The South Sandwich Islands (Southern Atlantic Ocean) tsunami as recorded in British Columbia

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2026

THE SOUTH SANDWICH ISLANDS (SOUTHERN ATLANTIC OCEAN) TSUNAMI AS RECORDED IN BRITISH COLUMBIA

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On 12 August 2021, a major earthquake occurred in the Antarctic sector of the Southern Atlantic Ocean near the South Sandwich Islands. This was a complex event that was initially reported as a magnitude 7.5 at 18:33 UTC at a depth of 47 km. Just three minutes later, an M_w 8.1-8.3 earthquake followed, rupturing the shallow subduction zone. This complex event generated a global tsunami that spread throughout the World Ocean, being observed in all three oceans, including such remote regions as the Aleutian Islands, Alaska and British Columbia, 17,000 – 18,000 km from the source area. The present study focuses on the North Pacific Ocean, where tsunami waves were measured by all DART buoys in this region. Based on known seismic parameters and Okada's equations, an effective numerical model of this event was developed that reproduced actual DART records in the Central and North Pacific. Tsunami waves were recorded along the entire coast of British Columbia, arriving at the coast of Vancouver Island about 23 h after the earthquake and at the northern BC coast about 1.0-1.5 hours later. The maximum observed tsunami wave heights of 11 -14 cm were recorded at Ucluelet, Pruth Bay, Rose Harbour and Port Alberni, at the other stations they were below 9 cm. Waves with periods of 10-20 min dominated at both coastal and open-ocean (DART) stations, apparently associated with the source properties. The findings from this event reveal that even tsunamis originating from source areas outside of the Pacific Ocean can reach the coast of British Columbia and be reliably reproduced by modern numerical models.

RÉSUMÉ

Rabinovich, A.B., Tsukanova, E.S., Sinnott, D.C., and Thomson, R.E. 2026. The South Sandwich Islands (Southern Atlantic Ocean) tsunami as recorded in British Columbia. Can. Tech. Rep. Hydrogr. Ocean Sci. 414: v + 25 p.

Le 12 août 2021, un séisme majeur s'est produit dans le secteur antarctique de l'océan Atlantique Sud, près des îles Sandwich du Sud. Cet événement complexe a été initialement signalé comme étant de magnitude 7,5 à 18h33 UTC à une profondeur de 47 km. Trois minutes plus tard, un séisme de magnitude 8,1-8,3 a suivi, rompant la zone de subduction peu profonde. Cet événement complexe a généré un tsunami mondial qui s'est propagé à l'ensemble de l'océan mondial et a été observé dans les trois océans, y compris dans des régions reculées comme les îles Aléoutiennes, l'Alaska et la Colombie-Britannique, à 17 000-18 000 km de la zone source. La présente étude se concentre sur l'océan Pacifique Nord, où les vagues du tsunami ont été mesurées par toutes les bouées DART de cette région. Sur la base des paramètres sismiques connus et des équations d'Okada, un modèle numérique efficace de cet événement a été développé, reproduisant les enregistrements DART réels dans le Pacifique central et le Pacifique Nord. Des vagues de tsunami ont été enregistrées le long de toute la côte de la Colombie-Britannique, arrivant sur la côte de l'île de Vancouver environ 23 heures après le tremblement de terre et sur la côte nord de la Colombie-Britannique environ 1,0 à 1,5 heure plus tard. Les hauteurs maximales des vagues de tsunami observées, de 11 à 14 cm, ont été enregistrées à Ucluelet, Pruth Bay, Rose Harbour et Port Alberni; aux autres stations, elles étaient inférieures à 9 cm. Des vagues de périodes de 10 à 20 minutes ont dominé aux stations côtières et en haute mer (DART), apparemment associées aux propriétés de la source. Les résultats de cet événement révèlent que même les tsunamis provenant de zones sources situées hors de l'océan Pacifique peuvent atteindre la côte de la Colombie-Britannique et être reproduits de manière fiable par les modèles numériques modernes.

Zavodovski Island, one of the South Sandwich Islands. Photo by *Maria Stenzel.*

1. INTRODUCTION

The South Sandwich Islands are a group of small, remote, and almost uninhabited islands located just north of Antarctica in the southern Atlantic Ocean. The islands are about 3000 km southwest of Africa, 700 km southeast from South Georgia Island and 1700 km northeast from the tip of the Antarctic Peninsula. The islands are part of an active volcanic arc in the eastern part of the Scotia Sea formed during the subduction of the South American Plate (SAP) under the South Sandwich Plate (SSP) [*Lutikov et al.,* 2022]. This process is ongoing, with the SAP subducting beneath the SSP at a speed of ~7 cm/year [*Pelayo and Wiens*, 1989]. The active interaction of the two plates makes the island chain one of the Earth's most dynamic seismic zones.

On 12 August 2021, a major earthquake struck the South Sandwich Islands region. The initial earthquake measured magnitude M_w 7.5. Just three minutes later, an $M_w > 8$ quake followed, rupturing the shallow subduction zone. The event lasted for about 260 s, an unusually long duration for such an event. This earthquake was the largest earthquake recorded in this region and the Atlantic Ocean as a whole since the M_w 8.1 earthquake of 27 June 1929 [*Lutikov et al.,* 2022]. The US Geological Survey (USGS) evaluated the 2021 event as M_w 8.1, while the Global Centroid Moment Tensor Catalog (GCMT) estimate was M_w 8.3 [*Lutikov et al.,* 2022] and the CalTech estimate was M_w 8.2 [*Jia et al.*, 2022].

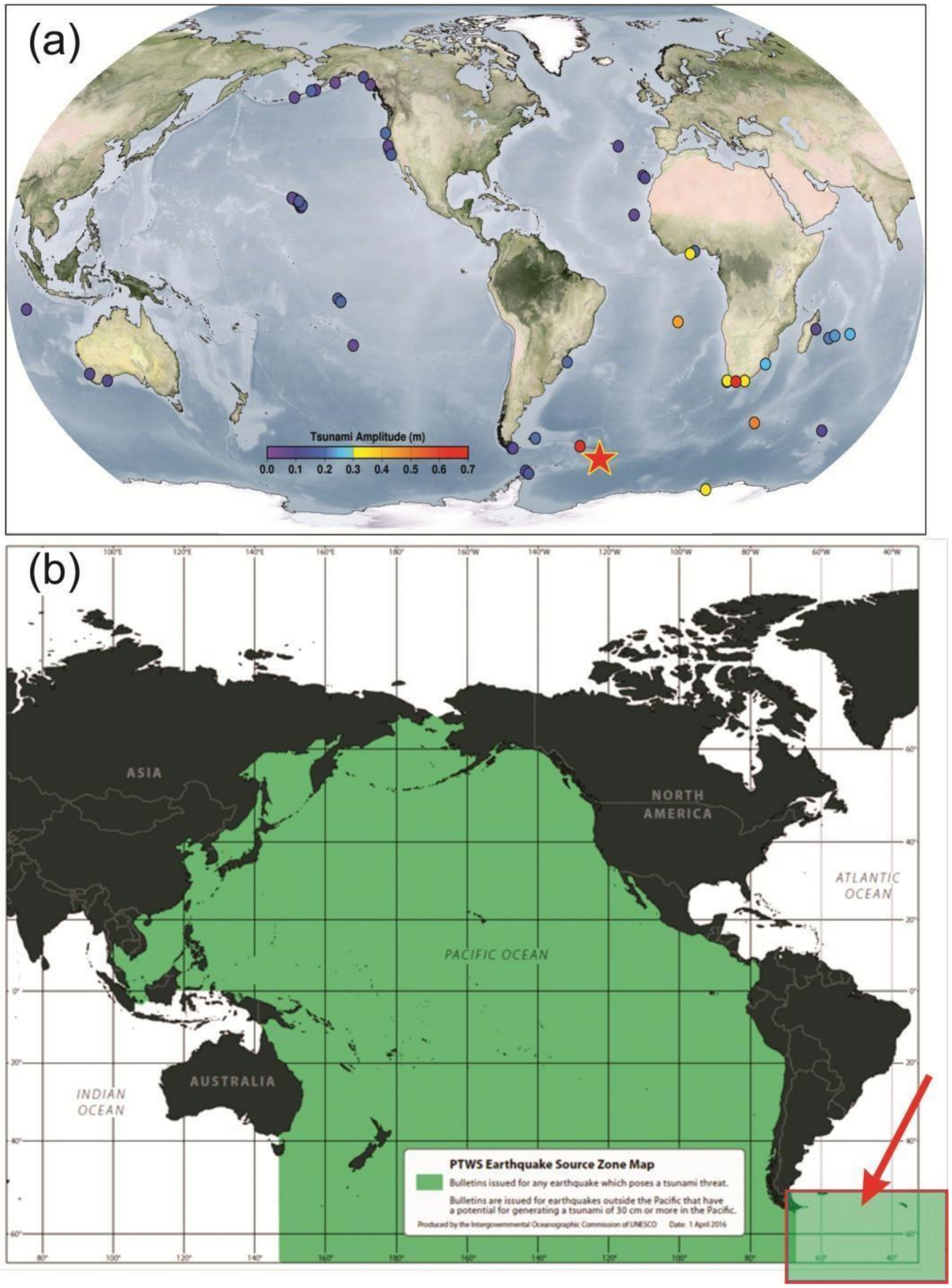

Figure 1. (a) Tsunami wave amplitudes originating from the South Sandwich earthquake of 12 August 2021 (M_w 8.1-8.3) as recorded by coastal tide gauges in the World Ocean. Each dot represents a gauge; the color of a circle indicates the tsunami amplitude in meters as shown in the color-bar legend according to the estimates of the Pacific Tsunami Warning Center (PTWC, Honolulu, Hawaii); and (b) the current PTWS Earthquake Source Zone (ESZ) indicated in green; the green box at the lower right with the red border indicates the approximate proposed addition to the PTWS ESZ that would include the seismic zone associated with the Scotia Arc and South Sandwich Islands. (From *McCreery* [2023]).

Because the M_w 8.1 earthquake occurred so closely after the M_w 7.5 event, the first quake had initially masked the second quake's seismic signature [*McCreery*, 2023]. Due to seismic interference from the earlier quake, the mechanism, faulting geometry, and rupture details of the mainshock are not yet fully understood. It was the unpredicted, global-spreading tsunami that gave scientists insight into the nature of the earthquake. Research models showed that the M_w 7.5 event would not have caused a tsunami of this extensive nature, so it helped reveal the larger, longer quake as the cause. A comprehensive examination of the earthquake nature and fault mechanism is presented in [*Jia et al.*, 2022] and [*Lutikov et al.*, 2022]. The focal mechanism solution indicates that the slip occurred on either a steep fault that dipped to the northwest or a shallow plane that dipped to the southeast within the lithosphere of the subducting plate.

Probably the most spectacular feature of the M_w 8.1-8.3 South Sandwich earthquake is that the earthquake generated a global-spreading tsunami that would only be expected for a larger and shallower event [*Jia et al.*, 2022]. The tsunami waves propagated throughout the entire World Ocean and affected far remote areas of the Indian, Atlantic and Pacific oceans, including Kamchatka, the Aleutian Islands, Alaska, and British Columbia, where tide gauges measured peak amplitudes of ~20 cm at over 10,000 – 15,000 km distance from the source (Figure 1a) [*McCreery*, 2023]. Fortunately, no one was injured and no damage occurred from either the earthquake or tsunami. Because of the remoteness of the uninhabited South Sandwich Islands, no photos from the 2021 earthquake or resulting tsunami exist.

Prior to the 2021 event, the region of the South Sandwich Islands was not within the areas of responsibility for the Pacific Tsunami Warning and Mitigation System (PTWS) (Figure 1b), the Indian Ocean Tsunami Warning System (IOTWS), or the Northeastern Atlantic and Mediterranean System (NEAMTWS). Authorities were, therefore, surprised when an examination of sea level records over a year after the 2021 earthquake revealed that tsunami waves had penetrated into the Pacific Ocean through the Drake Passage and arrived at the PTWS zone of responsibility (southernmost Chile and bases on the Antarctic Peninsula) within 4-6 hours of the event [*McCreery*, 2023]. In effect, the tsunami was missed by the PTWS because the source of the event in the Southern Atlantic Ocean was outside the Pacific Ocean and, therefore, not within their region of operational concern. The South Sandwich Islands event represents only the second time (after the global 2004 Sumatra tsunami [*Titov et al.*, 2005; *Rabinovich et al.*, 2006]) that tsunami waves generated outside of the Pacific Ocean were recorded along its southern and northern coastlines.

Formally, the southernmost region of the Atlantic Ocean, including the South Sandwich Islands, is currently a part of the Tsunami and Other Coastal Hazards Warning System for the Caribbean and Adjacent Regions (ICG/CARIBE-EWS) Earthquake Source Zone. Yet, as was emphasized by *McCreery* [2023] "…*Earthquakes from this region are less of a tsunami threat to CARIBE-EWS coasts than they are to PTWS coasts… The east-west directionality of the main beams of energy as well as the South America land mass effectively limit tsunami energy going towards the Caribbean… Aside from being more of a threat to the Pacific, such tsunamis are also more of a threat to IOTWMS coasts than to CARIBE-EWS coasts and they are obviously a threat to southern Atlantic coasts where there currently is no system.*"

Therefore, in response to the M_w 8.1 South Sandwich earthquake, the Pacific Tsunami Warning Center (PTWC, Honolulu, Hawaii) proposed to expand the Earthquake Source Zone of the PTWS to the Southernmost Atlantic region, including the South Sandwich Islands (Figures 1b and 2a). This proposal was accepted by ICG/PTWS-XXX in Tonga. The high seismic activity and importance of this region is clearly seen in Figure 2a.

2. NUMERICAL MODELLING

Numerical modelling of the 2021 South Sandwich tsunami proved challenging because of the lack of both detailed bathymetry of the region and reliable information about the source. Nevertheless, the NOAA Center for Tsunami Research (Pacific Marine Environmental Laboratory, Seattle, WA) constructed a preliminary global model of the event and got reasonable agreement with the observations (Figure 2b). The animation of the NOAA/PMEL model can be found on the following website: https://www.youtube.com/watch?v=PPylDTGuM0Y.

As was indicated by the NOAA/PMEL authors, "…*This* <the 2021 South Sandwich tsunami> *was the first tsunami since the 2004 Indian Ocean tsunami that was recorded in three different oceans*." Moreover, even the great tsunamis of the Twentieth century [*Rabinovich et al.*, 2019], including 1952 Kamchatka (M_w 9.0), 1960 Chile (M_w 9.5) and 1964 Alaska (M_w 9.2), generated "one-ocean" tsunamis, while the 2021 tsunami affected three oceans.

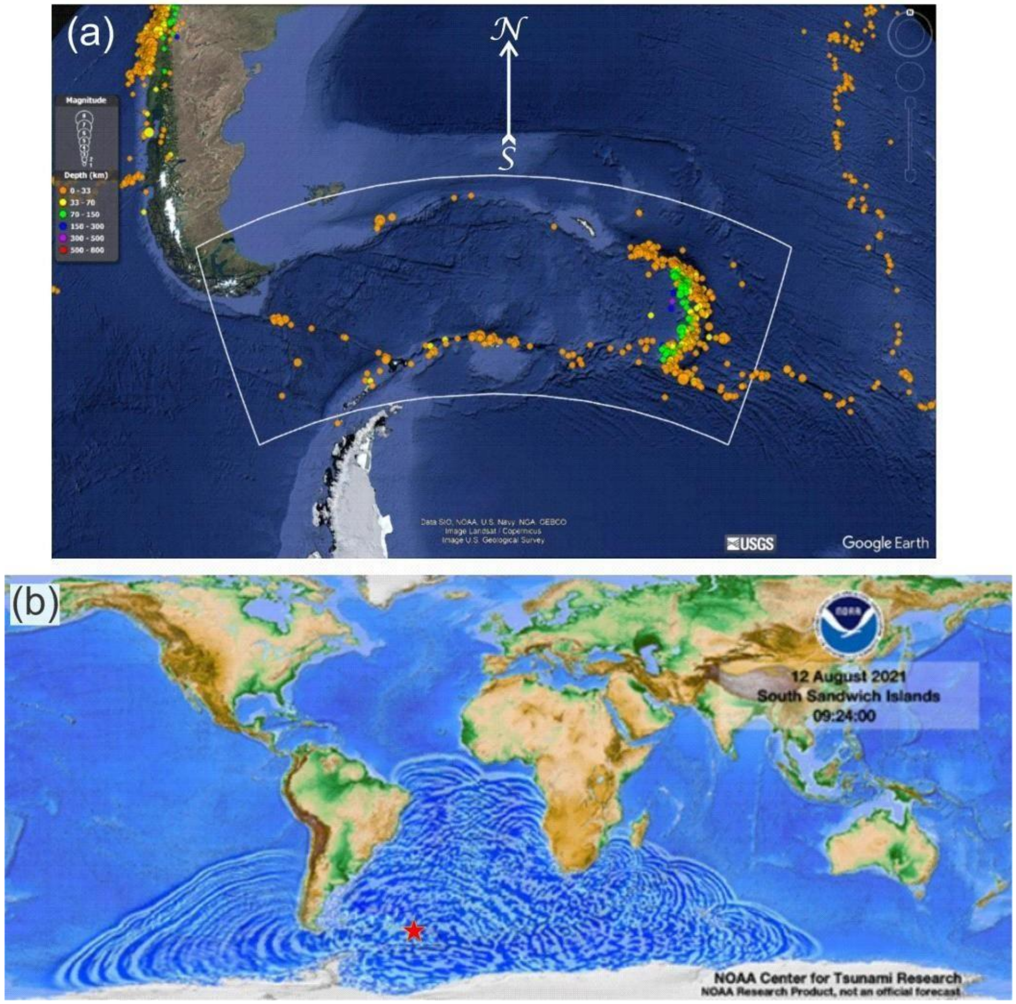

Figure 2. (a) Seismicity in the southern Atlantic Ocean including the Scotia Arc Subduction Zone. The polygon surrounding this seismicity, extending from 63° to 52° South latitude and from 72° to 18° West longitude, is the proposed extension of the PTWS ESZ. (From *McCreery* [2023]); and (b) a snapshot of the propagation animation model developed by the NOAA Center for Tsunami Research for the South Sandwich tsunami of 12 August 2021. (From the NOAA/PMEL website https://nctr.pmel.noaa.gov/sandwichislands20210812/)

As part this study, we constructed kinematic and dynamic numerical models of the 2021 Sandwich Islands for the North Pacific Ocean. The numerical computations were performed by Elizaveta Tsukanova (IORAS). For estimation of the tsunami propagation times, we used the method developed by *Fine and Thomson* [2013]; validation of the models was based on the retrieved DART[1] records for this tsunami. The tsunami propagation maps for the entire Pacific Ocean are shown in Figure 3a, and for the northern part of the ocean in Figure 3b. According to these maps, the tsunami waves arrived at the coast of British Columbia (the outer coast of Vancouver Island) about 23 hours after the main shock. These waves had first propagated through Drake Passage, between the Antarctic Peninsula and Cape Horn off the southernmost point of South America, then along the western coasts of South and North America to reach Vancouver Island (Figure 3a). The approximate travel distance from the source area to the coast of British Columbia is 17,000 - 17,500 km. The path of the waves through the Indian Ocean and then around Australia and New Zealand is much longer and less effective.

The shallow-water, finite-difference linear model developed by Isaac Fine [*Fine et al*., 2013; *Rabinovich et al*., 2008] was used to numerically simulate the South Sandwich Islands tsunami. This model, which is similar to the well-known TUNAMI model by *Imamura* [1996], has been widely used for numerical modelling of various tsunami events in the World Ocean, in particular, to estimate tsunami risk along the coasts of British Columbia (cf. *Fine et al.* [2018, 2023]). The model domain for the 2021 South Sandwich Islands tsunami was created using the 30 arcsec global bathymetry dataset GEBCO-2014 (https://www.gebco.net) but based on a coarser grid with a spatial resolution of 5 arcmin. The time step was calculated automatically to satisfy the CFL criterion. To reconstruct the initial source model, we used Okada's equations [*Okada*, 1985] and the seismic source parameters from *Lutikov et al*. [2022] (we tried several other sets of earthquake parameters, but this one gave the best results). Instead of applying the commonly used hydrostatic approximation, we used the non-hydrostatic correction technique [*Fine and Kulikov*, 2014] to convert the bottom floor displacement into a sea surface displacement. We validated the resulting tsunami source model by comparison with DART data (in particular, DART 51407) and this allowed us to customize the spatial parameters of the source.

[1] DART = Deep-ocean Assessment and Reporting of Tsunamis, is an effective network of deep-ocean stations designed for continuous monitoring of tsunami waves in the open ocean and for early tsunami warning [cf. *Rabinovich and Eblé*, 2015].

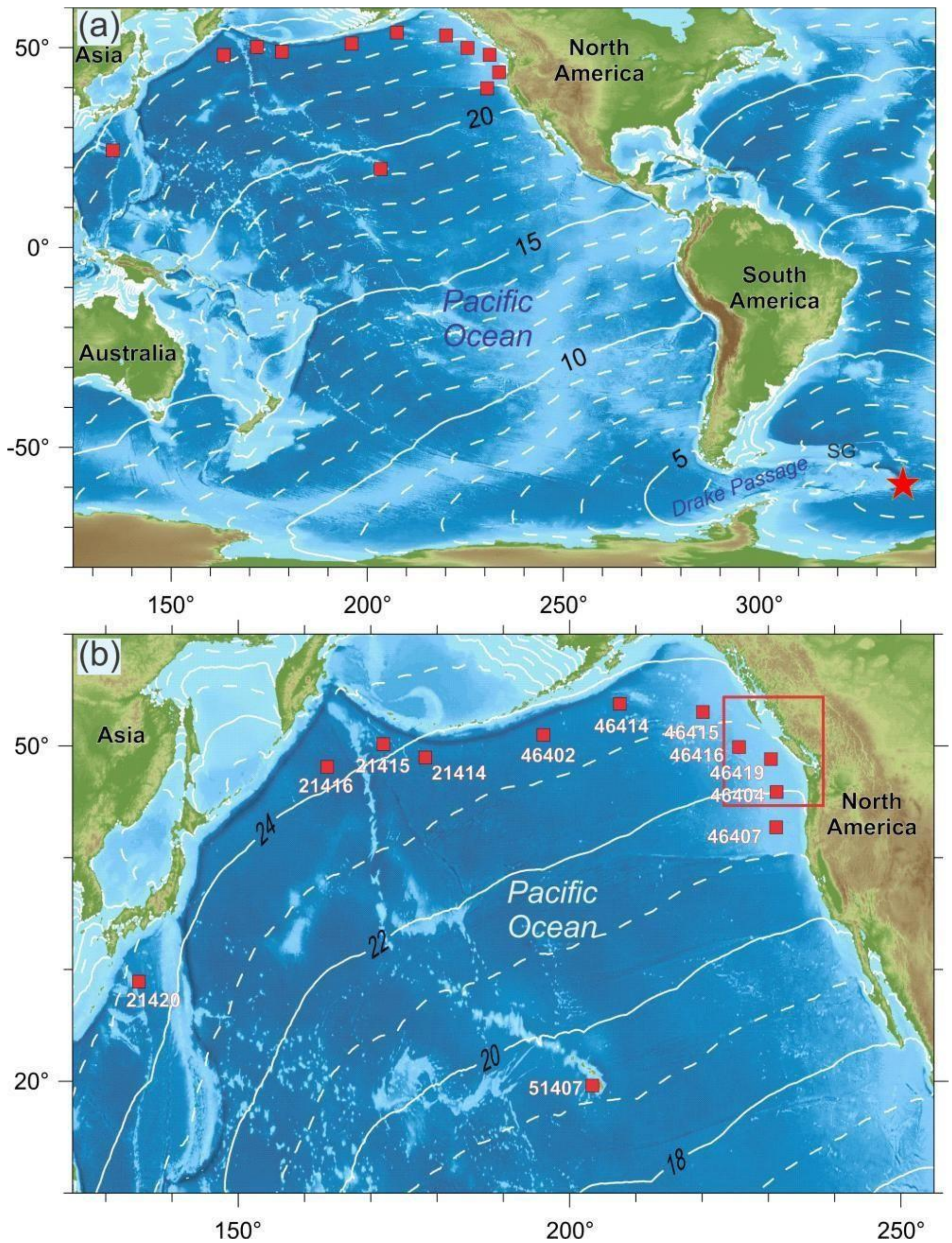

Figure 3. The travel times for the 2021 South Sandwich Islands tsunami for: (a) the entire Pacific Ocean; and (b) for the northern part of this ocean. The numbers show the travel times in hours; red squares show the locations of the DART stations used in this study. Location IDs are denoted in (b). The red star in (a) shows the epicenter of the earthquake, the red box in (b) frames the area of British Columbia.

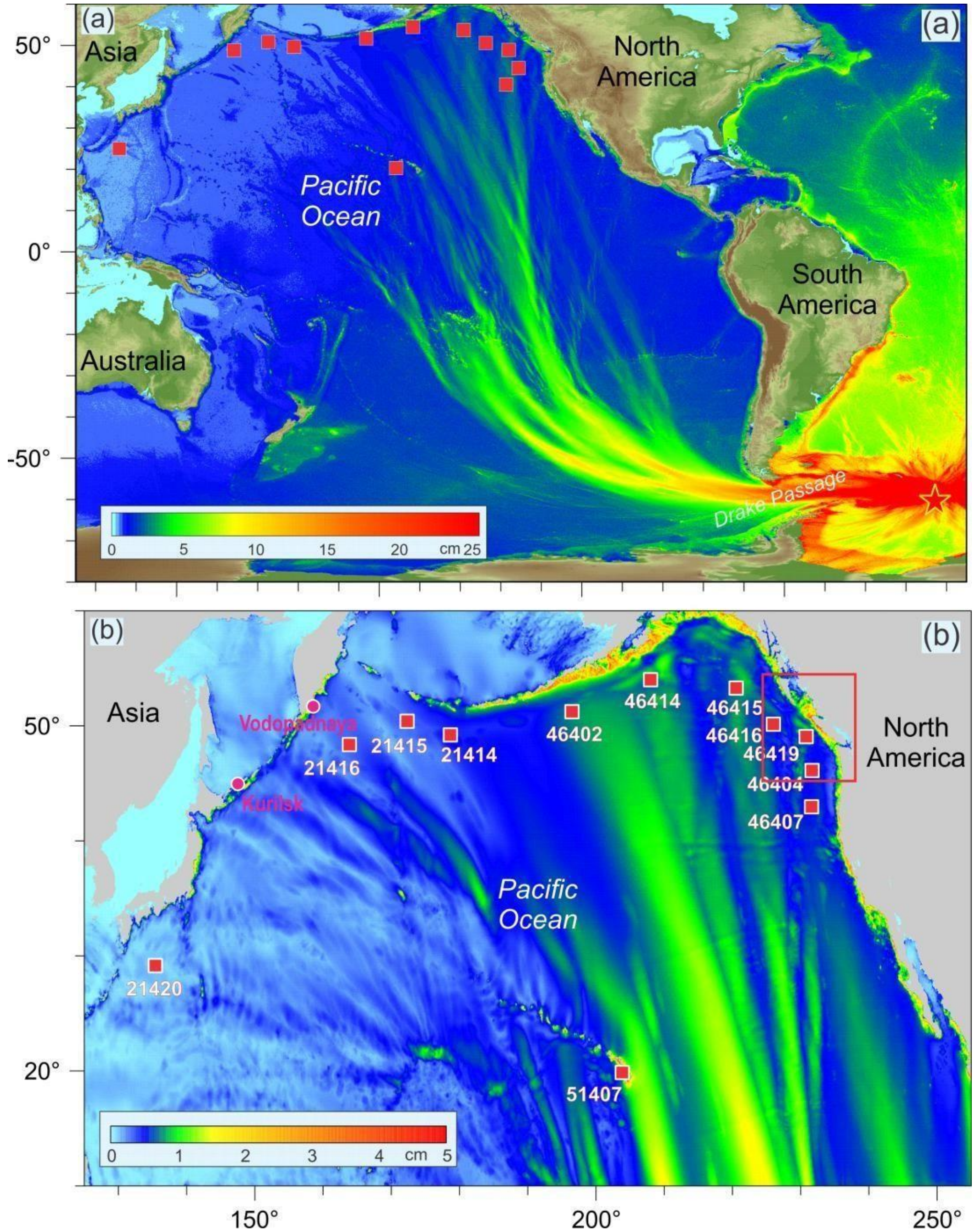

Figure 4. Numerically simulated maximum wave amplitudes of the 2021 South Sandwich Islands tsunami for: (a) the entire Pacific Ocean; and (b) for the North Pacific only. The red squares indicate the location of DART stations used in this study; see (b) for station identifications. The red star in (a) shows the epicenter of the earthquake, the red box in (b) frames the area of British Columbia. Also indicated are two Russian tide gauges, Kurilsk and Vodopadnaya, that recorded the tsunami.

Figure 4 shows maps of the computed maximum tsunami amplitudes for the entire Pacific Ocean and for the North Pacific separately. As indicated, a significant portion of the tsunami energy went westward in the direction of the Indian Ocean and north-northeastward into the Atlantic Ocean. Nevertheless, a prominent branch of energy also went westward through Drake Passage into the Pacific Ocean (Figure 4b). Then, making a large loop, this branch reached to the coasts of California and British Columbia. From Figures 4a and 4b it is evident that a relatively small amount of energy went to the northwestern part of the Pacific and that a rather larger amount to the northeastern corner of the Pacific Ocean. The DART observations in the North Pacific confirm these modelling results.

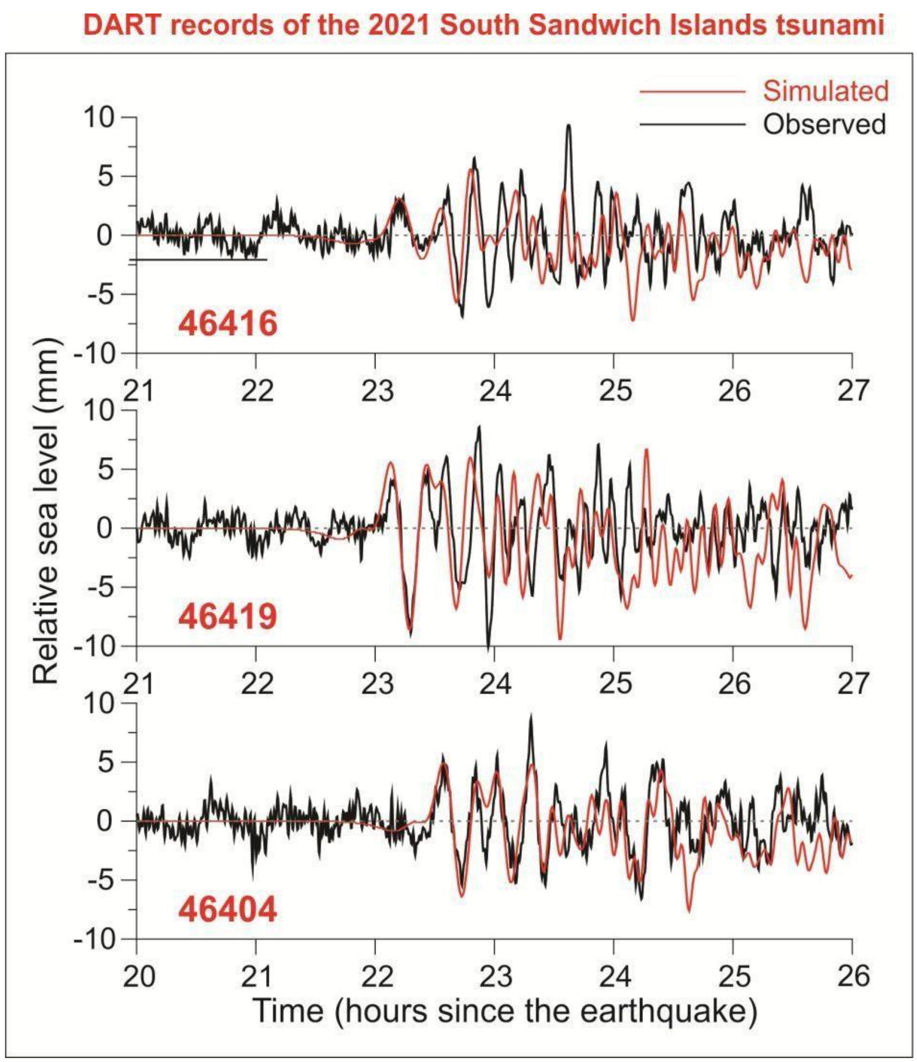

Figure 5. Numerically simulated (red lines) and observed (black lines) tsunami waveforms of the 2021 South Sandwich Islands tsunami for three DARTs in the North Pacific Ocean. The locations of the DARTs are shown in Figure 4b.

Figure 5 shows a comparison between the modelled tsunami waveforms and the observed waveforms from DARTs 45416, 46419 and 46404 in the Northeast Pacific Ocean (see Figures 3b and 4b for the DART locations). These and other DART data with 15-s sampling were downloaded from the instruments retrieved from the bottom (see *Rabinovich and Eblé* [2015] for details on the DART operational procedures). The agreement (at least for the first five hours) is excellent.

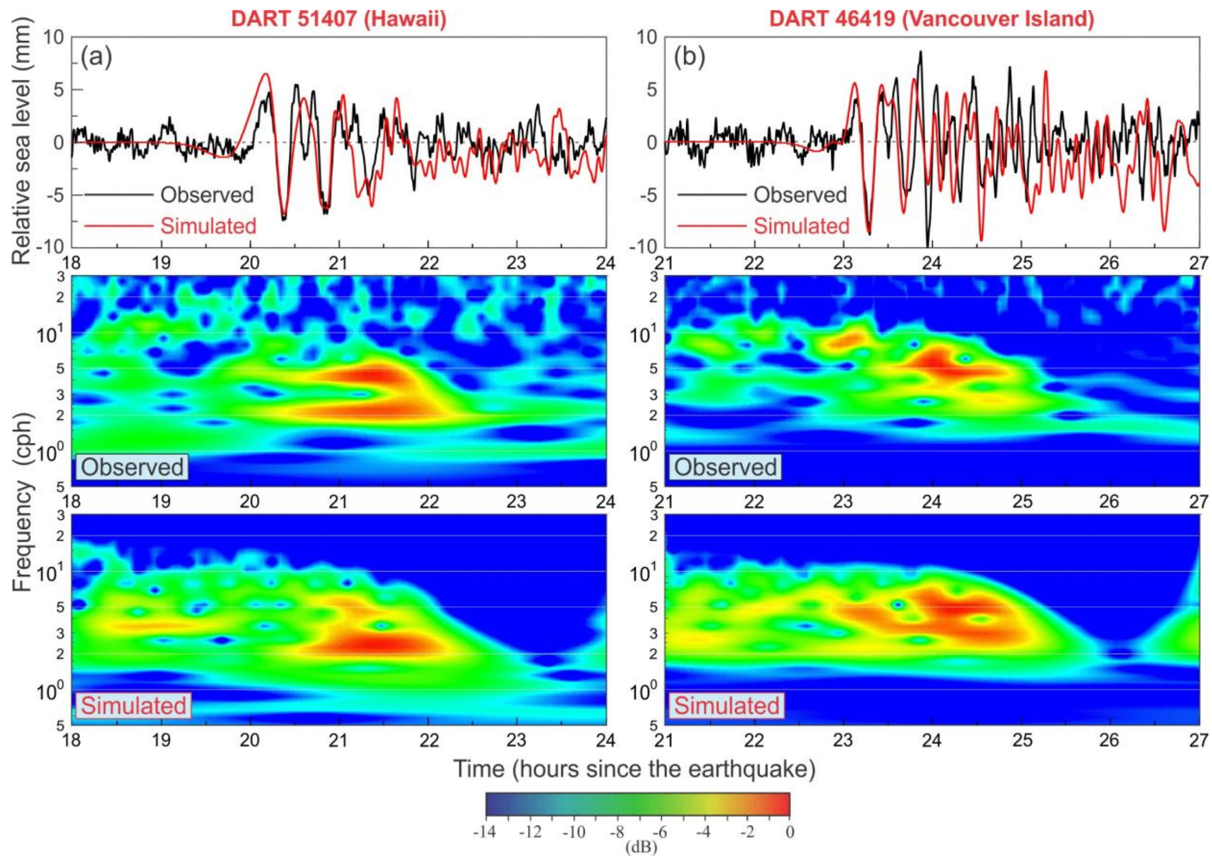

Figure 6. Numerically simulated (red lines) and observed (black lines) tsunami waveforms of the 2021 South Sandwich Islands tsunami for two DARTs in the North Pacific Ocean and their frequency-time (*f*-*t*) diagrams.

Additionally, we compared the frequency properties of the simulated and observed DART records for the 2021 South Sandwich Islands tsunami. Figure 6 shows the computed and observed records at two DARTs -- 51407 (near the Hawaiian Islands) and 46419 (near Vancouver Island) – and their frequency-time (*f*-*t*) diagrams, which are similar to wavelet plots [cf., *Thomson and Emery*, 2024]. These diagrams clearly demonstrate that the model correctly reproduces amplitudes of the actual records, but also reproduces the time evolution and frequency content.

3. OBSERVATIONS

As mentioned above, the 2021 South Sandwich Islands tsunami had propagated throughout the entire World Ocean but was almost unnoticed by various Tsunami Services. Only later, after receiving information from the PTWC (see Figure 1a), did these services began to examine the available tide gauge records. The 2021 tsunami was identified in many of the records. In particular, for the North Pacific Ocean, the tsunami was clearly detected at two Russian stations: Kurilsk, located on the Okhotsk side of Iturup Island, the South Kuril Islands (Figure 7a) and Vodopadnaya ("Waterfall"), located on the southeastern coast of the Kamchatka Peninsula (Figure 7b). At Kurilsk, the tsunami trough-to-crest wave height was only 4.0-4.5 cm, but the signal was evident both in the *f-t* diagram and in the record itself. At Vodopadnaya, the tsunami signal was stronger, about 10 cm, but in the record it was difficult to separate it from storm generated seiches. However, the corresponding *f-t* diagram enabled us to clearly isolate the tsunami signal. Typical periods of the tsunami waves were 5, 12 and 22 min at Kurilsk and 11 and 30 min at Vodopadnaya.

The tsunami signal was also identified at three other Russian stations – Paronaisk, Korsakov and Krilion – located at the eastern and southern coasts of Sakhalin Island. The signal-to-noise (s/n) ratio at all three stations was low; therefore, the tsunami waves at these stations were detected only with the help of their respective *f-t* diagrams. In the open ocean (at DART stations), the background noise level was quite low, and the tsunami signal was clearly evident. The 2021 South Sandwich Islands tsunami waves were identified in all DARTs located in the North Pacific (these DARTs are shown in Figures 3 and 4). As we noted above, open-ocean tsunami waves in the eastern part of the North Pacific were much higher than in the western part. As an example, observed waves at four DARTs are presented in Figures 5 and 6 together with the results of their numerical modelling.

Eastern-side intensification of the tsunami waves provided us a reason to believe that this tsunami event would be observed on the coast of British Columbia. For the analysis, we selected the 17 stations shown in Figure 8, and, for simplicity, separated them into two groups: all stations located on the coast of Vancouver Island, except Port Hardy, were called "*the southern group*" (eight tide gauges altogether), while Port Hardy and the other eight gauges were identified as "*the northern group*".

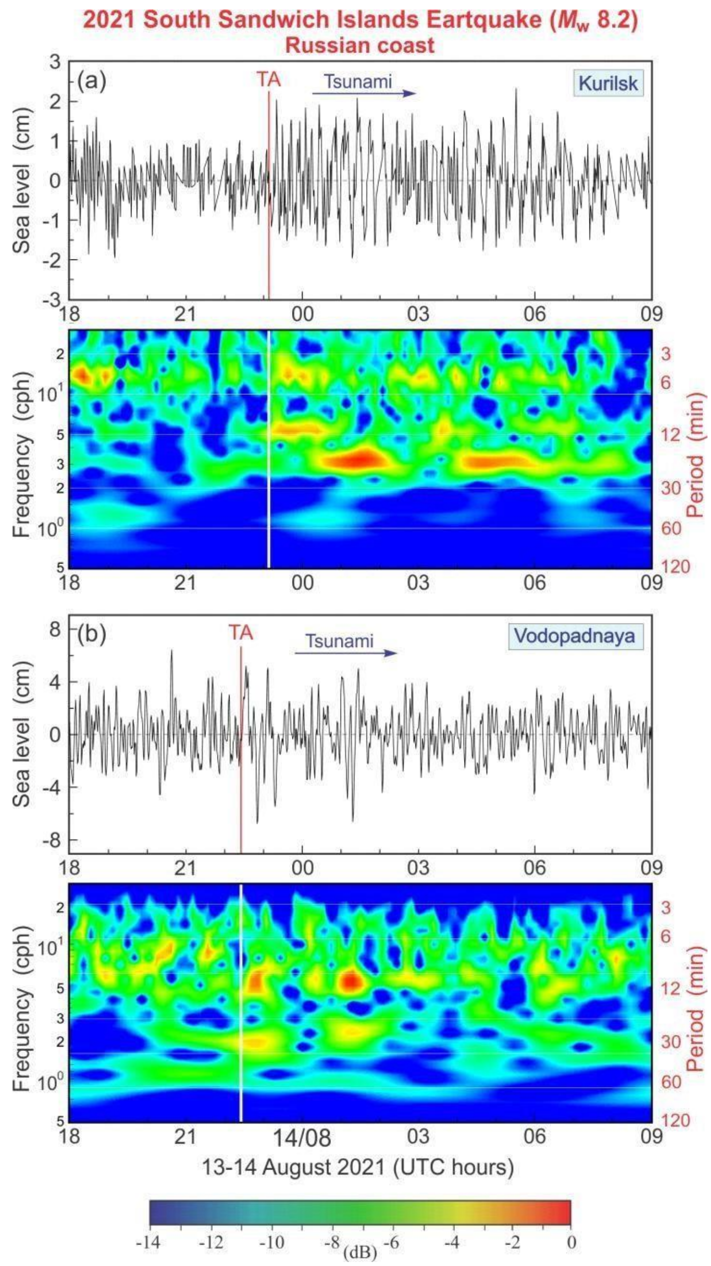

Figure 7. De-tided and high-pass filtered (3-hour Kaiser-Bessel (KB) window) records of the 2021 South Sandwich Islands tsunami at two Russian stations: (a) Kurilsk; and (b) Vodopadnaya, located on the western coast of the Pacific Ocean (the exact location is shown in Figure 4b) and their frequency-time (*f-t*) diagrams. The record at Vodopadnaya was additionally low-pass filtered with a 6-min KB window to suppress strong storm generated infragravity (IG) waves observed at this station. The vertical red/white lines labelled "TA" denote the tsunami arrivals at the specific stations.

All tide gauge records are from the Canadian Hydrographic Service (CHS); mostly (with a few exceptions) from gauges located on the outer (oceanic) coast of British Columbia. As a result of destructive tsunamis in the 1990s in the Pacific Ocean, the CHS in 1997 initiated a major upgrade of the existing tide gauge network on the BC coast, including those located in Dixon Entrance and Queen Charlotte Sound. These are digital instruments designed to continuously measure sea levels with high precision and to store recorded values with 1-min sampling interval increment [*Rabinovich and Stephenson*, 2004; *Stephenson and Rabinovich*, 2009].

Figure 8. Map of British Columbia showing the locations of the Canadian Hydrographic Service (CHS) coastal tide gauges (indicated by circles) and open-ocean DART stations (indicated by red squares). Yellow circles with blue contours (CHS S) are CHS stations of the southern group of tide gauges that recorded the 2021 South Sandwich tsunami, the yellow circles with red contours (CHS N) are the same but for CHS tide gauges from the northern group; the white circle with the red contour (CHS empty) indicates the Bonilla station that did not record this tsunami.

The digital records from all coastal stations have been examined using the data analysis procedures and tsunami detection methods described by *Rabinovich et al.* [2006, 2017]. We verified and corrected all data, subtracted predicted tides from the original records and high-pass filtered the de-tided time series using a 3-h Kaiser-Bessel (KB) window [cf. *Thomson and Emery*, 2014] to suppress low-frequency sea level fluctuations, mainly associated with atmospheric processes. These filtered sea level time series were then used to construct plots of tsunami records (Figures 9-12) for various sites and to estimate statistical characteristics of the recorded tsunami waves (Table 1). As a result, the 2021 South Sandwich Islands tsunami waves were identified in all examined records, except Bonilla; the latter record was too noisy and was adversely affected by instrumental problems that produced numerous regular spikes.

The South Sandwich Islands tsunami waves first arrived at Tofino on 13 August at 17:46 UTC, i.e., 23 h and 13 min after the main earthquake shock, in good agreement with the numerically computed travel time presented in Figure 3. Then, about 40 min later, these waves reached Ucluelet, Rose Harbour and Bamfield. At two important Tsunami Warning stations, Winter Harbour and Henslung Cove (Langara Island), the waves arrived 24 h 16 min and 24 h 39 min after the earthquake. To the most remote stations, Prince Rupert and Queen Charlotte City, the tsunami waves arrived about 3 h and 20-25 min later than at Tofino (Table 1). The arrival times at all stations were consistent and in good agreement with the theoretical arrival times (Figure 3). The recorded waves were small (Figures 9-12), with maximum wave heights measured at Ucluelet (13.7 cm), Pruth Bay (11.9 cm), Rose Harbour (11.4 cm) and Port Alberni (11.0 cm). At all other stations, the observed maximum wave height was below 9 cm. The tsunami wave periods strongly varied from one site to another, but mostly were in the range of 12-55 min. The only two exceptions were Port Alberni and Prince Rupert, both with an observed wave period of 110 min. Periods of 110 min are typical for recorded tsunami waves at these two stations [cf. *Rabinovich et al.*, 2019], as both Alberni Inlet and Dixon Entrance are well known to behave as low-pass filters that allow low frequency waves to propagate through while suppressing the transit of high frequency waves.

Table 1. Parameters of the South Sandwich Islands tsunami of 12 August 2021 recorded on the coast of British Columbia. All arrival times and times of the maximum wave (in UTC hours and minutes; hh:mm) are for 13 August 2021, except for those indicated by an asterisk (*).

Station	First wave			Max waves			Visible period (min)
	Arrival time (UTC)	Travel time (hh:mm)	Amplitude (cm)	Max amplitude (cm)	Time (UTC) of max amplitude	Max wave height (cm)	
Prince Rupert	21:06	26:33	2.6	3.2	01:39*	5.6	110
Masset	19:36	25:03	1.5	1.8	21:05	4.0	60
Henslung Cove	19:12	24:39	1.6	3.7	21:01	8.6	12, 30
Queen Charlotte C.	21:11	26:38	0.4	3.2	14:40*	7.6	15, 40
Rose Harbour	18:25	23:52	2.2	5.3	00:34*	11.4	20
Bella Bella	19:18	24:45	1.6	4.0	14:56*	7.2	30, 55
Pruth Bay	19:21	24:48	2.0	7.1	15:23*	11.9	25
Port Hardy	19:48	25:13	1.4	2.2	21:08	4.3	12, 20
Port Alice	19:08	24:35	0.8	3.3	20:47	6.1	50, 110
Winter Harbour	18:49	24:16	1.7	2.7	19:49	7.7	30, 50
Tofino	17:46	23:13	2.3	3.6	02:10*	6.6	20, 55
Ucluelet	18:24	23:51	1.5	5.8	19:26	13.7	15, 22
Port Alberni	19:34	25:01	3.5	3.6	23:40	11.0	110
Bamfield	18:27	23:54	0.6	2.5	20:20	5.0	18, 140
Port Renfrew	19:11	24:38	1.7	3.1	01:18*	6.3	35, 60
Victoria	?	?	?	2.0	02:47*	4.5	20, 60

* 14 August 2021.

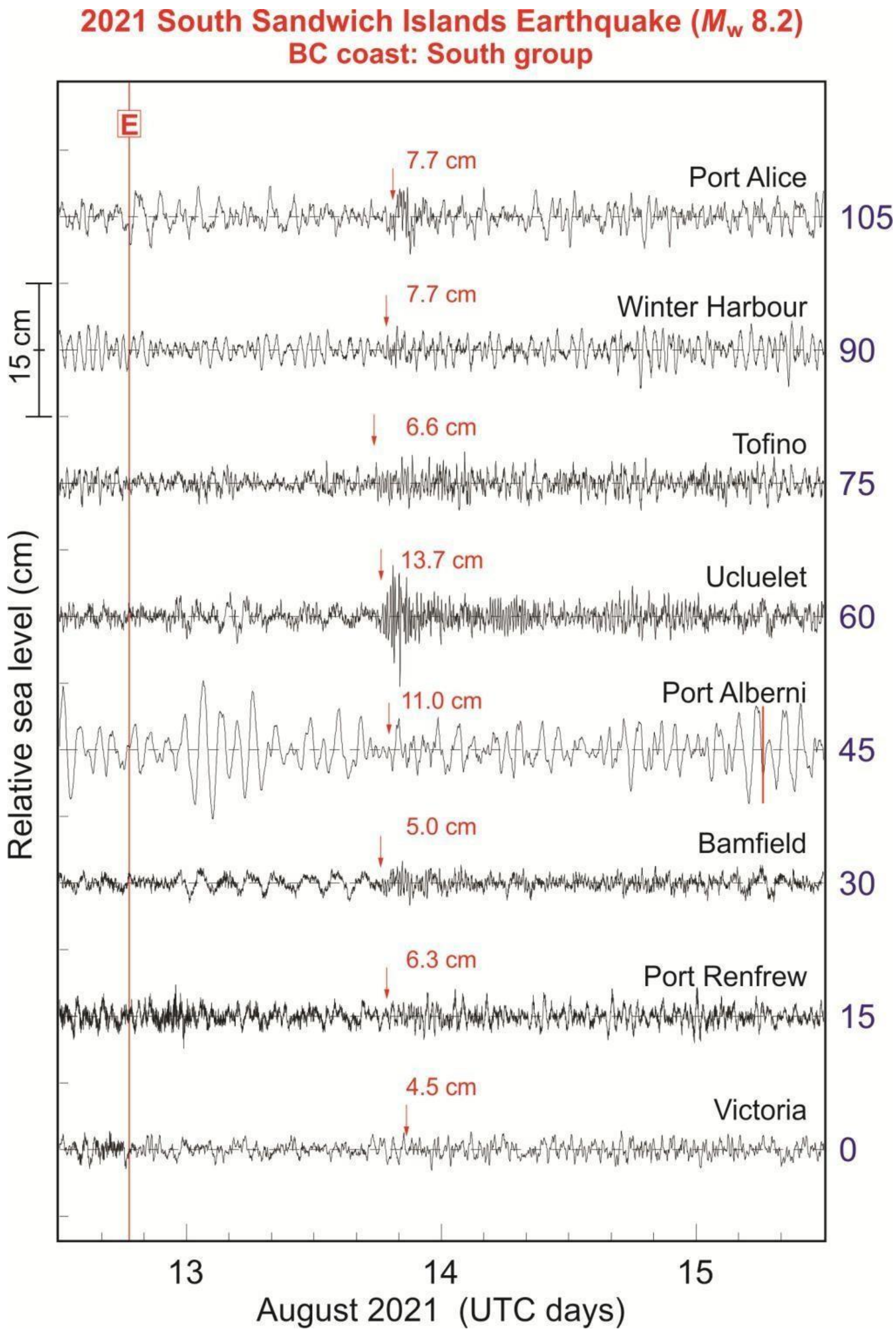

Figure 9. De-tided and high-pass filtered (3-hour Kaiser-Bessel window) 3-day records of the 2021 South Sandwich Islands tsunami recorded at the CHS stations of the southern group. The solid vertical red line labelled "E" indicates the time of the earthquake, the small red arrows denote the tsunami arrival times at the corresponding stations, while red numbers are maximum recorded tsunami wave heights at these stations. The individual records are shifted in the vertical relative to each other; the shift values (in cm) are listed along the right axis.

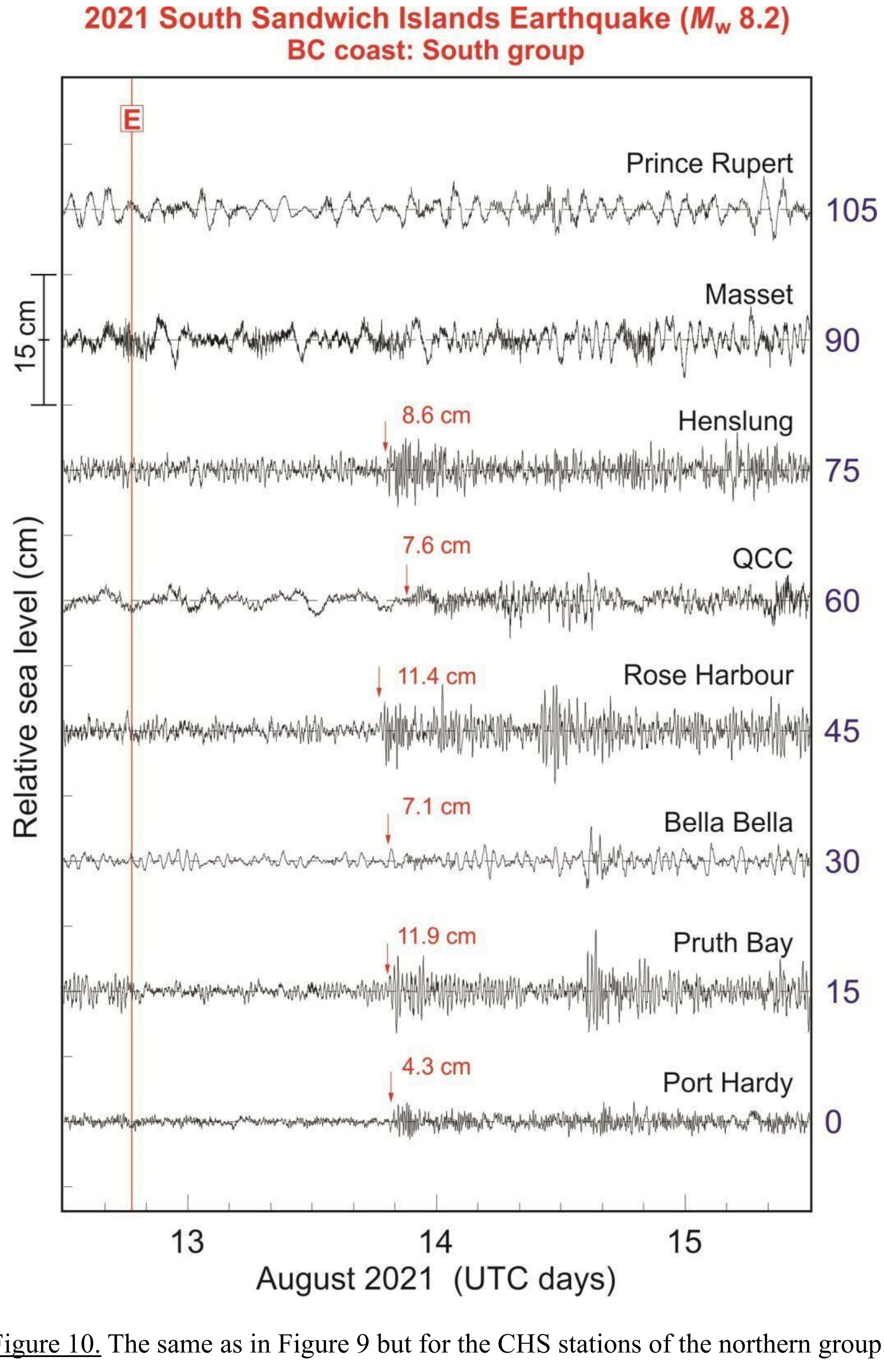

Figure 10. The same as in Figure 9 but for the CHS stations of the northern group.

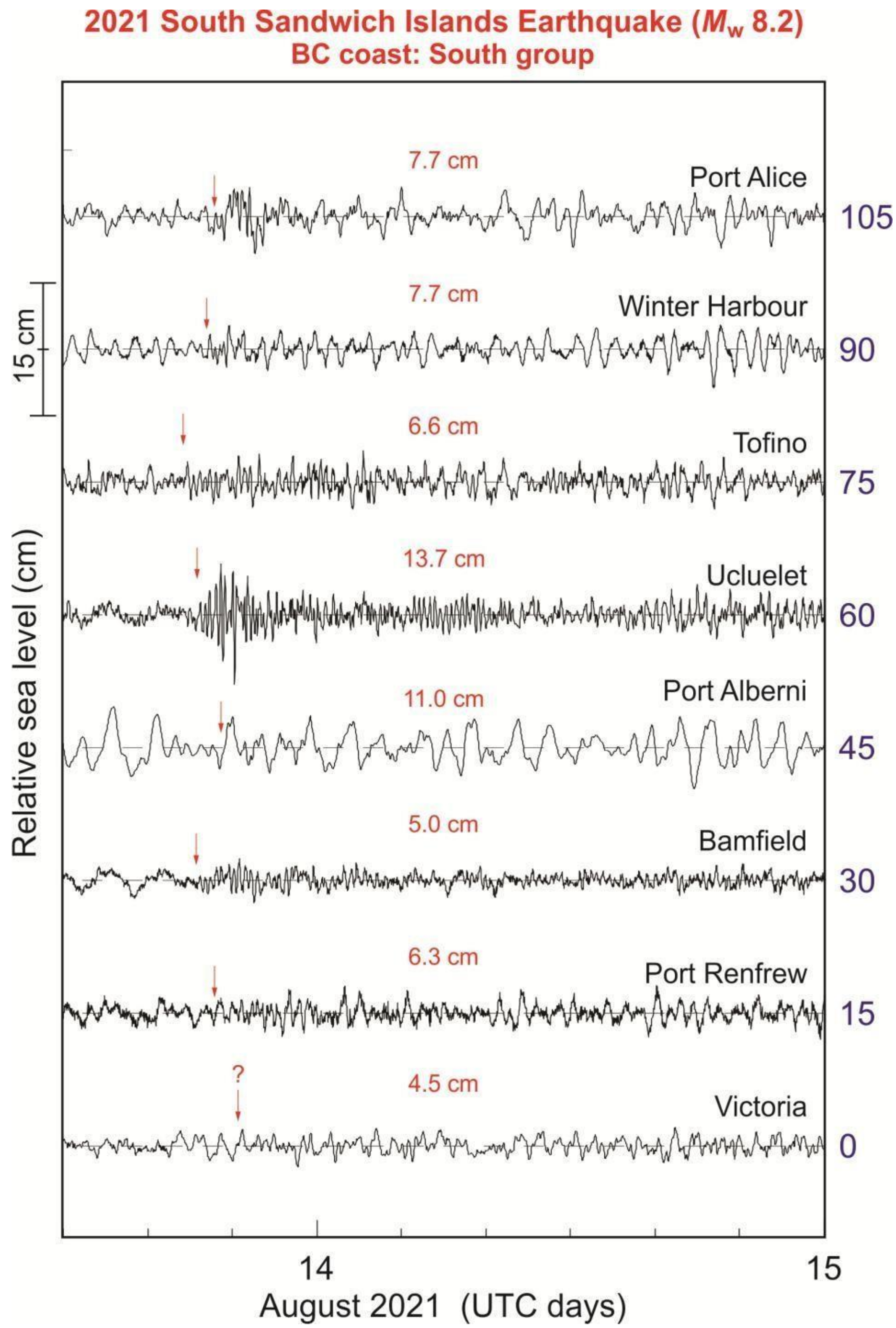

Figure 11. The same as in Figure 9 but for a 1.5-day period spanning the times of the tsunami wave arrivals.

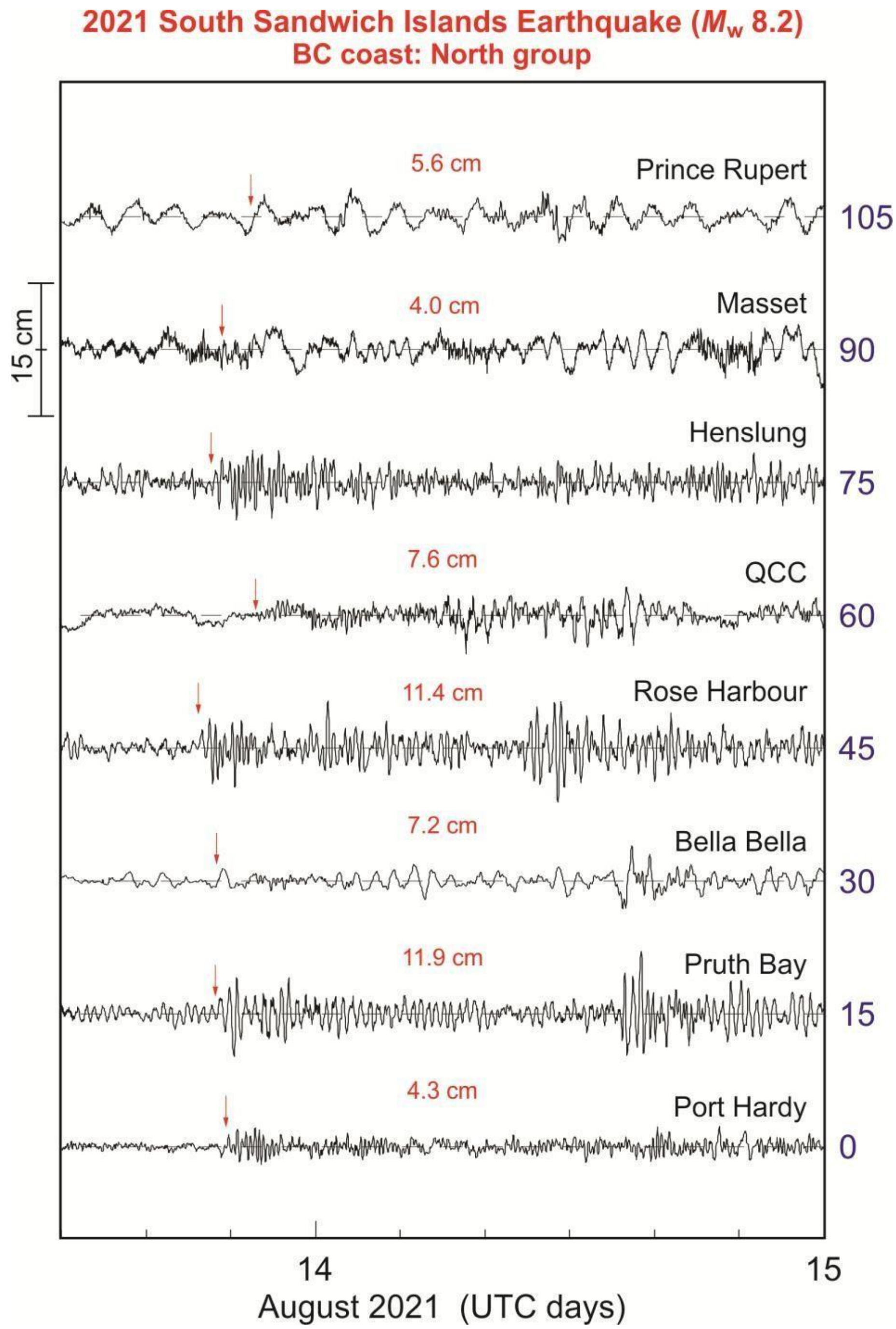

Figure 12. The same as in Figure 10 but for a 1.5-day period spanning the times of the tsunami wave arrivals.

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The frequency content of the South Sandwich Islands tsunami records on the coast of British Columbia and their time evolution is clearly seen in the *f-t* diagrams presented in Figures 13 and 14. Most of the plots are characterized by relatively narrow, well-defined bands of enhanced energy that are related to the resonant (eigen) frequencies of the corresponding sites. The periods of these specific bands are given in the rightmost column in Table 1. At some sites - Victoria, Port Renfrew, Bamfield and Tofino (Figure 13), Port Hardy, Pruth Bay, Rose Harbour, QCC and Masset (Figure 14) – the oscillations were either generated by, or strongly amplified by, the incoming tsunami waves. However, at some stations significant resonant oscillations existed before the event and the arriving tsunami wave train contained some new wave frequencies that were absent before the event.

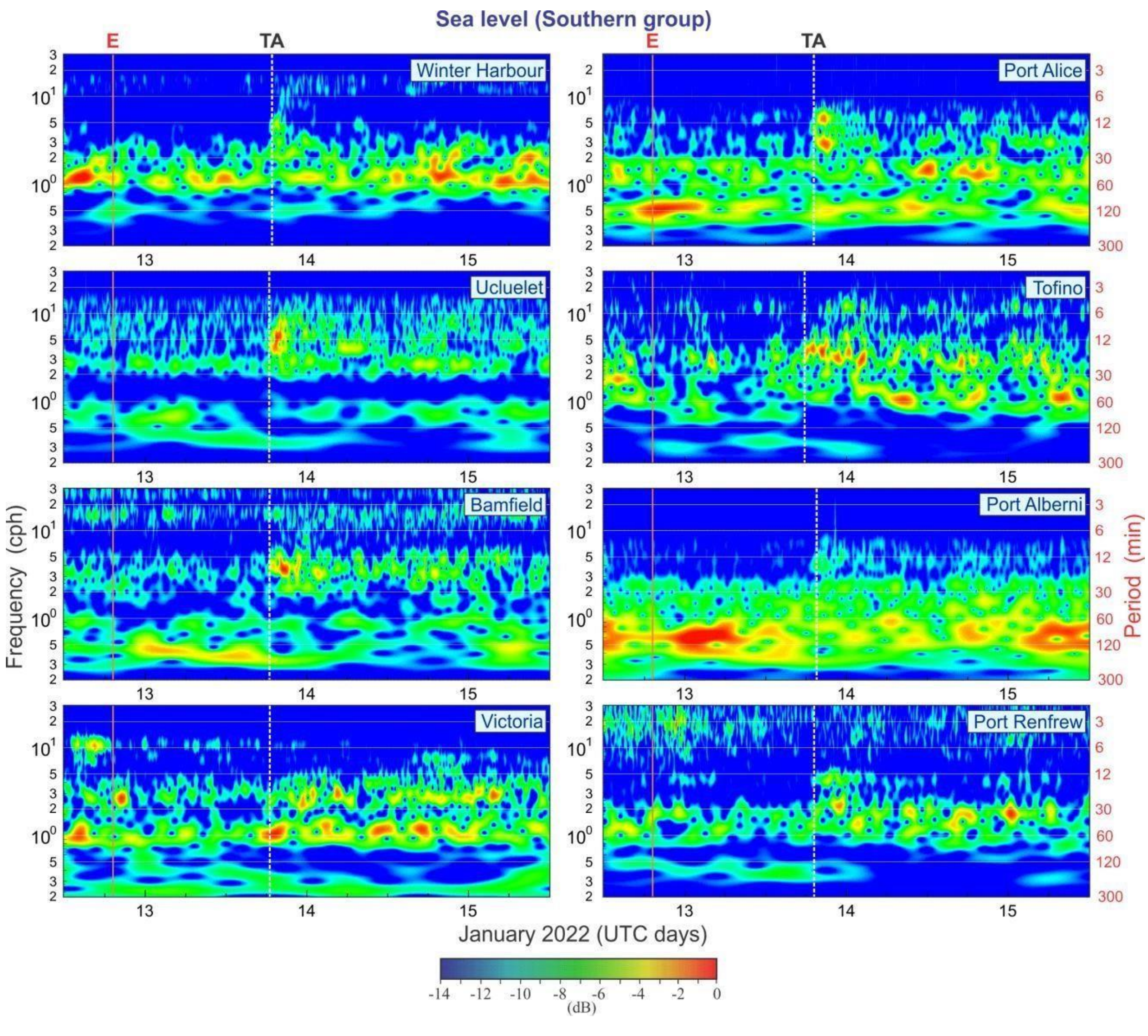

Figure 13. Frequency–time plots (*f–t* diagrams) for the 2021 South Sandwich Islands tsunami based on the CHS records shown in Figure 9. The solid vertical red lines labelled "E" indicate the time of the earthquake; the dashed thin vertical white lines labelled "TA" mark the tsunami arrival at the specific site.

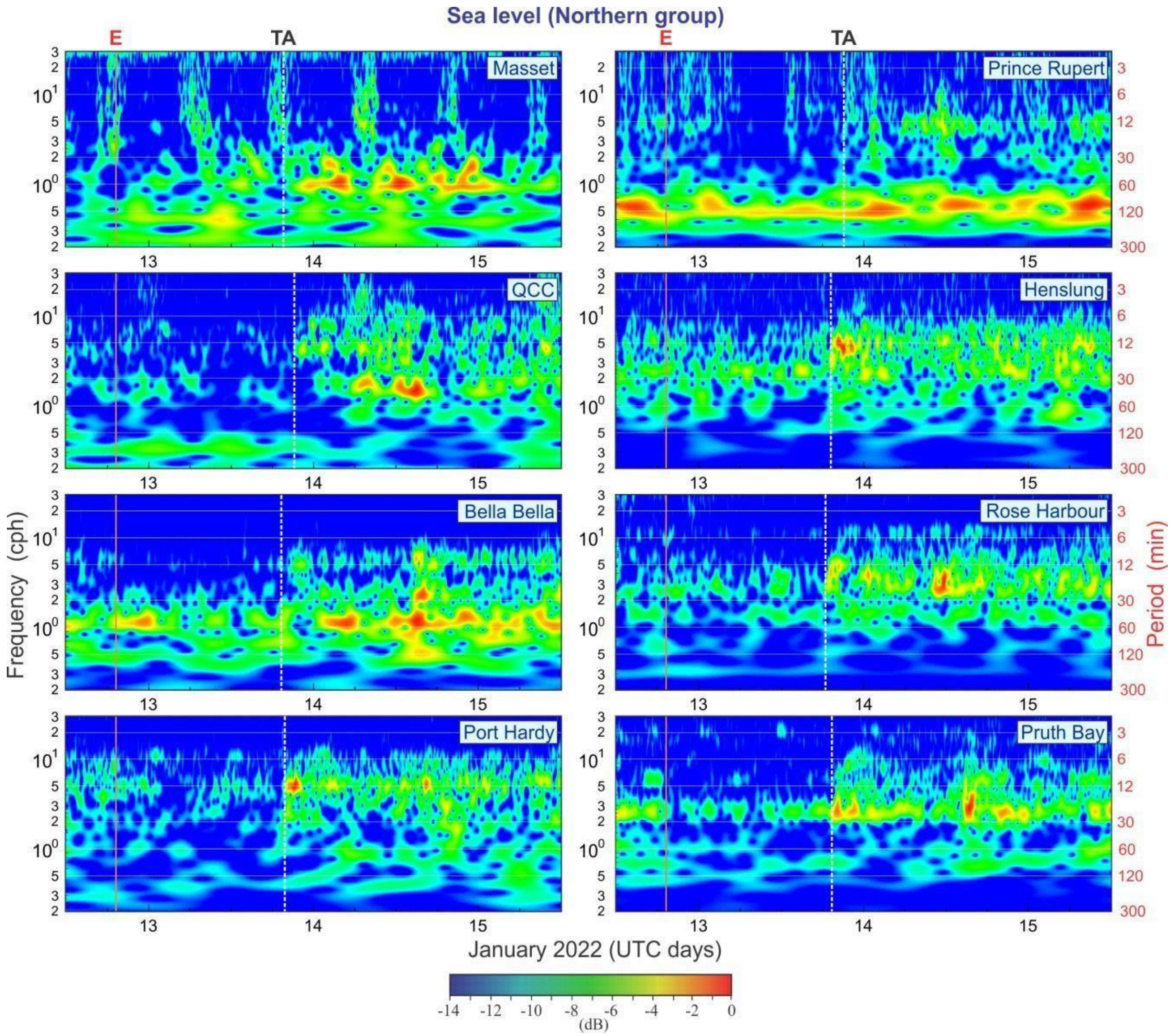

Figure 14. The same as in Figure 13 but for the records shown in Figure 10.

The "new" frequencies evident in the *f-t* plots simplify identification of tsunami waves and help us to specify their exact arrival times. For example, in the case of Port Alberni, which has recorded oscillations with the known dominant period of 110 min for Alberni Inlet, there are also weak, but noticeable oscillations with period of about 15 min that help determine the precise tsunami arrival time. A similar, but even more pronounced situation occurred at Ucluelet, where, in addition to amplified persistent oscillations with a period of 22 min during the event, prominent new oscillations (much stronger than the 22-min oscillations) were observed at this site with the same period of 15 min that appeared at Port Alberni. Also noteworthy are the water level oscillations at Winter Harbour and Port Alice, where the arrival of the South Sandwich Islands tsunami produced motions with periods of about 11 and 18 min. Similar periods were observed at Bamfield and Tofino (at Tofino, the prevailing period after two hours increased to 20 min). It appears that wave periods from 10 to 20 min were associated with the dominant open-ocean period of the incoming waves at the outer coast Vancouver Island (see *f-t* diagram of the nearby DART 46419 in Figure 6b). At Winter Harbour, Port Alice and Port Alberni, these periods do not match the resonant periods of the corresponding inlets and bays; as a result, the tsunami-induced oscillations decayed quite rapidly. In contrast, at Ucluelet, Tofino and Bamfield it appears that the incoming dominant frequencies were in close proximity to the resonant periods of the specific basins; consequently, the tsunami generated oscillations at these sites decayed slowly and continued ringing for a long time. (All stations listed in this paragraph are related to the southern group; their *f-t* diagrams are shown in Figure 13).

A similar situation was observed at stations of the northern group (Figure 14). At Pruth Bay, Bella Bella and partly at Masset, the arriving tsunami waves substantially enhanced the natural oscillations at these sites before the event and caused their long ringing. At Port Hardy, Rose Harbour, QCC and Henslung Cove, it appears that the incoming tsunami waves had frequencies that matched the resonant frequencies of these particular sites, and they produced long ringing oscillations, while at Prince Rupert they induced some high-frequency oscillations that decayed quickly. The dominant periods of generated or enhanced waves for the stations in the northern group were approximately the same as for the stations from the southern group (i.e., 10 -20 min) indicating the source origin of these periods.

4. CONCLUSIONS

A major earthquake occurred on 12 August 2021 in the Antarctic sector of the Atlantic Ocean near the South Sandwich Islands. This was a complex event that was initially reported as a magnitude 7.5 at 18:32:52 UTC at a deep depth of 47 km but generated a global tsunami that would only be expected for a larger and shallower event [*Jia et al*., 2022]. Seismologists were puzzled and sought to understand what happened that day in the remote South Atlantic. A new study revealed that the earthquake was not a single event, but a sequence of events spread out over several minutes; the strongest one with M_w 8.2[2] was at 18:35:17 UTC [*Jia et al.*, 2022]. It appears that this specific earthquake produced a worldwide tsunami that affected the remote areas of three oceans, including Alaska and British Columbia.

The main focus of this study is the coast of British Columbia. Results of our analyses are as follows:

- The 2021 South Sandwich earthquake generated a major tsunami that spread throughout the World Ocean and was clearly observed in both the open and coastal regions of the North Pacific Ocean, including the coast of British Columbia.
- The recorded tsunami waves at DART stations in the North Pacific Ocean were well reproduced by the numerical model specifically formulated for this study, despite the fact that the distance from the source to the observation sites was about 17,000 – 18,000 km.
- Tsunami waves observed and numerically simulated for the northeast Pacific Ocean were significantly higher than for the northwestern part.
- Tsunami waves arrived at the oceanic coast of Vancouver Island about 23 h after the earthquake and at the northern coasts about 1.0-1.5 h later.
- The maximum trough-to-crest tsunami wave heights of 11.0-13.7 cm were recorded at Ucluelet, Pruth Bay, Rose Harbour and Port Alberni; tsunami waves were identified at 12 other stations along the British Columbia coast, from Victoria in the south to Prince Rupert in the north, but at all these stations the tsunami heights were below 9.0 cm.
- Waves with periods of 10-20 min dominated both the coastal and open-ocean DART stations; it appears that these periods were associated with the source spectral properties.
- At those sites (Victoria, Port Renfrew, Bamfield, Tofino, Port Hardy, Pruth Bay, Bella Bella, Rose Harbour, Henslung Cove and Masset) that have major resonant (eigen) periods matching the dominant incoming wave periods (10-20 min), the arriving tsunami waves produced long ringing oscillations of 1.5-3 days.
- The entire event demonstrates that even distant events with source areas located in other oceans can reach the coast of British Columbia and, at the same time, can be reliably reproduced by the modern numerical models.

[2] The USGS NEIC and GCMT give slightly different estimates for this event of M_w 8.1 and M_w 8.3, respectively [*Jia et al.*, 2022; *Lutikov et al.*, 2022].

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