Mapping optical parameters of coastal sea waters using the Hyperion imaging spectrometer — Intercomparison with MODIS

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Current Ocean Color Satellite Sensors

- CZCS, OCTS, SeaWiFS, MODIS, MERIS, GLI
- Spatial resolution: typically 1 km
  - Not suitable for coastal region
  - (MERIS has a 300 m mode)
- Number of spectral bands: 6 – 12
  - OK for deep ocean
  - Insufficient for coastal waters
High Resolution Satellite Sensors

• Typically designed for land observation
• e.g. Landsat, SPOT, IKONOS
• High spatial resolution, 1 m to 30 m
• Limited no. of spectral bands
• Broad bandwidth
  – High SNR, but lack spectral specificity
Hyperspectral Satellite Sensor

- EO-1 Satellite, launched Nov 2000, first satellite in NASA's New Millennium Program Earth Observing series
- Primary Aim: To develop and test a set of advanced technology land imaging instruments
- Hyperion: first space-borne hyperspectral instrument
  – Over 200 spectral bands, with high spatial resolution of 30 m
Hyperion Imaging Spectrometer

- No. of bands: 220
  - 200 bands selected for processing
- Spectral range: 357 to 2576 nm
  - 436 to 2406 nm selected for processing
- Bandwidth: 10 nm (nominal)
- Pixel size: 30 m
- Swath: 7.5 km across track
- SNR designed for land observation
  - SNR: 192 (550 nm), 140 (700 nm)
  - Is it useful for coastal sea/ocean applications?
Reflectance Measurement

Sun

Scattering by atmosphere

Reflection from water surface

Transmission through the atmosphere

Air-Water Boundary

Transmission through the water-air boundary

Scattering by water and its constituents

Spectrometer
Model of Hyperion Top-of-Atmosphere (TOA) Reflectance

\[ R(\lambda) = T^\uparrow T^\downarrow \left[ \frac{(1-r)^2}{n^2} R_w + r \right] + R_p \]

- \( n \): water refractive index = 1.33
- \( r \): water surface reflectance
- \( R_w \): diffused water reflectance
- \( T^\downarrow \): downward transmittance
- \( T^\uparrow \): upward transmittance
Model of Diffused Water Reflectance

\[ R_W(\lambda) = 0.33 \frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)} + R_F(\lambda) \]

- \( a(\lambda) \): absorption coefficient
- \( b_b(\lambda) \): backscattering coefficient
- \( R_F(\lambda) \): chlorophyll fluorescence
Retrieval of Parameters

• Altogether 10 parameters in the model
  – Environmental parameters: A, B, α, r
  – Water parameters: $P_0$, G, X, F, S, y.
• Given a set of the parameter values, a reflectance spectrum can be calculated
• Find the set of best fit parameters that gives the smallest deviation between measured and calculated spectrum
Data Sets

- Hyperion
  - Day 137, 2001 - South China Sea, south-eastern coast of Peninsular Malaysia
  - Day 153, 2001 - Singapore Strait, south-west of the Singapore Island
- To improve SNR, apply low pass filter to Hyperion data cube, effectively reduce the resolution to about 300 m.
South China Sea
Day 137, 2001

Left: Hyperion
(start: 03:07 UTC)
R = 671nm,
G = 550nm,
B = 489nm.

Right: MODIS
(start: 03:43 UTC)
R = 667nm,
G = 551nm,
B = 490nm.

Both images are similarly stretched. The color and intensity features of both images are practically identical.
Hyperion TOA reflectance agrees very well with MODIS from 488nm to 668nm. At longer wavelengths, Hyperion reflectance is lower than MODIS.
Comparison with MODIS Level 1
TOA Reflectance

Generally high correlation: Regression coeff. $R^2 > 0.8$,
RMS difference $= 0.003$  (Except NIR wavelengths)
Comparison with MODIS Level 2
Water Leaving Reflectance

Water Leaving Reflectance at 748nm not available for MODIS (Atmospheric Correction Band)

Correlation slightly degraded: Regression coeff. $R^2 > 0.6$,
RMS difference = 0.004
Maps of Seawater Optical Parameters Derived from Hyperion Data

- Chlorophyll Absorption at 440 nm (m^{-1})
  - Range: 0 to 0.048

- CDOM Absorption at 440 nm (m^{-1})
  - Range: 0 to 0.80

- Sediment Scattering at 551 nm (m^{-1})
  - Range: 0 to 0.20
MODIS Chl-a concentration has low correlation with Chlorophyll absorption derived from Hyperion data. However, the correlation with CDOM absorption coefficient is significantly higher.
Comparison with Chlorophyll Concentration derived using SeaWiFS OC4v4 algorithm

Similar trend as before: OC4v4 Chl-a concentration has low correlation with Chlorophyll absorption, but the correlation with CDOM absorption coefficient is significantly higher.
Maps of Seawater Optical Parameters Derived from Hyperion Data

- MODIS Chlorophyll Concentration (mg/m³)
- OC4v4 Chlorophyll Concentration (mg/m³)
- Hyperion Chlorophyll Absorption at 440 nm (m⁻¹)
Singapore Strait
Southern coast of Singapore Island
Day 153, 2001
(MODIS Level 2 Ocean Color data not available, too close to land)
Rayleigh Subtracted Reflectance (Singapore Strait)

![Graph showing Rayleigh subtracted reflectance for different samples with fitted curves.](image)

**Legend:**
- #1
- #6
- #10
- #15
- #1 fitted
- #6 fitted
- #10 fitted
- #15 fitted

**Axes:**
- Y-axis: Reflectance (%)
- X-axis: Wavelength (nm)
The dark water area is due to abundance of dissolved organic matter, not lack of sediments.
Suspended Sediment Backscattering Coeff. at 550 nm

$y = 0.0123x + 0.0075$
$R^2 = 0.9277$

Dark Area

$y = 0.0144x - 0.0154$
$R^2 = 0.6337$

Bright Area

Reflectance at 550 nm, R550 (%)
Conclusions

• Hyperion data can be used to derived coastal water optical parameters
• The problem of SNR can be overcome by averaging over a larger area (10 x 10 pixels) - OK for sea water.
• A technique has been developed to derive water optical parameters from Hyperion measured reflectance spectra, by using a coupled atmosphere-seawater reflectance model.
• There is good agreement between the Hyperion TOA reflectance and MODIS level 1 TOA reflectance
Conclusions

• There is good agreement between Hyperion derived water leaving reflectance and MODIS Level 2 water leaving reflectance
• Chlorophyll absorption coefficient at 440nm retrieved from Hyperion has a low correlation with MODIS Chlorophyll Concentration.
• However, MODIS chlorophyll concentration seems to correlate well with Hyperion derived CDOM absorption coefficient.
• In situations of high CDOM, low chlorophyll, MODIS chlorophyll product seems to be sensitive to CDOM, instead of chlorophyll.