System Vicarious Calibration (SVC) for satellite ocean colour observations: Why? How? Where? Present & future

Review of historical and contemporary approaches

David Antoine
Curtin University, Perth Australia &
CNRS-LOV, Villefranche, France

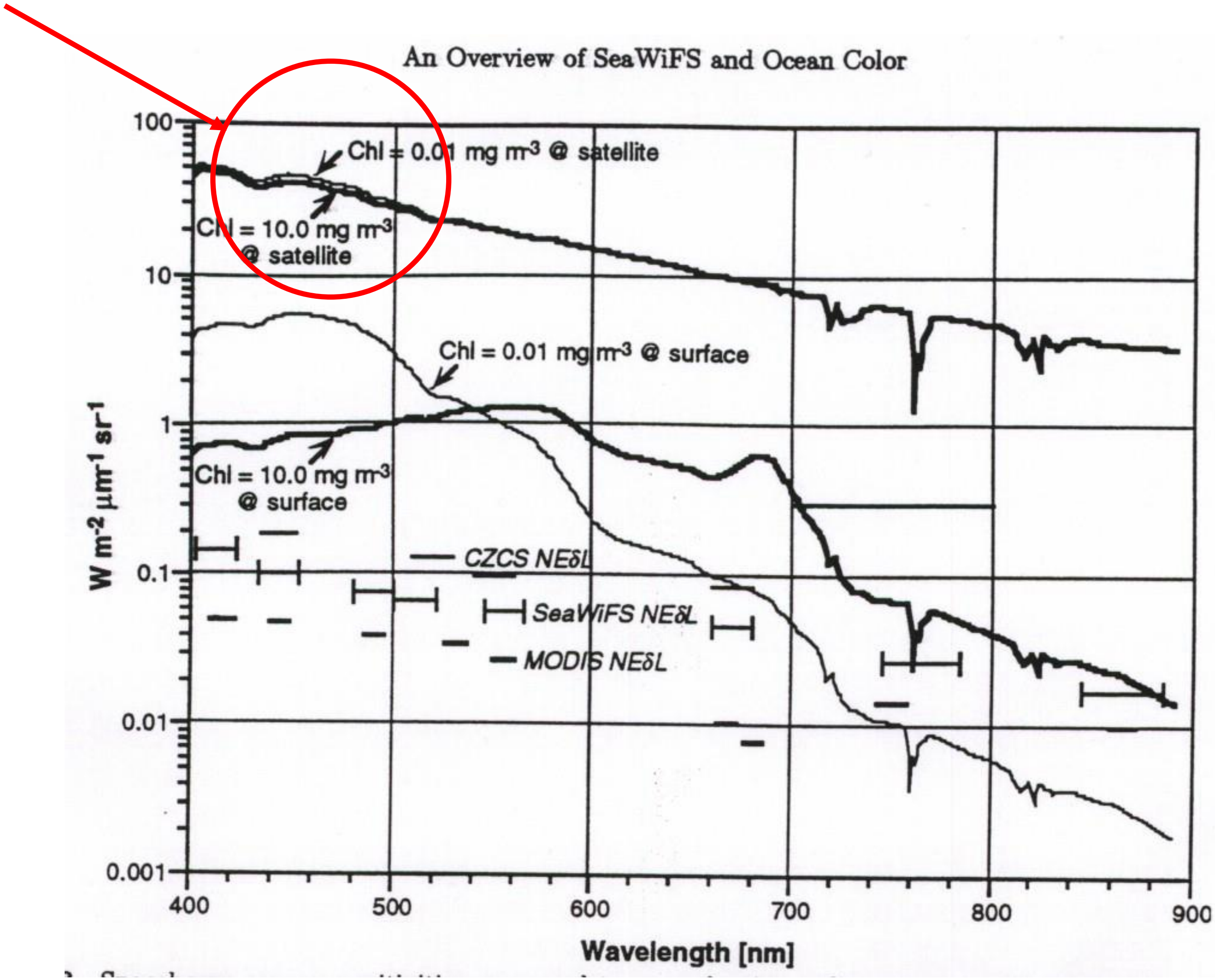
Constant Mazeran
Solvo, Antibes, France

International workshop on OCR System Vicarious Calibration Infrastructure, ESA/ESRIN, Frascati, 21-23 Feb. 2017

Outline

- The issue
- The goal
- Principle of Vicarious Calibration
- What VC should be, ideally?
- Terminology
- What’s been done until now?
- What a SVC site should “look like”?
- Difficulties, challenges
- What’s going to be done for future sensors?
- The future of SVC: main issues, non examined issues, open questions

The issue (1/2)



An Overview of SeaWiFS and Ocean Color
Chl = 0.01 mg m-3 @ satellite
Chl = 10.0 mg m-3 @ satellite
Chl = 0.01 mg m-3 @ surface
Chl = 10.0 mg m-3 @ surface
CZCS NEδL
SeaWiFS NEδL
MODIS NEδL
W m-2 µm-1 sr-1
100
10
1
0.1
0.01
0.001
400
500
600
700
800
900
Wavelength [nm]

The issue (2/2)

Essentially: L_w is a small fraction (<10%) of the measured signal at TOA level, so that a highly accurate calibration is needed

$$\frac{\Delta L_t}{L_t}(\lambda) = \frac{\Delta L_w}{L_w}(\lambda) * \frac{t_g t L_w(\lambda)}{L_t(\lambda)} \approx 5\% * 10\% \approx 0.5\%$$

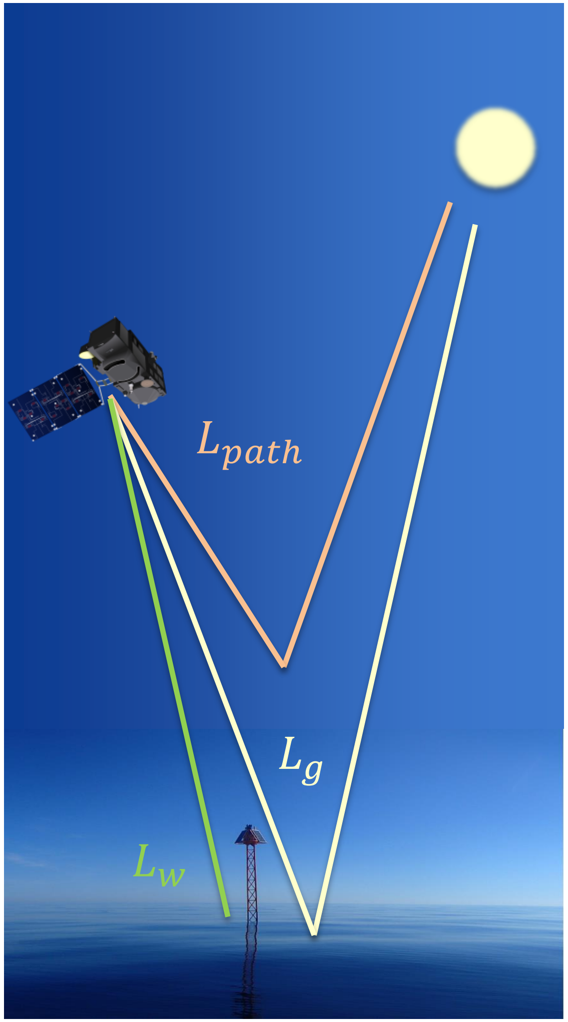
0.5% is not achieved today by only prelaunch calibration + onboard devices

Need for the “System Vicarious Calibration”, in particular because atmospheric correction remains inherently inaccurate

The goal

- "*The goal of modern ocean color sensors is to provide the water-leaving radiance in the blue part of the e.m. spectrum with a 5% accuracy over oligotrophic, chlorophyll-depleted, waters*.." (Gordon, 1997)
- This also corresponds to errors of ~$1\ 10^{-3}$ to $5\ 10^{-4}$ in reflectance at blue & green bands (Antoine & Morel, 1999)
- Maintaining a long-term stability at 0.5% per decade (climate studies; WMO / GCOS requirements),
- What else ??? Is this enough to really constrain the way we perform SVC ?

Principle of Vicarious Calibration



- Signal modelling:

$$L_t(\lambda_i) = \underbrace{t_g(\lambda_i) \cdot \big(L_{path}(\lambda_i) + T(\lambda_i)}_{\text{Atmosphere (}}\underbrace{L_g}_{\text{Sun-glint}} + t(\lambda_i)\underbrace{L_w(\lambda_i)}_{\text{Water}}\big)$$

TOA: $L_t(\lambda_i)$

- Reconstruction of a targeted (true) TOA signal L_t^t based on various possibilities:
  - Data screening: no glint, negligible aerosol …
  - Climatology or model, e.g. L_w over stable gyres
  - Assumptions: fixed aerosol type
  - In situ measurements: L_w^t
  - Ground-segment inversion, e.g. L_{path}
  - …

- Computation of gains at pixel level: $g(\lambda) = \frac{L_t^t(\lambda)}{L_t(\lambda)}$

- Averaging over mission life time, assuming temporal trends are already corrected by instrumental calibration → Unique set of spectral gains $\bar{g}(\lambda)$

What VC should (could) be, ideally?

Ideally:

- All needed quantities to drive a vector RT model are measured with the best possible accuracy. The RT calculation then provides the total radiance at TOA level, totally independently of which sensor is to be vicariously calibrated, and which atmospheric correction algorithm is subsequently used to process observations from that sensor

See: Gordon and Zhang, 1996, How well can radiance reflected from the ocean–atmosphere system be predicted from measurements at the sea surface? Applied Optics, 35(33), 6527-6543.

Why VC is not performed this way?

- Essentially because the "best possible accuracy" is actually not met by most field instruments / procedures etc..

Is it definitely illusory to go down that route?

- Open question to be discussed

Terminology

“Calibration” or “adjustment” ?

CEOS defined both, and insist that they are not the same process.

However, does not the CEOS definition of “calibration” fit with what we do for SVC?

Their definition: “Calibration as “the process of quantitatively defining a system's responses to known, controlled signal inputs”

In any case, we determine the instrument response when it aims at a target.

- Lab calibration: the target is a lamp (or lamp+plaque) of known uncertainty. Calibration coefficients make the instrument output to match the one of the lamp. What happens in between the target and the instrument does not really matter (or marginally)

- Vicarious calibration: a natural target is observed, whose properties are measured in the field with a known uncertainty. Calibration coefficients make the instrument output to match the target. What happens in between matters a lot (atmospheric path)

What's been done? overall

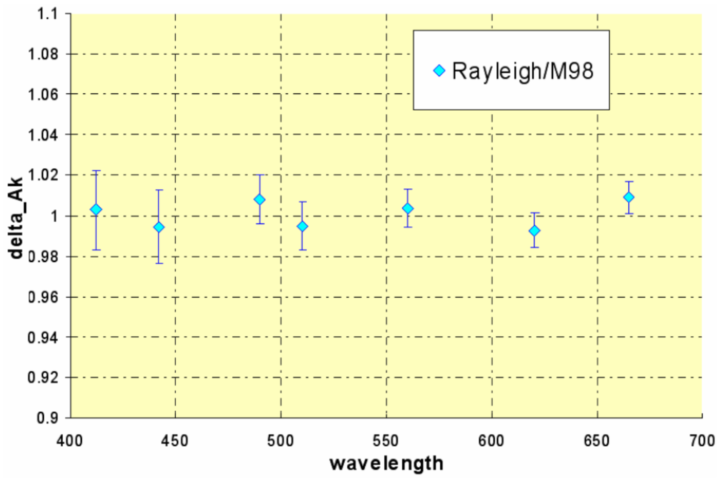
- CZCS: initial vicarious calibration by Gordon 1987, based on few points. Revised by Evans & Gordon 1994 using the clear-water radiance concept
- SeaWiFS, MODIS-A, MODIS-T, VIIRS : SVC based on MOBY
- MERIS: SVC based on MOBY+BOUSSOLE
- POLDER: Rayleigh (absolute) and Sun-glint (interband) calibration
- Other sensors ?

Example of method: Rayleigh scattering

- Developed by CNES (Hagolle et al. 1999, Fougnie et al. 2002) in particular for POLDER (no on-board calibration)

- Rayleigh method: absolute calibration
  - Stable & homogeneous oceanic sites
  - Marine reflectance model using Chl climatology
  - Atmospheric function using RTM. AOT (thresholded) computed in the NIR and propagated to VIS with MAR98

MERIS gains – from Hagolle et al. 2006



- Accuracy (Fougnie & Henry 2009) ~3% in the blue/green → mainly suitable for **verification** of the L1 calibration, not for climate studies

Example of method: SVC

- Main references:
  - Gordon 1998, In-orbit calibration strategy for ocean color sensors, Remote Sensing of Environment 63, 265-278
  - Franz et al. 2007, Sensor-independent approach to the vicarious calibration of satellite ocean color radiometry, Appl. Opt. 46, 5068-5082

- Basic principles in the VIS: computation over an instrumented site

From atmospheric correction *Avoided* *Sea-truth*

- Basic principles in the NIR: computation over oligotrophic waters

Assume 865 nm OK and fix an aerosol model *Avoided* *Neglected*

$$L_t^t(\lambda) = t_g(\lambda) \cdot \left(L_R(\lambda) + L_a(\lambda) + L_{Ra}(\lambda) + T(\lambda)L_g + t(\lambda)L_w^t(\lambda)\right)$$

Key aspects of SVC

- This is a calibration of the **satellite + ground segment system.** SVC gains in the VIS are **relative** to gains firstly computed in the NIR (Wang & Gordon 2002, Wang et al. 2016)

- By construction, at the SVC site:
  - Individual gains make the system **exactly match** the in situ L_w^t
  - Mission-average gains remove the **average bias**:

After SVC ⟶ $$L_w^{\overline{cal}}(\lambda) - L_w^t(\lambda) = \left(\bar{g}(\lambda) - g(\lambda)\right)\frac{L_t(\lambda)}{t_g(\lambda)t(\lambda)}$$

- Uncertainty & scattering of gains propagate to uncertainty on $L_w^{\overline{cal}}$

$$\frac{\sigma_{L_w^{\overline{cal}}}}{L_w^{\overline{cal}}} = \sigma_{\bar{g}} / \frac{t_g t L_w^{\overline{cal}}}{L_t}$$

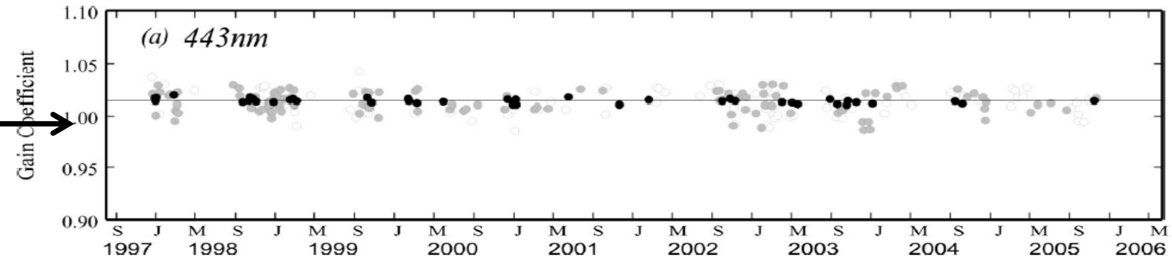
To date SVC is the only method able to reach the required 0.5% for g

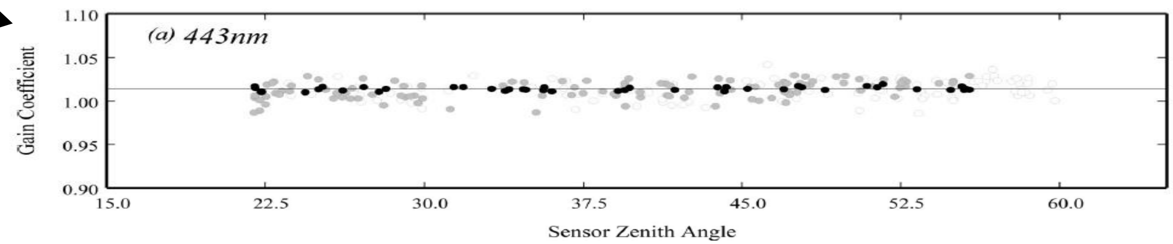
- Impact of SVC at other sites and at global scale depends on **robustness of the atmospheric correction**

Illustration of SVC: SeaWiFS

- Gains computed at MOBY. Results from Franz et al. 2007, AO

Stability with respect to time, view angle…





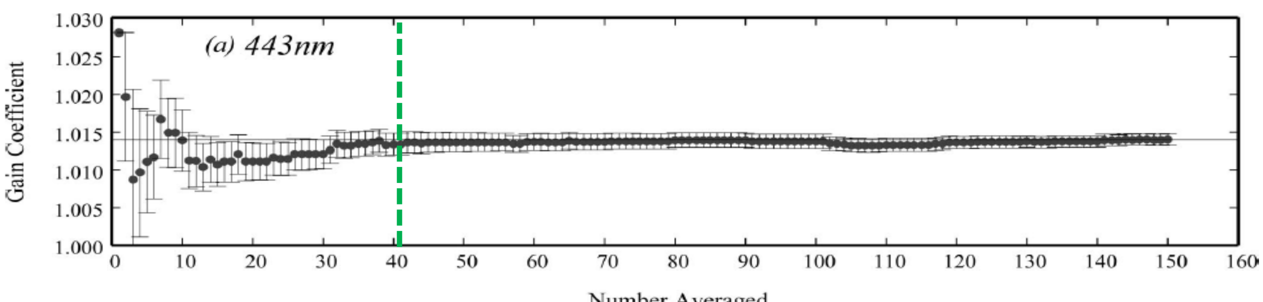
Validation against deep water in situ measurements

Without SVC

	Ratio[a]	MPD[a]	r^2	N^b
$L_{wn}(412)$	0.245	80.0	0.861	54
$L_{wn}(443)$	0.447	55.4	0.799	111
$L_{wn}(490)$	0.760	25.7	0.772	111
$L_{wn}(510)$	0.753	24.7	0.665	45

With SVC

	Ratio[a]	MPD[a]	r^2	N^b
$L_{wn}(412)$	1.002	11.8	0.930	188
$L_{wn}(443)$	0.950	15.5	0.873	318
$L_{wn}(490)$	0.942	12.2	0.817	318
$L_{wn}(510)$	0.957	10.6	0.579	164

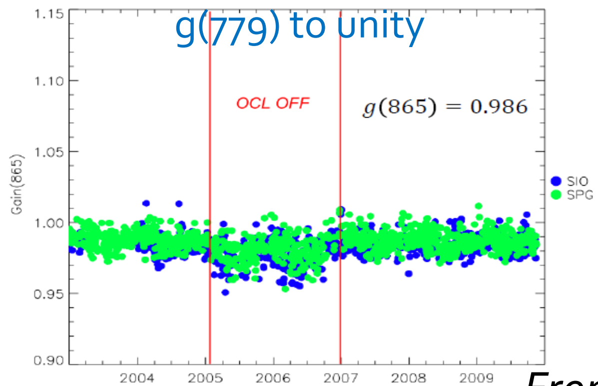


~ 40 match-ups required (~ 2.5 years of data at MOBY)

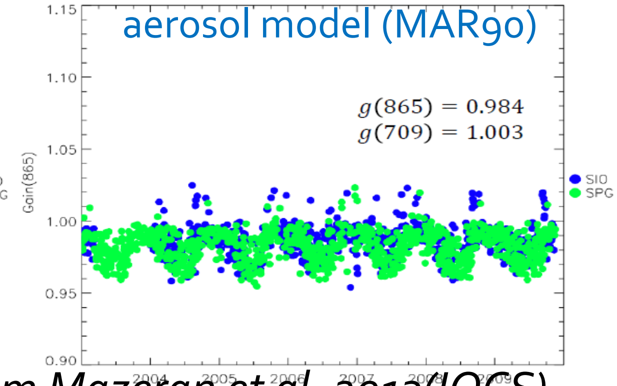
Illustration of SVC: MERIS 3rd reproc.

- MERIS NIR SVC does not choose an aerosol model but 2 bands (709 & 779)

g(865) when fixing g(709) & g(779) to unity

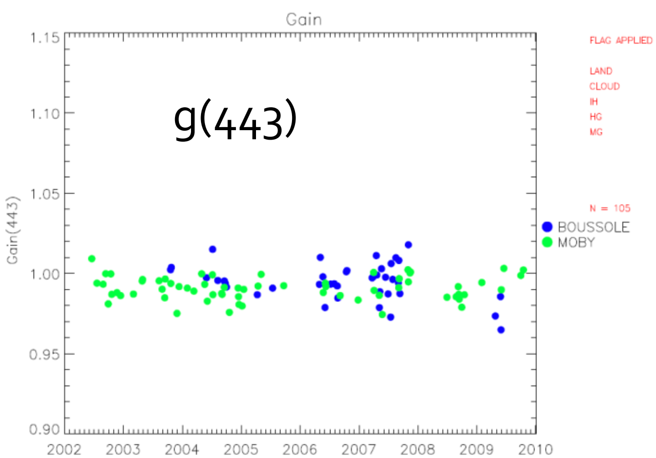


g(865) when fixing the aerosol model (MAR90)



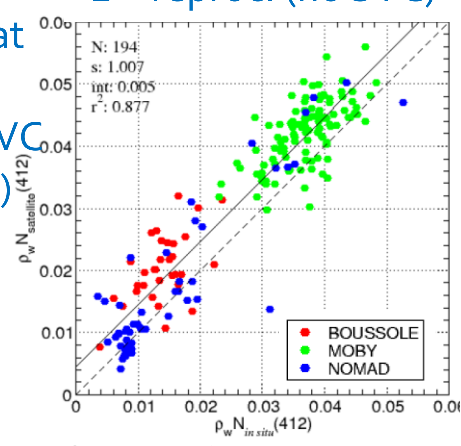
From Mazeran et al. 2013(IOCS)

- Gains in the VIS computed at MOBY and BOUSSOLE. SVC implemented after gas, smile & glint corrections

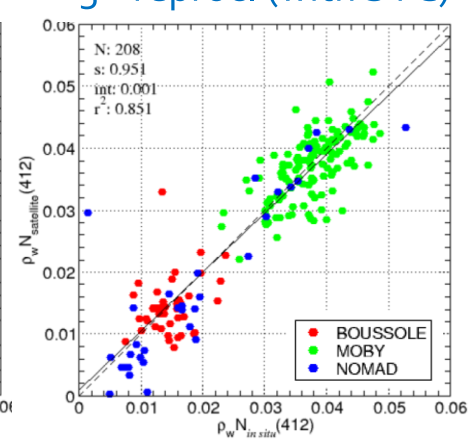


Validation at 412 nm (excluding SVC match-ups)

2nd reproc. (no SVC)



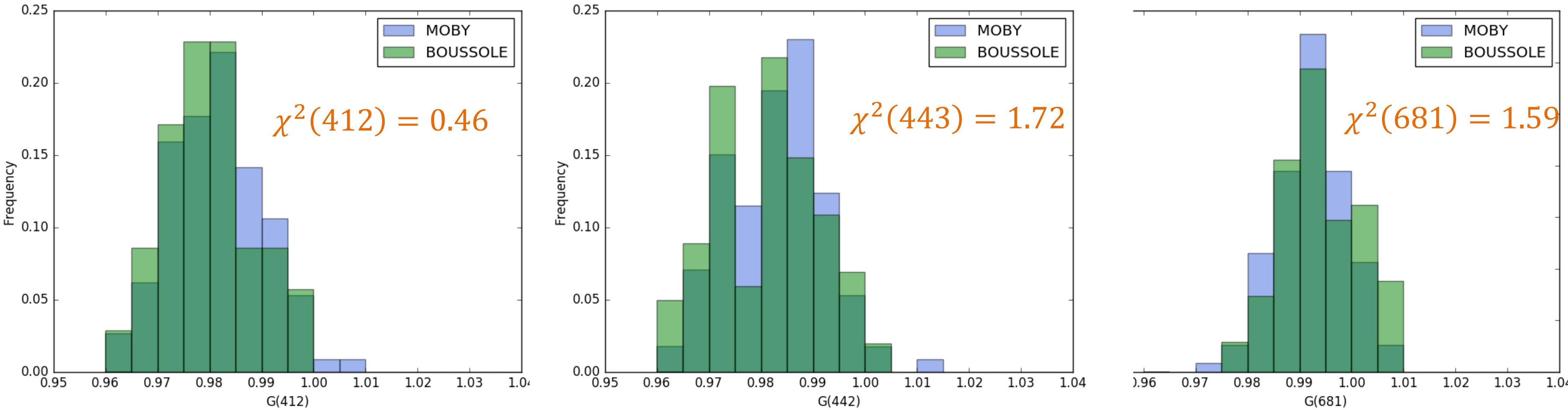
3rd reproc. (with SVC)



From Lerebourg et al. 2011 (MERIS ATBD)

Illustration of SVC: MERIS 4th reproc.

- MOBY and BOUSSOLE gains agree even better in 4th reproc.
- Chi2 test of homogeneity: if $\frac{|\bar{g}_M - \bar{g}_B|}{\sqrt{\sigma_M^2/N_M + \sigma_B^2/N_B}} < 1.96$, there is 95% probability that both sets of gains belong to the same distribution



- Reasons for this improvement include:
  - Update of in situ data (both datasets)
  - Various updates in the Level-2 processor, among which the NIR-precorrection (Bright Pixel Atmospheric Correction)

→ Quality in situ data + robustness of the AC = key success factor

What a SVC site should "look like"?

- Clear skies, no land or bottom influences
- Low aerosol load
- meso- to oligotrophic conditions
- Marine conditions well characterized, including spatial homogeneity
- Long-term logistical support and staff
- Linked to (collaboration with) a NMI
- Sufficient redundancy of equipment for 24/7 operations all year long
- Bi-monthly (at least monthly) servicing
- RT + field radiometry + satellite data processing expertise on site
- Among many other things.....

Some of the difficulties and challenges

- Field data collection still not really standardized
- Off the shelf instruments Ok?
- Maintenance of long-term sites always challenging
- Goals are actually not-so-well defined, therefore difficult to unambiguously decide what's appropriate and what's not for SVC
- No strategy for coastal waters
- No strategy for evaluation of SVC "solutions" (sites)
- Some paradigms to be revised? e.g. cal *vs*. val requirements
- ....

What's going to be done for future sensors?

- OLCI: likely as for MERIS in the short term (what means "short" here?). Dedicated infrastructure within Copernicus expected in the longer term (*cf*. EUMETSAT, ESA and JRC activities).

- S-GLI: unsure; might be similar to MERIS (e.g., MOBY+BOUSSOLE)

- PACE: still under evaluation (3 groups working on it at the moment). MOBY-NET, Wave glider, Profiling float ???

The future of SVC: main issues

- How to ensure the SI-traceability for OCR?

  Session 3 Metrology

- What are exactly the requirements?

  Session 4 Requirements

  - E.g. single data set *vs*. multiple data sets?

- Do we have the adapted field instrumentation?

  Sessions 5, 6, 7, 8 Instrumentations

- Are the methods mature and definitive?

  Sessions 4 & Session 9 Approaches

  - Slope model (assumes intercept=0); what does this mean exactly?
  - What to do for spectral matching algorithms? Method in the NIR?
  - Multi-detector, multi-camera instruments vs. single-detector?

- Do we have the organisation / structure etc.. for long-term SVC operations?

  Workshop round-tables

- How do we evaluate various SVC solutions? Validation datasets??

Thank you