Shallow-water Remote Sensing:

Lecture 3: The Unsolved Problem of Atmospheric Correction for Shallow-water Remote Sensing

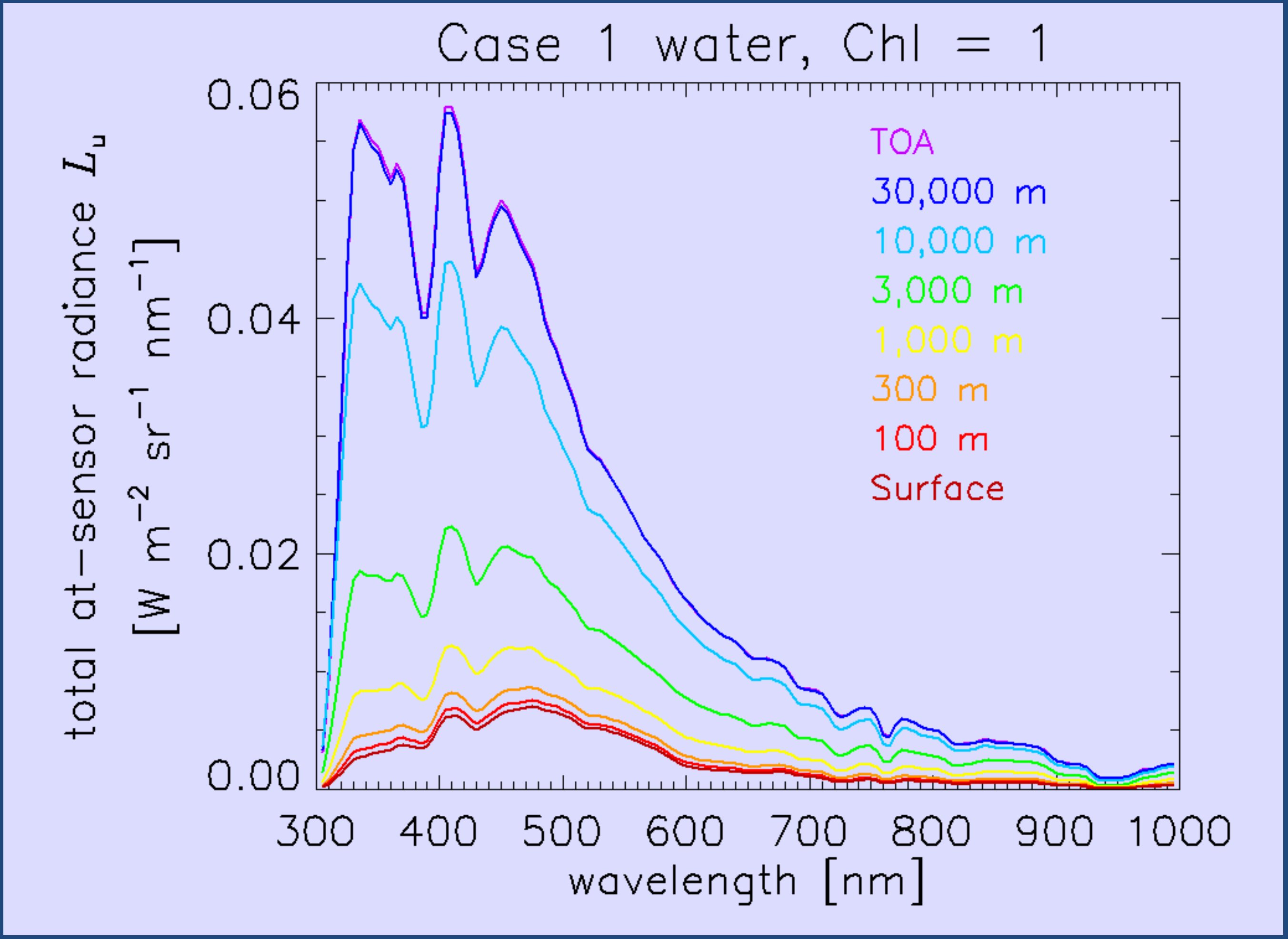
Curtis Mobley

Vice President for Science and Senior Scientist
Sequoia Scientific, Inc.
Bellevue, WA 98005
curtis.mobley@sequoiasci.com

IOCCG Course
Villefranche-sur-Mer, France
July 2012

Atmospheric Correction

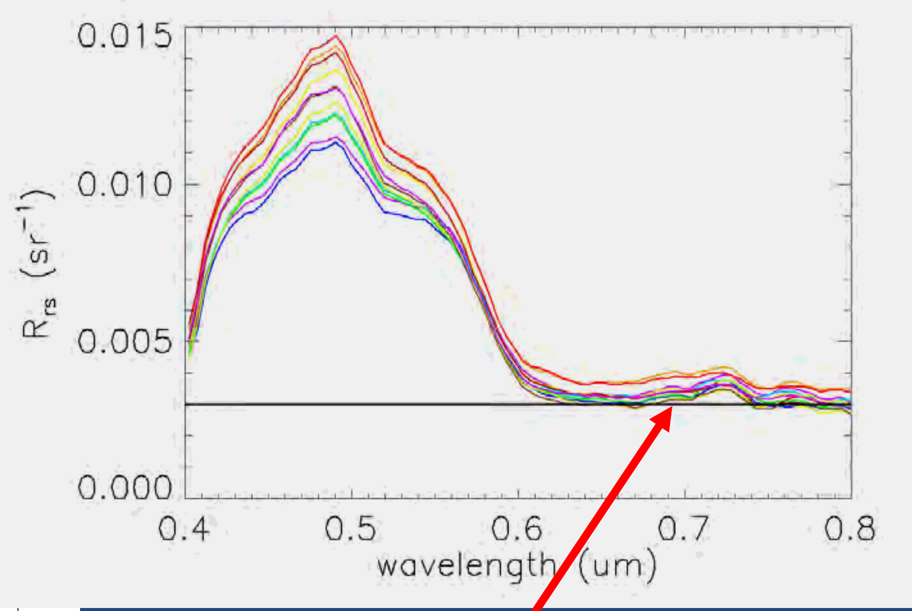
Most airborne remote sensing is done from altitudes of 1,000 to 10,000 m. Atmospheric path radiance is very important.

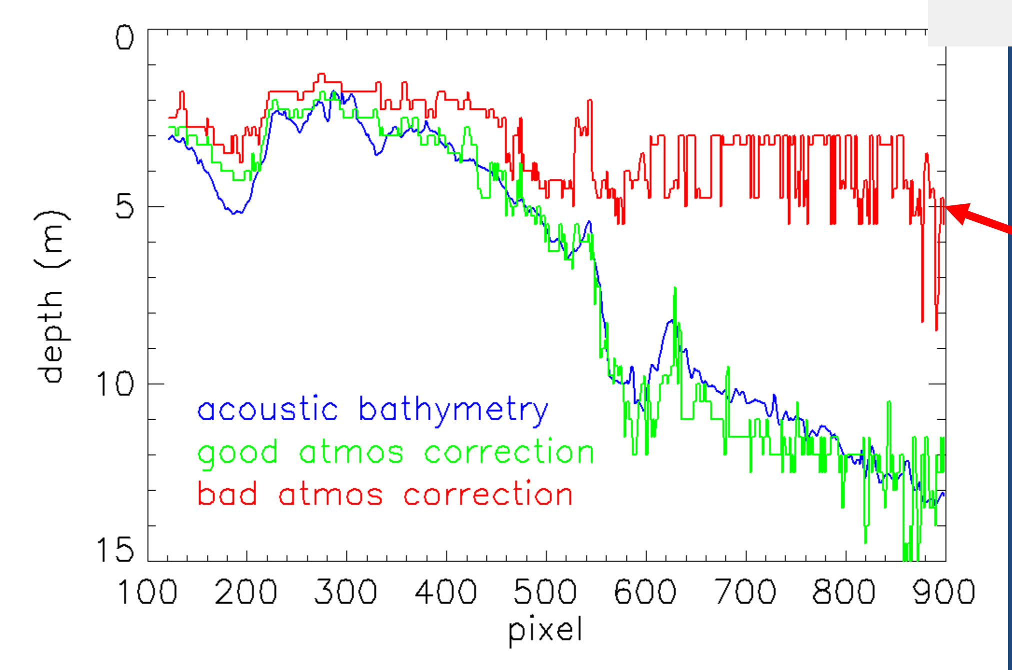


computations from combined HydroLight-MODTRAN code

Bad Atmospheric Correction = Bad Retrieval

As always, good retrievals depend on having a good atmospheric correction





atmospheric undercorrection by 0.003 1/sr gives bottom depths too shallow

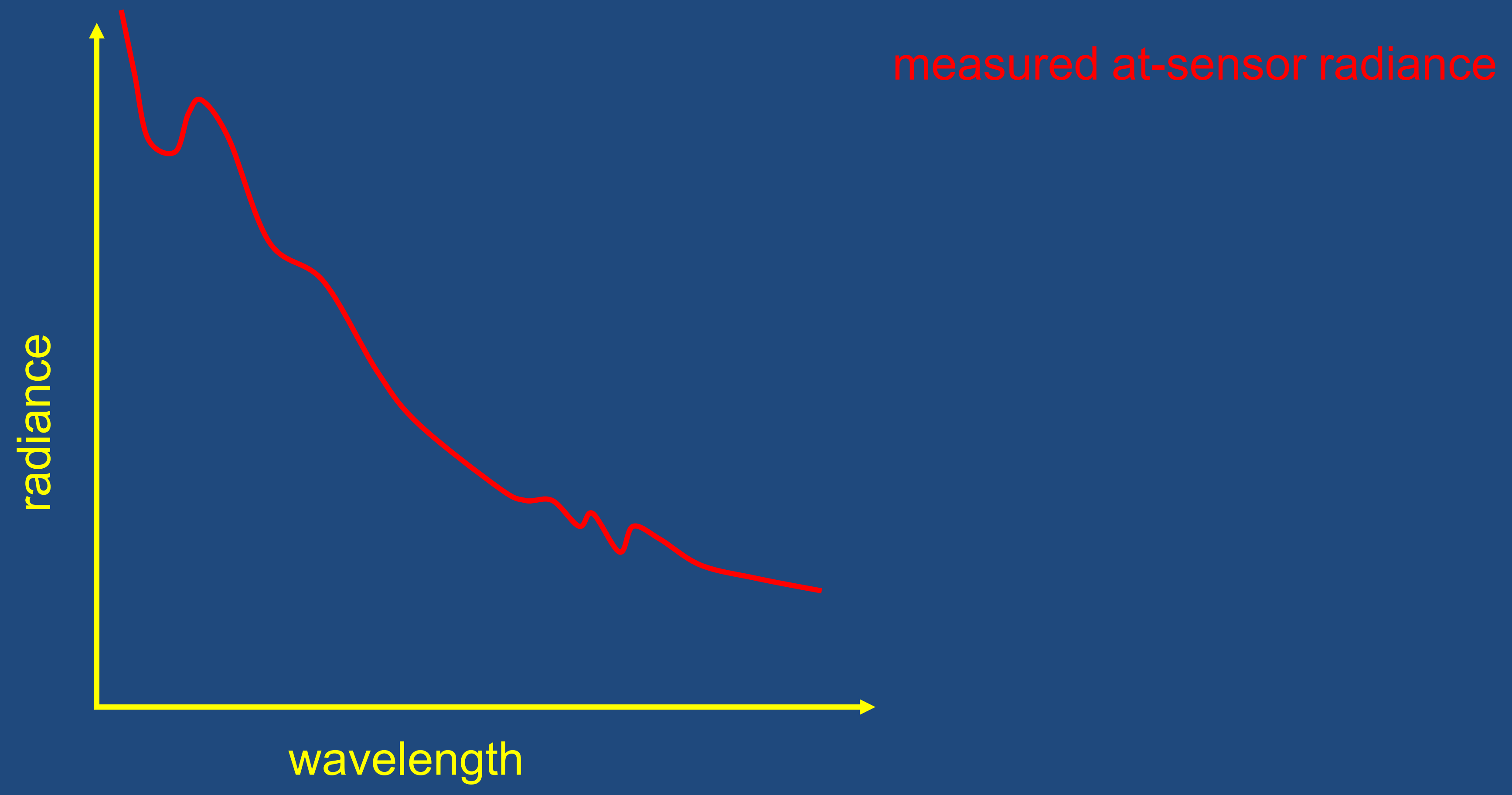
Three Techniques for Atmospheric Correction

- "Black-pixel" technique: developed for open-ocean (usually Case 1 water), multi-spectral, satellite ocean color remote sensing (SeaWiFS, MODIS, etc.) Many papers by Howard Gordon and others; Menghua Wang next week. Works well for deep Case 1 water, but fails for optically shallow and Case 2 waters.

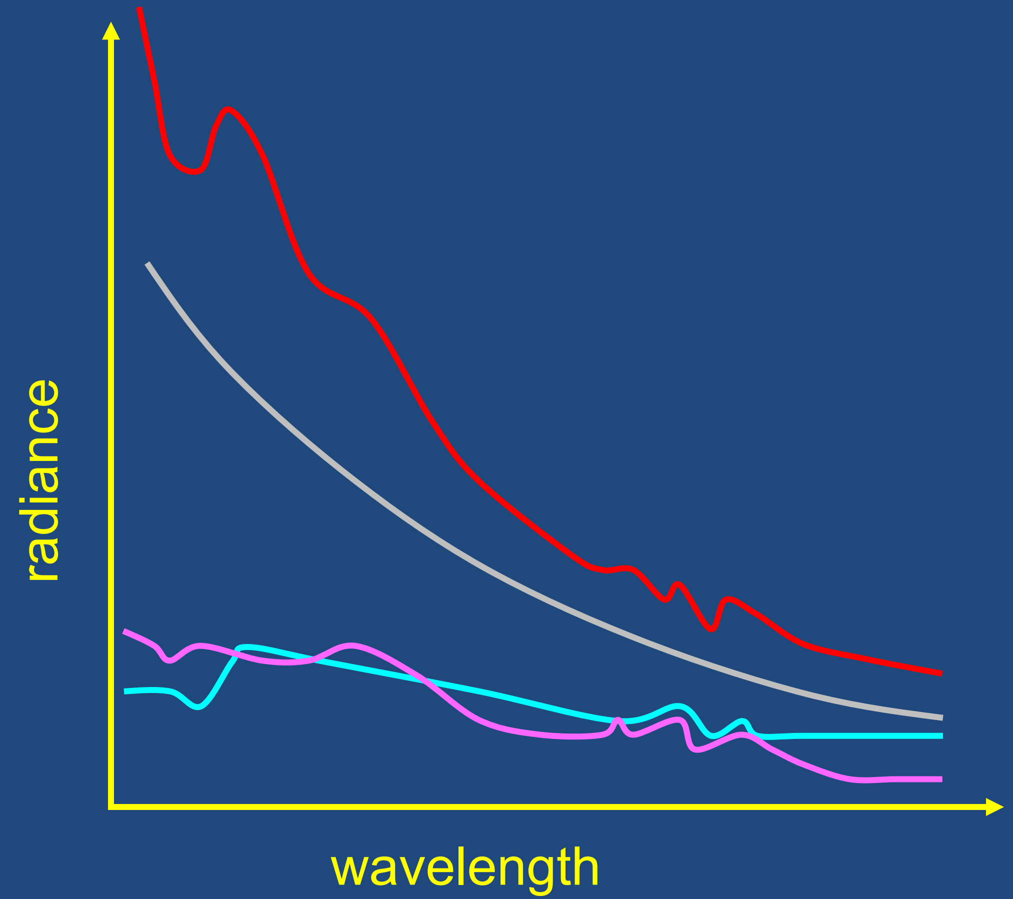
- Empirical Line Fit (ELF): A correlational technique that relates measured R_{rs} spectra to TOA radiances. In principle can correct for any atmospheric conditions, but requires field measurements of R_{rs} at time of image acquisition

- Radiative Transfer Techniques: Explicitly compute and remove the atmospheric path radiance for given atmospheric conditions and viewing geometry. In principle can correct for any atmospheric conditions, but requires knowledge of atmospheric conditions at time of image acquisition

Black-pixel Technique and Extrapolation



Black-pixel Technique and Extrapolation



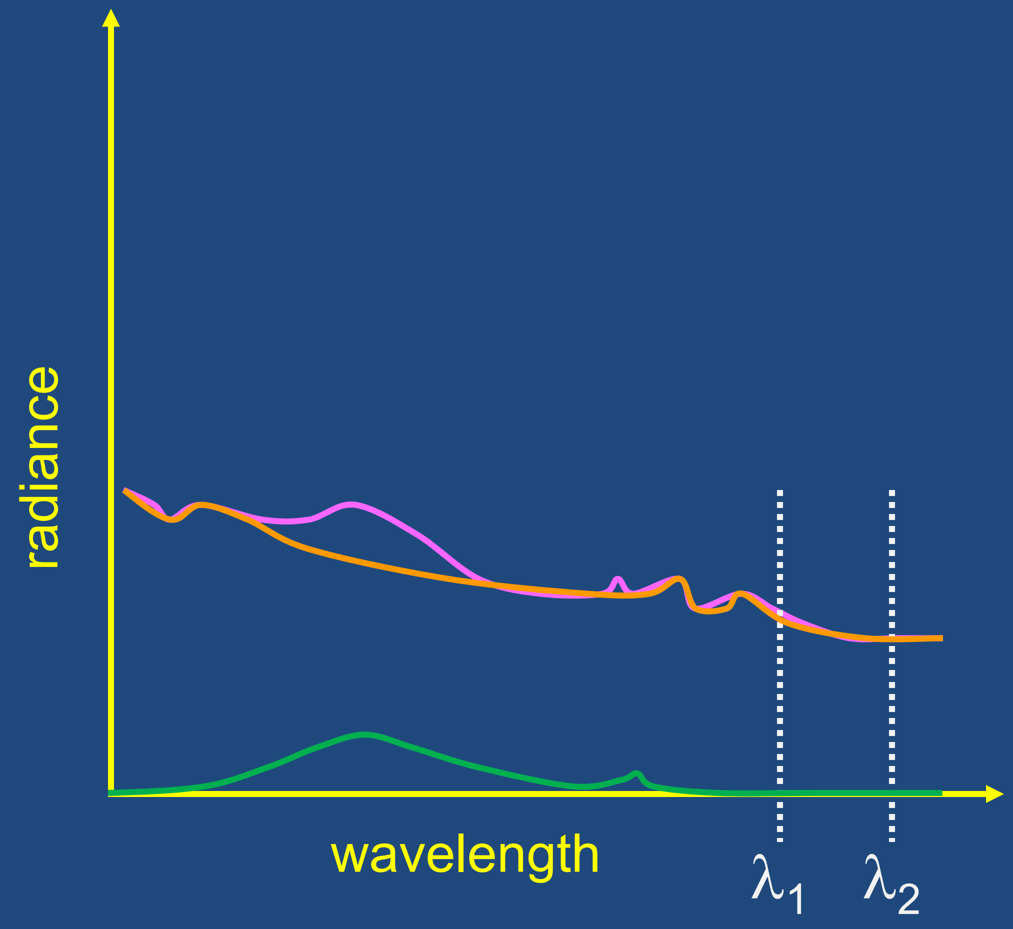
measured at-sensor radiance

compute the Rayleigh contribution

compute the surface-reflected contribution (sun and sky glint)

subtract to get the aerosol + water-leaving radiance

Black-pixel Technique and Extrapolation



aerosol + water-leaving radiance

Find an aerosol model that gives a good fit for $L(\lambda_1)$ and $L(\lambda_2)$ at 2 NIR wavelengths where L_w is zero. Use it to compute $L(\lambda)$ at all wavelengths (i.e., extrapolate from λ_1 and λ_2 to all wavelengths) and subtract

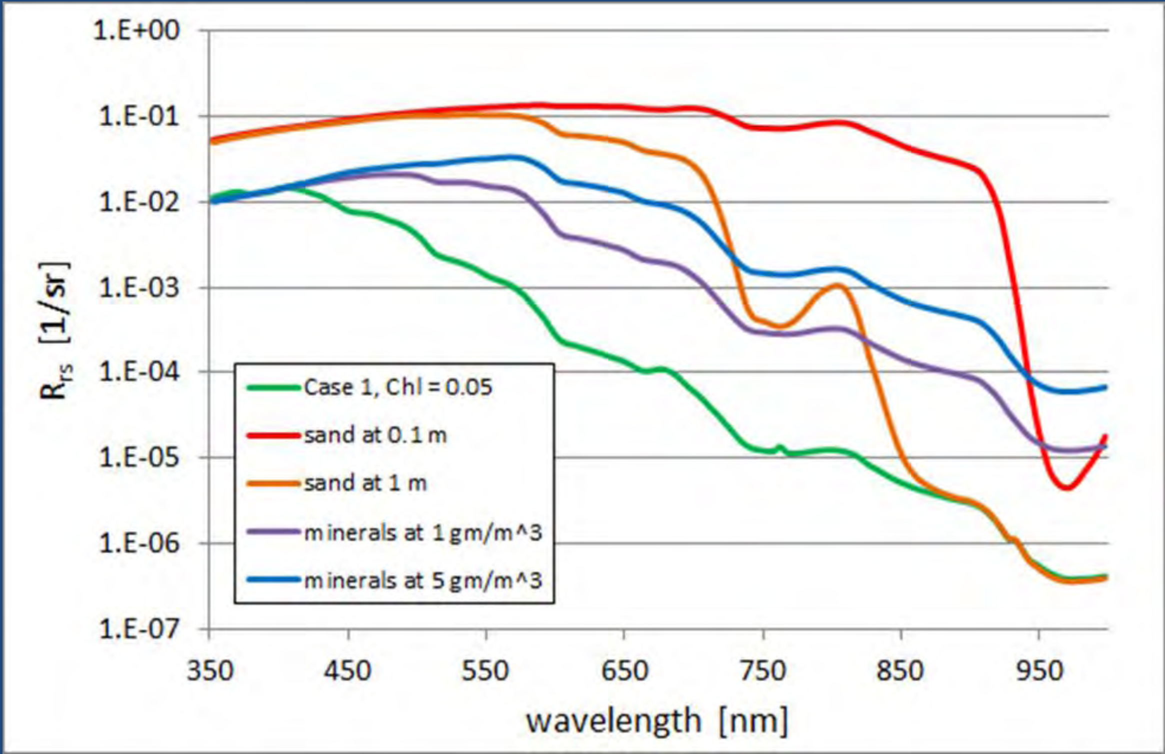
This leaves the water-leaving radiance L_w (i.e., R_{rs})

Black-pixel Technique and Extrapolation

This technique works well in many situations, but…

This technique DOES NOT WORK for remote-sensing of shallow waters, because bottom reflectance often makes $L_w(\lambda_1)$ and $L_w(\lambda_2)$ non-zero. It fails for Case 2 waters with high mineral concentrations, because scattering by mineral particles can also make $L_w(\lambda_1)$ and $L_w(\lambda_2)$ non-zero. It also fails if the aerosols are highly absorbing (dust, soot) as is often case in coastal waters.

It has inherent problems because small errors in the near IR can give big errors (even negative L_w) near 400 nm.



Requirements for Case 2 or Shallow Water

We need to have an atmospheric correction technique that

- does not require zero water-leaving radiance at particular wavelengths (no “black pixel” assumption)
- works for any water body (Case 1 or 2, deep or shallow)
- works for any atmosphere (including absorbing aerosols, which are common in coastal areas)
- does not require ancillary field measurements than cannot be obtained on a routine basis or in denied-access areas

Faster, cheaper better: pick any 2. Here it’s pick any 3.

Empirical Line Fit

- Measure R_{rs} at several points within the image area at the time of image acquisition

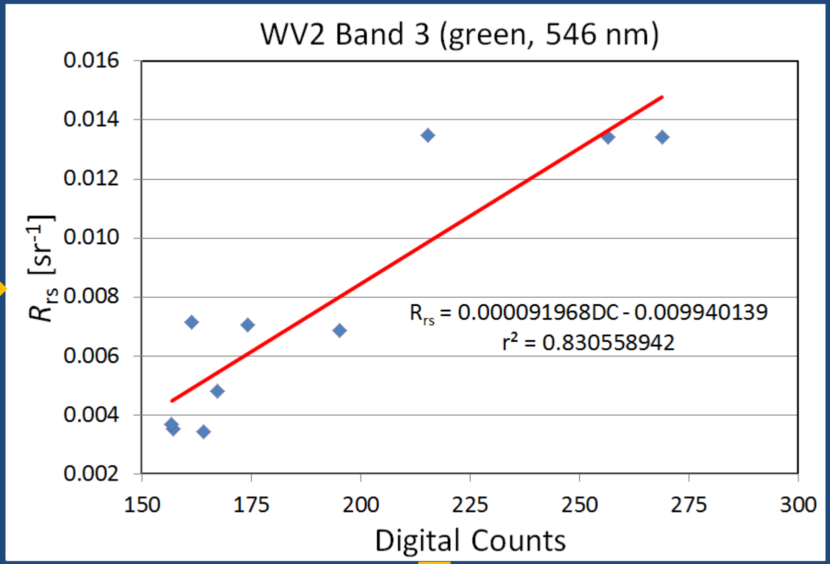
- Correlate the measured R_{rs} with the TOA signal at each wavelength to get a function—the empirical line fit—that converts TOA values to sea-level Rrs

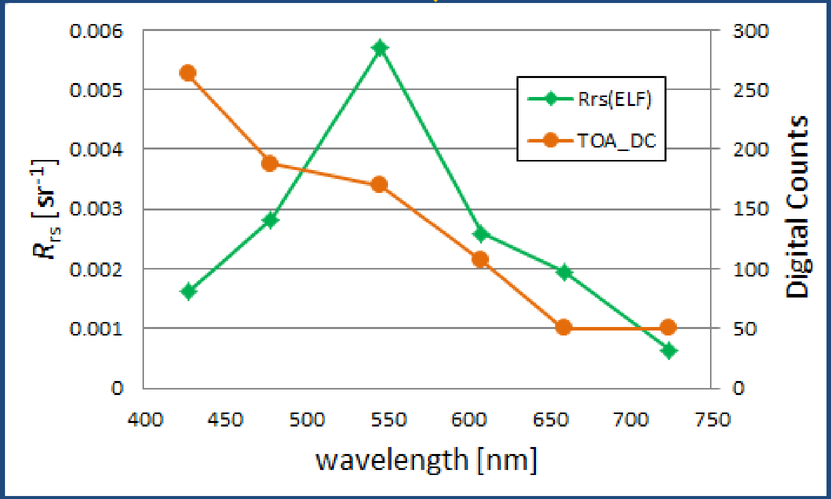
- Apply this ELF to all pixels in the image

- In principle, the ELF technique can correct for any atmospheric conditions (which do not need to be known)

Empirical Line Fit

Example using WorldView-2 satellite multispectral imagery of St. Joseph's Bay, FL





Empirical Line Fit

The major drawback of the ELF technique is that it requires someone in the field, usually in a small boat, to make the needed sea-surface R_{rs} measurements at the time of the overflight.

An ELF based on measurements in one part of the image will give a bad correction for an image if the atmospheric conditions vary over the image (clouds, variable aerosol concentration), or the sea surface reflectance varies (wind speed varies)

The ELF can also become inaccurate for large off-nadir viewing angles because of different atmospheric path lengths and scattering angles.

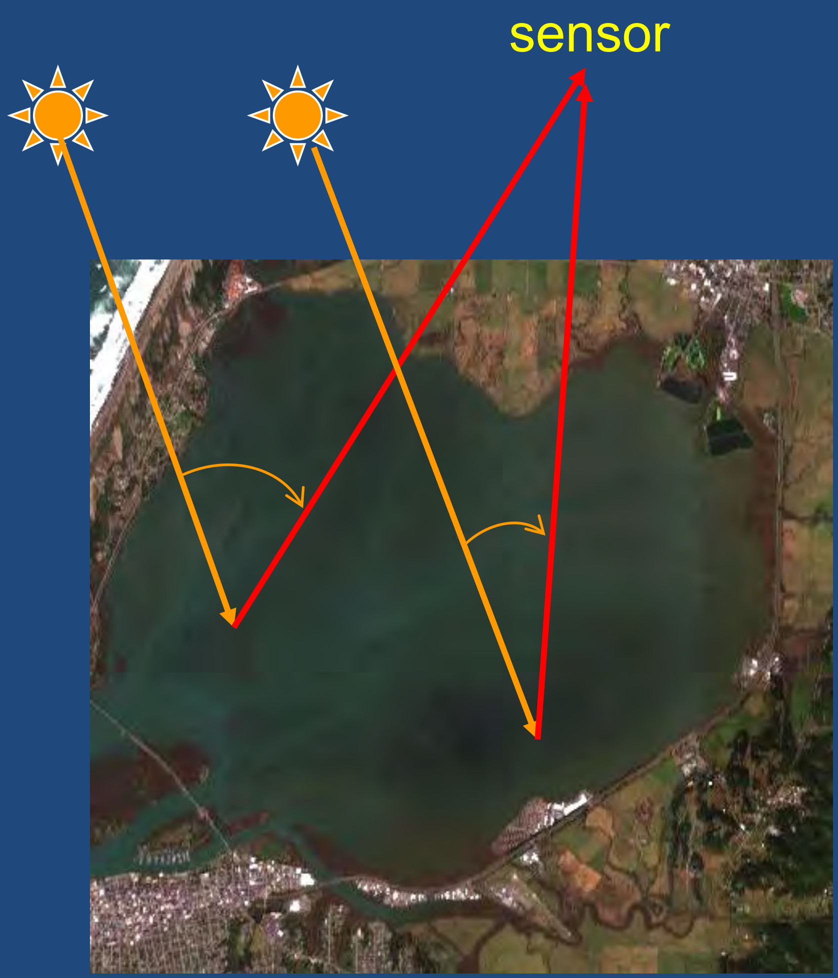
Radiative Transfer Techniques

If we know (or can estimate) the absorbing and scattering properties of the atmosphere, then we can use an atmospheric radiative transfer (RT) model to compute the atmospheric path radiance (and surface reflectance) contribution to the measured total, and subtract it out to obtain the water-leaving radiance.

Example: the TAFKAA RT model was developed by the US Navy for this purpose (Gao et al, 2000; Montes et al, 2001; TAFKAA = The Algorithm Formerly Known As ATREM; ATmospheric REMoval).

TAFKAA has been used to create large look-up tables for various wind speeds, sun angles, viewing directions, and atmospheric properties (aerosol type and concentration, surface pressure, humidity, etc). These calculations (including polarization) required ~6×10^7 RT simulations with TAFKAA, taking several months of time on a 256 processor SGI supercomputer.

Radiative Transfer Techniques

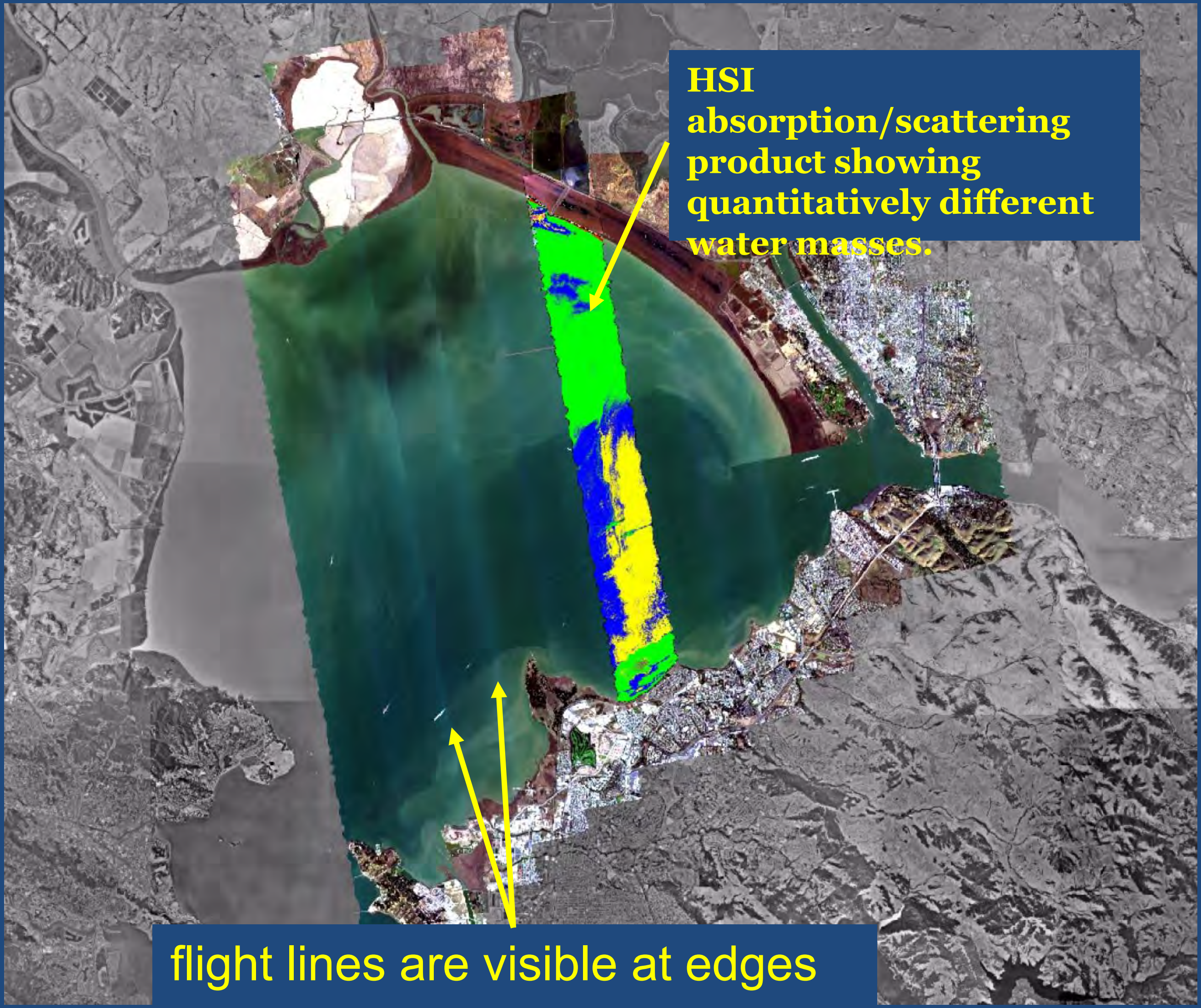


When correcting an image, each pixel in the scene has a different viewing geometry, and thus gets a different correction.

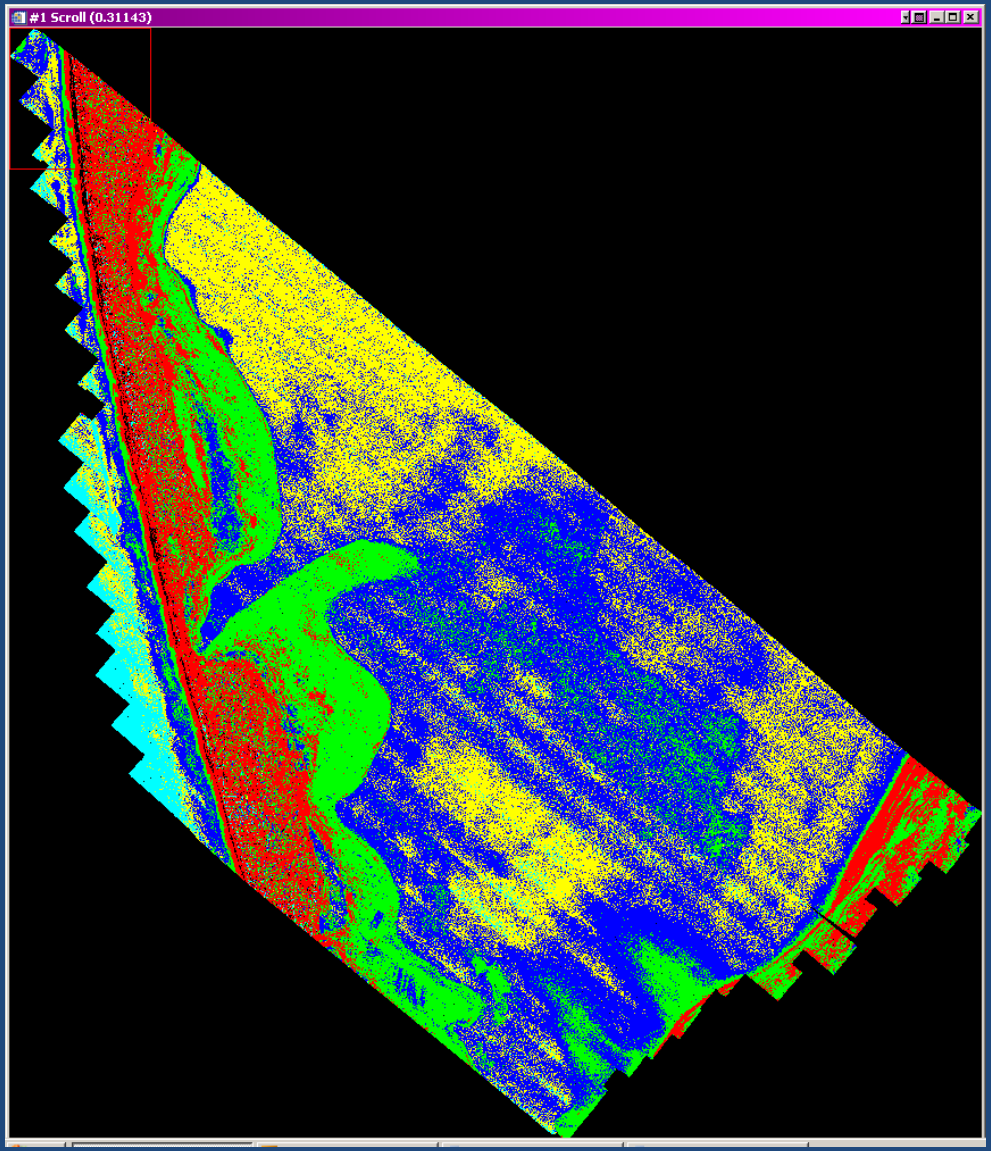
The main disadvantage of any RT method is that it requires measurement or estimation of the atmospheric properties.

This also requires having someone in the the field making meteorological measurements, or the use of atmospheric prediction models.

Imperfect Atmospheric Correction Visible in RGB



Imperfect Atmospheric Correction Effects on Bathymetry

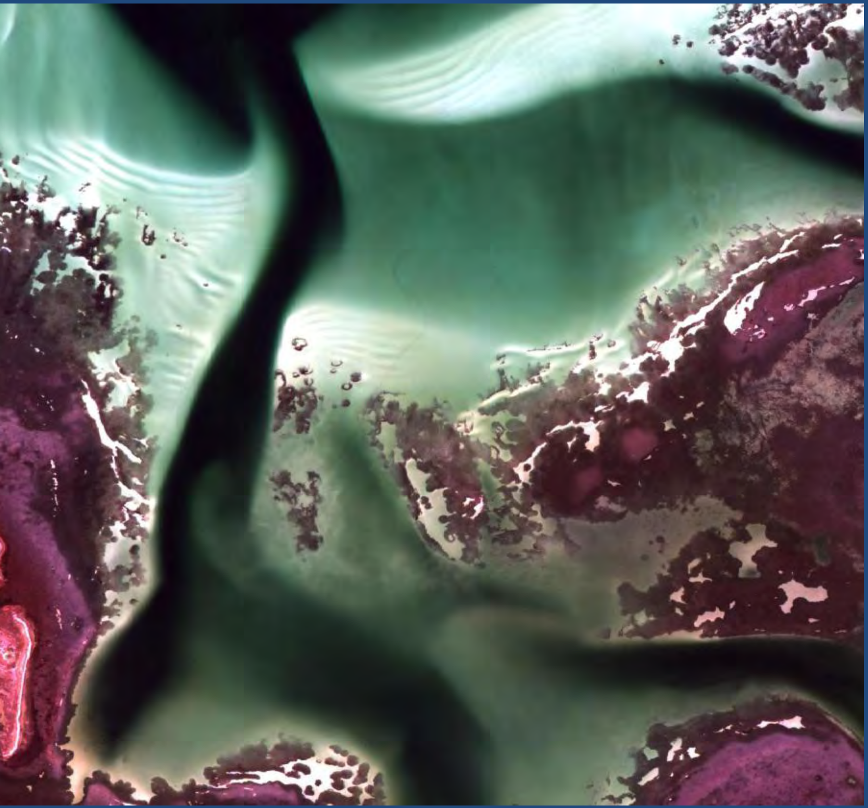


Effects of imperfect atmospheric correction on retrieved (by spectrum matching) bathymetry. The overall pattern is correct but note the “striping” in retrieved depths.

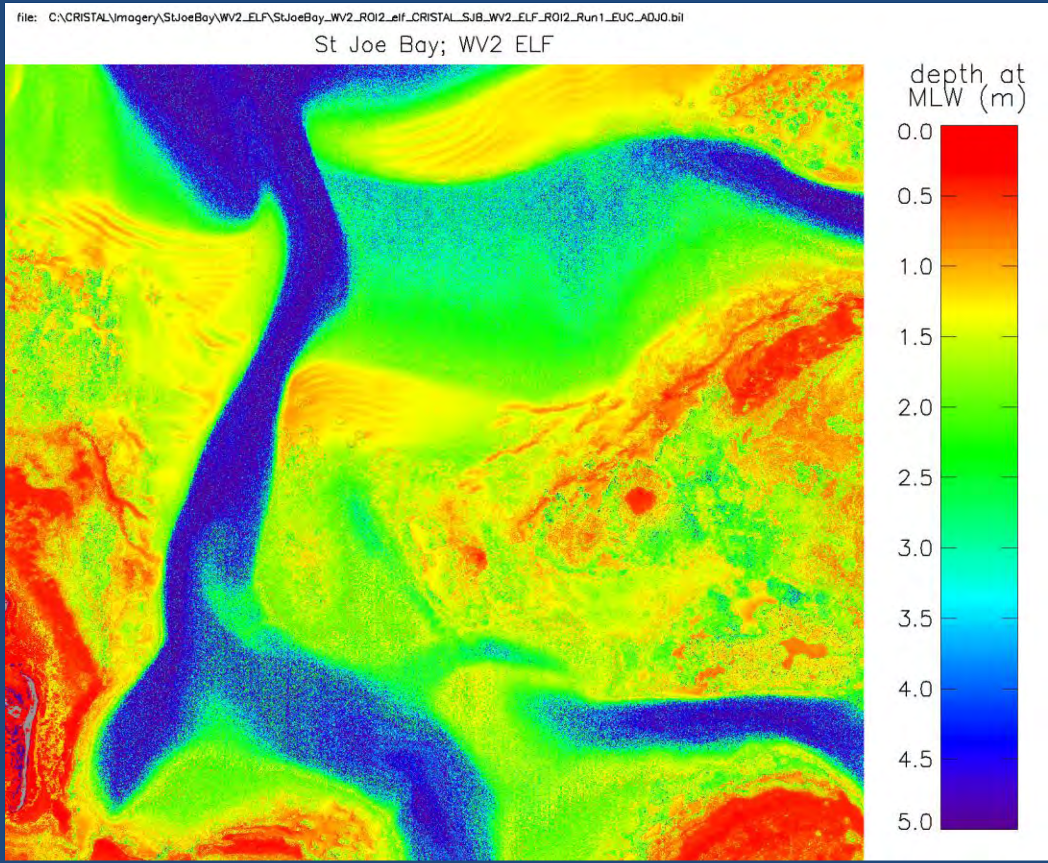
1 m contours (RGBYC =1-5 m)

courtesy of P. Bissett, FERI

Case Study: St. Joeseph Bay, FL and WorldView 2 Image; ELF vs TAFKAA-6S



RGB of WV2 image; 2.5 x 2.5 km, ~1m GSD

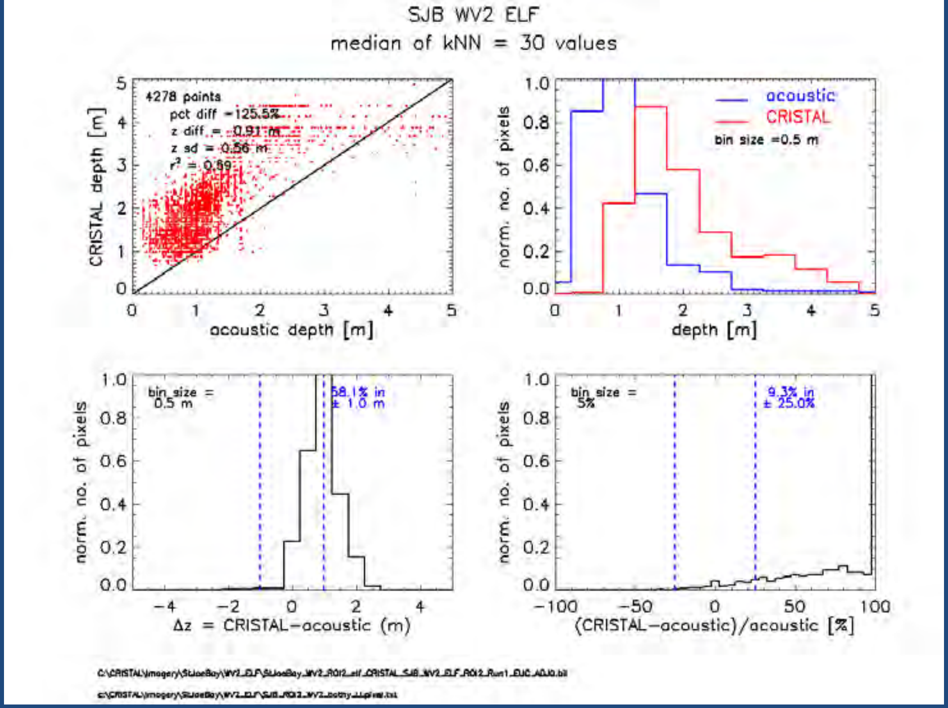


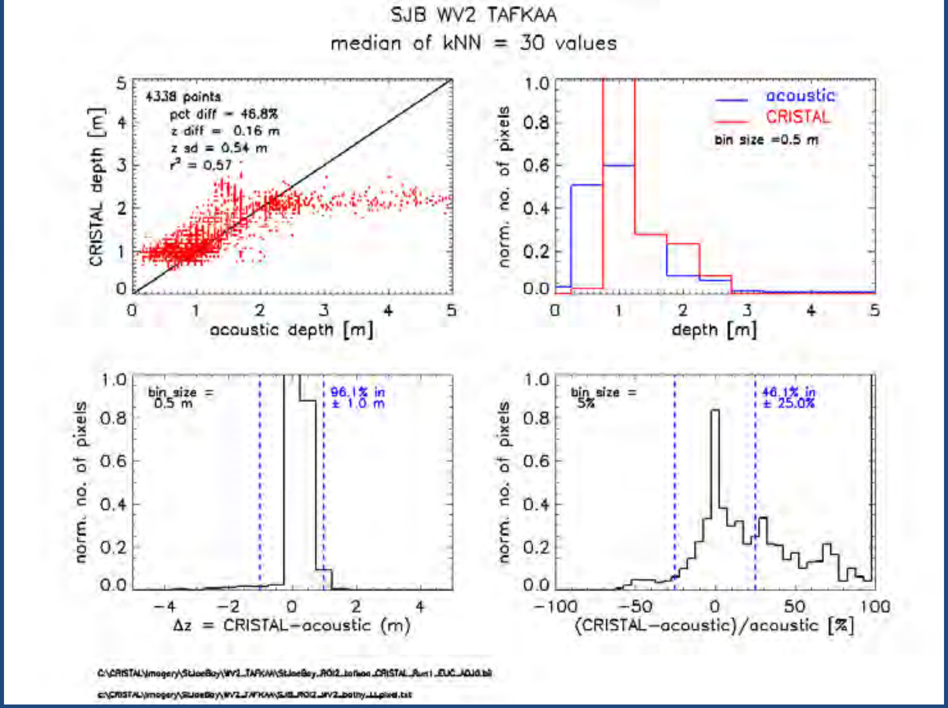
Depth retrievals are qualitatively correct

Case Study: St. Joeseph Bay, FL and WorldView 2 Image; ELF vs TAFKAA-6S

Quantitative comparison with acoustic bathymetry is not good for either the ELF or the TAFKAA corrected images. Why the poor result?

The R_{rs} database was created using measured IOPs and bottom reflectances from this area, so it contains spectra representative of this environment.

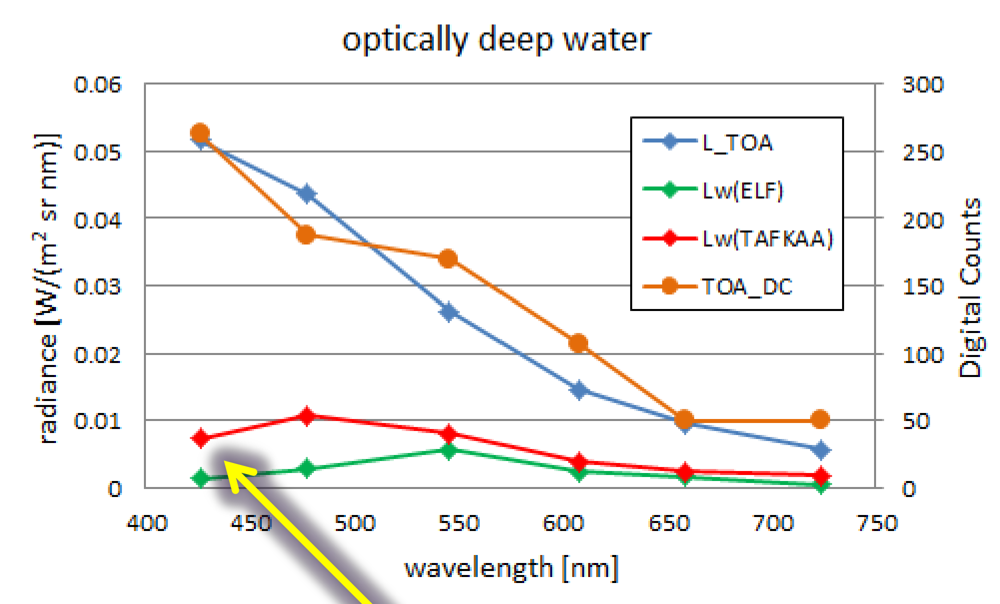




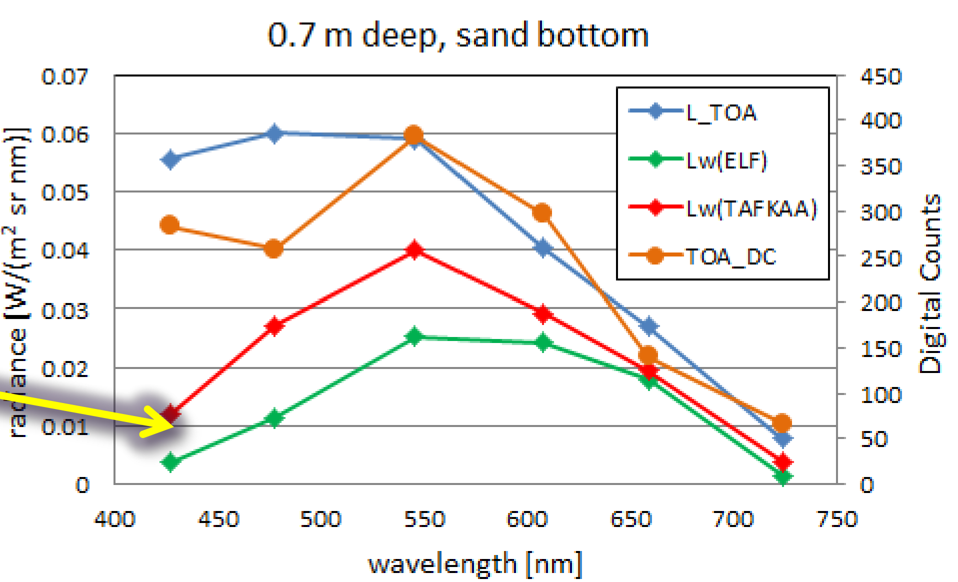
ELF-corrected image

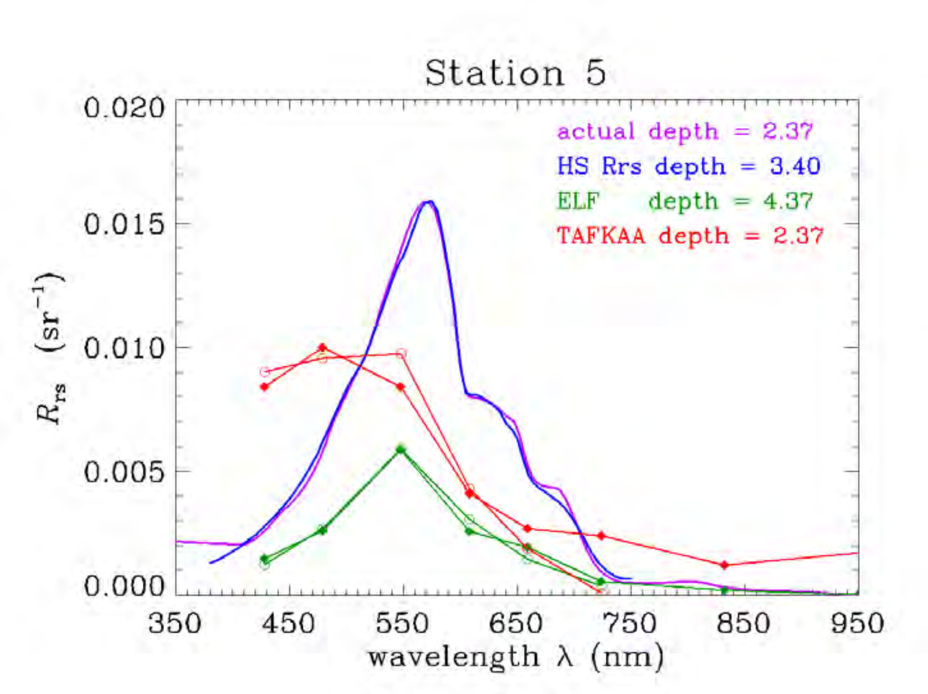
TAFKAA-corrected image

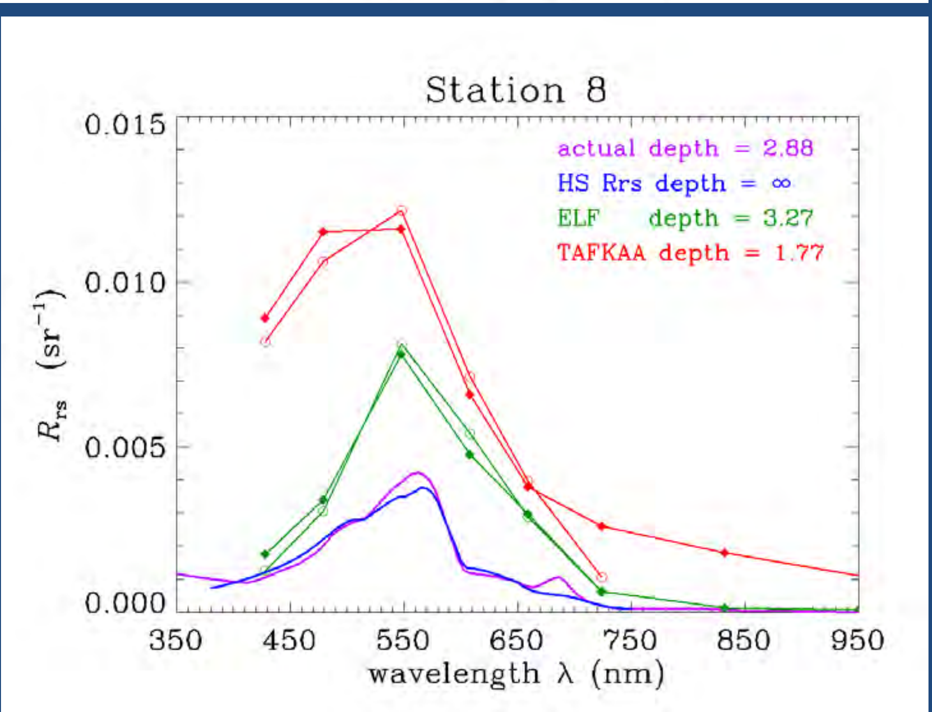
The ELF and TAFKAA corrections give much different water-leaving radiance spectra. Why?



These are HUGE differences—up to a factor of 5 at 427 nm—in ELF and TAFKAA-corrected R_{rs}







The R_{rs} measurements used to create the EFL were made 3-8 days before the time of WV2 image acquisition.

The atmospheric conditions used as input to TAFKAA-6S were just educated guesses because no atmospheric measurements were made.

Neither atmos correction is good for this image, so the retrievals are bad.

Note that the database gives a good fit to either set of atmos corrected R_{rs}, but we are just getting a good fit to bad spectra. GIGO.

Atmospheric Correction Techniques

Radiative transfer techniques such as TAFKAA can give good results for any atmospheric conditions, viewing geometry, and do not require extrapolation or zero water-leaving radiances. They are therefore widely used.

The disadvantage is that they require measurement, or modeling, or guessing, of the atmospheric properties needed to decide what correction to use at each pixel (for TAFKAA, the original look-up table had >60,000,000 values to chose from!)

RT corrections will fail if you input inaccurate atmospheric properties. You never have all of the measurements needed for exact calculations (altitude profiles of aerosols, humidity, etc.)

In Summary...

Spectrum-matching algorithms for simultaneous retrieval of ocean environmental properties (water IOPs, bottom depth, and bottom type) work well IF they have accurate R_{rs} spectra as input. Doing a good atmospheric correction on an image is the key to getting good retrievals from the image spectra.

However, atmospheric correction techniques are all imperfect, and sometimes fail completely to give useable R_{rs} spectra.

Atmospheric correction for shallow and Case 2 water is an extremely difficult problem that requires much more research, and perhaps new instrumentation (e.g., for easily and routinely measuring the atmospheric properties needed for input to RT models).

Acknowledgments

The development of the database spectrum matching techniques was funded by various contracts from the Ocean Optics and Biology Program, Code 322OB, U. S. Office of Naval Research.

Much of this work was done in collaboration with Dr. Paul Bissett of the Florida Environmental Research Institute (FERI) and WeoGeo, Inc.

The airborne hyperspectral imagery, atmospheric corrections, and ground truth were provided by colleagues at the Naval Research Lab Code 7200 (Curtiss Davis, Valery Downes, Karen Patterson, et al.), FERI and WeoGeo, and Drs. Richard Zimmerman and Victoria Hill of Old Dominion Univ.

References

Spectrum Matching:

Dekker A.G., Phinn S.R., Anstee J., Bissett P., Brando V.E., Casey B., Fearns P., Hedley J., Klonowski, W., Lee Z.P., Lynch M., Lyons M., Mobley C.D, and Roelfsema C., 2011. Inter-comparison of Shallow Water Bathymetry, Hydro-Optics, and Benthos Mapping Techniques in Australian and Caribbean Coastal Environments. *Limnol Oceanogr. Methods,* 9, 396-425.

Lee, Z. P., K. L. Carder, C. D. Mobley, R. G. Steward, and J. S. Patch, 1998. Hyperspectral remote sensing for shallow waters: 1. A semi-analytical model. *Applied Optics*, 37(27), 6329-6338.

Lee, Z. P., K. L. Carder, C. D. Mobley, R. G. Steward, and J. S. Patch, 1999. Hyperspectral remote sensing for shallow waters: 2. Deriving depths and optical properties by optimization. *Applied Optics*, 38(18), 3831-3843.

Mobley, C. D., L. K. Sundman, C. O. Davis, J. H. Bowles, T. V. Downes, R. A. Leathers, M. J. Montes, W. P. Bissett, D. D. R. Kohler, R. P. Reid, E. M. Louchard, and A. Gleason, 2005. Interpretation of hyperspectral remote-sensing imagery via spectrum matching and look-up tables. *Applied Optics*, 44(17), 3576-3592.

Atmospheric Correction:

Gao, B.-C., M. J. Montes, Z. Ahmad, and C.O. Davis, 2000. An atmospheric correction algorithm for hyperspectral remote sensing of ocean color from space. *Applied Optics* **39**(6), 887-896.

Montes, M. J., B.-C. Gao, and C. O. Davis, 2001. A new algorithm for atmospheric correction of hyperspectral remote sensing data, in *Geo-Spatial Image and Data Exploitation II*, W. E. Roper, Editor, Proc. SPIE **4383**, 23-30.

IOCCG Report 10, 2010: Atmospheric Correction for Remotely Sensed Ocean Colour Products., M. Wang, Ed., http://www.ioccg.org/reports_ioccg.html

HydroLight:

Mobley, C. D., 1994. Light and Water: Radiative Transfer in Natural Waters. Academic Press, 592 pages. See also www.oceanopticsbook.info

Everyone should go trekking in Nepal

Sunset on Machhapuchhre, 6993 m, from Annapurna South Base Camp