Breakout Workshop on

Vicarious Calibration and Validation Protocols

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Summary Report

The Breakout Workshop aimed at finding consensus on standardized protocols for the operational identification and application of *in situ* measurements to validation and system vicarious calibration (SVC) processes. Two short talks introduced the two sub-sessions on Validation and SVC. The first *Introduction to practices for the construction of in situ – satellite matchups, their application to the validation of data products and the presentation of matchup statistics,* was delivered by G. Zibordi. The second *Introduction to practices for the construction of in situ – satellite matchups, their application to SVC and the statistical assessment of derived calibration factors,* was delivered by K. Voss. Each talk was followed by discussions supported by tables listing key elements for the construction of matchups with the final objective to reach agreement on basic protocols (*i.e.,* standard guides) supporting validation processes and SVC. Care was put in ranking requirements by stressing the fact that different spatial/temporal/geophysical applications may impose very different levels of requirements.

The following main elements were debated during the validation and SVC sub-sessions:

i. The fundamental requirements for *in situ* measurements supporting single missions for regional/global applications or multiple-missions addressing climate studies (*e.g.,* geophysical quantities, spectral characteristics, uncertainty budgets and traceability, geographical relevance, …);

ii. The fundamental physical methods to enforce equivalence of satellite and *in situ* data (*e.g.,* application of identical corrections for BRDF effects, corrections for minimizing the impact of different spectral bands, …);

iii. The fundamental criteria to be met for the construction of matchups (*e.g.,* local spatial/ temporal variability, observation conditions, ranges of applicability, time-lags between *in situ* and satellite data, geographical origin of the *in situ* data, …) and additionally, the fundamental methods and criteria that should be commonly applied for the statistical analysis of matchup data and the following presentation of summary results (*e.g.,* the statistical methods for the determination of systematic differences and dispersions affecting satellite data with respect to *in situ* measurements, the information complementing matchup analysis when presenting results, …).

Outcomes from the workshop are summarized in the following two tables centred on Validation and SVC requirements. Future actions, benefitting of contribution from participants to the break out session and additional members of the ocean color community, envisage the consolidation of the tables with the possibility of formalizing requirements in a Report or a White Paper.

VALIDATION PROTOCOL

		Target Applications		Relevant references	Notes/Comments
		Regional, Environmental	Global, Climate		The target applications identify cases exhibiting different requirements where climate implies the most stringent ones
Generic Requirements	*Quantity*	Radiometry (e.g., Rrs, Lwn) & derived products (e.g., Chla, τ_a)	Radiometry (e.g., Rrs, Lwn) & derived products (e.g., Chla, τ_a)		Chla and any quantity derived from Rrs or Lwn, should be included in the validation process only if the related radiometric producs are are qualified for validation
	Measurement method and protocol	Declared and documented	Consolidated (sharing community consensous on protocol, data QA/QC and processing)		
	Illumination conditions	Clear sky (clouds away from the sun and coverage ideally not exceeding 2-octas)	Clear sky (clouds far from the sun and coverage ideally not exceeding 2-octas)		Relevant for measurement prtocols: sky cameras may help to better quantify and qualify cloud cover
	Distance from the coast	Declared	Avoid cases affected by adjacency effects (distance from land should be larger than at least 5 nautical miles)	*Bulgarelli and Zibordi, 2018. JRC Technical Report, doi: 10.2760/178467 (online), 40 pp.*	
	Bottom depth	Declared	Avoid cases affected by bottom effects (which depend on depth and water type)		
	Water type	Any	Prioritize mesotrophic/oligotrophic (but not excluding different water types assuming a statistical balance in the data set)		
	Multiple sites/sources	Yes	Yes		
Radiometric Requirements	*Uncertainties*	Declared and documented	Fulfilling GCOS requirements for Rrs and Lwn (i.e., lower than 5% for Rrs in the blue-green spectral regions), lower than 0.02 for τ_a, and than ~15% for Chla in the 0.01-10 $\mu g\ l^{-1}$ range.	*WMO, 2011. Report GCOS 154, 138 pp. Hooker et al, 2012. NASA/TM-2012-217503, 98 pp.*	Relevant to measurement prtocols: uncertainties should be declared per cruise, ideally per individual measurement (wind speed should be considered as a source of uncertainty)
	Spectral resolution	Comparable to that of the space sensor	At least comparable to that of the space sensor (typically 10 nm or better)		Relevant to measurement prtocols: spectral bands for the validation of future satellite sensors should be considered
	Spectral matching	Desirable to within a few nm	Required (i.e., in situ and satellite equivalent center-wavelengths closer than 2-5 nm, depending on the spectral location of the band)		When applyimg in situ hyperspectral data, an effort should be made to match satellite bands accounding for their spectral transmission functions
	BRDF corrections	Required (implies corrections equivalent to those applied to satellite data)	Required (implies corrections equivalent to those applied to satellite data)		It is recognized that corrections not suitable for specific water types may become a significant source of uncertainty
	Band-shift corrections	Desirable in the full visible spectrum for center-wavelengths differing by more than 1-2 nm	Required in the full visible spectrum for center-wavelengths differing by more than 1-2 nm (implying direct or indirect knowledge of local IOPs)	*Melin and Sclept, 2015. Optics Express, 23, 2262-2279.*	
Matchup Requirements	*Number of image elements N centered at the validation site (1-element ~ 1km for typical reduced resolution data)*	Tentatively 3x3 in coastal (in view of accounting for coastal variability and minimize land perturbations) and 5x5 in open sea regions	Tentatively 3x3 in coastal (in view of accounting for coastal variability and minimize land perturbations) and 5x5 in open sea regions		In the case of high spatial resolution satellite data, it is difficult to propose a generic N supported by published work (there are cases considering 3x3 and others just 1)
	Time-lag between satellite and in situ data	Less than 4 hr (still, the most suitable value should be determined accounting for local variability)	Less than 2 hr (sensitivity tests based on different time-lags, may provide elements in support of the selected value)		
	Agency Suggested Flags	All (each one not affecting any of the N image elements). In other words, 100% of the N elements should not be affected by suggested flags applied for products generation	All (each one not affecting any of the N image elements, In other words, 100% of the N elements should not be affected by suggested flags for products generation		The 100% requirement (i.e., the percent of image elements not affected by flags), could be reduced for some specific flags. But it should be applied to cloud relevant flags
	Viewing and illumination geometries	Viewing angle and sun zenith lower than given thresholds (e.g., 60 and 70 degrees)	Viewing angle and sun zenith lower than given thresholds (e.g., 60 and 70 degrees)		
	Threshold on the coefficient of variation (COV) of the N elements	Tentatively 0.2 at a single spectral band (e.g., 555 nm or equivalent for Rrs or Lwn, and 870 nm or equivalent for τ_a)	Tentatively 0.2 at a single spectral band (e.g., 555 nm or equivalent for Rrs or Lwn, and 870 nm or equivalent for ta). Sensitivity tests may support the selected value.		Thresholds on the COV of in situ data over periods of n*time-lags, may additionally help identify cases affected by high temporal (spatial) variability
Statistics Requirements	*Minimum number of matchups (for a given processing and period)*	No (but still enough to assume statistical representativity of regional spatial/temporal variability)	Ensure statistical representativity (tentatively more than several hundreds)		When satisfying statistical representativity, matchups should be constructed and analyzed for different water/atmospheric/seasonal cases
	Bias index (for each band)	Computed from the same matchups for all visible bands or products (e.g., median of percent differences)	Computed from the same matchups for all visible bands or products (e.g., median of percent differences)		Relevant for future reasearch activities: additional investigations are needed to comprehensively address in situ and satellite uncertainties
	Dispersion index (for each band)	Computed from the same matchups for all visible bands or products (e.g., median of percent absolute differences)	Computed from the same matchups for all visible bands or products (e.g., median of percent absolute differences)		
	Root mean square of differences (for each band)	Desirable	Computed from the same matchups for all visible bands or products		The application of Model-2 regressions is recommended. Still, the use of Model-2 or alternatively Model-1 regressions should be at least declared
	Ranges	Required (essential to determine the comparability of results across independent analysis from different geographic regions and water types)	Required (essential to determine the comparability of results across independent analysis from different geographic regions and water types)		
	Distributions	Desirable	Required for all visible bands or products (essential to determine the significance of statistical analyses)		

SYSTEM VICARIOUS CALIBRATION PROTOCOL

		Target Applications		Relevant references	Notes/Comments
		Regional, Environmental	Global, Climate		The target applications identify cases exhibiting different requirements where climate implies the most stringent ones
Generic Requirements	*Quantity*	Radiometry (i.e., Lw, Es, Rrs, Lwn)	Radiometry (e.g., Rrs, Lwn)		
Generic Requirements	*Measurement method and protocol*	Consolidated (sharing community consensus including criteria for data QA/QC and processing)	Consolidated (sharing community consensus including criteria for data QA/QC and processing)		
Generic Requirements	*Illumination conditions*	Clear sky (clouds away from the sun and cloud coverage ideally lower than 1-octas) with sun zenith angles representative of local satellite observation conditions	Clear sky (clouds far from the sun and very low cloud coverage ideally well below 1-octas) and sun zenith angles representative of global mean satellite observation conditions		Clear sky conditions should be detected with a mask exceeding the matrix of points used to construct matchups
Generic Requirements	*Distance from the coast*	Minimizing adjacency effects (larger than at least 5 nautical miles)	Ideally more than 25 nautical miles from the coast	Bulgarelli and Zibordi, 2018. JRC Technical Report, doi: 10.2760/178467 (online), 40 pp.	It should be considered that adjacency effects also depend on the sensor S/N ratio of the satellite sensor and that the impact of a small island is much lower than that of the main land
Generic Requirements	*Bottom depth*	Minimizing bottom effects (depth depending on water type)	Optically deep		
Generic Requirements	*Water type*	Mesotrophic/oligotrophic	Oligotrophic (e.g., Chla lower than 0.1 ug l^{-1})		The oligotrophic conditions are largely suggested to ensure best reproducibility of measurement conditions, which would enhance stability of g-factors over time
Generic Requirements	*Environmental conditions*	Maritime aerosol exhibiting low load (e.g., lower than 0.1 at 865 nm), moderate winds (e.g., lower than 5 m s^{-1})	Maritime aerosol exhibiting low load (e.g., lower than 0.1 at 865 nm), moderate winds (e.g., lower than 5 m s^{-1})	Gordon 1998. Remote Sensing of Environment, 63, 265-278.	Wind speed may be an additional element to account for. In fact low-mid wind speed conditions would increase reproducibility of in situ measurements
Generic Requirements	*Multiple sites/sources*	Yes (assuming equivalence of water types across sites and of uncertainties across sources)	No (to ensure highest reproducibility of conditions over time, unless this constraint is shown to be irrelevant)	Zibordi et al., 2015. Remote Sensing of Environment, 159, 361-369.	The use of a single site is important for climate applications to enhance stability of g-factors and their low uncertainties
Radiometric Requirements	*Uncertainties*	Declared and documented	Allow fulfilment of GCOS requirements (e.g., lower than 3-4% for Rrs in the blue-green spectral regions and tentatively 5% in the red)		Uncertainty requirements could be considered in conjunction with the atmospheric component away from the SVC site, as a function of the SVC method and target data application
Radiometric Requirements	*Stability*	Quantifiable	Quantifiable and ideally better than 0.5% per deployment (tentatively lasting 6 months)		
Radiometric Requirements	*Full radiometric corrections*	Desirable	Required (embracing: polarization sensitivity, temperature dependence, stray-light perturbations, non-linearity, non-cosine response, immersion factors)		
Radiometric Requirements	*Spectral resolution*	Comparable to that of the space sensor (typically 10 nm or better)	Sub-nanometer for Lwn and better than 2 nm for Rrs	Zibordi et al., 2017. Optics Express, 25, A798-A812.	
Radiometric Requirements	*Spectral matching*	Desirable to within 1-2 nm	Exact (i.e., ideally within 0.1 nm for high spectral resolution satellite sensors)		
Radiometric Requirements	*BRDF corrections*	Required (implying corrections equivalent to those applied to satellite data)	Required (implying corrections equivalent to those applied to satellite data)	Morel et al., 2002. Applied Optics, 41, 6289-6306.	Uncertainties are minimized by the water type (i.e., oligotrophic)
Radiometric Requirements	*Band-shift corrections*	Required in the full visible spectrum for center-wavelengths differing by more than 1-2 nm (implying direct or indirect knowledge of local IOPs)	No (as a result of the exact spectral matching)	Melin and Sclept, 2015. Optics Express, 23, 2262-2279.	
Matchup Requirements	*Number of image elements N centered at the in-situ site (1-element ~ 1km for reduced resolution data)*	Tentatively 3x3 minimum (5x5 minimum in open sea regions)	Tentatively 5x5 minimum (or more)		Considering that reproducibility of g-factors is essential, the number of N elements is an open issue being dependent on spatial resolution, viewing geometry, spatial variability, sensor S/N .
Matchup Requirements	*Time-lag between satellite and in situ data*	Less than 1-2 hrs	Less than 1 hr		
Matchup Requirements	*Viewing and illumination geometries*	Viewing angle and sun zenith lower than given thresholds (e.g., 60 and 70 degrees)	Viewing angle and sun zenith lower than given thresholds (e.g., 60 and 70 degrees)	Franz et al., 2007. Applied Optics, 46, 5068-5066.	These thresholds should/could be more restrictive than those applied for validation
Matchup Requirements	*Threshold on the coefficient of variation (COV) of the N elements*	0.2 at a single spectral band (e.g., 555 nm or equivalent)	0.1 at multiple spectral band (e.g., in the spectral region 412-555 nm or equivalent)		
Matchup Requirements	*Agency Suggested Flags*	All (each one not affecting any of the N image elements). In other words, 100% of the N elements should not be affected by suggested flags applied for products generation	All (each one not affecting any of the N image elements). In other words, 100% of the N elements should not be affected by suggested flags applied for products generation		
Statistic	*Number of matchups*	Typically several tens (function of the regional variability, uncertainty of in situ data and space sensor signal-to-noise ratio)	Typically several tens (function of the regional variability, uncertainty of in situ data and space sensor signal-to-noise ratio)	Franz et al., 2007. Applied Optics, 46, 5068-5066.	
Statistic	*Quality index*	Required (e.g., relative standard error of the mean)	Required (e.g., relative standard error of the mean)	Zibordi et al., 2015. Remote Sensing of Environment, 159, 361-369.	