Optical Classification of Red Tide Organism *Karenia brevis* in the Coastal Waters of Gulf of Mexico

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Introduction

Algal Bloom
A rapid increase in the number of microalgae

What is a Harmful Algal Bloom (HAB)?
HAB is a bloom that produces toxins which are harmful to plants & animals.
• Diverse Mix ~ 225 species, 12 classes (~75% are dinoflagellate)
• About 200 Hot Spot around the world
• In USA, more Hot Spot in East Coast than West Coast due to ocean circulation

What causes blooms?
• Warm water temperature
• High nutrients
• Sun light
• Low turbulence
• Water stratification
• Rain
• Transition from El nino to La nina
• If we remove the consumers
• ...

What are some of the negative impacts of these HABs?
• Kill marine life by oxygen depletion, light shading, gill irritation, and toxin production
• Cause millions of dollars in damages yearly to fisheries and aquaculture facilities
• Decrease revenues for businesses in coastal areas due to water discoloration and beach closures
• Human intoxication through shellfish consumption or direct contact with the toxic species
• Toxins can also get into the air and cause harm to human such as skin and eye irritation
In situ point measurements are expensive, time consuming.

Inadequate since they don’t have sufficient spatial and temporal coverage to monitor the complex dynamic phenomena of red tide.

Ocean Color sensors are ideal tools for HABs detection due to their spatial and temporal coverage and also relatively low cost.

http://research.myfwc.com/
Objectives of this Study

Using modeled data develop a bloom detection and a classification technique for *K. brevis* blooms which should be less sensitive to the atmospheric correction, should use bands with maximal signal-to-noise ratios (SNR), should be applicable to multiple ocean color sensors to reduce cloud coverage, eliminate errors due to retrieval algorithms, and should be able to discriminate *K. brevis* blooms from other bloom-like features such as CDOM plumes, sediment plumes, and bottom reflectance.
Karenia brevis

- Usually occur in late summer/fall (August to February)
- Impacts several states in Gulf of Mexico (a regional problem)
- Initiate in nutrient-poor waters located between 18 and 74Km offshore
- The water appears “red” in color - known as the red tide
- Fish kills, marine mammals may die, human concerns
- Absorbs strongly and scatter weakly due to large size (18-45µm) and low index of refraction (1.05)
- Co-exist with very low mineral particles
- Relatively slow growing doubles every 3-5 days and cannot out-compete other diatom or any other type of Bloom
- Temperature tolerance 15-30 °C and Salinity tolerance (25-45) ppt (parts per thousand)
Triggering Mechanisms of *K. brevis*

Images courtesy of the SeaWiFS Project and the Scientific Visualization Studio, NASA Goddard Space Flight Center and ORBIMAGE.

Stumpf et al., 2008
Spectral shapes of different constituents in water

\[ R_{rs}(\lambda) = \frac{Lw(\lambda)}{E_d(\lambda)} \]

\[ R_{rs}(\lambda) \sim \frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)} \]
Blue-green spectral region:

- Strong reflection from inorganic particles and shallow bottom
- Phytoplankton and CDOM absorbs blue and blue-green light and CDOM don’t correlate with phytoplankton in coastal waters so it is hard to tell which caused lower reflectance
- Uncertainty due to inappropriate atmospheric correction is higher
- Chlorophyll retrieval for extreme blooms (> 100 mg/m³) may often be inaccurate due to signal-to-noise errors

Red spectral region:

- CDOM absorption is negligible
- Chlorophyll has a absorption peak
- Fluorescence emission of chlorophyll
- Pure seawater absorption (well known)
- High Signal-to-Noise (SNR) ratio
Some satellite detection techniques for *K. brevis*

**Backscattering/Chl ratio:**
- Chlorophyll concentrations greater than 1.5 mg/m^3 and
- bbp(550) values less than the modeled Case 1 relationship (Morel, 1988)

**Disadvantages:**
- False positive bloom detection in CDOM rich waters
- Uncertainty due to retrieval and atmospheric correction algorithms

**Chlorophyll anomaly:**
\[ [\text{Chl}]_0 - [2 \text{ Mo. Mean Chl}]_{t-2wks} > 1 \text{mg/m}^3 \]

**Disadvantages:**
- False positive/negative bloom detected due to chlorophyll retrieval algorithms
- Uncertainty due to atmospheric correction, interference form organic and inorganic matters, and shallow bottom reflection

Cannizzaro et al., 2004

Stumpf et al., 2003
**Detection Algorithm:**

Red Band Difference (RBD)

\[ RBD = nLw(\lambda_2) - nLw(\lambda_1) \]

\[ \lambda_1 = 667\text{nm for MODIS and 665nm for MERIS} \]
\[ \lambda_2 = 678\text{nm for MODIS and 681nm for MERIS} \]

**Classification Algorithm:**

Karenia brevis Bloom Index (KBBI)

\[ KBBI = \frac{nLw(\lambda_2) - nLw(\lambda_1)}{nLw(\lambda_2) + nLw(\lambda_1)} \]
Particulate backscattering for *K. brevis* and non-*K. brevis* blooms are modeled based on the cell concentrations of *K. brevis* according to [Cannizzaro et. al 2004] and non-*K. brevis* simulated using standard bio-optical model assuming background concentration of NAP = 2 mg/l.

Chlorophyll ranges between 1 and 100 mg/m^3
Discrimination of *K. brevis* from *Trichodesmium* blooms

Walsh et al., 2006
Hu et al., 2005
FLH alone cannot discriminate between bloomed waters and highly scattering waters. However, both the RBD or KBBI could easily distinguish between the two types of waters: since they both result in negative values in the highly scattering waters and positive values in the bloomed waters.
The RBD technique gives similar results with either atmospheric correction algorithm because

- We are using the difference in magnitude of the reflectance signal at two adjacent red bands.
- These two bands are relatively close spectrally (667nm and 678nm), the magnitude of the optical impact of the atmosphere will be very nearly the same on either band, and thus will have no impact on the difference of the two magnitudes.
Application to regional waters

Florida

21 Jan 2005
KBBI

Texas

6 Oct 2006
KBBI
Tracing of the *K. brevis* bloom with MERIS imagery
Tracing of the *K. brevis* bloom with MODIS imagery
Advantages and Disadvantages of KBBI and RBD techniques

**Advantages**

- Errors due to retrieval algorithms are eliminated
- Variability due to atmospheric correction is minimized
- Uncertainties due to CDOM, sediment plumes, bottom reflectance, and even sensors SNR are reduced

**Disadvantages**

- The RBD and KBBI techniques often give noise values at the cloud edge pixels and spurious results for the stripe regions at the ends scan lines. However, these are easily distinguishable from blooms
- Additional errors may be introduced in the classification algorithm due to normalization, particularly when CDOM is very high and NAP is very low or due to inappropriate atmospheric correction algorithm. However, such problems are eliminated by the RBD technique.

Variability of quantum yield
The RBD and KBBI techniques are introduced as efficient tools for *K. brevis* bloom detection and classification respectively.

Our result shows the advantages of applying RBD and KBBI technique over other traditional algorithms such as standard FLH to correctly identify the potential bloom area and to distinguish *K. brevis* from other blooms, plumes, sediments, and even shallow bottom reflectance.

Technique developed was successfully applied to the satellite (MODIS and MERIS) to detect and monitor *K. bervis* blooms.

Quantification of extreme bloom event ( > $100 \text{mg} / m^3$ ) may be improved using RBD data since a strong correlation was observed between RBD and *K. brevis* bloom waters.

Upon future validation, the detection and classification techniques developed in this study may be used in the current and future monitoring programs to explore more accurately the dynamics of bloom formation.
Acknowledgments

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