# Remote detection of HABs in the Gulf of Mexico: Alerts for resource management


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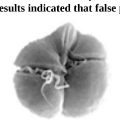
## INTRODUCTION

WFS *K. brevis* bloom, October 2001
Photo courtesy of C.Heil

Harmful algal blooms (HAB) of the toxic dinoflagellate *Karenia brevis* occur regularly in the Gulf of Mexico causing fish and marine mammal mortalities and human respiration irritation. Tourism and commercial fishing industries are often negatively impacted when blooms occur, with Florida losses estimated at ~$25M/year. Bloom concentrations above background levels (1-10³ cells l⁻¹) are typically observed in late summer and fall and concentrate most heavily along the central west Florida shelf (WFS) (~26-28°N).

Based on shipboard radiometry, a method was developed in 2004 to classify *K. brevis* populations (>10⁴ cells l⁻¹) based on low backscattering-to-chlorophyll ratios and quantify blooms using fluorescent line height (FLH) data (Cannizzaro et al., accepted; see Algorithm Description below).

Earlier this year, this technique was validated using 2005 shipboard data. Results indicated that false positive classifications occurred during a rare non-toxic dinoflagellate (*Scrippsiella sp.*) bloom and false negative classifications occurred in post-hurricane imagery when backscattering-rich suspended sediments were still present.

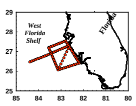


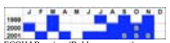
*Karenia brevis*
Photo courtesy of FWRI

Here, the technique is further validated using MODIS Aqua data from 2005. Also shown are examples of the early alerts and ecological model validation data that have been provided this year to Florida's Fish and Wildlife Research Institute (FWRI) and J.J. Walsh (USF).

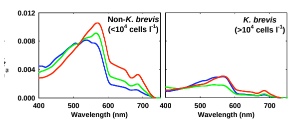
## ALGORITHM DESCRIPTION

Multi-year, multi-season ship data (1999-2001) were collected on the WFS as part of the Ecology and Oceanography of Harmful Algal Blooms (ECOHAB) program (Cannizzaro et al., accepted).



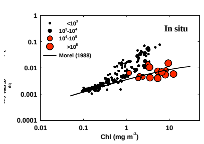



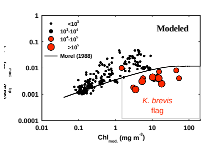

ECOHAB cruises (B=bloom present)




← Median $R_{rs}$ for Chl's:
1-2 mg m⁻³
2-5 mg m⁻³
5-10 mg m⁻³

- *K. brevis* blooms are ~4x's less reflective than non-*K.brevis* blooms.

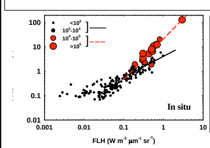



↑ *K. brevis* blooms (>10⁴ cells l⁻¹) exhibit low chl-specific $b_{bp}$ relative to high-chl, diatom-dominated estuarine blooms

- Modeling results (not shown) indicate that particulate backscattering and NOT absorption is responsible for the four-fold decreased reflectivity observed in *K. brevis* blooms (Cannizzaro et al., accepted).

↑ Similar patterns were observed when $b_{bp}(550)$ and Chl were modeled semi-analytically from shipboard $R_{rs}(\lambda)$ data (Carder et al., 1999) indicating that satellite radiometric data (SeaWiFS and MODIS) may be used to identify *K. brevis* blooms from space.




← Chlorophyll concentrations in positively identified blooms can then be quantified using fluorescence line height (FLH) data provided by MODIS.

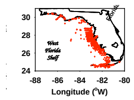
- However, since *K. brevis* bloom and non-bloom waters exhibit differing fluorescence efficiencies, bloom identification prior to chlorophyll estimations is important.

## 2005 BLOOM: ALGORITHM VALIDATION

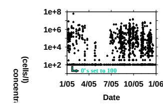
***K. brevis* classification technique was validated using 2005 MODIS Aqua (1km) and FWRI HAB data**

### FWRI HAB data:

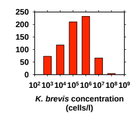
- Surface data only
- Bottom depths (NOAA-NGDC model) < 5m omitted
- *Karenia* species (*K.brevis*, *K. mikimotoi*, *K. papilionacea*, *K. selliformis*, *K.* "mexican hat") summed together
- Tampa Bay and <24°N (i.e. Florida Bay and Florida Keys) data omitted




↑ FWRI HAB data locations for 2005



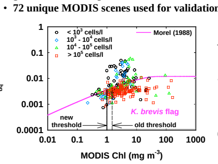

↑ FWRI bloom concentrations (>10⁴ cells l⁻¹) observed mostly from January-April and July-December




↑ FWRI data distribution skewed (i.e. not representative of natural distributions)

### MODIS Aqua (1km) data:

- Level-1 MODIS data retrieved from NASA DAAC and processed using SeaDAS (version 4.9) software
- Chlorophyll concentrations and particulate backscattering values, $b_{bp}$, obtained semi-analytically (Carder et al., 1999)
- Valid same-day MODIS data available for 31% (=261/864) of FWRI groundtruth data points
- 72 unique MODIS scenes used for validation




- *K.brevis* cell concentrations greater than 10⁵ cells l⁻¹ generally exhibit low chl-specific $b_{bp}$
- Original Chl threshold changed from 1.5 mg m⁻³ to 1.0 mg m⁻³ to minimize false negative classifications

(See error analysis in next column)

### Error Analysis:

**Example error matrix**

| Classified data | Reference data: bloom | Reference data: non-bloom |
|---|---|---|
| bloom | 139 (true positive) | 26 (false positive) |
| non-bloom | 34 (false negative) | 62 (true negative) |

**Accuracy calculations**

- Overall accuracy: 77% (=201/261)
- Producer's accuracy: positive: 80% (=139/173); negative: 70% (=62/88)
- User's accuracy: positive: 84% (=139/165); negative: 65% (=62/96)

**Interpretation**

(*K. brevis* cell concentration threshold for this example is 10⁴ cells l⁻¹)

- 80% (70%) of data with *K. brevis* concentrations greater than (less than) 10⁴ cells l⁻¹ are correctly classified
- 84% (65%) of points that are positively (negatively) classified have cell concentrations greater than (less than) 10⁴ cells l⁻¹

(Congalton, 1991)

Accuracy of *K. brevis* classification technique for changing *K. brevis* cell concentration thresholds:

| *K.brevis* threshold (cells/l) | True positive | False positive | True negative | False negative | Total | Overall accuracy | % Producer accuracy (positive) | % Producer accuracy (negative) | % User accuracy (positive) | % User accuracy (negative) |
|---|---|---|---|---|---|---|---|---|---|---|
| >1 * 10⁴ | 139 | 26 | 62 | 34 | 261 | 77% | 80% | 70% | 84% | 65% |
| >5 * 10⁴ | 122 | 43 | 72 | 24 | 261 | 74% | 84% | | | 75% |
| >1 * 10⁵ | 106 | 59 | 81 | 15 | 261 | 72% | 88% | | | 84% |
| >5 * 10⁵ | 51 | 114 | 91 | 5 | 261 | 54% | 91% | | | 95% |
| >1 * 10⁶ | 25 | 140 | 94 | 2 | 261 | 46% | 96% | | | 98% |

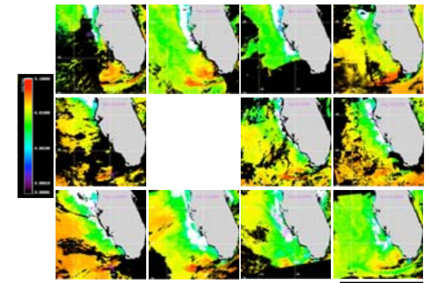
- ↑ 88% of points with greater than 10⁵ cells l⁻¹ (e.g. when fish kills occur) are correctly flagged as red tides; accuracy changes by 8% for one order of magnitude change in *K. brevis* cell concentration threshold
- 84% of points that are positively classified as red tide contain *K. brevis* cell concentrations greater than 10⁴ cells l⁻¹
- Negative producer accuracies and positive user accuracies not shown for *K. brevis* concentrations greater than 5 * 10⁵ because they are diluted down by red tides of lower concentrations

Accuracy of *K. brevis* classification technique for changing regions, seasons, and bottom depths (*K. brevis* cell concentrations threshold is 10⁴ cells l⁻¹):

| Region | Season[1] | Minimum bottom depth | True positive | False positive | True negative | False negative | Total | Overall accuracy | % Producer accuracy (positive) | % User accuracy (positive) | % User accuracy (negative) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 25-31°N | all | > 5m | 139 | 26 | 62 | 34 | 261 | 77% | 80% | 84% | 65% |
| 24-25°N | " | " | 3 | 3 | 57 | 43 | 106 | 57% | 7% | 50% | 57% |
| 25-31°N | Bloom | " | 125 | 15 | 52 | 32 | 224 | 79% | 80% | 89% | 62% |
| " | Non-bloom | " | 14 | 11 | 10 | 2 | 37 | 65% | 88% | 56% | 83% |

↑ Classification technique is more accurate:

- north of 25°N because south of this latitude (e.g. Florida Bay and Florida Keys) only 7% ( or 3/46) of blooms are correctly identified due to highly backscattering suspended sediments
- during typical bloom periods (i.e. non-summer) (44% (=100-56%) of time an area is classified as a bloom during summer, it is NOT a bloom)



+ <10⁴ cells l⁻¹
△ 10⁴ – 10⁵ cells l⁻¹
□ >10⁵ cells l⁻¹

↑ 11 of the 72 2005 MODIS Aqua validation scenes. Shown are $b_{bp}(551)$/Chl imagery with positively flagged *K.brevis* regions (i.e. Chl>1.0mg m⁻³ and $b_{bp}(551)$ less than Morel (1988) relationship) masked in white. FWRI validation data are overlaid on top of each plot (<10⁴ cells l⁻¹ (crosses); 10⁴–10⁵ cells l⁻¹ (triangles); >10⁵ cells l⁻¹ (boxes))

### Bloom chronology:

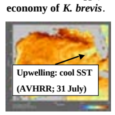
- Bloom originated ~30 miles offshore of west coast of Florida in January 2005
- Reports of manatee deaths (92=year total) due to red tide began in March following onshore transport of bloom
- April-May FWRI HAB validation data indicates that bloom diminished; classified MODIS imagery, however, suggests that bloom moved northward (>28°N) and was never sampled
- June validation imagery unavailable due to clouds
- Bloom reappeared alongshore between Tampa Bay and Charlotte Harbor (~26-28°N) in July and August, strengthened September to November, and diminished in December
- False positive classifications in August due to rare bloom of non-toxic dinoflagellate (*Scrippsiella sp.*) [Strong vertical stratification during this time led to severely anoxic conditions which caused a devastating benthic mortality event; such conditions had not occurred to such a high degree since 1971!]

## 2006 BLOOM: AGENCY ALERTS

During the summer and fall seasons of 2006, nine useable MODIS Aqua images were classified for use for red tide alerts to the Florida Fish and Wildlife Research Institute and for validating and updating ecological models (e.g. Walsh et al. 2006). Products for four of these images are shown to the right together with maps of FWRI validation data.

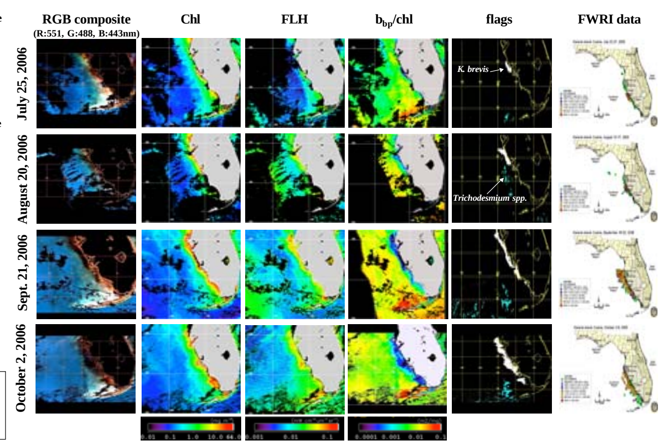
Note that high-Chl, high-FLH, and low $b_{bp}$/Chl regions that appear reddish-brown in the RGB composite were flagged (white) as *K. brevis*, while low-Chl, high $b_{bp}$/Chl, relatively deep (>30m) regions that appear blue-green in the RGB composite are flagged (cyan) as *Trichodesmium spp*. Comparisons between the MODIS flagged images and the FWRI in situ data indicates that the *K. brevis* classification technique adequately flagged regions with high *K. brevis* concentrations.

Imagery showing upwelling (below left) and Saharan dust events (below right) in the Gulf of Mexico were also provided to modelers. Walsh and Steidinger (2001) contend that wet deposition of Saharan aerosols in the eastern Gulf of Mexico may alleviate the iron limitation of diazotrophic cyanophytes (i.e. *Trichodesmium spp.*) which in turn fuel the nitrogen economy of *K. brevis*.



Upwelling: cool SST (AVHRR; 31 July)

Saharan dust: (SeaWiFS; 1 Aug.) RGB composite R:667nm G:551nm B:412nm




## CONCLUSIONS

- Using the *K. brevis* classification criteria developed by Cannizzaro et al. (accepted) (adjusted to include Chl's greater than 1 mg m⁻³) with 2005 MODIS Aqua and FWRI groundtruth data:
  - 80% of points with *K. brevis* concentrations greater than 10⁴ cells l⁻¹ are positively flagged, and
  - 84% of points that are positively classified as red tide contain *K. brevis* cell concentrations greater than 10⁴ cells l⁻¹
- Majority of false positive and false negative points in 2005 were located at bloom edges (i.e. effects of subpixel variability and/or mixing)
- Previous efforts revealed that
  - Rare, non-toxic dinoflagellate blooms of *Scrippsiella sp*. (24 Aug 2005) are responsible for several positively flagged points containing fewer than 10⁴ *K. brevis* cells l⁻¹ and may partially explain why the *K. brevis* classification technique is less accurate during summer months
  - False positive classifications may occur when gelbstoff:phytoplankton absorption ratios are high
  - False negative classifications may occur due to bottom reflectance, high suspended sediments (i.e. post-hurricanes), and co-existing populations of *K. brevis* and $b_{bp}$-rich *Trichodesmium spp*.

## FUTURE DIRECTION

- Provide confidence levels in future alerts to inform resource managers where blooms are strongest
- Flag gelbstoff-rich waters (Carder et al., 1999), optically shallow waters (Cannizzaro and Carder, 2006), and water with high suspended sediment levels to alert resource managers as to regions where confidence in *K. brevis* classifications is low
- Develop computer code incorporating new flagging techniques to be shared with resource agencies
- Further validate and refine *K. brevis* classification technique using SeaWiFS data
- Continue to provide alerts to FWRI and initiation/validation data for ecological models to J.J.Walsh


### ACKNOWLEDGEMENTS

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