Development of an algorithm of the maximum specific rate of photosynthesis: a case study for the Atlantic Ocean

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Abstract

Predicting the photosynthetic efficiency of phytoplankton remains one of **the main problems in determining marine primary production (PP)**. Due to the difficulty of obtaining shipboard (*in situ*) data on photosynthetic parameters, they are restored by other parameters. The dependence of the maximum specific rate of photosynthesis (**assimilation number, P_m^B**) on the seawater surface temperature (SST) is used when **restoring P_m^B** by various algorithms. However, the use of P_m^B recovery algorithms in PP models, as a rule, makes a significant contribution to prediction errors PP. Probably, the conditions in different water areas (regions of the same ocean), as well as the seasons of the year (periods of "bloom") affect the variability of P_m^B.

In this study, we considered **the seasonal and spatial variability of P_m^B**, which describes the photosynthetic abilities of marine phytoplankton. Moreover, the new empirical algorithms of P_m^B were developed due to the necessary to take into account the seasonal and regional variability of the parameters. <u>These new algorithms showed better performance compared to the other algorithms.</u>

Methodology

The ship (*in situ*) data from the global database of parameters of photosynthetic curves **PANGEA** (Bouman et al., 2017) were analyzed in the work: P_m^B [mg C (mg Chl)$^{-1}$ h^{-1}], chlorophyll-a concentration [mg m^{-3}] in **the surface horizon (0-30 m)** at 350 stations located between 83°N. and 55°S in 16 biogeographic provinces (Fig. 1) from **2002 to 2013**. Satellite estimates of SST were taken with a time resolution of one day and a spatial resolution of 0.01°x0.01° (JPL MUR MEaSUREs Project. 2015. v. 4.1.). The stations were divided into **8 areas** for convenience (Fig. 2). The data were analyzed according to the seasons of the year in their hemisphere: ***spring*** (North: March-May, South: September-November), ***summer*** (North: June-August, South: December-February), ***fall*** (North: September-November, South: March-May) and ***winter*** (North: December-February, South: June-August) in order to trace the influence of the growing season and seasonal variability of environmental factors. 326 more points were taken from PANGEA database **to develop regional empirical reconstruction P_m^B algorithms** - in this dataset, stations were measured in June-July and December and are located in areas 1,3 and 4 (Fig. 2). The algorithms developed for each area are linear equations of the first order. In the work, ***the validation of several temperature algorithms*** for the recovery of P_m^B was carried out: **Behrenfeld and Falkowski, 1997; Balch et al., 1992; Megard, 1972.**

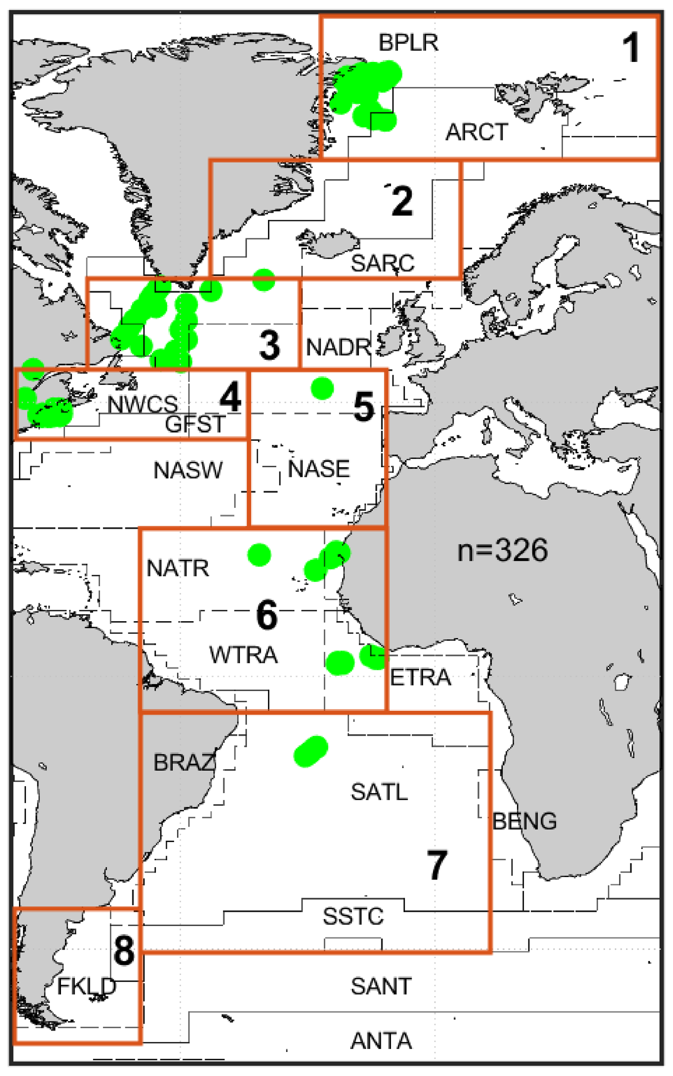
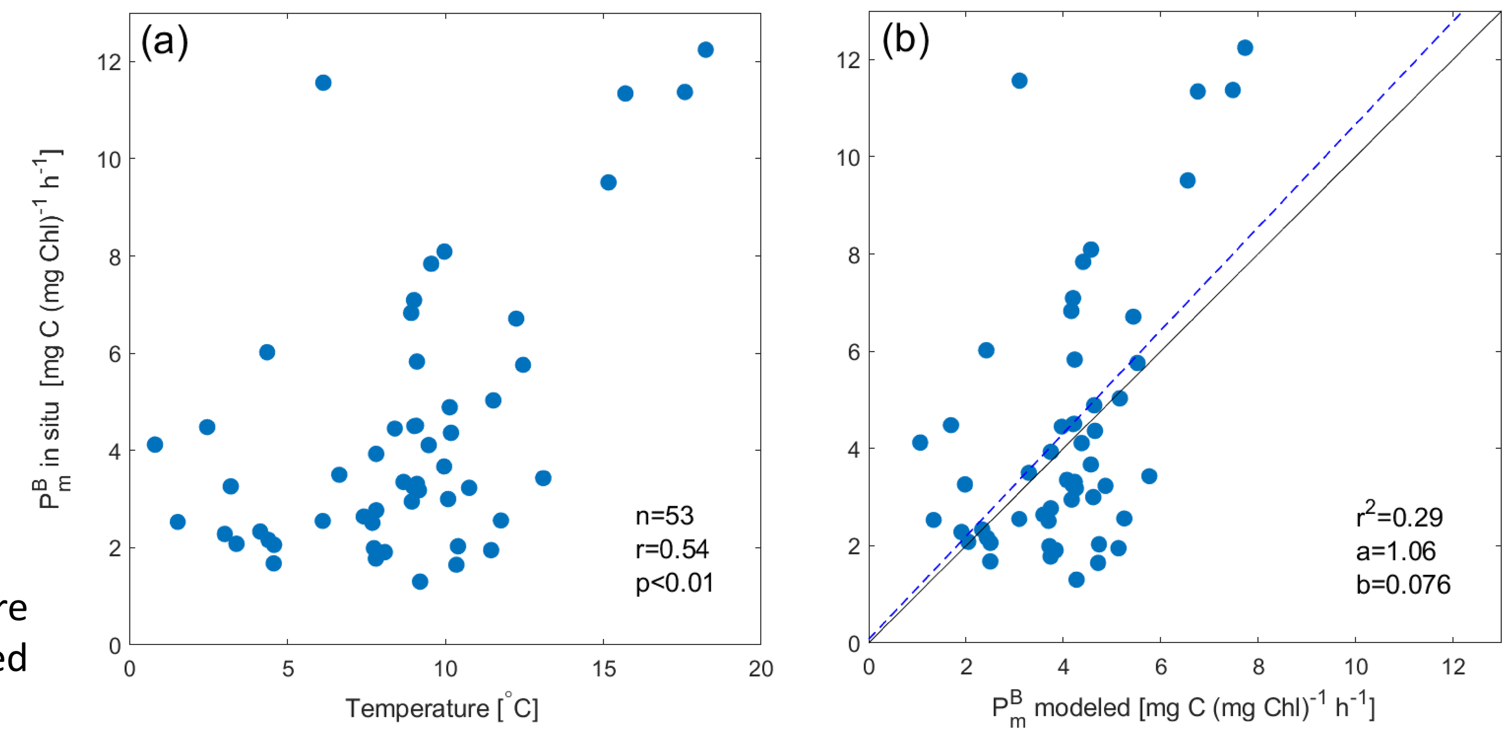


Figure 2. The test row stations (n=326) are marked in green. The study areas (8) are marked with a brown frame and numbered.

Figure 3. Scatterplots for areas 4: a) dependence of *in situ* values of P_m^B on SST; b) comparison of model estimates with *in situ* data (calibration). Solid line is the line of equality of modeled and in situ values; dotted line is the line of linear regression.



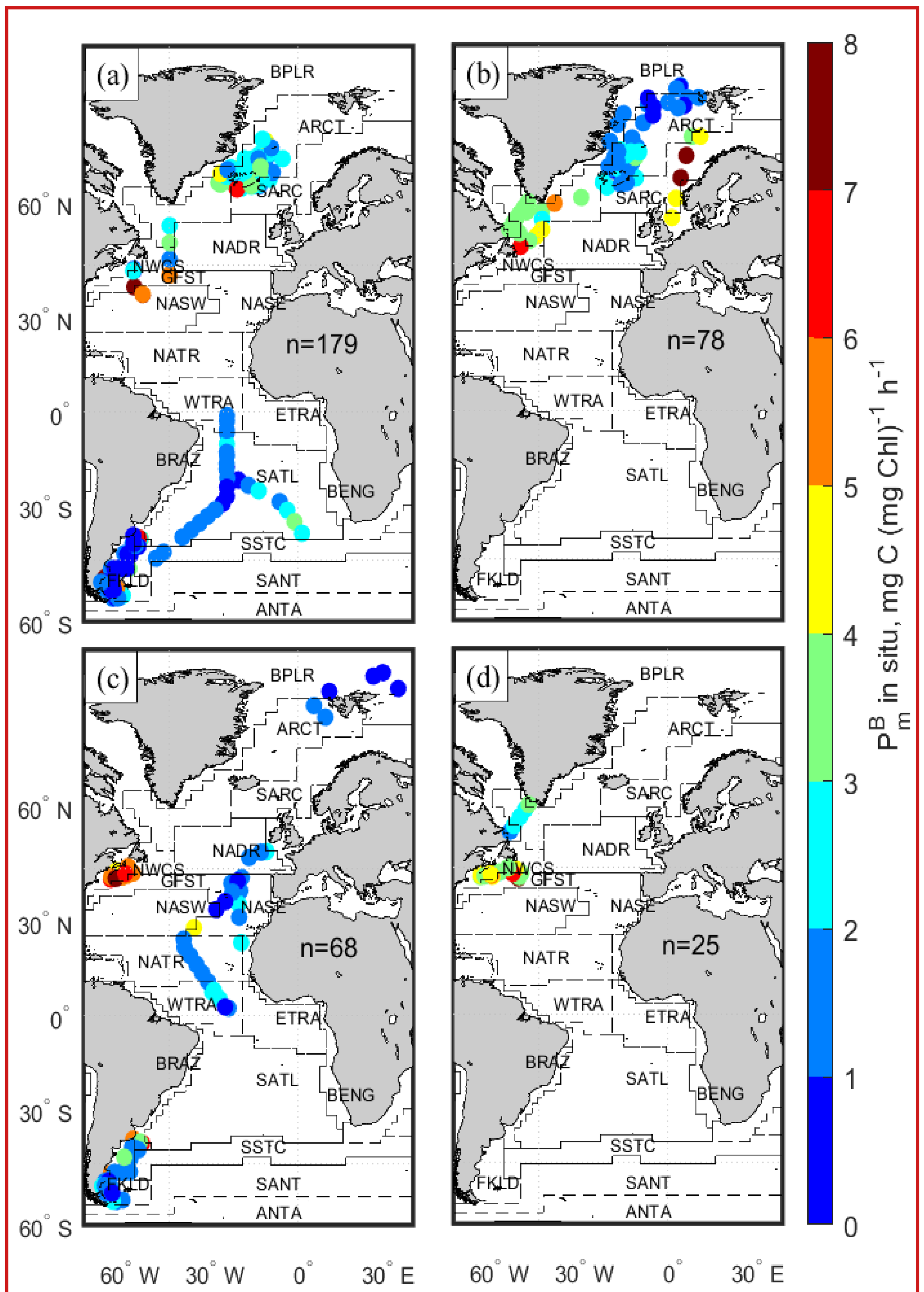


Figure 1. Spatial distribution of P_m^B (assimilation number) values by seasons by PANGAEA: a) spring; b) summer; c) fall; d) winter. The boundaries of biogeochemical provinces are drawn according to A. Longhurst, 2007. BPLR - Boreal Polar Province, ARCT - Atlantic Arctic Province, SARC - Atlantic Subarctic Province, NADR - North Atlantic Drift Province, NWCS – North-West Atlantic Shelves Province, GFST - Gulf Stream Province, NAS(W/E) - North Atlantic Subtropical Gyral Province (West/East), NATR - North Atlantic Tropical Gyral Province, WTRA - Western Tropical Atlantic Province, SATL - South Atlantic Gyral Province, BRAZ - Brazil Current Coastal Province, FKLD – South-West Atlantic Shelves Province, SSTC - South Subtropical Convergence Province.

Results

The algorithms were selected for areas (areas 1, 3, and 4) where there were **significant correlations between P_m^B and SST** (Fig. 3a) and there were data from the test set. Here we present **the calibration** (comparison of the model range with *in situ*) of the algorithm on the test set (Fig. 3b) and its **validation** in comparison with other algorithms using the example of **region 4** (Fig. 4, 5). The fitted algorithm (MY-22) for area 4:

$$P_m^B = 0.38 \cdot SST + 0.75$$

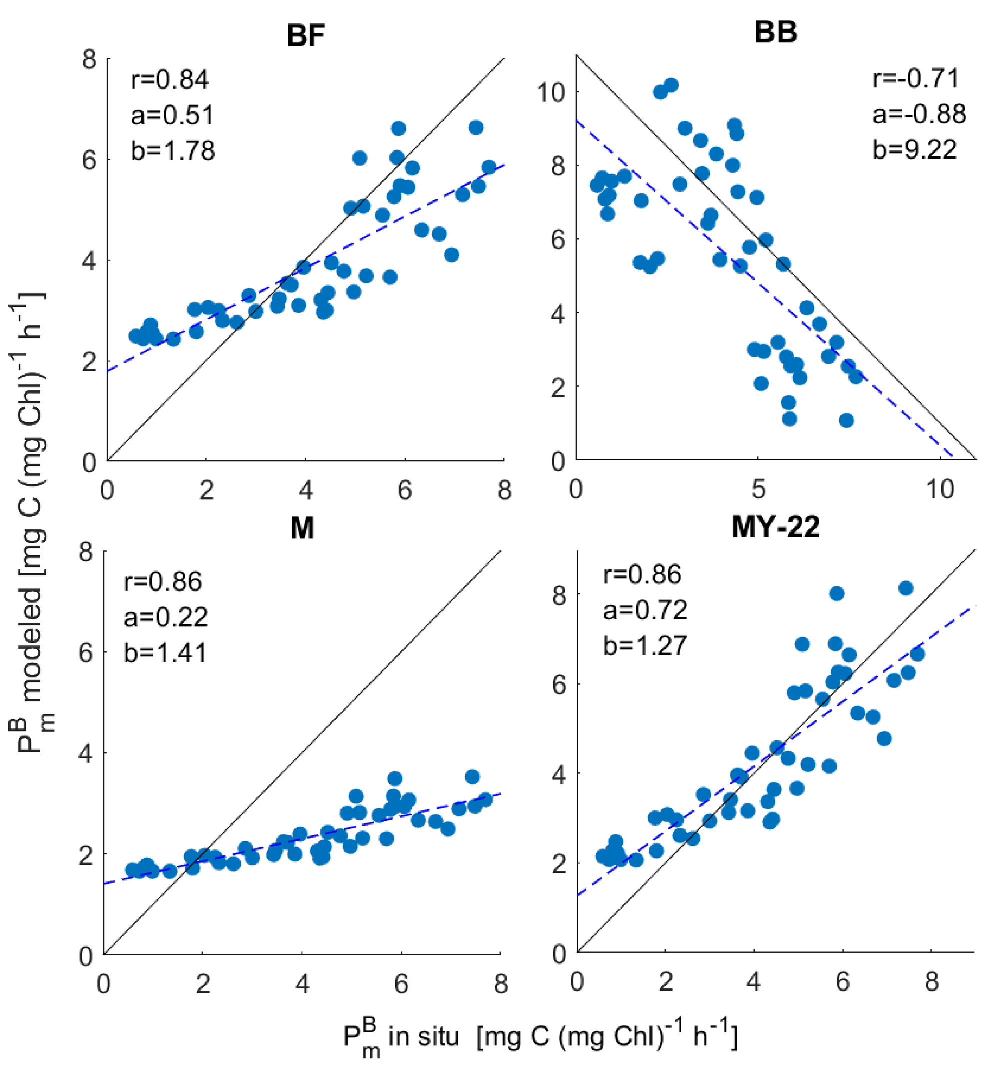


Figure 5. Scatter diagram of modeled and in situ P_m^B in area 4, n = 47. Solid line is the line of equality of modeled and in situ values; dotted line is the line of linear regression. Algorithms: BB - Balch et al., 1992; M - Megard, 1972; BF - Behrenfeld and Falkowski, 1997; MY-22 - fitted algorithm.

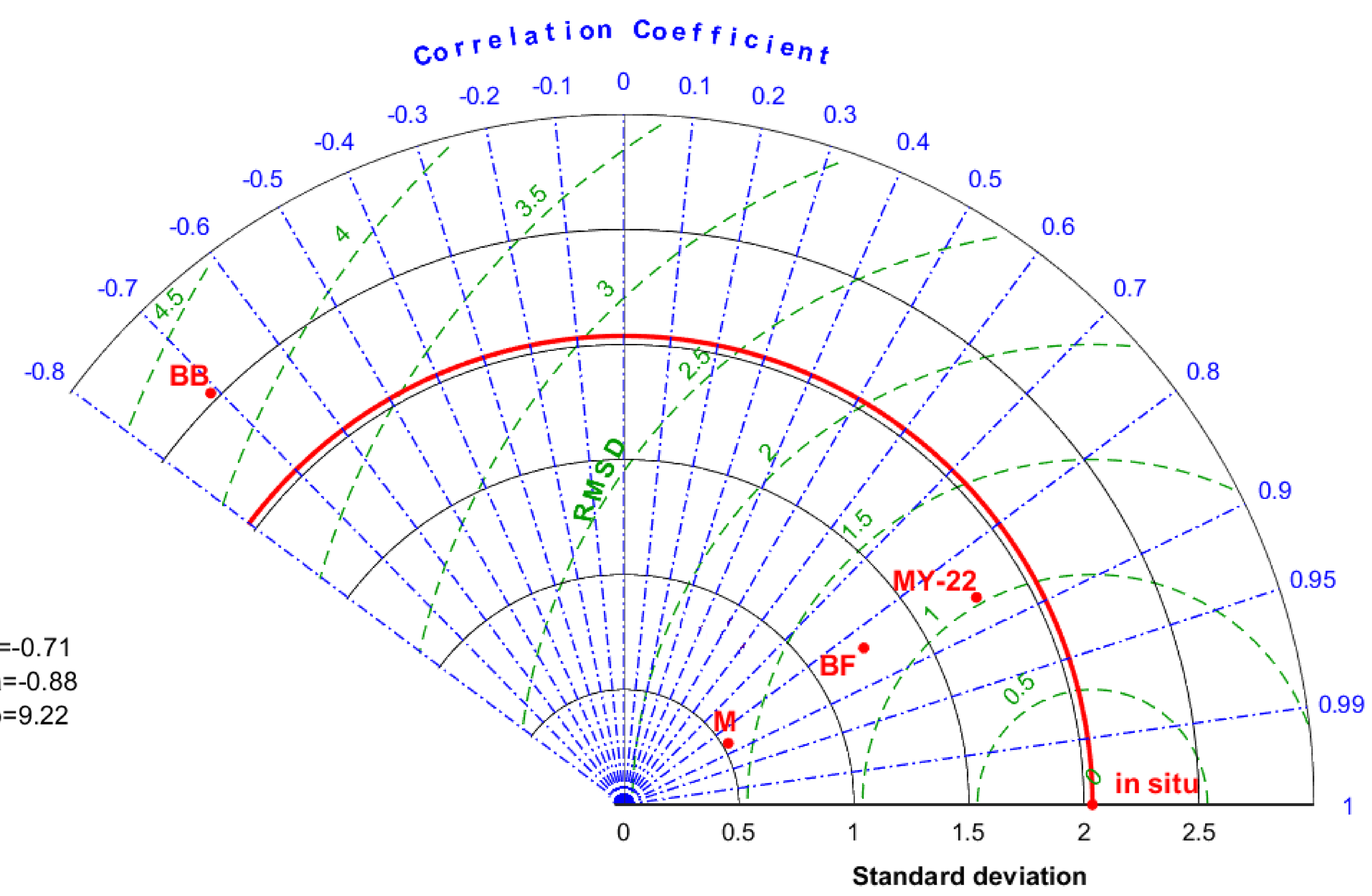


Figure 4. The Taylor diagram for modeled and *in situ* P_m^B [mg C (mg Chl)$^{-1}$ h^{-1}] at the station areas 4 according to the main dataset, n = 47. Standard Deviation - solid arcs, centre-pattern RMSE - dotted arcs, *r* (correlation coefficient) - dashed lines with dots. Algorithms: BB - Balch et al., 1992; M - Megard, 1972; BF - Behrenfeld and Falkowski, 1997; MY-22 - fitted algorithm.

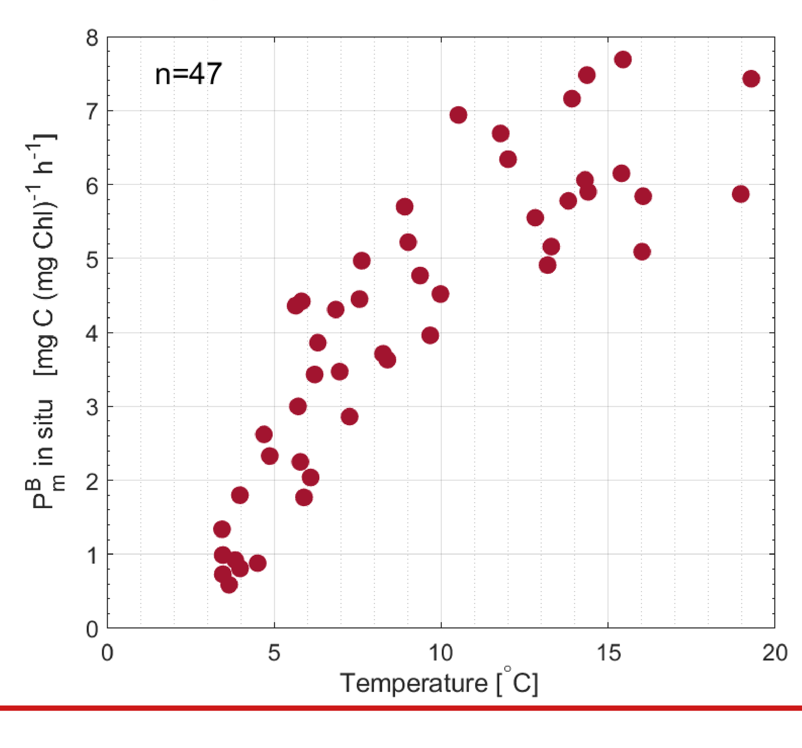


Figure 6. Dependent *in situ* P_m^B for SST at the areas 4

Conclusions

- An analysis of the long-term data series for the Atlantic Ocean (2002-2013) showed that there was **no significant relationship between P_m^B and Chl-a and SST concentrations for a whole series of data** (n=350). Therefore, in this work the P_m^B variability in certain areas of the ocean in different seasons of the year was considered.
- The strongest relationship between **P_m^B and SST (*r*=0.82 at p<0.01) was in winter**, while in spring and summer the relationship was moderate (*r*=0.30 at p<0.01), and no significant connection was observed in fall.
- The relationship between **P_m^B and Chl-a** was only near the Grand Banks of Newfoundland (area 4, *r*=-0.61 at p<0.01).
- **A connection between P_m^B values and the growing season of marine phytoplankton** was revealed and regional features and the range of P_m^B variability were compared: during spring flowering P_m^B values varied in a wide range: 0.6-12.7 mg C (mg Chl)$^{-1}$ h^{-1} (Fig. 1a), decreased over summer (on average, 2.53 mg C (mg Chl)$^{-1}$ h^{-1}) and reached a minimum in fall (2.35 mg C (mg Chl)$^{-1}$ h^{-1}), the maximum value was in winter (3.8 mg C (mg Chl)$^{-1}$ h^{-1}).
- In addition, well-known **algorithms of P_m^B as a function of SST** have been reviewed and validated: they showed a significant connection (*r*=0.44-0.81 at p<0.01) with *in situ* data depending on the study area (Fig. 4).
- **The new empirical algorithms of P_m^B** were developed due to the necessary to take into account the seasonal and regional variability of the parameters. The selected coefficients of the linear equation for a specific water area **give the closest estimates of P_m^B compared to the other algorithms** (according to statistical characteristics) (Fig. 4, 5).