On Spatial Scales Of Sub-Pixel Variability: Implications For Coastal Remote Sensing

S. G. Ackleson
W. J. Moses

Naval Research Laboratory, Washington, DC

Science Questions:

How does variability in optical properties change as a function of between sample distance and location?

Can this information inform us about in situ sampling uncertainty?

Is there an optimum ground sampling distance (GSD) that can be applied to future coastal imagers?

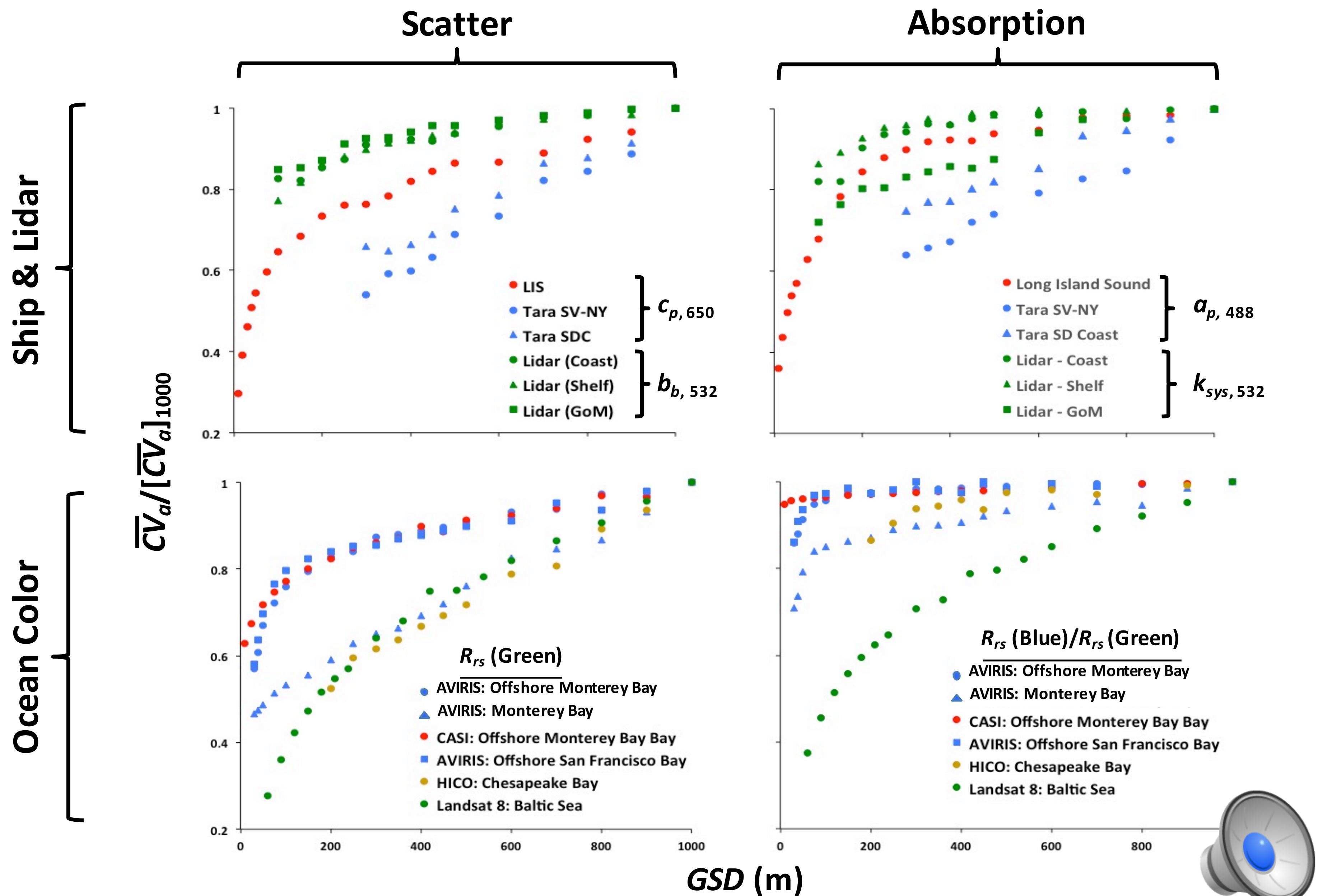
Approach:

High resolution, along-track in situ and shipboard IOPs, airborne lidar, and airborne and satellite and ocean color data used to compute average coefficient of variance ($\overline{CV}_a$) as a function of GSD.

Data Sets

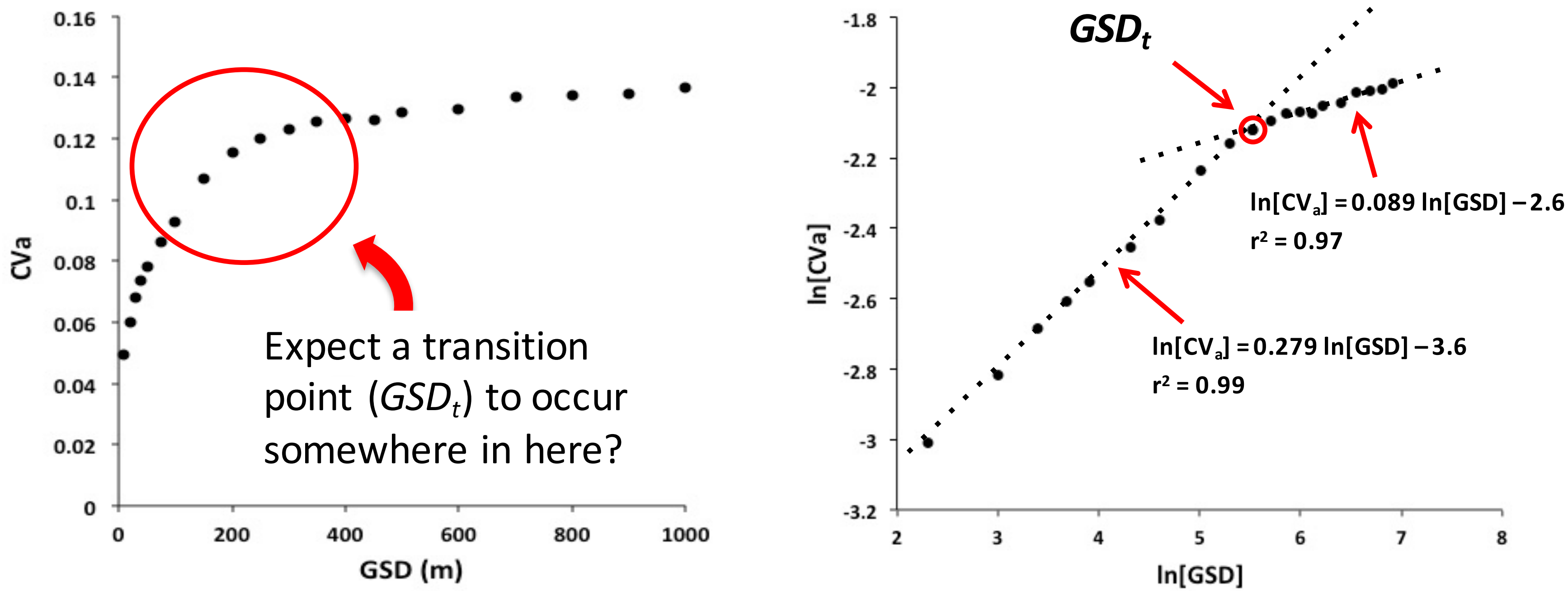
Data Set	Location	*GSD* m (Median)	GSD_{min}	*p*
Ship (in situ)	Long Island Sound	10	20	c_p , a_p
Ship (flow-through)	Mid-Atlantic Bight	141	300	c_p , a_p
Ship (flow-through)	Southern California	185	300	c_p , a_p
Airborne Lidar	Virginia Coast	54	100	b_b , k_{sys}
Airborne Lidar	Mid-Atlantic Bight	60	100	b_b , k_{sys}
Airborne Lidar	Georges Bank	48	100	b_b , k_{sys}
Airborne (AVIRIS)	San Francisco Bay	16	35	$R_{B,G,R}$, $R_{B:G}$
Airborne (AVIRIS)	Monterey Bay	16	35	$R_{B,G,R}$, $R_{B:G}$
Airborne (AVIRIS)	Monterey Bay	16	35	$R_{B,G,R}$, $R_{B:G}$
Airborne (CASI)	Monterey Bay	10	20	$R_{B,G,R}$, $R_{B:G}$
Satellite (Landsat-8)	Baltic Sea	30	60	$R_{B,G,R}$, $R_{B:G}$
Satellite (HICO)	Chesapeake Bay	90	200	$R_{B,G,R}$, $R_{B:G}$

Intra-Pixel Variability



Is there a common *GSD* where CV_a defines a transition between coastal scale features and scales associated with offshore features?

Particulate Absorption (488 nm), Long Island Sound



1) Starting with the first 4 data points from the left (minimum GSD in log space), a linear regression is computed as data points are sequentially added (increasing GSD) until r^2 is maximized.

2) Perform same operation from the right (maximum GSD).

3) Transition scale (GSD_t) is computed as the intersection of the two regression curves.

4) If maximum r^2 is achieved using all data points (i.e., points form a single line in log space), no transition scale exists ($GSD_t = 0$)

Mode/Sensor	**Location**	***p***	***GSD$_t$ (LL)***
In Situ	Long Island Sound	$[c_p]_{LIS}$	134
		$[a_p]_{\mathrm{LIS}}$	140
Ship	Mid-Atlantic Bight	$[c_p]_{\mathrm{SN}}$	0
		$[a_p]_{\mathrm{SN}}$	0
Ship	Southern California	$[c_p]_{\mathrm{SD}}$	0
		$[a_p]_{\mathrm{SD}}$	0
Lidar	Virginia Coast	$[b_b]_{\mathrm{CV}}$	273
		$[k_{sys}]_{\mathrm{CV}}$	270
Lidar	Mid-Atlantic Bight	$[b_b]_{\mathrm{MAL}}$	269
		$[k_{sys}]_{\mathrm{MAL}}$	277
Lidar	Georges Bank	$[b_b]_{\mathrm{GB}}$	252
		$[k_{sys}]_{\mathrm{GB}}$	217
AVIRIS	Offshore San Francisco Bay	$[R_{B,G,R}]_{\mathrm{SFB}}$	74, 74, 80
		$[R_{G:B}]_{\mathrm{SFB}}$	70
AVIRIS	Offshore Monterey Bay	$[R_{B,G,R}]_{\mathrm{M1A}}$	87, 87, 97
		$[R_{G:B}]_{\mathrm{M1A}}$	92
AVIRIS	Monterey Bay	$[R_{B,G,R}]_{\mathrm{M2A}}$	58, 0, 65
		$[R_{G:B}]_{\mathrm{M2A}}$	71
CASI	Offshore Monterey Bay	$[R_{B,G,R}]_{\mathrm{M1C}}$	0, 0, 0
		$[R_{G:B}]_{\mathrm{M1C}}$	0
Landsat-8	Baltic Sea	$[R_{B,G,R}]_{\mathrm{BS}}$	155, 167, 144
		$[R_{G:B}]_{\mathrm{BS}}$	153
HICO	Chesapeake Bay	$[R_{B,G,R}]_{\mathrm{CB}}$	0, 0, 0
		$[R_{G:B}]_{\mathrm{CB}}$	0

GSD_{min} = 300 m

$\overline{\mathrm{GSD}}_t$ = 144 m

(Excluding $GSD_t = 0$)

GSD_{min} =

Conclusions

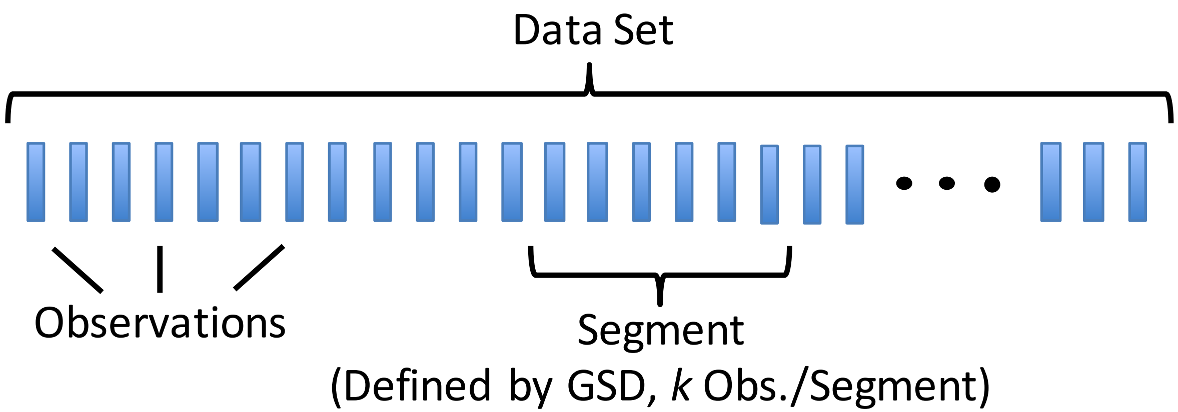
- CV_a increases with GSD, more rapidly at small scales ($GSD < 200$ m).
- Transition points in $dCV_a/dGSD$ range between $GSD_t = 58$ m and 277 m (average is 144 m).
- GSD_t is generally larger for offshore waters.
- No transition points are observed for data sets where $GSD_{min} \geq 200$ m, and several instances are observed for CASI data ($GSD_{min} = 20$ m).
- Optimum spatial resolution for a coastal sensor is $< GSD_t$.
- Curves also represent sampling uncertainty; increases with GSD most rapidly where $GSD < 200$ m; more gradual increase with GSD for $GSD > 200$ m.
- Measurements made with sensors plumbed into the ship flow-through sea water system are limited in the ability to resolve small-scale features;

  - Useful for mapping larger-scale changes (GSD > 300 m) and monitoring conditions while on station
  - Inadequate for estimating sub-pixel variability (GSD < 300 m)

Backup Slides

Average Coefficient of Variance ($\overline{CV}_a$)

(Intra-Pixel Variability)



$$\overline{CV}_{\mathrm{a}} = \frac{1}{n} \sum_{i=1}^{n} \left[\left(1 + \frac{1}{4k}\right) \frac{\sigma_{\mathrm{i}}}{\overline{X}_{\mathrm{i}}} \right]$$

Small sample correction

(*Sokal, R. R. and J. F. Rohlf. 1995. Biometry: The Principles and Practice of Statistics in Biological Research)*

$$2 * [GSD]_{\mathrm{MEDIAN}} \leq GSD_{min} \leq 1000\ \mathrm{m}$$