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

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Collaboration with

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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 $\boldsymbol{a_{ph443}}$ approx. α [*Chla*] and KB intensity

IV. We devise **filters** to eliminate non KB compatible pixels from retrieved $\boldsymbol{a_{ph443}}$ 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

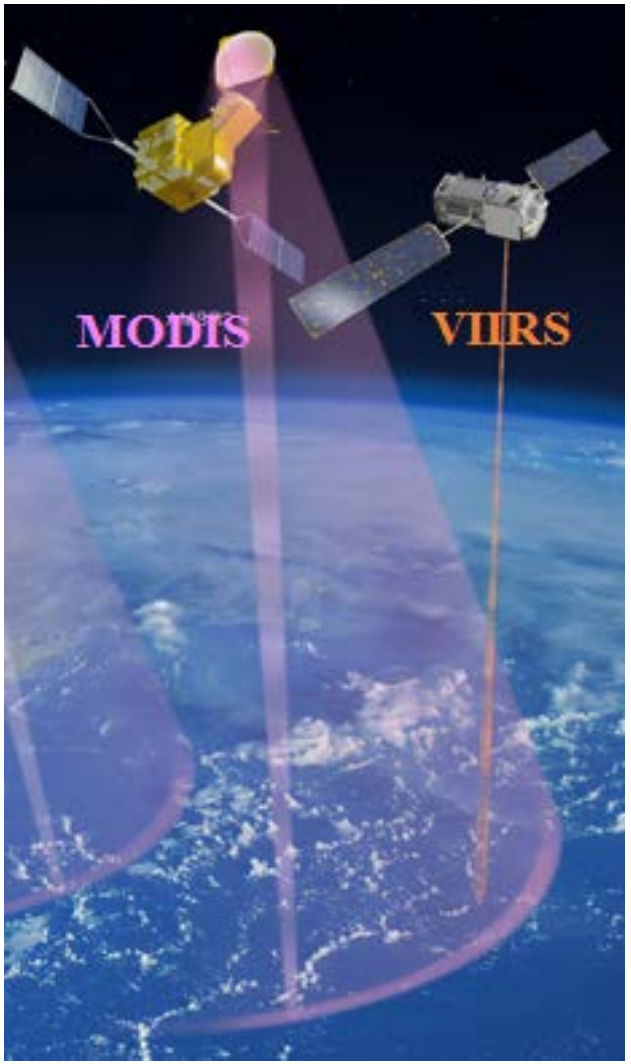
Background of *KB* HABS in WFS

- It has been estimated that $70 million is lost annually as a result of HABs (Fisher et al., 2003). Recent July 4th 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-*chlorophll*-a waters ~1-10 mg m^{-3}), ~ 3-4 fold decrease in *Rrs*(λ) compared to waters containing fewer than 10^4 cells L^{-1} of *KB*.
- Decrease in *Rrs*(λ) 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 (~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 *nFLH/RBD* Techniques which require 678nm Fluorescence band

- 678nm band not available on VIIRS providing impetus for *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**

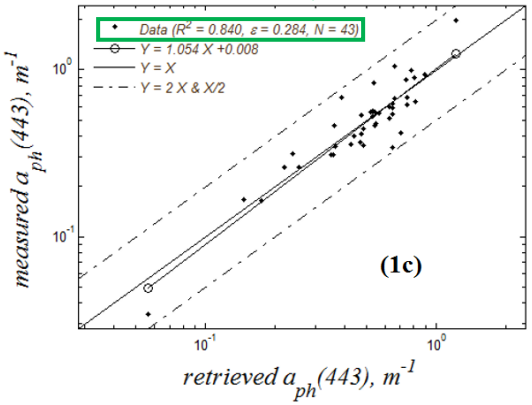
• **NN trained on 10,000 of these to retrieve as output** (*aph, adg, adm* & *bbp* all at 443 nm, which is at the peak of *aph* and thus exhibit most variation with **λ**)) from *Rrs* inputs at 486, 551 & 671 nm VIIRS bands (note these are **longer λ s** which are not greatly impacted by atmospheric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

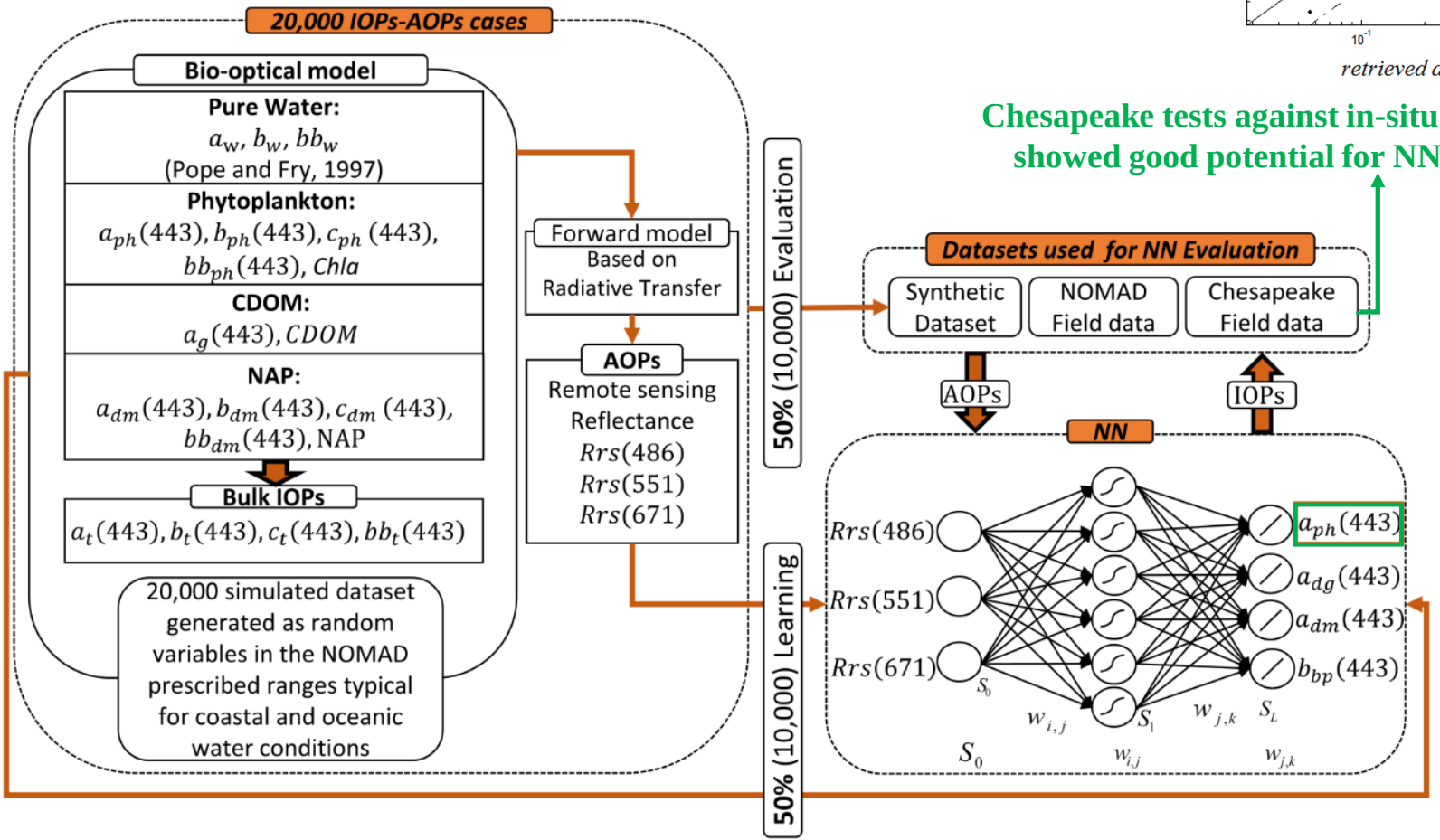
• **Tested** and validated NN retrieval capabilities on remaining **10,000** synthetic dataset, NOMAD field data, and against our field measurements in Chesapeake.

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

• **Refs.** Ioannou I., et al. Deriving ocean color products using neural networks. ***Remote Sens. Environ.*** **2013,** *134*, 78–91.
Ioannou I., et al. Neural network approach to retrieve the inherent optical properties of the ocean from observations of MODIS. ***Appl. Opt.*** **2011**.

NN retrieved $[a_{ph}(443)]$ R^2=0.84, n =43





Chesapeake tests against in-situ measurements showed good potential for NN Retrievals

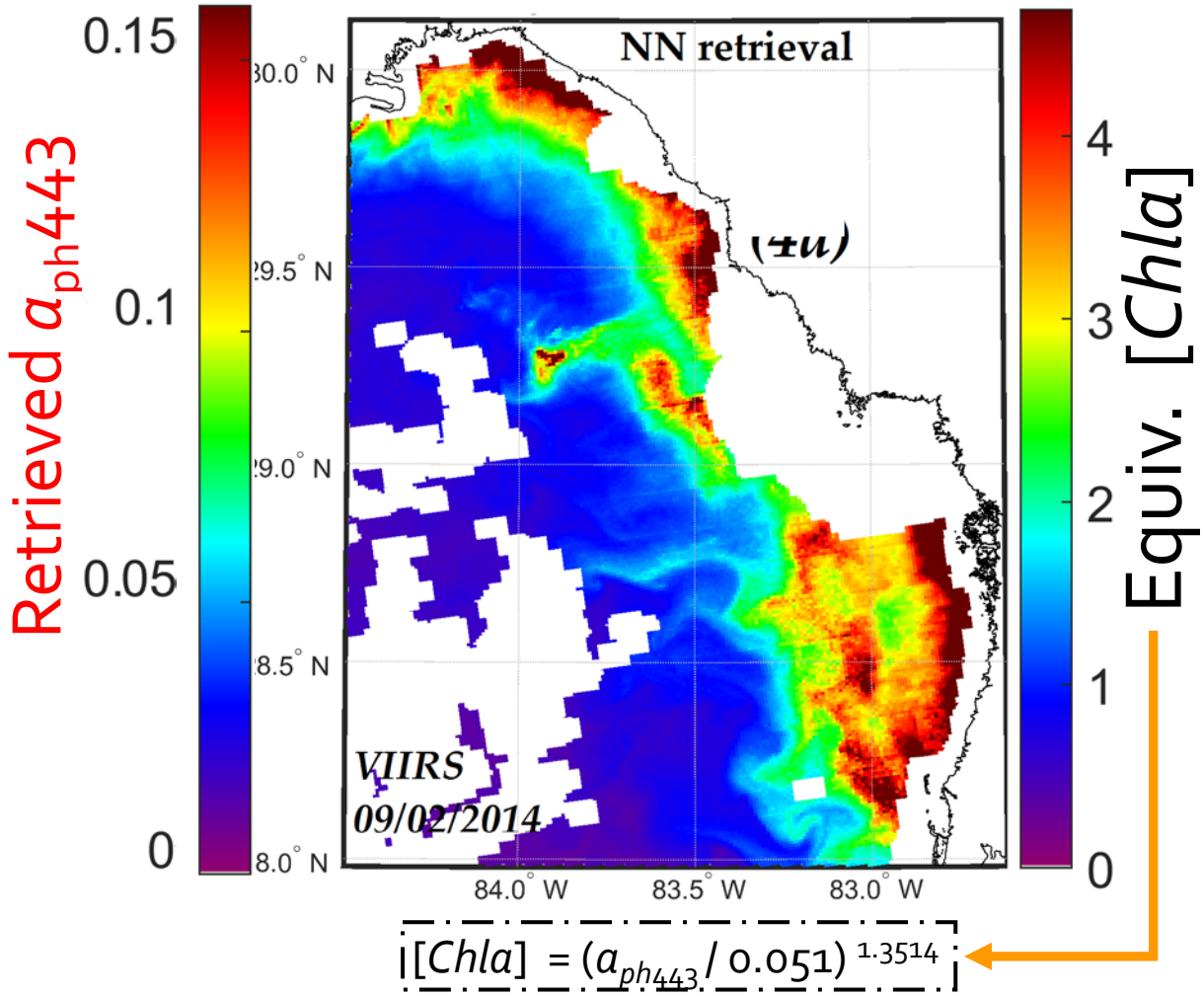
On 9/2/14 major KB bloom in WFS
VIIRS *NN* retrievals of a_{ph443} and equivalent [*Chla*] (and α KB intensity)from inputs of *Rrs at* 486, 551 & 671 nm
Next step: filter out non-kb compatible pixels

VIIRS Pixels flags applied

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.

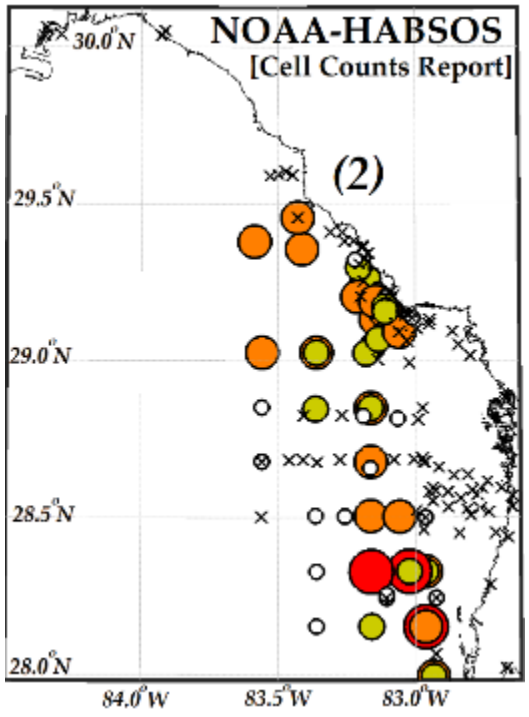
"Light gray represents cloud cover or invalid flagged data"



$[Chla] = (a_{ph443} / 0.051)^{-1.3514}$

Above empirical relationship determined from in-situ measurements and reported for the WFS. *Chengfeng Le & Chuanmin Hu, (2013)*

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.



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+)*

Approach applied in WFS for *KB*-HABs Detections

- **First** we use NN to retrieve aph443 from VIIRS Rrs (486,551,671) ***aph443 is approximately proportional to [Chla].***
- **Then**, in a second critical step, we evolve limiting criteria which make use of two facts (*Cannizzaro, 2009*)

I. *low backscatter* $bb_p551 \leq$ ***max specific value.***
&Equiv. $Rrs_{551} \leq 0.006\ sr^{-1}$
II. $a_{ph443} \geq$ ***min specific value.***
$a_{ph443} \geq 0.061\ m^{-1}$
&Equiv. [Chla] $\geq 1.9\ mg\ m^{-3}$

These limiting criteria are applied to retrieved VIIRS retrievals of $Rrs_{551} \leq 0.006\ sr^{-1}$ *&* $a_{ph443} \geq 0.061\ m^{-1}$
(to effectively delineate and quantify *KB*)

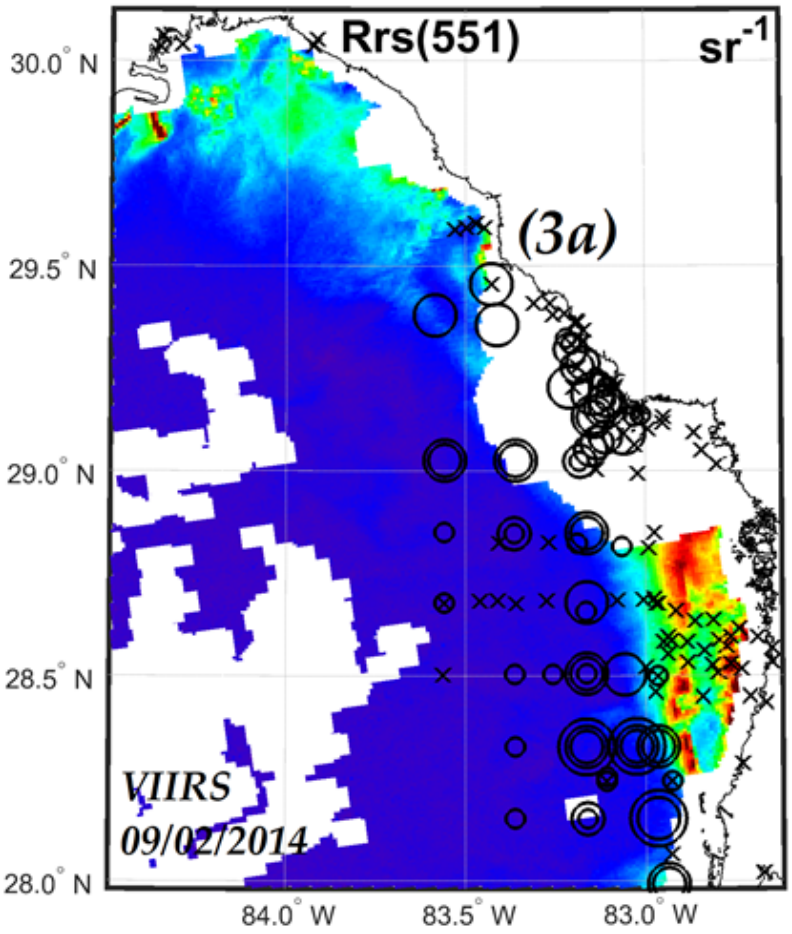
- NOAA HABSOS data with *in situ KB* concentrations, for period 8 August–17 September 2014.

F1 Filter

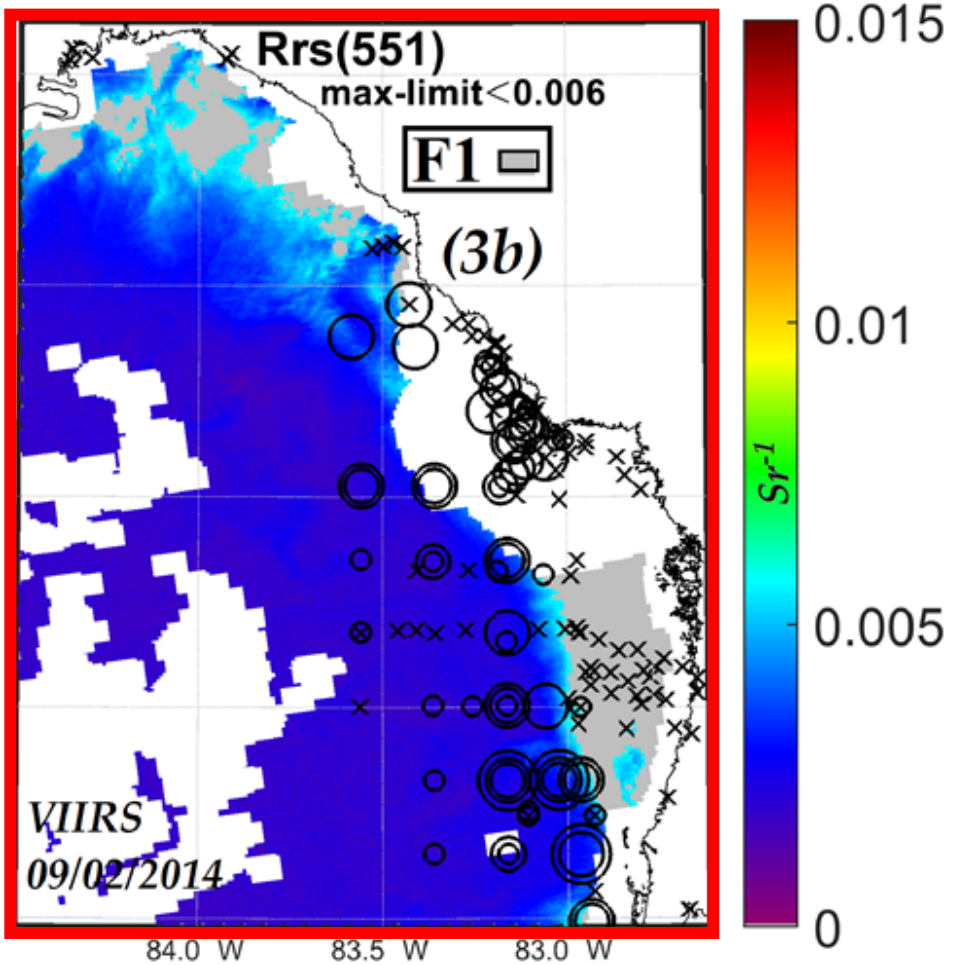
Known fact *KB* HABs are characterized by low backscatter therefore we devise a filter based on upper limit of backscatter and equivalent Rrs_{551} values to *NN* VIIRS retrievals.

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** $bb_p r$ 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_{551} image. Which we use it as a proxy for bbp, *BY inspection* we find that the highest value of Rrs551 consistent with the existence of KB HABs is $\{Rrs_{551}\} \leq 0.006\ sr^{-1}$



(3d) This max value used to generate a mask F1 mask (dark gray), which eliminate all values of $\{Rrs_{551}\} \geq 0.006\ sr^{-1}$ and therefore incompatible with KB HABS, when mask is applied to image residual pixels, are then compatible with KB HABs

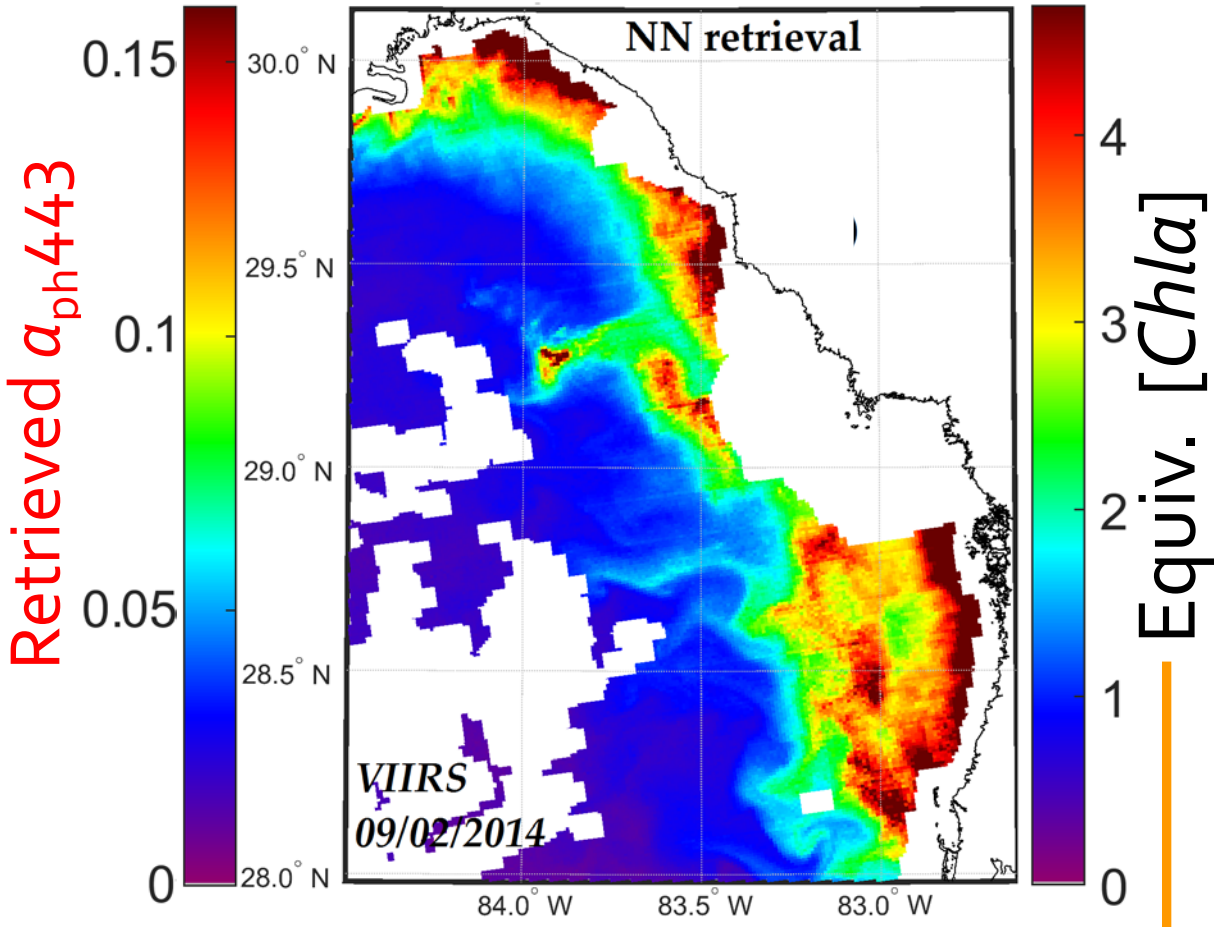
VIIRS *NN* retrievals of a_{ph443} and equivalent [*Chla*] (and α KB intensity)from inputs *Rrs at* 486, 551 & 671 nm (Similar for MODIS)

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.

"Light gray represents cloud cover or invalid flagged



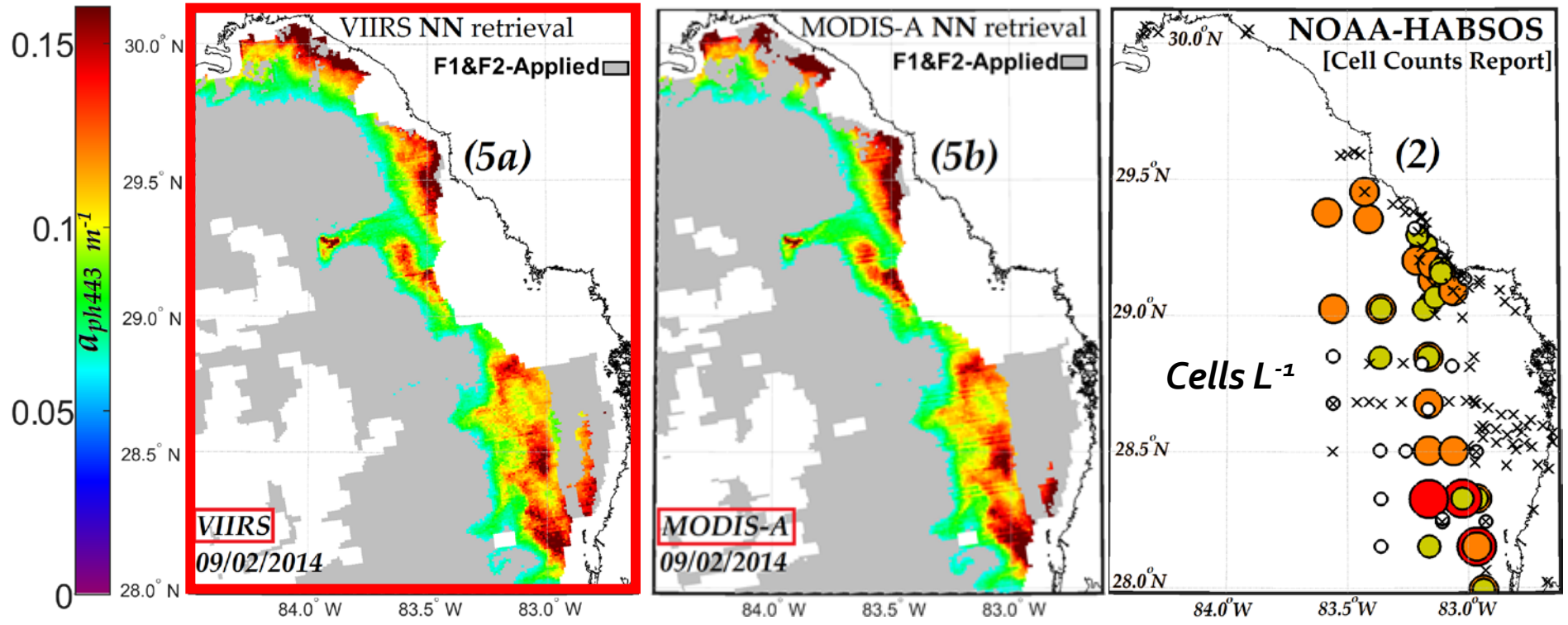
$$[Chla] = (a_{ph443} / 0.051)^{1.3514}$$

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 $a_{ph}443$ value compatible with *KB* HABs applied consecutively to residual pixels from F1.

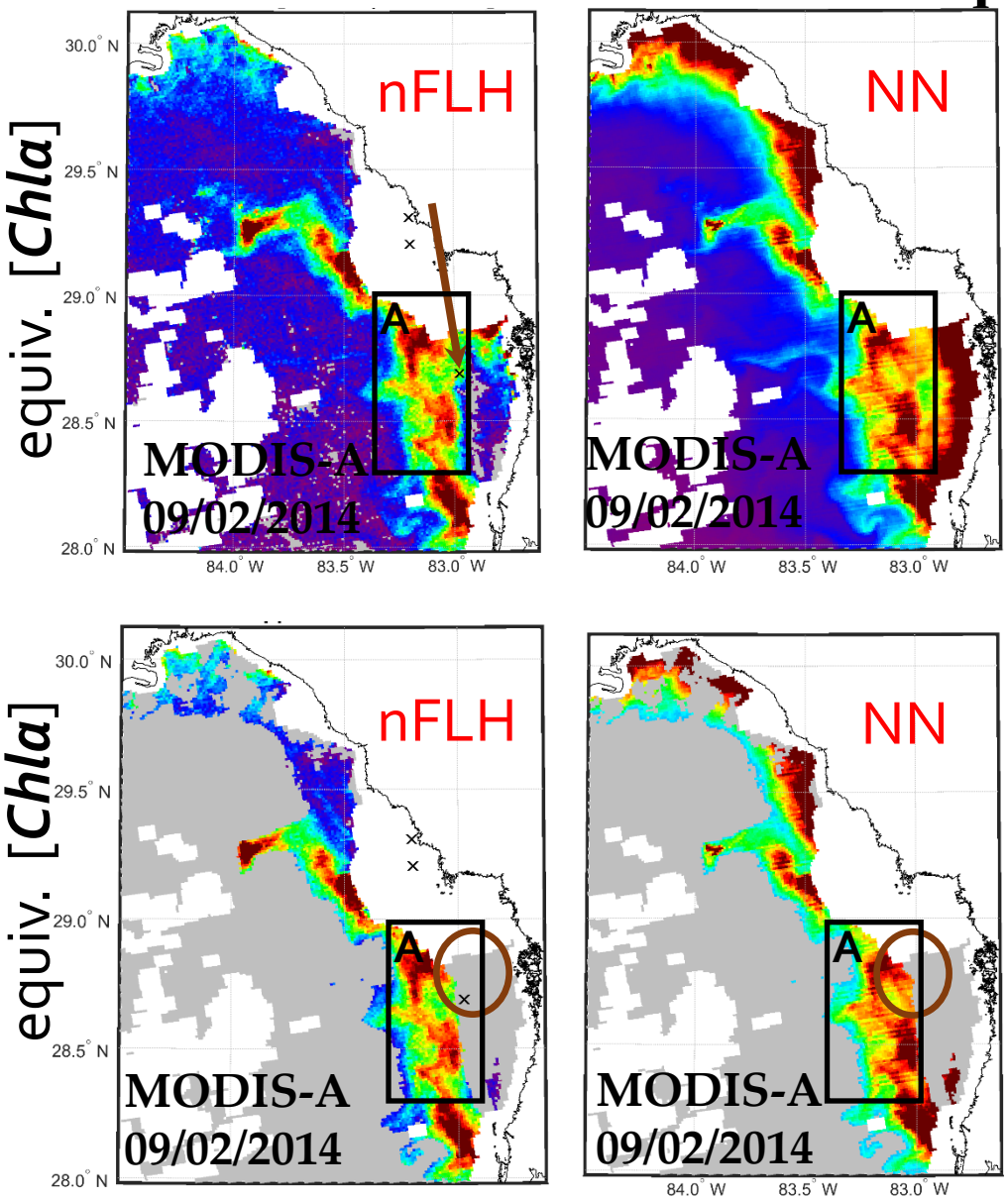
"Dark gray represents F1&F2 masks and Light gray represents cloud cover or invalid data"

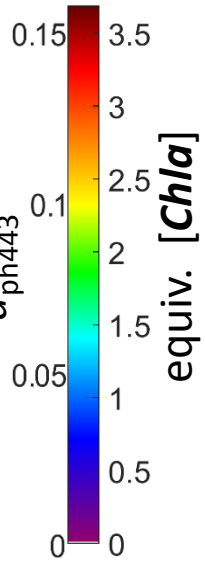


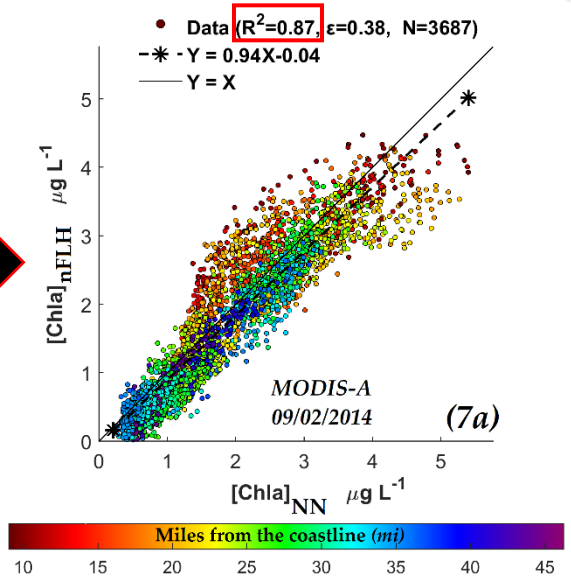
New residual pixels of both masks satisfy both maximum backscatter and minimum a_{ph443} criteria and there for compatible and represent KB HABs

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

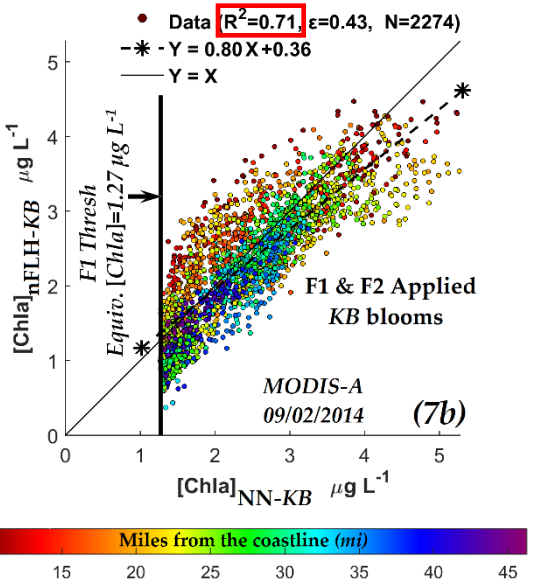
Comparisons of MODIS NN and nFLH retrievals, offshore area A - Equiv. [*Chla*]







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



"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

SW Florida nFLH equiv. **[*Chla*] = 1.255*(FLH*10)$^{0.86}$** Refs., Hu, C.; *Remote Sens. Environ.* **2005**

Comparisons of In-situ measurements *Vs.* VIIRS NN *KB*-HABs retrievals (2012-2015)

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

  ***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).

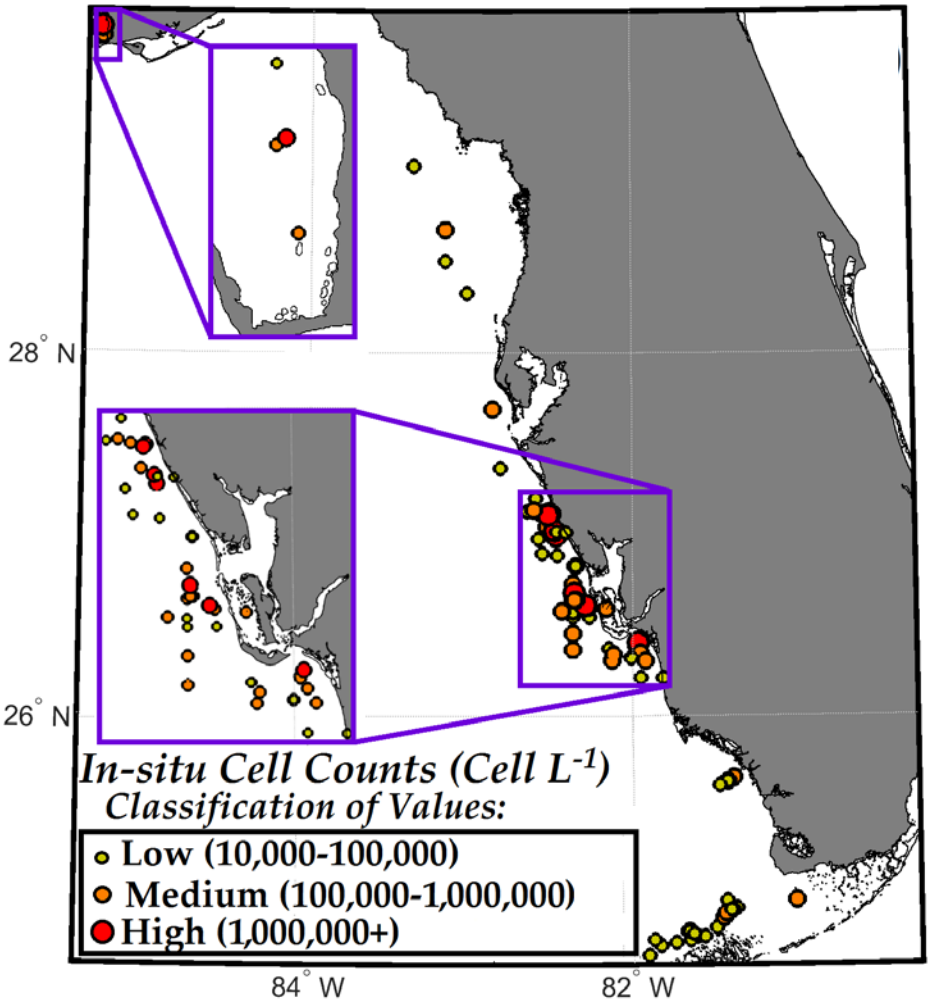
KB-HABs cell counts limitations applies are those shown below

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

•Sample depth ≤ 0.5 meter.

•Cell counts ≥ 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.



In-situ measurements *Vs.* VIIRS NN *KB*-HABs retrievals (2012-2015) w

KB In-situ observation within the same day of VIIRS image

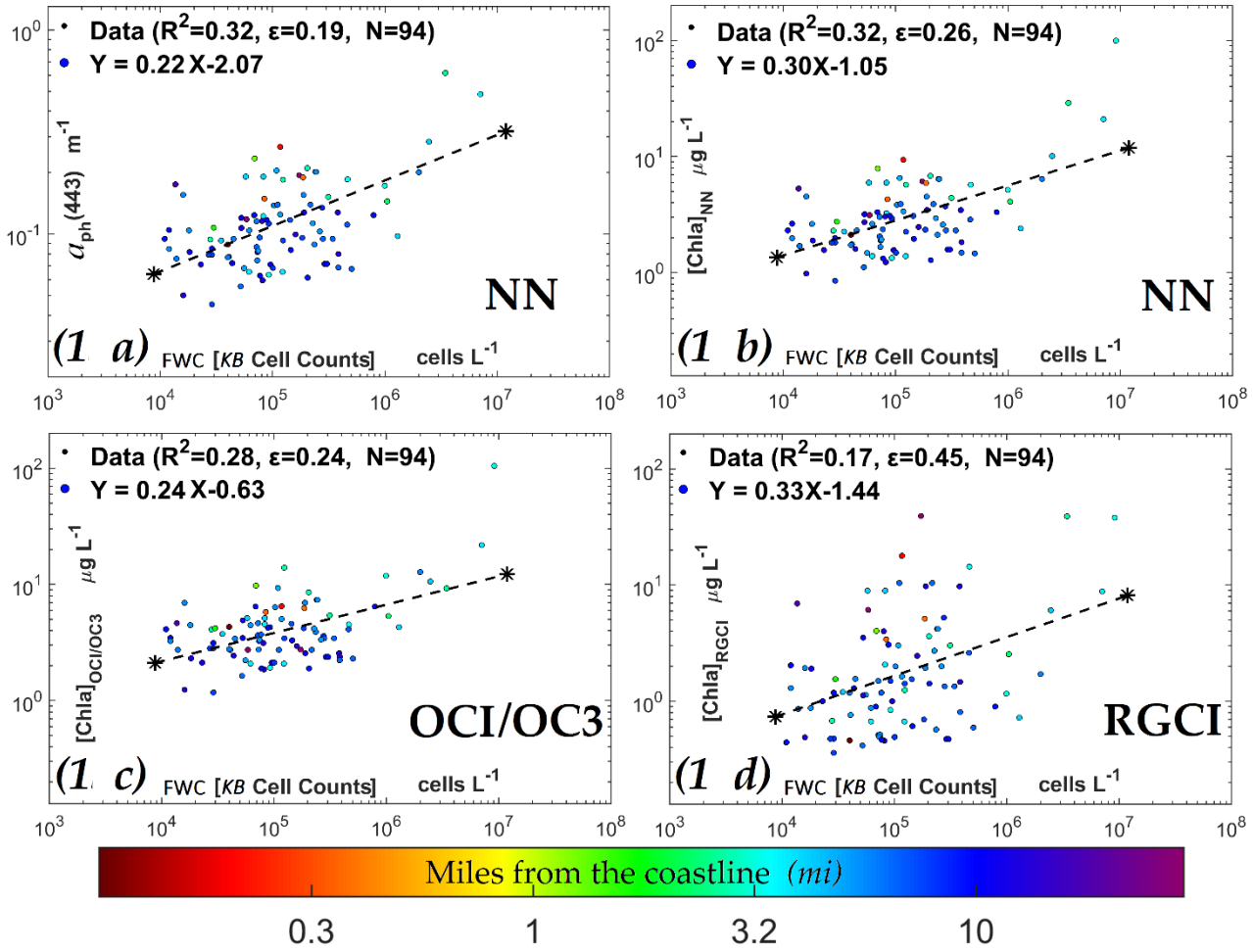


Fig. 13(a-d): In-situ observation within the same day of VIIRS image: (a) VIIRS NN retrieved a_{ph443} against In-situ *KB* cell counts; **(b)** VIIRS NN equiv. [*Chla*] against in-situ cell counts; **(c)** VIIRS OCI/OC3 retrieved [*Chla*] against in-situ *KB* cell counts; **(d)** VIIRS RGCI retrieved [*Chla*] against in-situ *KB* cell counts. Color coding of the dots denotes distance to shore, with blue being the closest.

OCI/OC3 Refs. NASA's Ocean Color chlorophyll-*a* index : http://oceancolor.gsfc.nasa.gov/cms/atbd/chlor_a/ [O'Reilly, 1998], [Hu, C., Lee, Z.; Franz, B. **2012**]
RGCI Refs. Red Green chlorophyll-*a* Index RGCI [*Chla*] retrievals [*Lin Qi, C. Hu* ***2015***]

Showing impact of temporal changes- In-situ measurements *Vs.* VIIRS NN *KB*-HABs retrievals (2012-2015) limited observation windows

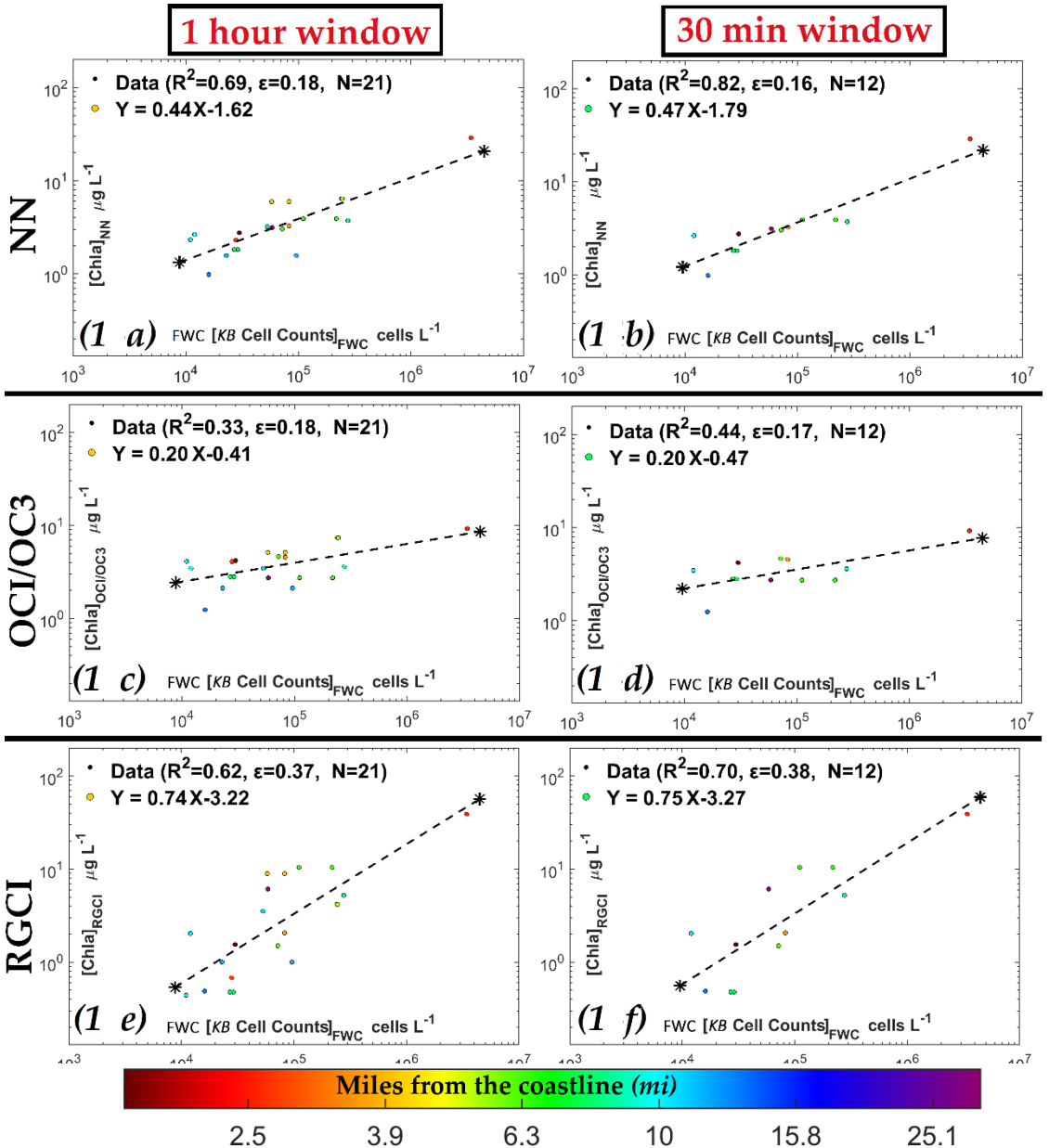
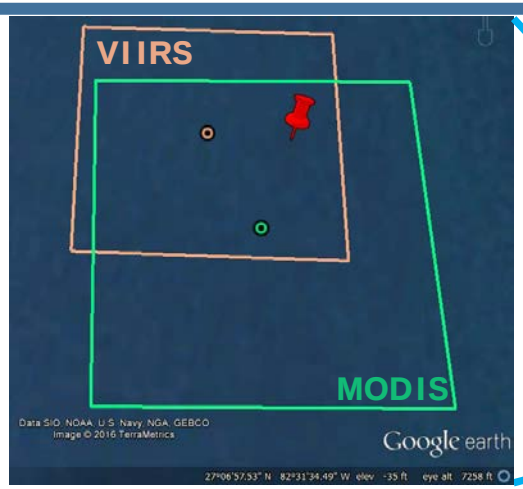
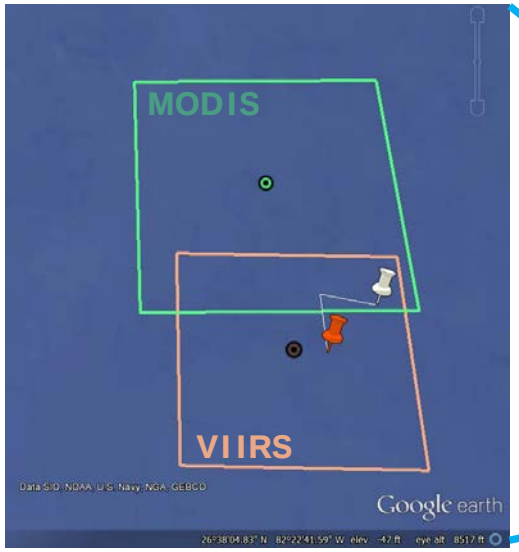


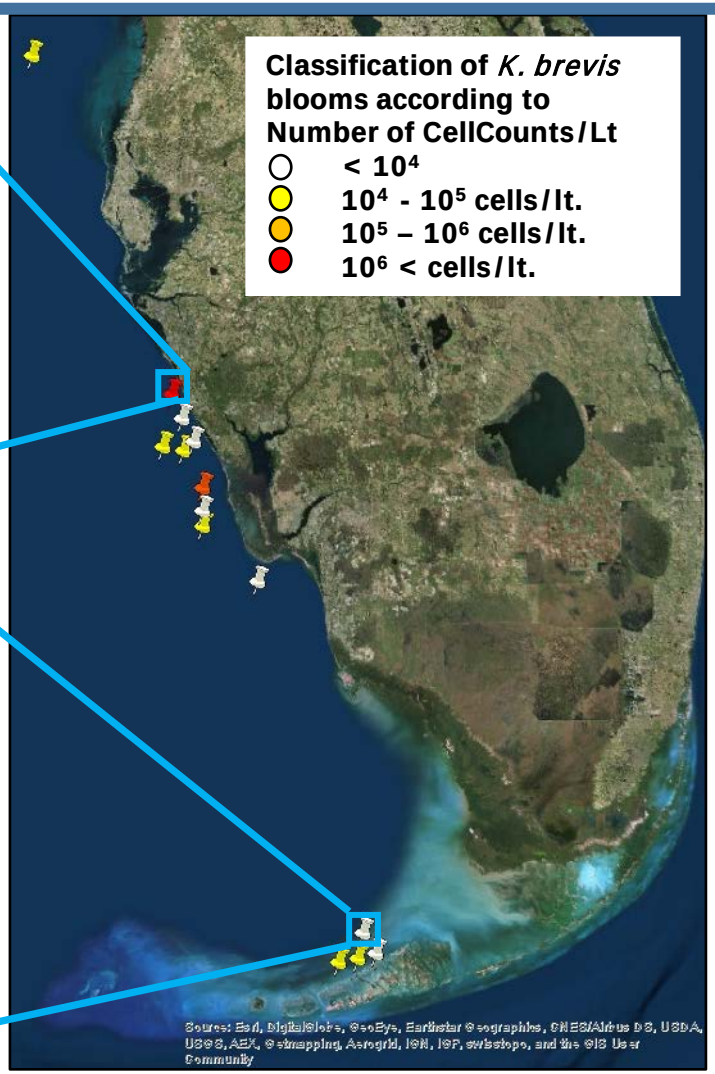
Fig. 1(a-f): Retrieved NN equiv. [*Chla*] and OCI/OC3 [*Chla*] and RGCI [*Chla*] against In-situ cell counts for 1 hour and 30 minutes observation time windows. Note that the vertical color bar is indicates distant (mi) from coastline with red being closest to shore.

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

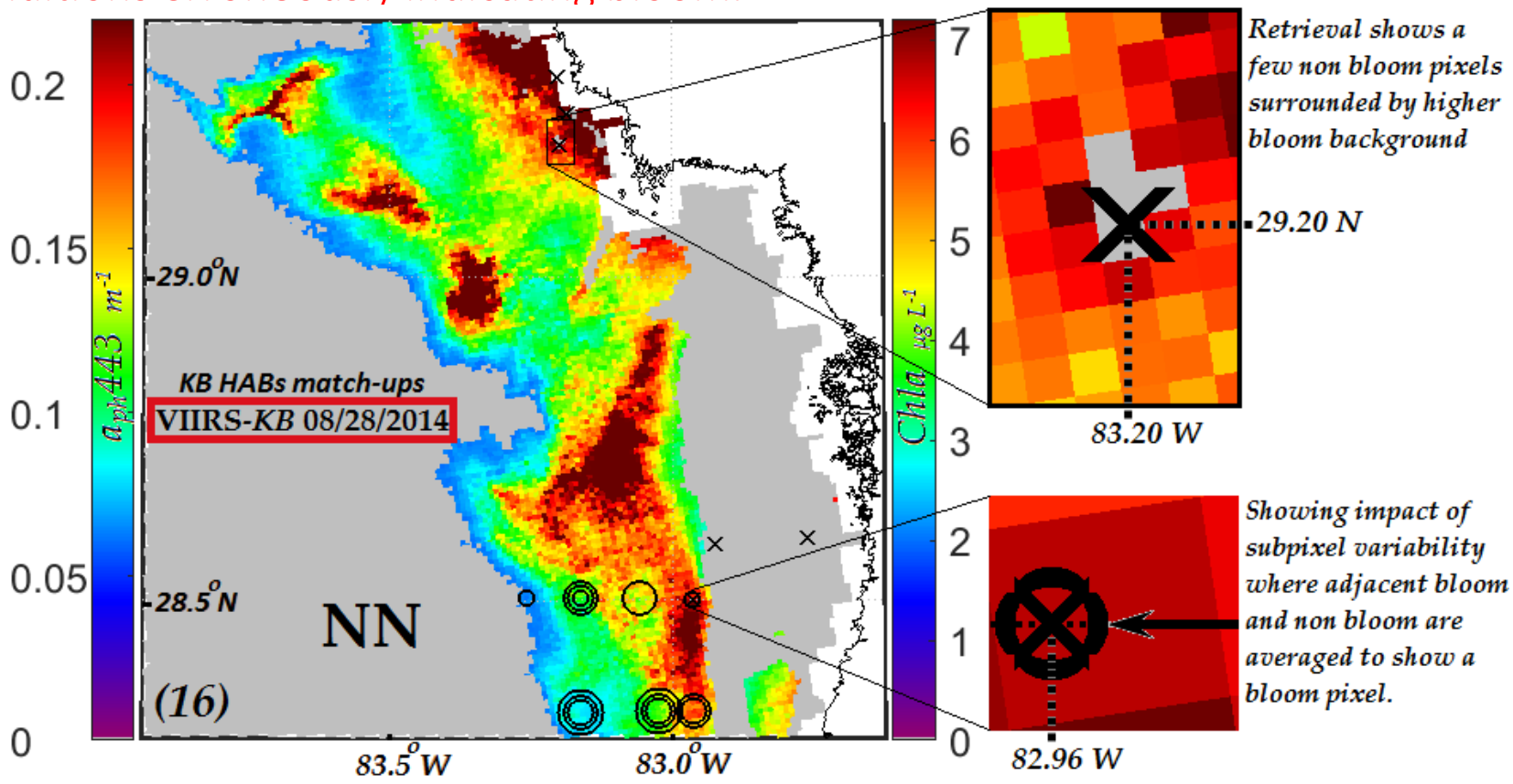
III. Field Data







08/28/2014 bloom: showing adjacent pixel variability and averaging effect of intra-pixel variability non-bloom-bloom conditions erroneously indicating bloom.

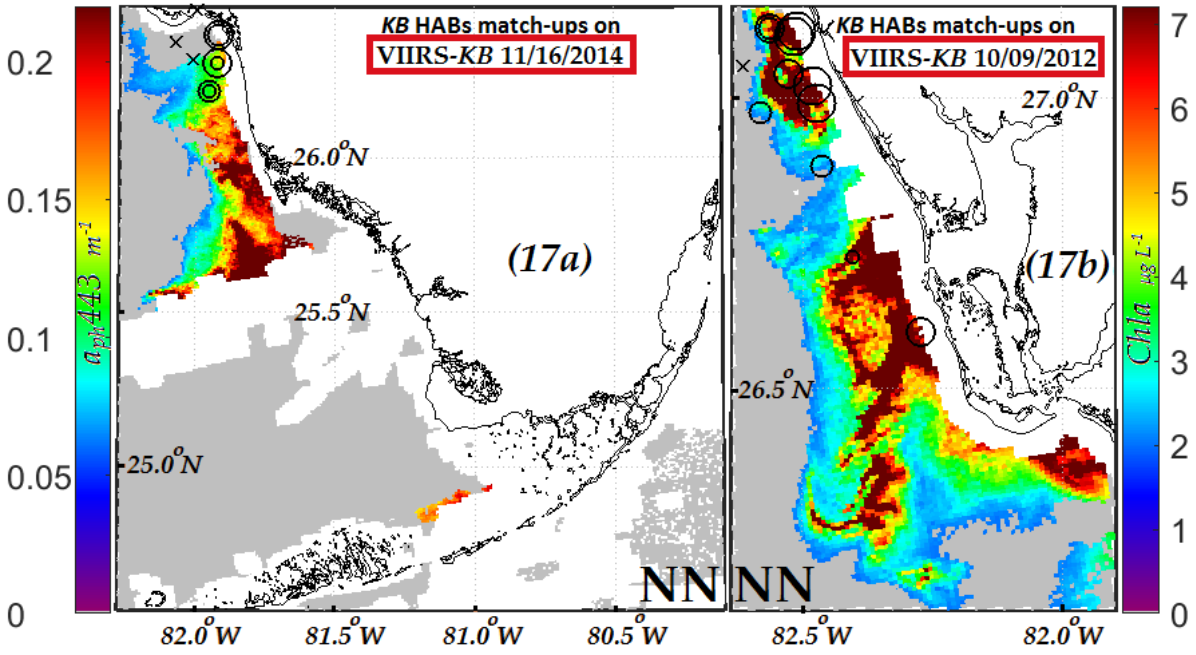


- **Figure 16.** VIIRS-NN *KB* HABs retrievals for blooms date (28 August 2014), showing bloom compatible a_{ph443} and equiv. [*Chla*] values. Notes image are overlaid with cell counts for this date. White areas represent cloud cover or invalid data. There are total of 20 match-ups on that day

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+)*

11/16/2014 & 10/09/2012, blooms:

showing good retrievals including closer to shore



Cell Counts/L Classification:

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- ◯ *High (1,000,000+)*

- **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).

Conclusion

- *NN* retrievals of *aph*443 from VIIRS appears to be viable technique for detecting and tracking *KB* HABs in the WFS, when combined with retrieved *Rrs*551 and *aph*443 criteria compatible with low *KB* backscatter and minimum *aph*443.

- 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.

- **Acknowledgment:**
- We thank NOAA JPSS and NOAA-Crest for support.

Thank you

Back up slides