

A MULTISATELLITE APPROACH FOR MESOSCALE PHYTOPLANKTON COMMUNITY STRUCTURE

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ABSTRACT

The biogeochemical role of phytoplankton organism varies considerably from one taxon to another and the presence in an oceanic region of a specific dominant phytoplankton group can greatly affect water properties like CO₂ uptake and the sustainability of zooplankton or larger predator populations. Monitoring plankton communities and understanding the mechanisms shaping their distributions is therefore crucial for issues ranging from the ocean response to climate change to fisheries management. Although the emergence of dominant planktonic groups is qualitatively explained with the paradigm 'everything is everywhere but the environment selects', understanding the spatiotemporal structure of plankton communities in any specific region is currently a challenge. Focusing on the mesoscale and submesoscale domains, here we propose to combine multisatellite data re-analysed by recently proposed techniques. This approach extracts from ocean color and altimetry high-resolution data the location of dominant groups and of transport barriers induced by mesoscale eddies. We argue that mesoscale turbulence organizes surface waters into filamentary patches of contrasted physical properties that may constitute relatively isolated 'natural mesocosms' able to support specific planktonic types. Through stirring, fluid dynamics can hence affect key ecological and evolutionary features, such as the localization of the bloom, the scales of dispersal and of competition. This

mechanism may suggest how to combine future remote and in situ observational networks for better understanding the coupling between the surface turbulence and the biotic component of the global oceans.

1. INTRODUCTION

Planktonic communities in the ocean are characterized by two apparently contradictory features: species are broadly distributed (up to the point of being detectable in water samples taken from very distant locations all over the world), but one or few species dominate locally the biomass. This fact, summarized by Baas Becking in the dictum 'everything is everywhere, but the environment selects', comprises on the one side local adaptation to the environment, and on the other side stirring of the oceans due to fluid dynamics. The emergence of a dominant planktonic type has a strong impact on the chemical and ecological properties of an ocean location [1]. For instance, coccolithophores are biocalcifiers that modify water alkalinity and are more affected by acidification. Diatoms have higher sedimentation rate than other taxa due to their heavy silicate walls, and are more efficient in CO₂ export to the deep ocean. Mineralized cell walls have also important ecological effects, since they confer resistance to zooplankton grazing. More in general, the size of different phytoplankton types can span several order of magnitude, affecting the structure of the web chain they sustain.

At the basin scale, recent analysis of ocean

color satellite images based on either particle size or pigment detection, as well as model studies, have shown that dominant types are climatologically distributed in large patches, often associated to specific physical and chemical water properties. This information however is of limited interest for issues like fishery management and in general for understanding the interaction with higher trophic levels - that occurs on a regional and smaller spatial scale and on a daily/week temporal frame. High resolution information on the planktonic communities is also needed for parameterizing ecological models for incoming mesoscale resolving, global coupled circulation models, as well as for extrapolating observations of quasi-synoptic in situ surveys [2].

Here we aim at developing observational tools for exploring the dynamics of planktonic community structure at a high spatiotemporal resolution (10-100 km, day-week). Mesoscale and submesoscale chlorophyll patches from daily satellite images have been found to compare well with transport barriers induced by the horizontal stirring. These barriers can be computed by a Lagrangian analysis of

altimetry-derived velocity field. Based on these observations, we suggest that geostrophic transport barriers could also organize planktonic communities at the mesoscale by isolating water patches long enough for ecological competition to set in. The algorithm PHYSAT, validated at the global scale for classifying dominant planktonic groups on the basis of water-leaving radiance, can then be used to single out the local dominance of planktonic types. The comparison with the horizontal transport barriers should shed light onto the role of lateral stirring in defining the borders among different types, as well as on the the timescale of niche persistence in the open ocean.

2. REANALYSIS OF GEOSTROPHIC VELOCITIES BY FINITE SIZE LYAPUNOV EXPONENTS

Ocean surface velocity field from AVISO delayed-time multisatellite global product was reprocessed for obtaining the largest Finite Size Lyapunov Exponent [3]. At any point, the Lyapunov exponent quantifies the speed of divergence of nearby water parcels due to the chaotic turbulent field. By doing

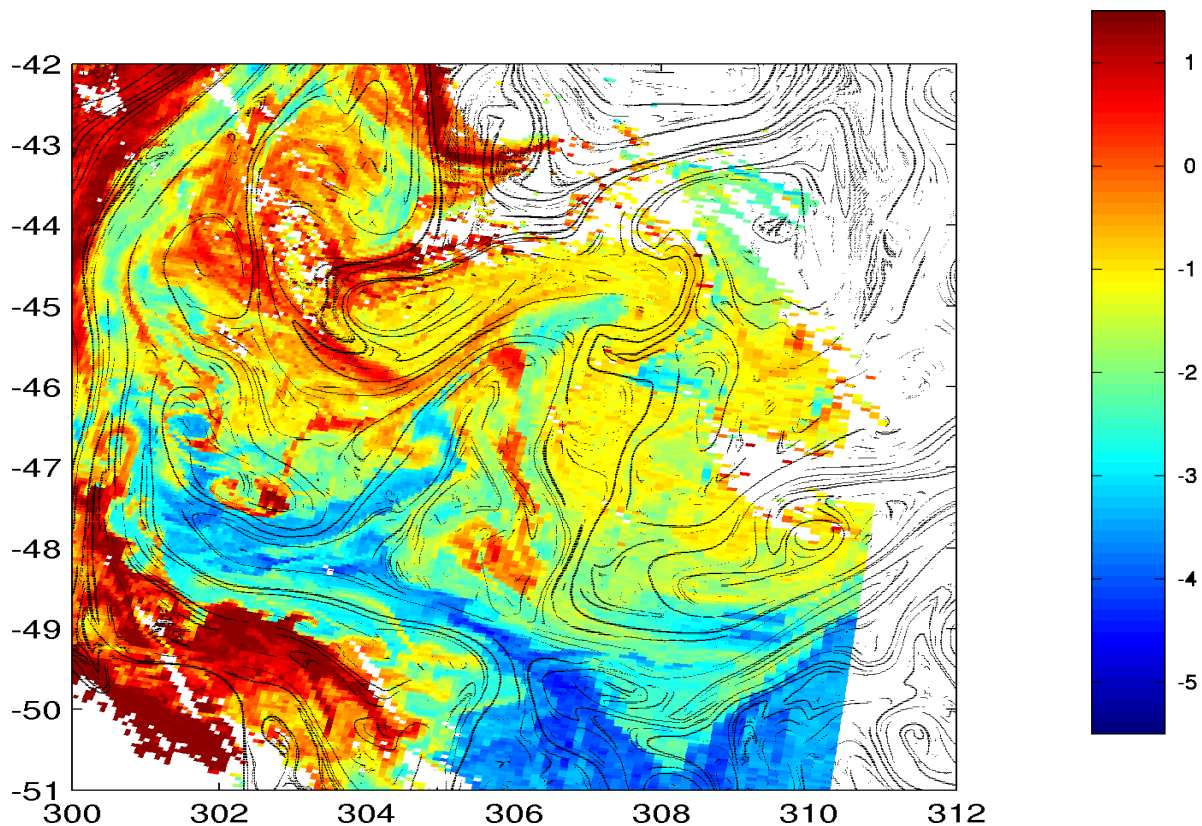


Figure 1: Chl distribution (in mg/m^3 , image of November 20, 2001) and largest Finite-Size Lyapunov exponent (black lines), identifying barriers to the horizontal transport.

this calculation backward in time, one can find the fronts that separate water masses of different origin as lines of maxima in a Lyapunov exponent map.

Fig. 1 shows that the barriers for the horizontal transport compare well to the Chl distribution. This picture refers to the region of the South West Atlantic ocean at the confluence of Brazil and Malvinas currents during the spring bloom 2001 (on 22/11/2001). This region is known for its particularly strong mesoscale activity and richness in planktonic species [4] (for other examples of close matching between transport barriers and Chl distribution, see ref [5]).

An important discontinuity in chlorophyll concentration is visible at the continental shelf break. Samples of phytoplankton collected in multiple stations along the shelf break showed the presence of several

planktonic groups during the spring bloom, associated to different water properties [6]. This suggests that borders among different communities may be determined by the history of the water mass sustaining the bloom rather than by ecological fronts of invasion/substitution.

The computation of the FSLE moreover allows to estimate the time span over which specific niches persist. Typically, this timescale ranges between few weeks for a filament detaching from an eddy, which is eventually dispersed by small-scale turbulence, to few months for the core of very stable eddies.

3. IDENTIFICATION OF DOMINANT GROUPS BY THE PHYSAT ALGORITHM

Changes in the composition of sampled planktonic communities are commonly observed in the course of cruise campaigns.

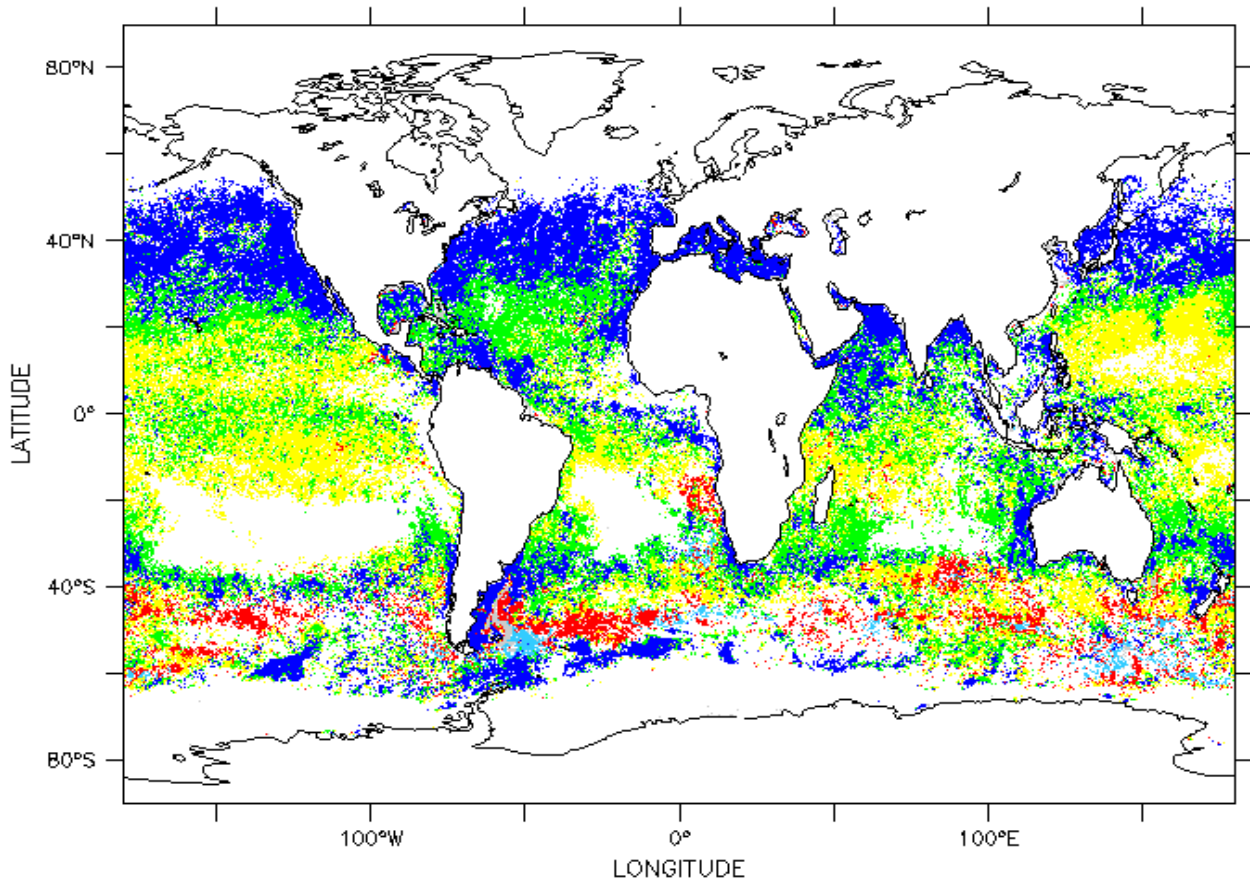


Figure 2: global image of dominant planktonic types (PHYSAT-reprocessed SeaWiFS images, average over November 2001), with the following color code: red, Diatoms; blue, Nanoeucaryotes; yellow, Synechococcus; green, Prochlorococcus; cyan, Phaeocystis-like and grey Coccolithophorids. When no group prevails over the chosen period, the pixels are associated with 'undefined' phytoplankton groups (white).

In situ measures however do not always allow to recognize whether these changes are due to ecological fronts or to the dynamics of water masses. Indeed, the problem of synopticity confines this kind of explorations to limited spatial ranges.

Alternative methods are currently explored for extracting from satellite images maps of dominating planktonic types. One of these methods is the algorithm PHYSAT that labels dominant phytoplankton groups on the basis of the water-leaving radiance (nLw from SeaWiFS sensor) spectrum [7]. Such empirical approach has been validated by comparison with a large in situ database of pigments (performed in a wide range of water types during GeP&CO cruises [8]). Note that 'dominant' has been defined by Alvain et al. 2005 as cases in which a given phytoplankton group is a major contributor to the total pigment, based on specific biomarkers. The ocean colour measurements nLw , between 412 and 555nm, were processed to obtain a specific normalized water-leaving radiance (nLw^*) in order to evidence the second order variability of the ocean colour signal. This was done by dividing the classical nLw by a mean nLw_{ref} which depends only on the standard SeaWiFS chlorophyll a (at the origin of the first order nLw variations). Alvain et al. have shown then that every dominant phytoplankton group sampled during GeP&CO cruises can be associated with a specific nLw^* spectrum [9]. These spectrum have then been defined by a set of criteria which can be applied to global daily SeaWiFS GAC archive.

Fig. 2 shows a global map of planktonic groups prevalence on November 2001. It is evident that the South West Atlantic region shown in Fig. 1 sustains during the spring bloom a high number of different planktonic types. Such high biodiversity can be associated with the confluence of water masses with distinct physicochemical properties.

4. DISCUSSION

On the basis of the physical properties of mesoscale turbulence and of the plankton bloom dynamics, we can speculate on the mechanism behind local dominance and broad distribution of microbes in the ocean. The life span of a mesoscale niche is sufficiently long for a group to become

dominant in a given area, considering that the exponential phase of a bloom lasts from few days to few weeks. As far as its environmental features remain stable, the species most adapted to the local environment will outcompete the others and eventually dominate the biomass. However, any such niche will be, on longer times, erased by turbulent mixing, thus redistributing the populations it supports on much wider regions. This mechanism of dispersal again strongly depends on mesoscale filaments, able to carry planktonic organisms very far from their original niche through the long and thin extrusions so often seen in satellite images. Understanding the dynamics of planktonic niches and the interaction between turbulence and ecology is a first step towards constructing predictive ecological models for marine communities. In order to do so, we need to greatly improve our knowledge of the scales of planktonic competition and dispersal [10], both of which are strongly related to mesoscale oceanic activity. In particular, we need improved observational and theoretical tools able to explore the submesoscale domain: here fluid dynamics and ecological timescales overlap and hence a strong coupling between the physics and the biology is expected.

Identifying populations from space has been proposed recently and is still in an early experimental stage. This objective would benefit from sea color sensors with many spectral bands, including some UV bands. Progress however depends mainly on the availability of satellite matching in situ data of phytoplankton populations composition and their optical properties. This will take much time and efforts as cruises are expensive and many oceanic conditions need to be sampled.

Considering the importance of populations detection from space, it should nevertheless be a priority for the near future.

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