Surface Biomass Flux across the Coastal Mississippi Shelf

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ABSTRACT

The exchange of water masses across the Mississippi shelf was used to determine the chlorophyll flux for an eight month period in 2013 through the major Mississippi River discharge period in Spring and Fall. Circulation models (NCOM and HYCOM) and SNPP satellite chlorophyll products were used to monitor the changes in the shelf transport and surface biological impact. The physical and biological response of cross shelf exchange was observed in rapidly changing dynamic movements of river plumes across the shelf as identified by the models and satellite products. Six sections on the shelf identified exchange corridors of transport and biomass chlorophyll flux of surface waters between the coast and offshore waters. During the eight month period, the nearshore waters show high carbon chlorophyll flux, averaging -60 x10^3 kg chl extending to offshore waters. However, at the outer shelf break, a significant carbon flux was observed moving shoreward onto the shelf from offshore waters, averaging +100 x10^3 kg chl, which is attributed to the dynamic Mississippi River plume. Results indicate a significant amount of offshore surface waters containing biological carbon can exchange across the shelf, clearly demonstrated through the combination of biological satellite products and physical models.

Keywords: Ocean Color, Circulation Models, Chlorophyll, Flux, Transport, Shelf, Satellite, SNPP VIIRS, Coastal,

1. INTRODUCTION

Cross shelf dynamics in a shallow coastal ocean region can be a significantly interaction of the circulation [*Huthnance, 1995*] and the ecosystem dynamics [*Chen et al., 2000*] and can strongly influence the biomass flux across the shelf. These complex processes are readily identified in ocean color satellite imagery as bio-optical and chlorophyll rich coastal surface waters as they are intermixed with offshore oligotrophic waters [*Toner et al., 2003*]. The cross shelf exchange processes are represented as an interaction of the physical advection and the bio-optical chlorophyll response. These processes can occur rapidly and can be identified through circulation models and satellite ocean color observations. In a river dominated coastal regime such as the northern Gulf of Mexico, the significant amount of fresh water on the shelf can influence the buoyancy driven circulation and the cross shelf transport and biomass flux in surface waters. These dynamic physical processes impacting the cross shelf exchange [*Hetland et al.,2012*] can strongly influence resulting biological activity which are observed in ocean color [*Lohrenz et al., 2008 Arnone et al., 2005 Jolliff et al.,2008*]. The Mississippi river plume has significant impact on the circulation and water quality on the waters to the west of the delta and had demonstrated a significant variability at temporal and spatial scales [*Hetland et al., 2012,*] and can influence the waters to the east of the delta. Satellite chlorophyll time series enables tracking the ecosystem response associated with coastal plumes by defining the development and decay of biological phytoplankton blooms [*Lihan et al., 2011*]. .

Our objectives are to characterize the variability of the physical and bio-optical processes on the Mississippi Shelf and define the exchange and transport processes on a fresh water dominated shelf. Our results will address how the physical and bio-optical processes are coupled at short (daily) and long (monthly) time periods and define biomass chlorophyll transport on the shelf at east and west corridors across the shelf for preferred chlorophyll transport. We will couple the physical circulation models with the satellite bio-optical observations across the shelf and determine the variability of shelf dynamics. The spatial and temporal variability of the physical and biomass transport flux across the Mississippi shelf will be characterized from May through Dec 2013 using daily time series. This time period captures the elevated spring discharge flux of the Mississippi river discharge and the spring phytoplankton bloom and extends to the diminished discharge summer period and into the fall bloom and entering into the low discharge winter period (Morey et al., 2002). The relationship of surface volume transport and chlorophyll response was examined at an eight month time scale to define the biomass flux and exchange pathways across the shelf. The carbon flux of the exchange across the shelf is critical for understanding the response of the ecosystem and how coastal carbon is exchanged between coastal and offshore waters.

2. MISSISSIPPI SHELF REGION

The Mississippi Shelf is characterized by a ~ 2000 km^2 gently sloping shelf between 20 – 100 m depth and extending 200 km offshore to the shelf break where it rapidly falls to a depth of 1000 m. The shallow coastal shelf of the MS coast is unique since it has significant amount of fresh water inputs from different rivers inputs including: Mississippi, Mobile, Pearl, Pascagoula, Biloxi rivers. These waters inputs have different ocean color optical signatures associated with varying chromophoric dissolved organic matter (CDOM) and phytoplankton types and concentrations [*Morey et al., 2002*]. Although tidal forcing is weak in this region, transport across the shelf can be rapid in response to strong currents as shown in circulation models.

Additionally, at the offshore shelf break (>1000 m), offshore waters of Gulf of Mexico from the loop current and warm core rings can interact across the shelf and can impact shelf biomass flux.

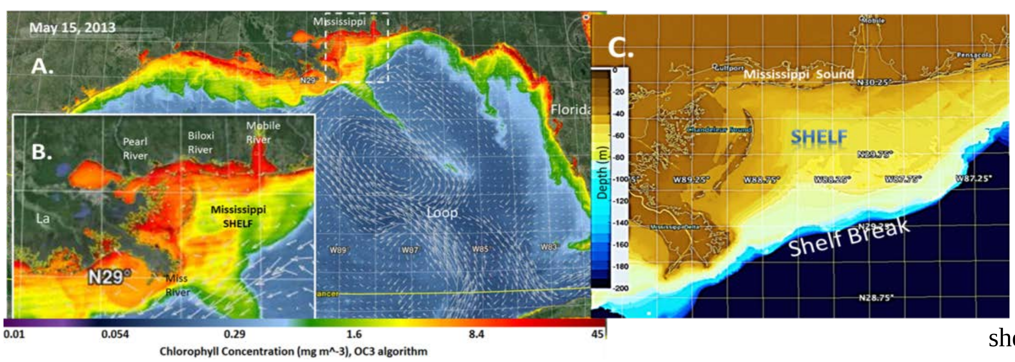

Figure 1: A. Location of Mississippi Shelf north east of the Delta B) Chlorophyll response on the shelf from multiple rivers C) Mississippi Shelf bathymetry is shallow gently sloping to the shelf break at < 60m**.**

3. METHODS

A time series from May – Dec 2013 of the satellite derived ocean products and circulation models were used to define the exchange processes across the MS Shelf. The physical transports across the shelf were tracked using 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) [*Barron et al., 2006*, *Halliwell et al, 2014*, *Zaron et al., 2015*].The two models are nested in the Atlantic HYCOM and the global NCOM respectively, and both are assimilated with satellite sea surface temperature (SST) and sea surface height (SSH) and other available in situ observations. Two models were used to address the uncertainty and similarity in the models. [*Zaron et al., 2015*] and the processes which influence plume dynamics (Schiller et al., 2011, Zhang et al., 2012). The surface salinity (Figure 2) of HYCOM and NCOM models shows the fresh water plumes for several fresh water sources from the Mississippi Sound, Chandelier Islands and Mobile Bay and the offshore Mississippi plume.

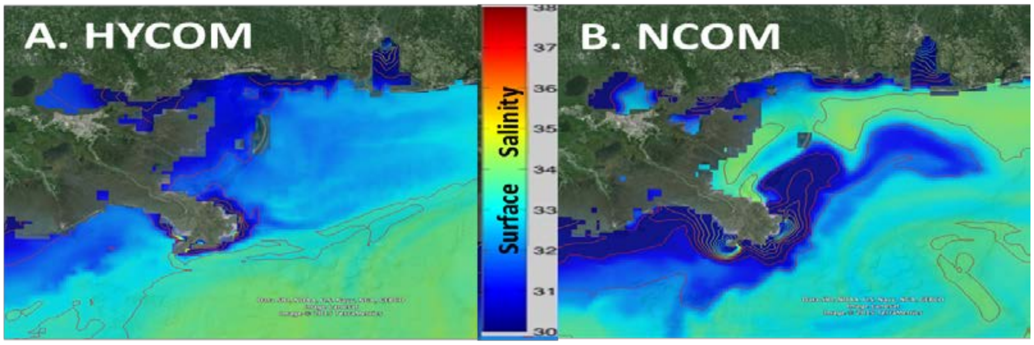

Figure 2 – Surface salinity on the Mississippi shelf A. HYCOM and B. NCOM on Sept 12, 2013.

4. SATELLITE OCEAN COLOR METHODS

Spectroscopy from ocean color has been used to define the bio-optical properties of water mass properties and applied to satellite ocean color observations (Arnone et al, 2006, Lee et al, 2002) for real time and long time monitoring ocean ecosystems. Satellite ocean products from the Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi National Polar-orbiting Partnership (NPP) were used to define the surface bio-optical and chlorophyll concentration at a spatial resolution of 750m . [*O' Reilly et al., 1998;* Arnone *et al., 2013, 2014; Vandermeulen 2015*]. Level 1b VIIRS data records (SDRs) were processed daily (raw radiance + calibration) to Level 2 environmental data records (EDRs; (geophysical parameters) using l2gen software from the NASA Ocean Biology Processing Group (OBPG NASA -SeaDAS [*Werdell et al., 2013*]). The VIIRS bio-optical products have been validated for coastal waters [*Arnone et al., 2013, 2014*].

5. VARIABILITY OF EXCHANGE ACROSS THE SHELF.

There were three major classes of cross shelf exchange observed during the May though Dec 2013 series at different time and space scales. Three major classes of shelf exchange are shown in Figure 3 A, B, C by the surface chlorophyll and surface HYCOM currents. The first class, Mississippi River Plume (Figure 3A) shows the fresh water filament extending northeastward across the shelf. The second class (Figure 3b), shows the episodic occurrence of oligotrophic offshore water intrusion across the shelf break and onto the shelf, which arise from offshore eddies can that interact with near shore coastal filaments. The third class from May 5,2013 (Figure 3C) shows the shelf exchanges in a less active state with the local rivers along the Mississippi and Alabama coast creating chlorophyll plumes which are transported across the shelf.

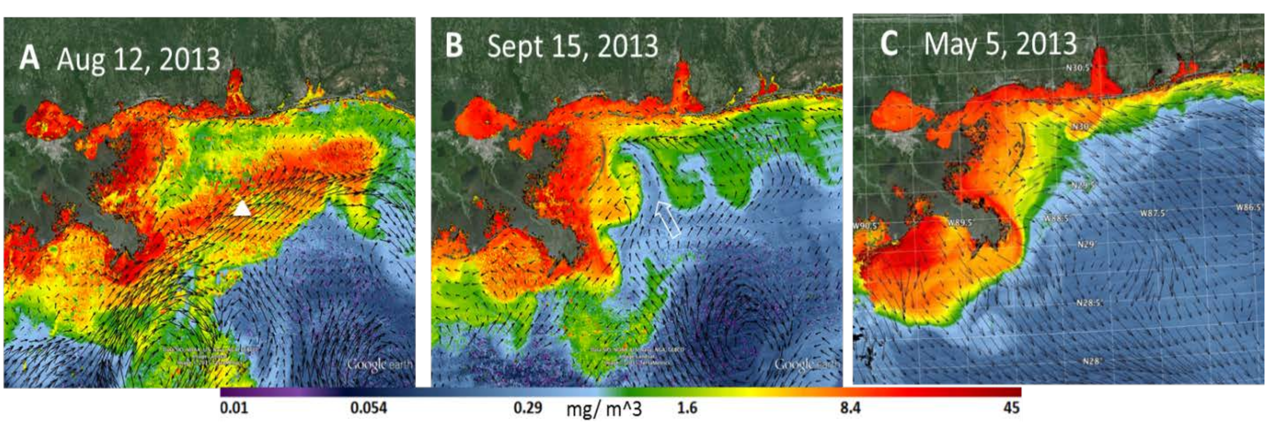

Figure 3- Three examples of the variation in cross shelf exchange processes are shown in satellite Chlorophyll and HYCOM surface currents a) MS River Filament, and location profile b) intrusion of offshore Gulf waters c) Inactive shelf with local coastal river plumes

Cross Shelf Transport: The interaction of coastal filaments with offshore water and the ecological exchange processes resulting from physical transport were defined by combining the satellite and model properties. The variability of physical and bio-optical processes across the MS shelf was determined from May 6 – Dec 12 2013 (eight months). Figure 4 shows the location of six sections, labeled 1-6, each 12.5 km in length, where daily and weekly cumulative net transports were computed from both models' current time series. The sections were evenly placed on the shelf: sections 1, 2, 3 are 30 km offshore along the 25m isobath; and sections 4,5,6 are 60 km offshore along the 40m isobath. At each section the meridional (north, south) daily transport exchange was defined to represent three zonal (east west) corridors which are defined as: West (section 1 and 4); Center (section 2 and 5); and East (section 3 and 6). The volume transports focuses on defining the flux: moving onshore (where northward is positive) and offshore (where southward is negative).

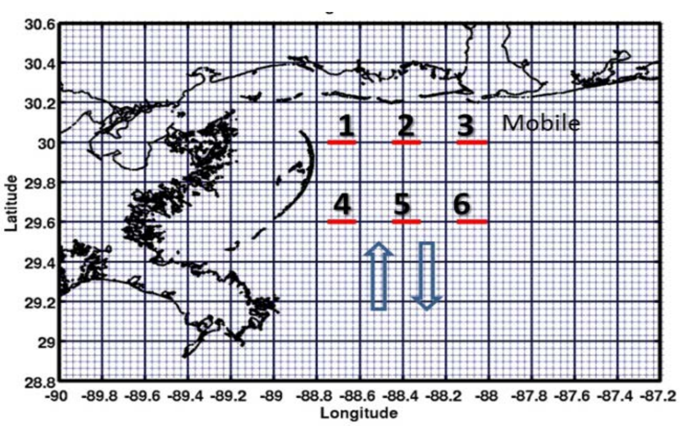

Figure 4 – A) Locations of transport sections on the shelf - coastal Sections 1-3 at 30°N in 25m depth and offshore Sections 4-6 at 26.6°N in 40m depth.

The surface volume biomass flux was determined by taking the 11 day running means of the daily surface chlorophyll along each of the six, 12.5 km sections at these 6 sections for the eight month period and combining with daily transports of the running mean-filtered volume transport from NCOM and HYCOM for the eight month time series. The running mean filter and temporal window were used to remove high frequency variations for the six sections.

6. DAILY TRANSPORT AND BIOMASS FLUX

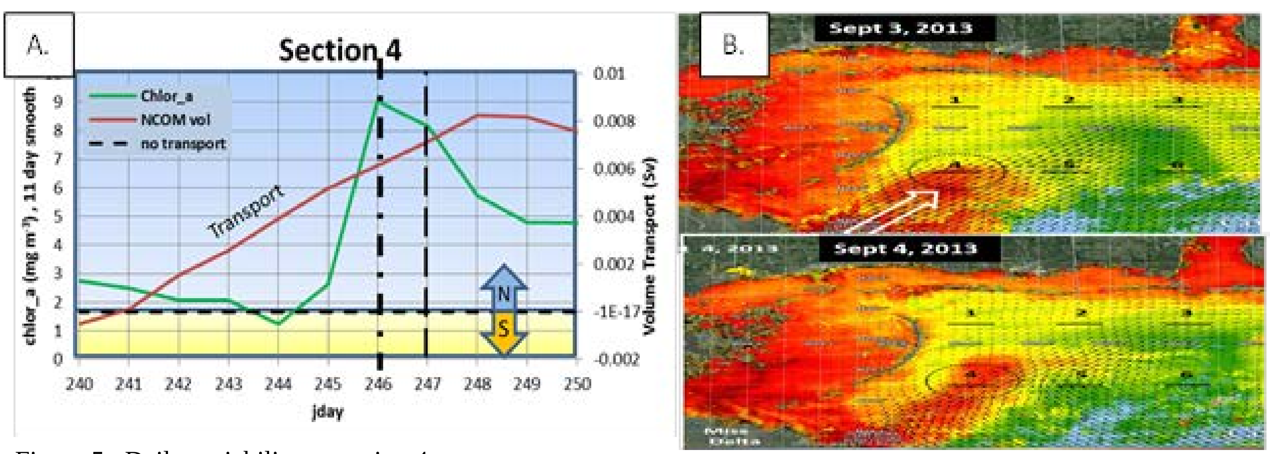

Figure 5. Daily variability at section 4 for 10 days (240 – 250) (A) volume transport (red) and chlorophyll (green) (B) VIIRS Chlorophyll and NCOM surface currents for days 246 and 247.

Rapid daily changes in the satellite bio-optics and the model transport were clearly identified in the September 2013 time sequence. Section 4 represents the offshore region that is closest to the Mississippi delta which is periodically impacted by the river plume. On September 2013, a major river pulse with elevated chlorophyll concentration passed through section 4 showing significant chlorophyll transport. The volume surface transport (0-5m) through section 4 (Figure 5a) shows increasing positive north transport (blue) for days 240 to 250 based on the NCOM model. On day 246 the surface transport peaked at 0.008 SV with a chlorophyll concentration of 9 mg/m^3. The increased chlorophyll represents the response of the Mississippi River jet shown in Figure 5 B, which rapidly changed on day 247 showing increased northward transport and a slightly reduced chlorophyll. The interaction of the surface transport and the surface bio-optical chlorophyll response can occur at different time scales and is observed at different sections.

The exchange at the center offshore corridor Section 5 represents the location for water mass exchanges entering and leaving closest to the shelf break. The surface transport and chlorophyll response at Section 5 (Figure 6) for the eight month period shows periodic pulses of onshore, north transport and offshore south transport Major pulses of northward transport (blue region) of offshore waters are shown entering the shelf at frequencies ranging from 10 days to larger fluxes at ~50 day increments. Both models show similar frequency oscillations response with NCOM (red line) showing a slightly elevated transport compared with HYCOM (blue line) However, the magnitude is different between the models with NCOM being larger. The major north intrusion of offshore water that was shown (figure 5) on day 247 at section 4 to the west is also observed intruding into section 5. A similar major northward transport event at section 5 occurred in June (day 160).

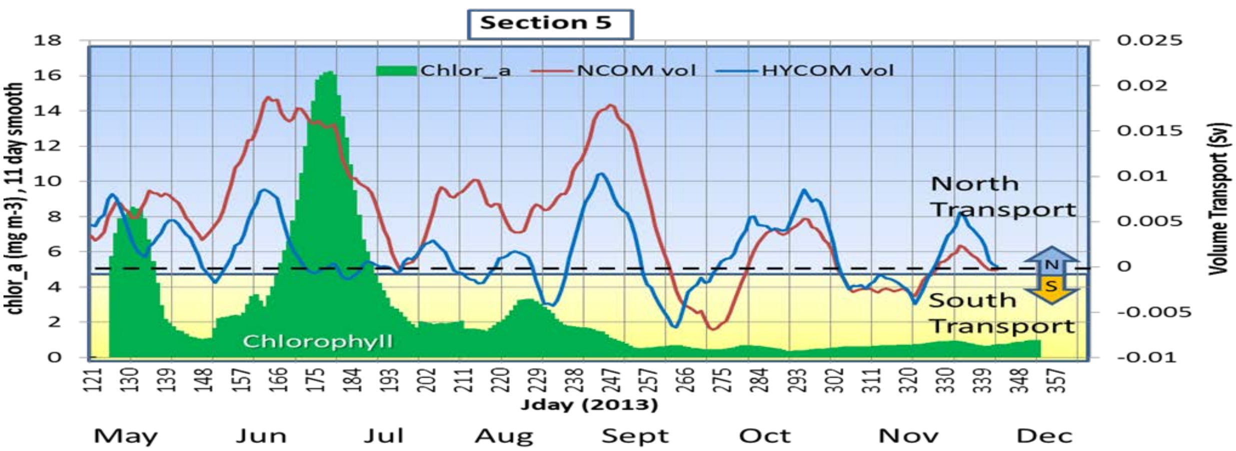

Figure 6 – Cyclic meridional pulsing at Section 5 - Center Corridor for eight months on the Mississippi Shelf. Surface volume transport from HYCOM and NCOM and VIIRS surface chlorophyll response.

Some of the onshore northward pulses can be associated with elevated chlorophyll from the offshore Mississippi river plume as shown in day 176. Other northward intrusions on the shelf are low chlorophyll oligotrophic waters such as day 290 which intrude northward. .

7. MISSISSIPPI SHELF EXCHANGE AND BIOMASS FLUX

The product of the daily satellite surface chlorophyll concentration and the surface northerly/ southerly transport across the 12.5 km section, the chlorophyll flux, was determined for each of the 6 sections for the eight month period. The total eight month summed volume transport of surface and bottom waters for each of the six sections were determined in Table 1. Positive transport values represent onshore northward flux and negative represents offshore southwards volume flux over each of the sections. Note the near shore sections (1,2,3) all show the surface waters as a negative or southerly offshore flux and the bottom waters all show a positive northerly flux during the 8 month period. The three offshore sections which are closer to the shelf break, show differences in the transport in these 3 corridors onto the MS shelf during this time period. The center and east sections: (# 5, 6) show a positive northward onshore flux onto the shelf at both the surface and bottom waters. The western offshore corridor, Section

4 which is closest to the MS river discharge and to the Chandelier Islands to the west, shows a negative southern flux at both the surface and bottom waters. The sum of all six sections over the shelf indicated a net negative or offshore volume transport of -86.74x10^9 m^3 at the surface and an net positive onshore flux of 54.4x10^9 m^3 at bottom waters.

May - Dec 2013 Transport

	Sections						Total all sections	
	1	2	3	4	5	6		
	West	Central	East	West	Central	East	-32.34	x 10^9 m3
Surface	-42.16	-25.75	-10.80	-69.38	31.97	29.38	-86.74	x 10^9 m3
Bottom	0.69	18.06	0.92	-26.18	43.46	17.45	54.4	x 10^9 m3
BioMass	-152.0	-64.00	-22.00	-215.00	105.00	68.00	-280.0	x 10^3 kg CHL

Table 1- Volume transport of HYCOM on the MS Shelf sections: positive is north and negative is south transport for the eight month period at the surface (<5m) and bottom (>20m) waters. Surface biomass flux at each sections period was determined by combining satellite chlorophyll with volume transport.

8. BIOMASS FLUX

Using the surface volume north south volume transport and combining with the daily surface satellite chlorophyll time series, an estimate of the surface biomass flux through these sections was determined (Table 1) over entire eight month period. Biomass was represented as carbon flux (kilograms carbon) which was determined using the carbon to chlorophyll ratio [*Lohrenz et al., 1991*] and the daily surface volume transport. The satellite chlorophyll is assumed to be vertical homogeneous over the upper 5 meters which is the surface transport from the models. This biomass represents an estimate of surface carbon that is transported across each section on the shelf and quantifies the exchange of coastal carbon with offshore waters across the Mississippi shelf. Sections 1,2,3,4 all resulted in negative or southerly offshore transport of biomass flux. The greatest offshore flux occurs at the western corridor of the MS shelf, at section 4 and 2 with values of -215 x10^3 kg and -153 x10^3 kg. Traditionally, carbon biomass enters the shelf at the coastal and exchanges offshore. Sections 5 and 6 located the outer shelf show a unique northward flux where increased biomass enters the shelf from offshore waters. . This northern flux is believed associated with the offshore Mississippi river water. The total Mississippi shelf biomass for all six sections for the total eight time period has a negative southerly offshore flux of -280 x10^3 kg Carbon). This value represents the total flux of all the local rivers on the LA, MS and AL coastal regions that exchanges with offshore waters into the Gulf of Mexico.

East -West Biomass Flux Corridors across the Mississippi Shelf: Biomass flux variability was determined across the shelf corridors during the eight month period**.** The west corridor shows the greatest offshore biomass exchange in the surface waters compared to the other two pathways. The central corridor also shows a northerly onshore biomass flux (+105 *10^3 kg) at the offshore section 5, while the coastal section shows an southerly offshore biomass flux (-25*10^3 kg). The eastward corridor; sections 3 and 6 is similar to the central corridor and has comparably reduced south and north transport and biomass flux compared to the other pathways.

9. CONCLUSIONS AND DISCUSSION:

The coupling of several ocean circulation models (NCOM and HYCOM) and satellite bio-optical chlorophyll products was used to characterize the physical and bio-optical response and biomass flux on the Mississippi Shelf during a 8 month period (May – Dec 2013) representing the major river discharge periods. The shallow shelf is influenced by several fresh water sources along the coast in addition to offshore Mississippi river plume which has significant impact on the cross shelf biomass flux. The satellite ocean color chlorophyll provided capability to track river plume water masses and to confirm the physical model plume locations and provided a substantially improved understanding of the bio-optical response and advection of fresh water masses.

Three typical different classes of shelf bio-physical dynamics and chlorophyll flux across shelf transport were identified: 1) Northeast offshore movement of the biologically rich Mississippi plume onto the shelf, 2) intrusions of offshore oligotrophic Gulf of Mexico waters onto and across the shelf. 3) Local coastal plumes waters from MS, AL LA, Rivers (Mobile Bay and Mississippi Sound etc) can enter the shelf from north. .

Six 12.5 km sections (#1-6) spaced evenly in 3 corridors (East Mid and West) on the shelf identified the northern and southern biomass flux and transport across the shelf on a daily basis for the eight month period. Rapid daily changes in the surface transport and chlorophyll response were clearly observed and confirmed between models and imagery. The example of offshore section 5 confirmed a major intrusion of the Mississippi plume water entering the shelf from offshore.

The surface volume transport was combined with the surface chlorophyll at the six sections on the shelf, to determine the biomass chlorophyll flux across the shelf on a daily and eight month flux. Daily changes in the coastal carbon flux were clearly observed and showed periodic oscillations over the eight months which was similar in both circulation models.

The total net surface biomass flux over the entire shelf for time period was to the south into the Gulf of Mexico and totaled -280.0 x 10^3 kg of Chl. During the time period, the greatest transport and biomass flux occurred on the western shelf corridor (Sections 1, 4) with a southerly biomass flux. The central offshore shelf at Section 5 showed a total northward transport over the monthly series for both surface and bottom waters. The surface biomass flux at the central shelf (Section 5) indicated a substantial influx of carbon entered the shelf from offshore (105x 10^3 kg of Chl). This suggests the central shelf can receive substantial influx of offshore waters.

The MS shelf physical and biological dynamic processes represent a complex interaction of coastal river plume and offshore waters. The capability to identify the interaction of these processes required coupling observations and models in order to estimate the biomass shelf flux. The limitations of models and the satellite ocean color bio-optical response were significantly improved by assembling and combing multiple models and satellite products. By developing a daily time series of the physical biological products, the limitations and understanding of shelf process was defined daily.

The Mississippi cross shelf processes represents a unique complex transport system for onshore and offshore carbon flux. The eastern, central, and western pathways across the shelf were shown to have significant surface transport and to rapidly vary both spatially and temporally.

Besides the volume transport, the biological response shown by the satellite chlorophyll and bio-optical properties clearly identified the surface response occurring across the shelf. Oil and their contaminants can be absorbed and associated with particles and bio-optical properties associated with satellite chlorophyll. The results of cross shelf biomass flux through the different corridors can provide an estimate of how oil absorbed on particles can be transported to the coast.

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11. REFERENCES

1. Arnone, R., S. Ladner, G. Fargion, P. Martinolich, R. Vandermeulen, J. Bowers, A. Lawson, (2013), Monitoring bio-optical processes using NPP-VIIRS and MODIS-Aqua ocean color products, *Proc. SPIE* 8724, Ocean Sensing and Monitoring V, 87240Q, http://dx.doi.org/10.1117/12.2018180.
2. Arnone, R., R. Vandermeulen, S. Ladner, J., Bowers, P. Martinolich, G.Fargion, M. Ondrusek, M. Wang (2014), Sensitivity of calibration "gains" to ocean color processing in coastal and open waters using ensembles members for NPP- VIIRS, SPIE 9111 Ocean sensing and Monitoing V1, 911105
3. Arnone, R., H. Loisel, K. Carder, E. Boss, S. Maritorena, and Z. Lee, (2006) Chapter 13, Examples of IOP Applications in IOCCG . Remote Sensing of Inherent Optical Properties: Fundamentals, Tests of Algorithms, and Applications. Lee, Z. P. (ed.), Reports of the International Ocean-Colour Coordinating Group, No. 5, IOCCG, Dartmouth, Canada
4. Arnone, R A., R. Parsons, D. S. Ko, B. J. Casey, S. Ladner, R. H. Preller, C. M. Hall, (2005), 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 STENNIS SPACE CENTER MS
5. Barron, C. N., P.J. Martin, A. B. Kara, R. C. Rhodes, L.F. Smedstad. (2006), Formulation, implementation and examination of vertical coordinate choices in the Global Navy Coastal Ocean Model (NCOM). Ocean Modelling 11:347–375
6. Chen, X., Lohrenz, S. E., & Wiesenburg, D. A. (2000). Distribution and controlling mechanisms of primary production on the Louisiana–Texas continental shelf. *Journal of Marine Systems*, *25*(2), 179-207
7. Halliwell Jr. G. R., A. Srinivasan, V. Kourafalou, H. Yang, D. Willey, M. Le Hénaff, and R. Atlas, (2014), Rigorous Evaluation of a Fraternal Twin Ocean OSSE System for the Open Gulf of Mexico. *J. Atmos. Oceanic Technol.*, **31**, 105–130.
8. Hetland, R. D., S. F. DiMarco, (2012), Skill assessment of a hydrodynamic model of circulation over the Texas-Louisiana continental shelf, Ocean Model., 43–44, 64–76, doi:10.1016/j.ocemod.2011.11.009.
9. Huthnance, J. M. (1995). Circulation, exchange and water masses at the ocean margin: the role of physical processes at the shelf edge. *Progress in Oceanography*, *35*(4), 353-431
10. Jolliff, J. K., J. C. Kindle, B. Penta, R. Helber, Z. Lee, I. Shulman, R. Arnone, C. D. Rowley (2008), On the relationship between satellite-estimated bio-optical and thermal properties in the Gulf of Mexico, J. Geophys. Res., 113, G01024, doi:10.1029/2006JG000373.
11. Lee, Z. P., K. L. Carder, R. Arnone, (2002) Deriving inherent optical properties from water color: A multi-band quasi-analytical algorithm for optically deep waters. Appl. Opt. 41: 5755-5772.25
12. Lihan, T M., A. Mustapha, S.A. Rahim, S. Saitoh K. Iida, (2011), Influence of River Plume on Variability of Chlorophyll a Concentration using Satellite Images, Journal of Applied Sciences, 11: 484-493.
13. Lohrenz, S. E., D. G. Redalje, W.-J. Cai, J. Acker, M. Dagg, (2008), A retrospective analysis of nutrients and phytoplankton productivity in the Mississippi River plume, Cont. Shelf Res., 28, 1466–1475.
14. Lohrenz, S. E., D. G. Redalje, G. L. Fahnenstiel, G. A. Lang, (1991), Regulation and distribution of primary production in the northern Gulf of Mexico,. In Proceedings of the Nutrient Enhanced Coastal Ocean Productivity

workshop. p. 95–104 Louisiana Universities Marine Consortium, National Oceanic and Atmospheric Administration, Coastal Ocean Program Office, New Orleans, Louisiana

15. Morey ,S J. J. O'Brien, W. W. Schroeder, J. Zavala-Hidalgo,(2002), 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 ·
16. O'Reilly, J. E., S. Maritorena, B. G. Mitchell, D. A. Siegel, K. L. Carder, S. A. Garver, M. Kahru, C. McClain (1998), Ocean color chlorophyll algorithms for SeaWiFS, J. Geophys. Res., 103(C11), 24937–24953, doi:10.1029/98JC02160.
17. Schiller, R. V., V. H. Kourafalou, P. Hogan, N. D. Walker, (2011), 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.
18. Toner, M., Kirwan, A. D., Poje, A. C., Kantha, L. H., Müller-Karger, F. E., & Jones, C. K. R. T. (2003). Chlorophyll dispersal by eddy-eddy interactions in the Gulf of Mexico. *Journal of Geophysical Research: Oceans (1978–2012)*,*108*, No C4, 3105 doi:10.1029/2002JC001499
19. Vandermeulen, R.A., R.A. Arnone, S. Ladner, P. Martinolich, (2015) Enhanced satellite remote sensing of coastal water using spatial improved bio-optical products from SNPP-VIIRS, Remote Sensing of the Environment, Volume 165 p 53-63
20. Werdell, P.J, Franz, B.A. Bailey, S.W. Feldman G.C. and 15 co-authors, (2013) Generalized ocean color inversion model for retrieving marine inherent optical properties", Applied Optics 52, 2019-2037
21. Zaron, E., P. Fitzpatrick, S.L, Cross, J.M. Harding. F.L. Bub, J.D. Wiggert, D.S. Ko, Y. Lau, K. Woodward, C. Moores, (2015), Initial evaluations of a Gulf of Mexico/Caribbean ocean forecast system in the context of the Deepwater Horizon disaster. Front. Earth Sci., doi:10.1007/s11707-014-0508-x:1-32, .
22. Zhang, X., R. D. Hetland, M. Marta-Almeida, *and* S. F. DiMarco *(*2012*)*, A numerical investigation of the Mississippi and Atchafalaya freshwater transport, filling and flushing times on the Texas-Louisiana Shelf, J. Geophys. Res., 117*, C11009*,

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http://dx.doi.org/10.1117/12.2240874
http://proceedings.spiedigitallibrary.org/proceeding.aspx?articleid=2524463