VIIRS Retrievals of *Karenia brevis*
Harmful Algal Blooms in the West Florida Shelf Using Neural Networks

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Outline

I. Background of *Karenia Brevis* (KB) Harmful Algal blooms (HABs) in West Florida Shelf (WFS)

II. MODIS uses 678 nm fluorescence channel to detect [Chla] and hence KB. VIIRS has no 678 nm channel new technique needed

III. NN retrievals of $a_{ph443}$ approx. $\alpha$ [Chla] and KB intensity

IV. We devise filters to eliminate non KB compatible pixels from retrieved $a_{ph443}$ and residual image indicates KB HABs

V. Comparisons NN KB HAB retrievals in WFS: against MODIS Fluorescence based nFLH techniques

VI. Comparisons of VIIRS NN retrievals against in-situ measurements

VII. Conclusion
Background of *KB* HABS in WFS

- **It has been estimated that $70 million is lost annually** as a result of HABs (Fisher et al., 2003). Recent July 4\textsuperscript{th} 2016 bloom had a major effect on economy and health.

- **Approximately 5,000 species of phytoplankton**, only about 300 of them could cause color change.

- **In waters containing *Karenia brevis (KB)*** greater than $10^4$ cells L\(^{-1}\) (high-chlorophyll-a waters $\sim$1-10 mg m\(^{-3}\)), $\sim$ 3-4 fold decrease in $R_{rs}(\lambda)$ compared to waters containing fewer than $10^4$ cells L\(^{-1}\) of *KB*.

- **Decrease in $R_{rs}(\lambda)$ for KB blooms would cause the water to appear darker** since the green reflectance peak at 570 nm is less (green, olive green, black “darker” with high Chla). Although a red reflectance peak ($\sim$685-700nm) due to chlorophyll a florescence becomes increasingly, KB blooms do not appear as red in color visually as they do radiometrically because receptors of the human eye are only slightly sensitive to this portion of the visible spectrum.
MODIS & VIIRS satellite capability for KB HABs detections

• MODIS Retrieval of KB uses \textit{nFLH/RBD} Techniques which require 678nm Fluorescence band

• 678nm band not available on VIIRS providing impetus for \textit{NN} technique, using as input 486, 551 and 671 nm available in VIIRS.
Neural Networks (NN) Algorithm output retrieves $a_{ph443}$ from 486,551 671nm VIIRS $Rrs$ inputs

• Previous work: Simulated 20,000 random data sets based on NOMAD range of coastal and oceanic IOPs 10,000 used with 4 component radiative transfer forward bio-optical model to generate 10,000 sets of $Rrs$ 486,551 and 671 nm

• NN trained on 10,000 of these to retrieve as output ($aph$, $adg$, $adm$ & $bbp$ all at 443 nm, which is at the peak of $aph$ and thus exhibit most variation with $\lambda$) from $Rrs$ inputs at 486, 551 & 671 nm VIIRS bands (note these are longer $\lambda$ s which are not greatly impacted by atmospheric correction). ($ag$ and $ad$ are mutually constrained through an empirically derived relationship based on a study of NOMAD values (Refs)

• Tested and validated NN retrieval capabilities on remaining 10,000 synthetic dataset, NOMAD field data, and against our field measurements in Chesapeake.

• We are only interested NN retrievals of $a_{ph443}$ for our KB retrievals


Chesapeake tests against in-situ measurements showed good potential for NN Retrievals
Above empirical relationship determined from in-situ measurements and reported for the WFS. Chengfeng Le & Chuanmin Hu, (2013)

“Light gray represents cloud cover or invalid flagged data”

Using the NASA Level 2, L2gen data processing system, all pixels under the following conditions were considered in the comparison:

• Any individual pixel is excluded from the image if it has been flagged land, cloud, failure in atmospheric correction, stray light, bad navigation quality, both high and moderate glint, negative Rayleigh-corrected radiance, viewing angle larger than 60°, and solar zenith angle larger than 70°. Moreover, data of any individual pixels which have water-leaving radiance spectra with negative values in one of the wavelength are also excluded from spatial averaging.

VIIRS NN retrievals of $\alpha_{ph443}$ and equivalent [Chla] (and $\alpha$ KB intensity) from inputs of $Rrs$ at 486, 551 & 671 nm

Next step: filter out non-kb compatible pixels

Rerieved $a_{ph443}$
Filter Development to eliminate non kb compatible pixels. Example of reported KB HABS in-situ measurements (8/27/2014-9/17/2014) against which we developed filter criteria and tested our retrievals.

Approach applied in WFS for KB-HABs Detections

- **First** we use NN to retrieve $\text{aph}_443$ from VIIRS $\text{Rrs}_{486,511,671}$. $\text{aph}_443$ is approximately proportional to $[\text{Chla}]$.

- **Then**, in a second critical step, we evolve limiting criteria which make use of two facts (Cannizzaro, 2009)

  I. low backscatter $\text{bb}_p551 \leq \text{max specific value}$.  
    & Equivalent. $\text{Rrs}_{551} \leq 0.006 \text{ sr}^{-1}$
  
  II. $\text{aph}_443 \geq \text{min specific value}$.  
     & Equivalent. $[\text{Chla}] \geq 1.9 \text{ mg m}^{-3}$

  These limiting criteria are applied to retrieved VIIRS retrievals of $\text{Rrs}_{551} \leq 0.006 \text{ sr}^{-1}$ & $\text{aph}_443 \geq 0.061 \text{ m}^{-1}$ (to effectively delineate and quantify KB)

- NOAA HABSOS data with *in situ* KB concentrations, for period 8 August–17 September 2014.
**F1 Filter**

**Known fact** *KB HABs are characterized by low backscatter therefore we devise a filter based on upper limit of backscatter and equivalent Rrs\textsubscript{551} values to NN VIIRS retrievals.*

Indeed, *K. brevis* is an **ineffective backscatterer** due to its large size (20–40 µm) and relatively low index of refraction (1.05). Instead, the primary source of bb\textsubscript{p}r in oceanic waters is particles less than 1 µm (Morel and Ahn, 1991; Stramski and Kiefer, 1991).

“Dark gray represents F1 mask and Light gray represents cloud cover or invalid data”

(3c) VIIRS Rrs\textsubscript{551} image. Which we use it as a proxy for bb\textsubscript{p}. **By inspection** we find that the highest value of Rrs\textsubscript{551} consistent with the existence of KB HABs is \( Rrs_{551} \leq 0.006 \text{ sr}^{-1} \)

(3d) This max value used to generate a mask F1 mask (dark gray), which eliminate all values of \( Rrs_{551} \geq 0.006 \text{ sr}^{-1} \) and therefore incompatible with KB HABs, when mask is applied to image residual pixels, are then compatible with KB HABs.
VIIRS NN retrievals of $a_{ph443}$ and equivalent [Chla] (and $\alpha$ KB intensity) from inputs $Rrs$ at 486, 551 & 671 nm (Similar for MODIS)

**VIIRS Pixels limitations**

Using the NASA Level 2, L2gen data processing system, all pixels under the following conditions were considered in the comparison:

• Any individual pixel is excluded from the image if it has been flagged land, cloud, failure in atmospheric correction, stray light, bad navigation quality, both high and moderate glint, negative Rayleigh-corrected radiance, viewing angle larger than 60°, and solar zenith angle larger than 70°. Moreover, data of any individual pixels which have water-leaving radiance spectra with negative values in one of the wavelength are also excluded from spatial averaging.

Using empirical relationships, which have been determined from in-situ measurements and reported for parts of the WFS. Chengfeng Le & Chuanmin Hu, (2013)
F1 & F2 Filters combined show the extent of KB blooms 9/02/2014

Application of filter F2 based on known minimum $a_{ph443}$ value compatible with KB HABs applied consecutively to residual pixels from F1.

“Dark gray represents F1&F2 masks and Light gray represents cloud cover or invalid data”

New residual pixels of both masks satisfy both maximum backscatter and minimum $a_{ph443}$ criteria and therefore compatible and represent KB HABs
Comparisons of MODIS NN and nFLH retrievals, offshore area A - Equiv. [Chla]

“Again, Dark gray represents F1 & F2 masks and Light gray represents cloud cover or invalid data.”

F1 & F2 Applied these eliminate erroneous bloom in nFLH image

“Color coding of the dots denotes distance to shore, with red being the closest.”

SW Florida nFLH equiv. [Chla] = 1.255*(FLH*10)^0.86 Refs., Hu, C.; Remote Sens. Environ. 2005
Comparisons of In-situ measurements \textit{Vs.} VIIRS NN KB-HABs retrievals (2012-2015)

- To verify the association between \textit{KB} cell abundance and VIIRS ocean color Level 2 $a_{ph443}$ phytoplankton absorption

  \textit{KB} cell abundance collected by Florida Fish and Wildlife Conservation Commission (FWC), were combined and compared to VIIRS retrievals, for the period between 2012 and 2015 (94 data points for same day observations).

- Over range 0.01–3.7 $10^6$ cells $L^{-1}$ and $a_{ph443}$ (chlorophyll-a) values from 0.085 to 1.53 m$^{-1}$ ([Chla]0.6449 to 99 $\mu$g $L^{-3}$) the regression coefficient was 0.32 (Shown next Slide).

\textit{KB-HABs cell counts limitations applies are those shown below}

Cell counts under the following conditions were considered in the comparison:

- Sample depth \leq 0.5 meter.
- Cell counts \geq 10,000 cell $L^{-1}$ (Low to High blooms)
- The nearest pixels used for match-up comparison are those less than (<0.3 mile) to the in-situ locations. Moreover all flags mentioned previously are excluded.
Fig. 13(a-d): In-situ observation within the same day of VIIRS image: (a) VIIRS NN retrieved $a_{ph443}$ against In-situ KB cell counts; (b) VIIRS NN equiv. [Chla] against in-situ cell counts; (c) VIIRS OCI/OC3 retrieved [Chla] against in-situ KB cell counts; (d) VIIRS RGCI retrieved [Chla] against in-situ KB cell counts. Color coding of the dots denotes distance to shore, with blue being the closest.


Fig. 1(a-f): Retrieved NN equiv. [Chla] and OCI/OC3 [Chla] and RGCI [Chla] against In-situ cell counts for 1 hour and 30 minutes observation time windows. Note that the vertical color bar is indicates distant (mi) from coastline with red being closest to shore.
III. Field Data

Location of 30 minutes coincident Field data (showing VIIRS and MODIS pixels – ongoing analysis)

Classification of *K. brevis* blooms according to Number of CellCounts/ L.t
- $< 10^4$
- $10^4 - 10^5$ cells/ L.t.
- $10^5 - 10^6$ cells/ L.t.
- $10^6 <$ cells/ L.t.
08/28/2014 bloom: showing adjacent pixel variability and averaging effect of intra-pixel variability non-bloom-bloom conditions erroneously indicating bloom.

- **Figure 16.** VIIRS-NN KB HABs retrievals for blooms date (28 August 2014), showing bloom compatible $a_{ph443}$ and equiv. [Chla] values. Notes image are overlaid with cell counts for this date. White areas represent cloud cover or invalid data. There are total of 20 match-ups on that day.
11/16/2014 & 10/09/2012, blooms: showing good retrievals including closer to shore

• **Figure 17.** VIIRS-NN $KB$ HABs retrievals on 2 different blooms dates, showing bloom compatible $a_{ph443}$ and equiv. $[Chla]$ values. (a) 11 November 2014, bloom; (b) 09 October 2012, bloom. Notes all images are overlaid with cell counts corresponding for these dates. White areas represent cloud cover or invalid data. There are total of 6 and 12 match-ups respectively for (11/16/2014) and (10/09/2012).

**Cell Counts/L Classification:**
- x Not Observed
- ○ Very Low (1-10,000)
- ○ Low (10,000-100,000)
- ○ Medium (100,000-1,000,000)
- ○ High (1,000,000+)
Conclusion

- NN retrievals of aph443 from VIIRS appears to be viable technique for detecting and tracking KB HABs in the WFS, when combined with retrieved Rrs551 and aph443 criteria compatible with low KB backscatter and minimum aph443.

- Retrievals show importance of temporal considerations.

- Further detail comparisons with in-situ measurements are planned and considerations of subpixel variability addressed. Factors affecting false positives and negatives remain to be investigated in detail.

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Thank you
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