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

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Acknowledgements

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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.
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.

MODIS-Aqua derived satellite images of $a_{CDOM}(355)$ (m$^{-1}$)
Approach: Coupled Terrestrial-Ocean Models

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

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

Approach: Dynamic Land Ecosystem Model

Dynamic Land-Ecosystem Model (DLEM2.0)

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

Contemporary land cover distribution across Mississippi-Atchafalaya river basin

*Tian et al.*
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

River Discharge

DIC

Tian et al.
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
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
## Decadal means of carbon export from MARB

<table>
<thead>
<tr>
<th>Decade</th>
<th>DOC (Tg C/year)</th>
<th>POC (Tg C/year)</th>
<th>TOC (Tg C/year)</th>
<th>DIC (Tg C/year)</th>
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</thead>
<tbody>
<tr>
<td>1950s</td>
<td>2.0</td>
<td>3.4</td>
<td>5.4</td>
<td>16.6</td>
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<tr>
<td>1980s</td>
<td>2.5</td>
<td>3.2</td>
<td>5.7</td>
<td>17.8</td>
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<tr>
<td>1990s</td>
<td>2.8</td>
<td>3.4</td>
<td>6.2</td>
<td>21.4</td>
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<tr>
<td>2000s</td>
<td>2.4</td>
<td>3.1</td>
<td>5.5</td>
<td>17.3</td>
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</tbody>
</table>
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

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

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

<table>
<thead>
<tr>
<th>Date Range</th>
<th>Vessel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jun 24-31 2003</td>
<td>R/V Pelican</td>
</tr>
<tr>
<td>Aug 1-8 2004</td>
<td>R/V Pelican</td>
</tr>
<tr>
<td>Oct 3-7 2005</td>
<td>R/V Pelican</td>
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<tr>
<td>Apr 27 - May 1 2006</td>
<td>R/V Pelican</td>
</tr>
<tr>
<td>Jun 6-11 2006</td>
<td>OSV Bold (EPA)</td>
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<tr>
<td>Sep 6-11 2006</td>
<td>OSV Bold (EPA)</td>
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<tr>
<td>Jul 10 - Aug 4 2007</td>
<td>R/V Brown (NOAA)</td>
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<tr>
<td>May 1-8 2008</td>
<td>R/V Pelican</td>
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<tr>
<td>31 Oct-7 Nov 2008</td>
<td>R/V Pelican</td>
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<tr>
<td>Jan 8-20 2009</td>
<td>R/V Cape Hatteras</td>
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<td>Apr 19 - May 1 2009</td>
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<td>July 18 - 30 2009</td>
<td>R/V Cape Hatteras</td>
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<td>Oct 28 - Nov 9 2009</td>
<td>R/V Sharp</td>
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<tr>
<td>Mar 11-21 2010</td>
<td>R/V Cape Hatteras</td>
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<tr>
<td>Jul 21 – Aug 13 2012</td>
<td>R/V Ronald H. Brown</td>
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</tbody>
</table>
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 $p\text{CO}_2$ observations

Satellite-derived and ship-based $p\text{CO}_2$ estimates

He, Xue et al.
Example of Ocean Model Output: Seasonal mean $\Delta pCO_2$ in surface water (ppm)

He, Xue et al.
Evaluation of Uncertainty

Courtesy of Wanninkhof and Barbero at NOAA

<table>
<thead>
<tr>
<th>Region</th>
<th>Mexico Shelf</th>
<th>Texas Shelf</th>
<th>Louisiana Shelf</th>
<th>West Florida Shelf</th>
<th>Open Ocean</th>
<th>Gulf-wide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>1.09</td>
<td>0.06</td>
<td>0.42</td>
<td>-0.11</td>
<td>1.06</td>
<td>0.86</td>
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<tr>
<td>Ship-based</td>
<td>0.09</td>
<td>0.18</td>
<td>0.44</td>
<td>-0.37</td>
<td>0.48</td>
<td>0.19</td>
</tr>
</tbody>
</table>

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

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

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

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

July 2010
http://www.gulfhypoxia.net
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 CO₂ coupled with respiration-enhanced CO₂
- 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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