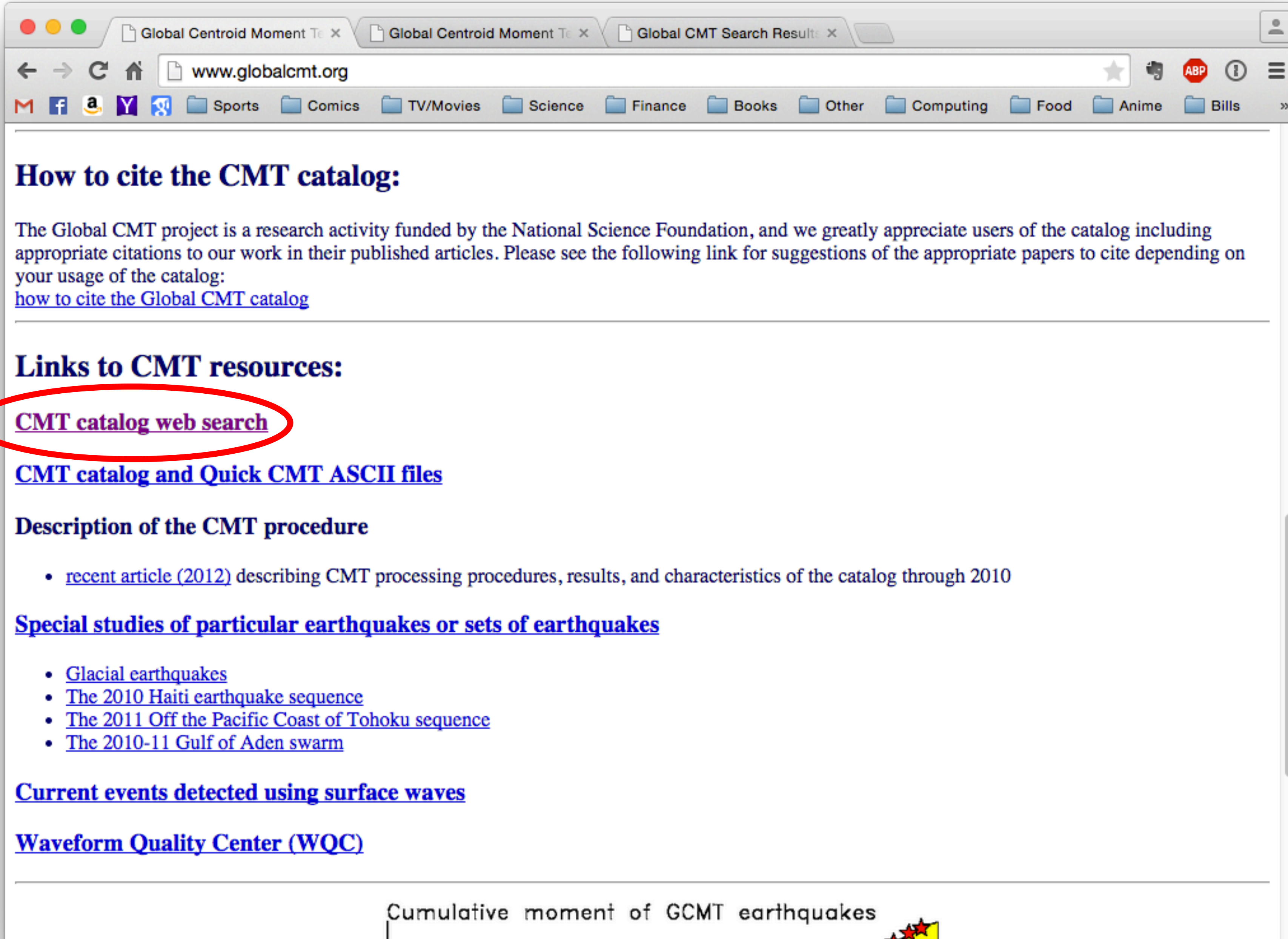
Global CMT Web Page

Introduction and Explanation

The Global Centroid-Moment-Tensor (CMT) Project is overseen by Principal Investigator Göran Ekström and Co-Principal Investigator Meredith Nettles at the Lamont-Doherty Earth Observatory (LDEO) of Columbia University. The project was founded by Adam Dziewonski at Harvard University and operated there as the Harvard CMT Project from 1982-2006, led first by Prof. Dziewonski and later by Prof. Ekström. During the summer of 2006, the activities of the CMT Project moved with Prof. Ekström to LDEO. This research effort is moving forward under the name "The Global CMT Project". The main dissemination point for information and results from the project is the web site **www.globalcmt.org**.
The CMT project has been continuously funded by the National Science Foundation since its inception, and is currently supported by award EAR-0824694.

Shallow earthquakes, 1976-2005.





How to cite the CMT catalog:

The Global CMT project is a research activity funded by the National Science Foundation, and we greatly appreciate users of the catalog including appropriate citations to our work in their published articles. Please see the following link for suggestions of the appropriate papers to cite depending on your usage of the catalog:
how to cite the Global CMT catalog

Links to CMT resources:

CMT catalog web search

CMT catalog and Quick CMT ASCII files

Description of the CMT procedure

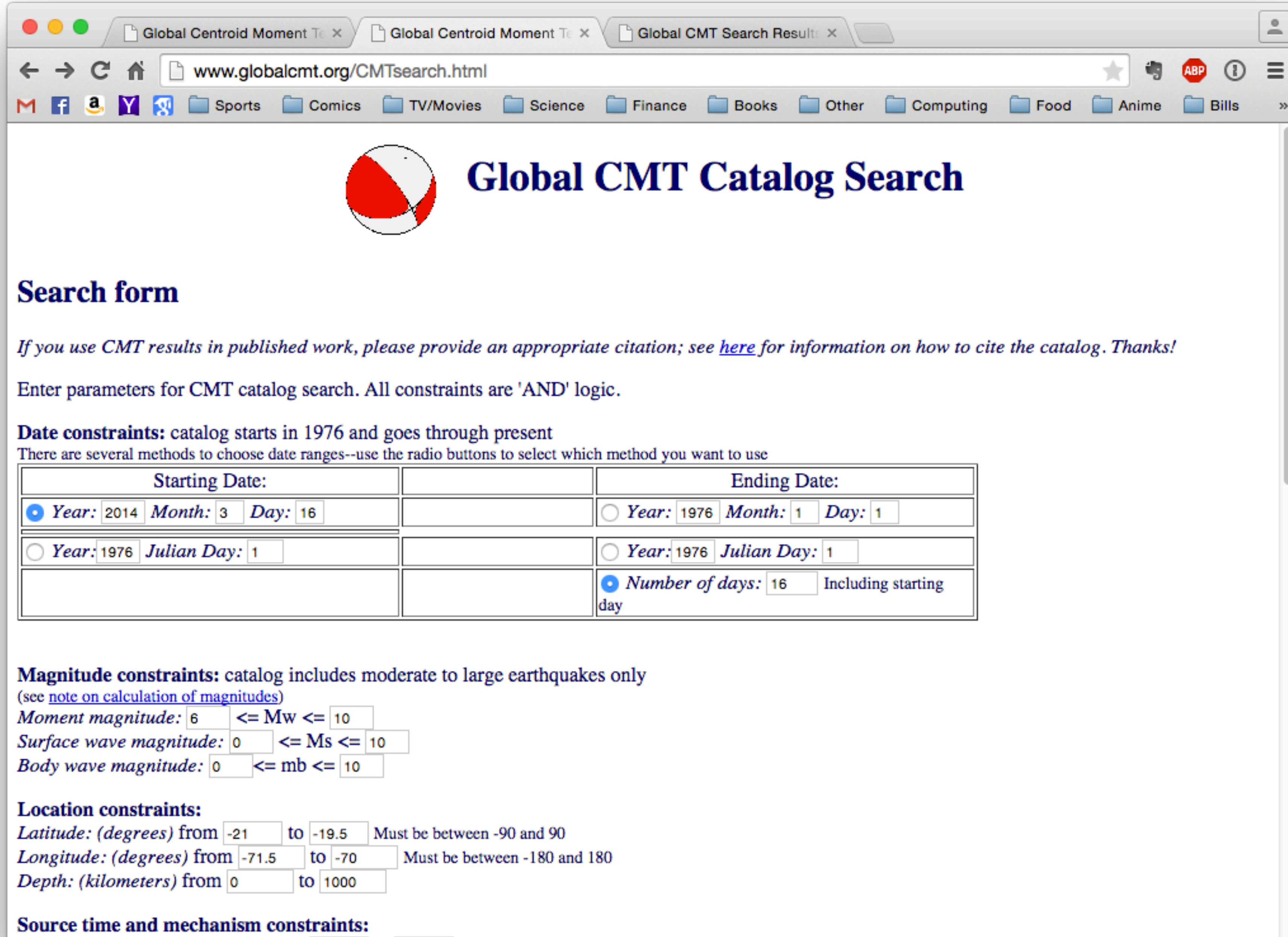
- recent article (2012) describing CMT processing procedures, results, and characteristics of the catalog through 2010

Special studies of particular earthquakes or sets of earthquakes

- Glacial earthquakes
- The 2010 Haiti earthquake sequence
- The 2011 Off the Pacific Coast of Tohoku sequence
- The 2010-11 Gulf of Aden swarm

Current events detected using surface waves

Waveform Quality Center (WQC)



Global Centroid Moment T
Global Centroid Moment T
Global CMT Search Result

www.globalcmt.org/CMTsearch.html

Sports Comics TV/Movies Science Finance Books Other Computing Food Anime Bills

Global CMT Catalog Search

Search form

If you use CMT results in published work, please provide an appropriate citation; see here for information on how to cite the catalog. Thanks!

Enter parameters for CMT catalog search. All constraints are 'AND' logic.

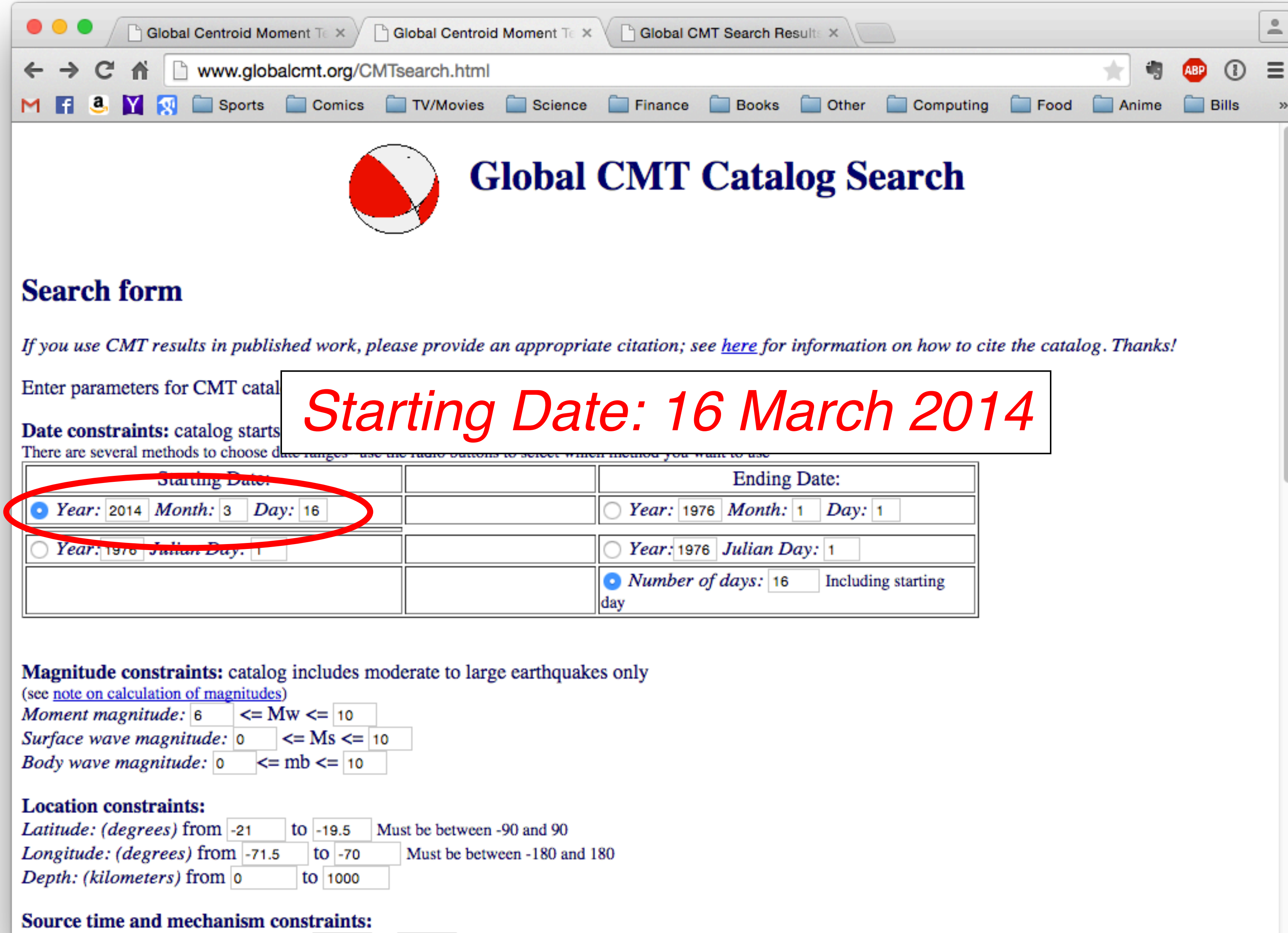
Date constraints: catalog starts in 1976 and goes through present
There are several methods to choose date ranges--use the radio buttons to select which method you want to use

Starting Date:		Ending Date:
Year: 2014 *Month:* 3 *Day:* 16		*Year:* 1976 *Month:* 1 *Day:* 1
Year: 1976 *Julian Day:* 1		*Year:* 1976 *Julian Day:* 1
		Number of days: 16 Including starting day

Magnitude constraints: catalog includes moderate to large earthquakes only
(see note on calculation of magnitudes)
Moment magnitude: 6 <= Mw <= 10
Surface wave magnitude: 0 <= Ms <= 10
Body wave magnitude: 0 <= mb <= 10

Location constraints:
Latitude: (degrees) from -21 to -19.5 Must be between -90 and 90
Longitude: (degrees) from -71.5 to -70 Must be between -180 and 180
Depth: (kilometers) from 0 to 1000

Source time and mechanism constraints:



Global Centroid Moment Te | Global Centroid Moment Te | Global CMT Search Result

www.globalcmt.org/CMTsearch.html

Sports | Comics | TV/Movies | Science | Finance | Books | Other | Computing | Food | Anime | Bills

Global CMT Catalog Search

Search form

If you use CMT results in published work, please provide an appropriate citation; see here for information on how to cite the catalog. Thanks!

Enter parameters for CMT catal

Starting Date: 16 March 2014

Date constraints: catalog starts

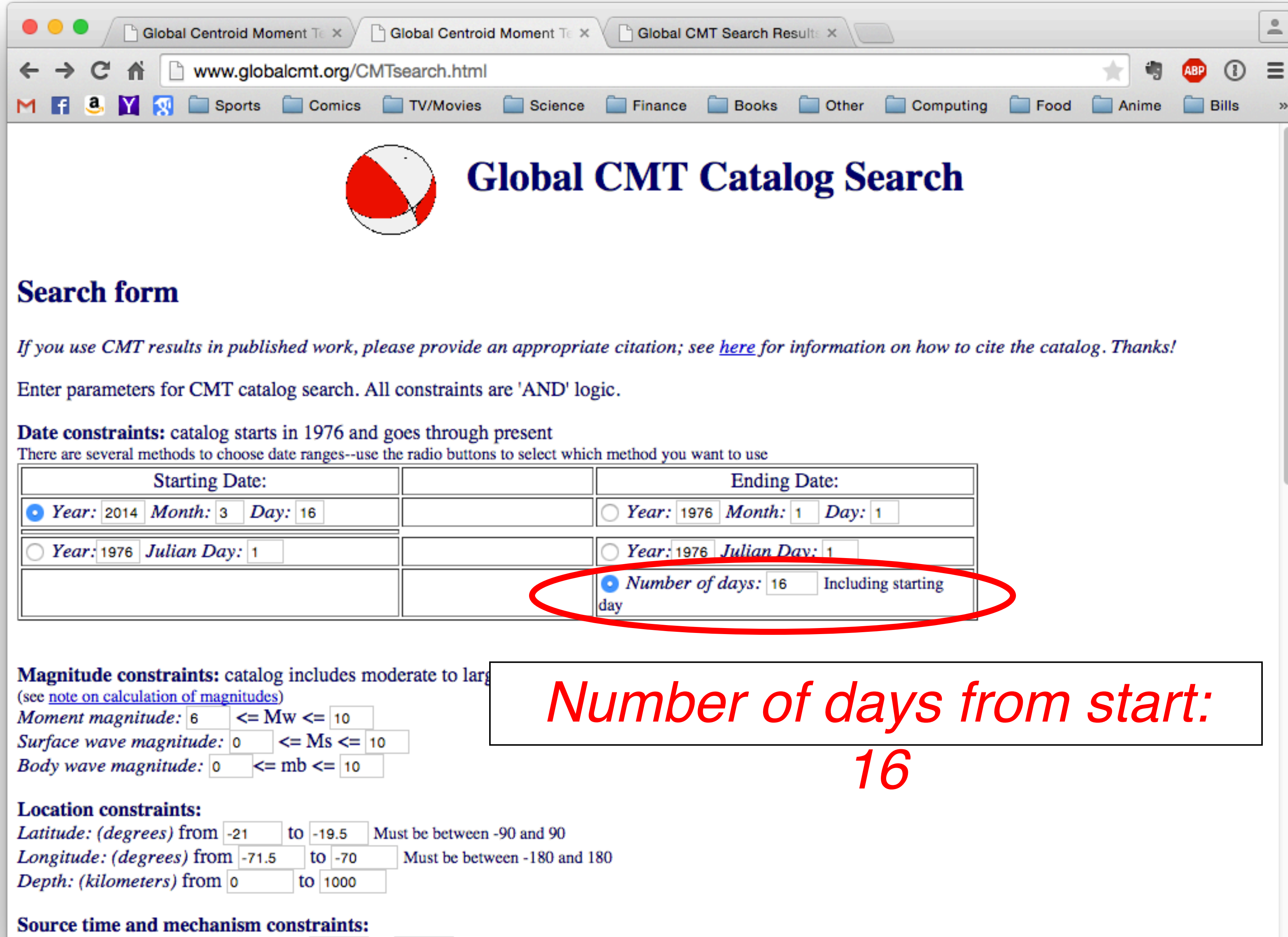
There are several methods to choose d

Starting Date:		Ending Date:
◉ *Year:* 2014 *Month:* 3 *Day:* 16		○ *Year:* 1976 *Month:* 1 *Day:* 1
○ *Year:* 1976 *Julian Day:* 1		○ *Year:* 1976 *Julian Day:* 1
		◉ *Number of days:* 16 Including starting day

Magnitude constraints: catalog includes moderate to large earthquakes only
(see note on calculation of magnitudes)
Moment magnitude: 6 <= Mw <= 10
Surface wave magnitude: 0 <= Ms <= 10
Body wave magnitude: 0 <= mb <= 10

Location constraints:
Latitude: (degrees) from -21 to -19.5 Must be between -90 and 90
Longitude: (degrees) from -71.5 to -70 Must be between -180 and 180
Depth: (kilometers) from 0 to 1000

Source time and mechanism constraints:


Global Centroid Moment Te × | Global Centroid Moment Te × | Global CMT Search Results ×

www.globalcmt.org/CMTsearch.html

Sports | Comics | TV/Movies | Science | Finance | Books | Other | Computing | Food | Anime | Bills

Global CMT Catalog Search

Search form

If you use CMT results in published work, please provide an appropriate citation; see here for information on how to cite the catalog. Thanks!

Enter parameters for CMT catalog search. All constraints are 'AND' logic.

Date constraints: catalog starts in 1976 and goes through present

There are several methods to choose date ranges--use the radio buttons to select which method you want to use

Starting Date:		Ending Date:
Year: 2014 *Month:* 3 *Day:* 16		*Year:* 1976 *Month:* 1 *Day:* 1
Year: 1976 *Julian Day:* 1		*Year:* 1976 *Julian Day:* 1
		Number of days: 16 Including starting day

Magnitude constraints: catalog includes moderate to larg

(see note on calculation of magnitudes)

Moment magnitude: 6 <= Mw <= 10

Surface wave magnitude: 0 <= Ms <= 10

Body wave magnitude: 0 <= mb <= 10

Location constraints:

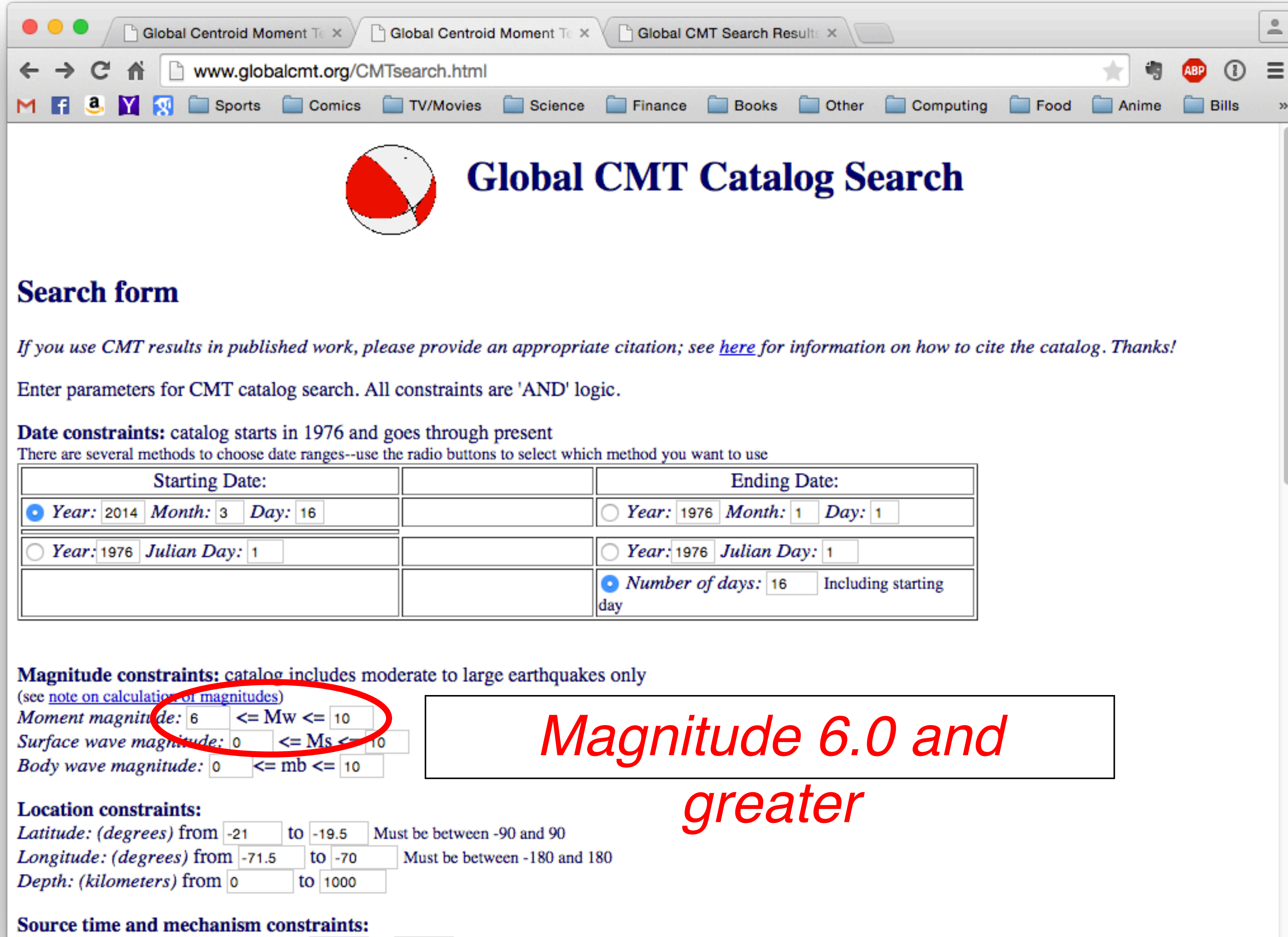
Latitude: (degrees) from -21 to -19.5 Must be between -90 and 90

Longitude: (degrees) from -71.5 to -70 Must be between -180 and 180

Depth: (kilometers) from 0 to 1000

Source time and mechanism constraints:

Number of days from start: 16



Global Centroid Moment T… | Global Centroid Moment T… | Global CMT Search Result…

www.globalcmt.org/CMTsearch.html

Sports | Comics | TV/Movies | Science | Finance | Books | Other | Computing | Food | Anime | Bills

Global CMT Catalog Search

Search form

If you use CMT results in published work, please provide an appropriate citation; see here for information on how to cite the catalog. Thanks!

Enter parameters for CMT catalog search. All constraints are 'AND' logic.

Date constraints: catalog starts in 1976 and goes through present

There are several methods to choose date ranges--use the radio buttons to select which method you want to use

Starting Date:		Ending Date:
Year: 2014 *Month:* 3 *Day:* 16		*Year:* 1976 *Month:* 1 *Day:* 1
Year: 1976 *Julian Day:* 1		*Year:* 1976 *Julian Day:* 1
		Number of days: 16 Including starting day

Magnitude constraints: catalog includes moderate to large earthquakes only

(see note on calculation of magnitudes)

Moment magnitude: 6 <= Mw <= 10

Surface wave magnitude: 0 <= Ms <= 10

Body wave magnitude: 0 <= mb <= 10

Location constraints:

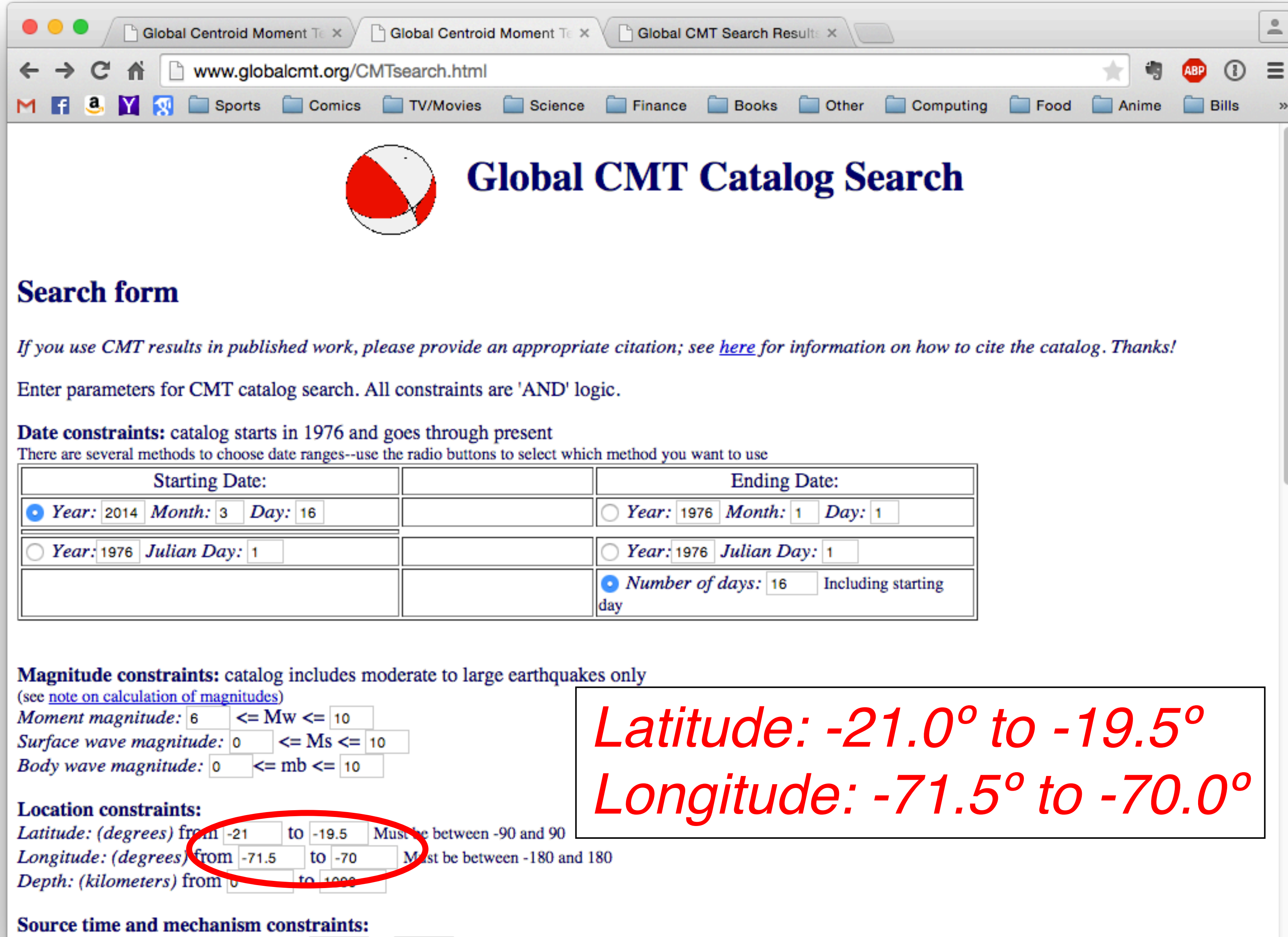
Latitude: (degrees) from -21 to -19.5 Must be between -90 and 90

Longitude: (degrees) from -71.5 to -70 Must be between -180 and 180

Depth: (kilometers) from 0 to 1000

Source time and mechanism constraints:

Magnitude 6.0 and greater


Global Centroid Moment Te
Global Centroid Moment Te
Global CMT Search Results
www.globalcmt.org/CMTsearch.html
Sports
Comics
TV/Movies
Science
Finance
Books
Other
Computing
Food
Anime
Bills
Global CMT Catalog Search
Search form
If you use CMT results in published work, please provide an appropriate citation; see here for information on how to cite the catalog. Thanks!
Enter parameters for CMT catalog search. All constraints are 'AND' logic.
Date constraints: catalog starts in 1976 and goes through present
There are several methods to choose date ranges--use the radio buttons to select which method you want to use
Starting Date:
Ending Date:
Year: 2014 Month: 3 Day: 16
Year: 1976 Month: 1 Day: 1
Year: 1976 Julian Day: 1
Year: 1976 Julian Day: 1
Number of days: 16 Including starting day
Magnitude constraints: catalog includes moderate to large earthquakes only
(see note on calculation of magnitudes)
Moment magnitude: 6 <= Mw <= 10
Surface wave magnitude: 0 <= Ms <= 10
Body wave magnitude: 0 <= mb <= 10
Location constraints:
Latitude: (degrees) from -21 to -19.5 Must be between -90 and 90
Longitude: (degrees) from -71.5 to -70 Must be between -180 and 180
Depth: (kilometers) from 0 to 1000
Source time and mechanism constraints:
Latitude: -21.0° to -19.5°
Longitude: -71.5° to -70.0°

Global CMT Catalog

Search criteria:

```
Start date: 2014/3/16   End date: 2014/4/1
-21 <=lat<= -19.5          -71.5 <=lon<= -70
0 <=depth<= 1000          -9999 <=time shift<= 9999
0 <=mb<= 10        0<=Ms<= 10           6<=Mw<= 10
0 <=tension plunge<= 90         0 <=null plunge<= 90
```

Results

201403162116A NEAR COAST OF NORTHERN C

```
  Date: 2014/ 3/16   Centroid Time: 21:16:37.8 GMT
  Lat= -19.94  Lon= -70.92
  Depth= 12.0   Half duration= 5.3
  Centroid time minus hypocenter time:  8.2
  Moment Tensor: Expo=26  0.930 -0.680 -0.250 0.352 -0.875 0.295
  Mw = 6.7    mb = 0.0    Ms = 6.7   Scalar Moment = 1.27e+26
  Fault plane:  strike=284    dip=26   slip=54
  Fault plane:  strike=144    dip=69   slip=106
```

201403170511A NEAR COAST OF NORTHERN C

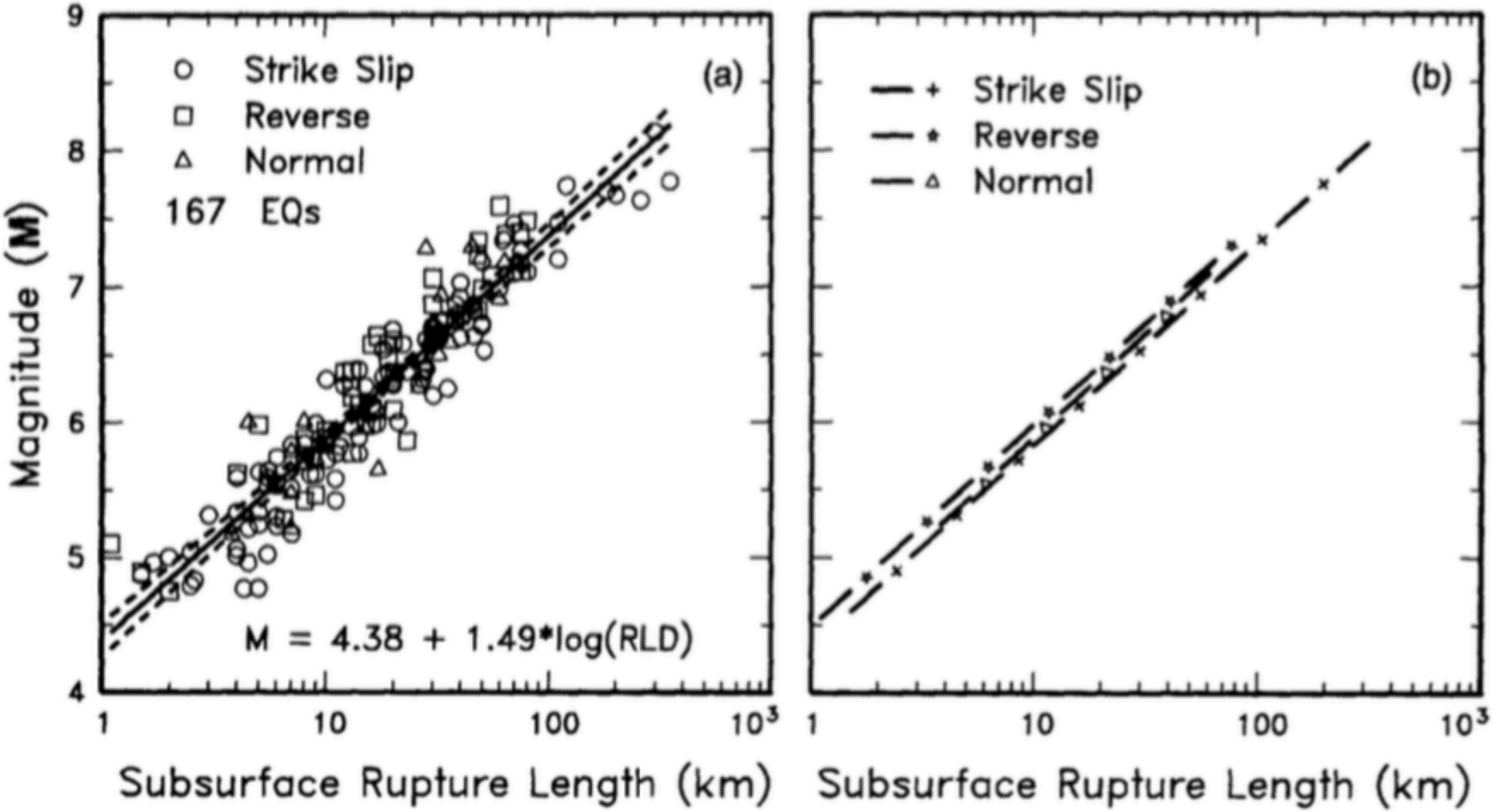
```
  Date: 2014/ 3/17   Centroid Time:  5:11:45.8 GMT
  Lat= -20.01  Lon= -71.05
  Depth= 17.8   Half duration= 3.8
  Centroid time minus hypocenter time: 10.9
  Moment Tensor: Expo=25  2.510 0.103 -2.610 0.839 -3.780 0.516
  Mw = 6.4    mb = 0.0    Ms = 6.4   Scalar Moment = 4.67e+25
  Fault plane:  strike=352    dip=17   slip=94
  Fault plane:  strike=168    dip=73   slip=89
```

201403221259A NEAR COAST OF NORTHERN C

Foreshock Displacements

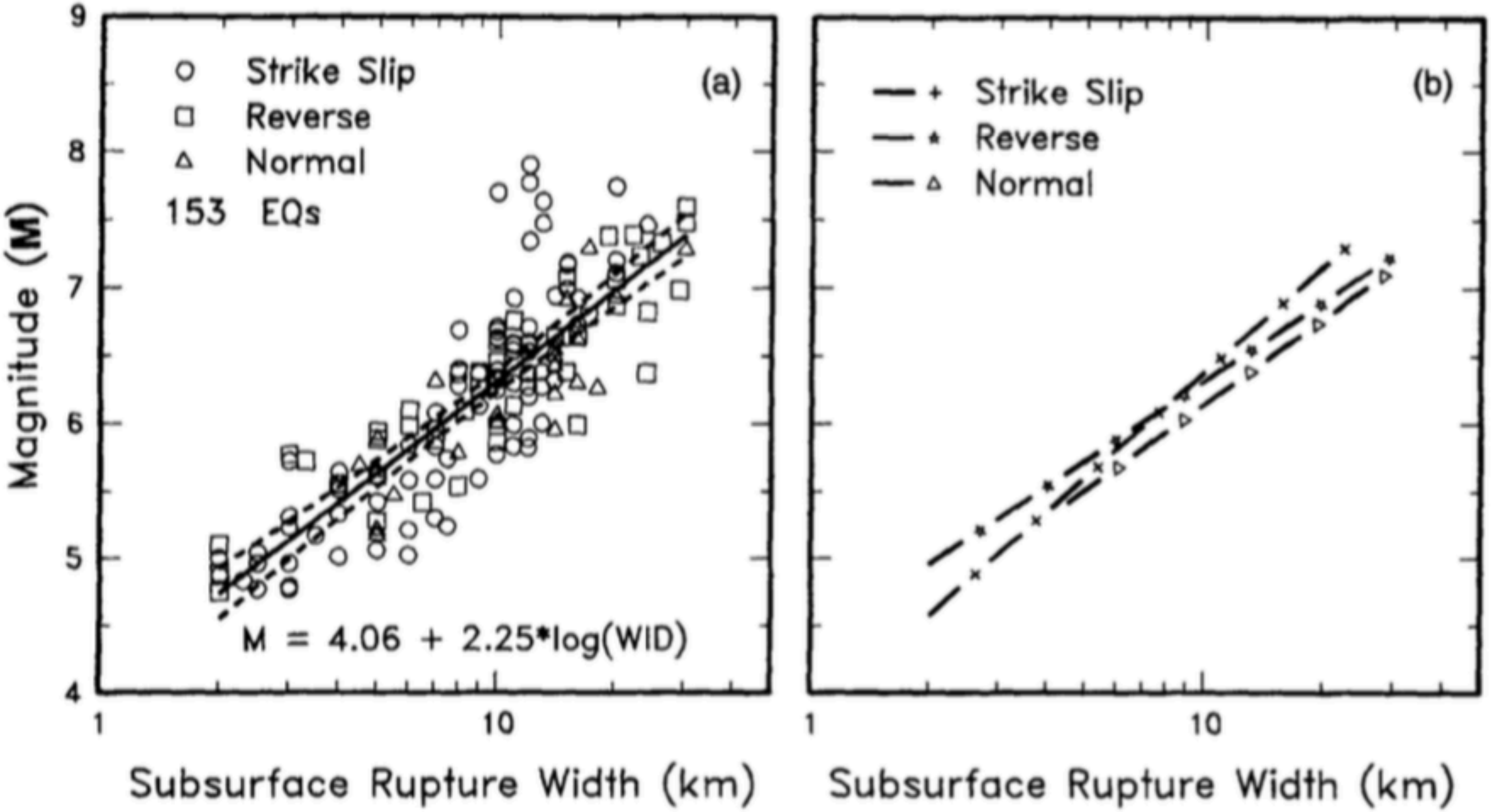
- Reminder from Chiang Rai, Thailand, case study: we usually know the *magnitude* of the earthquake, and have to estimate the *dimensions and slip* of the earthquake for use with O92UTIL
- Typically, both slip and fault area increase systematically with magnitude

Foreshock Displacements



Wells and Coppersmith (1994)

Foreshock Displacements



Wells and Coppersmith (1994)

Foreshock Displacements

- O92UTIL implements several empirical relations, allowing the user to put magnitude in the input fault file instead of fault slip and dimensions

Foreshock Displacements

- <u>Input fault file (fault.dat)</u>

```
-70.92 -19.94 12 284 26 54 6.7
```

Lon Lat Dep Strike Dip Rake Mag

Same as previous input format

Foreshock Displacements

- Input fault file (fault.dat)

```
-70.92 -19.94 12 284 26 54 6.7
```

Lon Lat Dep Strike Dip Rake Mag

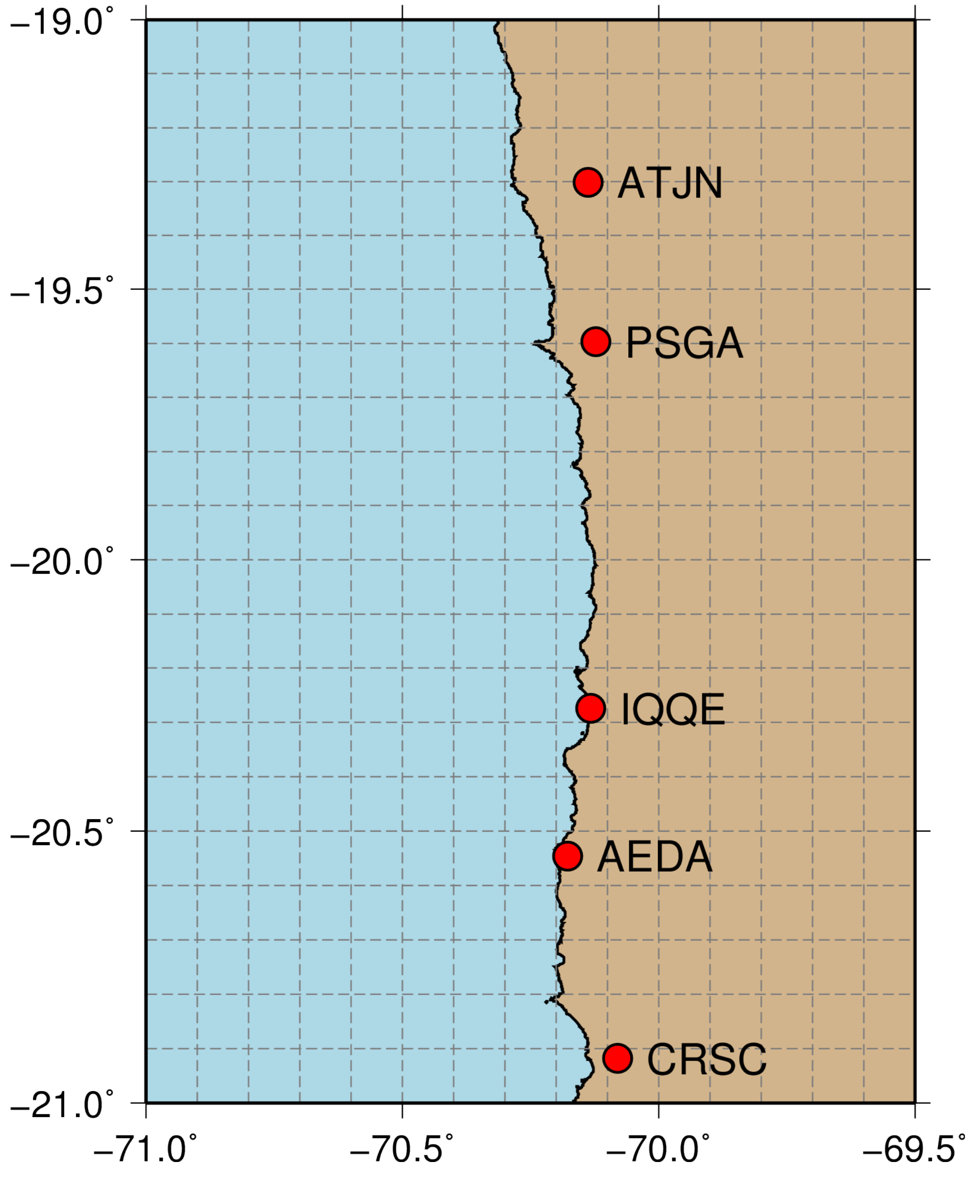
Foreshock Displacements

`o92util -mag fault.dat -sta station.dat....`

(instead of `o92util -flt fault.dat...`)

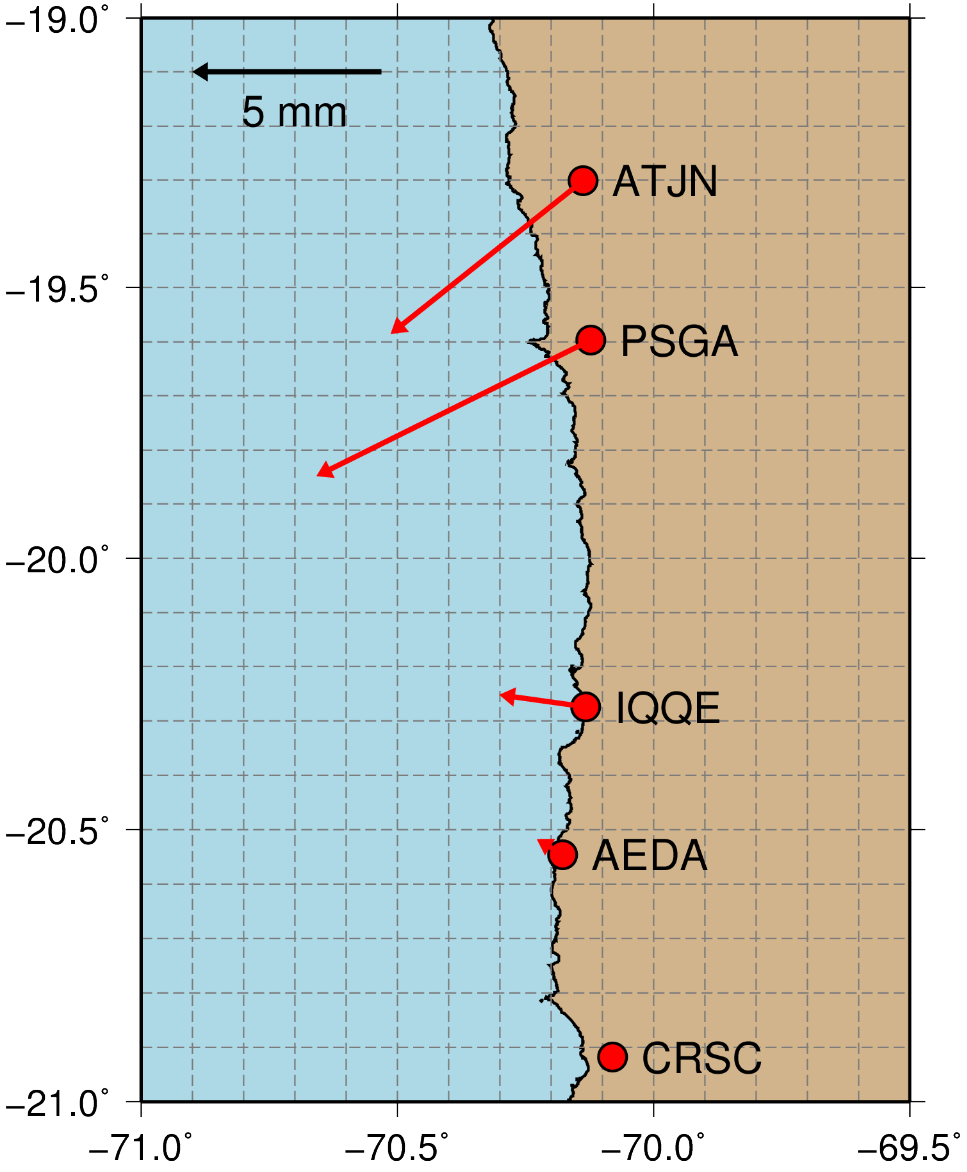
Foreshock Displacements

- GPS stations on west coast of Chile
- *What are the predicted horizontal displacements at these 5 stations?*



Foreshock Displacements

- GPS stations on west coast of Chile
- *What are the predicted horizontal displacements at these 5 stations?*

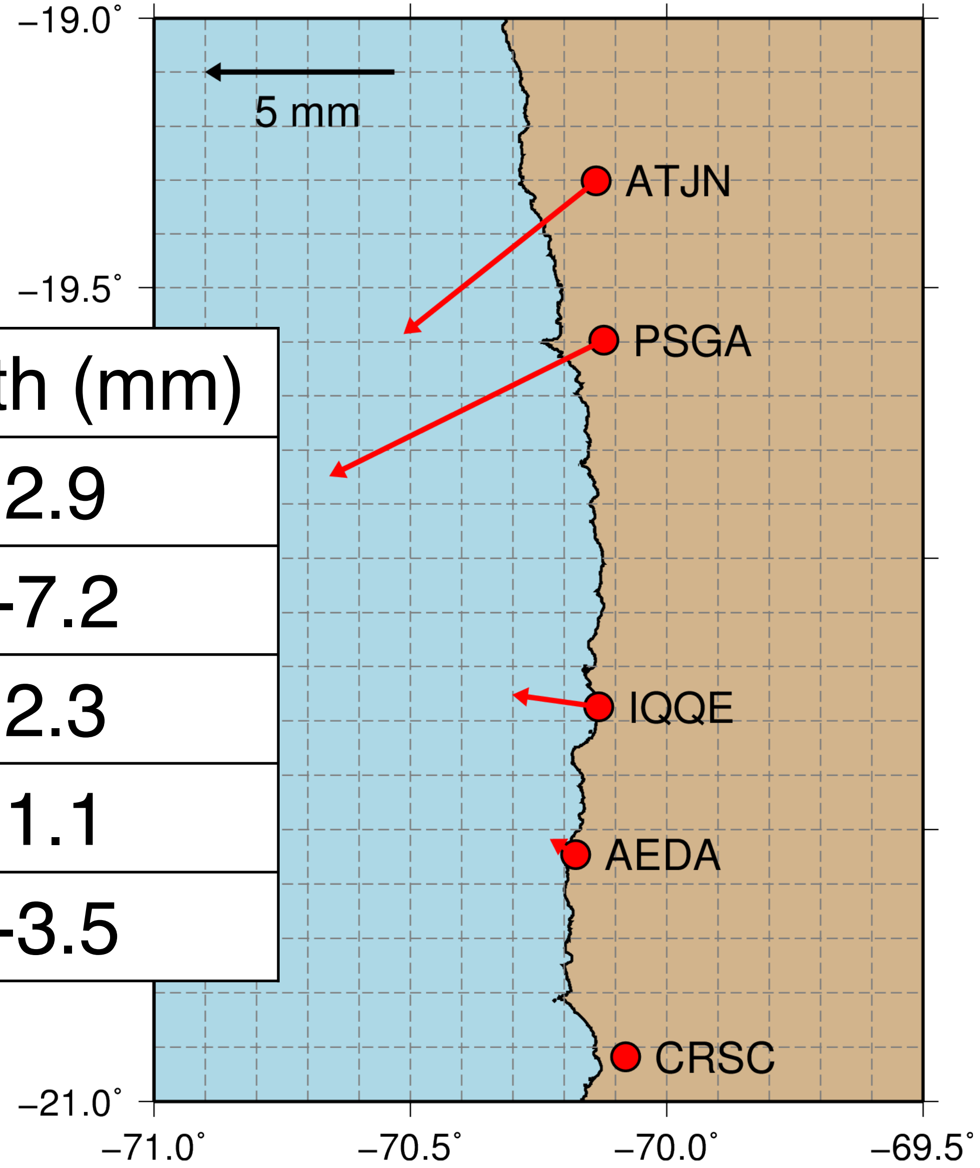


Foreshock Displacements

- GPS stations on west coast of Chile

Station	East (mm)	North (mm)
AEDA	-4.0	2.9
ATJN	-10.0	-7.2
CRSC	-2.4	2.3
IQQE	-7.9	1.1
PSGA	-14.5	-3.5

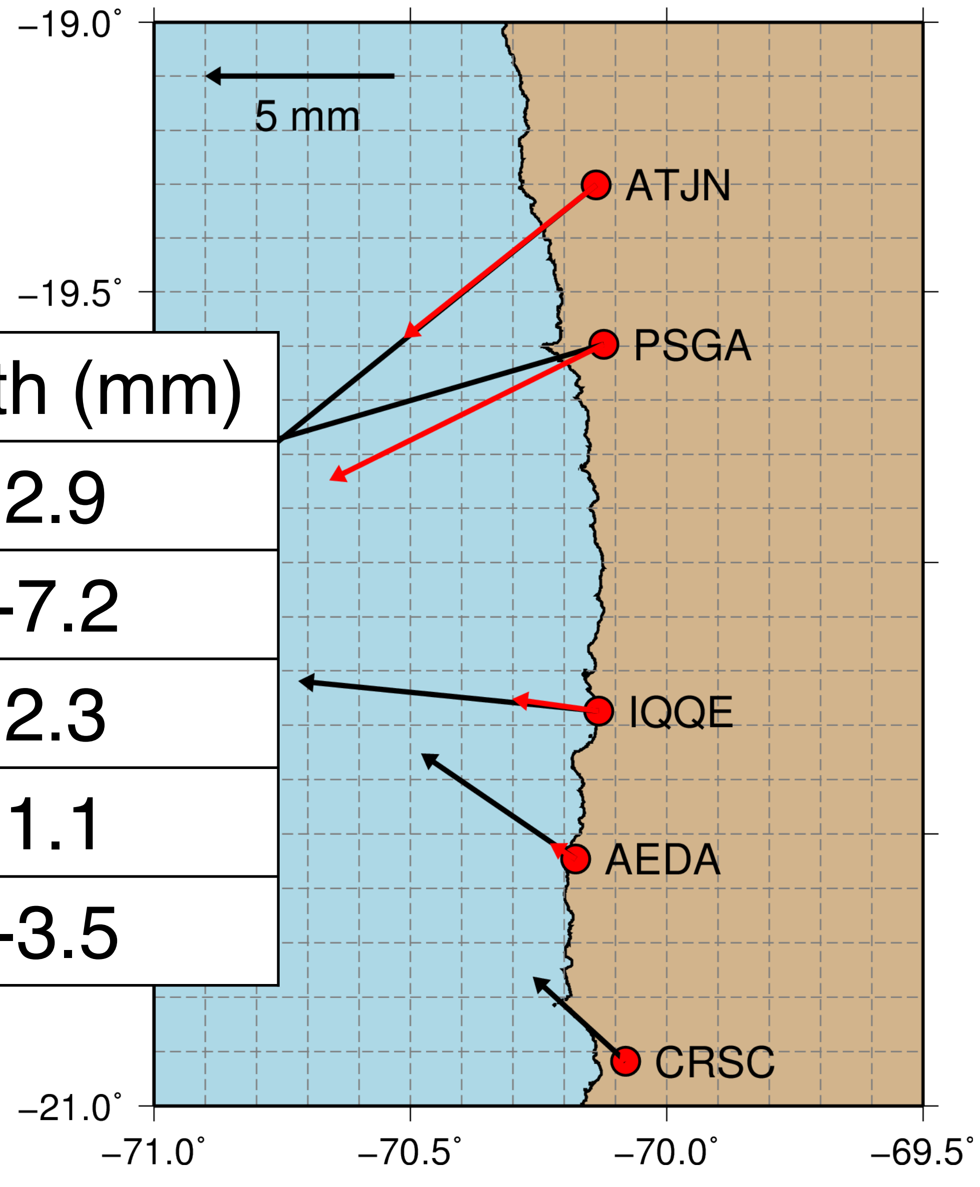
Observed displacements



Foreshock Displacements

- GPS stations on west coast of Chile

Station	East (mm)	North (mm)
AEDA	-4.0	2.9
ATJN	-10.0	-7.2
CRSC	-2.4	2.3
IQQE	-7.9	1.1
PSGA	-14.5	-3.5



Foreshock Displacements

- faults.dat:

```
-70.92 -19.94 12 284 26 54 6.7
-71.05 -20.01 18 352 17 94 6.4
-71.14 -19.73 19 346 20 90 6.2
-71.05 -19.70 22 350 21 100 6.2
```

Foreshock Displacements

- GPSloc.dat:

```
AEDA -70.178 -20.546 -4 2.9
ATJN -70.137 -19.301 -10 -7.2
CRSC -70.080 -20.918 -2.4 2.3
IQQE -70.132 -20.274 -7.9 1.1
PSGA -70.123 -19.597 -14.5 -3.5
```

Foreshock Triggering

- *Exercise: model the stress change evolution on the subduction zone plate boundary resulting from the largest foreshocks. Were these events triggered? How do these earthquakes change the state of stress at the Mw 8.2 hypocenter?*

Foreshock Triggering

- We have earthquake parameters from the previous exercise
- To resolve stresses, we need the location of the plate boundary at depth and the kinematics (orientation and slip direction) of the plate interface

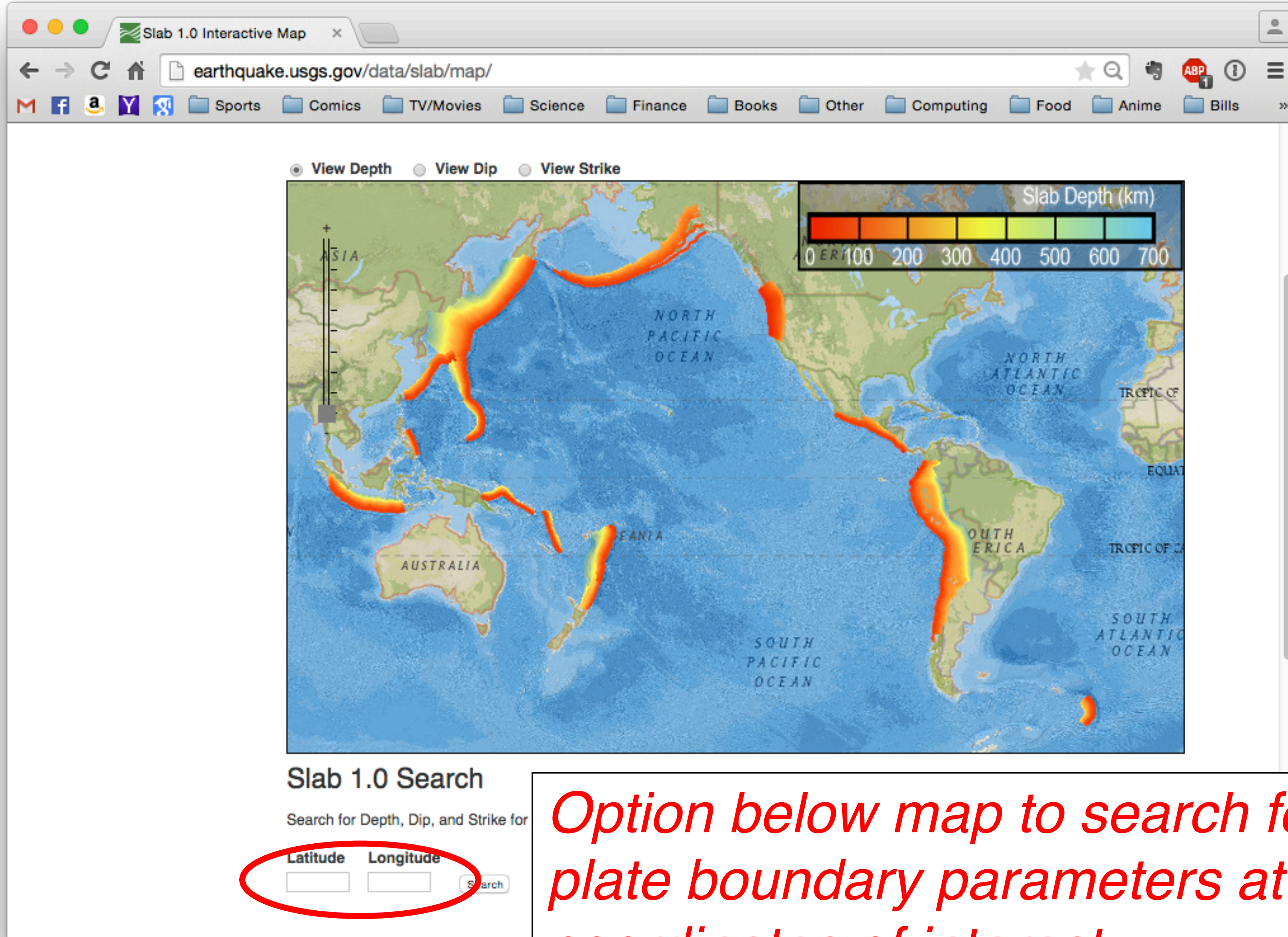
Foreshock Triggering

- Use GRID to generate the locations for computing ΔCS on the plate boundary
- Recall:
  - GRID can create a horizontal or a dipping plane; which is more appropriate for a subduction zone plate boundary?
  - What is a good reference point for the grid?

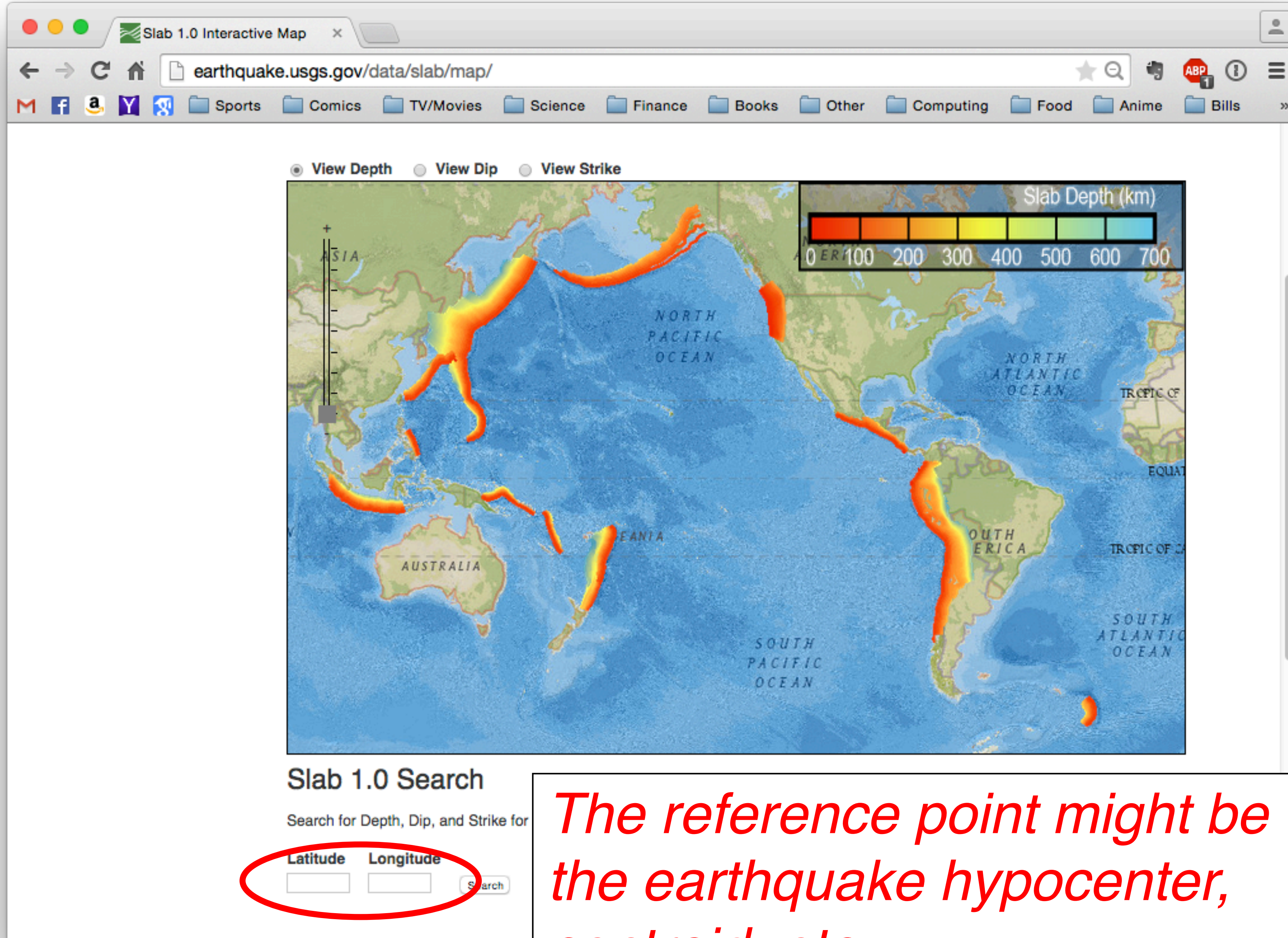
Foreshock Triggering

- One option is to use a plate interface model to determine a reference point on the plane of interest
- For example, USGS Slab 1.0
- earthquake.usgs.gov/data/slab/


Slab Models for Subductio
earthquake.usgs.gov/data/slab/
Sports
Comics
TV/Movies
Science
Finance
Books
Other
Computing
Food
Anime
Bills
USGS
science for a changing world
USGS Home
Contact USGS
Search USGS
Earthquake Hazards Program
Home
About Us
Contact Us
Search
EARTHQUAKES
HAZARDS
DATA & PRODUCTS
LEARN
MONITORING
RESEARCH
Data
Products
Slab Models for Subduction Zones
Models
Maps
References
Individual Events
Slab1.0 is a three-dimensional compilation of global subduction geometries, separated into regional models for each major subduction zone. Each model is based on a probabilistic non-linear fit to data from a combined catalog consisting of several independent data sets - historic earthquake catalogs, CMT solutions, active seismic profiles, global plate boundaries, bathymetry and sediment thickness information.
Slab 1.0 Interactive Map
Download all slab models in Goo
Download all slab models in NetCDF format
Hayes, G. P., D. J. Wald, and R. L. Johnson (2012), Slab1.0: A three-dimensional model of global subduction zone geometries, J. Geophys. Res., 117, B01302, doi:10.1029/2011JB008524.
Try the interactive map
Show More Information
Region
Depth Grid
Strike Grid
Dip Grid
Contours
Model Limits
Alaska-Aleutians
Last Updated: November 16, 2011
See detailed figure
[JPEG] [PDF - 12.4 MB]
NetCDF - 7 MB
alu_slab1.0_clip.grd [1]
NetCDF - 7 MB
alu_slab1.0_strclip.grd [1]
NetCDF - 7 MB
alu_slab1.0_dipclip.grd [1]
ASCII - 471.3 KB
alu_contours.in [3]
ArcGIS Shapefile - 99.8 KB
alu_slab.zip [6]
Perimeter - 9 KB
alu_slab1.0.clip [4]
ASCII - 31 MB
alu_slab1.0_clip.xyz
ASCII - 30.4 MB
alu_slab1.0_strclip.xyz
ASCII - 30.8 MB
alu_slab1.0_dipclip.xyz
Top - 7 KB



Option below map to search for plate boundary parameters at coordinates of interest.

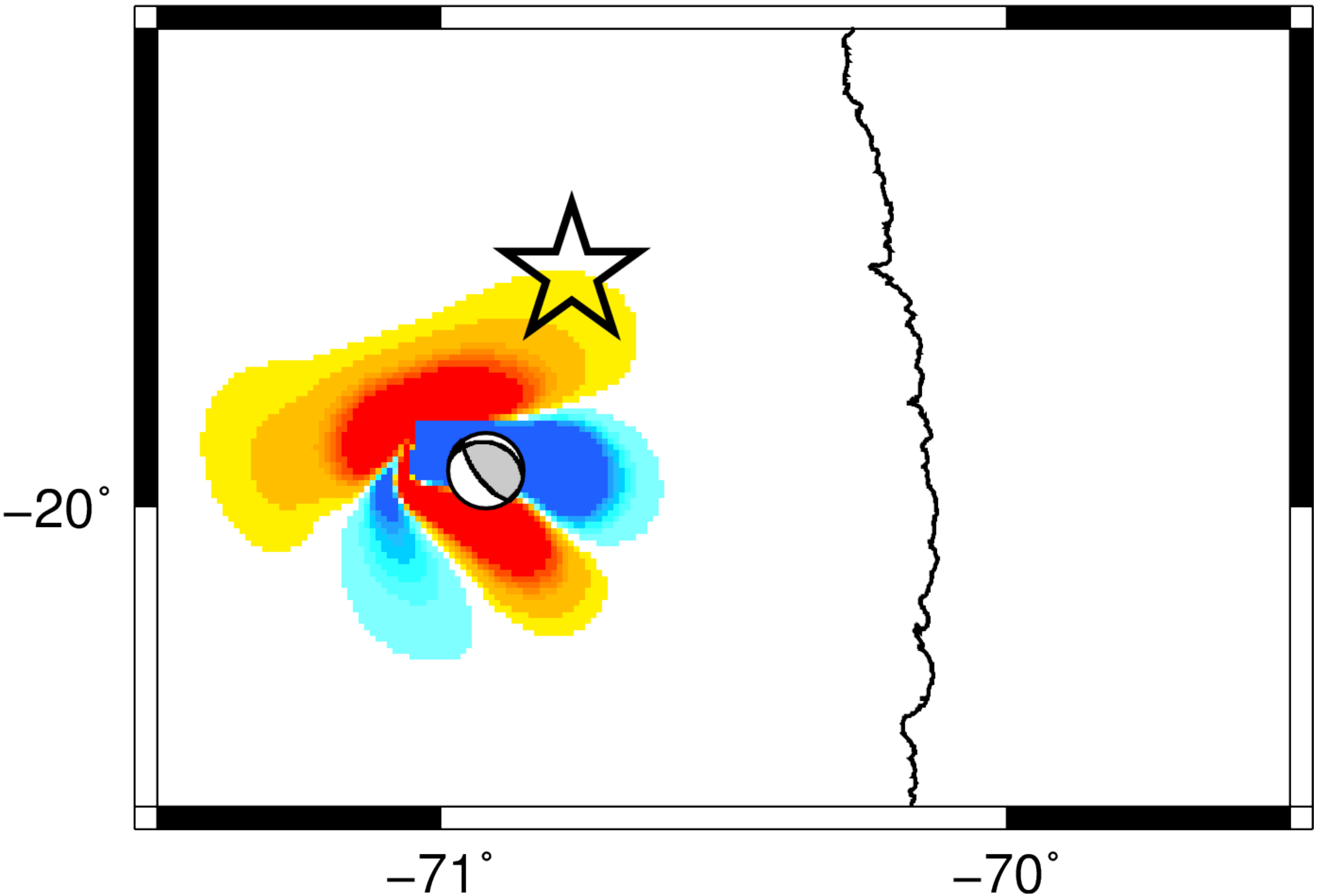


The reference point might be the earthquake hypocenter, centroid, etc.

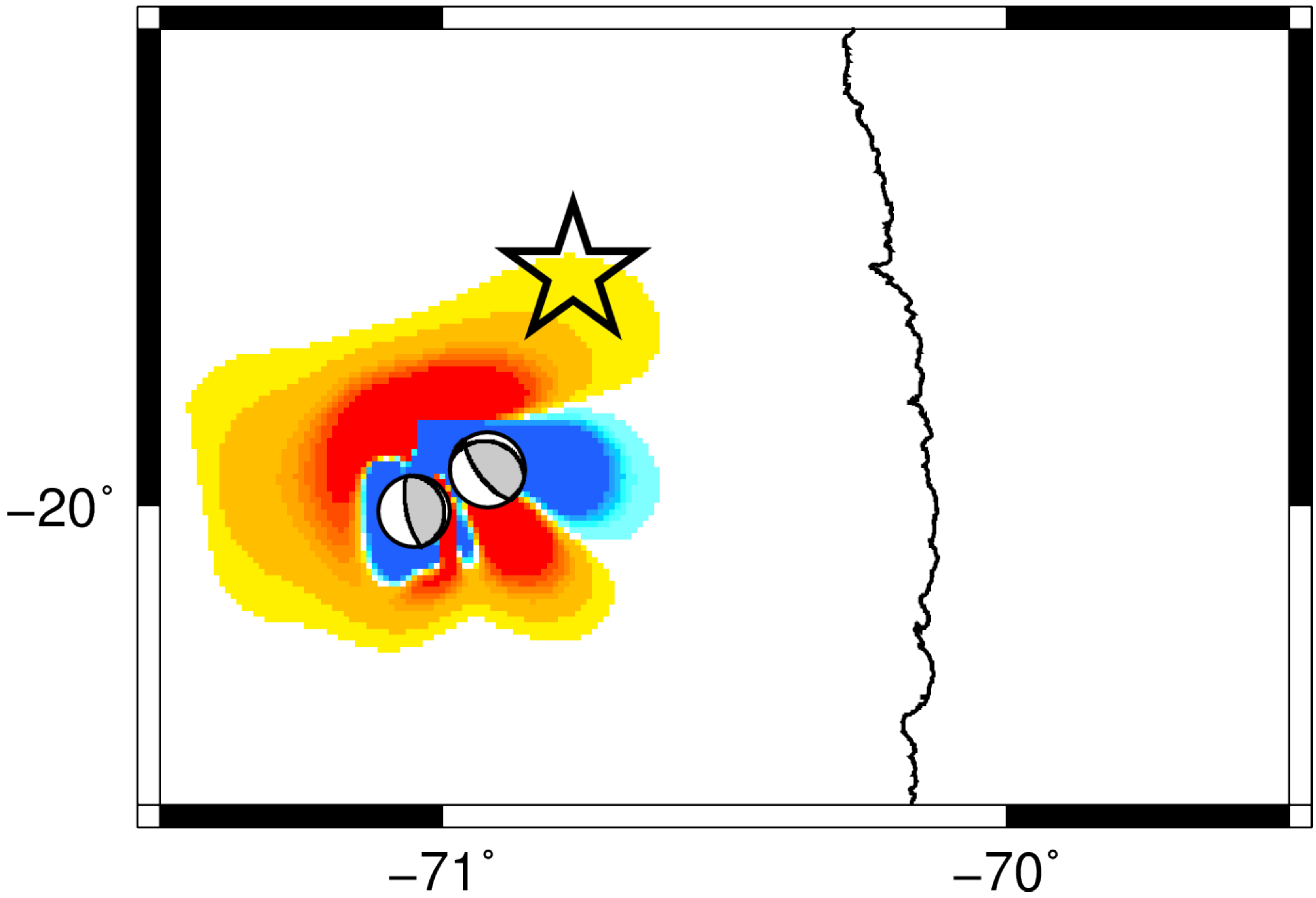
Foreshock Triggering

- Using the Mw 8.2 centroid as the reference coordinate (-70.5ºE, -19.8ºN), Slab 1.0 gives a depth for the plate boundary at this point of 36 km
- Also yields strike and dip; are these values consistent with the foreshock kinematics?

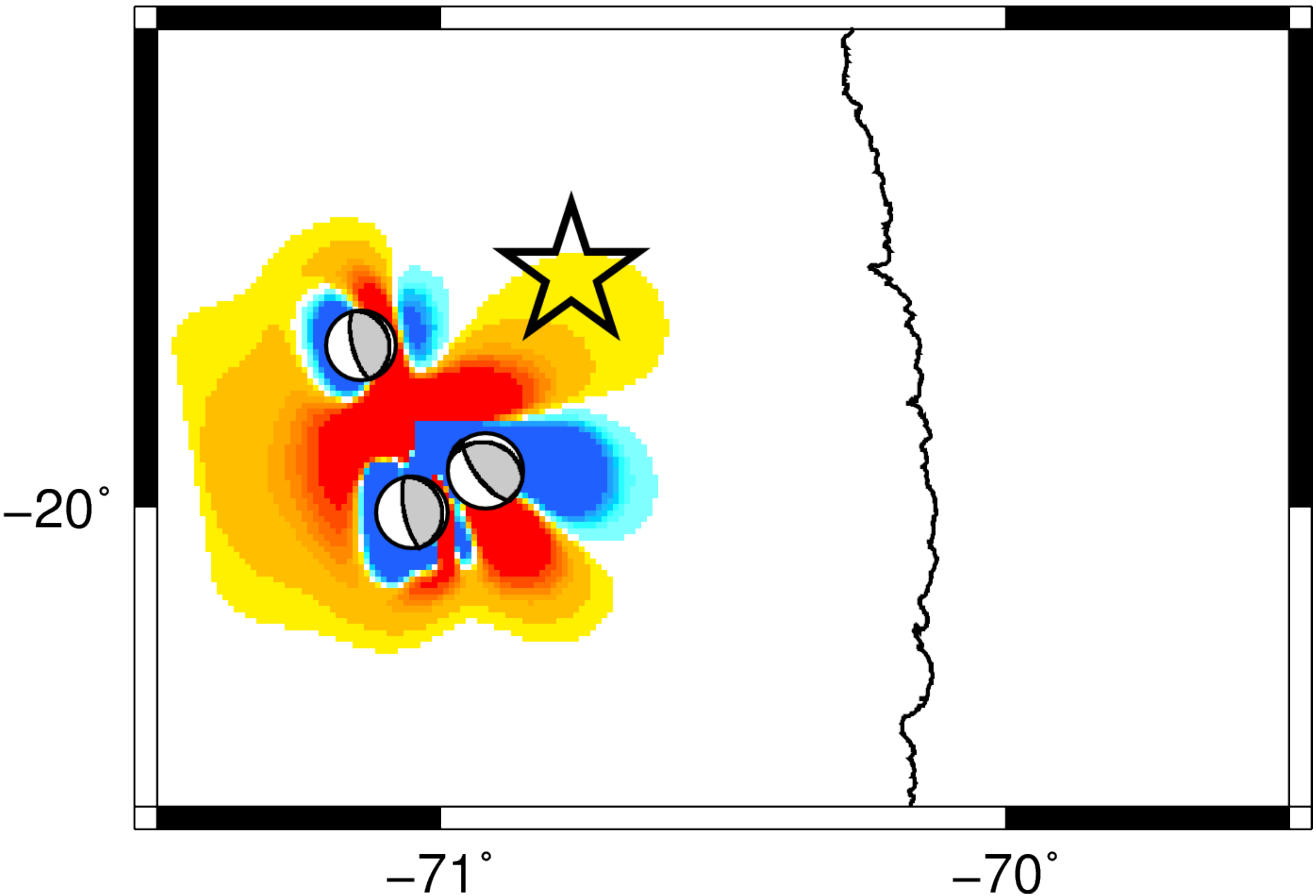
Foreshock Triggering



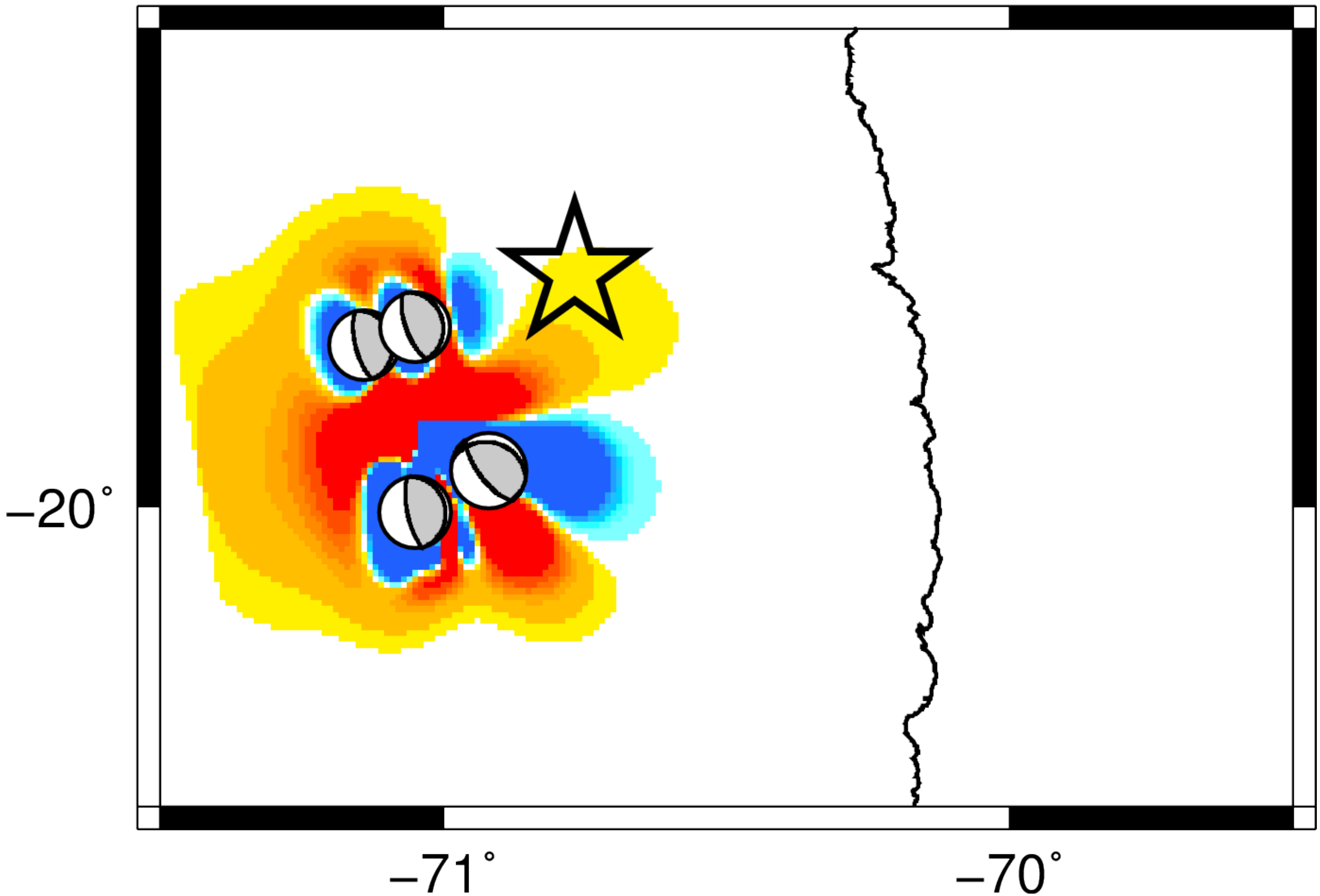
Foreshock Triggering



Foreshock Triggering



Foreshock Triggering



Main Shock Triggering

- *Exercise: model the stress change on the plate interface resulting from the 1 April main shock. How does this compare to the location of the 3 April Mw 7.7 aftershock?*
- *You can find the FFM on the USGS website.*

iquique_2014.ffm

iquique_2014.ffm

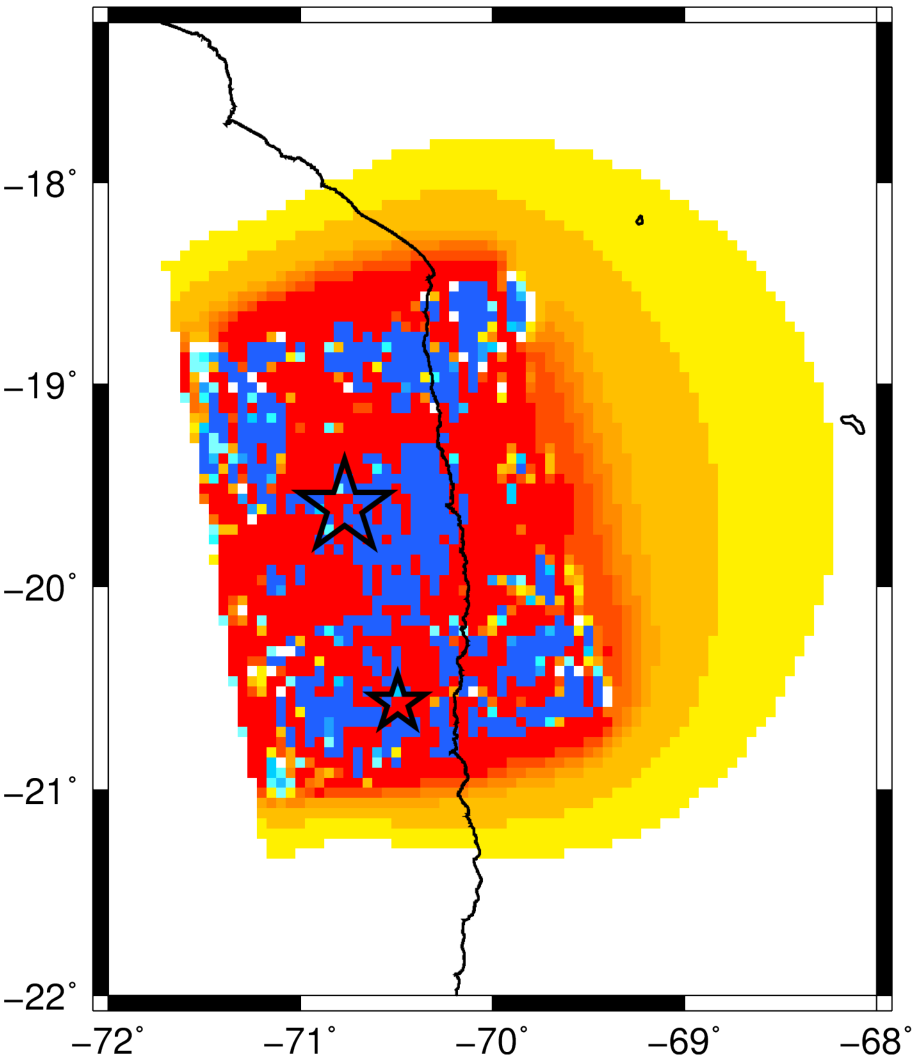
```
#Total number of fault_segments=     5
#Fault_segment =    1 nx(Along-strike)=  20 Dx= 12.00km ny(downdip)=   4 Dy= 10.00km
#Boundary of Fault_segment     1. EQ in cell 12,4. Lon: -70.8634   Lat: -19.6298
#Lon.  Lat.  Depth
      -70.87280      -20.88790      17.21850
      -71.38010      -18.81860      17.21850
      -71.04820      -18.74640      25.77820
      -70.54090      -20.81580      25.77820
      -70.87280      -20.88790      17.21850
#Lat. Lon. depth slip rake strike dip t_rup h_dur mo
     -20.887900     -70.872800     17.218500     14.849220     79.422050    347.000000     13.500000
     -20.782700     -70.898600     17.218500     14.312710     93.683830    347.000000     13.500000
     -20.677500     -70.924400     17.218500    124.392900    135.544100    347.000000     13.500000
     -20.572300     -70.950200     17.218500    164.064610    133.572910    347.000000     13.500000
     -20.467100     -70.976000     17.218500    155.227100    136.262500    347.000000     13.500000
     -20.361800     -71.001800     17.218500     13.849600     88.412810    347.000000     13.500000
     -20.256600     -71.027600     17.218500     33.400850    114.332100    347.000000     13.500000
     -20.151400     -71.053400     17.218500     13.635950     86.873340    347.000000     13.500000
     -20.046200     -71.079200     17.218500     10.225030    100.624800    347.000000     13.500000
     -19.940900     -71.105000     17.218500    124.706900    109.052000    347.000000     13.500000
     -19.835700     -71.130800     17.218500      1.924900    121.625000    347.000000     13.500000
     -19.730500     -71.156600     17.218500      3.633500     82.350270    347.000000     13.500000
     -19.625300     -71.182300     17.218500     11.729830    114.097500    347.000000     13.500000
     -19.520000     -71.208100     17.218500      2.238910     89.318940    347.000000     13.500000
     -19.414800     -71.233900     17.218500    131.928410     78.548540    347.000000     13.500000
     -19.309600     -71.259700     17.218500    228.784500     80.433100    347.000000     13.500000
     -19.204400     -71.285500     17.218500    218.679500     77.302260    347.000000     13.500000
     -19.099100     -71.311300     17.218500     44.104390    115.923600    347.000000     13.500000
     -18.993900     -71.337100     17.218500     26.272020     86.180990    347.000000     13.500000
     -18.888700     -71.362900     17.218500     47.487590    115.102700    347.000000     13.500000
     -20.868300     -70.782300     19.552900      4.816710     91.781960    347.000000     13.500000
     -20.763000     -70.808100     19.552900     55.566740     78.940600    347.000000     13.500000
     -20.657800     -70.833900     19.552900    114.640100     79.548490    347.000000     13.500000
     -20.552600     -70.859700     19.552900    129.108600    125.430700    347.000000     13.500000
     -20.447400     -70.885500     19.552900     65.343400     97.159540    347.000000     13.500000
     -20.342100     -70.911300     19.552900     19.472960    121.956100    347.000000     13.500000
     -20.236900     -70.937100     19.552900     11.742210     87.873300    347.000000     13.500000
     -20.131700     -70.962900     19.552900     17.585190    113.560600    347.000000     13.500000
     -20.026500     -70.988700     19.552900     15.518210    103.615400    347.000000     13.500000
     -19.921300     -71.014500     19.552900     53.217250    120.369600    347.000000     13.500000
     -19.816000     -71.040200     19.552900      4.997290     98.043730    347.000000     13.500000
     -19.710800     -71.066000     19.552900     15.300550    123.103500    347.000000     13.500000
     -19.605600     -71.091800     19.552900     62.859020     78.243420    347.000000     13.500000
     -19.500400     -71.117600     19.552900      5.251690     84.176060    347.000000     13.500000
     -19.395100     -71.143400     19.552900      5.510640    117.067500    347.000000     13.500000
     -19.289900     -71.169200     19.552900     23.786180    110.655800    347.000000     13.500000
```

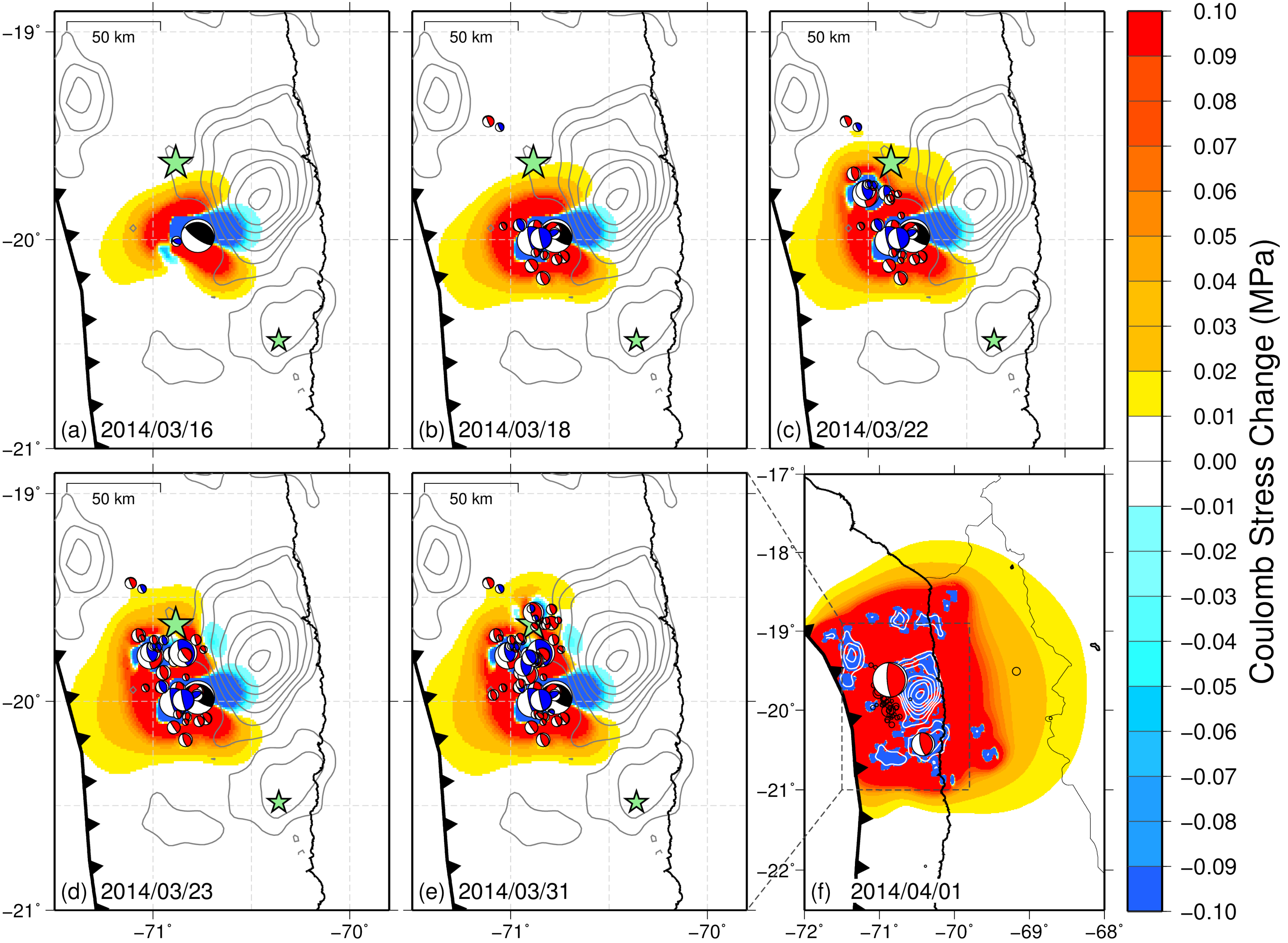
Main Shock Triggering

```
o92util -ffm iquique_2014.ffm...
```

Main Shock Triggering

- Noisy colors!
- Two reasons:
  - Slip in every subfault
  - Using one plane instead of plate boundary with changing dip





50 km
(a) 2014/03/16
(b) 2014/03/18
(c) 2014/03/22
(d) 2014/03/23
(e) 2014/03/31
(f) 2014/04/01
−19˚
−20˚
−21˚
−71˚
−70˚
−17˚
−18˚
−22˚
−72˚
−69˚
−68˚
Coulomb Stress Change (MPa)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
−0.01
−0.02
−0.03
−0.04
−0.05
−0.06
−0.07
−0.08
−0.09
−0.10

Main Shock Triggering

- *Exercise: What does the stress change from the 1 April main shock look like in cross-section?*

Main Shock Triggering