An Integrated Terrestrial-Coastal Ocean Observation and Modeling Framework for Carbon Management Decision Support

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Presentation to USDA – 18 November 2014

Acknowledgements

- Project is funded through the NASA Carbon Monitoring System program (NX14AO73G and prior projects NNX12AB21G and NX12AP84G)
- Additional funding, data and cruise support provided by NASA IDS, NSF, NOAA, EPA, and USGS

North American Carbon Program

Overview

- Introduction
  - The NASA Carbon Monitoring System – Goals
  - Managing carbon through land use, land use cover and forestry (LULUCF) -
  - Objectives of NASA Carbon Monitoring System project
- Background
- Approach and Findings
  - Coupled models of land-ocean-atmospheric fluxes and exchanges
  - Dynamic Land Ecosystem Model
  - Ocean Biogeochemistry Model
- Next Steps

Introduction

- The NASA Carbon Monitoring System effort seeks to apply satellite remote sensing resources along with observational and modeling capabilities to improve monitoring of carbon stocks and fluxes, particularly as they contribute to the development of Monitoring, Reporting and Verification (MRV) system capabilities
- Program goals include the development of capabilities for improved characterization, quantification, understanding, and prediction of the evolution of global carbon sources and sinks on regional, national and global scales

Introduction

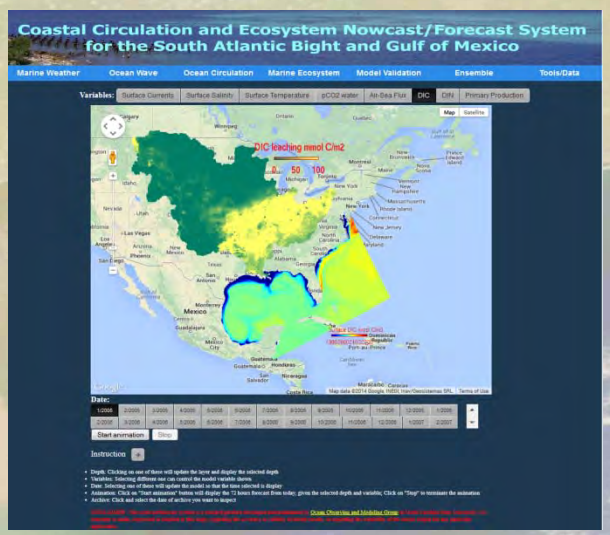
- Policy-based management involving land use, land–use change and forestry (LULUCF) is one prominent strategy as a means of either reducing carbon sources or increasing sequestration of carbon
- Effective implementation of regulatory and market approaches requires a greater understanding of the effectiveness of different carbon management actions and their persistence in the face of future climate extremes and human activity
- Managing carbon stocks and fluxes has the added challenge of potential unintended or indirect consequences, whereby actions taken in one sector have extended impacts in others, potentially offsetting benefits

Introduction

- We have developed an integrated suite of terrestrial and coastal ocean ecosystem models that were used to examine processes controlling fluxes on land, their coupling to riverine systems, the delivery of materials to estuaries and the coastal ocean, and the associated marine ecosystem responses
- Previously, we focused on the Mississippi-Atchafalaya River basin (MARB) and the northern Gulf of Mexico (GOM) as a testbed system
- ***Here we extend the domain of our integrated framework of terrestrial and ocean models beyond the MARB and GOM to include regions of the southern and southeastern U.S. and the South Atlantic Bight***
- ***We will examine carbon storage in soils and vegetation, land-atmosphere exchanges of carbon (including methane), export of materials to the coastal ocean and consequences for associated carbon fluxes in the coastal environment, and project into the future changes under different scenarios of climate and human impact***

Project Objectives

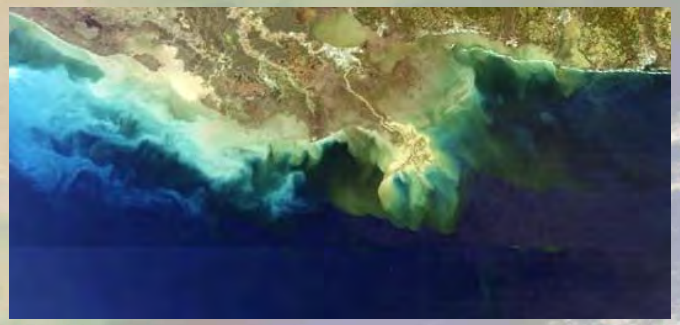
- Expand the spatial domain of our observational and integrated modeling approach to include the Mississippi River basin and southeastern U.S., and examine terrestrial carbon storage and fluxes including biomass and carbon stocks and land-atmosphere, land-ocean, and sea-atmosphere fluxes of carbon dioxide and methane;

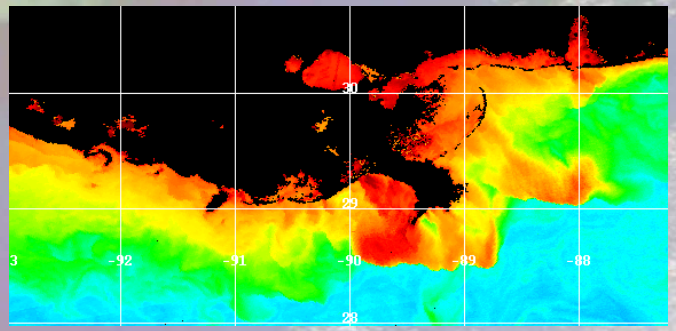


- Examine different LULUCF scenarios within the terrestrial domain and different climate scenarios to assess effectiveness of carbon management strategies;
- Engage with other CMS projects and stakeholders to identify user needs related to carbon management and MRV activities, modify and expand the scope of information based on user feedback, and explore possible transition of prototype products to fully operational status

Background

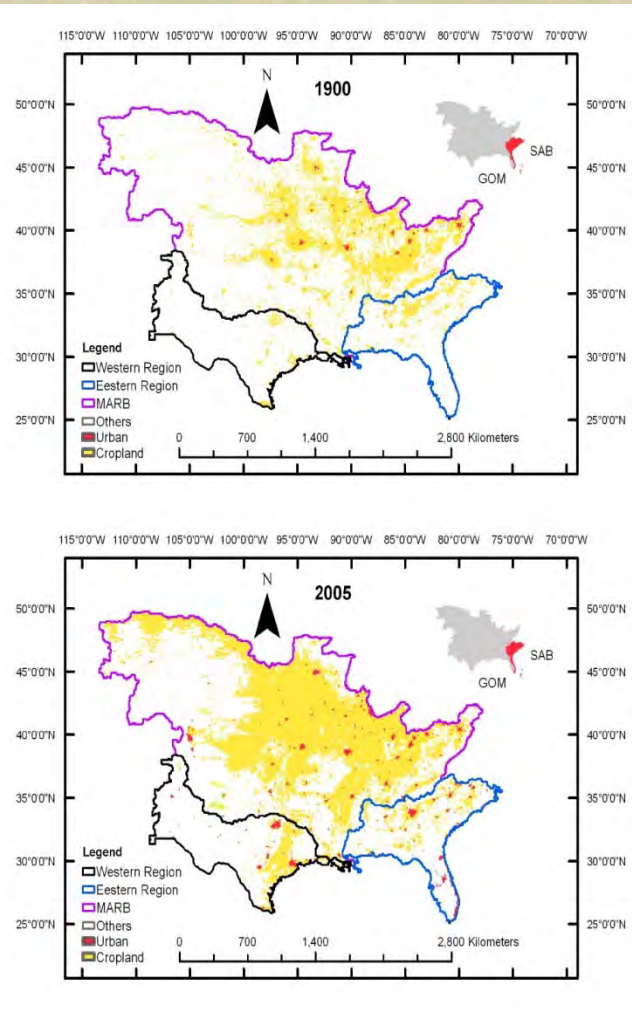
- The South, Southeast and MARB regions are undergoing significant and distinct anthropogenic and climate-related changes
- Terrestrial land cover and land use are major factors influencing the strength of the terrestrial carbon sink and the delivery of sediment, organic carbon, nutrients, and other constituents from land to rivers, and eventually to the ocean





Background

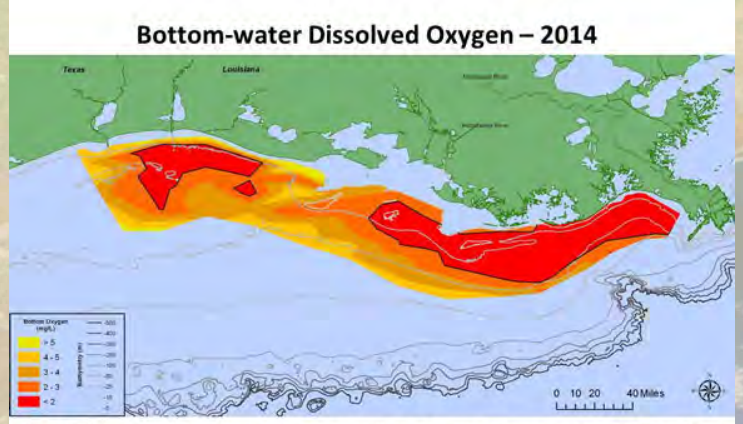
- The South and Southeast regions differ from the MARB in that they are experiencing relatively large increases in population growth and associated development of the rural landscape
- Land-use and land cover in the MARB is largely characterized by cropland and grassland areas and is heavily influenced by agricultural activities
- In contrast, the South and Southeast has a larger fraction of forested area, representing approximately 60% of the forest land in the conterminous U.S.
- This region has also been identified as the largest carbon sink among the six major bioclimatic regions in the nation and has the highest potential to be a significant carbon sink in the future due to the large area of young pine forests and increasing plantation forest area



Trends in land use and land cover from 1900 to 2005

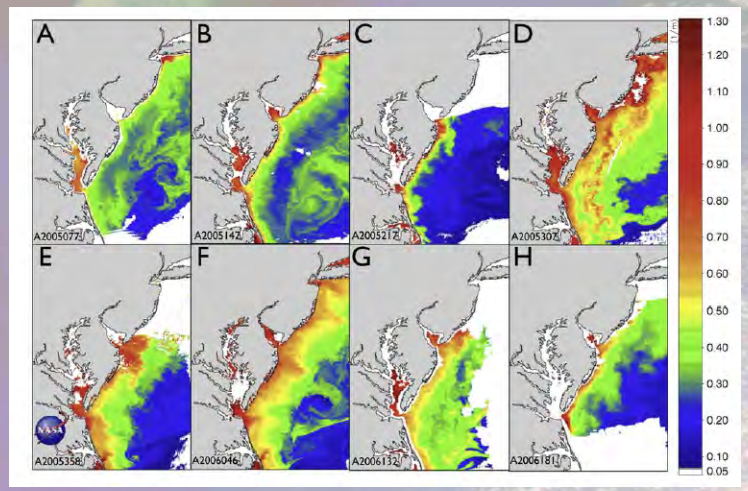
Background

- From an oceanographic and biogeochemical perspective, the GOM and the SAB are also very different
- River nutrients and organic and inorganic carbon are delivered to the northern GOM in almost a point source via one larger river system while rivers are nearly uniformly distributed along the SAB coastal region
- Hypoxia events are limited to a few localized areas in the SAB in contrast to extensive hypoxia in the GOM



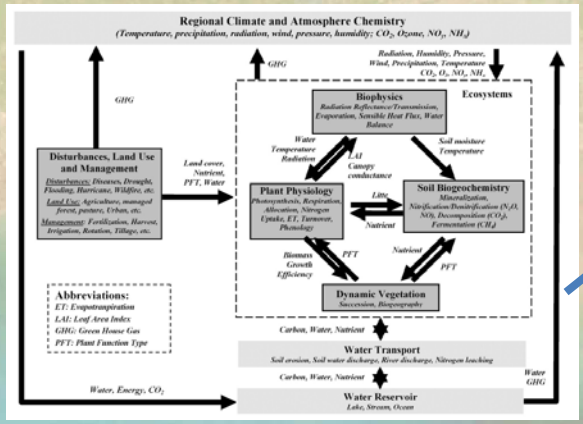
Distribution of bottom-water dissolved oxygen July 27-August 1 (west of the Mississippi River delta), 2014. Black line indicates dissolved oxygen level of 2 mg/L.

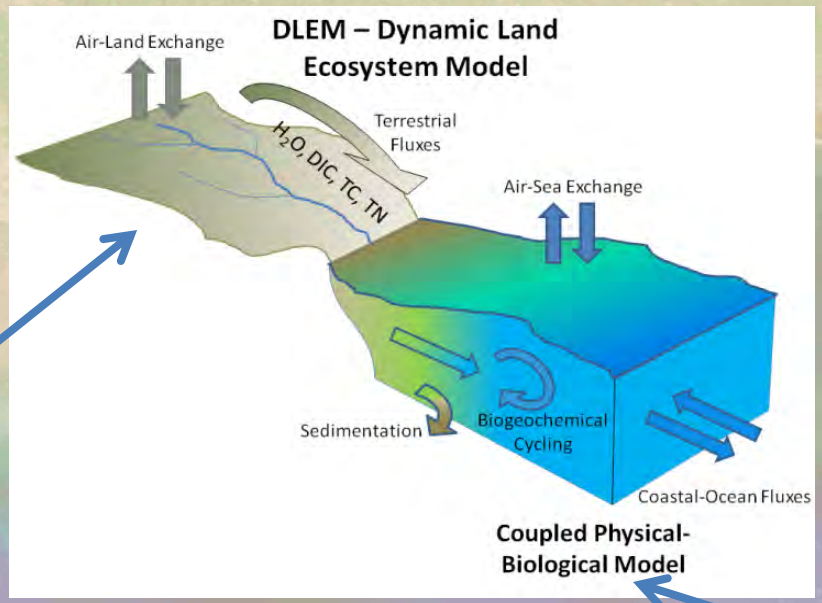
Data source: Nancy N. Rabalais, LUMCON, and R. Eugene Turner, LSU
Funding sources: NOAA Center for Sponsored Coastal Ocean Research and U.S. EPA Gulf of Mexico Program



MODIS-Aqua derived satellite images of $a_{CDOM}(355)$ (m^{-1})

Approach: Coupled Terrestrial-Ocean Models



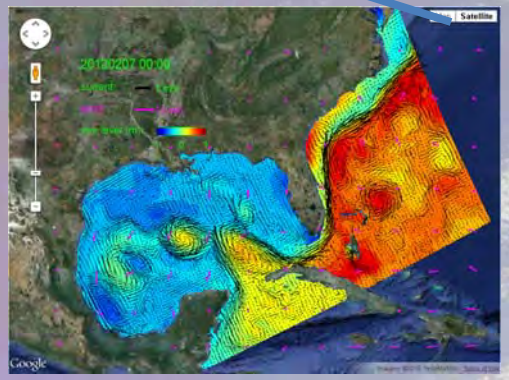


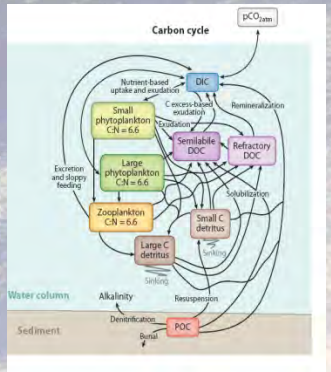
DLEM terrestrial outputs linked to a physical-biogeochemical model to characterize coastal carbon fluxes and ecosystem dynamics

Dynamic Land Ecosystem Model used to estimate spatial and temporal patterns of land-air carbon fluxes and lateral transport of water, carbon, and nitrogen

Tian et al., 2010a,b; Tian et al.,2011; Tian et al.,2012 ; Zhang et al., 2012

Modeling efforts supported by field survey-based and satellite-based observations of carbon fluxes and other biogeochemical processes

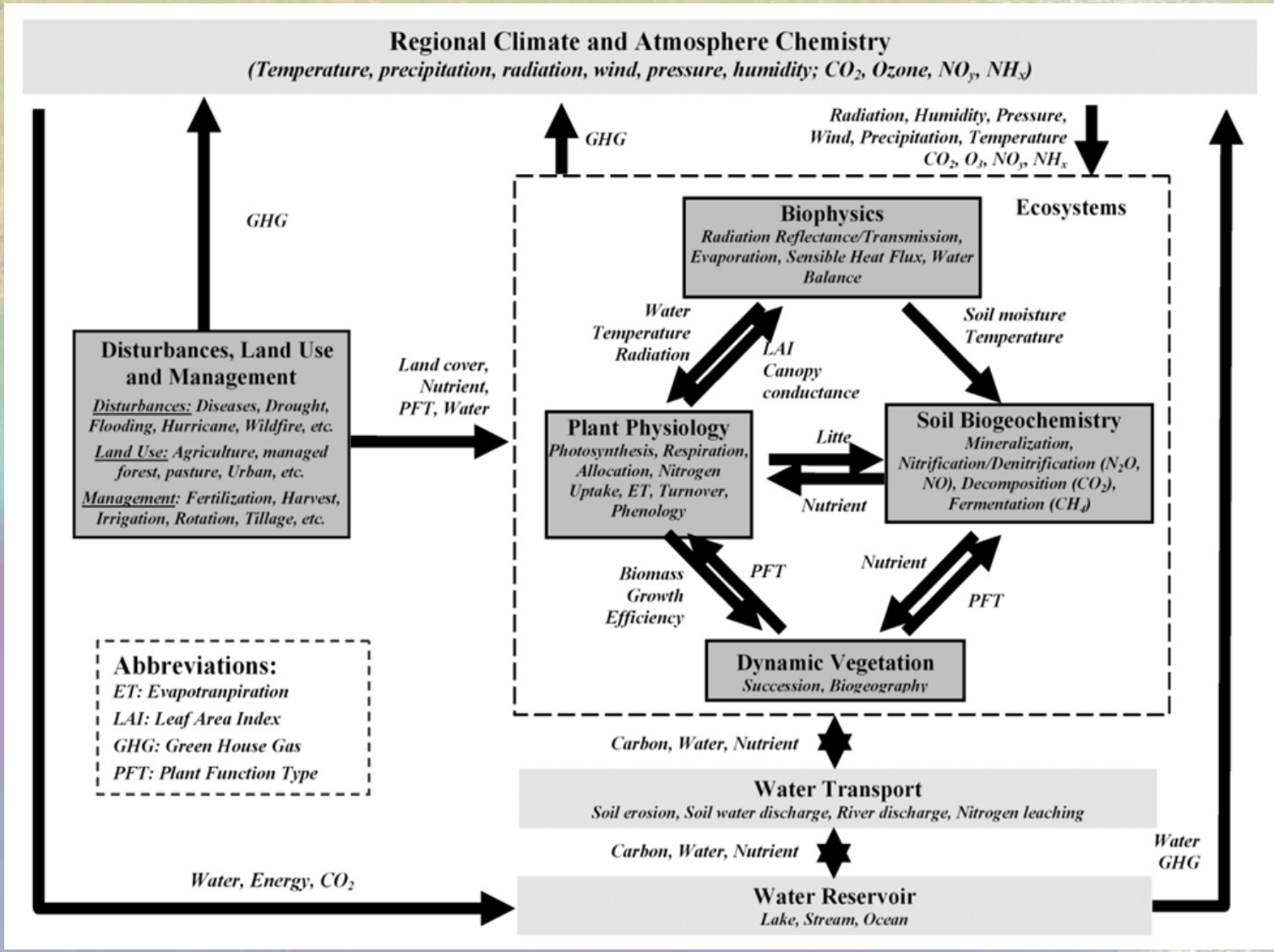




Hyun and He (2010); Xue et al., 2013, 2014

Hoffman et al., Ann. Rev., 2011; Fennel et al., 2011, 2013

Approach: Dynamic Land Ecosystem Model

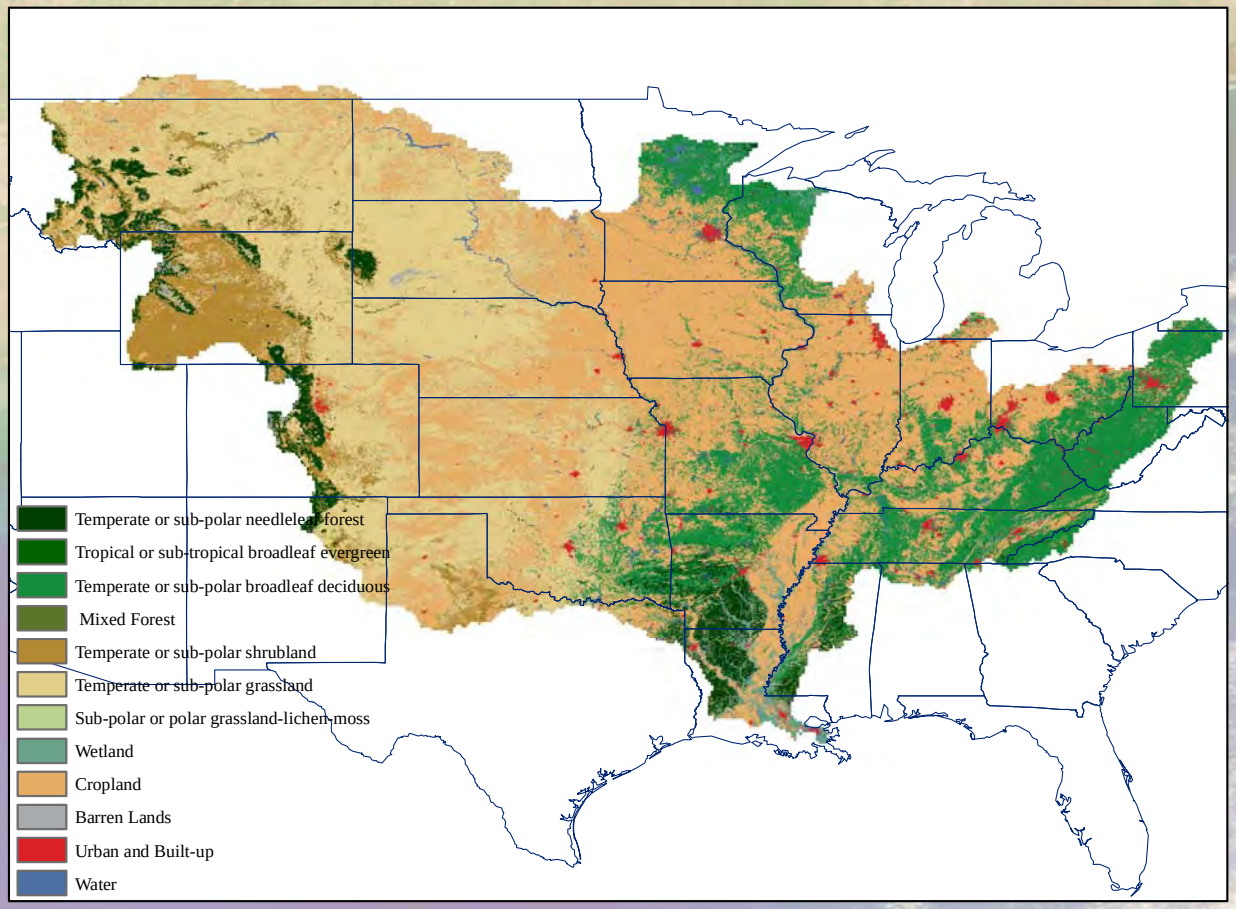


Tian et al., 2010a,b; Tian et al.,2011, Tian et al.,2012, Tao et al. 2013

Dynamic Land-Ecosystem Model (DLEM2.0)

Terrestrial Domain: Mississippi-Atchafalaya Basin

- The drainage basin for the Mississippi-Atchafalaya river system covers 41% of the conterminous U.S.
- Among the ten largest rivers in the world with respect to water and sediment discharge and the largest in the North American continent

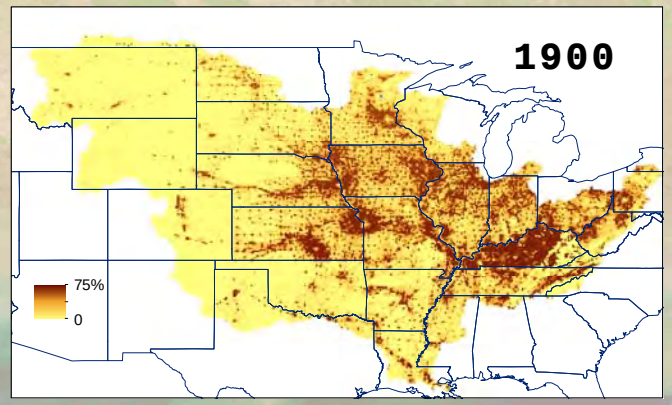


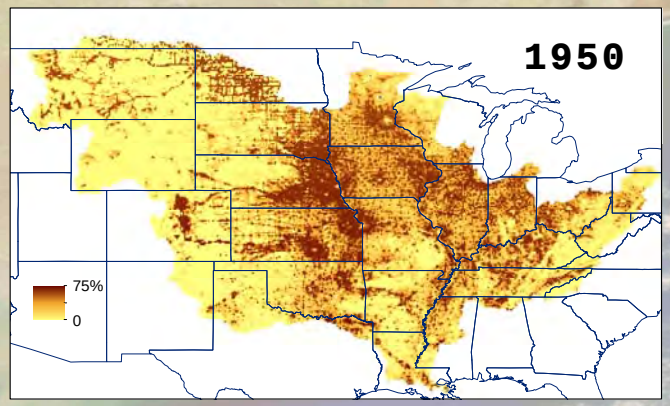
Tian et al.

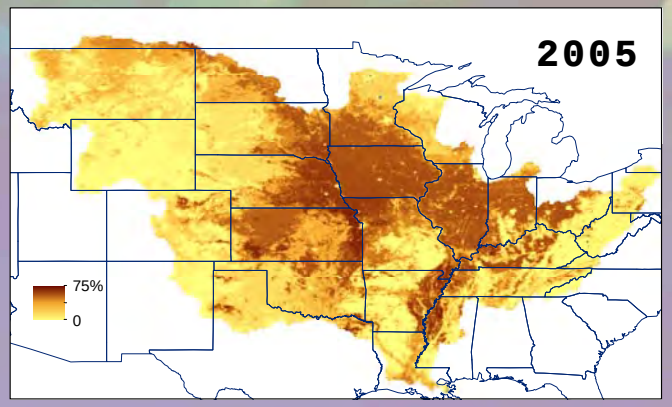
Contemporary land cover distribution across Mississippi-Atchafalaya river basin

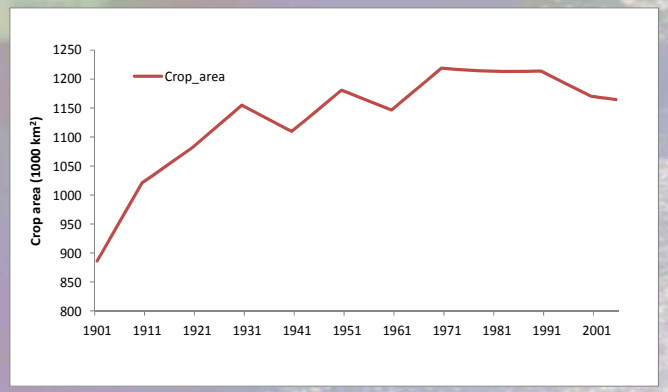
DLEM Model Implementation

- Assemble terrestrial data sets for model input
  - Land cover
  - Historical and projected climate
  - Land use
  - Disturbance and regrowth
  - Manure/fertilizer
  - Population data





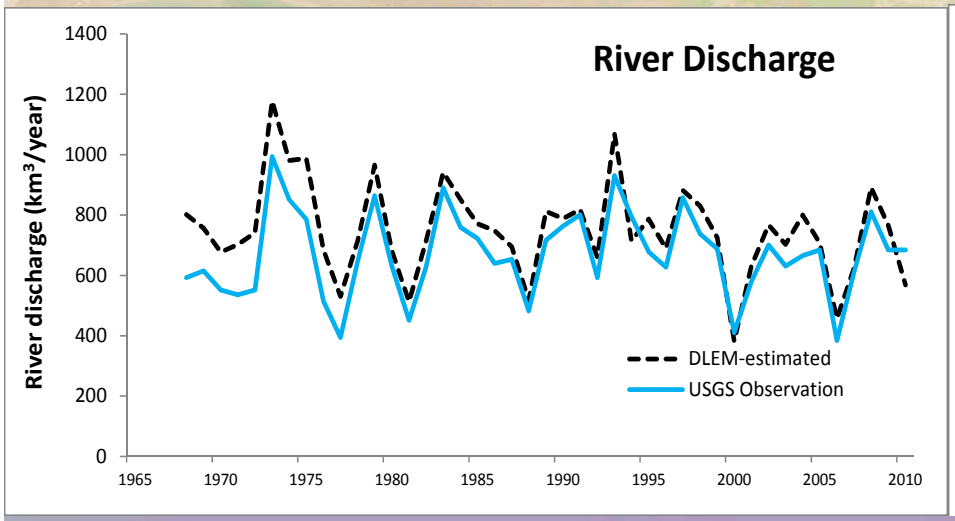


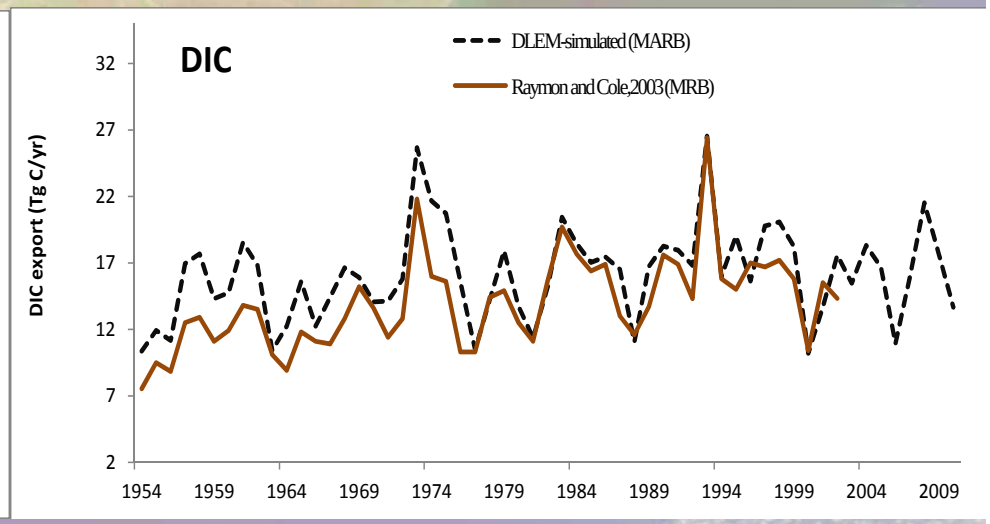


Spatial and temporal patterns of cropland in the Mississippi-Atchafalaya River Basin during 1901-2008 (Tian et al.)

DLEM Validation

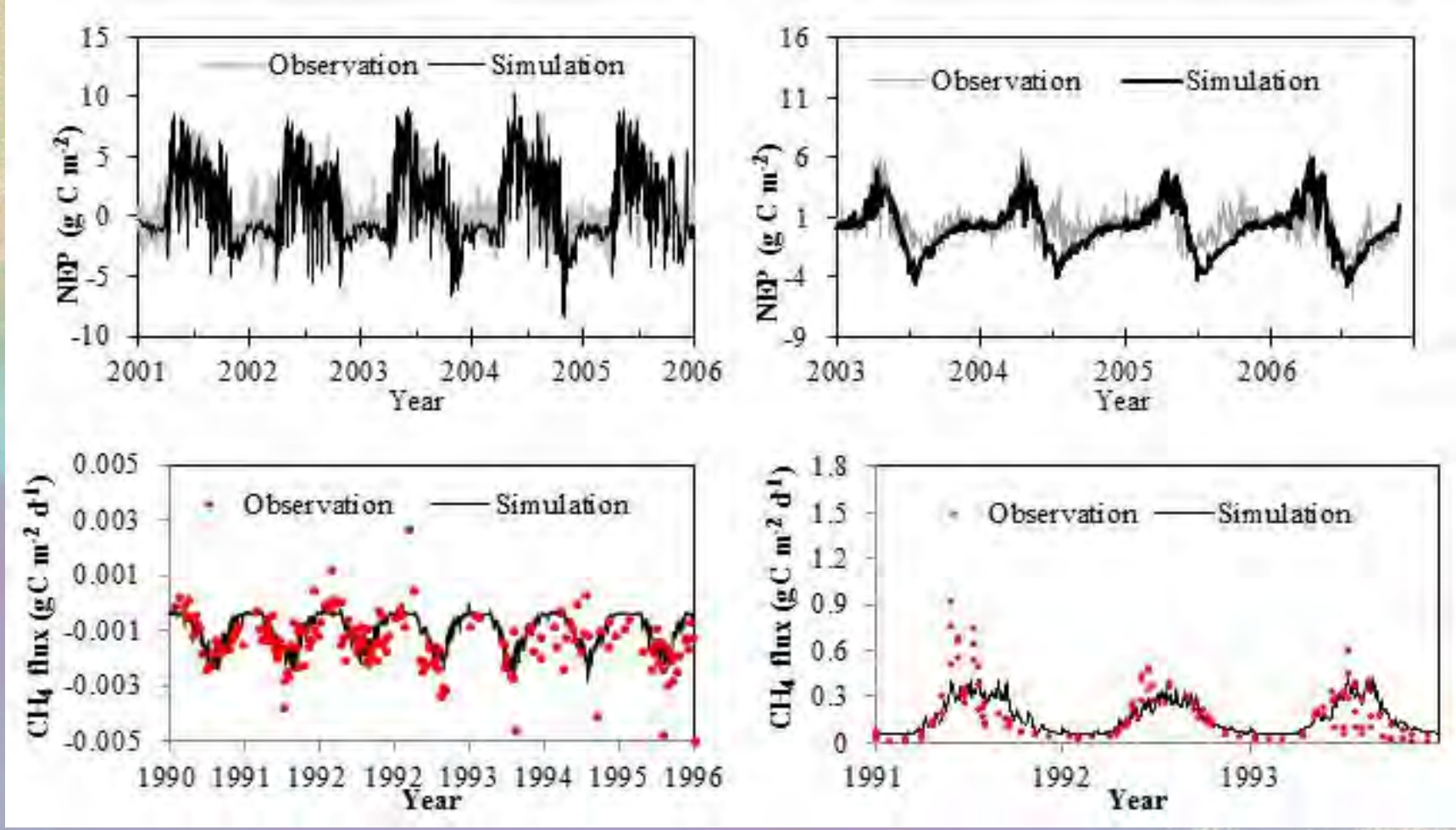
Validation of DLEM against ground based observations





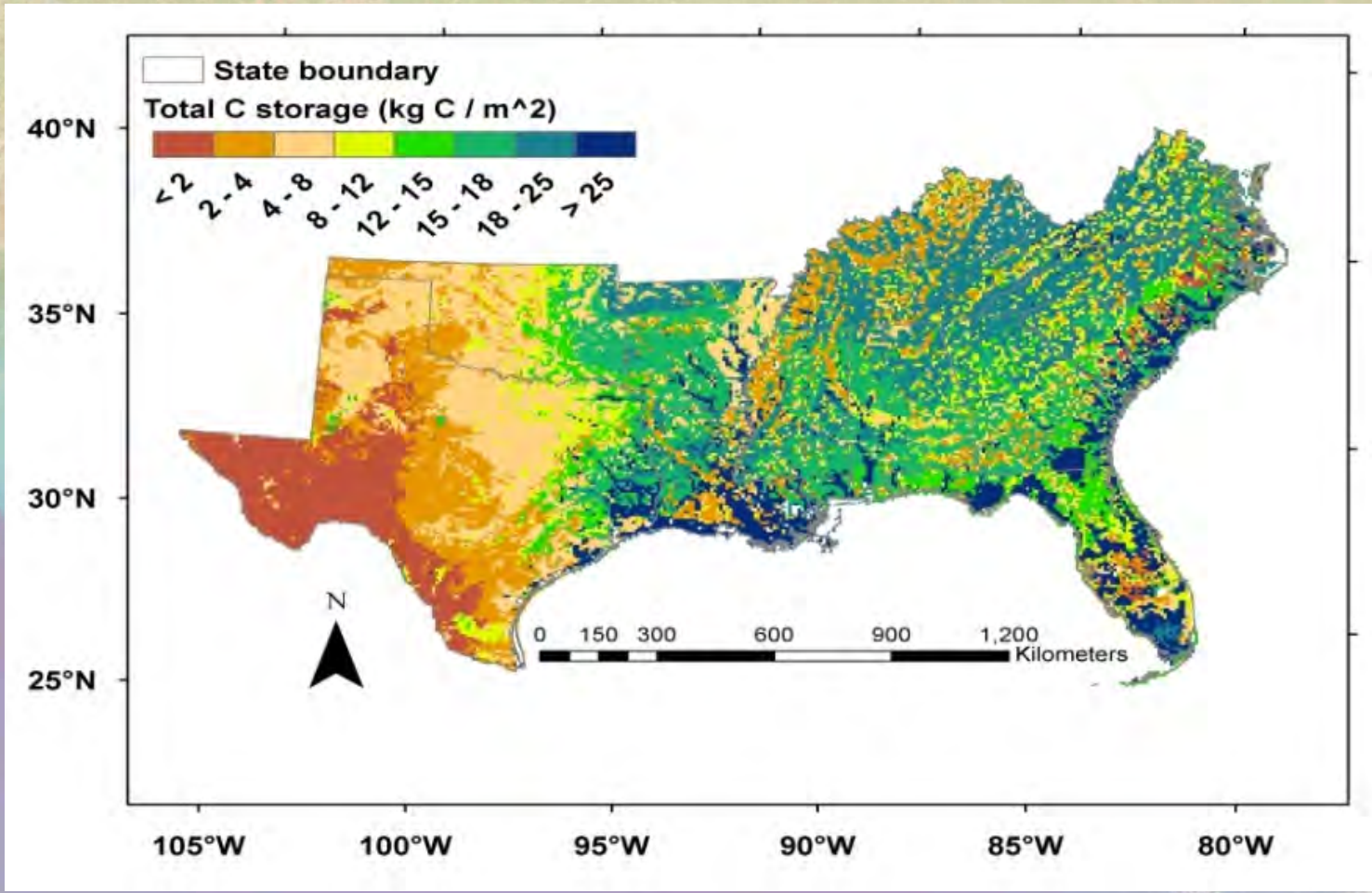
Tian et al.

DLEM Validation



Comparison of simulated and observed net ecosystem production (NEP) for US-DK2 AmeriFlux site (deciduous broadleaf forest) (upper left) and US-ARM AmeriFlux site (cropland) (upper right); CH4 flux for Durham Forest (lower left) and Buck Hollow Bog (lower right)

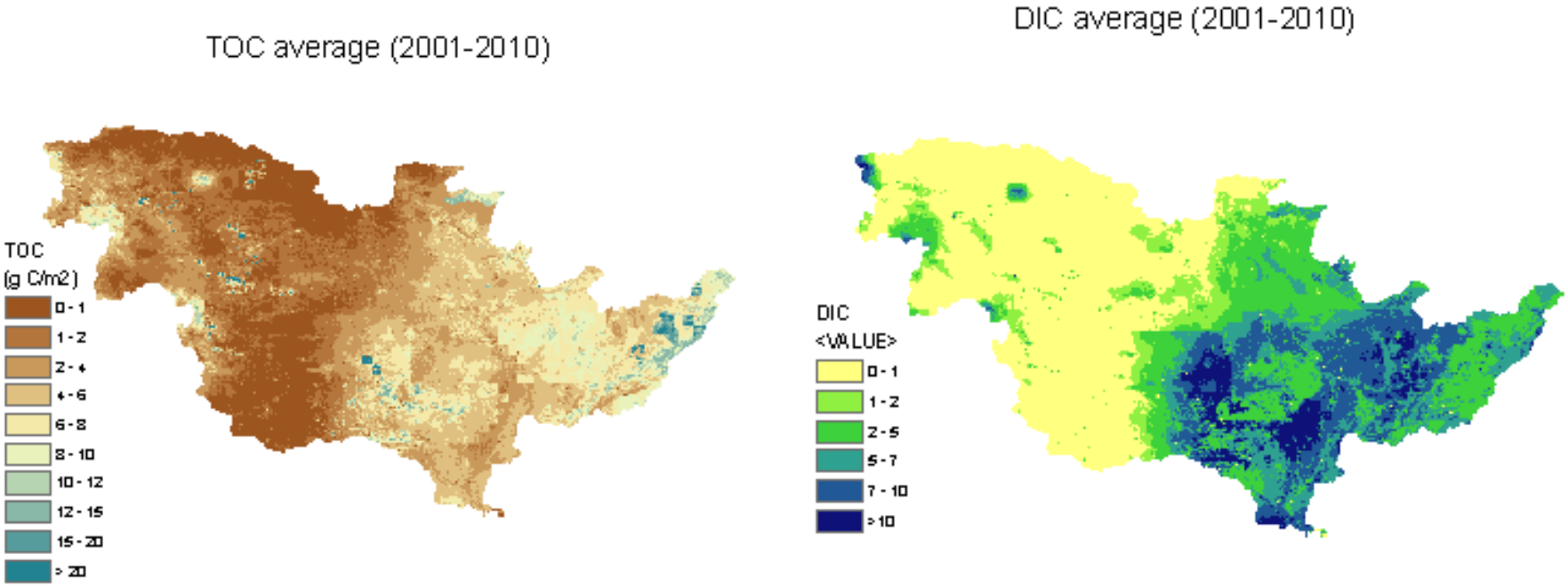
DLEM-Estimated Soil Carbon



Spatial distribution of C storage in the South and Southeastern United States in 2007 as simulated by the DLEM

Carbon export

Spatial patterns of C leaching

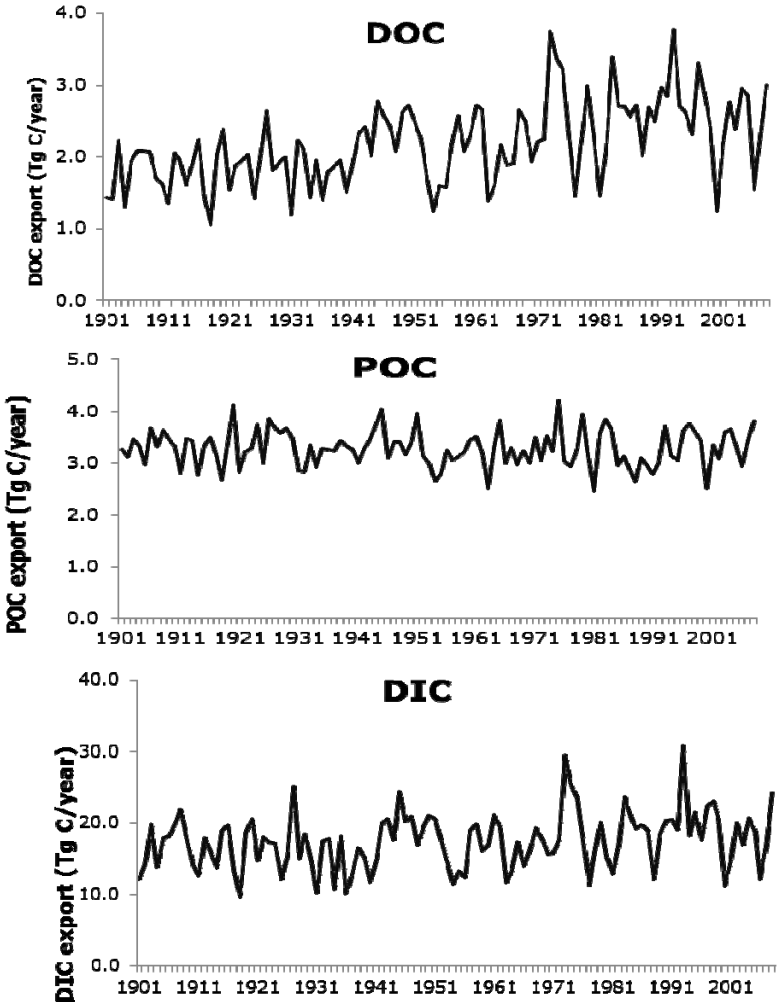


Spatial distribution of yearly total organic carbon (TOC) and dissolved inorganic carbon leaching in the MARB averaged during 2001-2010

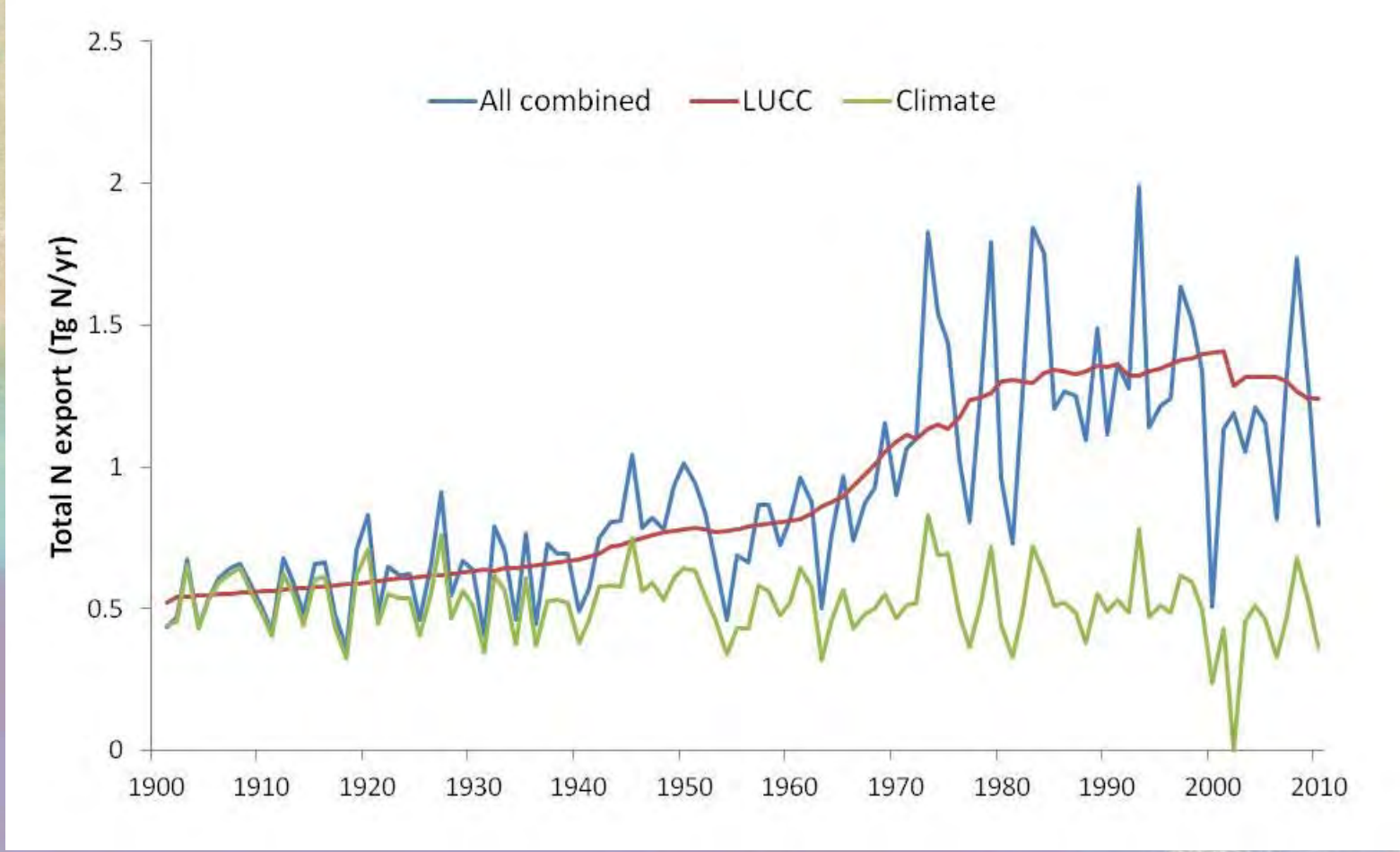
Carbon export

Decadal means of carbon export from MARB

	DOC	POC	TOC	DIC
	(Tg C/year)			
1950s	2.0	3.4	5.4	16.6
1980s	2.5	3.2	5.7	17.8
1990s	2.8	3.4	6.2	21.4
2000s	2.4	3.1	5.5	17.3



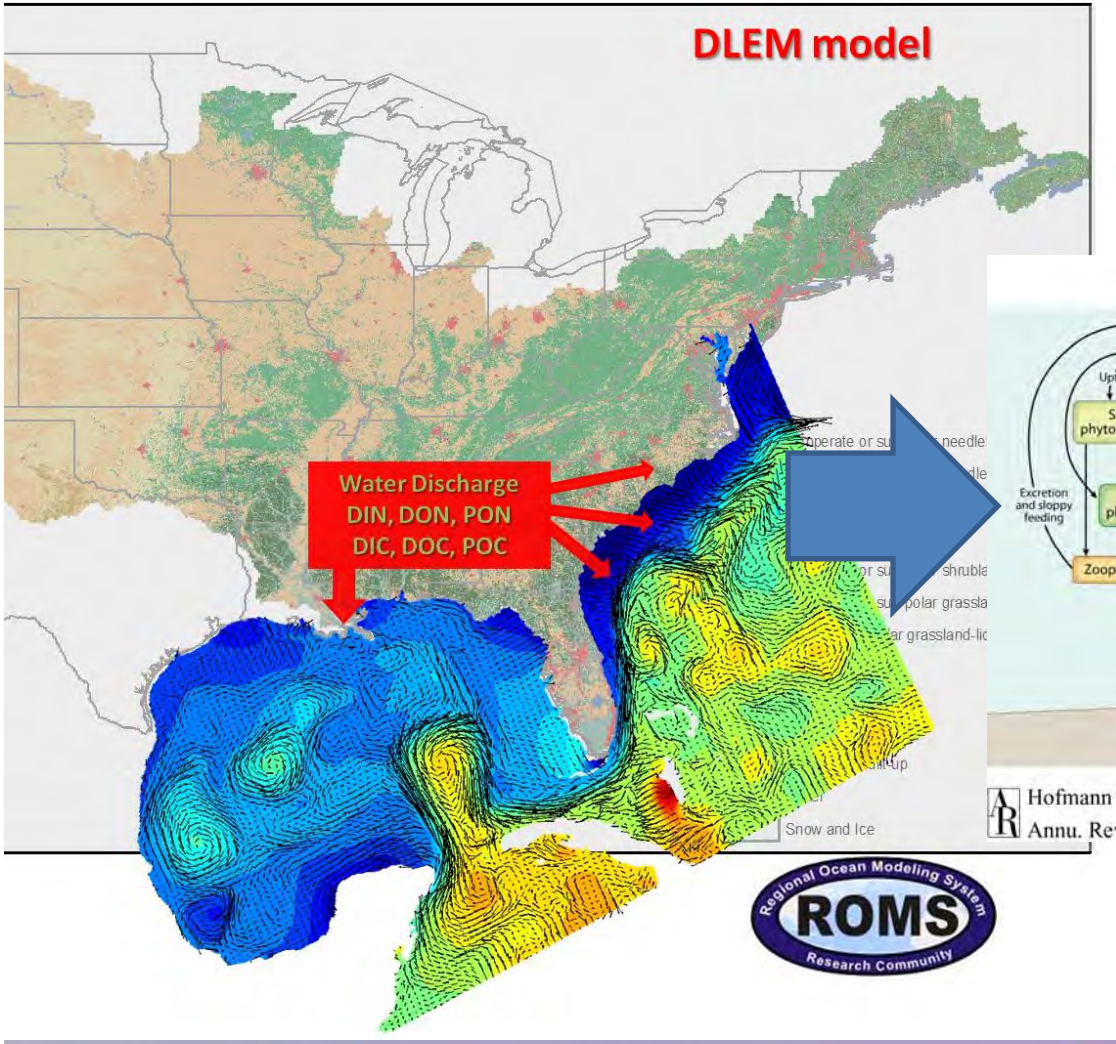
Relative contributions from LUCC and climate

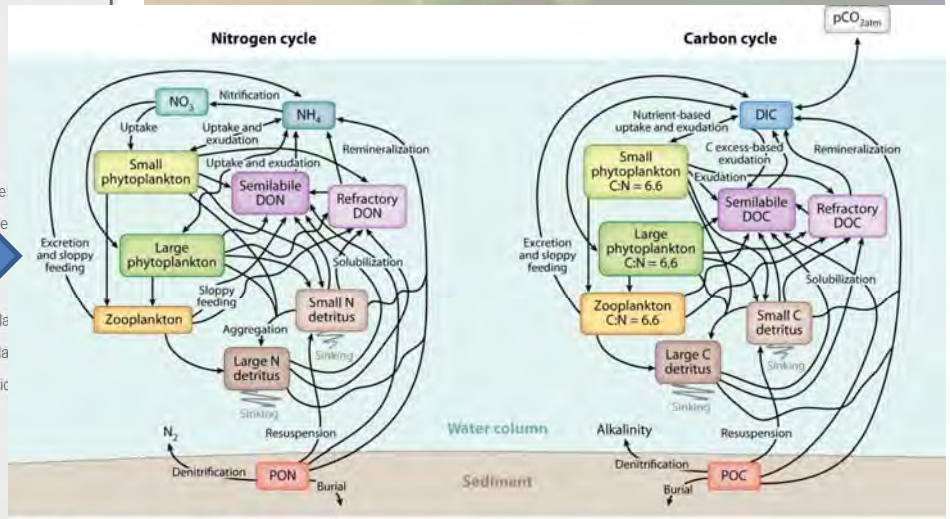


DLEM-simulated total N export (DIN+DON+PON) driven by land use/cover change (LUCC, including land management), climate change and all the environmental changes

Tian et al.

Approach: SABGOM





Hofmann EE, et al. 2011.
Annu. Rev. Mar. Sci. 3:93–122

Hoffman et al., Ann. Rev., 2011;
Fennel et al., 2011 and in prep.

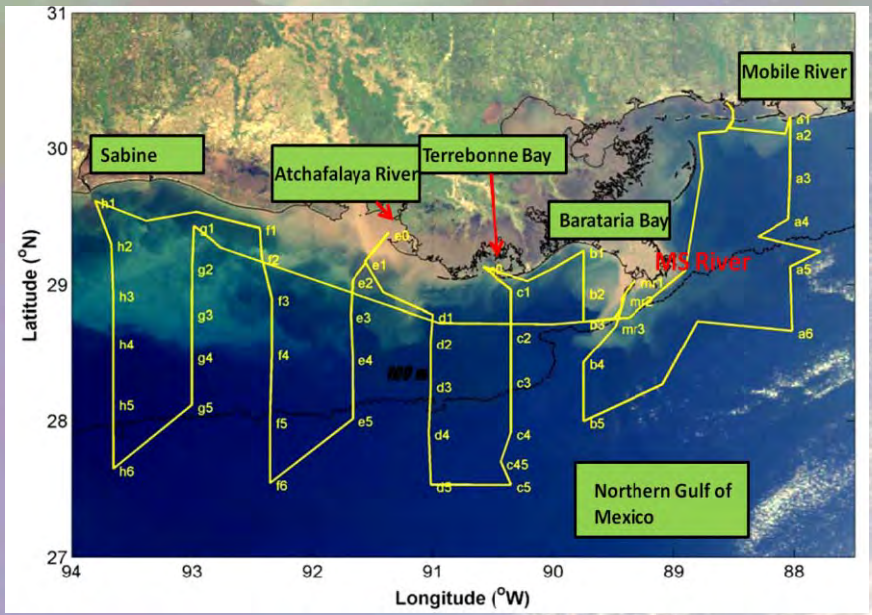
He et al.

Ocean Model Validation: Ship-based Observations

- Extensive ship-based observations in the northern Gulf of Mexico region from 2003 - 2012

Jun 24-31 2003	R/V *Pelican*
Aug 1-8 2004	R/V *Pelican*
Oct 3-7 2005	R/V *Pelican*
Apr 27 - May 1 2006	R/V *Pelican*
Jun 6-11 2006	OSV *Bold* (EPA)
Sep 6-11 2006	OSV *Bold* (EPA)
Jul 10 - Aug 4 2007	R/V *Brown* (NOAA)
May 1-8 2008	R/V *Pelican*
31 Oct-7 Nov 2008	R/V *Pelican*
Jan 8-20 2009	R/V *Cape Hatteras*
Apr 19 - May 1 2009	R/V *Cape Hatteras*
July 18 - 30 2009	R/V *Cape Hatteras*
Oct 28 - Nov 9 2009	R/V *Sharp*
Mar 11-21 2010	R/V *Cape Hatteras*
Jul 21 – Aug 13 2012	R/V *Ronald H. Brown*

- Huang et al., 2012, Biogeosci. and in review
- Guo et al., 2012, Limnol. Oceanogr.
- Cai et al., 2011, Nature Geosci.
- Cai et al., 2011, Ann. Rev. Mar. Sci.
- Two Ph.D. dissertations, other papers

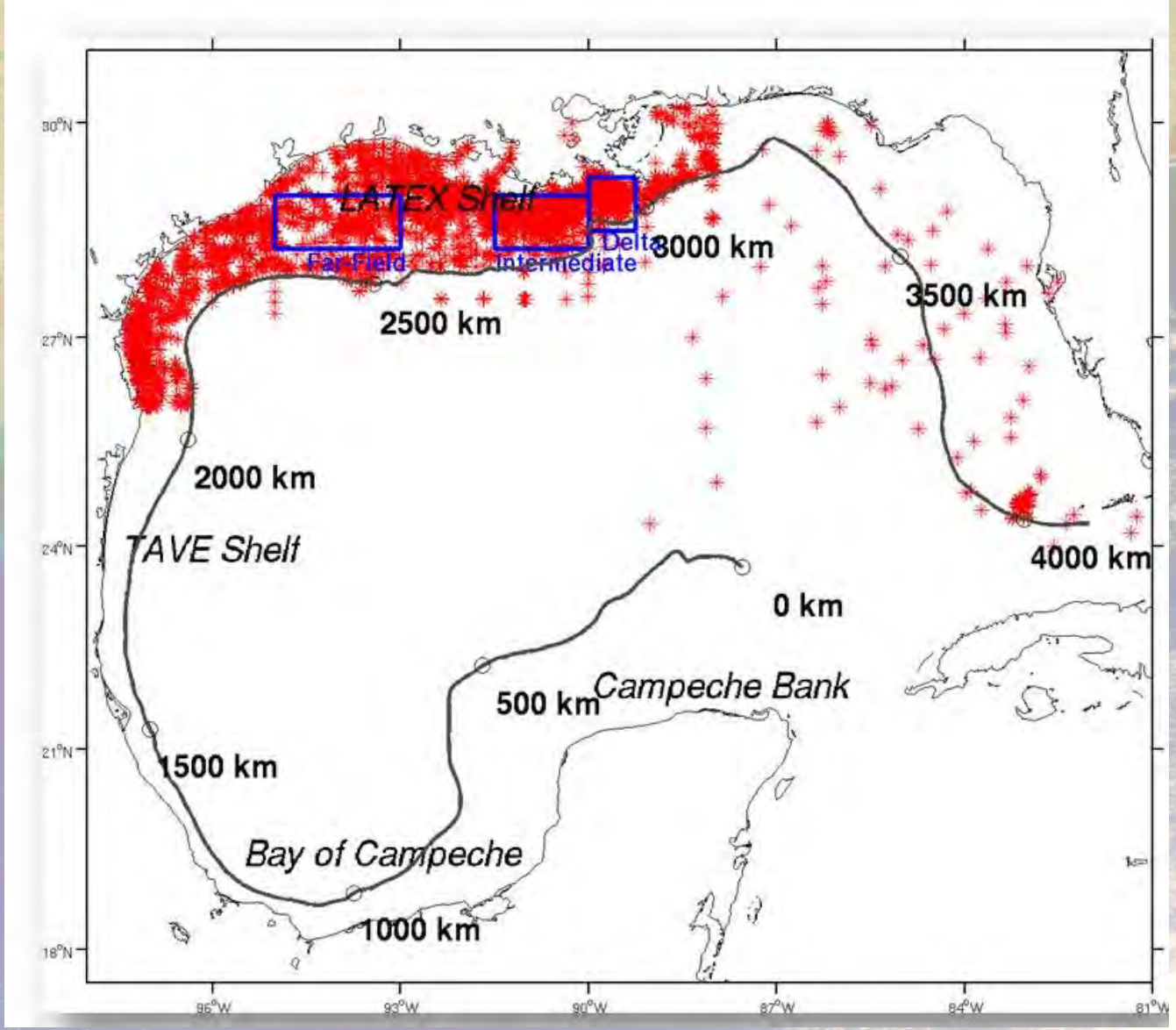


www.gulfcarbon.org

Ocean Model Validation

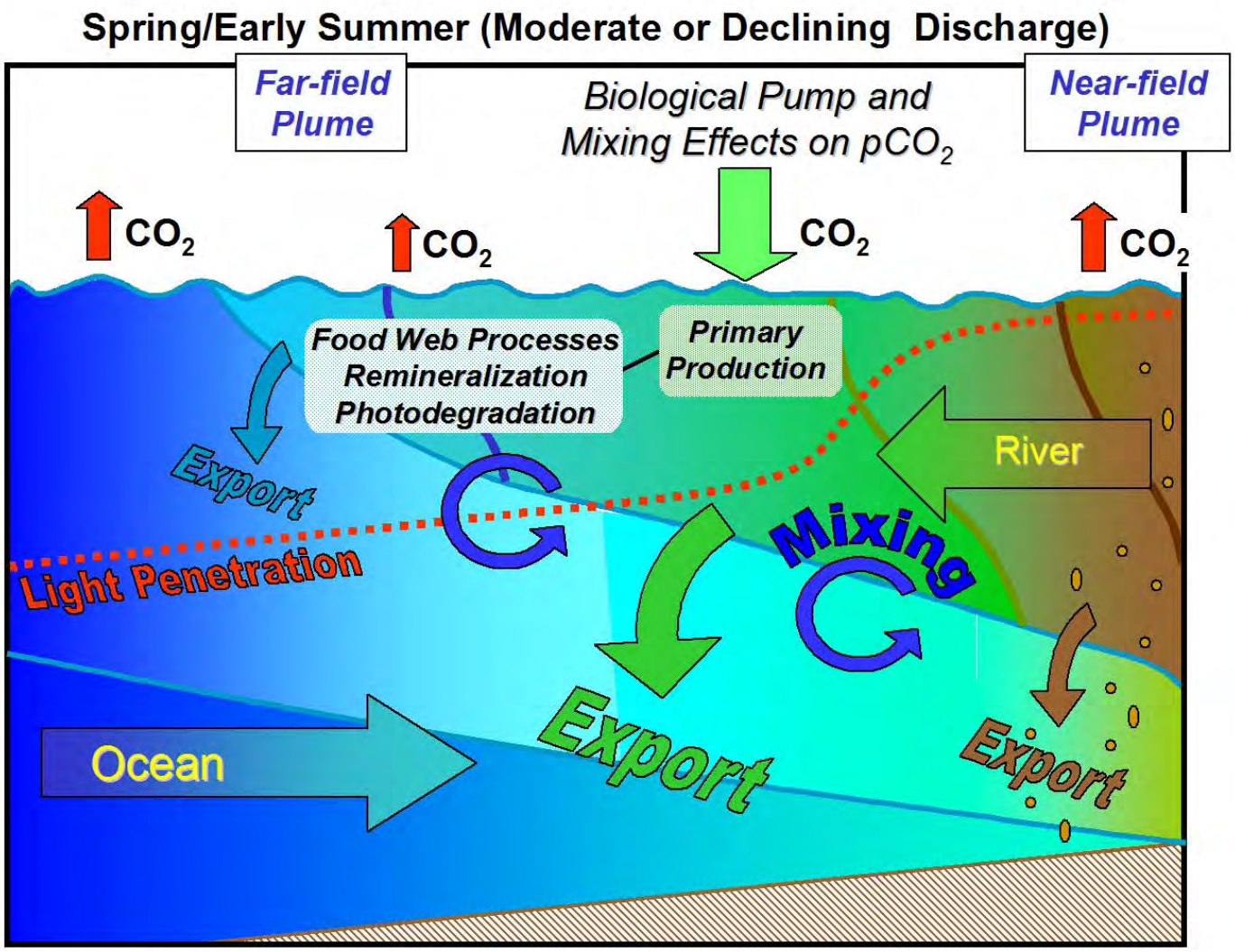
Model refinement and validation

Positions (red dots) of in situ observations and three sub-regions (near field, intermediate, and far field) where area-mean time series comparisons were made. Also shown is 50 m isobath



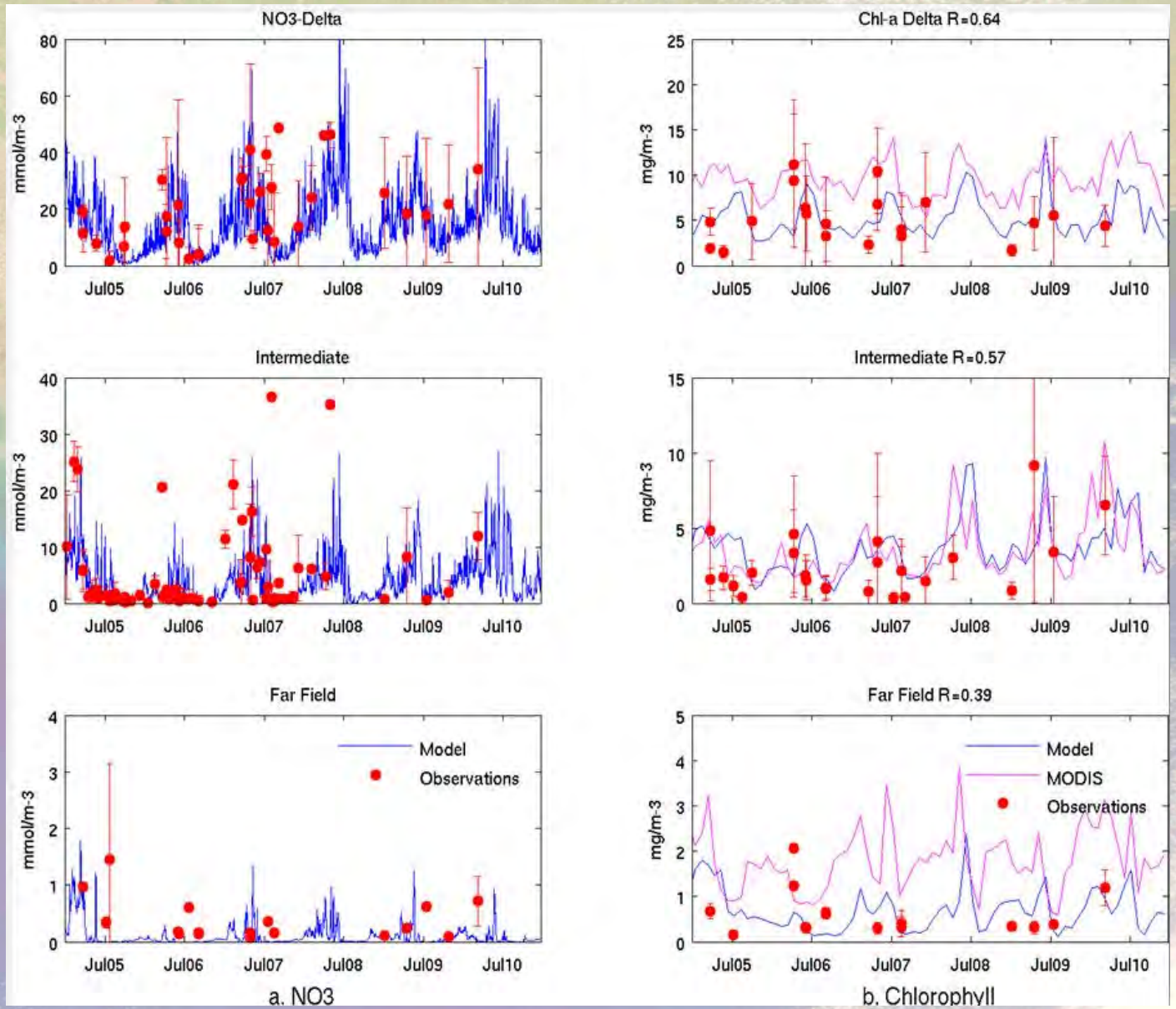
He, Xue et al.

Coastal Processes Affecting Carbon Cycling



Ocean Model Validation

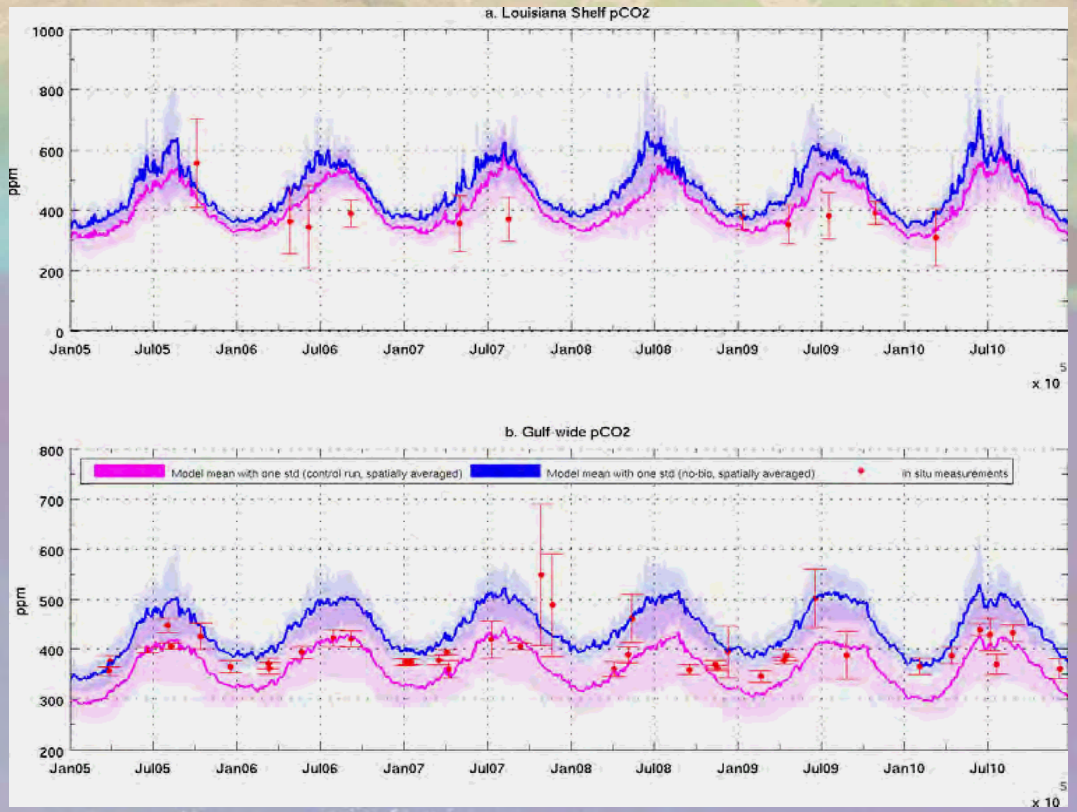
Time series comparisons between observed (red) and simulated (blue) NO3 and chlorophyll in three sub-regions of the northern Gulf



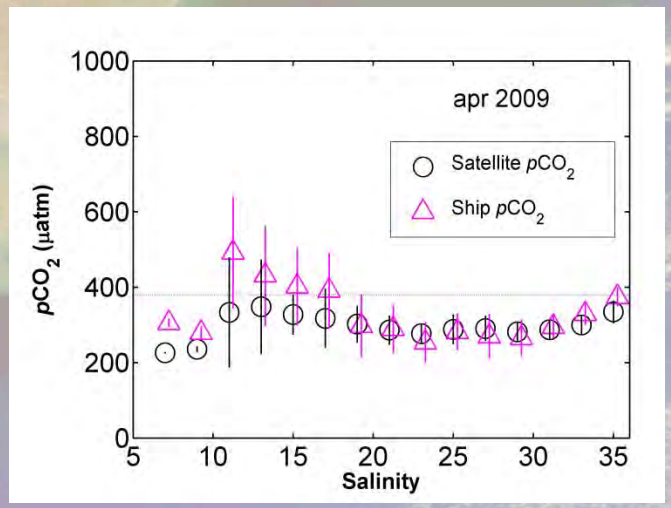
He, Xue et al.

Ocean Model Validation

Comparison of model and ship-based pCO_2 observations

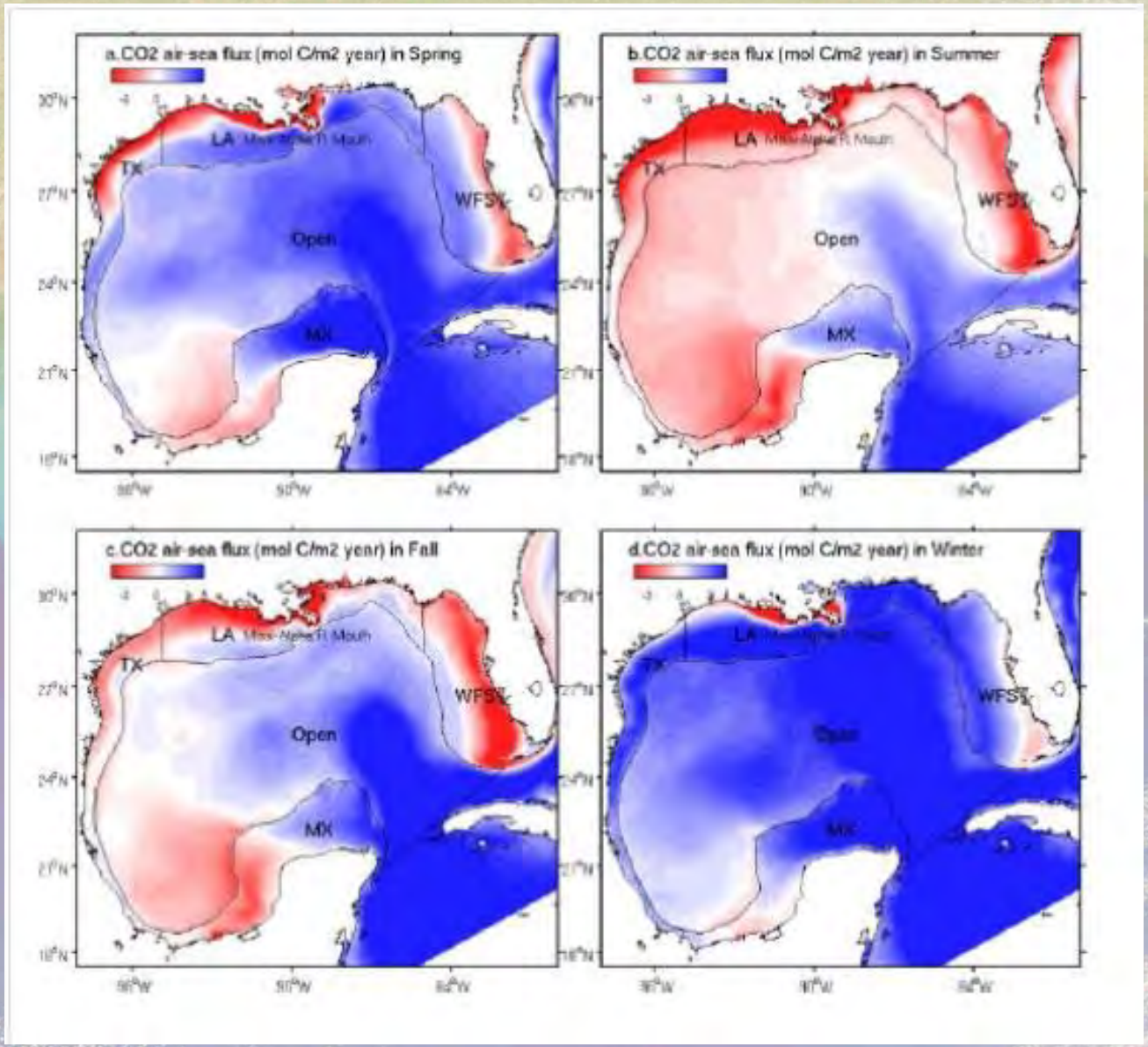


Satellite-derived and ship-based pCO_2 estimates



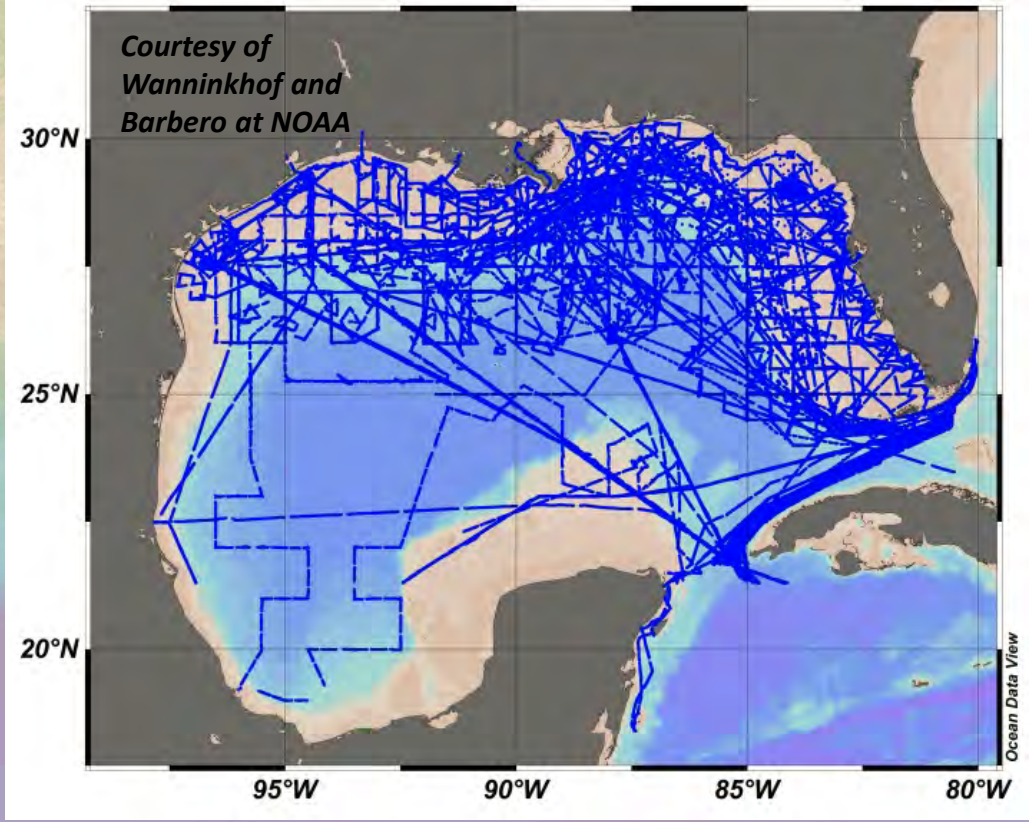
He, Xue et al.

Example of Ocean Model Output: Seasonal mean ΔpCO_2 in surface water (ppm)



He, Xue et al.

Evaluation of Uncertainty

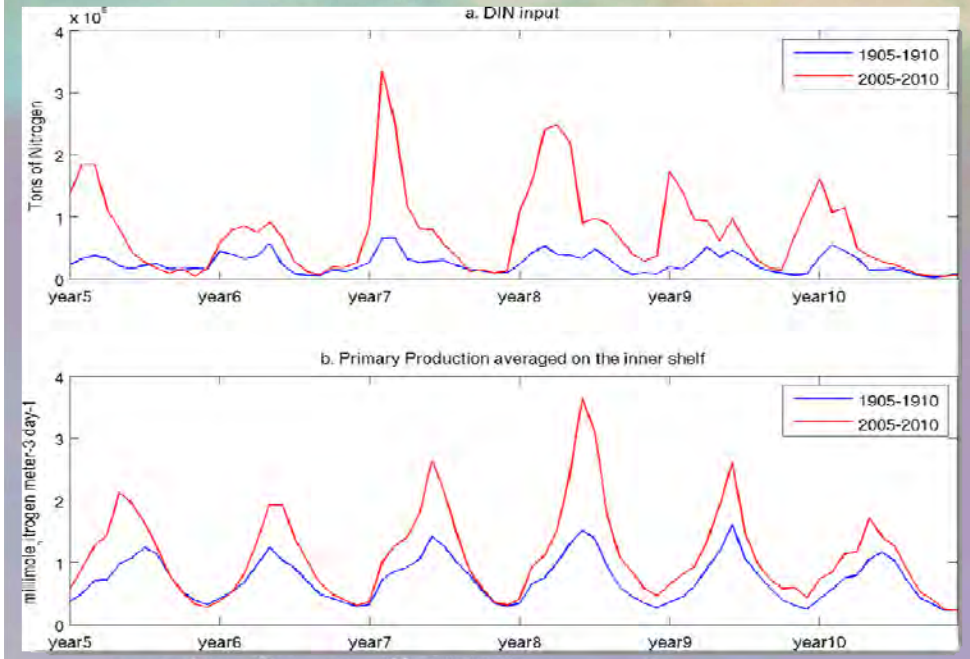


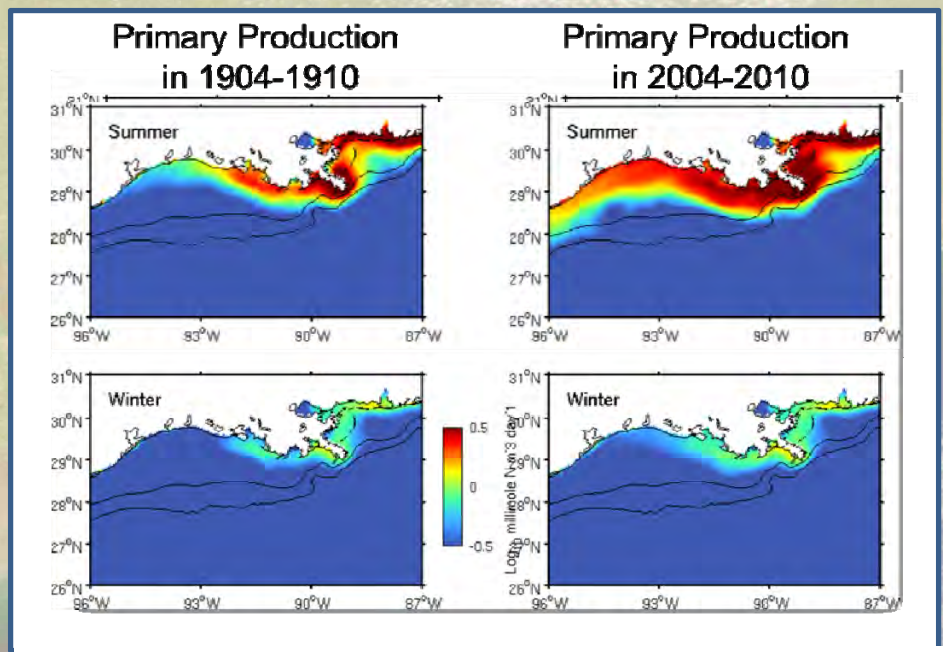
Region	Mexico Shelf	Texas Shelf	Louisiana Shelf	West Florida Shelf	Open Ocean	Gulf-wide
Model	**1.09**	**0.06**	**0.42**	**-0.11**	**1.06**	**0.86**
Ship-based	**0.09**	**0.18**	**0.44**	**-0.37**	**0.48**	**0.19**

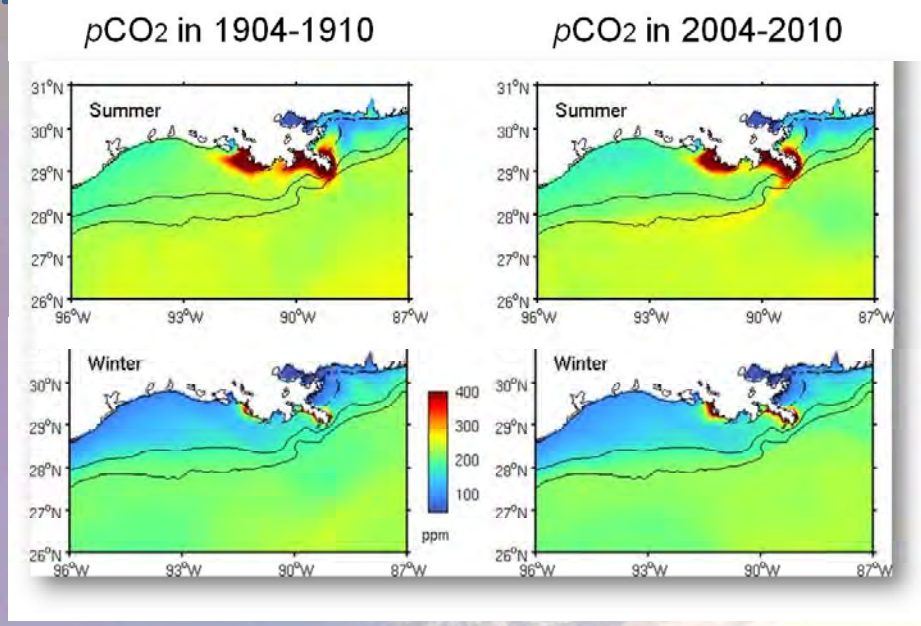
Units: mol C m^{-2} yr^{-1}; "+" indicates net sink

Coupled Model Simulations: 1904-1910 vs. 2004-2010

- Increase in DIN export from MARB from 1904-1910 compared to 2004-2010
- Significant increase (18%) in ocean primary production

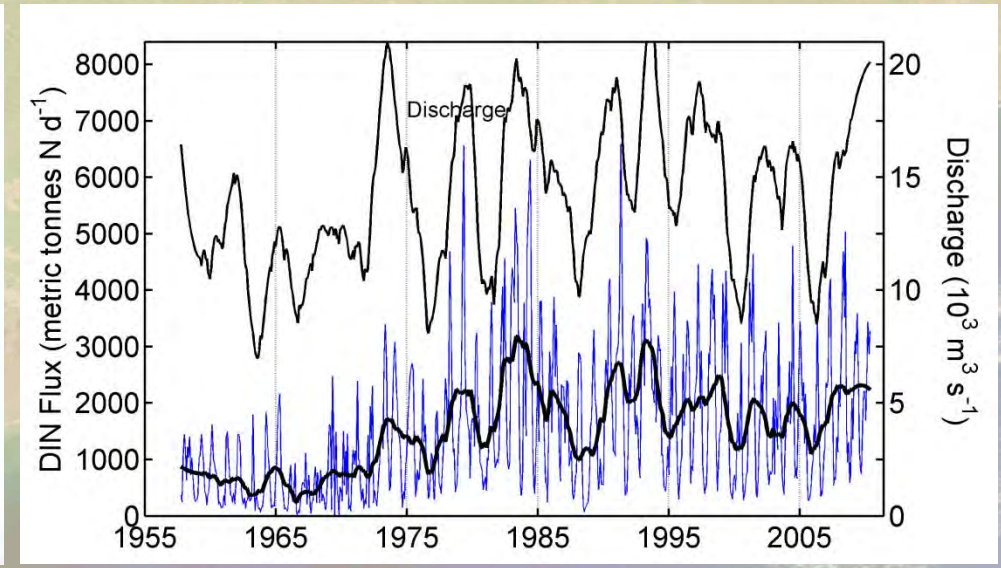






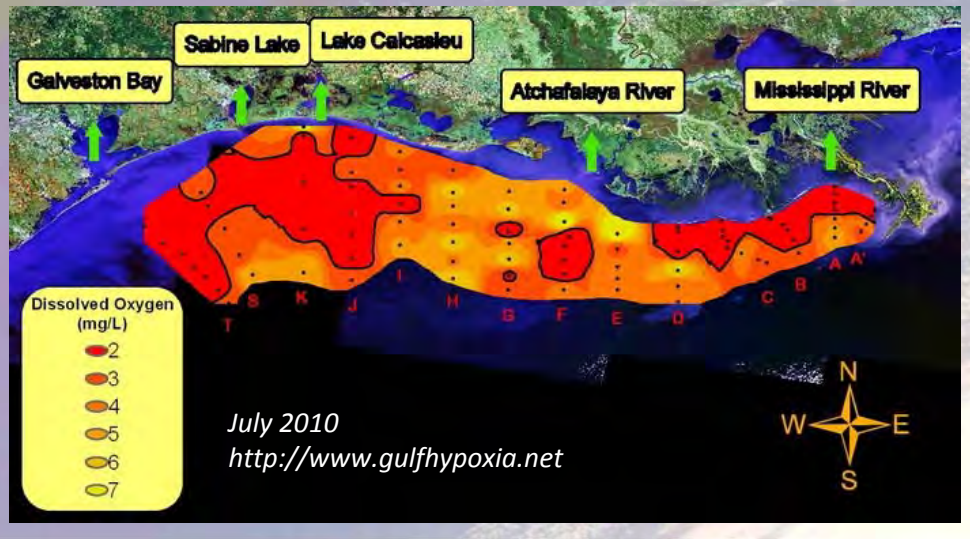
Model Applications: Nutrient Pollution and Hypoxia

Source: EPA, Mississippi River Gulf of Mexico Watershed Nutrient Task Force, 2011



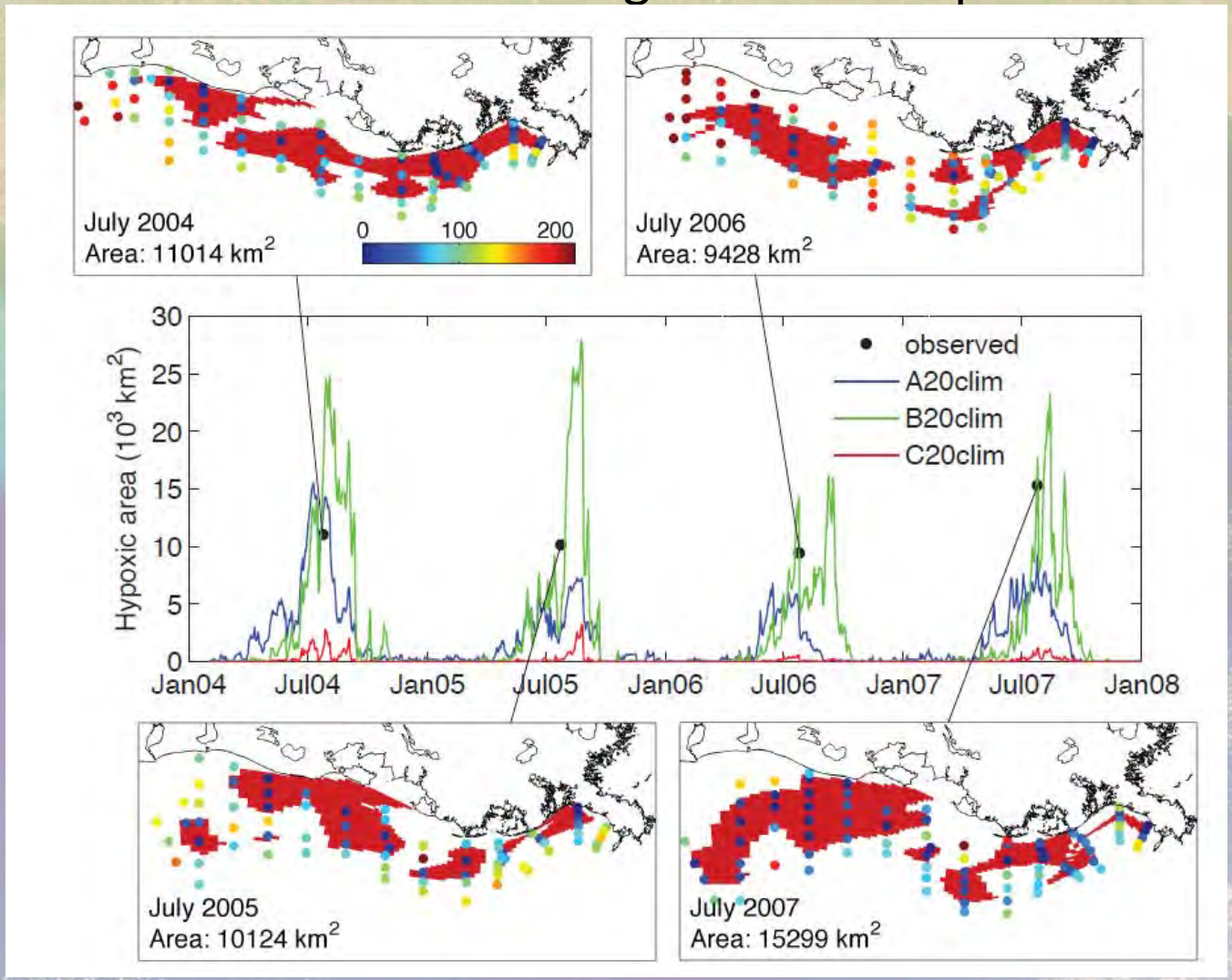
Source: USGS and Lohrenz et al. 2008 and in prep.

- Long term increases in dissolved inorganic nitrogen flux from Mississippi River basin
- Implications for hypoxia off Louisiana, a.k.a. the "Dead Zone"



Model Applications: Nutrient Pollution and Hypoxia

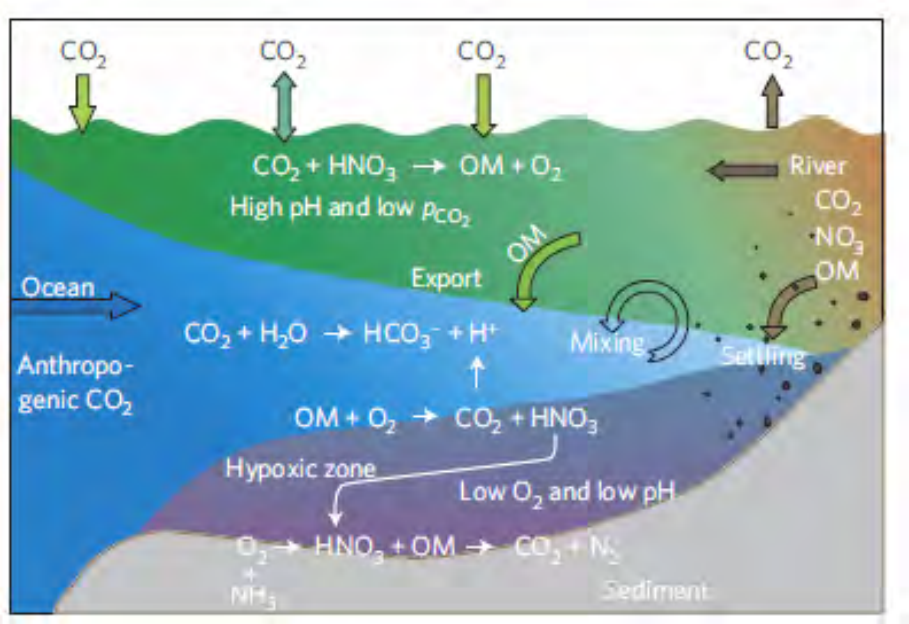
- Hypoxia simulation: evaluating different respiration scenarios

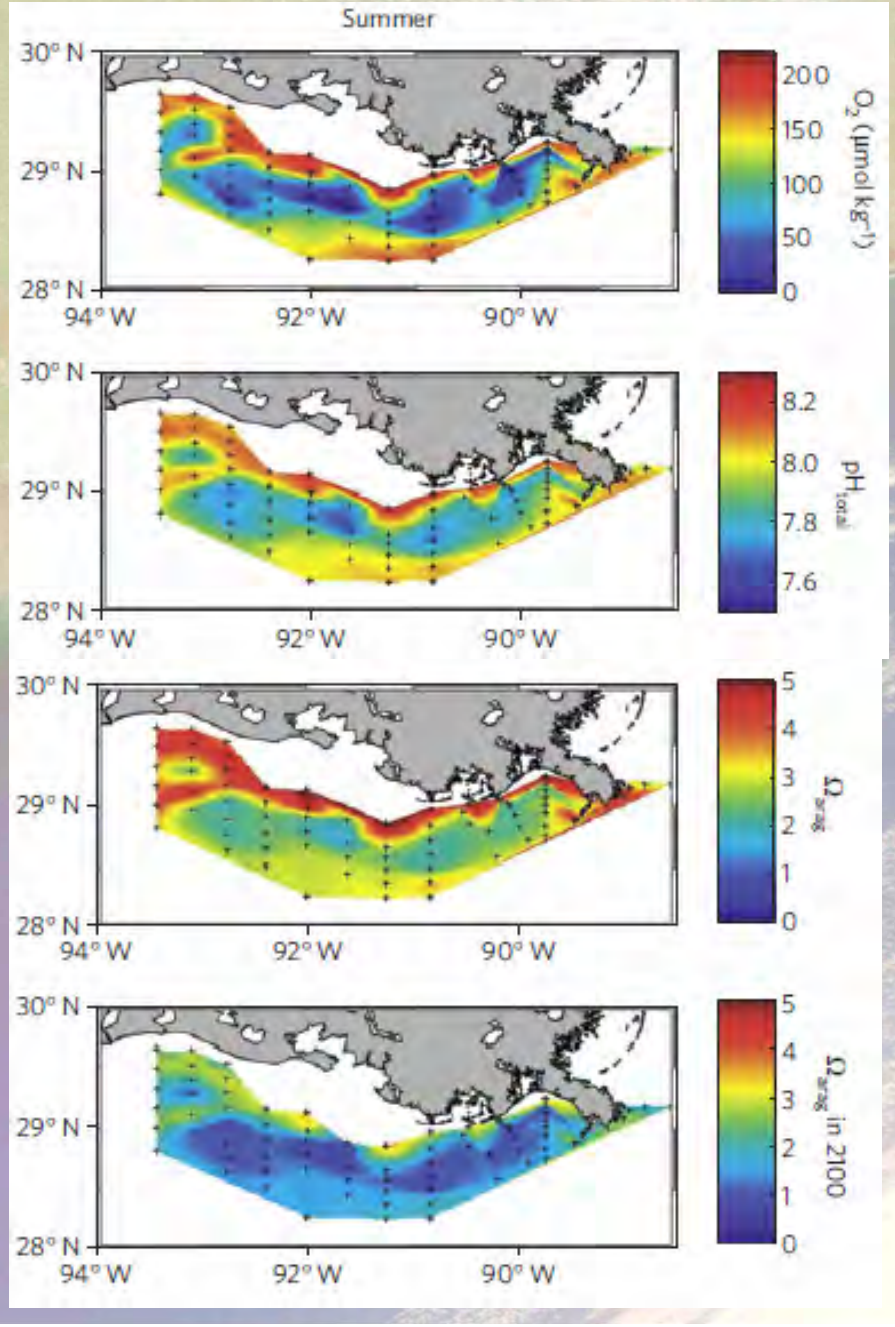


Fennel et al., in prep.

Model Applications: Hypoxia and Ocean Acidification

- Projected acceleration in ocean acidification in bottom waters due to increased atmospheric CO_2 coupled with respiration-enhanced CO_2
- Combined stresses of hypoxia and ocean acidification

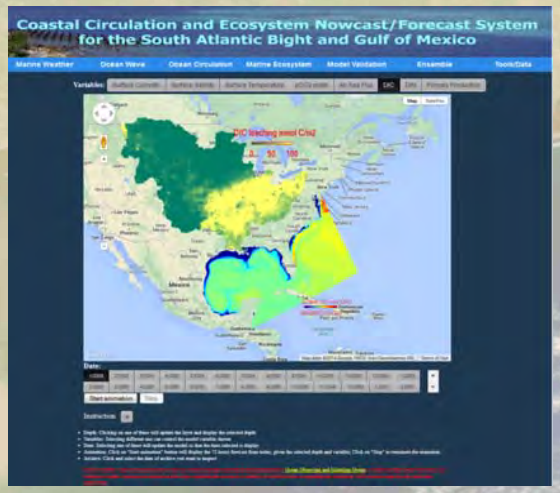


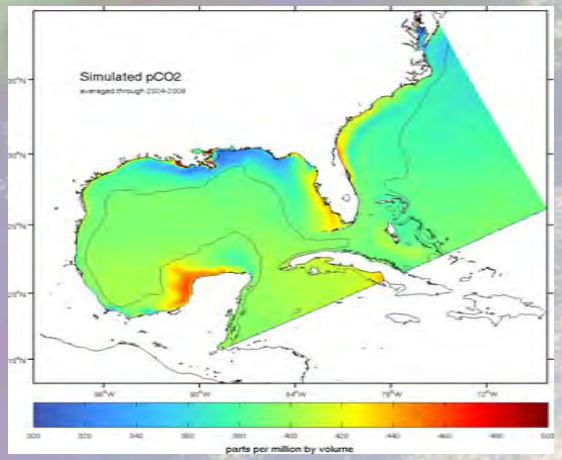


Cai et al., Nat. Geosci., 2011

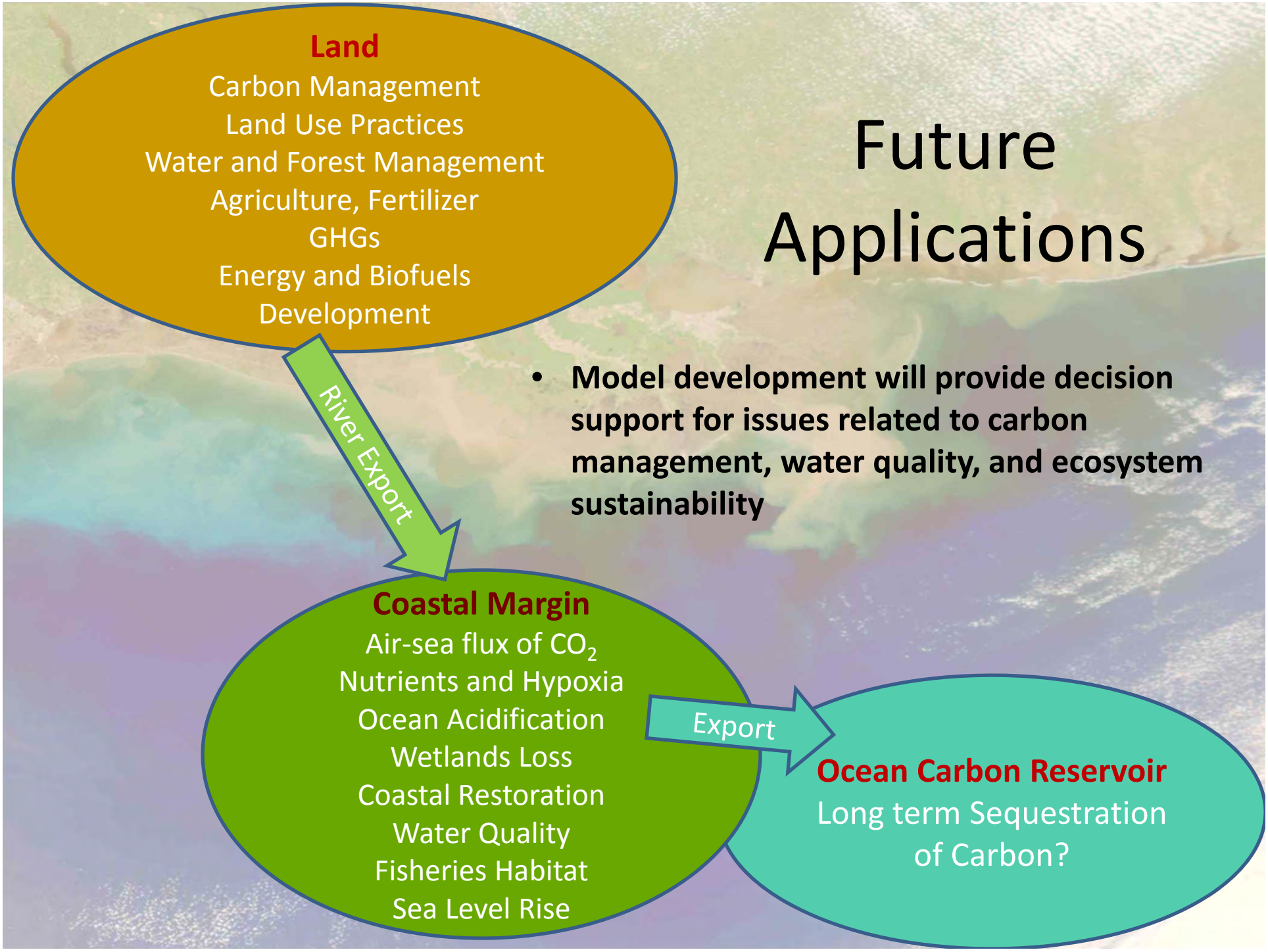
Next Steps

- As part of our 2014 project, we will expand the spatial domain of our observational and integrated modeling approach to include both the Mississippi River basin and southeastern U.S., and examine terrestrial carbon storage and fluxes including characterization and quantification of biomass and carbon stocks and land-atmosphere, land-ocean, and sea-atmosphere fluxes of carbon dioxide and methane
- Examine different LULUCF scenarios within the terrestrial domain and different climate scenarios to assess effectiveness of carbon management strategies as well as other model applications;
- Engage with other CMS projects and stakeholders to expand the scope of information provided based on user feedback, and explore possible transition of prototype products to fully operational status





Future Applications



- **Model development will provide decision support for issues related to carbon management, water quality, and ecosystem sustainability**

For more information

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