2nd Ocean Carbon from Space workshop

24-26 November 2025 Online

Assessing satellite estimates of particle backscatter in the Mediterranean Sea using the first array of Biogeochemical-SVP Lagrangian drifters

Marco Bellacicco[1], Jacopo Busatto[1], Giovanni La Forgia[1], Emanuele Organelli[1], Robert J. W. Brewin[2], Xuerong Sun[2], Guglielmo Lacorata[1], Federico Falcini[1], Gianluca Volpe[1], Salvatore Marullo[1], Rosalia Santoleri[1], Luca R. Centurioni[3], Maria Laura Zoffoli[1] and Jaime Pitarch[1]

[1] Institute of Marine Science, National Research Council of Italy, Italy

[2] Centre for Geography and Environmental Science, Department of Earth and Environmental Sciences, University of Exeter, Cornwall, United Kingdom

[3] Lagrangian Drifter Laboratory, Scripps Institution of Oceanography, University of California, San Diego, La Jolla, California, United States

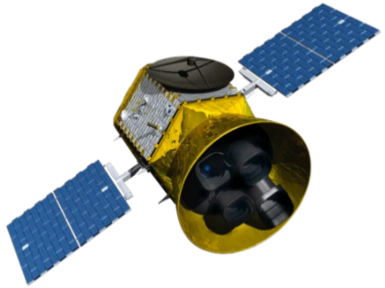
30/10/2025

Rationale

What is the plankton?

Plankton (from Greek: *planktos*; errant, **drifter**) is defined as the diverse collection of organisms unable to propel themselves and carried by the ocean currents (e.g. bacteria, algae)

Why is so important to study?



- *Mitigate* anthropogenic greenhouses gases
- *Modulate* biogeochemical cycles (e.g., carbon cycle)
- *Maintain* other trophic levels (e.g., fish)
- *Maintain* the ocean ecosystem functioning and productivity (e.g., ~50% of the primary production of the Earth)
- *Act* as sentinels of changes in the ocean because they rapidly respond to environment perturbations

Why from space?

- Synoptic observations
- Characterize and monitor phytoplankton dynamics at different spatial (e.g., from regional to global) and temporal (from daily to inter-annual) scales

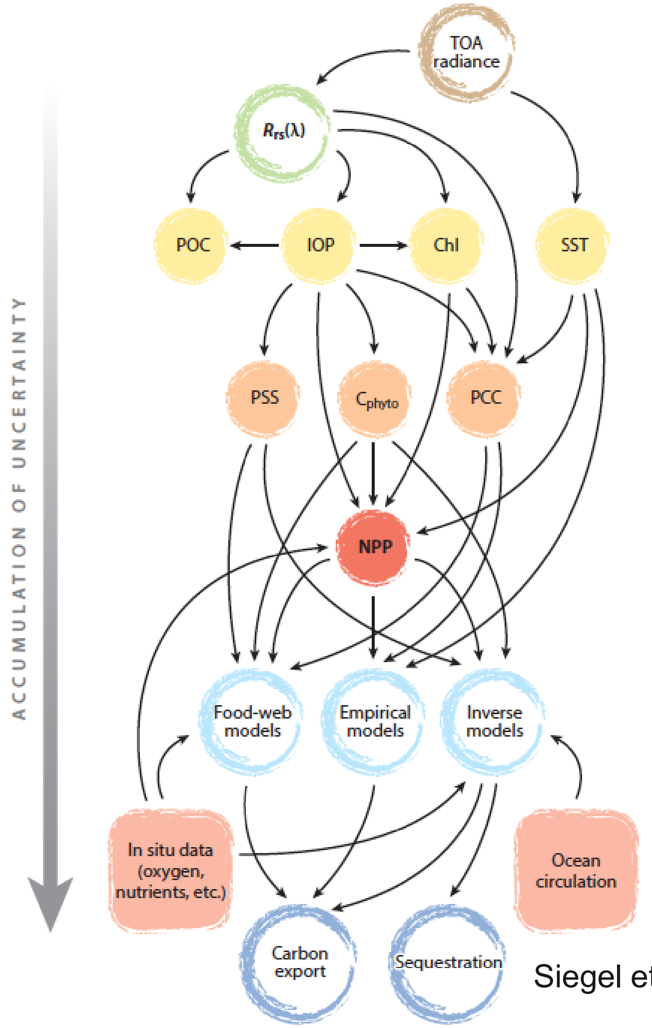
Rationale

Why should we measure the b_{bp} from space?

$b_{bp}(\lambda)$ is related to the particle concentration in seawater, on their size distribution, refractive index, shape and structure → 1-10 µm (Organelli et al., 2019)

↓

Particle growth (µ), phytoplankton carbon biomass (C_{phyto}), non-algal particles concentration (e.g. viruses, heterotrophic bacteria; NAP), particulate organic carbon (POC), phytoplankton physiology, net primary production (NPP), particles size distribution (PSD), organic enrichment of sea spray

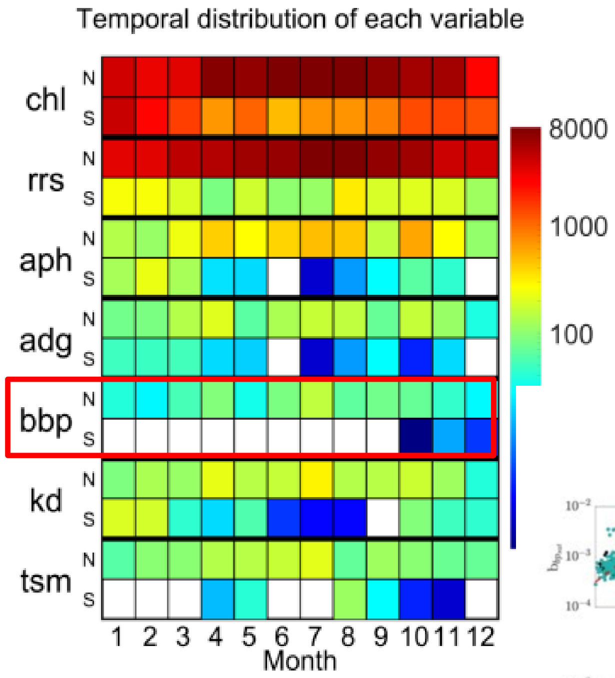


Siegel et al. (2023)

So, what‘s the problem?

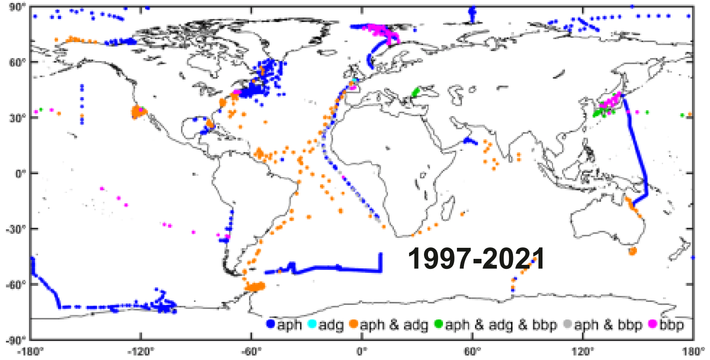
ESA OC-CCI project aims at creating a long-term, consistent, uncertainty-characterized time series of ocean color products, for use in climate-change studies

Rationale

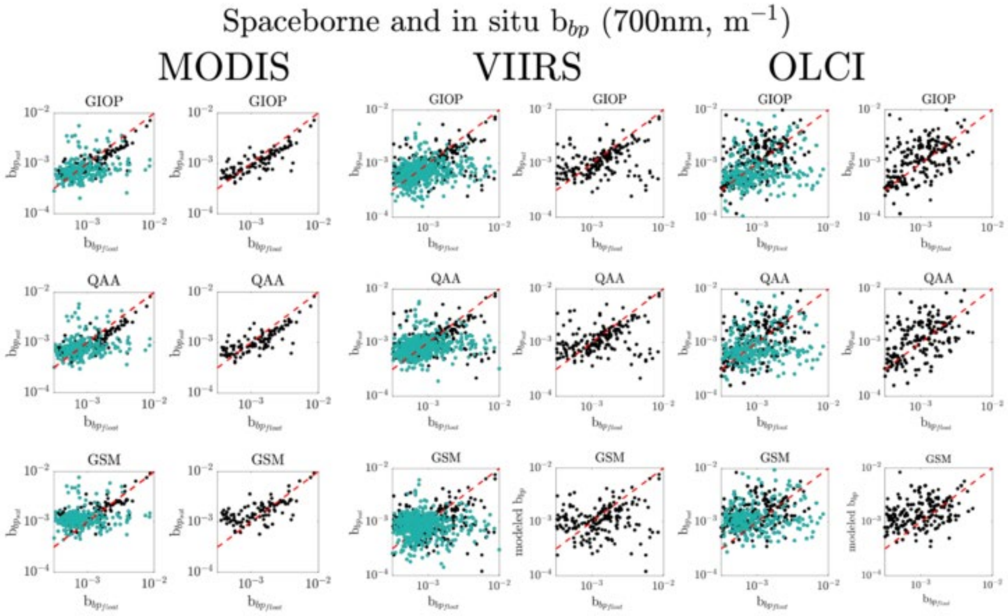


Valente et al. (2022)

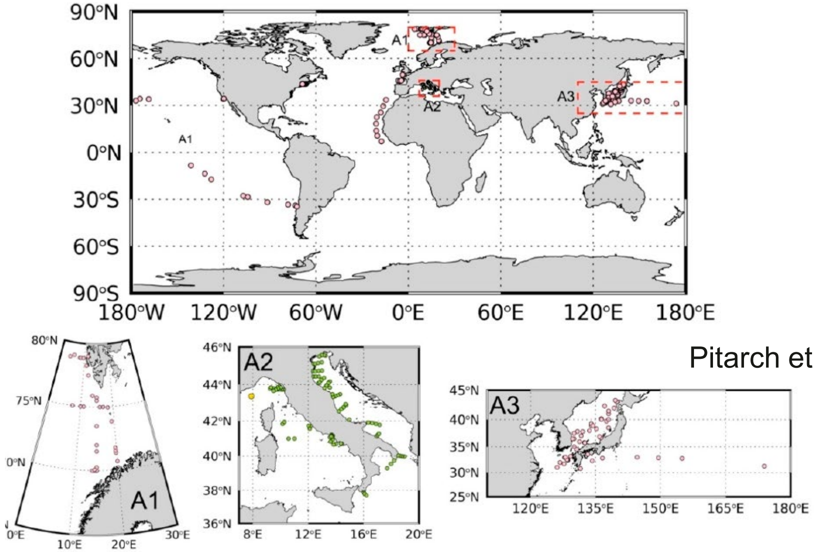
	Band (nm)	Bias (%)	RMS (%)	r^2	N
V19	412	24.2	51.8	0.66	147
	443	26.8	53.9	0.67	147
	490	29.1	56.0	0.68	147
	510	29.9	56.8	0.67	147
	555	31.0	58.1	0.67	147
	670	31.6	60.7	0.62	147
	All	28.8	56.3	0.68	882
BOU	442	56.6	62.7	0.67	97
	488	86.9	96.2	0.64	97
	550	41.9	50.2	0.70	97
	620	66.8	75.3	0.69	97
	All	63.1	73.1	0.69	388



Valente et al. (2022)

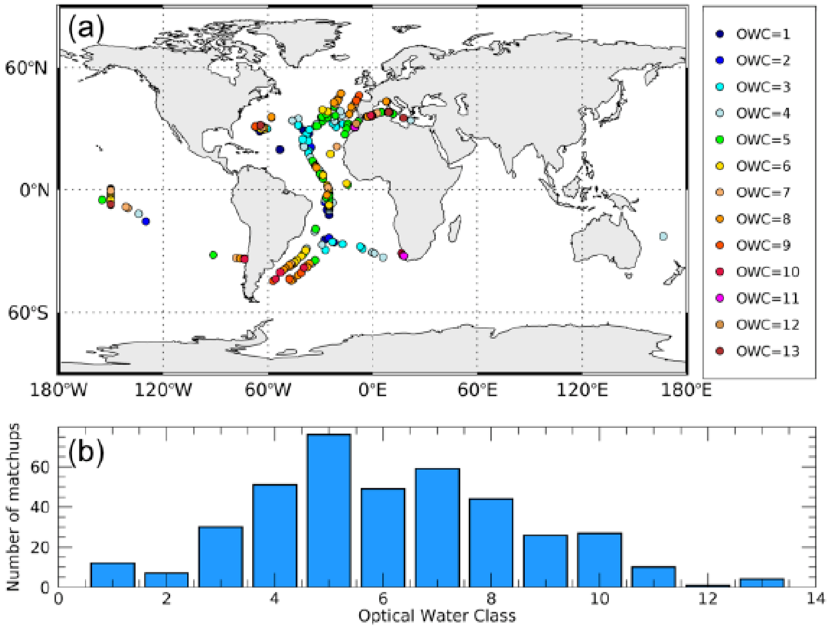


Bisson et al. (2019)

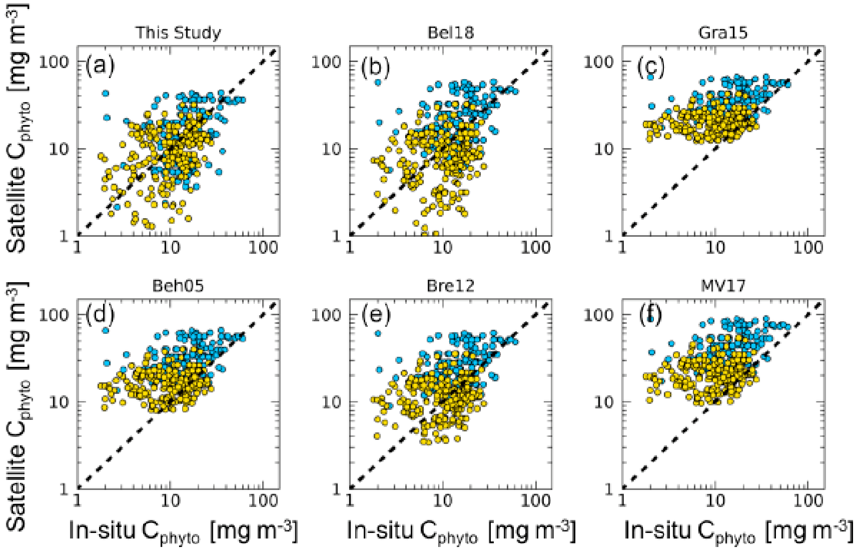


Pitarch et al. (2021)

Rationale

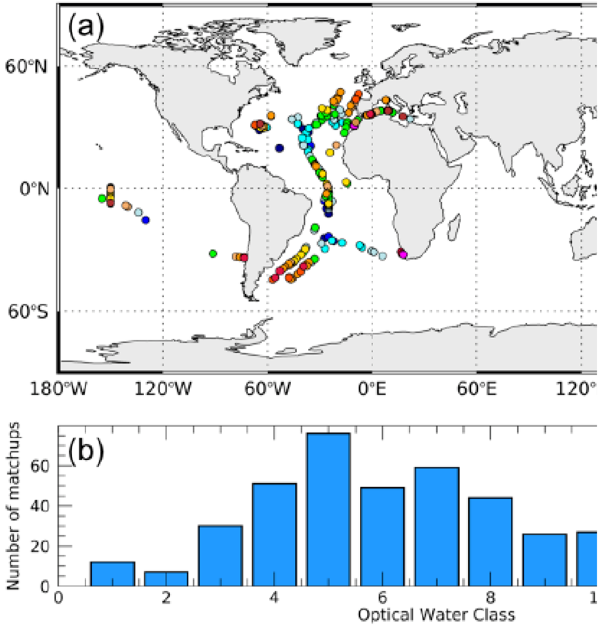


Bellacicco et al. (2020)

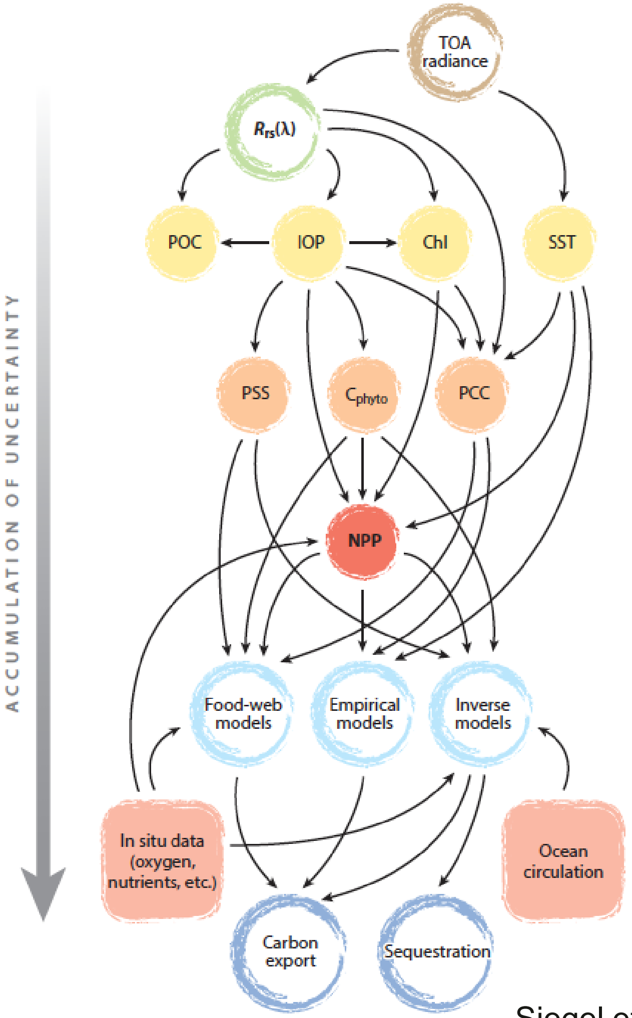


Bellacicco et al. (2020)

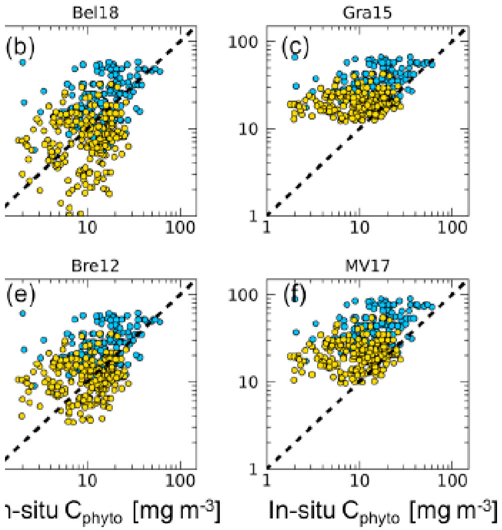
Rationale



Bellacicco et al. (2020)



Siegel et al. (2023)



llacicco et al. (2020)

Rationale

We need to **estimate uncertainties** on $b_{bp}(\lambda)$ retrievals to improve all the subsequent computations

Moorings

Gliders

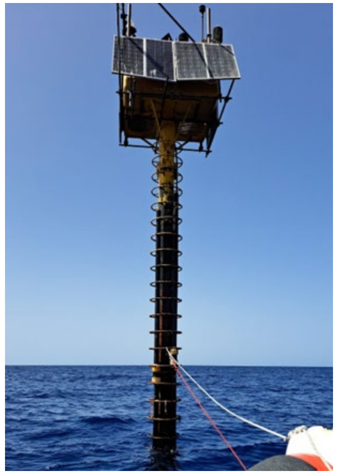
BGC-Argo floats

Cruises

Rationale

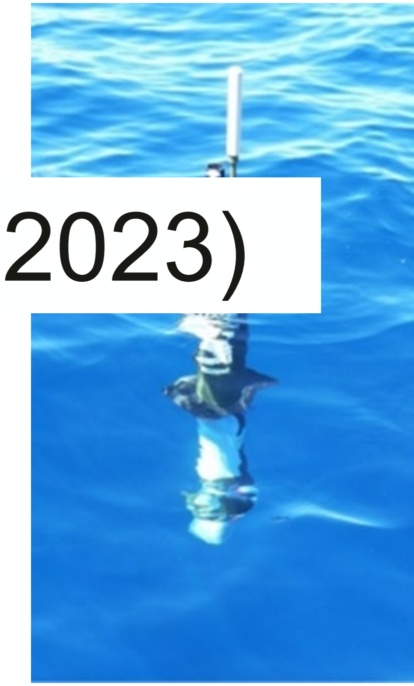
We need to **estimate uncertainties** on $b_{bp}(\lambda)$ retrievals to improve all the subsequent computations

Moorings



Gliders

BGC-Argo floats

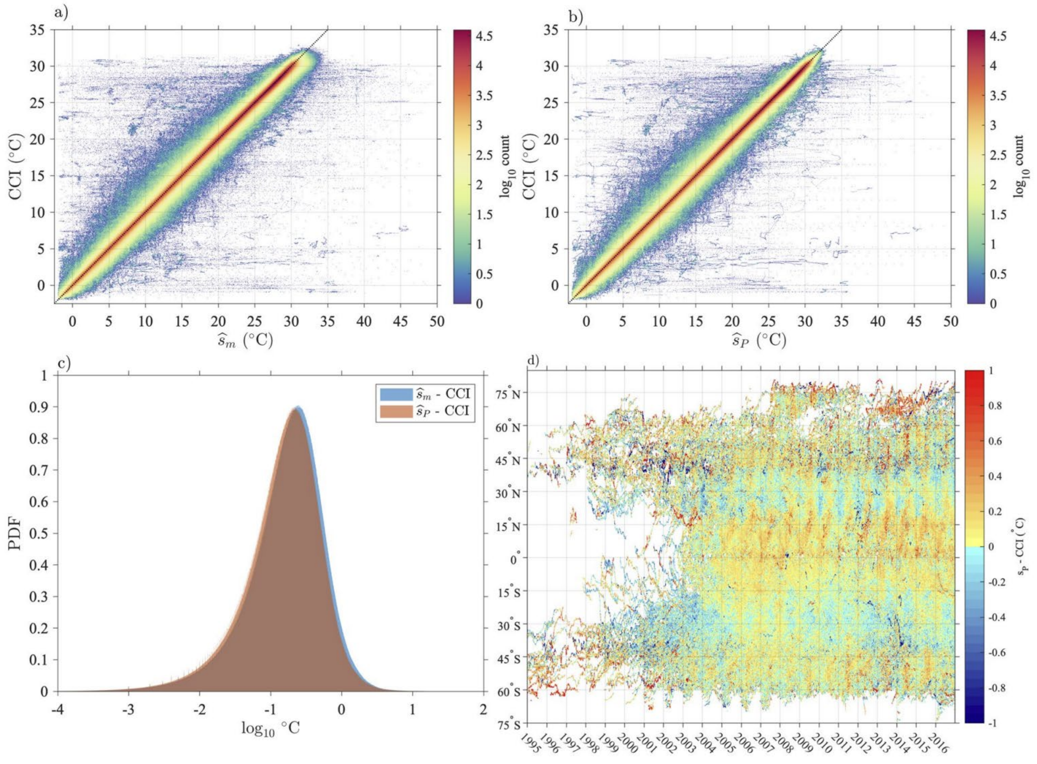


More in-situ observations (Brewin et al., 2023)

Cruises

Approach

…some years ago…

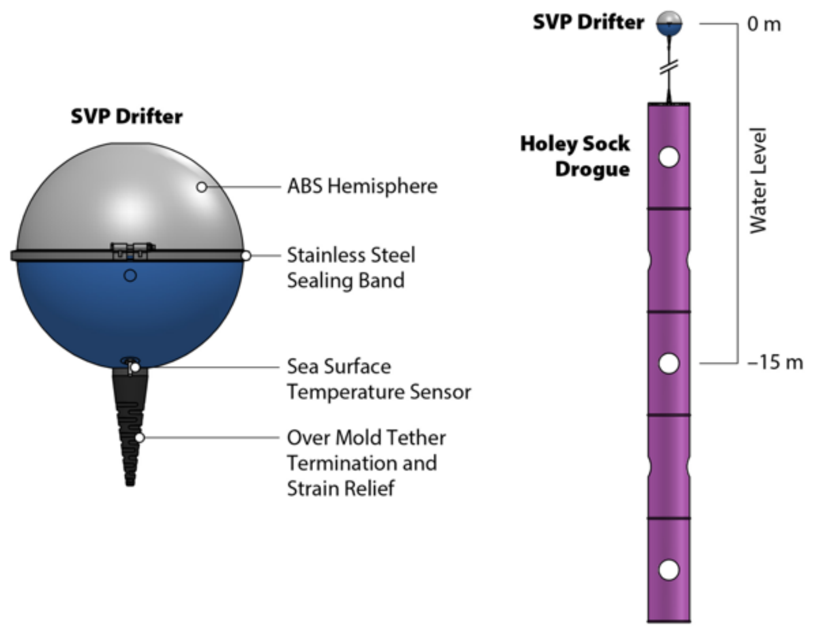


Elipot et al. (2022)

Approach

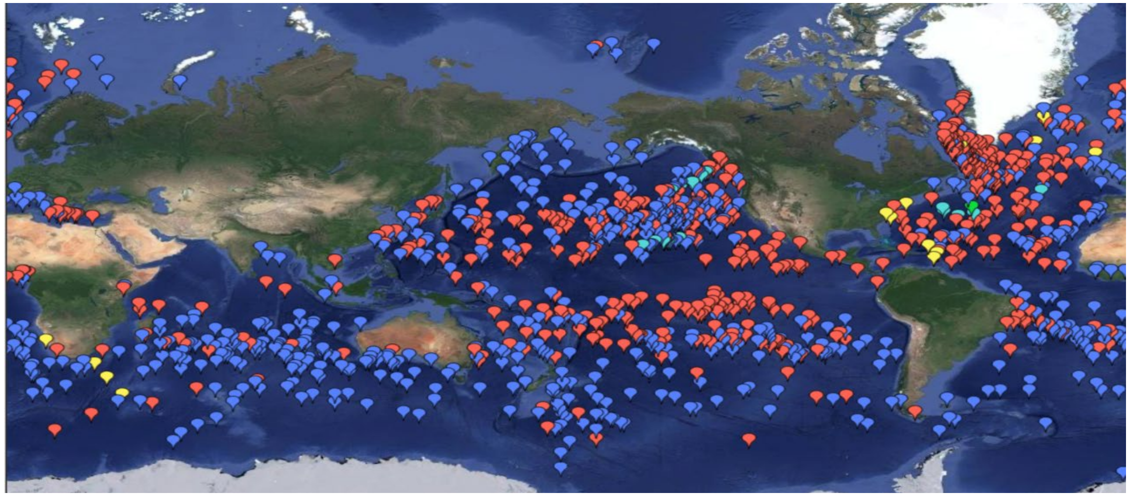
Technical Description:

•35 cm sphere surface float
•GPS-based tracking
•Iridium Short Burst Data (SBD) telemetry
•Sea surface temperature (±0.05 K accuracy)
•Holey sock drogue centered at 15 m depth
•Variable sampling rate down to 5 minutes
•Two-year lifespan
•TRL of 9
•Other sensors integrated: salinity, wind, barometer, etc..



SVP drifters with drogue at 15 m depth are the primary source of in-situ global observations of near-surface ocean currents and have been used for decades to study the ocean circulation and dynamics from sub-mesoscales (~1 km) to basin scales (1000 km) (Niiler et al., 2001; Centurioni, 2018)

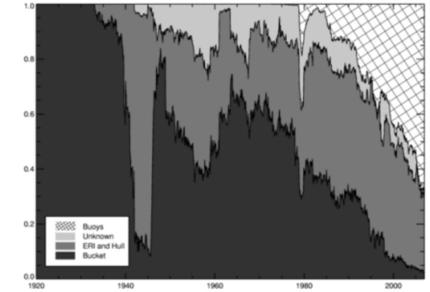
Approach



Overarching GDP goals:

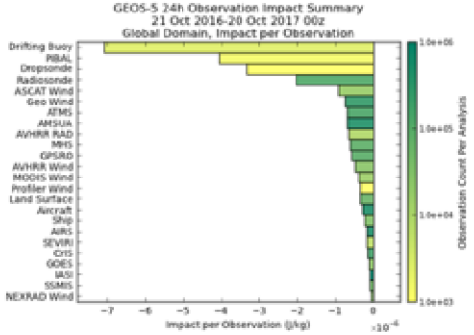
- Further our scientific understanding of the ocean, atmosphere and climate by observing surface physical processes in the global ocean.
- **Maintain a global 5ºx5º array of surface drifting buoys to meet the needs for an accurate and globally dense set of in-situ observations of near surface currents, SST, atmospheric pressure, winds, and salinity.**
- Build a collaboration with the international community to maintain the drifter array.

Main Critical Impact Areas



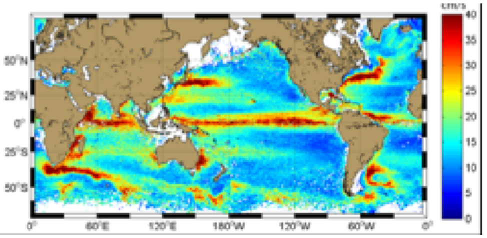
SST From Space Cal/Val

Left: Fractional contribution of SST data by platforms (buoys refers primarily to drifters, that provide more SST data than all the other sources combined). From Kennedy et al, 2011, JGR. Drifters provide X100 daily SST obs than Argo.



SLP for NWP and Climate Indices

Left: Drifters SLP data have the largest positive impact per observations (Centurioni et al. 2016, BAMS). Both forecasting and climate studies benefit from drifter data, especially in the southern ocean where the drifters are essentially the only source of in-situ SLP data.

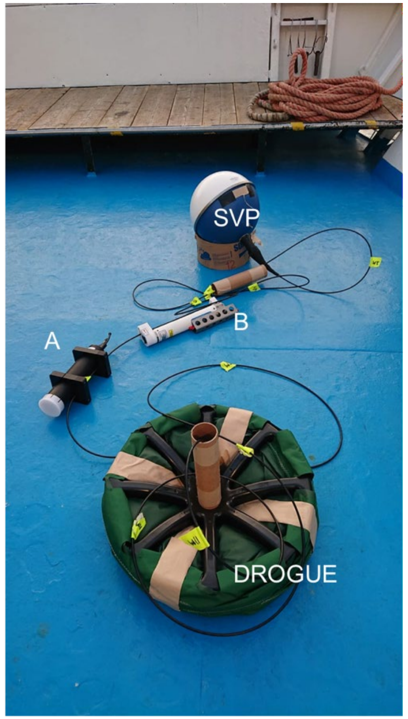


Science

Over 1,100 paper published to date use drifter data directly

By the courtesy of Dr. Centurioni

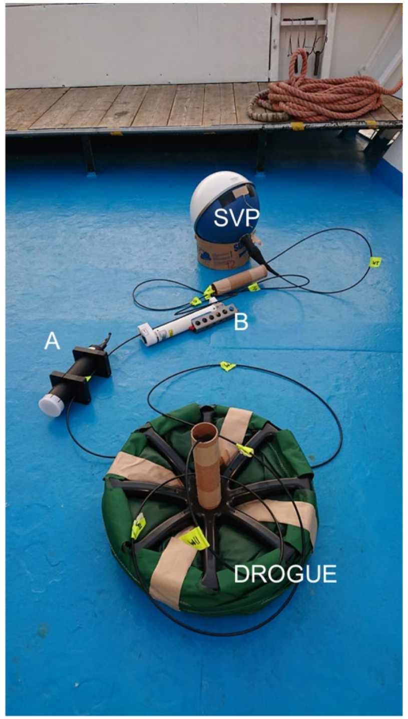
Biogeochemical-SVP drifter



Bellacicco et al. (2024)

- Standard SVP with SST sensor
- Conductivity and Temperature (CT) sensor @ 9 m depth
- Optical sensor for b_{bp} at different visible bands (470, 532 nm) @ 9 m depth
- High frequency time sampling (e.g., 1h to 3h)
- Internal memory
- Real-time data transmission by Iridium only of SST, CT and GPS data.

Biogeochemical-SVP drifter



Bellacicco et al. (2024)

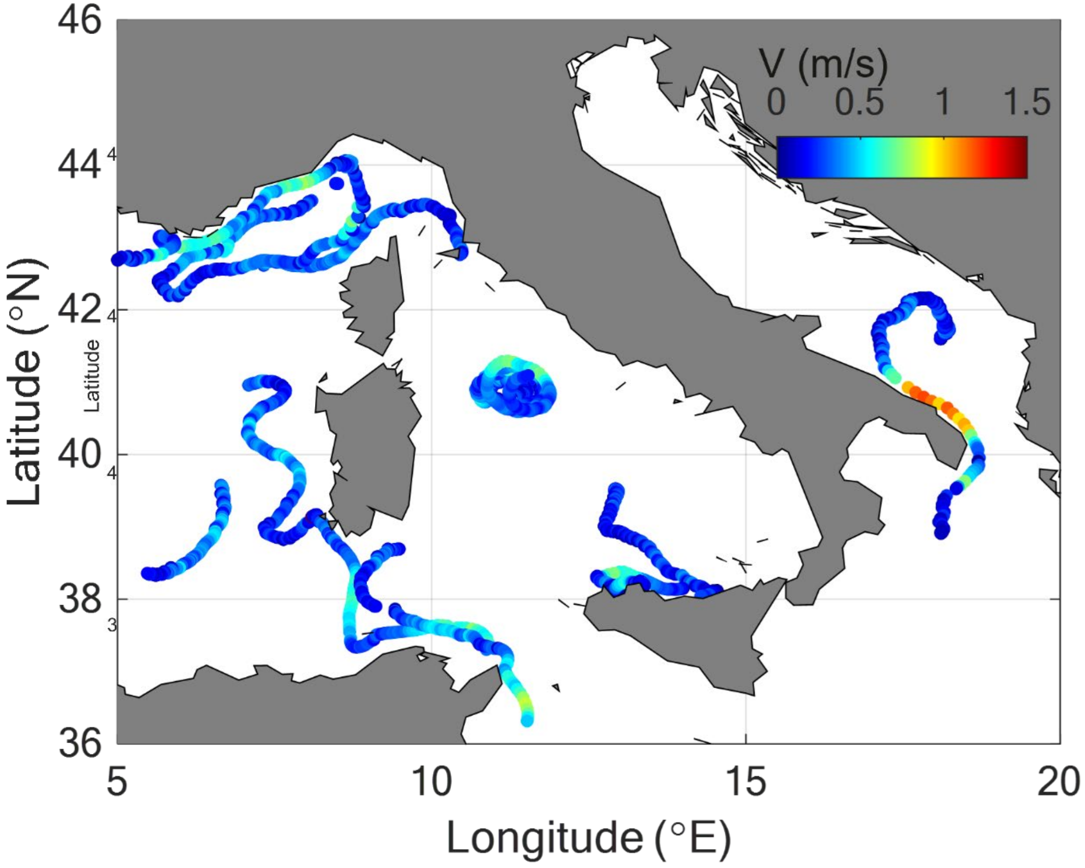
- Standard SVP with SST sensor
- Anemometer
- Barometer
- Conductivity and Temperature (CT) sensor @ 9 m depth
- Optical sensor for b_{bp} at two visible bands (470, 532 nm) and Chl-Fluorescence @ 9 m depth
- Oxygen sensor @ 9 m depth
- High frequency time sampling (e.g., 1h to 3h)
- Internal memory
- Real-time data transmission of entire payload by Iridium

Area of Study

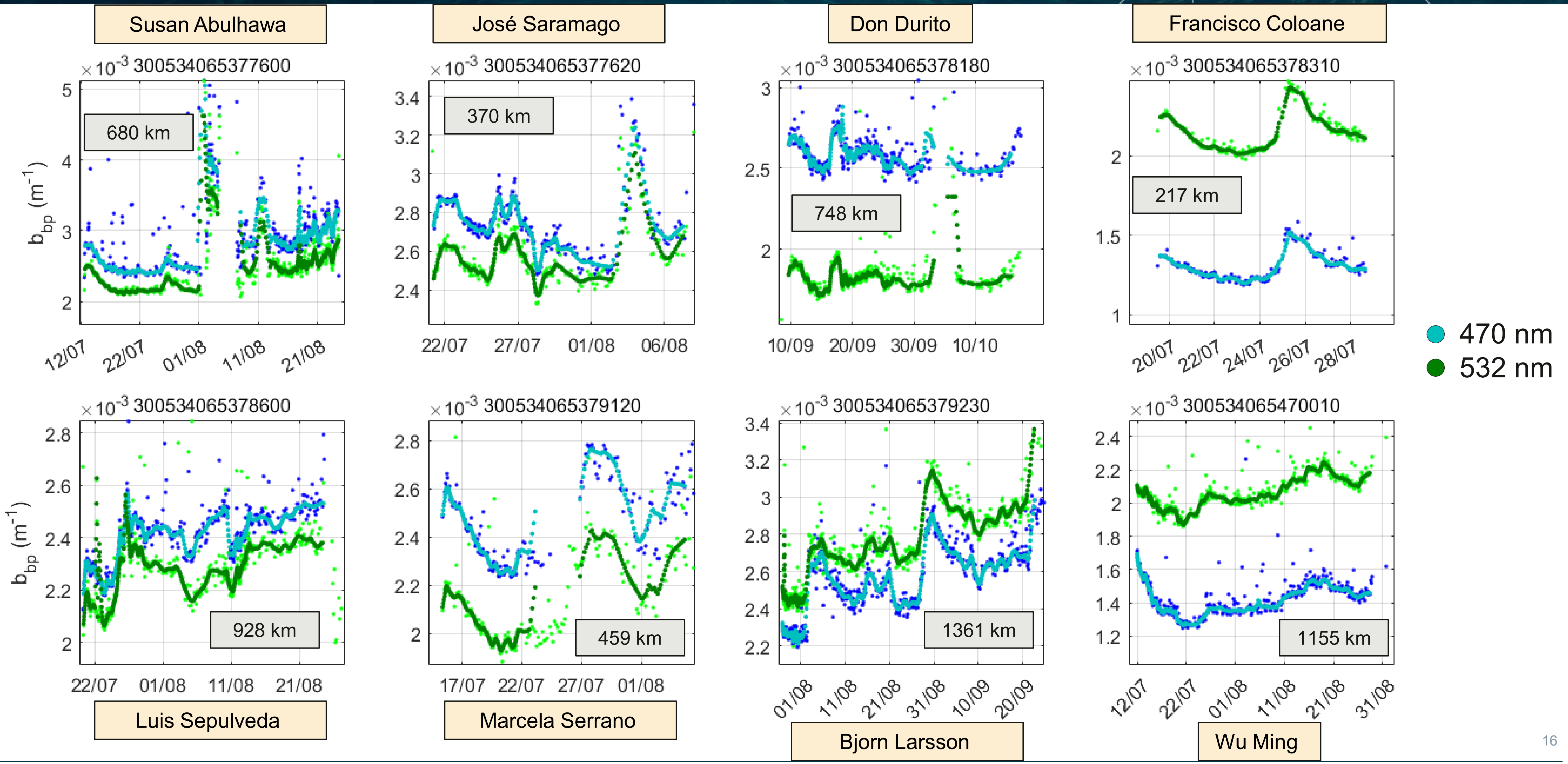
InTegrating, INnovating, Evolving Research InfraStructures for hEalthY and prEdicted marine ecosystemS

8-30 July 2025

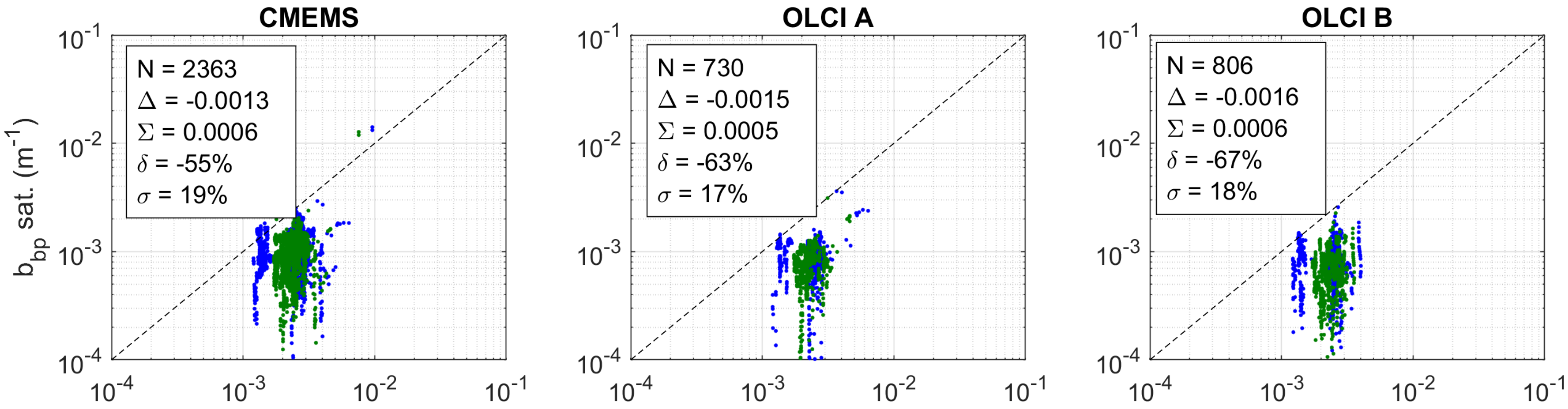
PI: Emanuele Organelli (CNR ISMAR)

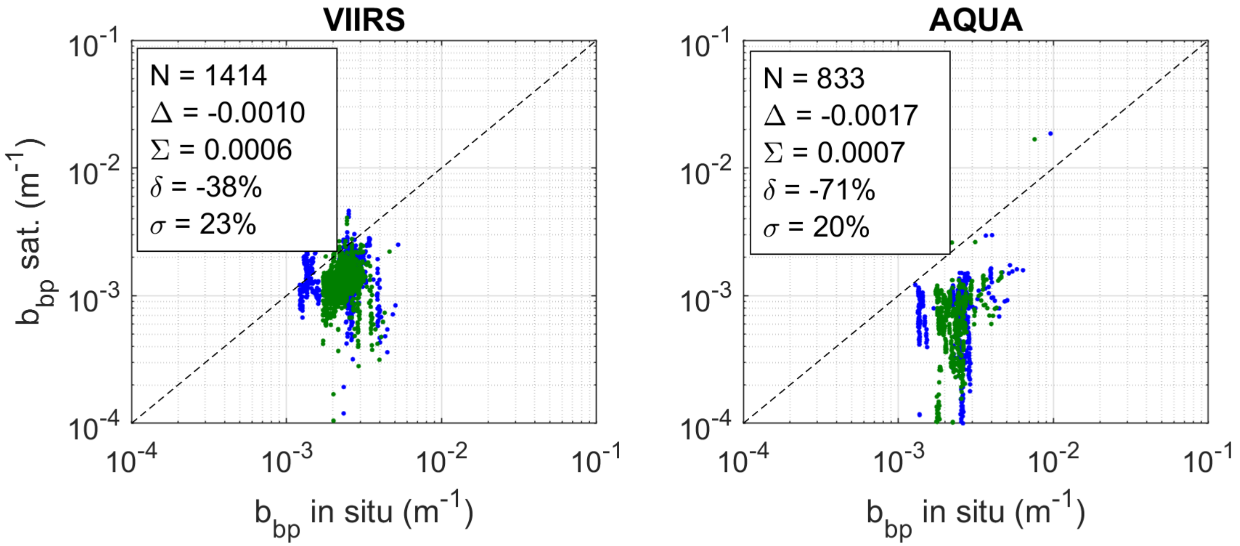


Data and Methods



Results and Discussion



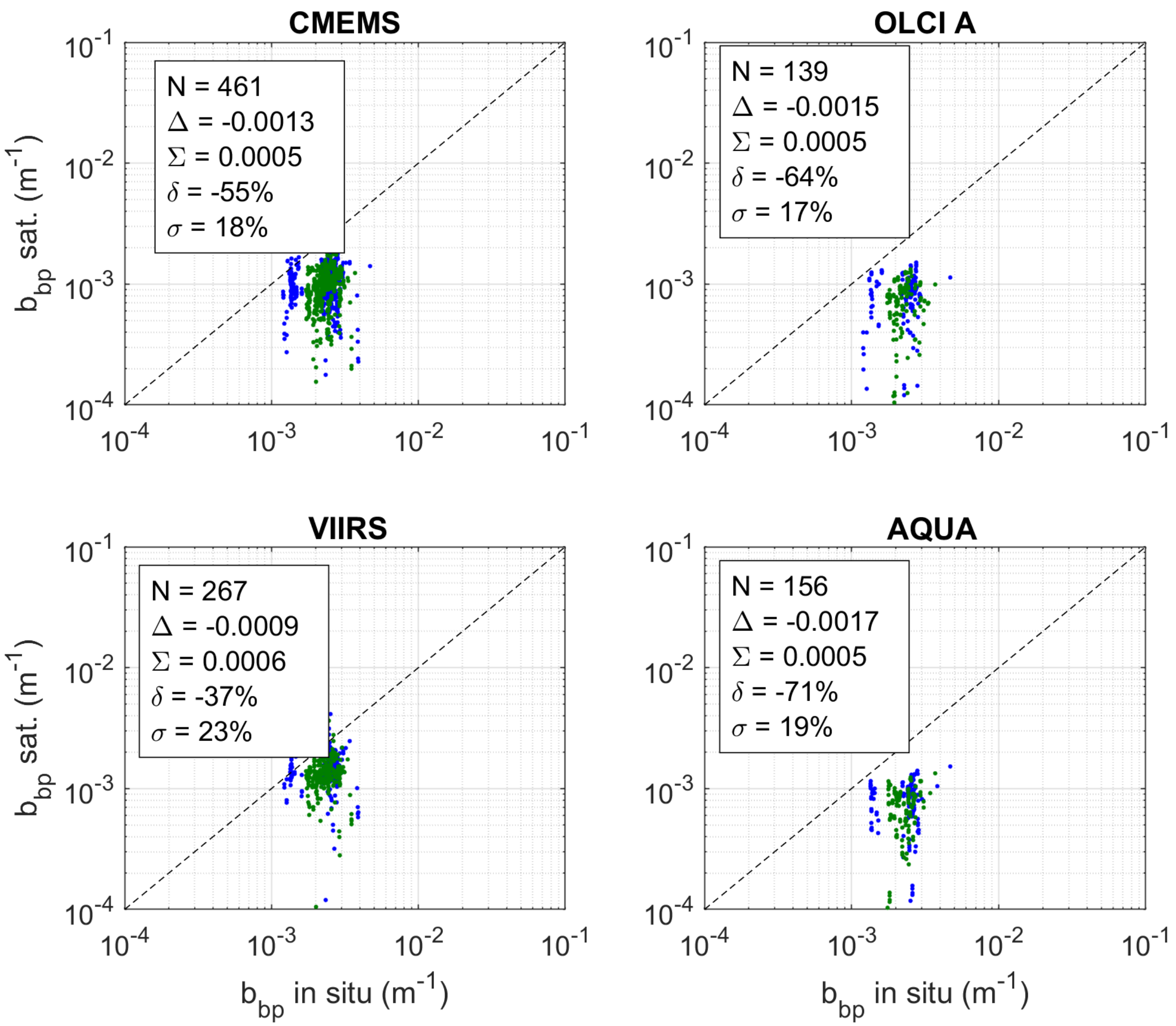


● 470 nm
● 532 nm

Oligotrophic waters
($1 \cdot 10^{-3}$ and $5 \cdot 10^{-3}$)

- Daily Rrs data of CMEMS, OLCI/A, OLCI/B, VIIRS and MODIS AQUA at 1 km resolution were downloaded.
- O25 algorithm has been applied (Pitarch et al. 2025).
- All in-situ data used → !!! we have more in-situ b_{bp} for the same pixel and daily map!!!

Results and Discussion



- 470 nm
- 532 nm

Oligotrophic waters
($1\cdot10^{-3}$ and $5\cdot10^{-3}$)

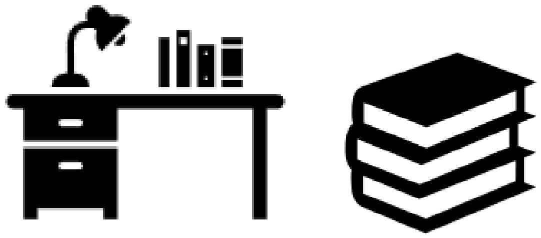
- Daily Rrs data of CMEMS, OLCI/A, OLCI/B, VIIRS and MODIS AQUA at 1 km resolution were downloaded.
- O25 algorithm has been applied (Pitarch et al. 2025).
- Daytime data between 9:00 UTC and 15:00 UTC

Conclusion and next steps

- Validation of satellite backscatter estimates for the following satellite Rrs: ESA OC CCI v6.0 (4km resolution), PACE/OCI (1km resolution) and application of many algorithms: QAA, GSM, GIOP, Sun et al. algorithm (under review) → any suggestions, more algorithms? Validation of chlorophyll-fluorescence measurements? Matchup with standard criteria 3x3 and intra-pixel variability

- Development of an Observing System (OS) specifically tailored for validating satellite bbp products, harmonizing remote sensing, Lagrangian modelling and in-situ data to pinpoint locations and time frames for drifter launching that maximises the number of in-situ observations usable for match-up activities.

- Demonstration with additional deployment of 2 BGC-SVP drifters at ALOHA station (Hawaii) and along the California current (we are working on this – Spring 2026).



Conclusion and next steps

esa

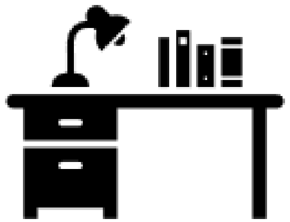
- Validation of satellite backscatter estimates for the following satellite Rrs: ESA OC CCI v6.0 (4km resolution), PACE/OCI (1km resolution) and application of many algorithms: QAA, GSM, GIOP, Sun et al. algorithm (under review) → any suggestions, more algorithms? Validation of chlorophyll-fluorescence measurements? Matchup with standard criteria 3x3 and intra-pixel variability

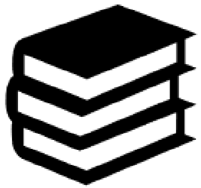
- Development of an Observing System (OS) specifically tailored for validating satellite bbp products, harmonizing remote sensing, Lagrangian modelling and in-situ data to pinpoint locations and time frames for drifter launching that maximises the number of in-situ observations usable for match-up activities.

- Demonstration with additional deployment of 2 BGC-SVP drifters at ALOHA station (Hawaii) and along the California current (we are working on this – Spring 2026).

!!! See poster of Dr. Laura Zoffoli at Session 1 → **11:20am - 12:20pm!!**
!!! See poster of Dr. Jacopo Busatto at Session 1 → **11:20am - 12:20pm!!**

INSPIRE





Conclusion and next steps

- Validation of satellite backscatter estimates for the following satellite Rrs: ESA OC CCI v6.0 (4km resolution), PACE/OCI (1km resolution) and application of many algorithms: QAA, GSM, GIOP, Sun et al. algorithm (under review) → any suggestions, more algorithms? Validation of chlorophyll-fluorescence measurements? Matchup with standard criteria 3x3 and intra-pixel variability

- Development of an Observing System (OS) specifically tailored for validating satellite bbp products, harmonizing remote sensing, Lagrangian modelling and in-situ data to pinpoint locations and time frames for drifter launching that maximises the number of in-situ observations usable for match-up activities.

- Demonstration with additional deployment of 2 BGC-SVP drifters at ALOHA station (Hawaii) and along the California current (we are working on this – Spring 2026).

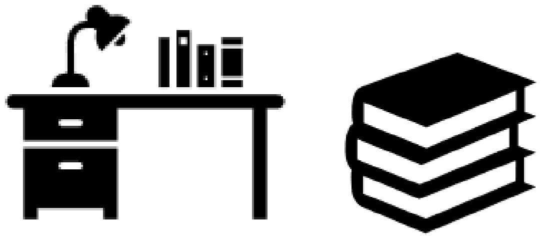
- Temporal resolution config. → which is the best resolution (e.g., 1h, 2h, 3h, 4h)? *ongoing*

- Development of a fit-to-purpose data quality control (QC)

- Evaluate the biofouling impact in long-term deployment → *ongoing*

- Study spikes → bubbles and particle size or the diel vertical migration signal at the surface (Bianchi et al. 2016; Behrenfeld et al., 2019)

- Estimation of biological productivity by diel cycle of bio-optical properties (Barbieux et al. 2022) → *ongoing*



Priority for next years

1-Year Priorities

- Initiate the setup of a coordinated validation network, including cooperation among space agencies (e.g., ESA, NASA, EUMETSAT, etc.) and the international scientific community.
- Define preliminary protocols for IOPs (b_{bp}) measurements, aligned with current radiometric standards, and applicable to multiple in-situ platforms (BGC-Argo floats, BGC-SVP drifters, cruises, moorings) → see IOCCG protocols for radiometry or for other IOPs.
- Funding acquisition for future developments and improvement of BGC-SVP drifters in collaboration with space agencies.
- Development of more compact and more durable technological solutions for the BGC-SVP drifters.
- Investigation of intra-pixel variability through increased sampling frequency and diversification of in situ observing technologies, improving the representativeness of satellite products.

5-Year Priorities

- Formalize standardized and widely adopted IOPs protocols tailored to each measurement system (platform-specific Cal/Val requirements).
- Conduct large-scale validation campaigns, similar in scale and ambition to PACE Mission Validation or SWOT-Adac Consortium, with dedicated budgets addressing IOPs, radiometry and derived products validation (e.g. POC, C_{phyto}) → e.g., Sentinel Next Generation
- Development of Observing System Simulation Experiments (OSSEs) for optimizing the number and spatial distribution of BGC-SVP drifters to enhance uncertainty characterization and bias control in satellite-derived estimates (evaluating configurations of 10/50/100/1000 units) following what has been done for the SST (Donlon et al. 2002; Zhang et al. 2006a).

10 years timescales

- Significant enhancement of in situ observing capacity to support global climate monitoring objectives, fully aligned with international climate initiatives (e.g., Climate Change Initiative – CCI), ensuring long-term uncertainty management and bias mitigation.
- Addition of above-water irradiance and radiance radiometers into the BGC-SVP drifters. Adoption of FRM protocols.

General reccomandations:

- Establishing a calibration laboratory, where the linear response, dark counts, temperature response are characterized.
- Pre-cruise and post-cruise calibrations: it needs instrument recovery following the approach of NASA PACE Validation Mission for the ongoing and future satellite missions.
- Instrument intercomparisons under a number of different conditions.

Acknowledgments

- CNR ISMAR colleagues rather than the co-authors :D
- ESA tech. staffs (Dr. Diego Fernandez Prieto, Dr. Marie-Helene Rio, Dr. Javier Concha).
- Tech. staff of Lagrangian Drifter Laboratory of the Scripps Institution of Oceanography/UCSD.
- Prof. Dr. Antonio Bellacicco (1943–2025), a statistician who believed in this idea and supported me from the very beginning
- Colleagues and technicians from other institutes who helped me with deployments and recovery activities (e.g., Marina Ampolla Rella) and supported my ideas with constructive criticism and suggestions over the past five years (e.g., Bruno Buongiorno Nardelli, Giorgio Dall'Olmo, Daniele Iudicone, Vincenzo Vellucci, Andrea Doglioli)

Thanks! Questions?

mail to: marco.bellacicco@cnr.it

Acknowledgments

CNR ISMAR ISTITUTO DI SCIENZE MARINE

esa

- CNR ISMAR colleagues rather than the co-authors :D
- ESA tech. staffs (Dr. Diego Fernandez Prieto, Dr. Marie-Helene Rio, Dr. Javier Concha).
- Tech. staff of Lagrangian Drifter Laboratory of the Scripps Institution of Oceanography/UCSD.
- Prof. Dr. Antonio Bellacicco (1943–2025), a statistician who believed in this idea and supported me from the very beginning
- Colleagues and technicians from other institutes who helped me with deployments and recovery activities (e.g., Marina Ampolla Rella) and supported my ideas with constructive criticism and suggestions over the past five years (e.g., Bruno Buongiorno Nardelli, Giorgio Dall'Olmo, Daniele Iudicone, Enzo Vellucci, Andrea Doglioli)

Thanks! Questions?

mail to: marco.bellacicco@cnr.it

"Science and scientists, in addition to advancing knowledge, must also contribute to creating a better world of equality and **peace**"

Approach

PERGAMON

Deep-Sea Research II 45 (1998) 1639–1667

DEEP-SEA RESEARCH PART II

Decorrelation scales of chlorophyll as observed from bio-optical drifters in the California Curre

Mark R. Abbott*, Ricardo M. Letelier

College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR 97331-5503, U.

Received 2 July 1998; received in revised form 6 January 1998; accepted 13 March 1998

GEOPHYSICAL RESEARCH LETTERS, VOL. 24, NO.4, PAGES 409-412, FEBRUARY 15, 1997

Chlorophyll natural fluorescence response to upwelling events in the Southern Ocean

Ricardo M. Letelier and Mark R. Abbott

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 100, NO. C7, PAGES 13,345–13,3

Scales of variability of bio-optical properties as observed from near-surface drifters

Mark R. Abbott,[1] Kenneth H. Brink,[2] C. R. Booth,[3] Dolors Blasco,[4]
Mark S. Swenson,[5] Curtiss O. Davis,[6] and L. A. Codispoti[7]

Abstract. A drifter equipped with bio-optical sensors and an automated water sampler was deployed in the California Current as part of the coastal transition zone program to study the biological, chemical, and physical dynamics of the meandering filaments. During deployments in 1987 and 1988, measurements were made of fluorescence, downwelling irradiance, upwelling radiance, and beam attenuation using several bio-optical sensors. Samples were collected by an automated sampler for later analysis of nutrients and phytoplankton species composition. Large-scale spatial and temporal changes in the bio-optical and biological properties of the region were driven by changes in phytoplankton species composition which, in turn, were associated with the meandering circulation. Variance spectra of the bio-optical parameters revealed fluctuations on both diel and semidiurnal scales, perhaps associated with solar variations and internal tides, respectively. Offshore, inertial-scale fluctuations were apparent in the variance spectra of temperature, fluorescence, and beam attenuation. Although calibration samples can help remove some of these variations, these results suggest that the use of bio-optical data from unattended platforms such as moorings and drifters must be analyzed carefully. Characterization of the scales of phytoplankton variability must account for the scales of variability in the algorithms used to convert bio-optical measurements into biological quantities.

The Use of Lagrangian Drifters to Measure Biogeochemical Processes and to Analyze Satellite Data Sets

John R. Moisan
Laboratory for Hydrospheric Processes
NASA Goddard Space Flight Center

Pearn P. Niiler
Scripps Institution of Oceanography, UCSD

Mark Abbott and Ricardo Letelier
Oregon State University

Research Funded by:
NASA EOS

URNAL OF GEOPHYSICAL RESEARCH, VOL. 95, NO. C6, PAGES 9393–9409, JUNE 15, 1990

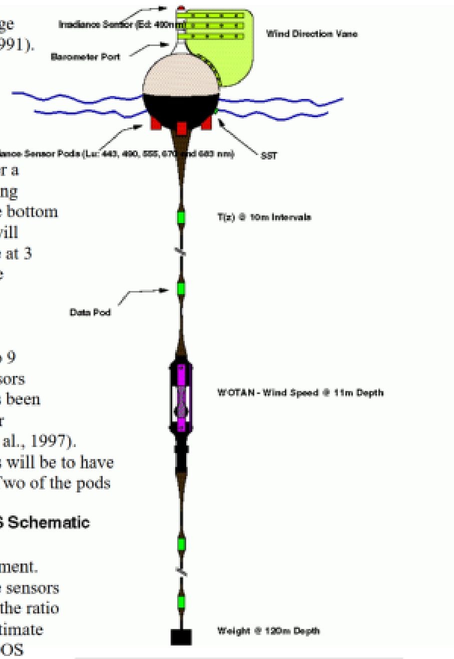
Observations of Phytoplankton and Nutrients From a Lagrangian Drifter off Northern California

Mark R. Abbott,[1] Kenneth H. Brink,[2] C. R. Booth,[3] Dolors Blasco,[4]
L. A. Codispoti,[5] Pearn P. Niiler,[6] and Steven R. Ramp[7]

A Lagrangian drifter was deployed in a cold filament off northern California as part of the Coastal Transition Zone program. The drifter was equipped with an optical package (consisting of a spectroradiometer, a fluorometer, and a beam transmissometer) suspended at 8.5–m depth and a water sampler suspended at 6.3–m depth. The drifter was recovered after 8 days. Optical, chemical, and biological properties changed considerably as the drifter moved offshore in the cold filament. Concentrations of phytoplankton chlorophyll increased rapidly in the first 2 days, in parallel with the disappearance of nitrate and nitrite. After this initial period, chlorophyll decreased gradually over the next 6 days with prominent diurnal fluctuations present in the last 3 days. Water transparency also showed similar long-term as well as diurnal fluctuations. The phytoplankton community became increasingly dominated by large centric diatoms throughout the deployment. Although total cell volume was higher towards the middle of the deployment, this increase occurred without a parallel increase in chlorophyll. In addition, total particulate concentrations were highest nearshore. Although the drifter slippage was approximately 1 cm/s, the biological, chemical, and physical characteristics of the water were affected by both in situ changes and vertical motions of the water. These results are generally consistent with results from other upwelling studies.

r package
et al. (1991).
re-
an
he top
he
nm over a
upwelling
d on the bottom
r pod will
adiance at 3
ithin the
he light
e pods
h gives
een 3 to 9
ese sensors
hich has been
n drifter
telier et al., 1997).
24 units will be to have
lease. Two of the pods
sors

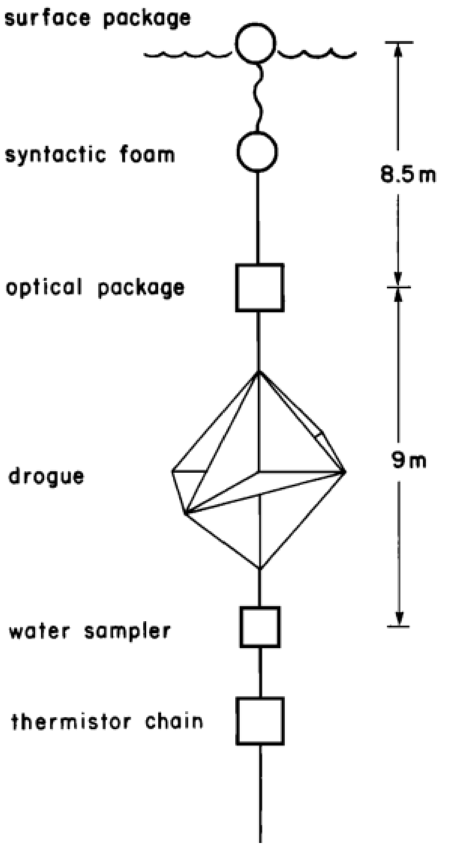
ADOS Schematic



deployment.
adiance sensors
to use the ratio
as an estimate
The ADOS
d with the
nsors once

Figure 3: ADOS Schematic.

a that was obtained from Abbott and Letelier (1998) where they
-fouling.



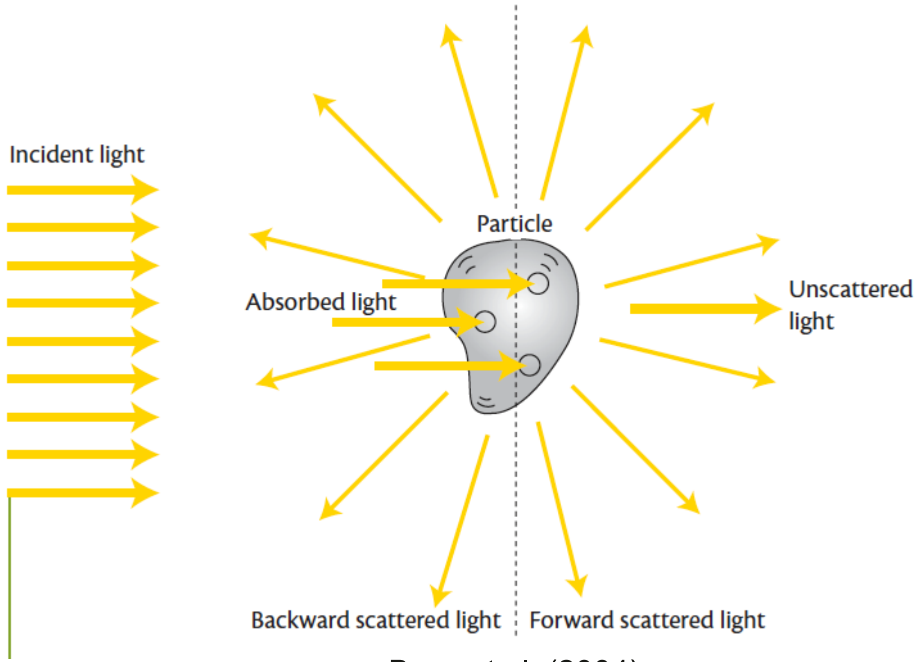
What is the optical particulate backscatter?

IOPs (Inherent Optical Properties)

Medium properties that depend only on the composition of this medium, regardless of light conditions → e.g. scattering (*b*) and absorption (*a*)

$$a(\lambda) = a_w(\lambda) + a_{ph}(\lambda) + a_{cdom}(\lambda) + a_{ys}(\lambda)$$

$$b(\lambda) = b_w(\lambda) + b_p(\lambda) + b_{ys}(\lambda) \; ; \; b_p(\lambda) = b_{fp}(\lambda) + \mathbf{b_{bp}(\lambda)}$$



Boss et al. (2004)