System Vicarious Calibration of Sentinel-3 OLCI

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CALCON Technical Meeting
Utah State University, Logan, UT, USA
August 23rd 2017

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outline

- Context
- System vicarious calibration (SVC) Objectives and Methodology
- SVC Implementation and Results
- Validation using Level 2 data
- Validation using Level 3 data
- Conclusion

Context

- Sentinel-3A (S3A), carrying the Ocean and Land Colour Instrument (OLCI), was successfully launched on February 16th 2016
- OLCI dedicated to land and ocean colour, continuity with MERIS, inheriting algorithmic evolutions from MERIS 4th reprocessing, this talk only on ocean SVC
- It is essential to ensure product quality prior public release for operational services such as Copernicus Marine Environment Monitoring Service
- Radiometric validation results demonstrate that OLCI absolute radiometric calibration is comparable with its heritage instrument, MERIS, and that OLCI has a positive bias of about 2 to 3 percent, OLCI being too bright. Actions are in place to achieve OLCI radiometric compliancy (2% absolute accuracy < 900 nm).
- As for any ocean colour mission, proper system vicarious calibration (or “adjustment”) must be made using fiducial reference measurements (i.e. high quality targets) at surface level
- “Adjustment” stands here for sensor (residual L1 calibration) + L2 processor adjustment

System Vicarious calibration

Objective & fundamental equations

❖ General principle :

Fiducial reference (FRM) in situ + exploitable satellite measurements of marine reflectance $\rho_w(\lambda)$

$$\rho_{TOA}(\lambda) = t_g(\lambda) \cdot \left(\rho_{path}(\lambda) + t_{up}(\lambda) \cdot t_{down}(\lambda) \cdot \rho_w(\lambda)\right)$$

→ compute theoretical TOA signal, $\rho_{TOA}^{T}(\lambda)$:

$$\rho_{TOA}^{T}(\lambda) = t_g(\lambda) \cdot \left(\rho_{path}(\lambda) + t_{up}(\lambda) \cdot t_{down}(\lambda) \cdot \rho_w^{T}(\lambda)\right) \text{ using in-situ } \rho_w^{T}(\lambda)$$

→ individual gain per matchup: $G(\lambda) = \dfrac{\rho_{TOAi}^{T}(\lambda)}{\rho_{TOAi}(\lambda)}$

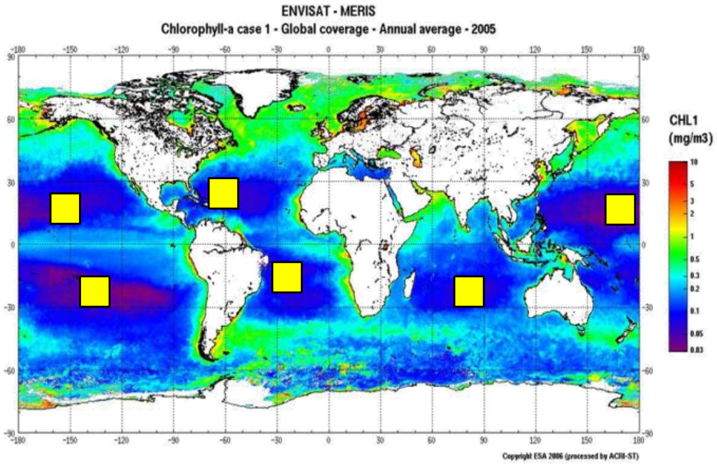
Compute gains from time series through a weighted average $\bar{G}(\lambda) = \dfrac{\sum_{i=1}^{N} \frac{1}{\sigma_{Gi}} G_i}{\sum_{i=1}^{N} \frac{1}{\sigma_{Gi}}}$

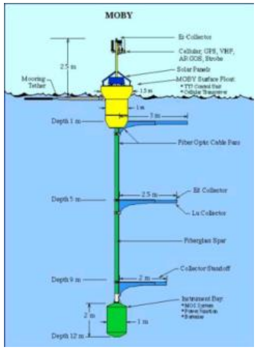
with $\sigma_{G_i} = \sqrt{\boldsymbol{\sigma}_{sat}^{2} + \boldsymbol{\sigma}_{IS}^{2}}$, σ_{sat} being local standard deviation of ρ_{w} and σ_{IS} being 5% of $\rho_{\text{w}}^{\text{T}}$

System Vicarious calibration
VIS/NIR two step procedure

- Historical approach decoupling VIS/NIR adjustment (Franz et al. 2007, Bailey et al 2008)
- NIR gains are firstly computed in the NIR to calibrate atmospheric correction bands
  - ✓ Make use of oligotrophic regions of the ocean (traditionally the South Pacific Gyre and the South Indian Ocean)
  - ✓ No need of actual in situ measurements as a the ocean is assumed to be representative of the pure water signal in the NIR
- Visible gains are then computed on a dataset already calibrated for NIR bands.
  - ✓ <u>**For this step FRMs are required**</u>, BOUSSOLE and MOBY have been used for past missions.
  - ✓ Matchup selection being very stringent for SVC, we do not reach enough **BOUSSOLE** and **MOBY** match-ups yet

→ A methodology based on in-situ + climatological radiometry (**GlobColour**) at oligotrophic sites has been implemented.





SVC implementation: NIR gains

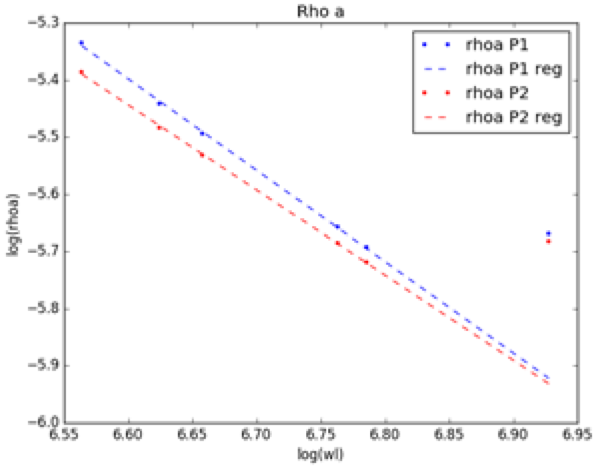
Different methodologies tested

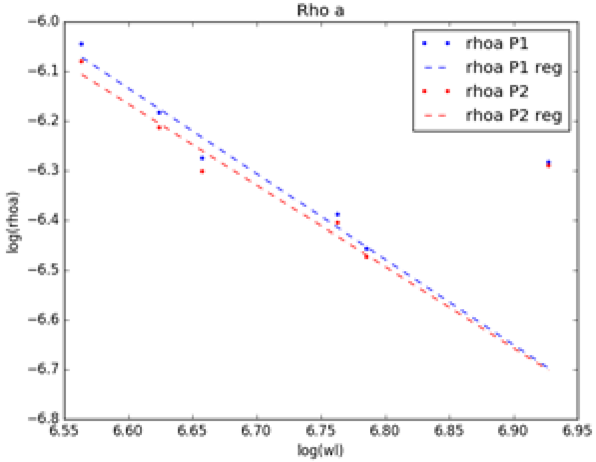
1. SeaWiFS (predefined aerosol and unit gain at 1 NIR band)
2. MERIS (free theoretical aerosol, 2 NIR bands at unit gain)
3. OLCI (free theoretical aerosol, log-log linear regression of ρ_a in [709, 885] nm against λ)
   - ✓ no fixed gain assumption
   - ✓ comparing well with other methodologies
   - ✓ 1020 nm excluded from regression as strong outlier
   - ✓ $\rho^T_{TOA}(\lambda) = \rho^T_{aer}(\lambda) + \rho_{rayleigh}(\lambda) + t(\lambda) * \rho^{NIR}_{purewater}(\lambda)$

$$\rho^T_{aer}(\lambda) = e^{a*log(\lambda)+b}$$

With a and b the slope and intercept respectively of the linear fine between $log(\rho^T_{aer}(\lambda))$ and $log(\lambda)$, $\lambda = [709, 754, 779, 865, 885]$

→ OLCI method retained and SeaWiFS (NASA) method used for comparisons





SVC implementation: NIR gains

Results:

OLCI method on SIO/SPG

site/band	709	754	779	865	885	1020
SIO (std)	0.996 (0.002)	1.003 (0.003)	1.005 (0.003)	1.000 (0.003)	0.996 (0.004)	0.912 (0.050)
SPG (std)	0.996 (0.003)	1.003 (0.004)	1.004 (0.003)	1.000 (0.004)	0.996 (0.004)	0.916 (0.05)
ALL (std)	0.996 (0.003)	1.003 (0.003)	1.005 (0.003)	1.000 (0.004)	0.996 (0.004)	0.914 (0.050)

NASA method on SPG (aerosol model constrained by relative humidity)

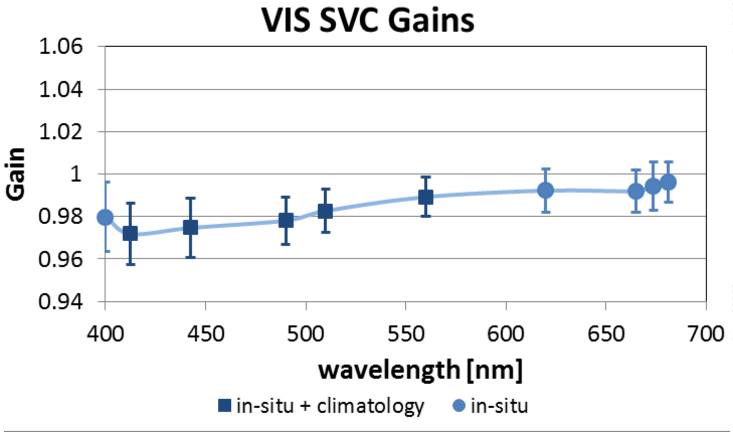
site/band	709	754	779	865	885	1020
SPG (std)	0.995 (0.020)	1.001 (0.016)	1.005 (0.013)	1.000 (0.000)	0.996 (0.007)	0.911 (0.040)

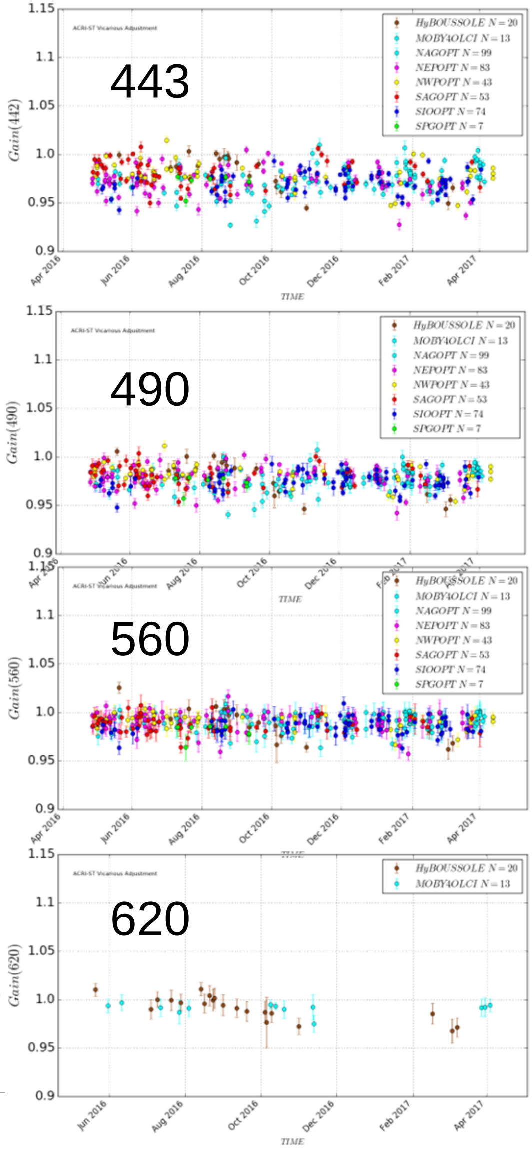
→ same gains but higher uncertainty in NASA method → OLCI method retained

SVC implementation: Visible gains

- **For visible bands, the objective is to reconstruct a $\rho_{TOA}^{T}(\lambda)$ signal based on in-situ measurements**
- **A combination of in situ measurements (λ=400nm, λ>=620nm) and climatology (412≤λ≤560nm) was used to derive the gains**
  - GlobColour 4km daily climatology over the 1997-2012 time period (11 days sliding average).

λ	Gain	σ_g	Ref.
400	**0.9798**	**0.0163**	**IS**
412.5	**0.9718**	**0.0145**	**IS+Cl**
442.5	**0.9747**	**0.014**	**IS+Cl**
490	**0.9781**	**0.0111**	**IS+Cl**
510	**0.9827**	**0.0101**	**IS+Cl**
560	**0.9892**	**0.0092**	**IS+Cl**
620	**0.9922**	**0.0101**	**IS**
665	**0.9920**	**0.0098**	**IS**
673.8	**0.9943**	**0.0115**	**IS**
681.3	**0.9962**	**0.0095**	**IS**

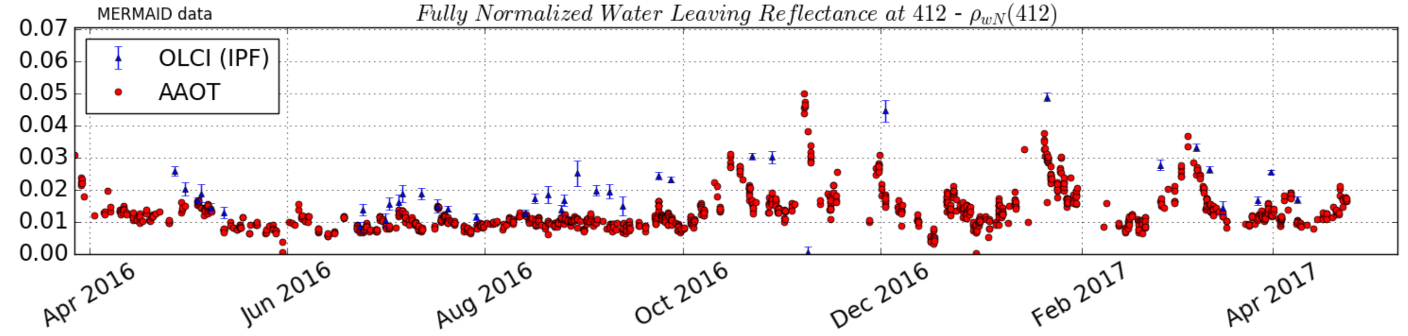




OCR VALIDATION USING LEVEL-2

Level-2 time series AAOT – No ViCal

412



Fully Normalized Water Leaving Reflectance at 412 - $\rho_{wN}(412)$

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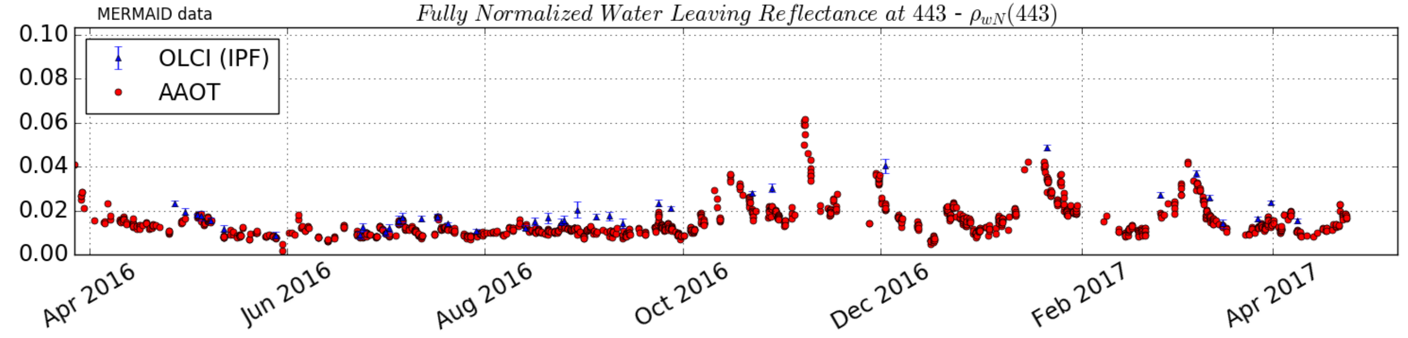
443



Fully Normalized Water Leaving Reflectance at 443 - $\rho_{wN}(443)$

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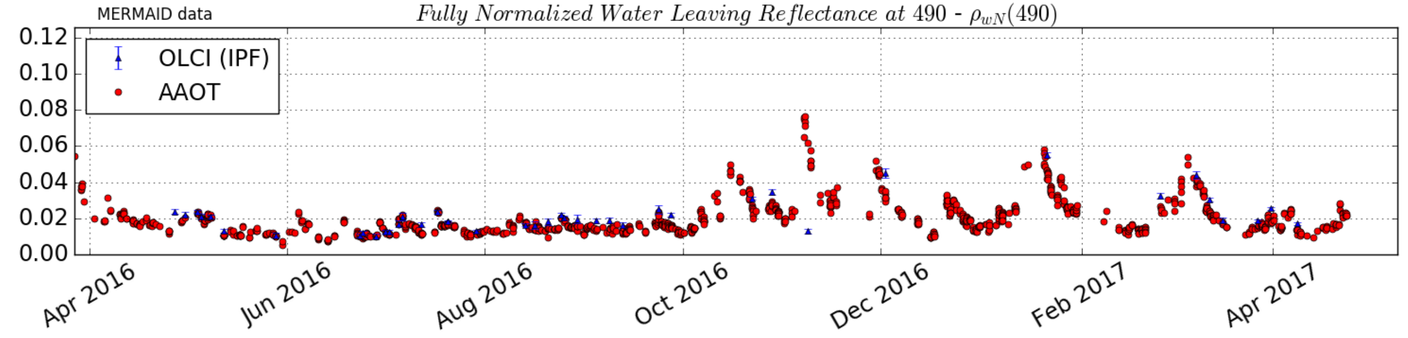
490



Fully Normalized Water Leaving Reflectance at 490 - $\rho_{wN}(490)$

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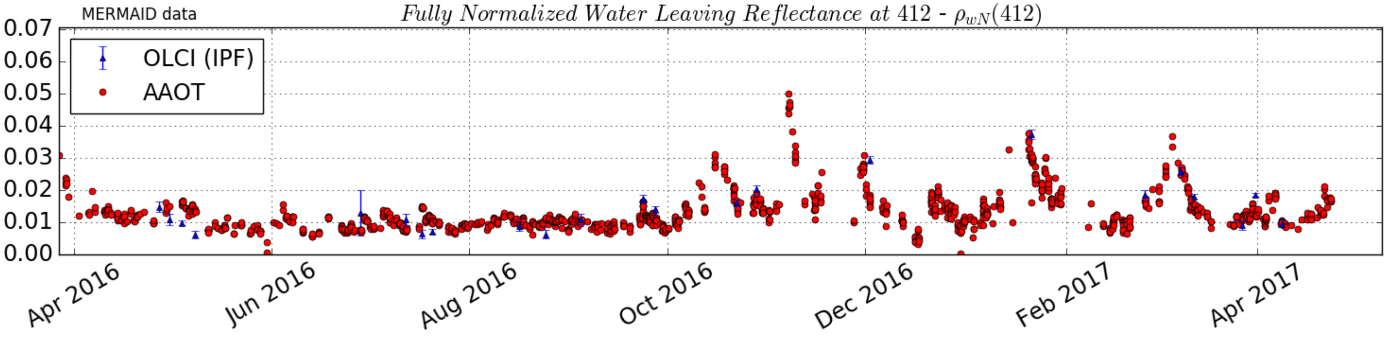
Level-2 time series AAOT - ViCal

412


MERMAID data

Fully Normalized Water Leaving Reflectance at 412 - $\rho_{wN}(412)$

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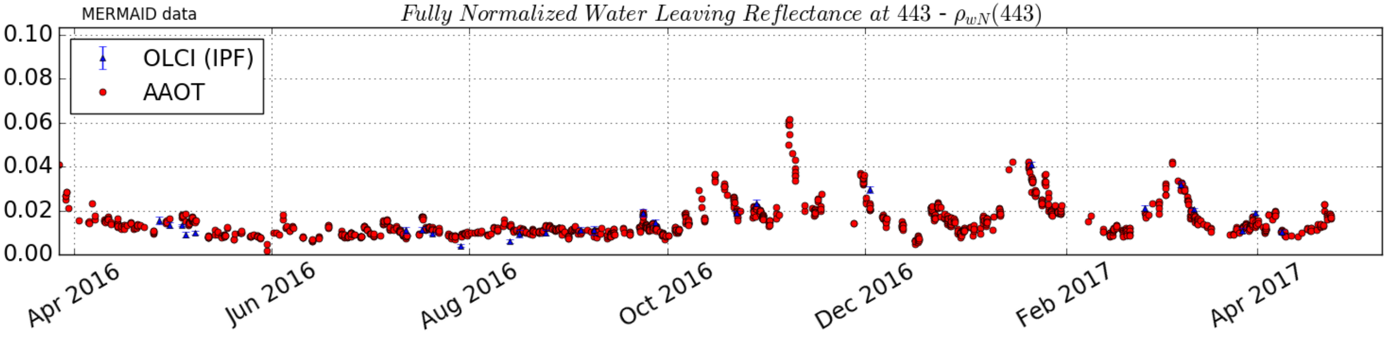
443


MERMAID data

Fully Normalized Water Leaving Reflectance at 443 - $\rho_{wN}(443)$

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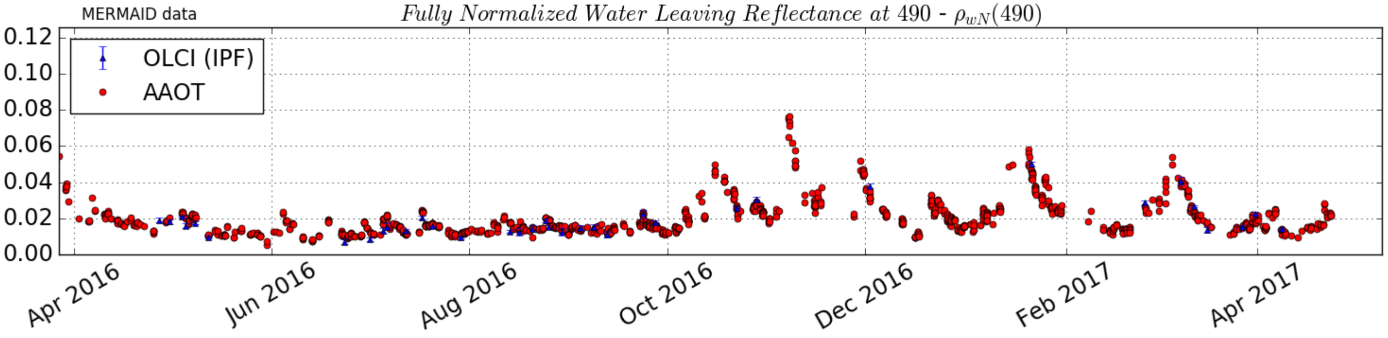
490


MERMAID data

Fully Normalized Water Leaving Reflectance at 490 - $\rho_{wN}(490)$

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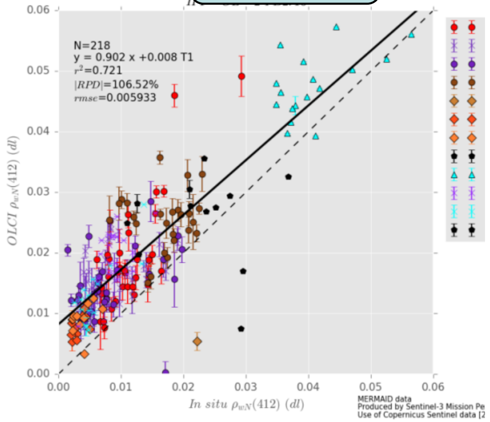
Validation 412-490

Used flags:

INVALID, CLOUD, CLOUD_AMBIGUOUS, CLOUD_MARGIN, SNOW_ICE, SUSPECT, HISOLZEN, SATURATED, HIGHGLINT, WHITECAPS, AC_FAIL, OC4ME_FAIL, ANNOT_TAU06, RWNEG_[O2-O8] + ANNOT_MIXR1

NO VIC

412



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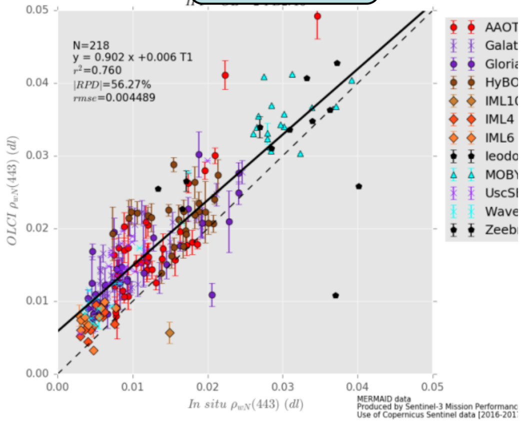

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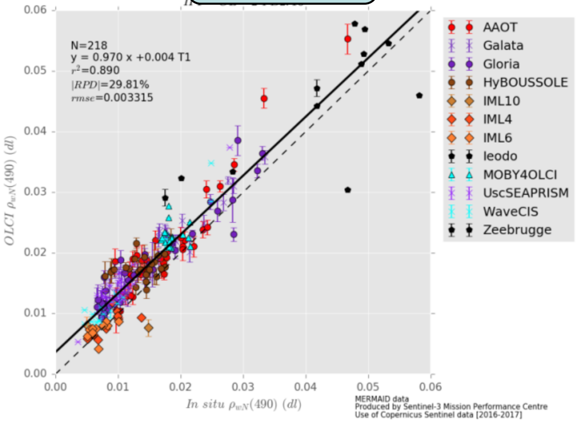
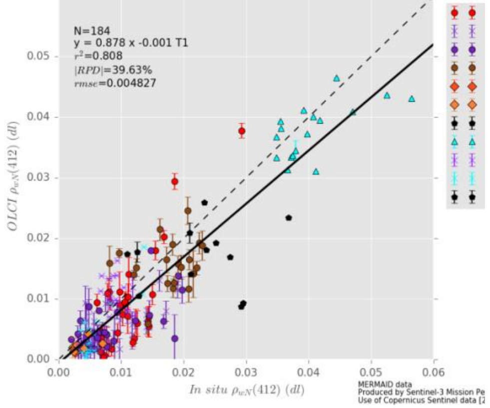


NIR + VIS vicarious

412



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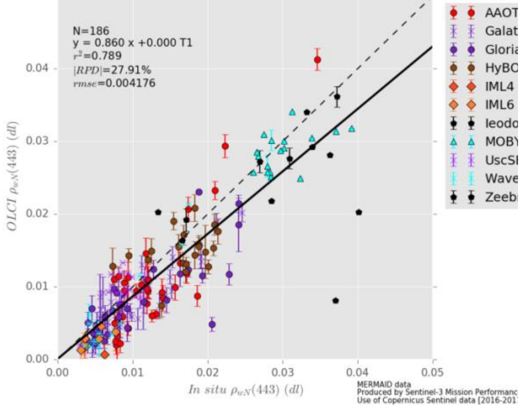

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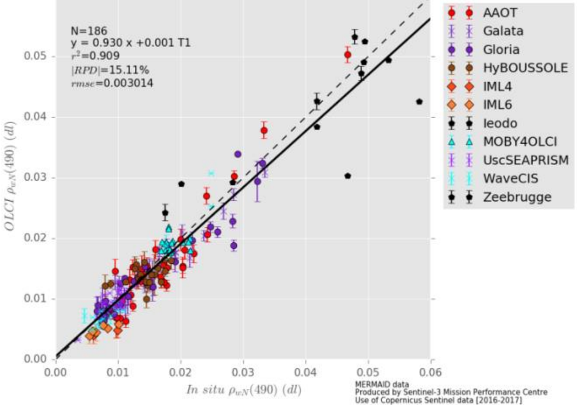


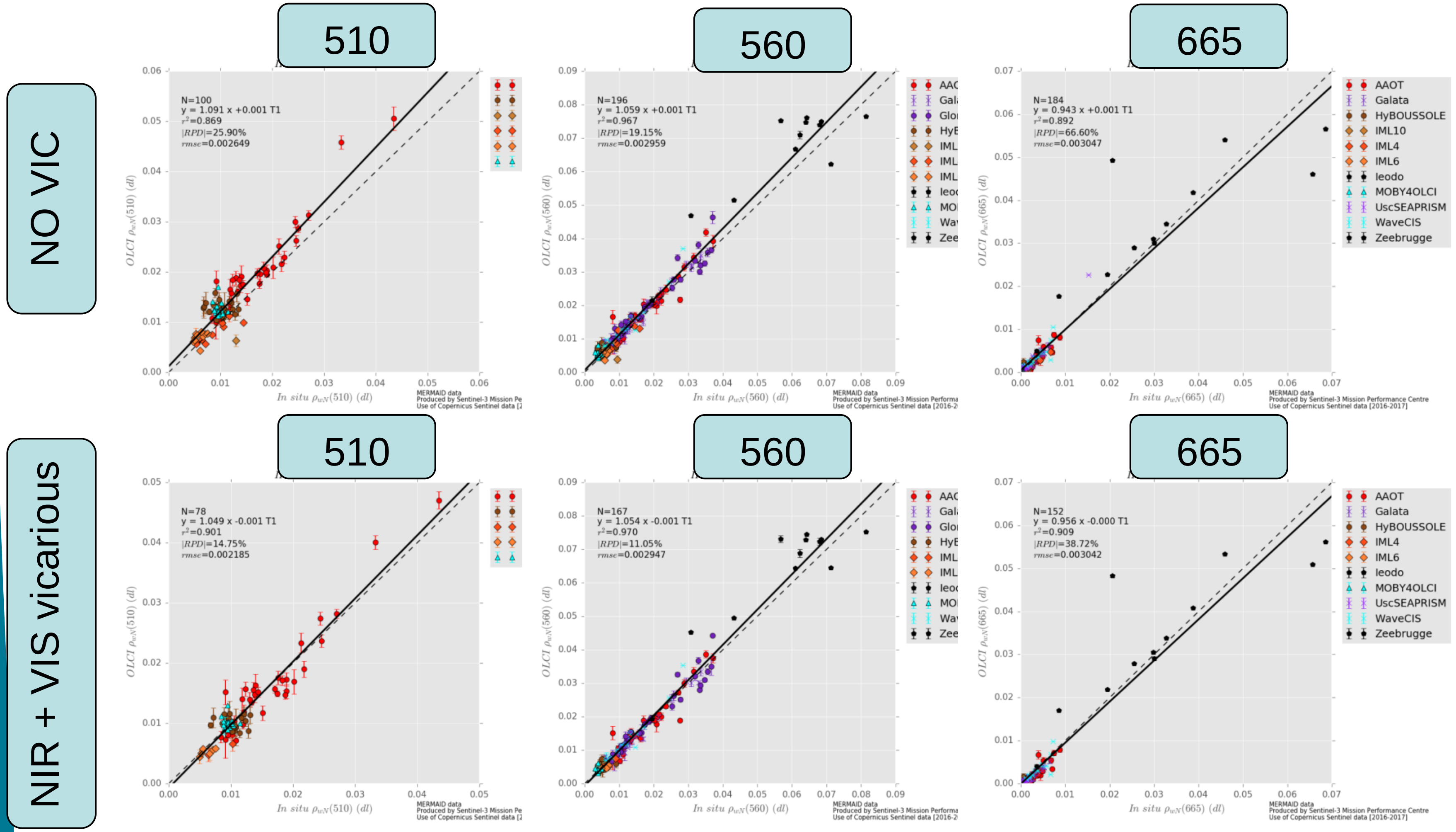
Acknowledgment to :

- G. Zibordi, D. Antoine and V. Vellucci , K. Voss , Y.-J. Park and H.-Y. You , S. Belanger and T. Jaegler , B. Jones and C. Davis, A. Weidemann, B. Gibson and R. Arnone, D. Van Der Zande

Validation 510-665

Used flags:

INVALID, CLOUD, CLOUD_AMBIGUOUS, CLOUD_MARGIN, SNOW_ICE, SUSPECT, HISOLZEN, SATURATED, HIGHGLINT, WHITECAPS, AC_FAIL, OC4ME_FAIL, ANNOT_TAU06, RWNEG_[O2-O8] + ANNOT_MIXR1



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Level-2 validation

Case 1 and Case 2 sites

- BOUSSOLE, MOBY, IML4, IML6, IML10, AAOT, Galata, Gloria, Ieodo, UscSEAPRISM, WaveCIS, Zeebrugge

No vicarious cal.

lambda	N	RPD	|RPD|	MAD	RMSE	ubRMSE	slope	intercept	r2
400	42	47%	48%	0.0084	0.0106	0.0066	0.829	0.013	0.790
412	195	105%	105%	0.0077	0.0092	0.0050	0.929	0.009	0.798
443	200	55%	56%	0.0050	0.0062	0.0037	0.956	0.006	0.827
490	214	27%	30%	0.0032	0.0046	0.0034	0.960	0.004	0.885
510	99	22%	26%	0.0023	0.0035	0.0026	1.087	0.001	0.869
560	193	15%	19%	0.0015	0.0034	0.0030	1.055	0.001	0.966
665	70	16%	30%	0.0005	0.0048	0.0047	0.928	0.001	0.880

Vicarious cal.

lambda	N	RPD	|RPD|	MAD	RMSE	ubRMSE	slope	intercept	r2
400	34	6%	22%	-0.0002	0.0057	0.0057	0.837	0.005	0.835
412	88	1%	30%	-0.0012	0.0055	0.0054	0.829	0.002	0.802
443	116	-3%	22%	-0.0011	0.0040	0.0039	0.866	0.001	0.814
490	173	-2%	15%	-0.0005	0.0032	0.0032	0.917	0.001	0.901
510	74	-1%	15%	-0.0001	0.0021	0.0021	1.060	-0.001	0.909
560	157	0%	11%	0.0002	0.0031	0.0031	1.052	-0.001	0.968
665	35	-3%	24%	0.0002	0.0061	0.0061	0.919	0.001	0.879

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

$$|RDP| = \frac{1}{N}\sum_{i}^{N}\left(\frac{|y_i - x_i|}{x_i}\right)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i}^{N}(x_i - y_i)^2}$$

$$ubRMSE = \sqrt{\frac{1}{N}\sum_{i}^{N}\left((x_i - \bar{x}) - (y_i - \bar{y})\right)^2}$$

Level-2 validation

Case 1 sites

- BOUSSOLE MOBY

No vicarious cal.

lambda	N	RPD	|RPD|	MAD	RMSE	ubRMSE	slope	intercept	r2
400	42	47%	48%	0.0084	0.0106	0.0066	0.829	0.013	0.790
412	42	45%	46%	0.0079	0.0098	0.0058	0.836	0.012	0.796
443	42	34%	34%	0.0054	0.0067	0.0041	0.807	0.010	0.739
490	42	29%	29%	0.0040	0.0047	0.0026	0.650	0.009	0.472
510	42	33%	34%	0.0029	0.0036	0.0021	0.003	0.013	0.000
560	41	37%	39%	0.0015	0.0020	0.0013	0.344	0.005	0.173

Vicarious cal.

lambda	N	RPD	|RPD|	MAD	RMSE	ubRMSE	slope	intercept	r2
400	34	6%	22%	-0.0002	0.0057	0.0057	0.837	0.005	0.835
412	34	-4%	21%	-0.0022	0.0055	0.0050	0.837	0.003	0.839
443	35	-4%	17%	-0.0015	0.0038	0.0035	0.842	0.002	0.786
490	36	2%	13%	0.0001	0.0022	0.0022	0.701	0.005	0.554
510	35	3%	14%	0.0002	0.0016	0.0016	0.005	0.010	0.000
560	29	6%	15%	0.0002	0.0009	0.0009	0.494	0.003	0.267

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

$$|RDP| = \frac{1}{N}\sum_{i}^{N}\left(\frac{|y_i - x_i|}{x_i}\right)$$

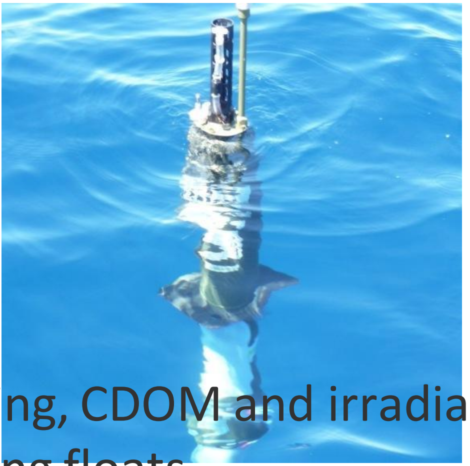
$$RMSE = \sqrt{\frac{1}{N}\sum_{i}^{N}(x_i - y_i)^2}$$

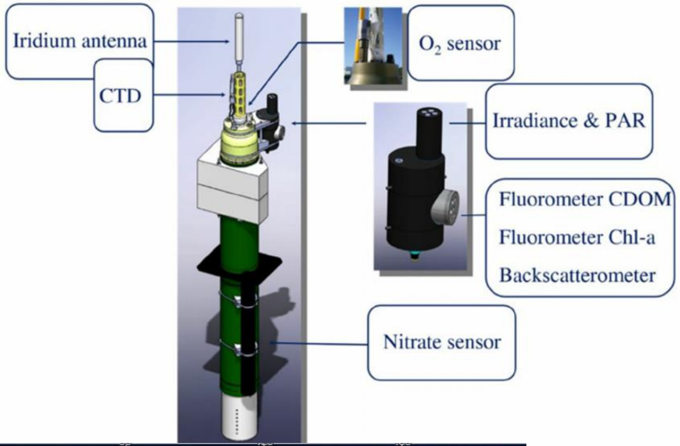
$$ubRMSE = \sqrt{\frac{1}{N}\sum_{i}^{N}\left((x_i - \bar{x}) - (y_i - \bar{y})\right)^2}$$

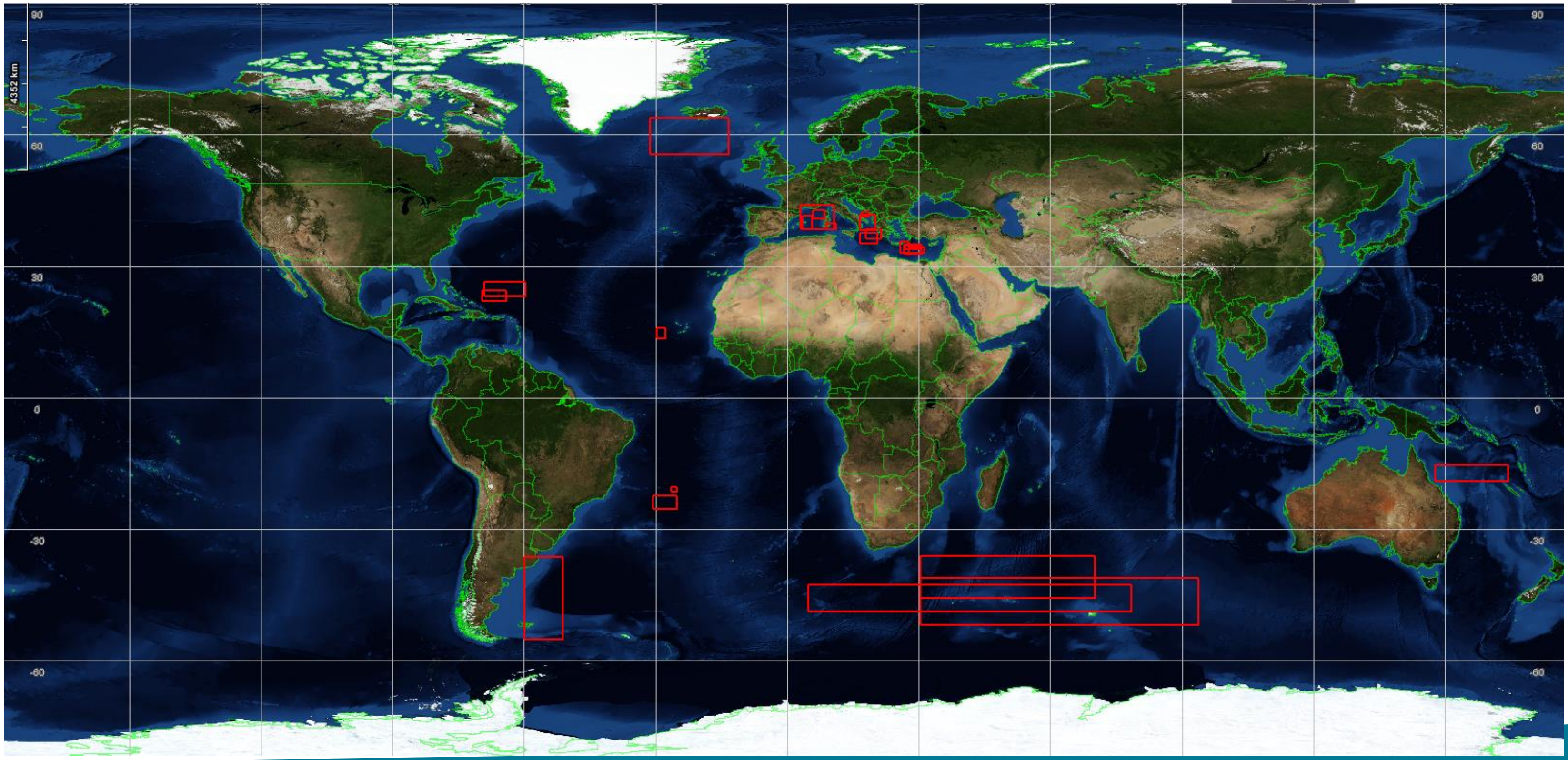
Level-2 validation

❖ Bio-Argo floats

- Chlorophyll, backscattering, CDOM and irradiance measurements on profiling floats.



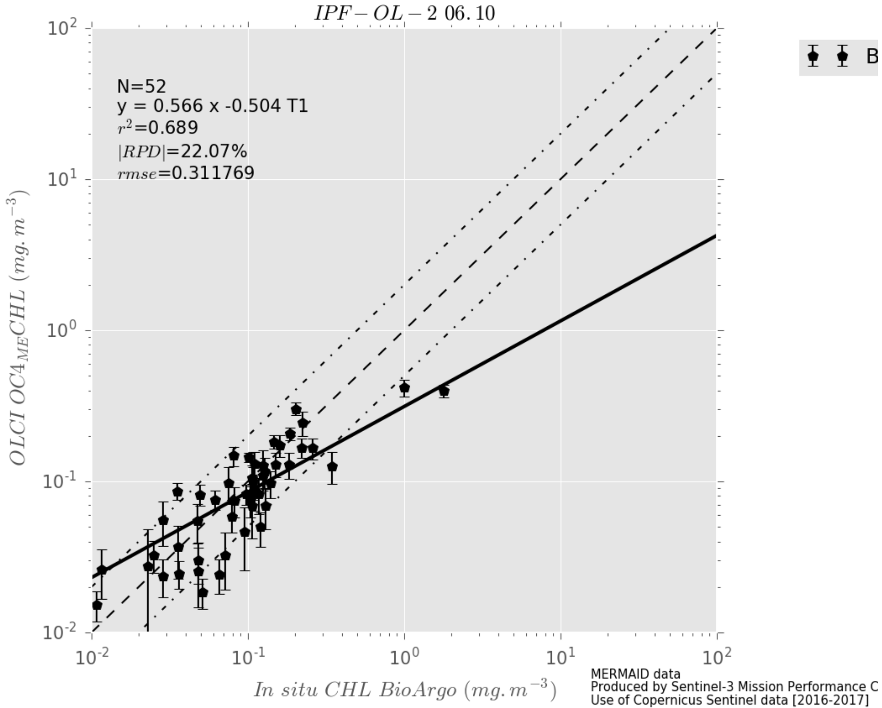




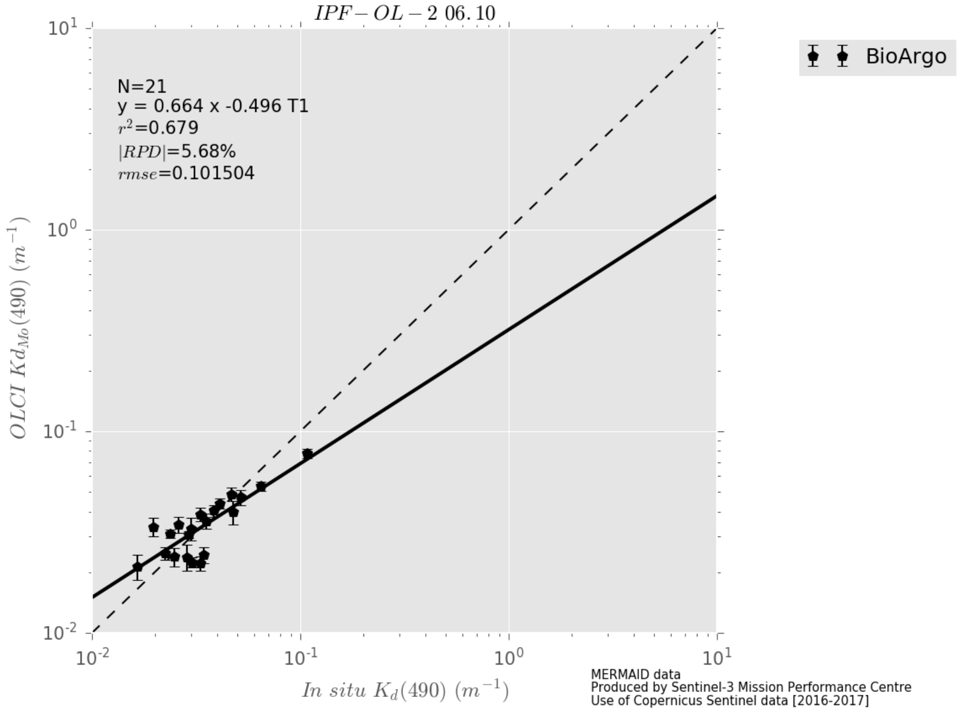
Level-2 validation

❖ Bio-Argo floats

- Chlorophyll, backscattering, CDOM and irradiance measurements on profiling floats.



MERMAID data
Produced by Sentinel-3 Mission Performance C
Use of Copernicus Sentinel data [2016-2017]

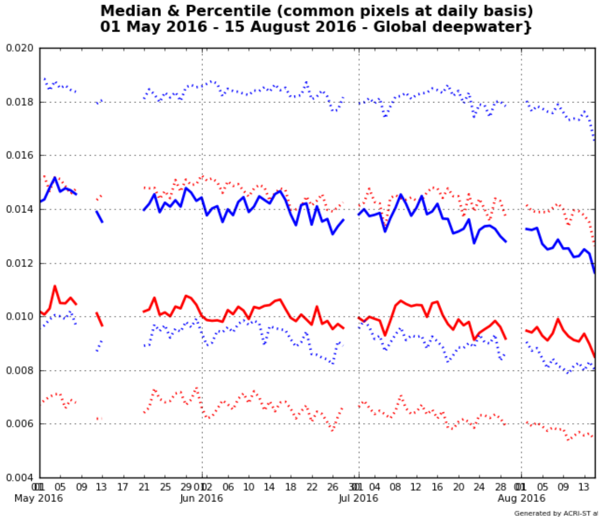


MERMAID data
Produced by Sentinel-3 Mission Performance Centre
Use of Copernicus Sentinel data [2016-2017]

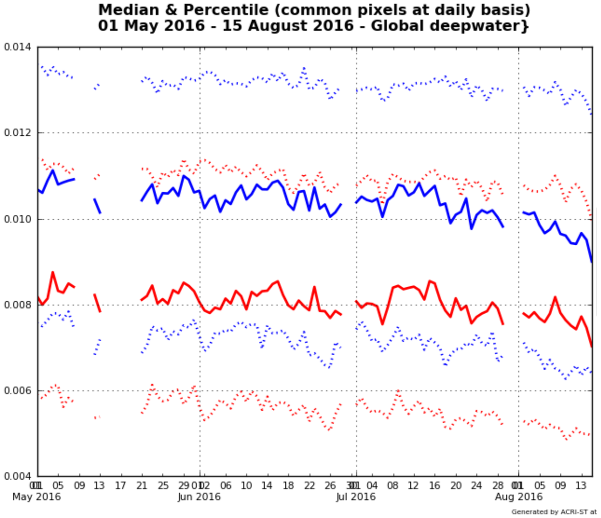
OCR VALIDATION USING LEVEL-3

Level 3
No ViCal

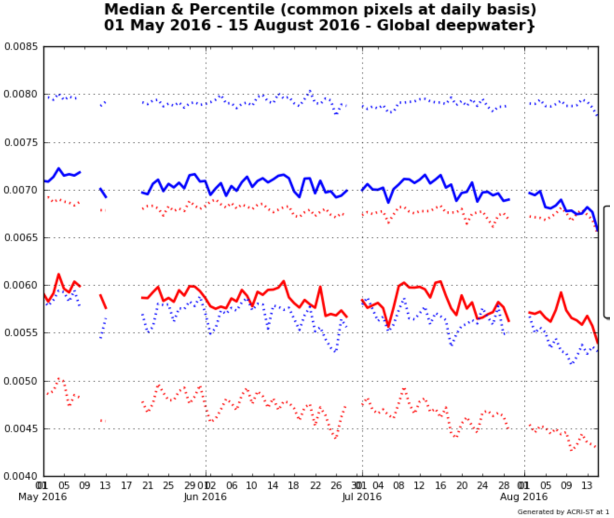
412


Median & Percentile (common pixels at daily basis)
01 May 2016 - 15 August 2016 - Global deepwater}

443


Median & Percentile (common pixels at daily basis)
01 May 2016 - 15 August 2016 - Global deepwater}

490


Median & Percentile (common pixels at daily basis)
01 May 2016 - 15 August 2016 - Global deepwater}

↔ ~6 months

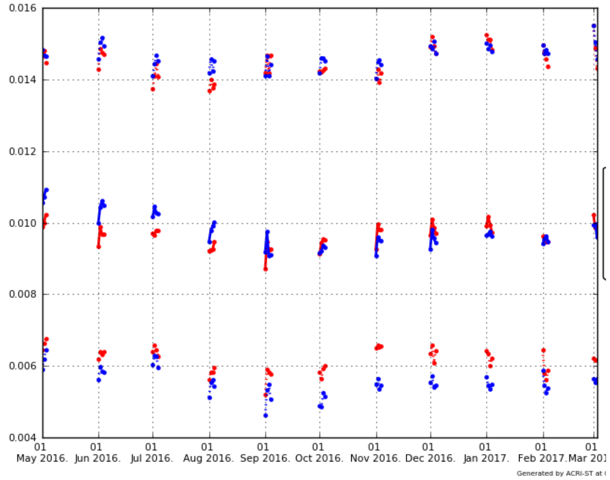
- ···· "GCclimato,GC-Climato,NRRS490,Perc(16)"
- ···· "GCclimato,GC-Climato,NRRS490,Perc(84)"
- ━ "GCclimato,GC-Climato,NRRS490,Median"
- ···· "ESA-WRR-4km-V004,OLCI-A,NRRS490,Perc(16)"
- ···· "ESA-WRR-4km-V004,OLCI-A,NRRS490,Perc(84)"
- ━ "ESA-WRR-4km-V004,OLCI-A,NRRS490,Median"

SENTINEL 3 Mission Performance Centre

ACRI ST

Level 3 ViCal

412



Median & Percentile (common pixels at daily basis)
01 May 2016 - 03 March 2017 - Global deepwater

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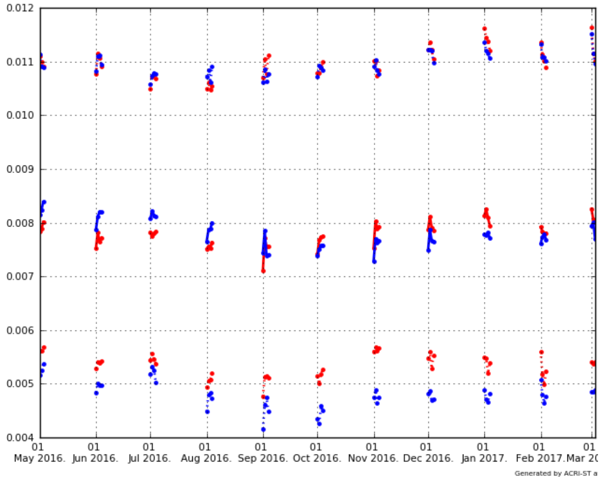
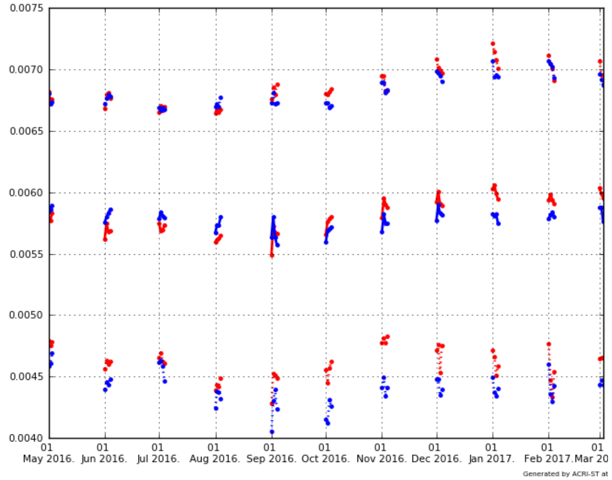


Median & Percentile (common pixels at daily basis)
01 May 2016 - 03 March 2017 - Global deepwater

490



Median & Percentile (common pixels at daily basis)
01 May 2016 - 03 March 2017 - Global deepwater

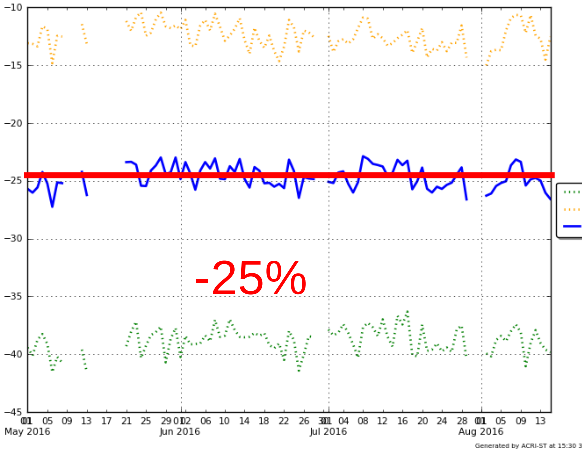
~11 months

- 🟥 "Climato-GC-R2016-19980101-20141231-mean-mean,GC-Climato,NRRS490,Perc(16)"
- 🟥 "Climato-GC-R2016-19980101-20141231-mean-mean,GC-Climato,NRRS490,Perc(84)"
- 🟥 "Climato-GC-R2016-19980101-20141231-mean-mean,GC-Climato,NRRS490,Median"
- 🟦 "ESA-WRR-4km-V005TER,OLCI-A,NRRS490,Perc(16)"
- 🟦 "ESA-WRR-4km-V005TER,OLCI-A,NRRS490,Perc(84)"
- 🟦 "ESA-WRR-4km-V005TER,OLCI-A,NRRS490,Median"

Level 3
No ViCal

412

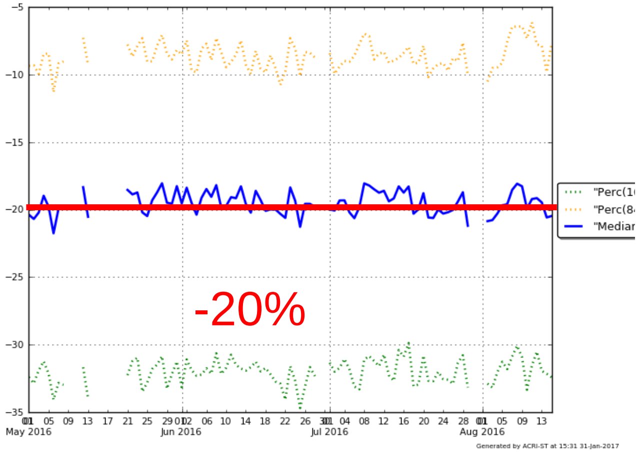
Relative Difference (%) (S1-S2)/S2
S1=GCclimato,GC-Climato,NRRS412
S2=ESA-WRR-4km-V004,OLCI-A,NRRS412
01 May 2016 - 15 August 2016 - Global deepwater}



Generated by ACRI-ST at 15:30 3

443

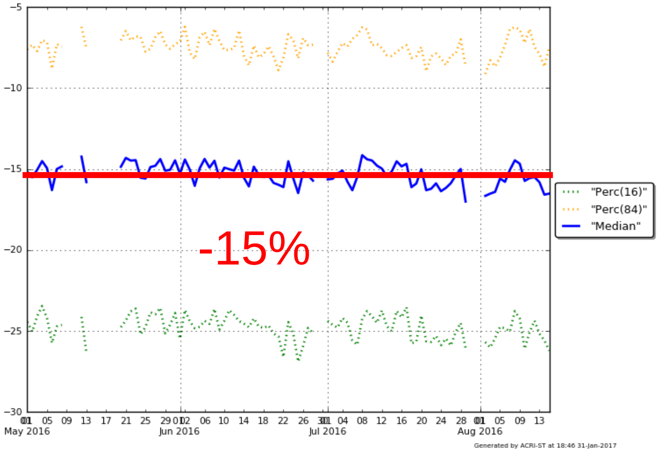
Relative Difference (%) (S1-S2)/S2
S1=GCclimato,GC-Climato,NRRS443
S2=ESA-WRR-4km-V004,OLCI-A,NRRS443
01 May 2016 - 15 August 2016 - Global deepwater}



Generated by ACRI-ST at 15:31 31-Jan-2017

490

Relative Difference (%) (S1-S2)/S2
S1=GCclimato,GC-Climato,NRRS490
S2=ESA-WRR-4km-V004,OLCI-A,NRRS490
01 May 2016 - 15 August 2016 - Global deepwater}



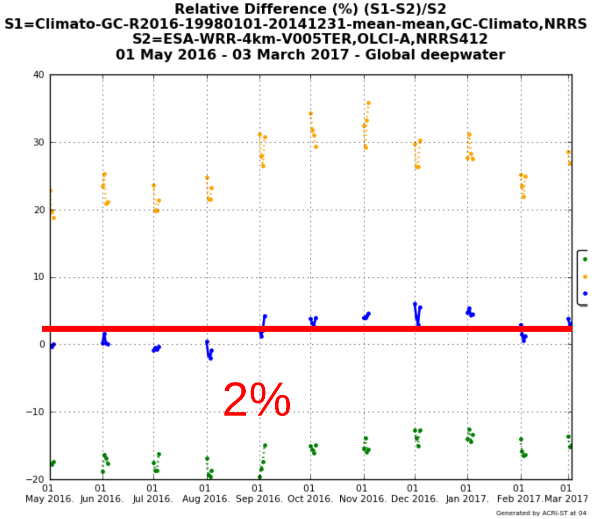
Generated by ACRI-ST at 18:46 31-Jan-2017

←→

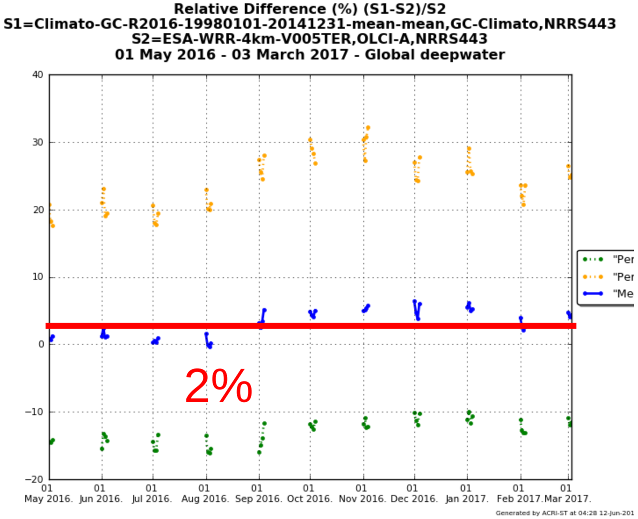
~6 months

Level 3
ViCal

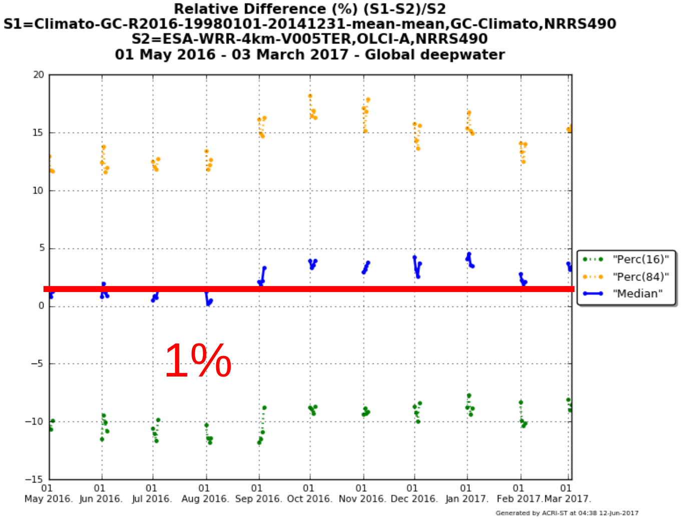
412



443



490

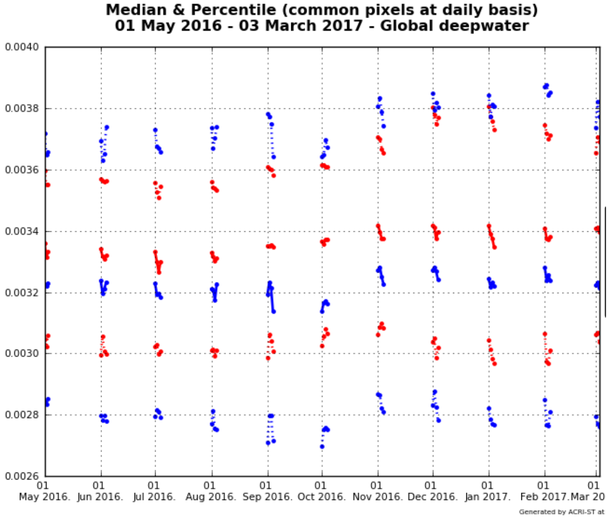


⟷

~11 months

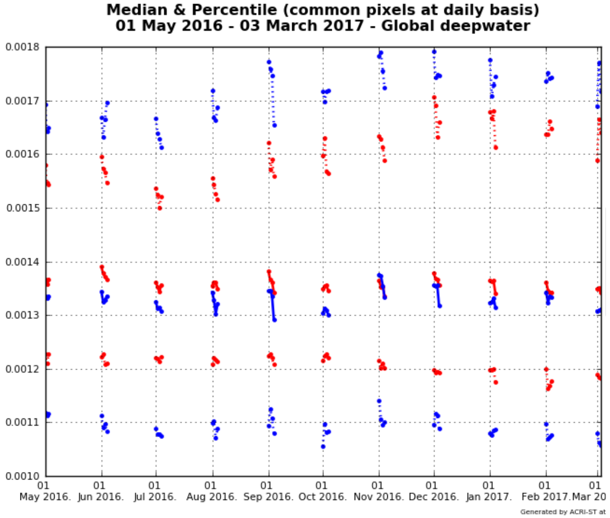
Level 3
ViCal

510



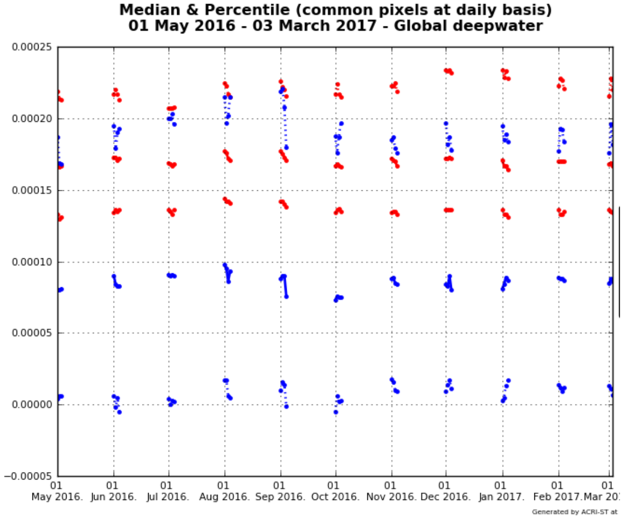
Median & Percentile (common pixels at daily basis)
01 May 2016 - 03 March 2017 - Global deepwater

560



Median & Percentile (common pixels at daily basis)
01 May 2016 - 03 March 2017 - Global deepwater

665/670



Median & Percentile (common pixels at daily basis)
01 May 2016 - 03 March 2017 - Global deepwater

↔

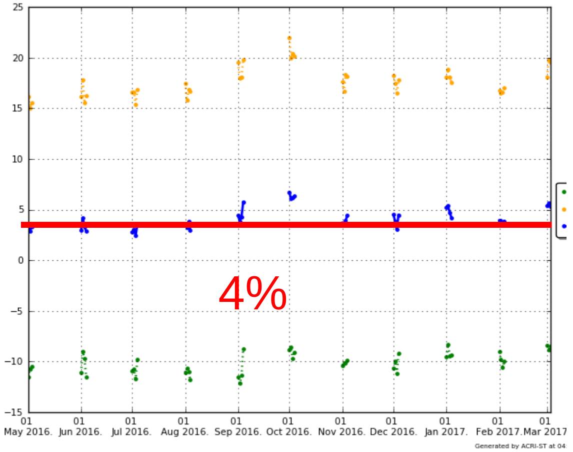
~11 months

- ●··● "Climato-GC-R2016-19980101-20141231-mean-mean,GC-Climato,NRRS670,Perc(16)"
- ●··● "Climato-GC-R2016-19980101-20141231-mean-mean,GC-Climato,NRRS670,Perc(84)"
- ●—● "Climato-GC-R2016-19980101-20141231-mean-mean,GC-Climato,NRRS670,Median"
- ●··● "ESA-WRR-4km-V005TER,OLCI-A,NRRS670,Perc(16)"
- ●··● "ESA-WRR-4km-V005TER,OLCI-A,NRRS670,Perc(84)"
- ●—● "ESA-WRR-4km-V005TER,OLCI-A,NRRS670,Median"

Level 3
ViCal

510

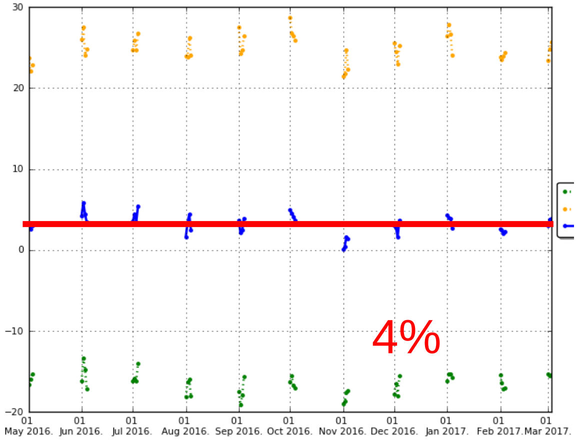
Relative Difference (%) (S1-S2)/S2
S1=Climato-GC-R2016-19980101-20141231-mean-mean,GC-Climato,NRRS
S2=ESA-WRR-4km-V005TER,OLCI-A,NRRS510
01 May 2016 - 03 March 2017 - Global deepwater



Generated by ACRI-ST at 04

560

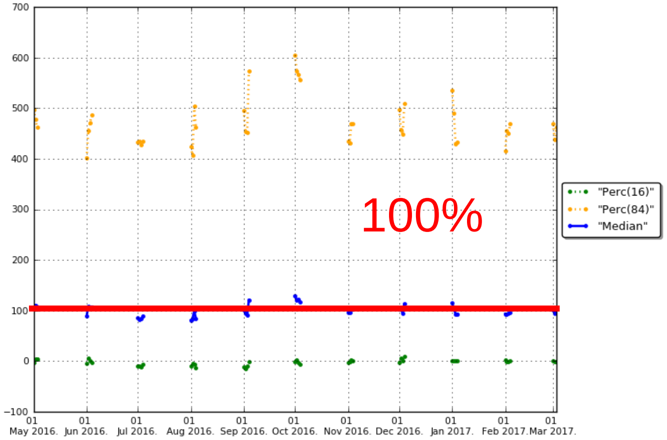
Relative Difference (%) (S1-S2)/S2
S1=Climato-GC-R2016-19980101-20141231-mean-mean,GC-Climato,NRRS5
S2=ESA-WRR-4km-V005TER,OLCI-A,NRRS560
01 May 2016 - 03 March 2017 - Global deepwater



Generated by ACRI-ST at 05:0

665/670

Relative Difference (%) (S1-S2)/S2
S1=Climato-GC-R2016-19980101-20141231-mean-mean,GC-Climato,NRRS670
S2=ESA-WRR-4km-V005TER,OLCI-A,NRRS670
01 May 2016 - 03 March 2017 - Global deepwater



Generated by ACRI-ST at 05:17 12-Jun-2017

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~11 months

Conclusions

- Historical principles of ocean color sensors vicarious adjustment adapted to recently launched OLCI sensor
- NIR adjustment performed through an interband calibration (relative consistency of NIR bands wrt log-log spectral shape over clear waters)
- VIS adjustment performed over both IS data and climatological matchups to handle lack of temporal coverage of IS
- Validation on IS shows improvment of bias and standard deviation of water-leaving reflectance
- Validation on climatology shows bias removal on water-leaving reflectance
- L2 OLCI and SLSTR Products are available for public distribution since the 6th of July 2017, SVC used for production

THANKS FOR YOUR ATTENTION