Monitoring Abnormal Bio-optical and Physical Properties in the Gulf of Mexico

Robert Arnone, Brooke Jones

University of Southern Mississippi,
Department of Marine Science, Stennis Space Center, MS 39529

ABSTRACT

The dynamic bio-optical and physical ocean properties within the Gulf of Mexico (GoM) have been identified by the Ocean Weather Laboratory. Ocean properties from VIIRS satellite (Chlorophyll and Bio-Optics and SST) and ocean-circulation models (currents, SST and salinity) were used to identify regions of dynamic changing properties. The degree of environmental change is defined by the dynamic anomaly of bio-optical and physical environmental properties (DAP). A Mississippi River plume event (Aug 2015) that extended to Key West was used to demonstrate the anomaly products. Locations where normal and abnormal ocean properties occur determine ecological and physical hotspots in the GoM, which can be used for adaptive sampling of ocean processes. Methods are described to characterize the weekly abnormal environmental properties using differences with a previous baseline 8 week mean with a 2 week lag. The intensity of anomaly is quantified using levels of standard deviation of the baseline and can be used to recognize ocean events and provide decision support for adaptive sampling. The similarities of the locations of different environmental property anomalies suggest interaction between the bio-optical and physical properties. A coral bleaching event at the Flower Garden Banks Marine Protected Area is represented by the salinity anomaly. Results identify ocean regions for sampling to reduce data gaps and improve monitoring of bio-optical and physical properties.

Keywords: Ocean Color, Circulation Models, Hotspots, Anomalies, Chlorophyll, Satellite, SNPP VIIRS

1. INTRODUCTION

The dynamic processes which occur in the Gulf of Mexico make it difficult to identify where unusual events are occurring that can affect the ecosystem. Real time ocean monitoring using satellite and model products is available to define current conditions at the USM Ocean Weather Laboratory. However, methods are required to identify locations of abnormally changing properties and their spatial-temporal scales, so that ocean conditions can be accurately monitored. Data gaps in ecosystem monitoring can be identified by defining the spatial and temporal variability of marine conditions using historical data sets and determining if anomalous conditions are occurring. Characterizing the dynamic scales in ocean parameter anomalies is critical to establishing an ocean observation network (1-5, 13). Identifying the abnormal response of the ocean properties to local events (i.e., floods, hurricanes, dredging, river diversion, etc.) can provide managers tools to know where and when to sample so that there are minimal gaps in critical datasets. Studies have demonstrated satellite chlorophyll anomalies for harmful algal blooms (20, 23) .Our scientific objective is to create a product to identify the spatial and temporal locations of bio-physical dynamic anomaly properties (DAP) that are occurring in the Gulf by using the daily real time satellite and circulation model environmental properties. The OWL has created weekly dynamic environment anomaly products from 2014 – 2017 to identify events occurring in the Gulf of Mexico. The DAP properties include surface chlorophyll, euphotic depth, ocean currents, salinity, and temperature to identify the bio-physical events and possible hotspots that can impact the ecosystem. The procedure to identify abnormal events requires defining the degree of abnormality to see how each non-uniform product can affect the ecosystem. The DAP products have applications to users for identifying ocean regions for adaptive sampling, to reduce data gaps and improve sampling regions where changing environmental events are occurring. Identifying abnormal regions can support understanding how the ecosystem is responding to changing property events. For example, is the location of the Mississippi river plume which is represented by daily currents and surface chlorophyll products in a normal or abnormal location and intensity. If recognized as a regional event, than how is the ecosystem responding to different abnormal environmental properties at this location. For example do abnormal currents have a corresponding location of an abnormal chlorophyll response. Our goals are to monitor where and when these possible events occur and improve characterizing the biological and physical impacts. Identifying the abnormal location and intensity

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conditions can improve the interpretation of fisheries and other data that has been collected at DAP locations. The differences between the physical and biological anomaly products can provide support to understanding how the ecosystems responds to each and the intensity of each environmental products.

2. DATA ASSEMBLAGE

The Ocean Weather Laboratory monitors the Gulf of Mexico using an assemblage of satellite ocean color, SST and circulation models products (Figure 1). Daily ocean products are used to support ship and glider adaptive sampling for data collection [(23)].

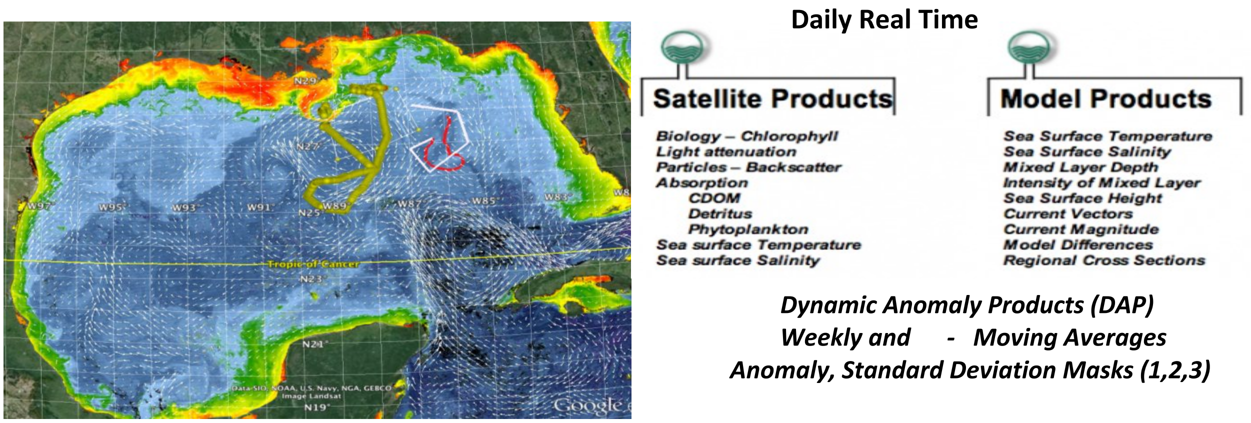

Figure 1 - Ocean Weather Lab determines real time Ocean conditions in the GOM from Satellites and Models. A) Chlorophyll Map with surface currents B) The list of daily satellite and model products and C) Anomaly Products

Daily real time observations of water quality and physical properties from ocean color satellites and physical circulation models are used for monitoring the Gulf of Mexico in the USM Ocean Weather Laboratory (OWX). https://www.usm.edu/marine/research-owx [(3).] These data provide spatial and temporal coverage to establish a baseline and identify active events in the Gulf of Mexico. The bio-optical parameters from ocean color satellites (NOAA – VIIRS) provide a reliable real time assessment of coastal and open waters [(2,7, 15,16,18,19)] which is also used by the EPA as direct observations of the water quality at resolutions of 750m [(12)]. VIIRS processing is performed using NASA – SeaBass [(24)].

Two regional operational circulation models including the 1/25-degree Gulf of Mexico Hybrid Coupled Ocean Models (HYCOM-GoM) and the 1/36-degree Navy Coastal Ocean Models in American Seas (NCOM-AmSeas) [(8, 9, 11,19,25,26).] Together the satellite and model data sets provide the spatial and temporal coverage of bio-physical processes, required to identify the active events in the Gulf [(1,5,6)].

3. DYNAMIC ANOMALY PRODUCT – LOOP CURRENT EVENT

The procedure for developing the anomaly product will be demonstrated using the satellite VIIRS chlorophyll product and will be applied to other bio-physical environmental products. An environmental event occurred on Aug 25, 2015 (figure2) where the Mississippi river plume waters was advected into the Loop current eddy, and a cylonic eddy, and then into the Florida current and Key West, Florida. Figure 2 shows the surface chlorophyll and the surface currents identifying this event. This event is representative of the Loop current eddy that breaks off from the Florida current periodically and forms a warm core eddy that migrates to the west [(4, 17).] This dynamic event clearly has large scale bio-physical changes. In this example, the procedure to determine where the abnormal chlorophyll regions that occurred during this event and how abnormal are these regions.

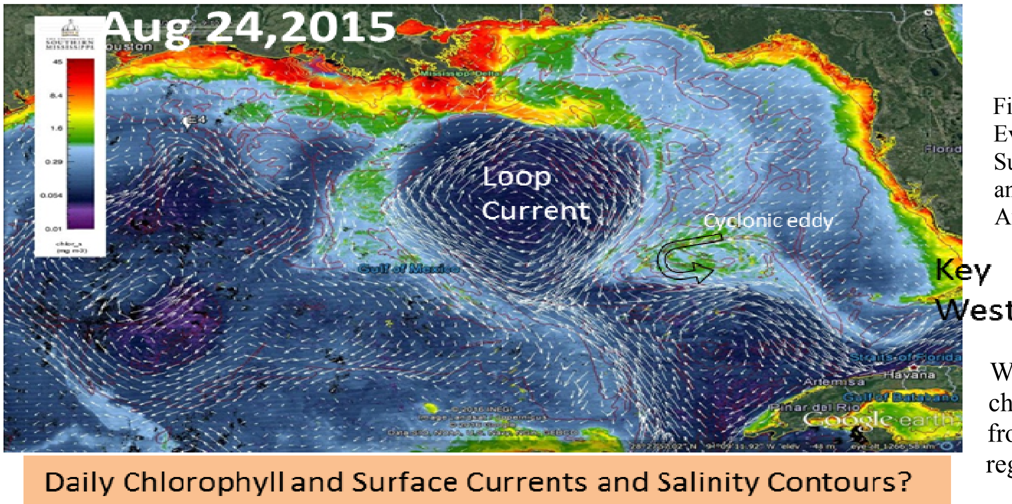

Figure 2: Mississippi Plume Event reached Key West. Surface satellite chlorophyll and NCOM currents for Aug24, 2015.

What were the abnormal chlorophyll properties from this event? What regions were affected?

The impact of the bio-physical impacts of this event can be identified by comparing this event to a time period prior to the event. The dynamic anomaly is focused on using a short-term time window to identify period events which the ecosystem responds within a short time scale. A weekly average (Figure3a) of the chlorophyll product for 8-21-2015 is used to represent the present conditions. This time period provides a realistic nowcast, to remove clouds and uncertainty in diurnal changes. The goal is to determine the abnormal chlorophyll during this week. The time period of a normal baseline condition is the prior 8-week mean with a 2-week lag from the weekly time period (Figure 3b). The 2-week lag is required so that the present weekly properties are not influencing the baseline.

The 2-week lag with an 8-week mean has been used by NOAA for harmful algal bloom detection to identify abnormal regions which need to be tested [20, 21,22]). The baseline time period was evaluated for several time periods ranging from 2 weeks to 1 year and we found the 8-week period to best identify the dynamic anomaly. This baseline time period represents the stable period in a seasonally changing ecosystem. Longer time periods have larger variances to the baseline mean which can be influenced by other non-dynamic processes such as seasonal trends. A larger variance in the baseline time period will affect the degree on abnormality.

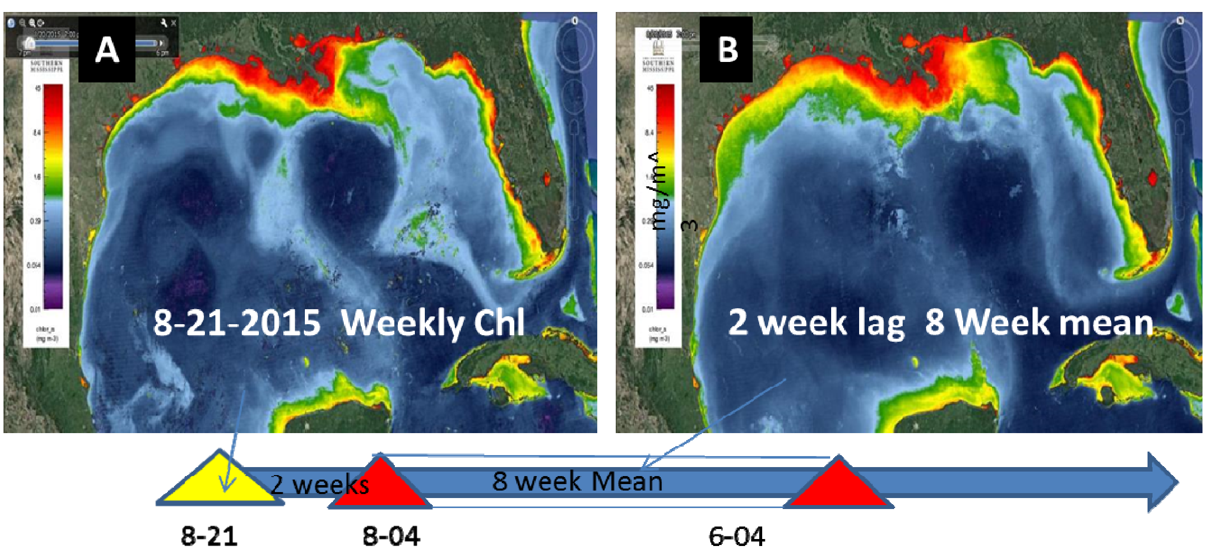

Figure 3: A The weekly Chlorophyll 8-21-2015 B: 8Week Chlorophyll mean (8-04- 604, 2015)

The changes in chlorophyll between the weekly and baseline show the elevated values alone the loop current front and extending south. The chlorophyll anomaly field is identified as the difference between the Weekly and the 8 Week baseline.

$$A_{Chl\ (i)} = Mean_{(CHL)} - W_{Chl(i)} \qquad (1)$$

Where: A= Anomaly Mean= 8 week baseline W= Weekly (i) date Chl= chlorophyll

The chlorophyll weekly anomaly (Figure 4a) represents the regions where elevated (red) and decreasing (blue) regions are occurring during this week. The white regions represent minimal or normal regions and are close to the baseline and not dynamically changing. The red, yellow anomaly regions at the loop current front are identified as elevated chlorophyll from 0.05 – 2.5 mg/m^3. There are dark blue regions at the northern coast indicating abnormal lower chlorophyll than baseline.

To provide a level of accuracy in the degree of abnormal chlorophyll, the variability and standard deviation in the baseline must be taken into consideration. If the baseline chlorophyll has a high standard deviation, then the difference shown by the anomaly may fall inside the variability and therefore may not be abnormal. The standard deviation for the chlorophyll baseline (Figure 4b) identify the level of abnormal regions. The coastal circle area (fig 5) with high chlorophyll standard deviation variability (red) >5mg/m3) shows a low blue chlorophyll anomaly (-3 mg/m) for the same area indicating this is not an anomaly since is within several chl standard deviations.

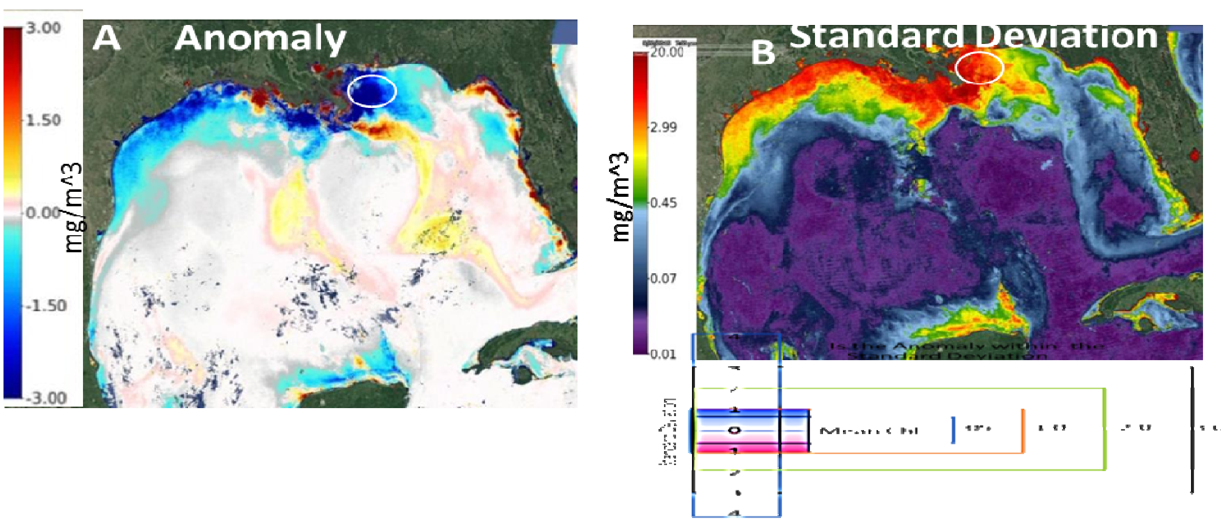

Figure 4- A- Chlorophyll Anomaly 8-21-2015 B: Standard Deviation of the Chlorophyll Baseline Log scale (.01- 20 mg.m3) This represents the variability of the 8week mean.

4. STANDARD DEVIATION MASKS

By combining different levels of standard deviation, of the 8 week baseline mean chlorophyll with the anomaly products, an intensity level of the anomaly product can be determined. This is done by creating standard deviation masks over locations where the chlorophyll values falls within selected standard deviation ranges (0.5, 1, 2, 3, and 4 standard deviations from the mean). By overlaying each of these masks with the anomaly products, the locations not covered by the mask define the level of abnormal chlorophyll to the baseline (Fig 5).

$$SD\ Mask(_X)\_ = \quad Mean_{Baseline\ Chl} + X_{Chl}SD \text{ and } - X_{Chl}\ SD \qquad 2$$

Where: SD MASK = Black Standard Deviation Mask X= 0,5, 1.0, 2.0. 3.0 4.0 Standard Deviation levels of the baseline (these values of x have been determined and are under evaluation.)

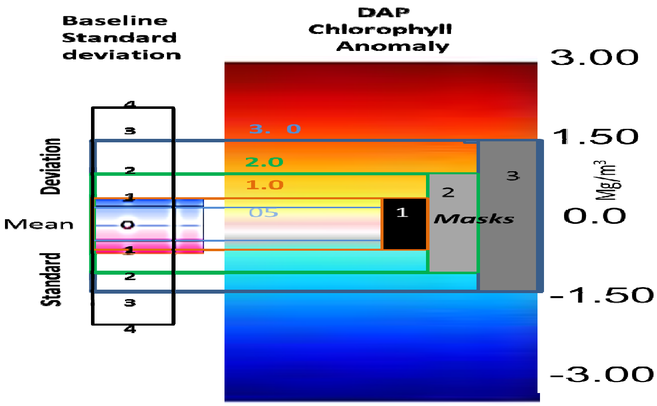

Figure 5- For each location, the standard deviation of the chlorophyll baseline mean is used to define a mask. A SD of 1 mask (black) represents locations where the chlorophyll mean, plus and minus one standard deviation. For each location where this SD1 mask occurs is placed over the DAP anomaly product.

Every location has a different StDev mask values and a Anomaly Value. Different SD Mask values can also be overlaid on the anomaly to see regions of high variability. The pixels locations where there are High Anomalies and low St Dev mask (1) are considerably not normal. Areas with a low anomaly and High StdDev are more normal.

The areas not covered by the black mask are where the anomaly values are outside of a standard deviation mask level. The different mask levels identify locations of where abnormal values occur from the baseline. An example application for identifying a chlorophyll Hotspots can be: impact on fisheries occur: a) at regional locations greater than 1 standard deviation from the baseline and b) have abnormal values is greater than 1 mg/m2. The procedures to identify specific hotspot criteria can be addressed with available ecosystem data sets.

The regions where the chlorophyll anomaly is greater than the 1 and 3 standard deviation masks are shown in Fig6, 1,b. The different masked products identify the intensity of these abnormal chlorophyll regions. The yellow /red regions represent abnormally higher and the blue regions are lower chlorophyll. The regions which are greater than 1 standard deviation mask and not covered (Fig 6a) indicate the eastern loop current and the cyclonic eddy has higher chlorophyll (~ + 0.6mg/m) than the baseline mean. Abnormal chlorophyll levels red (higher) and blue (lower) regions occur along the coastal regions of La, MS and Fl. The 3.0 Standard deviation (Fig 6b) mask eliminated much of the coastal region since the coastal areas are highly variable. The areas not covered by the masks have a higher degree of being abnormal. The arrow in Fig 6b is showing a chlorophyll hotspot which is outside the 3 standard deviations and has an abnormal chlorophyll value of ~2 mg/m^2. This indicates the anomaly at this location is different from the baseline. This area can represent a chlorophyll event is occurring.

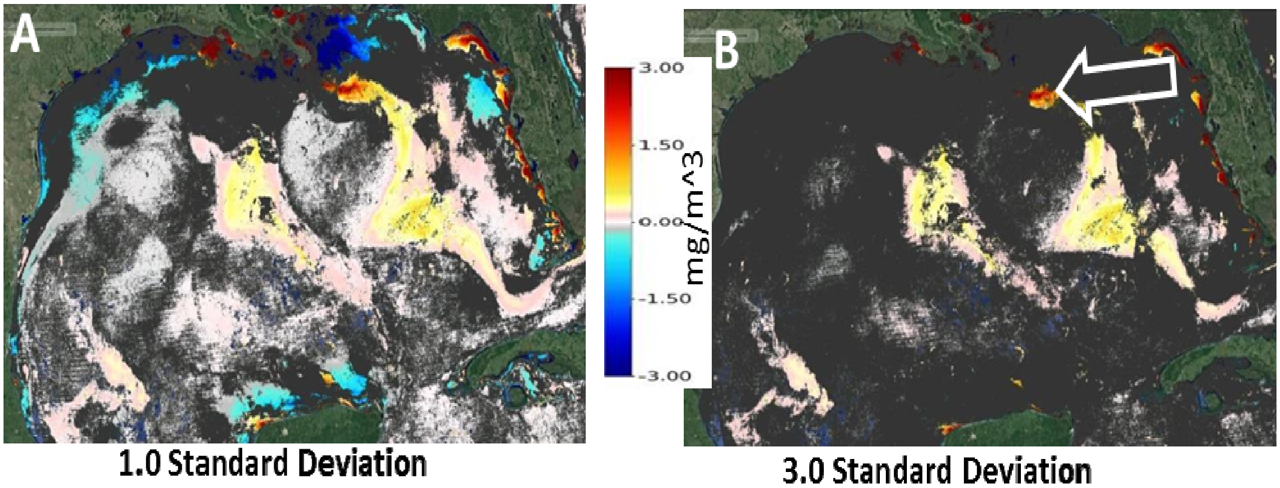

Figure 6- Degree of abnormal Chlorophyll (8-21-2015) for regions greater than A) Standard Deviation mask of 1.0 B) Standard deviation mask of 3.0 from the baseline chlorophyll.

The differences that are shown by changing the standard deviation mask are used for identifying how abnormal conditions can affect the ecosystem and can be used in adaptive sampling and monitoring data gaps. For example, if a ship is collecting data at a certain locations, then the level of dynamic abnormal products for that location can be compared with the baseline by overlaying different standard deviation masks. This will determine if the environmental conditions at the time of the data collection at the station were abnormal from the baseline and can determine if the station represents a data gap. The Fig 6 masks show that the Loop current and the cyclonic eddy are areas which are outside of the 1, 3 SD. These areas have abnormally high chlorophyll values (yellow and pink). Additional research is required to determine how various levels of standard deviation relate to individual oceanic events (i.e. which parameter(s) at which standard deviation mask level highlight fish density, coral bleaching, etc.) How abnormal does a product have to be to represent a major event?

The procedure to determine the dynamic anomaly property (DAP) that was presented for chlorophyll was similarly done for other satellite and circulation models products from the Ocean Weather Laboratory. DAP products were determined for the physical ocean products from AmSeas NCOM model outputs including salinity, temperature, current magnitude and current direction. DAP products were calculated for the VIIRS satellite products including the bio-optical water quality properties of particle backscatter, absorption, euphotic depth and SST. The regional distribution of the physical and biological anomaly products can be compared to see how different processes can affect each other. At the same time period as the chlorophyll anomaly, the anomaly products of the surface current magnitude and salinity from the Am Seas circulation model (Figure 7a, b) identified the abnormal locations of the loop current during the event. A standard deviation mask of 2 and 1 show the degree of abnormal physical properties. These anomalies identified the loop current and advection of the Miss River plume. The standard deviation masks identified the different levels of the abnormal products.

The regions of abnormal higher currents (red) (figure 7A) are located at the similar chlorophyll Hotspots (figure 6b) and the loop current. Abnormal lower salinity (blue Fig7B) waters on the east side of the loop current (Arrow) suggest this is offshore advection of the MS plume water. These blue waters are 2 psu below the baseline which is quite low for offshore waters.

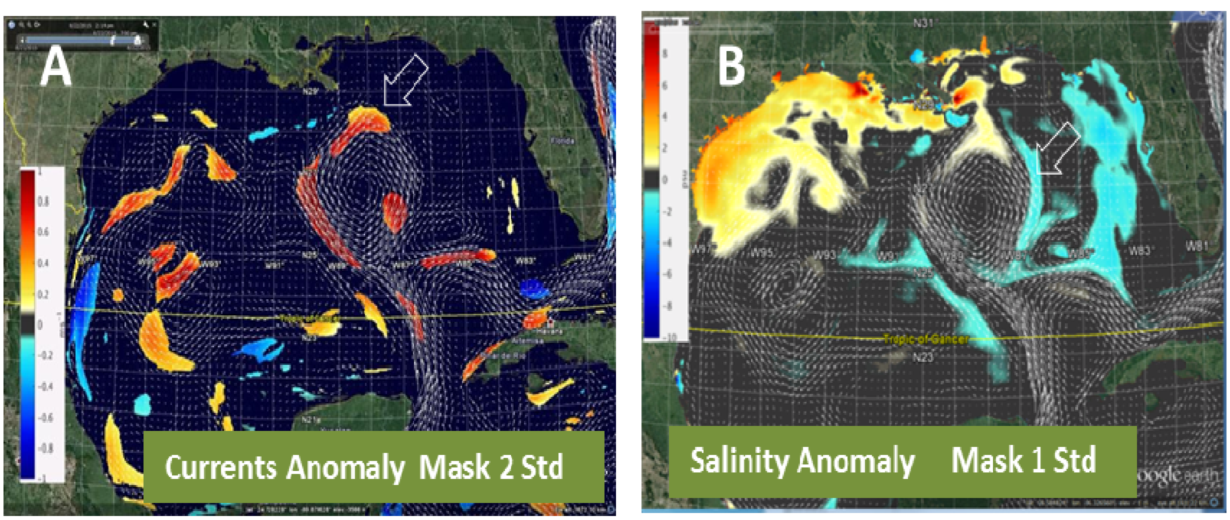

Figure 7- Physical Dynamic Anomaly products determined for the MS Plume Event 8-21-2015
A) surface Currents dynamic anomaly St dev mask 2 B) surface Salinity dynamic anomaly Std Dev mask 1.

The relationship between the different bio-optical and physical anomaly products shows some larger scale similarities and has some complex small scale relationships. The difference can result because of the 1) differences between the physical model and the satellite products (such as frontal locations), and 2) irregular relationships between the physical processes and the bio-optical response (such as the time required for chlorophyll to respond surface currents.)

Presently there are a total of eleven environmental anomaly products to identify the bio-optical and physical ocean events in the Gulf of Mexico These products include: 1) Chlorophyll, Euphotic depth , Diffuse attenuation Coefficient, Backscattering, Absorption, Salinity, Sea Surface Temperature, Salinity, surface current magnitude, direction [4, 14].

5. DAP APPLICATIONS – FLOWER GARDEN BANKS

The dynamic anomaly products was applied, during an event that was detected on July 27, 2016 at the Flower Garden Banks (FGB) [10,145] where coral beaching was shown to occur in these shallow waters. Ship measurements identified a bleaching event was occurring during this time period. The anomaly products were used to identify events in this area. The weekly surface salinity during the time of detection (Figure 8a) Jul27, 2016 shows the low salinity waters located at FGB at the time of the ship cruise (circle). Was this surface salinity an abnormal and by how much? The DAP anomaly (Figure 8b) using the Std Dev of 1 mask identified a relatively small region near the FGB (Circle) which had a 2 psu lower (blue) than the baseline for this week. The change in the weekly anomaly regions to previous time was examined all using the same standard deviation mask of 1. The previous week Jul 19 (Fig 8c), identified a larger anomaly region (Blue) at the FGB, extending to the coast. This suggests a stronger bleaching event was occurring at this week. The salinity anomaly several weeks prior on July 3, 2016 (figure 8d) which shows the salinity anomaly region was much larger with abnormally lower salinity of ~ 4psu. This indicated that the bleaching event was occurring about a month before the ship had determined the bleaching event was occurring. The time period after the July 27, 2016 event, the bleaching event was ending as is shown by the small regional scale of the anomaly salinity. The bleaching event began to occur in late June 2016 and was shown in the weekly anomaly field for the July 3 products. Weekly DAP products could have been available to identify abnormal regions prior to when the bleaching event was detected and provided to decision makers to define the spatial location and intensity of a possible bleaching event. These DAP products can provide the capability to monitor the Gulf for possible abnormal events so these waters can be tested for impacts on the ecosystem. The other anomaly products are available for the FGB during the time of this event and are being evaluated for the response to the bleaching event. These products can determine anomaly currents that brought the lower salinity water to the FGB. Other anomaly products of chlorophyll and euphotic depth will identify the response biological and light levels which could have on the bleaching event.

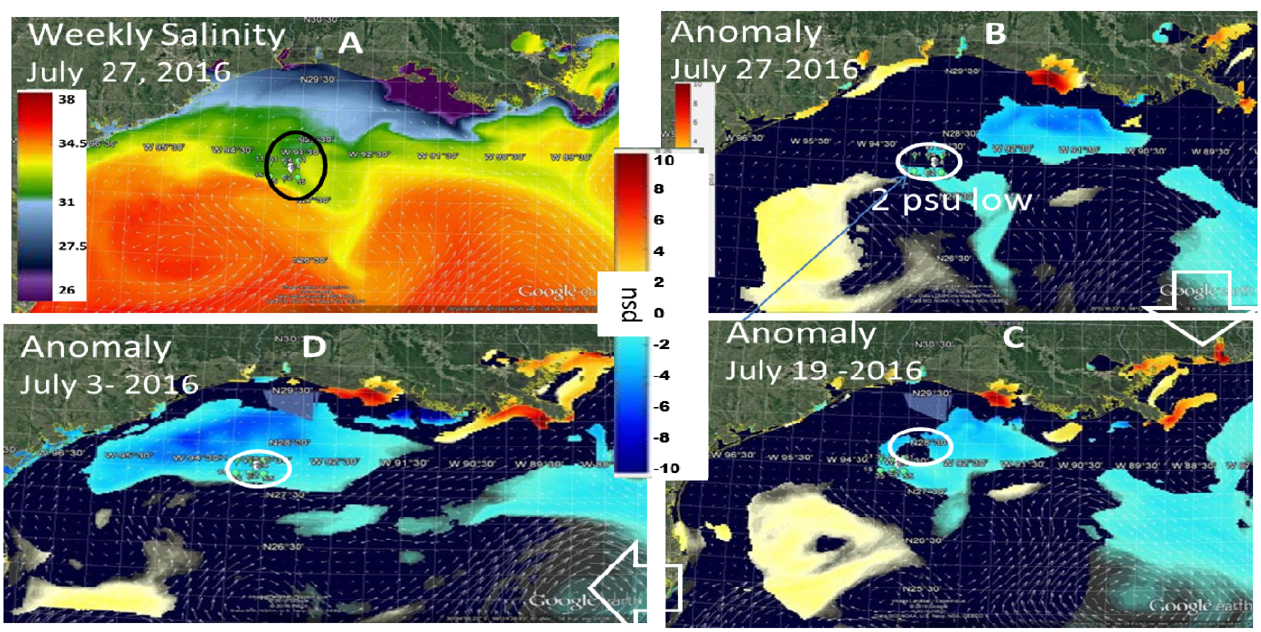

Figure 8: Bleaching Event 2016 at Flower Gardens Banks (circle) A. Surface Salinity on July 2016 B. Salinity Anomaly July 27, 2016 with St Dev mask 1. C. July 19 D. July 3, 2016 with St Dev mask of 1.

A similar application occurs with the NOAA Harmful Algal Bloom program which uses a chlorophyll anomaly to identify waters for sampling of Karenia Brevis. The DAP environmental products can provide a capability and forecast for ecological events that can occur before they are detected. We recognize that abnormal events can affect the ecosystem, but we need to determine the intensity of the event from different environment products and their timely response to the ecosystem. The abnormal salinity event occurred and the coral bleaching may have taken some time to respond.

7. CONCLUSIONS AND DISCUSSION:

A weekly anomaly field for 7 environmental OWX products from satellites and circulation models are being generated weekly for the last 3 years 2014- 2017 to identify abnormal events in the Gulf of Mexico. These abnormal products represent the environmental properties that can affect the ecosystem and include: A. biological properties of chlorophyll, euphotic depth, backscattering, and B. physical properties of currents, salinity and temperature. The dynamic anomaly products (DAP) are generated using the difference of the weekly product with the prior 8-week baseline with a 2-week lag to determine if the weekly property is abnormal. The spatial and temporal coverage of the abnormal products is at a 750 and 3 km spatial resolution for VIIRS satellite and NCOM circulation models. The level of abnormal environmental properties is determined from masks of different standard deviation levels of the 8-week baseline. A hotspot for a specific property can be assigned using: a) regions at a certain mask level from the baseline and b) the value of the anomaly (such as areas > 1 std deviation from baseline and anomaly > 2 $_{mg/m3}$ chl, and >1 $_{m/sec}$ current. The procedures to identify specific hotspot criteria can be addressed with the available data sets.

A method presented is used to identify anomaly conditions for environmental biological, optical and physical water properties and to evaluate how conditions are related. For example, locations of abnormal currents may have abnormal chlorophyll and salinity.

The spatial and temporal anomalies products use GOOGLE EARTH as a tool to display the abnormality for each product with the baseline mask levels. The display tool recognizes weekly relationship between the locations of the different bio-physical abnormal events. This tool enables a method to identify hotspots in the ecosystem in response to different events.

The process has been demonstrated for several events (Mississippi Plume, Key West and Flower Garden Banks). These research products are being used to identify the location of abnormal events to improve methods for adaptive sampling and fill data gaps by using environmental anomaly products. Identifying these regions to improve sampling will determine the impact of DAP events on the ecosystem so that the Gulf can be better monitored. The Flower garden banks bleaching event was recognized in the salinity anomaly products. The event was observed before was detected and demonstrates that a weekly anomaly forecast can provide managers regional events to see the impact on the ecosystem.

The OWL has developed weekly anomaly products from 2014 – 2017 for the are available which can location regions in the Gulf of Mexico that can be tracked with time and make decisions for monitoring and adaptive sampling. This can provide support to recognizing the occurrence of bio-optical physical events that can affect the ecosystem. Continued sampling and monitoring using the DAP anomaly database and tool with help identify the influence of occurring events.

8. ACKNOWLEDGEMENTS

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