A revisit of SVC for non-standard atmospheric correction

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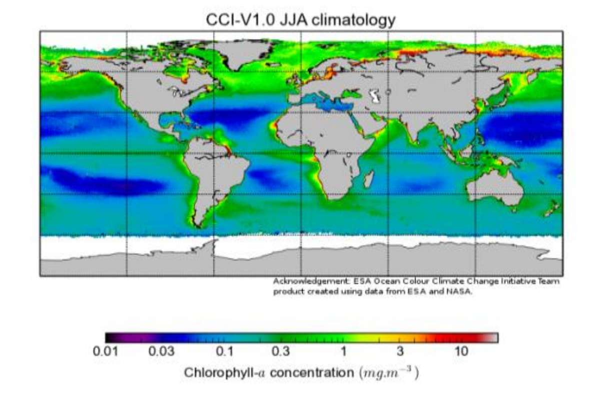
ESA Ocean Colour Climate Change Initiative

Context: ESA Ocean Colour CCI



- Long term global EO archive of Ocean colour ECVs: ρ_w, Chl, IOPs
- Phase 2 started in February 2014: continuous update of data products following review of climate researchers + extension to new sensors

- Past and in-flight sensors considered: SeaWiFS, MODIS, MERIS, VIIRS. OLCI planned
- Two types of atmospheric corrections are used in the OC-CCI:

1) Standard/historical AC (Gordon & Wang): **aerosol computed from two NIR bands**

$$\rho_w(\lambda) = \frac{\frac{\rho_t(\lambda)}{t_g(\lambda)} - \left(\rho_R(\lambda) + \rho_a(\lambda) + \rho_{Ra}(\lambda)\right)}{t(\lambda)}$$

2) Non-standard ACs (HYGEOS-POLYMER, HZG-NN, FUB-SIACS): **aerosol from full spectrum inversion + marine model ρ_w^{mod}**

- SVC goal: strategy to remove systematic bias in ρ_w and harmonise all sensors

SVC for standard AC

- Basic principle for standard AC (Gordon 98): *"If $t\rho_w$ is 10% of ρ_t, and we want ρ_w with an uncertainty of ±5%, one would expect that it would be necessary to know ρ_t with an uncertainty of no more than ±0.5%"*

$$\frac{\Delta\rho_w}{\rho_w}(\lambda) = \frac{\Delta\rho_t}{\rho_t}(\lambda) \Bigg/ \frac{t_g t \rho_w(\lambda)}{\rho_t(\lambda)}$$

$$\rho_w(\lambda) = \frac{\frac{\rho_t(\lambda)}{t_g(\lambda)} - \left(\rho_R(\lambda) + \rho_a(\lambda) + \rho_{Ra}(\lambda)\right)}{t(\lambda)}$$

- What is implicitly achieved by standard AC:
  - Decoupling between all bands and linearity between TOA and BOA
  - Possibility to reconstruct a targeted TOA signal through very same physics as AC and compute explicitly gains

$$\rho_t^t(\lambda) = t_g(\lambda)\left(\rho_R(\lambda) + \rho_a^t(\lambda) + \rho_{Ra}^t(\lambda) + t^t(\lambda)\rho_w^t(\lambda)\right)$$

$$g(\lambda) = \frac{\rho_t^t(\lambda)}{\rho_t(\lambda)}$$

POLYMER algorithm

- Signal formulation (Steinmetz et al. 2011, Steinmetz et al. 2015):

$$\rho_t(\lambda) = t_g(\lambda)\left(\rho_R(\lambda) + \rho_{ag}(\lambda, c_0, c_1, c_2) + t(\lambda)\left(\rho_w^{mod}(\lambda, \varphi) + \varepsilon(\lambda)\right)\right)$$

Residual

Aerosol + glint residual:

$$\rho_{ag}(\lambda, c_0, c_1, c_2) = c_0 T_0(\lambda)\lambda^{p_0} + c_1\lambda^{p_1} + c_2\rho_R(\lambda)$$

Marine model wrt IOP
(φ= set of bio-optical unkwnons = Chl, bbp)

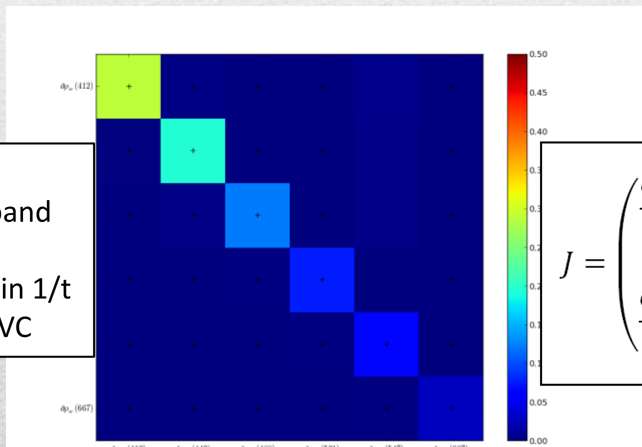
- Spectral-matching algorithm: minimisation of the residual
  - Use of <u>all bands (VIS+NIR)</u>, <u>simultaneously</u>, to retrieve the 5 unknowns: c0, c1, c2, Chl, bbp
- How to reconstruct the targeted TOA signal?
  - The standard SVC gains cannot be computed

SVC formalised as TOA to BOA sensitivity

- SVC = how much do we need to calibrate TOA to reach the BOA target
- This is a sensitivity problem.
- Consider a general formulation of AC:

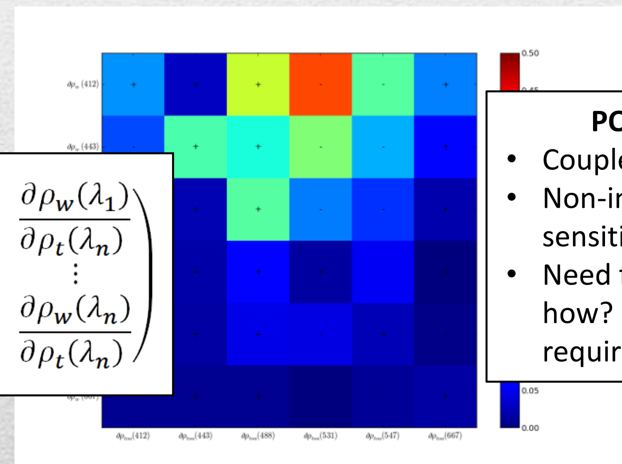
$$\rho_{wN}(\lambda_i) = f_i(\rho_t(\lambda_1), \cdots, \rho_t(\lambda_n)), \;\; i = 1 \dots m$$

- The key object is the Jacobian matrix of the processor:



l2gen
- Band per band calibration
- Sensitivity in 1/t
- Need for SVC

$$J = \begin{pmatrix} \frac{\partial \rho_w(\lambda_1)}{\partial \rho_t(\lambda_1)} & \cdots & \frac{\partial \rho_w(\lambda_1)}{\partial \rho_t(\lambda_n)} \\ \vdots & \ddots & \vdots \\ \frac{\partial \rho_w(\lambda_n)}{\partial \rho_t(\lambda_1)} & \cdots & \frac{\partial \rho_w(\lambda_n)}{\partial \rho_t(\lambda_n)} \end{pmatrix}$$



POLYMER
- Coupled calibration
- Non-intuitive sensitivity
- Need for SVC - but how? Calibration requirements?

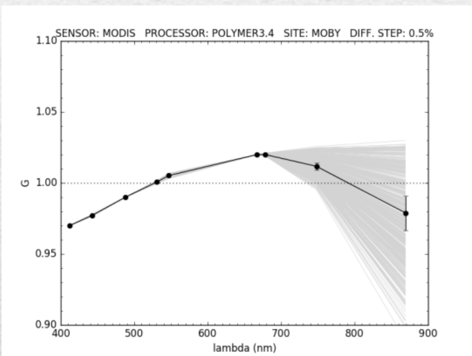
- Generalising SVC definition: *gains that make the {sensor + processor} system exactly match the in situ measurements*

$$\rho_w(\lambda_i) = f_i(g_1 * \rho_t(\lambda_1), g_2 * \rho_t(\lambda_2), \cdots) = \rho_w^t(\lambda_i)$$

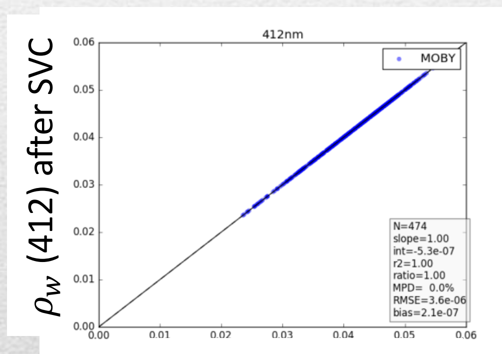
Multiplicity of POLYMER SVC gains

- By construction, POLYMER inversion is invariant to any calibration that follows

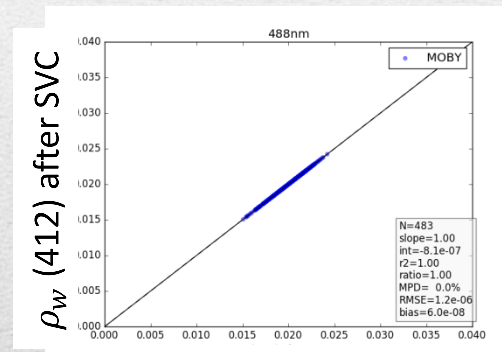
$$g(\lambda) = 1 + t_g(\lambda)\,(c_0 T_0(\lambda) + c_1 \lambda^{-1} + c_2 \lambda^{-4})/\rho_t(\lambda)$$ for any arbitrary c_0, c_1, c_2



SVC gains



ρ_w (412) before SVC



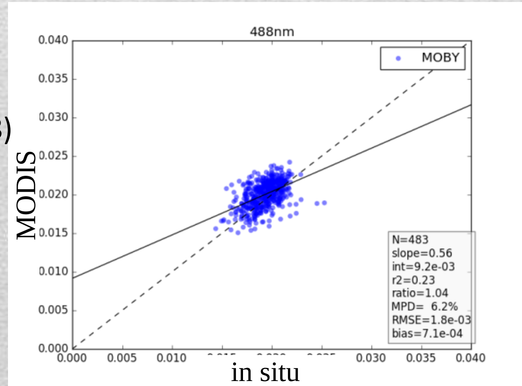
ρ_w (488) before SVC

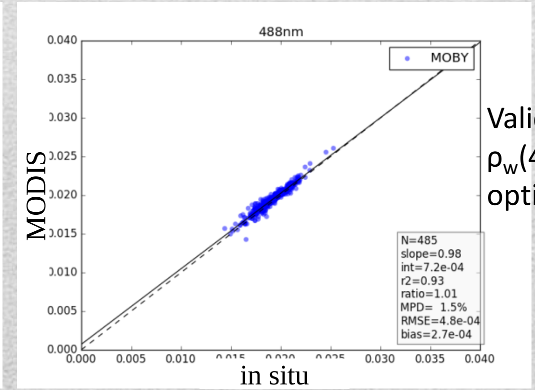
- Practical implication: instability in the gain computation; irrelevance of averaging the individual gains
- Solution: fix gains at 3 bands, e.g. NIR bands for calibration at MOBY
- Note: in the standard case, VIS gains are relative to NIR gains

SVC method for POLYMER

- For POLYMER, we can demonstrate that the strict SVC problem cannot be solved, unless there exist IOPs such that $\rho_w^t(\lambda) = \rho_w^{mod}(\lambda, IOP)$
- The best we can do is a SVC in a *least-square sense*: with $\rho_w(\lambda_i)=f_i(\boldsymbol{\rho_t})$, find $\mathbf{g}=(g_1, g_2\ldots)$ to minimise $$\sum_{i=1}^{n}\left(f_i(\boldsymbol{g} * \boldsymbol{\rho_t}) - \rho_w^t(\lambda_i)\right)^2$$
- Proposed numerical method: 1st order approx. of the non-linear problem
  - Revert to the standard SVC gain when applied to the standard (linear) AC
  - Iterative approach also possible fi too strong non-linearity
- How to be sure the (individual) gains are relevant? → pixel-by-pixel recalibration

Validation of MODIS $\rho_w(488)$ at MOBY before SVC

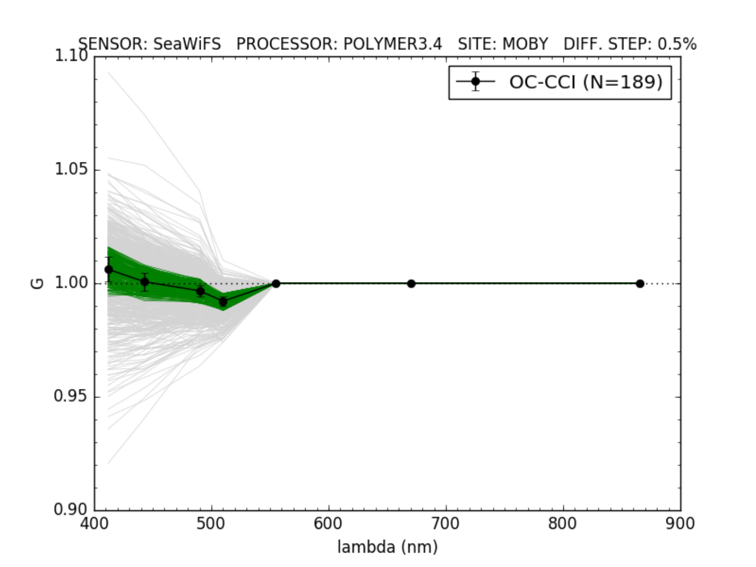


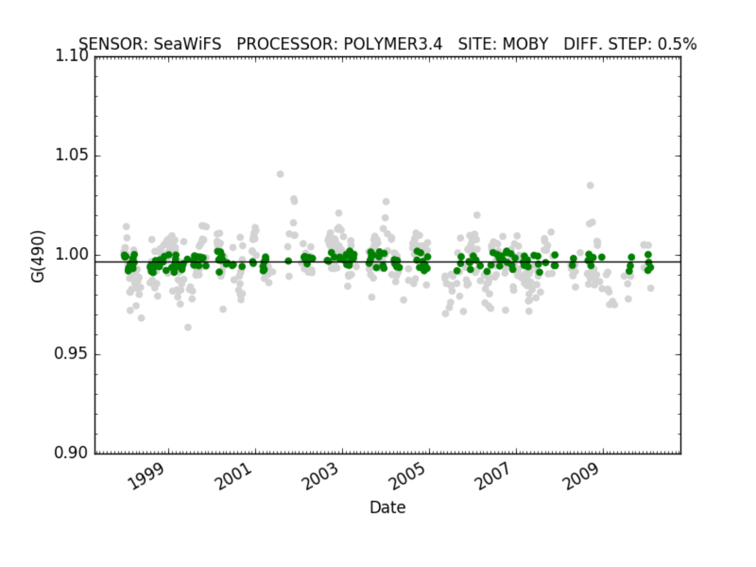


Validation of MODIS $\rho_w(488)$ at MOBY after optimal pixel-by-pixel SVC

Example of POLYMER gains: SeaWiFS

- Gains computed at MOBY
- Features: large amount of match-ups; relatively low amplitude of gain; good stability; low dispersion





λ	412	443	490	510	555	670	865	N
$\bar{g}$	1.006	1.001	0.997	0.992	$1^{(*)}$	$1^{(*)}$	$1^{(*)}$	189
σ	0.005	0.004	0.003	0.002	NA	NA	NA	

(*) fixed gains

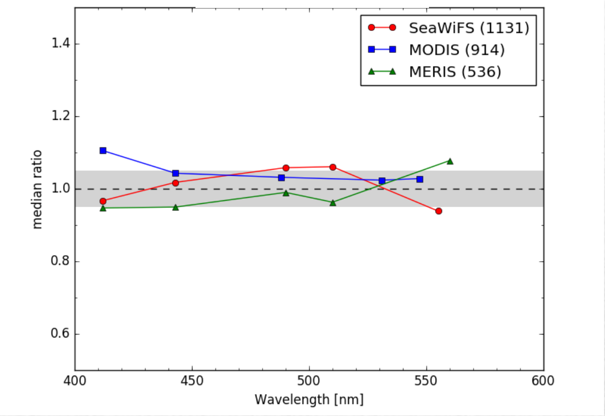
Impact over very clear waters

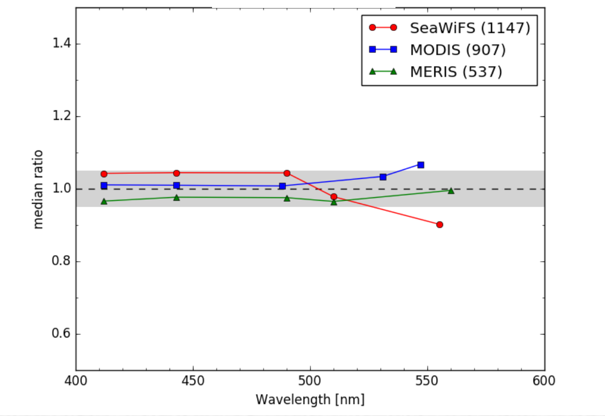
- Sensor harmonisation

Without SVC

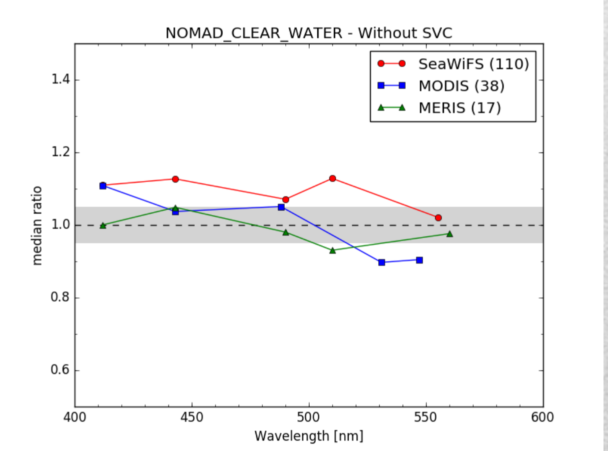
After SVC

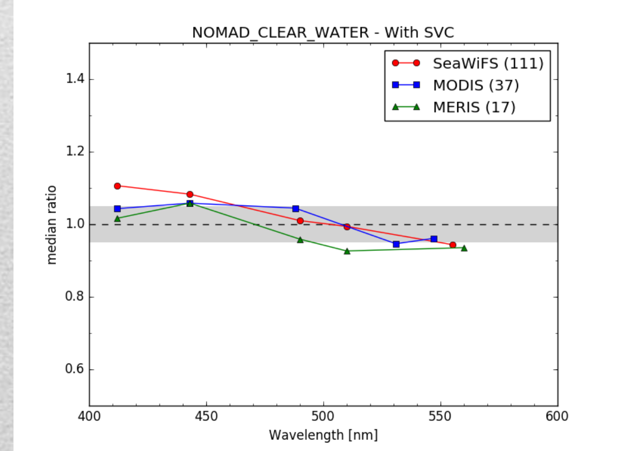
MOBY





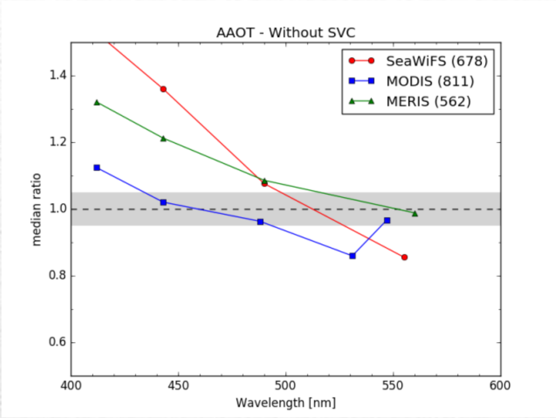
NOMAD clear waters

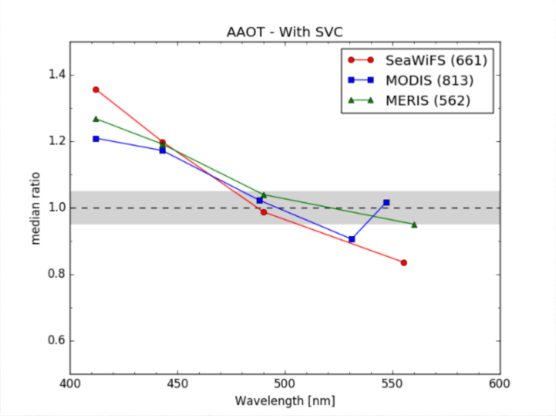




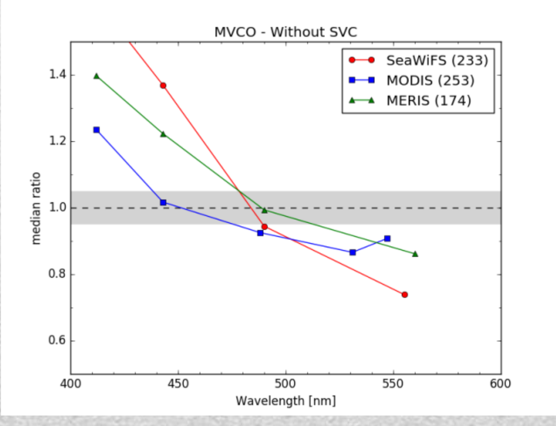
Impact over other water types

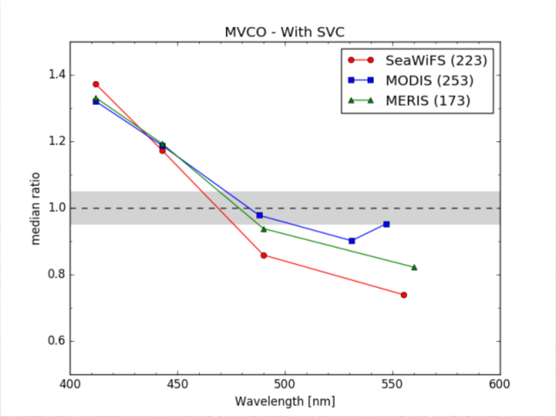
AAOT





MVCO





- Not perfect (classical limitation of SVC), still there's a better sensor harmonisation

→ MOBY gains can be used operationally in the OC-CCI for POLYMER SVC

Conclusion

- Spectral matching ACs are more and more used in the OC community:
  - Within CMEMS: OC-CCI dataset has the most downloads among all products provided by the OC TAC
  - Specific SVC must be addressed, in complement to the standard case (baseline)

	Standard AC (Gordon & Wang)	Spectral matching AC (POLYMER)
Existence	Gains always exists	Strict gains only exist if marine model exactly fits in-situ data
Uniqueness	Gains are unique, relatively to a first NIR calibration	Multiplicity of gains are possible; need to fix some bands
Computation	Gains are computed explicitly at each band	Gains are computed numerically to solve a non-linear spectrally coupled system
Relevance	Gains yield to a perfect match with reference data at all bands	Gains yields to an approximate match, in a least-square sense; error vary with bands
Bias removal	Average gains remove bias by construction	Average gains do not strictly remove the bias due to non-linear effect

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