PACE Science Team 2016:

Atmospheric Correction over Bright Water Targets with Non-negligible Radiances in the Near Infrared

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Photo by Bill Lindsay

current NASA atmospheric correction approach

Observed TOA, Rayleigh, Aerosol + Ray-Aer, foam & whitecaps, Sun glint, water-leaving

$$L_t = \left(L_r + \left[L_a + L_{ra} \right] + t_{dv} L_f + T_s T_v L_g + t_{dv} L_w \right) t_{gv}\, t_{gs}\, f_p$$

$$R_{rs} = \frac{L_w}{F_0 \cos(\theta_s)\, t_{ds}\, f_s} f_b\, f_\lambda$$

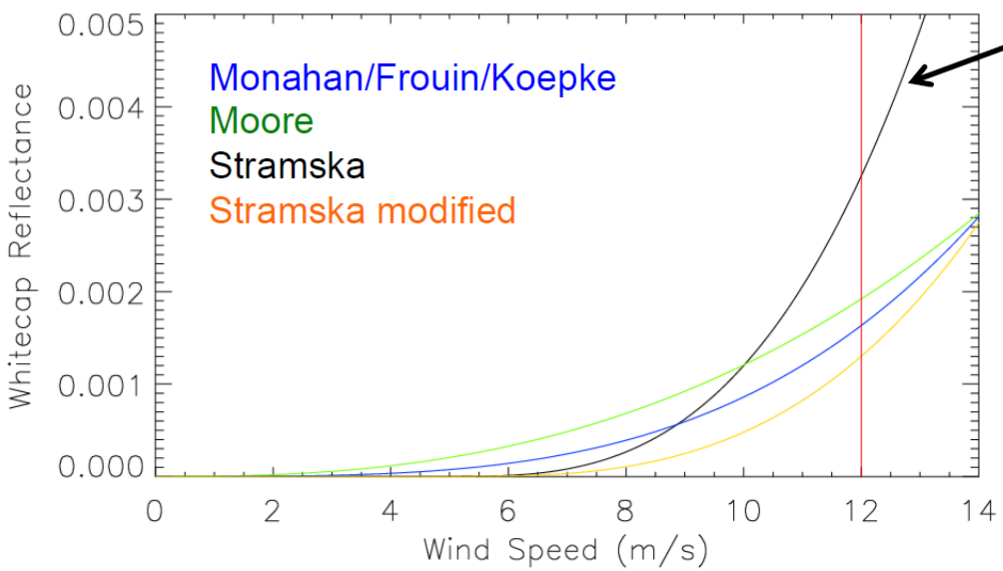
foam & whitecaps

$$L_f(\lambda) = \rho_f(\lambda)\ \ [a\,(U_{10} + b)^3]\ \ \ F_0 \cos(\theta_0) / \pi$$

$\rho_f(\lambda)$ = effective whitecap reflectance

22% from Koepke 1984
NIR spectral dependence from Frouin 1999

U_{10} = wind speed at 10-meters (<= 12 m/s)



Stramska & Petelski, JGR, 2003

Whitecap Coverage

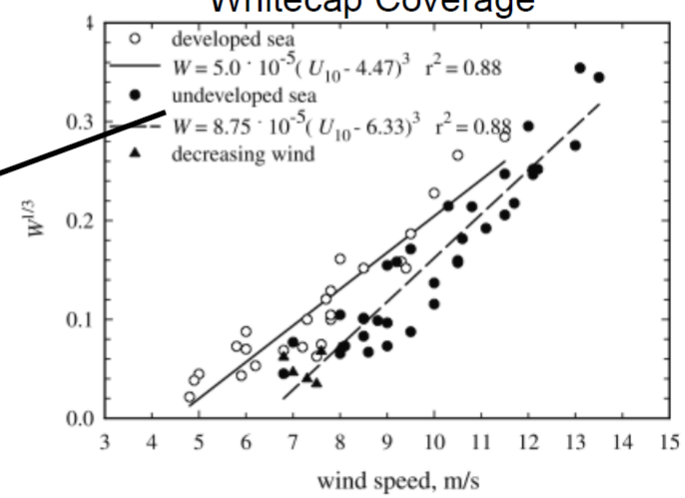


Figure 8. Oceanic whitecap coverage as a function of wind speed. Different symbols are used for the developed wave field, the undeveloped wave field, and the decreasing wind speed. See text for details.

note: NIR aerosol reflectance is an error bucket

- any error in subtraction of Rayleigh, whitecaps, or glint, or any signal that is not identified and subtracted (e.g., thin cirrus, cloud edges, straylight, atmospheric adjacency) will add to the aerosol reflectance in the NIR and be extrapolated to the visible via the aerosol model.

- many of these sources are approximately white, so likely the effect is to flatten the retrieved spectral dependence proportionate to the residual signal.

- both the aerosol concentration and aerosol type will be altered by such errors, and thus the aerosol properties will be inaccurate, but the reflectance that is subtracted “may” be approximately correct.

2) Relationship between wind and whitecap coverage is variable

At 6 m/s, whitecap fraction varies from 0.02% to 2% -- 2 orders of magnitude

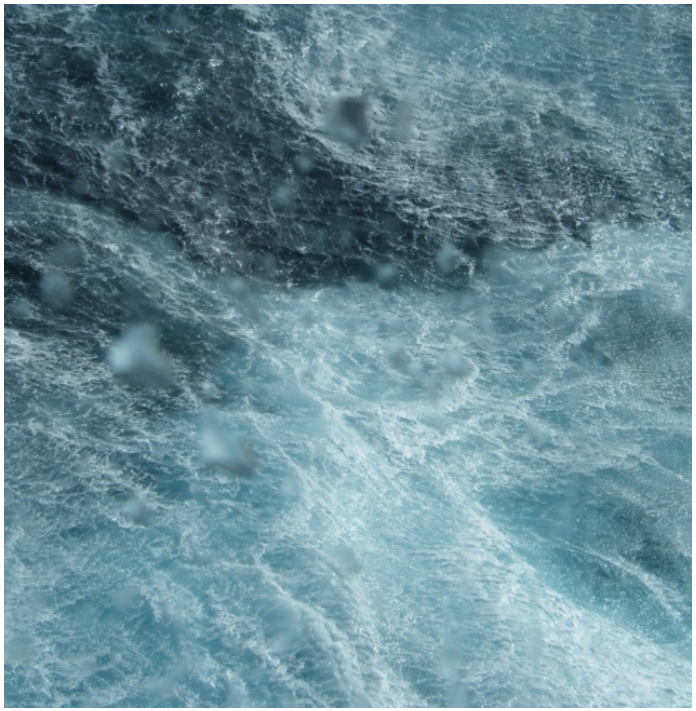
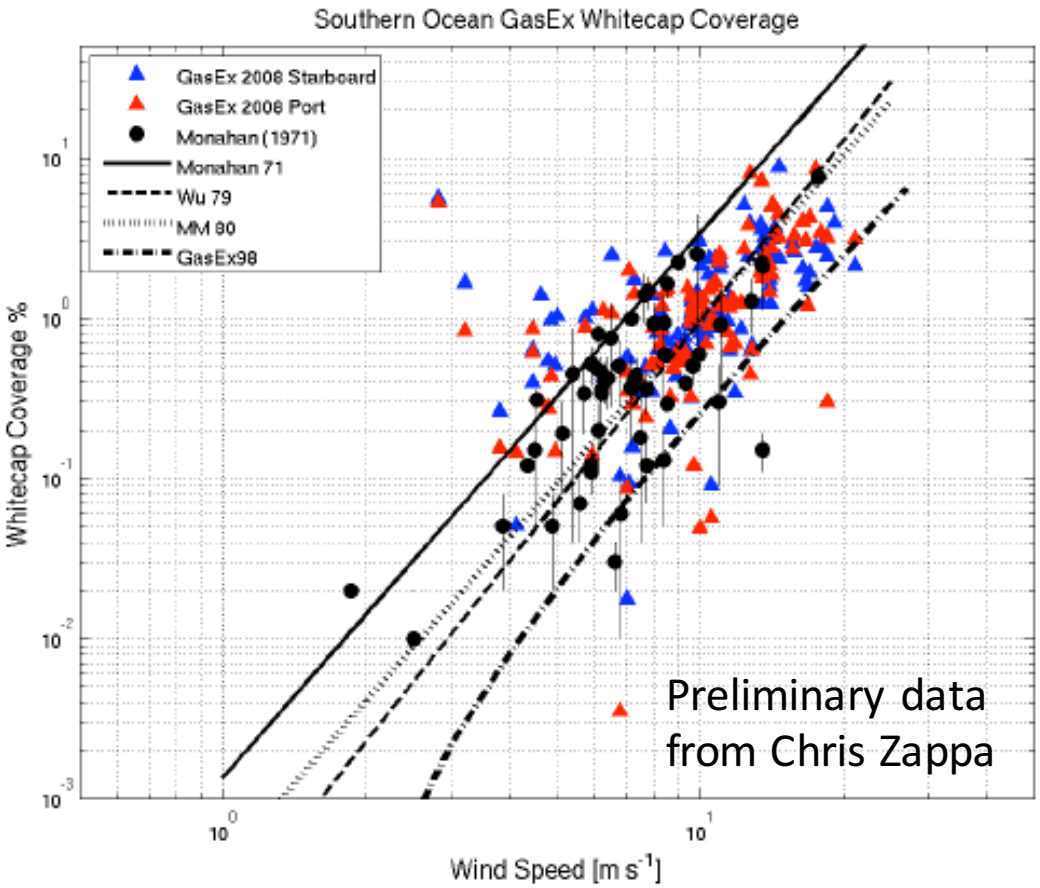


Photo by Scott Freeman



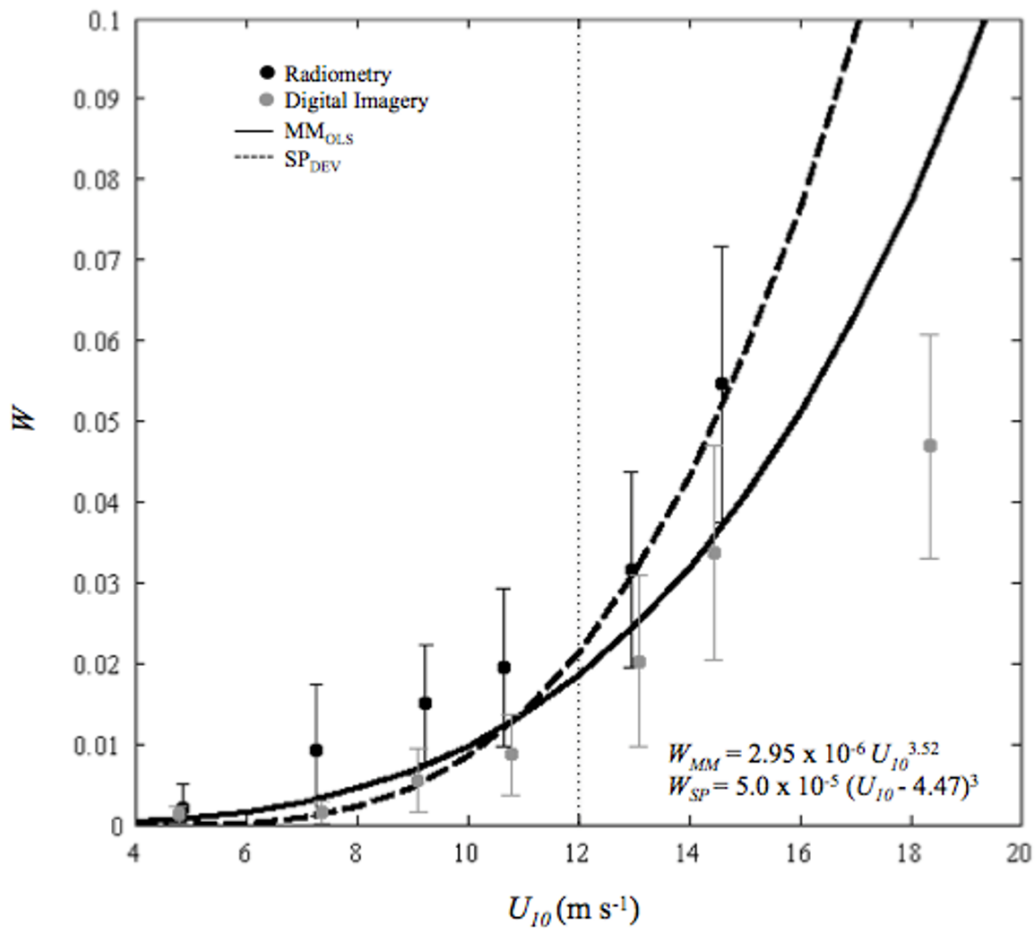
Different stages of waves

- active, breaking phase (Stage A)
- quiescent or mature phase (Stage B)
- spatial extent increases and reflectance decreases with age.

3) Whitecap fraction is not appropriate from an optics perspective

- “Whitecap fraction” is fundamentally flawed from an optics perspective
- Randolph (2015) showed that much of the bubble impacted Stage B portion of the plume is missed from visual assessments of photographs
- New method to assess whitecap coverage from above water radiance

Enhanced area of Stage B Whitecap vs. Windspeed



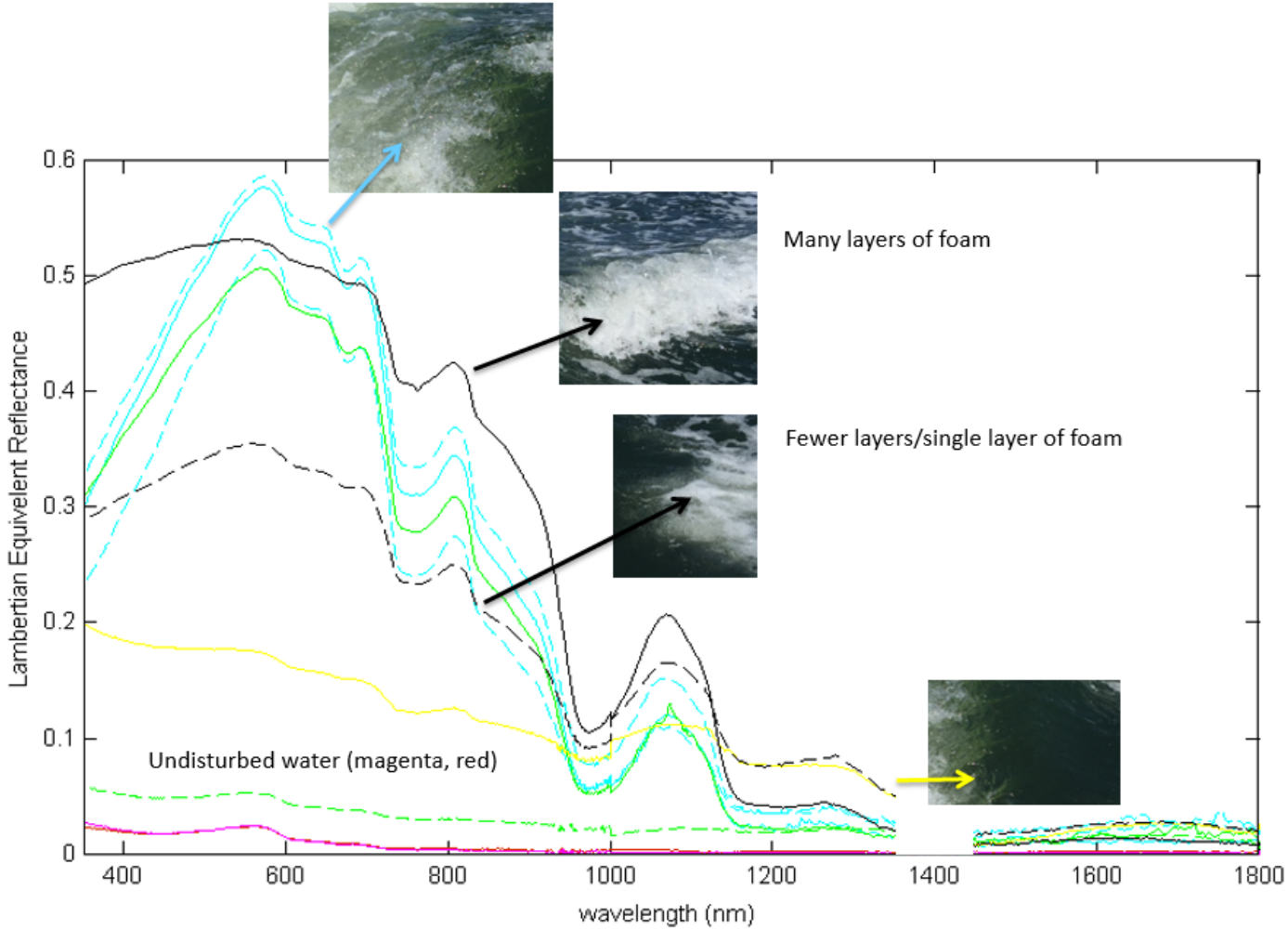
Question 2: What are the spectral properties of Whitecaps?

1) Manufactured foam and bubbles
   - Visible to SWIR
2) Natural breaking waves
   - Southern Ocean (Visible) Randolph Ph.D.
   - Long Island Sound waters (Visible to SWIR) PACE

Methods

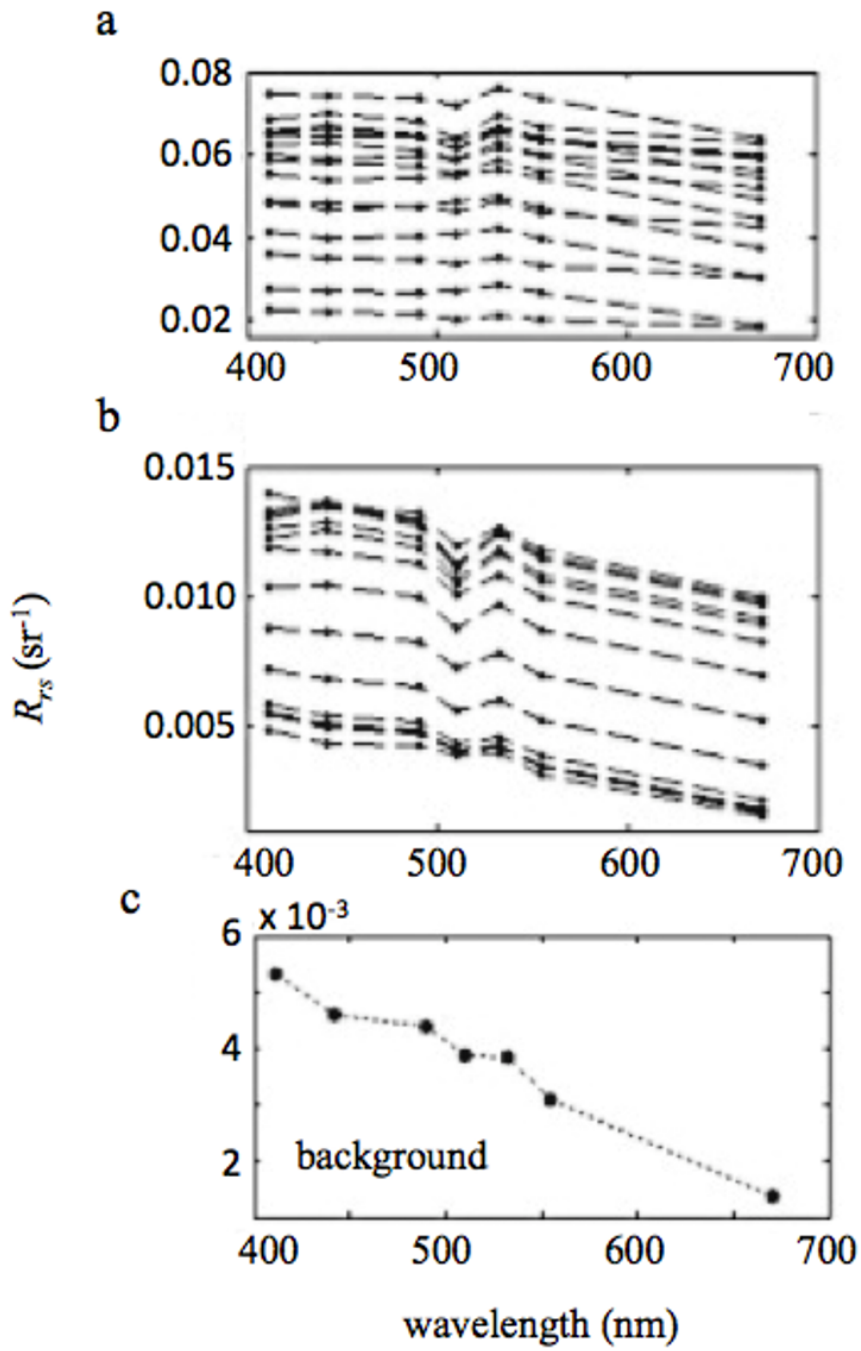
- Analytical Spectral Devices Fieldspec VNIR/SWIR
- Small boat operations when allowable
  - small craft warnings
- Developed a gimbal for the plaque for Ed
  - Much of error in above water measurements come from non-planar measurements of Ed
- Maneuver the boat and probe to minimize glint and still be in wave field
- Collections at 3-8 Hz depending on integration time

Manufactured foam is not a good proxy for breaking waves leads to higher R



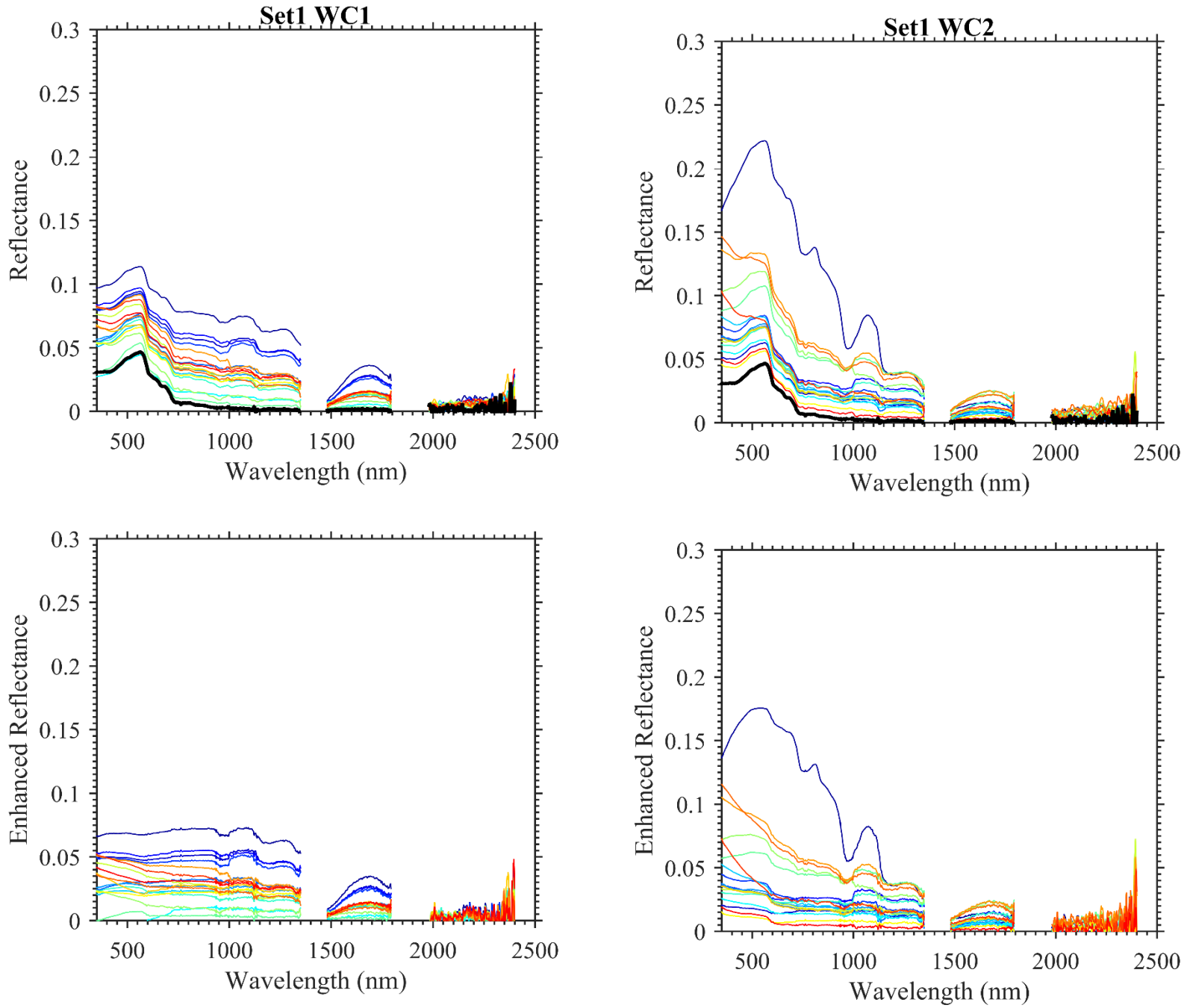
Southern Ocean Gas Ex

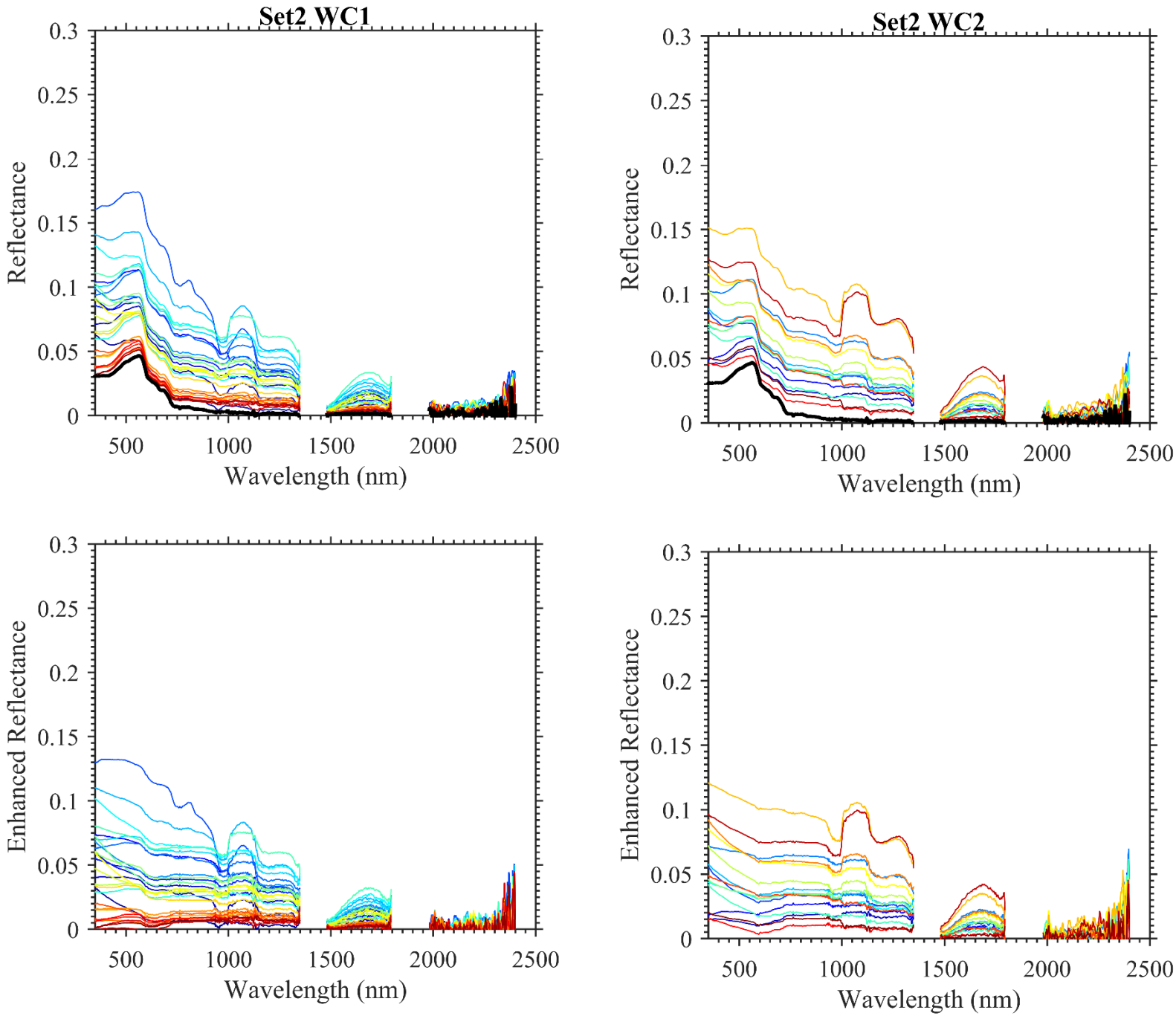
As the whitecap matures decrease in reflectance occurs in the red portion of the spectrum due to the strong absorption properties of water molecules



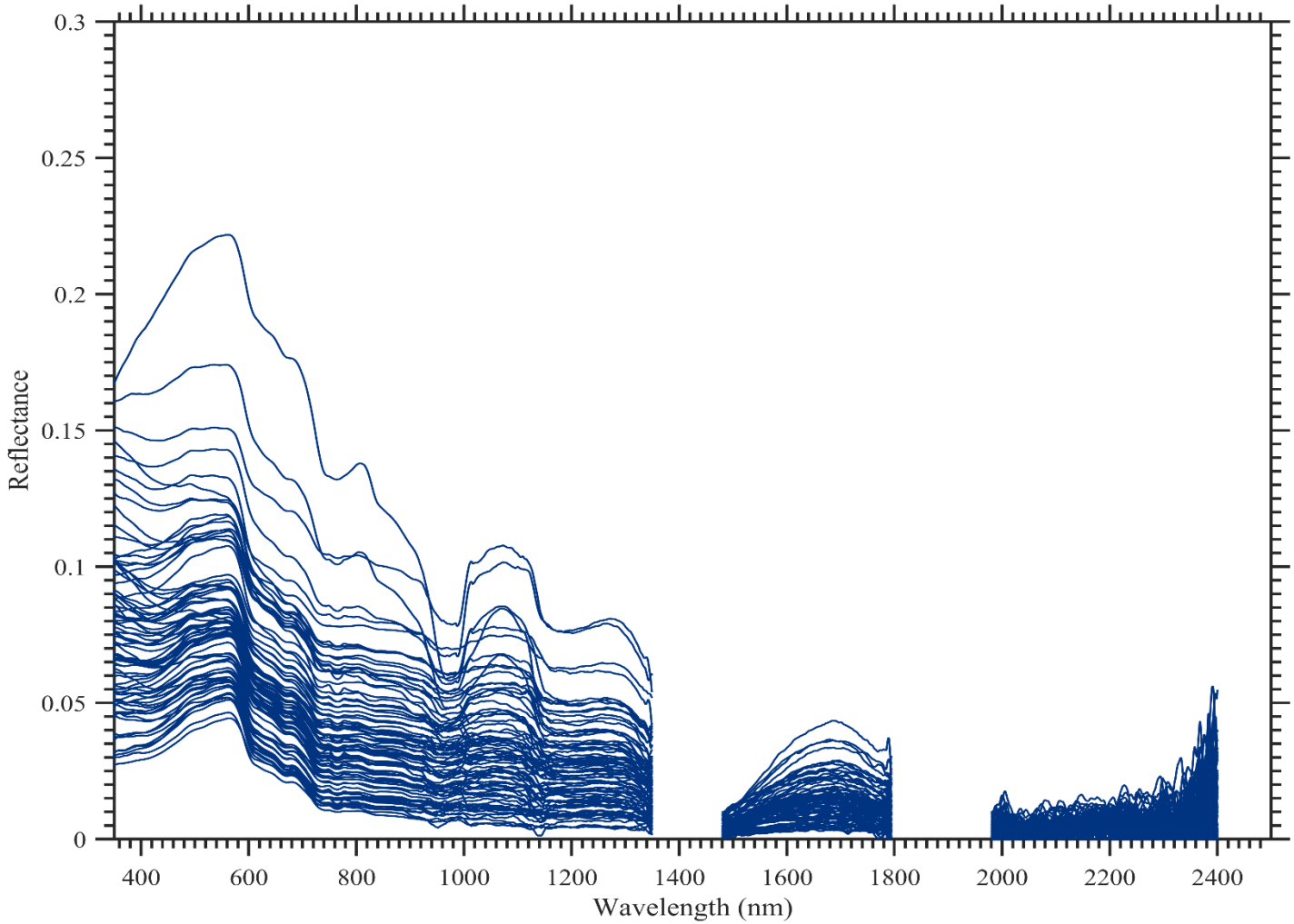
Long Island Sound,

10-11 m s^{-1} winds, 1.5-2 m significant wave heights


Set1 WC1
Set1 WC2
Reflectance
Enhanced Reflectance
Wavelength (nm)
0
0.05
0.1
0.15
0.2
0.25
0.3
500
1000
1500
2000
2500


Set2 WC1
Set2 WC2
Reflectance
Enhanced Reflectance
Wavelength (nm)
0
0.05
0.1
0.15
0.2
0.25
0.3
500
1000
1500
2000
2500

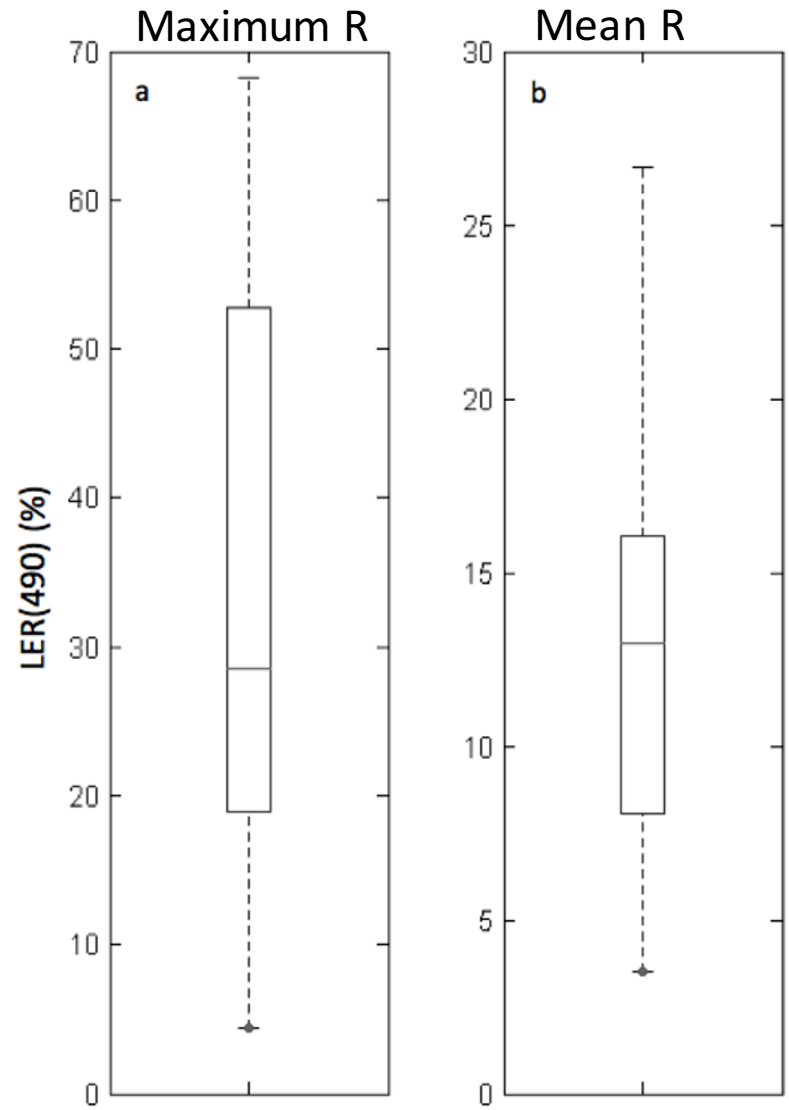
All whitecap spectra



What is the effective reflectance?

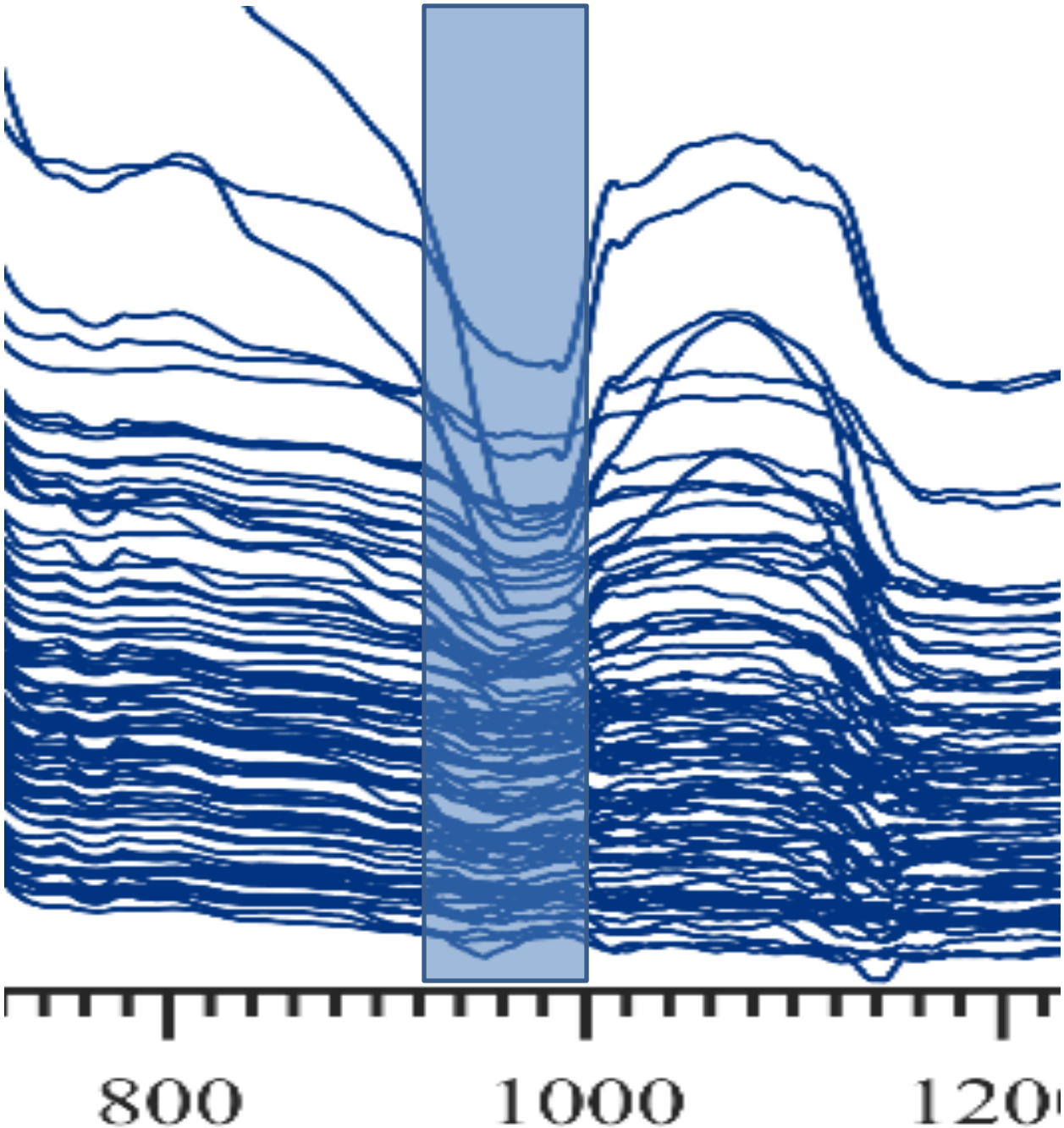
- Koepke “effective R” = 22%
- Higher than Southern Ocean and Long Island Sound 13%
- 8.5 deg foreoptic at 2 m above sea surface

= footprint of X m on sea surface

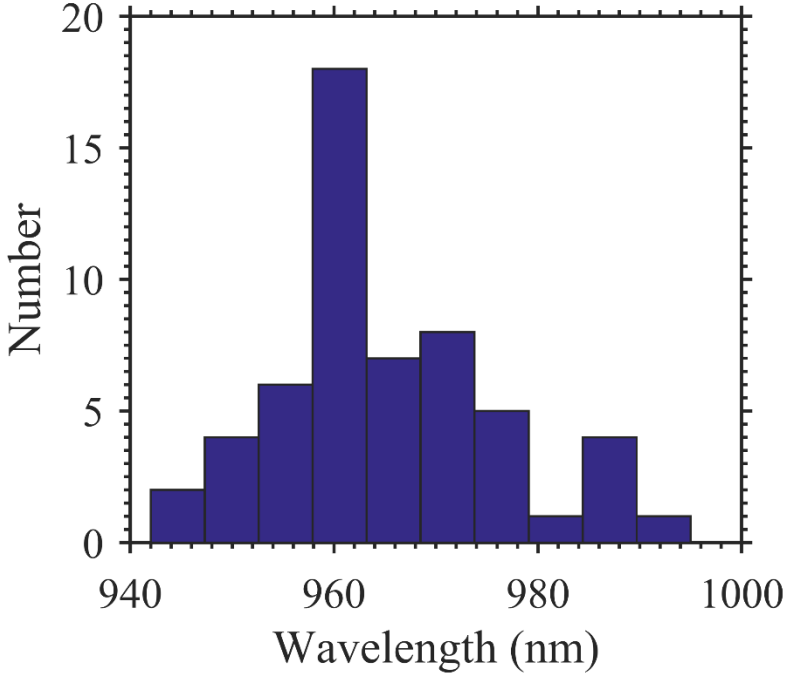


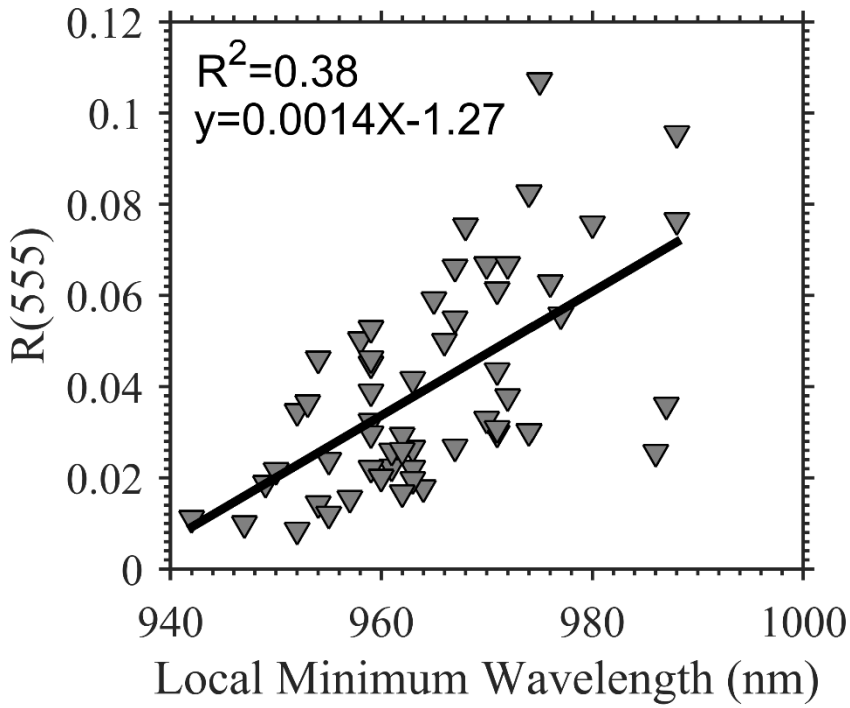
Randolph (2015) from 49 individual whitecap events in the Southern Ocean

What are the spectral bands necessary to assess whitecaps?


800
1000
120

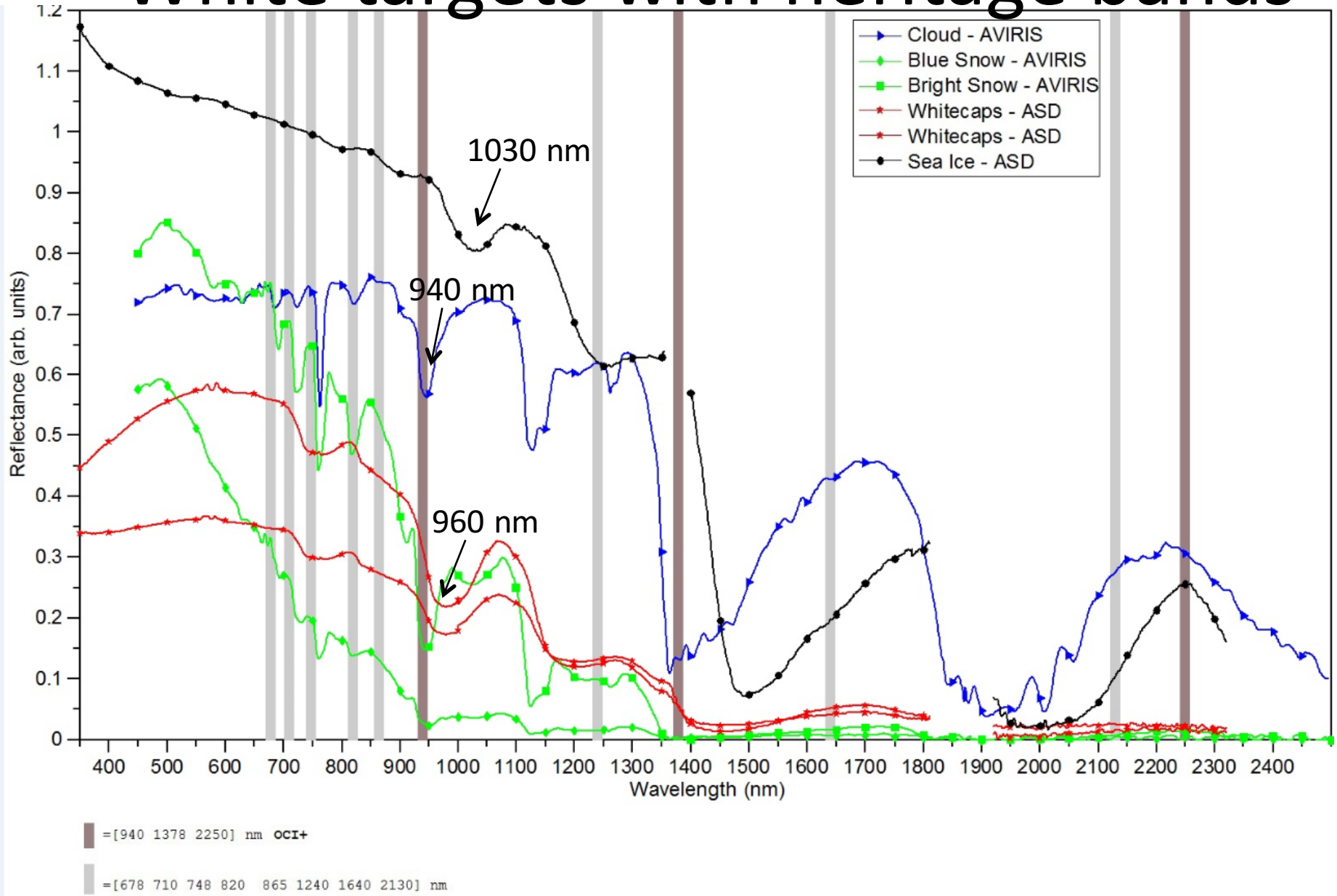
Local water absorption minimum is variable



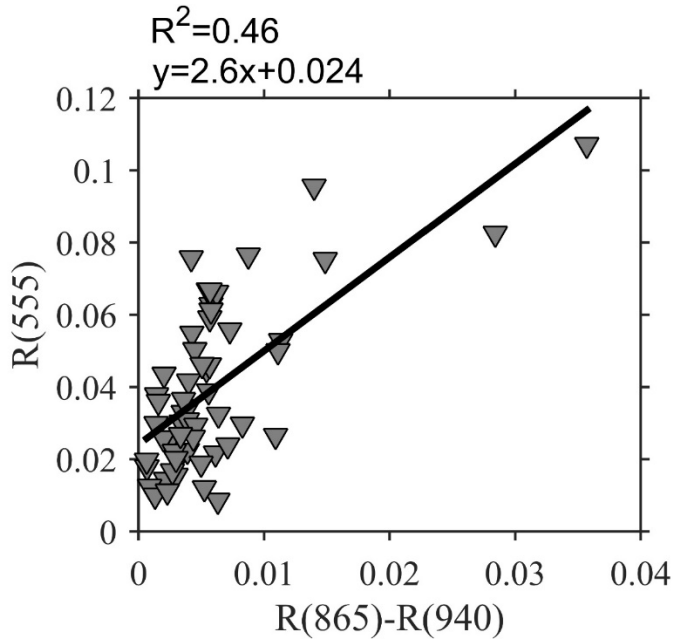


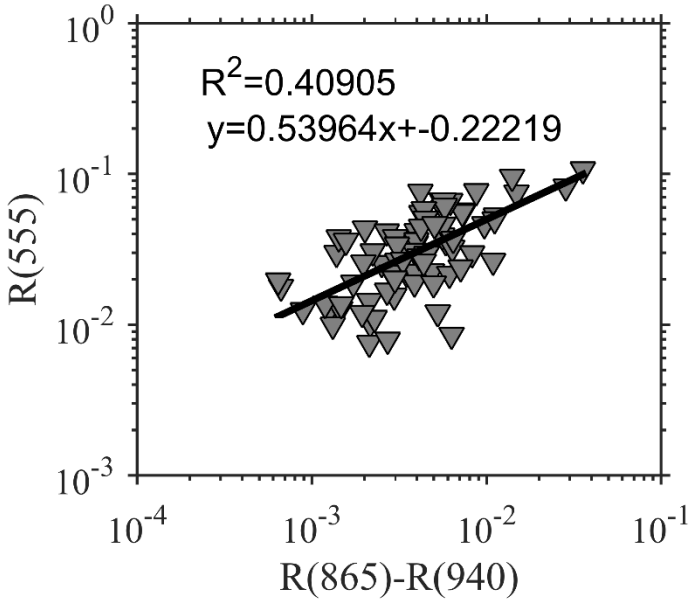
The minimum shifts to longer wavelengths with higher reflectance whitecaps. Need hyperspectral imagery

White targets with heritage bands



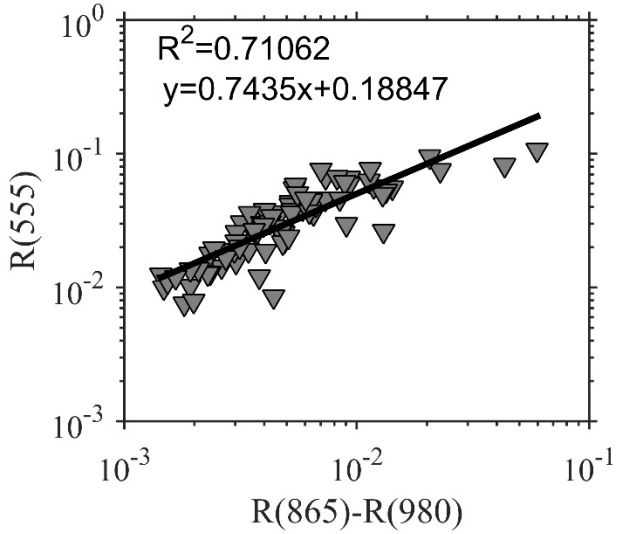
NIR band depth is also related to reflectance



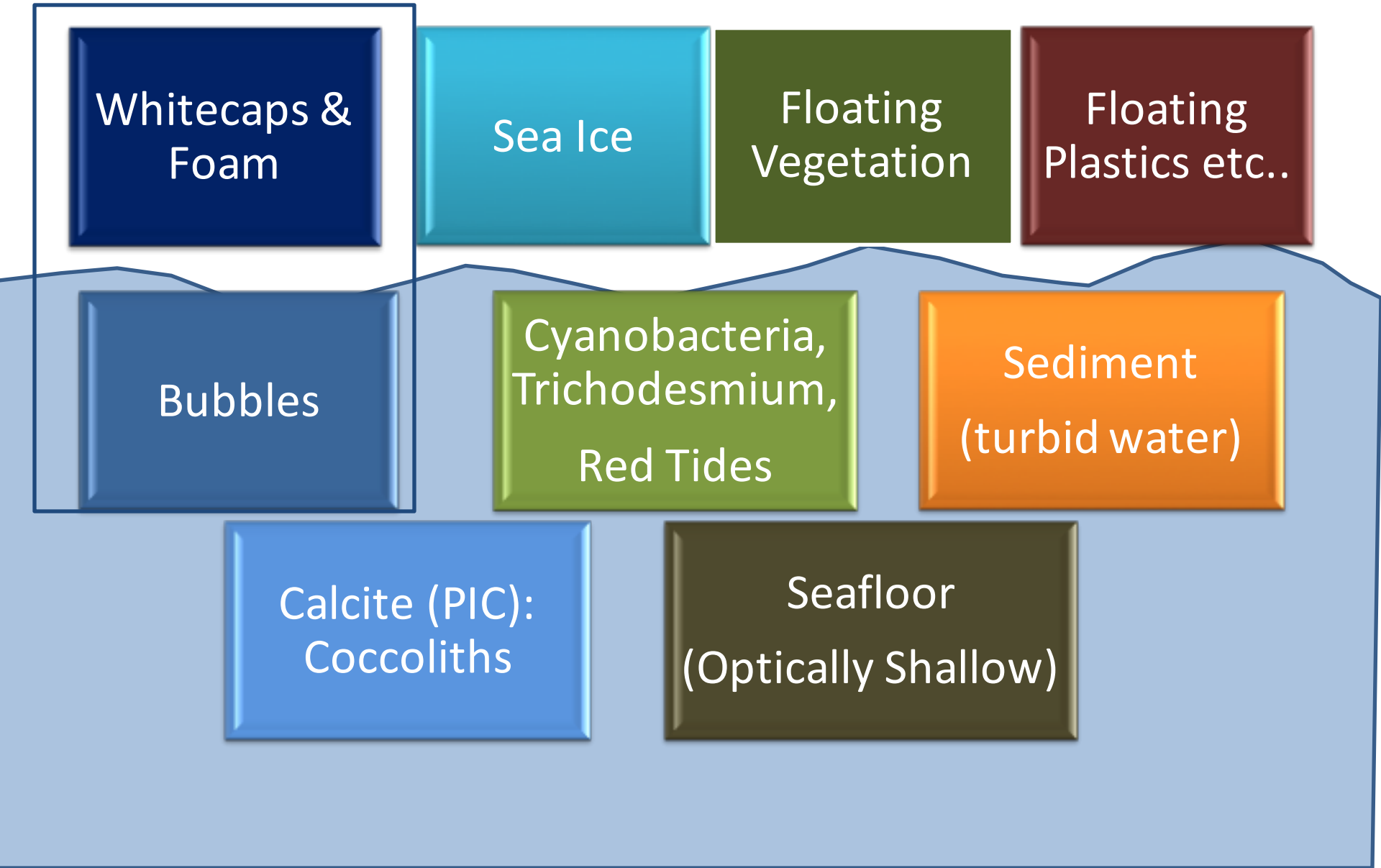


No significant improvement to relationship if you add 960 or 980 nm channels

Preliminary data suggest significant improvement to relationship if you add 980 nm channels

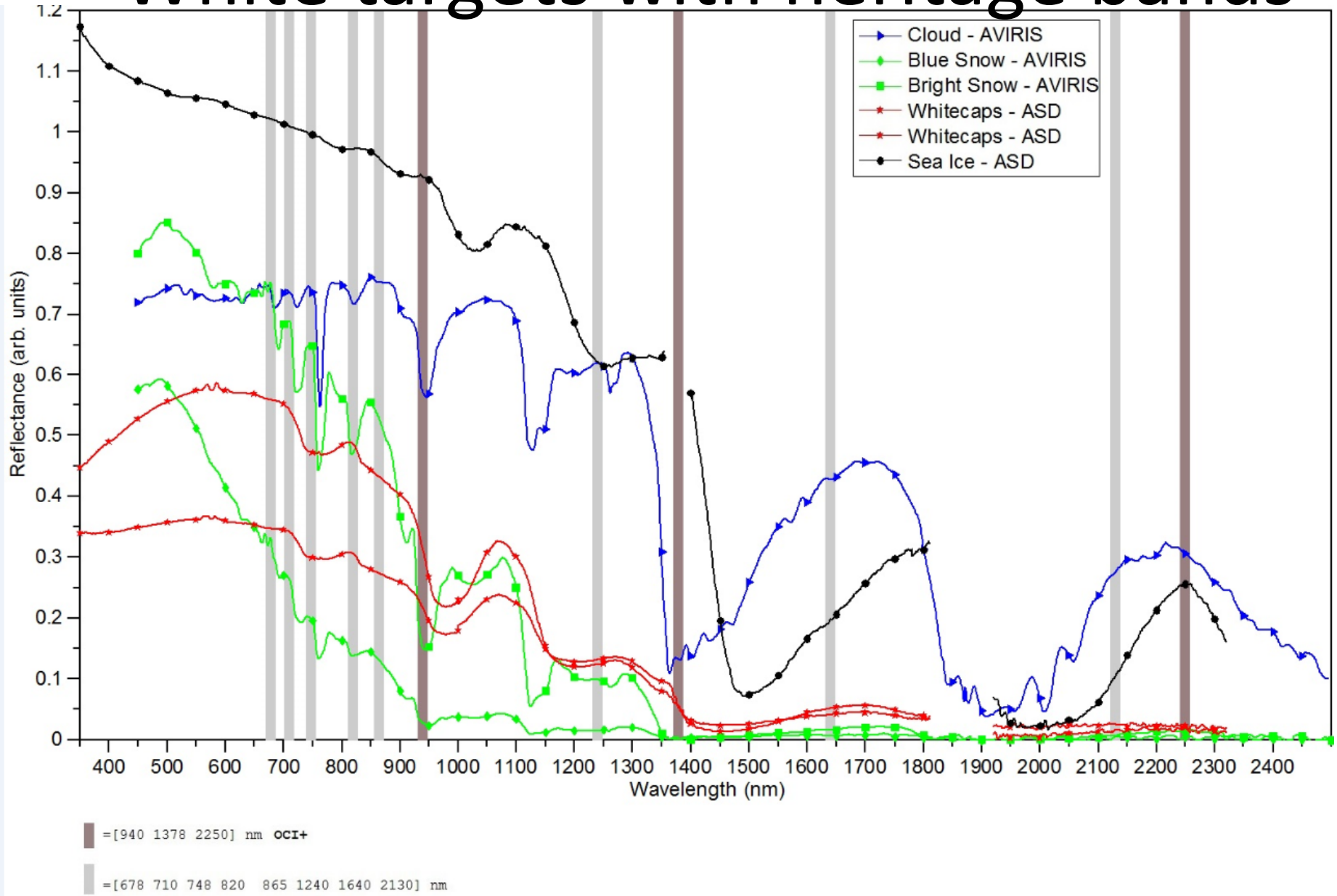


How to Differentiate "Bright Targets"

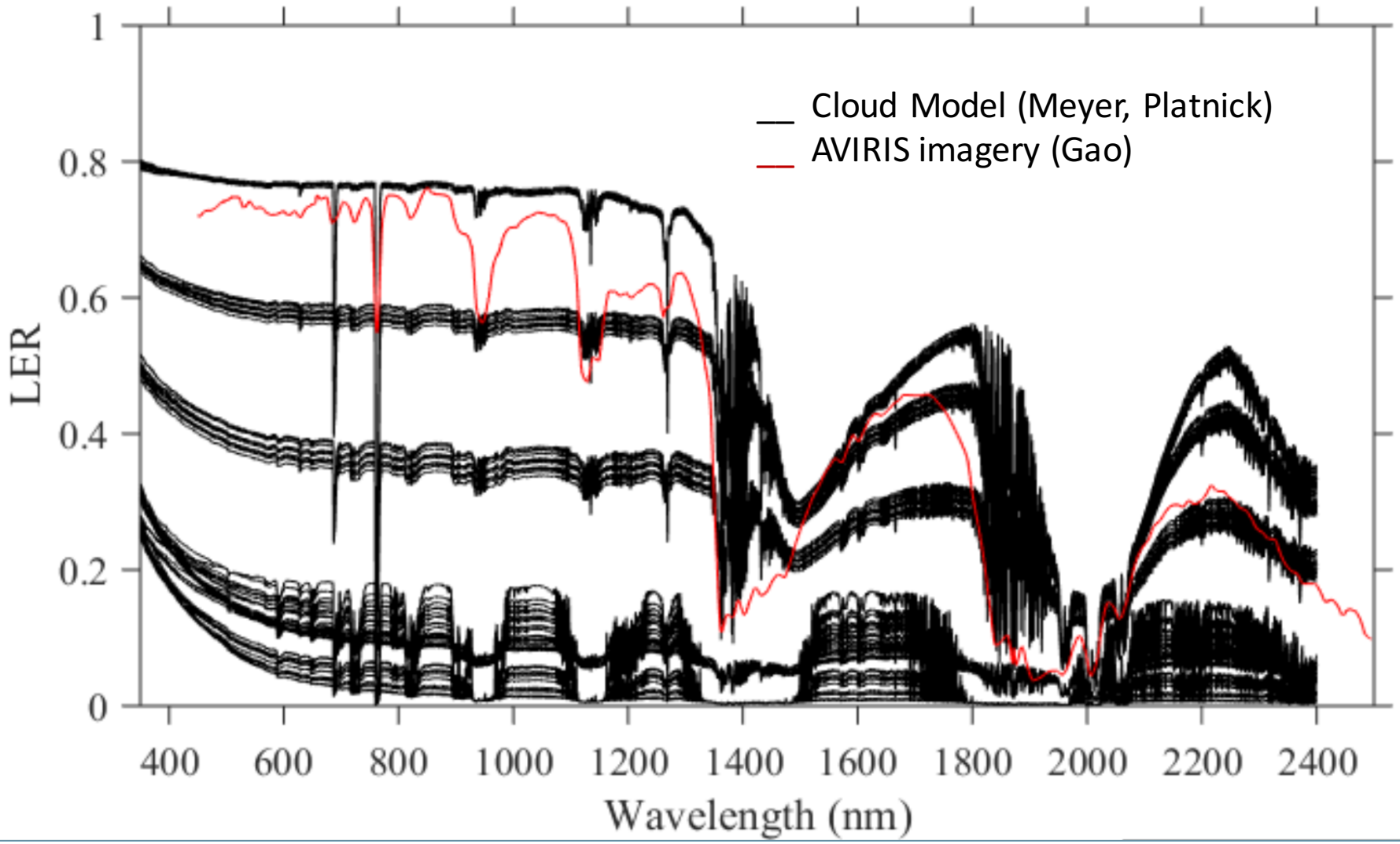


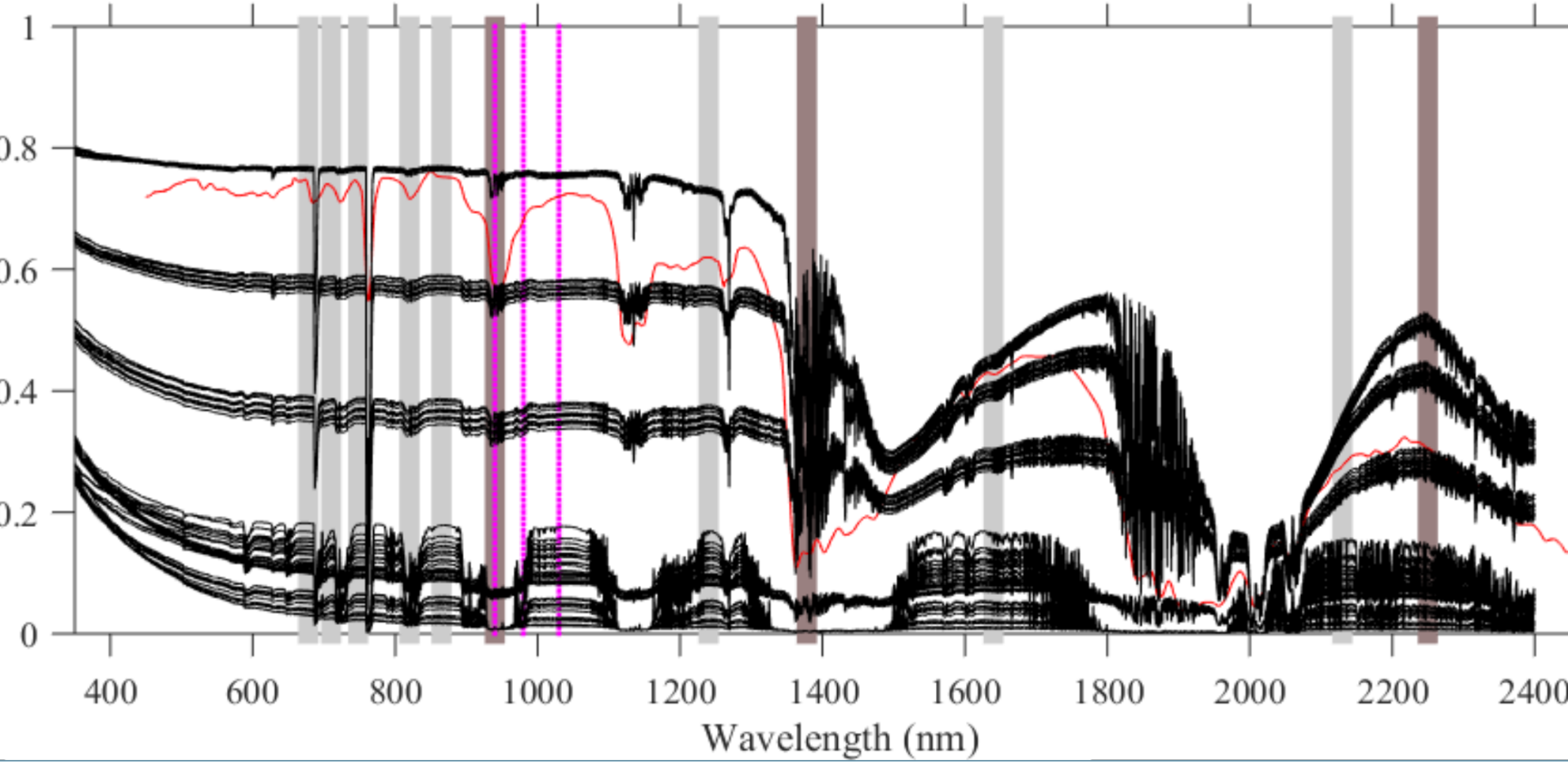
- Heidi Dierssen, Shungu Garaba, Kate Randolph
- Steve Platnick and Kerry Meyers
- Robert Frouin
- Bo-Cai Gao
- Lachlan McKinna
- Bryan Franz

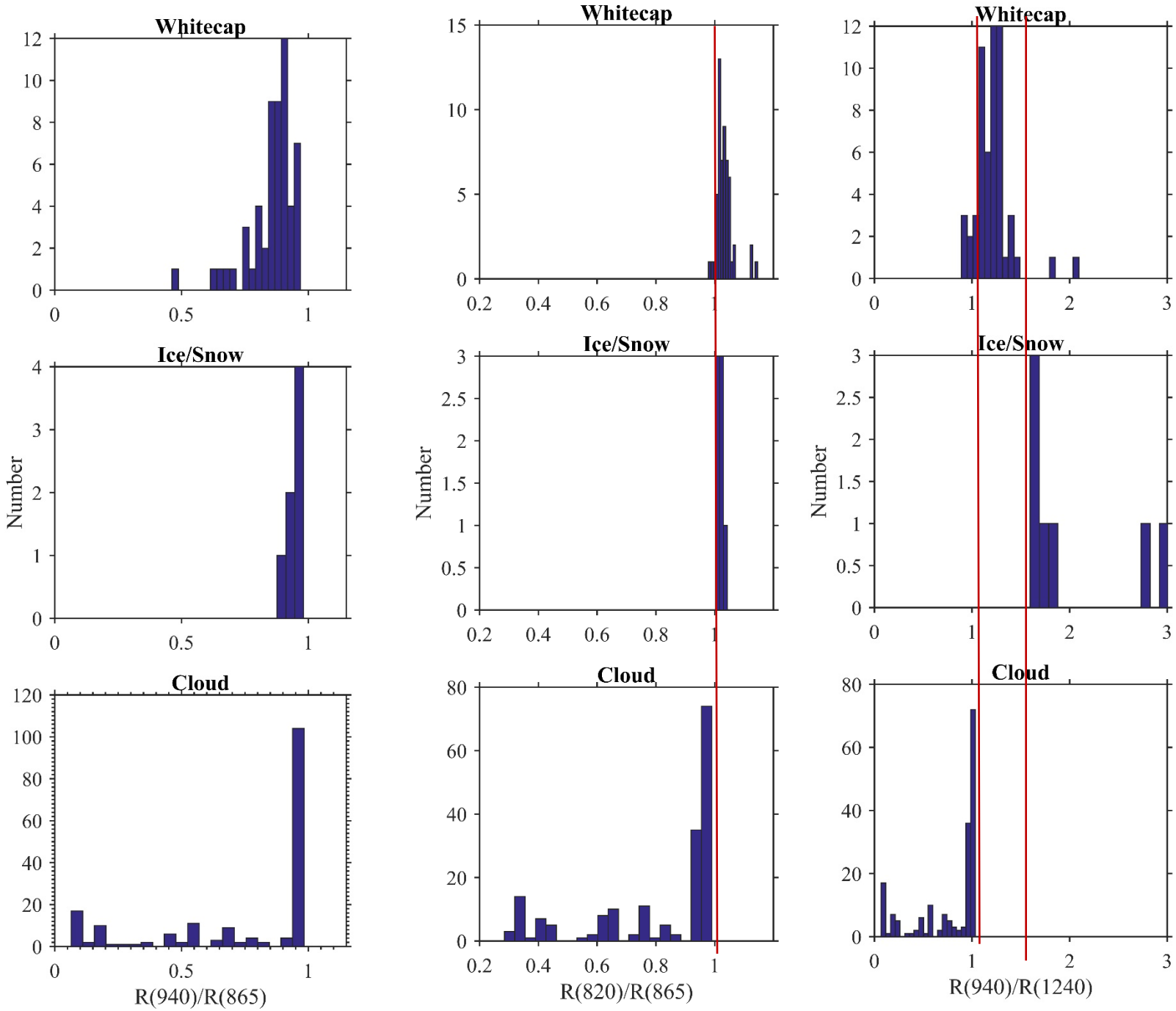
White targets with heritage bands



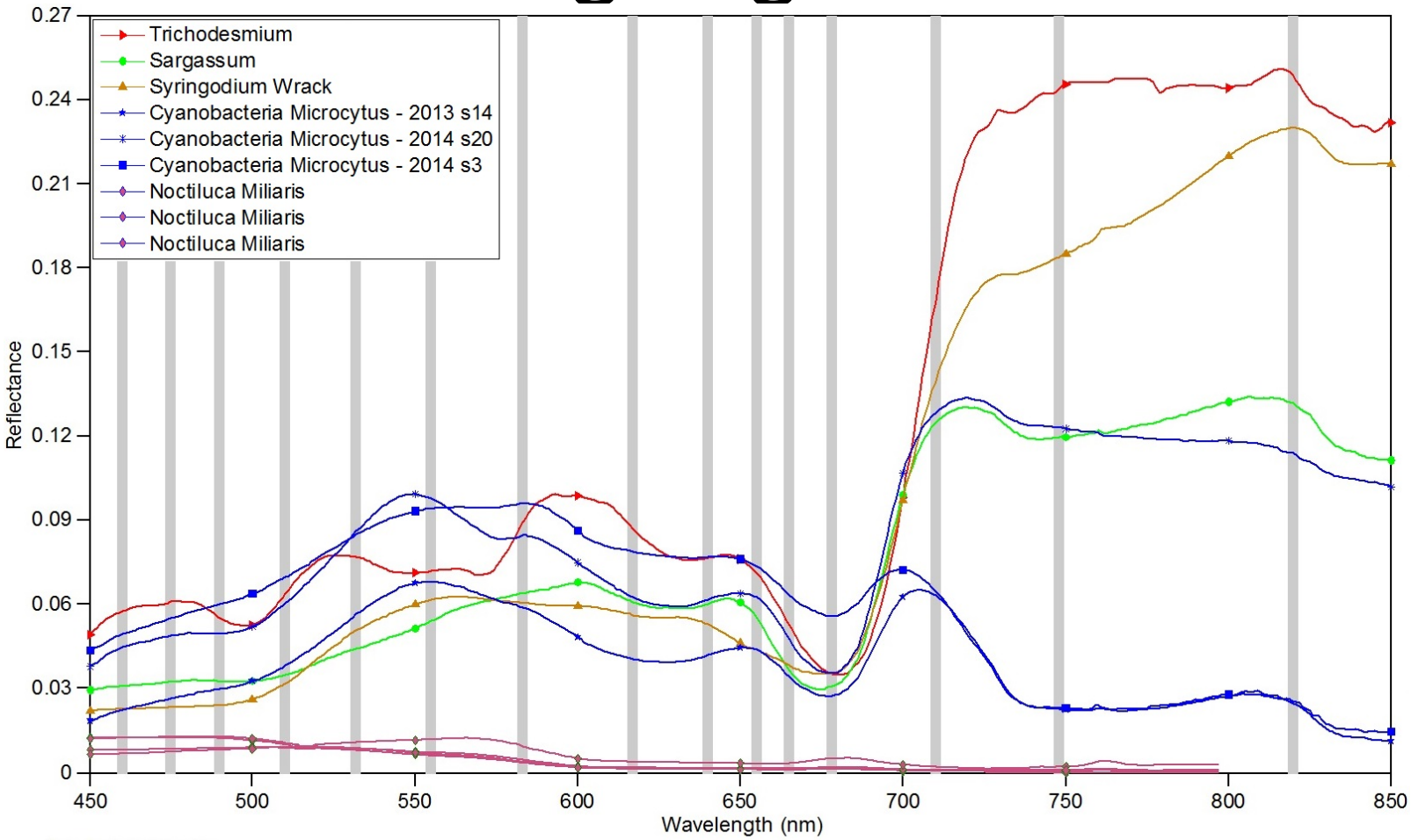
Clouds reflectance




1
0.8
0.6
0.4
0.2
0
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavelength (nm)


Whitecap
Ice/Snow
Cloud
Number
R(940)/R(865)
R(820)/R(865)
R(940)/R(1240)

Floating Vegetation



Cyanobacteria Microcytus

2013 station 14

[yyyymmdd]	Longitude	Latitude	Chlorophyll-a	PC	microcystin	Secchi disk depth
20130823	83.37825	41.716717	100.992	138.2895	43.105	0.5

.....

2014 station 20

20140821	83.1117	41.689883	85.475	213.314389	NaN	0.8

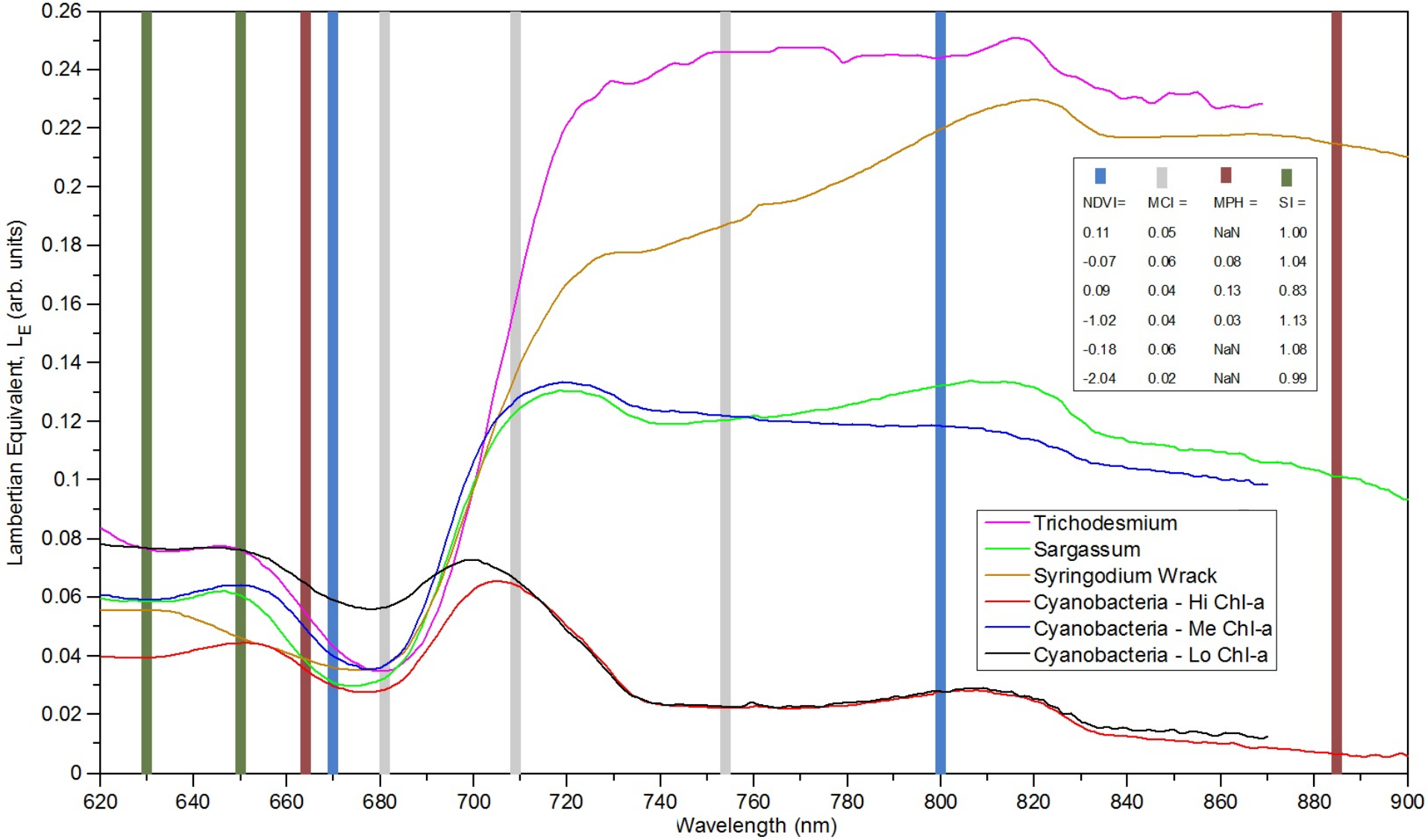
.....

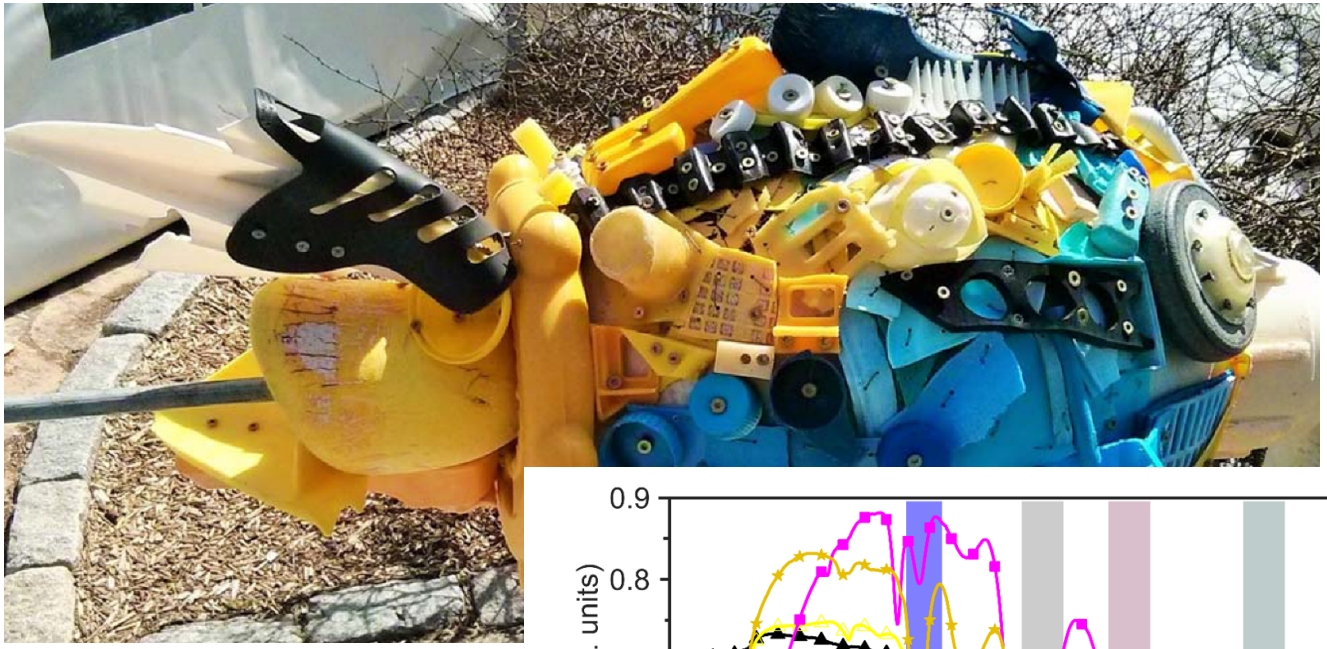
2014 station 3

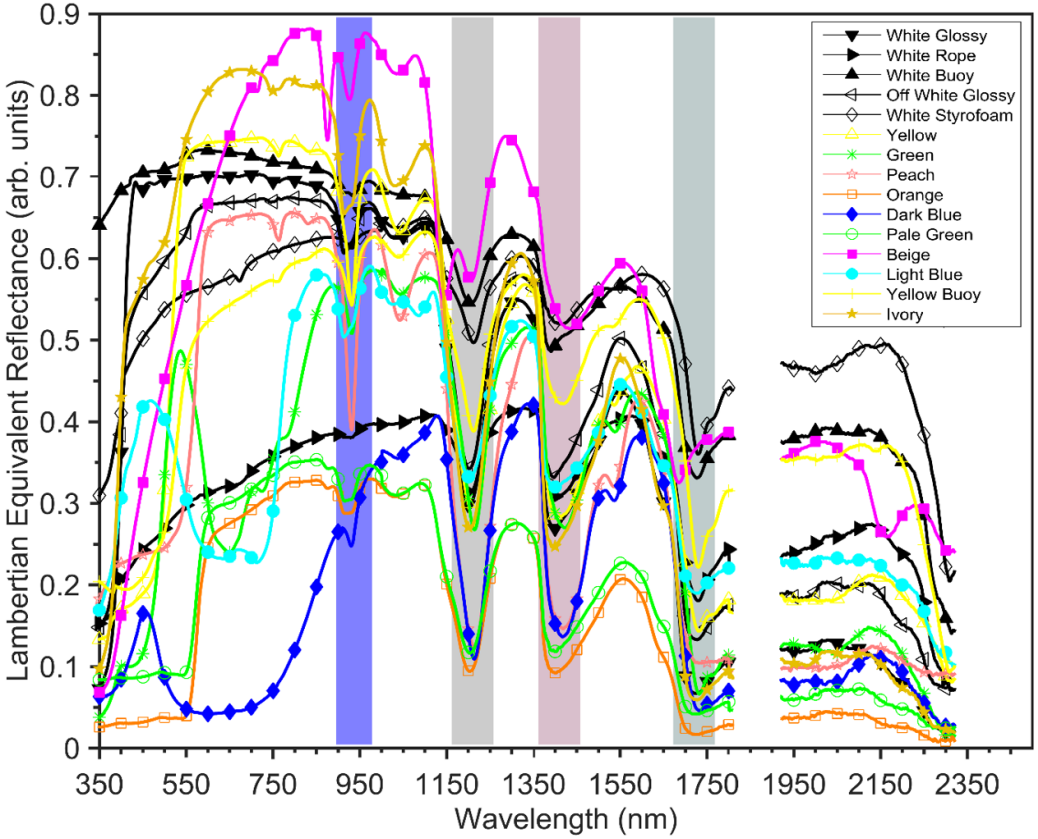
20140818	83.259817	41.704067	33.35	15.780386	3.39	0.5

Marked Waveband
[460 475 490 510 532 555 583 617 640 655 665 678 710 748 820] nm

Floating Vegetation






Lambertian Equivalent Reflectance (arb. units)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
350
550
750
950
1150
1350
1550
1750
1950
2150
2350
Wavelength (nm)
White Glossy
White Rope
White Buoy
Off White Glossy
White Styrofoam
Yellow
Green
Peach
Orange
Dark Blue
Pale Green
Beige
Light Blue
Yellow Buoy
Ivory

1.68 mm – 2.00 mm

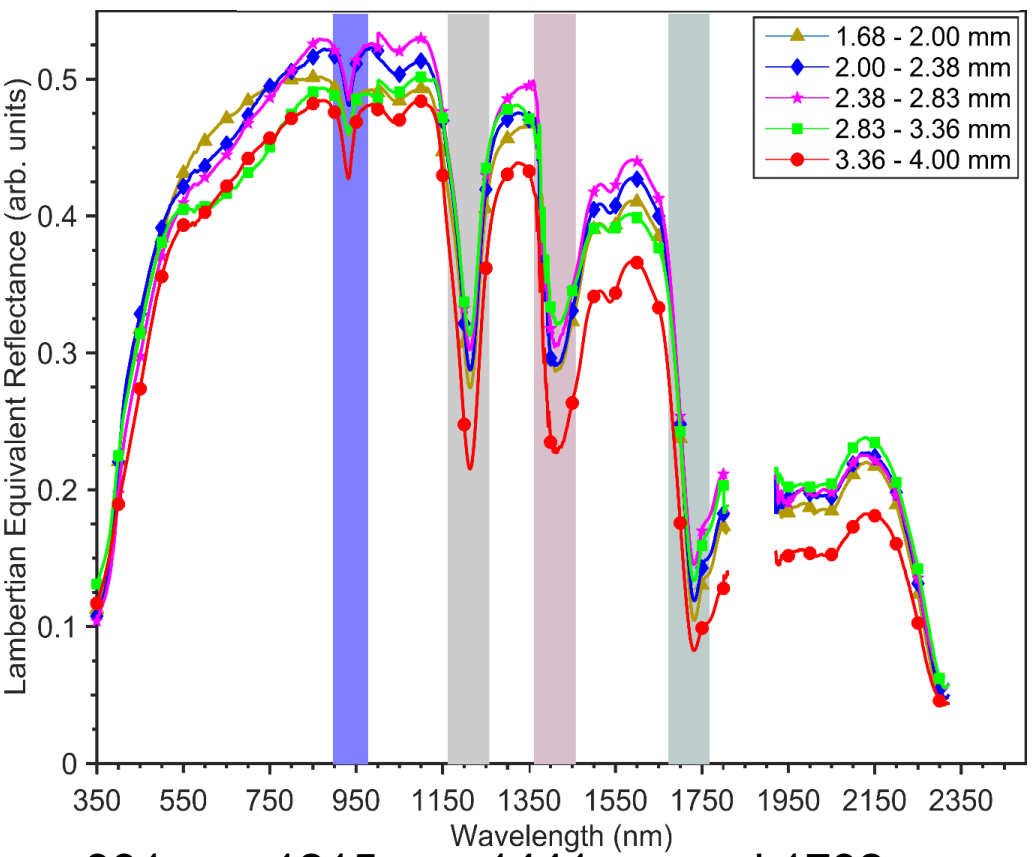
2.00 mm – 2.38 mm

2.38 mm – 2.83 mm

2.83 mm – 3.36 mm

3.36 mm – 4.00 mm

Sampling setup

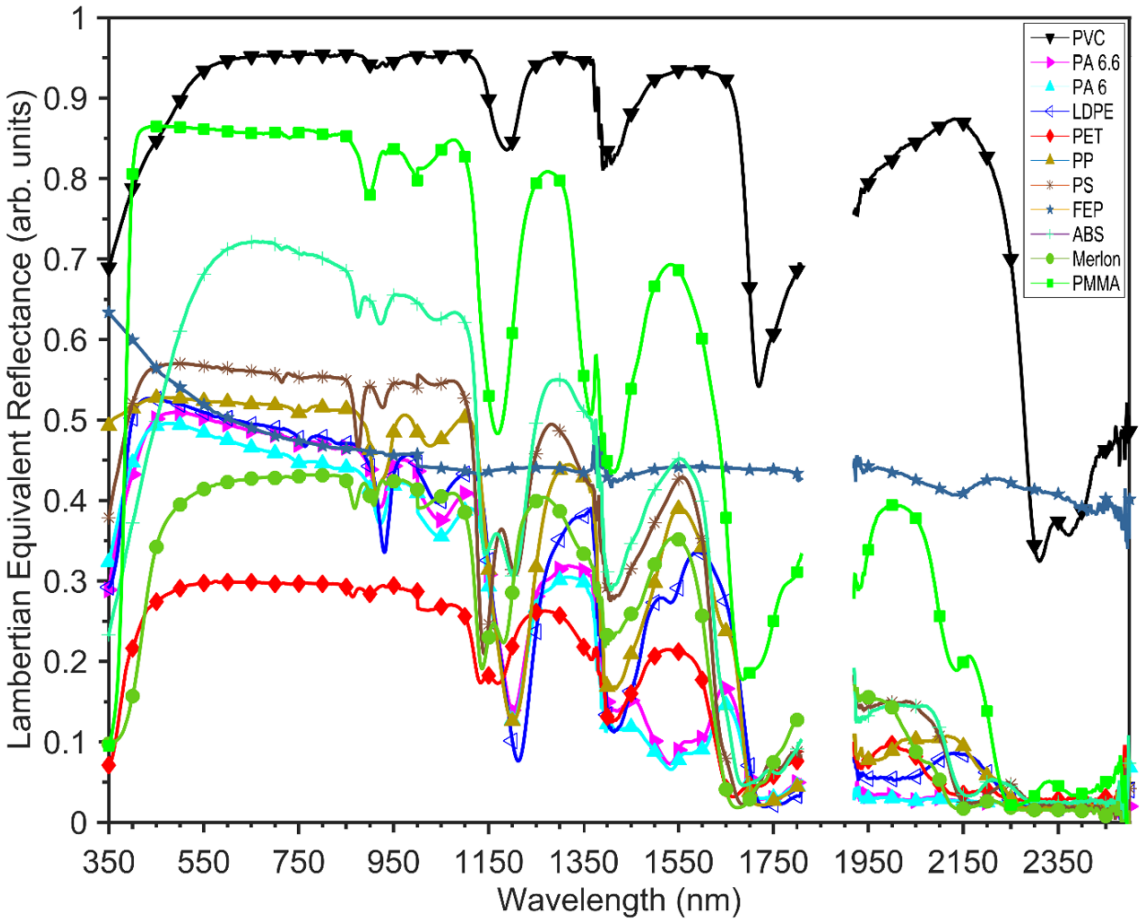


=[940 1378 2250] nm **OCI+**

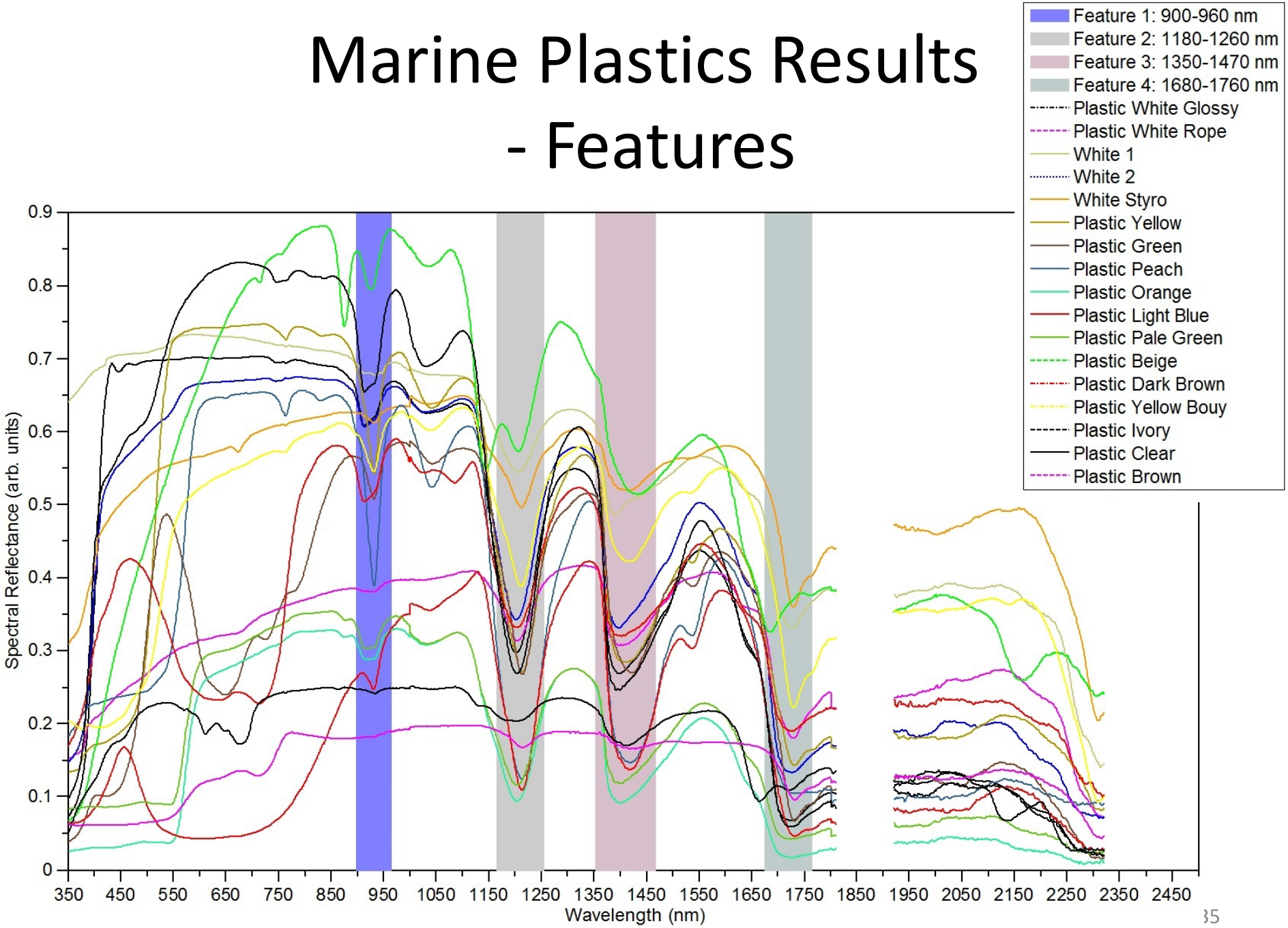
=[678 710 748 820 865 1240 1640 2130] nm

931 nm, 1215 nm, 1441 nm and 1732 nm.

Spectral Library of Plastic



Marine Plastics Results - Features



Conclusions

- New whitecap database into SWIR
- Progressing on methods to estimate whitecap R without winds and whitecap fraction using OCI+ bands, but 980 nm better than 940 nm
- Simple algorithms to differentiate white or “bright” targets using OCI+ bands
  - Cloud, Sea Ice, Whitecap
  - Floating vegetation
  - Plastics

ORCAS Campaign Currently underway in Southern Ocean

NSF-sponsored O_2/N_2 Ratio and CO_2 Airborne Southern Ocean (ORCAS) campaign
NASA funded rapid response to get concurrent hyperspectral PRISM imagery