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Development and application of Phyto-VFP model (Variable Fluorescence Phytoplankton Production) to estimate primary production in highly vulnerable marine pelagic ecosystems

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Background

- Marine phytoplankton production (PP) represents an influential force on the carbon cycle and the climatic processes on a global scale, being responsible for up to 40% of the biological fixation of atmospheric CO_2.
- Understanding and predicting the effects of climate change on marine phytoplankton is crucial within the analysis of climate change scenarios as it affects the ecological responses of the higher trophic levels.
- In this context, the development of predictive models for the estimation of PP provides useful scientific responses to address the issues of sustainability in a climatically changing world. The need to estimate PP more accurately allows to face the impacts of global change on highly vulnerable areas such as such as regional seas and polar regions.

Aim of the work

In this work we present the **Phyto-VFP (Variable Fluorescence Phytoplankton Production)**, a new bio-optical model which enables to compute PP by integrating the effects of the photo-acclimation processes of phytoplankton with the dynamic conditions of the water column.

To parametrise the photo-physiological behavour of phytoplankton cells a series of laboratory experiments based on *in vivo* variable fluorescence measures were conducted on culture species selected according to the ecological features of the investigated areas.

Phyto-VFP functioning

Phyto-VFP (Variable Fluorescence Phytoplankton Production):
a new bio-optical model of pelagic primary production
based on variable fluorescence measures.

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Phyto-VFP: a new bio-optical model of pelagic primary production based on variable fluorescence measures

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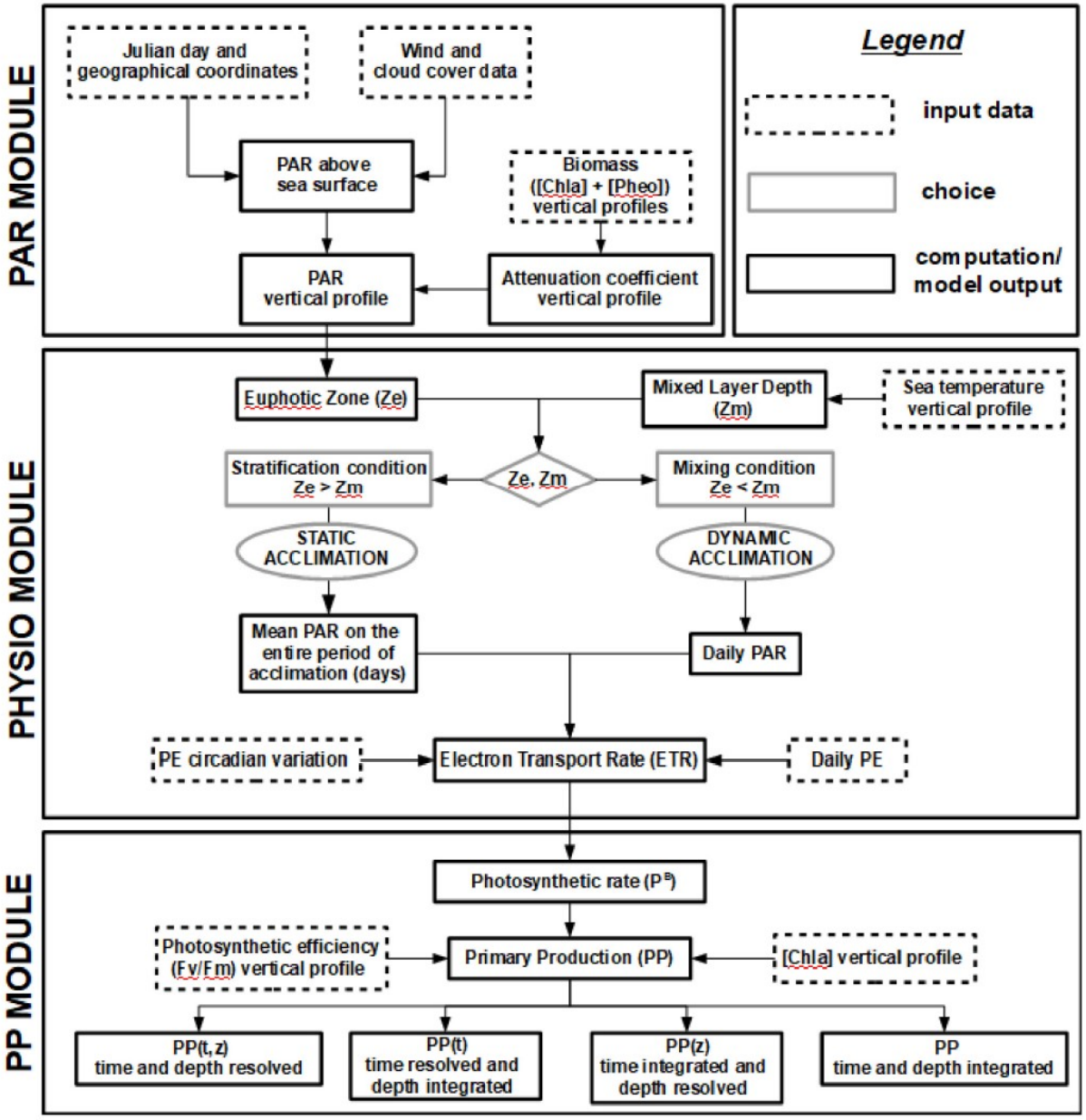
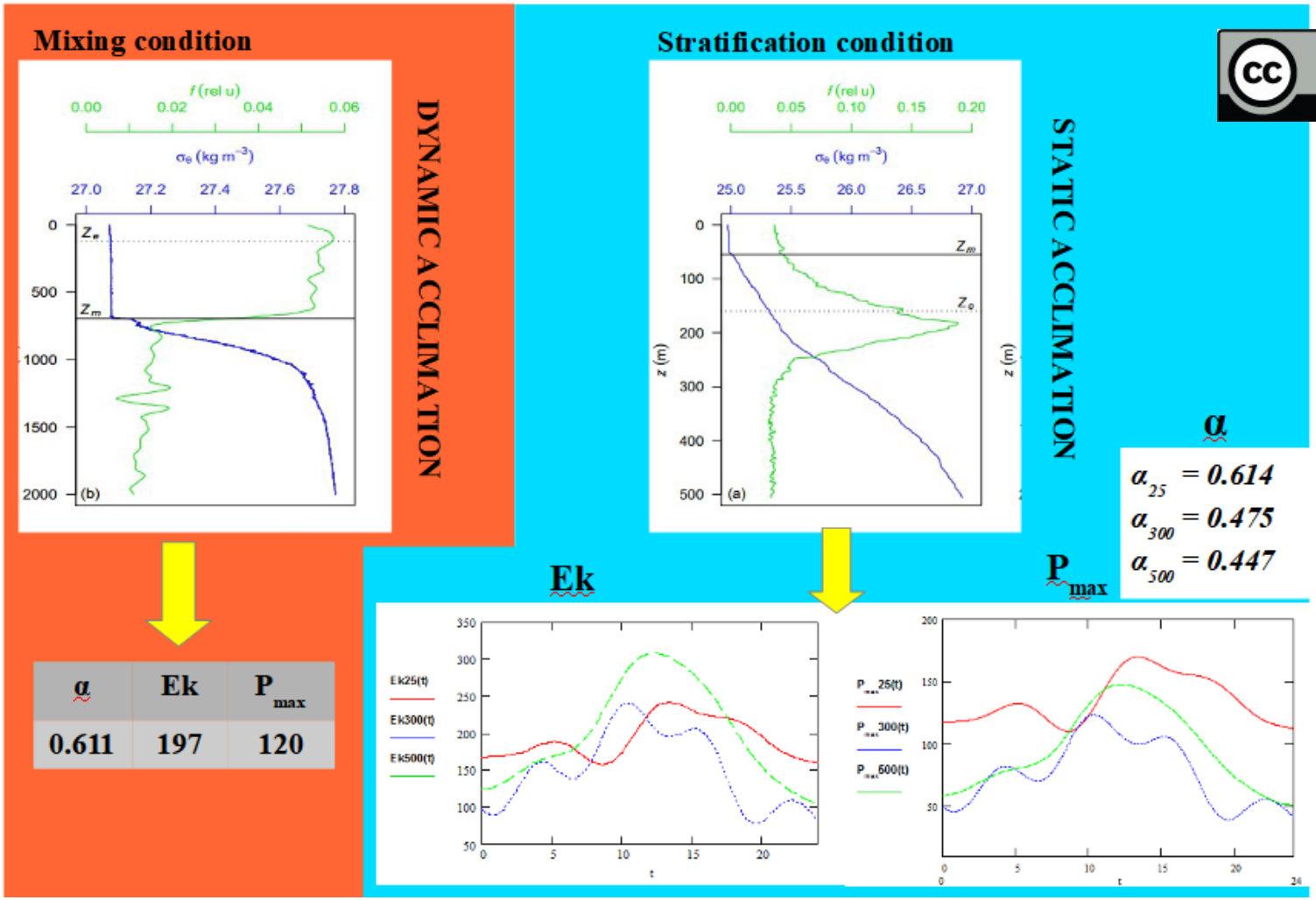
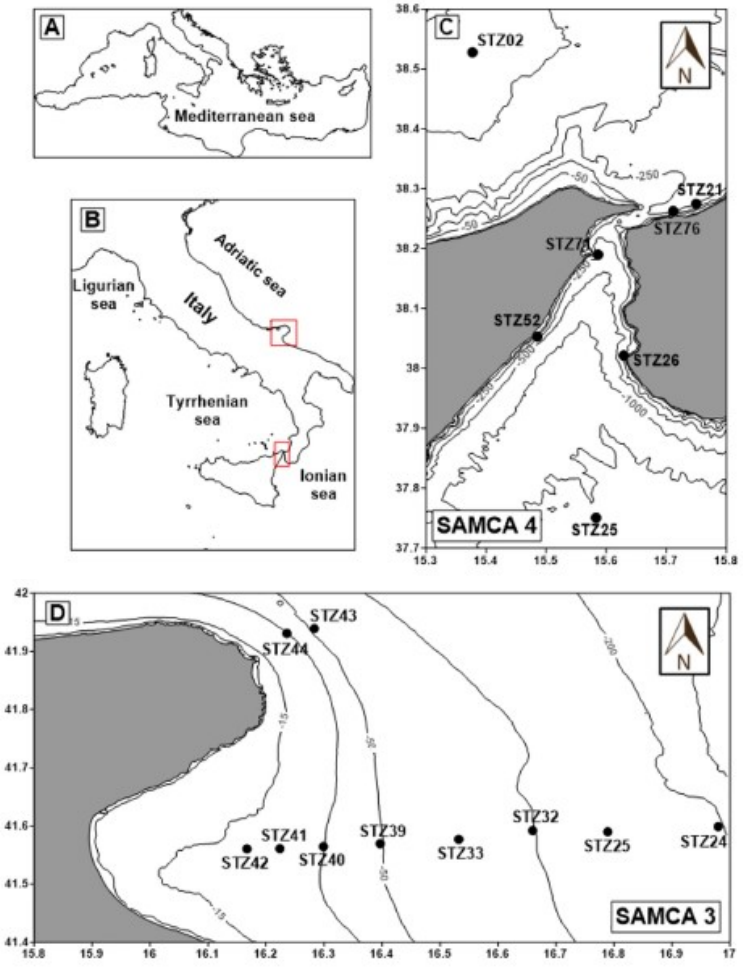


Simulation of photo-physiological behavour of phytoplankton

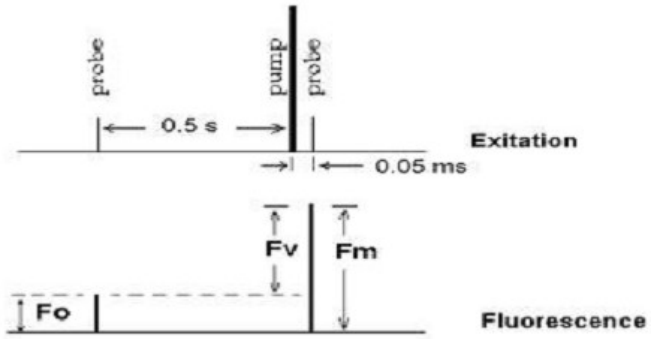


The model couples photosynthetic (PE) parameters with the dynamic condition of the water column. In the mixing condition, Phyto-VFP simulates a **dynamic acclimation** of phytoplankton cells with a homogeneous photosynthetic response along the water column, assigning constant values to PE parameters. In the stratified condition, **static acclimation** (SA) processes are dominant and significant differences in photosynthetic parameters occur both in time and depth. For each of the three optical layers characterised by different photo-physiological behaviours of phytoplankton cells, the diel variation of PE parameters over time is considered.

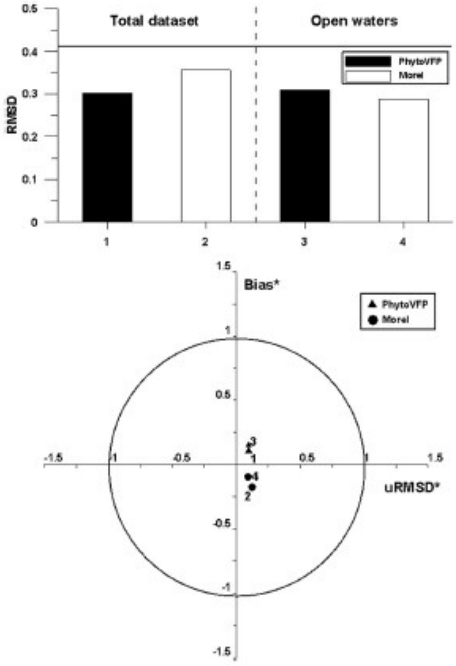
Phyto-VFP application in the Mediterranean sea



The Mediterranean basin (A);the SAMCA cruises sampling areas (B); focus on SAMCA4 (C) and SAMCA3 (D) stations where 14C analysis has been performed.



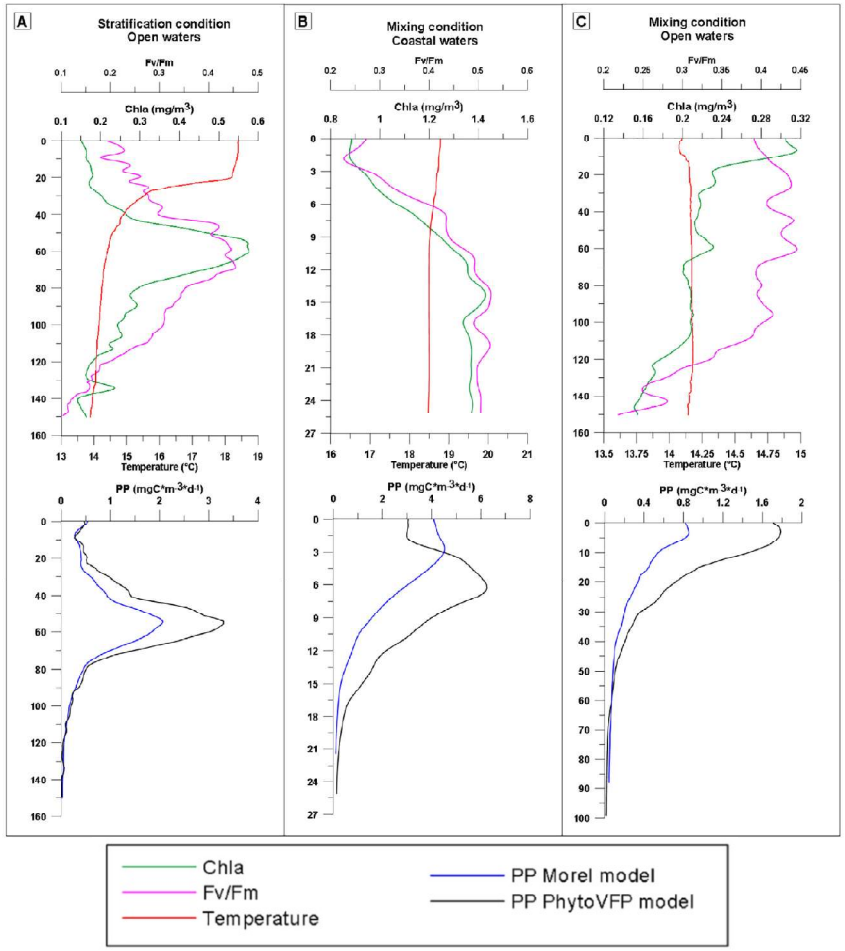
Primprod probe and Pump and probe method



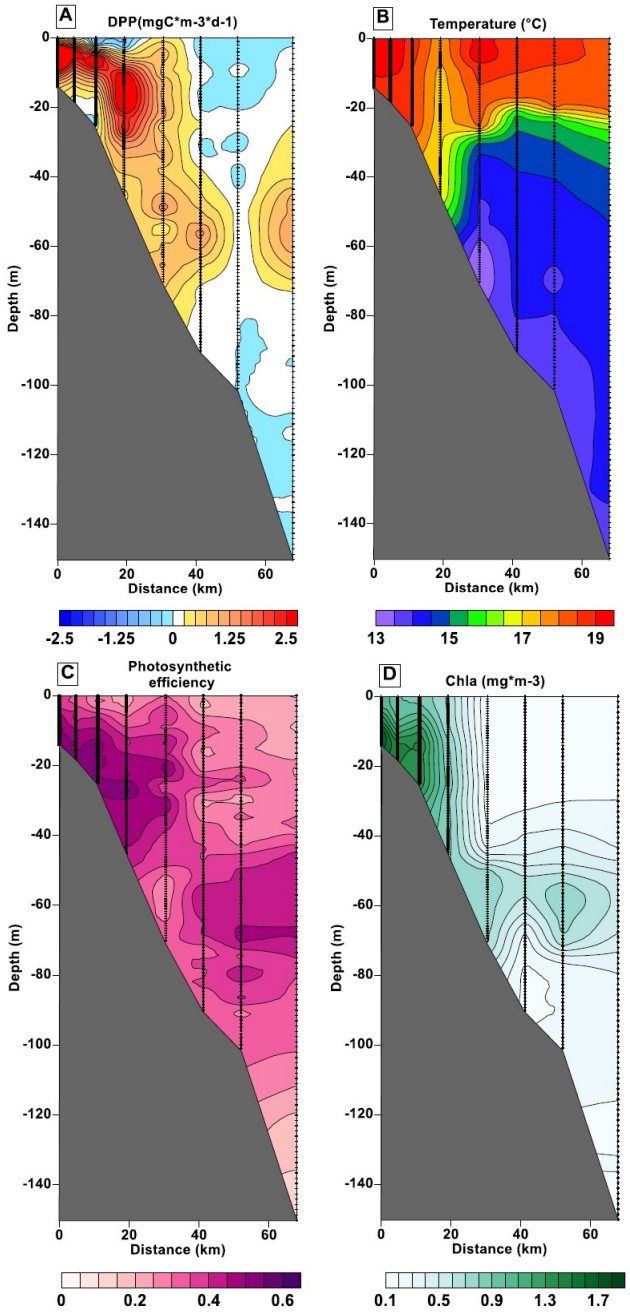
Statistical evaluation of Phyto-VFP and Morel model performances. (A) RMSD values estimated over the total dataset and excluding the coastal stations; (B) the Target diagram.

Comparison with Morel model (Morel 1991)

Phyto-VFP application in the Mediterranean sea

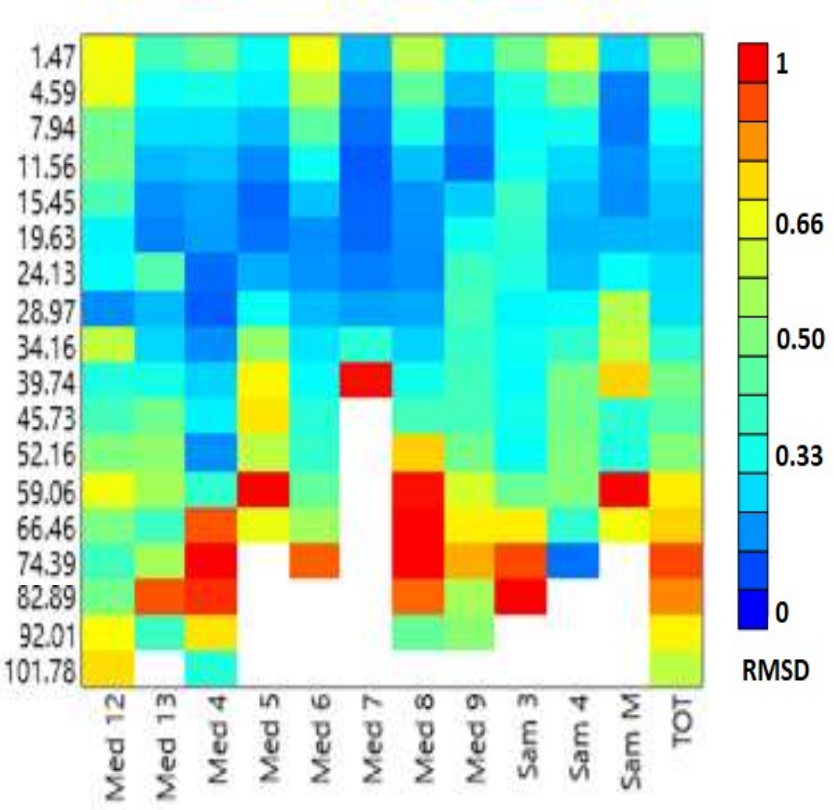


Biophysical conditions and PPs of stations 24 (A) and 40 (C) oftheSAMCA3 cruise and 71 (B) of SAMCA4.

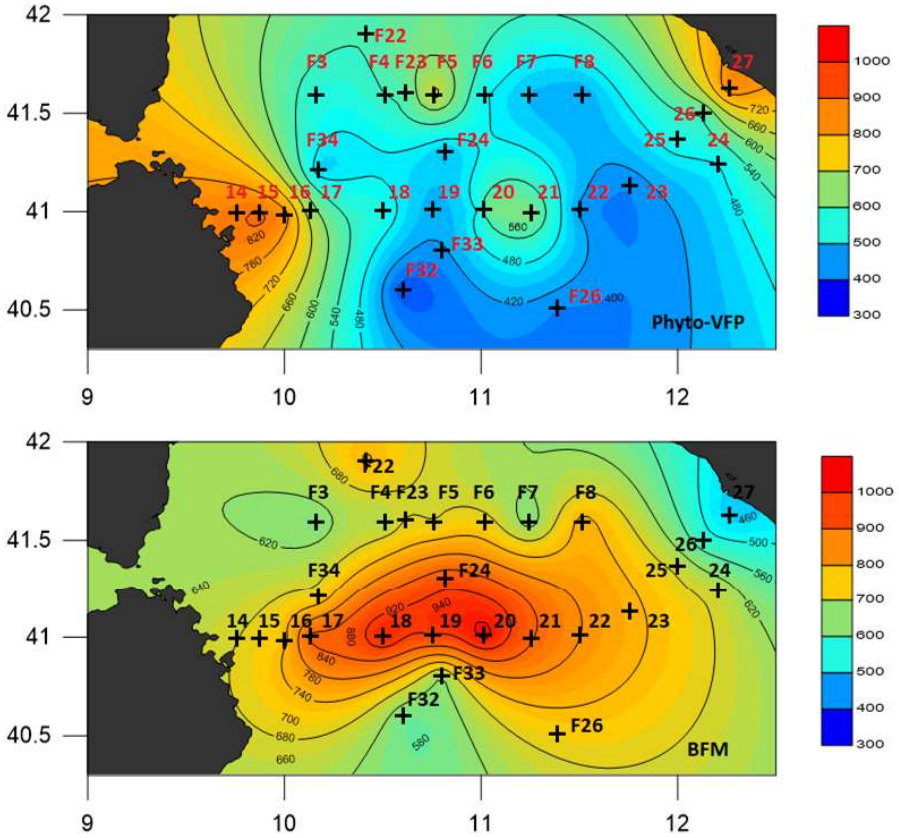


Vertical distribution of temperature (B), photochemical efficiency (C), chlorophyll-a concentration (D), and the difference between PP calculated with PhytoVFP and Morel model (A) along the transect 42-24 of SAMCA 3 cruise.

Phyto-VFP application in the Mediterranean sea



The greatest discrepancies between the models (high RMSD values) are shown on the sea surface during springtime and at lower depth. In the first case BFM overestimates the PP as it is not considered the photo-inhibition process; in the second case the two models identify the PP peak at different depths.



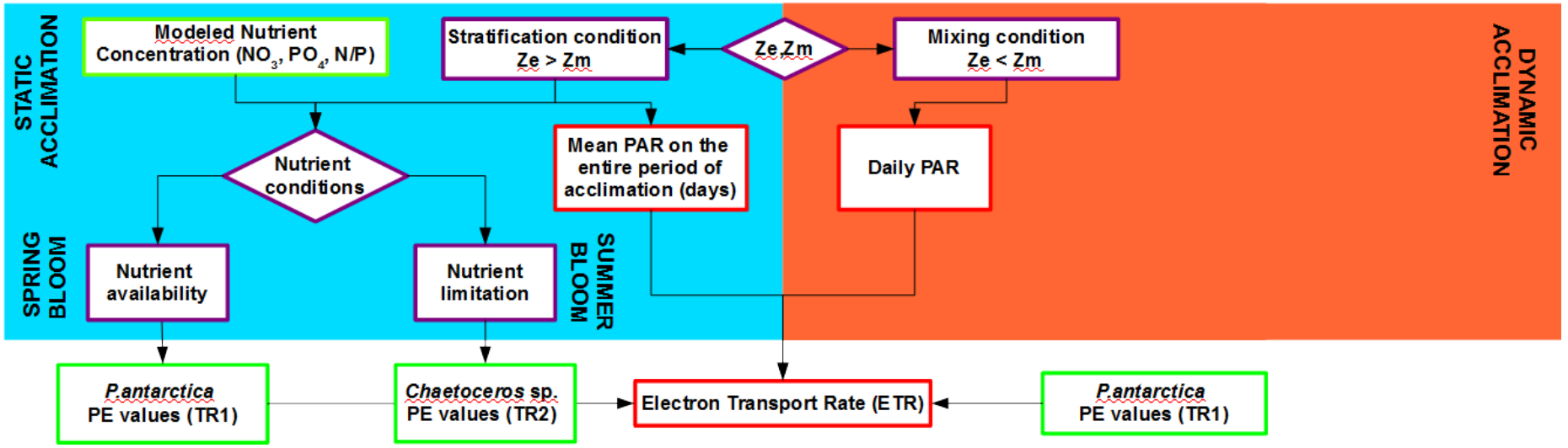
Application of Phyto-VFP (in the figure above) and BFM (in the figure below) in the northern Tyrrhenian sea where the biological response of mesoscale cyclonic gyre has been detected from both models (high PP in the centre).

Comparison with BFM model (Vichi et al. 2007)

Phyto-VFP application in the Ross sea (Southern Ocean)

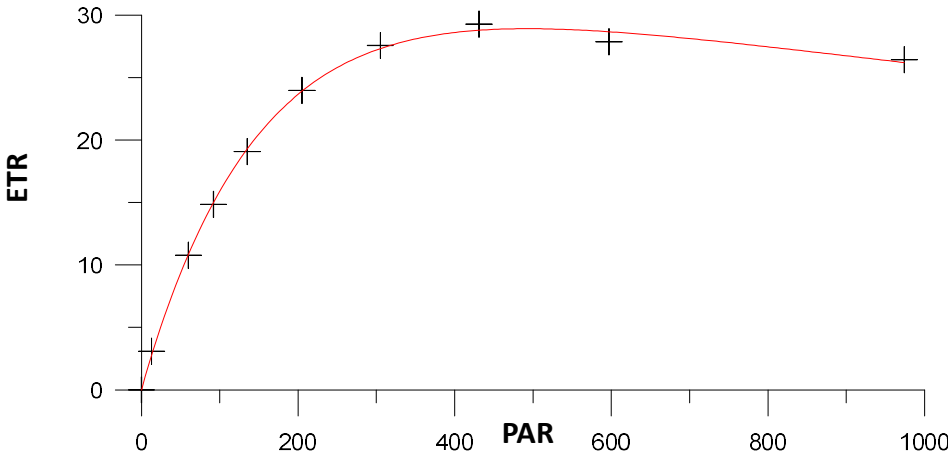
Within **the BioAPRoS project** (PNRA16_00065 - A1) Phyto-VFP has been specifically set-up with remote sensing (chla) and global ocean model data (Mixed Layer Depth, Nutrient concentrations) from the **Copernicus Marine Service** to estimate PP in the Ross Sea, simulating the phytoplankton dynamics during the 2018-19 spring-summer season.

Optimization of the Phyto-VFP *Physio module* to estimate PP in the Southern Ocean

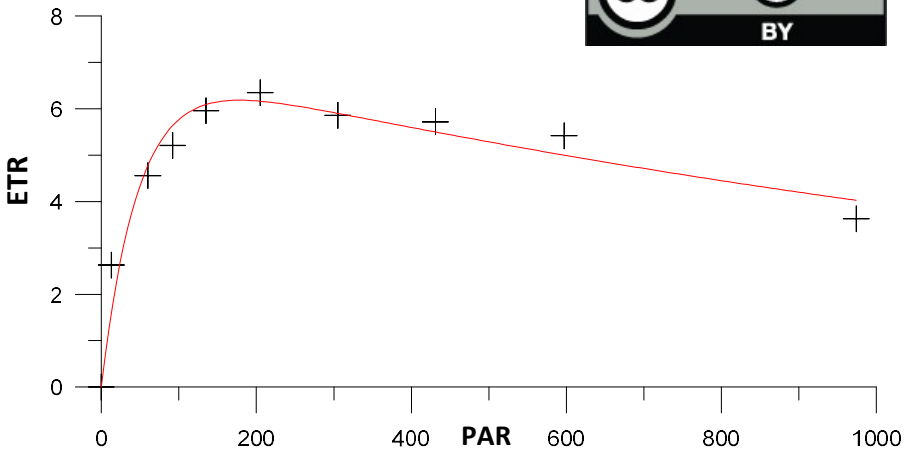


Laboratory tests and *in vivo* fluorescence measures on polar species

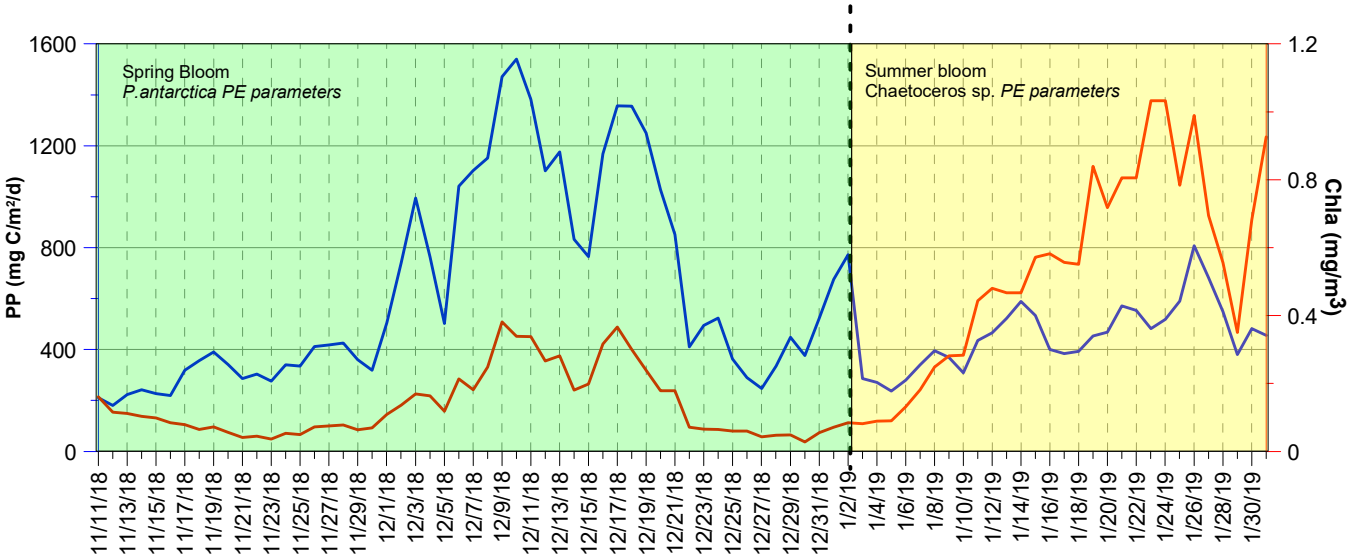
***Phaeocystis antarctica* - Spring bloom**

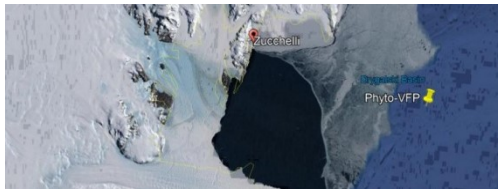


***Chaetoceros sp.* - Summer bloom**



Phyto-VFP application in the Ross sea (Southern Ocean)

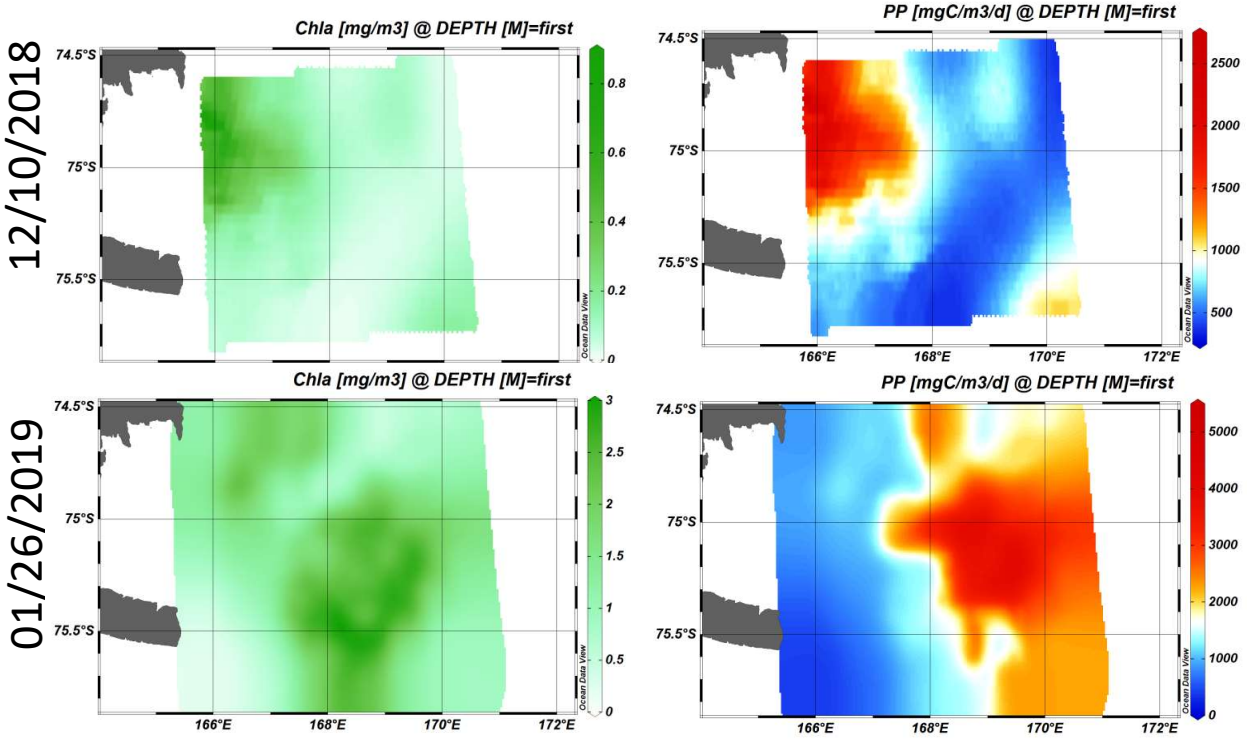




PP (blue line) and **Chla** (red line) **time series** during the 2018-19 spring-summer season. The model correctly simulated the occurrence of two main phytoplankton blooms as widely described in literature (Arrigo et al., 2008).

Chla and PP distribution maps of the days when the maximum peaks were detected in December and January, respectively.

The model allowed to identify the areas where higher phytoplankton abundance and PP are observed. A shift from a coastal to an off-shore distribution is also evidenced in correspondence to the beginning of the summer season.



Discussion and Conclusions

As a response to the lack of primary production models that take into account the photo-acclimation process, **Phyto-VFP** was developed to estimate PP according to the photo-physiological behaviour of phytoplankton, considering both the light field and the dynamic conditions of the water column.

To parametrise the effect of photo-acclimation processes on the phytoplankton population, a series of laboratory experiments based on ***in vivo* variable fluorescence measures** were performed on phytoplankton species, which have been selected based on the dynamic (*S. costatum*) and trophic (*P. antarctica* and *Chaetoceros sp.*) conditions of the marine environment.

In the Mediterranean application, model validation using radiocarbon (^{14}C) uptakes shows that **Phyto-VFP performance is comparable with Morel model** in the offshore marine area and greater in reproducing PP in coastal waters. **The comparison with BFM model highlights that the two models produce qualitatively and quantitatively similar values of PP along the water column in mixing conditions**; otherwise the PP values differ in surface and in the lower depth during the stratification.

The application of Phyto-VFP to the Ross Sea allowed to estimate PP by taking into account the typical phytoplankton dynamics of the spring/summer austral season, answering to the need of a dedicated effort to provide greater certainty in PP models and climate projections for the Southern Ocean (Laufkötter et al. 2015, Kaufman et al., 2017). PP values are in agreement with the ranges reported in literature, **confirming the good performance of Phyto-VFP model** in simulating phytoplankton PP according to its photo-physiological and ecological behavour.