Time and space variability of Rangiroa atoll circulation: implementation and validation of a wave-current numerical model of the atoll

Context

Atolls, low-lying coral reef systems, are highly vulnerable to sea-level rise, coastal flooding, and erosion, and many atolls are predicted to become uninhabitable by the mid-21st century because of sea-level rise exacerbating wave-driven flooding (Storlazzi et al. 2018). Extreme events such as cyclones, tsunamis, and particularly storm-generated “mega-swells” can cause significant damage to infrastructure, ecosystems, and populations (Duvat et al., 2017; Canavesio 2019,; Andrefouet et al., 2023). Rangiroa, the largest atoll in French Polynesia and second largest in the world, has repeatedly experienced devastating events (cylones Orama and Veena in 1983, mega-swell of July 1996, August 2011 and July 2022), making it a natural laboratory for studying hydrodynamics under extreme forcing.

As part of the French “Ocean and Climate Priority Research Program” FUTURISKs—focused on mitigating coastal risks in French tropical overseas territories—the Ifremer/LOPS-SIAM team is investigating nearshore processes that drive extreme water levels in barrier reef-lagoon systems. The Rangiroa atoll has been selected for detailed study, including field campaigns, numerical modeling, and remote sensing analysis.

The objective of the proposed internship is to develop a numerical configuration of Rangiroa atoll at high-resolution (O(100m), with zooms at higher resolution over the reef), to study lagoon water dynamics, and then provide a framework to reconstruct past mega-swell events (e.g. events of July 1996, August 2011, and July 2022), and identify drivers of extreme flooding.

Background

The dynamics of barrier reef-lagoon systems, such as atoll reef islands and their inner lagoons, is heavily influenced by incident wave conditions that modify the momentum balance across the reef through wave breaking (Sous et al., 2020). Additionally, tidal wave propagation through narrow, shallow passes generates time-varying barotropic pressure gradients, leading to complex tidal flows over a tidal cycle. Moreover, astronomical tides impact the water depth at the reef crest, thus affecting wave-induced processes. Finally, resonant processes may also occur in (semi-)enclosed lagoons as a result of long-wavelength oceanic (e.g., infragravity waves) or atmospheric forcings (e.g., wind setup). Recent studies of SWOT satellite high-resolution maps of sea surface height (Postec et al. 2025, Cottour et al. 2025) have revealed significant gradients within the lagoon, between the atoll’s exterior and interior, as well as between the northern and southern regions. However, discrepancies exist between some SWOT observations and tide gauge data, possibly due to uncertainties in the vertical datum, geoid spatial gradients, or inaccuracies in atmospheric and sea state bias corrections. Additionally, the semi-diurnal tidal signal in the lagoon exhibits notable asymmetry, with flood durations extending up to 8 hours and abrupt changes in inflow rates. While this complex tidal signal has been shown to be influenced by wave and tide conditions, there is still a need to provide comprehensive explanation.

Rangiroa’s morphology and exposure makes it a natural laboratory for analyzing the complex tidal propagation in the atoll, the interactions between wind sea, swells, and currents, and the climate variability of these forcings.

Proposed work

During this internship, the selected candidate will implement a high-resolution model of the atoll circulation at O(100 m) resolution with the CROCO ocean model and the WAVEWATCH-III (WW3) wave model to study the circulation and water levels of the Rangiroa atoll. Waves, and wave–current interactions within the lagoon will be studied using coupled/uncoupled CROCO-WW3 experiments. Wave-driven flow across the barrier reef will be investigated either by running simulations with local zooms at ~20m resolution or by applying a parameterization of the wave-induced flow as that of Aucan et al (2021). The model physics will be parameterized and validated against SWOT observations and field measurements obtained with a recent extensive hydrodynamic field campaign carried out in Rangiroa from May to August 2025. More than 50 instruments (pressure sensors, wave buoys, current meters, weather stations) have been deployed on the atoll, in the lagoon, in the pass, over the reef barrier and outside the atoll, in order to capture the complex hydrodynamics of this large barrier reef-lagoon system.

Simulations will be carried out for over the 3-month~~s~~ period of the field campaign (May –June - July 2025), which includes several swell events that have impacted Rangiroa atoll and significantly increased the lagoon water level.

Working Conditions

The candidate will be based at the Ifremer center in Brest, working with the Laboratory for Ocean Physics and Remote Sensing (LOPS) within the Satellite and Air Sea Interface (SIAM) team. Supervision will be provided by Guillaume Dodet and Swen Jullien. Internship compensation will be 800€/month.

Application Requirements:

Candidates should meet the following criteria:

- Academic background (M2) in Geophysics or Physical Oceanography
- Proficiency in Unix operating systems
- Skilled in Python and/or Matlab programming
- Proficient in oral and written English

CV and cover letter should be sent to guillaume.dodet@ifremer.fr, swen.jullien@ifremer.fr

References

Aucan, J., Desclaux, T., Le Gendre, R., Liao, V., Andréfouët, S., 2021. Tide and wave driven flow across the rim reef of the atoll of Raroia (Tuamotu, French Polynesia). Marine Pollution Bulletin 171, 112718. https://doi.org/10.1016/j.marpolbul.2021.112718

Andréfouët, S., Bruyère, O., Liao, V., Le Gendre, R., 2023. Hydrodynamical impact of the July 2022 ‘Code Red’ distant mega-swell on Apataki Atoll, Tuamotu Archipelago. Global and Planetary Change 228, 104194. https://doi.org/10.1016/j.gloplacha.2023.104194

Canavesio, R., 2019. Distant swells and their impacts on atolls and tropical coastlines. The example of submersions produced by lagoon water filling and flushing currents in French Polynesia during 1996 and 2011 mega swells. Global and Planetary Change 177, 116–126.https://doi.org/10.1016/j.gloplacha.2019.03.018.

Cottour, E., Dodet, G., Chupin, C., Testut, L., Postec, T., Maillard, L., Jullien, S., Bouchette, F., 2025. Assessing SWOT Performance to Measure SSH Variability over Rangiroa Atoll, French Polynesia. Presented at the SWOT Science Team.

Duvat, V.K.E., Salvat, B., Salmon, C., 2017. Drivers of shoreline change in atoll reef islands of the Tuamotu Archipelago, French Polynesia. Global and Planetary Change 158, 134–154. https://doi.org/10.1016/j.gloplacha.2017.09.016

Postec, T., Dodet, G., Ardhuin, F., 2025. Wave, wind and sea level observations across a barrier reef-lagoon system from wide swath radar altimetry. Proceedings of the Coastal Dynamics 2025, Aveiro.

Sous, D., Dodet, G., Bouchette, F., Tissier, M., 2020. Momentum Balance Across a Barrier Reef. Journal of Geophysical Research: Oceans 125, e2019JC015503.https://doi.org/10.1029/2019JC015503

Storlazzi et al. 2018, Most atolls will be uninhabitable by the mid-21st century because of sea-level rise exacerbating wave-driven flooding, https://doi.org/10.1126/sciadv.aap9741