Seasonal trends of biophysical ocean properties and anomalies across the Mississippi Shelf

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ABSTRACT

The seasonal cycle in surface biological, optical and physical properties across the river dominated Mississippi (MS) Shelf changed during years 2015 to 2017 at different locations across the shelf. VIIRS satellite and ocean model products were used to monitor cycles for different properties of both the nowcast and anomalous water properties. MS Shelf water properties vary spatially between offshore waters and coastal MS Sound waters, as well as temporally throughout the year. Ten selected regions spanning east to west from the MS Sound to the shelf break characterized the cross shelf seasonal fluctuations in satellite-derived chlorophyll-a, backscattering, euphotic depth, sea surface temperature, and modeled salinity currents. The seasonal relationships between physical and bio-optical properties were determined for different regions across the shelf and the seasonal eastward movement of the MS river plume across the shelf was identified in June. Yearly MS Sound seasonal cycles of coastal bio-physical properties are different from the shelf regions' offshore seasonal cycles and indicate a time-lag between the bio-optical responses to the physical properties. Bio-optical and physical results on the shelf indicated seasonal movements of the MS River plume locations. Results show the seasonal bio-physical response of the shelf waters which can be used to address and understand the timing of data collection and how ocean events are influenced by the natural seasonal cycle interactions between biological and physical properties. The seasonal cycle study will enable the ability to monitor the shelf water quality and to identify non-typical conditions and the impact of an event on the cycle. Correlations between the monthly seasonal cycle of bio-optical and physical properties such as salinity, ocean color, chlorophyll-a and particle scattering were not consistent over the shelf. Seasonal cycles of salinity and chlorophyll-a show improved correlation if chlorophyll-a is delayed one month from the salinity at offshore locations on the shelf. Results of the seasonal trends support how data collected at a single image location on the shelf during a certain month can be different from other seasons. The seasonal cycle of the dynamic anomaly properties (DAP) of bio-physical properties were determined to show how seasonal abnormal changes and trends at locations across the shelf can provide a method for seasonal adaptive sampling. The yearly differences in monthly cycles from 2015 to 2017 at shelf locations, identified elevated chlorophyll-a in several months of 2016 and yearly temperature differences in multiple areas. The seasonal cycle of Euphotic depth, solar UV light penetration, showed a maximum peak (deeper Euphotic depth) at certain shelf locations during the months of September and October and minimal penetration in Aug of 20152016,2017. This information could be useful to understand months for maximum oil UV degradation in case of an oil spill

Keywords: Ocean Color, Circulation Models, Seasonal, bio-physics Satellite, SNPP VIIRS, NCOM

1. INTRODUCTION

The Mississippi Shelf is a river dominated region with major influence from rivers along the Louisiana, Mississippi and Alabama coasts (Mississippi, Mobile, Pearl River, Biloxi etc) (1,2,3,4,5,26,27). The shelf region represents exchanges of offshore Gulf of Mexico and the coastal Mississippi Sound waters. The physical and bio-optical properties change significantly across the shelf in response to the variability in river discharges affecting seasonal changes and interaction between clear and turbid waters. The offshore waters along the shelf are seasonally influenced by the eastward movement the Mississippi river plume (16,26,27) across the shelf to the Mississippi and Alabama coast (6,26,27). The MS Shelf region is highly variable and provides an understanding of the seasonal variability and correlation between bio-optical and physical properties. The seasonal variability of these dynamic and highly variable regions provides an understanding of how offshore events, such as oil spills, may be affected by seasonal coastal waters cycles. The objective is to identify the seasonal cycles and variability between bio-optical and physical properties at different locations on the MS Shelf and to identify how the cycle trends change during the years 2015, 2016 and 2017. The effort will define the seasonal cycles of ocean properties at different locations across the shelf and the inter-annual changes over the three years.

The goals are: **1)** How does the monthly seasonal cycle of the nowcast and Dynamic Anomaly Properties (DAP) [7, 2] change across the shelf waters from offshore to inshore. **2)** How representative of the cycle is the data collected at shelf locations at a certain time of year? **3)** How are bio-physical seasonal cycles correlated at different locations?. **4)** How does the seasonal cycle of the bio-physical properties change inter-annually between 2015- 2016-2017? This can identify abnormal year cycles in observed properties at different locations to address climate/event change. **5)** When are the best and worst months for penetration depth of solar ultraviolet (UV) radiation at different shelf locations which affect degradation of oil [21]. The seasonal cycle provides a forecast and method for adaptive sampling along the shelf such as: what time of year is the river plume expected to be at a particular location along the shelf. The seasonal cycle of salinity and chlorophyll-a can be used to identify the location of MS river plume waters. The changes in the seasonal cycle at different locations identify when the plume occurs and the response of bio-optical to physical changes across the MS shelf waters. Seasonal correlations can identify how the biological (chlorophyll-a) cycle is related and responding to the physical (salinity) cycle for the river plume [6,27]

2. DATA ASSEMBLAGE

Daily bio-optical and physical ocean properties are processed by USM Ocean Weather Lab **(OWX)** in near real-time from the VIIRS SNPP satellite at 750m spatial resolution (chlorophyll, backscattering 551nm, MC Sea Surface temperature, photic depth) [8,9,10,11,12,17] and the NCOM NRL physical ocean model [13] at 3km resolution (salinity , temperature, currents). Satellite processing was done using a version of the Navy's Automated Processing System (APS) which is built around NASA's l2gen (SEADAS) [14,15] and the ocean model was obtained from NOAA NCEI. These daily ocean data products were assembled for selected regions into monthly mean nowcast [2,8] and the Dynamic Anomaly Properties ***(DAP)*** [7] which represents the difference of the weekly products from the previous 8 week mean, with a 2 week delay.

3: MISSISSIPPI SHELF CROSS SHELF - REGIONS OF INTEREST (ROI)

The monthly seasonal cycles for 10 Regions of Interest (ROIs #) (figure1) are used to represent the MS shelf Western, Middle and Eastern corridors and the cross shelf cycles from North to South and West to East transects [2]. Each ROI is ~285km^2 except for MS Sound ROI#10 which is 1200km^2. The ROIs are **A)** offshore shelf including East MS River delta blue #1,4,7; **B)** mid shelf green #2,5,8 ; **C)** coastal shelf red #3,6 and #9 is Mobile Bay plume and **D)** MS Sound brown #10. The seasonal cycles for all bio-physical products were determined as mean of the ROI. The relationships between these bio-physical seasonal cycles are used to recognize how seasonal cycle of physical properties affects the seasonal bio-optical properties.

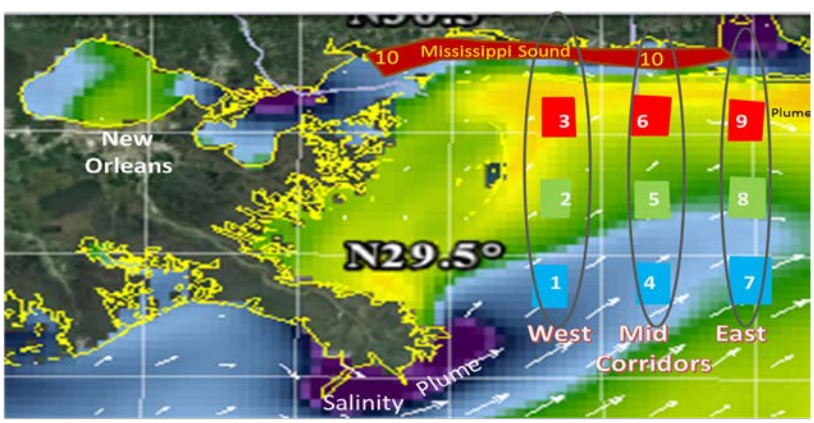

Figure 1- Ten Region of Interest (ROI) (~ 285 km^2) showing the West, Mid and East corridors and MS Sound. **Offshore (blueROI1,4,7), Mid (green ROI2,5,6), Coastal(red ROI3,6,9), Mississippi Sound (Brown10)**
- Surface salinity of MS Plume

4: SEASONAL CHLOROPHYLL

The seasonal chlorophyll-a cycles for the monthly and anomaly (DAP) for 2016 (Figure 2) shows variability in the 10 ROIs. The white arrows in Figure 2-A,C,E show the south (offshore blue) to north (coastal MS Sound) cross shelf chlorophyll-a changes for each month. January shows a low to high chlorophyll-a increase from offshore (blue) to inshore MS Sound (Brown). These cross shelf trends changes seasonally especially in July. The seasonal cycle (white dotted line) for the offshore blue ROI's (#1,4,7) waters of the 3 corridors show a similar pattern with a seasonal peak in July (yellow arrows). The seasonal cycle provides a forecast of what type conditions will occur for each month. The corresponding seasonal chlorophyll-a anomaly (Figure 2-B,D,F) identifies the changes from the previous 2 month period [7] and identifies dynamic changing conditions for that month. The June and July anomalied identify the monthly chlorophyll-a increase that is shown in the elevated nowcast for the same months. The seasonal MS sound (ROI#10 brown Figure 1) cycle is elevated compared to the shelf waters and has a different seasonal trend. The MS Sound shows a decrease in November and December. The cross shelf seasonal cycle for the middle (green ROI #2,5,8)) and coastal (red ROI# 3,6,9) shelf waters are different from the offshore (blue ROI #1,4,7) and MS Sound (ROI#10 brown) and indicates that average water properties are highly dependent on the location and season for MS shelf waters. The West to East corridor trends represented by Figure 2-A,C,E identify an Eastern movement of MS River plume. The offshore (blue #1,4,7) waters in July show higher chlorophyll-a in West (Figure2-A) and decreased to the East (Figure2-E) in response to the eastward movement of the MS river plume. This will be compared with Salinity (Figure4).

The seasonal cycle or forecast for selected locations provide a capability to determine if data collected at a location during a particular month is representative of the region. This seasonal forecast provides a method to adaptively sample a location and identify how data that was collected at a particular time compares with the spatial and seasonal variability at the location. For example, if users want to monitor elevated chlorophyll-a from the MS river plume, they can use the seasonal forecast to identify the month and location when the plume is typically occurring. Another application of the seasonal forecast is to determine uncertainty for data collection. For example, how representative of the MS Shelf is data that was collected at west corridor at ROI #2 (green) in February (Figure 2-A). The seasonal forecast (yellow line) shows the monthly variability and how representative February is during the yearly cycle. Knowledge of the seasonal cycle at different locations provides the uniqueness of the location.

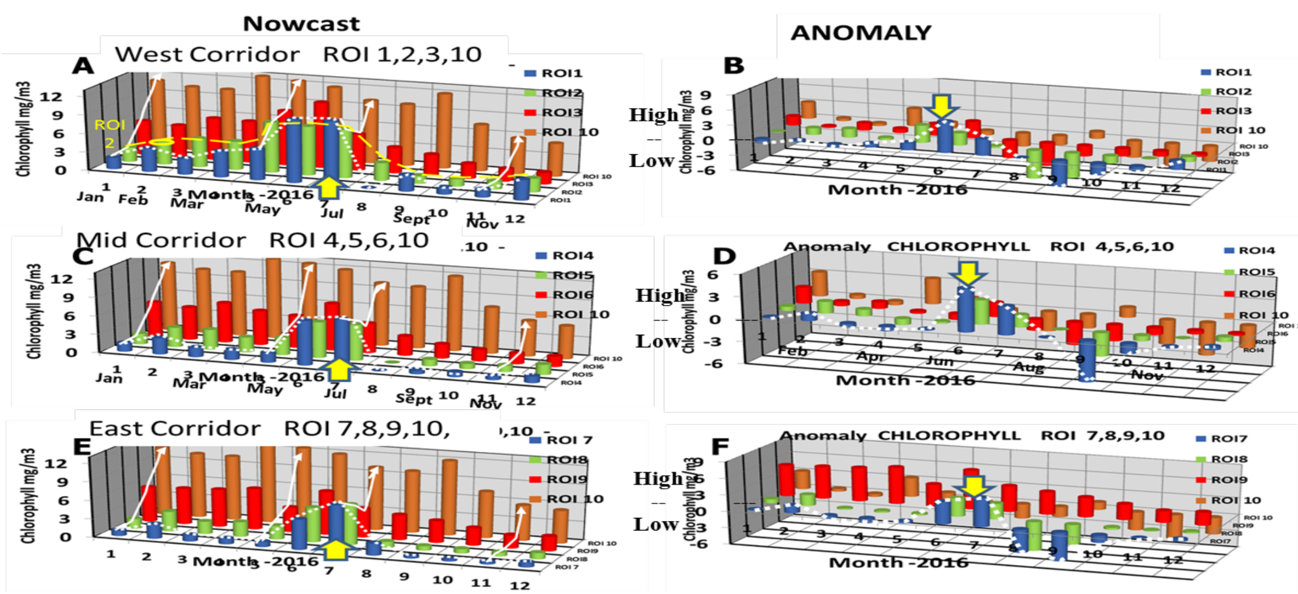

Figure 2: The 2016 Chlorophyll-a seasonal cycle for the 10 ROI. **A)** West Corridor Nowcast and **B)** Anomaly: Mid Corridor **C)** Nowcast and **D)** anomaly; East corridor E**)** Nowcast and **F)** Anomaly. The corridors include the MS sound ROI10. Positive and negative anomaly values represent chlorophyll-a increase and decrease from previous 2 months.

The different locations can have significant changes throughout the year both in a) temporal/monthly and b) spatial variability. This procedure of characterizing MS Shelf water variability provides a technique to identify station data collection quality for sampling and locating data gaps. The seasonal cycle of these multiple ROI's identifies how data collection at a location may not represent the yearly cycle for these shelf waters. For example, the chlorophyll-a uniqueness in February 2016 at location ROI #2 is compared to the other monthly changes (Figure 3-A). July has 122% higher and September has 73% lower chlorophyll-a than February at ROI #2 location. Chlorophyll-a or other water quality data that is collected at this location in February can determine how the monthly seasonal variability can influence how representative the data is at this location.

Similarly, the spatial variability of chlorophyll-a of MS shelf waters in February shows how the ROI #2 location compares with the other 9 ROIS (Figure 3-B). ROI #7 (Offshore) is 47% lower in chlorophyll-a and ROI #3,6,9 is 45% higher and ROI #10 is 155% higher than ROI #2. ROI #1 and #8 are similar to the ROI #2 during February. This procedure for characterizing the seasonal cycles identifies that the spatial and seasonal variability on the shelf is highly variable throughout the year and requires adaptive sampling to best characterize the Shelf waters to minimize data gaps. The commonness of the 2016 seasonal cycle can be compared to 2015 and 2017 in the yearly seasonal cycle (Figure 7).

Figure 3: The chlorophyll-a uniqueness in February 2016 at Location ROI#2 in 2016. Seasonal forecast applications. **A)** Temporal; percent change of Feb of ROI2 to the other months. **B)** Spatial: percent change in Feb of ROI#2 to the other 9#ROIS on the shelf.

5: SEASONAL SALINITY CYCLE

The seasonal salinity cycle for nowcast and anomaly from the NCOM model [13] for the 10 ROIs for 2016 represents a seasonal ***forecast*** cycle (Figure 4). The cross shelf salinity exchange (Figure 4-A,C,E) from offshore #1,4,7(blue) to the lower salinity coastal MS Sound #10 (brown) is shown to also vary for each month. In May and June, the offshore waters (blue) have lower salinity than the middle shelf #2,5,8 (green) and coastal #3,6,9 (red) locations. The salinity seasonal cycle of the offshore waters (blue) shown in the dashed white line (Figure 4-A, C, E) describes the variability occurring offshore. The lower salinity (32psu) offshore waters are indicators of the east movement of the Mississippi river plume [16] (***Yellow arrows***) which has an eastward movement occurring in May at West Corridor (Figure 4-A) and June at Middle & Eastern Corridor (Figure 4-C, E). The seasonal forecast provides a capability to identify when the MS River plume will be present at a location offshore on the MS shelf and can be used for adaptive sampling of the plume in Shelf waters. The monthly salinity changes across the shelf from offshore (blue) into the fresh coastal (brown) waters (Figure 4-A,B,C). The coastal (red) locations have higher salinity than the offshore and MS sound waters during certain months (June and July) in response the offshore river plume. This is a unique MS shelf characteristic for elevated salinity region between the offshore and coast waters.

The seasonal salinity anomaly at the corridors (Figure 4-B,D,F) identifies the dynamic anomalies [7] that are occurring each month from previous 8 week mean. The lower salinity (1-2 PSU) MS River Plume in the offshore (blue) is shown in the anomaly as a salinity decrease (May and June) (***Yellow arrows***). The anomaly also shows the lower salinity at the middle shelf (ROI #2,5,8 green) occurring in May in all corridors (Figure 4-B,D,F). The coastal MS Sound (ROI #10 brown) anomaly shows a salinity increase of 3 PSU in June and July. The seasonal anomaly provides a capability to improve identifying the intensity of the seasonal nowcast for each month at each location. The combined nowcast and anomaly seasonal cycles provide a method to improve identifying seasonal impacts at each location in the MS shelf and method to identify anomalous events [7].

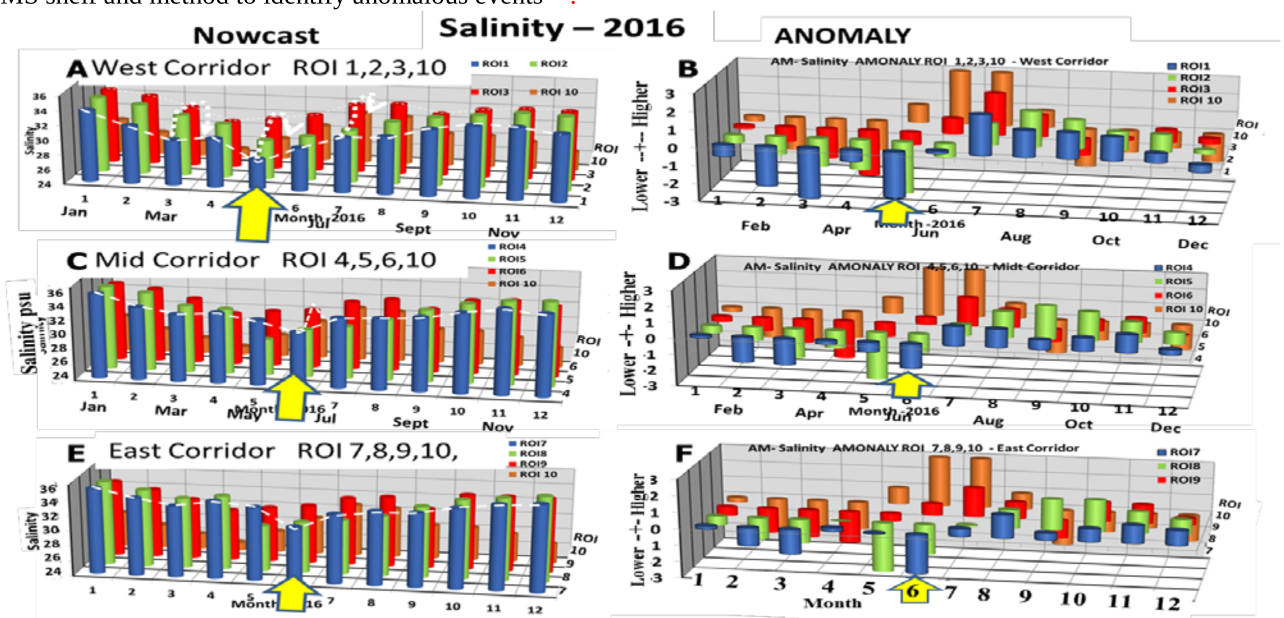

Figure 4: The 2016 salinity seasonal cycle for the 10 ROI from the NCOM model. A) West Corridor Nowcast and B) Anomaly: Mid Corridor C) Nowcast and D) anomaly; East Corridor E) Nowcast and F) Anomaly. The corridors include the MS sound ROI10. Positive and negative anomaly values represent salinity increase and decrease from previous 2 months.

6: CORRELATION OF SEASONAL BIO-PHYSICAL PROPERTIES.

The monthly cycles of chlorophyll-a and salinity show some similar trends for 2016 in Figures 2 and 4 with lower salinity and elevated chlorophyll-a in June response to the east due to movement of the MS river plume in offshore shelf ROI#1,4,7 (blue) waters. The lower salinity of the MS River plume with elevated nutrients can have a responding elevated chlorophyll-a level due to growth. The linear correlation (Figure 5-A) equations and R^2coefficient between these bio-physical properties was determined for the period from January to December 2016 for the monthly sequence of chlorophyll-a (Figure 2) and salinity (Figure 4) for the 10 ROIs. These correlations determine how the monthly chlorophyll-a cycles respond to the monthly salinity cycle at different locations. The highest correlation coefficient R^2=0.84 is at ROI #2 (green) and the weakest is at ROI #10=0.01 in the MS Sound. The higher R^2 indicates a rapid response between chlorophyll-a and salinity. There are similar seasonal response (R^2 ~0.3) in the bio-physical linear equations and relationships for the offshore (blue), middle (green) and coastal (red) across the shelf (Figure 5-A).

Time may be required for chlorophyll-a concentration growth in response to the river plume salinity decrease and nutrient increase. The monthly correlation coefficient R^2 can increase if chlorophyll-a is delayed or lag time in the 12 month sequence (Figure 5-B). The R^2 for a one-month chlorophyll-a delay represents the linear correlation between salinity January – December 2016 and chlorophyll-a one month advancement (February 2016- January 2017). The R^2 for the different ROIs (Figure 5-B) for chlorophyll-a monthly delays of 0, 1, 2 and 3 months shows that higher R^2 values occur with a one month delay for the offshore ROI #1,4,7 (blue) and ROI #3 (red). This indicates that the eastward movement of the MS River plume takes a month for chlorophyll-a to respond in the seasonal cycle at these locations. Note also that at middle ROI #2,5,8 (green) and coastal ROI #6,9 (red) the bio-physical properties have highest correlation with no monthly delay between chlorophyll-a and salinity meaning that the chlorophyll-a responds instantly to the salinity changes.

The differences in the correlation between the bio-physical seasonal cycles at the different locations show the seasonal changes in the ecosystem are strongly dependent on the location within the dynamic shelf. The monthly chlorophyll-a delay results provide a method to identify seasons and locations for understanding how river plumes and their constituents affect the bio-physical interaction at different locations. The seasonal response can be used for adaptive sampling to improve identifying the changing water quality on the MS shelf in response to river plumes.

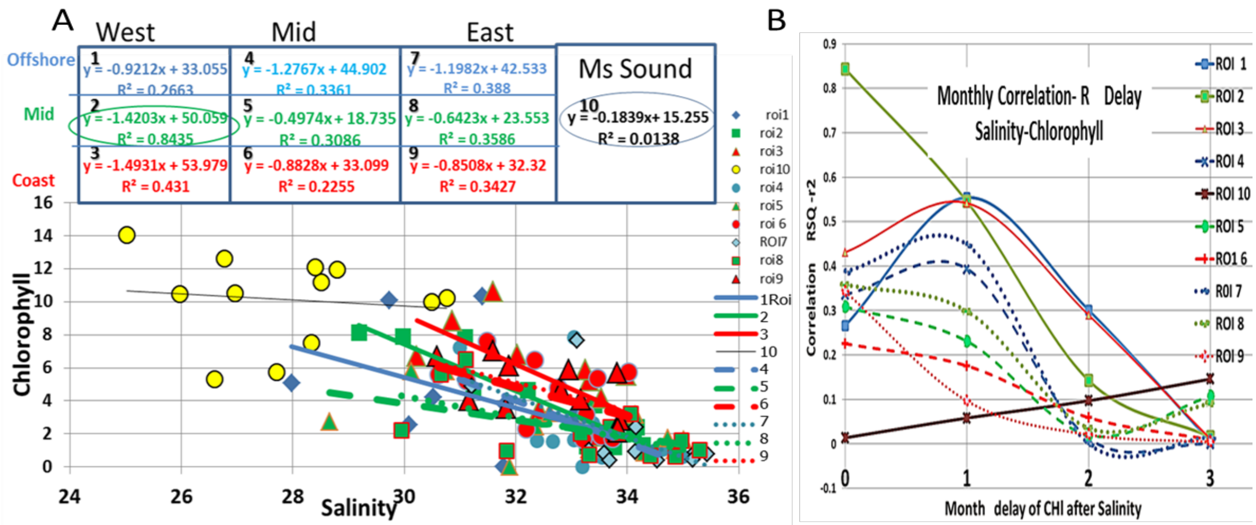

Figure 5: Correlation of monthly salinity and chlorophyll-a properties for 2016 for the 10 ROIs. **A)** Linear correlation coefficient (R^2) and equation between the 12 months Jan-Dec for each corridor of the 10 ROIS. **B)** Variability in 12 month R^2 Coefficient correlations with a 0 to 3 monthly delay between chlorophyll-a and salinity for all the ROI locations. Higher R^2 determines a monthly delay required for monthly chlorophyll-a to response the monthly salinity at each ROI.

The seasonal correlation between chlorophyll-a and backscattering (551 nm) for the 10 ROIs (Figure 6) shows similar high R^2 (0.9) at the offshore (blue) water and lower R^2 (0.006) in the coastal (red) and MS Sound waters. The lower R^2 is related to backscattering variability from suspended sediment particles in the coastal MS Sound waters [22, 23] in addition to chlorophyll particles, whereas higher R^2 in offshore waters is backscattering is mainly dominated by chlorophyll particles. Therefore, seasonal cycles between these bio-optical properties will be different at locations which are influenced by suspended particles due to shallow bathymetry and increased winds / currents near the bottom.

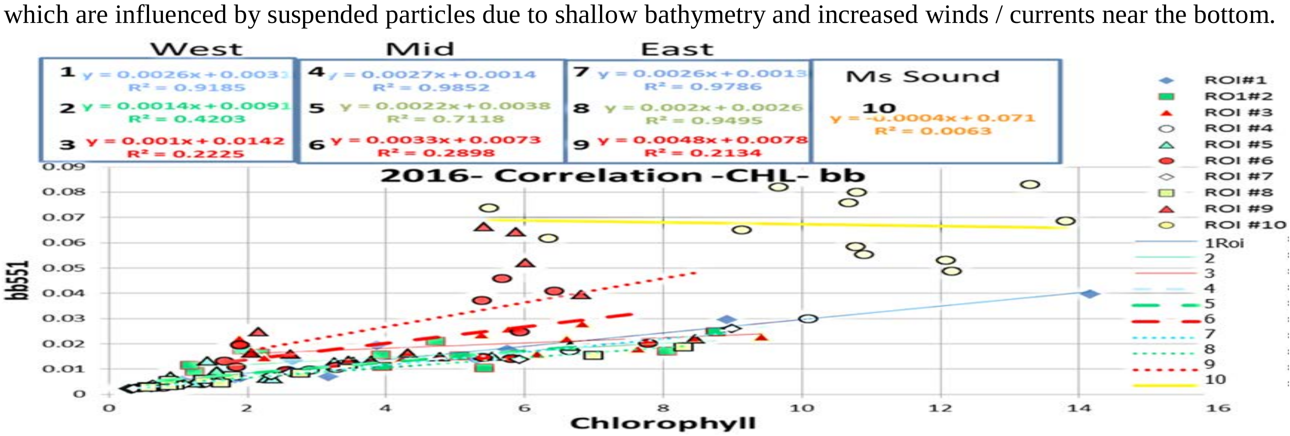

Figure 6: Monthly seasonal linear correlation of chlorophyll-a and backscattering for Jan – Dec 2016 for the 10 shelf locations (ROIs)

7: YEARLY SEASONAL CYCLES 2015, 2016, 2017

Chlorophyll-a: The seasonal monthly chlorophyll-a cycle of each three shelf water corridors in 2015, 2016 and 2017 (Figure 7) are similar for all three years. The satellite images show similar ocean features from one year to the next which were quantified at ROI locations for each year, to identify the changes in seasonal forecast. Seasonal cycles of the inner cross shelf ROIs (red, green and brown) show similar yearly trends with some small changes for the three years. The 6 dotted white lines in Figure 7 shows the monthly cycle of offshore (ROI #1,4,7 blue) waters in all three corridors. Cycle changes and differences in intensity for certain months are identified. Elevated chlorophyll-a months shown by the yellow arrows occur in July in all three corridors in 2015 and 2016 and in the western corridor in 2017. Elevated chlorophyll-a occurred a month later in August in 2017 in middle and eastern corridors. Seasonal forecast results for the three years indicate the months when MS River Plume represented by elevated chlorophyll-a moved east across the MS shelf (July and August) which can be confirmed with salinity cycle and shown for 2016 in Figure 4.

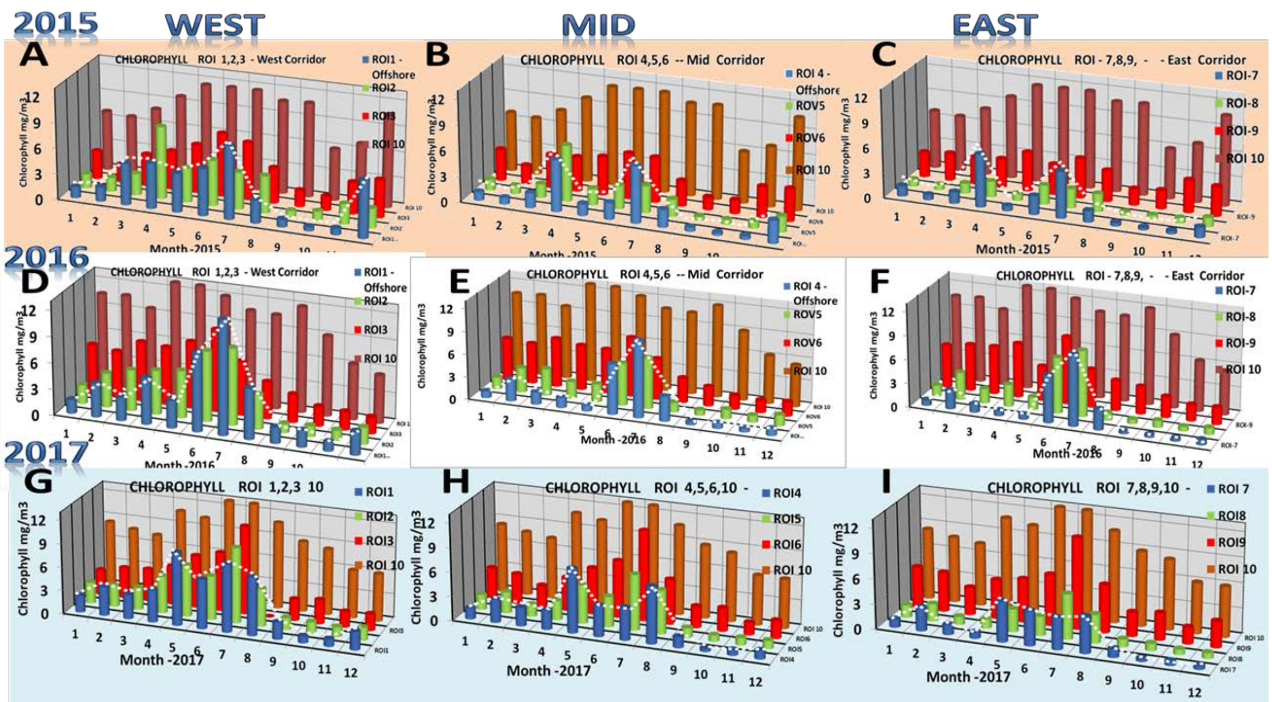

Figure 7- MS Shelf Chlorophyll-a Monthly Seasonal Cycle for 10 ROIs for the Western, Middle, Eastern corridors: for 2015 **(A,B,C):** 2016 **(E,F,G)** and 2017 **(G, H, I),**

The monthly chlorophyll-a difference between 2016-2015 (Figure 8-B) and 2017-2016 (Figure 8-A) for the monthly ROIs show how the monthly cycles in 2016 year compare with the bordering years. The dotted line represents the yearly trend. The positive chlorophyll-a difference (2016-2015) (Figure 8-B) indicates higher chlorophyll-a occurred in 2016 and a negative difference indicates higher in 2015. Elevated chlorophyll-a of about 2-4 mg/m^3 occurred in 2016 in the majority of the ROIs from January to July and then decreases in November and December when 2015 was higher (2mg/m^3) than 2016. In April (Figure 8-B) there are a few offshore ROIs #2, 4, 5 and 7 that had lower chlorophyll-a values in 2016 compared to 2015. The positive chlorophyll-a difference (2017 minus 2016) (Figure 8-A) indicates elevated concentration in 2017 and negative difference indicates higher in 2016. Similar to the previous year, 2016 chlorophyll-a was higher than 2017 between January and April for inshore ROI locations and the offshore locations (blue) was similar in 2017. In July through September, 2017 had elevated chlorophyll-a (~4mg/m^3). Similar chlorophyll-a levels (Figure 8-A) occurred between August and December (2017-2016) with a difference of 0.3mg/m^3 for the ROIs. The overall three years results show chlorophyll-a was slightly higher in 2016 for a large portion of the

2015 and 2017 months. The uniqueness of the seasonal cycle of ROI #2 green (Figure 3) for 2016 can be compared with yearly differences (Figure 8) showing that slightly elevated chlorophyll-a occurring at months in 2016 compared to 2015 and 2017 except in April 2015 which was higher.

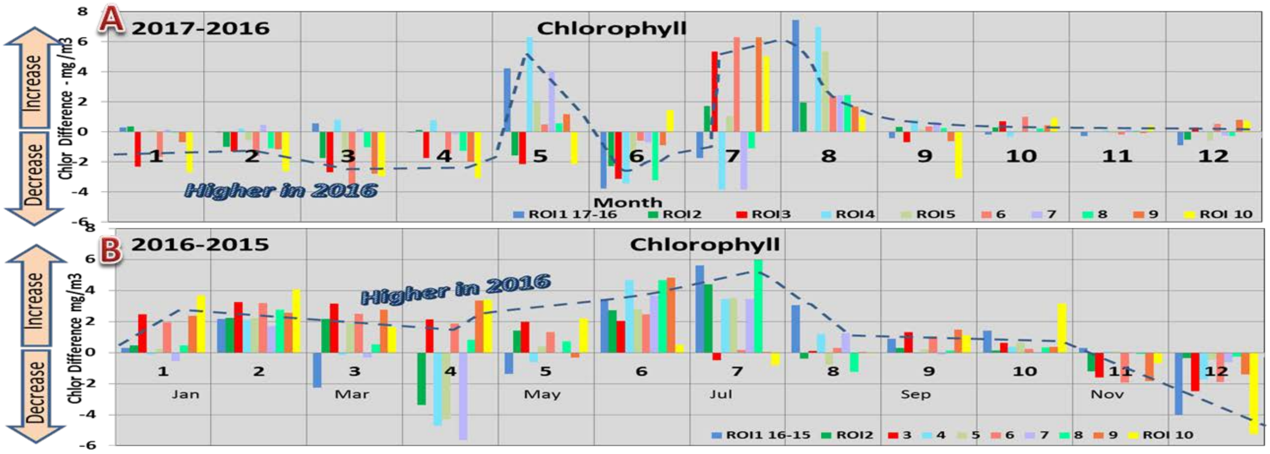

Figure 8 –Yearly differences for each month in the chlorophyll-a seasonal cycle: **(A)** 2017 minus 2016 and **(B)** 2016 minus 2015 for each ROI. Scales: (**A)** Positive Chlorophyll-a in 2017 is higher than 2016 **(B)** Positive Chlorophyll-a in 2016 is higher than 2015.

Sea Surface Temperature: The 2015, 2016, 2017 changes in the monthly sea surface temperature for the ROIs (Figure 9) show the similarities in the cycles for the three corridors. The monthly temperature changes across the shelf occurs in the offshore waters (blue) which have warmer temperatures than the cooler MS Sound waters during winter periods. The yearly cycles for the offshore waters (blue) showed in the dotted white line (Figure 9) for the corridors shows the monthly cycle which has relatively similar seasonal cycles in all three years. Overall, the SST shows warmer waters occurring from June through August in all three corridors which is somewhat similar to the seasonal elevated chlorophyll-a that occurs during July (Figure 7). The increased chlorophyll-a and water turbidity can influence the surface heating during these months [24]. The seasonal SST cycle does not appear to respond to dynamic features such as the eastward movement of the MS River plume.

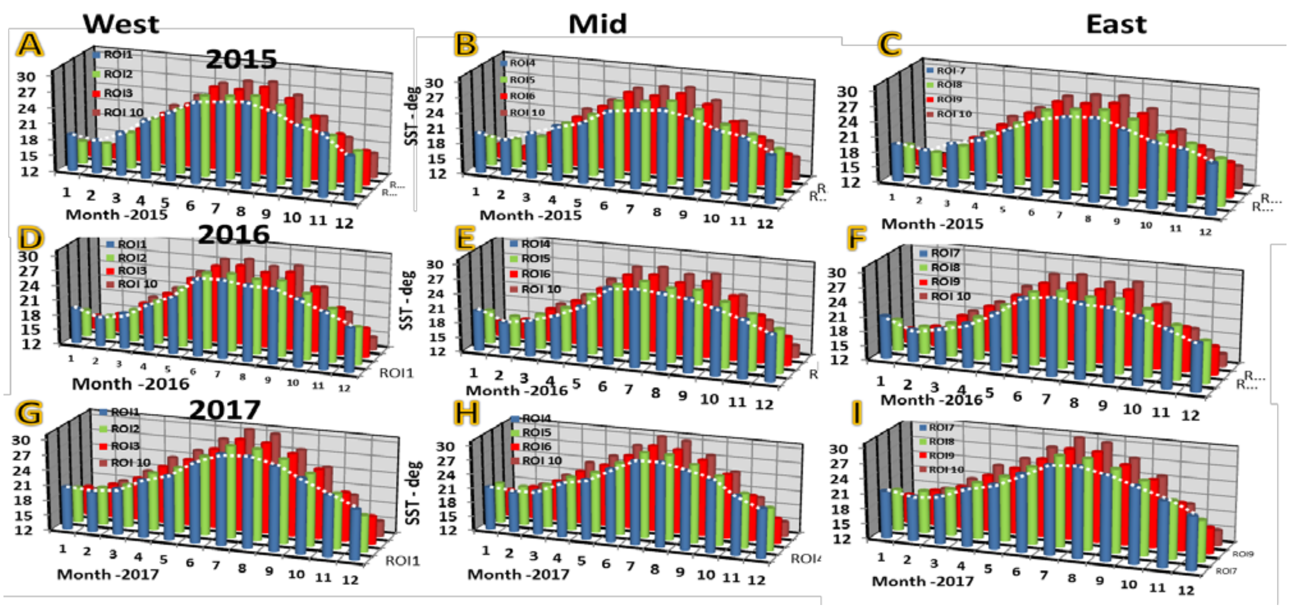

Figure 9- MS Shelf Sea Surface Temperature Seasonal Cycle for 10 ROIs for the West, Mid, East corridors: for 2015 **(A,B,C)** , 2016**(E,F,G)** and 2017**(G, H, I)**

The monthly differences in SST 2016-2015 (Figure 10-B) and 2017-2016 (Figure 10-A) shows yearly heating and cooling for each month at each of the 10 ROIs on the MS shelf. The positive difference in 2016-2015 (Figure 10-B) indicates that 2016 SST was warmer and a negative difference indicates 2015 is warmer. Similarly, the positive difference in 2017-2016 (Figure 10-A) indicates warmer 2017 waters and negative difference represents warmer 2016 waters. The dashed line (Figure10-A,B) shows the trend cycle of warming (+) and cooling (-) of the monthly differences in 3 years. Results show January and February had ~1-2 degree warmer waters in 2016 than 2015 (Figure 10-B) and warming in 2017 than 2016 (Figure 10-A) waters. March and April show a warming in 2017 (Figure 10-A) and a cooling in 2016 (Figure 10-B). May through December months show a cooling in 2017 from 2016 (Figure 10-A) and a warming in 2016 from 2015 except for August and December. The results of these seasonal trends show that seasonal SST warming and cooling cycles changed for different months for these three years. Each year has different months when the heating and cooling occur. Defining the monthly cycle is an important role on understanding the ocean heating and cooling and how yearly heating can be occurring. There are certain months when there is warming compared to the previous year and other months a cooling which can affect the seasonal ecosystem response. The yearly heating intensity changes at different ROIs and the entire shelf ROIs for each month and year do not have the same SST response. The seasonal SST ROI cycle identifies the cross shelf monthly warming and cooling locations which advances ecosystem impact than just a yearly SST average of the entire MS shelf waters.

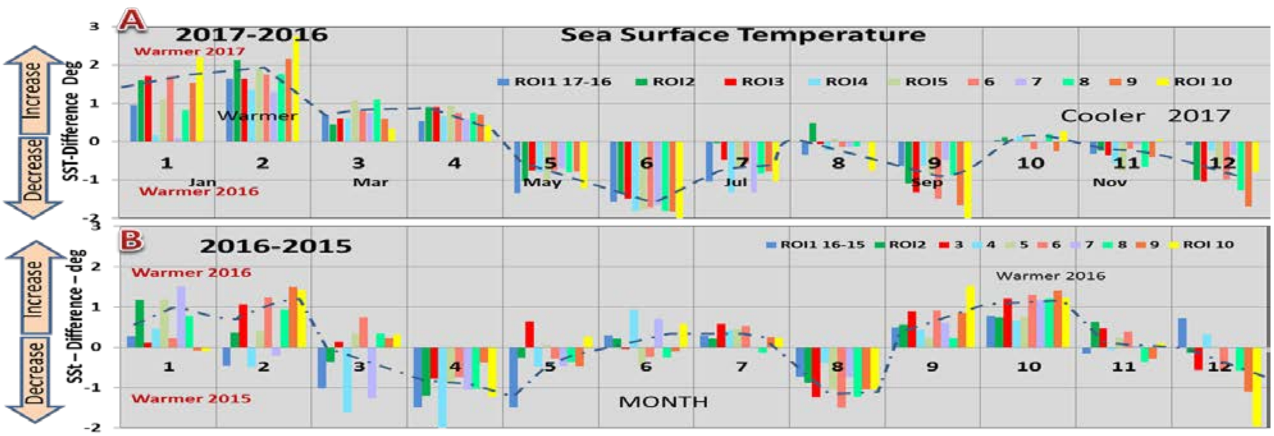

Figure 10: Yearly differences in the Sea Surface Temperature for the monthly seasonal cycle at the 10 ROI locations across the Shelf: **(A)** 2017 minus 2016 and **(B)** 2016-2015 for each of the ROI. Warmer months have positive increased yearly SST in **A)** 2017 and **B)** 2016. Negative SST is monthly cooling from previous year

Euphotic Depth: The satellite euphotic depth [12, 19] represents the water depth of the 1% surface solar light level. The intensity of solar light including the visible and ultraviolet light in the water column can strongly impact the ecosystem including the biological activity [20] and degradation of oil [21]. Deeper solar penetration will have a positive impact on both the subsurface biological growth and oil degradation [25]. The seasonal monthly cycle forecast for the euphotic depth for the 10 ROIs for the western, middle and eastern corridors from 2015 through 2017 are shown in Figure 11 which identifies the months and regions on the MS Shelf for maximum solar penetration. The seasonal across shelf cycles shows a penetration is minimal (<5meters) in MS Sound (brown) compared to the higher (10-60 meters) in offshore waters (blue) for each corridor. For the offshore (ROI #1,4,7) blue waters (Figure11) for all corridors, the yellow arrows show the month and location of maximum deep solar penetration and black arrows the minimum penetration. In 2015 (Figure 11,-A,B,C) the deepest penetration ~60m is observed in October for all corridors in the offshore blue waters. The minimum solar penetration (~10 meters black arrows) occurs in July for these offshore waters which corresponds to the month and ROI locations when elevated chlorophyll-a (Figure 7-A, B,C) occurs due to the eastward movement of the Mississippi River plume waters. In 2016 (Figure 11-E,F) for the offshore waters, the deepest solar penetration (~60m) occurs in the middle and eastern corridors from September through October and the minimum solar penetration occurs in July. In 2017, (Figure 11-G,H,I) a similar solar penetration cycle shows maximum in October and minimum in August. In addition, a deep solar penetration occurred in all corridors in April at the offshore ROI in 2017.

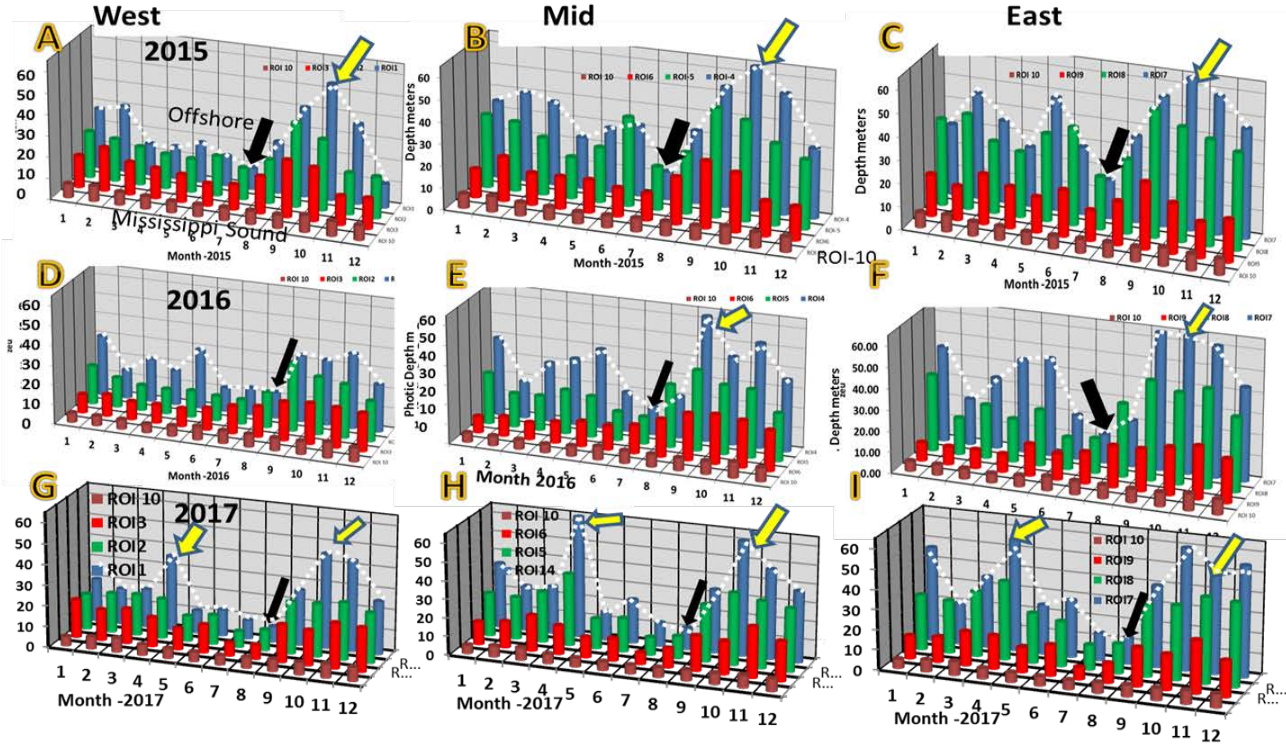

Figure 11 – Seasonal Euphotic Depth Seasonal Cycle for 10 ROI for the West, Mid and East Corridors 2015 **A)B)C)**: 2016 **E)F)G)** and 2017 **G) H) I)** . The solar penetration depth influences oil degradation during certain months and ROI locations.

8. SUMMARY:

Seasonal monthly cycles in bio-physical water properties is shown to have significant changes at different locations across the Mississippi shelf during 2015, 2016, and 2017. Ten regions (~80km^2) were selected to identify the across shelf's variability in seasonal cycle and provide a monthly forecast of expected properties from offshore to the MS sound (nearshore) for western, middle and eastern corridors. The results show the variability in the seasonal cycle can be significant for these river dominated shelf waters. The offshore shelf waters are influenced by the eastward movement of the Mississippi river plume which normally occurs in June and July. The seasonal cycle of the lower surface salinity changes at different locations identified the plume at the different locations. The seasonal chlorophyll-a cycle showed corresponding elevated concentrations with the lower salinity. The monthly correlation between the bio-physical properties identified how chlorophyll-a is responding to the salinity cycles at different locations. Higher correlation (R^2) occurred at the offshore shelf waters locations with a one month delay indicating that the chlorophyll-a monthly cycle increase required one month delay after the lower salinity plume at certain locations on the shelf. Other shelf regions had different correlation responses of chlorophyll-a to salinity.

The changes in the seasonal cycles of the bio-physical properties in 2016 were compared with 2015 and 2017 to evaluate similarity in seasonal cycles. It was shown that similar cycles occurred for chlorophyll-a, sea surface temperature and photic depth for these three years so that the seasonal cycle can be used as a forecast of the expected cycle at a particular location and can be evaluated on a global scale. There were some monthly seasonal cycle differences between 2016 compared to 2015 and 2017 at each shelf location. It was noted that 2016 had elevated chlorophyll-a concentration compared to 2015 and 2017 for certain months. Similarly sea surface temperature showed changes in the seasonal cycle across the MS shelf and how the cycle compared with 2016 compared to 2015 and 2017. The monthly difference cycle for each year shows that during certain months and locations, 2016 was warmer or cooler than in 2017. The results show the seasonal sea surface temperature cycle changes at locations due to the monthly warming and cooling. The diversity in the cycles at various locations indicates that a mean overall MS shelf condition may not be representative of ocean properties. The seasonal cycle for each location is required to identify data sampling period and the impact on the ecosystem.

Applications for the monthly seasonal bio-physical properties cycle forecast can be used to identify when and where to sample the shelf to identify water mass characteristics of interest. The seasonal cycle at a location can be used to determine how representative that month is of the seasonal variability and can be used for adaptive sampling, for example the best time to sample the offshore MS river plume is in June. The seasonal cycle of the euphotic depth showed the months of deepest solar penetration at different locations on the shelf. The deepest solar penetration month which occurs in October in the offshore waters is optimum for UV oil degradation at depth. Minimal penetration and worst months for UV degradation occurred in July for offshore waters. The yearly changes in the euphotic depth provide a seasonal forecast at different locations to estimate oil degradation rates.

Seasonal cycles provide methods to describe changes in ocean environment and to better define data gaps and how representative is data collection of ocean waters at a certain month and location. This was clearly shown for high variability of monthly cycles at Mississippi Shelf waters locations.

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10. REFERENCES

[1] Cambazoglu, M. K., Soto, I. M., Howden, S. D., Dzwonkowski, B., Fitzpatrick, P. J., Arnone, R. A., Jacobs, G. A., & Lau, Y. H.. “Inflow of Shelf Waters into the Mississippi Sound and Mobile Bay Estuaries in October 2015” J. Applied Remote Sensing. 11(3), 032410. http://dx.doi.org/10.1117/1.JRS.11.032410 (2017)

[2] Arnone, R., Vandermeulen, R., Donaghay, P., Yang, H., “Surface biomass across the Coastal Mississippi Shelf” *SPIE* 9827, Ocean Sensing and Monitoring VIII, 98270Z (May 17,(2016); http://dx.doi.org/10.1117/12.2240874

[3] Cowan . J. L. et al., “Seasonal and interannual patterns of sediment-water nutrient and oxygen fluxes in Mobile Bay, Alabama (USA): regulating factors and ecological significance,” Mar. Ecol. Prog. Ser. 141, 229–245 (1996).

[4] Seim, H., Kjerfveb, B., Sneed, J., “Tides of Mississippi Sound and the adjacent continental shelf,” Estuarine Coastal Shelf Sci. 25, 143–156 (1987).

[5] Morey, S O’Brien, J., Schroeder, W,. Zavala-Hidalgo,J. “Seasonal Variability of the Export of River Discharged Freshwater in the Northern Gulf of Mexico”, CONFERENCE PAPER · NOVEMBER 2002 DOI: 10.1109/OCEANS.2002.1191856 (2002)

[6] Jolliff, J, Kindle, J, Penta, B., Helber, R., Lee, Z., Shulman, I., Arnone, R, Rowley C., “On the Relationship Between Satellite-Estimated Bio-Optical and Thermal Properties in the Gulf of Mexico” *J. Geophy. Res.*, 113, G01024,. 15 March (2008)

[7] Arnone, R., Jones, B. "Monitoring abnormal bio-optical and physical properties in the Gulf of Mexico", *Proc. SPIE* 10186, Ocean Sensing and Monitoring IX, 101860O; doi:10.1117/12.2266789 (2017)

[8] Arnone, R., Ladner, S., Fargion, G., Martinolich, P., Vandermeulen, R., Bowers, J., Lawson, A. “Monitoring bio-optical processes using NPP-VIIRS and MODIS-Aqua ocean color products”. Proc. SPIE 8724, Ocean Sensing and Monitoring V, 87240Q. doi: 10.1117/12.2018180 (2013).

[9] Gordon, H.R., Wang, M.. “Retrieval of water-leaving radiance and aerosol optical thickness over the oceans with Sea-WiFS: a preliminary algorithm” Applied Optics 33, 443- 52. (1994)

[10] Arnone, R., Vandermuelen, R ; Soto,I; Ladner,S; Ondrusek, M; Yang, H: "Diurnal changes in ocean color sensed in satellite imagery", *J. Appl. Remote Sens*. 11(3), 032406 May 09, (2017) http://dx.doi.org/10.1117/1.JRS.11.032406http://remotesensing.spiedigitallibrary.org/article.aspx?articleid=2627267

[11] Lee, Z.P., Carder, K.L., Arnone, R.. “Deriving inherent optical properties from water color: a multi-band quasi-analytical algorithm for optically deep waters” Applied Optics 41, 5755-5772. (2002)

[12] Lee, Z. P., K.P. Du, R. Arnone, S.C. Liew, B. Penta, “Penetration of solar radiation in the upper ocean A simple and accurate model for oceanic and coastal waters,” *J. Geophy. Res.*, 110(C9): C09019 (2005)

[13] Barron, C. N., P.J. Martin, A. B. Kara, R. C. Rhodes, L.F. Smedstad. , “Formulation, imple-mentation and examination of vertical coordinate choices in the Global Navy Coastal Ocean Model (NCOM)”, Ocean Modelling 11:347–375 (2006)

[14] Arnone, R., Ladner, S., Fargion, G., Martinolich, P., Vandermeulen, R., Bowers, J., Lawson, A.. “Monitoring bio-optical processes using NPP-VIIRS and MODIS-Aqua ocean color products”. Proc. SPIE 8724, Ocean Sensing and Monitoring V, 87240Q. doi: 10.1117/12.2018180 (2013)

[15] Werdell, P.J, Franz, B.A., Bailey, S.W., Feldman, G.C., et al. “Generalized ocean color inversion model for retrieving marine inherent optical properties”. Applied Optics 52, 2019-2037 (2013)

[16] Schiller, R. V., V. H. Kourafalou, P. Hogan, N. D. Walker, “The dynamics of the Mississippi River plume: Impact of topography, wind, and offshore forcing on the fate of plume waters”, J. Geophys. Res., 116, C06029, doi:10.1029/2010JC006883 (2011)

[17] Arnone, R A., R. Parsons, D. S. Ko, B. J. Casey, S. Ladner, R. H. Preller, C. M. Hall, “Physical and Bio-Optical Processes in the Gulf of Mexico--Linking Real-Time Circulation Models and Satellite Bio-Optical and SST Properties”. No. NRL/PP/7330-05-5226. Naval Research Lab (2005)

[18] Arnone, R., Vandermeulen, R, Ignatov, A, Cayula, J., "Seasonal trends of ACSPO VIIRS SST product characterized by the differences in orbital overlaps for various water types," Proc. SPIE 9459, Ocean Sensing and Monitoring VII, 94590T (9 May (2015)

[19] Lee, Z : Hu, C, Shang, S., Du, K,; Lewis, M ;Arnone, R ; Brewin,R : “ Penetration of UVvisible solar radiation in the global oceans: Insights from ocean color remote sensing” *J. Geophy. Res.*,: OCEANS, VOL. 118, 1–15, doi:10.1002/jgrc.20308, (2013)

[20] Penta, B., Lee, Z., Kudela, R., Palacios, S., Gray, D., Jolliff, J., Shulman, I. “An underwater light attenuation scheme for marine ecosystem models”. *Opt. Express* 16, 16581-16591(2008).

[21] M. Alloy, *et al*., “Ultraviolet radiation enhances the toxicity of Deepwater Horizon oil to mahi-mahi (*Coryphaena hippurus*) embryos”. *Environ. Sci. Technol.* 50(4), 2011-2017, doi: 10.1021/acs.est.5b05356 (2016)

[22] Sydor M., Arnone R., "Effect of suspended particulate and dissolved organic matter on remote sensing of coastal and riverine waters," Appl. Opt. 36, 6905-6912 (1997)

[23] Millera, R., McKeeb,B., “Using MODIS Terra 250 m imagery to map concentrations of total suspended matter in coastal waters”, Remote Sensing of Environment 93 259 – 266 (2004)

[24] Arnone, R., Vandermeulen, R., Ignatov, A., Cayula, J., “Seasonal trends of ACSPO VIIRS SST product characterization by the difference in orbital overlaps for various water types:, Proc. SPIE 9459, Ocean Sensing and Monitoring VII, 94590T http://doi:1117/12.2179731(2015)

[25] Arnone, R., Ladner, S., LA Violette, P., Brock, J, Rochford, P, “Seasonal and interannual variability of surface photosynthetically available radiation in the Arabian Sea” J. *Geophy. Res.*, VOL. 103, NO. C4, PAGES 7735-7748, APRIL 15, 1998 : https://www.researchgate.net/publication/240487120 (1998)

[26] Jones, E. B. and Wiggert, J. D., "Characterization of a high chlorophyll plume in the northeastern Gulf of Mexico," Remote Sensing of Environment 159, 152-166 (2015)

[27] Jones, E. B., “Assessing biogeochemical impacts and environmental conditions associated with cross-shelf high chlorophyll plumes in the northern Gulf of Mexico,” Univ. of Southern Miss. Dissertation, https://aquila.usm.edu/dissertations/132/ (2015)

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