Internship Topic: **Wave Climatology in La Réunion for Energy Potential Assessment: A Combined Approach Using High-Resolution Modelling, In-Situ Data, and Machine Learning**

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Desired Profile: Scientific computing, data analysis and statistics, machine learning

Scientific and Technical Context

Island regions, often reliant on fossil fuel imports, are seeking to strengthen their energy autonomy. While renewable sources such as solar and wind are expanding rapidly, they remain limited by intermittency and spatial constraints. In this context, marine energies — waves, currents, tides — represent a promising resource, particularly well-suited to island environments. Still underexplored, these resources offer strategic potential to diversify the energy mix and enhance the resilience of coastal territories.

This internship proposal fits within that framework, aiming to better understand wave characteristics in tropical zones through a detailed climatological analysis. The goal is to contribute to the valorisation of marine energy resources and the development of sustainable solutions for island territories.

La Réunion's location in the western Indian Ocean gives it a marine weather climate influenced by a wide range of wave conditions — from short trade wind swells to powerful southern and cyclonic swells, which can be highly energetic and sometimes destructive. Understanding wave characteristics is essential for identifying the wave energy potential near the island's coasts. This assessment relies on a detailed analysis of wave parameters derived from spectral energy density, including significant wave height (Hs), energy period (Te), peak period (Tp), and propagation direction (Dir).

Several studies have contributed to formalizing methods for quantifying wave energy potential:

- **Falnes (2007)** provides a comprehensive review of the physical principles behind wave energy extraction, emphasizing the importance of directional spectra and wave regularity for optimizing devices.
- **Cornett (2008)** conducts a global assessment of wave energy resources by combining in-situ data and numerical simulations, producing global energy density maps.
- At the regional scale, in Madeira and the Black Sea, **Rusu (2011)** outlines strategies for using numerical wave modeling in coastal applications and defines the energy transported toward the shore per unit wave front (in W/m).
- **Rusu and Venugopal (2019)** publish a book on offshore marine renewable energies, detailing technical aspects of wave energy converters, resource prediction, and system optimization for cost reduction.
- In the Indian Ocean, **Kamranzad et al. (2022)** analyze the wave energy potential around La Réunion and Mauritius and its future evolution. Their model, with a minimum resolution of 5 km and based on outdated climate scenarios, would benefit from updated data.

- **Sinama (2011)** explores wave conditions in La Réunion as part of a thesis on ocean thermal energy, integrating wave modeling components.
- **Kovaltchouk et al. (2016)** examine technological barriers to wave energy converters and propose solutions tailored to island contexts, based on measured wave data.
- Finally, **Cerema (2022)** highlights the revival of dockside wave energy devices, emphasizing the minimum wave conditions required for operation and their integration into port infrastructure.

These studies converge toward an integrated approach combining numerical modelling, in-situ data, and spectral analysis to characterize wave energy flux.

Internship Objectives

The main objective of this internship is to develop a high-resolution (100 m) and validated wave climatology for the coastal zone (within 1 km of the shoreline) around La Réunion. This will serve to quantify the current wave energy potential and assess its future evolution in the context of climate change.

To achieve this goal, the internship will be structured around three methodological pillars:

1. **Post-processing using Machine Learning (ML):** The aim is not only to compare the WW3 model outputs with in-situ data (CANDHIS), but also to develop a supervised machine learning model to statistically calibrate and correct the model outputs. The AI will learn the systematic biases of the WW3 model based on ground truth data (CANDHIS) in order to produce a more robust final dataset.
2. **Fine-scale Resource Characterization via Clustering (ML):** Rather than using a simple threshold-based classification (e.g., Douglas scale), the intern will apply unsupervised learning methods (clustering) to objectively identify distinct "sea state regimes" based on the full set of parameters (Hs, T, Dir).
3. **Prospective Analysis (Climate Change):** The analysis of future projections (CMIP6) will help assess the long-term robustness of the wave energy resource over the coming decades.

Available Data

To support these analyses, the intern will have access to the following datasets:

- **Regional Model (Present):** High-resolution WAVEWATCH III (WW3) data from the FUTURISKs project, using an unstructured grid with 100 m resolution near the coast.
- **Wind Data (Present):** Wind fields from the Arome Indian Ocean model.
- **Validation Data (In-Situ):** Time series from CANDHIS measurement buoys (CEREMA) around La Réunion, including Hm0, Te, Tp, Tm02, and wave direction.
- **Global Models (Future):** Climate projections from the CNRM-HR-WAV model (CMIP6) under SSP1-2.6 and SSP5-8.5 scenarios (1970–2100). Additional data from the COWCLiP project may be used if needed.

Expected Work and Methodology (Phasing)

The internship will be organized into successive phases:

Phase 1: Familiarization and Data Preprocessing (Weeks 1–4)

- Targeted literature review (wave energy potential, WW3 models, ML methods).
- Extraction, formatting, and temporal alignment of various datasets (WW3, CANDHIS, Arome, CMIP6) in NETCDF format or equivalent.

Phase 2: Post-processing with Machine Learning (Weeks 5–10)

- Classical comparison analysis: statistical comparison between raw WW3 data and in-situ CANDHIS measurements at buoy locations.
- Development of a calibration model (AI):
  - Training a supervised learning model using Scikit-learn / PyTorch.
  - Predictive variables (features): WW3 parameters (Hs, Te, Tp, Dir), Arome wind data (U10, V10), temporal variables (month, hour).
  - Target variables: CANDHIS measured parameters (Hs, Te, Tp).
- Generation of the "Corrected Climatology" dataset: applying the trained model to the full high-resolution WW3 dataset over the study area to produce a 100 m resolution climatology.

Phase 3: Climatological Analysis and Sea State Classification (Weeks 11–16)

- Identification of sea state regimes (AI):
  - Application of an unsupervised clustering algorithm to the corrected dataset (using Hs, Te, Tp, Dir) to objectively identify dominant sea state classes.
- Production of analyses and maps (based on corrected data):
  - Maps of average wave energy potential (flux in kW/m) and its variability.
  - Frequency of occurrence of the identified sea state regimes.
  - Quantification of "calm" (zero production), "active" (optimal production), and "extreme" (device survival) periods.

Phase 4: Prospective Resource Analysis (Weeks 17–20)

- Comparison between simulated historical climatology (CMIP6) and corrected climatology (WW3) to assess the relevance of global models at the local scale.
- Analysis of future evolution (2050, 2100) of wave energy potential (kW/m) under SSP1-2.6 and SSP5-8.5 scenarios.
- Analysis of changes in sea state regime frequency.

Phase 5: Synthesis and Reporting (Weeks 21–24)

- Writing of the internship report, highlighting the contribution of the ML approach to climatology reliability.
- Preparation of the oral defense.

References

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