MSc internship - 6 months - 2025

Time and space variability of Rangiroa atoll water levels from satellite altimetry

Context

Atoll reef islands are notably vulnerable to oceanic climate changes due to their low elevation, geomorphic features (characterized by poorly consolidated materials), and dependence on sediment from coral reefs (Duvat et al., 2017). 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). However, due to limited measurements and the limitations of local sensors, spatial variations in sea surface height within large atolls have been understudied. The most extensive studies to date rely on high-resolution modelling systems combining atmospheric, circulation, and wave models, although these models are typically validated at only a few sites with available in situ measurements.

For over three decades, satellite altimeters have monitored global sea surface height (SSH) with centimeter accuracy. However, until recently, using radar altimeters near coastal zones (within approximately 10 km of shore) was challenging due to low spatial resolution of conventional altimeters, coastal surface heterogeneity impacting the radar backscattered signal, and the limited accuracy of radiometer-based atmospheric measurements (Chupin et al., 2023). Advances in spaceborne radar technology, including Synthetic Aperture Radar (SAR) altimetry (e.g., SRAL instrument on the Sentinel-3A mission) and wide-swath altimetry from radar interferometry (e.g., KaRin instrument on the SWOT mission), now offer higher-resolution and 2D spatial mapping capabilities for coastal zones (Morrow et al., 2019).

(Left) Google Earth map of Rangiroa atoll, at the western edge of the Tuamotu archipelago, with Sentinel-3A tracks (red lines) and SWOT nadir tracks (blue lines) and left/right swath (shaded area); (Right) Aerial photograph of a section of the southern barrier reef of Rangiroa atoll showing wave breaking over the reef top (credit: Robert Harding)

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, located in the Tuamotu Archipelago and the world’s second-largest atoll, has been selected for detailed study, including field campaigns, numerical modeling, and remote sensing analysis. Recent analyses of SWOT LR 2km gridded maps of SSH in Rangiroa (Postec et

al., in preparation) have revealed significant gradients within the lagoon, between the atoll's exterior and interior, as well as between the northern and southern regions. These spatial gradients align with observed water level variations between lagoon tide gauge measurements and simulated water levels on the atoll's southern and northern sides. 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.

Proposed work

During this internship, the selected candidate will analyze an extensive dataset comprising radar altimetry, tide gauge data, GNSS station data, and tide and wave model results at Rangiroa with three primary goals:

1. **Validate Altimeter SSH Observations:** Improve the validation of altimeter SSH measurements against lagoon tide gauge data. This will involve analyzing potential error sources, including atmospheric corrections, geoid models, and sea state bias, as outlined by Chupin et al. (2023). This task may also include analyzing GNSS-based sea surface estimates obtained during the planned May 2025 field campaign using a low-cost GNSS system.
2. **Assess Water Level Variability:** Utilize eight years of tide gauge and altimeter SSH measurements to investigate the temporal and spatial variability in water levels. This will involve the analysis of 20Hz SSH measurements from Sentinel-3A (2016-2025) and SSH maps from SWOT (2023-2025), using existing methodologies developed in the lab (Dechamps et al. 2023; Postec 2024). Harmonic analysis of tide gauge data will help identify primary tidal constituents affecting tidal transformation through the Avatoru pass.
3. **Develop a Conceptual Model of the Rangiroa Lagoon Circulation:** Integrate newly gathered spatial and temporal SSH data with modelled tide and wave information to identify key circulation patterns that support the observations.

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 (researcher at LOPS, 70%), Laurent Testut (researcher at LIENSs, 15%), and Clémence Chupin (lecturer at ENSTA and researcher at Lab-STICC, 15%). Internship compensation will be 800€/month.

Application Requirements:

Candidates should meet the following criteria:

- Academic background (M2) in Geophysics or Physical Oceanography, including coursework in Remote Sensing
- Strong understanding of coastal dynamics and radar altimetry
- 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

References

Chupin, C., Ballu, V., Testut, L., Tranchant, Y.-T., Aucan, J., 2023. Nouméa: a new multi-mission calibration and validation site for past and future altimetry missions? Ocean Science 19, 1277–1314. https://doi.org/10.5194/os-19-1277-2023

Dechamps, S., Dodet, G., Duphil, M., Jullien, S., 2023. Observations of sea state variability across the south-west barrier reef-lagoon system of New-Caledonia from high-resolution Sentinel-3 measurements. Presented at the 2023 Ocean Surface Topography Science Team meeting, Puerto Rico.

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

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

Morrow, R., Fu, L.-L., Ardhuin, F., Benkiran, M., Chapron, B., Cosme, E., d'Ovidio, F., Farrar, J.T., Gille, S.T., Lapeyre, G., Le Traon, P.-Y., Pascual, A., Ponte, A., Qiu, B., Rascle, N., Ubelmann, C., Wang, J., Zaron, E.D., 2019. Global Observations of Fine-Scale Ocean Surface Topography With the Surface Water and Ocean Topography (SWOT) Mission. Frontiers in Marine Science 6.

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