Hunga Tonga – Hunga Ha`apai
Volcanic Tsunami Hazard Response

PTWS Interim Procedures Implementation Plan

Version 1.1, 1 March 2022

Due to the potential for another Hunga Tonga–Hunga Ha`apai volcanic eruption and tsunami, immediate implementation of this Plan was begun following the proposal presentation to Member States, their feedback, and agreed upon 'Actions Forward' concluded from the PTWS Post-Event Brief I: 15 January 2022: Hunga Tonga–Hunga Ha`apai Volcanic Eruption and Tsunami held on 20 January 2022. Further Member State feedback was provided during PTWS Post-Event Brief II on 3 February 2022 and PTWS Post-Event Brief III on 10 February 2022.

This document presents the ICG/PTWS Interim Procedures Implementation Plan for the Hunga Tonga–Hunga Ha`apai Volcanic Tsunami Hazard Response for urgent consideration and adoption by the ICG/PTWS Steering Committee.

INTRODUCTION

This Implementation Plan describes interim standard operating procedures (SOP) that will be carried out by the Pacific Tsunami Warning Center (PTWC) as a Pacific Tsunami Warning and Mitigation System (PTWS) Tsunami Service Provider (TSP) to address the possibility of future tsunamis originating from additional volcanic eruptions or associated processes at the Hunga Tonga - Hunga Ha`apai Volcano (HTHH) that erupted explosively on 15 January 2022 and generated a Pacific-wide tsunami.

The SOP is designed to alert Member States to a potential tsunami threat from the HTHH volcano and to help guide their response with information about expected tsunami amplitudes and arrival times. This interim plan has been constructed by the PTWC and a ICG/PTWS Working Group 2 Task Team on Hunga-Tonga Hunga-Ha'apai (HTHH) Volcano Tsunami Hazard Response.

The procedures contained in this plan describe a best-endeavours response by PTWC to any further tsunamigenic activity in the HTHH region. Because of the large uncertainties involved in forecasting volcanic tsunamis, the SOP allows for expert interpretation of data, including consideration of data sources other than seismic or sea level observations (e.g. other data to suggest a volcanic eruption has occurred).

The operational procedures, including the message texts, and forecast Estimated Tsunami Arrival (ETA) times and wave amplitude computation, will be described in the HTHH User's Guide.

Annex 1 (Plan of Actions) will be updated as necessary.

1. BACKGROUND

The 15 January 2022, Hunga Tonga – Hunga Ha`apai explosive volcanic eruption came from an existing largely submerged volcanic edifice represented at the surface by two small islands. The volcano had a summit caldera with a floor that was ~150 m below sea level. The activity on 15 January was part of a broader eruption episode that started in 2009 and continued in 2014 and 2015. The latest eruptive phase that led to the 15 January tsunami started on 20 December 2021. On 14 January, an explosive eruption excavated the central scoria cone and may have involved collapse. It did not generate a damaging tsunami but did generate small tsunami waves. A day later, on 15 January at about 0407 UTC, the active submerged vent violently exploded resulting in the generation of tsunami waves, with the first wave arriving on 0427 UTC at the Nuku'alofa, Tongatapu sea level gauge.

The eruption plume ascended very quickly and punctured the stratosphere ~30 km above sea level and produced a massive acoustic pressure wave that travelled in the atmosphere around the globe at least three times. The role of this acoustic/atmospheric wave in tsunami generation is still being researched, but its occurrence provided both a significant tsunami natural warning and increased challenges for tsunami forecasting. Processes associated with the volcanic eruption generated a series of tsunami waves that impacted local, regional and distant coastlines (Figure 1 and 2). These waves caused land threats (>1m amplitude) at local, regional and distant coastlines. An immediate response by the PTWS TSP PTWC and PTWS Member States was challenging because of the volcanic source of the tsunami. Volcano tsunamis are difficult to forecast because large uncertainties exist in our ability to rapidly characterise both the complex eruption process and the mechanism by which this process generates tsunamis.

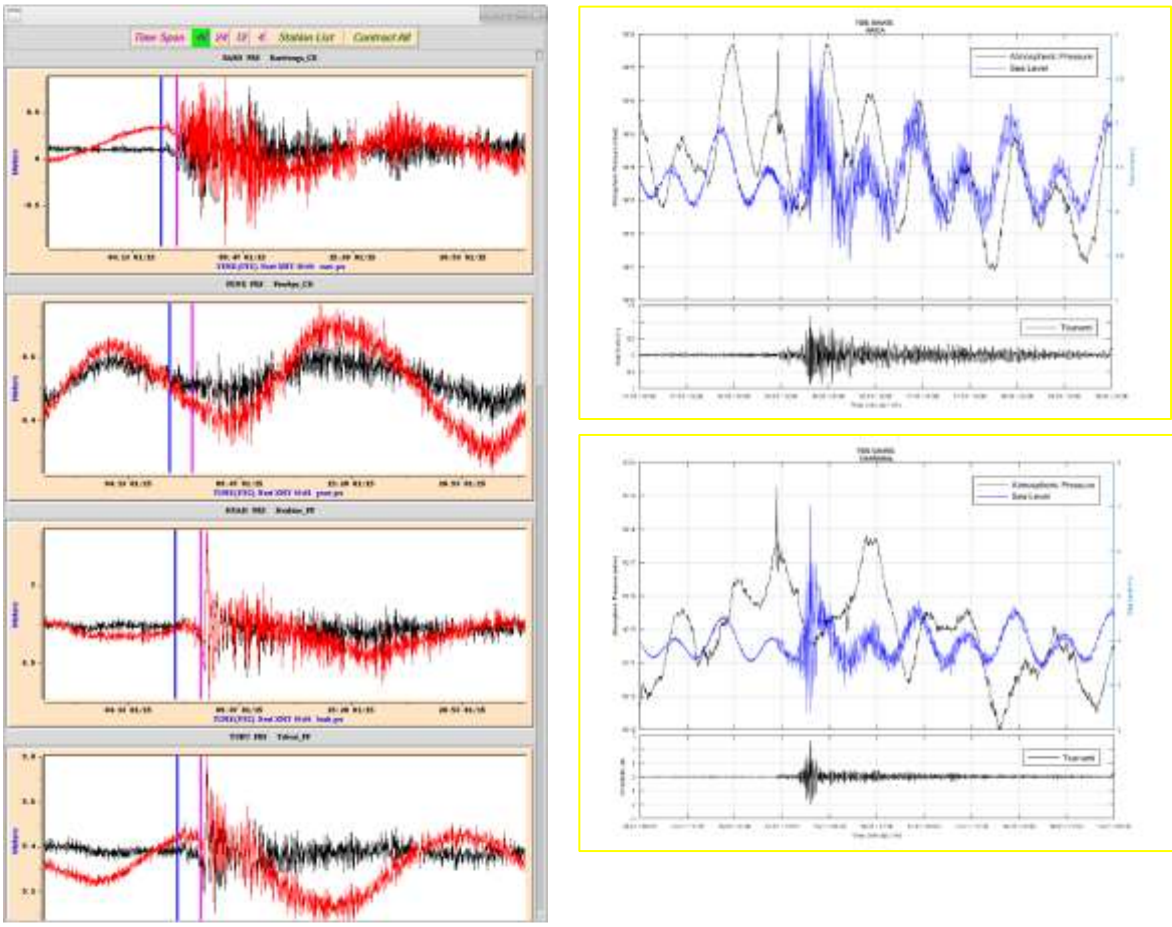

Figure 1.

Left: PTWC Tide Tool marigrams from Cook Island and French Polynesia stations showing at least two tsunami generation mechanisms at work in the far field. The magenta line indicates the usual expected travel time based on the long-wave speed of tsunamis. The blue line indicates the expected arrival time of tsunamis generated by the propagating sonic boom (sound of speed 313 m/s).

Right: SHOA marigrams from Arica (top) and Chañaral (bottom) stations in Chile showing the earlier and smaller wave arrival at the same time as a spike in atmospheric pressure (topmost black record in each figure).

Unique features of this event include the very high plume, and a relatively small erupted volume (~0.5 km^3 of magma) that was smaller than expected from a very short duration eruption. Enhanced explosivity was likely related to a near perfect mix between magma and water (too much of either dampens explosivity), suggesting the vent was covered by 10's, but not 100's m of sea water. This vent geometry probably led to a detonation near the sea surface-atmosphere boundary and generation of the shockwave(s) and increased tsunami amplitudes.

With limited near real-time monitoring, it is very difficult to assess what activity might follow in the days and months afterward. After large eruptions, recovery of the magma system will likely lead to small events that begin to rebuild the vent area. A new cone or island may form in the coming months. Flank stability may be compromised, and a partial edifice collapse in the shortterm is possible. It is less likely that a much larger event will follow because of 'un-roofing' of the overlying rock during this eruption. However, the potential for further tsunamigenic events at HTHH is significant and is the primary motivation for this SOP.

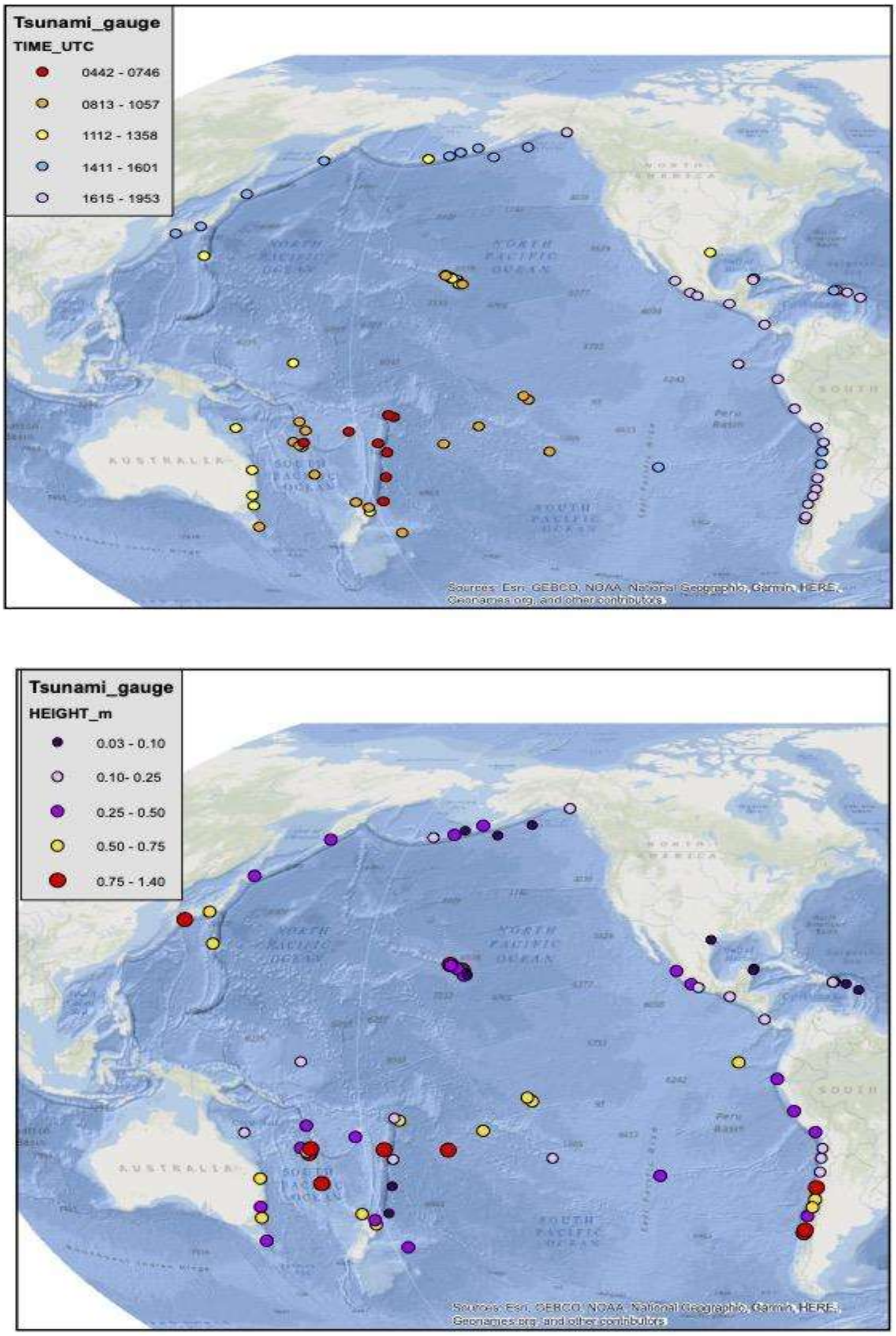

Figure 2: Top: Time of arrival of maximum tsunami amplitude recorded on coastal sea level gauges and DARTs. Bottom: Maximum tsunami amplitudes reported by PTWC on 15 January.

2. INTERIM STANDARD OPERATING PROCEDURES (SOP)

Background

The PTWC response to the 15 January 2022 tsunami presented some extraordinary challenges, as its operational procedures, forecasting tools, and message generation and dissemination are all predicated on earthquake sources. Its initial pre-forecast threat is based only on the preliminary earthquake parameters. Its later forecast threat is underpinned by an estimation of the earthquake fault parameters – the strike, dip, and rake of the fault and the total seismic moment. These parameters are used to estimate seafloor displacement that becomes the initial condition for the hydrodynamic tsunami forecast model.

Tsunami generation in the 15 January 2022 HTHH volcanic eruption was driven by entirely different processes that still are not fully understood, but likely involve several mechanisms including forcing by atmospheric gravity waves. Consequently, there currently is no method to dynamically model this type of event in real time to estimate a forecast, nor is there a method to even quickly detect or characterize the volcanic source.

Operationally, the Nuku'alofa sea level gauge stopped transmitting about one hour after the explosion, leaving uncertainty in confirming how severe the waves would be. Internet and voice communications were also cut at about 0530 UTC presumably due to breakage of the undersea telecommunications cable.

Interim SOP

Noting the above, the PTWC will use first available information that a tsunami has been generated to underpin PTWC Threat Messages for future HTHH events. Specifically, PTWC

- Will use observed tsunami amplitudes as the basis of a forecast. These include amplitudes from the sea level gauge at the Nuku`alofa and the deep ocean NZG DART gauge, which is the nearest DART to the HTHH volcano. Tsunamis generated at the HTHH volcano will arrive at those stations within approximately 20 to 30 minutes. Observations on these stations will likely constitute the first evidence of a tsunami threat.

- Create the forecast for the future HTHH event by scaling observed maximum amplitudes across the Pacific from the 15 January 2022 event with observed amplitudes of the future HTHH event, starting with the observed amplitudes at Nuku`alofa and the NZG DART. Forecast values are only for specific sea level locations and do not represent a wider forecast for that coast.

- Calculate estimated tsunami arrival (ETA) times according to tsunami propagation generated by an earthquake.

NTWCs will need to apply their knowledge of what happened along all their coasts during the 15 January event and also scale it accordingly. A useful reference can be the comparison of the barometric pressure change of the 15 January eruption with record(s) during the future HTHH event from any country weather station or nearby stations.

These interim Threat Messages for HTHH are not meant to provide the same level of detail and/or certainty as normal forecasting products delivered during earthquake-generated tsunami responses. It is expected that this interim SOP will evolve as appropriate based on advancing science as well as recommendations from WG 2. No graphic products will be provided for this interim service.

This will be a best endeavours approach to creating Threat Messages. Some judgement of the PTWC duty staff will be applied to limit or extend the region around the volcano designated to have a threat and to raise or lower forecast amplitudes based upon the evolving observations as the tsunami propagates across the Pacific.

Message Content
Messages will contain:

1. Estimated Tsunami Arrival time of tsunami waves generated by the volcano along with the HTHH coordinates,
2. Names of the countries or territories with a possible tsunami threat (threat region),
3. Aforementioned tsunami amplitude forecast and estimated arrival times at gauge locations in the threat region (only those where the 15 January 2022 tsunami was recorded),
4. Estimated Tsunami Arrival times at the normal warning points in the threat region, and
5. Observed Tsunami Arrival time and amplitudes on coastal and DART gauges.

Message Dissemination
Messages will be disseminated to all the normal designated PTWS recipients (TWFP and NTWC) via the standard methods used by PTWC for earthquake-generated tsunamis. These include:

- WMO Global Telecommunications System (WEPA40 PHEB header)
- Aeronautical Fixed Communications Network (AFTN)
- Email
- SMS of first message to Member States in the region around the HTHH volcano.
- Voice Phone Call to Tonga. PTWC will inform the Tonga National Tsunami Warning Centre by telephone voice call to one of their operational phone numbers.
- Fax
- Website. For the interim service, the PTWC messages will also appear on the tsunami.gov website but with reference to a magnitude 1.0 earthquake at the site of HTHH volcano. It will require much more work to modify the website to reflect a volcano source

ANNEX 1
PLAN OF ACTION
(V 1.0 - 19 February 2022)

I. PTWC ACTIONS

	ACTION	PTWC Implementation Date	PTWC STATUS	TESTING, VALIDATION
1	Tsunami detection alarm on Nuku`alofa gauge and nearby DARTS	13/01/22	Done	PTWC validated
2	Procedure to immediately notify Tonga by telephone	16/01/22	Done	Tonga validated
3	Pacific message software modified for HTHH tsunami with scaled forecast	26/01/22	Done	TBD
4	Add user control of areal extent of threat in message	15/03/22	Ongoing	
5	SMS notification to region with first message	15/03/22	Ongoing	

STATUS :
1 Ongoing (PTWC)
2 Done (PTWC)
3 Testing (PTWC – HTHH TWFP (Tonga, NZ, Japan, France, Chile)
4 Validated (PTWC – TT)

II. DOCUMENTATION AND TRAINING

DOCUMENTATION
1. Implementation Plan – PTWC – ITIC - TT
2. User's Guide (technical) – PTWC – ITIC - TT

TRAINING on this service (virtual) PTWC – ITIC

	DOCUMENT/ACTION	Expected Implementation Date	STATUS
6	HTHH Implementation Plan (this document)	10/02/22	Draft
	HTHH Implementation Plan (this document)	14/03/22	Final
7	HTHH User's Guide	01/04/22	
8	Training	01/04/22	