Sensor Characteristics for Remote Sensing of Inland and Coastal Waters

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Sensor Characteristics

- Spatial Resolution
- Spectral Resolution
- Signal-to-Noise Ratio
- Temporal Resolution

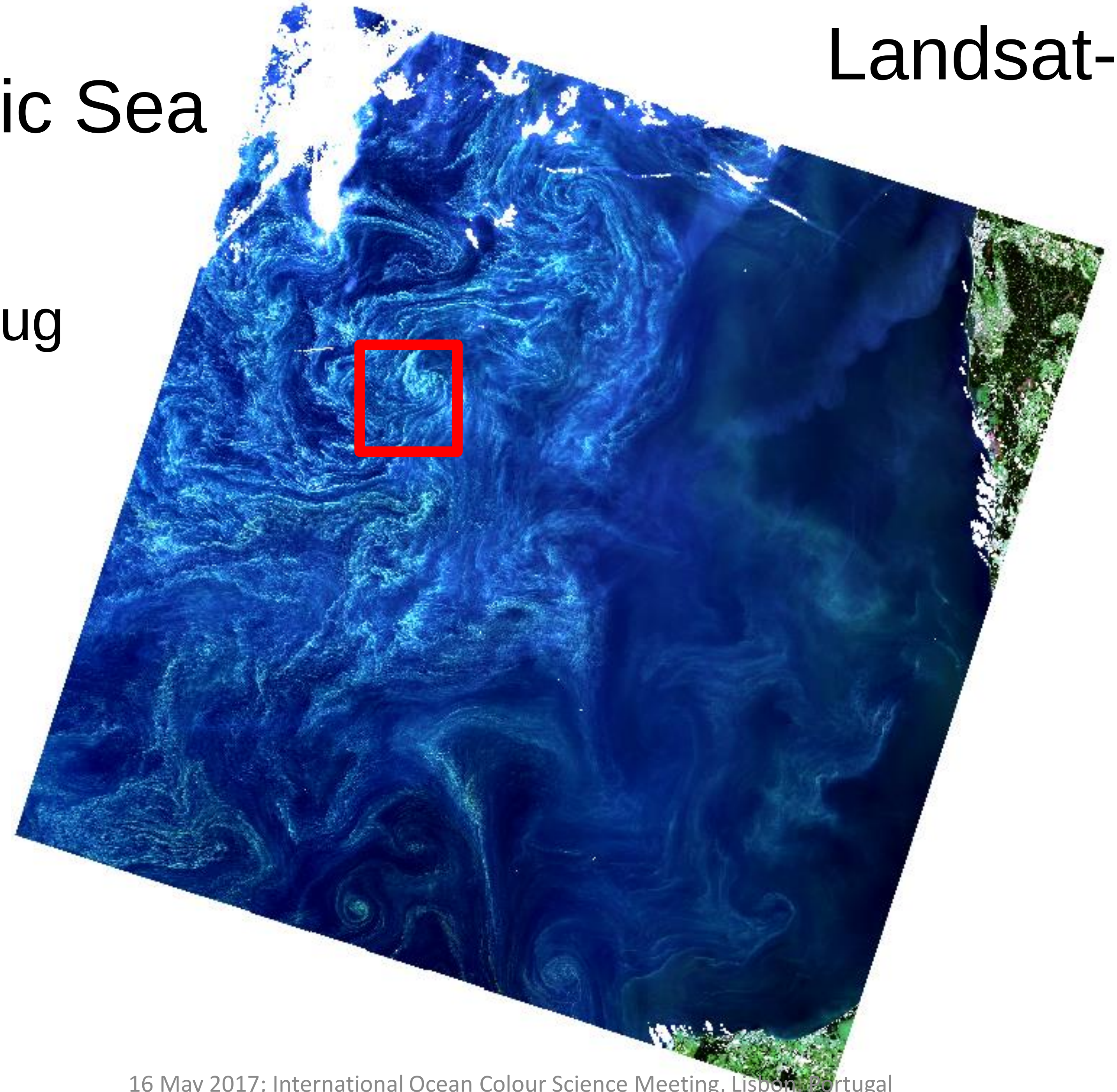
Spatial Resolution

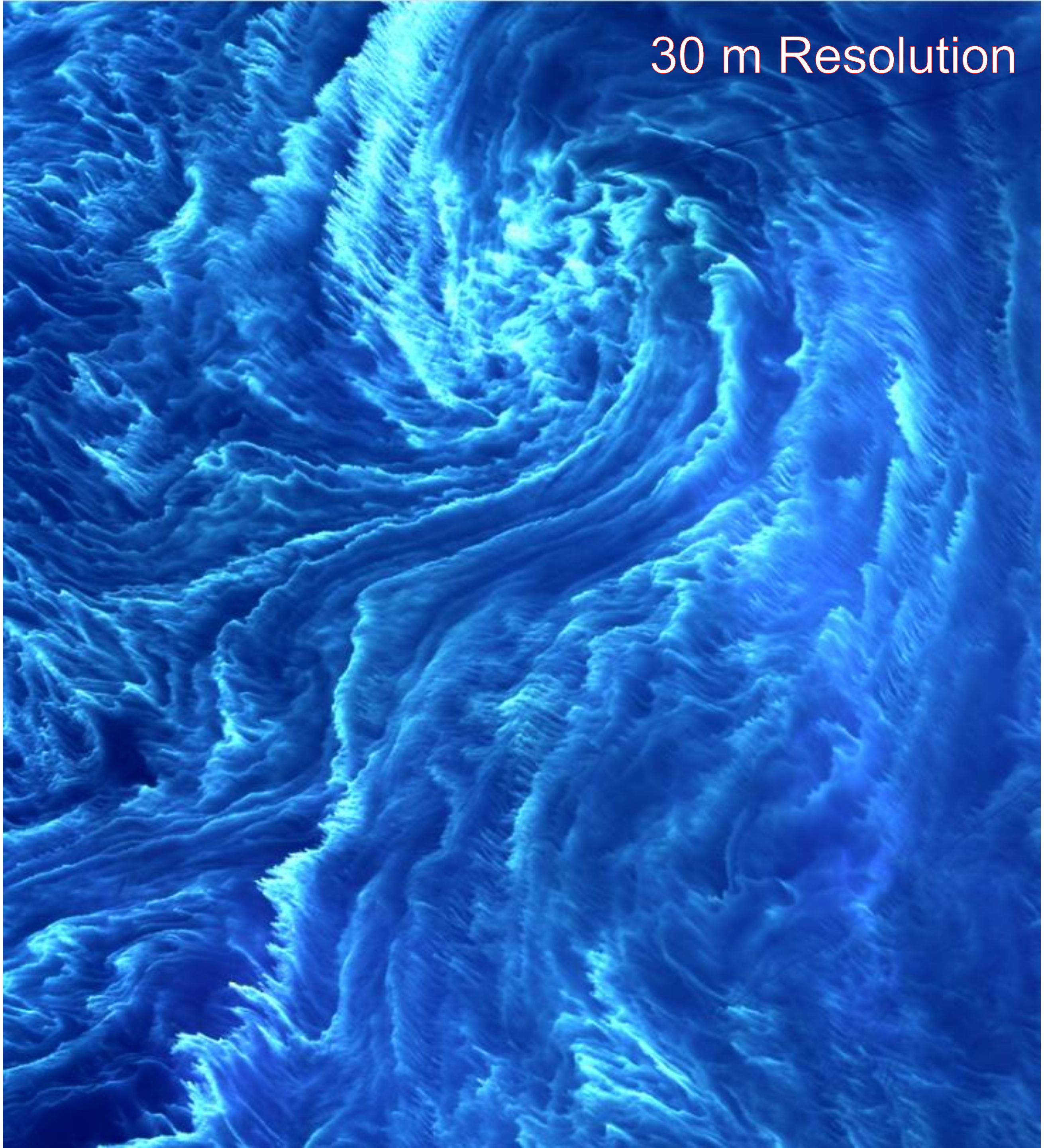
What is the dominant spatial scale of variability of optically discernible biophysical features in coastal and inland waters?

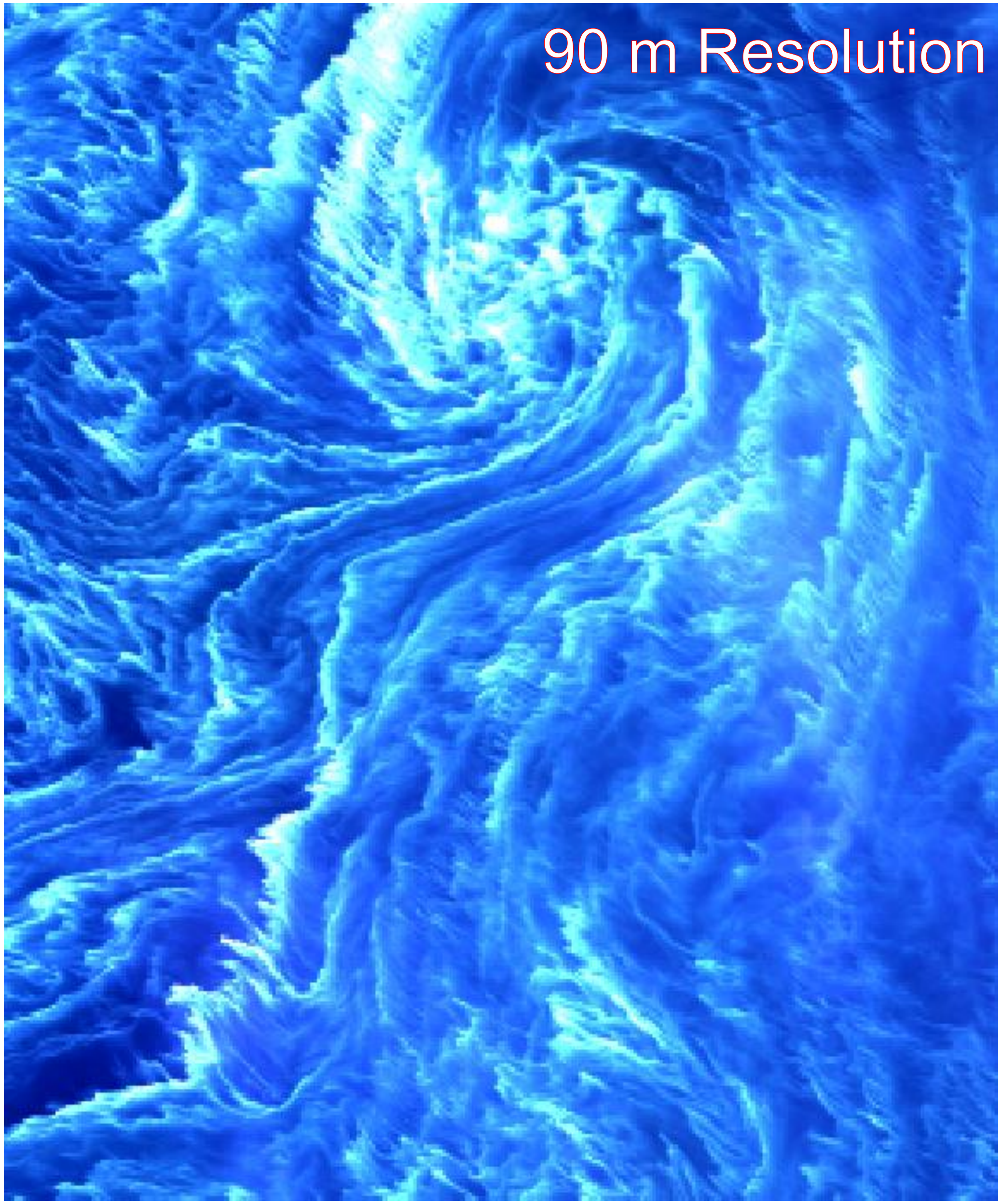
Landsat-8

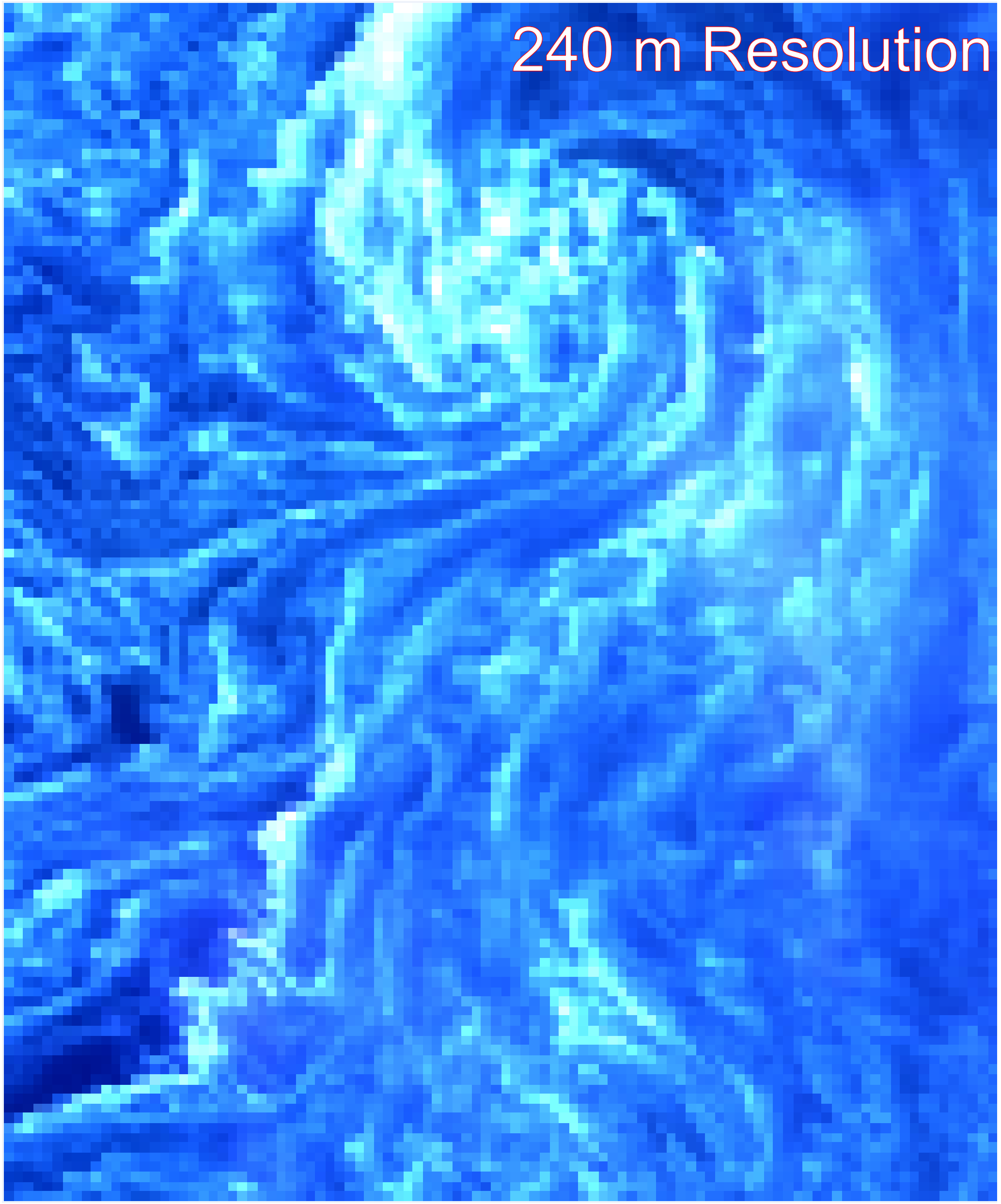
Baltic Sea

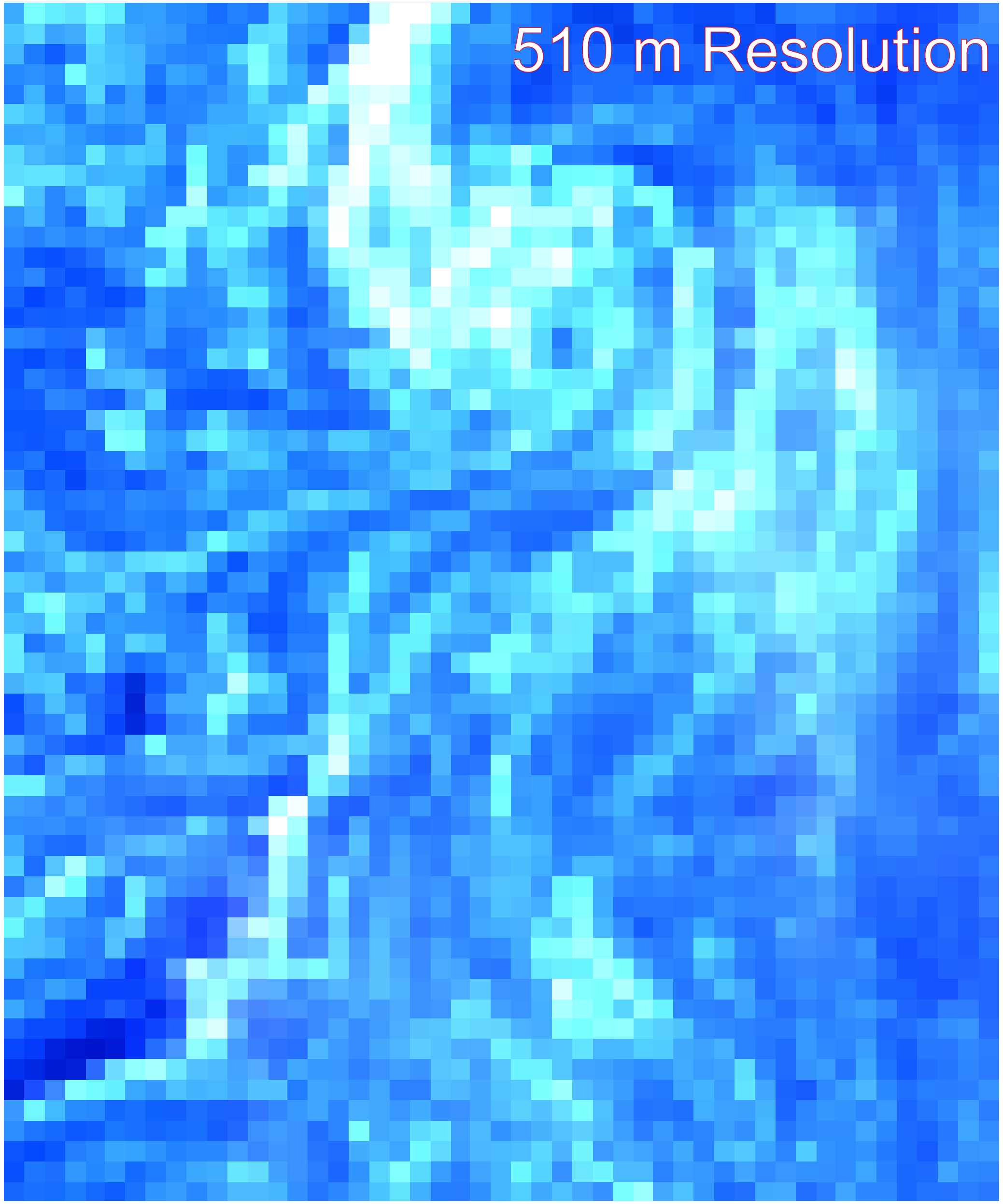
11th Aug
2015

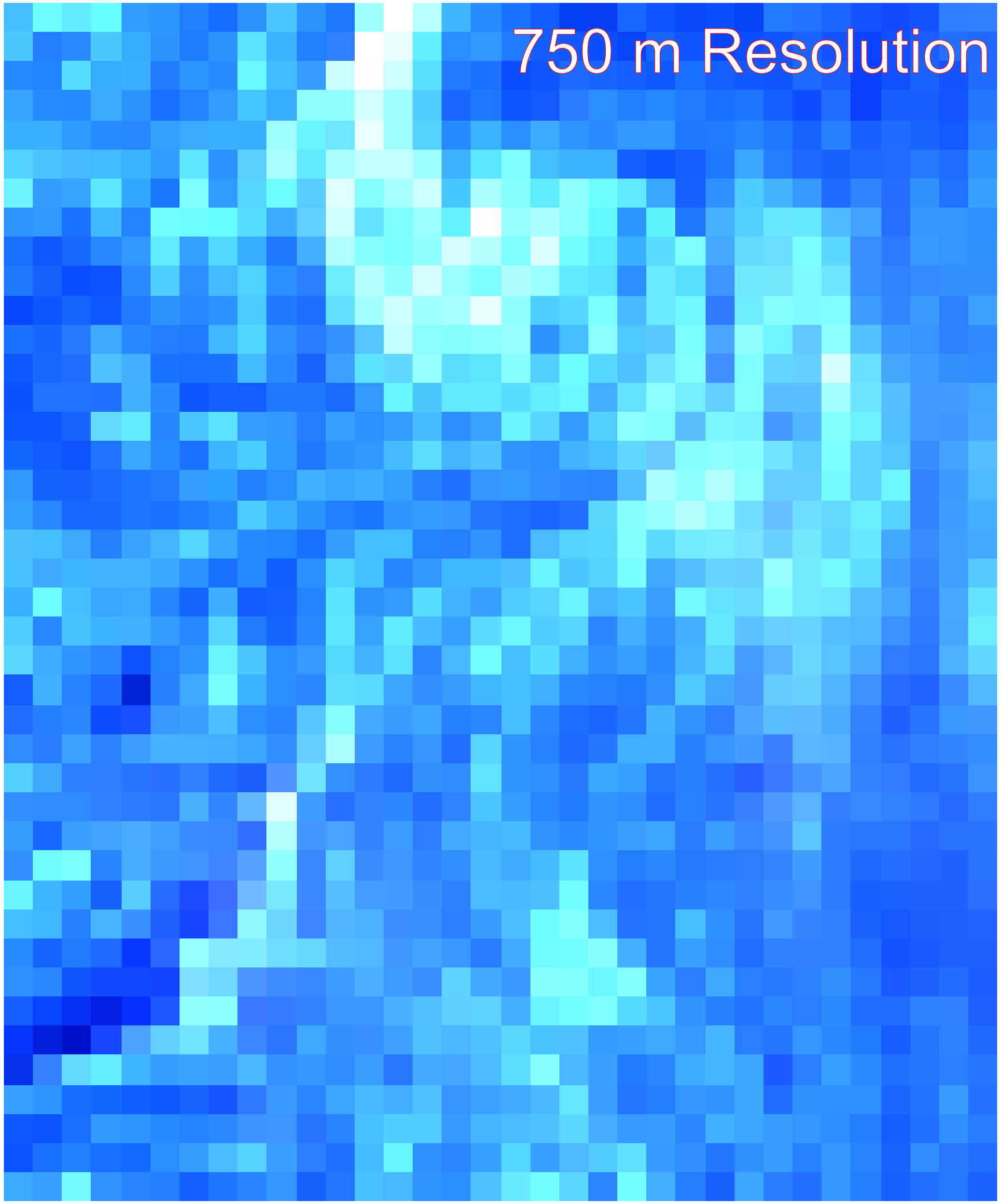


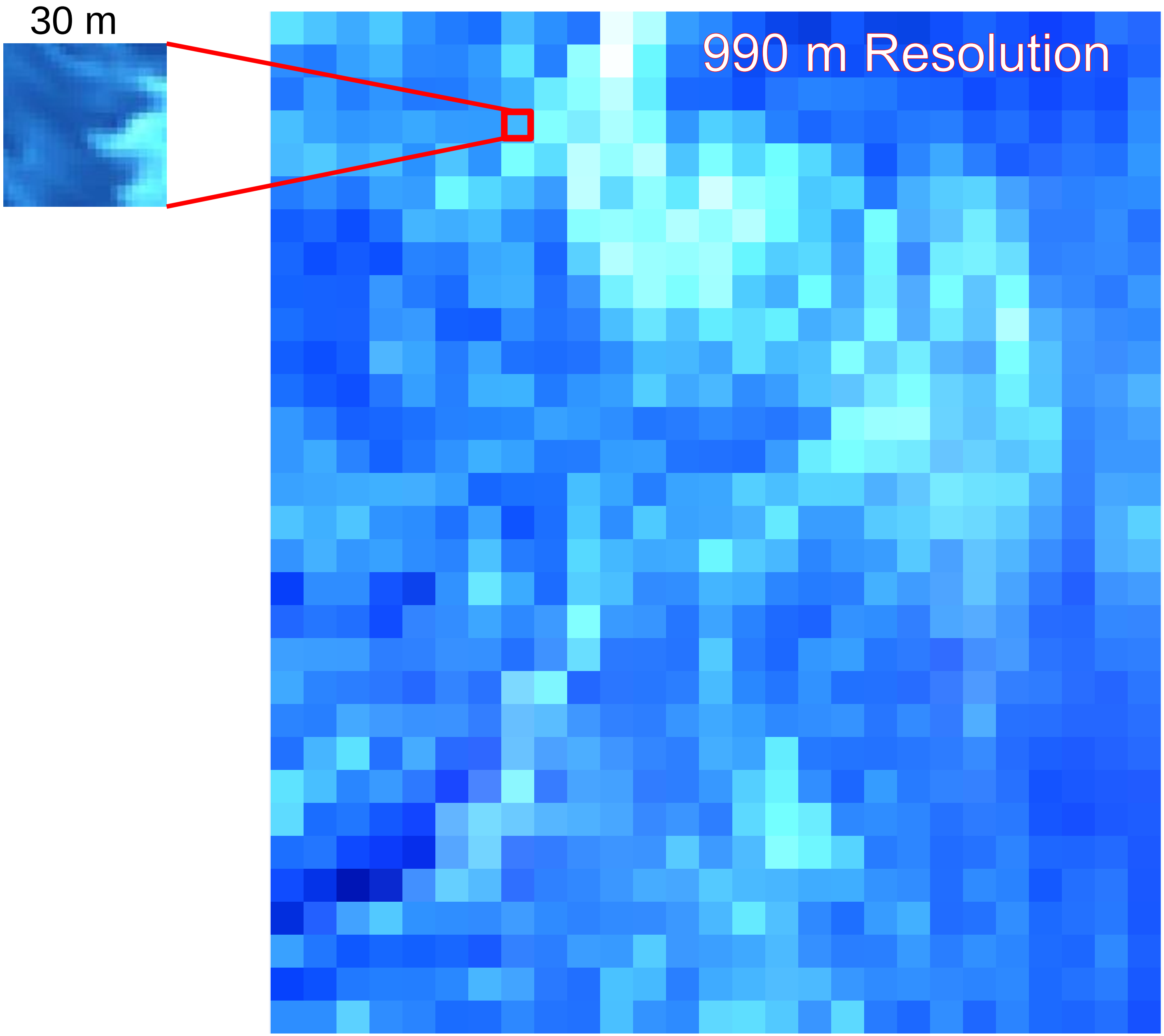

30 m Resolution


90 m Resolution


240 m Resolution

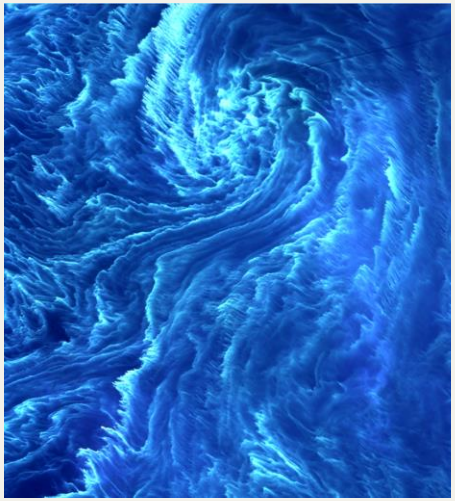

510 m Resolution


750 m Resolution

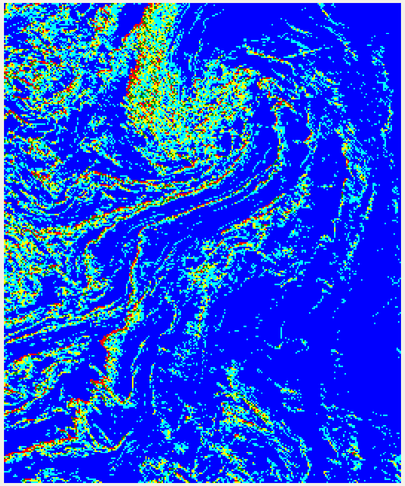

30 m
990 m Resolution

Sub-pixel Coefficient of Variation

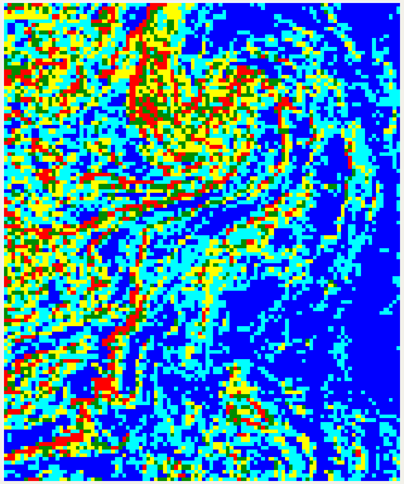
30 m True Color



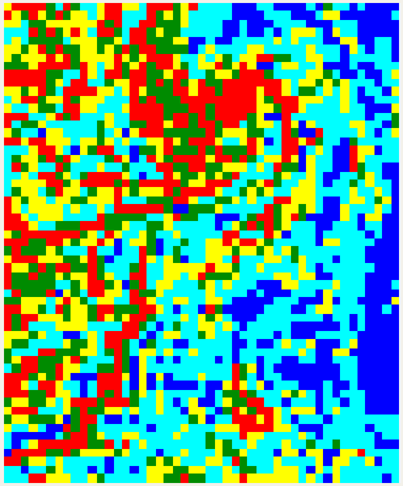
90 m



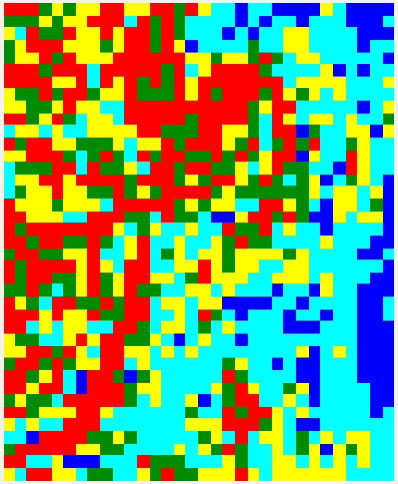
240 m



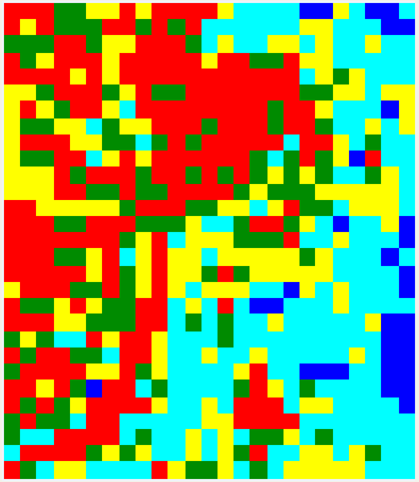
510 m



750 m



990 m



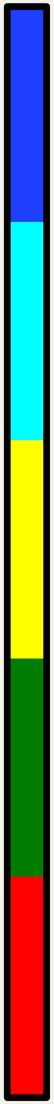
< 0.075

0.075 – 0.15

0.15 – 0.225

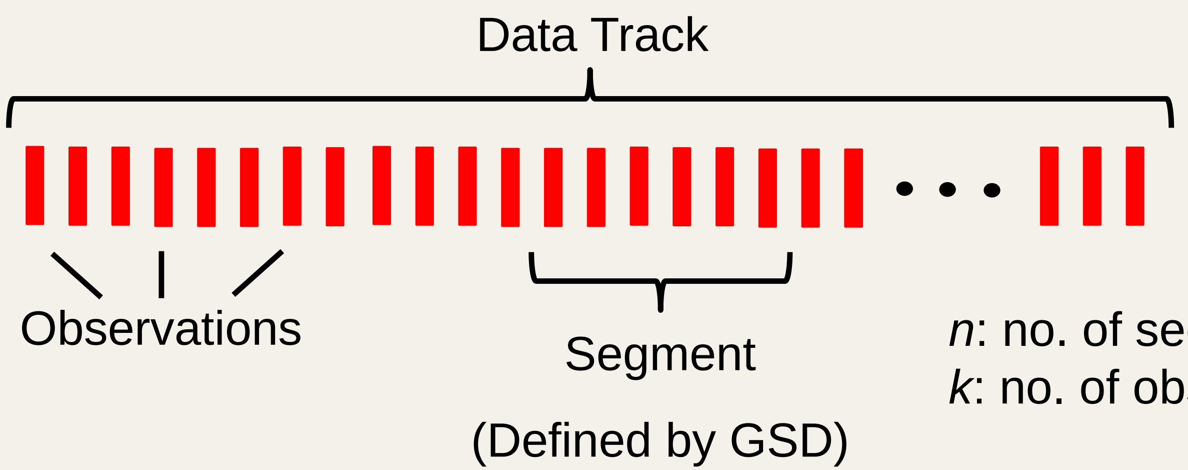
0.225 – 0.3

> 0.3



Spatial Variation Study

Along-track data of IOPs and AOPs from in-water, ship-board, airborne, and spaceborne platforms



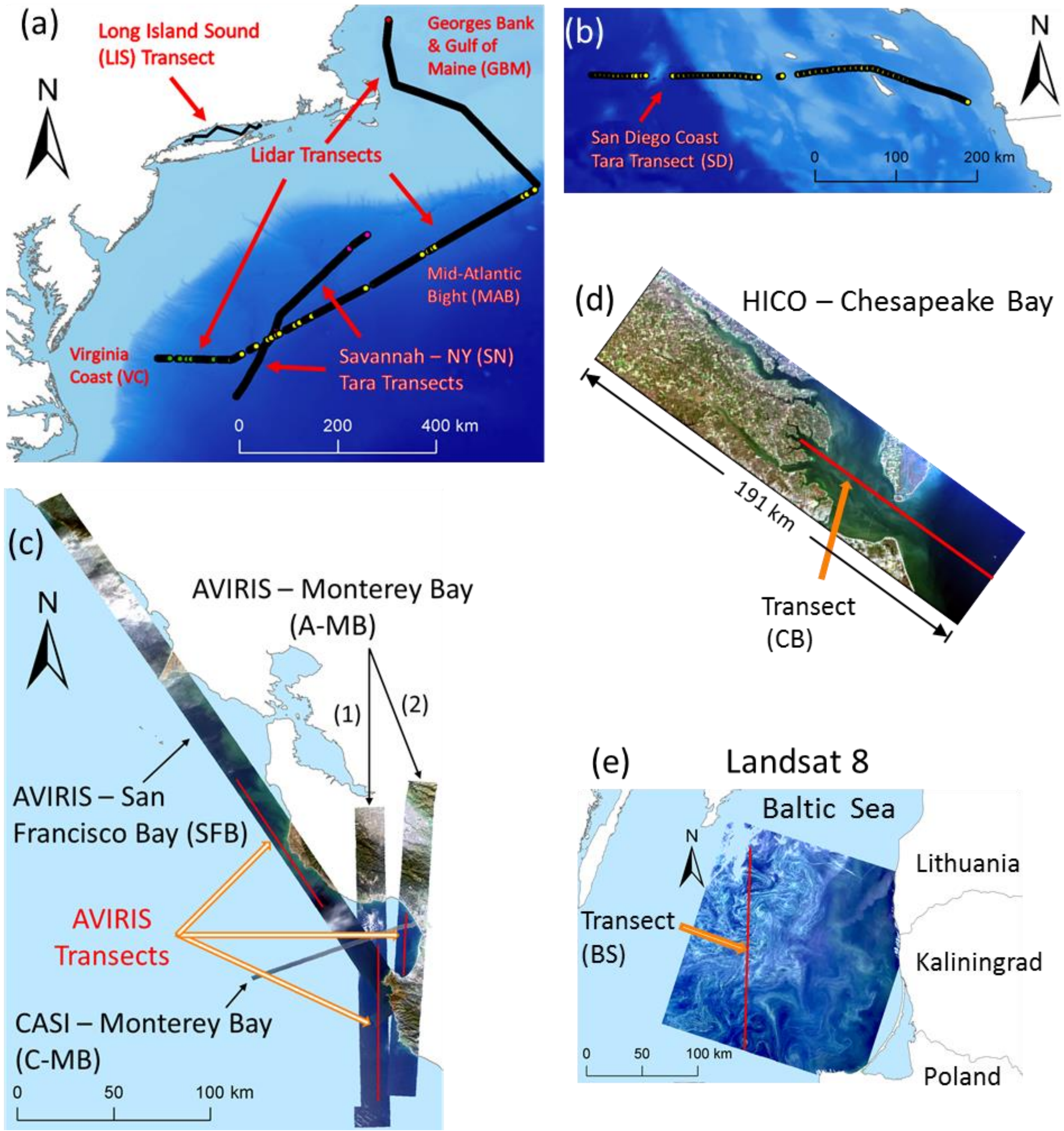
n: no. of segments
k: no. of observations in a segment

Sub-pixel Variation, $\overline{CV}_a = \frac{1}{n}\sum_{i=1}^{n}\left[\underline{\left(1+\frac{1}{4k}\right)}\,\frac{\sigma_i}{\bar{x}_i}\right]$

2 * [*SI*]$_{median}$ ≤ *GSD*$_{min}$ ≤ 1000 m

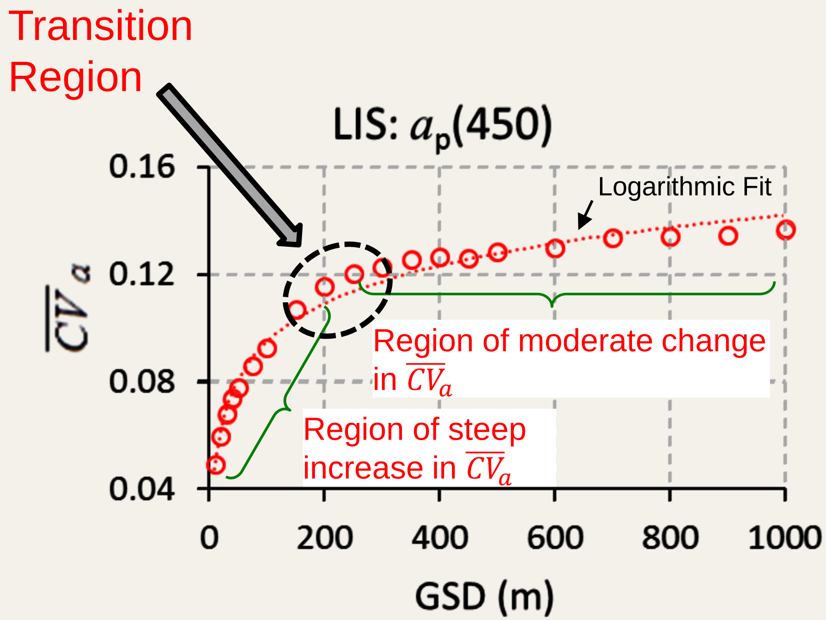
Bias correction
(*Sokal, R. R. and J. F. Rohlf. 1995. Biometry: The Principles and Practice of Statistics in Biological Research)*

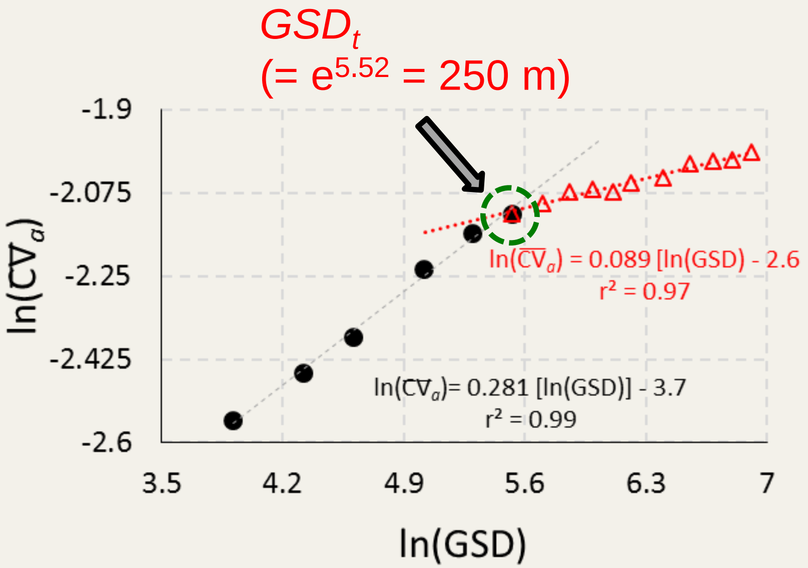
Data


(a)
Long Island Sound
(LIS) Transect
Georges Bank
& Gulf of
Maine (GBM)
N
Lidar Transects
Mid-Atlantic
Bight (MAB)
Virginia
Coast (VC)
Savannah – NY (SN)
Tara Transects
0
200
400 km
(b)
N
San Diego Coast
Tara Transect (SD)
0
100
200 km
(d)
HICO – Chesapeake Bay
191 km
Transect
(CB)
(c)
N
AVIRIS – Monterey Bay
(A-MB)
(1)
(2)
AVIRIS – San
Francisco Bay (SFB)
AVIRIS
Transects
CASI – Monterey Bay
(C-MB)
0
50
100 km
(e)
Landsat 8
Baltic Sea
N
Lithuania
Transect
(BS)
Kaliningrad
0
50
100 km
Poland

Platform	Instruments	Location	Parameters Analyzed	Transect Length (km)	Spatial Sampling Interval (m)	
					SI_{med}	GSD_{min}
In-water	*ac*-s	Long Island Sound (LIS)	$a_p(450)$, $c_p(650)$	LIS: 158	2.8	10
Shipboard	*ac*-s	Savannah-New York (SN)	$a_p(489)$, $c_p(649)$	SN: 396.8	141	300
		San Diego Coast (SD)	$a_p(488)$, $c_p(650)$	SD: 400	185	400
Airborne	Lidar	Virginia Coast (VC), Mid-Atlantic Bight (MAB), Georges Bank & Gulf of Maine (GBM)	$b_{bp}(532)$, $K_{sys}(532)$	CV: 120	54	150
				MAB: 595	60	150
				GBM: 439	48	100
	AVIRIS	San Francisco Bay (SFB)	R_{rs_B}, R_{rs_G}, R_{rs_R}, $R_{rs\_B/G}$	SFB: 74	16.5	40
		Monterey Bay (A-MB1, A-MB2)	R_{rs_B}, R_{rs_G}, R_{rs_R}, $R_{rs\_B/G}$	A-MB1: 60	16.2	40
				A-MB2: 36	16.1	40
	CASI	Monterey Bay (C-MB)	R_{rs_B}, R_{rs_G}, R_{rs_R}, $R_{rs\_B/G}$	C-MB: 63.5	1.55	5
Spaceborne	HICO	Chesapeake Bay (CB)	R_{rs_B}, R_{rs_G}, R_{rs_R}, $R_{rs\_B/G}$	CB: 102	97	200
	Landsat-8	Baltic Sea (BS)	R_{rs_B}, R_{rs_G}, R_{rs_R}, $R_{rs\_B/G}$	BS: 175	30	60

Transition GSD (GSD_t)



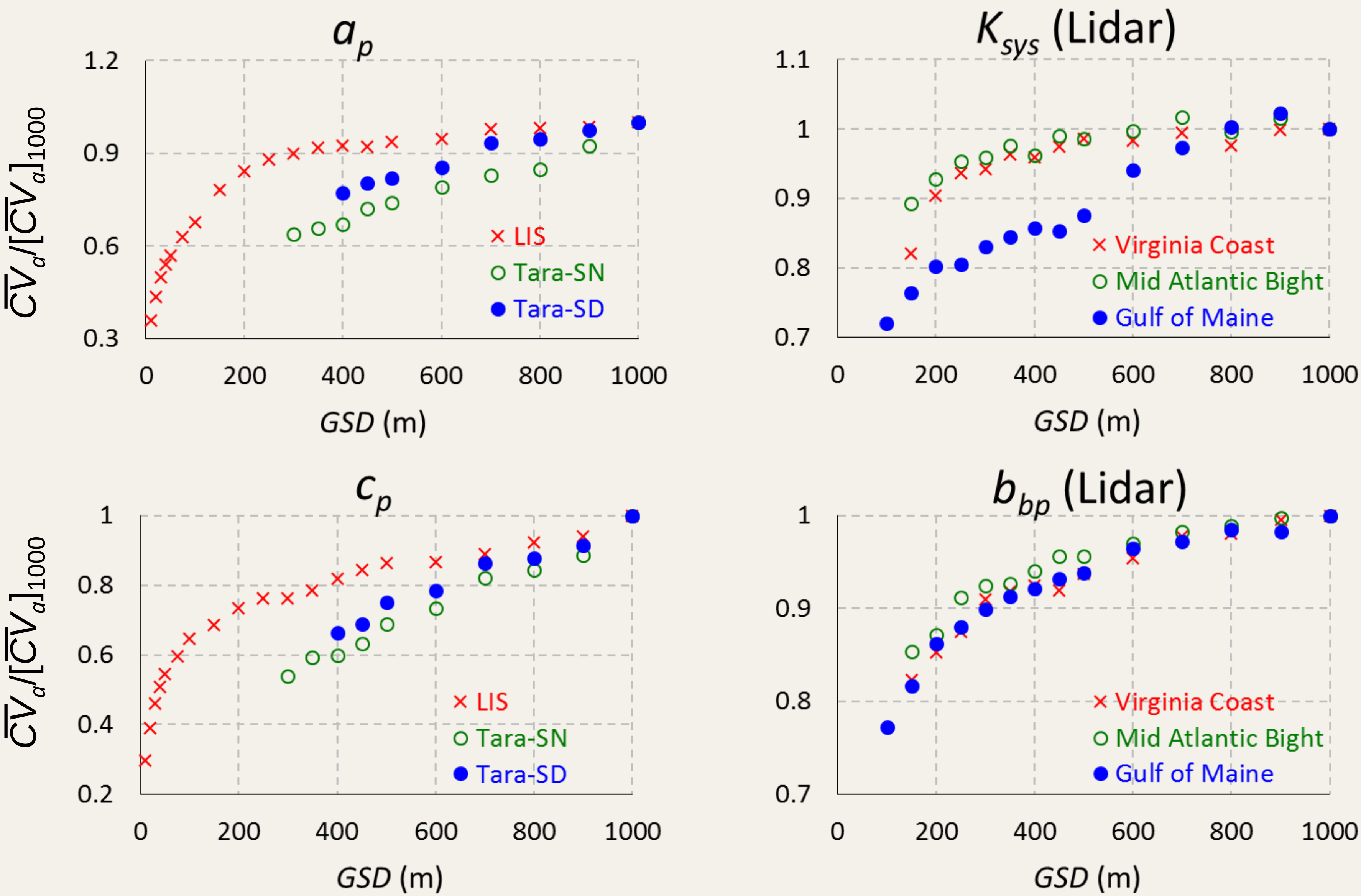


Methods:

- Log-Log (LL) Method
- Slope Percentile (SP) Method

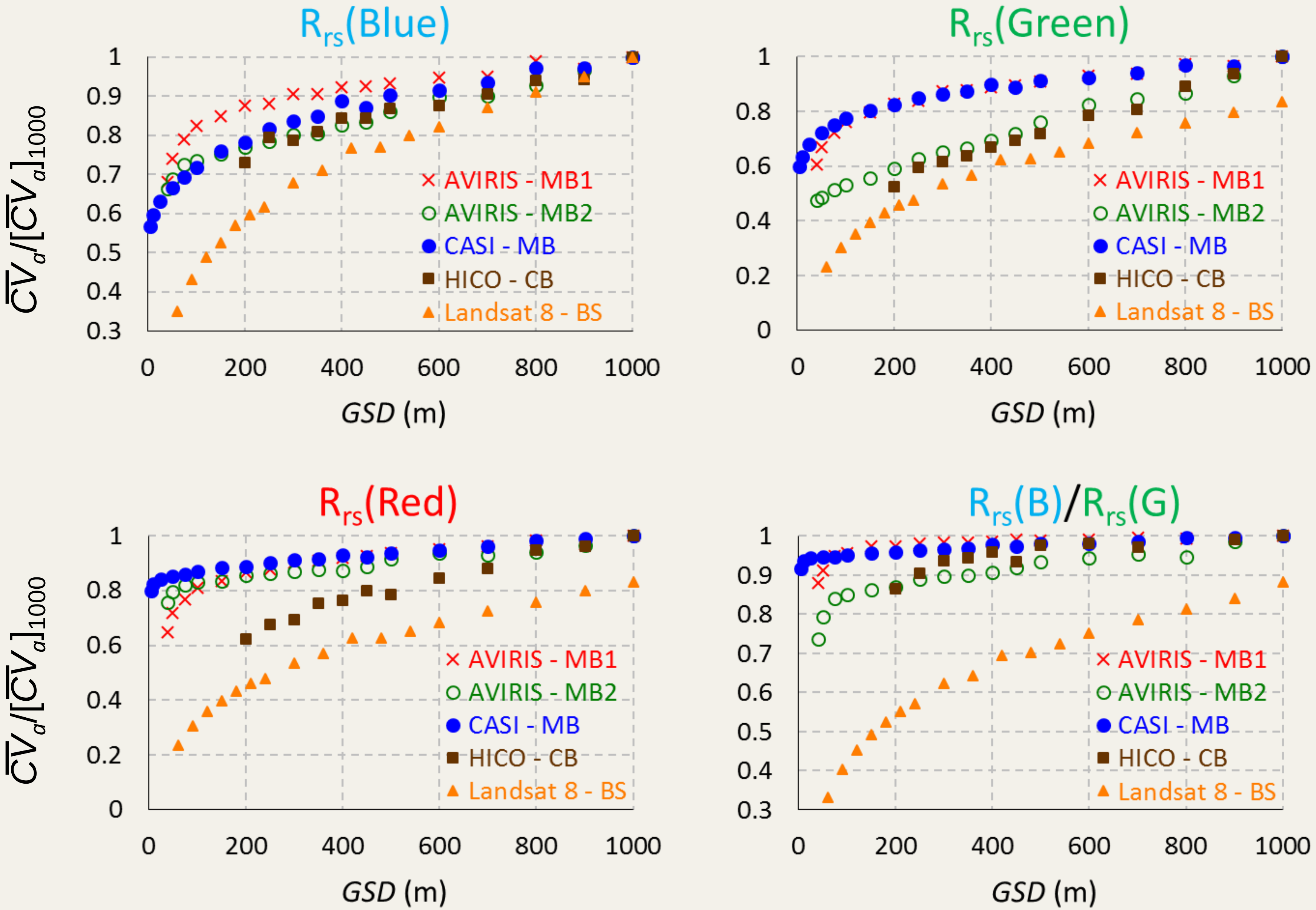
For Details: **Moses, W. J.**, Ackleson, S. G., Hair, J. W., Hostetler, C. A. and Miller, W. D. (2016). *Spatial scales of optical variability in the coastal ocean: Implications for remote sensing and in situ sampling*, Journal of Geophysical Research: Oceans, **121**(6): 4194-4208, doi: 10.1002/2016JC011767.

CV vs. GSD



a_p
1.2
0.9
0.6
0.3
0
200
400
600
800
1000
$\overline{C}V_a/[\overline{C}V_a]_{1000}$
GSD (m)
LIS
Tara-SN
Tara-SD
K_{sys} (Lidar)
1.1
1
0.9
0.8
0.7
Virginia Coast
Mid Atlantic Bight
Gulf of Maine
c_p
1
0.8
0.6
0.4
0.2
b_{bp} (Lidar)

CV vs. GSD


Rrs(Blue)
Rrs(Green)
Rrs(Red)
Rrs(B)/Rrs(G)
$\overline{CV}_a/[\overline{CV}_a]_{1000}$
GSD (m)
AVIRIS - MB1
AVIRIS - MB2
CASI - MB
HICO - CB
Landsat 8 - BS

Platform & Instrument	Transect	Parameter	GSD_t (m) LL Method	GSD_t (m) SP Method
In-water; *ac*-s	Long Island Sound	$[a_{\mathrm{p}}(450)]_{\mathrm{LIS}}$	250	150
		$[c_{\mathrm{p}}(650)]_{\mathrm{LIS}}$	40	100
Shipboard; *ac*-s	Savannah – New York	$[a_{\mathrm{p}}(450)]_{\mathrm{SN}}$, $[c_{\mathrm{p}}(650)]_{\mathrm{SN}}$	None	None
	San Diego Coast	$[a_{\mathrm{p}}(450)]_{\mathrm{SD}}$, $[c_{\mathrm{p}}(650)]_{\mathrm{SD}}$	None	None
Airborne; lidar	Virginia Coast	$[b_b(532)]_{\mathrm{VC}}$	350	300
		$[K_{sys}(532)]_{\mathrm{VC}}$	350	500
	Mid-Atlantic Bight	$[b_b(532)]_{\mathrm{MAB}}$	300	450
		$[K_{sys}(532)]_{\mathrm{MAB}}$	600	450
	Georges Bank and Gulf of Maine	$[b_b(532)]_{\mathrm{GBM}}$	200	350
		$[K_{sys}(532)]_{\mathrm{GBM}}$	200*	200*
Airborne; AVIRIS	San Francisco Bay	$[R_{rs\_\mathrm{B}}]_{\mathrm{SFB}}$, $[R_{rs\_\mathrm{B/G}}]_{\mathrm{SFB}}$	75	150
		$[R_{rs\_\mathrm{G}}]_{\mathrm{SFB}}$	100	150
		$[R_{rs\_\mathrm{R}}]_{\mathrm{SFB}}$	100	200
	Monterey Bay 1	$[R_{rs\_\mathrm{B}}]_{\mathrm{A\text{-}MB1}}$, $[R_{rs\_\mathrm{G}}]_{\mathrm{A\text{-}MB1}}$, $[R_{rs\_\mathrm{R}}]_{\mathrm{A\text{-}MB1}}$	100	200
		$[R_{rs\_\mathrm{B/G}}]_{\mathrm{A\text{-}MB1}}$	75	150
	Monterey Bay 2	$[R_{rs\_\mathrm{B}}]_{\mathrm{A\text{-}MB2}}$	75	100
		$[R_{rs\_\mathrm{G}}]_{\mathrm{A\text{-}MB2}}$	None	None
		$[R_{rs\_\mathrm{R}}]_{\mathrm{A\text{-}MB2}}$, $[R_{rs\_\mathrm{B/G}}]_{\mathrm{A\text{-}MB2}}$	75	100
Airborne; CASI	Monterey Bay	$[R_{rs\_\mathrm{B}}]_{\mathrm{C\text{-}MB}}$	75	100
		$[R_{rs\_\mathrm{G}}]_{\mathrm{C\text{-}MB}}$	None	150
		$[R_{rs\_\mathrm{R}}]_{\mathrm{C\text{-}MB}}$	200	150
		$[R_{rs\_\mathrm{B/G}}]_{\mathrm{C\text{-}MB}}$	None	None
Spaceborne; HICO	Chesapeake Bay	$[R_{rs\_\mathrm{B}}]_{\mathrm{CB}}$, $[R_{rs\_\mathrm{G}}]_{\mathrm{CB}}$, $[R_{rs\_\mathrm{R}}]_{\mathrm{CB}}$	None	None
		$[R_{rs\_\mathrm{B/G}}]_{\mathrm{CB}}$	300	400
Spaceborne; Landsat-8	Baltic Sea	$[R_{rs\_\mathrm{B}}]_{\mathrm{BS}}$, $[R_{rs\_\mathrm{G}}]_{\mathrm{BS}}$, $[R_{rs\_\mathrm{R}}]_{\mathrm{BS}}$, $[R_{rs\_\mathrm{B/G}}]_{\mathrm{BS}}$	None	None

Results

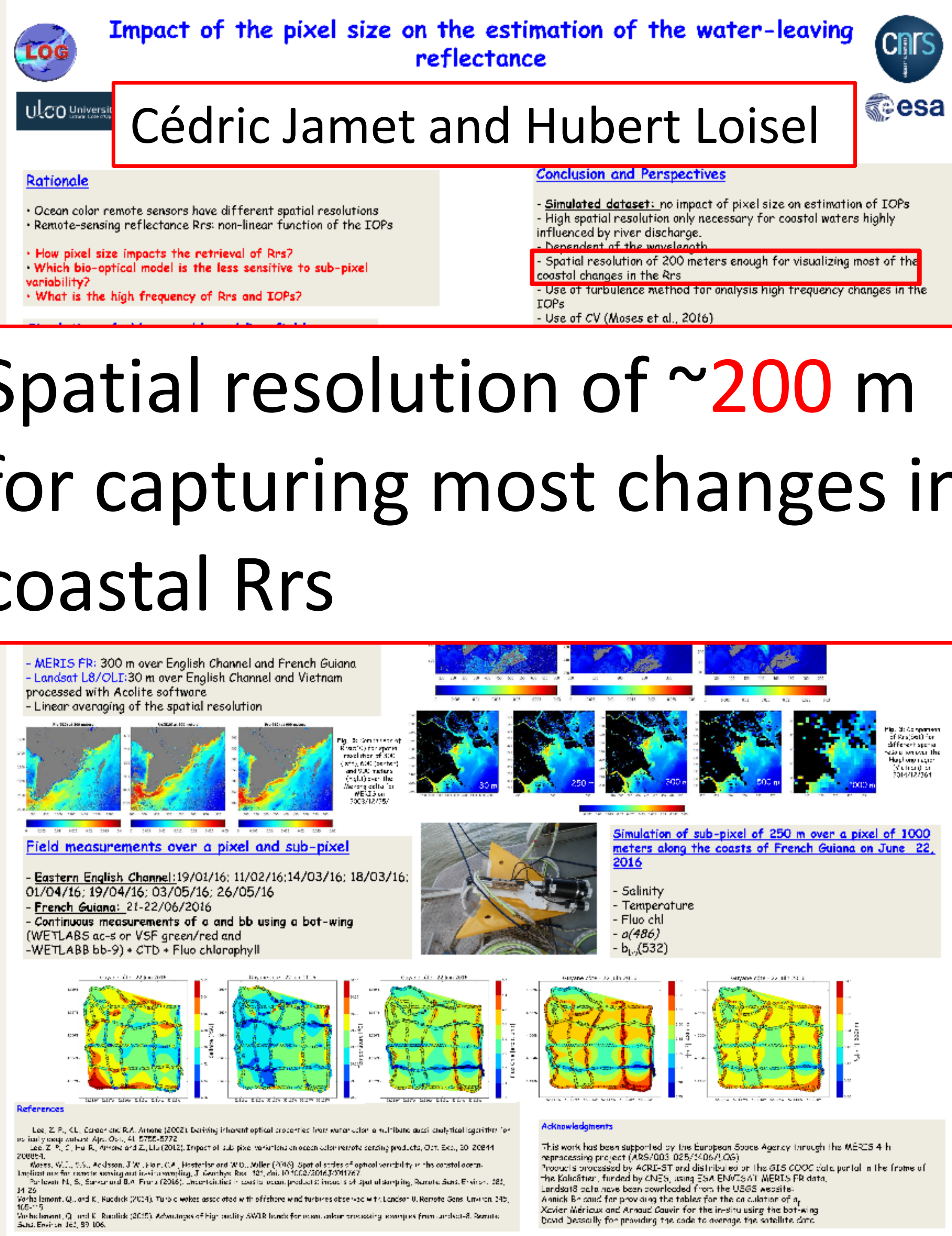
(for coastal waters)

- Average $GSD_t(LL)$: 173 m
- Average $GSD_t(SP)$: 217 m

~ 200 m

- GSD_t generally smaller for regions closer to the shore (dominated by scattering processes)

Does not imply that 200 m is sufficient; it simply means that beyond 200 m there is a significant loss in the ability to capture spatial variability



Cédric Jamet and Hubert Loisel

Spatial resolution of ~200 m for capturing most changes in coastal Rrs

Spectral Resolution

What spectral resolution is required to resolve spectral features in complex inland and coastal waters?

Determining the Optimal Spectral Sampling Frequency for Various Water Types

Ryan Vandermeulen, Antonio Mannino, and Aimee Neeley

CONCLUSIONS

1. A *MINIMUM* of 5 nm spectral resolution is required to resolve variability across mixed spectrum

2. Certain spectral regions may benefit from enhanced spectral subsampling (e.g. fluorescence channel)

3. Results show that even most sensitive regions of the spectrum are resolved at ~4 nm, but does not account for capturing the location of shifting peaks.

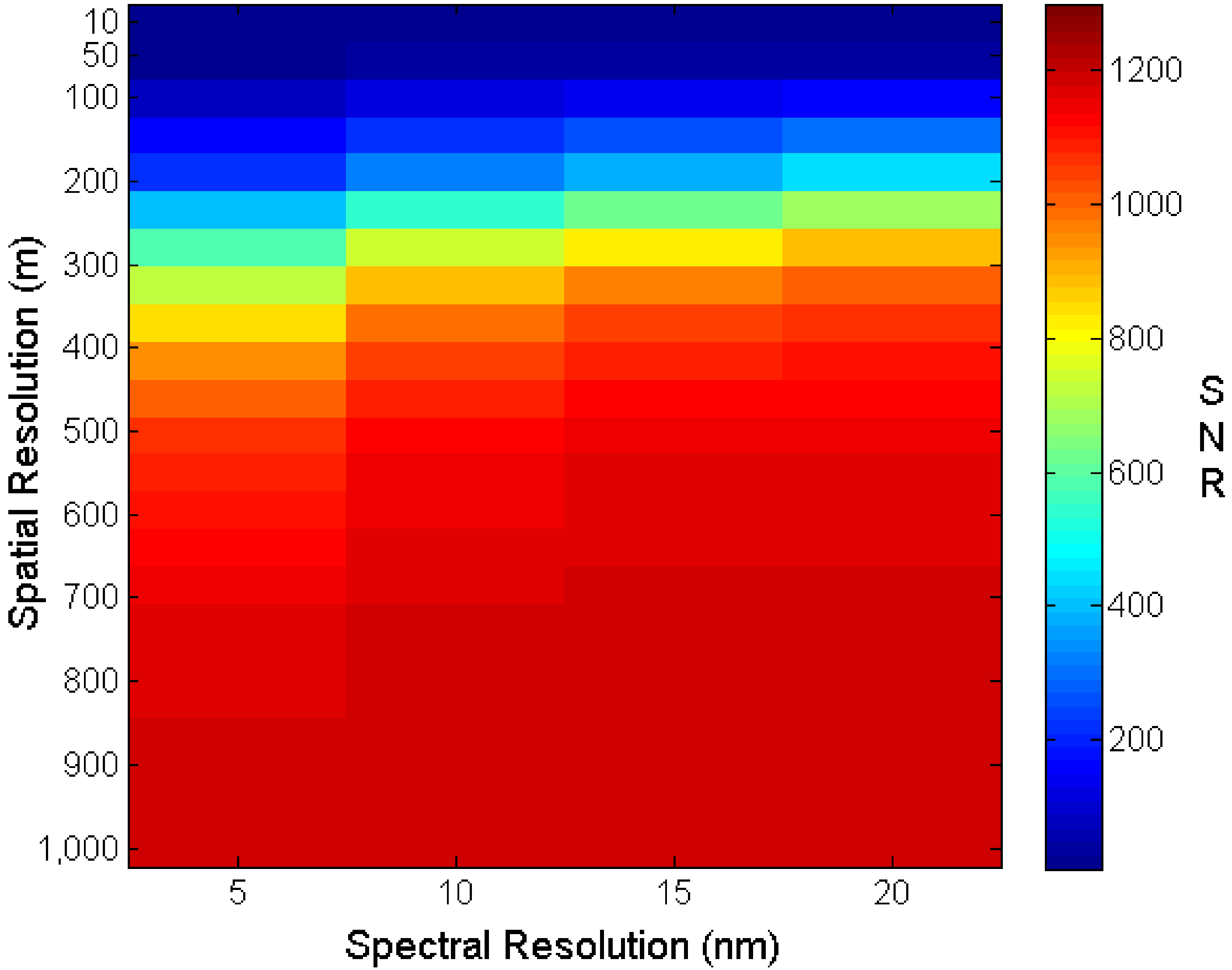
4. At 5 nm spectral resolution, SNR may be ultimate limiting factor for distinguishing fine scale peaks

Signal-to-Noise Ratio (SNR)

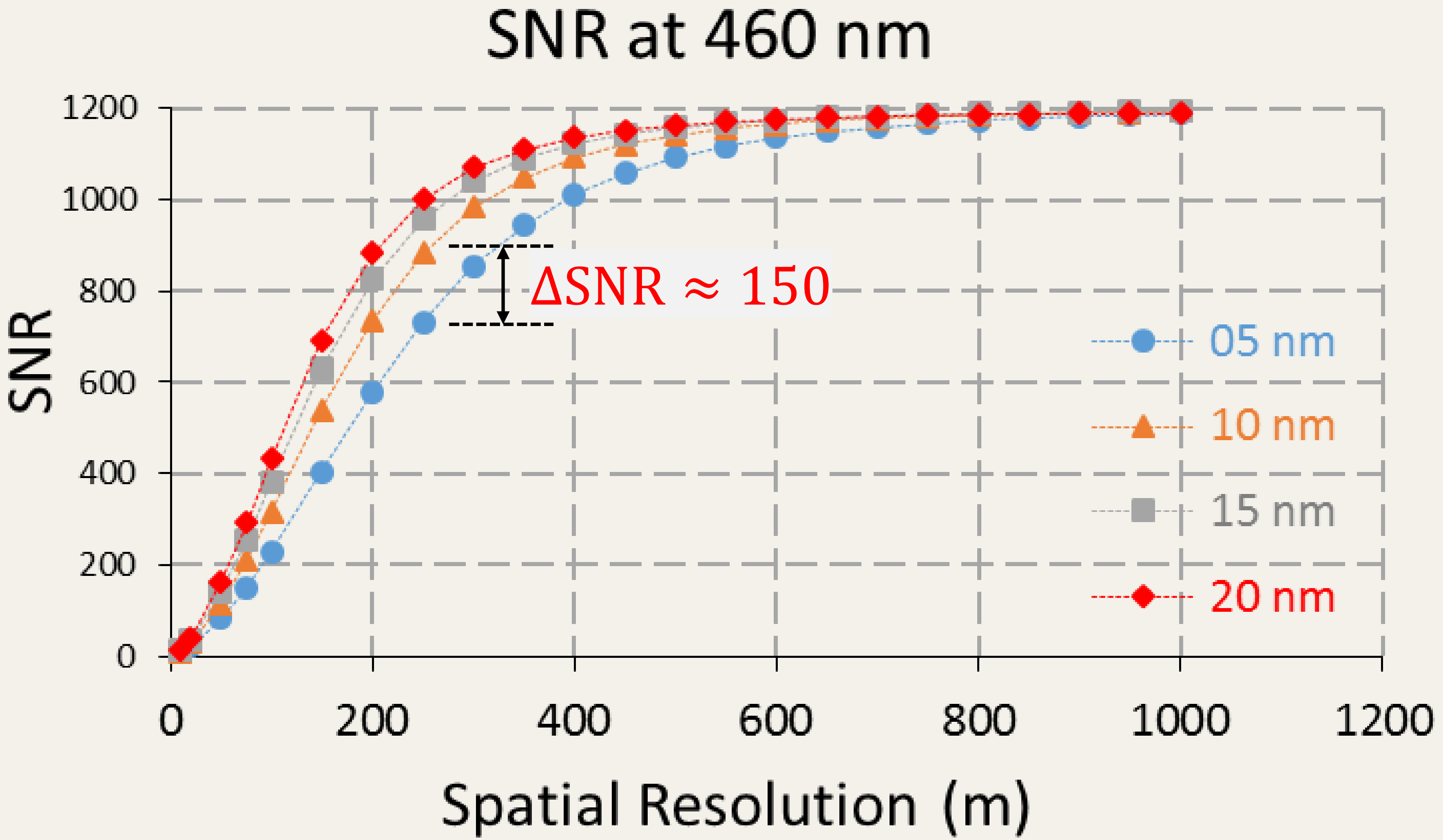
Trade-off amongst

- Spatial Resolution
- Spectral Resolution
- SNR

Trade-off


10
50
100
200
300
400
500
600
700
800
900
1,000
Spatial Resolution (m)
5
10
15
20
Spectral Resolution (nm)
1200
1000
800
600
400
200
S
N
R

Trade-off


SNR at 460 nm
1200
1000
800
600
400
200
0
SNR
0
200
400
600
800
1000
1200
Spatial Resolution (m)
ΔSNR ≈ 150
05 nm
10 nm
15 nm
20 nm

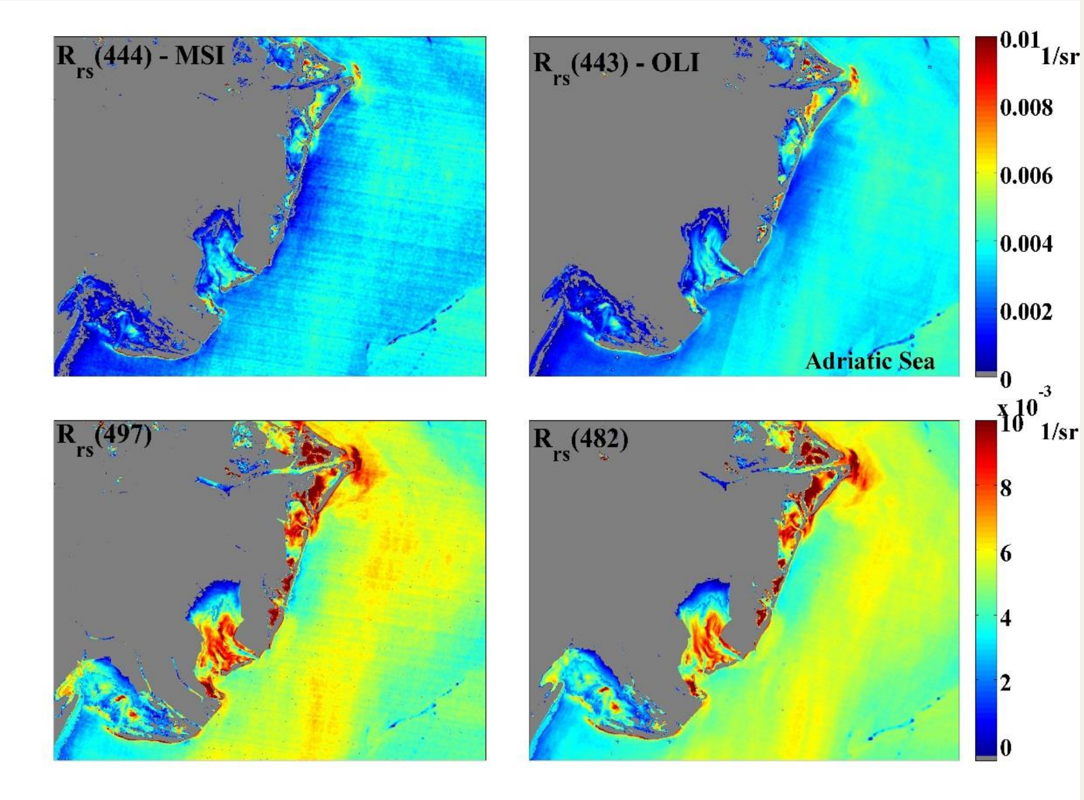
What does $\Delta\mathrm{SNR} \approx 150$ mean for retrievals?

A single case study

- Add noise to Rrs spectrum at SNR = 700 and 850
- Estimate chl-*a* for both cases and compare to the estimate from noiseless Rrs spectrum to determine the uncertainty due to noise, U_{SNR}
- Effects of SNR on atmospheric correction not considered here
- $U_{SNR=700}$ = 0.17 ± 4.5%
- $U_{SNR=850}$ = 0.15 ± 3.7%

Impact of spatial aggregation on R_{rs} (blue)

Pahlevan et al. (2017)



Spatial averaging can only qualitatively improve the product quality.

Even after spatial averaging, the OLI-derived products are of higher quality (due to its better SNRs).

Pahlevan, N. , Sarkar, S., Franz, B. A., He, J. "**Sentinel-2 MultiSpectral Instrument (MSI) data processing for aquatic science applications: Demonstrations and preliminary validations".** Submitted to *Remote Sensing of Environment*

Signal-to-Noise Ratio (SNR)

- Atmospheric correction is a major contributor of uncertainties in retrievals

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Oceans

RESEARCH ARTICLE

10.1002/2016JC012558

Requirement of minimal signal-to-noise ratios of ocean color sensors and uncertainties of ocean color products

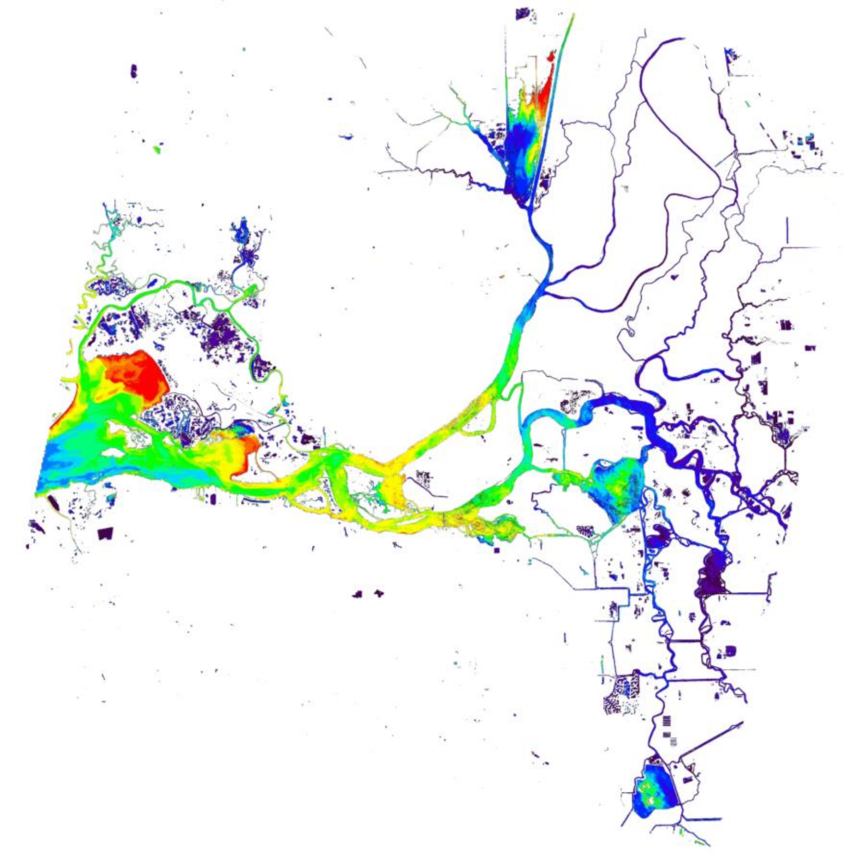
Key Points:

Lin Qi, Zhongping Lee, Chuanmin Hu, and Menghua Wang

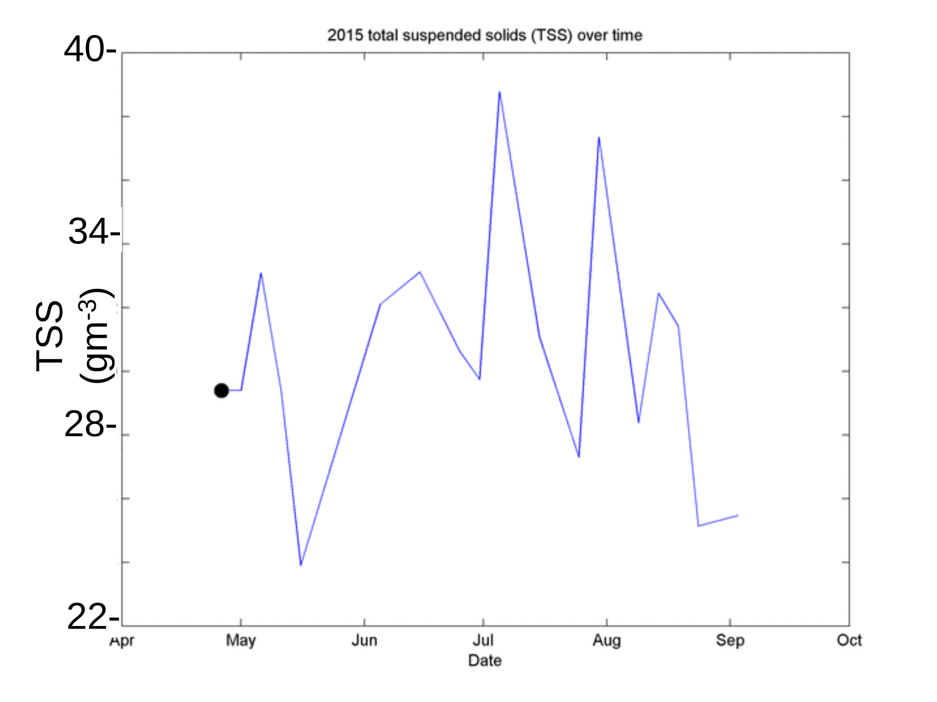
"…once SNR(NIR) is above 600:1, an SNR(vis) better than 400:1 will not make a significant reduction in product uncertainties…"

Temporal Resolution

TSS concentration in Sacramento-San Joaquin River – from SPOT Take 5 Data



Christiana Ade et al. (see poster)



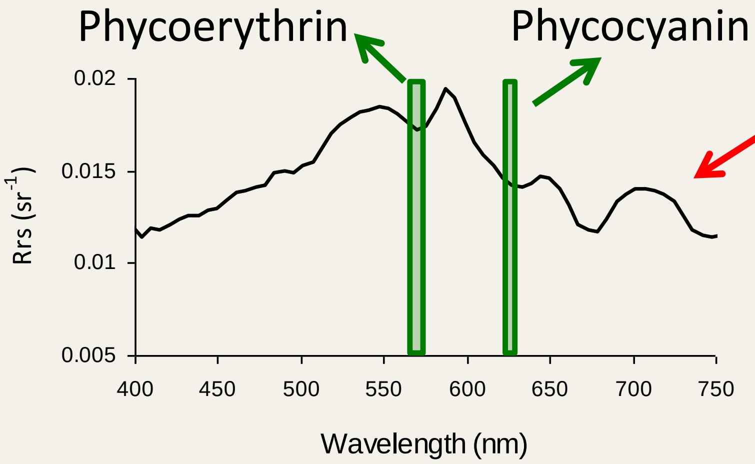
Synergistic Use of Satellite Data

Lake Kinneret (Israel)

HICO Image 11 Mar 2013

14 Mar 2013

MODIS R645



The presence of phycoerythrin and phycocyanin was confirmed by lab analysis of water samples

Acknowledgments

Help with data and analysis for the Spatial Resolution Study:

- Dr. Steven Ackleson (Naval Research Laboratory)
- Dr. Dave Miller (Naval Research Laboratory)
- Dr. Emmanuel Boss (University of Maine)
- Dr. Chris Hostetler (NASA Langley Research Center)
- Dr. Jonathan Hair (NASA Langley Research Center)

Thank You!

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