WWRP Warning Value Chain Project

Warning Chain Database questionnaire

Hunga Tonga-Hunga Ha'apai eruption, 15 January 2022

Note - this is a test using the HTHH eruption as an example of how this form could be used in a multi-hazard approach. Comments to Andrew Tupper.

I. Purpose

Please use this form to record as much information as possible on the end-to-end warning chain for a hazardous weather event. This information will:

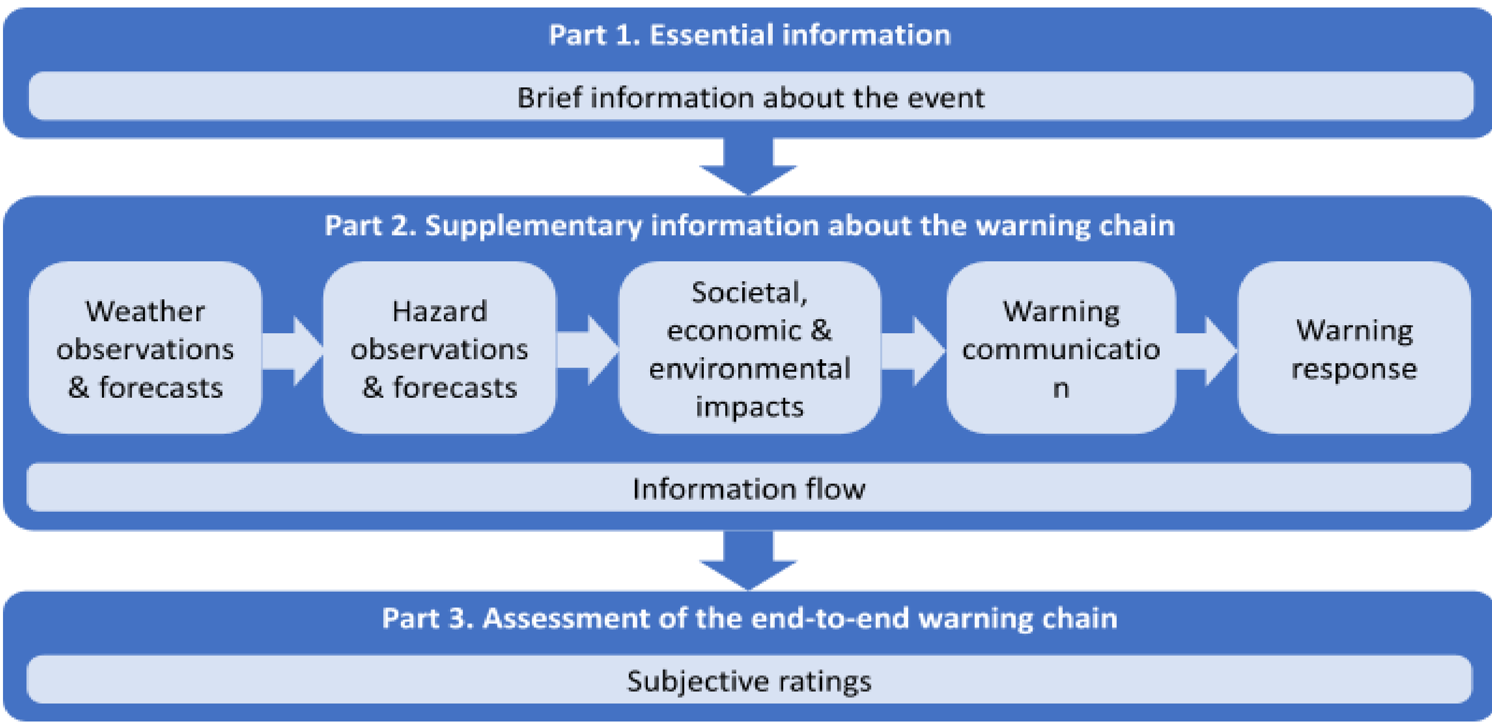
- add to a global database of hazardous weather events with rich information covering the many components of the warning value chain
- enable case studies and cross-cutting analysis of end-to-end warning value chains, from simple to complex, to understand effective practices.

The warning value chain database tries not to duplicate data collected in databases for other purposes. This template provides for a comprehensive picture of the information flow, decision making and response during a high impact weather event.

More information about the WWRP Warning Value Chain Project can be found at http://hiweather.net/Lists/130.html.

II. Structure and format

The form consists of three main parts.



Part 1. The **essential information table** requests brief facts about a particular event, such as what happened, when, where, impacts and responses. This information will help users to filter events. Please provide numerical and short text entries. Links to other databases and catalogues (e.g., ECMWF Severe Event Catalogue, EM-DAT, DesInventar, etc.) about this event should be provided.

Part 2. The second part requests **supplementary information** about different stages in the warning value chain. This more detailed information and analysis about the weather, the hazards, the impacts, the warning communication and warning response will help users understand what was unique about the warning chain for this event. The guidelines are just suggestions, they are not exhaustive. Information here might include:

- Graphics (for example, forecast charts, reanalysis maps, warning graphics, photos of impacts, etc.). Pay attention to licences/copyright!
- Videos (for example, from social media, weather service outlooks, etc.). Pay attention to licences/copyright!
- Free-form text (for example, description of meteorology, selected extracts from reports, data analysis, tables, etc.)
- Links (e.g., to other databases/catalogues, external reports, media, etc.)

Note:

⇒ Part 2 is optional, provide what you feel able to.

⇒ Each section has an "additional analysis" where you can add further information not covered by the items in the template.

⇒ Try to keep your entries brief and include references and links (URLs) to where additional information can be found.

⇒ Many people may contribute information on this event. Where you disagree try to provide evidence to support your position.

⇒ You can acknowledge contributors that provided you with information for the template at the end of the template before Annex 1. This is optional.

Part 3. The subjective assessment asks contributors to rate the effectiveness of the individual elements of the end-to-end warning chain, and its overall effectiveness, on a scale of 1 (poor) to 5 (excellent). This may assist users of the database in choosing cases and performing meta-analysis (recognising the large variability in contributors' judgments).

III. How to add resources

All resources for the supplementary material should be stored in the event data library of the respective case study. Preferably, resources such as forecast maps and warning graphics should be in the corresponding section of the template directly. Others such as reports and extensive graphics are not suitable to be embedded in the template but should be referred to. Best practice for referring to such information is to store the resources in the event data library first and then insert as a hyperlink to the template. To do so, follow these steps:

a) First, check your resources for any copyright violations. Any Creative Commons licenced items are fine to use. If unsure, check with the creator of the resource you like to use.
b) Go to the event data library on Google Drive [open to anyone].
c) For an existing case study, locate the folder for the event for which you would like to add resources. If the event does not exist yet in the library, refer to the README guide to open a new case study (project members only).
d) Place your resources in the folder and give an appropriate name so others know what it is about.
e) Right-click the file you want to embed/refer to and select 'Copy link' to retrieve the hyperlink pointing to the file.

IV. Tips

- Detailed instructions, explanations and examples about the data asked for are provided in the dedicated Guidance document <insert link to guide on Google>.
- The Value Chain Glossary provides a common terminology. Use the names of hazard types listed in *Annex 1* of this template or the guide.
- A series of prompts (i) in this template provide some quick information to assist with entering the required data. Simply put your cursor over the information symbol i and text should pop up next to it (ignore the “Ctrl+click to follow link” instruction). *Note, that this feature is only available in the Microsoft Word App, not in the SharePoint or Google Drive browser page.* Consult the Guidance document <insert link to guide> instead if this feature does not work for you.
- It is not anticipated that a single person can fill in the entire template. Rather, we encourage you to share the template with colleagues who can provide information.
- See HERE <insert link to NSW flood case study template> for a worked example of the template.

Part 1. Essential information

Editors (Name & Institute)	*Andrew Tupper, Bureau of Meteorology and Natural Hazards Consulting*

HAZARDOUS EVENT		
Unique identifier i	*25*	
Name of event	*Tonga eruption and tsunami Jan 2022*	
When did it happen i?	14-15 January 2022	
Where did it happen i?	Tonga	☐ rural ☐ **populated**
Links/UIDs to other databases *(ECMWF catalogue of severe events, WMO CHE, DesInventar, EM-DAT, GLIDE, etc.)*		

WHAT HAPPENED – Phenomenon **PHENOMENON**, **HAZARDS**, **IMPACTS**, **WARNINGS**, **RESPONSES**	
Event type/system that caused hazards i *Refer to Annex 1*	*Volcanic eruption leading to tsunamis, ashfall, intense lightning, stratospheric SO2 injection, ionospheric effects. Likely the largest eruption since Pinatubo in 1991, with many meteorological and oceanographic tie-ins and implications for warning strategies.*
If possible, provide more detail about phenomenon observations & forecasts *(link to page)*	
Hazards that caused the main impacts i *Refer to Annex* 1	Tsunamis and ashfall. Link to summary of event from Tonga Meteorological Services.
Classify hazard according to the location's climatology i	*Tonga is located in the SW Pacific part of the 'Ring of Fire' and has 21 Holocene volcanoes. Hunga Tonga and Hunga Ha'apai are above-water remnants of a large submarine caldera with historical activity. (see https://volcano.si.edu/volcano.cfm?vn=243040). Typically such a volcano would pose pumice and volcanic ash risks for minor-moderate activity, with potential for tsunami risks in a major eruption (such as in this instance) or with underwater landslides (even not during an eruption). A major marine eruption such as this will produce hazards in the ocean, in the atmosphere, and on land, with significant cross-disciplinary effort required in real-time operations to manage the potential impacts.*
If possible, provide more detail about hazard observations & forecasts *(link to page)*	
Were any impacts forecast?	☐ **yes** ☐ no

Main direct impacts i	*Tonga: 4 deaths in Tonga, 9 major resorts destroyed, 160 homes destroyed, many crops destroyed by ash and waves, waves up to 20 m. Main communications cut, and other communications affected by volcanic ash. Elsewhere: Tsunamis in Pacific and other oceans generated through gravity wave propagation. Severe damage to some homes, schools, infrastructure in Fiji. Vessels lost in Japan, flight cancellations. 2 deaths and significant damage in Peru from tsunami. Various other impacts across Pacific. Chile reported tsunami amplitudes of 2 metres.*
Economic damage in USD i	*World Bank estimated USD 90.4 M Tonga, minor-moderate elsewhere*
Fatalities	*6 (4 in Tonga, 2 in Peru)*
If possible, provide more detail about impact observations & forecasts *(link to page)*	
Were any warnings issued?	**Yes**
Main warnings issued i	Tsunami warnings in Tonga on 14 and 15 January. The warnings on 14 January were associated with large pre-climactic eruptions but also served to educate public on potential impacts from climactic 15 January eruption. There are various reports of the broader tsunami warning systems failing or performing suboptimally in the wider region, due principally to the focus of the system on seismic tsunami originating from subduction zones. Ashfall warnings were issued in Fiji, although not apparently in Tonga. Marine warnings for both ash and tsunami for marine users were sub-optimal.
Who issued the warnings? i	*Tonga Meteorological Services. Other tsunami warning service providers (various) in the wider region, including American Samoa, Fiji, Vanuatu, Samoa, Solomon Islands, Federated States of Micronesia, Tuvalu, New Zealand, Australia, New Caledonia, Japan, USA, most Central American countries*
If possible, provide more detail about the warnings & communication *(link to page)*	
Main responses to warnings i	*Tongan public self-evacuated to a large degree - warnings were broadcast on radio immediately prior to impact given short distance to land from volcano. Eruptions were visible and extremely audible to Tongan community. Many online accounts available.*
If possible, provide more detail about responses to warnings *(link to page)*	

Part 2a. Supplementary information about phenomenon

Wherever possible, please include references to information you provide!

Editors (Name & Institute):
Andrew Tupper, Bureau of Meteorology and Natural Hazards Consulting

Situational overview

Volcanic eruption

A narrative of the eruption will be given at the Smithsonian Global Volcanism Program, and it is expected that copious literature will be published in the coming years. This was an enormous volcanic eruption, occurring in conditions of excellent visibility (during the day and with a clear view of the eruption from Tonga's capital). The event will be much studied from many angles, as the second-largest eruption of the satellite era and including marine impacts as well as atmospheric impacts up to the ionosphere.

The basics of the explosive drivers are summarised by Shane Cronin here. The volcano had been relatively inactive since early 2015, with eruptions recommencing in December 2021, a large eruption on 14 January, and a very large and highly explosive eruption on 15 January.

========================= Forecast (Primary event) =========================

The volcano was in eruption, with known potential hazards. The potential for a major eruption at the volcano was known through recent scientific research, with the last such eruption occurring in AD1100. The occurrence and timing of the climactic eruption in the sequence was not forecastable in this case, particularly because the volcano was not seismically monitored.

Traditional weather forecasts are not highly applicable to this case. However, an area of exploration could be whether routine ashfall & gas dispersion forecasts could have been produced for the volcanic activity, which had been ongoing, with scenarios given for highly explosive phases of the eruption. Related issues include the incorporation of volcanic risk into marine information, as templated products in Tonga focused on particular hazards (eg seas, swell, cyclones).

========================= Forecasts (Secondary events) =========================

Note: When a volcano is in eruption, it is possible to develop scenario-based forecasts of secondary events, depending on the nature of the eruption. For example, a common tool used by volcanologists is a volcanic hazard map, which shows integrated zones for the potential hazards.

This idea can be further extended to adjust for changing contexts, such as the weather. In this case, ashfall, and ash and dispersion forecasts could be developed and issued daily, to go with tsunami scenarios for various possible events at the volcano. These forecasts were not made for this event.

Special/non-traditional observational data used in the forecasts or assimilated into predictive models

None known, but there is potential to do so in a variety of applications (e.g. statistical eruption models, ash/gas transport, tsunami propagation) for volcanic gases and aerosols.

Were the observations available adequate for the forecasts?

No. Tonga has no instrumental volcanic monitoring, meaning that Tongan authorities were limited in what they could observe or predict. Meteorologically, Tonga also has no upper air stations for atmospheric modelling support, and a limited amount of surface stations. It is doubtful whether Tongan AWSs are being assimilated into global models. One tide gauge was operational in the capital, although communications to that gauge failed following the eruption.   There were no physical observations of any kind (including sea-level) available between the eruption site and the capital, meaning that no confirmation of tsunami generation was available before the tsunami hit Tonga's most populated areas.
Notably, because of the lack of real-time observations and communications compromised by the tsunami and by volcanic ashfall, Tongan Meteorological Services' only source of information about what was happening at the volcano was through a satellite link to Wellington Volcanic Ash Advisory Centre, operated by MetService NZ. NZ agencies, including GNS NZ, have provided considerable support to Tonga.

Predictive models
Nil tsunami modelling, eruption of ashfall prediction used in Tonga. Adaptive approach used in tsunami warning centres, given tsunami travelled faster than a seismically generated tsunami (more information needed). Wellington and Darwin Volcanic Ash Advisory Centres used HYSPLIT for ash dispersion modelling for aviation.

Post-processing/calibration applied to model output i N/A

Hazard forecast outputs and examples i **See** Link to summaries of event from Tonga Meteorological Services and Tonga Geological Services.

Interpretation/guidance for forecast users i N/A

What was the level of agreement between the different forecasts? i N/A

How reliable and accurate were forecasts at different lead times? i N/A

When was the potential event first detected in the models? i N/A

================================ Observations ================================

Observations and analyses i

To be completed - refer above text for summary

How did the observed event relate to historical experience and/or previous extreme events? i

A similar event occurred in AD1100

Additional analysis i

Successes/issues/challenges experienced? i

Refer above discussion

Part 2b. Supplementary information about hazards i

Wherever possible, please include references to information you provide!

Andrew Tupper, Bureau of Meteorology and Natural Hazards Consulting

Brief overview of the hazard event(s) i

The primary hazards were tsunami and volcanic ashfall. Secondary hazards included an oil spill reported in Peru.

=================================== Hazard forecast ======================================

Observational data used in the hazard forecast or assimilated into the hazard model i
No ashfall forecast was done. Tsunami warning centres primarily used tide gauges and DART buoys in an adaptive process.

Were the observations available adequate for the hazard forecast?
Tsunami warning centres had limited near-source information to work with, and particularly lacked detailed information about the volcanic activity.

Hazard prediction models/tools i - to be completed.

Name	Resolution	Ensemble size	Forecast length

Hazard forecast outputs and examples i

How reliable and accurate were the hazard forecasts? i

Initially, warnings were confused by the orientation of the tsunami warning system towards a seismic source, and by the faster travel time of the tsunami. As the event proceeded, the warning systems adapted, with varying degrees of success. Warning system performance will be extensively studied.

What was the trigger used to classify the event as hazardous and start the warning process? i

In Tonga, authorities used the volcanic eruption as a trigger for tsunami warnings. The awareness of the population was already high owing to the previous eruptions.

================================= Hazard Observations ====================================

Hazard observations and analyses i

See above summaries

How did the hazard(s) relate to historical experience and/or previous extreme events? i

The hazard was outside the historical experiences of Tongans, apart from inhabitants of volcanically active islands.

How was the hazard(s) made worse by pre-existing conditions? i

The tsunami and ashfall acted as a compound hazard

Additional analysis i

Successes/issues/challenges experienced? i

Part 2c. Supplementary information about impacts i

Wherever possible, please include references to information you provide!

Editors (Name & Institute):
Andrew Tupper, Bureau of Meteorology and Natural Hazards Consulting

Brief overview of the impact(s) i
Tsunami and ashfall impacts principally affecting Tonga, but the tsunami were observed across the Pacific and in the Caribbean

==================================== Impact forecast ====================================

Data used in the impact forecast or assimilated into the impact model

Impact prediction models/tools (if used) i

Name	Method

Impact forecast outputs and examples i

Were the observations available adequate for the impact forecast?

Comparison of predicted/expected and actual impacts i

Informal rules/tools used to identify impacts i

================================ Impact Observations ==================================

Atmospheric impacts
Shock waves from the eruption travelled around the world, with the sound being heard at least as far away as Alaska. The associated ash/gas/ice cloud reached around 50 km in altitude (based on various remote sensing measurements including OMPS at 48 km (Ghassan Taha, personal communication). Sulphur Dioxide and associated species were observed circling the Southern Hemisphere in the stratosphere.

Marine impacts
Meteorologically, it appears that the mass ejection of the eruption was the most significant factor influencing local conditions, with strong/gale force wind gusts at ground level immediately following the eruption and the umbrella cloud spreading radially out from the eruption site, meaning that ashfall patterns most likely influenced by distance from eruption site (yet to be confirmed). Once the eruption ceased, tropospheric and stratospheric winds determined the ash/SO2 dispersal patterns.

Oceanographically, it appears that the tsunami generated were driven primarily by the interaction of atmospheric gravity waves with the ocean, meaning that they arrived earlier than would have been the case had they propagated as a seismically driven tsunami would have.

Land impacts
Volcanic ashfall was recorded across Tonga (data from Fiji appears unclear), with the ash causing considerable disruption including communications interference, power and instrumental damage, crop damage and building damage.

Observed impacts:

Health and social impacts i:

Property and business impacts i:

Critical infrastructure damage and service disruption i:

Environmental damage observed i:

Who and what were exposed to the hazards, when, for how long and why? i

Out of those exposed, who and what were vulnerable to the hazards and why? i

Additional analysis i

Successes/issues/challenges experienced? i

Part 2d. Supplementary information about warning communication

Wherever possible, please include references to information you provide!

Editors (Name & Institute):
Andrew Tupper, Bureau of Meteorology and Natural Hazards Consulting

Brief overview of the communication "story" i

Good, but broad information was provided prior to the major eruption.

What information was provided to emergency responders, government and other stakeholders about the hazard and its possible impact(s), and by whom? i

Tsunami potential was well publicised through media and social media. It is not clear that ashfall potential was discussed as much, although Tongan Geological Services recommended on 14 January that "people on the islands of Tongatapu, the islands of Ha'apai and Vava'u group needed to stay indoors as much as possible, wear a mask if they were outside and cover rainwater reservoirs and rainwater harvesting systems"

On 11 January, the word 'dormant' was used in a social media post from Tongan Geological Services (https://www.facebook.com/tongageologicalservice/posts/232425525715182), which may have been misleading, but would not have had a lasting effect given the subsequent eruptions.

Public warnings in detail i

Warning name	Warning lead time	Issued by	Warning area i	Type of warning i	Did it include safety advice?	Scaled i	Channel i	Warning frequency

How was warning information communicated by other organizations (commercial weather providers, local & national news organizations, municipalities, etc)?

Tongan and overseas media outlets picked up the potential for impacts:
https://www.rnz.co.nz/international/pacific-news/459572/underwater-volcano-hunga-tonga-hunga-ha-apai-erupts-again

https://matangitonga.to/2022/01/14/marine-tsunami-warning_tonga

Warning outputs and examples

Was uncertainty included in the warning? If so, how? i

Yes, it was implicit in the communication

Were communication systems in place and operating effectively?

Yes, to a degree. The use of a tsunami siren was reported. Tsunami warnings were relayed on radio, although the time between the warning issue and the tsunami occurrence was minimal.

Were warning messages received and understood by the public? How did you know?

The death toll was extremely low in Tonga, and there were widespread accounts of self-evacuation, which were informed by pre-warning messaging and warnings the previous day.

Were the needs of specific communities and populations addressed? If so, how?

Additional analysis i

Communication success/issues/challenges experienced i
(to be completed)

Part 2e. Supplementary information about responses to warnings

Wherever possible, please include references to information you provide!

Editors (Name & Institute):

To be completed

Brief overview of the response to the hazard by emergency services and other partners i

What were the main response actions by the public to the warnings? i

Institutional responses i

Response actions	Taken by whom	When taken	On the basis of what information?	Benefit (if any)	Cost

How did the overall response to this event compare to similar previous events? i

How knowledgeable was the community about the hazard?

Were disaster preparedness and response plans in place and used?

What capacity did the community have to respond to warnings?

Additional analysis i

Success/issues/challenges experienced i

Part 2f. Analysis of the warning chain

Information flow through the warning chain

Warning chain	**Was all necessary input information available? (yes/no)**	**If no, what input information was missing?**	**Who should have provided the missing information?**
Phenomenon forecast	No	Volcanic monitoring, near-source sea level data, some meteorological data	A partnership with NZ or USA could have helped establish volcanic monitoring in advance. Meteorological observations could be improved through the SOFF project. Some tide gauge observations available, but the system is not oriented towards volcanic tsunami.
Hazard forecast	No	Eruption observations minimal, no systems developed to forecast volcanic tsunami propagation or ashfall amounts.	
Impacts forecast	Partially	Local agencies did well in advising of potential impacts. Rest of world less prepared.	
Warning communication	Partially	Great work locally in the circumstances. A more confused response globally.	
Warning response	Partially	Tongan population extremely responsive to situation. Regional responses varied.	

Outcome of most significant avoidance action (if any)
Very low death toll in the circumstances

Tools and operational workflows for sharing information between partners

How were social media used in the warning chain? i
Widely used prior to and during eruption (until comms cut off)

Evidence that warning chain was effective in reducing fatalities, injuries, damage, and/or disruption
Low death toll despite the magnitude of the tsunami, survivor accounts.

What were the strongest links in the warning chain? i
Information given to public before major eruption, including prior tsunami drills.

What were the weakest links in the warning chain? i
The lack of ability to make predictions.

What procedures were used to identify lessons learned from the event? i
TBA

Did lessons learnt from previous events contribute to greater warning success for this event?
Tonga has experienced many natural disasters, including tropical cyclones and tsunami, and have been working on their multi-hazard early warning system arrangements. Despite the lack of a working seismic network, public information suggests a good degree of coordination in managing an extreme hazard.

Additional analysis

Part 3. Assessment of the end-to-end warning chain

Profession: Meteorologist

Please rate your level of expertise on a scale of 1 (no expertise) to 5 (established expert) for:

Phenomenon causing hazards (volcanic eruption): 3	
Hazard (tsunami, ashfall)s:	3
Impact:	3
Warning/communication:	4
Response: 2	
High-impact event evaluation:	3

HOW SUCCESSFUL WERE THE FORECASTS, WARNINGS AND RESPONSES?

How well was the event observed? *Scale of 1 (poor) to 5 (excellent) 3*
Reason for this rating i
Fantastic remote sensing observations, but lack of local seismic observations

How well was the phenomenon **forecast?** *Scale of 1 (poor) to 5 (excellent) 1*

Reason for this rating i

No forecast could be made

How well were the hazards forecast? *Scale of 1 (poor) to 5 (excellent) 3*
Reason for this rating i
The hazards were identified in advance as potential issues in a major eruption.

How well were the impacts predicted? *Scale of 1 (poor) to 5 (excellent) 2*
Reason for this rating i
The scale of the impacts were well outside was was expected

How well were warnings communicated? *Scale of 1 (poor) to 5 (excellent) 3*
Reason for this rating i
In the circumstances, warnings were communicated as promptly and widely as possible.

How well were the warnings used? *Scale of 1 (poor) to 5 (excellent) 5*
Reason for this rating i
The population of Tonga apparently paid very strong attention to the situation

How well did the entire warning chain perform overall? *Scale of 1 (poor) to 5 (excellent) 3*

Thank you very much for contributing to the WWRP Warning Value Chain Project database!

Acknowledgements (e.g., information providers) i

Annex 1: *List of hazards adopted from the [UNDRR-ISC Hazard Information Profiles]()*

1. Convective-related
   - Downburst
   - Lightning (Electrical Storm) Thunderstorm or Volcanic Eruption
2. Flood
   - Coastal Flood
   - Estuarine (Coastal) Flood
   - Flash Flood
   - Fluvial (Riverine) Flood
   - Groundwater Flood
   - Ice-Jam Flood Including Debris Ponding (Drainage)
   - Flood Snowmelt Flood
   - Surface Water Flooding
   - Glacial Lake Outburst Flood
3. Lithometeors
   - Black Carbon (Brown Clouds)
   - Dust storm or Sandstorm
   - Fog
   - Haze
   - Volcanic gases and aerosols
   - Polluted Air
   - Sand haze
   - Smoke
4. Marine
   - Ocean Acidification
   - Rogue Wave
   - Sea Water Intrusion
   - Sea Ice (Ice Bergs)
   - Ice Flow
   - Seiche
   - Storm Surge
   - Storm Tides
   - Tsunami
   - Pumice
5. Pressure-related
   - Depression or Cyclone (Low Pressure Area)
   - Extra-tropical Cyclone
   - Sub-Tropical Cyclone
6. Precipitation-related
   - Acid Rain
   - Rain
   - Blizzard
   - Drought
   - Hail
   - Ice Storm
   - Snow
   - Snow Storm
   - Ash/Tephra Fall
7. Temperature-related
   - Cold Wave
   - Dzud
   - Freeze
   - Frost (Hoar Frost)
   - Freezing Rain (Supercooled Rain)
   - Glaze
   - Ground Frost
   - Heatwave
   - Icing (Including Ice)
   - Thaw
8. Terrestrial
   - Avalanche
   - Mud Flow
   - Lahar
   - Rock slide
   - Lava
   - Ballistics
   - Pyroclastic Density Current
   - Ground Shaking
9. Wind-related
   - Derecho
   - Gale (Strong Gale)
   - Squall
   - Subtropical Storm
   - Tropical Cyclone (Cyclonic Wind, Rain [Storm] Surge)
   - Tropical Storm
   - Tornado
   - Wind