# Modernising Marine Heatwave Detection: Design Document

## (note: AI was definitely used to format and formalize this document)

## Purpose

To develop a modern, scalable, and extensible framework for marine heatwave (MHW) detection that builds upon existing tools and scientific standards, enabling analysis of large 3D ocean model datasets using xarray and dask. Additionally, to allow for the propagation of new metrics and techniques, while maintaining legacy code abilities in one consistent framework to make comparisons easy.

## Existing Codebases

|  |  |  |  |
| --- | --- | --- | --- |
| Codebase | Author(s) | Strengths | Limitations |
| marineHeatWaves | Eric Oliver | Gold-standard methodology; widely cited; replicates published MHW stats | Not xarray-compatible; inefficient for large or 3D datasets |
| bipMHW (internal) | Benjamin Richaud | Efficient and practical on large datasets; extensible | Lacks formal architecture; just a collection of functions; limited documentation and modularity |
| xMHW | Paula Petrelli | xarray-based; designed for modern workflows | Not scalable for large datasets; no longer maintained |

## Project Goals

1. Modernization: Fully compatible with xarray, using dask for parallelism and scalability. Should be able to calculate statistics from OISST globally in one pass.  
2. 3D Support: Extend to 3D (lat, lon, depth) ocean model data for subsurface MHW detection.  
3. Performance: Handle large datasets with optimized chunking and lazy evaluation. Improvement to come from use of libraries such as numba to speed up loops, and improved percentile calculations (such as bottleneck move\_percentile)  
4. Modularity: Clear separation of stages with reusable components.  
5. Dual Modes:  
 - legacy: strict replication of published methodologies (e.g., Oliver et al. 2018)  
 - active: support for methodological advances (e.g., selection of baselines, better smoothing to remove seasonal biases)

## Detection Pipeline

### Step 1: Climatology and Thresholds

Compute seasonal climatology and 90th percentile threshold.  
Methods:  
- Legacy: fixed 1982–2011 baseline, ±5 day moving window, 11-day smoothing.  
- Active: fixed, WMO or detrended baseline (Smith et al., 2025), non-biased smoothing based on (Brunner and Voigt., 2024).

### Step 2: Continuous Severity Index

Defined as Severity(t) = (SST(t) - Climatology(t)) / (Threshold(t) - Climatology(t))  
Mask values below threshold unless specified otherwise

### Step 3: MHW Event Statistics

Identify events exceeding threshold for ≥5 consecutive days  
Compute duration, peak and mean intensity, cumulative severity, start/end date  
Optionally compute for each depth level independently

## Validation Strategy

Compare outputs with:  
- marineHeatWaves (1D surface time series)  
- benMHW (large dataset performance)  
Create synthetic benchmark datasets (1D, 2D, 3D)  
Match known cases from literature

## Dissemination and Publication Strategy

Prepare a short methods-oriented paper describing the design and implementation of the updated code. Two options here:  
- Journal of Open Source Software (JOSS): lightweight, GitHub-integrated, and focused on scientific software.  
- Geoscientific Model Development (GMD): high-impact, Earth science–focused journal with a dedicated model description format. (this is only if we want to increase the scope, such as merging with Zijie Zhang’s work on smoothing biases)  
  
The paper will provide a permanent scholarly reference for the software and its application to large-scale MHW analysis.

To maximize visibility, adoption, and continuity with the established marine heatwave research community, the updated code may be added to the original `marineHeatWaves` GitHub repository (Eric had suggested it – are you ok with this idea?). This strategy takes advantage of the existing user base, reinforces credibility, and simplifies discovery for users already familiar with the original tool. While a standalone repository may be cleaner and easier, embedding the modernized version as a dedicated subdirectory or branch (e.g., `xarray/` or `v2-modern`) within the original repo ensures strong linkage to prior work while clearly signposting new capabilities. (I’m very happy to have an open discussion about this)

## References

Brunner, L., & Voigt, A. (2024). Pitfalls in diagnosing temperature extremes. *Nature Communications*, *15*(1), 2087.

Oliver, E. C., Donat, M. G., Burrows, M. T., Moore, P. J., Smale, D. A., Alexander, L. V., ... & Wernberg, T. (2018). Longer and more frequent marine heatwaves over the past century. *Nature communications*, *9*(1), 1324.

Smith, K. E., Gupta, A. S., Amaya, D., Benthuysen, J. A., Burrows, M. T., Capotondi, A., ... & Wernberg, T. (2025). Baseline matters: Challenges and implications of different marine heatwave baselines. *Progress in Oceanography*, *231*, 103404.