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Best practices for the integration of in situ observations and large scale analysis and forecast systems: case study of the phytoplankton blooming off a Tyrrhenian coastal site

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Objectives

Our goal is to understand the **spatial and temporal distribution of phytoplanktonic biomass in coastal waters** to evaluate the phytoplankton dynamics in a coastal polluted area located in the northern Tyrrhenian Sea.

The **focus of this work is twofold**:

1. to analyse the **phytoplankton bloom dynamics of the Civitavecchia coastal ecosystem** by adopting a multi-platform approach which integrates the Copernicus Marine Environment Monitoring Services (**CMEMS**) products and the Civitavecchia Coastal Environment Monitoring System (**C-CEMS**) in situ data;
2. to **propose best practices to integrate multi-platform data streams**, that may be adopted also in other similar contexts of coastal ecosystems.

Problem

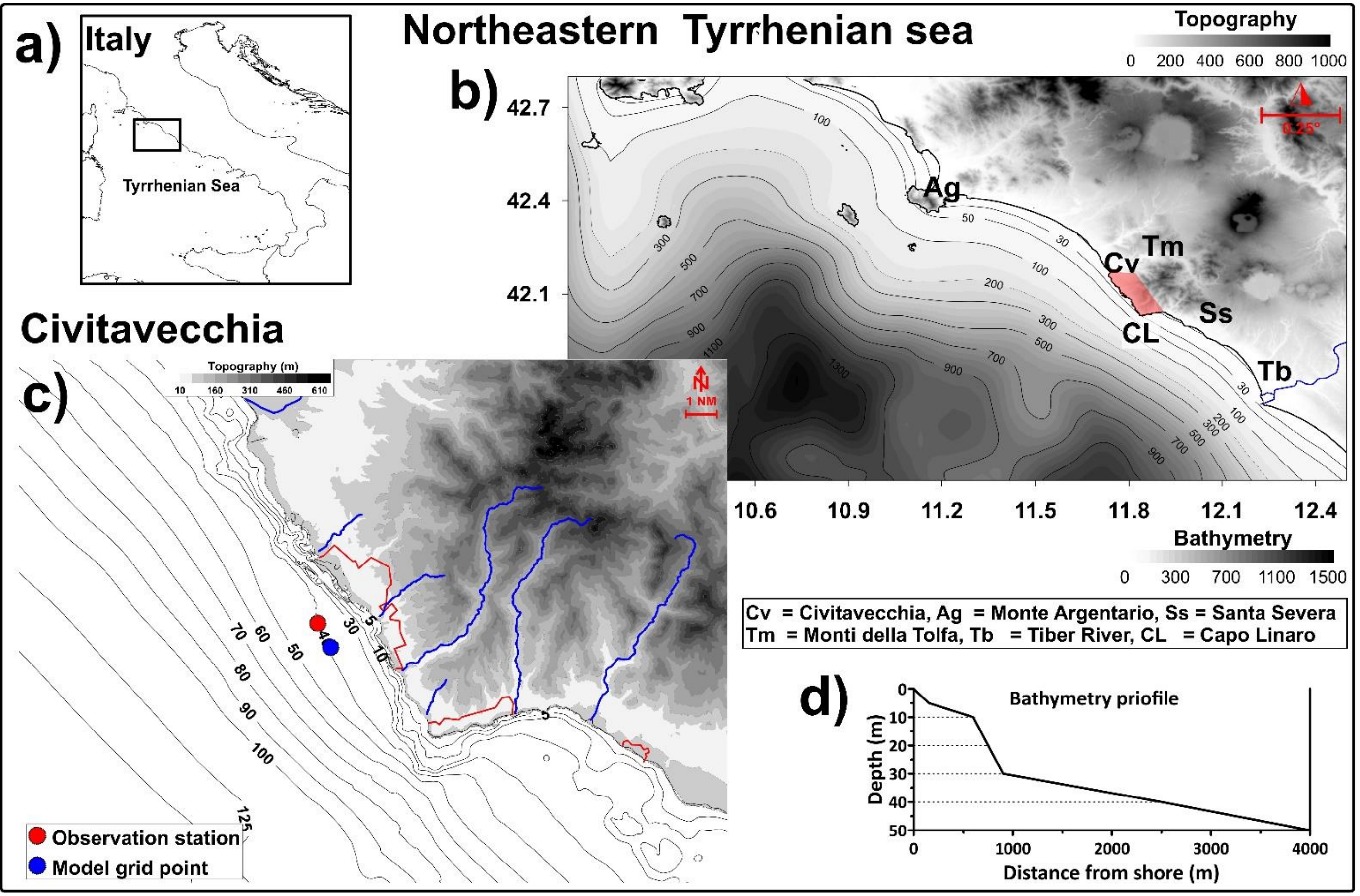
In marine processes studies **the knowledge of a phenomenon depends observations**, which are usually extremely complex because of the intrinsic difficulty of the type of measurements that have to be made. These issues are specifically urgent and strategic for **coastal areas, that present an extremely high spatial-temporal variability.**

In this work, we aim to overcome the difficulties of the "classical" observation, **applying a Multi-Platform Monitoring System (MPMS)**, where the in situ dataset provides the local observations, , the satellite or the model the coast-open sea extension and the model the vertical dynamics along the coast-open sea direction.

Best pratices

Element of best practice	Relevant methodology	Proposed application to case study
0. Definition of the process to be investigated	Variables, temporal dimension (frequency and length of the time series monitoring), spatial dimension, synoptic level.	Interannual variability of phytoplankton blooms in the Tyrrhenian coastal area
1. Characterization of the study site	Background analysis based on literature and other available historical data.	Slide 5
2. MPMS data collection	In situ observations. Satellite data. Model data.	Slide 6-7
3. Consistency analysis among multi-platform datasets	EOFs. Multi-variate correlation analysis.	Slide 8-9
4. Integrated and coherent multi-variate analysis to extract information on the investigated process	Statistical analysis of external drivers, spatial interpolation, temporal evolution analysis.	Slide-10-11

1. Characterization of the study site



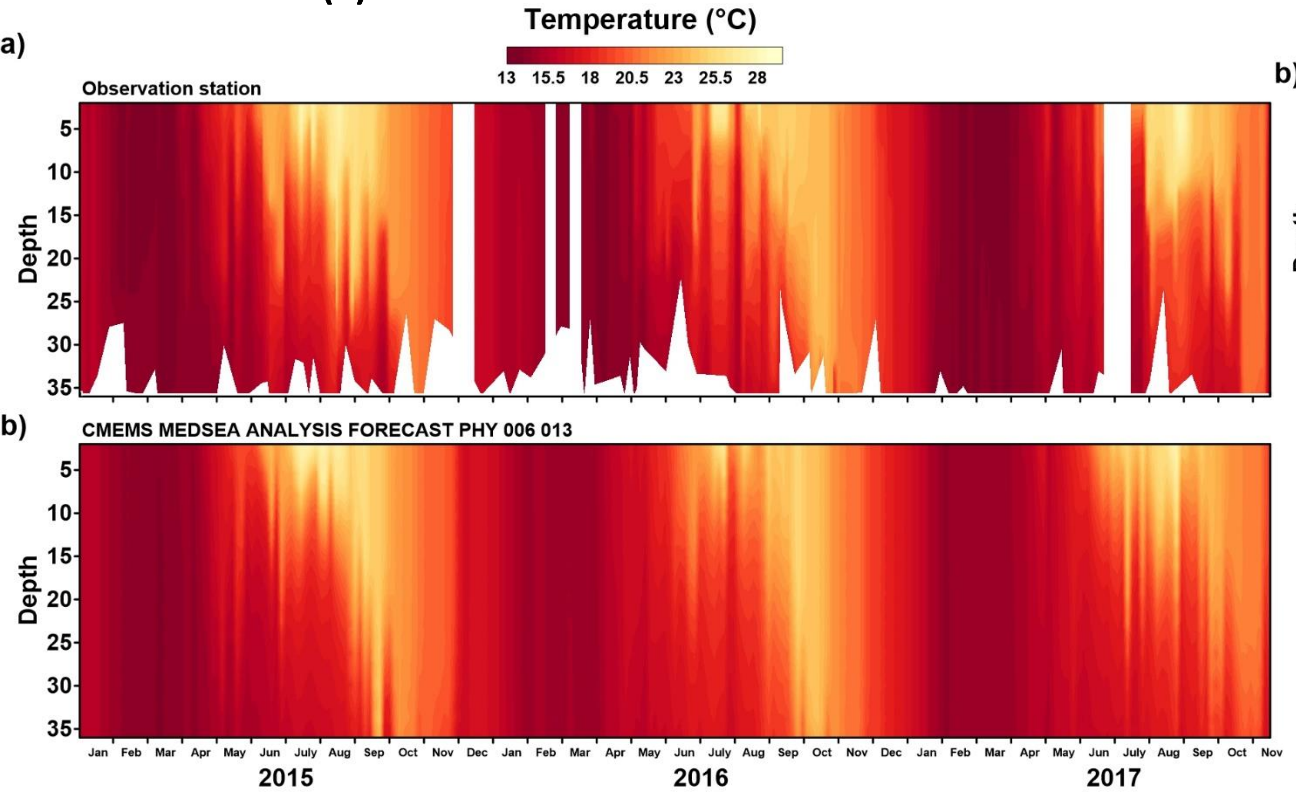
Location of the study area (a); bathymetry and orography of the north eastern Tyrrhenian coast (b) whit) geographical details of the study area; (c) map of the Civitavecchia coastal area (red area in b), inclusive of streams and rivers (blue lines), urban areas (delimited by red lines) and the location of the observation station and model grid point and the bathymetry profile (d, see inlet).

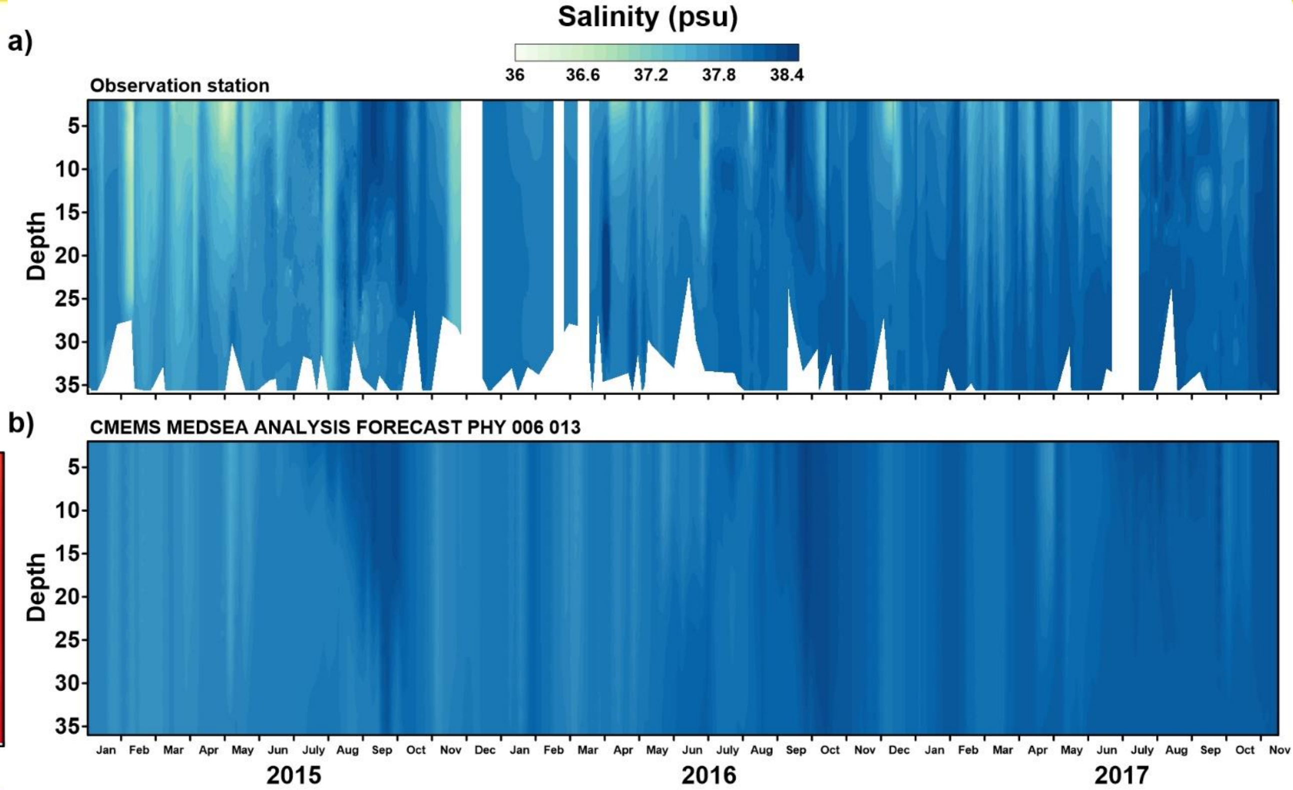
- **Economic, environmental and cultural importance**
- **Morphology: marine terraces and cliffs**
- **Freshwater input: minor streams**
- **Winds: South/East and North/Northeast**
- **Alongshore current: northwestwards (<10 cm s^{-1})**
- **Surface currents: 2-3 day timescale variability**
- **Sea level: ±35 cm , strong component at 12 h**
- **Significant wave height > 3 m**
- **Studies of the coastal phytoplankton dynamics in the Tyrrhenian coastal zone are very limited**
- **Phytoplankton features the classical scheme of the temperate climate, presenting two annual blooms**
- **During the year, diatoms and dinoflagellates alternate**

2. MPMS data collection

Sea temperature

- Definite seasonal variations
- Elevated interannual variability
- Winter-Spring cold and vertically mixed
- Summer: thermally stratified water
- Very good correlation (R^2 = 0.95) between model (b) and observations (a).

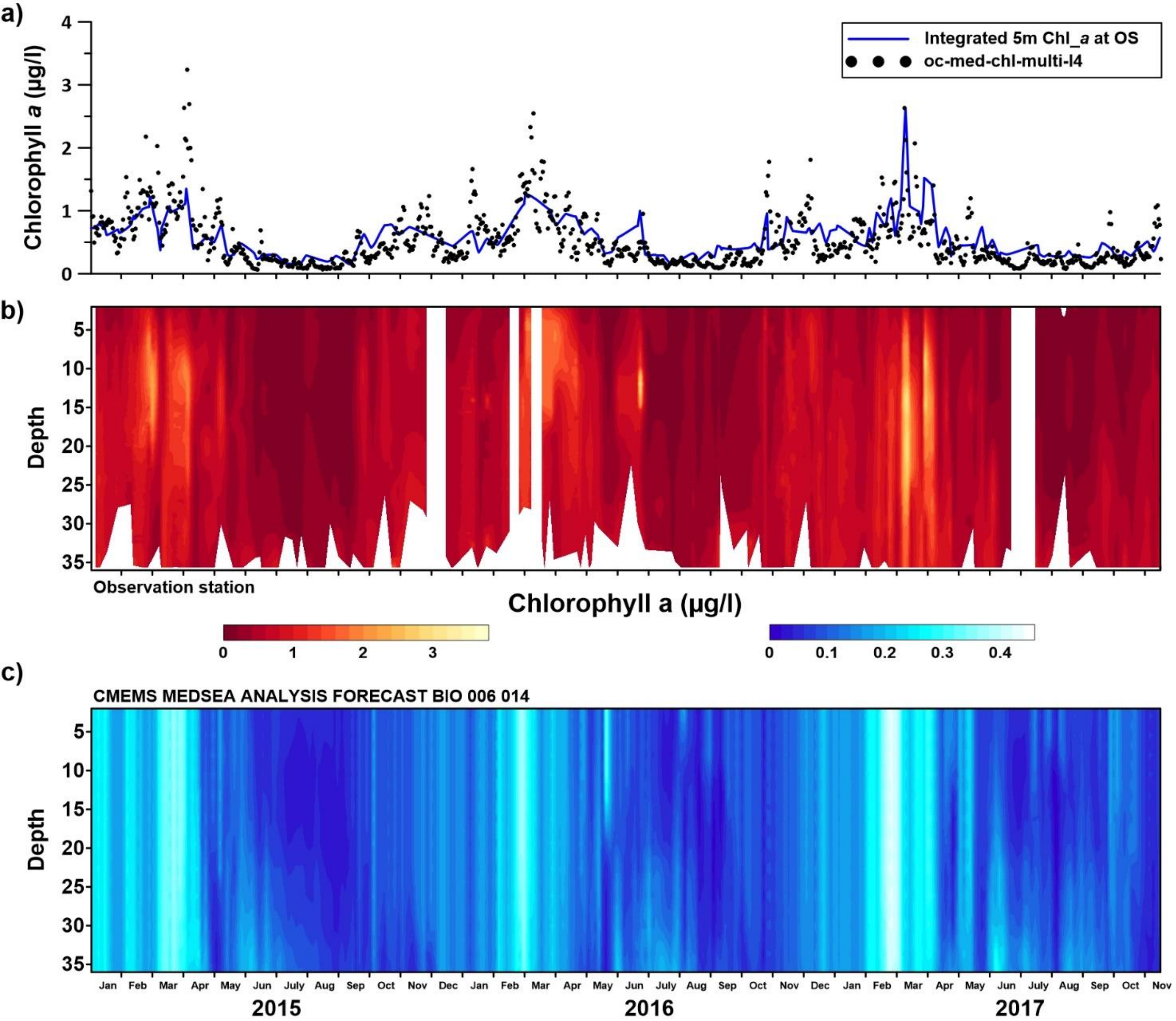




Salinity

- High degree of variability
- Salinity increase
- Salinity minima: winter and autumn
- Salinity maxima occurs during summer
- Good agreement (R^2 = 0.76) between model (b) and observations (a).

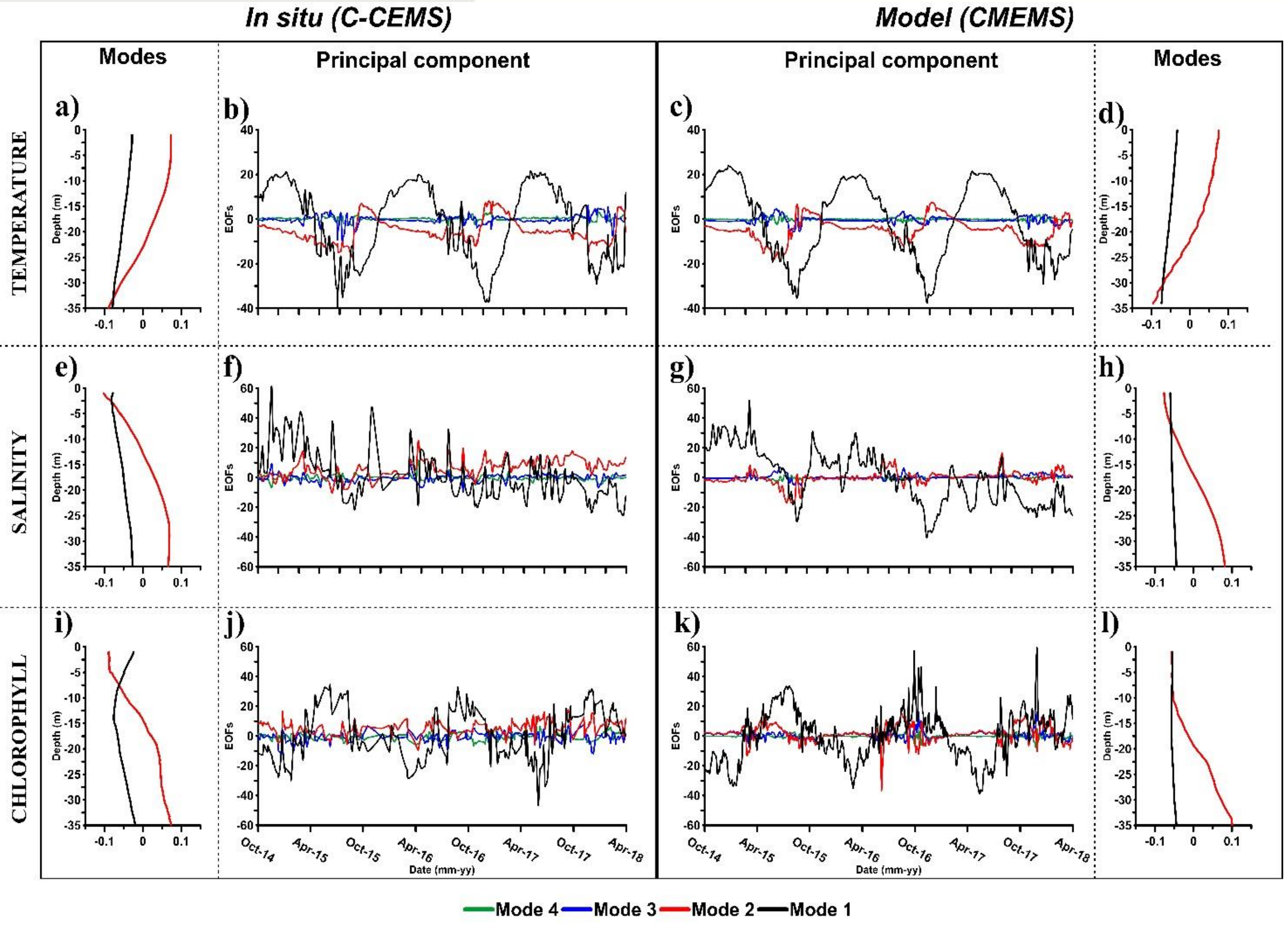
2. MPMS data collection



Phytoplankton

- Spring and autumn blooms.
- Great degree of variability.
- Definite seasonal variations .
- Elevated interannual variability.
- Early winter: homogeneously distributed < 0.5 µg/l.
- Spring bloom: beginning of February, subsurface layers >2 µg/l.
- Summer: surface layer < 0.1 µg/l; below the thermocline < 1 µg/l.
- Autumn bloom: confined in the bottom layer below 20 m depth, <1.5 µg/l.
- Satellite data and model outputs show the same trend of in situ observations.

3. Consistency analysis among multi-platform datasets



First two spatial (a,d,e,h,i,l) and first four temporal (b,c,f,g,l,k) modes of the EOF decomposition for temperature, salinity and chlorophyll for in situ (left panels) and model data (right panel).

EOF

Generally, the first two modes explain up to 95% of the variance.

Temperature:

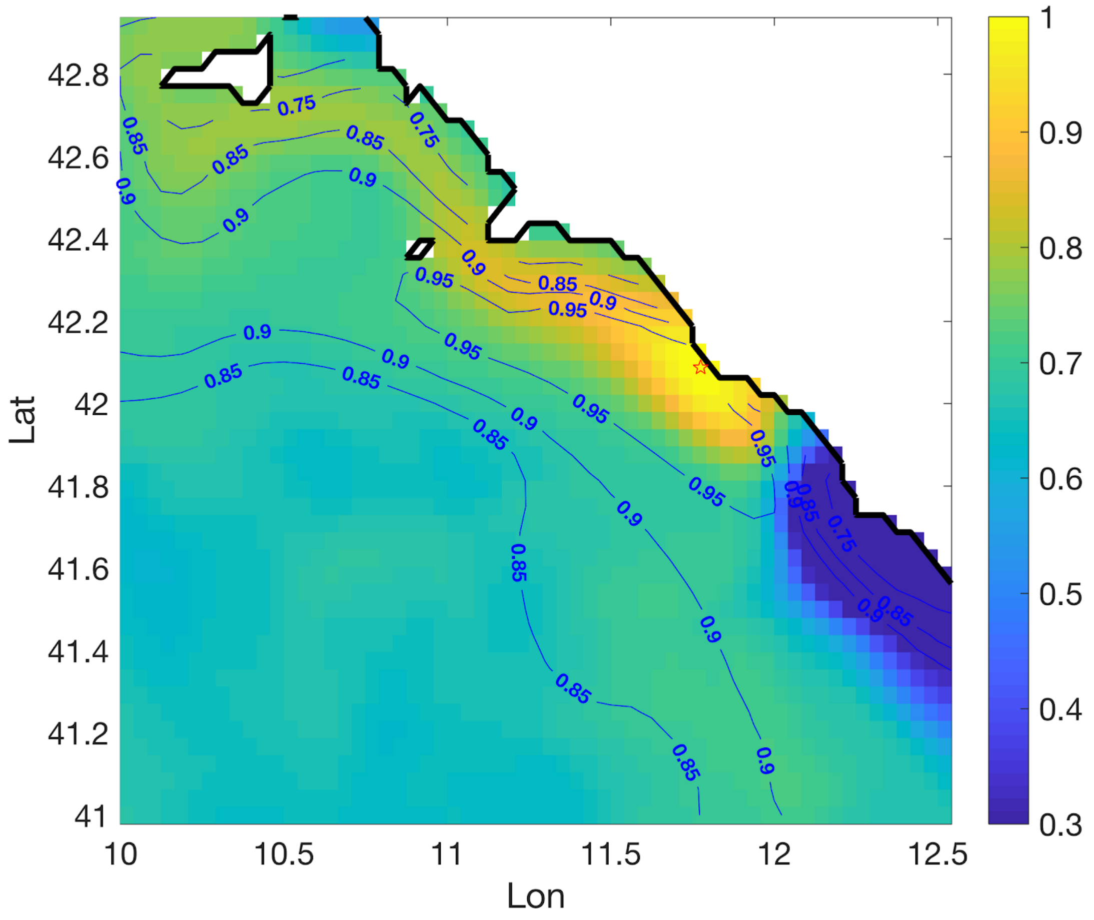
- **Same trend for in in situ and in the model.**
- **Well synchronized.**
- **First mode: seasonal cycle of heating and cooling.**
- **Second mode: the onset of the summer stratification and autumn vertical mixing.**

Salinity:

- **Mostly synchronized.**
- **Negative tendency from 2015 to 2017.**
- **First mode: barotropic term of decrease.**
- **Second mode: general vertical positive gradient.**

Phytoplankton:

- **High consistency.**
- **Well synchronized.**
- **First mode: winter and the autumn bloom.**
- **Second mode: higher concentration during summer and autumn.**



Map of multivariate autocorrelation between the OS (red star) and each gridpoint of the model domain at surface. Correlation is computed from CMEMS reanalysis (blue contours and label) and Analysis and Forecast (coloured shaded area) datasets.

Multivariate autocorrelation analysis

The representativeness of the observations stations (OS) variables (temperature, salinity and chlorophyll *a*)

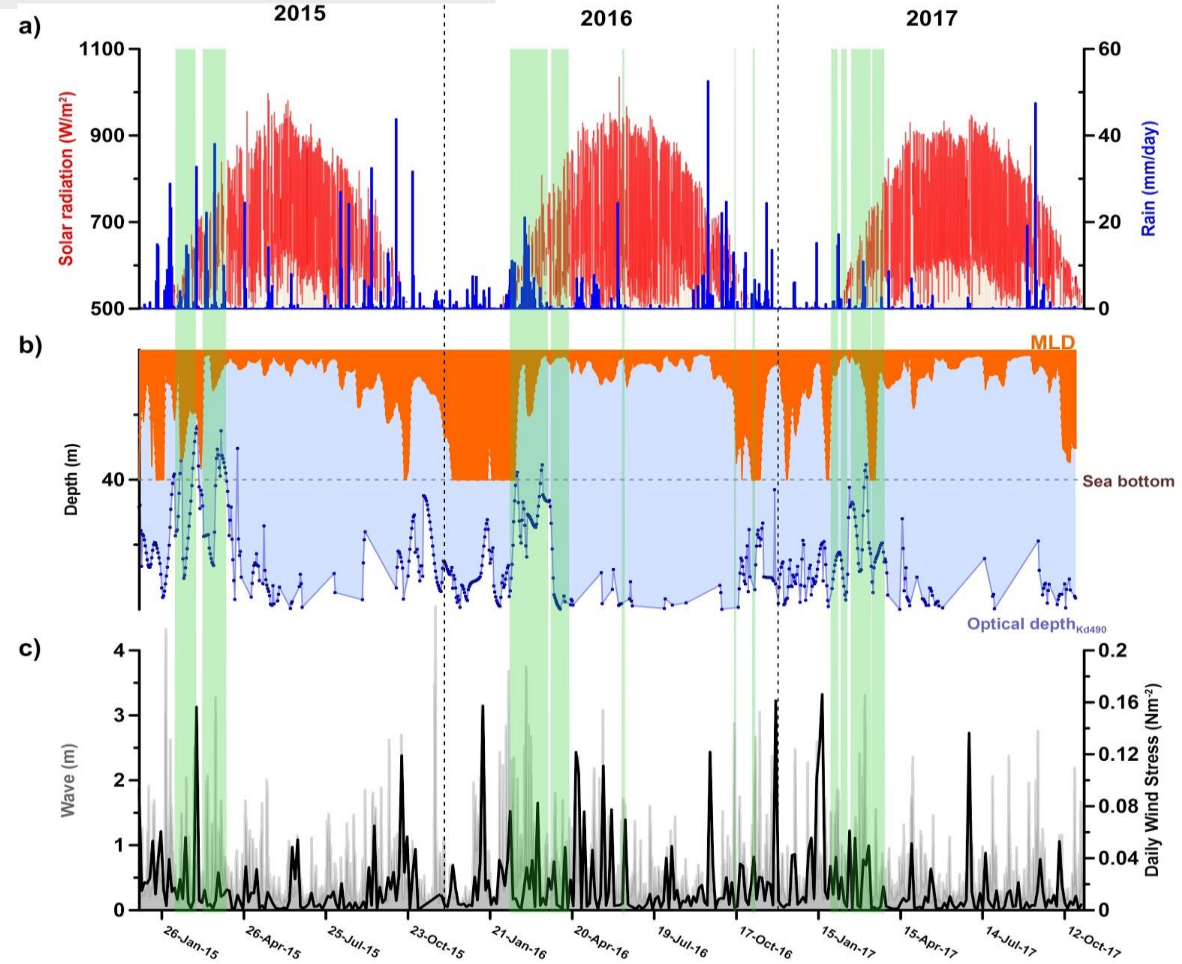
<u>Long term evolution extracted by the 1999-2017 CMEMS reanalysis</u>

- **OS has a high correlation (R^2>0.85, p<0.0025)**
- **Large strips along the Tyrrhenian coast (large 70-80 km)**
- **Correlation identifies typical/common seasonal cycle along the Tyrrhenian coast**
- **Decrease of the correlation of the OS with the nearshore areas at 30-40 km far from the OS**

<u>Analysis and forecast products 2015-2017</u>

- **Correlation higher than 0.85**
- **Its shape is elongated and northward oriented**
- **Dynamics of the southern near shore area is almost not correlated with the OS**

4. Integrated and coherent multi-variate analysis to extract information on the investigated process



Time series of external forcing, in the box on top (a) solar radiation (redline) daily rain (blue line); in the center box (b) optical depth (blue dotted line), mixed layer depth (orange filled line); in the box below (c) wind stress (black line) and significant wave height (gray line). The green rectangles that cross the boxes represent the spring bloom periods.

External forcing

Quite different during the three investigated years
Interannual variability in shaping the spatial-temporal scales of the coastal bloom dynamics.

- **Solar radiation (a): typical seasonal cycle of temperate climate.**
- **Rainy periods (a): Significant interannual variability** *(i.e., year 2017 reports a much lower winter cumulative rain w.r.t. year 2015: 2821 mm/period in 2015, 1493 mm/period in 2016, and 795 mm/period in 2017).*
- **Optical depth (b): high variability during the winter/spring season**
- **Wind stress (b): elevated variability** *(i.e., year 2017 reports the highest wind intensity, while year 2016 shows a high intensity over a long period).*
- **Significant wave height (c): higher waves during winter**
- **Mixed layer depth (b): Elevated variability** *(In winter extends from the surface down to the bottom)*

4. Integrated and coherent multi-variate analysis to extract information on the investigated process

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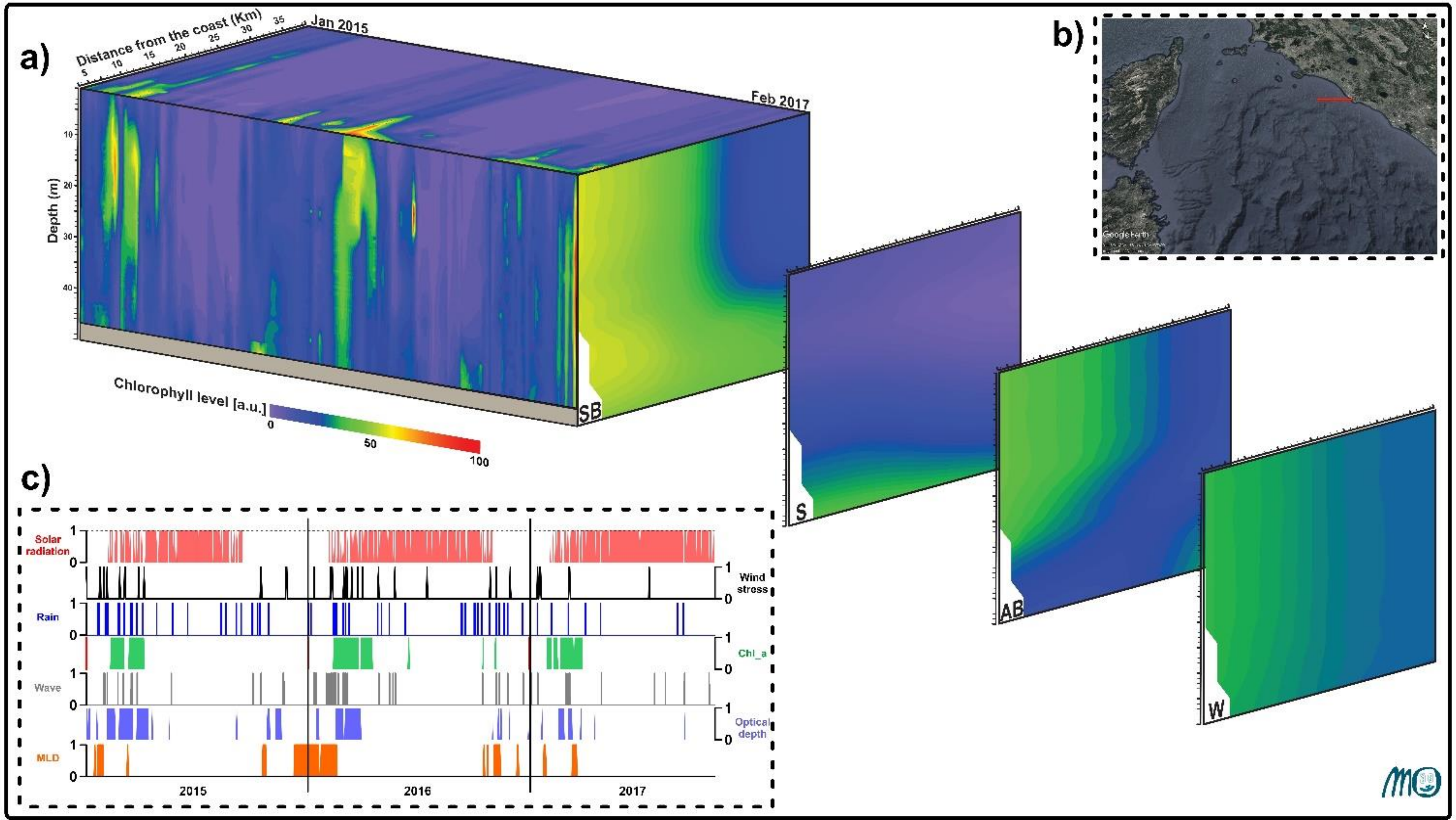

Integration of different data sets: (a) Chlorophyll vertical and cross-shore representativeness of the MPMS. Backward face is chlorophyll from in situ data (y-depth/x-time); upward face is chlorophyll from satellite data (z-distance from coast/x-time) and sections are the averaged seasonal period from model outputs (y-depth/z-distance from coast) in which SB is the Spring Bloom period, S is the Summer, AB is the Autumn Bloom and W is the Winter. Colour scale is normalized between 0 and 100 for each dataset. (b) Location of the study area (the red line represents the section transect for satellite products. (c) Synthesis of external forcing time series based on blooming time. They are represented as logical values (1= true, 0=false) based on chosen threshold. The bloom period is defined with chlorophyll a concentrations greater than 1 $\mu g l^{-1}$ Forcing thresholds are > 500 Wm-2 for solar radiation, < 60 m for optical depth, > 50 mmd-1for rain, > 0.08 Nm-2 ≈ (7 ms-1) for wind stress, > 3 m for wave, and > 35 m for mixed layer depth.

Conclusions

- The analysis of the **time series of phytoplankton** provided by **in situ, satellite and model** data shows **the typical dynamics of coastal temperate climate**, characterized by **spring and autumn blooms**, together with a **significant interannual variability.**

- Following our data integration approach, the **EOF analysis** has shown **consistency among the multi-platform datasets**.

- Notwithstanding the incongruences related to model representativeness error (i.e. river nutrient inputs based on climatological information and grid resolution), **the intercomparison** results beneficial to **provide information** of the phytoplankton dynamics and drivers **at different temporal and spatial scales.**

- Indeed, **in situ data** describe the **very local dynamics** by integrating all the on-site physical and biogeochemical processes, **satellite data** provide the **evolution of the large-scale surface chlorophyll** patterns at high resolution, and **model extends the 3-D structure of the physical and biogeochemical processes**, quantifying the role of the different drivers.

Through the study of the dynamics of coastal blooms in the Civitavecchia coastal system (Tyrrhenian Sea), we propose a best practice framework that can be potentially applied to any multi-platform monitoring system (MPMS) to provide a comprehension of coastal phenomena deeper than any individual dataset which, being not integrated with other data streams, may provide.