Author(s): Ahmed El-habashi and Sam Ahmed

Title: **A new technique for satellite retrievals of *Karenia brevis* harmful algal blooms in the west Florida Shelf using neural networks**

Type of Presentation: ______ Poster

__√__ Oral

Short Abstract:

We apply Neural Networks (NN) to the detection and tracking, of *Karenia brevis* Harmful Algal Blooms (*KB* HABs) that plague the coasts of the West Florida Shelf (WFS) using Visible Infrared Imaging Radiometer Suite (VIIRS) satellite observations. Previous approaches primarily used observations from the Moderate Resolution Imaging Spectroradiometer Aqua (MODIS-A) satellite. They depended on the remote sensing reflectance signal at the 678 nm chlorophyll fluorescence band (*Rrs*678) needed for the normalized fluorescence height (nFLH) algorithms which proved effective for *KB* HABS retrievals. VIIRS which has replaced MODIS-A, unfortunately does not have a 678 nm fluorescence channel. To overcome that hurdle, we customized our NN approach to retrieve phytoplankton absorption at 443 nm (a_{ph443}) using only *Rrs* measurements from existing VIIRS channels at 486, 551 and 671 nm. The a_{ph443} values in these retrieved VIIRS images, can in turn be correlated to chlorophyll-*a* concentrations [*Chla*] and *KB* cell counts. To retrieve *KB* values, the VIIRS NN retrieved a_{ph443} images are filtered by applying limiting constraints, defined by (i) low backscatter at *Rrs* 551 nm and (ii) a minimum a_{ph443} value known to be associated with *KB* HABs in the WFS. The resulting filtered residual VIIRS images are shown to very effectively delineate and quantify existing *KB* HABs in the WFS. Comparison with historical in-situ measurements and MODIS-A satellite retrievals over the 2011-15 period confirm the viability and efficacy of the NN approach.

A new technique for satellite retrievals of *Karenia brevis* harmful algal blooms in the west Florida Shelf using neural networks

Ahmed El-habashi[1] (PhD Candidate, Presenter) and Sam Ahmed[1] (Herbert Kayser Professor).

[1]*The City College of New York, CCNY, NOAA-CREST, Optical Remote Sensing Laboratory, Dept. of Electrical Engineering.*

Outline

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

II. Neural Networks (***NN***) algorithm architecture.

III. ***NN*** retrievals of $\boldsymbol{a}_{ph443}$ and its equivalent [*Chla*]

IV. Application of **filters** we devised for *KB* HABs detection.

V. Inter-technique comparisons *of KB* HAB retrievals in WFS:

- ***NN*** against other available MODIS Fluorescence based techniques including: ***nFLH***

- ***NN*** against other available non Fluorescence based techniques : ***OCI/OC3*** and ***RGCI*** (*Note:* **OCI** very similar to **OC3** and gives almost identical results)

I. Comparisons of VIIRS ***NN, OCI and RGCI*** techniques against **in-situ** measurements, including an evaluation of the ***NN*** technique for specific bloom dates.

II. Conclusion

Background of *KB* HABS in WFS

- In united states alone it has been estimated that $30-$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

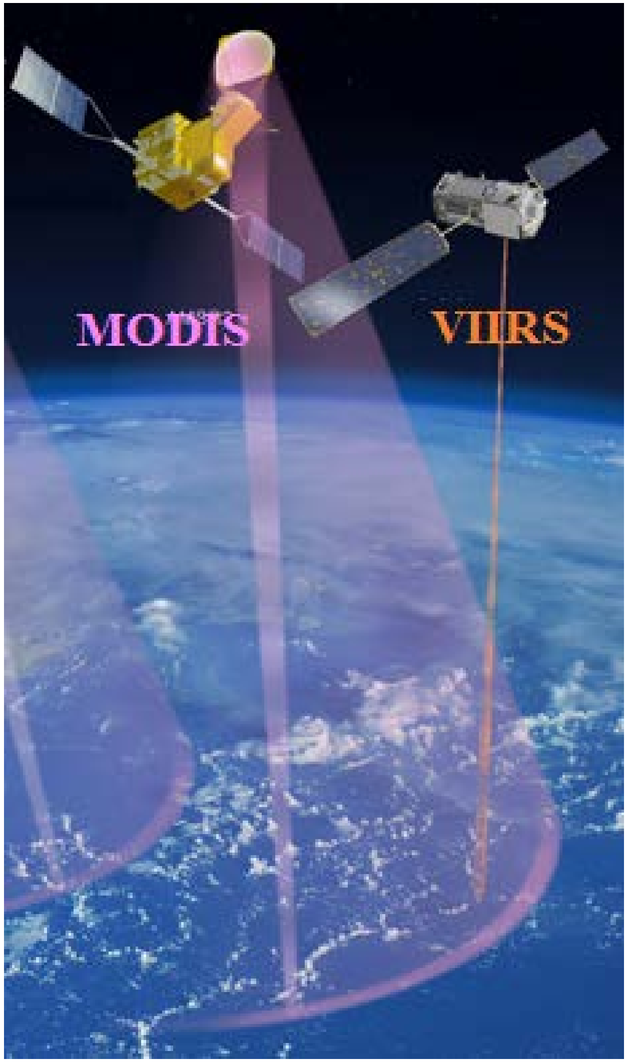
(KB HABs)
Kareina Brevis, Harmful Algal blooms present nearly every year in Florida

MODIS & VIIRS satellite capability for *KB* HABs detections

- MODIS Retrieval of *KB* uses *nFLH* Technique which requires 678nm Fluorescence band

- Unfortunately spectral analysis showed that VIIRS could not discriminate these high-phytoplankton water patches within the dark water due to its lack of fluorescence band (678nm).

- Band not available on VIIRS providing impetus for *NN* technique, using as input 486, 551 and 671 nm available in VIIRS.



<u>Goal:</u>

To have an effective *KB* HAB, detection and tracking approach for use with VIIRS satallite without the availability of fluorescence channel.

So that NOAA can extend its HAB monitoring capabilities to VIIRS and continue to support local authorities in their forecasting of beach conditions, including health warnings etc.

Outline

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

II. Neural Networks (***NN***) algorithm architecture.

III. ***NN*** retrievals of $\boldsymbol{a_{ph443}}$ and its equivalent [*Chla*]

IV. Application of **filters** we devised for *KB* HABs detection.

V. Inter-technique comparisons *of KB* HAB retrievals in WFS:

- ***NN*** against other available MODIS Fluorescence based techniques including: ***nFLH***
- ***NN*** against other available non Fluorescence based techniques : ***OCI/OC3*** and ***RGCI*** (*Note:* **OCI** very similar to **OC3** and gives almost identical results)

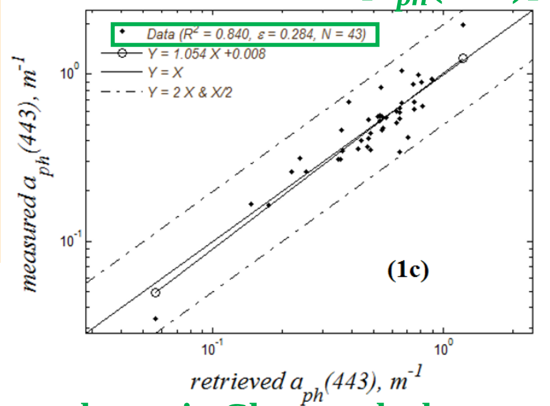
I. Comparisons of VIIRS ***NN, OCI and RGCI*** techniques against **in-situ** measurements, including an evaluation of the ***NN*** technique for specific bloom dates.

II. Conclusion

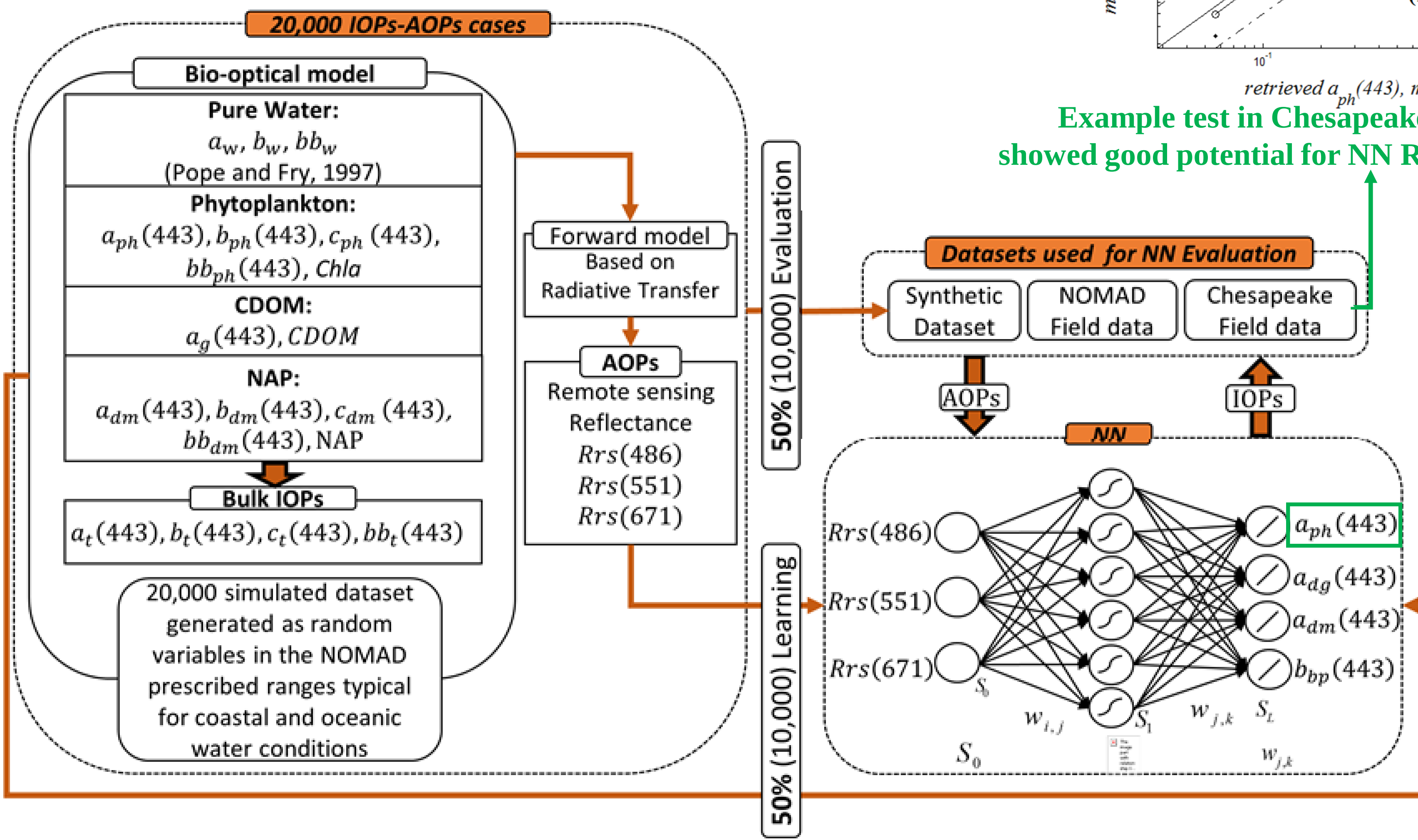
Neural Networks (NN) Algorithm Architecture.

- **NN** developed in previous work, was trained on (**10,000**) simulated dataset based on wide range of coastal and oceanic NOMAD IOPs.
- **Tested** and validated on another **10,000** simulated dataset and field measurements.
- **Uses** VIIRS *Rrs* input at 486, 551 & 671 nm, values used **at a longer λ** which are not greatly impacted by atmospheric correction
- **Output** of (*aph, adg, adm* & *bbp*) all at 443 (which at the peak of *aph* and thus exhibit most variation)
- We are only interested at aph443 at this work

Retrieved NN [$a_{ph}(443)$]



Example test in Chesapeake bay, showed good potential for NN Retrievals



Outline

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

II. Neural Networks (***NN***) algorithm architecture.

III. ***NN*** retrievals of $\boldsymbol{a}_{ph443}$ and its equivalent [*Chla*]

IV. Application of **filters** we devised for *KB* HABs detection.

V. Inter-technique comparisons *of KB* HAB retrievals in WFS:

- ***NN*** against other available MODIS Fluorescence based techniques including: ***nFLH***
- ***NN*** against other available non Fluorescence based techniques : ***OCI/OC3*** and ***RGCI*** (*Note:* **OCI** very similar to **OC3** and gives almost identical results)

I. Comparisons of VIIRS ***NN, OCI and RGCI*** techniques against **in-situ** measurements, including an evaluation of the ***NN*** technique for specific bloom dates.

II. Conclusion

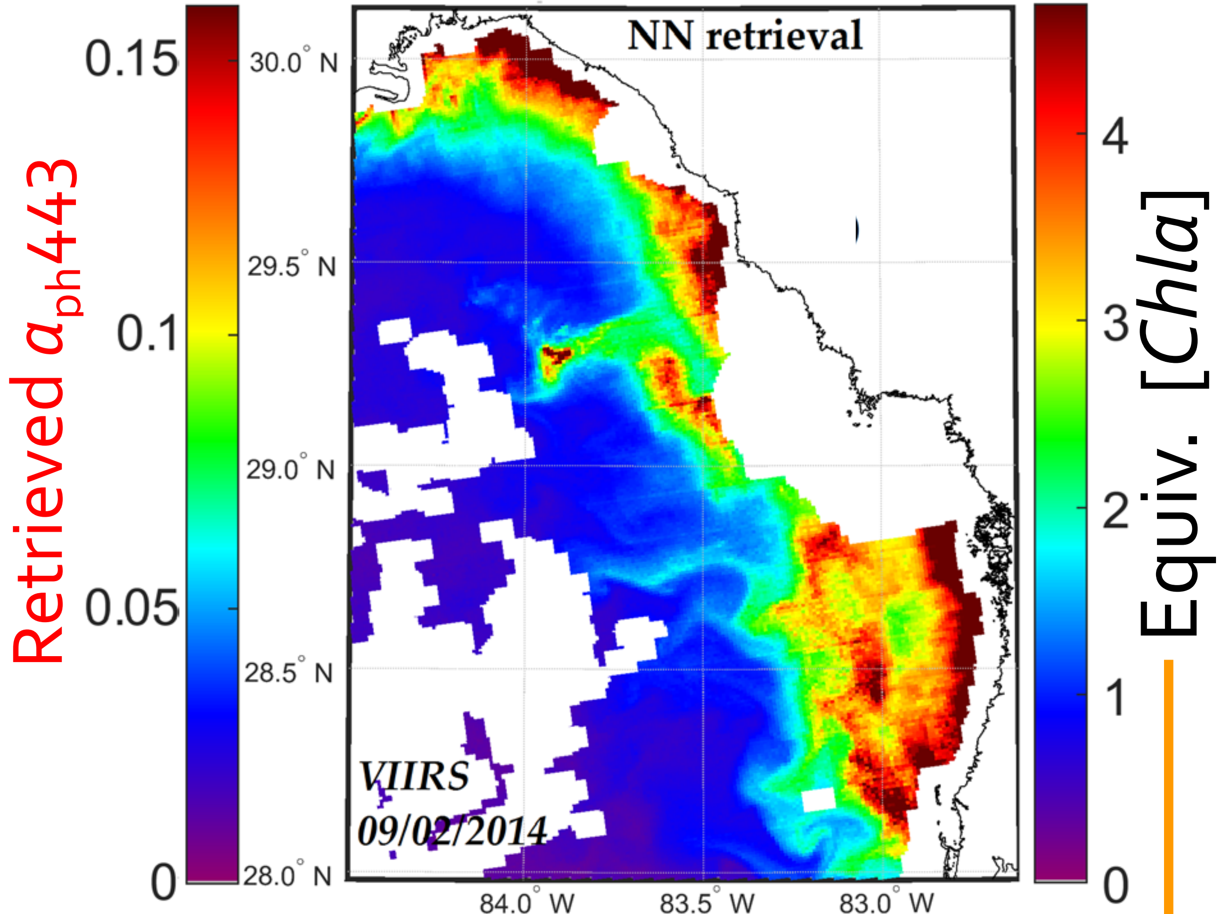
VIIRS *NN retrievals* of a_{ph443}, and its conversion to equivalent [*Chla*]. From *Rrs at* 486, 551 & 671 nm

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 the WFS. *Chengfeng Le & Chuanmin Hu, (2013)*

Outline

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

II. Neural Networks (***NN***) algorithm architecture.

III. ***NN*** retrievals of $\boldsymbol{a}_{ph_{443}}$ and its equivalent [*Chla*]

IV. Application of **filters** we devised for *KB* HABs detection.

V. Inter-technique comparisons *of KB* HAB retrievals in WFS:

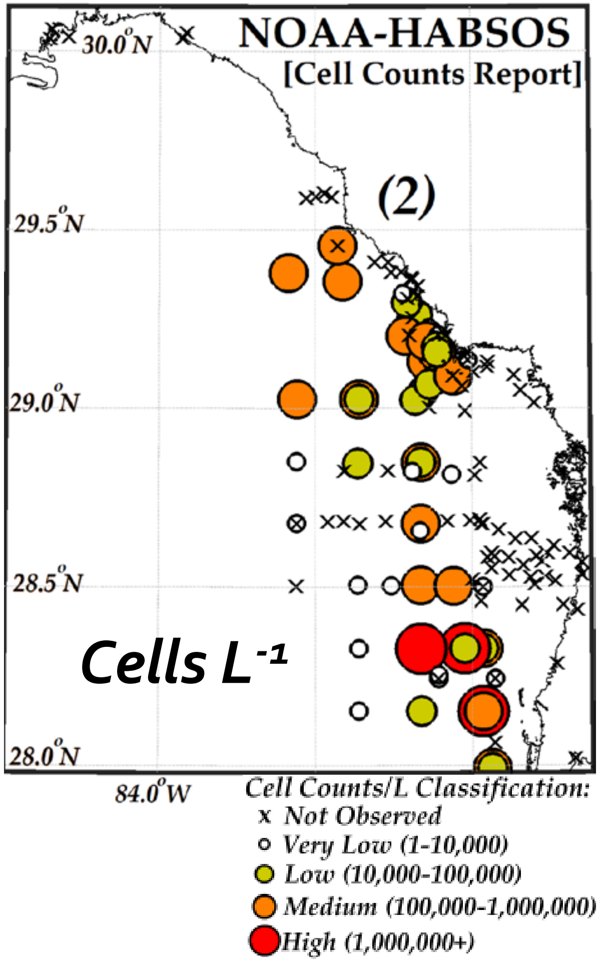
- ***NN*** against other available MODIS Fluorescence based techniques including: ***nFLH***
- ***NN*** against other available non Fluorescence based techniques : ***OCI/OC3*** and ***RGCI*** (*Note:* **OCI** very similar to **OC3** and gives almost identical results)

I. Comparisons of VIIRS ***NN, OCI and RGCI*** techniques against **in-situ** measurements, including an evaluation of the ***NN*** technique for specific bloom dates.

II. Conclusion

Example of reported *KB* HABS in-situ measurements (8/27/2014-9/17/2014) against which tested our retrievals.

We based our study on this major bloom 09/2014. which had concurrent or near concurrent in-situ measurements reported by NOAA HABSOS.



NOAA HABSOS data with in-situ *KB* concentrations, for period 8/27/2014-9/17/2014.

Approach applied in WFS for *KB*-HABs Detections

- **First** we relate VIIRS Rrs (486,551,671) to aph443 using NN for estimation of Concentrations *aph*443 which is α [*Chla*].
- **Then**, in a second critical step, we evolve limiting criteria which make use of two facts (*Cannizzaro, 2009*)

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

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

We know KB HABS are characterized by low backscatter at 551 nm and aph443 above certain minimum value.

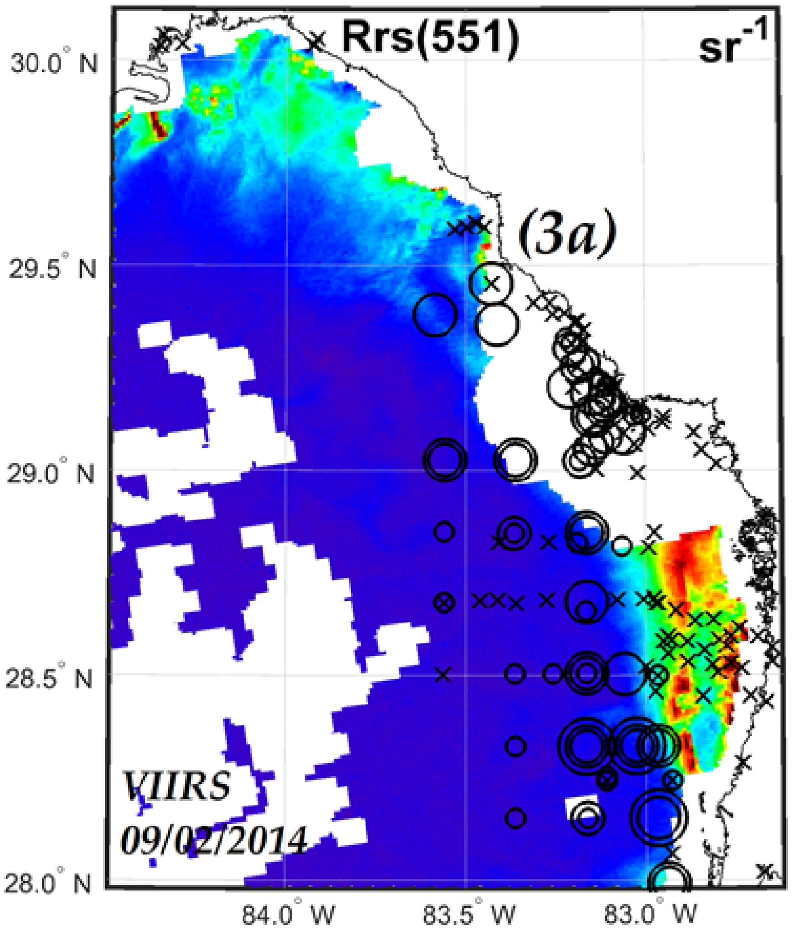
Rrs 551nm is proportional to backscatter. So we examine *Rrs* 551nm and *aph*443 that are compatible with KB existence from HABSOS in-situ retrievals which are overlaid on *Rrs* 551 nm and NN *aph*443 retrievals to establish limiting compatible values of these two. These are then applied to retrieved *Rrs* 551 nm, as Filter 1, and to retrieved NN *aph*443, as Filter 2, limiting filter values and thus excluding all other pixels that are outside these values.

F1 Filter

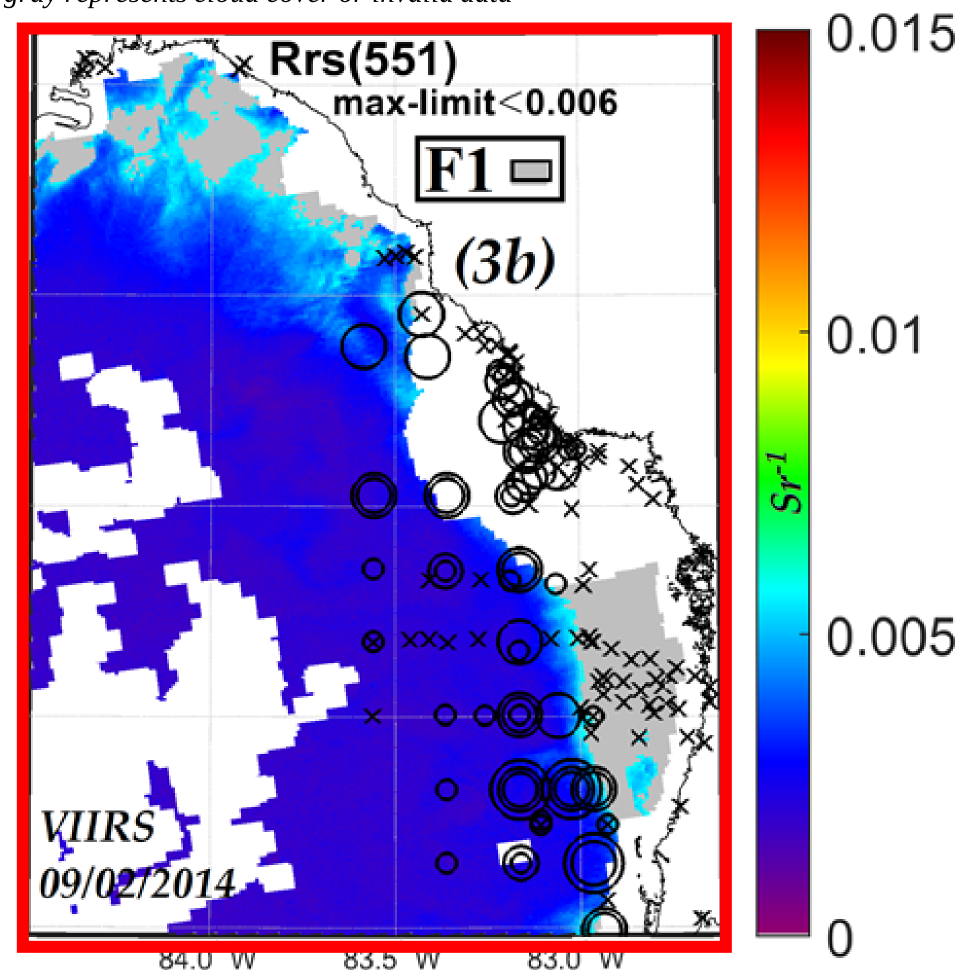
Known fact *KB* HABs are characterized by low backscatter therefore we devise a filter based on upper limit of backscatter and equivalent Rrs_{551} values to *NN* VIIRS retrievals.

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_pr 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

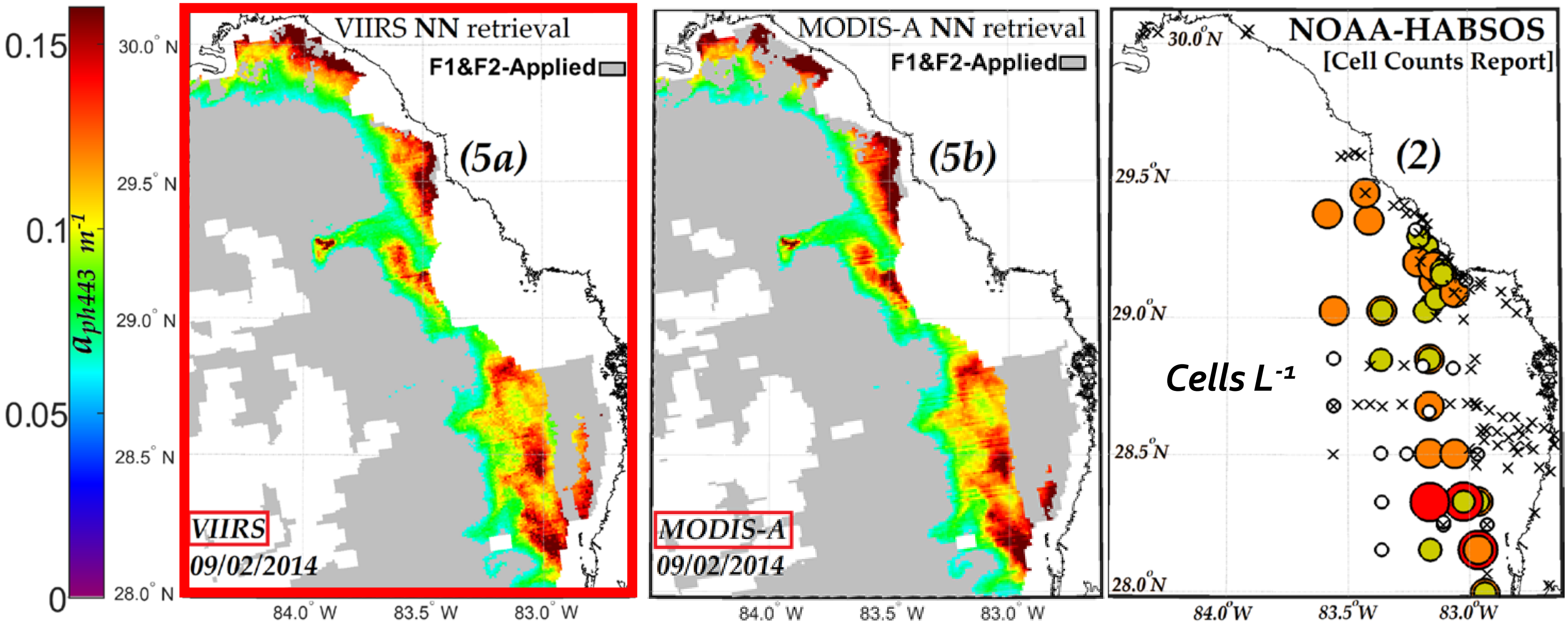


(3d) This max value used to generate a mask F1 mask (dark gray), which eliminate all values of $\{Rrs_{551}\} \geq 0.006$ sr⁻¹ and therefore incompatible with KB HABS, when mask is applied to image residual pixels, are then compatible with KB HABs

F1 & F2 Filters combined show the extent of *KB* blooms

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+)*

Outline

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

II. Neural Networks (***NN***) algorithm architecture.

III. ***NN*** retrievals of $\boldsymbol{a_{ph443}}$ and its equivalent [*Chla*]

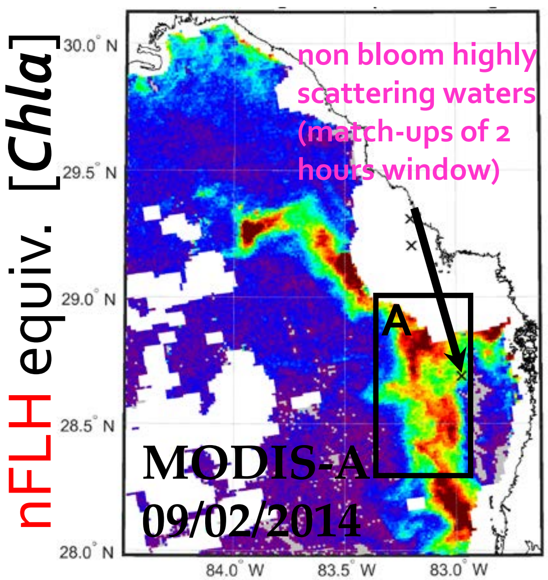
IV. Application of **filters** we devised for *KB* HABs detection.

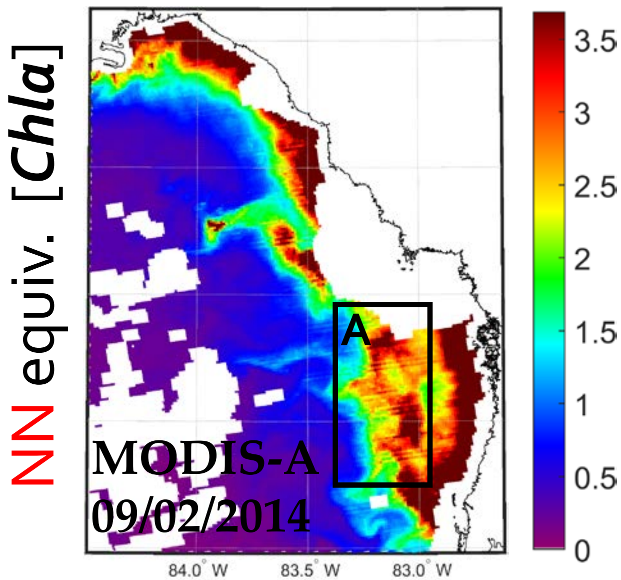
V. Inter-technique comparisons *of KB* HAB retrievals in WFS:
   - ***NN*** against other available MODIS **Fluorescence based** techniques including: ***nFLH***
   - ***NN*** against other available **non Fluorescence based** techniques : ***OCI/OC3*** and ***RGCI*** (*Note:* **OCI** very similar to **OC3** and gives almost identical results)

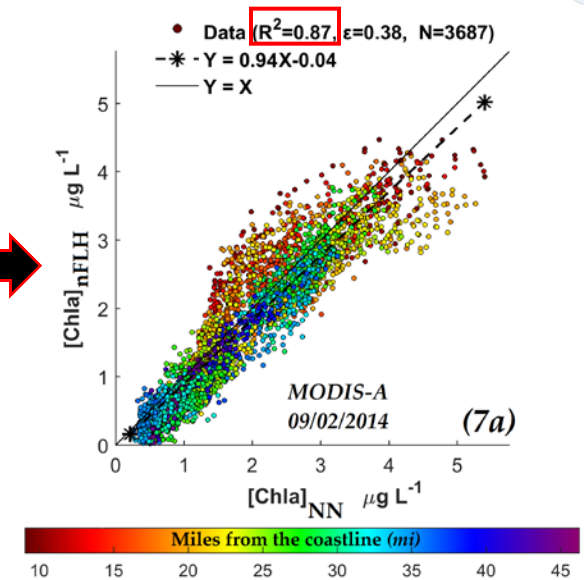
I. Comparisons of VIIRS ***NN, OCI and RGCI*** techniques against **in-situ** measurements, including an evaluation of the ***NN*** technique for specific bloom dates.

II. Conclusion

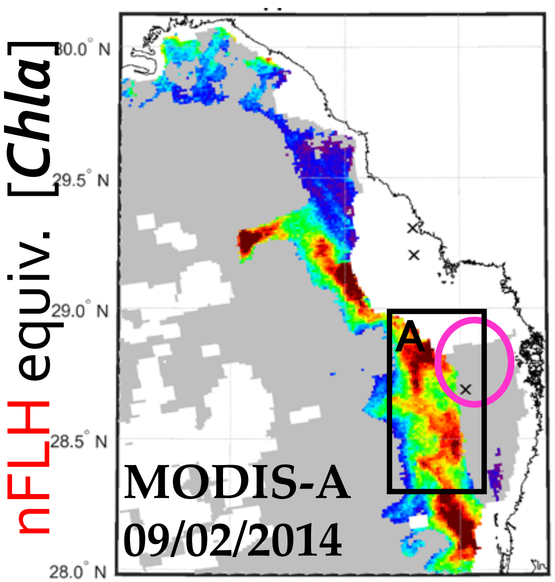
Comparisons of MODIS NN and nFLH retrievals of Equiv. [*Chla*]

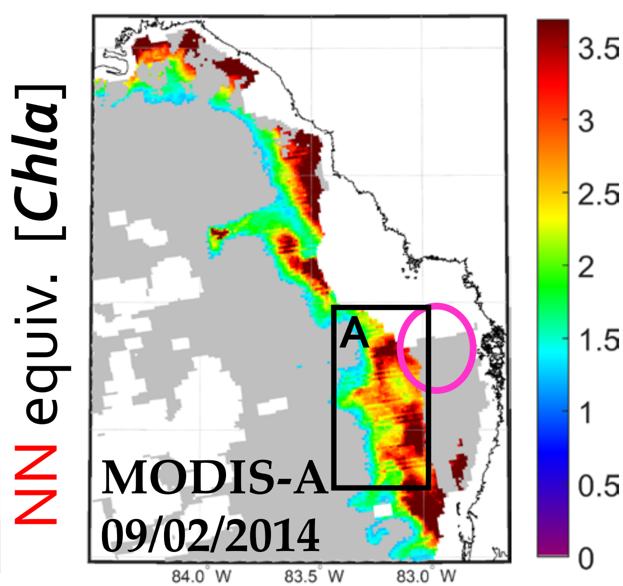


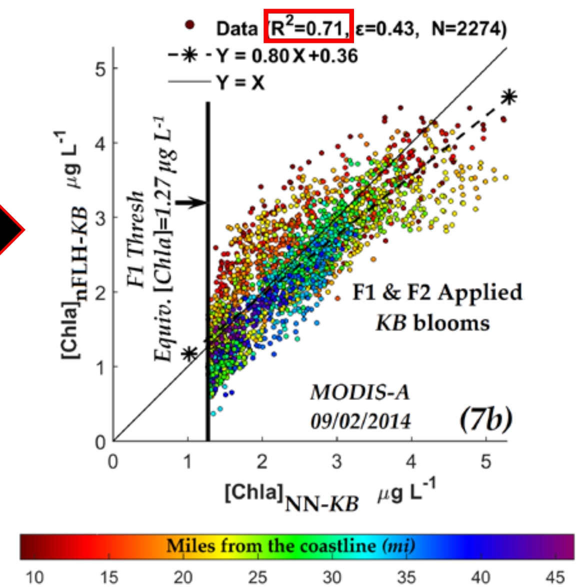




"Color coding of the dots denotes distance to shore, with red being the closest."







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

Outline

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

II. Neural Networks (***NN***) algorithm architecture.

III. ***NN*** retrievals of $\boldsymbol{a}_{ph443}$ and its equivalent [*Chla*]

IV. Application of **filters** we devised for *KB* HABs detection.

V. Inter-technique comparisons *of KB* HAB retrievals in WFS:

- ***NN*** against other available MODIS **Fluorescence based** techniques including: ***nFLH***
- ***NN*** against other available **non Fluorescence based** techniques : ***OCI/OC3*** and ***RGCI*** (*Note:* **OCI** very similar to **OC3** and gives almost identical results)

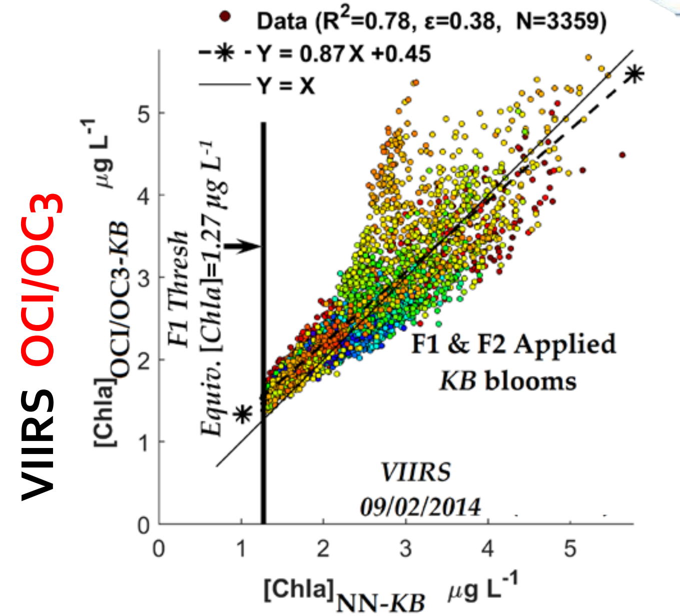
I. Comparisons of VIIRS ***NN, OCI and RGCI*** techniques against **in-situ** measurements, including an evaluation of the ***NN*** technique for specific bloom dates.

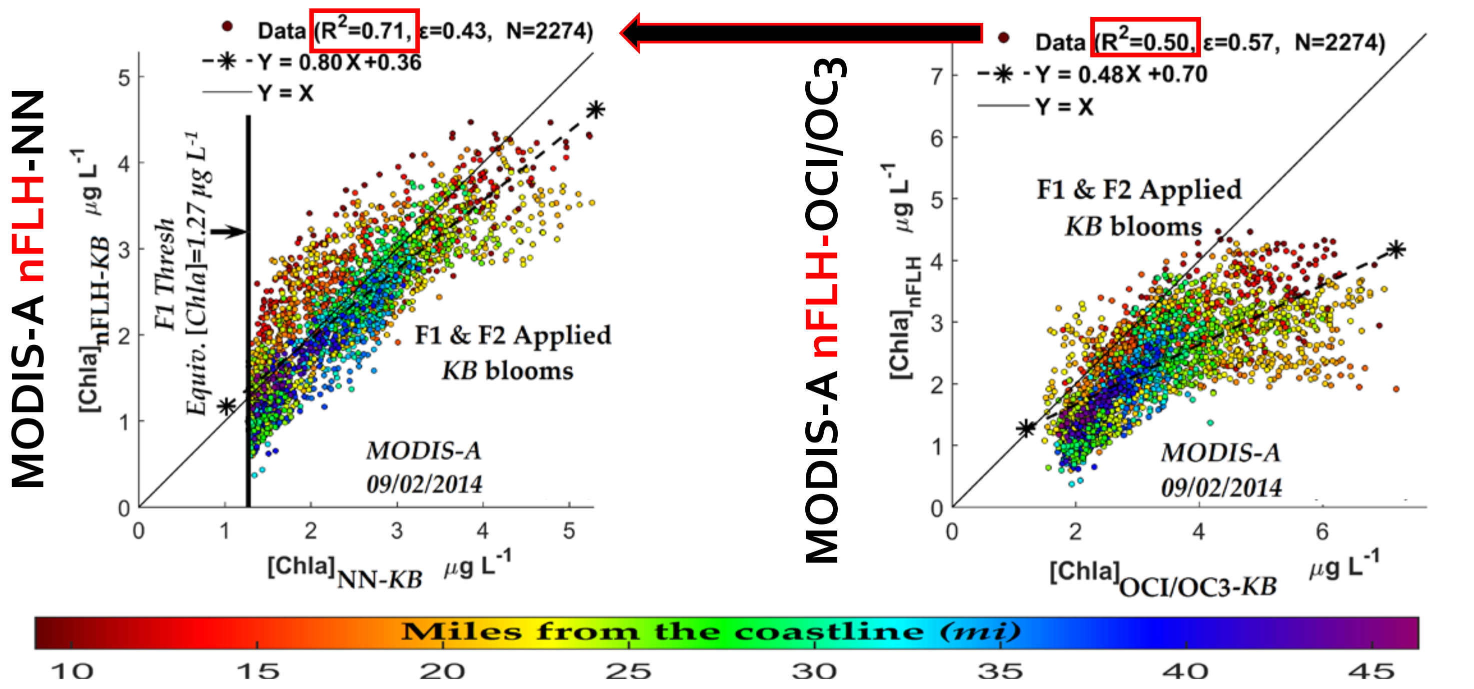
II. Conclusion

OCI/OC3 , VIIRS NN and MODIS *nFLH* Equiv. [*Chla*] retrievals and comparisons.

OCI/OC3 NASA Ocean Color product for chlorophyll-a **[2]**:

- This algorithm returns the near-surface concentration of chlorophyll-a (chlor_a) in $\mu g\ L^{-1}$, calculated using an empirical algorithm to estimate [*Chla*] concentrations in the global ocean.
- (the relative height of Rrs(555) from a background, i.e., difference between Rrs(555) and a baseline formed linearly between Rrs(443) and Rrs(670))





[2] NASA's OceanColor Web by the Ocean Biology Processing Group (OBPG) at NASA's Goddard Space Flight Center. Available online: http://oceancolor.gsfc.nasa.gov/cms/atbd/chlor_a/

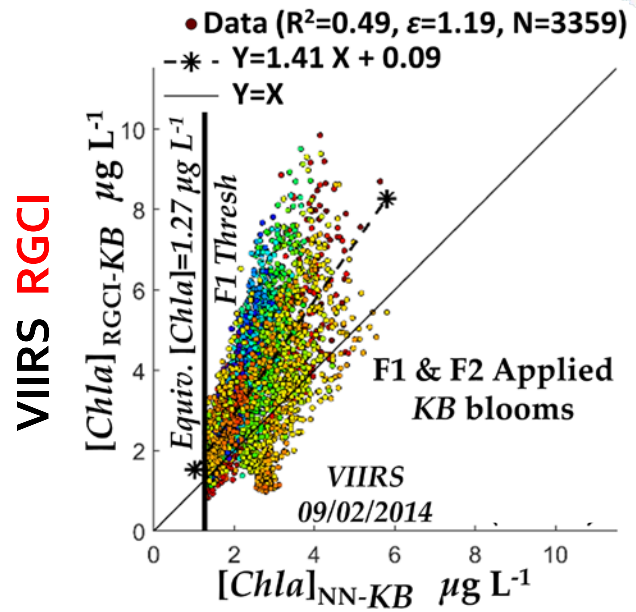
RGCI , VIIRS NN and MODIS *nFLH* Equiv. [*Chla*] retrievals and comparisons.

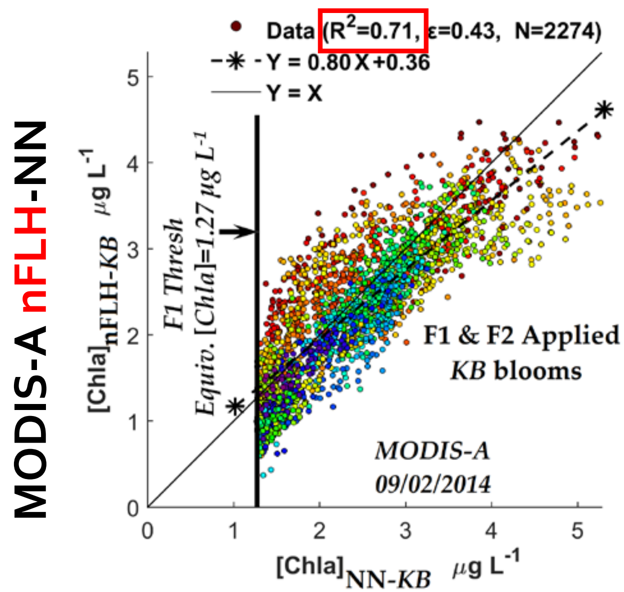
We next examine the Red Green chlorophyll-*a* Index RGCI [*Chla*] retrievals [*Lin Qi, C. Hu 2015*]:

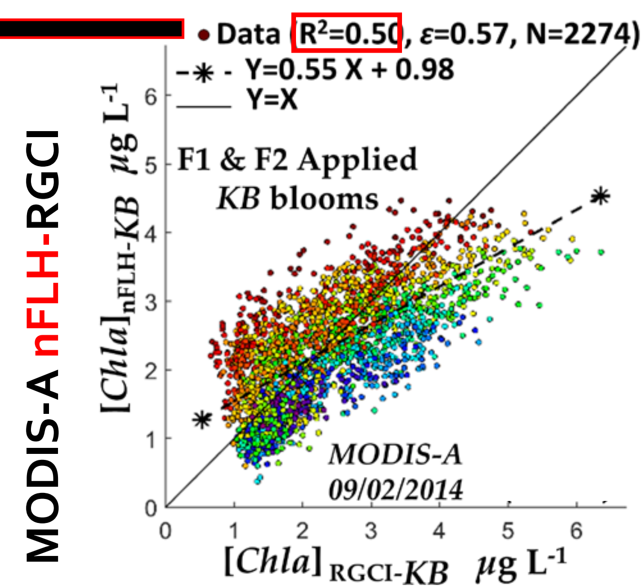
for the same 9/2/2014 date and locations as in the above Sections. Equation a below gives the relationship for RGCI MODIS [*Chla*] retrievals (a), and (b) that for RGCI VIIRS [*Chla*] retrievals.

(a) $$[Chla]_{RGCI} = 0.1 * \exp\left(11.8 * \frac{Rrs667}{Rrs547}\right) \text{ , } \mu g\ L^{-1}$$

(b) $$[Chla]_{RGCI} = 0.1 * \exp\left(11.8 * \frac{Rrs671}{Rrs551}\right) \text{ , } \mu g\ L^{-1}$$







Outline

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

II. Neural Networks (***NN***) algorithm architecture.

III. ***NN*** retrievals of $\boldsymbol{a_{ph443}}$ and its equivalent [*Chla*]

IV. Application of **filters** we devised for *KB* HABs detection.

V. Inter-technique comparisons *of KB* HAB retrievals in WFS:
- ***NN*** against other available MODIS Fluorescence based techniques including: ***nFLH***
- ***NN*** against other available non Fluorescence based techniques : ***OCI/OC3*** and ***RGCI*** (*Note:* **OCI** very similar to **OC3** and gives almost identical results)

I. Comparisons of VIIRS ***NN, OCI and RGCI*** techniques against **in-situ** measurements, including an evaluation of the ***NN*** technique for specific bloom dates.

II. Conclusion

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

- **To verify the association between K. brevis cell abundance and VIIRS ocean color Level 2 phytoplankton absorption**

  values for K. brevis 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).**

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

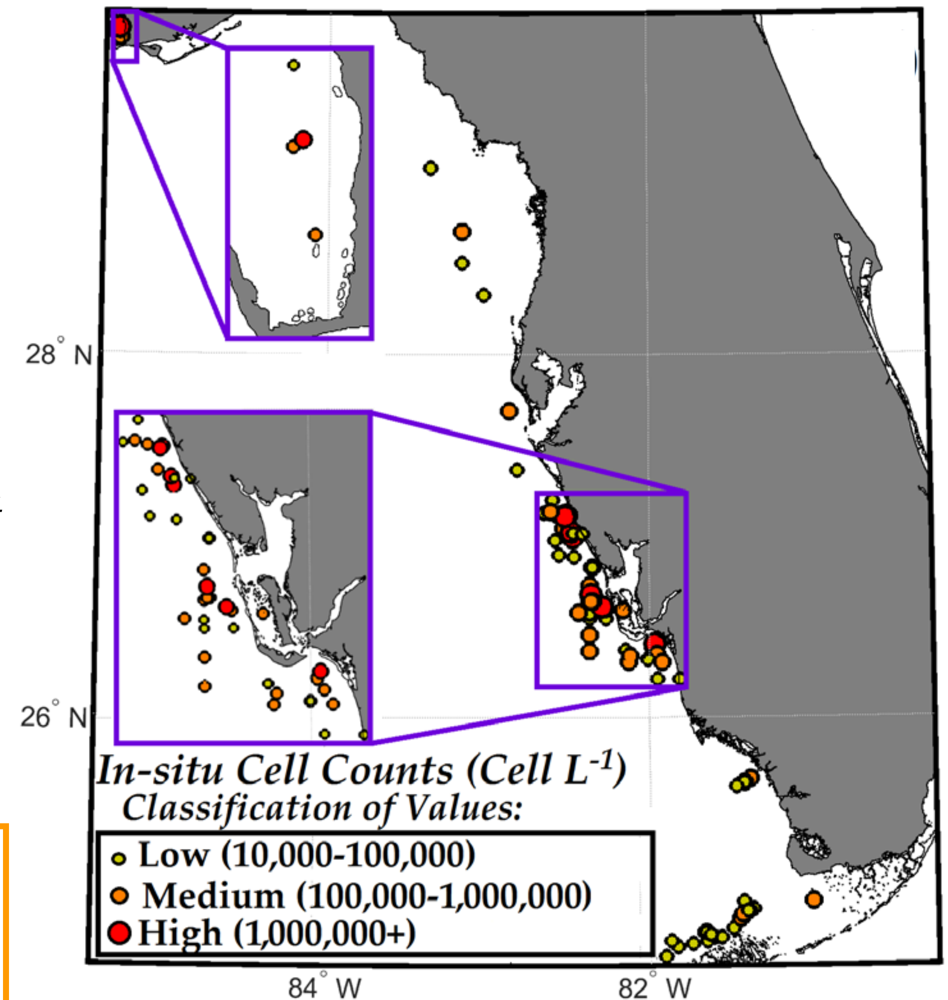
KB-HABs cell counts limitations

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 pixels used for match-up comparison are all extracted from a smaller region, nearest pixel (<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

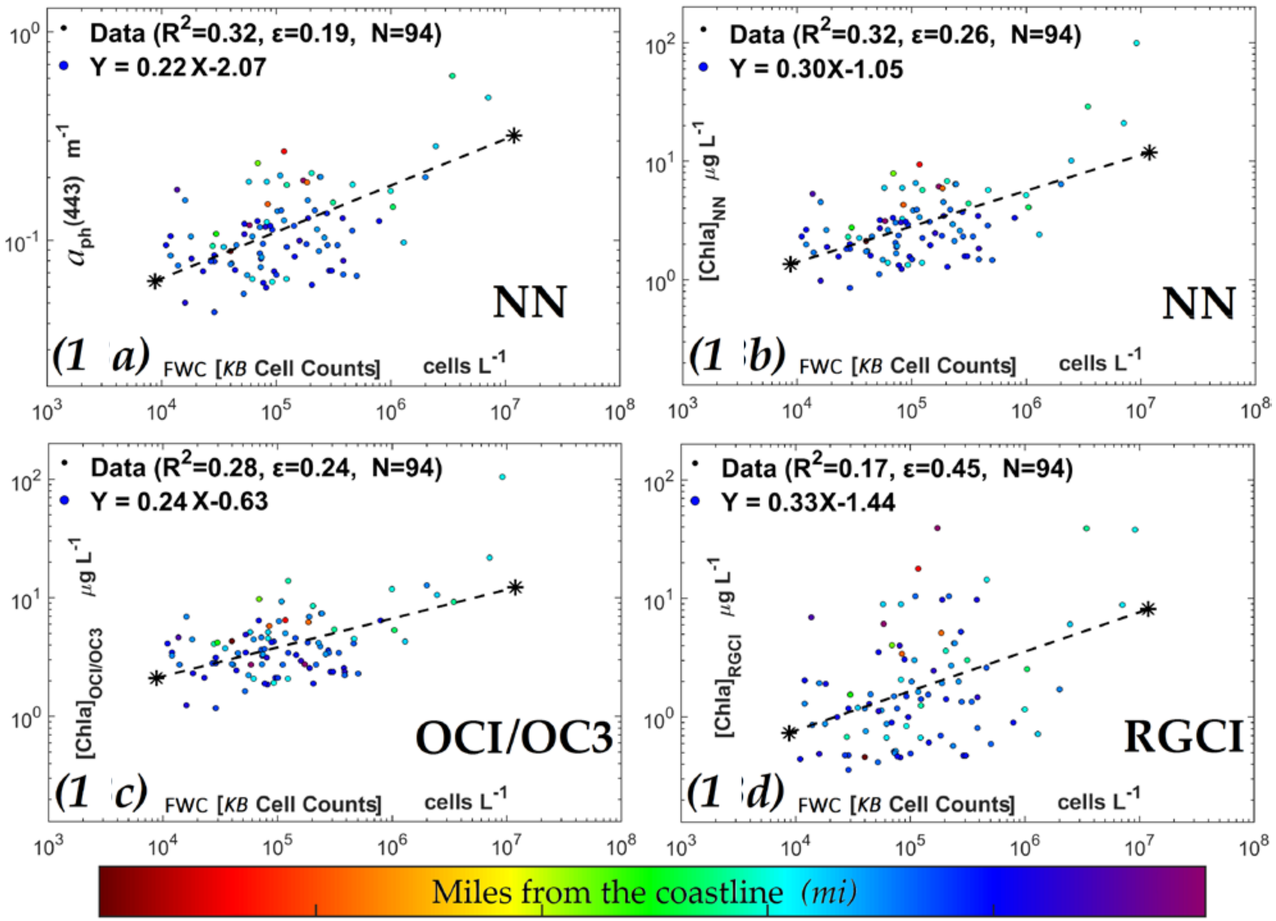
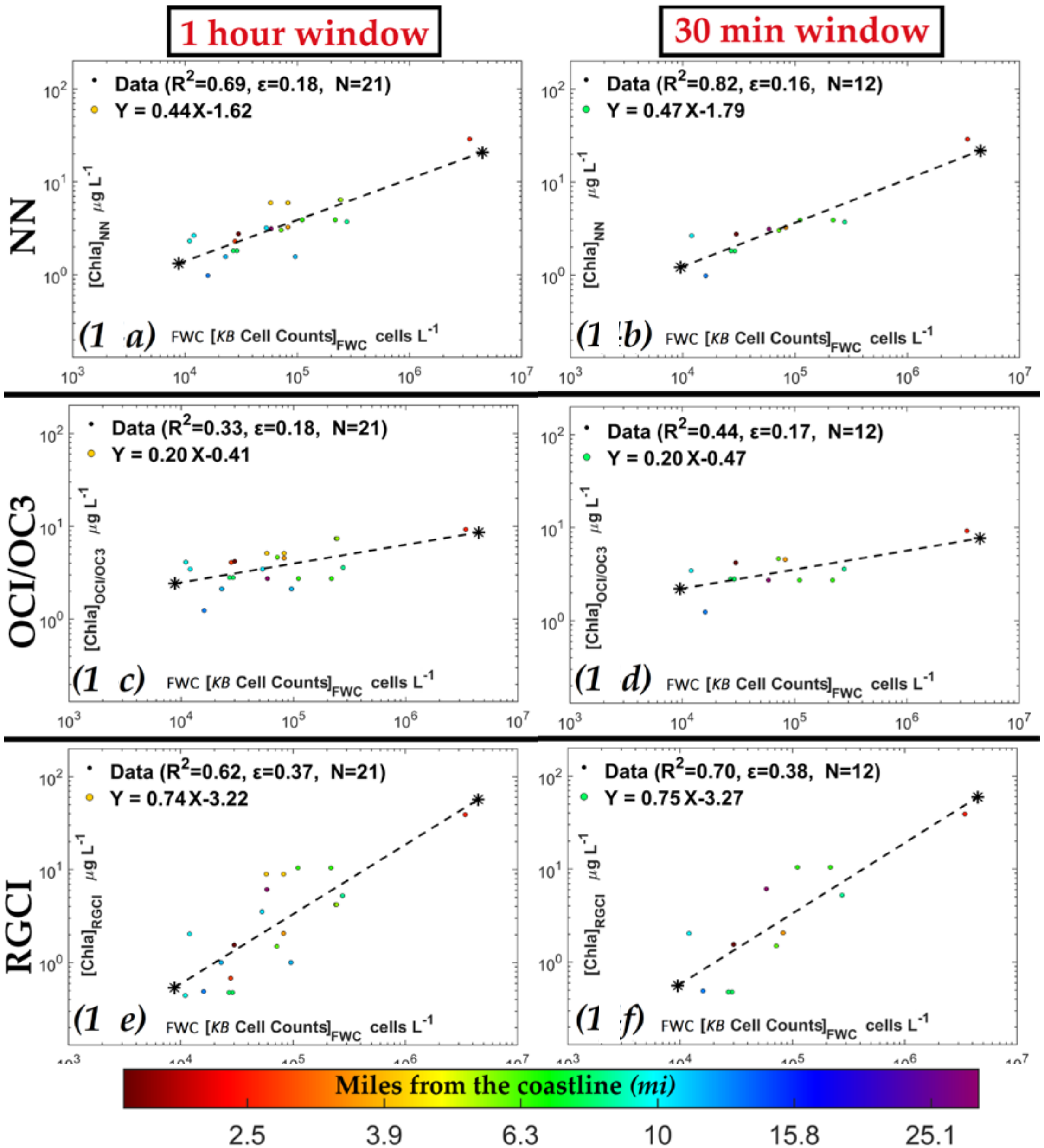


Fig. 13(a-d): In-situ observation within the same day of VIIRS image: (a) VIIRS NN retrieved a_{ph443} against In-situ *KB* cell counts; **(b)** VIIRS NN equiv. [*Chla*] against in-situ cell counts; **(c)** VIIRS OCI/OC3 retrieved [*Chla*] against in-situ *KB* cell counts; **(d)** VIIRS RGCI retrieved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

To compare the impact of temporal changes between satellite observations and in-situ measurements for NN, OCI/OC3 and RGCI retrieval, windows of
(<1 hours & < 30 minutes were selected).

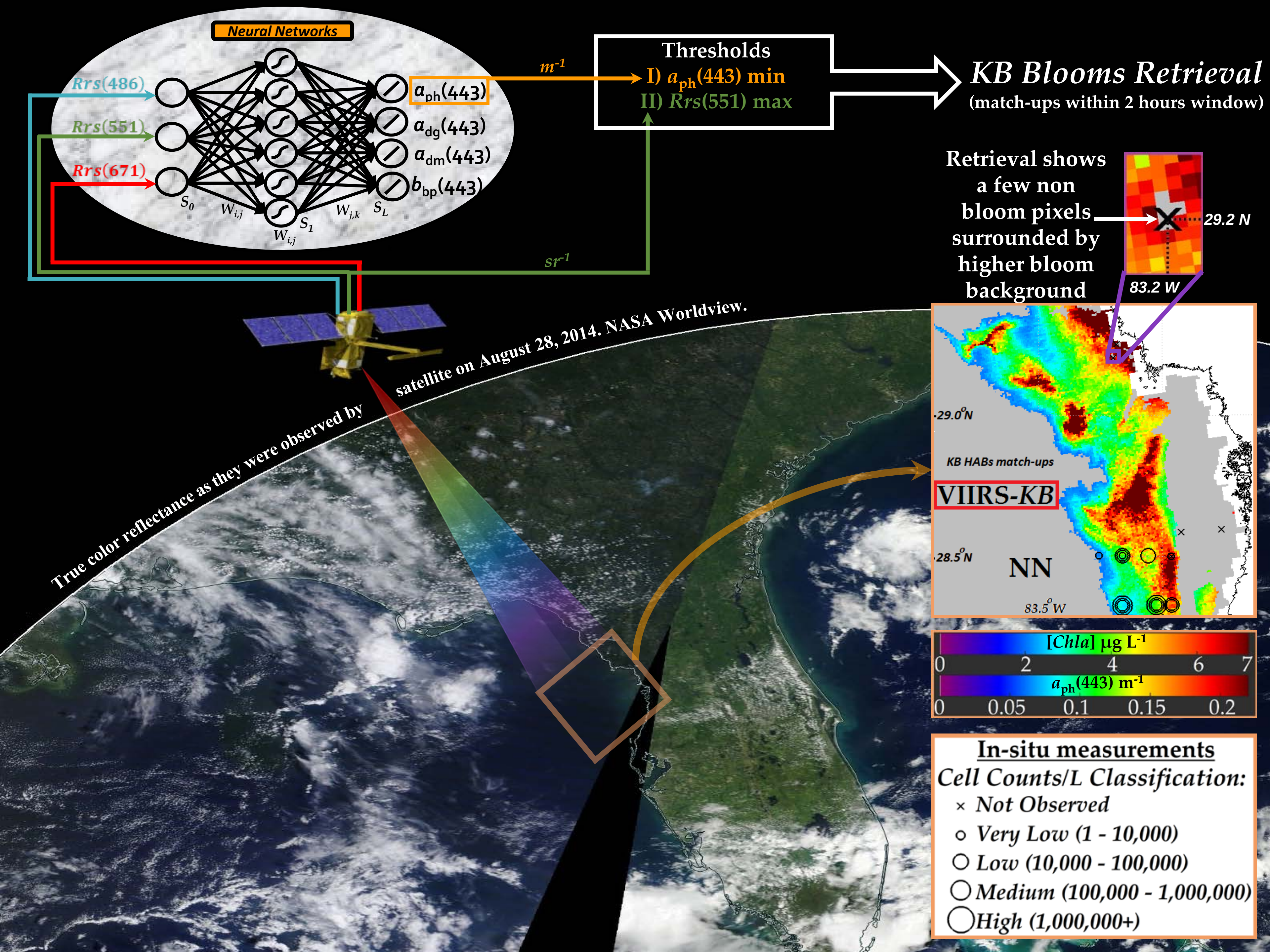
In-situ measurements *Vs.* VIIRS NN *KB*-HABs retrievals (2012-2015) limited observation windows

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.



Evaluation of NN *KB* HABs retrievals for specific bloom events.

(08/28/2014, 11/16/2014and 10/09/2012, blooms.).



Neural Networks
Rrs(486)
Rrs(551)
Rrs(671)
$a_{ph}(443)$
$a_{dg}(443)$
$a_{dm}(443)$
$b_{bp}(443)$
S_0
$W_{i,j}$
S_1
$W_{j,k}$
S_L
m^{-1}
sr^{-1}
Thresholds
I) $a_{ph}(443)$ min
II) $Rrs(551)$ max
KB Blooms Retrieval
(match-ups within 2 hours window)
Retrieval shows a few non bloom pixels surrounded by higher bloom background
29.2 N
83.2 W
29.0°N
28.5°N
83.5°W
KB HABs match-ups
VIIRS-KB
NN
[Chla] µg L-1
0 2 4 6 7
$a_{ph}(443)$ m-1
0 0.05 0.1 0.15 0.2
In-situ measurements
Cell Counts/L Classification:
× Not Observed
Very Low (1 - 10,000)
Low (10,000 - 100,000)
Medium (100,000 - 1,000,000)
High (1,000,000+)
True color reflectance as they were observed by satellite on August 28, 2014. NASA Worldview.

08/28/2014 bloom

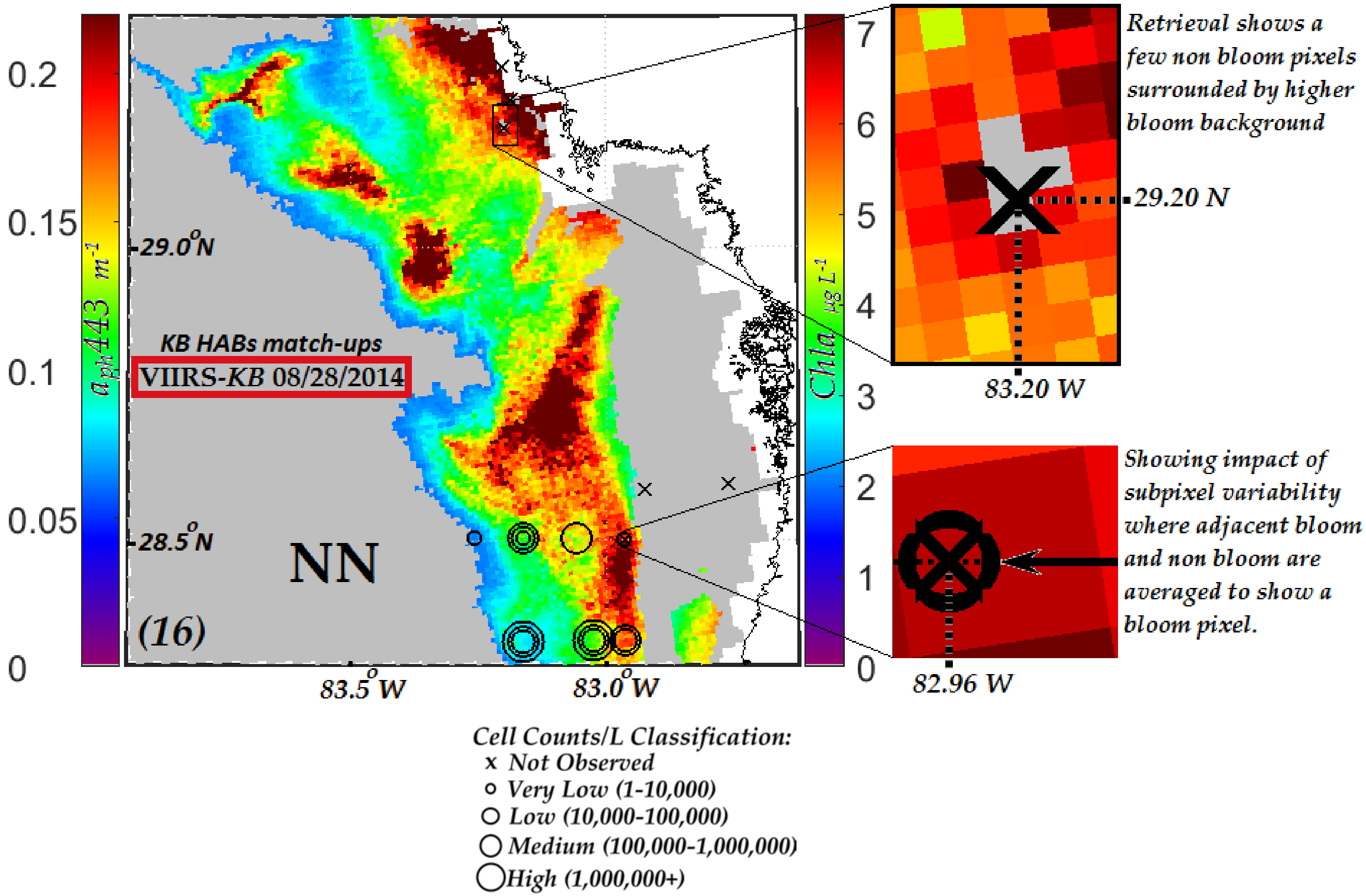
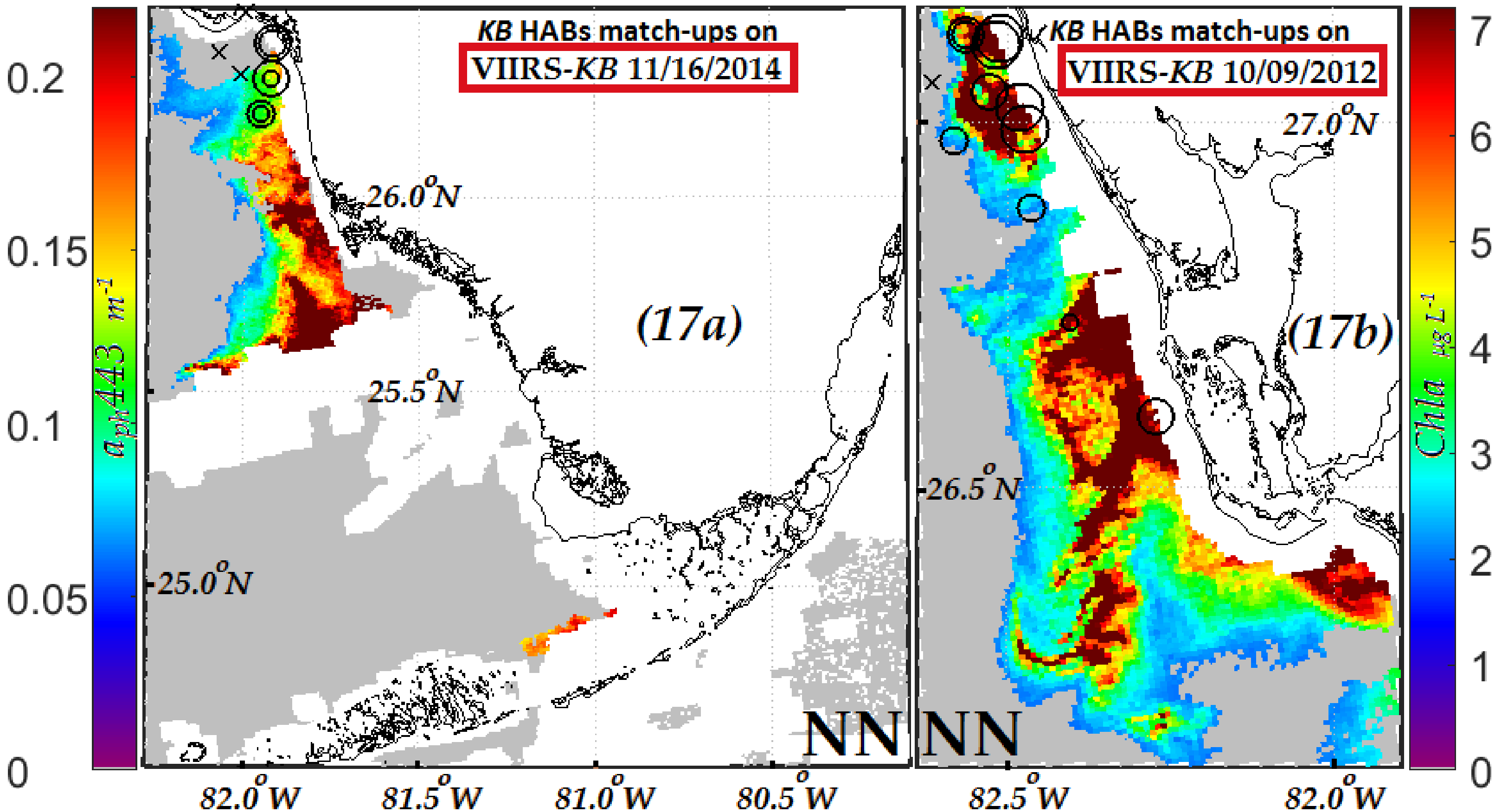


Fig. VIIRS-NN *KB* HABs retrievals for blooms date (08/28/2014), showing bloom compatible a_{ph443} and equiv. [*Chla*] values. There are total of 20 match-ups in that day. Notes image are overlaid with cell counts for this date. **There are total of 20 match-ups in that day.**

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



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

Fig. 16. VIIRS-NN *KB* HABs retrievals for blooms date (11/16/2014 & 10/09/2012), showing bloom compatable a_{ph443} and equiv. [*Chla*] values. Notes image are overlaid with cell counts for this date. . **There are total of 6 and 12 match-ups respectively in these days.**

Outline

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

II. Neural Networks (***NN***) algorithm architecture.

III. ***NN*** retrievals of $\boldsymbol{a_{ph443}}$ and its equivalent [*Chla*]

IV. Application of **filters** we devised for *KB* HABs detection.

V. Inter-technique comparisons *of KB* HAB retrievals in WFS:
- ***NN*** against other available MODIS Fluorescence based techniques including: ***nFLH***
- ***NN*** against other available non Fluorescence based techniques : ***OCI/OC3*** and ***RGCI*** (*Note:* **OCI** very similar to **OC3** and gives almost identical results)

I. Comparisons of VIIRS ***NN, OCI and RGCI*** techniques against **in-situ** measurements, including an evaluation of the ***NN*** technique for specific bloom dates.

II. Conclusion

Conclusions

- The use of *NN* retrievals of *aph*443 from VIIRS show promise as a 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.

- Retrieval 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 details.

Acknowledgment:
We thank JPSS and NOAA-Crest for the support to continue this work.

Thank you