PhysioGlob

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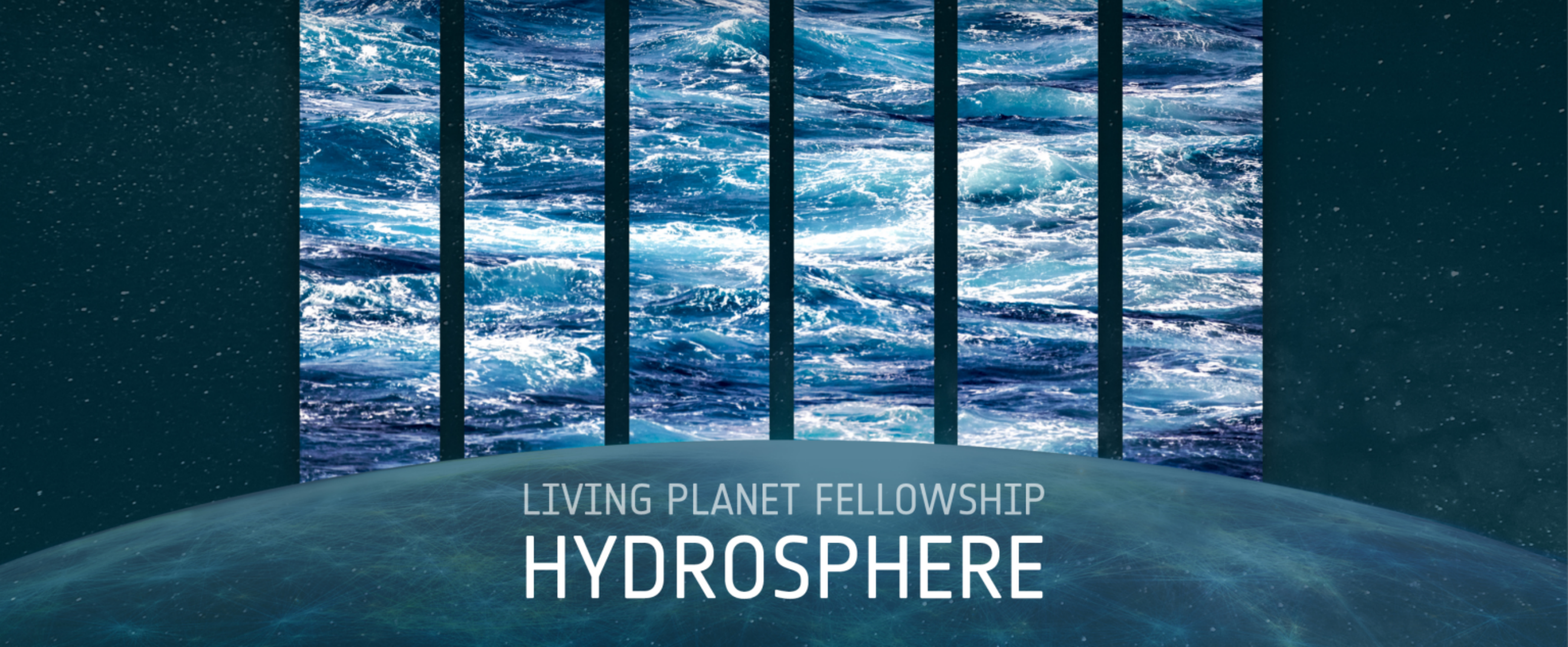
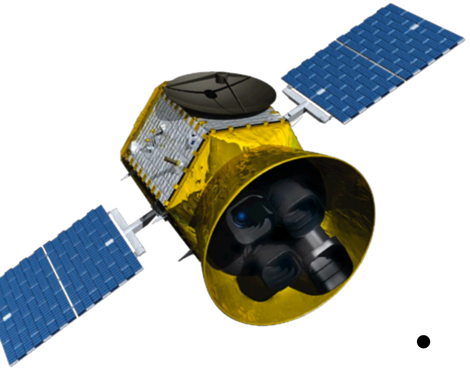


General Context

Assessing the inter-annual **Physio**logical response of phytoplankton to **Glob**al warming using long-term satellite observations



Why is important study phytoplankton from space?

- Phytoplankton produces ~50% of the **primary production** of the Earth
- Phytoplankton are basis of oceanic trophic chain through the photosynthesis process: fundamental actress in the **global carbon cycle**
- Phytoplankton are **sentinels** of **changes** in the ocean because they rapidly respond to environment perturbations

Scientific objectives

Goals:

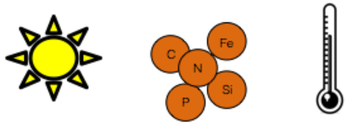
- Which is the physiological response – in terms of temporal oscillations – of phytoplankton to global warming/climate change on both global and regional scales?

- Which are the main drivers of the phytoplankton changing and physiological temporal oscillations?

Scientific objectives

What is the physiological response and how we can detect it from space?

Light, nutrients and temperature are the most important variables that drive the phytoplankton production and define the so-called "*Integrated Growth Environment*" (*Behrenfeld et al.*, 2008)



Phytoplankton cells respond to fluctuations in light and nutrients with physiological strategies that enhance the efficiency of light capturing and photosynthetic capacity, growth and persistence

Photoadaptation

Changes that might happen at the genotype level, and are expected to occur on a long evolutionary time-scale

(*Moore et al.*, 2006)

Photoacclimation

Phenotypic response at the cellular level:
1) Regulation of the pigment amounts (e.g. chlorophyll-*a*)
2) Other components of the photosynthetic machinery (such as, electron transport chain, photosystem I and II, and their efficiency)

(*Dubinsky and Stambler*, 2009)

The most important and easily observable effect due to photoacclimation is the variation of the cellular concentration of photosynthetic pigment such as chlorophyll-*a* (Chl).

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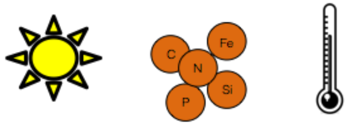

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The most important and easily observable effect due to photoacclimation is the variation of the cellular concentration of photosynthetic pigment such as chlorophyll-*a* (Chl).

Satellite Chl cannot distinguish between community and intra-cellular dynamics

High abundance of cells with low Chl

Low abundance of cells with high Chl

$Chl:C_{phyto} = 1$

$Chl:C_{phyto} = 4$

Alternative index to define algal biomass concentration in terms of phytoplankton carbon (C_{phyto}; in mg m^{-3}) based on particulate backscattering coefficient, b_{bp}.
A direct index of phytoplankton physiology is provided through changes in chlorophyll-carbon ($Chl:C_{phyto}$) ratios

Scientific objectives

Backscattering-based phytoplankton carbon - C_{phyto} - from space

$$C_{phyto} = [b_{bp}(\lambda) - b^{k}_{bp}(\lambda)] \cdot SF$$ (*Behrenfeld et al.*, 2005)

C_{phyto} is phytoplankton carbon biomass [mg C m^{-3}]

b_{bp} is the total particulate backscattering retrieved by satellite [m^{-1}]

b^{k}_{bp} is the *background* contribution of non-algal particles to total b_{bp} (*i.e.* heterotrophic bacteria, viruses, particles aggregates)

SF is a scaling factor equal to 13000 mg m^{-2} taken from literature (*Behrenfeld et al.*, 2005)

What we have:
- Daily Chl from OC-CCI at 4 km resolution (1997-today) v4.2
- Daily R_{rs} from OC-CCI at 4 km resolution (1997-today) v4.2
- In-situ C_{phyto} data for validation (*Martinez-Vicente et al.*, 2017)

What we want:
Daily C_{phyto} from space at 4 km resolution (1997- today)

Status @MTR

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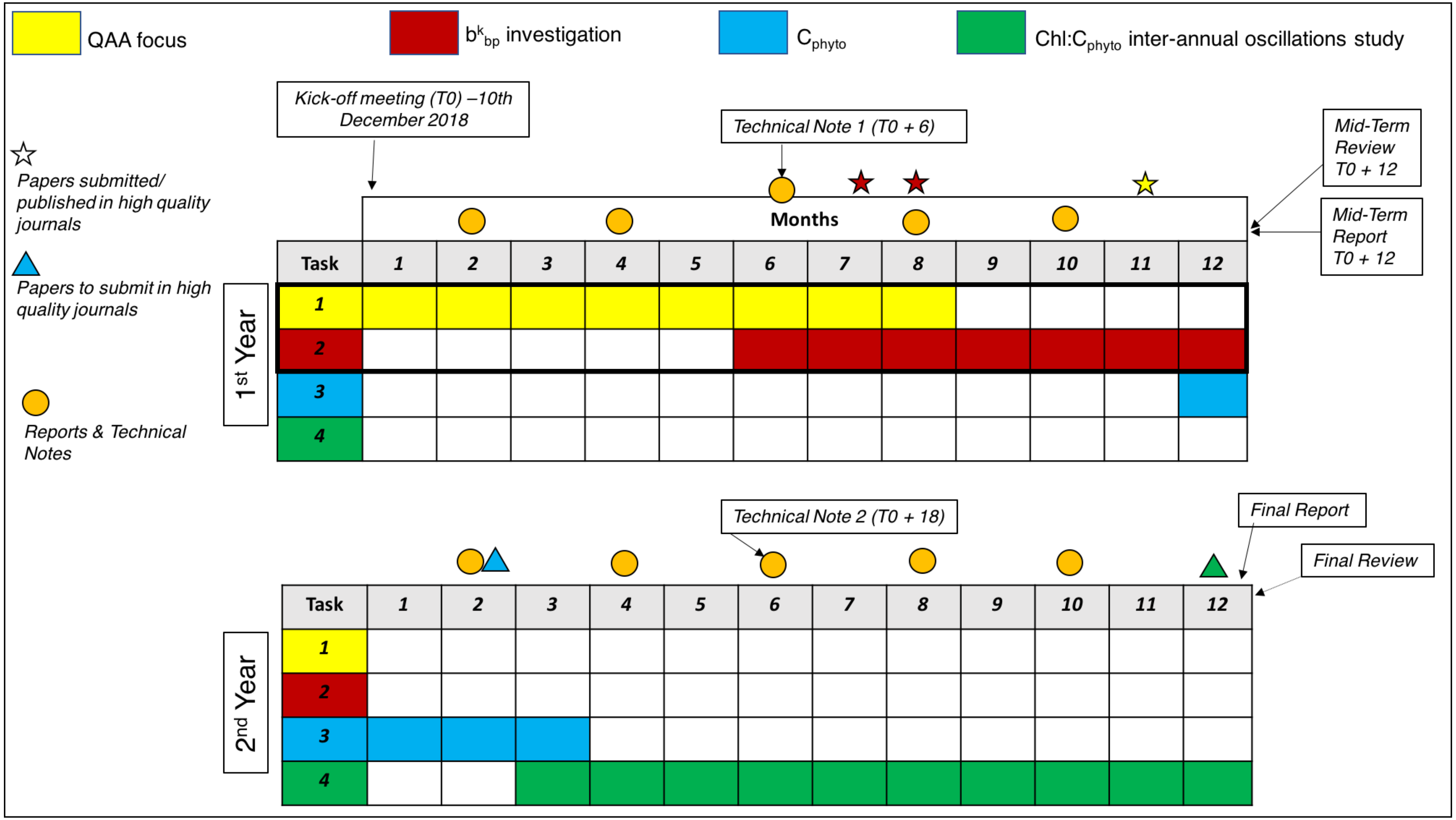
Is Quasi Analytical Algorithm - used in OC-CCI - a good algorithm to retrieve b_{bp} from R_{rs}? Can we improve it?

Does b^{k}_{bp} varies in space and time or not? Which is the best method for its computation?

Status @MTR



QAA focus
b^{k}_{bp} investigation
C_{phyto}
Chl:C_{phyto} inter-annual oscillations study
Papers submitted/ published in high quality journals
Papers to submit in high quality journals
Reports & Technical Notes
Kick-off meeting (T0) –10th December 2018
Technical Note 1 (T0 + 6)
Mid-Term Review T0 + 12
Mid-Term Report T0 + 12
Months
Task
1 2 3 4 5 6 7 8 9 10 11 12
1st Year
2nd Year
Technical Note 2 (T0 + 18)
Final Report
Final Review

Status @MTR

$$C_{phyto} = [b_{bp}(\lambda) - b^{k}_{bp}(\lambda)] \cdot SF$$

Resume of work tasks @MTR:

1. Focus on QAA algorithm for detection of b_{bp} from space: a possible update?
2. Does b^{k}_{bp} varies in space and time or not?
3. Estimation of a refined C_{phyto} from space and validation with in-situ data
4. Extraction and study of the main oscillatory modes of the physiological signal ($Chl{:}C_{phyto}$) in relation to physical and climate forcing agents on a global ocean scale by using long-term satellite observations (from 1997 up to today)

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Resume of work tasks @MTR:

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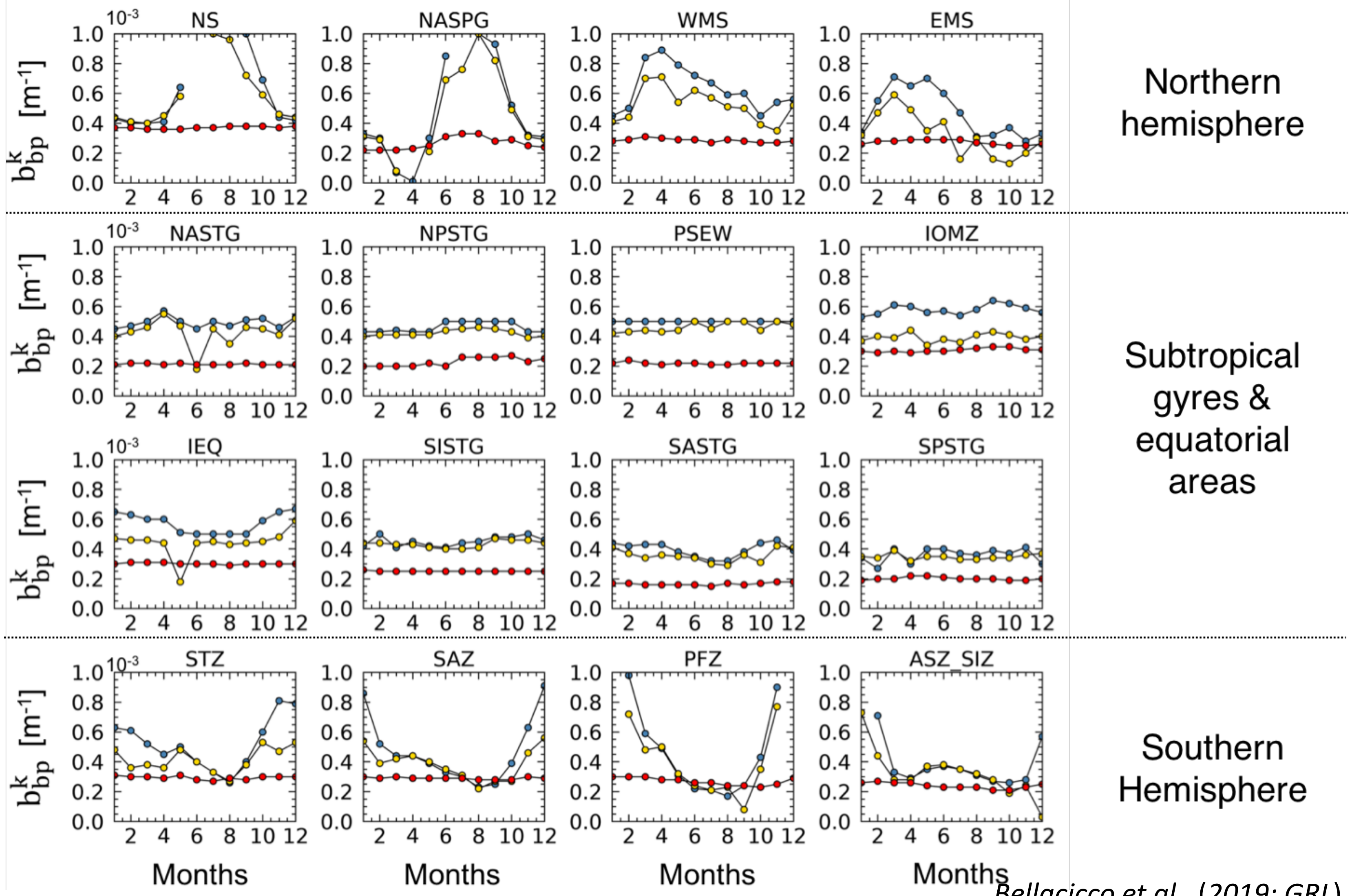
Results @MTR – Task #2

b^k_{bp} spatially and temporal resolved

b^k_{bp} varies in space and time capturing seasonal cycle at mid- and high latitudinal regions

Inclusion of its spatio-temporal variability in C_{phyto} is mandatory



Bellacicco et al., (2019; GRL)

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Resume of work tasks @MTR:

1. Focus on QAA algorithm for detection of b_{bp} from space: a possible update? Raman Correction inclusion (Pitarch et al., 2020) ✓
2. Does b^{k}_{bp} varies in space and time or not? $b^{k}_{bp}(\lambda) = f$ (lat, lon, time) by using a non-linear/linear model between Chl and b_{bp} (Bellacicco et al., 2019; 2020) ✓
3. Estimation of a refined C_{phyto} from space and validation with in-situ data
4. Extraction and study of the main oscillatory modes of the physiological signal ($Chl:C_{phyto}$) in relation to physical and climate forcing agents on a global ocean scale by using long-term satellite observations (from 1997 up to today)

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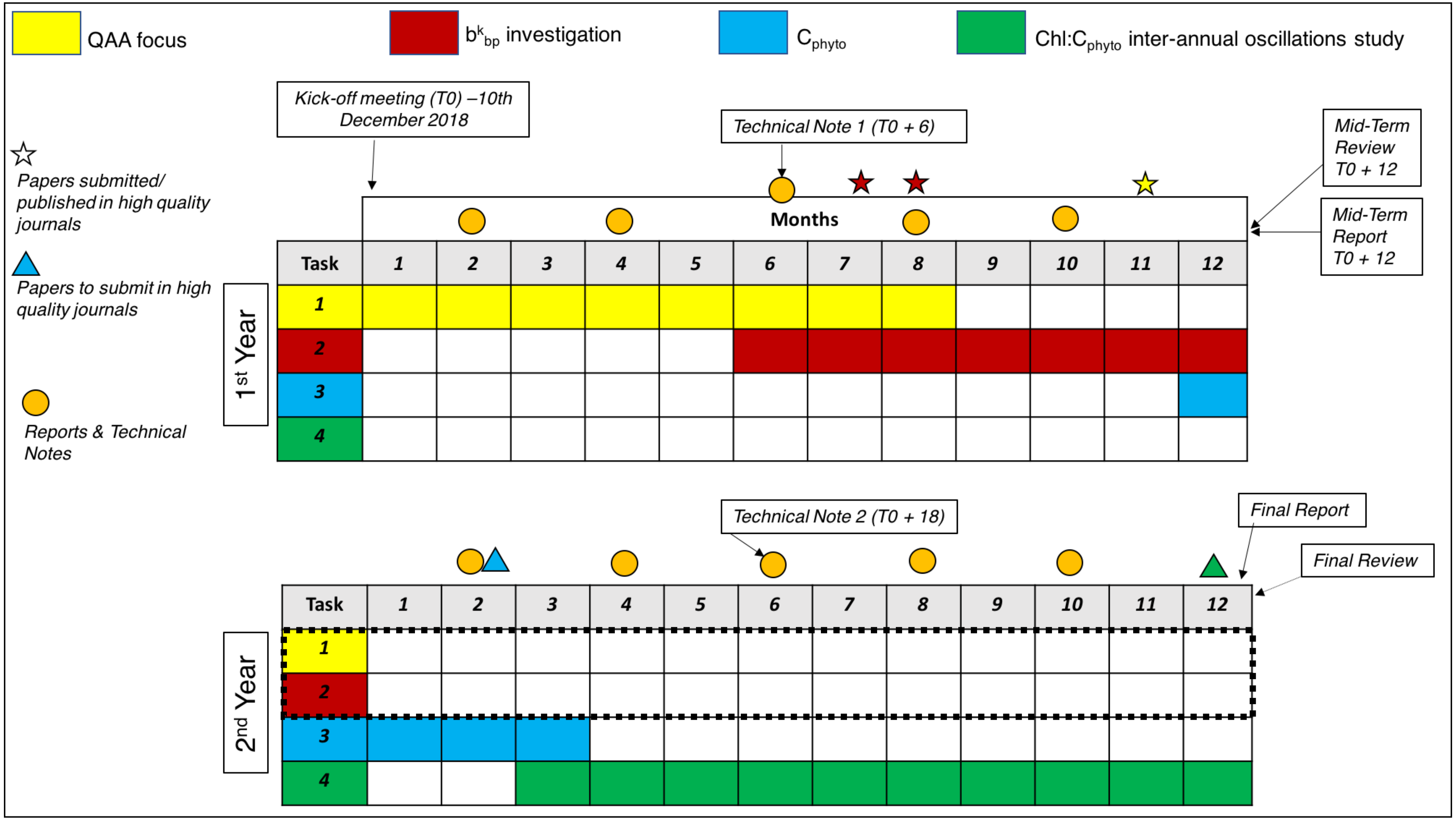
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2nd year – Task #3

$$C_{phyto} = [b_{bp}(\lambda) - b^{k}_{bp}(\lambda)] \cdot SF$$

HOW???

2nd year – Task #3

$$C_{phyto} = [b_{bp}(\lambda) - b^{k}_{bp}(\lambda)] \cdot SF$$

- **Inputs Data:**
  - ✓ ESA OC-CCI daily Chl and R_{rs} (λ) v4.2 time-series at 4 km resolution for the period 1997-2019
- **Algorithm**:
  - ✓ Application of QAA to R_{rs} (λ) for b_{bp} retrievals including the Raman-Correction on R_{rs} (λ)

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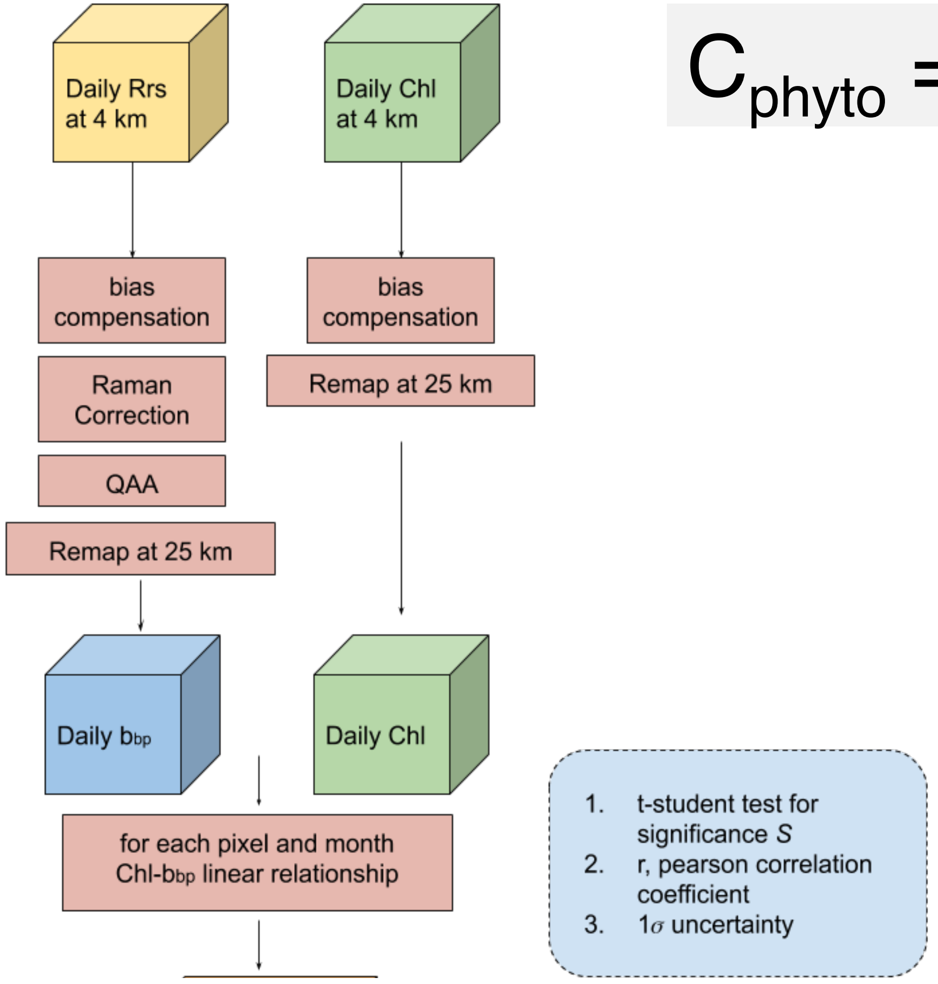

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Bellacicco et al., (2020; RS)

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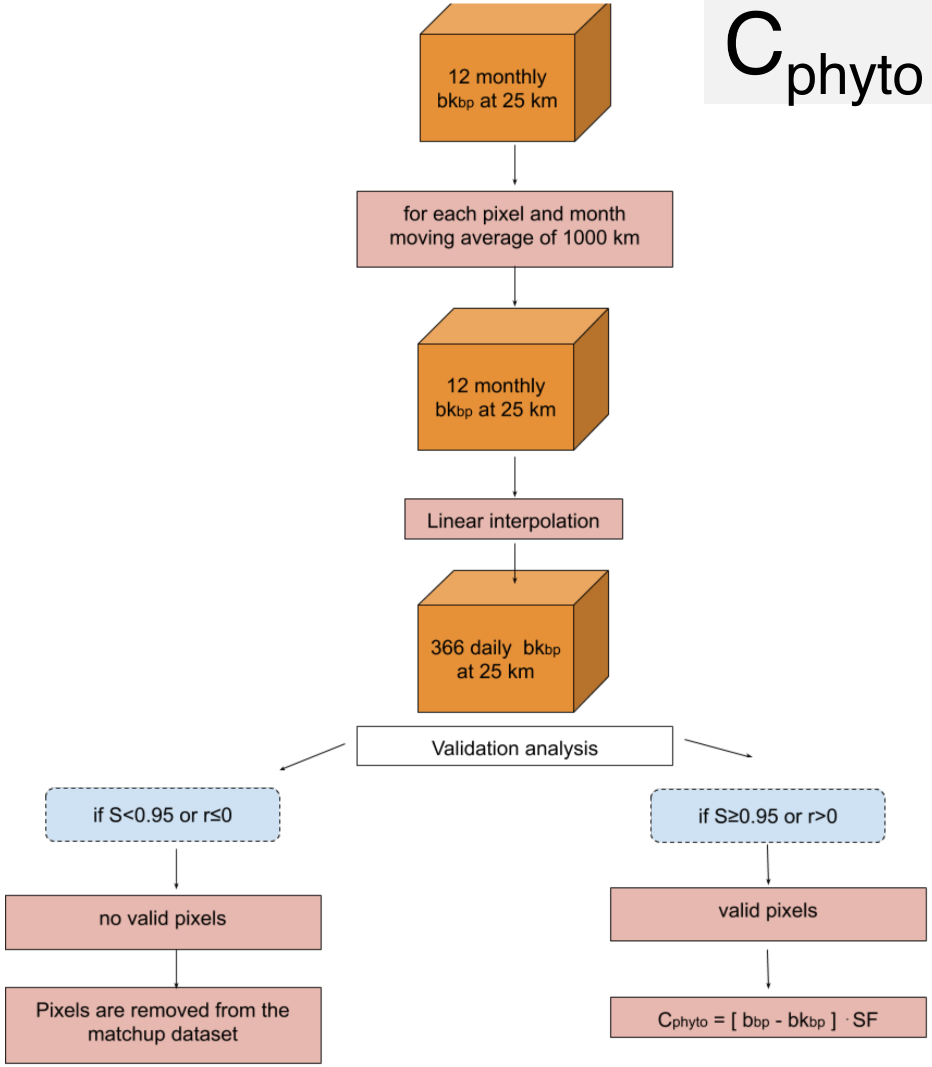

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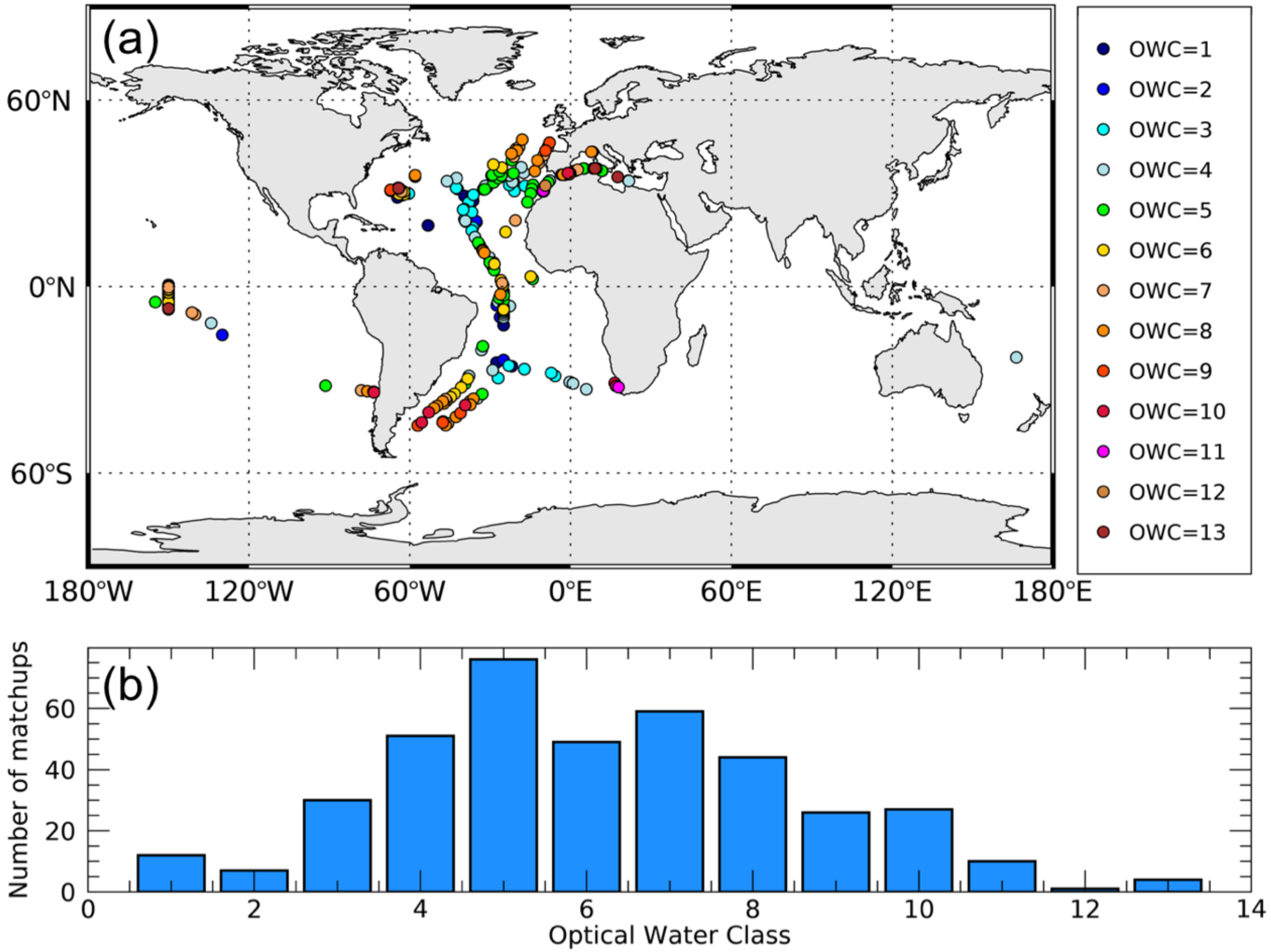
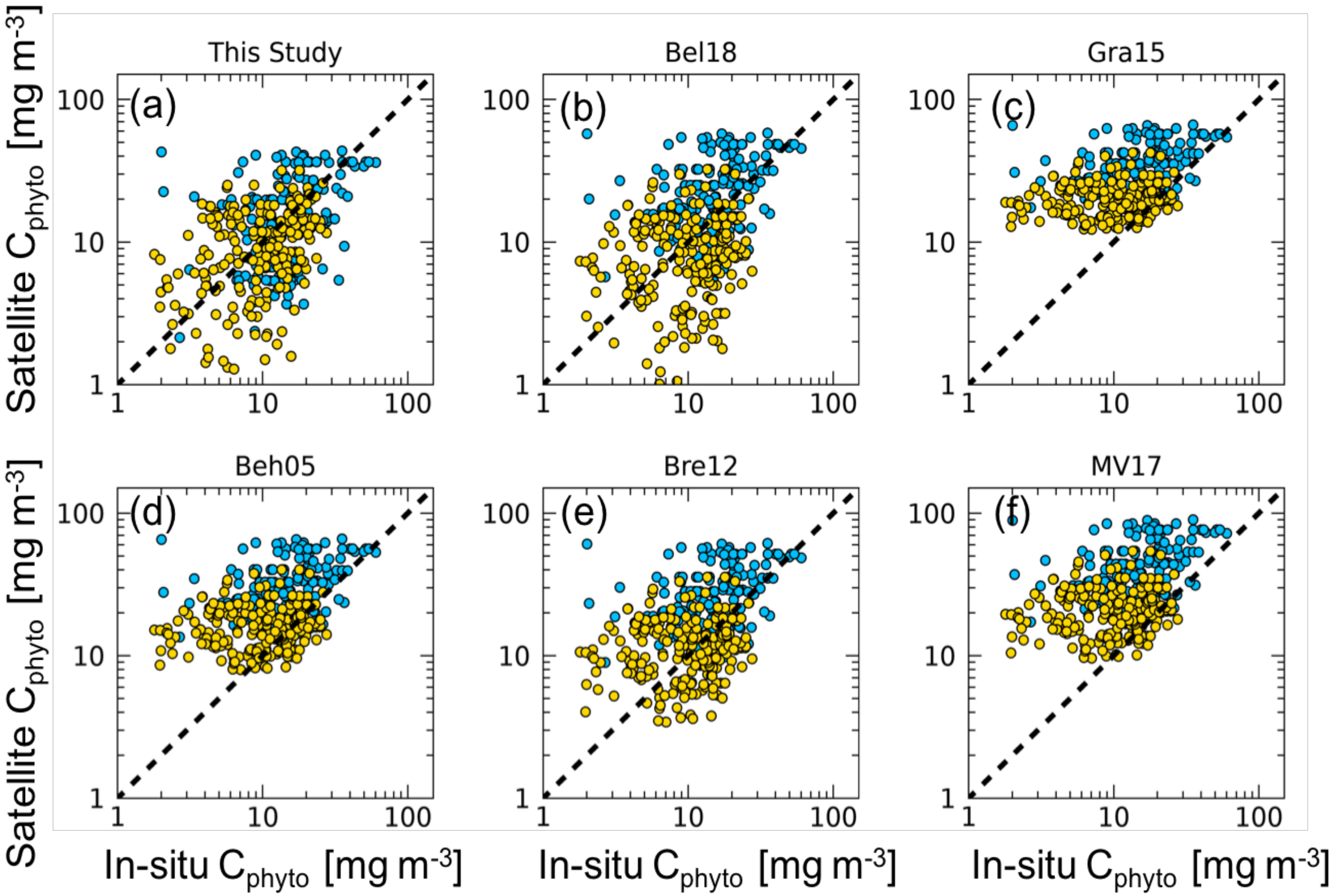
2nd year – Task #3



Bellacicco et al., (2020; RS)

1. The in situ C_{phyto} database is a compilation of data for a total of N=557 data points and consists of carbon biomass of picophytoplankton organisms (i.e., cell size < 2 μm).
2. Only pixels with a good (S > 0.95 and r > 0) satellite relationship between Chl and b_{bp} were retained so that the original 557 data points decreased to a **total of 396 matchups.**
3. The final matchup database encompassed from oligotrophic to mesotrophic waters and OWCs from 1 to 13. OWC from 1 to 6, corresponding to less productive waters, representing 56% of the in situ data.

2nd year – Task #3



Bellacicco et al., (2020; RS)

$$\delta = \frac{1}{N}\sum_{i=1}^{N}(y_i - x_i)$$

Bias (mg m^{-3})

$$\nabla = 100 * \frac{1}{N}\sum_{i=1}^{N}\frac{(y_i - x_i)}{x_i}$$

Rel. Bias in % (mg m^{-3})

$$\sigma_\Delta = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}[(y_i - x_i) - \overline{(y_i - x_i)}]^2}$$

Standard Deviation of the Differences (mg m^{-3})

2nd year – Task #3

Bellacicco et al., (2020; RS)

OWCs	N. obs.	This Study			Bel18			Gra15			Beh05			Bre12			MV17		
		δ	σ_Δ	∇	δ	σ_Δ	∇	δ	σ_Δ	∇	δ	σ_Δ	∇	δ	σ_Δ	∇	δ	σ_Δ	∇
1:2	19	−1.9	5.0	5.0	−2.6	6.2	8.8	9.2	6.0	259.4	5.2	6.2	174.9	0.7	6.2	78.0	8.5	7.2	250.0
3	30	−1.8	3.4	−13.9	−2.8	3.4	−27.3	9.1	3.3	211.8	5.0	3.4	129.8	0.5	3.4	38.2	7.9	3.9	189.2
4	51	−1.7	7.6	18.2	−2.1	8.5	31.3	9.4	8.6	193.1	5.7	8.5	141.1	1.2	8.5	77.0	10.7	10.6	213.6
5	76	−1.6	6.6	8.1	−3.2	7.9	5.9	8.2	7.7	122.8	4.6	7.9	85.8	0.03	7.9	39.2	9.4	9.2	142.6
6	49	1.5	7.9	38.7	−0.2	9.3	26.9	11.0	9.0	131.4	7.6	9.3	99.7	3.1	9.3	57.2	14.4	11.4	163.0
7	59	−1.9	8.4	−0.4	0.2	9.5	13.7	11.3	9.0	102.9	8.0	9.5	76.0	3.5	9.5	39.7	15.2	12.4	132.3
8	44	−0.5	10.1	38.8	5.2	10.3	73.6	15.8	9.9	164.99	13.0	10.3	139.9	8.5	10.3	101.3	23.3	13.1	220.0
9	26	1.9	11.8	39.2	13.8	12.3	113.4	23.6	12.2	181.5	21.6	12.3	166.5	17.1	12.3	135.5	36.4	14.6	259.1
10	27	4.6	16.5	103.4	17.2	17.6	206.2	26.7	17.0	278.2	25.0	17.6	266.2	20.4	17.6	231.2	41.1	22.6	396.0
11:13	15	3.2	14.0	51.7	12.2	15.2	148.8	22.6	15.2	275.9	20.0	15.2	241.4	15.5	15.2	187.3	31.5	30.4	355.6
1:6	225	−1.0	6.8	14.0	−2.2	7.9	12.0	9.3	7.7	164.0	5.6	7.9	114.7	1.1	7.9	54.8	10.7	9.6	178.4
7:13	171	0.5	11.8	36.6	7.3	13.7	86.5	17.8	13.0	173.8	15.1	13.7	150.7	10.6	13.7	113.3	26.0	18.4	235.4
All	396	−0.4	9.2	23.7	1.9	11.8	44.2	13.0	11.1	168.2	9.7	11.8	130.3	5.2	11.8	80.1	17.3	16.0	203.0

The new C_{phyto} algorithm proposed here performs better than any previously published model, with a relative error of 24% with respect to a reference in situ dataset.

Bellacicco et al., (2020; RS)

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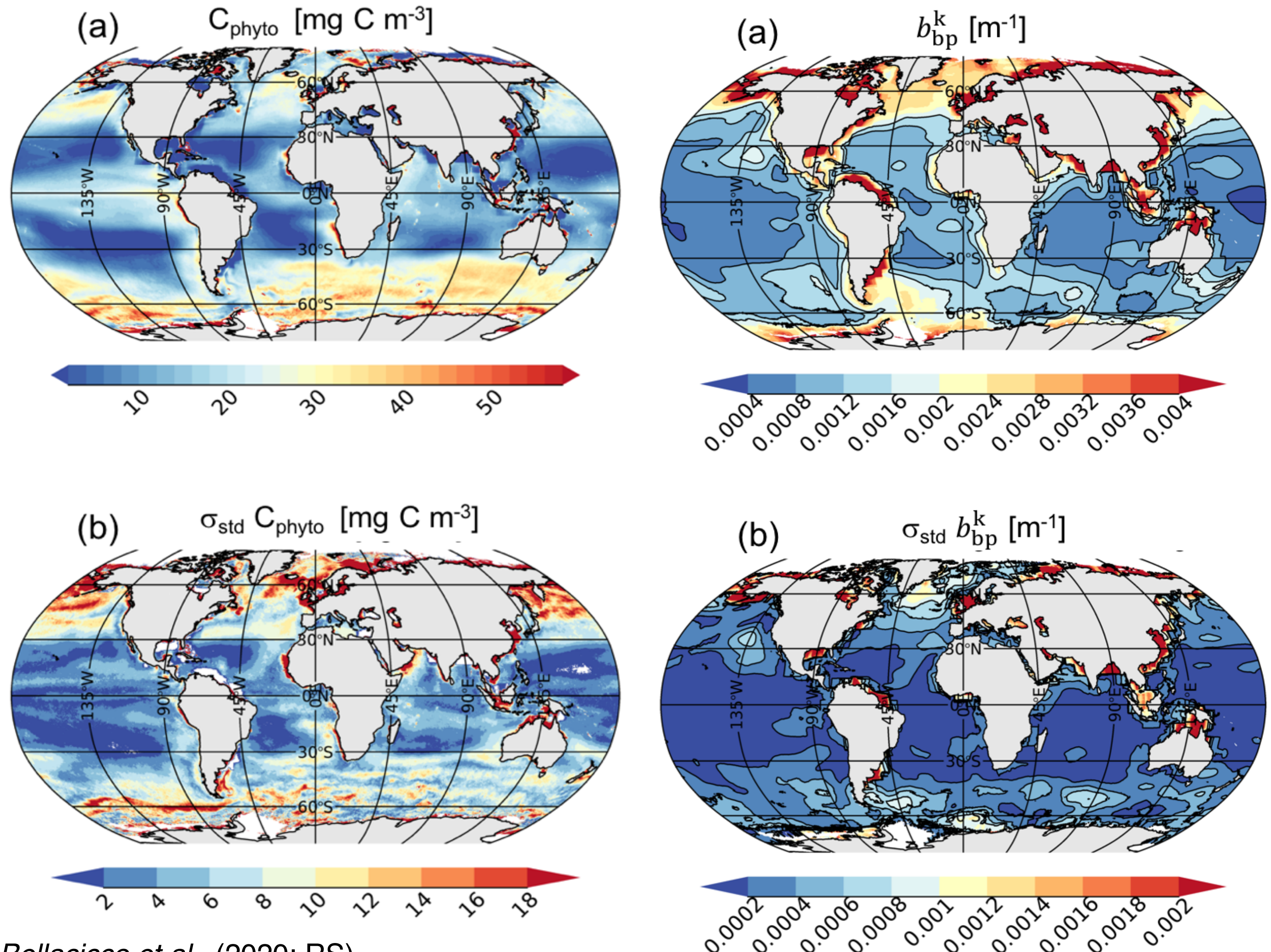
The new C_{phyto} algorithm shows the lowest error (14.0%) across most of the OWCs in which the picophytoplankton population dominates. On the contrary, the highest errors (36.6%) occur in OWCs 7–13 in which larger phytoplankton cells are supposed to dominate → the algorithm performance has to be interpreted with caution in those areas.

2nd year – Task #3



Bellacicco et al., (2020; RS)

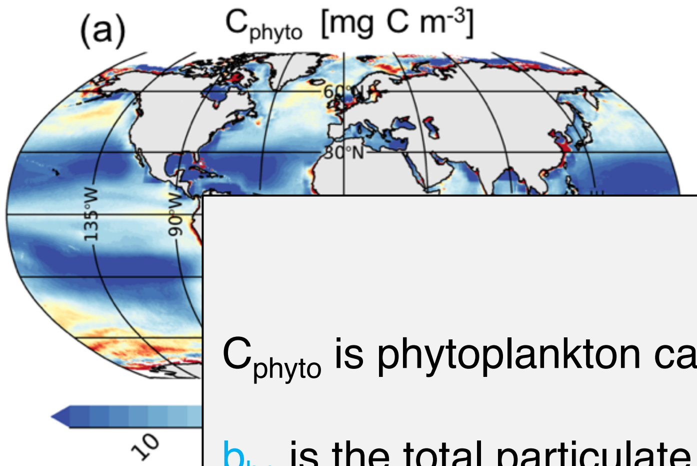
Caveats:

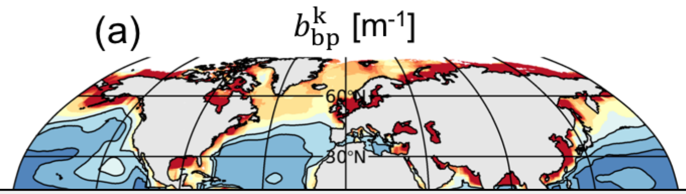
1. C_{phyto} assumes a constant value of 13000 mg m^{-2} as in Behrenfeld et al. (2005) → *Future efforts should be to investigate a refined scaling factor relating b_{bp} to C_{phyto} coupled with the b^{k}_{bp} space–time variability; additional laboratory work should be done to evaluate if change in SF values can affect the C_{phyto} estimations*

2. C_{phyto} algorithm relies on a tight relationship between b_{bp} and Chl, which is also influenced by the algorithms used for Chl and b_{bp} retrievals coupled with environmental conditions → *This points is a future challenge to be solved with other statistical methods mostly in the subtropical gyres.*

3. The algorithm validation is restricted only to in situ C_{phyto} data associated with picophytoplankton carbon → *one future necessity is to improve the in situ C_{phyto} dataset with new measurements representative of all phytoplankton size classes.*

2nd year – Task #3





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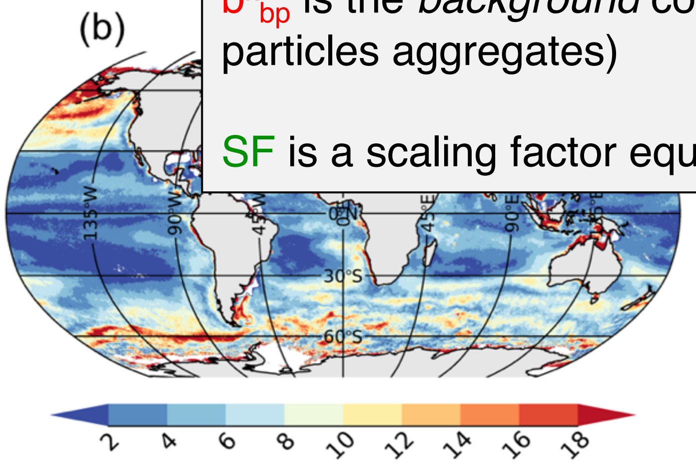

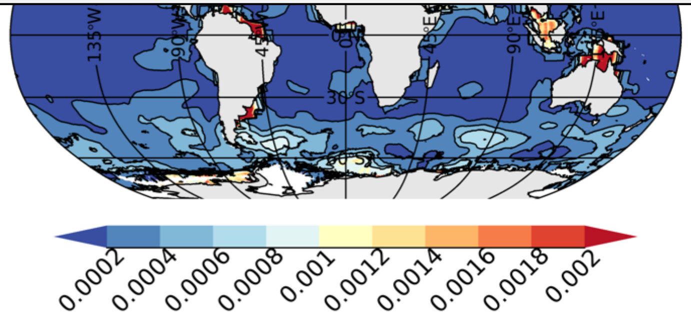

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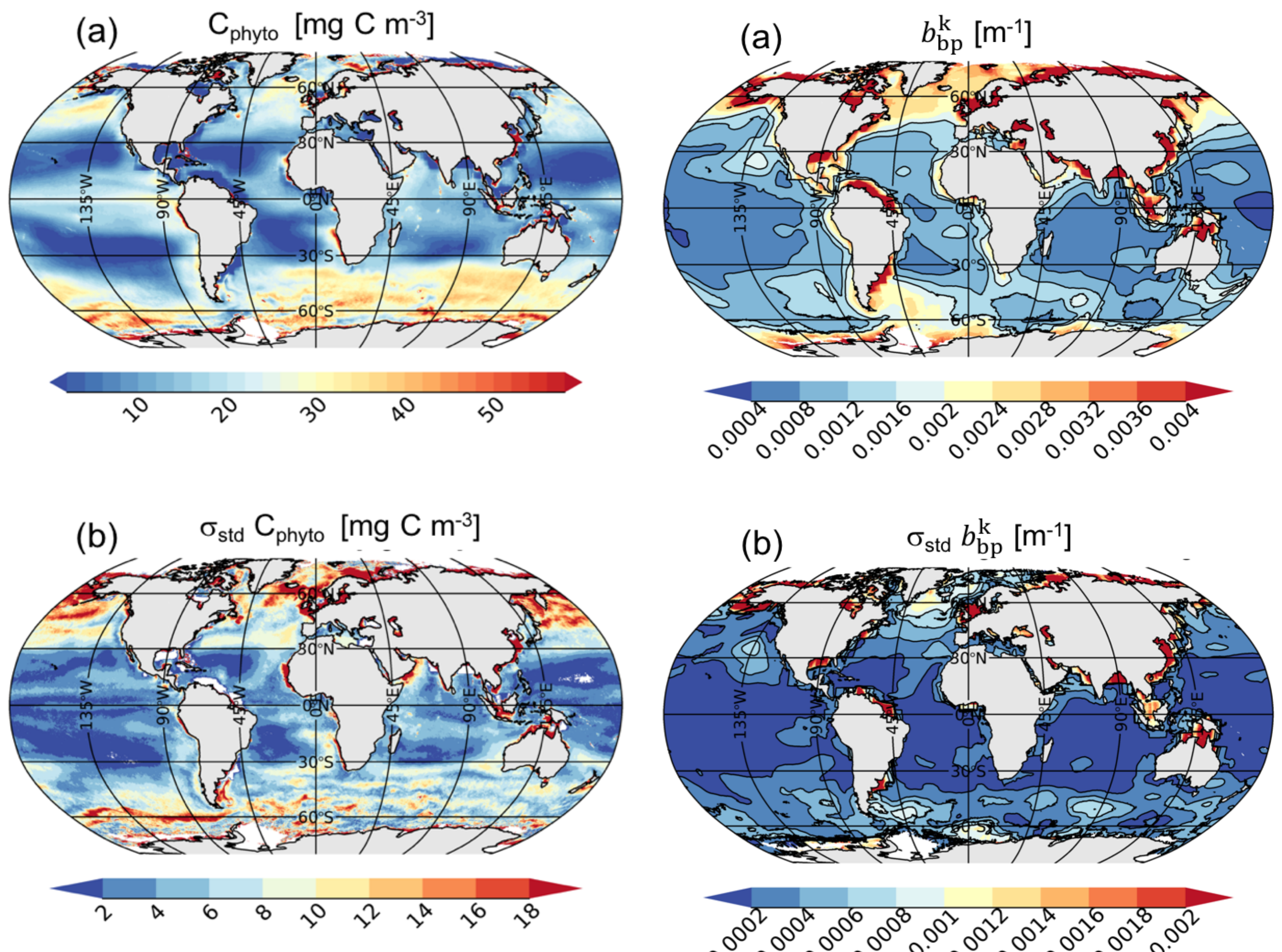
3. The algorithm validation is restricted only to in situ C_{phyto} data associated with picophytoplankton carbon → *one future necessity is to improve the in situ C_{phyto} dataset with new measurements representative of all phytoplankton size classes.*

2^{nd} year – Task #3



Bellacicco et al., (2020; RS)

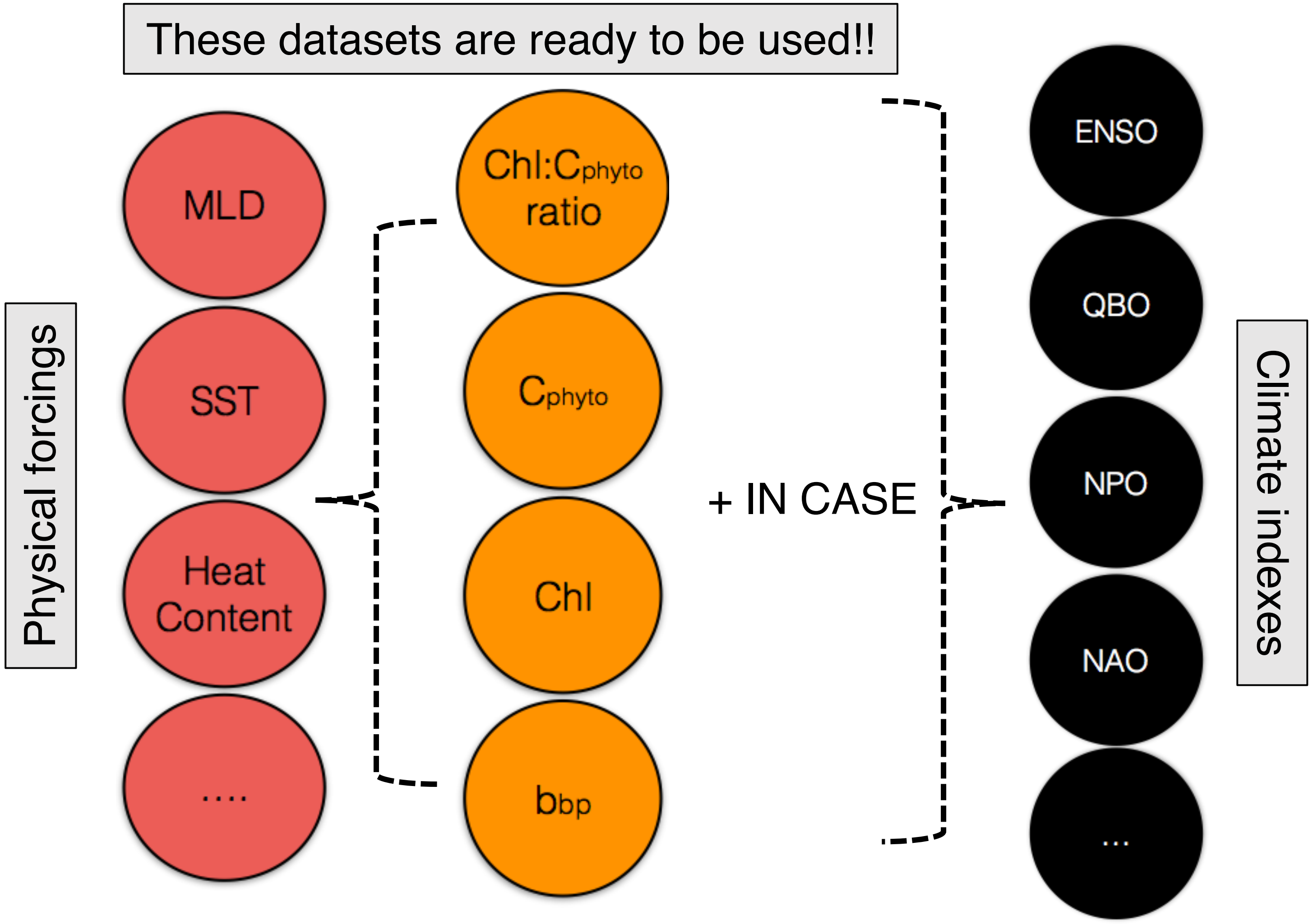
Caveats:

1. C_{phyto} assumes a constant value of 13000 mg m^{-2} as in Behrenfeld et al. (2005) → *Future efforts should be to investigate a refined scaling factor relating b_{bp} to C_{phyto} coupled with the b^k_{bp} space–time variability; additional laboratory work should be done to evaluate if change in SF values can affect the C_{phyto} estimations*

2. C_{phyto} algorithm relies on a tight relationship between b_{bp} and Chl, which is also influenced by the algorithms used for Chl and b_{bp} retrievals coupled with environmental conditions → *This points is a future challenge to be solved with other statistical methods mostly in the subtropical gyres.*

3. The algorithm validation is restricted only to in situ C_{phyto} data associated with picophytoplankton carbon → *one future necessity is to improve the in situ C_{phyto} dataset with new measurements representative of all phytoplankton size classes.*

Last Steps – Task #4



Sub-Goals:

- to classify components of single, and coupled, time series into trends, oscillatory patterns, and noise;
- to evaluate similarities among the inter-annual variabilities of parameters;
- to understand the spatio-temporal structure associated with oscillatory modes in the biological/physiological proxies and global ocean physical fields following *Ghil et al.,* (2002), *Marullo et al.,* (2011) and *Groth et al.,* (2017).

Methodology:

- Multi-Channel Spectral Analysis (M-SSA)
- Principal Component Analysis (PCA)

Main Conclusions

1. Assessment of QAA for b_{bp} retrievals with in-situ and satellite data.

2. Demonstration of b^k_{bp} spatio-temporal variability and importance of its inclusion in C_{phyto} computation → b^k_{bp} is thus not a single constant value but can be a series of maps.

3. Development of new C_{phyto} algorithm with higher accuracy in respect to others published models.

4. Highlight of the necessity to increase number of b_{bp} in situ observations to improve robustness of the satellite algorithms and to estimate satellite products uncertainties.

5. Highlight of the necessity to increase C_{phyto} in situ data of the different size classes to increase robustness of the satellite algorithms.

Final Step & Papers for 2nd year

1. M-SSA & PCA analysis of the Chl:C_{phyto} time-series alone and together with others parameters.

2. One paper about inter-annual Chl:C_{phyto} oscillations modes in relation to physical forcings (*e.g.* temperature, ocean heat content in the mixed layer depth, clouds coverage, etc...) and, in case of relevance, climate indexes (*e.g.,* QBO, NAO, NPO, ENSO).

Publications

Papers published within PhysioGlob (1st Year):

- **Bellacicco, M.,** Vellucci, E., Scardi, M., Barbieux, M., Marullo, S and D'Ortenzio, F. (2019). Quantifying the impact of linear regression model in deriving bio-optical relationships: the implications on ocean carbon estimations. *Sensors*, 19, 3032.

- **Bellacicco, M.**, Cornec, M., Organelli, E., Brewin, R., Neukermans, G., Volpe, G., Barbieux, M., Poteau, A., Schmechtig, C., D'Ortenzio, F., Marullo, S. Claustre, H. and Pitarch, J. (2019). Global variability of optical backscattering by non-algal particles from a Biogeochemical-Argo dataset. *Geophysical Research Letters*, 46 (16), 9767-9776.

Other papers published (1st Year):

- **Bellacicco, M.,** Vellucci, V., D'Ortenzio, F. and Antoine, D. (2019). Discerning dominant temporal patterns of bio-optical properties in the northwestern Mediterranean Sea (BOUSSOLE site). *Deep-Sea Research: Part I*, 148, 12-24.

Papers published/in revision within PhysioGlob (2nd Year):

- Pitarch, J., **Bellacicco, M.,** Organelli, E, Volpe, G., Colella, S., Vellucci, V. and Marullo, S. (2020). Retrieval of particulate backscattering using field and satellite radiometry: assessment of the QAA algorithm. *Remote Sensing,* 12 (1), 77.

- **Bellacicco, M.**, Pitarch, J., Organelli, E., Martinez-Vicente, V., Volpe, G., and Marullo, S. (2020). Improving retrieval of carbon-based phytoplankton biomass from ocean colour observations. *Remote Sens. 12, 3640;* doi:10.3390/rs12213640.

- Pitarch, J., **Bellacicco, M.**, Marullo, S. and H. J. van der Woerd. Global monthly maps of Forel-Ule index, hue angle and Secchi disk depth from twenty years of ESA-OC-CCI data (1997-2018) (*under discussion on Earth System Science Data*).

Publications

Other papers published (2nd Year):

- Mansour, K., Decesari, S., **Bellacicco, M.**, Marullo, S., Santoleri, R., Bonasoni, P., Facchini, M. C., Ovadnevaite, J., Ceburnis, D., O'Dowd, C. and Rinaldi, M. (2019). Particulate methanesulfonic acid over the central Mediterranean Sea: Source region identification and relationship with phytoplankton activity. *Atmospheric Research*, 104837

- Karam Mansour, Stefano Decesari, **Marco Bellacicco**, Salvatore Marullo, Rosalia Santoleri, Paolo Bonasoni, Maria Cristina Facchini, Jurgita Ovadnevaite, Darius Ceburnis, Colin O'Dowd, Matteo Rinaldi (2020). Linking Oceanic Biological Activity to Aerosol Chemical Composition and Cloud-Relevant Properties over the North Atlantic. *Journal of Geophysical Research: Atmospheres*. doi: 10.1029/2019JD032246.

Thanks!

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