Refining *Karenia brevis* Detection: An Assessment of Ensemble Imagery Products for Operational Forecasting

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Introduction

The Harmful Algal Bloom Operational Forecast System (HAB-OFS) employs a combination of automated processing and manual analyses of data to create decision support tools and products to mitigate HAB impacts. Satellite ocean color imagery is a key component of this analysis, used for early detection and monitoring of *Karenia brevis* bloom location, movement and intensification in the Gulf of Mexico. Moderate Resolution Imaging Spectroradiometer (MODIS) Aqua imagery, provided by NOAA's CoastWatch Program, is processed using an algorithm that highlights areas of anomalously high chlorophyll.[1] Although the chlorophyll anomaly product is effective, it is not *K. brevis*-specific and may highlight blooms of other algal species. To refine *K. brevis* detection, an ensemble approach[2] was evaluated that combined the currently used chlorophyll anomaly with algorithms that target specific properties of *K. brevis* blooms - the relative particulate backscatter and the spectral shape characteristics in the blue-green portion of the spectrum, centered on 490 nm. A comparative analysis of the current chlorophyll anomaly product and the ensemble products was performed on a sample set of images from the southwest Florida coast between April 2010 and December 2013. Results from the evaluation indicated that the ensemble imagery products performed better than the chlorophyll anomaly alone 77.5% of the time, decreasing false positives, targeting the spatial extent of *K. brevis* blooms more specifically than the chlorophyll anomaly alone, and reducing the over-prediction of bloom presence. Based on these results, the ensemble product was transitioned to operations and incorporated into the HAB-OFS bulletins beginning in September 2015.

Objective

Evaluate the effectiveness of ensemble satellite imagery products at detecting *K. brevis* blooms compared to chlorophyll anomaly satellite imagery products.

Methods

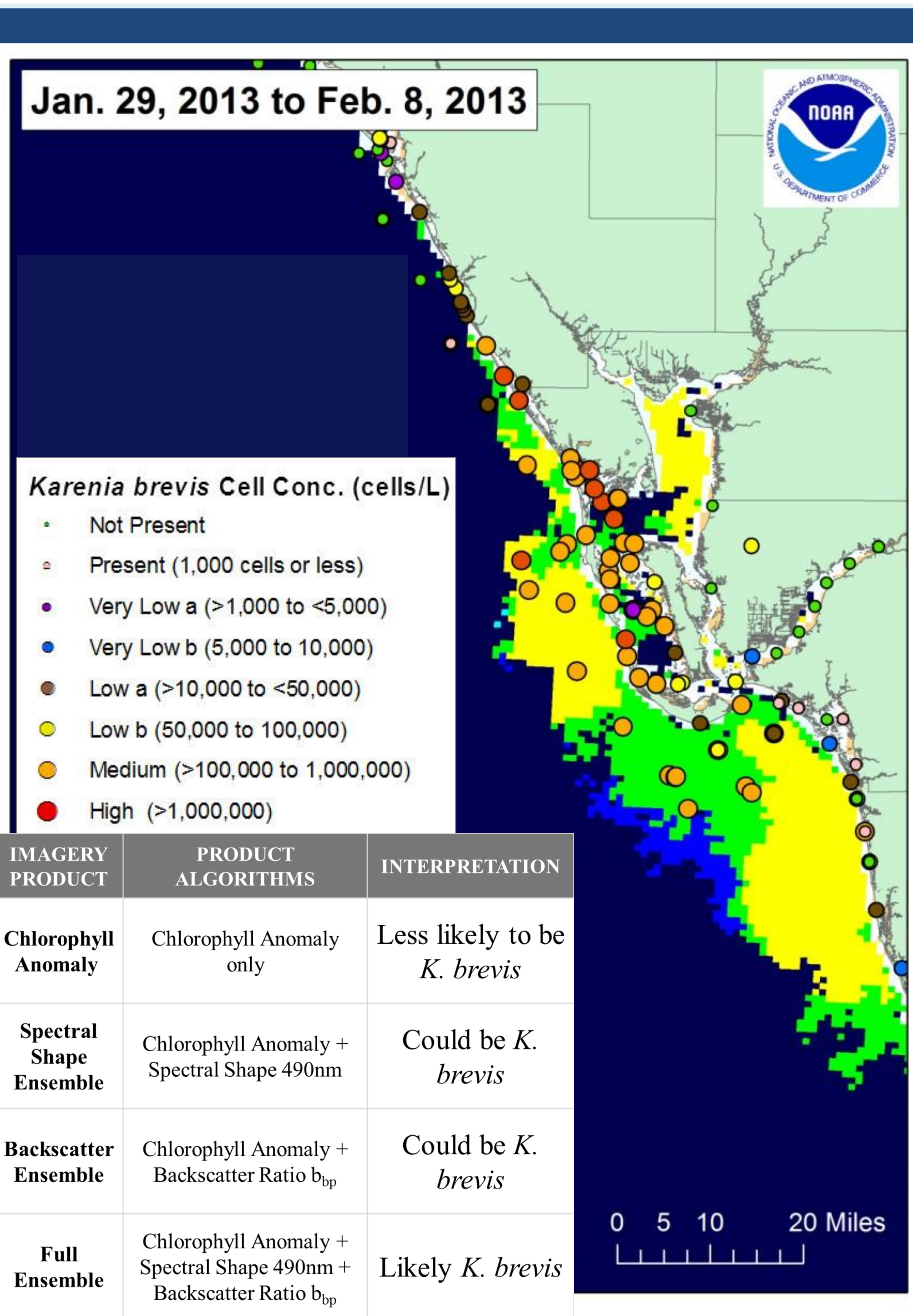
Study Region

- Coastal southwest Florida from Pinellas to Monroe counties, including Florida Bay and Florida Keys region.
  - Focus on bloom initiation area offshore from approximately Tampa to Cape Romano.
  - Bays and inland waterways excluded due to satellite imagery resolution.

Figure 1. Study region map, highlighting the bloom initiation area offshore SW Florida from Pinellas to Collier counties.

Assessment

- **Imagery Assessment**
  - Compared chlorophyll anomaly and ensemble MODIS Aqua imagery
  - Clear, cloud-free images from April 2010 – December 2013 (~100 images)
  - Manual imagery analysis of each ensemble product validated using *K. brevis* water samples (>50,000 cells/L) collected up to 3 days before and after each image date
    - Only ensemble flags greater than 5x5 pixels considered
- **Ensemble Products** (see Figure 2)
  - ***Spectral shape at 490nm***: accounts for changes in the Rrs spectral shape at 490nm combined with the chlorophyll anomaly algorithm [3,4]
  - ***Backscatter ratio*** b_{bp}: accounts for differences in particulate backscatter (b_{bp}) spectra between K. brevis blooms and non-K. brevis blooms combined with the chlorophyll anomaly algorithm[5,6]
  - ***Full ensemble***: includes the above ensemble products and the chlorophyll anomaly algorithm



PIXEL COLOR	IMAGERY PRODUCT	PRODUCT ALGORITHMS	INTERPRETATION
(blue)	**Chlorophyll Anomaly**	Chlorophyll Anomaly only	Less likely to be *K. brevis*
(green)	**Spectral Shape Ensemble**	Chlorophyll Anomaly + Spectral Shape 490nm	Could be *K. brevis*
(cyan)	**Backscatter Ensemble**	Chlorophyll Anomaly + Backscatter Ratio b_{bp}	Could be *K. brevis*
(yellow)	**Full Ensemble**	Chlorophyll Anomaly + Spectral Shape 490nm + Backscatter Ratio b_{bp}	Likely *K. brevis*

Figure 2. Analysis of chlorophyll anomaly and ensemble imagery products along with *in-situ K. brevis* water samples.

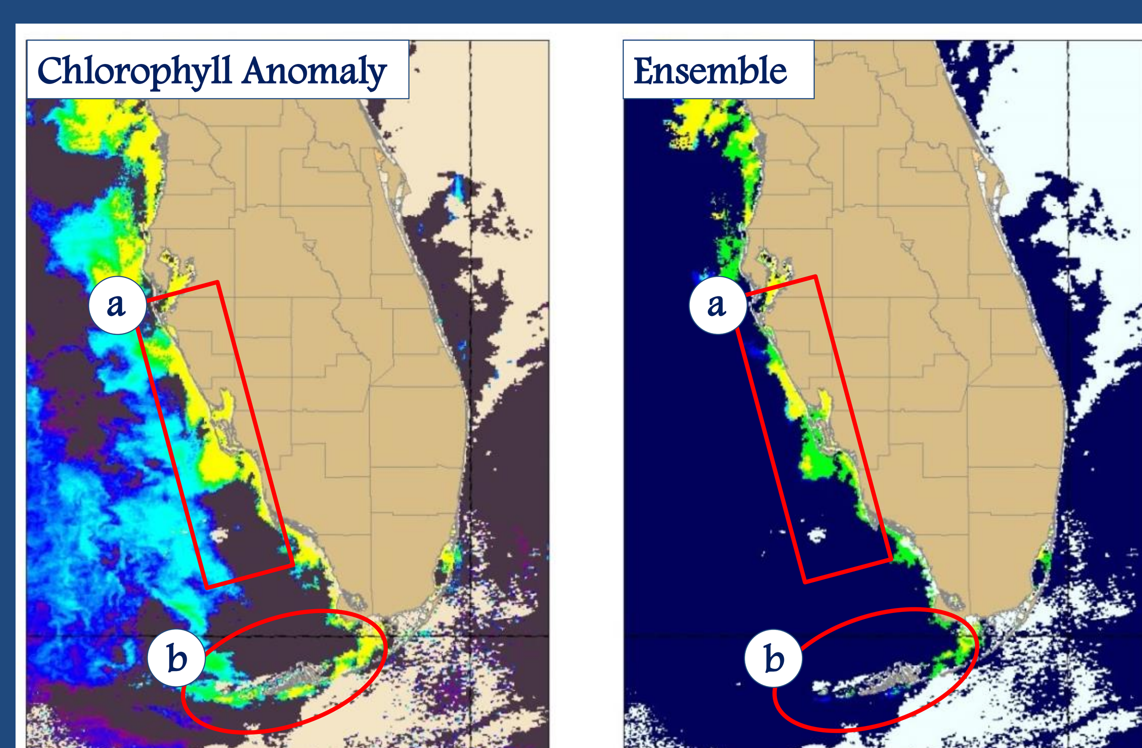


Figure 3. (a) The full and backscatter ensemble products enhanced analysis alongshore SW FL from approximately Tampa to Cape Romano. (b) Ensembles did not completely eliminate false positives in the FL Bay and FL Keys region, but HAB flags were smaller.

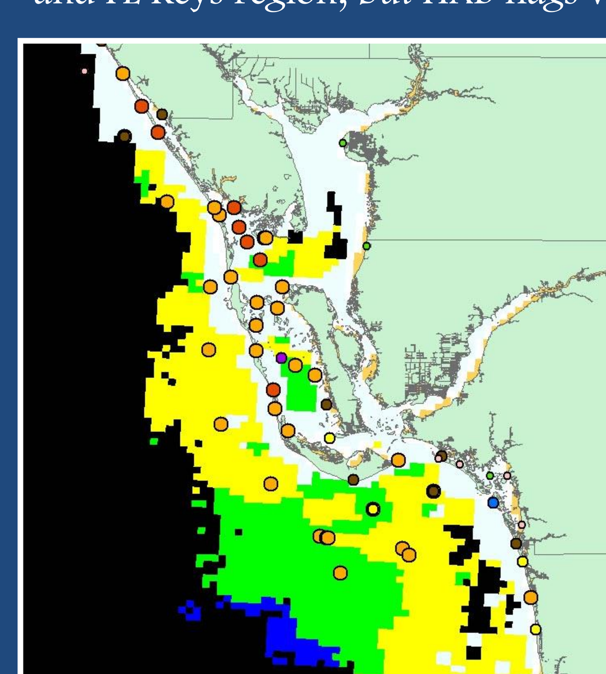


Figure 4. Ensemble image from 2/6/13. While the spectral shape 490nm ensemble product helps with definition, it tends to overflag more often than the other ensemble products. The backscatter and full ensemble flags better refined *K. brevis* bloom boundary detection.

Results

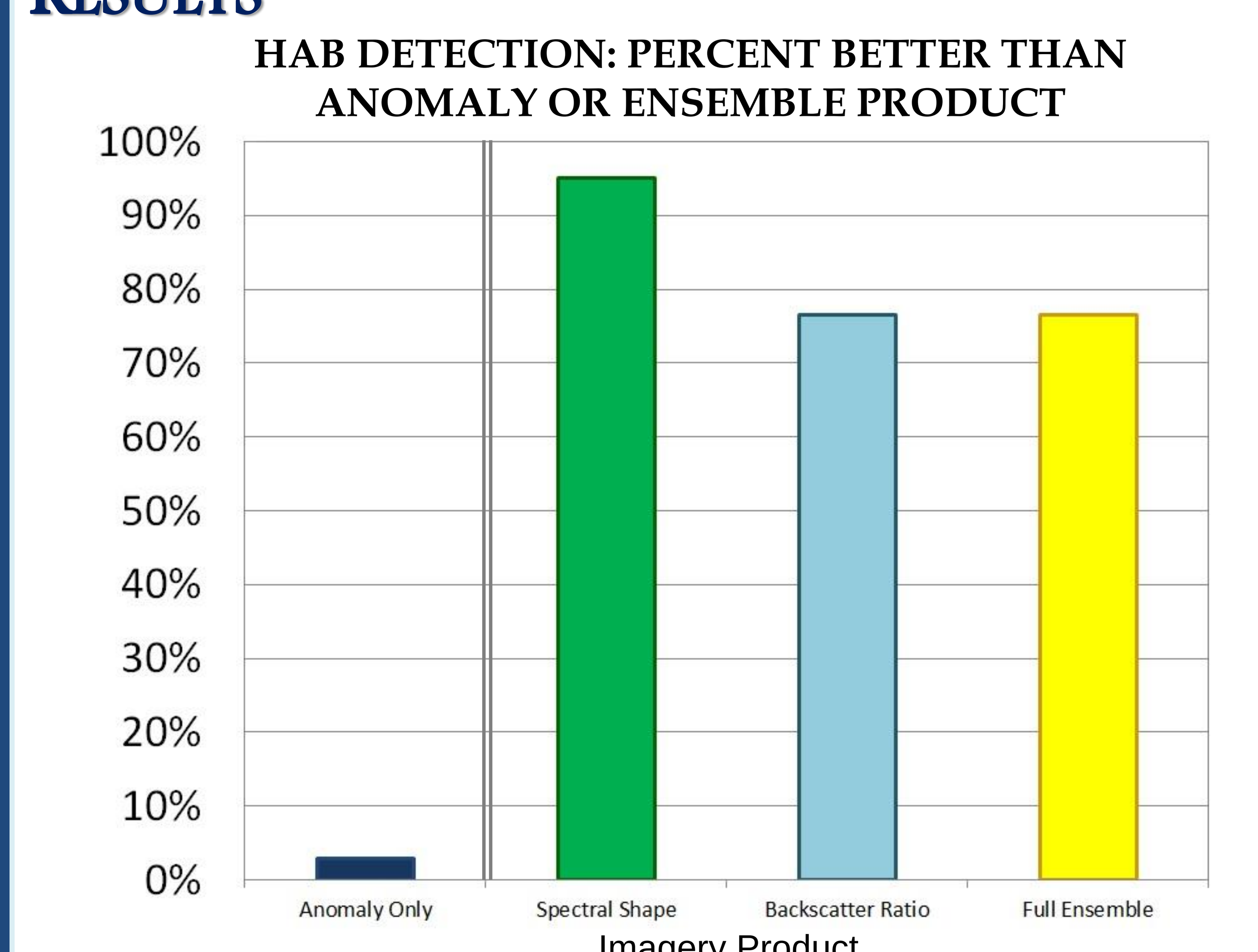


Figure 5. Percentage of images for which either the chlorophyll anomaly alone or the ensemble product was evaluated to be more effective at identifying the presence or absence of *K. brevis* blooms. While the spectral shape 490nm ensemble product performed the best over the chlorophyll anomaly alone, the backscatter and full ensemble products were more effective in reducing false positives, discerning between blooms of *K. brevis* and blooms of other species, especially in coastal areas outside of the FL Bay and FL Keys region. Despite enhanced specificity gained through ensemble products, both the backscatter and full ensemble missed blooms that were flagged by the chlorophyll anomaly 20.6% of the time, highlighting the continued importance of examining the chlorophyll anomaly in addition to the ensemble.

Discussion

While the chlorophyll anomaly alone has proven effective in highlighting areas of high chlorophyll, using this product in conjunction with other algorithms in ensemble imagery products enhances *K. brevis* bloom detection capabilities and forecasting skill. The ensemble imagery evaluation underscored several benefits favoring the use of ensemble imagery, including:

1. Increased specificity in determining the spatial extent of K. brevis bloom location/boundaries,
2. Reduction of false positives alongshore southwest Florida from Pinellas to Monroe counties, primarily in the main bloom initiation area extending approximately from Tampa to Cape Romano,
3. Decreased tendency toward over-prediction compared to the chlorophyll anomaly alone, and
4. Improved identification of correct rejections outside the Florida Bay and Florida Keys area.

While there are several benefits to including the ensemble imagery products for operational use, analysis also highlighted the continued examination of the chlorophyll anomaly alone in addition to the ensemble products.

Conclusions

As of September 2015, the full ensemble product, incorporating the chlorophyll anomaly, spectral shape ensemble, and backscatter ratio ensemble has been generated for operational use by the HAB-OFS and analyzed in conjunction with the chlorophyll anomaly imagery. The combined analysis of these products provides enhanced *K. brevis* detection and monitoring, and should be particularly useful in analysis of the *K. brevis* initiation area from Tampa to Cape Romano, outside of the Florida Bay and Florida Keys region. Future work for consideration includes analysis of the ensemble imagery in other forecast regions, such as northwest Florida and Texas, and the use of ensemble products with new satellite imagery products as they become available.

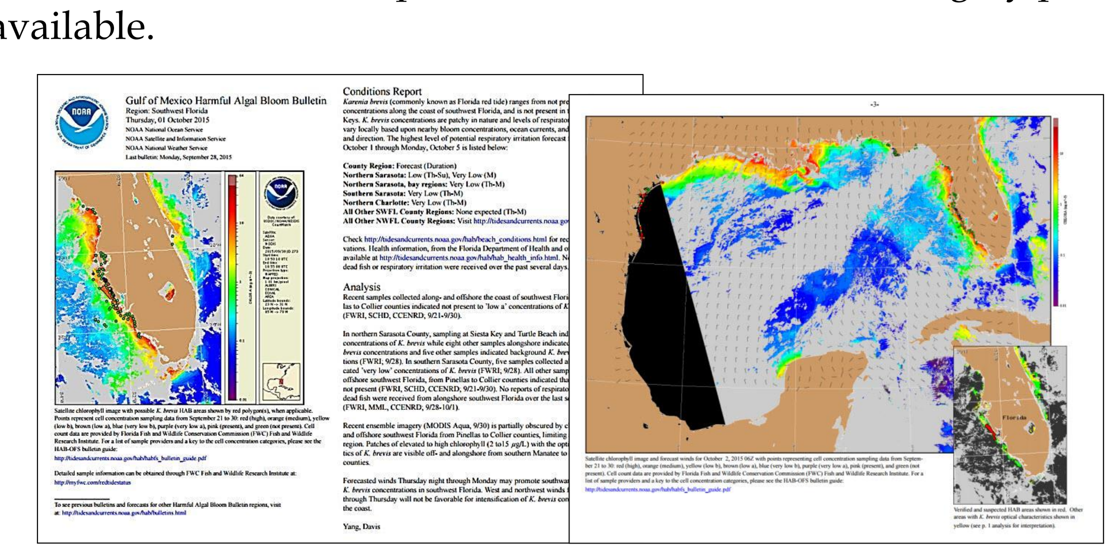


Figure 6. HAB-OFS southwest Florida bulletin with ensemble imagery.

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