An earthquake swarm beneath Sulzberger Ice Shelf in Antarctica, I: Spatial-temporal distribution from 2010 to 2017

Juan Zhu[1](zhujuan@mail.ustc.edu.cn), Lianxing Wen[2,1]

1. Laboratory of Seismology and Physics of Earth's Interior; School of Earth and Space Sciences, University of Science and Technology of China
2. Department of Geosciences, Stony Brook University

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1. INTRODUCTION

While it used to be thought seismically inactive, recent years have witnessed more and more seismic events identified in Antarctica. Those events provided critical information about the volcanic, glacial or tectonic processes of Antarctica. In 2012, seven events with magnitude larger than 3.0 are detected in the area of Sulzberger ice shelf in west Antarctica (fig.1), an ice shelf that has undergone a series of complex geological phenomenon such as ice melting and calving. In the companion presentation (Xu and Wen, S21C-0442), the focal mechanism of the largest event of 2012 Mw 5.6 West Antarctica event in this region is studied. In this presentation, we perform detailed analysis of the seismicity associated with those events and explore their implications to the tectonics in the region.

2. DATA AND PROCEDURE

Twenty-three components' seismic stations are employed which are mainly located within 1,300 km away from the horizontal location of 2012 Mw 5.6 west Antarctic event (Fig.1). Among these stations, three stations belong to the Mount Erebus Volcano Observatory Seismic Network (ER), one from Global Telemetered Seismograph Network (GT), one from a Broadband Seismic Experiment to image the Lithosphere beneath the Gamburtsev Mountains, East Antarctica (ZM) and one from Global Seismograph Network (IU). The remaining 17 stations are part of seismic stations from Polar Earth Observing Network (YT).

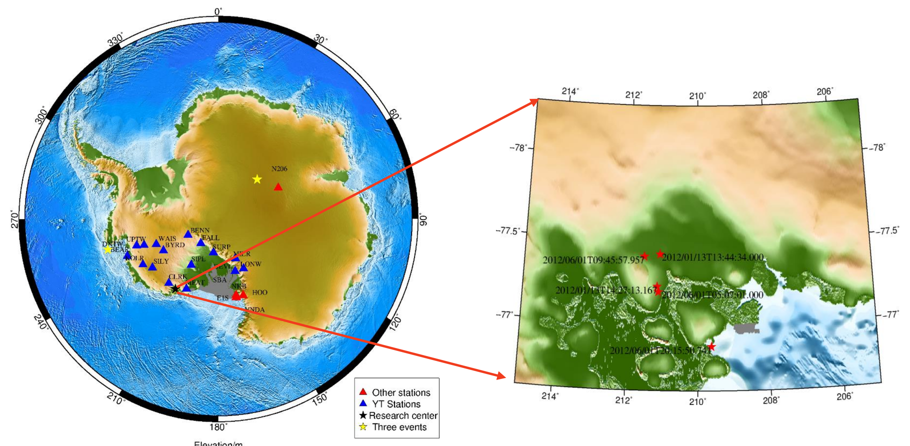


Fig.1: The topography of Antarctica with seismic stations and the research center marked with black star shown in right panel. Blue triangles represents the seismic stations from Polar Earth Observing Network (YT). And the other 6 red triangles are seismic stations from other networks. The black star marks the center in this research. The yellow stars show the locations of three seismic events which would be employed in the later panel of "SPECTRAL CHARACTERISTICS". The red stars in the right panel mark the five events from ISC.

Seven events occurred in this region in total. We only reserve five of them happened in 13 January and 1 June in 2012 (Fig.1, right), in that the other two events' waveforms are poor in quality. We first relocate them using the master event location method (Wen, 2006) (Fig.4).

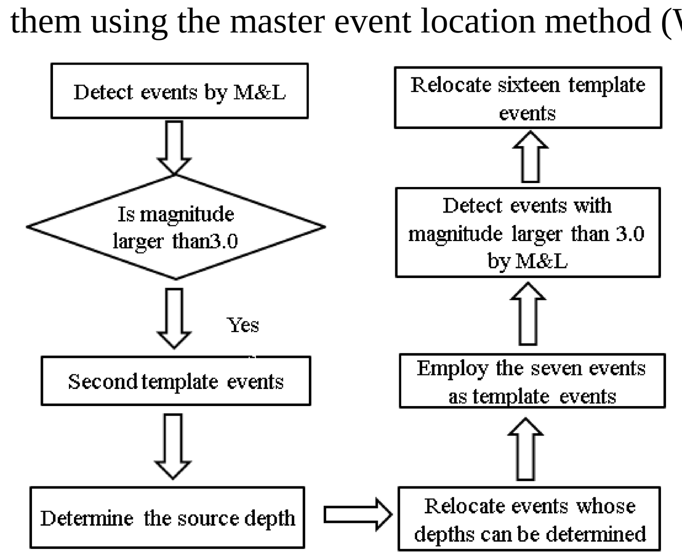


Fig.2: The procedure to detect the seismicity in Sulzberger of West Antarctica.

Tab.1: The information of seven template events whose source depths can be determined by SMAC.

number	Origin time	Magnitude	Latitude	Longitude	Time (s)	Depth(km)
1	2012/02/18 14:39:02.606	3.48	-77.3888	-148.7715	6.71s	20.47
2	2012/03/10 09:08:54.273	3.66	-77.1881	-148.7678	4.83	14.73
3	2012/04/03 07:46:34.268	3.90	-77.2261	-148.4748	3.75	11.43
4	2012/06/01 05:07:01.000	5.60	-77.1883	-148.8670	3.68	11.22
5	2012/06/01 20:15:48.454	4.40	-76.8283	-149.6214	4.01	12.23
6	2012/06/06 04:23:18.294	3.55	-77.3222	-148.5677	4.15	12.66
7	2012/06/20 02:03:43.722	3.30	-77.3904	-148.4384	4.41	13.45

According to the following procedure (Fig.2) , we catch up more seismic events as the template events based on the five template events.

- **Detect events by M&L**. We employ M&L method (Zhang and Wen, 2015) to detect events in Sulzberger ice shelf between 2010 and 2017. We fix the depth of the events and search in the horizontal
- **Selection of second template events**. 760 events have been detected by M&L. We pick out 23 template events whose magnitudes are larger than M 3.0
- **Determination of the source depth of template events.** We consider determining the template events source depths by stacking multiple-station autocorrelograms for P code waves (Fig.3) (Zhang, 2014). Robust energy peak (Fig.4) emerge in seven events (Tab.1).
- **Relocate the seven template events**. Based on the 2012 Mw 5.6 West Antarctica event, we relocate the seven events.
- **The source depths for other 16 event.** Those 7 events are the template events to detect the 16 template events (Tab.1). The source depth of 16 events would directly come from their template event.

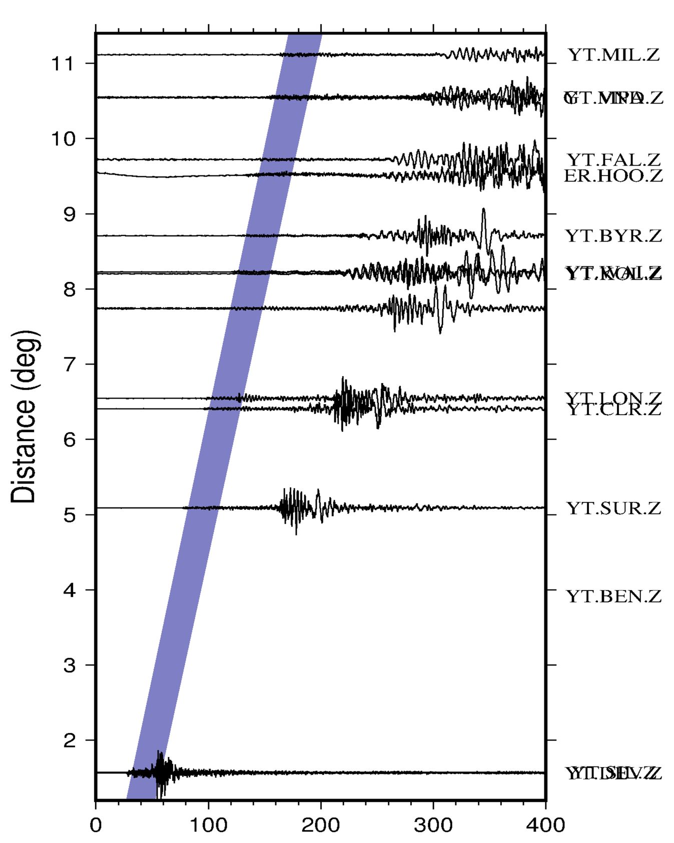


Fig.3: The seismic waveforms to do SMAC for 2012 Mw 5.6 west Antarctic event. The blue shallow periods the waveforms show the starting time windows from the P arrival time to the later 40 s.

3. SEISMICITY IN SULZEBGER ICE SHELF

1645 events have been detected in the second time detection based on the 23 template events from January 2010 to December 2017. We accept the locations of detected events whose magnitude of the detected events is no less than 2.0. If the magnitude is smaller than 2.0, we consider a reliable location for the event only if the cross coefficient is larger than 0.8. 158 events have been picked out based on the procedure above.

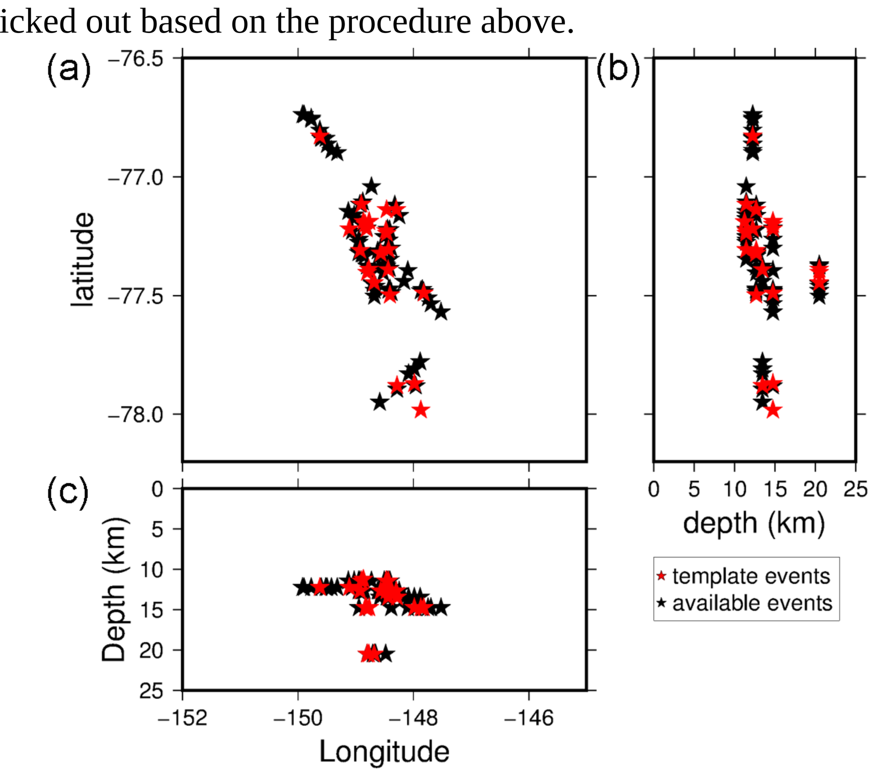


Fig.7. The spatial distributions of detected events in 3D regions. Figure in (a) depicts the spatial distributions along the longitude and latitude. (b) The detected events are lain along the latitude and depth. (c) The locations in the plane composed of longitude and depth.

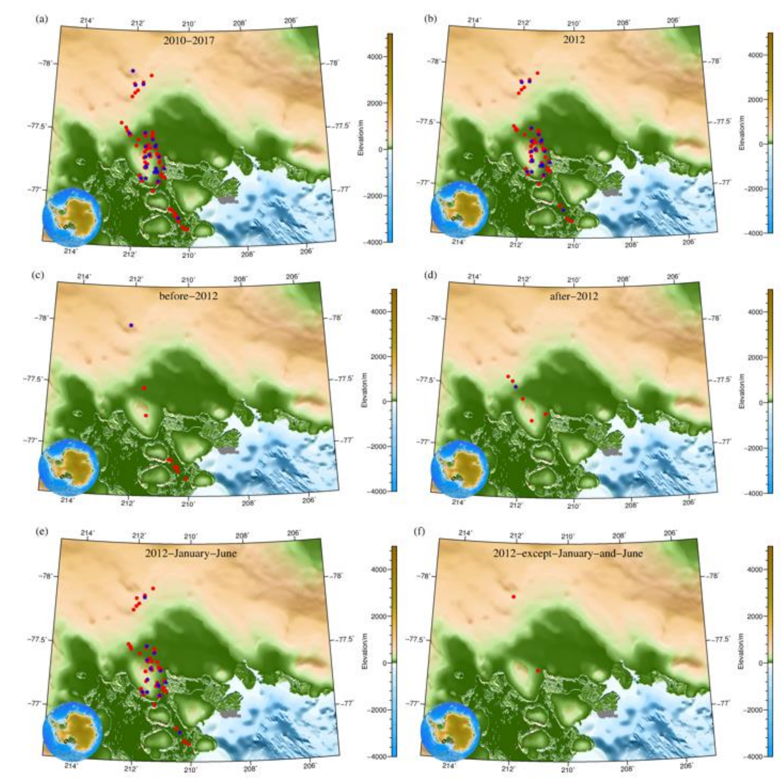


Fig.8. The spatial distribution of detected events in each time period. (a) The locations in the whole time period from 2010 to 2017. (b) The events happened in 2012. (c) The events occurred from 2010 to 2011. (d) The events emerged from 2013 to 2017. (e) The events happened in January and June 2012. (e) The detected events emerged in 2012 except for January and June.

The spatial-temporal distribution of the detected events presents a surprising characteristic. Spatially, a north-south spatial extension in the horizontal plane were obvious(Fig.8). Along the depth direction, most detected events were spanning in the depth region from 11 km to15 km, indicating a more possibility of a non-ice quake source property which is mainly triggered in the shallow area with a depth of less than 5 km (Fig.7).

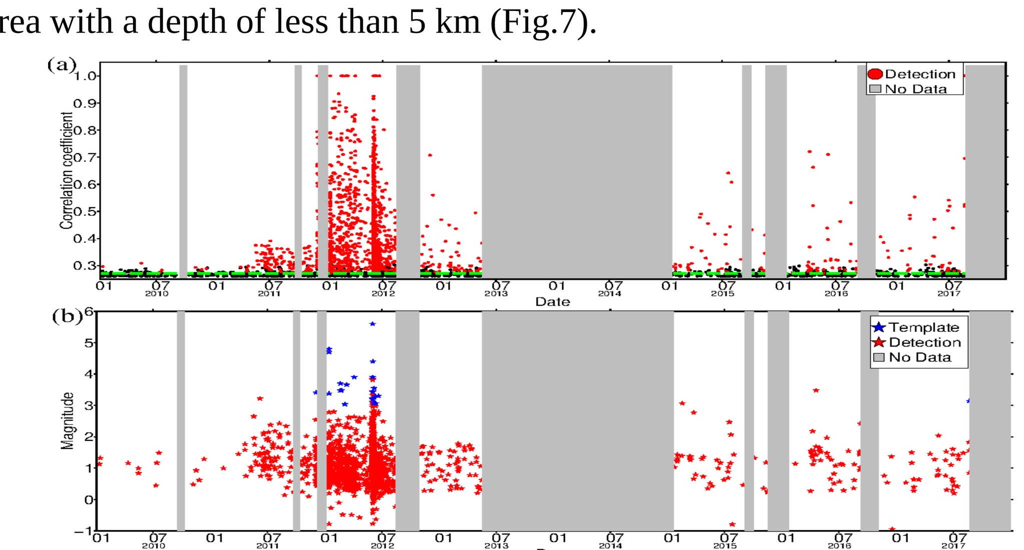


Fig.9: The temporary characteristics of detected events. (a) The correlation coefficient for each detected events in the time period. The grey shadow areas remain us of the absence of seismic data. (b) The magnitude of each detected events in the time period. The blue stars means 23 template events. And the red stars is the detected events.

Temporary, the cluster mainly occurred in the whole year of 2012(fig.9), with a time sequence different from a typical aftershock distribution following a main shock. A mount of events, whose magnitudes range from 0.0 to 2.0, sprang up in June 2012. The correlation coefficient of those events in this year presents a high value, indicating a reliable of detection.

- **Relocate the sixteen template events**. After that, we relocate the 16 events based on the master event location method (Wen, 2006). The master event for each event waited to be relocated will come from its template events in M&L.
- **Second time small event detection.** Based on the twenty-three events(Fig.6), we detect the events for the second time.

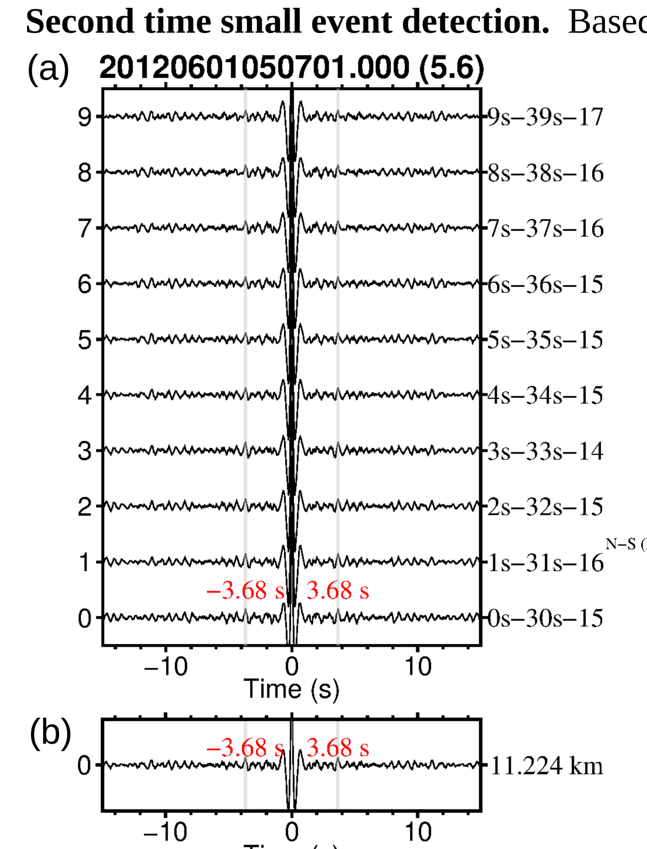
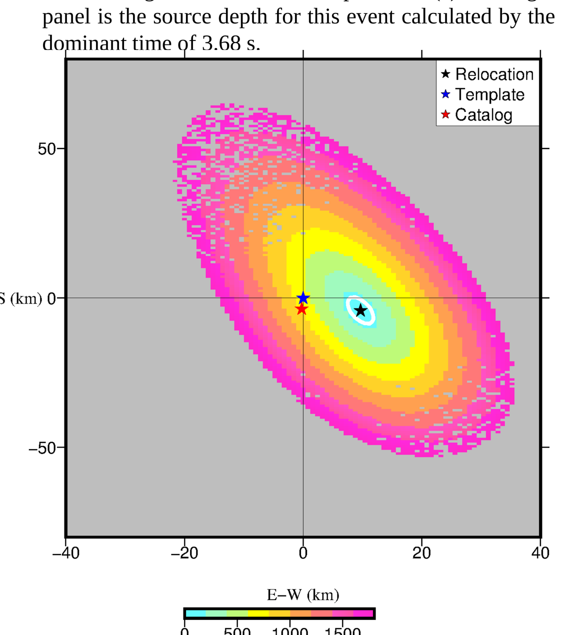


Fig.4: (a) Multiple-stacked autocorrelograms in each time period of P coda wave for 2012 Mw5.6 West Antarctica event. The right panel marks the time window from the start time related to the P wave arrival to 30 s after the start time. And the number of seismic stations used to do SMAC. (b) The stacked multiple-stacked autocorrelogram form each time period in (a). The right panel is the source depth for this event calculated by the dominant time of 3.68 s.



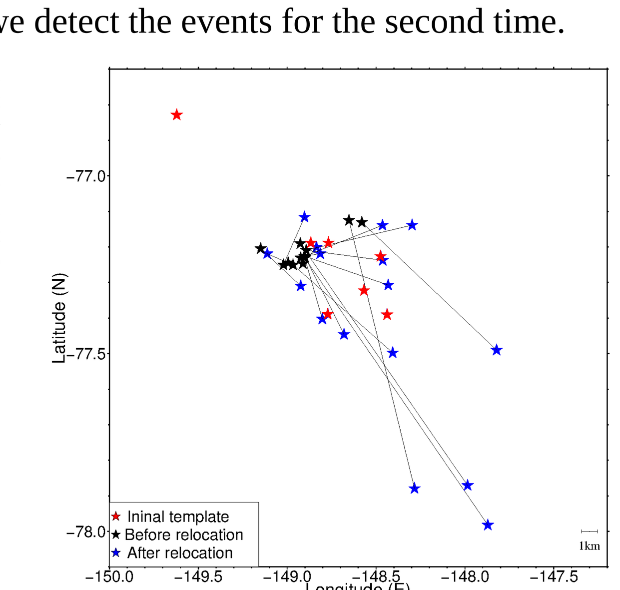


Fig.6. The spatial distribution of the 23 template events. The events in red stars are those template events whose source depth can be determined by using stacked multiple-stations autocorrelograms. The events in black stars marked the locations of other 16 template events. Blue stars present the locations of 16 template events after relocation.

Fig.5: The root mean square (RMS) of relocation for event 20120403074633.085. Blue star represents the master event 2012 Mw 5.6 West Antarctica event. Red star performs the location before relocation. The black star is the best-fitted location of relocation. The ellipsoid is the 95 % confidence of the RMS.

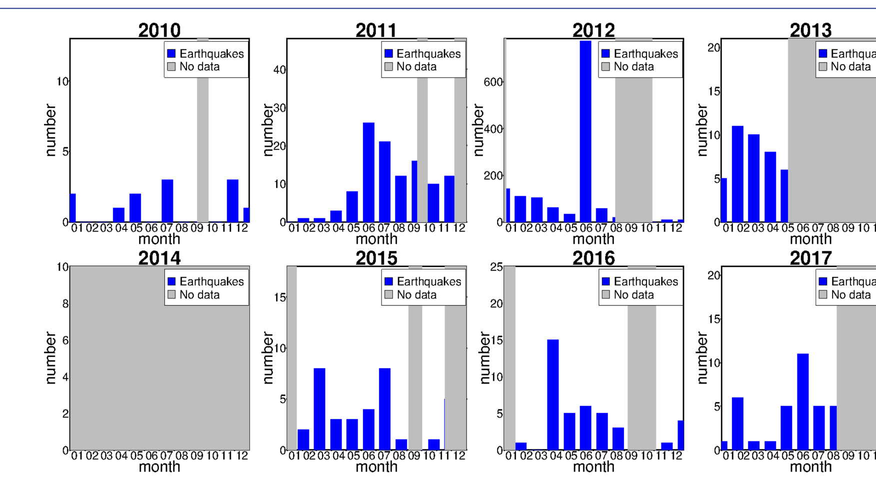


Fig.10: The number of detected events of each month in each year from 1 January 2010 to 31 November 2017. The grey shadow areas shows the absence of seismic data.

In reality, continuous seismicity activities in the whole time period from 1 January 2010 to 31 November 2017 gives the evidence of the non-weakness of seismicity of Sulzberger in Antarctica.

4. SPECTRUM CHARACTERISTICS

Since the seismic waveforms of small events are affected by background noise originating from wind events and tides from the oceans etc. with frequencies below 1 Hz, we band pass the seismic signals between 1 Hz to 15 Hz before the fourier transform to the frequency domain.

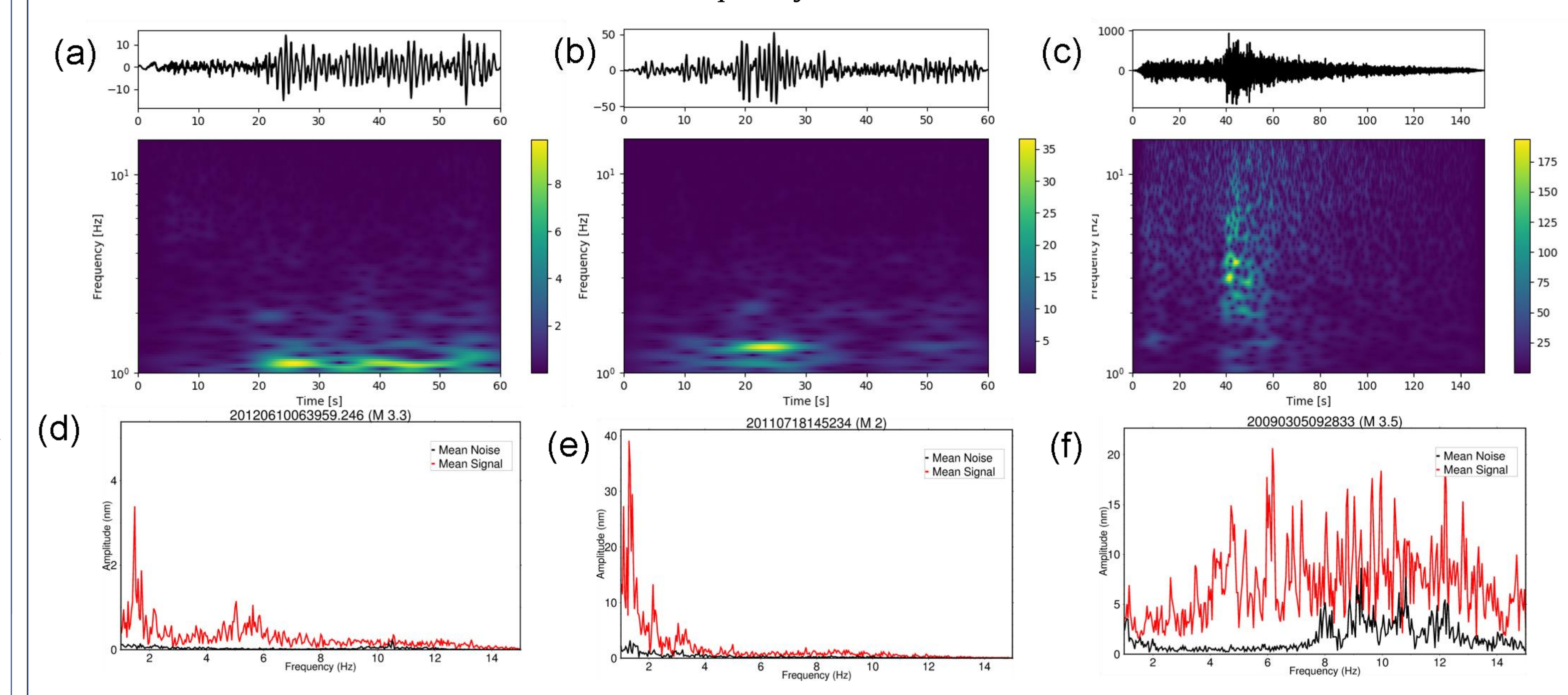


Fig.11: Spectral characteristics for event 20120610063959.246 in Sulzberger of West Antarctica, event 20110718145234 in Marie Byrd Land, West Antarctica and event 2009030509833 in East Antarctica. (a) The spectral characteristics of station of SIPL which belongs to YT network for event 20120610063959.246 beginning at the P arrival time with a length of 60 s. (b) The spectral characteristics of station of BEAR belonged to YT network for event 20110718145234 beginning at the P arrival time with a length of 60 s. (c) The spectral characteristics of station of N20 belonged to ZM network for event 2009030509833 beginning at the P arrival time with a length of 150 s. (d) The frequency characteristics of event with the time periods from the p arrival time to the later 20 s. (e) The frequency characteristics of event 20110718145234. (f) The frequency characteristics of event 2009030509833.

The spectral characteristics varied with time enhance the robust energy peak of frequency characteristics for each time period. We cut off the twenty-three template events' the waveform from the time of P wave arrival to the later 60 s to generate the spectrums (Fig.11 (a)). We also cut off the seismic waveforms from the P wave arrival time to the later 20 s to analyze the spectral characteristics (Fig. 11 (d). Large energy emerges under 3 Hz for SIPL stations with an epicenter-station distance of about 497 km. These spectral characteristics are similar with those from BEAR station of YT network with an epicenter-station distance of about 355 km for event 20110718145234 in Marie Byrd Land, West Antarctica with a magnitude of M2.0, which belongs to the volcanic earthquake (Fig.11(b, e)). Energy scatters in the frequency range between 1 and 15 Hz with a dominant frequency of 6Hz for the tectonic earthquake 2009030509833 (M3.5), which occurred in March 5, 2009 in East (Fig. (b)) from station of N20 of ZM network with an epicenter-station distance of about 400 km, respectively.

5. CONCLUSION

1. We detect 1645 events along the Sulzberger Ice Shelf from 2010 and 2017. Temporally, the cluster processed a time sequence different from a typical aftershock distribution following a main shock; Spatially, they were distributed along a north-south region in which the terrain changes dramatically.
2. We succeed determining seven template events' source depths by employing the stacking multiple-station autocorrelograms (SMAC) for P code waves.
3. The cluster exhibits a special source property with the energy of the source spectrograms of below 5 Hz, indicating a probability of volcanic earthquakes.

6. REFERENCE

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