# Heading to our 20s
# Some reflections from the BOUSSOLE project

David Antoine
Vincenzo Vellucci

BOUSSOLE is supported by:

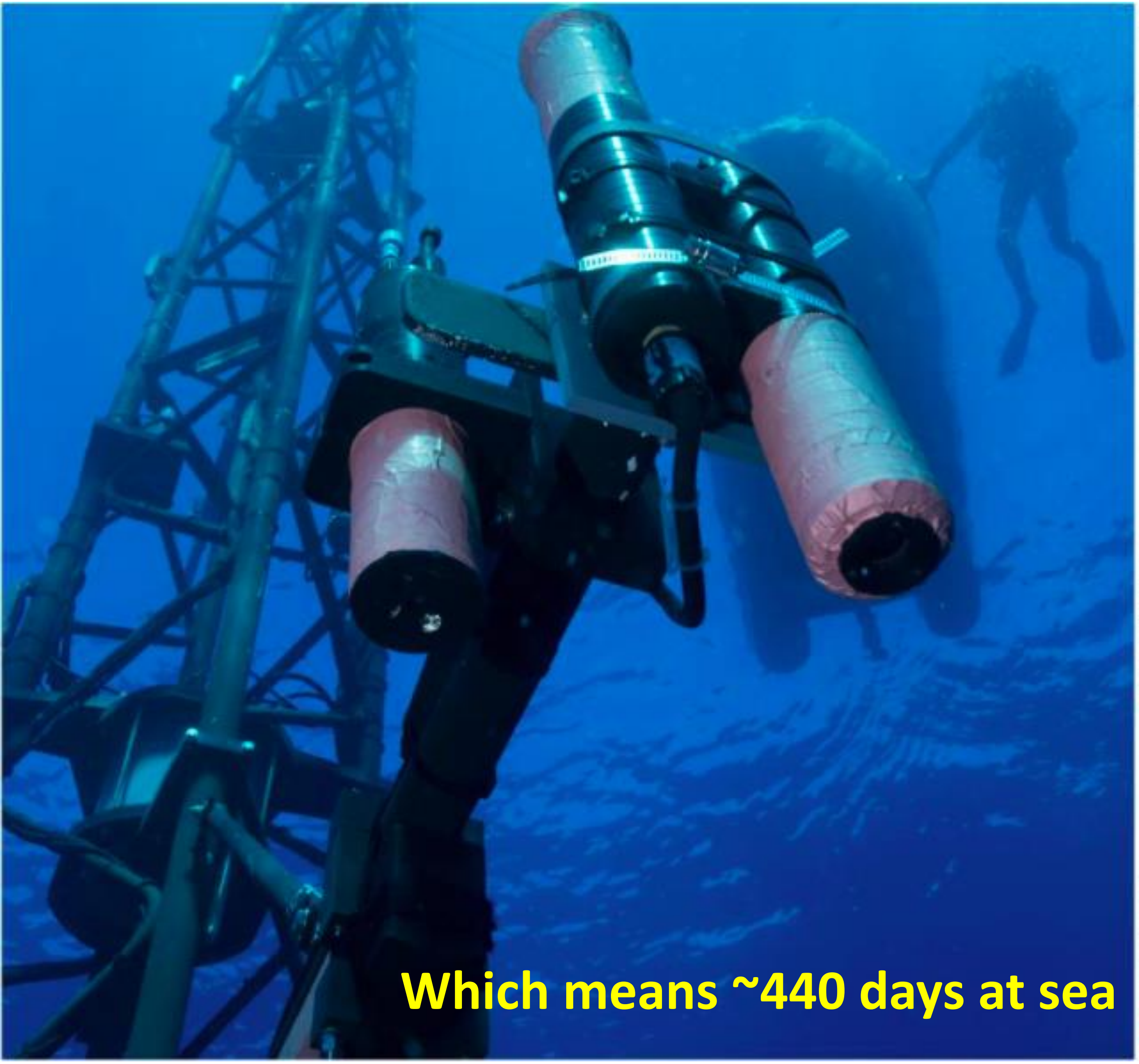
# Let's start with a celebration

On 6th September 2018,
BOUSSOLE buoys had been at sea and had been collecting data for an uninterrupted 15 years sequence

Totals, at the end of 2017:
- 5114 days total since 1st January 2004
- 4870 days with a buoy at sea (95%)
- 4206 days with data acquisition (86%)

This goes with:
- ~64 days at sea for buoy deployments/recoveries
- ~135 days of on-demand, short maintenance operations

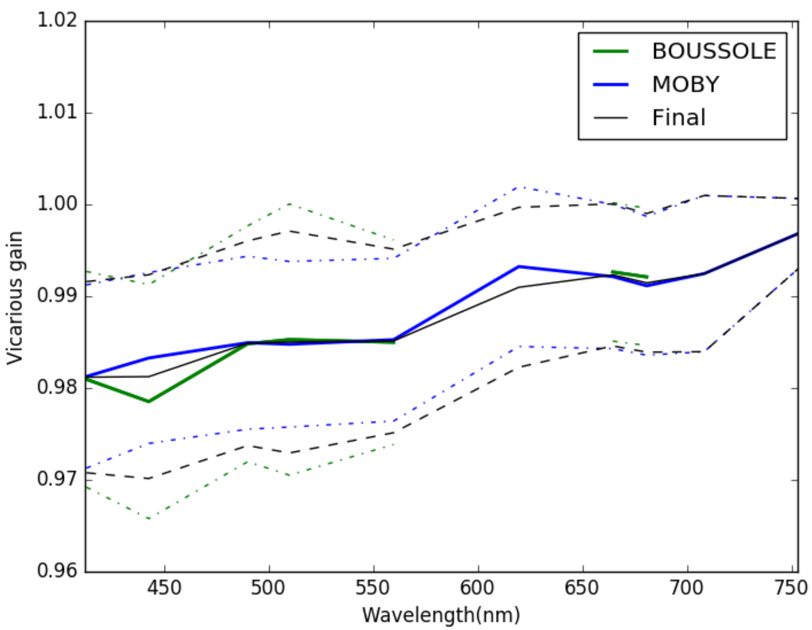
# the **200th monthly cruise** to the BOUSSOLE site was carried out on 18th-19th September 2018



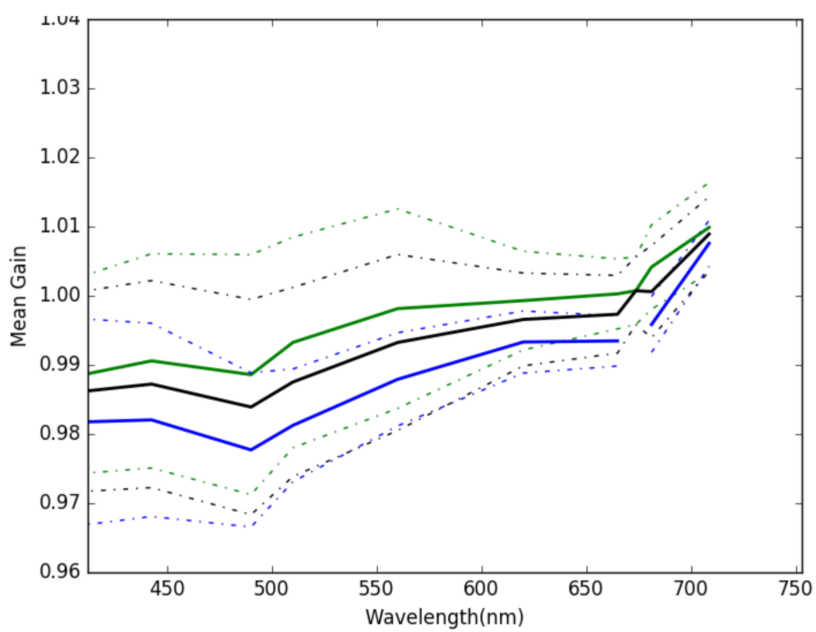


# Why all this?

# Calibration matters; most recent SVC results



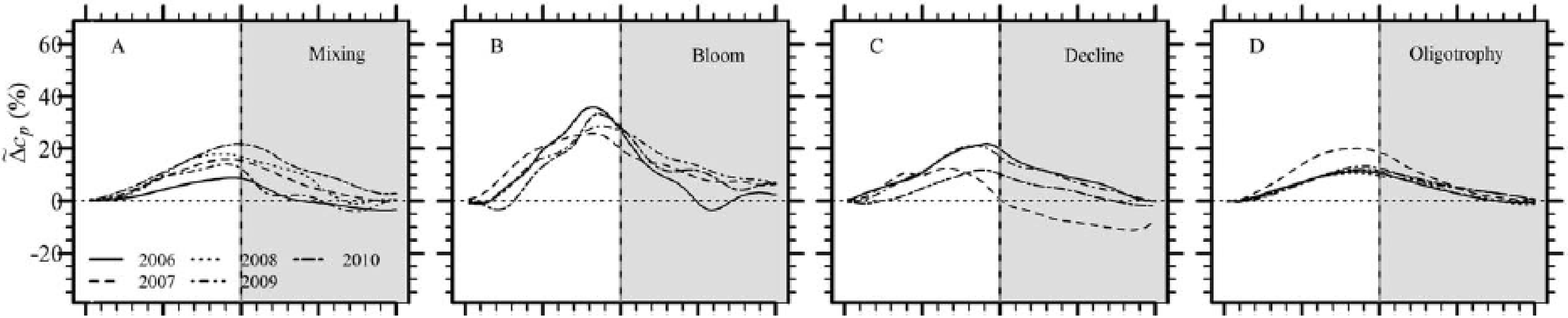

MERIS 4$^{th}$ reprocessing



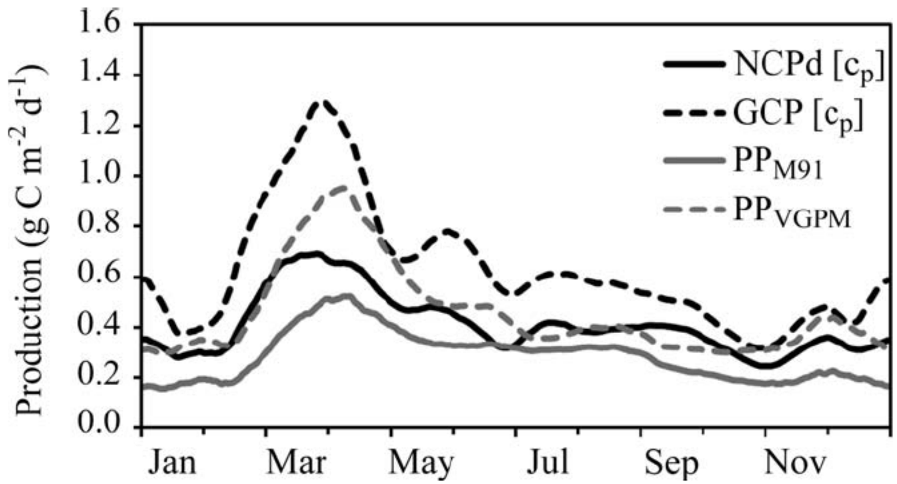

OLCI, preliminary SVC gains

# Why all this?

# Science matters; recent examples




Kheireddine M, Antoine D (2014) Diel variability of the beam attenuation and backscattering coefficients in the north-western Mediterranean Sea (BOUSSOLE site). ***Journal of Geophysical Research***, 119, 5465-5482




Barnes M, Antoine D (2014) Proxies of community production derived from the diel variability of particulate attenuation and backscattering coefficients in the northwest Mediterranean Sea. ***Limnology and Oceanography***, 59(6), 2133-2149.

# How did we get there?

| | |
|---|---|
| 1998 | First thoughts about developing an optics mooring |
| 1999 | Buoy conception & design (->engineering pool tests), in search of funding supports |
| | 1$^{st}$ grant from CNES (TOSCA) |
| | Development essentially made from remainder money from past ESA contracts |
| 2000 | Construction buoy “v0”, qualification deployment, still in search for funding |
| 2001 | Start of monthly cruises (July 2001). Hiring first technical staff. |
| | June 2001: signature of the UPMC/NASA LOA |
| | First specific ESA funding for BOUSSOLE |
| 2002 | 1$^{st}$ deployment of the instrumented buoy → failed (total loss, construction defect) |
| | Reimbursement by our insurance: continuation of the project |
| | Complementary engineering studies (IFREMER/MARINTEK) → buoy version 2 |
| | ENVISAT / MERIS launch |
| 2003 | Construction of the new buoy |
| | Operational deployment: September 2003 |
| | |
| 2003-.. | Operational period (2 sister buoys & instrumentations; rotations every 6 months) |
| | Progressive development of scientific exploitation of the data |
| | |
| 2006 | Unsuccessful request to being “labelled” as a “SO” at INSU |
| 2009 | Long-term commitment from CNES (2019 at least) in the frame of Sentinel-3 |
| 2011 | Start of the “BIOCAREX” project funded by ANR (2011-2014) |
| 2016 | S3A launch |
| 2018 | S3B launch |
| …. | |

# Who did this?

**PROJECT PRINCIPAL INVESTIGATOR**

| | |
|---|---|
| **David ANTOINE** | **Chief Scientist** |

| **Staff members (100% working for BOUSSOLE)** | **Project responsibilities** |
|---|---|
| Vincenzo VELLUCCI | Responsible for buoy maintenance and data processing (October 2007 - ongoing) |
| Melek GOLBOL | Responsible for monthly cruises (March 2013 - ongoing) |
| **Staff members (shared with other activities of our laboratory)** | **Project responsibilities** |
| Edouard LEYMARIE | Radiance camera development |
| Joséphine RAS | HPLC and absorption measurements |
| Céline DIMIER | HPLC and absorption measurements |
| Edoardo SOTO GARCIA | Maintenance / deployment of the CTD |
| Vincent TAILLANDIER | Maintenance of the CTD / CDT data processing |
| Emilie DIAMOND | Responsible for DYFAMED monthly cruises |
| David LUQUET | Management of diving operations on site |
| Didier ROBIN | Management of diving operations on site |
| Guillaume DE LIEGE | Management of diving operations on site, servicing |
| **Past staff members** | **Project responsibilities** |
| Bernard GENTILI | Data processing codes |
| Francis LOUIS | Servicing, electronics, design |
| Grigor OBOLENSKY | Maintenance / deployment of the CTD/IOP package |
| Mustapha OUHSSAIN | HPLC and absorption measurements |
| Dominique TAILLIEZ | CTD + IOPs, all monthly cruises |
| Catherine BROWN | Web site design and data base development |
| Guislain BECU | Responsible for monthly cruises, data processing (2004-2007) |
| Alec SCOTT | Responsible for monthly cruises, data processing (2003-2004) |

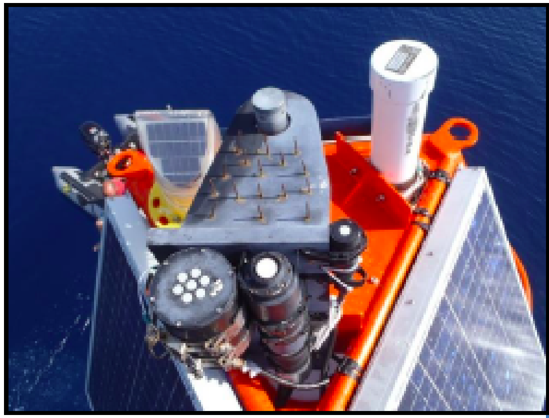
# BOUSSOLE: fact sheet

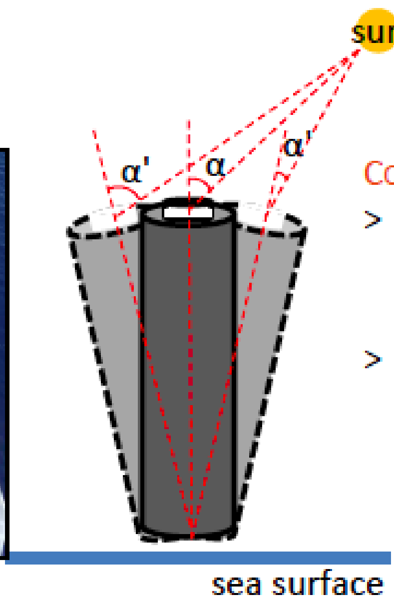
- 18+ years of existence
- 15+ years of operational data production (95% success rate for data acquisition in the 4 years before 2018)
- Currently one of the 2 sites used for vicarious calibration of satellite ocean colour, along with MOBY
- A unique radiometry + optics + BGC data set
- A model for how science & operational objectives come together for mutual benefits
- Permanent effort towards increased data quality (calibration, characterization, QA/QC in general etc…)
- A small, yet highly efficient, technical staff team
- A number of scientific users (publications)
- In good standing to continue for the coming decade

# Progressive improvement in radiometric data quality

- Essentially rely on manufacturer calibration (Satlantic)
- SQM-II: we tried and abandoned
- Immersion coefficients: did some experiments
- Inter-comparison of sensors
- Extrapolation of underwater $L_u/E_u$ measurements
- Identification and quantification of uncertainty sources
- Better bio-fouling mitigation
- Progressive move from multi- (7 $\lambda$'s) to hyper-spectral
- Many incremental improvements in data processing (shading, tilt effects, changes of instruments depth, long-term corrections for instrument drifts or biofouling, short-term events identification..)
- Future improvements: cosine response correction, BRDF correction for tilt effects.

# Correcting $E_s$ for tilt






COSINE CORRECTION OF SURFACE IRRADIANCE

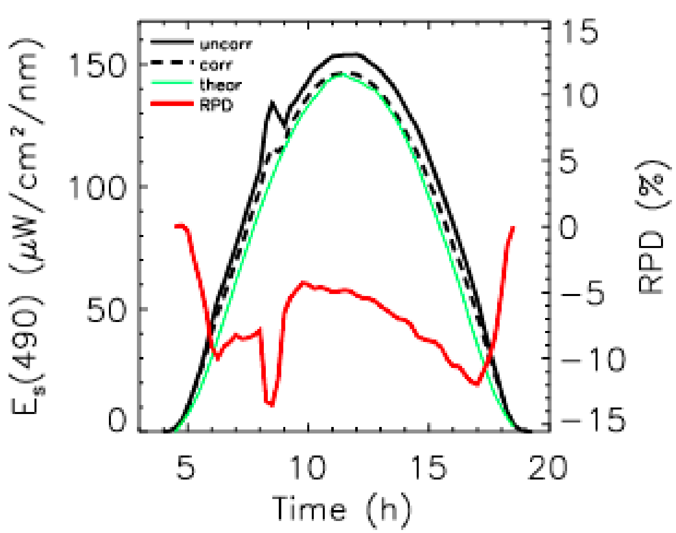
> First the direct fraction of *Es* is estimated following *Gregg & Carder, 1990*

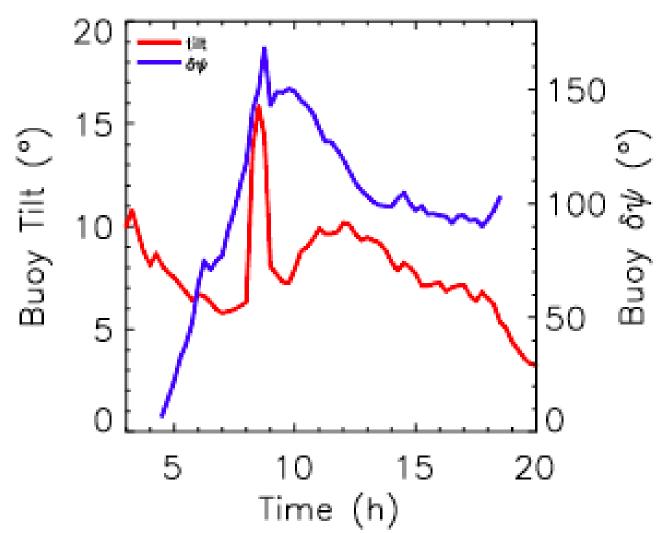
– $\overline{E_S(t,\lambda)'} = \overline{E_S(t,\lambda)'} \cdot f_{dir} + \overline{E_S(t,\lambda)'} \cdot (1 - f_{dir})$

> The correction is then applied to the direct fraction of *Es*

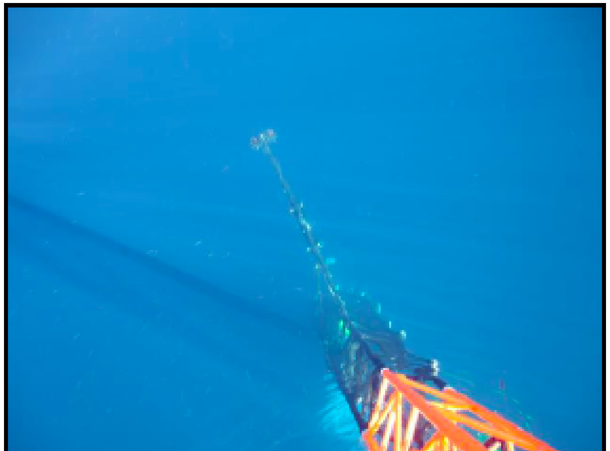
– $E_S(t,\lambda) = \overline{E_S(t,\lambda)'} \cdot f_{dir} \cdot f_{tilt} + \overline{E_S(t,\lambda)'} \cdot (1 - f_{dir})$

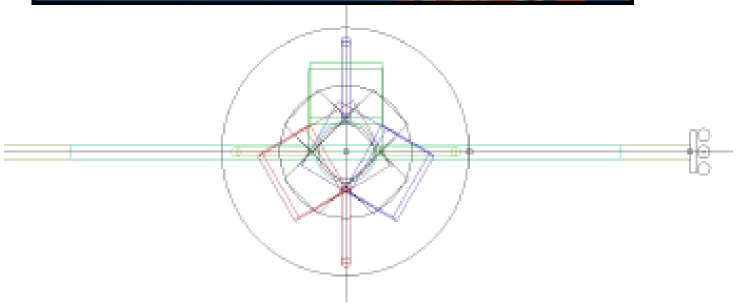
– Where $f_{tilt} = \frac{\cos(\alpha')}{\cos(\alpha)}$

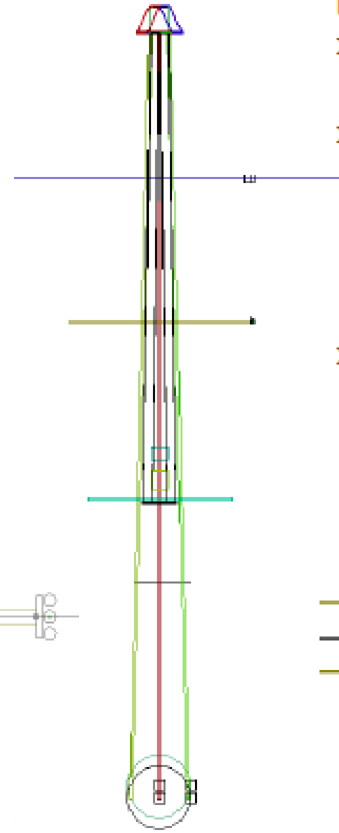


# Shading corrections

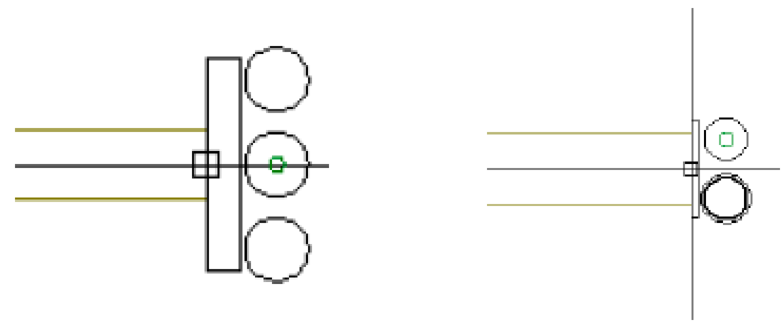


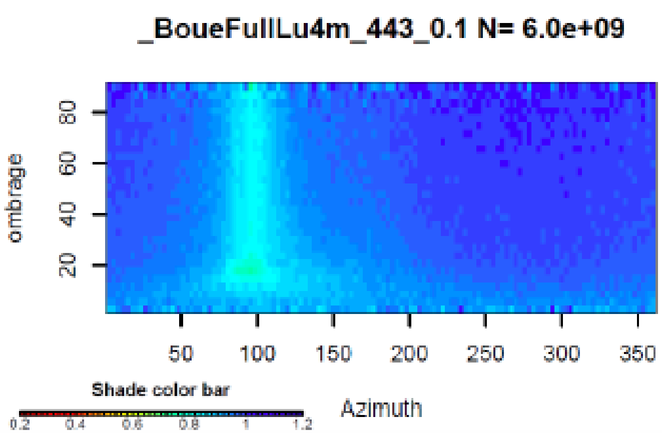


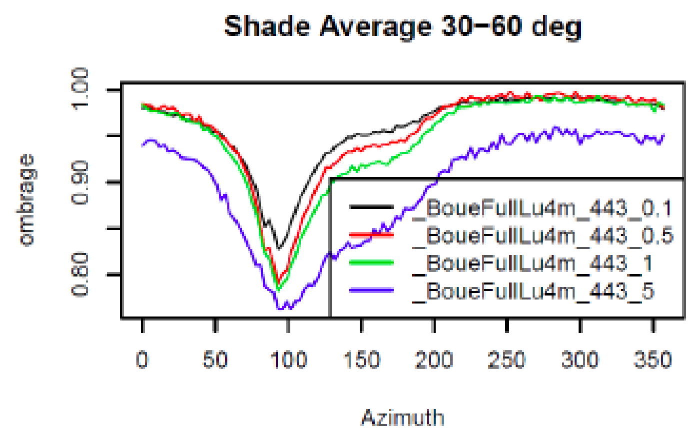


**Buoy Structure shading and Instrument self-shading**

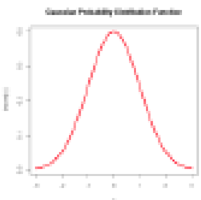
- Backward 3D *Montecarlo* simulation (*SimulO*) replaces the *Gordon & ding (1992)* correction scheme
- Simulation for each underwater instrument
  - Chl = 0.1, 0.5, 1.0, 5.0 µg l-1
  - Azimuth angle from 0° to 360°, with 5° step
  - Zenith angle from 0° to 90°, with 5° step
  - 7 wavelengths (412, 443, 490, 510, 555, 670 nm)
- A correction factor from LUTs is applied
  - $\overline{L_u(z_4,t,\lambda)}=\overline{L_u(z_4,t,\lambda)'}\cdot f_{s4}$
  - $\overline{L_u(z_9,t,\lambda)}=\overline{L_u(z_9,t,\lambda)'}\cdot f_{s9}$

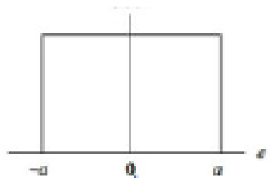




# Defining/quantifying uncertainties
# The measurement equation






$$R_{rs} = \frac{\overline{L_{u4}}\, f_{cal} f_{s4} \, exp\left[ z_4 \left( \frac{-\ln\left(\overline{L_{u9}}\, f_{cal} f_{s9} / \overline{L_{u4}}\, f_{cal} f_{s4}\right)}{z_9 - z_4} \right) \right] f_H f_{\rho n}}{\overline{E_s}\, f_{cal} f_{cos} f_{tilt} f_{dir} + (1 - f_{dir}) \overline{E_s}\, f_{cal}}$$

# Preliminary error budget

| $u$ in % / $\lambda$ in nm | $E_s$ | $L_{u4}$ | $L_W$ | $R_{rs}$ | $u_{abs}(R_{rs})$ |
|---|---|---|---|---|---|
| 412 | 2.1 | 2.6 | 3.1 | 3.7 | 0.000215 |
| 443 | 2.0 | 2.6 | 3.1 | 3.7 | 0.000225 |
| 490 | 2.0 | 2.6 | 3.0 | 3.7 | 0.000175 |
| 510 | 2.0 | 2.6 | 3.0 | 3.7 | 0.000155 |
| 560 | 2.0 | 2.6 | 3.1 | 3.7 | 0.0000725 |
| 665 | 2.1 | 3.9 | 5.9 | 6.3 | 0.00000410 |
| 681 | 2.1 | 4.0 | 5.9 | 6.3 | 0.00000195 |

# Do we need an "error budget"?

What matters are the uncertainties

How we combine them into a "budget" might actually be confusing, and might be hardly comparable among different systems

What matters for SVC is the number of match-ups with the lowest uncertainty
What matters for validation is the N° of match-up with (maybe) a lightly higher threshold
What matters for science are data with uncertainties below that of the signals to study

The goal: each measurement comes with an uncertainty. Then, it is up to the users to set the uncertainty threshold above which data are rejected.

# Where do we set the bar?

Full characterization and calibration of radiometers is a time consuming and expensive process.

Therefore the question is: can we find the right balance between the effort that we put on calibration/characterisation and the benefit in terms of improved data quality?

Example of the SQM-II: was way too much work for marginal benefit

Corollary: is this where the effort has to be put? Are protocols more important?

And, in the same vein: is a lot of this needed because we do not have the appropriate instruments?

# What about science?

Since inception, BOUSSOLE was conceived as a sustained research activity, rather than as a truly “operational” system.

It has actually become very close to the latter, but still includes a significant research programme

You cannot do otherwise when you operate from a research environment, which in our case is CNRS-INSU-Sorbonne University

It is vital for the motivation of staff

Can provide additional Capex investment

# The challenges we faced in 2018

**Year 2018:**

| Month | Days with data | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | -- | -- | -- | 28 | 29 | 30 | 31 |
| Feb | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | | | |
| Mar | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Apr | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | |
| May | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Jun | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | |
| Jul | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Aug | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Sep | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | |
| Oct | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Nov | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | |
| Dec | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

Unfortunately, in 2018 the buoy has taken a “gap year”.

The DacNET (central data acquisition system) definitely died, and Satlantic/Seabird were in the process of transitioning their activity from Canada to the US. This has generated unusually long delays for the system maintenance, recalibration etc..

# Why did we end up with this situation?

The DacNET (central data acquisition system) was conceived in the late 1990s, and our units built in 2001-2002.

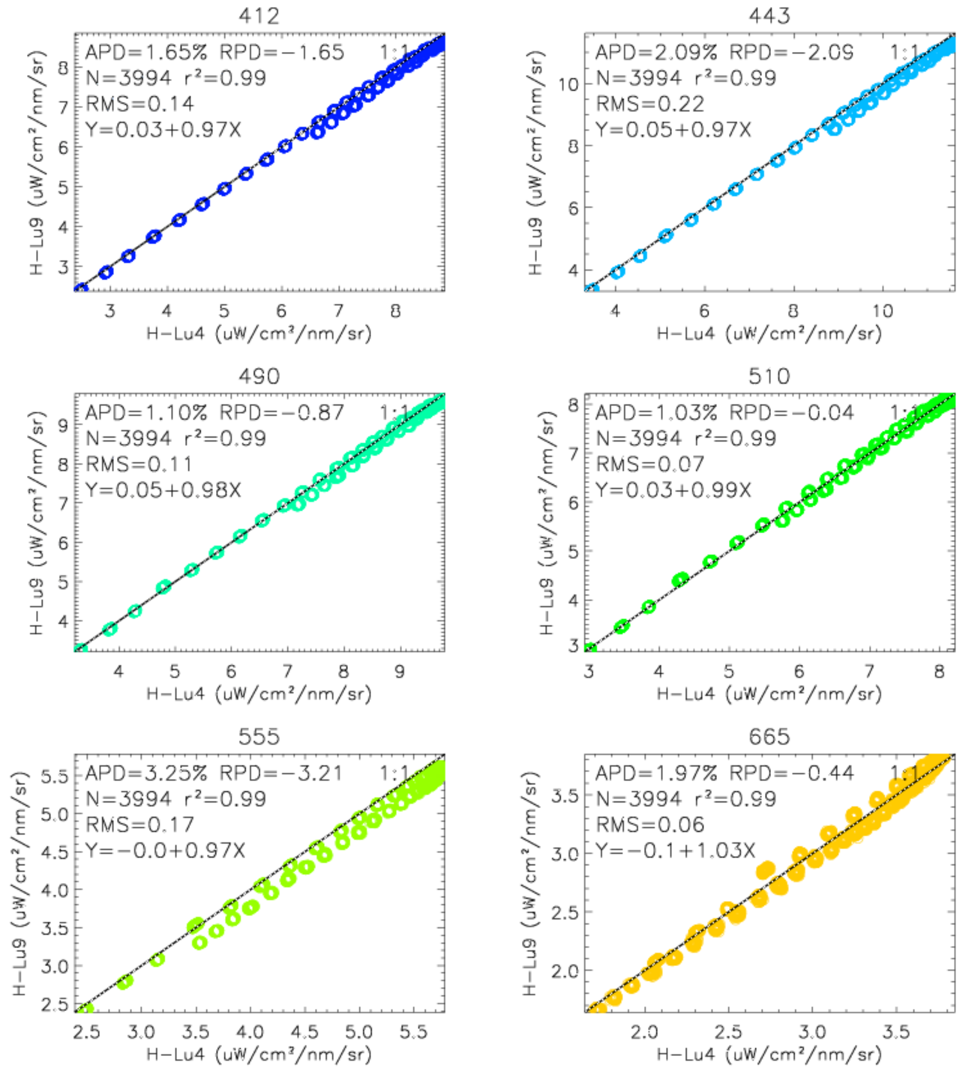
They have proven extremely reliable, but we warned many times about the need to prepare for replacement.

This was not feasible at constant funding, so it was not done.

Lesson: regular capex investment has to be included at regular intervals in the life of such a long-term activity

# Operations will resume soon

# Inter-comparisons, pre-deployment



# Where to now?

# Radiometry for Ocean Colour SAtellites Calibration & Community Engagement

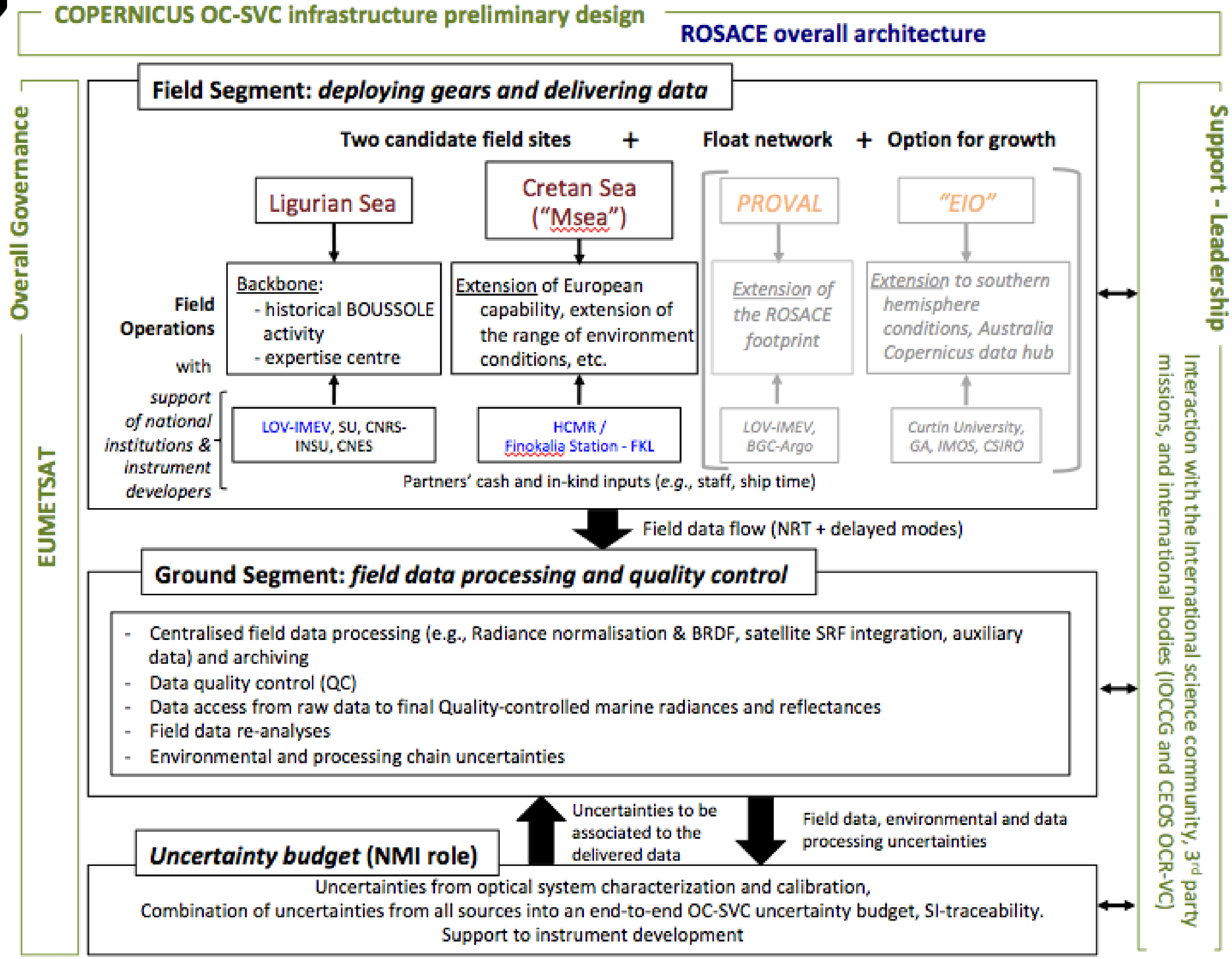
# ROSACE

Laboratoire d'Océanographie de Villefranche,
Institut de la Mer de Villefranche

LOV IMEV SORBONNE UNIVERSITÉ

Hellenic Centre for Marine Research | ACRI-ST | UK National Physical Laboratory | University of Tartu, Tartu Observatory | CIMEL Electronique

# ROSACE overall logic



Thanks for your attention