Future Indonesian Tsunamis: Towards End-to-end Risk quantification (FITTER) 2019-2022

Lloyd's Tercentenary Research Foundation and Lighthill Risk Network

End of project: Summary of outputs and impacts
27 February 2023

Summary

1. The FITTER project has developed the **first high-resolution tsunami risk model for Indonesia**, capable of estimating economic losses from local and regional tsunami hazard. The information provided by the model supports risk-informed decision making for Disaster Risk Management and Disaster Risk Financing, including support to ex-ante disaster risk financing and the development of a national Risk Pooling Fund (World Bank and Ministry of Finance).

2. The project has **estimated economic losses** to livelihoods based on damage to household assets. The model can be extended to estimate losses to other public and private asset types **to assess the protection gap**.

3. A key **innovation to address societal risk** is the estimation of impact on the livelihoods of affected people. A new set of livelihood functions accounts for impacts of household and business assets, and health expenditure due to tsunamis. This information can **support design of social safety nets and risk financing strategies as well as DRM activities.** Examples of *clear, practical, and positive societal impact* include the following:

- The enhanced risk output can be used to design **social impact bonds** to mitigate livelihood loss following a tsunami. Social impact bonds are an innovative financial tool to mitigate impact of climate risk in developing countries. Some of the FITTER team are in preliminary discussions with PLAN Indonesia about the possibility of designing gender and inclusion sensitive social impact bonds using better risk output. This is work that may be carried out after the end of the FITTER project subject to funding from sources such as the UKRI.

- The FITTER team supported Dr. Semeidi Husrin of BRIN (the National Research and Innovation Agency, Indonesia) to secure funds from BRIN to work on establishing an improved tsunami early warning system over areas of South Java in 2022. The FITTER project contributions in terms of developing an Oasis-based case study of the impact of tsunamis will enable quantifying the potential **benefits of investing in early warning systems.** This will support buy-in from government agencies that are to implement the system.

- The project has also estimated **health costs to households** based on changes to out-of-pocket health spending. The methods can be used as the basis to develop health-related, disaster sensitive, social protection measures.

4. The model is provided in the open-source Oasis Loss Modelling Framework and uses open data. The model is **available to technical users in Indonesian agencies** to maintain and extend their view of tsunami risk supporting LTRF's *open and collaborative approach* to research.

5. FITTER's research on **vessel evacuation modelling for ports** introduces new ways of mitigating impacts. The modelling will be incorporated by Dr. Semeidi Husrin into his BRIN-funded work on early warning systems.

6. Further than including earthquake-generated tsunamis the project also provides, for the first time, estimates of tsunami hazard generated by **submarine landslides**, crucial for full consideration of tsunami risk to Indonesia, especially over East Kalimantan, the new capital region of Indonesia.

7. To foster **collaboration and practical application** of the data and models beyond the project, the project team with the assistance of IDF, is establishing **relationships with disaster researchers and practitioners in Indonesia**, via the National Research and Innovation Agency (BRIN), National Board for Disaster Management (BNPB), and Ministry of Finance. The aim is to support a *diverse community of users that can collaborate in addressing tsunami risk and similar research areas*. Examples are provided below.

Dissemination and pathways to impact

- The **FITTER project workshop** took place in Bandung, Indonesia, on 10-11 November 2022. See additional FITTER write-up document from Stuart Fraser for more details and picture. The aim of the workshop was to share the innovations of the tsunami risk model and research and the benefits of open risk modelling for improving risk management, with potential users in the hazard and disaster risk management community of Indonesia.

The workshop was organised by the Insurance Development Forum in collaboration with the Research Center for Geological Disaster of the National Research and Innovation Agency (Badan Riset dan Inovasi Nasional, BRIN). The workshop was attended by over 75 people, with 15 speakers from the FITTER project, financial sector, and Indonesia scientific and disaster management agencies. The attendees represented several departments of BRIN, Bandung Mitigasi HUB, BMKG (meteorological agency), BNPB (national disaster management authority), Bappenas (national planning agency), Disaster Risk Initiative (thinktank working in DRFI and DRM), Fiscal Policy Agency, IATSI (Indonesian Tsunami Scientists Society), the World Bank, six Indonesian universities.

Key outcomes

- All local **stakeholders saw huge value** in **tsunami model** and **open risk modelling** framework. Current BRIN modelling is mostly scenario based and not probabilistic. This means disaster management is mostly based on a worst scale hypothetical scenario. Probabilistic modelling gives a more complete view from a range of possible inundations based on a greater number of events. This benefit was appreciated by stakeholders.

- Appreciation for getting **risk outputs**, not just scenario outputs. The FITTER model and its availability in Oasis LMF could help address the existing gap in translating tsunami hazard information into risk estimates. This provides opportunities for more risk-informed decision-making and to unlock public and private sector investment in

resilience measures, including risk financing and insurance. BRIN researchers are now using Oasis LMF to advance their risk analytics capabilities.

- Acknowledgement that current work of BNPB is based on high resolution modelling in limited areas. So the FITTER modelling across Java and Sumatra is **complementary** and offers real value.

- Keen interest in **capacity building regarding tsunami modelling, innovations in hazard and vulnerability modelling and application on Oasis**. Several early career researchers are already learning to use and implement Oasis.

- Participants pointed out the need for **local engagement with villages classified as 'tsunami ready'** to see how the work can **inform anticipatory action**.

- Dimitra Salmanidou continues to disseminate findings in her role as co-chair of AGITHAR at meetings and workshops. For example, the talk 'Understanding tsunami hazard and risk and reaching out to communities: Study cases from Indonesia' was part of a Working group meeting on risk communication and dissemination organised by BRIN and Research Centre for Geotechnology. A meeting in May 2023 is now in preparation at UCL with various stakeholders invited, including BRIN and UNDP.

- Dimitra Salmanidou was panel speaker at World Tsunami Awareness Day event in December 2021, international webinar series: chapter 3 Building the coastal regional and community resilience in times of turbulence' organised by BNPB, U-INSPIRE Indonesia, the Indonesian Consortium of Regional and Community Resilience and the iABi Indonesia.

- Rozana Himaz was panel speaker presenting on 'Advancing disaster resilience planning through catastrophe loss modelling' at the International Tsunami Day webinar on 'Innovative Financing for Tsunami Resilience' by the Indonesian National Board for Disaster Management (BNPB) and United Nations Development Programme (UNDP), November 2021.

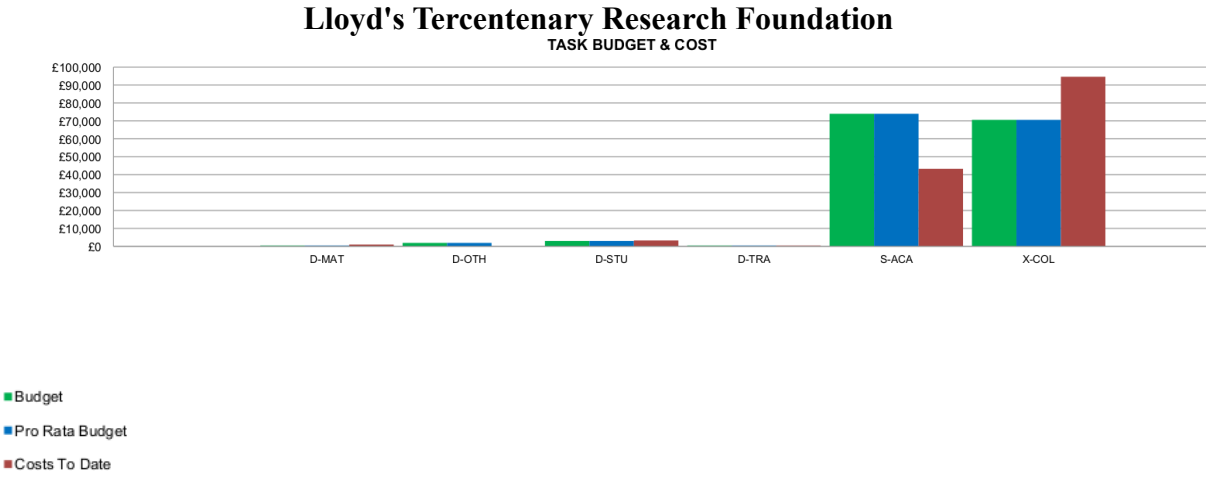
- Rozana Himaz was chair and presenter at the Sustainability and Development conference organised by the University of Michigan, January 24-28, 2022. Topic- 'Business Recovery in Aceh and North Sumatra following the Indian Ocean Tsunami'

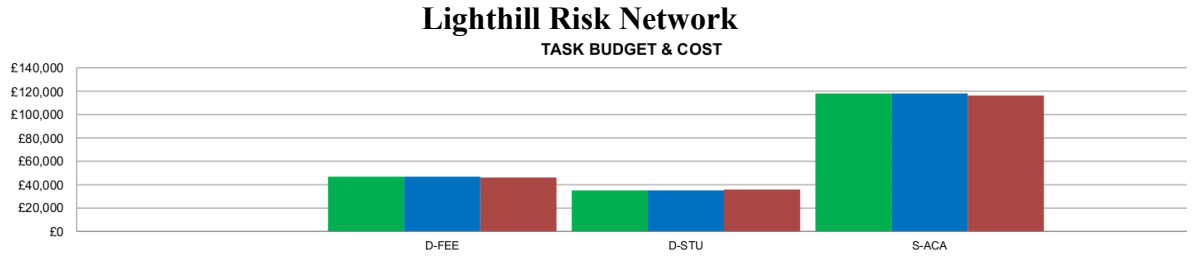
- Serge Guillas was invited speaker at SIAM Computational Science and Engineering 2021, SIAM Parallel Processing 2022, SIAM Uncertainty Quantification 2022, SIAM Geosciences 2023. He presented some of the work underpinning the probabilistic tsunami hazard modelling, with feedback from, and impact on, the academic community.

Financial summary of spending against original budget

Staff needs increased, to both substitute for Indonesian partners (RAs hired are both Indonesians -- one PhD RA and one MSc RA applying for PhD), and for the lack of access to Indonesia during the COVID period and increased modelling needs. The travel budget decreased due to reduced access during COVID restrictions, and the availability of online meetings (e.g. UNDP). We also built new partnerships (BRIN) that supplemented the project with additional funding from Indonesia. We also found ressources from NERC (PhD student Jack Dignan) to boost the FITTER project objectives and deliver on the landslides modelling.

Overall spending profile (UCL final spending items still processing)

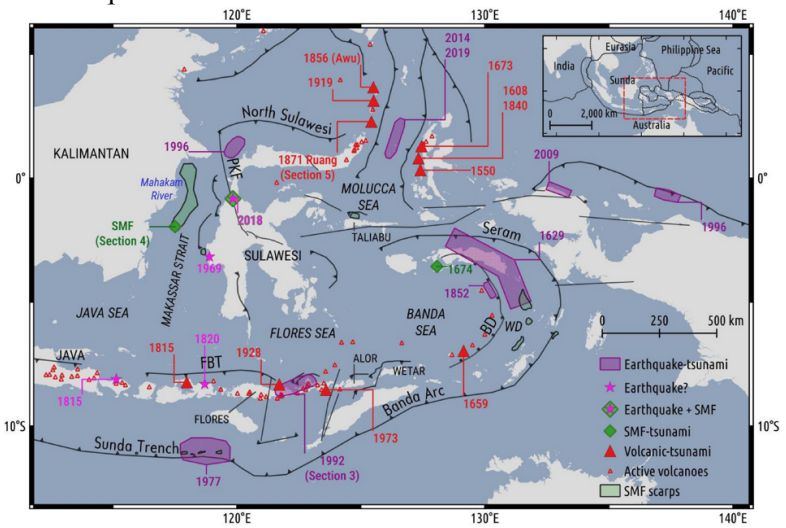




D-MAT and D-OTH: materials, journal fees, equipment, recruitment and other expenses
D-STU: Studentship stipend
D-FEE: Studentship fees
D-TRA: Travel
S-ACA: salaries of staff (investigators and RAs)
X-COL: subcontracts to Oxford Brookes (till July 2021), Brunel (till July 2022), Bath (from July 2022).

Table 1: Objectives and outputs at 27 February 2023

Objectives	Achievements	Status
1. To deliver an unprecedented high-resolution numerical model of physically plausible tsunamis resulting from earthquakes, as well as from landslides triggered by volcanoes and earthquakes.	• Achieved the highest possible resolution modelling of 30 m in Salmanidou et al. (2021), Ehara et al. (2021b), and in papers in writing up stages for earthquake sources in South Java and Sumatra. • Made use of the most refined bathymetries and corresponding mesh sizes for a tsunami model. • New postdoc at Brunel University (May-November 2022) delivered modelling for landslide sources, while landslides constitute a small proportion of the total number of tsunamis they can be locally very damaging if the exposure is large. The main region of landslides in the Makassar strait has been fully modelled.	**Fully achieved**
2. To carry out new uncertainty quantification of tsunami footprints in terms of both heights and velocities.	• Achieved the uncertainty quantification of tsunami footprints in terms of heights over Cilacap as proof-of-concept in 2021-2022, and for earthquake sources over South Java and Sumatra in 2023. • In terms of both heights and velocities, the ideal combination is through the so-called momentum flux, a quantity that reflects the pressure on structures generated by a tsunami wave, and is thus much more related to damages than heights only. The work by Kaiyu Li (FITTER PhD student RA 2019-2022) is on the uncertainty quantification of time series of the momentum flux integrated over time, to measure overall damages from the whole time series of pressure on structures, a first in tsunami modelling. This is now achieved and in the writing up stage for Sumatra, beyond the initial objectives of FITTER. • Roughness has a significant impact on tsunami force but is considered to be fixed in modelling, but forests or mangroves on the coast will increase roughness and will reduce tsunami damage. Kaiyu Li achieved the quantification of the uncertainties in future tsunamis due to varying sources, but also accounted for the unknown values of roughness -- potentially changed with planning. This is now achieved and in the writing up stage for Sumatra, beyond the initial objectives of FITTER. • PhD student Jack Dignan started simulating at unprecedented resolution (about 1 metre and in 3-D) the pressure on buildings resulting from both height and velocities using particle-based methods (DualSPHysics), with NERC funding. We obtained EPSRC Tier-2 funding to run these simulations on the supercomputer Wilkes 3 at Cambridge. Due to the large computational burden, a key coastal area has been selected in South Java to collect information at that resolution and display the power of this approach in characterising damages on selected local areas of interest to	**Fully achieved**

	stakeholders (e.g. critical infrastructures supporting livelihoods). This is now in progress for South Java, beyond the initial objectives of FITTER.	
3. To produce high volume event sets for each source, delivering a probabilistic view usable by risk modellers in all sectors.	• Achieved the creation of a high volume event set (2000 tsunamigenic earthquakes) of tsunamis that can affect the entire coastline of South Java, and Sumatra, by only simulating a limited number of high resolution tsunami simulations. We expanded our parameterization from Gopinathan et al. (2017). • Made use of our new technique of multi-level emulation (Ehara et al. 2023a, 2023b) and Bayesian Quadrature (Li et al 2023) introduced in Ehara et al. (2023b) for tsunamis. We modelled the impacts of these wide ranges of sources and showed the computational benefit. • Produced probabilistic landslide tsunami events (2000) for the Makassar strait, making use of 50 initial runs.	**Fully achieved**
4. To provide a national open hazard model reflecting the uncertainties in the source	We fully achieved the objective for the major zones that contribute to the overall disaster risk financing of Indonesia: • Parameterised the earthquake sources for the two main tsunami-prone regions of South Java and Sumatra-Andaman. • Simulations and corresponding statistical emulation over these two key regions produced regional hazard modelling. • Simulations of tsunamis from landslides in the Makassar strait have been produced and a paper is in preparation. Our previous paper (Pranantyo et al. 2021, see figure below) already models selected deterministic tsunami scenarios from tectonic, submarine mass failure (SMF), and volcanic sources. This is the first time that tsunami hazards modelling from such diverse sources in Indonesia has been performed. 	**Fully achieved**

5. To provide a case study in resilient infrastructure by modelling physical and	**Our focus has shifted towards local needs with Indonesian partners setting the agenda**. The need is for better warning systems to increase resilience, supported by our modelling at high resolution	**Fully achieved (by partnership**

economic impact on selected ports.	and new advances in speed and accuracy of probabilistic modelling. Thanks to funding from BRIN secured in 2022 by our partner Dr. Semeidi Husrin (BRIN), we are obtaining high quality data on port activities (fishing, transport, tourism). For example Pangandaran (South Java) where the fleet consists of many tourism boats, which sustain a local economy that suffered from the 2006 tsunami. Due to the much more involved international collaboration and the high resolution modelling, the timescale it will be done will be in the next 12 months by Jack Dignan (UCL NERC PhD student 2020-2024) with underpinning research from Dimitra Salmanidou (UCL). • Our focus on ports has been on detecting the number and location of boats present in a port at key times by satellite, and modelling evacuation of boats following a warning, if these warnings are early enough. This was achieved using the project "Vessels Evacuation from Tsunamis in India and Indonesia" (VETII) funded by Research England in 2020.	**with Indonesia)**
6. To provide estimates of risk to residential and commercial buildings, applying the above hazard research to the best available proxy exposure data sets (e.g. earth observations data (METEOR), Oasis database and Open Street Map).	• Made use of the high resolution exposure data set now available for Indonesia, the High Resolution Settlement Layer (HRSL): https://www.ciesin.columbia.edu/data/hrsl/ . This provides estimates of the human population distribution at a resolution of 1 arc-second (approximately 30m) for the year 2015. The population grids provide detailed delineation of settlements in both urban and rural areas. It is much more precise than the data sets METEOR, Oasis database and Open Street Map that we considered earlier. We employed this data set in Salmanidou et al. (2021) and full studies of South Java and Sumatra, now achieved at regional levels. • Furthermore, in our regional tsunami studies for South Java and Sumatra-Andaman, we are incorporated the recently produced GHSL - Global Human Settlement Layer which provides even more detailed information across Indonesia. • Employed in Salmanidou et al. (2021), and full studies of South Java and Sumatra, now achieved at regional levels, the Indonesian household survey STAR1 of how much assets of any kind have been reduced in each household after the 2004 tsunami. These include all business and household assets such as non-business related farm and non-farm land, buildings, machinery and equipment, livestock, vehicles, raw material,	**Fully achieved**

	unsold stock, hardwood trees (e.g. coconut and rubber), furniture and durable goods, gold, jewellery, cash and financial market instruments (e.g. bonds). Due to this work, our estimates of risk now extend beyond those to residential and commercial buildings.	
7. To produce welfare and livelihood vulnerability functions for various metrics of impacts such as debt and health expenditure	• Our new livelihood vulnerability function (Salmanidou et al. 2021) covers more than debt as it covers the entire set of all business and household assets (see above, STAR1 survey). • Generated a new health expenditure vulnerability function. This enables catastrophe modelling to produce EP curves that can inform about health related costs associated with tsunami risk, useful for better management of health related plans and interventions. • Increased understanding of business interruption and recovery patterns based on a historical tsunami event, the 2004 Indian Ocean Tsunami, and its effect on households in Aceh and North Sumatra (Himaz 2022) • Increased understanding of physical and mental health costs of the tsunamis in the short and medium term based on three rounds of the longitudinal STAR data collected 12, 24 and 36 months after the 2004 tsunami for 5500 households and 8800 individuals (Himaz and Syukriyah, work-in-progress)	**Fully achieved**
8. To provide all data outputs in an accessible and interoperable format (to IDF standards), made available on the Oasis open modelling platform.	• Curate all data using the Oasis LMF standards for hazard, vulnerability, exposure. • Produced a proof-of-concept study that displayed this end-to-end data interoperability (Salmanidou et al., 2021). • Oasis Hub FITTER organisation created as a free open access repository to deposit all our data (after final validation).	**Fully achieved**

Publications

Ehara, A., & Guillas, S. (2021a). An adaptive strategy for sequential designs of multilevel computer experiments. Accepted, *International Journal for Uncertainty Quantification*

Ehara, A., Salmanidou, D.M., Heidarzadeh, M. and Guillas, S., (2023), Multi-level emulation of tsunami simulations over Cilacap, South Java, Indonesia, *Computational Geosciences* **27**, 127–142.
Open access: https://doi.org/10.1007/s10596-022-10183-1

Himaz, R. (2022), 'Business recovery in Aceh and North Sumatra following the 2004 tsunami', International *Journal of Disaster Risk Reduction, 73*, p.102868. https://doi.org/10.1016/j.ijdrr.2022.102868

Li, K., Giles, D., Karvonen, T., Guillas, S., & Briol, F. X. (2022). Multilevel Bayesian Quadrature. Accepted, *AISTATS 2023*.

Pranantyo, I. R., Heidarzadeh, M., & Cummins, P. R. (2021). Complex tsunami hazards in eastern Indonesia from seismic and non-seismic sources: Deterministic modelling based on historical and modern data. *Geoscience Letters*, *8*(1), 1-16.

Rafliana, I., Jalayer, F., Cerase, A., Cugliari, L., Baiguera, M., Salmanidou, D., Necmioğlu, Ö., Ayerbe, I.A., Lorito, S., Fraser, S. and Løvholt, F., 2022. Tsunami risk communication and management: Contemporary gaps and challenges. *International Journal of Disaster Risk Reduction*, p.102771.

Salmanidou, D.M., Ehara, A., Himaz, R., Heidarzadeh, M. and Guillas, S., 2021. "Impact of future tsunamis from the Java trench on household welfare: Merging geophysics and economics through catastrophe modelling". *International Journal of Disaster Risk Reduction*, 61, p.102291. Open Access: https://www.sciencedirect.com/science/article/pii/S2212420921002570

Work in writing-up stage

The three papers below (with tentative titles) will constitute the core outputs of the FITTER project, and underpin the data provided in the Oasis Hub for users.

- **Hazard modelling**

Probabilistic modelling of tsunamis generated by landslides in the Makassar strait, in preparation for *Journal of Geophysical Research.*

- **Risk modelling**

South Java future tsunamis and regional impact on household welfare. *Note: To facilitate policy relevance the paper includes an analysis of alternative scenarios that shows how linking microeconomic data to Oasis can help develop fiscally prudent and better targeted disaster risk management strategies.*

Sumatra future tsunamis and regional impact on household welfare, and health.

Work in progress

- **Hazard modelling**

Jack Dignan (PhD student): modelling with SPH very local impacts at ultra high resolution, for infrastructure resilience (port of Cilacap in South Java).

- **Vulnerability and social costs**

Himaz, R and d. Syukriyah, Short and medium-run effects of the Indian Ocean tsunami on health costs in Indonesia, paper to be submitted to *Health Economics*

Administration of funding

Matthew Hayward, research assistant for Tsunami modelling (supporting Mohammad Heiderzardeh) started 16 May 2022 for 6 months, to accelerate this aspect and its impact. Mohammad moved from Brunel University London to the University of Bath on 1 July 2022. The RA is Matthew Hayward, PhD from Auckland in New Zealand, and moved to Bath 1 July 2022.

Funds were allocated for a full-time research assistant in economics at UCL IRDR to work from 1 December 2021- 30 November 2022. The position is now shared by Daim Syukriyah (finishing her PhD in Economics at Royal Holloway London), part-time starting 1 March 2022 and two MSc research assistants Khonsa Zulfa and Giovanni Pradeepta on casual basis starting June 1, 2022. Daim has prior working experience in World Bank Indonesia and UNDP Indonesia. Both MSc RAs have prior professional experience in tsunami disaster risk reduction in Indonesia and are members of U-INSPIRE (Global Disaster Risk Reduction Platform for Young Scientists), Indonesia. RAs with knowledge of local language and policy/institutional environment will be very important in translating the local literature including government documents and contextualising vulnerability results.