Shallow-water Remote Sensing:

Lecture 1: Overview

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Overview

Lecture 1: Overview

- What's the problem and who cares
- Basic definitions as needed
- Why deep-water and terrestrial techniques don't work for shallow water
- Sensors

Lecture 2: Spectrum-matching Techniques for Shallow-water remote sensing

- Semianalytical models
- Database methods
- Example results
- Error analysis

Lecture 3: Atmospheric Correction for Shallow Waters

- Why "black pixel" techniques for deep, case 1 water don't work
- Empirical Line Fit
- Radiative Transfer

Who Cares About Shallow Waters?

- Military needs maps of bathymetry and bottom classification in denied-access areas for amphibious operations; water clarity maps for optical mine finding and diver operations

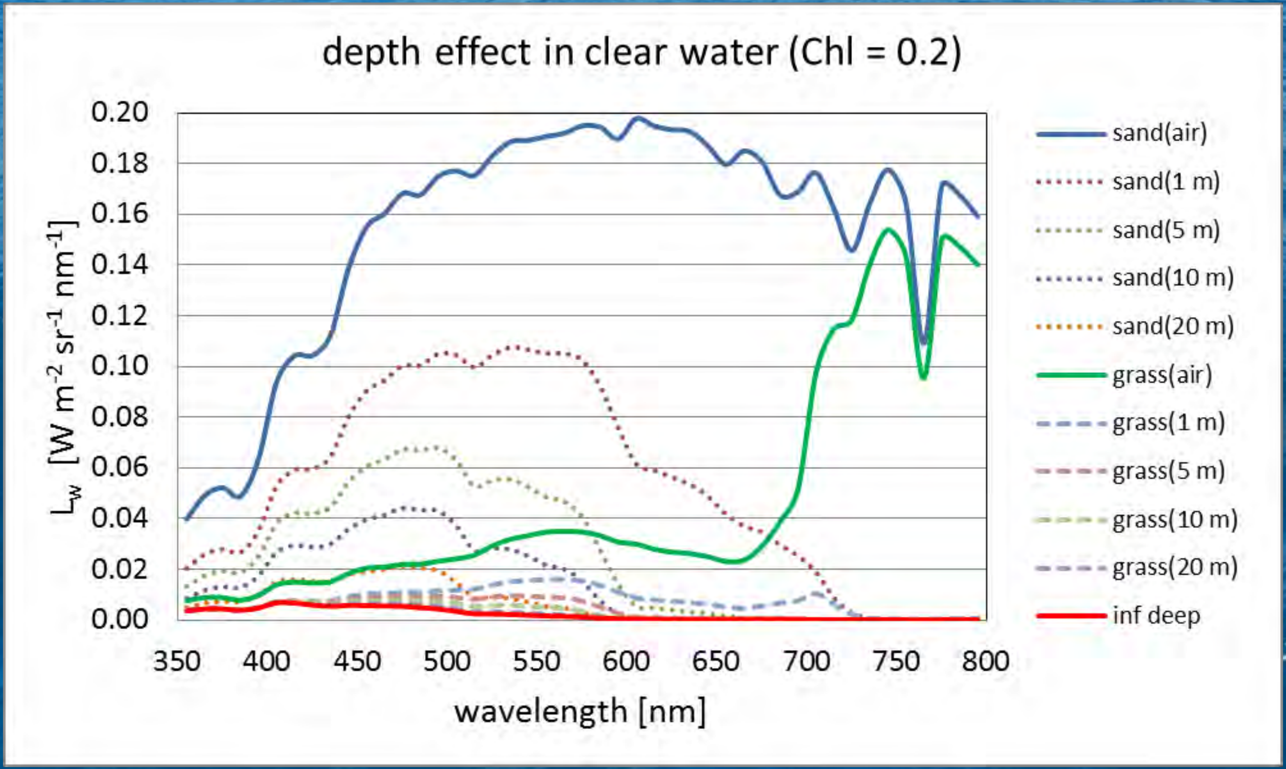
- Ecosystem managers need to map and monitor bottom type and water quality for management of coral reefs, sea grass beds, kelp forests, fisheries, and recreation
  - episodic (hurricane effects, harmful algal blooms, pollution events)
  - long-term (global climate change, anthropogenic changes from coastal land usage)

- Maps needed at 1-10 meter spatial scales (not kilometers), and sometimes within ~1 day of image acquisition

Terrestrial vs Ocean Remote Sensing

Ocean remote sensing is much more difficult than terrestrial remote sensing.

Land is much brighter than water, so the total TOA radiance is much larger over land, and the atmospheric contribution to the total is less, so that atmospheric correction is easier. Sensor signal-to-noise ratio is greater over land.



Terrestrial vs Ocean Remote Sensing

Ocean remote sensing is much more difficult than terrestrial remote sensing.

Terrestrial remote sensing is usually concerned only with mapping the type of surface (thematic mapping).

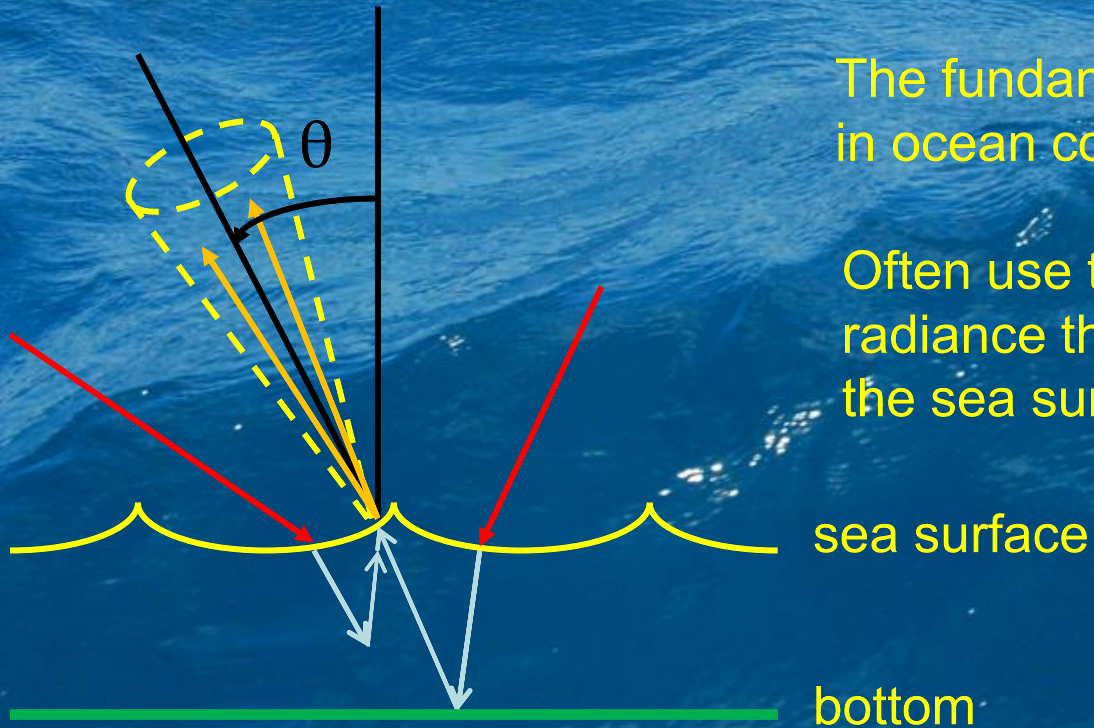
Shallow-water remote sensing usually must do a *simultaneous* retrieval of depth, bottom reflectance (bottom type), and water-column absorption and scattering properties.

Ocean retrievals are complicated by surface effects such as sun and sky glint, whitecaps.

Remote-sensing Reflectance R_{rs}

$$R_{rs}(\theta,\varphi,\lambda) = \frac{\text{upwelling water-leaving radiance}}{\text{downwelling plane irradiance}}$$

$$R_{rs}(\text{in air},\theta,\varphi,\lambda) \equiv \frac{L_w(\text{in air},\theta,\varphi,\lambda)}{E_d(\text{in air},\lambda)} \qquad [\text{sr}^{-1}]$$

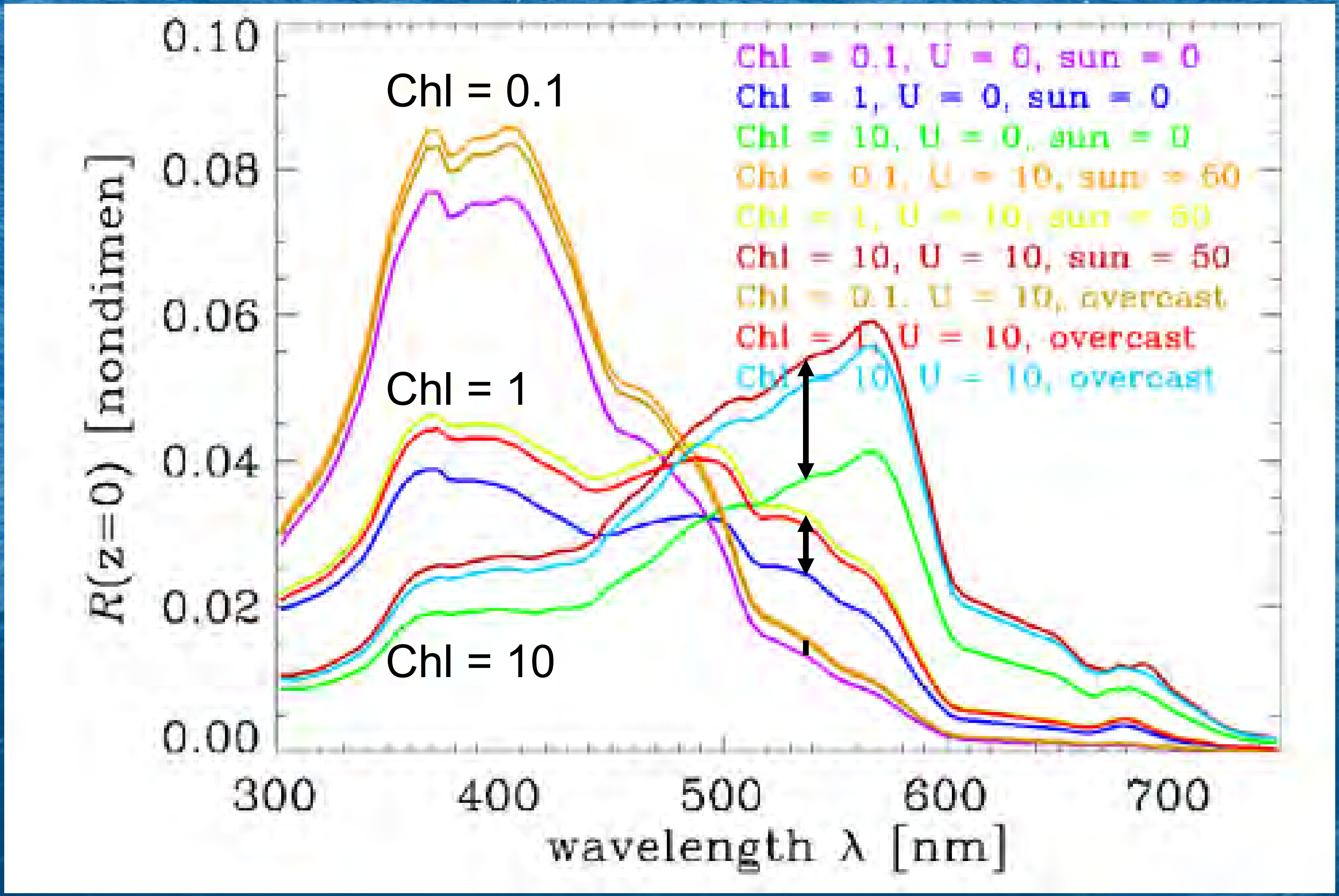


The fundamental quantity used today in ocean color remote sensing

Often use the nadir-viewing R_{rs}, i.e. the radiance that is heading straight up from the sea surface ($\theta = 0$)

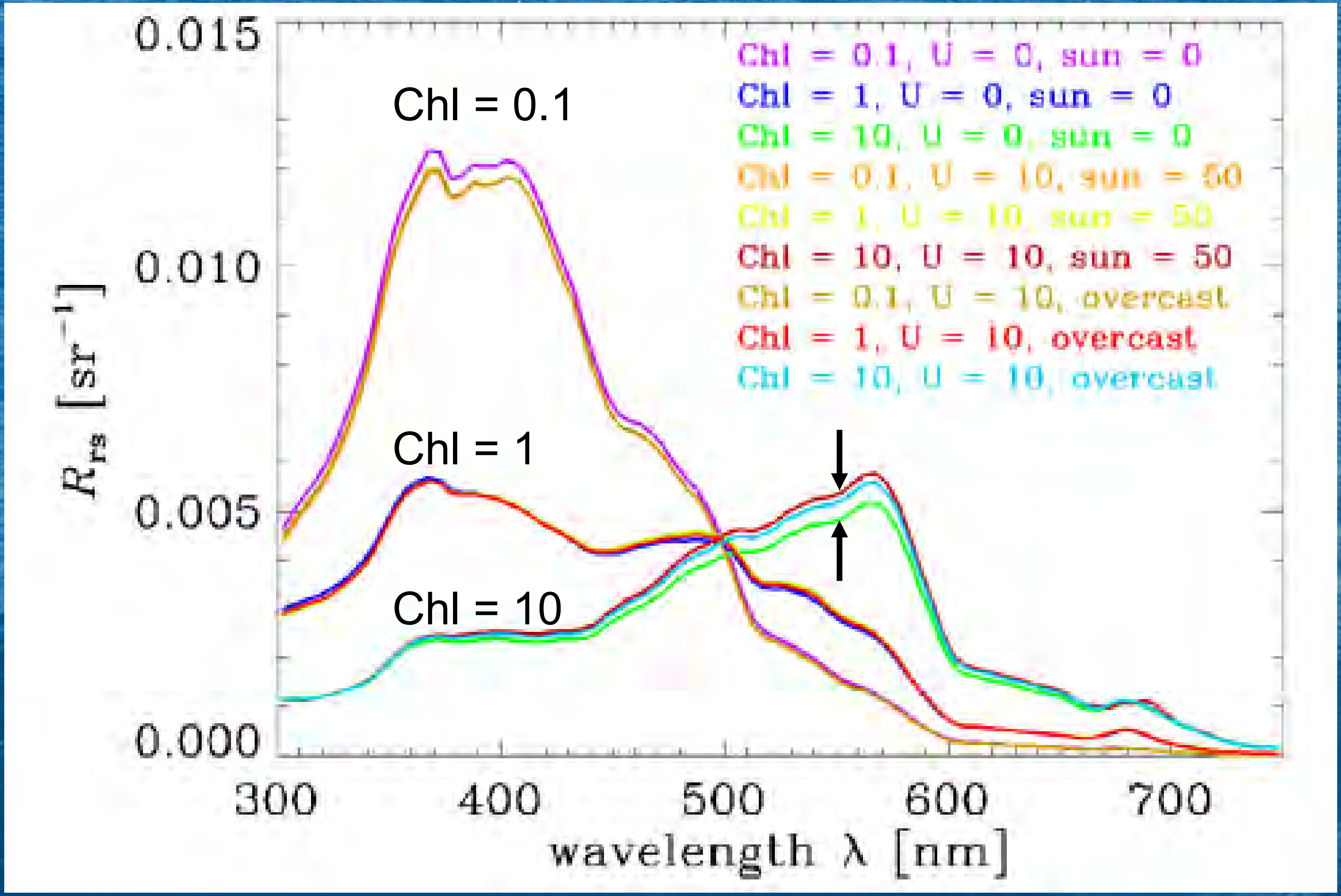
Equivalent non-dimensional reflectance: $\rho = \pi R_{rs}$

Dependence of $R = E_u/E_d$ on IOPs and Environmental Conditions



Curves separate by *Chl* value, but still show a significant dependence on sky conditions and wind speed. Can we find a better AOP?

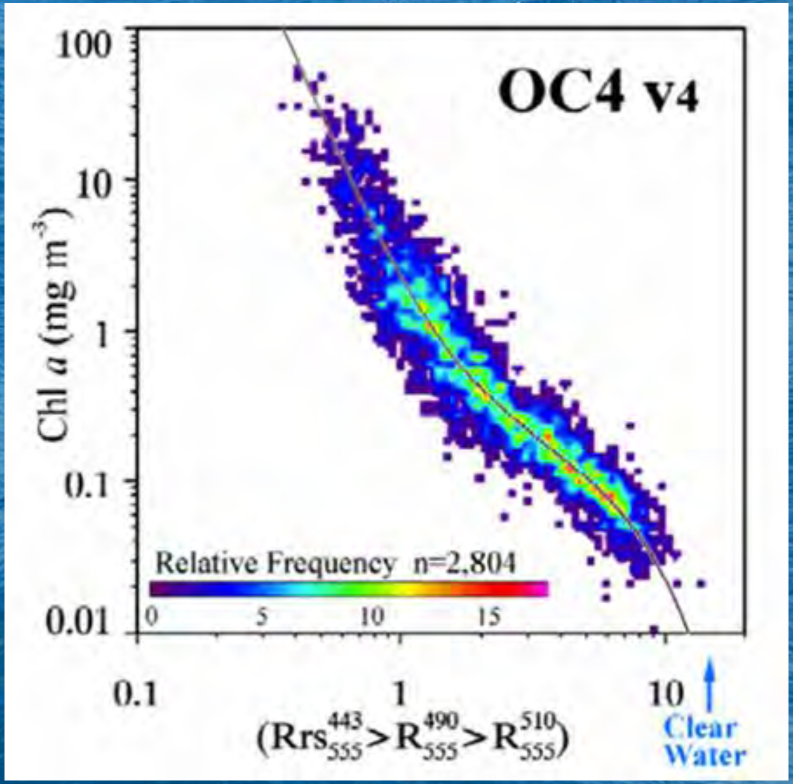
Dependence of R_{rs} on IOPs and Environmental Conditions

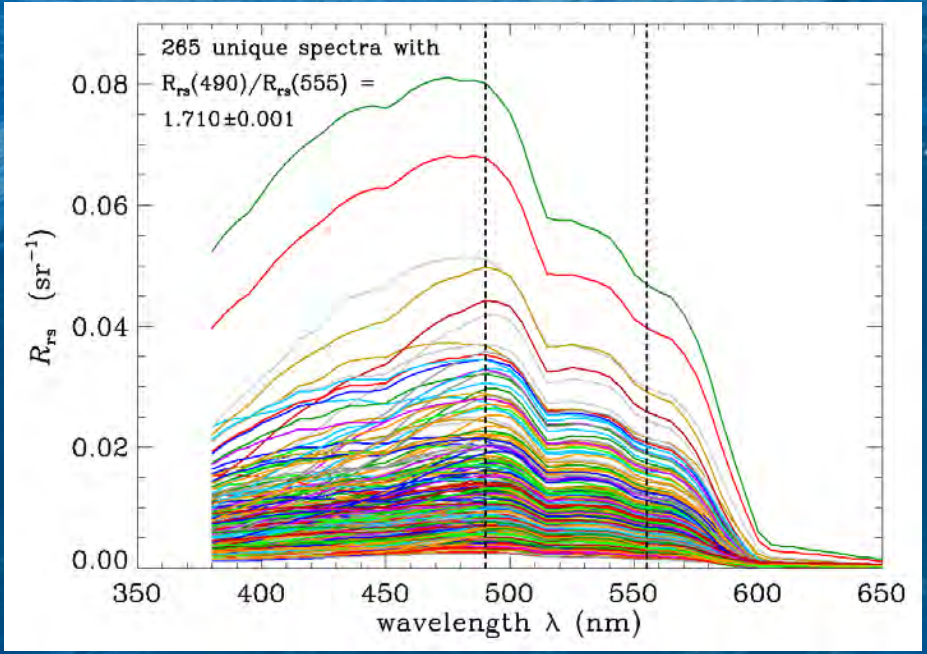


Curves separate by *Chl* value, and show very little dependence on sky conditions and wind speed: R_{rs} is a much better AOP than R.

Deep-water Statistical Algorithms Don't Work

Statistical or correlational algorithms for multispectral measurements (5-10 wavelengths, 10-20 nm bandwidth) work reasonably well for the open ocean (e.g., chlorophyll retrieval in phytoplankton-dominated waters with marine atmospheres)

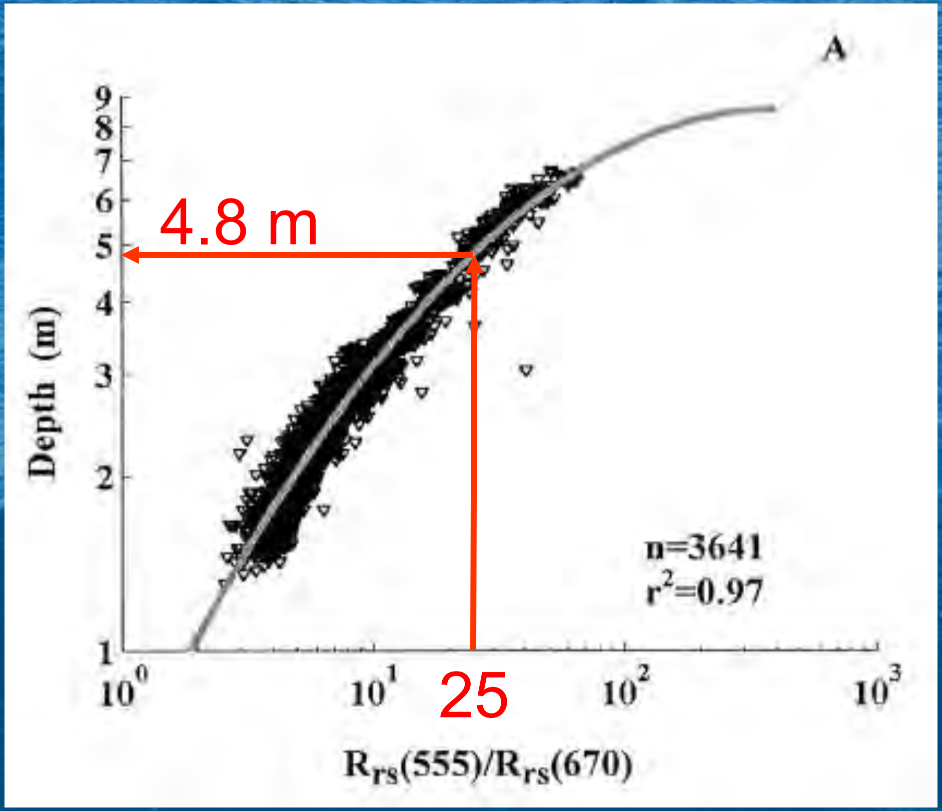




Statistical algorithms often fail in coastal waters (complex mixtures of phytoplankton, minerals, dissolved substances) and in optically shallow waters (bottom-reflectance effects)

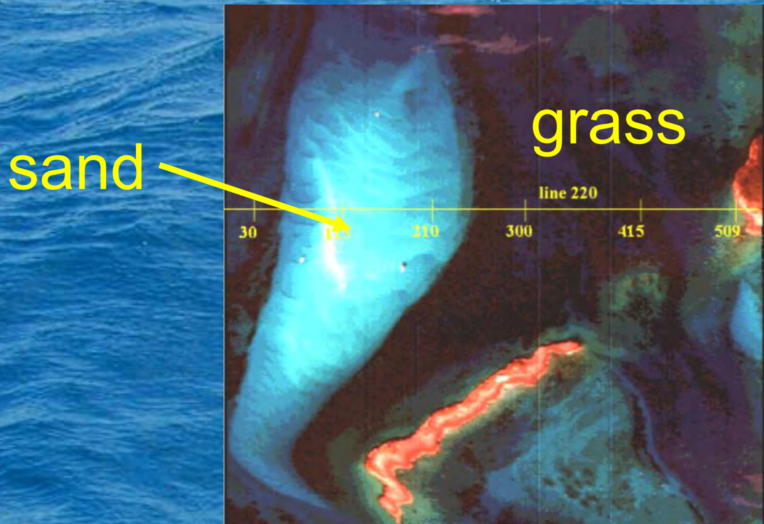
Shallow-water Statistical Algorithms Have Nonuniqueness Problems

Dierssen et al. (*Limnol. Oceanogr*. 41(1), 444-455, 2003) developed a band-ratio algorithm for bottom depth in clear Bahamas waters:

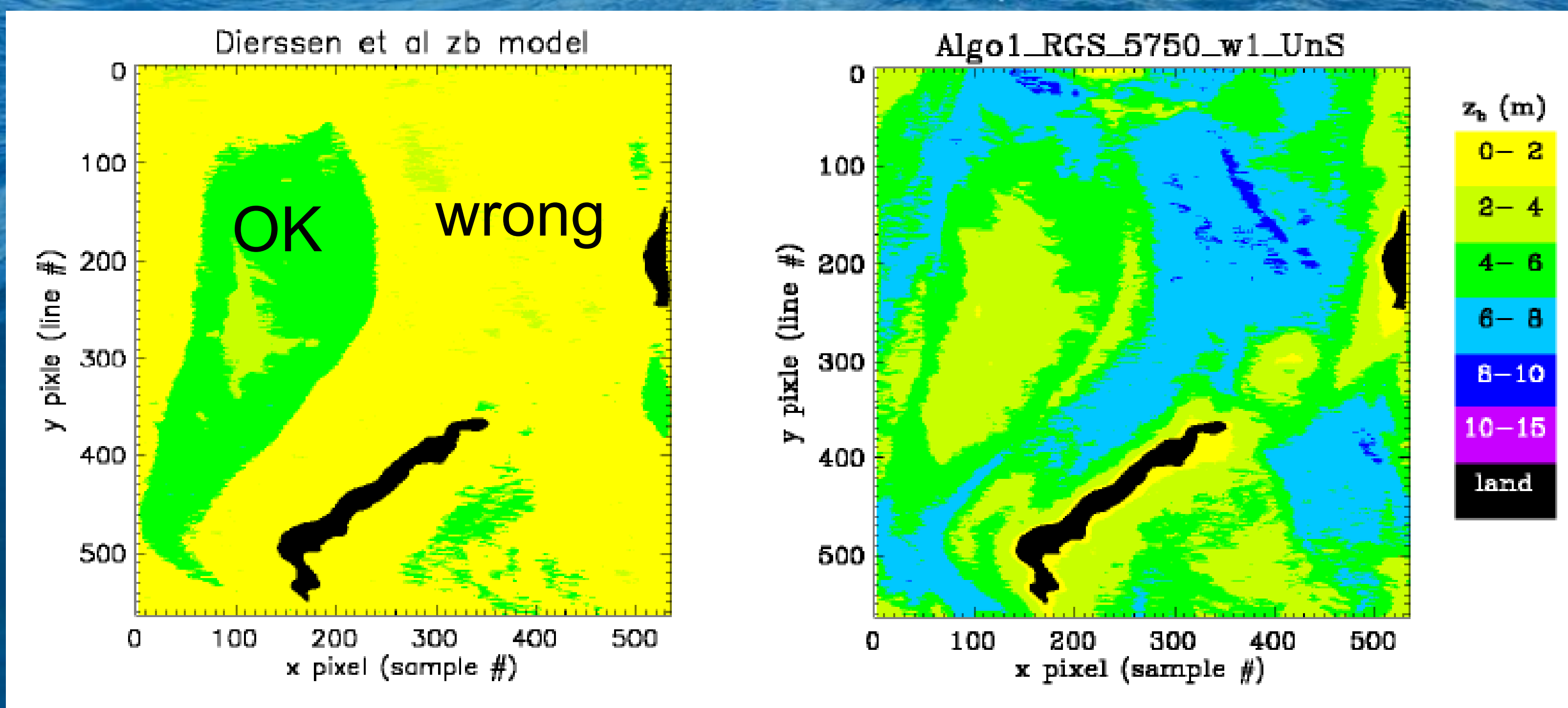


$$x = \log_{10}[R_{rs}(555)/R_{rs}(670)].$$

$$\log_{10}(z_b) = -0.1706\, x^2 + 0.8913\, x - 0.2316.$$

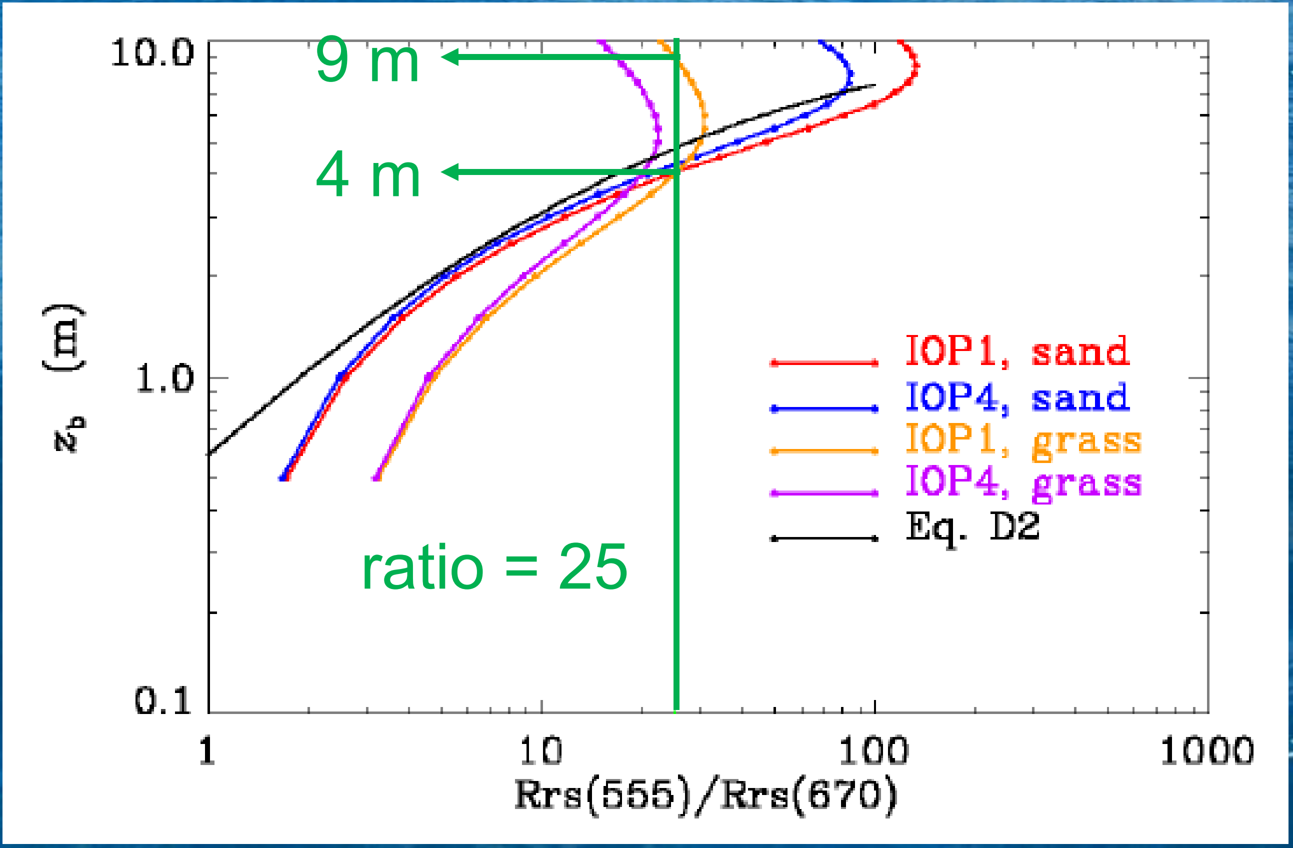


The Dierssen algorithm did OK over shallow sand bottoms, but totally failed over deeper sea grass bottoms. Why?



Nonuniqueness

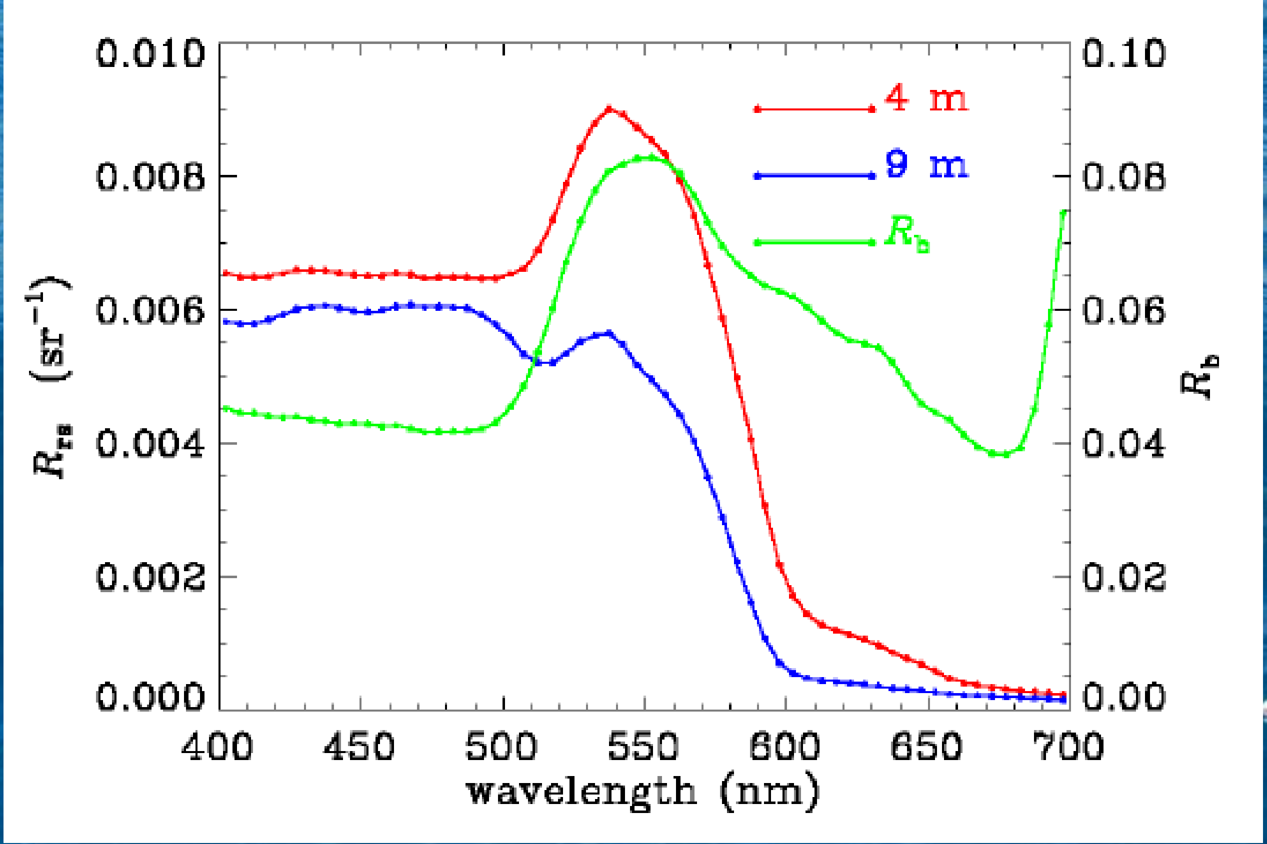
HydroLight simulations of $R_{rs}(555)/R_{rs}(670)$ for two sets of IOPs and two different bottoms (sand and grass), as a function of bottom depth. Nonuniqueness for z_b > 5 m and grass bottom.



Nonuniqueness

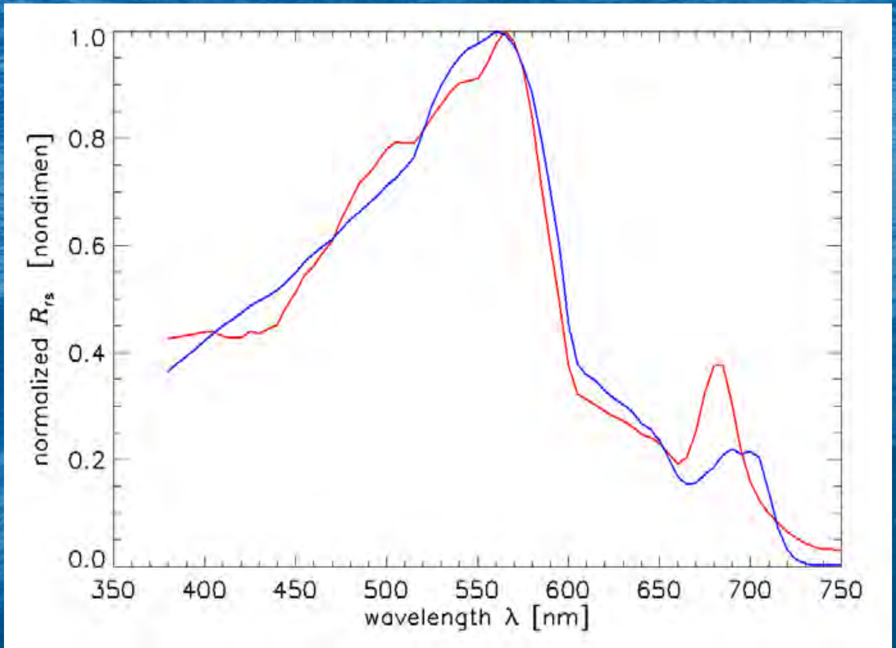
The R_{rs} spectra for z_b = 4 and 9 m depth, grass bottom, are clearly different, but both spectra have $R_{rs}(555)/R_{rs}(670) = 25 \pm 0.1$. The Dierssen model gives z_b = 4.8 m.

Need to use the full calibrated spectrum to avoid nonuniqueness



Uniqueness for R_{rs}

Having well calibrated R_{rs} spectra removes the non-uniqueness that plagues band-ratio and other techniques that depend only on spectral shape. Both spectral shape and magnitude are critical.



normalized R_{rs} spectra

Red: infinitely deep water, Chl = 10 mg m^{-3}
Blue: 2 m deep clear water, sea grass bottom

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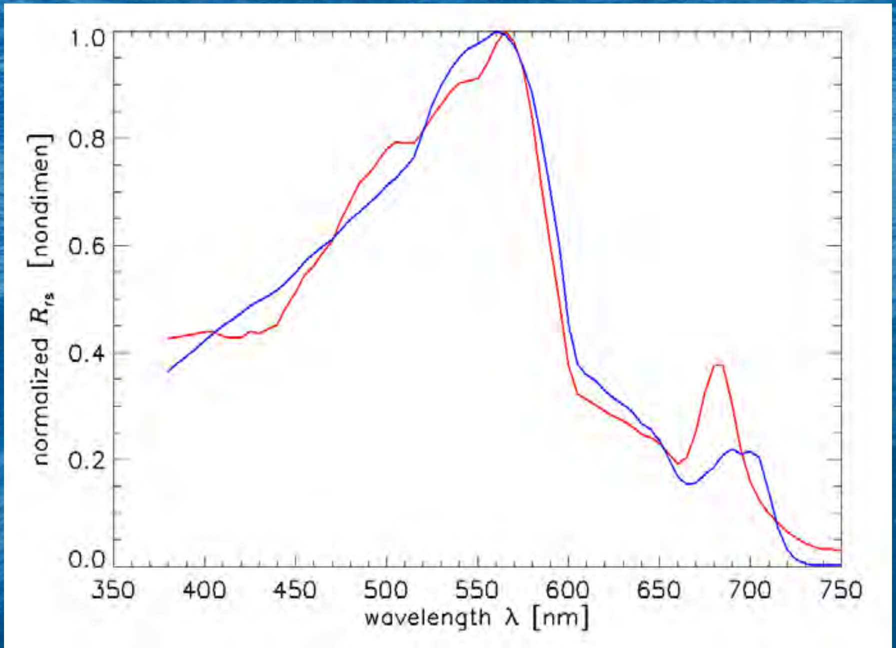
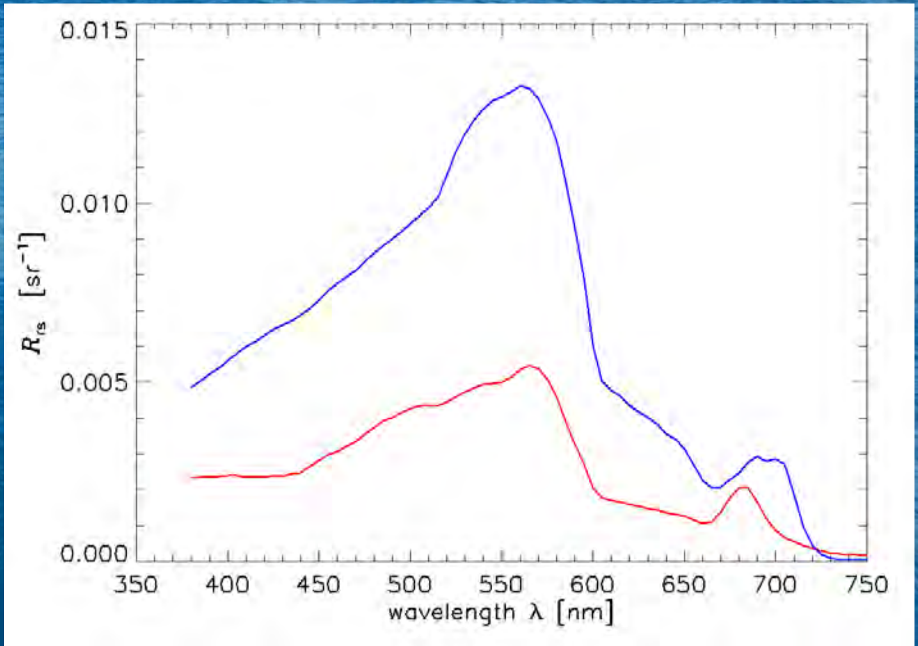


normalized R_{rs} spectra



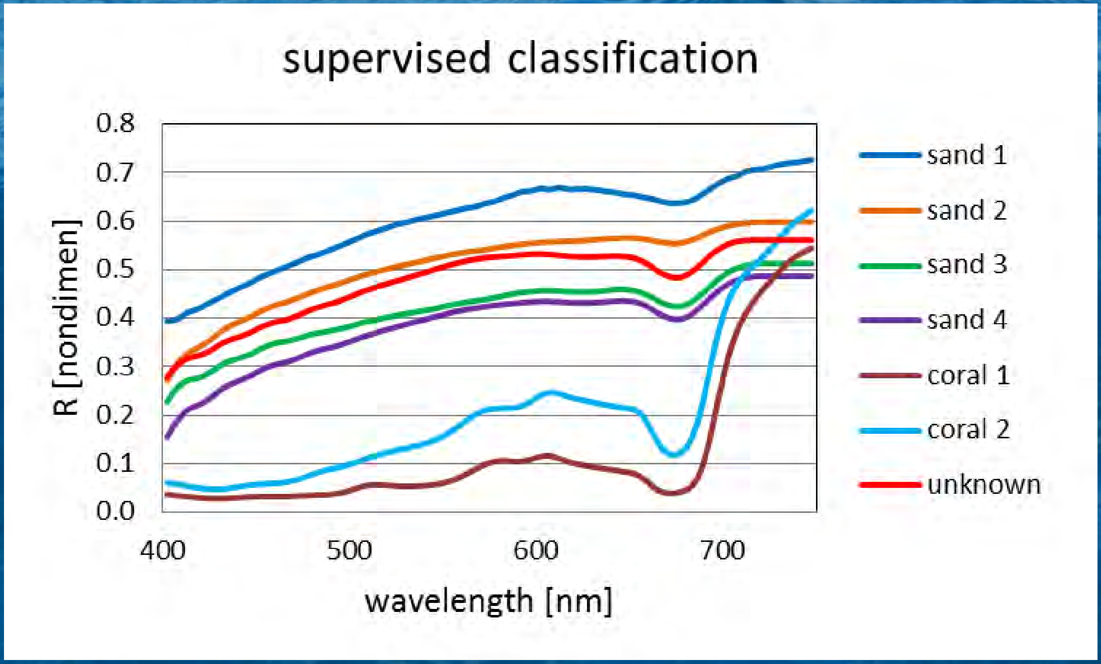
calibrated R_{rs} spectra

Red: infinitely deep water, Chl = 10 mg m^{-3}
Blue: 2 m deep clear water, sea grass bottom

Thematic Mapping Doesn't Work

Supervised classification associates a given image spectrum with one of several pre-determined classes of spectra, e.g, sand, mud, coral, sea grass. This works well if you can define classes that don't overlap much.

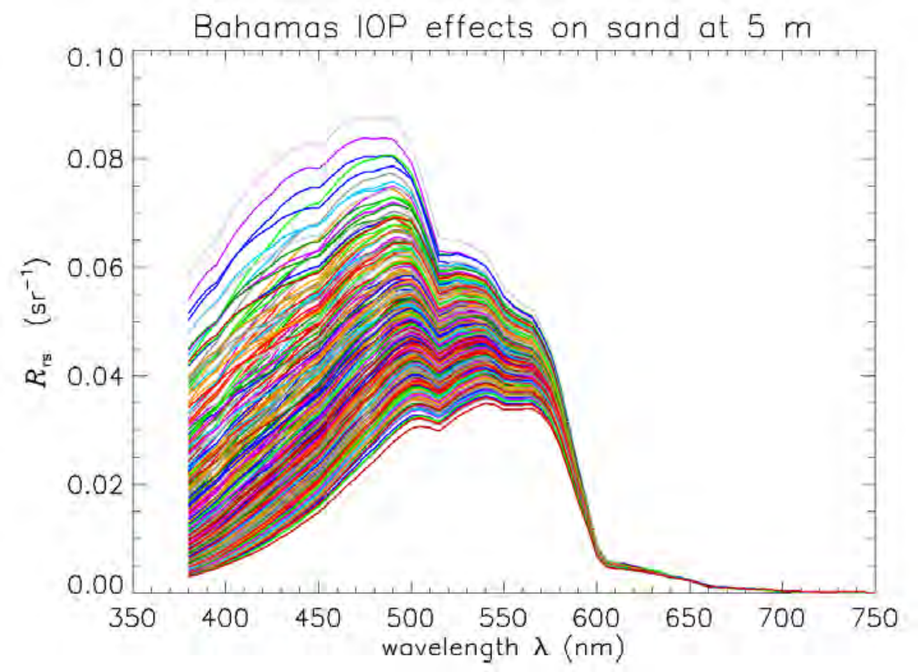
Usually use maximum likelyhood estimation to assign an unknown spectrum to one of the predetermined classes. See Richards and Jia, *Rem. Sens. Digital Image Analysis* or www.oceanopticsbook.info/view/remote_sensing/level_2/thematic_mapping for the math and numerical examples..

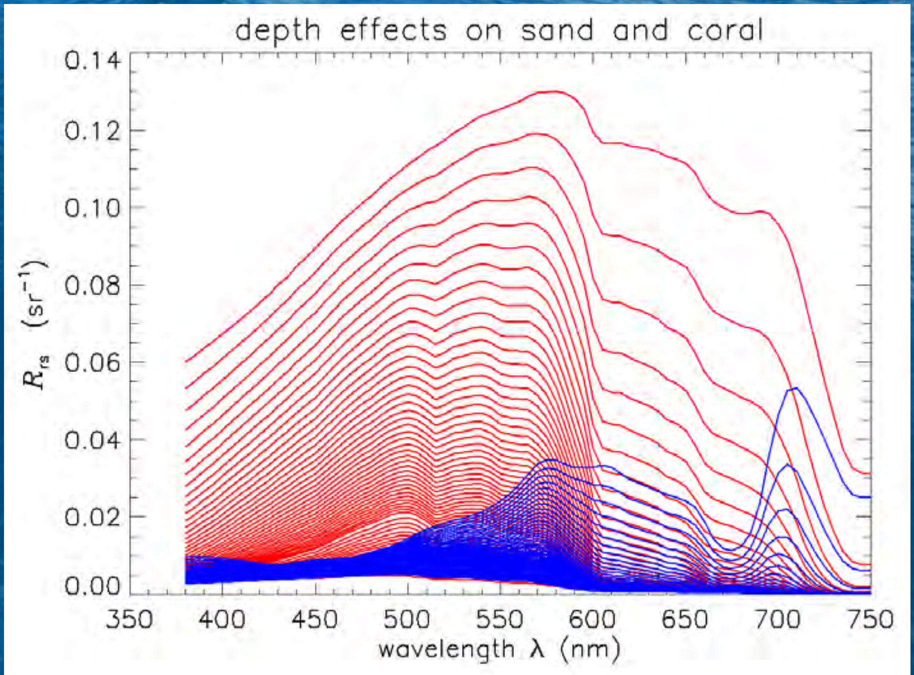


Thematic Mapping Doesn't Work for Shallow Water Remote Sensing

The effects of depth and water IOPs mean that we can't define classes in a meaningful way for bottom mapping. Every combination of bottom type, depth, and water absorption and scattering properties would be a different class.

Must to avoid the need to define predetermined classes





Where does this leave us?

Need spatial resolution of 1-10 m

Can’t use band ratio algorithms

Can’t use thematic mapping

Need high SNR for dark (compared to land) water targets

R_{rs} depends strongly on bottom depth, bottom reflectance, and water absorption and backscatter; only weakly on wind speed, sun angle, etc.

So spectrum matching to radiometrically well calibrated and atmosphericlly well corrected R_{rs} spectra might work, but we need high-wavelength-resolution (5-10 nm) R_{rs} spectra over at least 400-750 nm (350-1000 better)

How do we get these spectra?

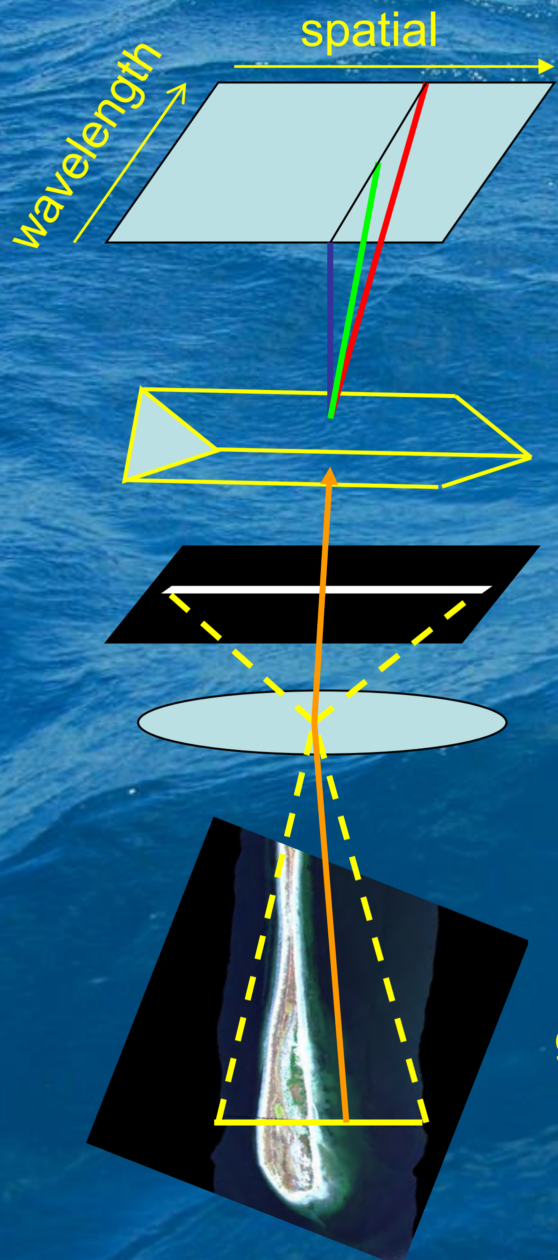
Counting Photons

You can't get meter-scale hyperspectral imagery from a polar-orbiting satellite because there just aren't enough photons reaching the TOA. See http://www.oceanopticsbook.info/view/remote_sensing/level_2/counting_photons for back-of-the-envelope estimates.

- View a larger surface area, which both increases the number of photons leaving the surface and allows for longer integration times.
- View the surface area for a longer time, e.g., from a geostationary satellite that can stare at the same point for very long times (but a geostationary satellite has an altitude of 36,000 km, which makes the solid angle much smaller).
- Increase the bandwidth.
- Increase the aperture of the receiving optics.
- Use multiple detector elements to observe the same ground pixel nearly simultaneously, either on the same or successive scans, and then combine the photons collected from the different sensors
- Get closer to the surface, e.g. by using an airborne sensor flying at a few kilometers above the sea surface. This greatly increases the solid angle of the sensor and allows for longer integration times for a slowly flying aircraft.

Fly low and slow with an airborne hyperspectral sensor

Pushbroom Optical Design



2D CCD records radiance as a function of across-track position (1024 pixels) and wavelength (128 or 256 bands)

prism disperses the light, 400-1000 nm

slit selects the across-track spatial dimension

camera optics image the ground onto a narrow slit

ground scene

build up radiance (and remote sensing reflectance) as a function of (x,y,λ) as the plane flies

Example Airborne Hysperspectral Sensors

AVIRIS: Airborne Visible/InfraRed Imaging Spectrometer (NASA, 1989). 224 bands 380-2500 nm by 10 nm. Mostly terrestrial applications; $70K/flight/scientist. Large instrument; uses a scanning mirror ("whiskbroom"); 20x20 m or 4x4 m pixels.

Ocean PHILLS: Ocean Portable Hyperspectral Imager for Low-Light Spectroscopy (US Naval Research Lab, 1999). 128 bands 400-1000 nm by 4.6 nm. 1-2 m pixel size.

SAMSON: Spectrographic Aerial Mapping System with On-board Navigation. (improved son of PHILLS; Florida Environ. Res. Inst. mid 2000's; now operated by Northrup-Grumman) 256 bands at 3.5 nm

CASI: Compact Airborne Spectrographic Imager. (ITRES) 228 bands 380-1050 nm. Commercially available and widely used.

There are some satellite hyperspectral systems:
Hyperion: (NASA; 2000) 220 bands 400-2500 nm; 30m x 30m pixels
HICO: Hyperspectral Imager for the Coastal Ocean (NRL; on ISS 2009); 380-960 nm by 5.7 nm; ~100 m pixel size. Curt Davis next week

See http://www.geo.unizh.ch/~schaep/research/apex/is_list.html for a list of imaging spectrometers. There are many more, but most are not for ocean applications.

Ocean PHILLS in Use

Data Management

One SAMSON flight typically results in a Terabyte of data.

This requires a lot of people, expertise, software, and computer power to process: radiometric calibration, geocorrection, atmospheric correction, image processing to obtain environmental information, merging of imagery and results with other types of geospatial information, archiving of imagery and results, etc. The data processing can be overwhelming.

In the course of developing and flying SAMSON, a whole new company was created just to process the data (www.weogeo.com).

see ann-and-curt.smugmug.com