The USGS-NEIC Response to the 2011/03/11 Mw 9.0 Tohoku Earthquake

Magnitude and Rupture Modeling

Gavin P. Hayes, Paul S. Earle, Harley M. Benz, David J. Wald, Rich W. Briggs, and the USGS/NEIC Response Team

SSA 2011

Thanks to: Mike Hearne, Kristin Marano, Kuo-Wan Lin, Emily So, Daniel Garcia, Dan McNamara, Juan Cantavella, Rob Williams, Linda Lastowka, Lisa Wald, George Choy, Greg Smoczyk, Eric Martinez, Madeleine Zirbes, Dale Grant, and the rest of the NEIC Analysts.

Tohoku Earthquake Response

2011/03/11 05:46 UTC (10:46 pm in Golden, CO)

Timeline of knowledge & products @ NEIC

- Details of Magnitude Evolution.

- Comparisons to Sumatra EQ Response, 2004

- Prompt Assessment of Global Earthquakes for Response (PAGER)

- Fast Finite Fault Inversions


HYDRA location
Mar 11, 2011 5:50:12 AM
OT + 3.8 minutes
2011-03-11 05:46:21 (2 seconds from reference time)
38.16, 143.25 (79.018 km from reference location)
Depth 60.0 km
NEIC Public Release
Mar 11, 2011 6:05:01 AM
OT + 18.6 minutes
Event usc0001xgp (version A)
M 7.9 (coordinated with Tsunami Warning Centers and Japan Meterological Agency)
2011-03-11 05:46:23 (0 seconds from reference time)
38.3215, 142.3693 (0.061 km from reference location)
Depth 24.4 km
PTWC Public Release
Mar 11, 2011 5:56:03 AM
OT + 9.7 minutes
Event pt11070000 (version B)
M 7.9
2011-03-11 05:46:00 (23 seconds from reference time)
38.00, 142.90 (58.591 km from reference location)
Depth 10.0 km
ATWC Public Release
Mar 11, 2011 5:59:00 AM
OT + 12.6 minutes
Event at00lhvpd9 (version 1)
M 7.9
2011-03-11 05:46:28 (5 seconds from reference time)
38.0000, 142.9000 (58.591 km from reference location)
Depth 10.0 km
Global ShakeMap V1
Mar 11, 2011 6:07:00 AM
OT + 20.6 minutes
M7.9 Point Source approximation
TWC Coordination Call
Mar 11, 2011 6:09:06 AM
OT + 33.6 minutes
Phone call to coordinate/confirm magnitude increase for pending update #1.
PAGER V2 - Red Alert
Mar 11, 2011 6:20:14 AM
Global ShakeMap V2
Mar 11, 2011 6:55:00 AM
W-Phase Vertical Component Inversion V1, Distributed
Mar 11, 2011 6:43:00 AM


ATWC Public Release
Mar 11, 2011 5:59:00 AM
OT + 12.6 minutes
Event at00lhvpd9 (version 1)
M 7.9
2011-03-11 05:46:29 (5 seconds from reference time)
38.0000, 142.9000 (58.591 km from reference location)
Depth 10.0 km
Earthquake Origin Time
Mar 11, 2011 5:46:23 AM
PTWC Mwp Magnitude
Mar 11, 2011 5:51:07 AM
OT + 4.7 minutes
Mwp 7.5
Contributed magnitude
Global ShakeMap V1
Mar 11, 2011 6:07:00 AM
OT + 20.6 minutes
M7.9 Point Source approximation
PAGER V1 - Yellow Alert
Mar 11, 2011 6:09:59 AM
OT + 23.6 minutes
M7.9
Yellow Alert (yellow economic, green fatalities)
GSM V1
HYDRA Mwp Magnitude
Mar 11, 2011 5:54:45 AM
OT + 8.3 minutes
Mwp 8.5
Mar 11, 2011 6:00:00 AM
Mar 11, 2011 6:15:00 AM


HYDRA location
Mar 11, 2011 5:50:12 AM
OT + 3.8 minutes
2011-03-11 05:46:21 (2 seconds from reference time)
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Global ShakeMap V1
Mar 11, 2011 6:07:00 AM
OT + 20.6 minutes
M7.9 Point Source approximation
PAGER V1 - Yellow Alert
Mar 11, 2011 6:09:59 AM
OT + 23.6 minutes
M7.9
Yellow Alert (yellow economic, green fatalities)
Research CMT V1, Distribution
Mar 11, 2011 6:19:00 AM
OT + 32 minutes
Mw 8.9
NEIC Public Release, Update #1
Mar 11, 2011 6:24:13 AM
OT + 37.8 minutes
M 8.8
Global ShakeMap V2
Mar 11, 2011 6:29:00 AM
PAGER V2 - Red Alert
Mar 11, 2011 6:29:14 AM
OT + 42.8 minutes
M 8.8
Earthquake Origin Time
Magnitude

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OT + 19.6 minutes
Mw 9.0

Centroid: 36.822 142.869
Depth 24 No. of sta: 6

Best Double Couple: Mo=3.9*10^22
NP1:Strike=223 Dip=17 Slip= 135
NP2: 357 78 78

Research CMT V1 (Internal Release)
Mar 11, 2011 6:14:00 AM

OT + 27 minutes
Mw 8.9

Centroid: 38.212 143.072
Depth 24 No. of sta: 5

Best Double Couple: Mo=2.6*10^22

NEIC Public Release
Mar 11, 2011 6:05:01 AM

OT + 18.6 minutes
Event usc0001xgp (version A)
M 7.9 (coordinated with Tsunami Warning Centers and Japan Meterological Agency)
2011-03-11 05:46:23 (0 seconds from reference time)
38.3215, 142.3693 (0.061 km from reference location)
Depth 24.4 km

HYDRA location
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38.16, 143.25 (79.018 km from reference location)
Depth 60.0 km

PTWC Public Release
Mar 11, 2011 5:56:03 AM

OT + 9.7 minutes
Event pt11070000 (version B)
M 7.9
2011-03-11 05:46:00 (23 seconds from reference time)
38.00, 142.90 (58.591 km from reference location)

Mar 11, 2011 6:19:00 AM

OT + 32 minutes
Mw 8.9

Centroid: 37.845 143.565
Depth 24 No. of sta: 7

Best Double Couple: Mo=2.8*10^22
NP1:Strike=187 Dip=12 Slip= 83
NP2: 15 78 92

TWC Coordination Call
Mar 11, 2011 6:20:00 AM

OT + 33.6 minutes
Phone call to coordinate/confirm magnitude increase for pending update #1.

NEIC Public Release, Update #1
Mar 11, 2011 6:24:13 AM

OT + 37.8 minutes
Event usc0001xgp (version A)
M 8.8
2011-03-11 05:46:23 (0 seconds from reference time)
38.3660 (0.000 km from reference location)

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science for a changing world

W-Phase Vertical Component Iteration #1 (Internal Release)
Mar 11, 2011 6:06:00 AM

OT + 19.6 minutes
Mw 9.0

Centroid: 36.822 142.869
Depth 24 No. of sta: 6

Best Double Couple: Mo=3.9*10*22
NP1:Strike=223 Dip=17 Slip= 135
NP2: 357 78 78

Research CMT V1 (Internal Release)
Mar 11, 2011 6:14:00 AM

OT + 27 minutes
Mw 8.9

Centroid: 38.212 143.072
Depth 24 No. of sta: 5

Best Double Couple: Mo=2.8*10*22
NP1:Strike=186 Dip=12 Slip= 76
NP2: 20 78 93

NEIC Public Release
Mar 11, 2011 6:05:01 AM
OT + 18.6 minutes
Event usc0001xgp (version A)
...coordinated with Tsunami Warning Centers and
...logical Agency)
...seconds from reference time)
...from reference location)

PAGER V2 - Red Alert
Mar 11, 2011 6:29:14 AM

OT + 42.9 minutes
M 8.8
Tsunami text included (FOR TSUNAMI INFORMATION,
SEE: tsunami.noaa.gov)
Red Alert (red economic, yellow fatality)
GSN V2

...Distribution

USGS
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B)

conds from reference time)
rom reference location)

ase
:00 AM

(version 1)

28 (5 seconds from reference time)
(58.591 km from reference location)

Mar 11, 2011 6:19:00 AM

OT + 32 minutes
Mw 8.9

Centroid: 37.845 143.565
Depth 24 No. of sta: 7

Best Double Couple: Mo=2.8*10**22
NP1:Strike=187 Dip=12 Slip= 83
NP2: 15 78 92

TWC Coordination Call
Mar 11, 2011 6:20:00 AM

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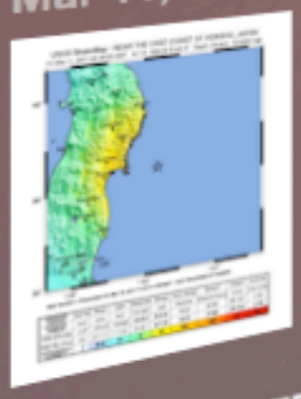
Phone call to coordinate/confirm magnitude increase for pending update #1.

NEIC Public Release, Update #1
Mar 11, 2011 6:24:13 AM

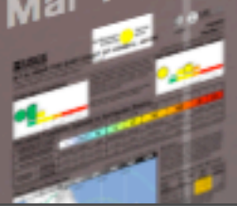
OT + 37.8 minutes
Event usc0001xgp (version A)
M 8.8
2011-03-11 05:46:23 (0 seconds from reference time)
38.3220, 142.3690 (0.000 km from reference location)
Depth 24.4 km

Global ShakeMap V1
Mar 11, 2011 6:07:00 AM



OT + 20.6 minutes
M7.9 Point Source approximation

PAGER V1 - Yellow Alert
Mar 11, 2011 6:09:59 AM



OT + 23.6 minutes
M7.9
Yellow Alert (yellow economic, green fatalities)
GSM V1

Global ShakeMap V2
Mar 11, 2011 6:26:00 AM

OT + 39.6 minutes
M 8.8, location slightly shifted to NE, point source.

W-Phase Vertical Component Inversion V1, Distribution
Mar 11, 2011 6:34:00 AM

OT + 47.6 minutes
Mw 8.94

Centroid: 37.822 141.869
Depth 24 No. of sta: 74

Best Double Couple:Mo=3.2*10**22
NP1:Strike=204 Dip=15 Slip= 104
NP2: 10 76 86

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93

PAGER V2 - Red Alert
Mar 11, 2011 6:29:14 AM

OT + 42.9 minutes
M 8.8
Tsunami text included (FOR TSUNAMI INFORMATION,
SEE: tsunami.noaa.gov)
Red Alert (red economic, yellow fatalities)
GSM V2

tion

inutes

37.845 143.565
No. of sta: 7

ble Couple: Mo=2.8*10*22
ke=187 Dip=12 Slip= 83
15 78 92

confirm magnitude increase

Release, Update #1
6:24:13 AM

nutes
(version A)
om reference time)
e location)

W-Phase 3-Component Inversion V1, Published
Mar 11, 2011 6:48:00 AM

OT + 61.6 minutes
Mw 8.90

Centroid: 37.321 141.769
Depth 24 No. of sta: 89

Best Double Couple:Mo=2.8*10**22
NP1:Strike=162 Dip=17 Slip= 45
NP2: 28 78 102

NEIC Public Release, Update #2
Mar 11, 2011 6:51:47 AM

OT + 65.4 minutes
Event usc0001xgp (version A)
M 8.9
2011-03-11 05:46:23 (0 seconds from reference time)
38.3220, 142.3690 (0.000 km from reference location)
Depth 24.4 km

Global ShakeMap V3
Mar 11, 2011 6:56:00 AM

OT + 68.6 minutes
M 8.9, point source.

PAGER V3 - Red Alert
Mar 11, 2011 7:02:06 AM

OT + 75.7 minutes
M 8.9
Alert (red economic, orange fatalities)

Tectonic Summary Posted
Mar 11, 2011 7:21:00 AM
OT + 94.6 minutes

W-Phase 3-Component Inversion V1, Published
Mar 11, 2011 6:48:00 AM

OT + 61.6 minutes
Mw 8.90

Centroid: 37.321 141.769
Depth 24 No. of sta: 89

Best Double Couple:Mo=2.8*10**22
NP1:Strike=162 Dip=17 Slip= 45
NP2: 28 78 102

NEIC Public Release, Update #2
Mar 11, 2011 6:51:47 AM

OT + 65.4 minutes
Event usc0001xgp (version A)
M 8.9
2011-03-11 05:46:23 (0 seconds from reference time)
38.3220, 142.3690 (0.000 km from reference location)
Depth 24.4 km

Global ShakeMap V3
Mar 11, 2011 6:55:00 AM

OT + 68.5 minutes
M 8.9, point source.

PAGER V3 - Red Alert
Mar 11, 2011 7:02:06 AM

OT + 75.7 minutes
M 8.9
Red Alert (red economic, orange fatalities)
GSM V3

Tectonic Summary Posted
Mar 11, 2011 7:21:00 AM

OT + 94.8 minutes

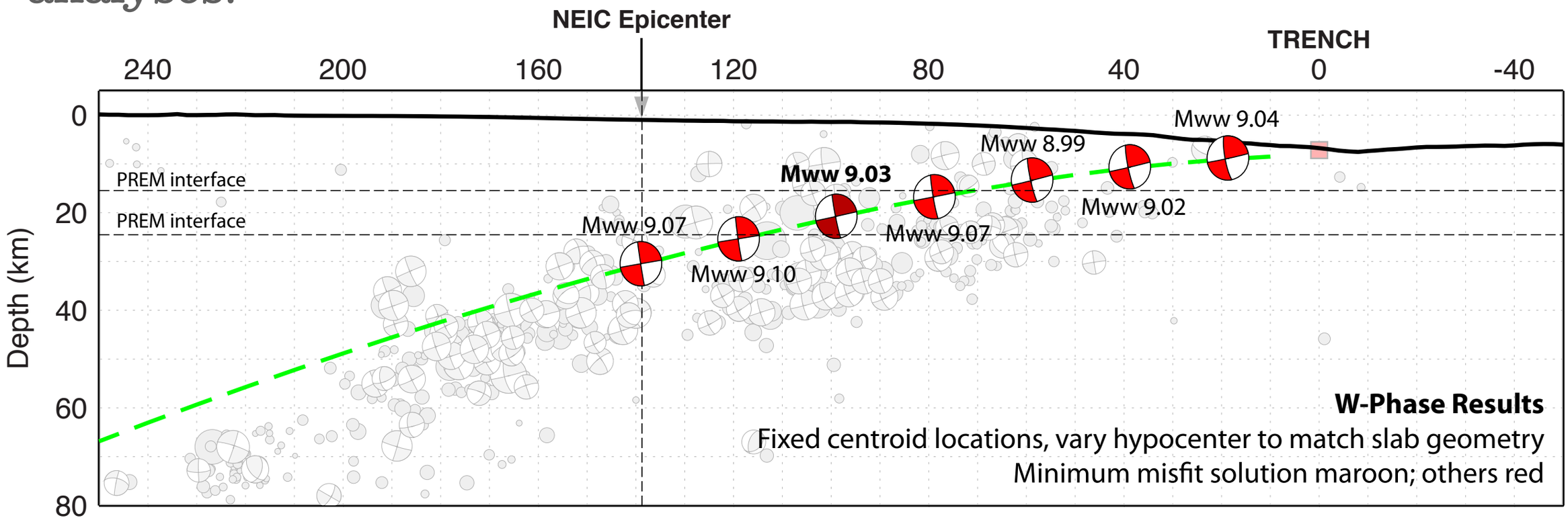
Evolution of Earthquake Magnitude

OT + 19 minutes: Initial NEIC release, M 7.9 (coordinated with TWC's and JMA).

OT + 38 minutes: First update, Mw 8.8 (coordinated with TWC's).

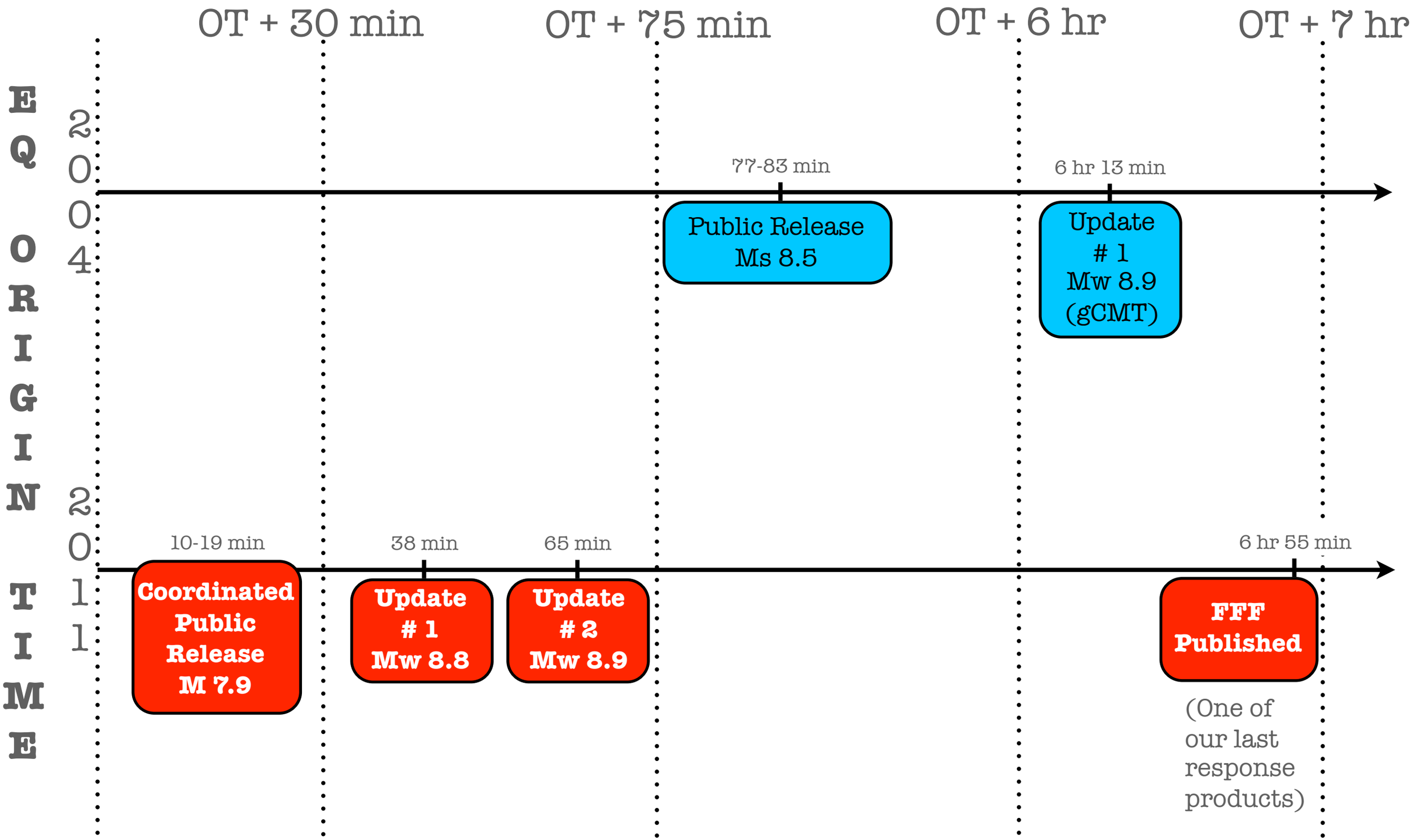
OT + 65 minutes: Second update, Mw 8.9 (automated 3 component W-Phase inversion and research CMT results).

OT + 3 days: Final update, Mw 9.0. In-depth W-Phase inversion analyses.



Evolution of Earthquake Magnitude

Comparison to Sumatra- 12/04 Response



Evolution of PAGER

USGS science for a changing world

Earthquake Shaking: Yellow Alert

GSN ANSS USAID FROM THE AMERICAN PEOPLE

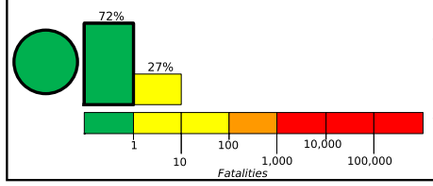
M 7.9, NEAR THE EAST COAST OF HONSHU, JAPAN

Origin Time: Fri 2011-03-11 05:46:23 UTC (14:46:23 local)
Location: 38.32°N 142.37°E Depth: 24 km

PAGER Version 1

Created: 22 minutes, 58 seconds after earthquake

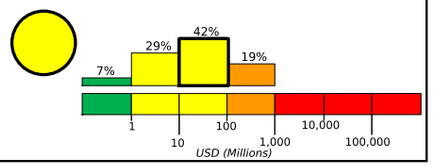
Estimated Fatalities



Yellow alert level for economic losses. Some damage is possible and the impact should be relatively localized. Estimated economic losses are less than 1% of GDP of Japan. Past events with this alert level have required a local or regional level response.

Green alert level for shaking-related fatalities. There is a low likelihood of casualties.

Estimated Economic Losses



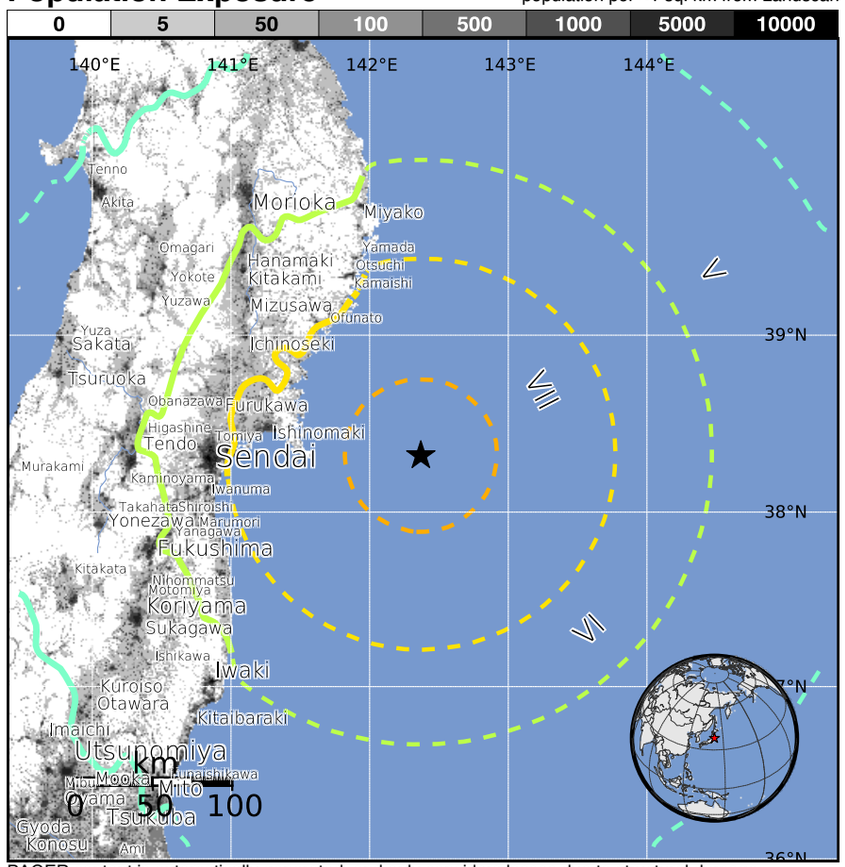
Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	- -*	3,227k*	6,192k	2,918k	719k	0	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan



Structures:
Overall, the population in this region resides in structures that are resistant to earthquake shaking, though some vulnerable structures exist. The predominant vulnerable building types are ductile reinforced concrete frame and heavy wood frame construction.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1998-06-14	363	5.7	VII(428k)	0
1994-12-28	263	7.7	VII(132k)	3
1983-05-26	369	7.7	VII(174k)	104

Recent earthquakes in this area have caused secondary hazards such as tsunamis, landslides, and fires that might have contributed to losses.

Selected City Exposure

from GeoNames.org

MMI	City	Population
VII	**Ishinomaki**	**117k**
VII	Yamoto	32k
VII	Shiogama	60k
VII	Kogota	20k
VII	Rifu	35k
VI	**Ofunato**	**35k**
VI	**Sendai**	**1,038k**
VI	Yamagata	255k
V	**Morioka**	**295k**
V	**Fukushima**	**294k**
IV	**Utsunomiya**	**450k**

bold cities appear on map (k = x1000)

PAGER content is automatically generated, and only considers losses due to structural damage. Limitations of input data, shaking estimates, and loss models may add uncertainty.

http://earthquake.usgs.gov/pager

Event ID: usc0001xgp

OT + 21 minutes: GSM V1
OT + 24 minutes: PAGER V1

Preliminary estimates of Global ShakeMap (GSM) shaking distributions and PAGER population exposure were low relative to final estimates because they relied on the low (M 7.9) initial earthquake magnitude.

Evolution of PAGER

USGS science for a changing world

Earthquake Shaking — Red Alert

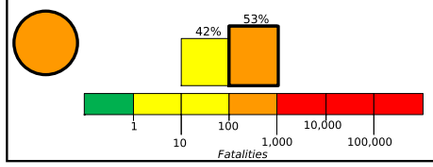
GSN · USAID FROM THE AMERICAN PEOPLE · ANSS

M 8.9, NEAR THE EAST COAST OF HONSHU, JAPAN

Origin Time: Fri 2011-03-11 05:46:23 UTC (14:46:23 local)
Location: 38.32°N 142.37°E Depth: 24 km
FOR TSUNAMI INFORMATION, SEE: tsunami.noaa.gov

PAGER
Version 3
Created: 1 hour, 15 minutes after earthquake

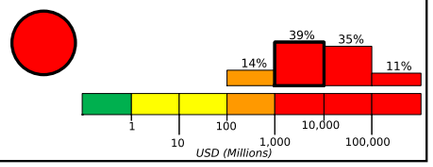
Estimated Fatalities



Red alert level for economic losses. Extensive damage is probable and the disaster is likely widespread. Estimated economic losses are less than 1% of GDP of Japan. Past events with this alert level have required a national or international level response.

Orange alert level for shaking-related fatalities. Significant casualties are likely.

Estimated Economic Losses



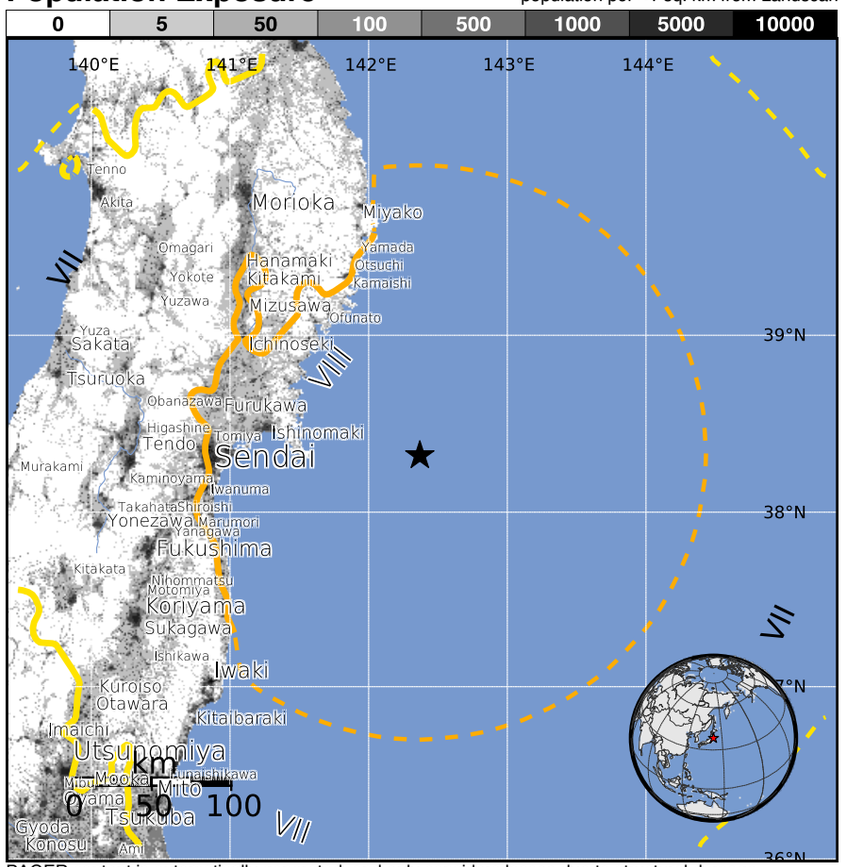
Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	- -*	- -*	- -*	2,472k*	7,986k*	2,598k	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan



PAGER content is automatically generated, and only considers losses due to structural damage.
Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

Structures:
Overall, the population in this region resides in structures that are resistant to earthquake shaking, though some vulnerable structures exist. The predominant vulnerable building types are ductile reinforced concrete frame and heavy wood frame construction.

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Selected City Exposure

from GeoNames.org

MMI	City	Population
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VIII	Shiogama	60k
VIII	Yamoto	32k
VIII	Kogota	20k
VIII	Rifu	35k
VIII	**Furukawa**	**76k**
VIII	Yamagata	255k
VII	**Morioka**	**295k**
VII	**Sendai**	**1,038k**
VII	**Fukushima**	**294k**
VII	**Utsunomiya**	**450k**

bold cities appear on map (k = x1000)

Event ID: usc0001xgp

OT + 1 hour, 09 minutes: GSM V3
OT + 1 hour, 16 minutes: PAGER V3

Both ShakeMap and PAGER (and related alert levels) rapidly increased towards their final estimates as magnitude estimates were updated.

Evolution of PAGER

USGS science for a changing world

Earthquake Shaking **Red Alert**

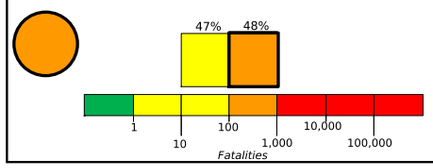
GSN ANSS USAID FROM THE AMERICAN PEOPLE

M 8.9, NEAR THE EAST COAST OF HONSHU, JAPAN

Origin Time: Fri 2011-03-11 05:46:23 UTC (14:46:23 local)
Location: 38.32°N 142.37°E Depth: 24 km
FOR TSUNAMI INFORMATION, SEE: tsunami.noaa.gov

PAGER Version 5
Created: 2 hours, 44 minutes after earthquake

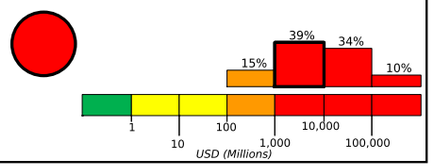
Estimated Fatalities



Red alert level for economic losses. Extensive damage is probable and the disaster is likely widespread. Estimated economic losses are less than 1% of GDP of Japan. Past events with this alert level have required a national or international level response.

Orange alert level for shaking-related fatalities. Significant casualties are likely.

Estimated Economic Losses



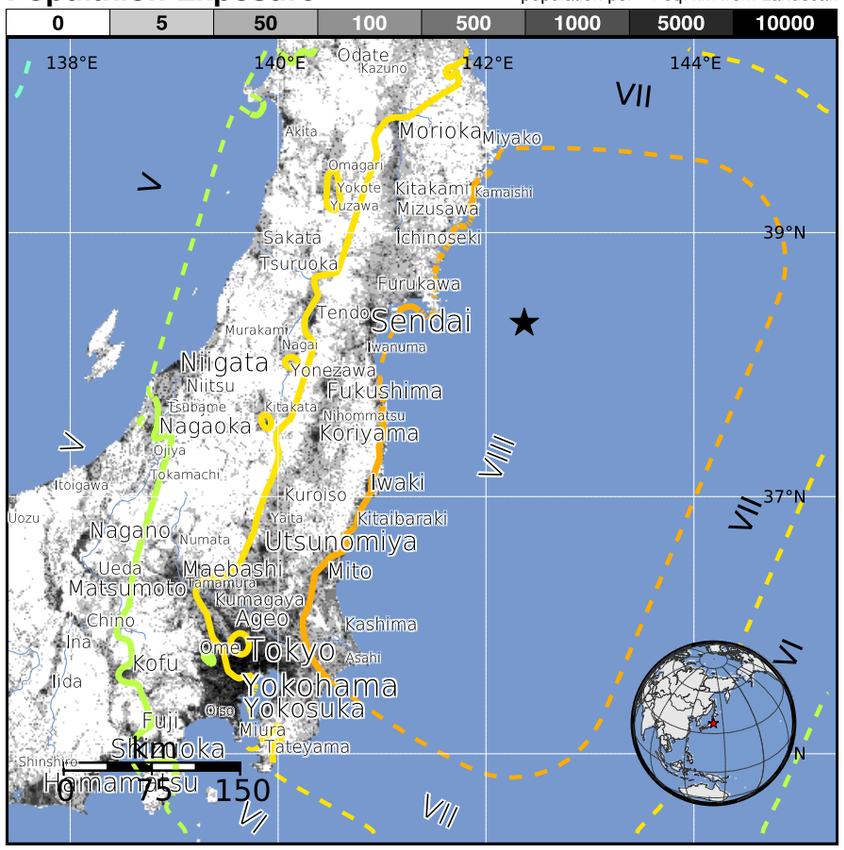
Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	- -*	- -*	7,071k*	19,695k*	29,969k*	2,144k	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan



Structures:
Overall, the population in this region resides in structures that are resistant to earthquake shaking, though some vulnerable structures exist. The predominant vulnerable building types are non-ductile reinforced concrete frame and heavy wood frame construction.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1998-06-14	363	5.7	VII(428k)	0
1994-12-28	263	7.7	VII(132k)	3
1983-05-26	369	7.7	VII(174k)	104

Recent earthquakes in this area have caused secondary hazards such as tsunamis, landslides, and fires that might have contributed to losses.

Selected City Exposure

from GeoNames.org

MMI	City	Population
VIII	Omigawa	26k
VIII	Oarai	19k
VIII	Hasaki	39k
VIII	Itako	26k
VIII	Ofunato	35k
VIII	Takahagi	34k
VII	**Sendai**	**1,038k**
VII	Chiba	920k
VII	**Tokyo**	**8,337k**
VI	**Yokohama**	**3,574k**
V	**Shizuoka**	**702k**

bold cities appear on map (k = x1000)

Event ID: usc0001xgp

PAGER content is automatically generated, and only considers losses due to structural damage. Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

OT + 2 hours, 42 minutes: GSM V4
OT + 2 hours, 45 minutes: PAGER V5

Estimates of fault finiteness were included in shaking estimates within 3 hours of the earthquake, using a preliminary finite fault model and the early aftershock distribution.

Evolution of PAGER

USGS science for a changing world

Earthquake Shaking — Red Alert

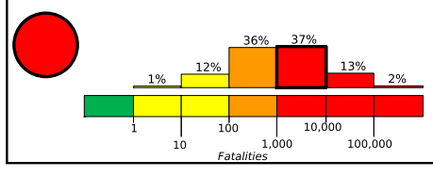
GSN · USAID FROM THE AMERICAN PEOPLE · ANSS

M 9.0, NEAR THE EAST COAST OF HONSHU, JAPAN

Origin Time: Fri 2011-03-11 05:46:23 UTC (14:46:23 local)
Location: 38.32°N 142.37°E Depth: 32 km
FOR TSUNAMI INFORMATION, SEE: tsunami.noaa.gov

PAGER
Version 12
Created: 2 weeks, 1 day after earthquake

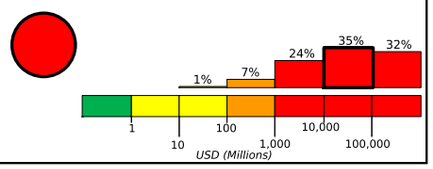
Estimated Fatalities



Red alert for shaking-related fatalities and economic losses. High casualties and extensive damage are probable and the disaster is likely widespread. Past red alerts have required a national or international response.

Estimated economic losses are 0-1% GDP of Japan.

Estimated Economic Losses



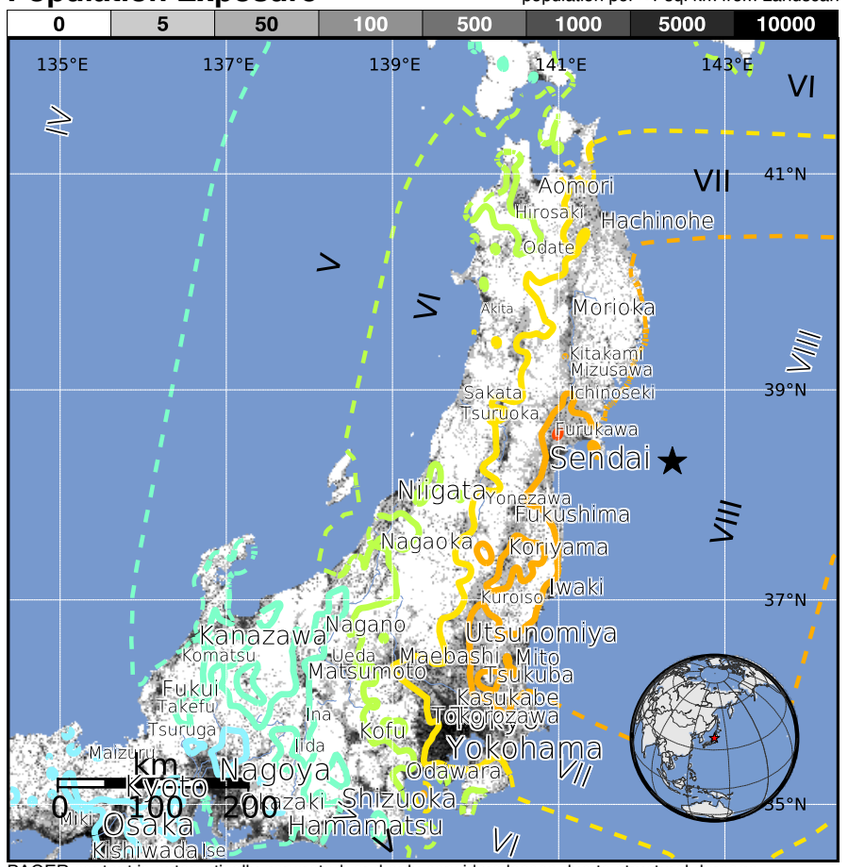
Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	13,068k*	21,353k*	8,612k*	10,080k*	34,125k*	6,009k*	251k	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan



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Selected City Exposure

from GeoNames.org

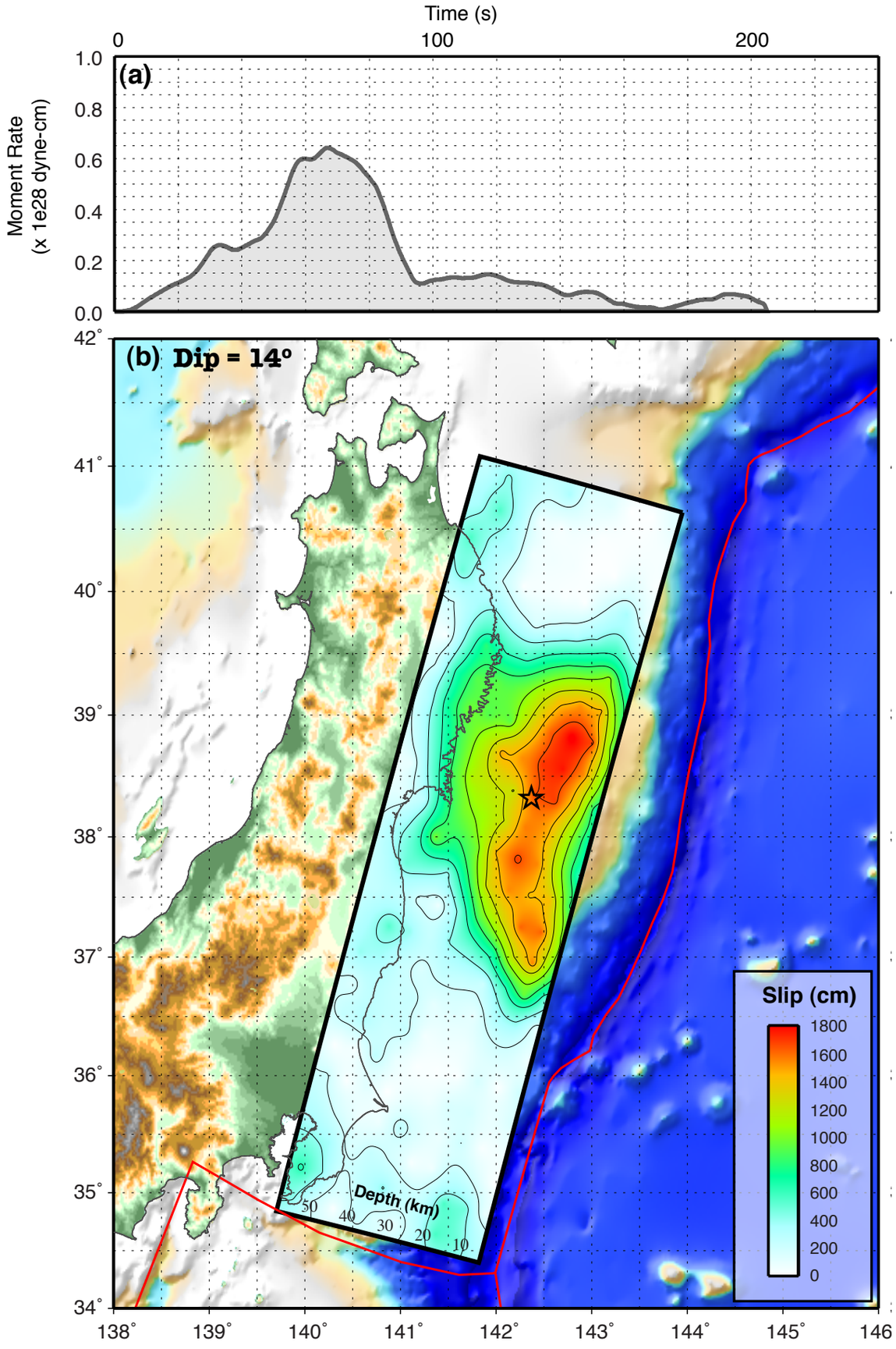
MMI	City	Population
IX	**Furukawa**	**76k**
IX	Iwanuma	42k
IX	Hitachi	186k
IX	Kogota	20k
VIII	Shiogama	60k
VIII	Sukagawa	69k
VII	**Tokyo**	**8,337k**
VII	**Yokohama**	**3,574k**
IV	**Nagoya**	**2,191k**
III	**Osaka**	**2,592k**
III	Kobe	1,528k

bold cities appear on map (k = x1000)

Event ID: usc0001xgp

Over the following days, as strong motion data became available from K-Net and KiK-Net, GSM and PAGER were updated several times. None of these subsequent versions diverged significantly from ShakeMap V4 (PAGER V5), released within 3 hours of the earthquake.

Evolution of Finite Fault Models



OT + 6 hours, 55 minutes

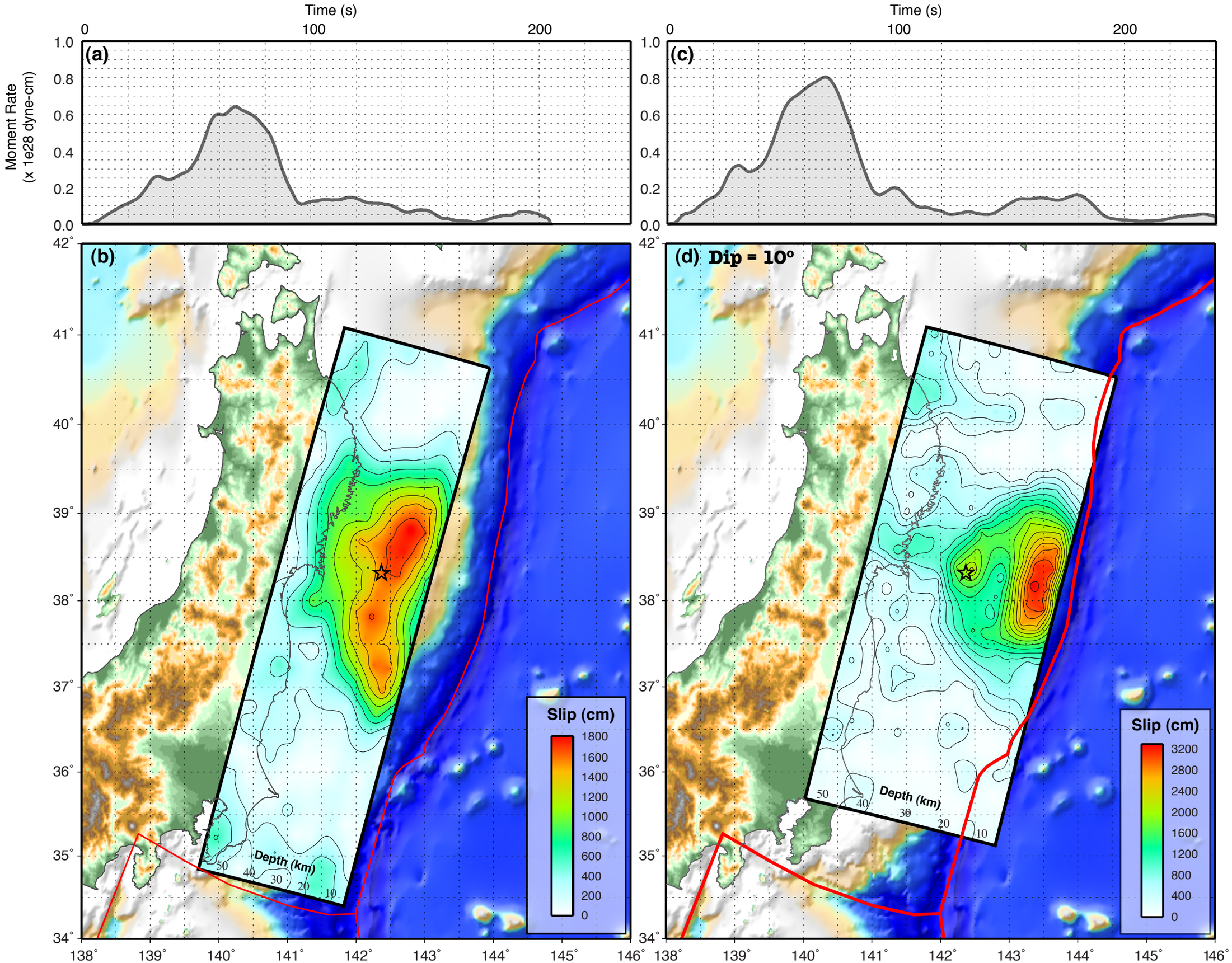
First published fast finite fault model.

Earlier estimates suffered from:

- misaligned fault strike (initial automated W-Phase solution was rotated wrt the Japan Trench).
- poorly constrained rupture velocity
- inaccurate peak slip parameterization

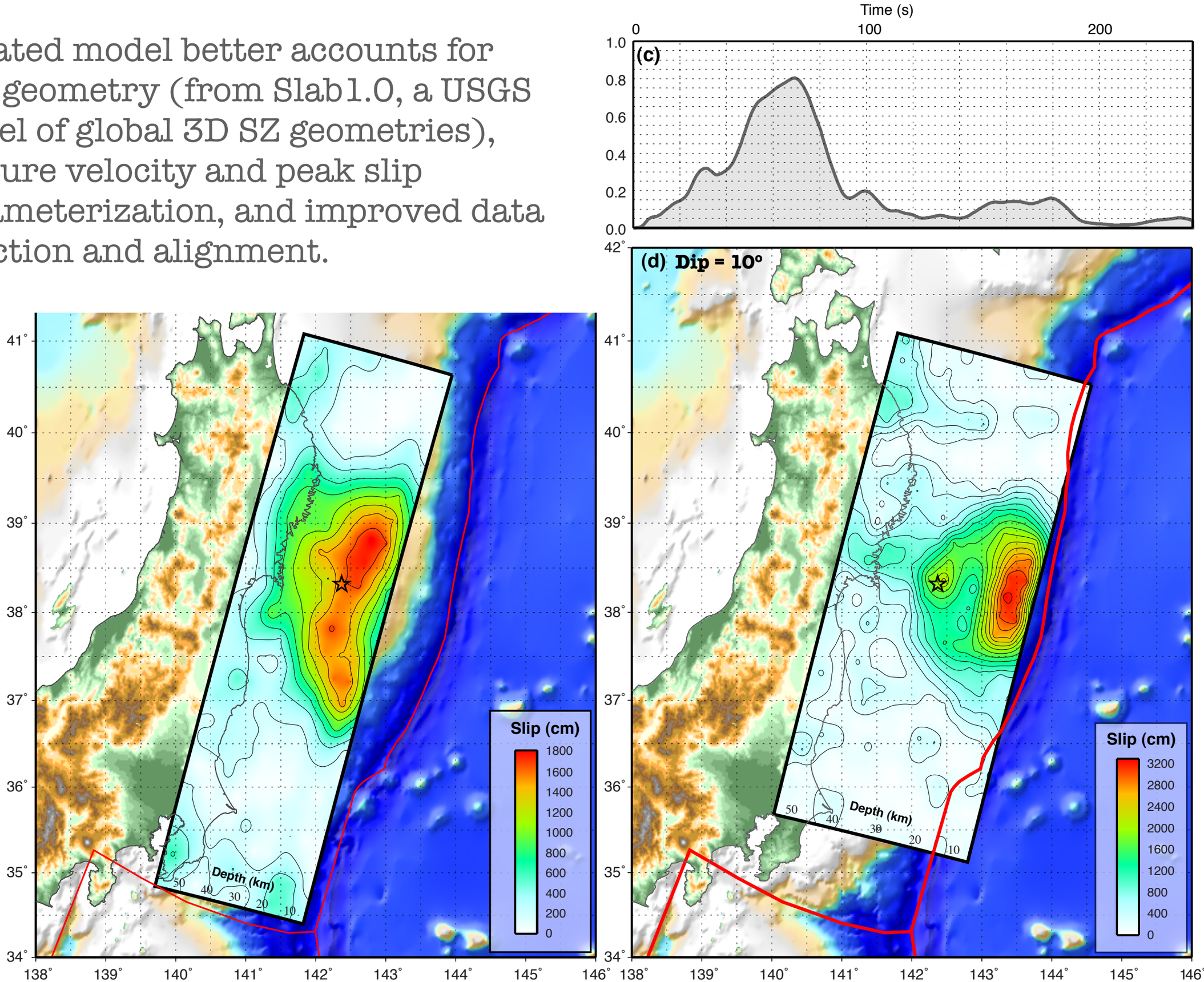
While this model has been updated both by the USGS and by many others, the general along-strike and up-dip nature of rupture estimated by this first model has not changed significantly.

Evolution of Finite Fault Models



Evolution of Finite Fault Models

Updated model better accounts for slab geometry (from Slab1.0, a USGS model of global 3D SZ geometries), rupture velocity and peak slip parameterization, and improved data selection and alignment.



Evolution of Finite Fault Models

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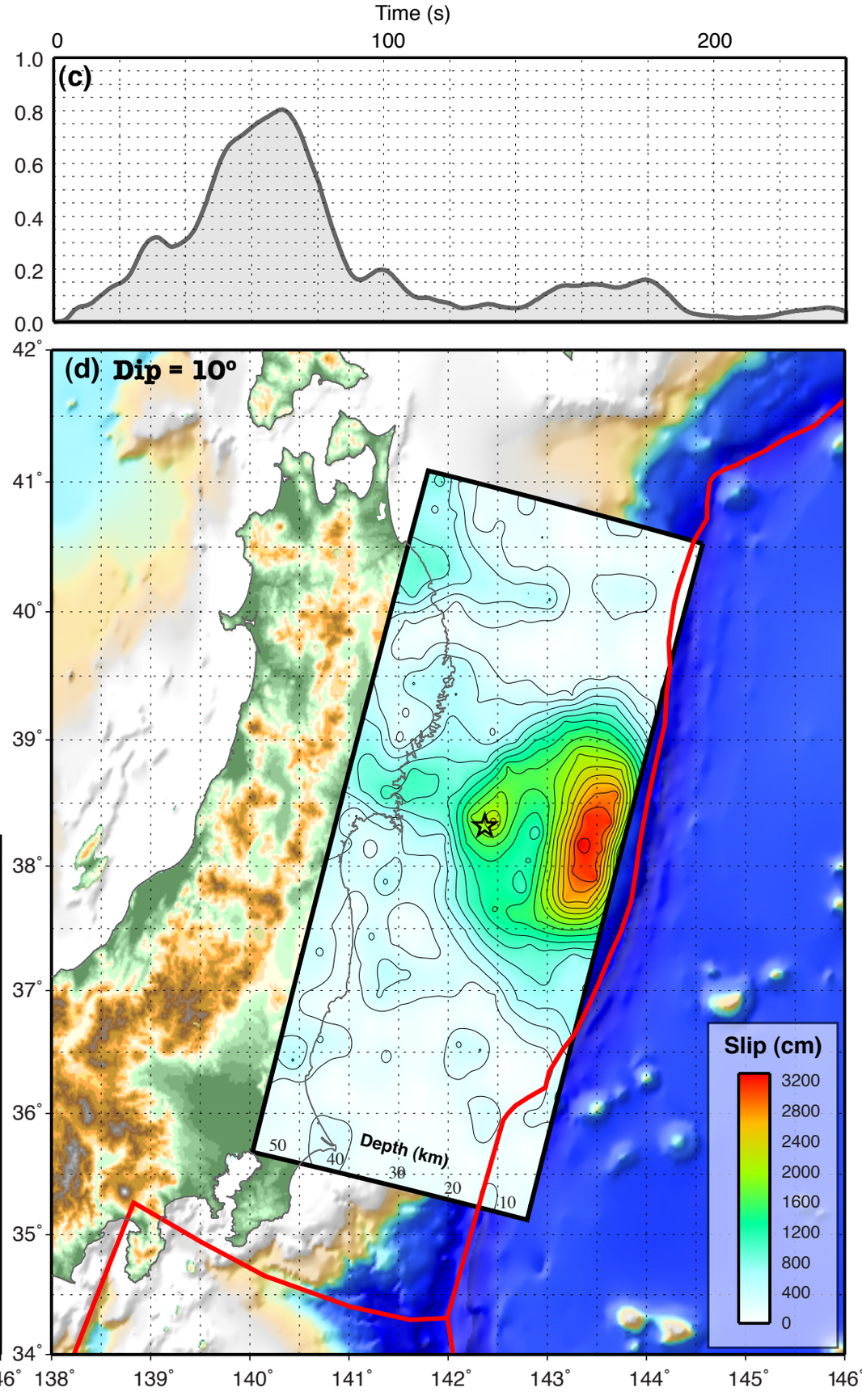
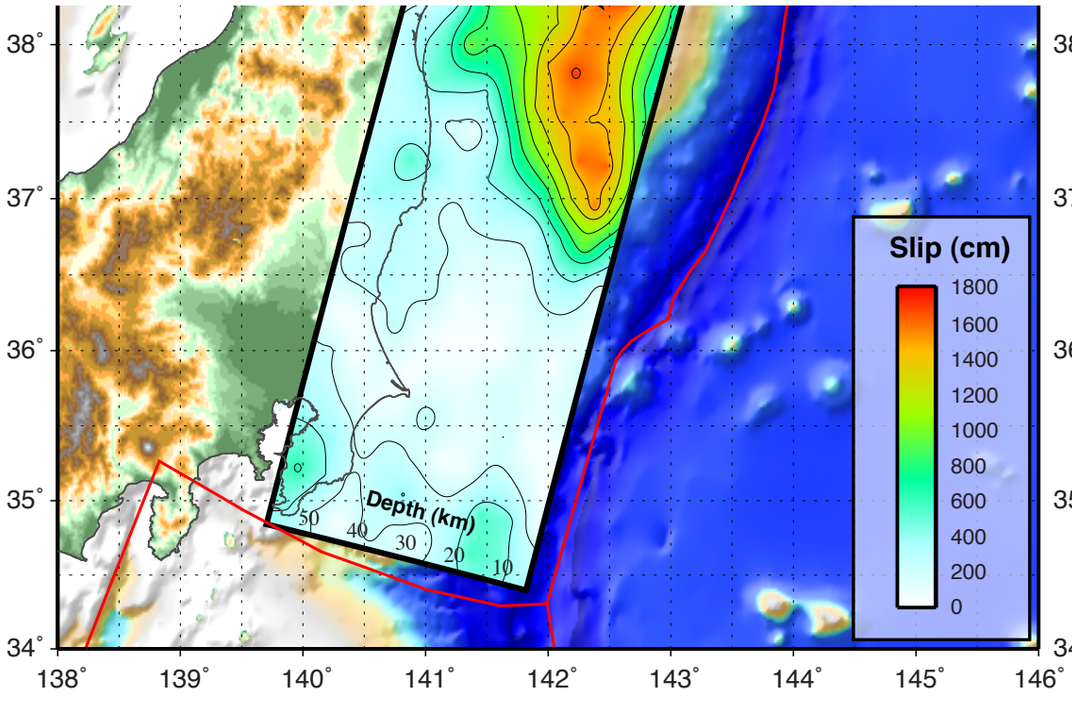
Further tests of rupture velocity, fault plane dip, and fault plane down-dip and along strike extents show late slip (>140 s) and deep slip poorly constrained; peak slip also likely higher still.





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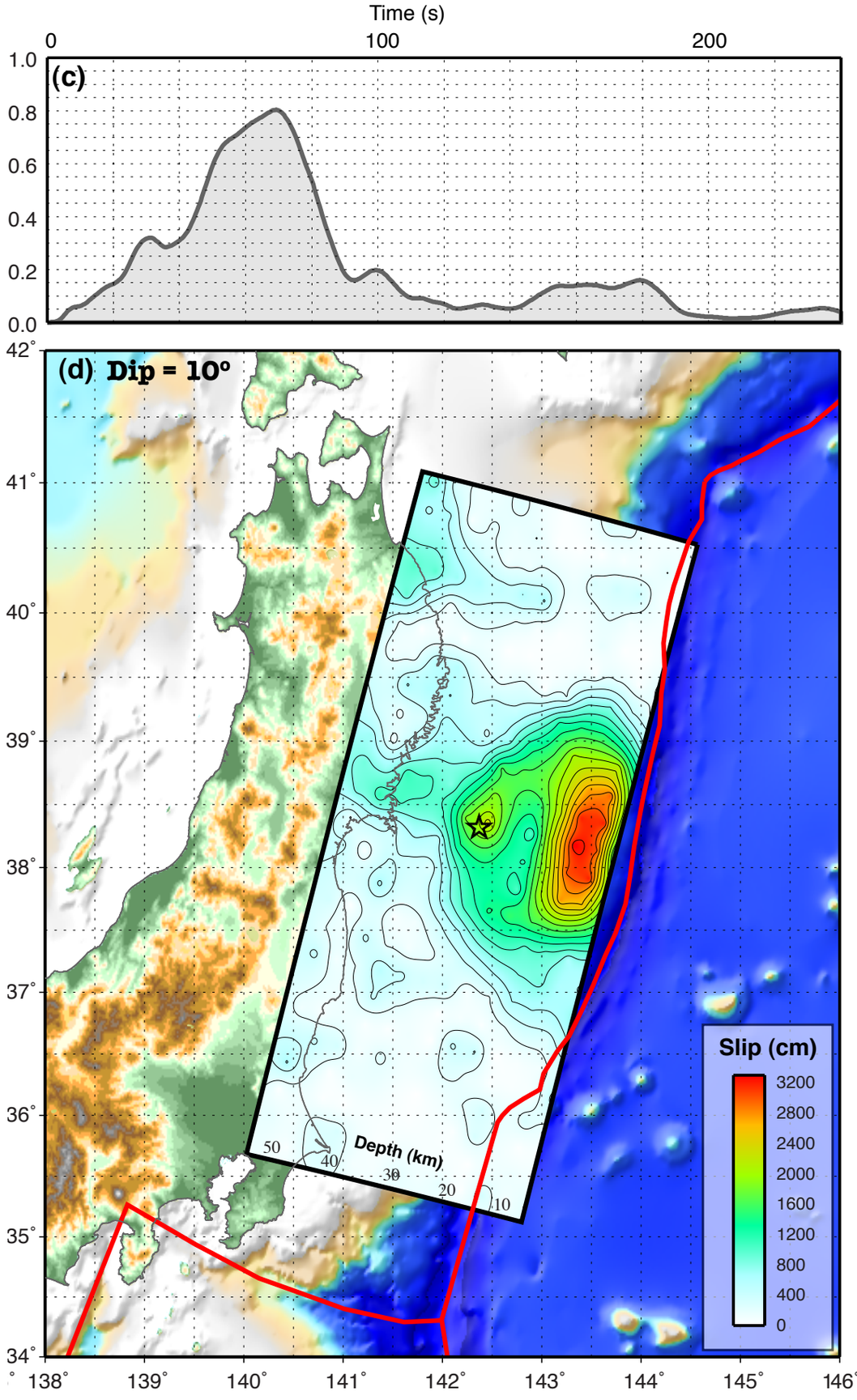
Further tests of rupture velocity, fault plane dip, and fault plane down-dip and along strike extents show late slip (>140 s) and deep slip poorly constrained; peak slip also likely higher still.

Uncertainty in the nodal planes of early moment tensors (and of models since) speak to the usefulness of a prior information from existing geometry models, such as Slab1.0.



Discussion

Our ability to rapidly & accurately characterize large earthquakes at the NEIC has significantly improved over the last 6 years.

- in 2011 the world was aware of the great size of the Tohoku event in minutes to hours, played out in near real time as EQ information was released. In 2004 it took hours to days for accurate seismological information to be disseminated.

Room for improvement; initial magnitude (M 7.9) much lower than actual size of EQ (M 9.0). Requires further exploration of reliability of rapid magnitude estimates (Mwp; Empirical Green Functions), and uncertainty assessment of early (20 min) W-Phase estimates; regional W-Phase inversions?

Rapid finite fault analyses can be improved by better data selection (based on W-phase data set) and sped up by use of a priori geometry information.

Initial FF released at OT+7 hrs captured general characteristics of the earthquake rupture accurately (with the exception of peak slip).