The Dynamic Land Ecosystem Model (DLEM): Overview

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Chesapeake Hypoxia Analysis and Modeling Program (CHAMP)
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Outline

• DLEM – Dynamic Land Ecosystem Model

• DLEM applications:
  ➢ NASA IDS project – US Eastern Coast
  ➢ NASA IDS project - Chesapeake and Delaware Watershed

• DLEM for NOAA CHAMP

• Future plan
The DLEM Framework

Tian et al., 2015-JGR-Biogeoscience
DLEM - A coupled biogeochemical model

Key processes, pools, fluxes and their coupling
Major natural and human driving forces and key biogeochemical fluxes (C: Carbon; N: Nitrogen; and P: phosphorus) along the terrestrial-aquatic interfaces.

Tian et al., 2015-JGR-Biogeoscience
Dynamic Land Ecosystem Model

**INPUT**

**Driving Factors**
- Climate
  - Temperature
  - Precipitation
  - Radiation
  - Relative Humidity
- Atmospheric Compositions
  - CO$_2$
  - O$_3$
  - Nitrogen Deposition
- Land Use
  - Deforestation
  - Urbanization
  - Harvest
  - Fertilization
  - Irrigation
- Other Disturbances
  - Wildfire
  - Disease
  - Climate Extremes

**Controlling Factors**
- Soil
  - Physical Properties
  - Chemical Properties
  - Depth
- Geomorphology
  - Elevation
  - Slope
  - Aspect
- River Network
  - Flow Direction
  - Accumulative Area
  - River Slope
  - River Length
  - River Width
- Vegetation Functional Type
- Cropping System

**MODEL**

**Biogeochem.-hydrolog. cycles**

**OUTPUT**

**Carbon Fluxes and Storage:**
- Carbon fluxes (GPP, NPP, Rh,NCE, NEP, CH$_4$, VOC, DOC, DIC)
- Carbon storages (LeafC, stemC, litterC, rootC, reproductionC, soilC)

**Water Fluxes and Storage:**
- ET, Runoff, Soil moisture

**Nitrogen Fluxes and Storage:**
- Nitrogen fluxes (N$_2$O, NO, N$_2$)
- Nitrogen storages (LeafN, stemN, litterN, rootN, reproductionN, soilN), TN

*(Phosphorus Fluxes and Storage:)*

**Ecosystem Goods and Services**

**Climate related:**
- GHG emissions (e.g. CO$_2$, CH$_4$, N$_2$O fluxes); VOC flux, Black carbon, …

**Ecosystem Goods**
- Crop yield; Wood Products; Biofuel, …

**Water related**
- Surface Runoff; Subsurface Flow;
- ET; Soil Moisture; water use efficiency
- River Discharge;

**Nutrients related:**
- N and P Storage and leaching;
- Export of TN and TP;
- Export of DOC and POC
Key Features of the DLEM

- Coupled cycles of C, N, P and water at multiple temporal and spatial scales

- Simultaneous consideration of three major GHGs (CO$_2$, CH$_4$ and N$_2$O)

- Multiple stresses including climate, CO$_2$, O$_3$, N deposition, land use/cover change, natural disturbance (fire, insect/disease, hurricane, etc.), and land management practices (e.g. irrigation, fertilization, cropping system)

- Surface-groundwater coupling

- Water and material movement over space
The study domain along the US eastern coast

NASA IDS Project: Impacts of Changing Climate and Land Use on Carbon Cycling and Budgets of the Coastal Ocean Margin: Observations, Analysis, and Modeling
Model Evaluation: River discharge in the US Eastern Coast
Model Evaluation: C and N in the US EC

Kennebec River

R² = 0.87

Merrimack River

R² = 0.3253

Housatonic River

R² = 0.90

Connecticut

R² = 0.59

Patuxent

R² = 0.84

Pee Dee

R² = 0.70

James

R² = 0.71
Evapotranspiration

Average ET of NAECoS was 648.3±38.6 mm ET exhibited significant inter-annual variability with the maximum ET of 708 mm occurred in 1973 and the minimum ET of 603 mm in 1904.
Climate change was responsible for the interannual variability in ET; Land use Change increased ET; CO2 elevation reduced ET but not comparable with that of Land use change
Runoff

Temporal variations of Runoff

Runoff (mm/year)

Year

Temporal variations of Runoff

- Runoff
- Linear (Runoff)

p=0.092

mean annual runoff was 420.5±122.2 mm (95% confidence interval) during 1901-2008. Increased runoff generation occurred in norther NAECOS, whereas in most part of the southern NAECoS, runoff was reduced.
Climate change was responsible for the interannual variability in runoff; Land use Change decreased runoff and reduction in runoff by land use change increased With time.
Carbon export

DOC

DIC

POC
Carbon export

DOC export fluctuated with climate change. N disposition, CO2 elevation, N fertilizer use had positive impacts whereas land use change had negative impacts.

POC export varied with climate change in different years. N disposition, CO2 elevation, N fertilizer use had positive impacts whereas land use change had negative impacts.
Carbon export

The diagram illustrates the trend of DiC export anomaly (TgC/year) from 1901 to 2006. It categorizes the factors influencing carbon export into Management, N Deposition, Climate change, CO2, and Landcover change. The data shows a fluctuating pattern with a general downward trend over the years.
Nitrogen Export

**NH4**

**NO3**
Nitrogen Export

![Graph showing DON and PON exports over years with various labels and lines representing different regions or categories.]
Nitrogen Export

NH4

GOM

MAB

SAB

Legend

Country Boundary
Changes of NH4 leaching
<VALUE>
-0.003
-0.003 - 0.003
-0.003 - 0.003
0.003 - 0.003
>0.003

NO3

GOM

MAB

SAB

Legend

Country Boundary
Changes of NO3 leaching
<VALUE>
-0.003
-0.003 - 0.003
-0.003 - 0.003
0.003 - 0.003
>0.003

DON

GOM

MAB

SAB

Legend

Country Boundary
Changes of DON leaching
g Nm2/year
-0.003
-0.003 - 0.003
-0.003 - 0.003
0.003 - 0.003
>0.003

PON

GOM

MAB

SAB

Legend

Country Boundary
Changes of PON leaching
g Nm2/year
-0.003
-0.003 - 0.003
-0.003 - 0.003
0.003 - 0.003
>0.003
Nitrogen Export

NH4

NO3

Year

N Deposition
Management
Climate change
Manure
CO2
CO2
Land use change
All
Population
Population

Management
Climate change
Manure
N Deposition
CO2
Land use change
All
Population
Population


\[ \text{NH}_4 \text{ export Anomaly (TgN/year)} \]

\[ \text{NO}_3 \text{ export Anomaly (TgN/year)} \]
Nitrogen Export

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**Nitrogen Export Diagrams**

**DON**

- Management
- CO2
- All
- Manure
- N Deposition
- Climate change
- Landcover change
- Population

**PON**

- Management
- CO2
- All
- Manure
- N Deposition
- Climate change
- Landcover change
- Population

---

*Figure 1: Nitrogen Export Diagrams showing DON and PON trends from 1901 to 2006.*
Projected climate change across the US EC

Temperature (°C)

Precipitation (mm)
Future Land use change

**Cropland**

- EC_A2
- EC_B1

**Urban area**

- EC_A2
- EC_B1


Cropland area (M ha):
- 8 to 18

Urban area (M ha):
- 2 to 16
River Discharge
Carbon export

DIC

DOC

POC

USECoS TC
Nitrogen export

**NO₃**

**DON**

**PON**

**USECoS TN**
Future total carbon export from GOM, MAB and SAB Sub Basins
Future total nitrogen export from GOM, MAB and SAB Sub Basins
The study domain of the New IDS project

NASA IDS Project: synergistic impacts of population growth, urbanization, and climate change on watersheds and coastal ecology of the northeastern United States
Development of input datasets

Climate Data (PRISM Climate Data)

• Covering the period of **1895 – present**
• Spatial resolution: **4km**
• Daily or monthly weather parameter: **tmax, tair, tmin, precipitation**
  - Monthly: 1895-1980 (Reconstruct the daily pattern by randomly selected the daily pattern of climate data from 1981-2016)
Development of input datasets

Temperature

[Graph showing temperature changes from 1895 to 2005 with a linear trend line: $y = 0.0161x + 9.5563$ and $R^2 = 0.1995$.]

Annual Temperature

<table>
<thead>
<tr>
<th>Year</th>
<th>1895</th>
<th>1935</th>
<th>1975</th>
<th>2014</th>
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<td>5 - 6</td>
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<td>10 - 11</td>
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<td>11 - 12</td>
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<td>12 - 13</td>
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<tr>
<td>&gt; 13</td>
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</tr>
</tbody>
</table>
Development of input datasets

Precipitation

Precipitation (mm/yr)

- Precipitation

- $y = 2.9411x + 823.01$
- $R^2 = 0.0924$

Year

Precipitation (mm/yr)

- < 600
- 600 - 700
- 700 - 800
- 800 - 900
- 900 - 1000
- 1000 - 1100
- 1100 - 1200
- 1200 - 1300
- 1300 - 1400
- 1400 - 1500
- 1500 - 1600
- > 1600

1895
1935
1975
2014
Development of input datasets

Nitrogen Input

Atmospheric component

Nitrogen Deposition

Global Nitrogen Deposition Data
(http://daac.ornl.gov/CLIMATE/guides/global_N_deposition_maps.html)

Human-induced

Nitrogen Fertilizer Use

Nfer for different crop types from 1961 to 2008 was collected from FAO

Livestock Farming

County-level manure nitrogen inputs from USDA

Nitrogen \((\text{gN/m}^2/\text{yr})\)

Year


Nitrogen \((\text{gN/m}^2/\text{year})\)


CBP N Deposition

- NH4
- NOY
- Manure

- NH4
- NO3
Development of input datasets - Land use data

NLCD 2006

Vegetated Area
- Forest
- Grass
- Shrub
- Crop
- Wetland

Non-Vegetated Area
- Urban
- Glacier
- Bare Ground
- Inland Water

Deciduous Forest
Evergreen Forest

Reclassify Based on North American 2005 Land Use

C3 grass
C4 Grass

Reclassify Based on global C4 vegetation map

Linear regression

2001-2011 based on NLCD

1900-2001 County inventory data

2001-2011 based on NLCD

HYDE Land Use Data

Reclassify Based on GLWD

River

Lake

Ocean

TBDF
TBEF
TNDF
TNEF
Development of input datasets- Land use data

- Land use and land cover data
  - National Land Cover Dataset (NLCD) – (Spatial Resolution 30 m)

NLCD 2001

NLCD 2006

NLCD 2011

NLCD Land Cover Classification Legend

- 11 Open Water
- 12 Perennial Ice/Snow
- 21 Developed, Open Space
- 22 Developed, Low Intensity
- 23 Developed, Medium Intensity
- 24 Developed, High Intensity
- 31 Barren Land (Rock/Sand/Clay)
- 41 Deciduous Forest
- 42 Evergreen Forest
- 43 Mixed Forest
- 51 Dwarf Scrub*
- 52 Shrub/Scrub
- 71 Grassland/Herbaceous
- 72 Sedge/Herbaceous*
- 73 Lichens*
- 74 Moss*
- 81 Pasture/Hay
- 82 Cultivated Crops
- 90 Woody Wetlands
- 95 Emergent Herbaceous Wetlands
Development of input datasets

- Cropland

![Cropland Development](image)

<table>
<thead>
<tr>
<th>Year</th>
<th>Area (10^4 km^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1900</td>
<td></td>
</tr>
<tr>
<td>1920</td>
<td></td>
</tr>
<tr>
<td>1940</td>
<td></td>
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<tr>
<td>1960</td>
<td></td>
</tr>
<tr>
<td>1980</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td></td>
</tr>
</tbody>
</table>

**Cropland Fraction**
- 0 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1
Development of input datasets

- Forest

![Graph and images showing the development of forest area from 1900 to 2010.](attachment://graph.png)
Development of input datasets

- Grassland

![Graph showing the development of Grassland area from 1900 to 2000](#)

![Maps showing Grassland development from 1900 to 2010](#)
Development of input datasets

- Impervious surface

![Impervious Surface Graph](image)

![Legend](image)

![Map Images](images)
Development of input datasets

Urban Sewage

Flow

- Industry: $y = 16.017x + 2032.2$, $R^2 = 0.4932$
- Municipal: $y = -6.0169x + 588.73$, $R^2 = 0.6146$

TSS

- Industry: $y = 0.0251x + 2.8995$, $R^2 = 0.9549$
- Municipal: $y = 0.0337x + 1.0408$, $R^2 = 0.8122$

Point source sewage operation distribution map
Development of input datasets

- Urban Sewage Nitrogen

**NH₃**

- Industry
- Municipal

**NO₂³**

- Industry
- Municipal

**TON**

- Industry
- Municipal

**Total Nitrogen**

- Industry
- Municipal
- Linear (Industry)
- Linear (Municipal)

Equations:

- **NH₃**:
  
  \[ y = 0.2839x + 11.381 \]
  
  \[ R^2 = 0.8747 \]

- **NO₂³**:
  
  \[ y = 0.5981x + 39.034 \]
  
  \[ R^2 = 0.8978 \]

- **TON**:
  
  \[ y = -0.5981x + 39.034 \]
  
  \[ R^2 = 0.8978 \]

- **Total Nitrogen**:
  
  \[ y = -0.2839x + 11.381 \]
  
  \[ R^2 = 0.8747 \]
DLEM validation

- Susquehanna River

Discharge

Discharge

- James River

Discharge

Discharge
DLEM validation

- Potomac River

- Rappahannock River
DLEM validation

- Delaware River

Discharge

USGS  DLEM

Drainage (ft³/s)

0 5000 10000 15000 20000 25000 30000

Discharge (ft³/s)


DLEM simulation

Discharge

USGS observation

Discharge (ft³/s)

0 5000 10000 15000 20000 25000 30000

Discharge

0 10000 20000 30000

y = 0.686x + 2315
R² = 0.8333
DLEM validation

- Susquehanna River-DIN

![Graph showing monthly and annual DIN (gN/day)]
DLEM validation

- James River

Dissolved Inorganic Nitrogen

DIN (gN/day)

Date

USGS  
DLEM
DLEM validation

- Organic Nitrogen Export
DLEM validation

- Inorganic Nitrogen Export
DLEM validation

- Carbon Export

DOC

TOC

Susquehanna River
Savannah River
Delaware River
Hudson River
Potomac River
Connecticut River
Pee Dee River
Atamaha River
Cape Fear River

Concentration (mg/L)

Concentration (mg/L)

0
2
4
6
8
10
12
14

0
2
4
6
8
10
12
14

DLEM
USGS

DLE
M

DLEM validation
DLEM Simulation and Analysis: an update

- Total Export into the Chesapeake Bay

<table>
<thead>
<tr>
<th>Decades</th>
<th>Total Export (Gg)</th>
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<tbody>
<tr>
<td></td>
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</tr>
<tr>
<td>1900s</td>
<td>160.95</td>
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<tr>
<td>1950s</td>
<td>157.07</td>
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<td>1980s</td>
<td>178.94</td>
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<tr>
<td>2000s</td>
<td>210.52</td>
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<td>2011-2015</td>
<td>174.81</td>
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Nitrogen Export

Organic Carbon Export
Comparison with other study

<table>
<thead>
<tr>
<th>Year</th>
<th>CBP WM* Shenk and Linker[2013]</th>
<th>DLEM May 2016</th>
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<tbody>
<tr>
<td></td>
<td>Discharge</td>
<td></td>
</tr>
<tr>
<td>2001</td>
<td>55</td>
<td>47</td>
</tr>
<tr>
<td>2002</td>
<td>57</td>
<td>52</td>
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<td>2003</td>
<td>138</td>
<td>136</td>
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<td>2004</td>
<td>106</td>
<td>108</td>
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<tr>
<td>2005</td>
<td>81</td>
<td>79</td>
</tr>
<tr>
<td>mean 2001-2005</td>
<td>87 ± 35</td>
<td>84±37</td>
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<tr>
<td></td>
<td>DIN</td>
<td></td>
</tr>
<tr>
<td>2001</td>
<td>65</td>
<td>51</td>
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<td>2002</td>
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<td>2004</td>
<td>88</td>
<td>124</td>
</tr>
<tr>
<td>2005</td>
<td>84</td>
<td>104</td>
</tr>
<tr>
<td>mean 2001-2005</td>
<td>86 ± 21</td>
<td>112±49</td>
</tr>
<tr>
<td></td>
<td>TON</td>
<td></td>
</tr>
<tr>
<td>2001</td>
<td>32</td>
<td>31</td>
</tr>
<tr>
<td>2002</td>
<td>33</td>
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<td>2003</td>
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<td>2004</td>
<td>67</td>
<td>55</td>
</tr>
<tr>
<td>2005</td>
<td>49</td>
<td>45</td>
</tr>
<tr>
<td>mean 2001-2005</td>
<td>53 ± 21</td>
<td>46±16</td>
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</table>

Needs to improve the DLEM representation of biogeochemical processes within the water body.
Future Work Plan in the NOAA Project

- Extend the new high-resolution gridded datasets to 2015. We are currently developing a consistent 1-km gridded database for 1950-2010, which includes land use, climate forcing, sewage water information, and river networks, to drive DLEM simulations of carbon and nutrient biogeochemistry in human-dominated regions.

- Improve model representation of phosphorus (P) cycling.

In the proposed task, we will further calibrate and evaluate this P submodel and apply it to simulate and predict the P export from land to the Chesapeake Bay as influenced by climate and land use changes.
DLEM simulation implementation for the NOAA Project

Theme 1 – Diagnosis: Realistic hindcasts (1985-2015)  
(DLEM forced by multiple factors)

Theme 2 – Prediction: Realistic future simulations (2015-2050)  
(DLEM forced by projected climate and land use scenarios)

Theme 3 – Attribution: Factorial (natural/climate vs. anthropogenic) simulations  
(DLEM Factorial simulation experiments forced by individual or combined factors)

Theme 4 – Decision Support: Alternative management scenario simulations  
(DLEM forced by alternative management scenario)
Other ongoing relevant work

Scale adaptive gas emission model

The new water transport model extend the biogeochemical processes within the grid cell, it could be used to reduce the scale effect of the large scale gas emission simulations such as NH3 or N2O emission.

Decision support model

Develop a sub-model with LID and BMP controls (methods generalized from SWMM or SUSTAIN model) and incorporate into DLEM.

We plan to use swarm intelligence algorithms (such as genetic algorithm or ant-colony algorithm) to balance the benefit gain from BMP/LID facilities and the cost by calculating the local optimization.