

Coastal Climate Change Impacts for Easter Island in 2100

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Abstract

Easter Island is the most isolated inhabited island on earth. Even as a high relief volcanic island, Easter Island is vulnerable to coastal climate change impacts as its only settlement and iconic cultural heritage monuments are located on the coast. This study assessed the coastal climate change impacts on Easter Island based on projections contained in IPCC's Assessment Report 4. A consultative risk-based approach was adopted in the development of an overview of potential coastal impacts with a focus on coastal (oceanic) inundation. Valuable information was obtained in meetings with key stakeholders during an ACCARNSI funded field trip to the Island. Coastal inundation estimates for up to a 100 year average recurrence interval (ARI) storm event under current and projected 2100 sea levels found that some significant sites are at serious risk. All harbour infrastructure will be at risk of regular tidal inundation in 2100. Beach shoreline recession with sea level rise is likely to result in one of the two beaches on the island to be permanently inundated. Instability of coastal cliffs may be exacerbated. Tsunami inundation was identified during the field trip as a greater risk than that from extreme ocean storms. Security of water supply has also been identified as being at serious risk due to climate changes in precipitation, evaporation and sea level rise.

Keywords: climate change impact, consultative risk-based approach, coastal inundation, cliff instability, beach erosion.

1. Introduction

Easter Island, also known as Isla de Pascua (Spanish), or Rapa Nui (indigenous) is the most isolated inhabited island on Earth. It is located in the south east region of the Pacific Ocean 3580km off the coast of Chile on the same latitude as Brisbane, Australia, 27°S. The volcanic island is 21km wide with an area of 166km² and has been Chilean territory since 1888. Even as a high relief (507m) volcanic island, Easter Island is vulnerable to climate change due to its isolation, size and location of its only settlement and significant cultural heritage on the coast.

This paper summarizes a component of an UNSW Environmental Engineering Honours Thesis completed in June 2011 by the lead author. The project was initiated in discussions with the aid agency *International Help Fund Australia* (IHFA). The project sought to achieve an overview of climate change impacts specific for an isolated pacific island where funding for such a project may not be normally or readily available.

A two week field trip was undertaken in February/March 2011 and was made possible by a Research Grant from the Australian Climate Change Adaptation Research Network for Settlements and Infrastructure (ACCARNSI).

2. Methodology

Essential background information collated for the project included geographic, geologic, climatic, cultural, archaeological, land use, governance, utilities and infrastructure aspects.

Climate change is not projected to be regionally uniform around the globe. The local climate changes that Easter Island can expect to experience in 2100 were based on the projections contained in IPCC's Assessment Report 4 [5].

The major impacts of climate change for Easter Island were assessed in preliminary consultations with IHFA prior to embarking on the field trip. Potential high risk coastal sites were identified based on social, environmental, and economic criteria. During the field trip, meetings were held with numerous stakeholders to:

- Create awareness of the projected climate changes for the island in 2100.
- Adopt a risk-based approach to consult on the major climate change impacts and confirm the high risk coastal sites and criteria used to define them.
- Obtain relevant unpublished and anecdotal data and reports.

Stakeholders consulted during the field trip included the Governor, Mayor and senior government and private officials from the Navy, Air

Force, Port Authority, National Parks, water and electricity utilities, private and community organisations and local fisherman and elders.

3. Background data on Easter Island

Easter Island is a triangular volcanic island that emerged over 3 million years ago with the most recent volcanic activity being 10,000 years ago. The island rises directly from the deep ocean without a continental shelf - 2,500m depths are located within 15km of the island's coastline. Sea cliffs up to 340m high surround the southern and eastern volcanoes, Rano Kau and Poike (Figure 1). The central and most recent volcano, Terekava, has the highest elevation of 507m.

The climate on Easter Island is classified as subtropical marine with a mean annual sea level pressure of 1020hPa. Annual mean temperature is 20.8°C with an annual average daily variation of 6.3°C. The warmest monthly mean of 28.2°C is in February and the coolest monthly mean of 17.8°C is in July [4]. Annual mean precipitation recorded near the only settlement of Hanga Roa is 1,217mm. Winds are consistent with a median range of 11-13kts and are dominated by the easterly trade winds year round. Although not exposed to tropical cyclones Easter Island has a consistently high energy coastline. The south east coast receives the highest energy ground swell propagating from southern ocean storms whilst the north coast is relatively sheltered. Easter Island is located in the centre of the South Pacific Gyre, a basin-wide anti clockwise turning current circulation. Large scale climate drivers that affect Easter Island include: El Nino, La Nina, Southern Annular Mode and the Decadal and Inter-decadal Pacific Oscillation.

Easter Island had a flourishing civilisation peaking at between 2,000 and 20,000 in a large monolith statue building period, 1050-1600AD [6]. The civilisation declined to an indigenous population of only 111 in the 1880s. The cultural heritage remaining is abundant and widespread throughout the island. The most iconic are the Moai statues which stand up to 10m tall and weigh up to 90 tonnes [9]. Lesser known are the Ahu platforms on which the erected Moai stand. The Ahu platforms are the burial sites of the tribal and spiritual leaders of the ancient Easter Islanders. Of the 887 Moai carved, only 228 were erected on Ahu's and all were toppled in tribal conflicts [9]. Only five sites on the island have had Ahu's restored and Moai re-erected. Stone houses, petroglyphs, cave paintings, and agricultural structures are also widespread and abundant. The Rapa Nui National Park (administered by the Chilean national agency, CONAF) covering 47% of the island has been declared an UNESCO World Heritage listed National Park.

The permanent population estimated for 2010 was 4,944 with an annual increase of 3.5%. The daily tourist population estimated for the summer of 2010 was 4,802 increasing at 20% per annum. The sustainable population has been projected to be 18,979 [1]. The economy is driven by tourism where the main attraction for tourists is the resurrected Moai statues and cultural heritage. Artisanal fishing and small scale agriculture on the Island does not meet the population's demand and significant quantities of food are imported from Chile. Due to the highly permeable geology, surface runoff is minimal except during major rainfall events. Water supply for the only settlement of Hanga Roa is sourced from groundwater extraction wells located on the periphery of Hanga Roa. Wastewater is discharged without treatment directly into numerous "black wells". Fuel oil for electricity generation and bottled gas for cooking are imported.

4. Projected climate change for 2100

Easter Island is projected to experience less climate change than the rest of the world in all parameters other than precipitation. Climate changes presented here are based on projections contained in IPCC Assessment Report 4 [5]. Recent literature suggests that the climate is changing in line with or greater than the IPCC's high emission scenarios [7]. Projected climate changes reported here will be for the high emissions scenario. Quantitative changes are presented in Table 1 (for comparison with Brisbane) and qualitative changes are discussed below.

Table 1 Projected climate change for 2100

Climate Change Parameter		Easter Island	Brisbane
Mean Temperature increase	Annual	1.8°C	3.1°C
	Summer	1.9°C	3.2°C
	Winter	1.7°C	3.1°C
Mean Precipitation change	Annual	-10% to -20%	0% to -5%
	Summer	-20% to -30%	0% to +10%
	Winter	-5% to -10%	-5% to -10%
Mean Evaporation increase		0.1 to 0.2 mm/day	0.0 to 0.2 mm/day
Sea level Rise	Global average	0.26 to 0.59 m	0.26 to 0.59 m
	Local density and circulation	-0.1 to 0.0m	0.0 to 0.1m
	Ice sheet dynamics	0.1 to 0.2 m	0.1 to 0.2 m
	Total	0.26 to 0.79m	0.36 to 0.89m

As the mean global temperature increases, the trade winds affecting Easter Island are likely to weaken. A weakening of La Nina events and more frequent El Nino events are projected. Precipitation

is projected to reduce significantly especially in summer. Dry periods are expected to lengthen but rainfall intensity may increase. Sea level rise is projected to be similar to Brisbane with negligible contribution from vertical tectonic movement [10]. Ocean salinity is expected to increase for Easter Island due to increased temperatures, evaporation and ocean circulation effects.

5. Coastal impacts of climate change.

The risk based approach adopted for stakeholder consultations on the island was intuitive rather than quantitative. The social, economic and environmental based criteria devised prior to undertaking the field trip was:

- Population and buildings density
- Cultural heritage
- Tourism

These criteria proved robust as all stakeholders agreed on them. Coastal inundation and water supply security were defined as the main likely climate change impacts prior to embarking on the field trip. The high risk coastal sites selected prior to the field trip were confirmed during stakeholder consultation. The risk to harbour infrastructure will increase as sea level rises. Cliff instability was an identified concern which climate change may exacerbate. Stakeholders identified that coastal inundation due to extreme storm events is less of a risk than that due to tsunami.

Stakeholders on the island were distressed to learn of declining precipitation projections for 2100 especially in the light of current deficiencies in drinking water quality and groundwater aquifer supply capacity. Groundwater recharge volumes are likely to decrease by up to 50% annually with greater evaporation than precipitation exacerbating this decrease during summer. The impacts of sea level rise on fresh groundwater supply warrants detailed investigation.



Figure 1 Location of the Hanga Roa settlement (yellow boundary), high risk coastal sites (red arrows) and locations of the island forming volcano's (*italic*).

5.1 Coastal Inundation

Consultation with fishermen and elders on Easter Island revealed that there have been no “really big” storms in living memory - storms being reported as “weakening over the last decade”. Every question regarding extreme water levels was answered with stories of the 2010 or 1960 tsunamis. Extreme water levels on the west coast during storms are reported to be less than 1m above normal tides.

The identified four high risk sites are Hanga Roa, Tahai, Anakena Beach and Tongariki (Figure 1). Coastal inundation due to storm events up to 100 year ARI incorporating 0.8m sea level rise was calculated. Inundation water levels are comprised of astronomical tide, barometric, wind and wave setup and wave runup. Wave runup forces have the potential to damage the seaward Ahu wall on which the Moai statues stand (Figure 2).

Various ARI design storms were defined based on data obtained from an unpublished report obtained on express permission from the Chilean Department of Public Works [2]. 22 years of wave buoy data was transformed using MIKE21-SW model to nearshore positions on each coast of the island. An extreme wave analysis was performed using the maximum annual wave data series for each coast by fitting the data to a Fisher-Tippett I distribution and extrapolated to obtain the various ARI wave heights (Table 2).

Table 2 Wave heights for various average recurrence intervals

Site	Design Period (s)	Design significant wave height (m)					
		100 year ARI	50 year ARI	20 year ARI	10 year ARI	5 year ARI	2 year ARI
Hanga Roa & Tahai	14.5	7.1	6.6	6.0	5.6	5.1	4.3
Anakena Beach	11.0	5.9	5.5	5.0	4.7	4.3	3.7
Tongariki	16.0	6.7	6.3	5.6	5.2	4.6	3.9

Barometric setup for storm waves impacting Easter Island is negligible. The 100 year ARI maximum sustained wind was found to be 30.6 knots [2] and with the absence of a continental shelf and the size of the island, wind setup is also considered to be negligible. Wave setup and runup were modelled for each of the four sites using the SBEACH model with the following inputs:

- conservative spring tide predictions over 2 semi diurnal periods (50hrs)
- current sea level and with a 0.8m sea level rise
- constant wave heights for various ARIs
- constant swell period, taken as the upper bound of the median range of the maximum annual wave data series
- incident wave direction assumed shore normal
- shoreline profiles as discussed below - all sites except Anakena Beach being entirely rocky

Shoreline profiles from a depth of 50m offshore to 10m above mean sea level were collated from nautical charts [9] and a field survey performed during the field trip. Equipment used for the field survey was a Sokkia SET550RX total station for the Hanga Roa profile and Leica SR50 differential GPS kindly loaned from the Chilean Lands Office for the three other sites. Wave setup and runup results are presented together with the Ahu seawall base and crest elevations in Table 3. All elevations are given relative to the local chart datum, nivel de reducción de sondas (NRS). The runup values given in Table 3 are considered conservative. The walls are composed of dry stack basaltic slab structure as shown in Figure 2.



Figure 2 Example of seaward Ahu wall with standing Moai statues at Anakena Beach.

Table 3 Ahu elevations and coastal inundation modelling results for each site

Site	Ahu elevation (m NRS)		Wave setup (m NRS)			Wave runup (m NRS)			Tsunami Inundation risk [9] 2006 (m NRS)		
	Seawall base	Seawall crest	2000		2100		2000			2100	
			100 year ARI	2 year ARI	100 year ARI	2 year ARI	100 year ARI	2 year ARI		100 year ARI	2 year ARI
Hanga Roa	5.6	6.7	3.3	3.4	4.2	6.6	6.0	7.4	6.5		
Tahai	3.9	6.0	2.5	3.3	3.9	6.6	5.9	7.4	6.5		
Anakena Beach	11.2	14.4	2.3	2.8	3.2	5.5	5.2	6.3	7.5		
Tongariki	5.6	9.3	2.5	2.7	3.8	7.3	6.8	8.2	13.0		

5.2 Beach erosion/recession

Anakena Beach is an enclosed NNW facing embayment 200m wide and is the only non rocky unconsolidated sediment high risk site identified. It is a high use tourist area and dune vegetation has receded almost 200m from the high water mark since 1980. The beach reportedly experiences dominant local onshore winds. Aeolian transport of the fine to medium grained sand inland creates sand build up against the seaward Ahu wall eventually covering the Ahu platform. Twice a year CONAF removes approximately 40m³ of built up sand. Stakeholder consultation indicated that Anakena Beach has not experienced a storm erosion event of any size generally noticeable to the community within living memory.

Beach shoreline recession related to sea level rise was estimated using the Bruun Rule [3] to be approximately 30m for a 0.8m sea level rise. The SBEACH model was used to examine beach erosion during storm events – the model being run for a fine sand ($D_{50} = 0.25\text{mm}$) unconsolidated

shoreline with the 2100 profile incorporating 30m recession and 0.8m sea level rise assuming sand remains within the embayment during shoreline recession as per [3].

Figure 3 shows model inputs and results. Erosion volume above sea level and shoreline setback due to the 100 year ARI storm event in 2100 were found to be 23m³ per meter width of beach and a 4m decrease in beach width. Analysis of five Google Earth satellite images between 2003 and 2007 showed 1-2m shoreline variability for Anakena, this being consistent with the decrease in beach width of 4m predicted by SBEACH for the 100 year ARI storm.

The one other permanent sandy beach on the island, Ovahe, is located 1km east of Anakena. The 2003 to 2007 satellite time series indicates shoreline variability of at least 30m for Ovahe with a maximum beach width of 40m. Ovahe is at serious risk of permanent inundation due to a 0.8m sea level rise assuming induced recession of 30m.

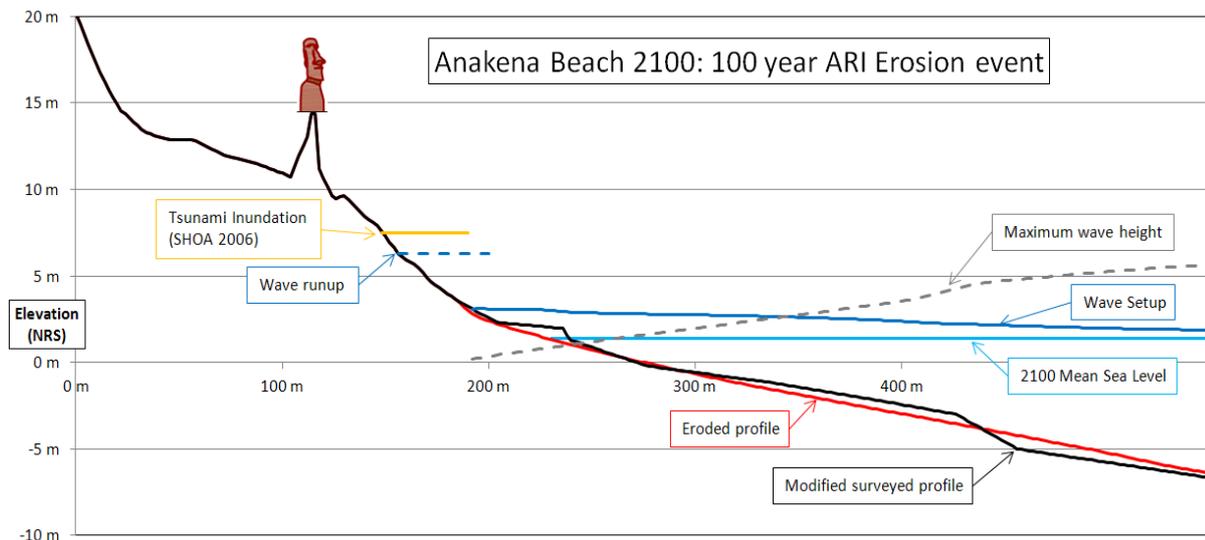


Figure 3 SBEACH - 100 year ARI erosion event in 2100 at Anakena Beach with 30m recession due to 0.8m sea level rise. The input profile was modified from the profile surveyed to incorporate 30m recession and 0.8m sea level rise whilst assuming that sediment remains within the system during recession.

5.3 Cliff instability

Cliff instability was identified during stakeholder consultation as a significant risk under the current climate. In 2008, a 100m wide section of the 300m high southern sea cliff of the Rano Kau crater collapsed. Orongo, one of the most significant cultural, archaeological, and tourist sites (containing ceremonial stone houses and petroglyphs) is located on the cliff edge only 400m to the west of the 2008 collapse. Inspections of collapses along the sea cliffs surrounding Rano Kau were made by Chilean Armada (Navy) patrol boat. The geologic stratigraphy showed significant layers of ash and breccia intermingled with fractured basaltic layers. This potentially unstable geology is reportedly common in all sea cliffs around the island. Until the mechanisms for sea cliff instability are better understood, the degree to which climate change may exacerbate the existing issues cannot be quantified. As sea level rises, high energy waves may be able to deliver greater energy to the cliff bases increasing the rate of undercutting of the cliffs. It was evident that undercutting had occurred underneath the 2008 collapse as shown in Figure 4.



Figure 4 Southern sea cliff of Rano Kau showing undercutting and a large collapsed section.

5.4 Harbour infrastructure

Port infrastructure is limited and cargo ships are unable to berth at any harbour on the island. All cargo is transferred to a mid-sized landing ship which then unloads at the Hanga Piko harbour (1km south of Hanga Roa). There are four other smaller harbours used for small open vessel fishing fleets. All harbours are currently at risk of inundation due to a 100 year ARI storm. With a 0.8m sea level rise, all harbours will be at risk of tidal inundation during spring tides.

6. Discussion of coastal inundation results

The SBEACH model results for inundation (Table 3) indicate that wave runup from the 100 year ARI event with year 2000 sea levels would:

- Overtop the Ahu seawall by 0.6m at Tahai.
- Reach almost to the crest of the Ahu seawall at Hanga Roa.
- Reach 1.1m up the 3.7m high Ahu seawall at Tongariki.

Waves under these conditions will attack the Ahu seawalls possibly causing damage or failure. These results are considered conservative as there have been no reports of overtopping at Tahai. Results for the 100 year ARI event in 2100 show:

- Wave setup water levels will reach the base of the Ahu seawall at Tahai.
- Wave runup will overtop the Ahu seawalls by 1.4m at Tahai and 0.7m at Hanga Roa.
- Wave runup will reach 2.6m up the 3.7m high Ahu seawall Tongariki.

Under such conditions, the Ahu and Moai at Tahai may be at serious risk. Every wave will heavily impact the Ahu seawall and overtopping of 1.4m

may topple the Moai even before the Ahu platform fails.

Wave impact and overtopping at Hanga Roa can be expected to threaten the integrity of both the Ahu and Moai. Wave overtopping at Hanga Roa is likely to inundate surrounding buildings, roads, the Hanga Roa and Hanga Piko Harbours and could also cause significant damage to harbour breakwaters and nearby seawalls and revetments. The smaller harbours on the island and the boats within them would sustain significant damage or destruction in such a storm event.

Wave impact at Tongariki may damage the Ahu wall. However, the mass of the blocks forming this Ahu wall and Moai standing upon it are significantly larger and should be more stable than the Ahu at the other sites.

The Ahu at Anakena Beach will not be affected by any of these events.

Current tsunami inundation risk [8] as per Table 3 is seen to be the same magnitude as 100 year ARI storm runup for east coast sites, 2.0m greater for Anakena and 4.7m greater for Tongariki. Tsunami inundation risk will increase as sea levels rise.

7. Conclusion

Coastal climate change impacts for Easter Island will increase with sea level rise and are likely to be significant for 2100. The coastal sites assessed for inundation are central to tourism and port infrastructure and hence the economy of Easter Island.

Ahu platforms on which the Moai statues stand will be at increased risk of damage possibly resulting in toppling of the Moai due to a 100 year ARI storm event. Ahu and Moai at Tahai and Hanga Roa are at greatest risk.

Some buildings and coastal protection structures are also at risk in the settlement of Hanga Roa. All harbour infrastructure will be at regular risk of tidal inundation and possibly at risk of serious damage or destruction due to a 100 year ARI event.

Beach shoreline recession is likely to cause one of the two beaches on the island to be permanently inundated. Cliff instability may be exacerbated.

Inundation from tsunami was identified during the field trip as of greater risk than that from extreme ocean storms. Security of water supply has also been identified as being at serious risk due to climate changes in precipitation, evaporation and sea level rise.

8. Acknowledgements

Stakeholders consulted during the field trip (including the Governor, Mayor and senior

government and private officials from the Navy, Air Force, Port Authority, National Parks, water and electricity utilities, private and community organisations and local fisherman and elders) were all very supportive. The assistance of Mr Alvaro Atan in providing timeless support (organisation, translation, field surveying and transport) throughout the field trip warrants special thanks.

9. References

- [1] AMBAR Paisaje, (2004). *ESTRATEGIAS Y ACCIONES PARA LA CONSERVACION, USO Y APROVECHAMIENTO SUSTENTABLE DE LOS RECURSOS PATRIMONIALES DE ISLA DE PASCUA*, for: GOBIERNO DE CHILE, CORPORACIÓN DE FOMENTO DE LA PRODUCCIÓN (FDI), MINISTERIO DE PLANIFICACIÓN – CORPORACION NACIONAL DESARROLLO INDIGENA, Santiago, Chile (unpublished)
- [2] Arias, P. (2010). *Estudio de Prefactibilidad Construcción Infraestructura Portuaria Isla de Pascua*. Santiago, Chile: GHD. (unpublished)
- [3] Bruun, P., (1962). Sea-level rise as a cause of shore erosion, *Journal Waterways and Harbours Division*, vol. 88(1-3), pp. 117-130.
- [4] Hoffer, M.C. (2010). *CARACTERIZACIÓN HIDROGEOLÓGICA DE LA ISLA DE PASCUA*, for: GOBIERNO DE CHILE, MINISTERIO DE OBRAS PÚBLICAS, DIRECCION GENERAL DE AGUAS, Santiago, Chile (unpublished).
- [5] IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.
- [6] Mann, D., Chase, J., Edwards, J., Beck, W., Reanier, R., Mass, M., (2003). Prehistoric Destruction of the Primeval Soils and Vegetation of Rapa Nui (Isla de Pascua, Easter Island. In: J. Loret, & J. Tanacredi (eds.), *Easter Island: Scientific Exploration into the World's Environmental Problems in Microcosm* (pp. 133-153). New York: Kluwer Academic/Plenum Publishers.
- [7] Manning, M., Edmonds, J., Emori, S., Grubler, A., Hibbard, K., Joos, F., et al. (2010). Misrepresentation of the IPCC CO2 emission scenarios. *Nature Geoscience*, pp. 376-377.
- [8] Servicio Hidrografico y Oceanografico de la Armada de Chile. (2006). *CARTAS DE INUNDACIÓN POR TSUNAMI DE ISLA DE PASCUA*, Nos. TSU-2510A, TSU-2510B, TSU-2510C.
- [9] Van Tilburg, J.A., (1989). *Easter Island: archaeology, ecology and culture*, London : British Museum Press
- [10] Willis, P. (2011), personal communication relating to: IGN/JPL series, Willis, P.; Boucher, C.; Fagard, H.; Garayt, B.; Gobinddass, M.L., 2010. Contributions of the French Institut Geographique National (IGN) to the International DORIS Service, in: *DORIS: Scientific Applications in Geodesy and Geodynamics*, P. Willis (Ed.), *ADVANCES IN SPACE RESEARCH*,45(12):1470-1480, DOI: 10.1016/j.asr.2009.09.019