Room C | General session：S17. Tsunami

📅 Tue. Sep 17, 2019 9:15 AM - 10:30 AM JST | Tue. Sep 17, 2019 12:15 AM - 1:30 AM UTC | 🏛 ROOM C Research Bldg No 8 NS Hall

[S17]AM-1

chairperson:Shingo Watada(Earthquake Research Institute, the University of Tokyo), Akio Katsumata(Meteorological Research Institute, JMA)

9:15 AM - 9:30 AM JST | 12:15 AM - 12:30 AM UTC

[S17-01] Mechanism of the 2018 Sunda Strait Tsunami

*Shingo Watada[1], Masumi Yamada[2], Iyan Mulia[1], Karyono Karyono[3], Arif Aditya[4], Dimas Sinipar[5] (1. Earthquake Research Institute of the University of Tokyo, 2. Disaster Prevention Research Institute, Kyoto University, 3. Meteorological Climatological and Geophysical Agency, 4. Geospatial Information Agency of Indonesia, 5. National Central University, Taiwan)

9:30 AM - 9:45 AM JST | 12:30 AM - 12:45 AM UTC

[S17-02] **Tsunami simulation due to the Anak Krakatau Volcano activities on 22 December 2018 and analyses on the potential future observing systems**

*Iyan E. Mulia[1], Shingo Watada[1], Tung-Cheng Ho[1], Kenji Satake[1], Yuchen Wang[1], Arif Aditya[2] (1. The University of Tokyo, 2. Geospatial Information Agency of Indonesia)

9:45 AM - 10:00 AM JST | 12:45 AM - 1:00 AM UTC

[S17-03] Investigation for the Tsunami and Earthquake Source of the 2018 M7.5 Sulawesi Earthquake

*Tung-Cheng Ho[1], Kenji Satake[1], Shingo Watada[1], Iyan E. Mulia[1], Yosuke Aoki[1], Ray Y. Chuang[2] (1. Earthquake Research Institute, Univ. of Tokyo, 2. Dept. Geography, NTU, Taiwan)

10:00 AM - 10:15 AM JST | 1:00 AM - 1:15 AM UTC

[S17-04] A Method of Real-Time Tsunami Detection

*Yuchen Wang[1], Kenji Satake[1] (1. Earthquake Research Institute, The University of Tokyo)

10:15 AM - 10:30 AM JST | 1:15 AM - 1:30 AM UTC

[S17-05] Rapid magnitude estimation method for slow tsunami earthquakes (4)

*Akio Katsumata[1], Masayuki Tanaka[1] (1. Meteorological Research Institute, JMA)

Mechanism of the 2018 Sunda Strait Tsunami

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2018年12月22日UT14時30分頃、インドネシアスンダ海峡周辺のジャワ島・スマトラ島を津波が襲い400名余が犠牲となった。この津波の発生とほぼ同時期にAnak Krakatau火山が噴火し、火山の標高が噴火前後で300mから100mへと低下したと報告されているため、津波は陸上または海中の山体崩壊が引き起こしたと考えられている。噴火直後のSAR画像から南西方向に山頂部を含め山体が崩落し海中に消失している。周辺の検潮記録から、津波の発生は13時58分頃と推定される。インドネシア国内では火山噴火や津波発生時に強い地震の発生の報告はないが、日本を含むインドネシア国内外の広帯域地震計には周期50-100秒の長周期の地震波（S波・レイリー波）が明瞭に記録されている。S波は14時11分に日本の南西諸島へ、14時16分に北海道へ到達している。表面波も14時27分に北海道を通過している。どの地震波も13時56分頃にAnak Krakatau火山付近で長周期の地震波発生イベントがあったことを示している。遠地実体波から震源時間関数は100秒以内（1分程度）であり、スンダ海峡周辺の４観測点の地震波形３成分は、最大5x1011 Nの力が、最初に

20秒間でほぼ北東方向わずかに上向き、さらに50秒で南西方向に方向でわずかに下向き向きに働いたことで説明できる。力の方向と角度は、Krakatau海底カルデラ外縁部に成長していたAnak Krakatau山体の低角（8度）南西方向へ水深250mのカルデラ底へ崩壊とそれに伴う津波の可能性を指摘していたGiachetti et al. (2012, Geol. Soc. London)　の山体崩壊モデルとほぼ一致する。山体崩壊の質量はEkstrom and Startk (2013, Science) が経験的に求めた陸上地滑りの最大力と質量の比例式から3x1011 kgと推定され、山体の密度を2gr/cm3 を仮定すると山体崩壊体積はおよそ0.15km3 となり、検潮記録から推定されている海底地滑りを引き

起こした体積0.2km3 とおよそ一致している。

津波を引き起こすような地震が現地では検知されなかったため、津波警報は発令されなかった。一方、津波の発生と共に発生したと考えられる長周期地震波は地震発生イベントの40秒後にはJakartaに到達した。もし

今回観測されたような長周期地震動が定常的にインドネシアでモニターされれていれば、Anak Krakatau山体崩壊の早期検知とそれに伴う津波発生の可能性は津波被害発生前に把握できたかもしれない。

Tsunami simulation due to the Anak Krakatau Volcano activities on 22 December 2018 and analyses on the potential future observing systems

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A deadly tsunami occurred on 22 December 2018 claimed hundreds of lives, as well as injured and displaced thousands of people living across the Sunda Strait regions. The tsunami was associated with the Anak Krakatau volcano, which according to the Indonesian Centre for Volcanology and Geological Hazard Mitigation, had exhibited an increase in seismic activity followed by explosions and volcanic ash emissions prior to the event (https://magma.vsi.esdm.go.id/, last accessed 22 May 2019). However, the Anak Krakatau had never been known to generate significant tsunami. During the 2018 event, the edifice formed by the accumulation of pyroclastic material partly collapsed and slid down the water, triggering an impulsive wave.

We use numerical models to reveal the generation (NHWAVE, Ma et al., 2012) and propagation (FUNWAVE-TVD, Shi et al., 2012) of the tsunami caused by the southwest flank collapse of the Volcano. With the estimated volume of 0.24 km^3 and the relatively short duration (˜3 to 5 min), the landslide of volcanic edifices triggers the tsunami of approximately 40 m in the vicinity. The tsunami, however, attenuates rapidly as it propagates away from the generation area resulting in <2 m wave heights at tide gauges around the Sunda Strait. The observed tsunami waveforms at these tide gauges are well reproduced by our model. The maximum tsunami energy is mainly distributed towards the west coast of Java leading to significant number of casualties compared to other areas.

To mitigate future tsunami disasters in the region, we assess the efficacy of potential tsunami observations using ship height positioning and oceanographic radars. We demonstrate that the relatively small tsunami amplitudes of the event are still considerably larger than the noise level of a typical observation by ship height positioning. Furthermore, applying a tsunami data assimilation (Maeda et al., 2015) to the tsunami velocity field detected by radars can produce accurate forecasts of coastal tsunami heights.

Investigation for the Tsunami and Earthquake Source of the 2018 M7.5 Sulawesi Earthquake

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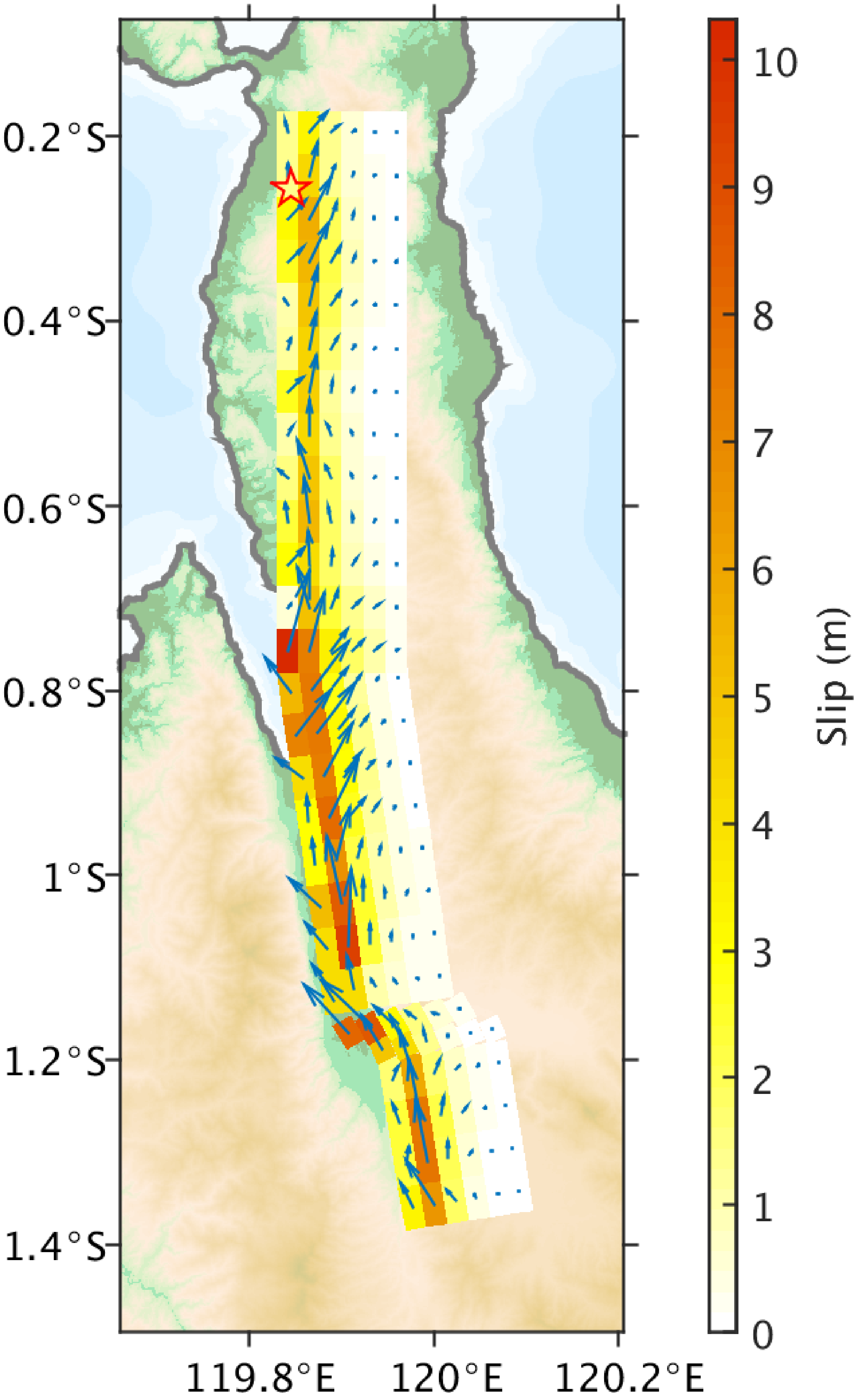
A devastating tsunami struck the bay of Palu, Indonesia after the M7.5 (U.S. Geological Survey; USGS) Sulawesi (Palu) earthquake. This earthquake mechanism was a left-lateral strike slip fault. Large horizontal offsets of up to 5 meters were measured near the bay area by satellite images. According to the researches of Bao et al. (2019, Nat. Geosci.) and Socquet et al (2019, Nat. Geosci.) a rupture velocity 4.1 km/s was suggested indicating that this earthquake was a supershear event. The tsunami was recorded by two tide gauges: 2-m wave height was observed by a tide gauge at the port of Pantoloan in the Palu bay, and 20 cm wave height observed by a ~200-km-far tide gauge at Mamuju port. In addition to the tide gauges, up to 10 m runups were measured near the coastal area by field surveys (Omira et al., 2019, *Pageoph*; Muhari et al., 2019, *JDR*). Other than the earthquake, landslide events were captured by videos which also induced local tsunamis.

Our analyses showed that the tsunami leading wave at the Pantoloan port may have directly induced by the earthquake rupture deformation, but the initial tsunami waves at Mamuju port should be from the source outside the bay or the earthquake source area. We applied the back-tracing method and the result indicates that the potential tsunami source for Pantoloan located inside the bay but the source for Mamuju should located outside the bay at about 2°S, 119.3°E.

To understand the tsunami induced only from the fault deformation, we utilized the InSAR data and tsunami waveform at Pantoloan to estimate the source of the earthquake. Two InSAR datasets of ascending and descending data from Sentinel-1 operated by the European Space Agency were used in this study.

The InSAR images revealed clear traces of the rupture. We assumed a fault plane consisted of 27 by 6 subfaults along the traces and performed a source inversion. In our inversion, the two InSAR datasets constrained horizontal land deformations in two different azimuths and the tsunami waveform constrained the vertical deformation at the offshore area. The combination of the InSAR and tsunami data provided complete information for the rupture deformations.
Our result suggested that the rupture extended southward from the epicenter and changed its direction or strike at the bay where also showed a large asperity of a 10 m slip (Figure 1). The rupture changed the strike again at near 1.2°S and had an offset slip there. In addition to the dominant strike-slip components, normal fault components were also estimated at the asperity area which agrees with the finite fault solution of USGS and the plate motion recorded by GPS (Socquet et al., 2006, *JGR*). Our model reconstructed the tsunami waveform at Pantoloan and the offset data by InSAR. However, we underestimate the inundations and runups for the coastal area. The local landslides may explain for the high inundations and runups.


0.2°S
0.4°S
0.6°S
0.8°S
1°S
1.2°S
1.4°S
119.8°E
120°E
120.2°E
10
9
8
7
6
5
4
3
2
1
0
Slip (m)

Seismological Society of Japan Fall Meeting

A Method of Real-Time Tsunami Detection

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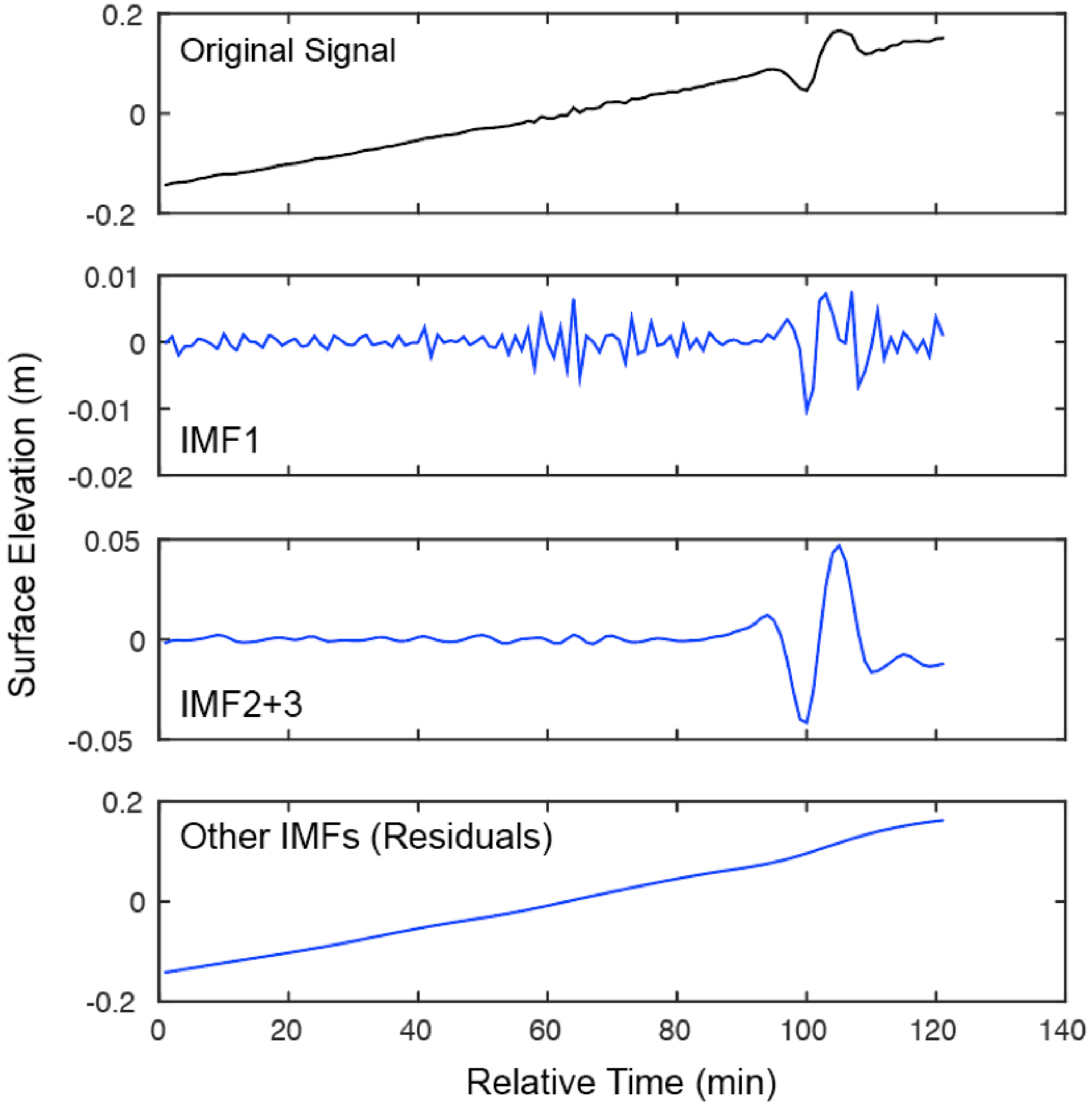
Real-time tsunami detection plays a key role in tsunami early warning system. The best way to confirm the tsunami arrival is to use the ocean bottom pressure gauges (OBPGs) (Sanderson, 2008). A reliable tsunami detection algorithm for OBPGs should be able to identify the tsunami signals and characterize the tsunami amplitude accurately, at a small computational cost. Traditional methods, like the DART algorithm adopted by the National Oceanic and Atmospheric Administration (NOAA), or the Algorithm based on artificial neural network (Beltrami, 2008), have to rely on the prediction of the tides and other lower frequency signals. These algorithms can detect a tsunami by subtracting predicted pressures from the observation, but they cannot properly identify its waveform. And they are unable to capture the feature of the background sea noise.

In our research, we propose a method of real-time tsunami detection based on Ensemble Empirical Mode Decomposition (EEMD). EEMD decomposes the time series into a set of intrinsic mode functions (IMFs) (Huang et al., 1998; Wu, 2005). Unlike Fast Fourier Transform or wavelet analysis, it does not need a priori basis. Instead, it adaptively determines the natural oscillatory modes embedded in the original signal. Therefore, it is applicable to nonlinear, non-stationary data like tsunami signals. In our practice, we use the series of the OBPG record of the past three hours, and then we conduct EEMD and obtain the IMFs. The tsunami signals can be separated from the tide signals, seismic signals, as well as background noise. By comparing the value with the threshold, we could decide whether the tsunami has arrived or not.

We apply our method to the tsunami record of OBPGs of the 2016 Fukushima earthquake (M7.4; Gusman et al., 2017). Five OBPGs owned and operated by the Earthquake Research Institute recorded the tsunami generated by the earthquake. We retroactively conduct EEMD to the data. Our method separates the high-frequency components and extracts tsunami signals automatically, without the need of predicting the tides. The tsunami arrival is easily determined by comparing with a threshold. In addition, the tsunami waveforms are also characterized in the IMFs, without the need of filtering. Because our method uses an ensemble with the help of white noise, it becomes robust to background noise.


Original Signal
IMF1
IMF2+3
Other IMFs (Residuals)
Surface Elevation (m)
Relative Time (min)
0.2
0
-0.2
0.01
0
-0.01
-0.02
0.05
0
-0.05
0.2
0
-0.2
0
20
40
60
80
100
120
140

Rapid magnitude estimation method for slow tsunami earthquakes (4)

*Akio Katsumata[1], Masayuki Tanaka[1]

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(1)はじめに
継続時間が長く地震波の励起が相対的に小さいが、高い津波を発生させる地震(スロー津波地震)対策として、これまで変位を積分した波形の振幅から規模を推定する手法を開発してきた。これは地震発生後最初期の津波警報に役立てるために検討してきた。最初の津波警報は地震検出後3分以内に発表されるため、規模の推定には通常振幅に基づくマグニチュードが用いられている。地震モーメントは津波警報の更新に役立てられている。変位振幅はおおよそモーメントレートに比例しているために、スロー津波地震に対しては過小評価を与えると考えられる。変位を積分した値に基づけば、モーメントに比例した値が求められると期待される。発想としてはTsuboi et al.(1995)と同じであるが、ここで対象とする地震波は観測点近傍で観測されるものであり、P波もS波も表面波も混ざって観測点に到来するような波動である。

これまでに、F-net速度型強震計などで記録されてきた日本国内のデータを用いて、経験的な回帰式を提案してきた。この経験式を用いてこの積分変位マグニチュードが即時な利用可能であることを確認してきた。しかし、実際のスロー津波地震の震源近傍のデータを用いた確認は十分にはできていなかった。スロー津波地震としては、1992年ニカラグア地震、1994ジャワ沖地震、1996年ペルー沖地震、2006年ジャワ沖地震などが知られている。ところがここで対象とするような震源距離数100km以内の記録はIRISのサイトでみても2,3しかない。そこで、ここでは理論波形を用いた検討と、少し距離のある観測点における観測波形の振幅比の検討を行った。

(2)方法と結果
理論波形を用いた検討としては、まず、2003年十勝沖地震において浦幌(URH)観測点において得られた記録とある程度似た理論波形記録を求めた。理論波形の計算には、点震源・三角形の震源時間関数を仮定した。その震源時間関数のモーメントは維持したまま、震源時間関数の時間幅を伸ばしてゆき、変位及び積分変位の振幅がどのように変化するかを確認した。その結果、理論波形の変位及び積分変位の振幅は震源時間関数の時間幅が大きくなるにつれて、減少していった。震源時間関数が約10倍になると理論変位振幅は1/100以下に、理論積分変位振幅は1/10以下になった(Fig. 1)。変位ばかりでなく積分変位の振幅が減少したのは、時間幅の広い震源時間関数によってグリーン関数の移動平均が計算されてしまったためと見られる。期待したような破壊の継続時間によらず一定となるような結果とはなっていないが、積分変位振幅は少なくとも変位振幅を用いたときに現れるほどの振幅減少となっていない。

1992年ニカラグア地震(Mw 7.6)の地震記録は、震央距離約1500kmのUNM観測点において得られている。1992年の地震と震央位置(140km以内)と発震機構(Kagan角14度以内)が比較的近い地震の振幅を比較した。対象とした地震は2012年Mw 7.3の地震と2004年Mw 6.9の地震である。その結果をFig. 2に示す。変位振幅の比較では1992年(Mw7.6)の地震と2012年(Mw7.3)の地震の関係が逆転していたが、積分変位で比較した場合には振幅はMwの違いに応じた値となっていた。

以上のように積分変位に基づく規模推定手法は、スロー津波地震の規模を即時に適正には求めることは難しい可能性はあるものの、変位振幅に基づいた手法に比べるとその過小評価を低減する効果がある。

謝辞
当調査において、国立研究法人防災科学技術研究所及びIRISによって保管されている地震記録を用いた。理論波形の計算にはTakeo (1985)によるプログラムを用いた。

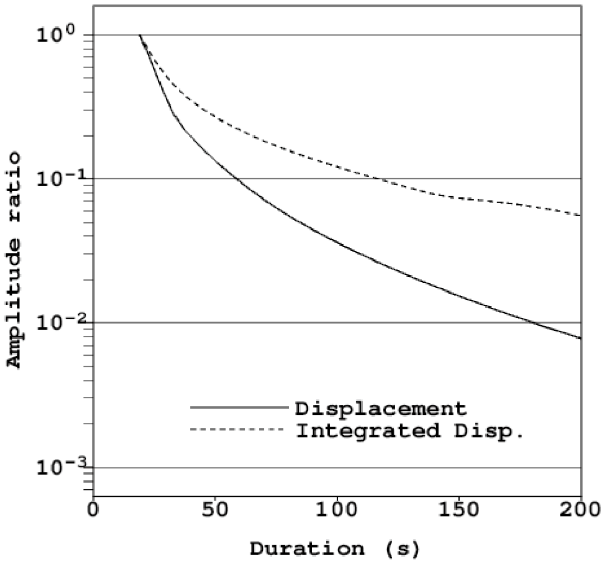
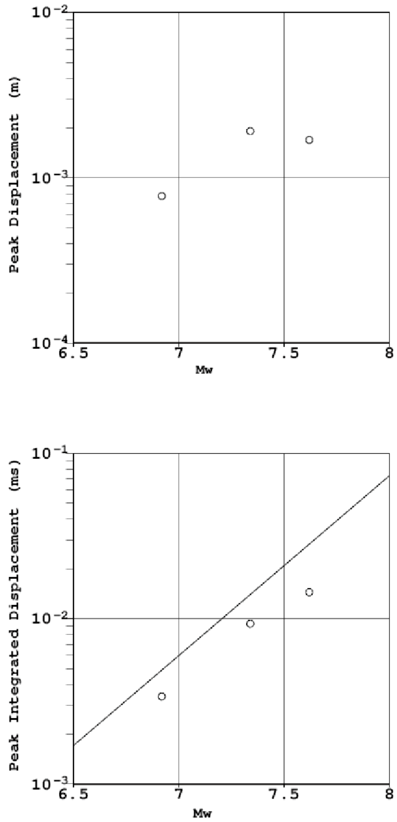


Fig. 1 Relationship between amplitude and source duration obtained for synthetic records.



Fi.g 2 Observed amplitudes at UNM station for earthquakes off Nicaragua. The solid line indicates the relationship obtained for earthquakes around Japan.