PACE Science Team 2016: Atmospheric Correction over 

Bright Water Targets with Non-negligible 

Radiances in the Near Infrared 

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current NASA atmospheric correction approach

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

\[ R_{rs} = \frac{L_w}{F_0 \cos(\theta_s) t_{ds} f_s} f_b f_\lambda \]
foam & whitecaps

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

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

22% from Koepke 1984
NIR spectral dependence from Frouin 1999

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

Monahan/Frouin/Koepke
Moore
Stramska
Stramska modified

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
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

\[ W_{MM} = 2.95 \times 10^{-6} U_{10}^{3.52} \]

\[ W_{SP} = 5.0 \times 10^{-5} (U_{10} - 4.47)^3 \]
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
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?
Local water absorption minimum is variable

The minimum shifts to longer wavelengths with higher reflectance whitecaps. Need hyperspectral imagery
White targets with heritage bands

- 1030 nm
- 960 nm
- 940 nm

Reflectance (arb. units)

Wavelength (nm)

Cloud - AVIRIS
Blue Snow - AVIRIS
Bright Snow - AVIRIS
Whitecaps - ASD
Whitecaps - ASD
Sea Ice - ASD

=[940 1378 2250] nm OCl+
=[1678 710 748 820 865 1240 1640 2130] nm
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”

Whitecaps & Foam

Sea Ice

Floating Vegetation

Floating Plastics etc..

Bubbles

Cyanobacteria, Trichodesmium, Red Tides

Sediment (turbid water)

Calcite (PIC): Coccoliths

Seafloor (Optically Shallow)
• 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

Cloud Model (Meyer, Platnick)
AVIRIS imagery (Gao)
Floating Vegetation

![Graph showing different types of floating vegetation with wavelength on the x-axis and equivalent lambertian on the y-axis.](image-url)
931 nm, 1215 nm, 1441 nm and 1732 nm.
Spectral Library of Plastic
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