# A Mesoscale Events Classifier for Sea Surface Temperature Data

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The identification of mesoscale phenomena, such as upwelling, countercurrents and filaments, is an important task for oceanographers. Indeed, the occurrence of such processes involves variations in the density of nutrients which, in turn, influences the biological parameters of the habitat. In this work, we describe a novel method for an automatic classification system, the Mesoscale Events Classifier (MEC), dedicated to recognising marine mesoscale events. MEC is devoted to the study of these phenomena through the analysis of Sea Surface Temperature (SST) images captured by satellite missions.
Figure 1 shows the steps of the MEC algorithm and a classification example. MEC is able to detect different upwelling regimes; in this paper it is shown the case study of the southwestern part of the Iberian Peninsula, where four main types of patterns can be recognised, hereby called E1–E4. Two sources of SST data have been used in this analysis: the satellites of EUMETSAT's Metop programme and the satellite Aqua of NASA. In particular, SST data has been downloaded from the respective data centres in form of NetCDF files, and a preliminary selection has been performed in order to discard files without a significant amount of data located in our area of interest (between 35° and 40° latitude N, and 12° and 6° longitude W).

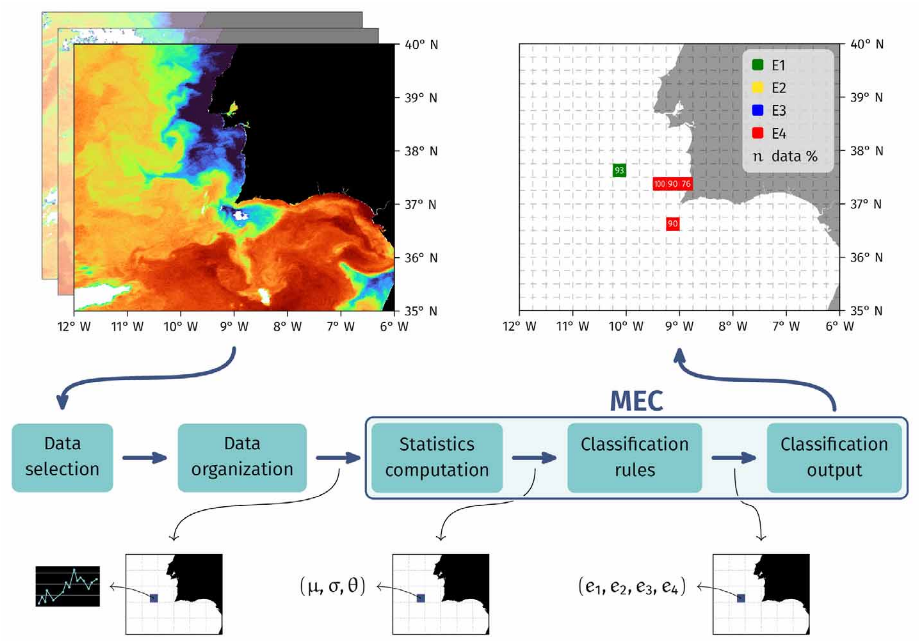


**Figure 1** Block description of the MEC algorithm. Top left: map representing the SST at a certain time, as extracted from satellite data (blue: lower SST, red: higher SST); top right: map resulting from the application of the algorithm, where different types of patterns are located and classified.

A custom tool has been developed to extract the relevant information from the files and prepare it to be fed to the main part of the algorithm. The area of interest is first subdivided in squares with side length of 0.25°; for each square a time series is computed by averaging the SSTs acquired in the 15 days preceding the final observation. The multiple time series obtained by repeating such operation within a given region can be plotted in a common reference system to obtain a spaghetti plot that can be visually analysed to recognise patterns in the different temperature trends of the squares and associate them with a corresponding mesoscale event.

Once all the time series have been collected, the main part of MEC can begin. The first step consists of the computation of three statistics for each series, namely the temporal mean (μ) of the SST, the standard deviation (σ) and the slope of the straight line that better interpolates the data (θ). Next, these values are passed to a set of custom-crafted classification rules, such that for each square a vector of four scores ($e_1$, $e_2$, $e_3$, $e_4$) is computed depending on the values of μ, σ and θ in the square and in its neighbourhood. Each score $e_i$ is a real number between 0 and 1 that represents a belief index for an event of type E*i* to have occurred in the square in the considered time period.

Finally, the last step determines a label ideally for every square in the map depending on its scores, without considering that the occurrence of such phenomena is usually observed only in quite defined geographical domains. The introduction of geographical constraints allows to filter out physically unrealistic classifications. This way, a label is assigned only to squares that fulfil the following conditions: considering the maximum score of the square (suppose that it is $e_k$), if it is higher than a fixed threshold and the square belongs to a geographical zone in which an event of type E*k* may occur, then the square is given the label "E*k*". Moreover, the percentage of the actual amount of data with respect to the expected one (computed using the spatial resolution and the temporal frequency of the satellite images) is reported for each square. This provides immediate feedback about the reliability of the classification.

The application of MEC to remote sensing data has been presented in previous works [Pieri et al., 2023; Reggiannini et al., 2023]. In particular, a promising alignment between the classifier output and the ground truth has been clearly observed and described.

It is worth pointing out that a geometrical model for a mesoscale pattern cannot be defined with a sufficiently general criterion. This fact, which is due to the variability of the spatial configurations of mesoscale phenomena, actually prevents the problem from being tackled with a template matching approach. The extension from the analysis of the mere spatial properties of the SST data, considered at fixed time, to the analysis of the data within an extended spatial/temporal domain enables to counterbalance the lack of information about the geometry of the pattern with the information related to the history of the pattern formation. Hence, the search for a specific temperature spatial pattern is replaced by the detection of a specific temperature behaviour over time, within a specific spatial domain. To the best of the authors' knowledge this represents the main novelty introduced by MEC to the detection and classification of mesoscale phenomena. Moreover, under a classical approach a given SST map is associated, at most, with a single mesoscale class only. As mentioned, MEC integrates within a single frame the joint analysis of the temperature spatial and temporal properties. Thanks to this approach, it may occur that fragments of the life cycles of multiple patterns fall within the same observation window considered by MEC. These patterns, concurrently forming and developing, may then be detected thanks to the MEC enriched point of view.

The tools described in this paper have been implemented in a Python framework and are available on GitHub (https://github.com/ospapini/nautilos-T8.5-sst).

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