Details on the early inversion models (for your information)

Roesler and Perry 1995 JGR

- Eigenvectors
  - absorption
    - $a_\phi(\lambda) = chl\ a_\phi^*(\lambda)$ average from in situ data base
    - $a_{nap+cdom}(\lambda) = a_{cdm}(440)\ \exp(-0.0145\ (\lambda-\lambda_o))$
  - backscattering
    - $b_{bplarge}(\lambda) = b_{bplarge}(440)\ (\lambda/400)^0$
    - $b_{bpsmall}(\lambda) = b_{bpsmall}(440)\ (\lambda/400)^{-1}$
- Reflectance equation (hyperspectral)
  - Irradiance Reflectance

    $R(\lambda) = 0.33\ b_b(\lambda)/a(\lambda)$
- non-linear regression: Levenberg-Marqhardt
- model testing
  - measured irradiance reflectance
  - a_ϕ, a_{cm}, total particle cross-section
  - residual analysis to obtain a_ϕ spectral variations

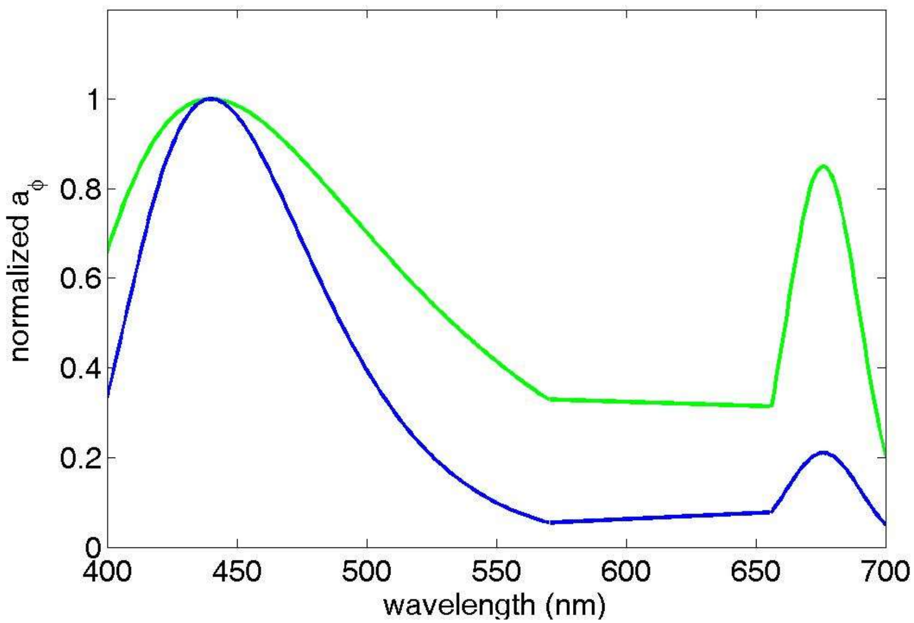
Lee et al. 1996 Applied Optics

- Basis vectors
  - absorption
    - $a_\phi(\lambda) = a_\phi(440) \exp[-F \left(\ln\left(\frac{\lambda-440}{100}\right)\right)^2]$ λ=400 to 570 nm
    - $a_{cm}(\lambda) = a_{cm}(440) \exp(-S(\lambda-\lambda_o))$ S = 0.012 to 0.016
  - backscattering
    - $b_{bp}(\lambda) = b_{bp}(400)(400/\lambda)^\eta$ η = 0 to 3
- Reflectance equation (hyperspectral)
  - Radiance Reflectance

    $R_{RS} = 0.0949(b_b/(b_b+a)) + 0.0794(b_b/(b_b+a))^2$

    plus terms for sunglint and Fresnel reflectance
- Constrained non-linear regression
- model testing
  - measured radiance reflectance
  - a from K_d, measured a_ϕ
  - not independent data (data used to derive empirical values, used to test)

Lee: Basis Vectors



$$b_{bp}(\lambda) = (\lambda/\lambda_o)^{-n}$$

$$a_{CM}(\lambda) = a_{CM}(410)\ \exp[-S\ (\lambda-410)]$$

$$a_\phi(\lambda) = a_\phi(440)\exp(-F*\{[\ln(\frac{\lambda-340}{100})]^\wedge 2\}) \qquad 400 < \lambda < 570\ \text{nm}$$

$$a_\phi(\lambda) = a_\phi(570)\ \frac{a_\phi(656) - a_\phi(570)}{656-570}\ (\lambda-570) \qquad 570 < \lambda < 656\text{nm}$$

$$a_\phi(\lambda) = a_\phi(676)\exp(-(\frac{\lambda-676}{2\sigma^2})^2) \qquad 656 < \lambda < 700\ \text{nm}$$

Lee: Measured $R(\lambda) = L_u(\lambda)/E_d(\lambda)$

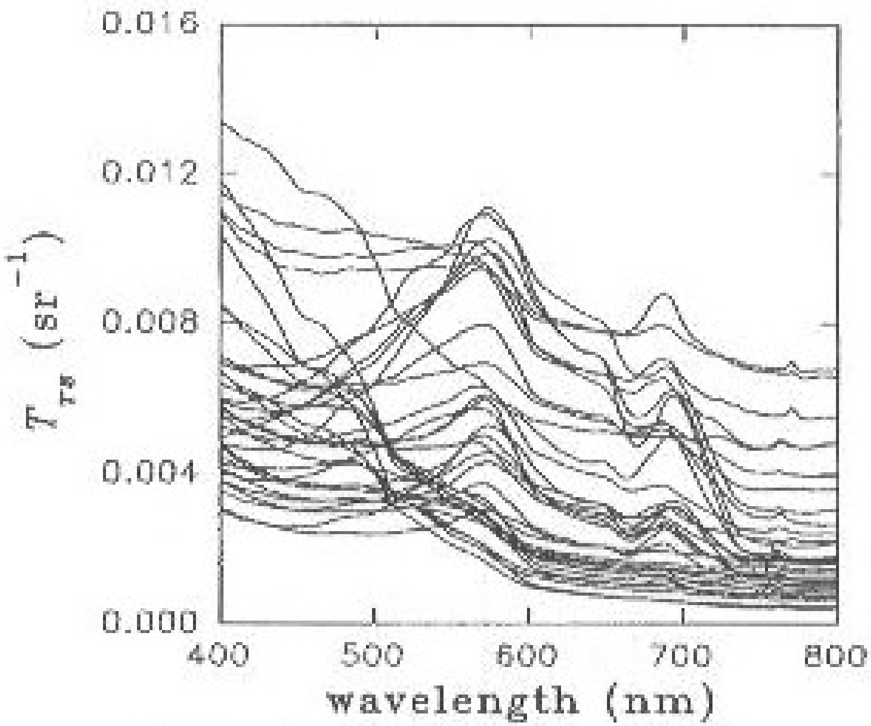


Fig. 3. Measured $\overline{T}_{rs}$ of the stations.

Chl = 0.09 to 21 μg/l
$a_\phi(440)$ = 0.01 to 0.83 m^{-1}

Lee: IOP model test

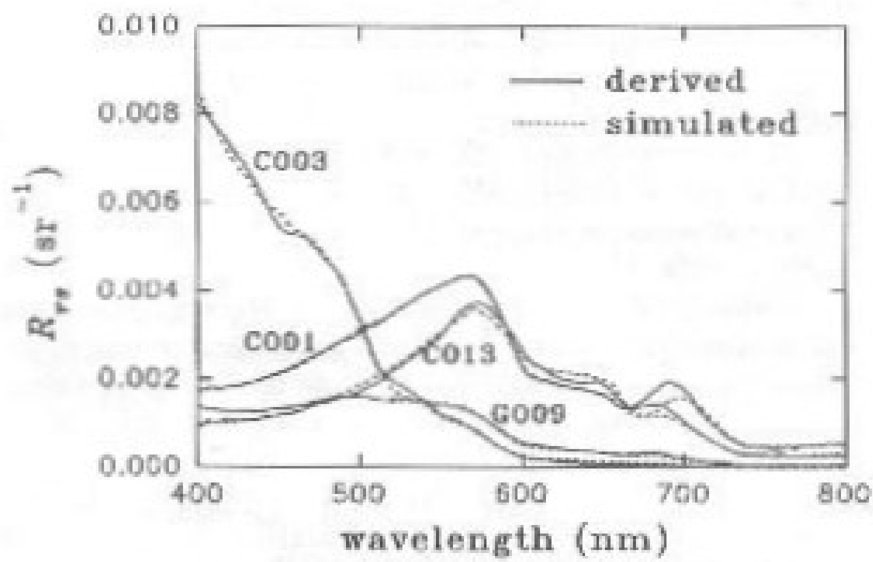


Fig. 8. Examples of derived and simulated $R_{rs}(\lambda)$.

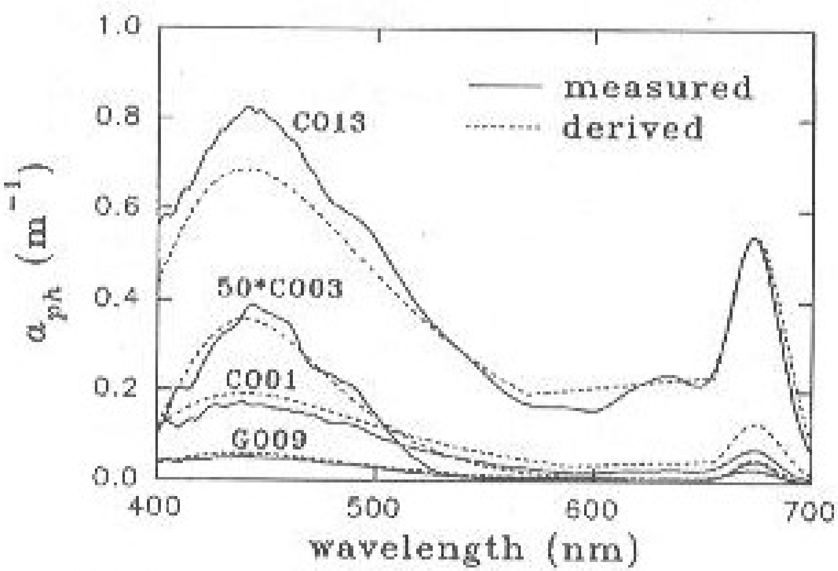


Fig. 9. Examples of derived and measured $a_{ph}(\lambda)$.

37.9% error

QAA Products SeaWiFS MODIS

Z. Lee, K. L. Carder, and R. A. Arnone, "Deriving Inherent Optical Properties from Water Color: a Multiband Quasi-Analytical Algorithm for Optically Deep Waters," Appl. Opt. 41, 5755-5772 (2002)

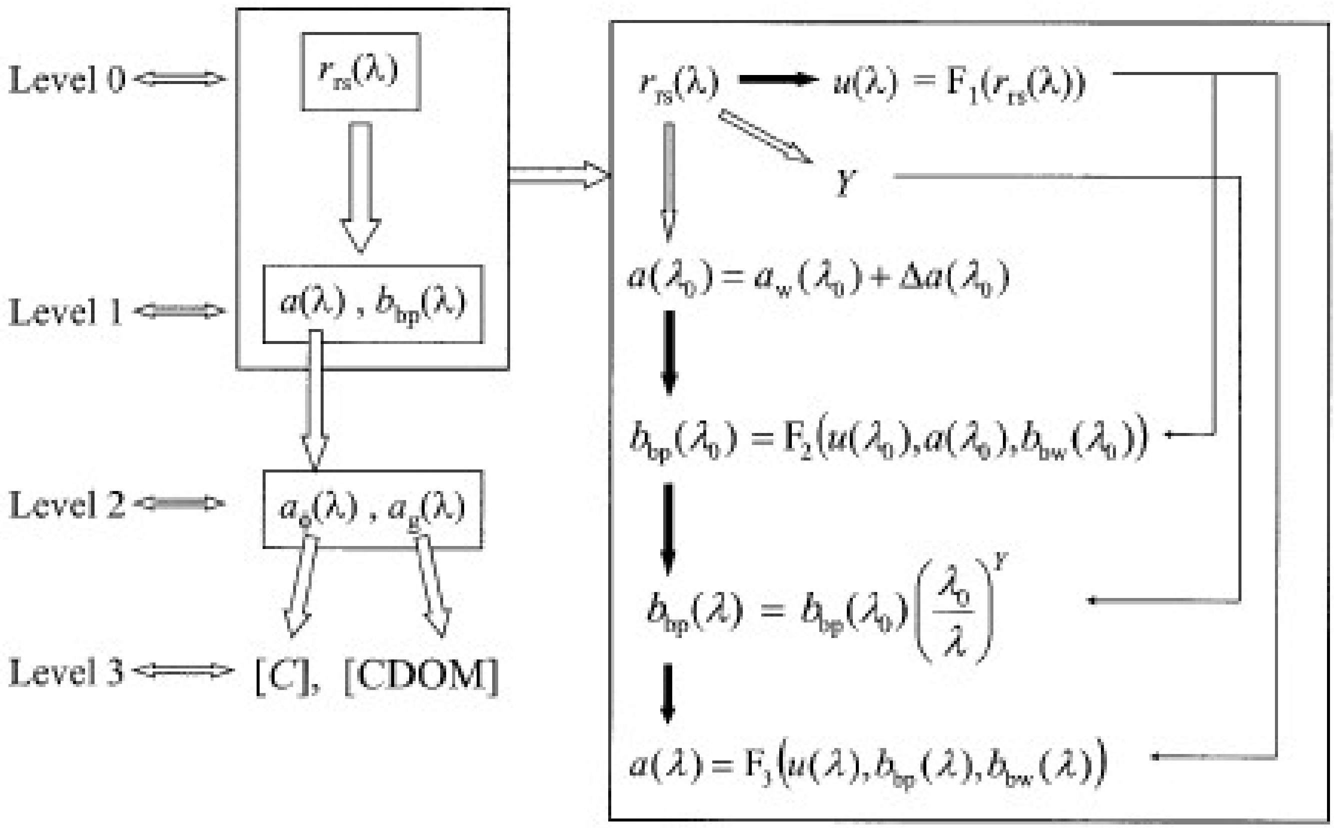


Fig. 1. Concept and schematic flow chart of the level-by-level ocean-color remote sensing and the QAA.

QAA: Inversion Steps

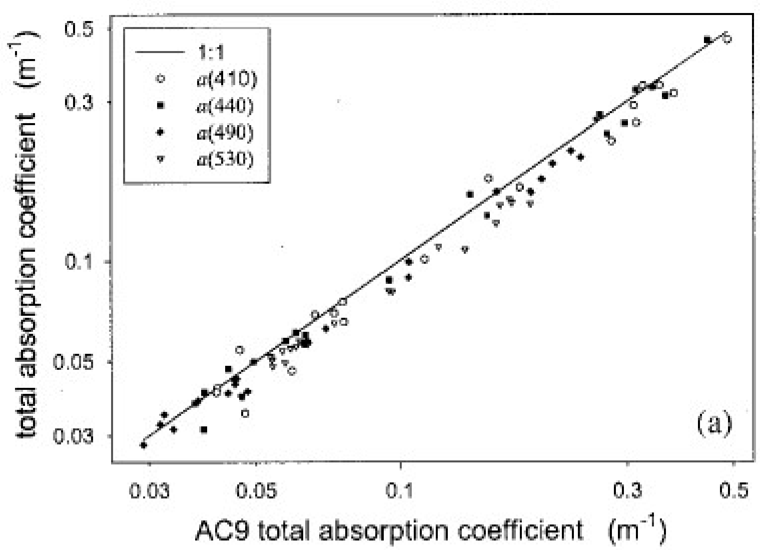
Table 2. Steps of the QAA to Derive Absorption and Backscattering Coefficients from Remote-Sensing Reflectance with 555 nm as the Reference Wavelength

Step	Property	Math Formula	Order of Importance	Approach
0	r_{rs}	$=R_{rs}/(0.52 + 1.7R_{rs})$	1st	Semianalytical
1	$u(\lambda)$	$=\frac{-g_0 + [(g_0)^2 + 4g_1 r_{rs}(\lambda)]^{1/2}}{2g_1}$	1st	Semianalytical
2	$a(555)$	$=0.0596 + 0.2[a(440)_i - 0.01]$, $a(440)_i = \exp(-2.0 - 1.4\rho + 0.2\rho^2)$, $\rho = \ln[r_{rs}(440)/r_{rs}(555)]$	2nd	Empirical
3	$b_{bp}(555)$	$=\frac{u(555)a(555)}{1-u(555)} - b_{bw}(555)$	1st	Analytical
4	Y	$=2.2\left\{1 - 1.2\exp\left[-0.9\frac{r_{rs}(440)}{r_{rs}(555)}\right]\right\}$	2nd	Empirical
5	$b_{bp}(\lambda)$	$=b_{bp}(555)\left(\frac{555}{\lambda}\right)^Y$	1st	Semianalytical
6	$a(\lambda)$	$=\frac{[1-u(\lambda)][b_{bw}(\lambda)+b_{bp}(\lambda)]}{u(\lambda)}$	1st	Analytical

QAA: Inversion Steps and testing

Table 3. Steps to Decompose the Total Absorption to Phytoplankton and Gelbstoff Components, with Bands at 410 and 440 nm

Step	Property	Math Formula	Order of Importance	Approach
7	$\zeta = a_\phi(410)/a_\phi(440)$	$= 0.71 + \dfrac{0.06}{0.8 + r_{rs}(440)/r_{rs}(555)}$	2nd	Empirical
8	$\xi = a_g(410)/a_g(440)$	$= \exp[S(440\text{–}410)]$	2nd	Semianalytical
9	$a_g(440)$	$= \dfrac{[a(410) - \zeta a(440)]}{\xi - \zeta} - \dfrac{[a_w(410) - \zeta a_w(440)]}{\xi - \zeta}$	1st	Analytical
10	$a_\phi(440)$	$= a(440) - a_g(440) - a_w(440)$	1st	Analytical



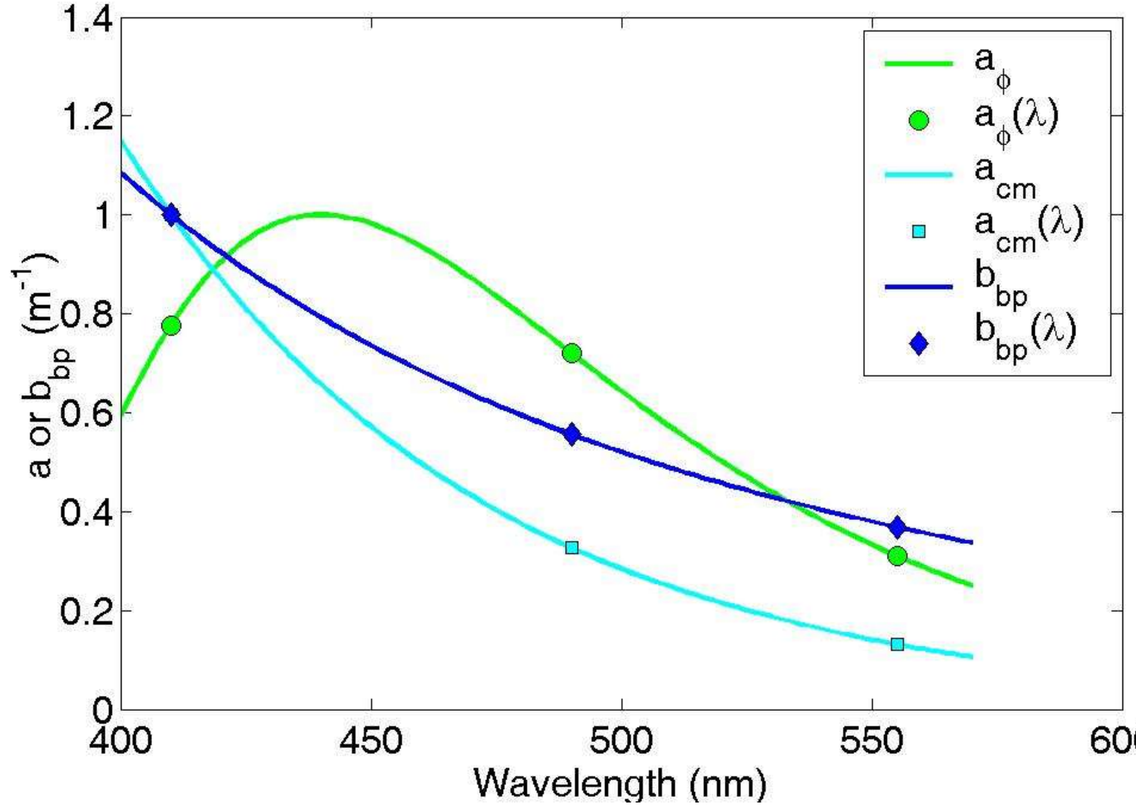
- Tested against simulated data set
- Simulated data plus noise
- Tested against n<20 obs made with an ac9 off Baja California

Hoge and Lyon 1996 JGR

- Basis vectors
  - absorption
    - $a_\phi(\lambda) = a_\phi(440) \exp[(\lambda - 440)^2/2g^2)]$ for λ=400 to 570 nm
    - $a_{cm}(\lambda) = a_{cm}(440) \exp(-0.014 (\lambda-\lambda_o))$
  - backscattering
    - $b_{bp}(\lambda) = b_{bp}(440) (\lambda/440)^{-3.3}$
- Reflectance equation (410, 490 555)
  - Radiance Reflectance

    $R_{RS} = 0.0949(b_b/(b_b+a)) + 0.0794 (b_b/(b_b+a))^2$
- Linear regression: singular value decomposition
- model testing
  - synthetic data using basis vector parameterization
  - a_ϕ, a_{cm}, b_{bp} at 3λ
  - sensitivity analysis to radiance (IOP uncertainties by bootstrap)

Hoge: Basis Vectors



$$b_{bp}(\lambda) = (\lambda/\lambda_o)^{-3.3}$$

$$a_\phi(\lambda) = \exp(-2*\{\ln[(\frac{\lambda-340}{100}).\hat{}2]\})$$

$$a_{CM}(\lambda) = a_{CM}(410)\ \exp[-0.014\ (\lambda-410)]$$

Hoge: Synthetic Reflectance Spectra

Used basis vector formulations in Rrs equation with magnitudes varied such that $5*10^5$ of each IOP were generated

$a_\phi(410) = 0$ to $0.74\ m^{-1}$
$a_{cm}(410) = 0.01$ to $0.5\ m^{-1}$
$b_{bp}(410) = 0.0005$ to $0.05\ m^{-1}$

Hoge: Sensitivity Analysis

Examined IOP error in response to:	a_ϕ	a_{cm}	b_b
• 5% uncertainties in L(555)	55%	10%	28%
• 5% uncertainties in L(490)			
• 5% uncertainties in L(410)			
• uncertainties in all three $L(\lambda)$			
• 10% in width of a_ϕ peak	9%	5%	9%
• 100% uncertainty in S_{cm}	20%	20%	20%
• 100% uncertainty in n	>20%	>20%	>20%

Garver and Siegel 1997 JGR

- Basis vectors
  - absorption
    - $a_\phi(\lambda)$ = $a\phi(440)$ $a_\phi^*(\lambda)$ 3 models
    - $a_{cm}(\lambda) = a_{cm}(440) \exp(-S(\lambda-\lambda_o))$
  - backscattering
    - $b_{bp}(\lambda) = b_{bp}(440) (\lambda/400)^n$ n= 0, 1, 2
- Reflectance equation (8 λs)
  - Radiance Reflectance

$$R_{RS} = 0.0949(b_b/(b_b+a)) + 0.0794 (b_b/(b_b+a))^2$$

- non-linear regression (but see Maritorena et al. 2002 for improved optimization method)
- model testing
  - measured radiance reflectance, 2-yr BATS data
  - sensitivity analysis to af models, S, n
  - comparison with biogeochemical observations (no validation)

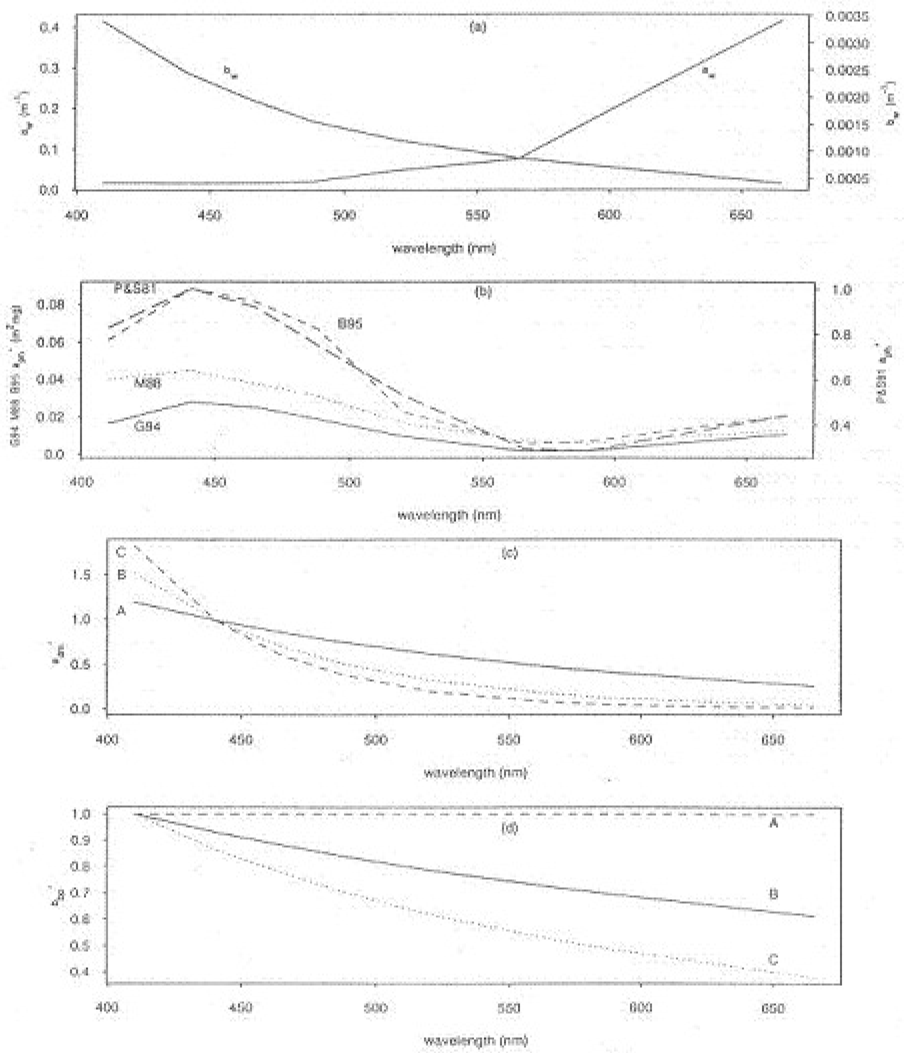
Garver: Basis Vectors

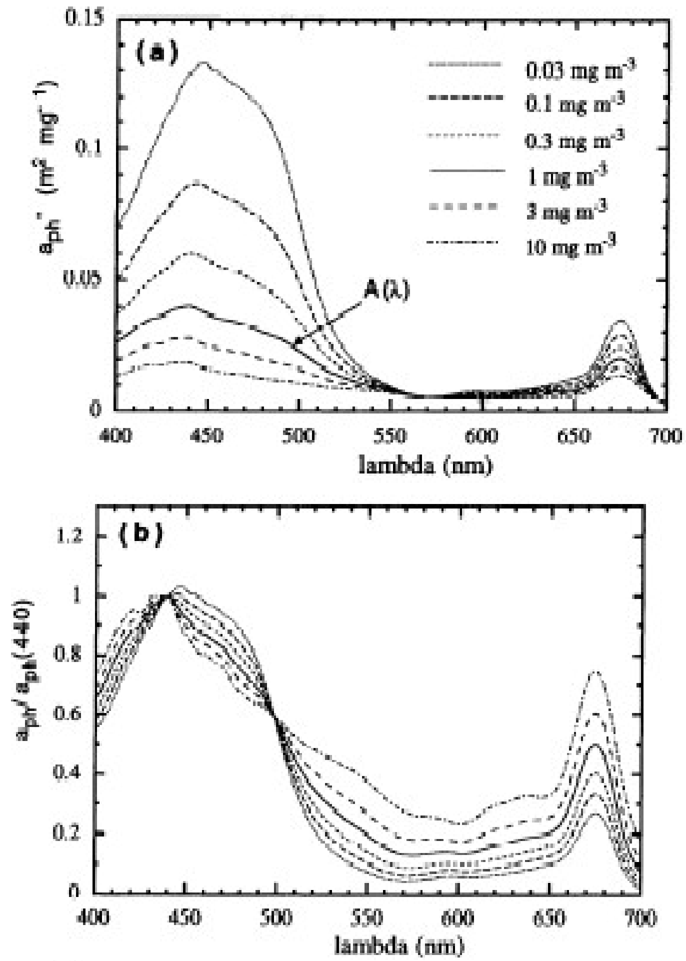
a_w
b_{bw}

a_{phyt}

a_{cm}

b_{bp}





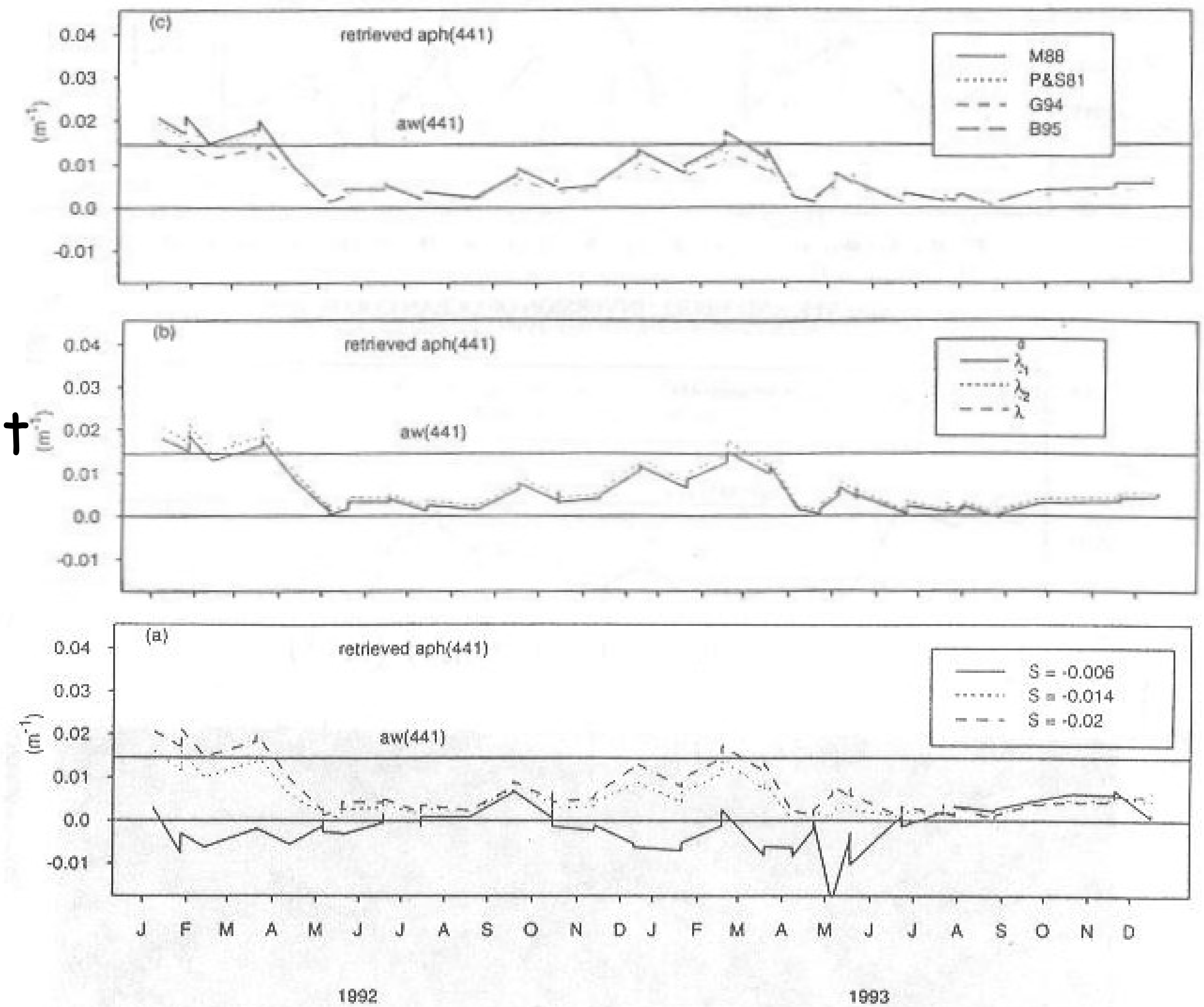
Bricaud et al. 1995 JGR

Garver: IOP model sensitivity analysis

a_{phyt} model

b_{bp}exponent

S_{cm}



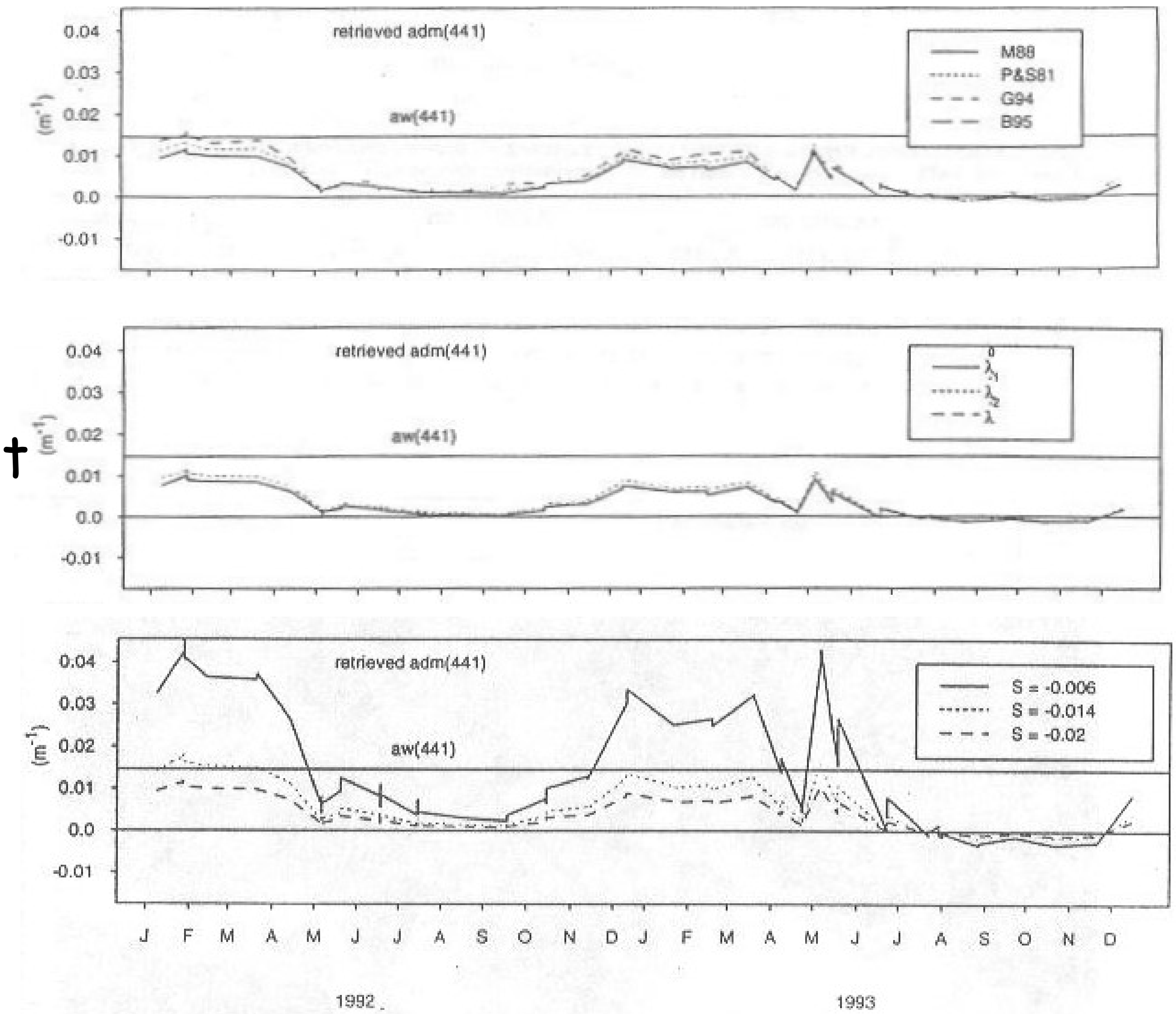
a_{ϕ} retrieval most sensitive to S_{cm}

Garver: IOP model sensitivity analysis

a_{phyt} model

b_{bp}exponent

S_{cm}



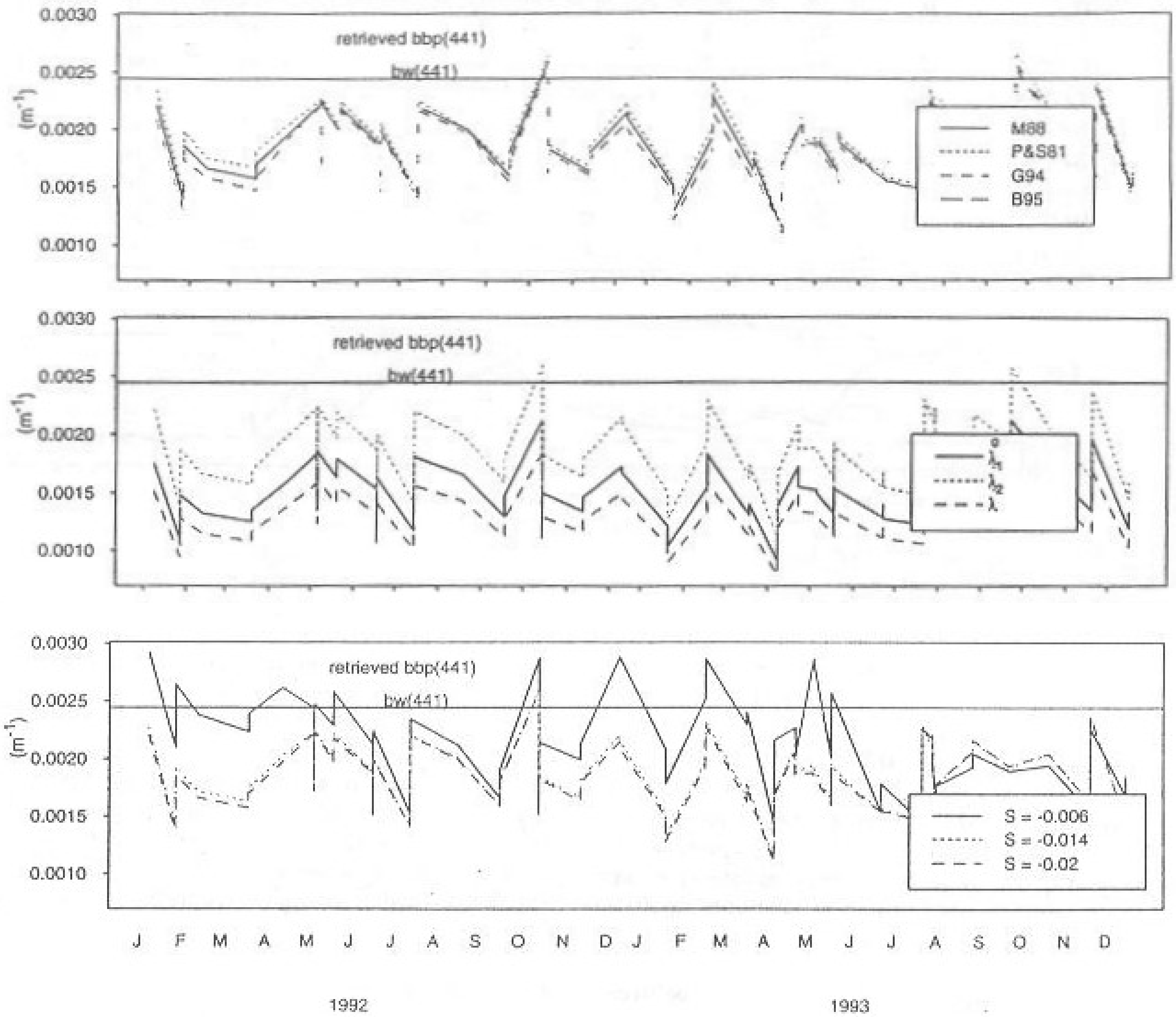
a_{cm} retrieval most sensitive to S_{cm}

Garver: IOP model sensitivity analysis

a_{phyt} model

b_{bp}exponent

S_{cm}



b_{bp} retrieval most sensitive to S_{cm} and n

Garver, Siegel, Maritorena 2002
GSM SeaWiFS MODIS product

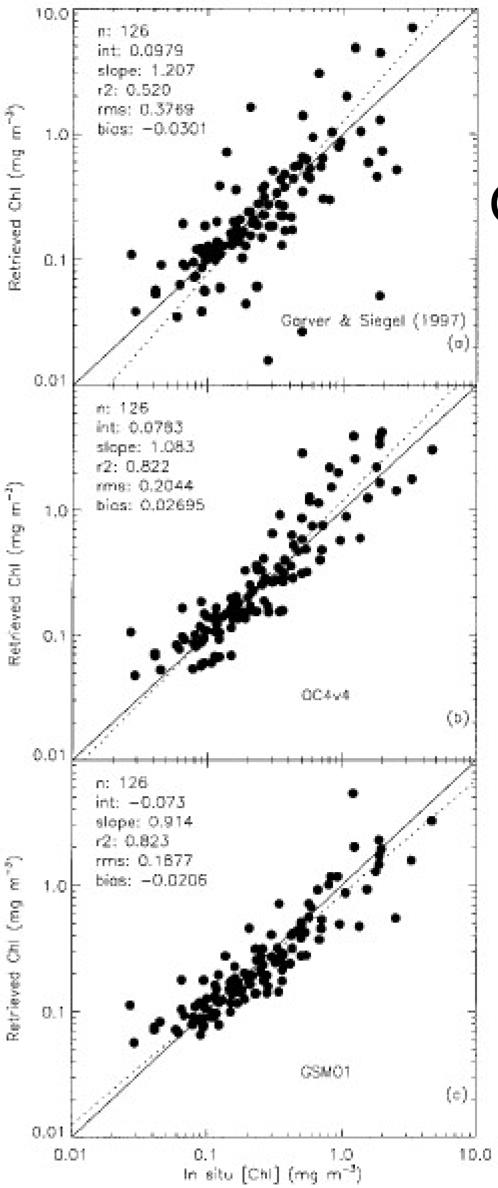
Simulated Annealing Technique

- "Compared with other steepest descent minimization techniques that look for the quick and nearby solution, simulated annealing is an iterative heuristic method that permits the search of solutions in the uphill i.e., lower performance direction. This allows the system to ultimately find a global minimum."

- "This feature also reduces the importance of the first guesses used to initiate the process that is often a critical aspect of minimization techniques based on the steepest descent methods."

- "Simulated annealing includes three basic elements:
  - 1 a cost function that, given a set of parameters, evaluates the performance of the model;
  - 2 a candidate generator that randomly proposes new values for the **eigenvector**, and
  - 3 a decreasing temperature that introduces some randomness in the process and controls its overall progress."

GSM test on SeaWiFS data



GS97

OC4.4

GSM

$a_{phyt}{}^{*}$

Retrieved $a_{phyt}{}^{*}(\lambda)$

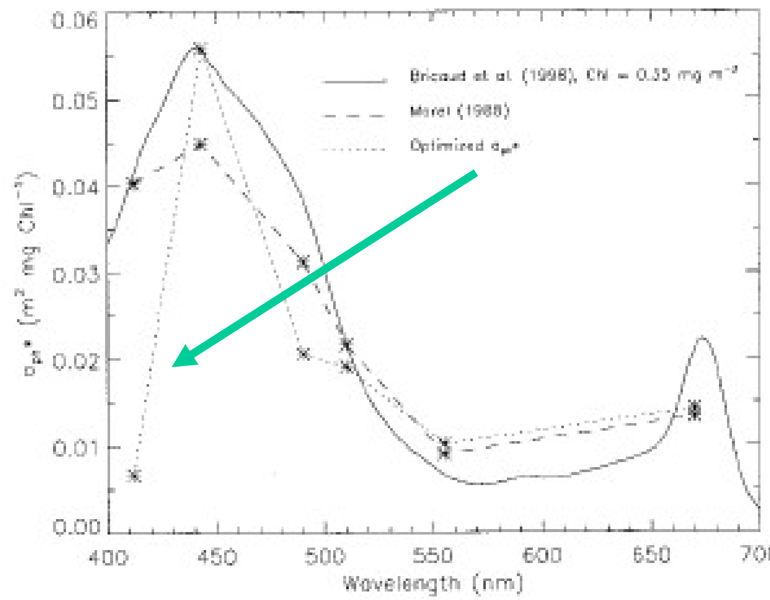


Fig. 3. Comparison of the optimized $a_{ph}{}^{*}(\lambda)$ spectrum with the mean spectrum of Morel[2] and a spectrum generated with the model of Bricaud *et al.*[9] for a Chl concentration of 0.35 mg m^{-3}.