Observing submesoscale activity in the Bay of Biscay with satellite-derived SST and Chlorophyll concentration

Özge Yelekçi[1], Guillaume Charria[1], Daneeja Mawren[1], Xavier Capet[2], Gilles Reverdin[2], Francis Gohin[3], Joël Sudre[4], Hussein Yahia[5]

[1] IFREMER, DYNECO/PHYSED, Technôpole de Brest-Iroise, BP 70, F-29280 Plouzané, France. e-mail: ozge.yelekci@ifremer.fr [2] LOCEAN/IPSL, CNRS/UPMC/IRD/MNHN, Paris, France. [3] IFREMER, DYNECO/PELAGOS, Technôpole de Brest-Iroise, BP 70, F-29280 Plouzané, France. [4] LEGOS/CNRS, UMR5566, 18 Avenue E. Belin, F-31401 Toulouse Cedex 4, France. [5] GeoStat team, INRIA Bordeaux Sud-Ouest, 351 Cours de La Libération, F-33405 Talence Cedex, France.

Introduction

Sub-mesoscale activity in the upper ocean is linked to vertical velocities that enable transport of nutrients to the euphotic zone and trigger primary production [1], and yet its contribution to the global production budget is still to be fully investigated. This contribution is especially of great importance for ocean modeling to assess the need for higher resolution models [2]. Sampling the sub-mesoscale is a challenge, due to its horizontal scales of O(1-10) km and its life span of a few days [3]. This study is an attempt to develop an approach for observing the existence and occurrence of these activities in the Bay of Biscay, by making use of high resolution ($\sim$ 1km) satellite images of sea surface temperature (SST) and chlorophyll concentration (Chl-a). The overall objectives of this study are: (1) to construct an inventory of satellite images that would serve as an observational tool, (2) to analyze satellite SST and Chl-a together with prevailing environmental conditions towards identification and classification of sub-mesoscale activities based on their driving mechanisms.

Materials & Methods

Datasets:

- **SST:** MODIS (Moderate Resolution Imaging Spectroradiometer) onboard Aqua and Terra satellites. 2003 - 2013, daily , $\sim$1 km resolution, L2, 4 μ, night-time product. [4]
- **Chl-a:** MODIS onboard Aqua satellite. 2003 - 2013, daily , 800 m resolution, L3, day-time product, processed with OC5 algorithm for French coastal waters. [5]
- **Wind:** ARPEGE meteorological model by Météo-France. 2003 - 2010, 3 hourly, 0.5° resolution; 2010 - 2013, hourly, 0.1° resolution. [6]
- **River:** Dataset constructed by CDOCO (data center for French coastal operational oceanography). 2003 - 2013, daily.
- ***in situ*:** The RECOPESCA project observation network, based on voluntary fishing vessels. 2007 - 2013, vertical temperature and salinity profiles. [7]

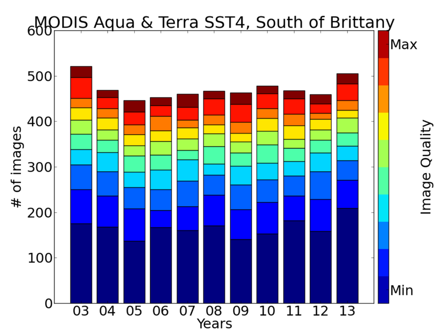

Figure 1 : Years vs. number of images, and the distribution of image quality.

From the satellite images, we selected the ones that are only $\leqslant$ 10% cloud covered. Because the number of clear images is very limited (Figure 1), making the dataset is discontinuous in time and space, we discretized our dataset into sub-regions and into 'events' in time. Results shown here cover only the continental shelf south of Brittany upto 200 m isobath, including the vicinity of the Loire estuary (Figure 3).

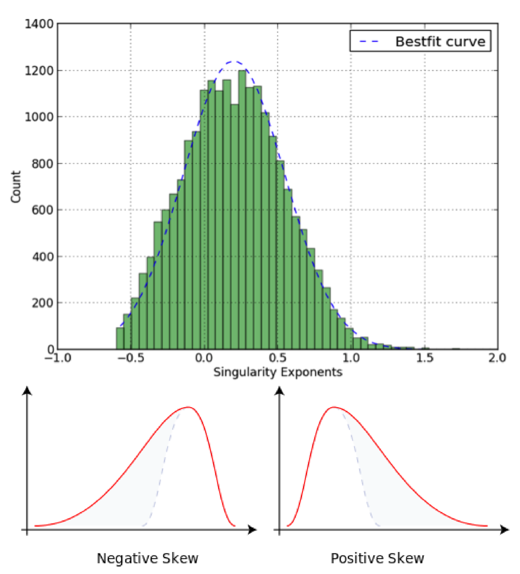

Figure 2 : (top) An example of probability distribution of singularity exponents. (bottom) skewness of a distribution[8]

To quantify the occurrence of sub-mesoscale activity, we applied singularity analysis[9]. The dimensionless quantity, *Singularity Exponent*, is negative when distribution shows strong gradients (fronts in the case of SST) and *vice versa*. We computed the skewness (Figure 2) of the probability distribution of the singularity exponents, such that the positive skewness indicates enhanced frontal activity.

Results

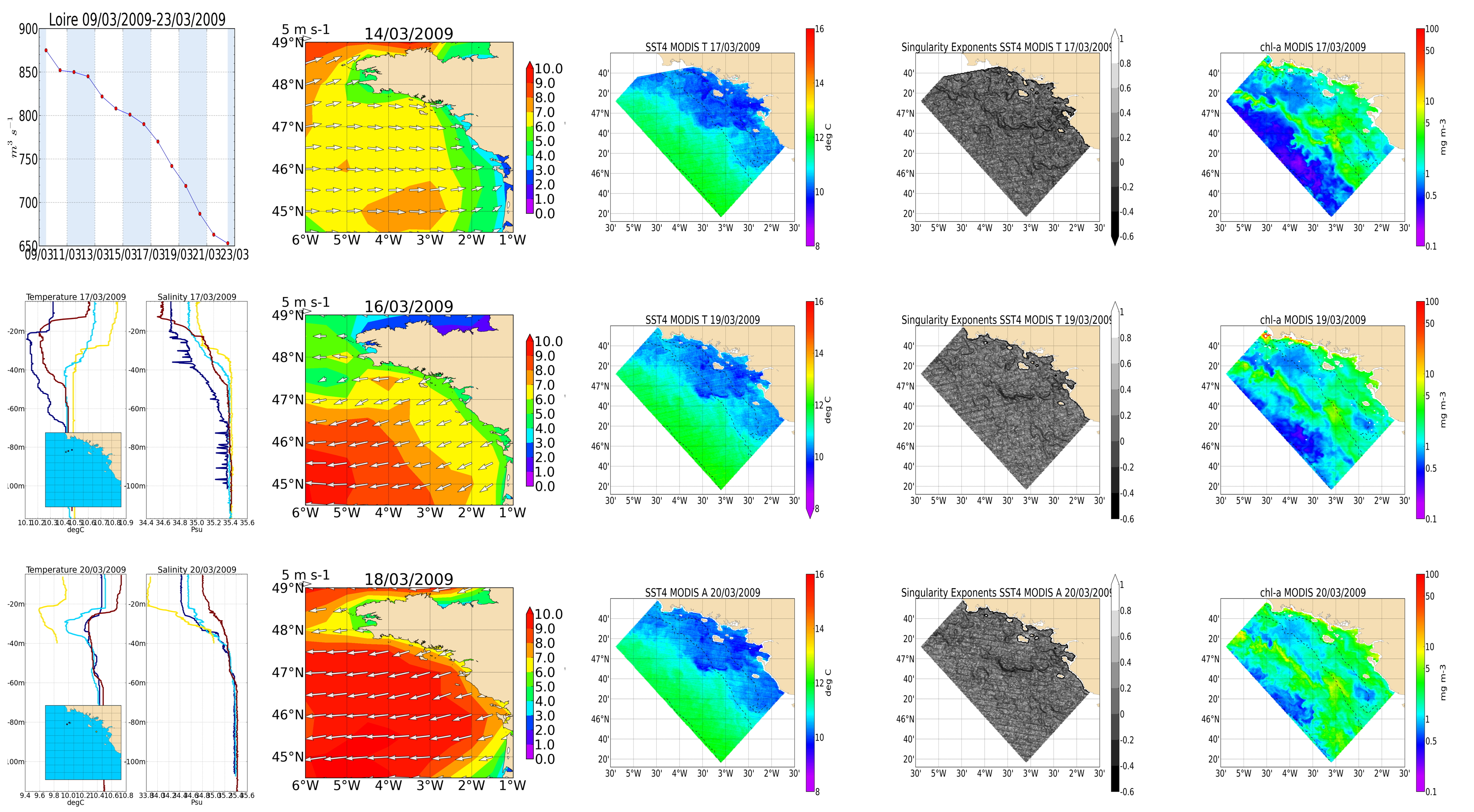

Figure 3 : An example of an event between 17/03/2009 and 20/03/2009. Column 1: (top) Daily run-off of Loire river. (bottom) *in situ* profiles of temperature and salinity. Column 2: Daily modeled wind distribution. Column 3: MODIS Aqua and Terra SST. Column 4: Singularity exponents of the SST. Column 5: MODIS Chl-a concentration.

In the first stage of the analysis we evaluated the individual 'events' to assess the capability of the dataset in capturing the sub-mesoscale features. We investigated SST (with Singularity Exponents) and corresponding Chl-a against prior wind forcing and river run-off, and if available, vertical temperature and salinity. Figure 3 is an example of an event. It can be seen that prior to the event there is relatively weak winds in south-east direction and no significant river run-off. On the 17th there is a clear front in temperature that is observed both in SST and in vertical profiles. In the singularity exponents of this SST image this front is highlighted. The patch of increased Chl-a can also be seen in direct vicinity of this front on the same date. On the following days as the wind changes direction and increase in intensity, the front in SST starts to diffuse but continues to exist, whereas the Chl-a patch grows in size and intensity.

In the second stage of the analysis, we took into consideration the entire dataset of 11 years. Spatially averaged skewness is selected as an indicator of the turbulence regime such that the higher values of average skewness indicates higher frontal activity. We applied a time-series approach to investigate the seasonality. We aimed at evaluating the correlation, if any, between the occurrence of sub-mesoscale activity and the potential driving factors behind them. In Figure 4, it is seen that a moderately high values of Loire run-off in spring months is only weakly effective in enhancing fronts, whereas the maximum run-off observed in winter has no such effect. The wind intensity, on the other hand, does not show any apparent correlation with the average skewness.

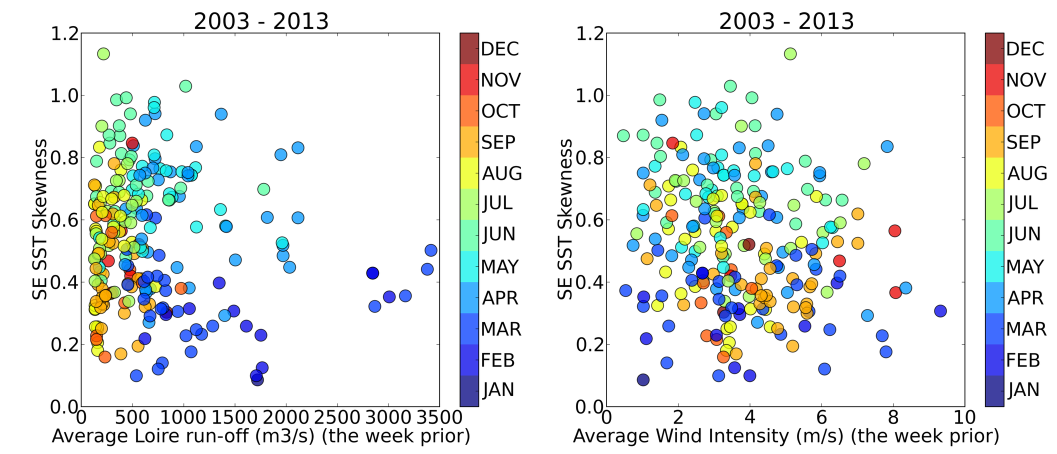

Figure 4 : (left) Average Loire run-off, (right) average wind intensity a week prior to a clear image day vs the skewness of the singularity exponents distribution of the SST image of the same day.

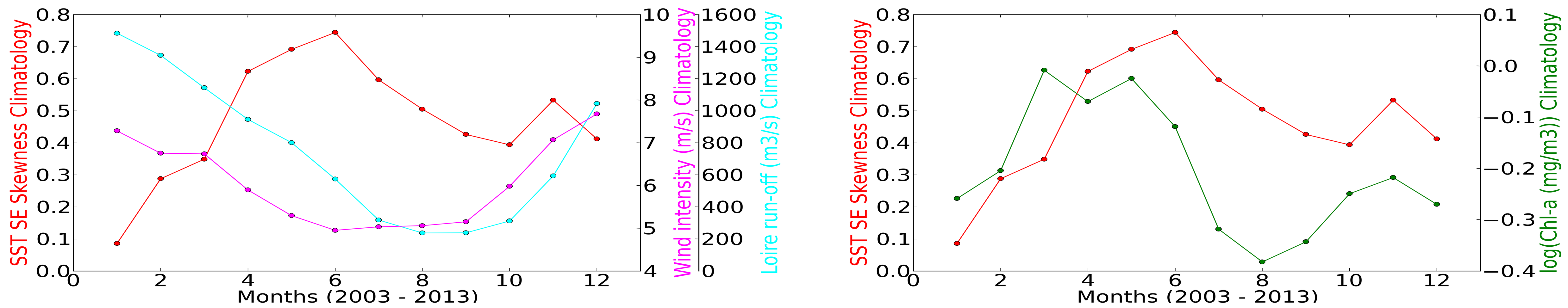

Figure 5 : Time-series of (top) skewness, wind intensity, and Loire run-off; (bottom) skewness and Chl-a climatologies.

In Figure 5, the climatology shows that the average skewness, thus the turbulence regime, possesses an apparent seasonality. Considering the climatology of forcings and of skewness, it can be seen that there exists an inverse relationship. In winter, when wind is strongest and the Loire run-off is at a maximum, the skewness is at its lowest, and in the more moderate spring months, it reaches its maximum. In autumn, this condition reverses and the increase in the wind intensity and the run-off is accompanied by an increase in the frontal activity. This reversing might be related to the warm waters carried to the region from the south in autumn months [10] and may not be related to the prevailing conditions. Between frontal activity and the Chl-a there appears a significant coherence. Enhanced primary production coincides with the increased activity both in the onset of spring and autumn. The correlation appears to be off towards late spring and in summer, but it should be noted that solely the surface distribution of the Chl-a is not sufficient to account for the sub-surface maxima observed during these months.

Conclusion

The analyses of past 11 years' high resolution images of MODIS SST and Chl-a shows that:

- There exists a correlation between the occurrence of sub-mesoscale activity in the Bay of Biscay and enhanced primary production.
- Mechanisms behind the occurrences, however, are not revealed within the limits of these observations, but it can be stated that the increased wind and fresh water run-off play a role in inhibiting these structures.

Due to the very limited number of clear images of the region the analyses had certain limits. Especially the winter months, when even in some years there are no clear images, are poorly represented in the dataset. While with an 'event' based approach, a qualitative picture of the frontal structures can be investigated, this lack of temporal and spatial continuity does not allow for a quantitative investigation. It should be noted that factors other than wind and rivers such as tides and surface heat fluxes should be taken into account to explain the sub-mesoscale features. Another point to bear in mind is that, this analyses of satellite images consists only of the surface distributions and may not be sufficient for a full quantitative understanding.
This study is planned to be continued with a series of numerical model applications with varying resolutions, which will serve as a tool that will allow for an evaluation of the contribution of sub-mesoscale activity to the primary production budget, and help assess the the need for the high resolution coastal ocean models

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