Question: What is the accuracy with which aerosol parameters need to be determined to meet accuracy requirements for water-leaving radiance and marine biogeochemistry applications?

- *Accuracy requirements for water-leaving radiance.*

- *Sensitivity of TOA aerosol radiance to aerosol parameters and implications for atmospheric correction.*

Robert Frouin, SIO/UCSD, PACE SDT Meeting, 14 March 2012

Requirements for Essential Climate Variables (GCOS-154, 2011)

Variable/ Parameter	**Horizontal Resolution**	**Vertical Resolution**	**Temporal Resolution**	**Accuracy**	**Stability**
Water Leaving Radiance	4km	N/A	Daily	5%*	0.5%
Chlorophyll-a concentration	30km	N/A	Weekly averages	30%	3%

*this 5% requirement is specifically for the blue and green wavelengths

-<u>Rationale</u>: To detect global and regional changes of a few percent in ocean chlorophyll cycles.

-<u>Current achievable accuracy</u>: 5-15% for water leaving radiance (blue and green wavelengths) and 30-70% for chlorophyll in the concentration range 0.01-10 mg/m^3, Case 1 waters. For coastal waters and regional seas, (typically Case 2), errors are considerably higher, on the order of 60-70 per cent for chlorophyll-a, but in areas of extreme optical-complexity as high as 200-300%.

"Planned, next generation, OCR sensors (e.g. PACE and ACE) aim at achieving improved accuracy (i.e. < than 5% for water-leaving radiance and 20% for chlorophyll-a concentration)."

Impact of Rrs errors on GSM retrieval of chlorophyll concentration, CDOM absorption and backscattering coefficients. (By Stephane Maritorena.)

-12 Rrs spectra from NOMAD bio-optical data set, varied waters.

-$Rrs\_noise(\lambda) = Rrs\_no\_noise(\lambda)*(1 + U*e_u(\lambda) + C*e_c)$, where U and C are noise amplitudes, uncorrelated and correlated spectrally, and e_u and e_c are random numbers with a mean zero and a variance of unity.

Noise Cases:

1) U = 0.05, C = 0

2) U = 0.10, C = 0

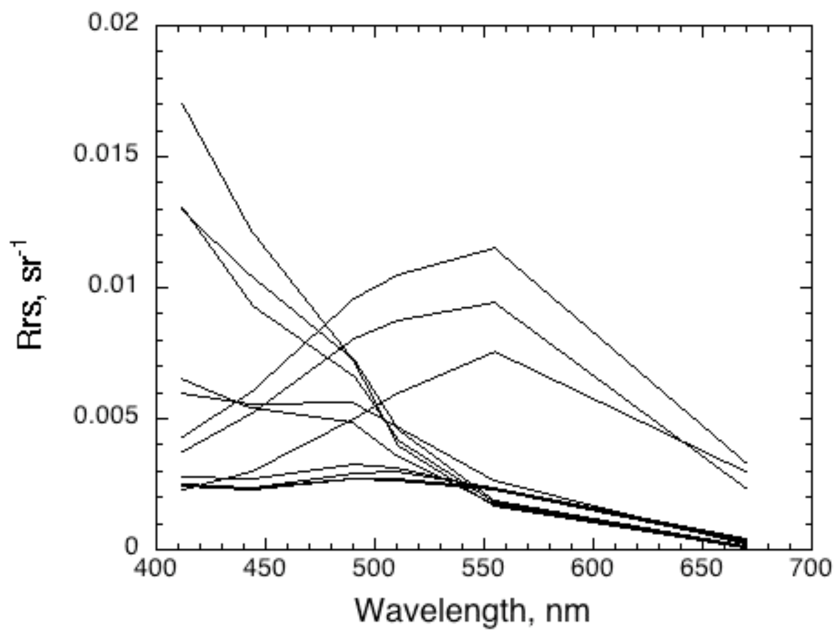
3) U = 0.025, C = 0.025

4) U = 0.05, C = 0.05

5) U = 0, C = 0.05

6) U = 0, C = 0.10

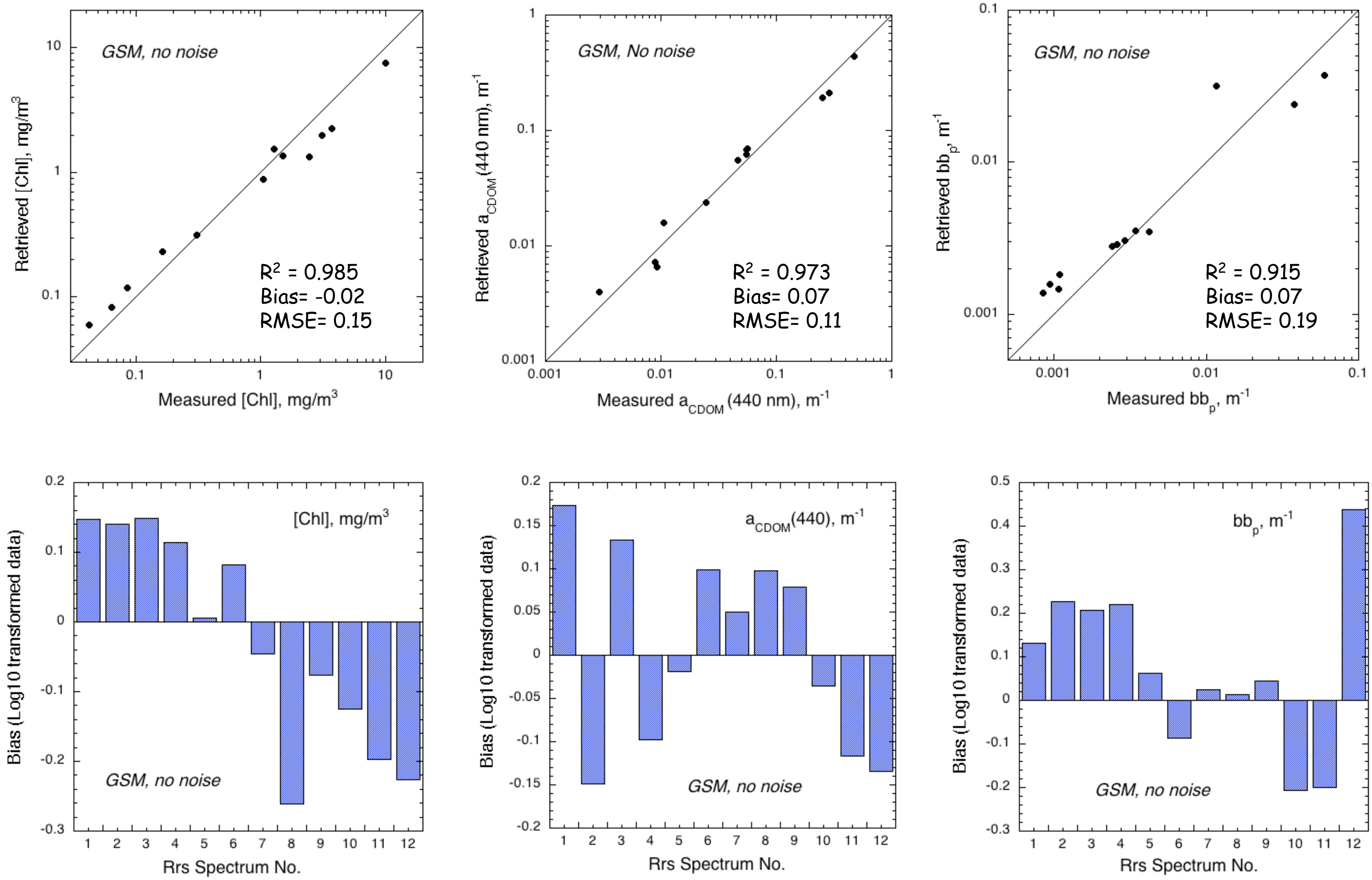
1000 Rrs realizations for each case



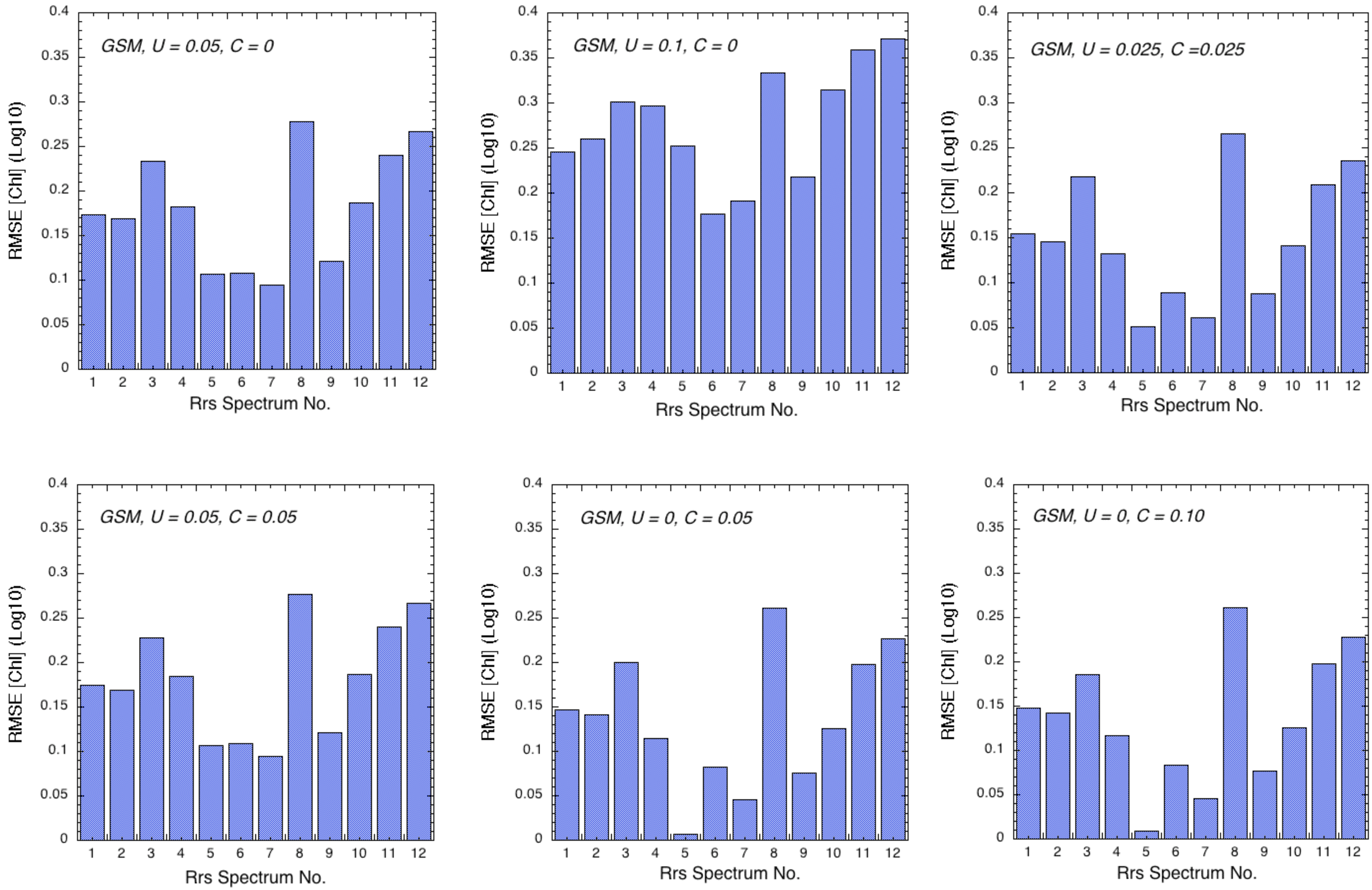
Bio-Optical parameters

	[Chl] mg/m^3	$a_{CDOM}(440)$ m^{-1}	$bb_p(440)$ m^{-1}
Rrs1	0.16	0.0107	0.0011
Rrs2	0.08	0.0092	0.0009
Rrs3	0.04	0.0029	0.0008
Rrs4	0.06	0.0090	0.0011
Rrs5	0.31	0.0247	0.0024
Rrs6	1.27	0.0547	0.0042
Rrs7	1.51	0.0549	0.0029
Rrs8	2.45	0.0558	0.0034
Rrs9	1.05	0.0463	0.0026
Rrs10	9.99	0.4716	0.0601
Rrs11	3.14	0.2492	0.0379
Rrs12	3.76	0.2900	0.0117

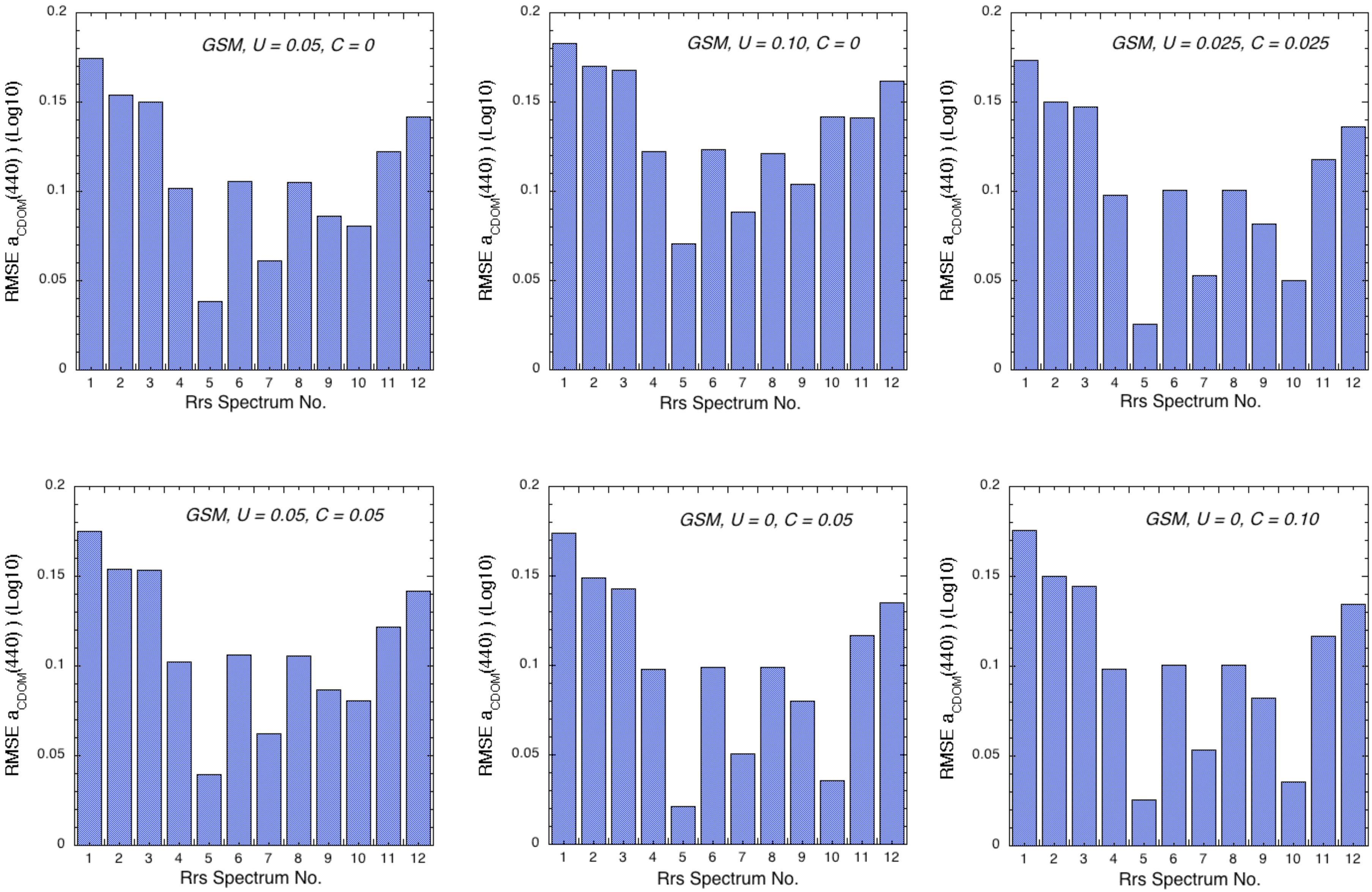
GSM derived results, no noise on Rrs



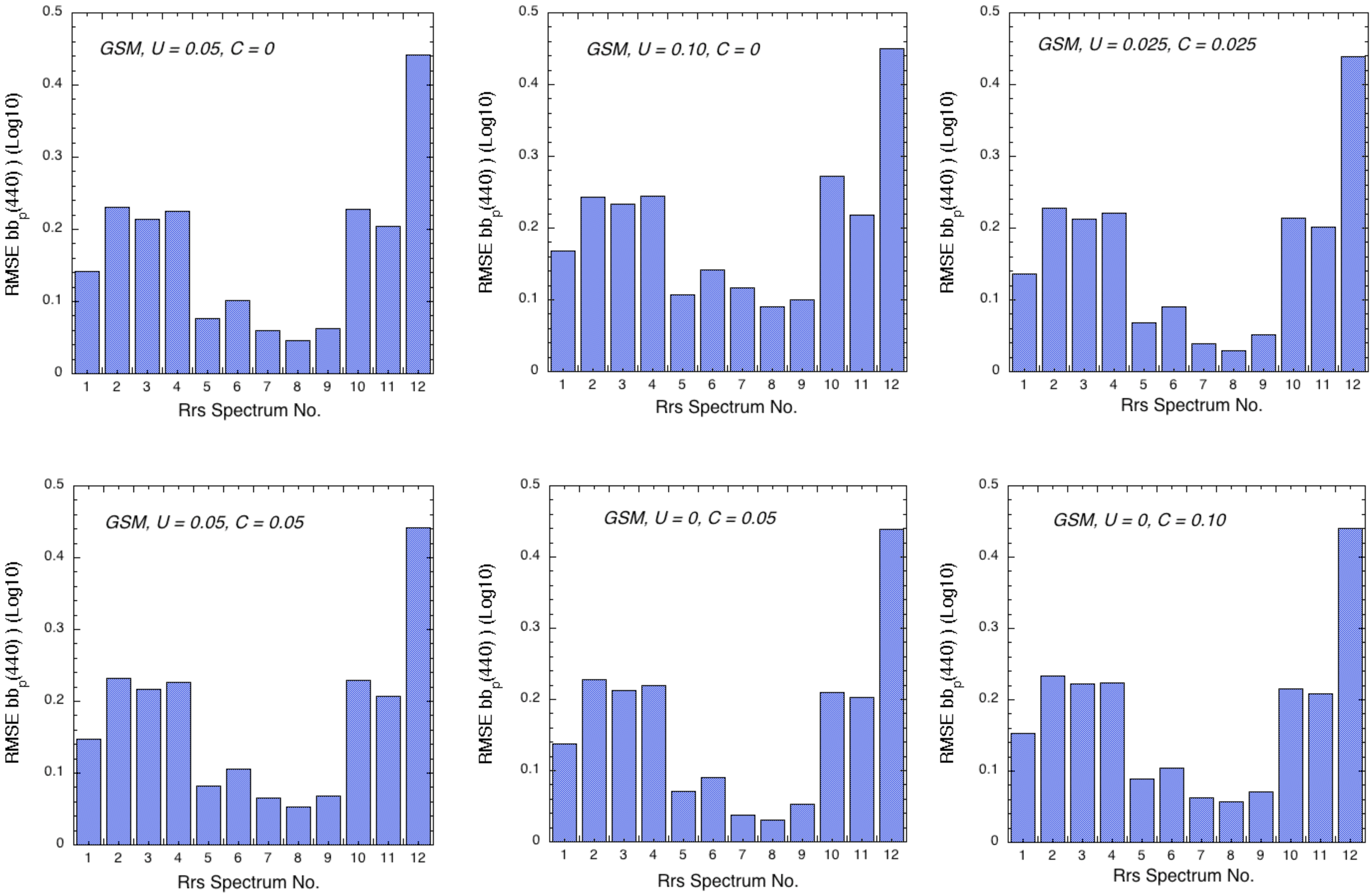
Effect of Rrs noise on [Chl] retrieval



Effect of Rrs noise on $a_{CDOM}(440)$ retrieval



Effect of Rrs noise on $bb_p(440)$ retrieval



Conclusions:

-GSM inherent errors (i.e., without Rrs noise) dominate when total Rrs noise is 5%.

-[Chl] retrieval is more sensitive to Rrs noise than a_{CDOM} and bb_p retrieval.

-Errors are increased substantially when total Rrs noise is 10% and uncorrelated spectrally, especially when the inherent errors are small.

-Effect of uncorrelated Rrs noise is small, even at 10% Rrs noise level.

-Variability in data set is adequately described in the presence of 5% uncorrelated Rrs noise, with errors generally less than 0.2 on log10 scale.

-Results for [Chl] are consistent with GCOS requirements.

2. Sensitivity of TOA aerosol signal at ocean-color wavelengths to aerosol parameters

Simplified RT modeling (Tanré et al., 1979; Torres et al., 2002):

$\rho \approx \rho_a - \rho_m m(1 - \omega_a)\tau_a (p_s - p_a)/p_s$
$\rho_a \approx \omega_a \tau_a P_a(\Theta)/4\cos\theta_s \cos\theta_v$; $\rho_m \approx \tau_m P_m(\Theta)/4\cos\theta_s \cos\theta_v$

ρ_a : Aerosol reflectance; ρ_m : Rayleigh reflectance

θ_s : Solar zenith angle; θ_v : Viewing zenith angle; Θ : Scattering angle; m: Air mass

$P_{a,m}$: Scattering phase function (modified to account for surface reflection); ω_a : Aerosol single scattering albedo; τ_a : Aerosol extinction optical thicknes; p_a : Aerosol pressure level; p_s : Surface pressure level

Aerosol parameters are: ω_a, τ_a, P_a, p_a.

-Note: ρ = 0 when there are no aerosols (τ_a = 0); $\rho \approx \rho_a$ when aerosols are weakly absorbing ($\omega_a \approx 1$) or concentrated near the surface ($p_a \approx p_s$).

Sensitivity of ρ to aerosol parameters

-Phase function

$\partial \rho / \partial P_a = \rho_a / P_a$

-Single scattering albedo

$\partial \rho / \partial \omega_a = \rho_a / \omega_a + \rho_m m \tau_a (p_s - p_a)/p_s$

-Optical thickness

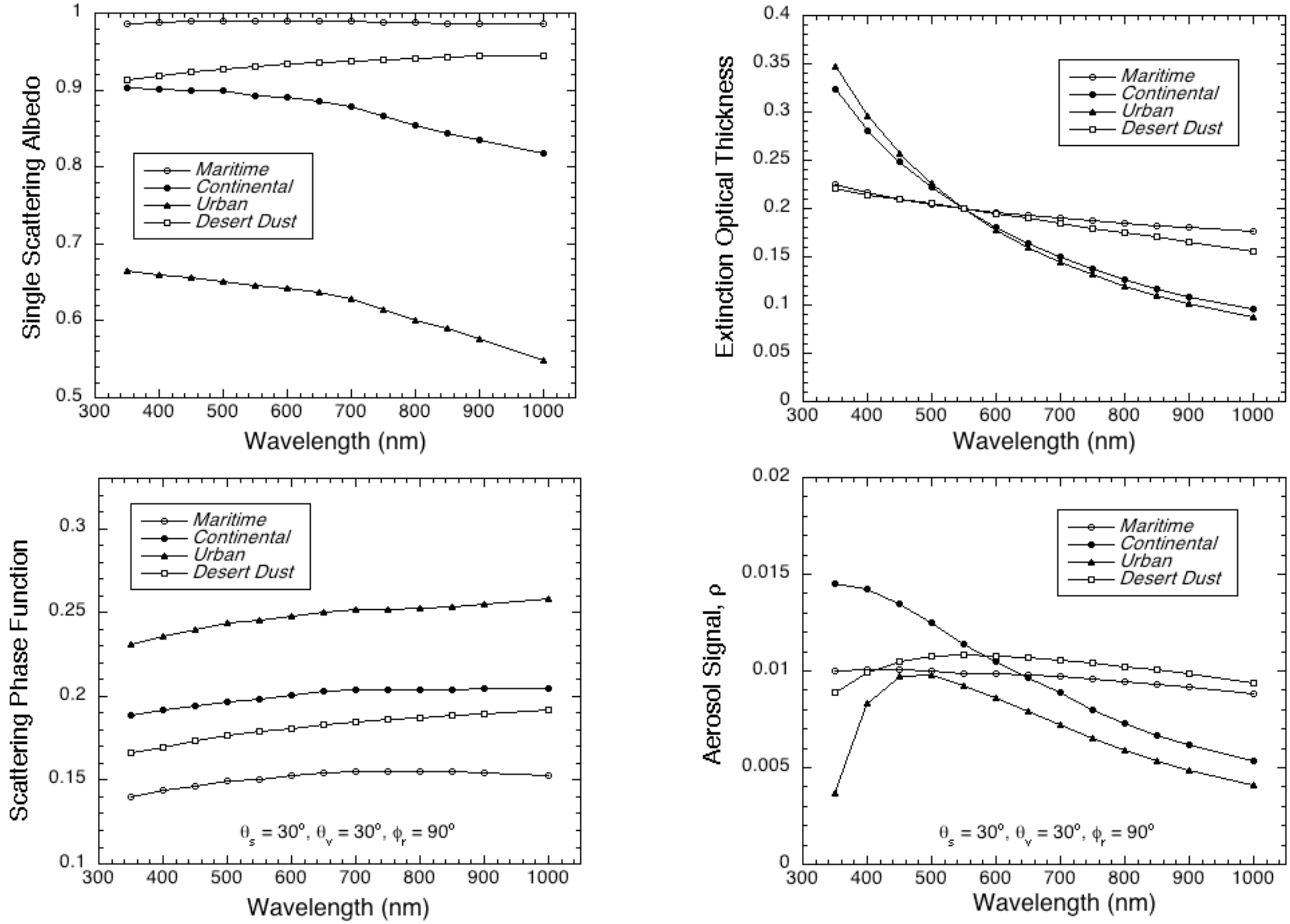
$\partial \rho / \partial \tau_a = \rho_a / \tau_a - \rho_m m (1 - \omega_a)(p_s - p_a)/p_s$

-Pressure level

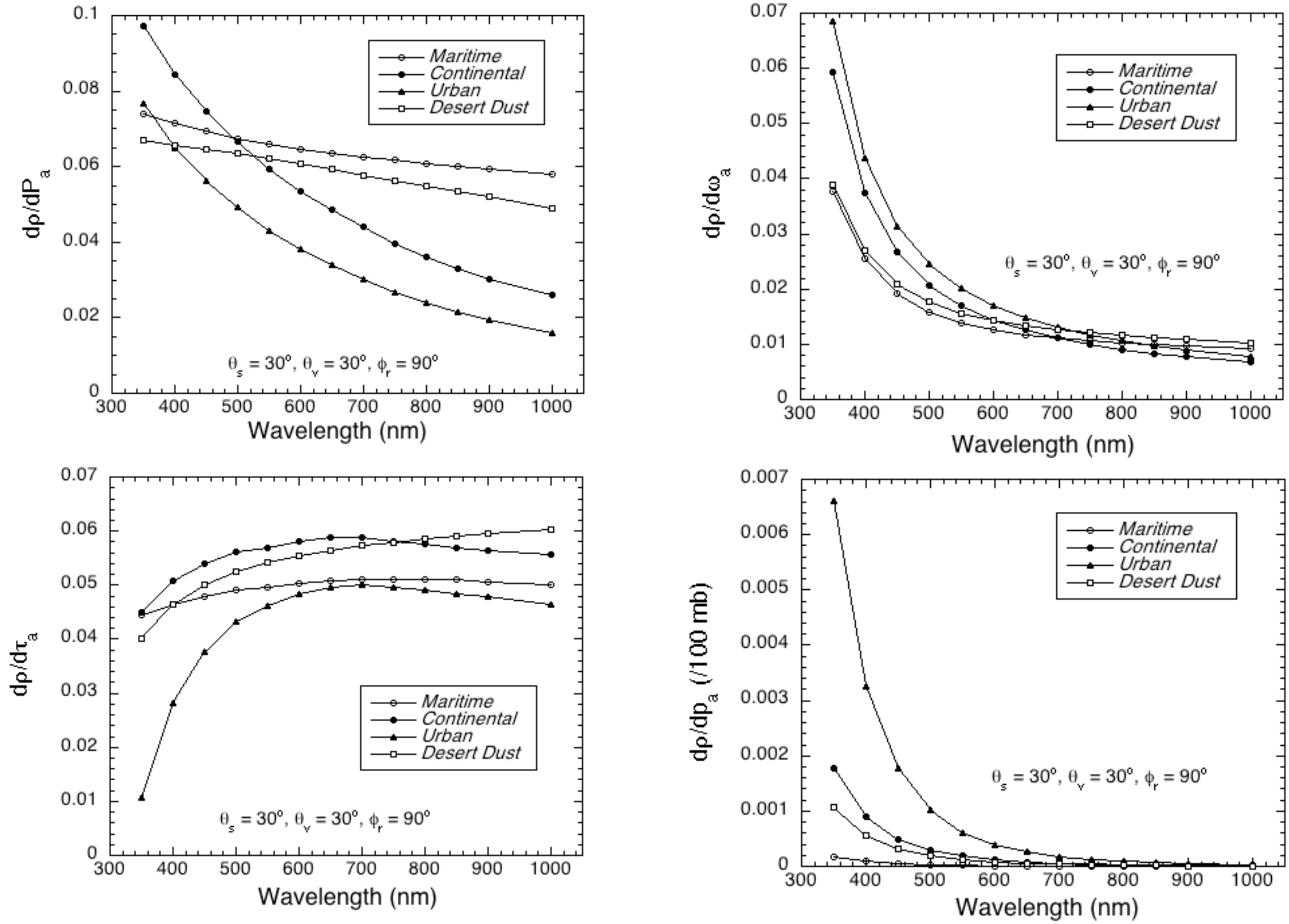
$\partial \rho / \partial p_a = \rho_m m \tau_a (1 - \omega_a)/p_s$

Geometry and aerosol conditions

-Geometry: (θ_s = 30°, θ_v = 30°, ϕ_r = 90°)
-Aerosol optical thickness: 0.2 (at 550 nm)
-Aerosol pressure level: 800 mb
-Aerosol model: Maritime, Continental, Urban, Desert Dust



Aerosol single scattering albedo (top left), optical thickness (top right), and phase function (bottom left) for the selected geometry and aerosol conditions (see previous slide). Resulting aerosol signal, ρ (bottom right).



Sensitivity of the aerosol signal, ρ, to aerosol parameters: (Top left) Phase function; (Top right) Single scattering albedo; (Bottom left) Optical thickness; (Bottom right) Pressure level. In the case of continental aerosols, for example, an uncertainty requirement of ±0.001 on ρ at 450 nm translates into uncertainty requirements of ±0.01 on P_a, ±0.04 on ω_a, ±0.02 on τ_a, and ±200 mb on p_a.

Uncertainty on marine reflectance and aerosol reflectance for clear and turbid waters.

Wavelength (nm)	ρ_w	$\Delta\rho_w$(5%)	$\Delta\rho$ (Mar)	$\Delta\rho$ (Con)	$\Delta\rho$ (Urb)	$\Delta\rho$ (DD)
Clear Water ([Chl] = 0.06 mg/m^3)						
350	0.0201	±0.0010	±0.0004	±0.0004	±0.0003	±0.0004
450	0.0321	±0.0016	±0.0011	±0.0011	±0.0009	±0.0011
550	0.0065	±0.0013	±0.0003	±0.0003	±0.0002	±0.0003
Turbid Water ([Chl] = 3.14 mg/m^3)						
350	0.0063	±0.0003	0.0001	±0.0001	±0.0001	±0.0001
450	0.0041	±0.0002	0.0001	±0.0001	±0.0001	±0.0001
550	0.0094	±0.0005	0.0004	±0.0004	±0.0003	±0.0004

Accuracy requirements on aerosol parameters, 350 nm

Aerosol Model	$\Delta\tau_a$	$\Delta\omega_a$	ΔP_a	Δp_a (hPa)
	λ= 350 nm, *[Chl]* = 0.06 mg/m^3			
Maritime	±0.010	±0.011	±0.006	±248
Continental	±0.009	±0.007	±0.004	±22
Urban	±0.029	±0.004	±0.004	±5
Desert Dust	±0.010	±0.011	±0.006	±39

Aerosol Model	$\Delta\tau_a$	$\Delta\omega_a$	ΔP_a	Δp_a (hPa)
	λ= 350 nm, *[Chl]* = 2.34 mg/m^3			
Maritime	±0.003	±0.003	±0.002	±77
Continental	±0.003	±0.002	±0.001	±7
Urban	±0.009	±0.001	±0.001	±1
Desert Dust	±0.003	±0.003	±0.002	±12

Accuracy requirements on aerosol parameters, 450 nm

Aerosol Model	λ = 450 nm, *[Chl]* = 0.06 mg/m^3			
	$\Delta\tau_a$	$\Delta\omega_a$	ΔP_a	Δp_a *(hPa)*
Maritime	±0.024	±0.058	±0.016	>1013
Continental	±0.020	±0.040	±0.014	±214
Urban	±0.024	±0.028	±0.016	±51
Desert Dust	±0.022	±0.052	±0.017	±344

Aerosol Model	λ = 450 nm, *[Chl]* = 2.34 mg/m^3			
	$\Delta\tau_a$	$\Delta\omega_a$	ΔP_a	Δp_a *(hPa)*
Maritime	±0.006	±0.007	±0.002	±308
Continental	±0.002	±0.005	±0.002	±27
Urban	±0.003	±0.004	±0.002	±6
Desert Dust	±0.003	±0.006	±0.002	±43

Accuracy requirements on aerosol parameters, 550 nm

Aerosol Model	$\Delta\tau_a$	$\Delta\omega_a$	ΔP_a	Δp_a *(hPa)*
	λ = 550 nm, *[Chl]* = 0.06 mg/m^3			
Maritime	±0.005	±0.019	±0.004	>1013
Continental	±0.004	±0.015	±0.004	±134
Urban	±0.005	±0.011	±0.005	±36
Desert Dust	±0.005	±0.017	±0.004	±215

Aerosol Model	$\Delta\tau_a$	$\Delta\omega_a$	ΔP_a	Δp_a *(hPa)*
	λ = 550 nm, *[Chl]* = 2.34 mg/m^3			
Maritime	±0.008	±0.028	±0.006	>1013
Continental	±0.006	±0.022	±0.006	±195
Urban	±0.007	±0.016	±0.008	±53
Desert Dust	±0.007	±0.024	±0.006	±312

State-of-the art retrieval errors on aerosol parameters

-Hasekamp et al. (2011), multi-angle photopolarimetry:

$0.1 < \tau_a(550) < 0.3$

$\Delta r_f = 0.036$; $\Delta r_c = 0.24$ (micron)
$\Delta \sigma_f = 0.071$; $\Delta \sigma_c = 0.30$
$\Delta m_{rf} = 0.055$; $\Delta m_{rc} = 0.016$;
$\Delta m_{if} = 0.018$; $\Delta m_{ic} = 0.02$

$\Delta \tau_a = 0.024$
$\Delta \omega_a = 0.02\text{-}0.05$
$\Delta P_a = 5\text{-}10\%$

-Dubuisson et al. (2007), oxygen A-band technique:

$\Delta h_a = 1\text{-}2$ km ($\Delta p_a = 100\text{-}200$ hPa)

Retrieval errors are generally too large to meet the 5% accuracy requirement for water-leaving radiance.

Conclusions:

-Aerosol parameters are not currently retrieved with sufficient accuracy to compute aerosol radiance correctly and perform suitable atmospheric correction.

-Strategy for atmospheric correction cannot be based on the retrieval of individual aerosol parameters. One needs to consider/estimate the aerosol signal more directly.

-Aerosol information will be helpful to constrain the solution to the inherently ill-posed inverse problem in determining the aerosol radiance.