Exports of Water, Carbon and Nutrients to the U.S. East Coast during 1901-2008 as simulated by DLEM: Results from a NASA IDS Project

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Background

Supported by NASA IDS project, scientists working on land and ocean components have built up a cooperative research team to investigate the coupling effect of climate and land use on carbon cycling within land-sea system. This work is part of the entire effort to assess how climate variations and climate change, land-use conversions, and land management practices have affected regional hydrological cycles, carbon and nutrients exports in the East Coast (EC) region, the most populous area in the U.S. Here, an integrative global ecosystem model, the Dynamic Land Ecosystem Model (DLEM), has been applied to characterize the temporal and spatial variations of riverine water, carbon and nutrient exports in this area during 1901-2008. Currently, the DLEM has coupled hydrologic process, soil biogeochemical processes, vegetation dynamics, and aquatic biochemical processes into its conceptual framework. Performance of the model has been intensively evaluated against USGS hydrological and water quality observation data.

Method

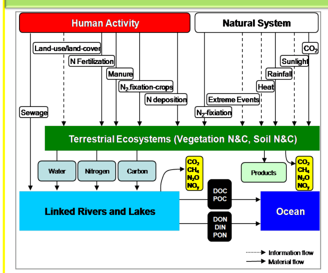

Figure 1 Coupling of biogeochemical cycles among land, ocean and the atmosphere in DLEM

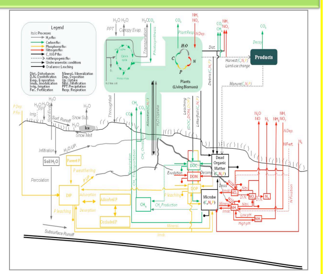

Figure 2 Major biogeochemical and hydrological cycles in DLEM

The model we used for this study is the Dynamic Land Ecosystem Model (DLEM, Tian et al., 2011). The DLEM couples major biogeochemical cycles, water cycle, and vegetation dynamics to make daily and spatially-explicit estimates of water, carbon (CO_2, CH_4), nitrogen fluxes (N_2O), and pool sizes (C and N) in terrestrial ecosystems. The time step of simulating water flow from the land to the river and water pools is 30 minutes. We expanded DLEM model with Nutrient Export (NE) component to track the leached nutrients from terrestrial ecosystems to freshwater aquatic systems and eventually to the coastal regions (Figure 1). The DLEM model is capable of assessing the impacts of natural and anthropogenic driving forces on nutrients (currently we consider forms of DOC, POC, DON, DIN, and PON) leaching and delivering from terrestrial system to coastal regions. The export of nutrients from landscape to coastal area includes three major processes: the productions of nutrients in inland watersheds; the leaching of nutrients from land along with overland flow and base flow; and the transport of nutrients through river networks to river outlets in coastal region.

Input Data

Input data sets were developed from difference sources. The land use datasets were derived from the Global Lakes and Wetlands Database, GLC2000 dataset, the History Database of the Global Environment (HYDE) with version of HYDE2005 and the U.S. Census of Agriculture datasets. Climate data used in this study were obtained from the CRU TS 2.1 and North America Regional Reanalysis (NARR) datasets.

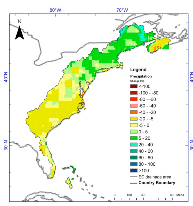

Figure 3 Precipitation changes during 1901-2008

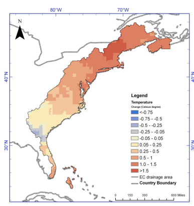

Figure 4 Temperature changes during 1901-2008

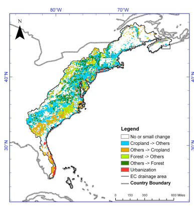

Figure 5 Land use changes during 1901-2008

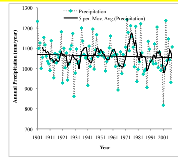

Figure 6 Mean Precipitation variation during 1901-2008

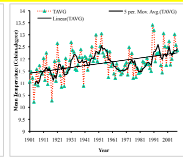

Figure 7 Mean Temperature variation during 1901-2008

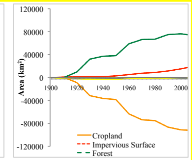

Figure 8 Land cover changes during 1901-2008

During 1901-2008, mean annual precipitation in the East Coast area does not show significant changing trend (Figure 6). Precipitation variation over the whole drainage area demonstrates strong spatial heterogeneity. The increasing precipitation mainly occurs in the northern part of the EC. A significant increasing trend of temperature has been found from 1901 to 2008 ($p < 0.01$, Figure 7). Similarly, the changes of temperature vary significantly over the entire drainage area. The annual average temperature has decreased in the southern EC but increased in the rest of study area (Figure 4). The EC region has experienced substantial land use changes over the past century. Up to this point, cropland area has decreased by 46.7%, while impervious surface has expanded by 246.2% (Figure 8). Cropland expansion mainly centered in the southern EC while crop abandonment occurred in the central and northern EC (Figure5).

Model Validation

To verify the model performance in simulating water and nutrient exports, we compared simulated results with observations from Ameriflux and Fluxnet sites(Figure 12), USGS river gauges (Figure 9-11) and water quality experiments (Figure 13). It indicates that the DLEM model is capable of well capturing the temporal patterns of riverine fluxes, but missing the extreme high fluxes in the EC area.

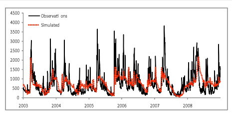

Figure 9 Simulated and Observed Runoff of the Connecticut River

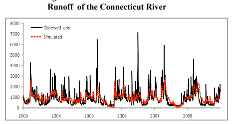

Figure 10 Simulated and Observed Runoff of the Hudson River

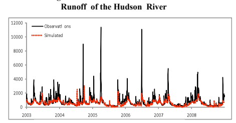

Figure 11 Simulated and Observed Runoff of the Delaware River

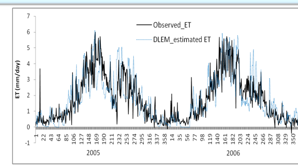

Figure 12 Simulated vs. observed ET of the Missouri Ozark site

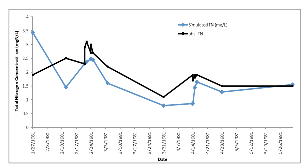

Figure 13 Simulated vs. observed TN of the Potomac river

Preliminary Results

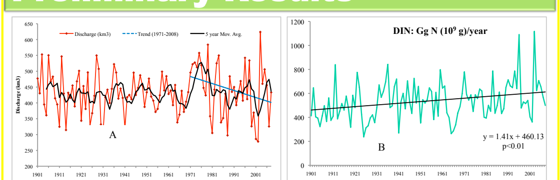

Figure 14 Annual runoff (A) and DIN export (B) during 1901-2008.

Annual runoff demonstrates evident inter-annual variations, especially during 1970-2008. Dissolved inorganic nitrogen (NH_4^+ and NO_3^-) export gradually increased over the past 108 years

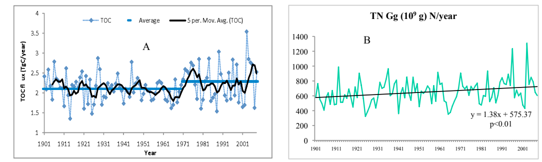

Figure 15 Annual total organic carbon (TOC, A) and total nitrogen (TN,B) export during 1901-2008.

Our preliminary results on water, carbon and nitrogen export show significant inter-annual variations (Figure 14-15). Since the 1970s, TOC export has markedly increased, compared with that in the previous years. TN export shows a significant increasing trend over the whole time period ($P<0.01$).

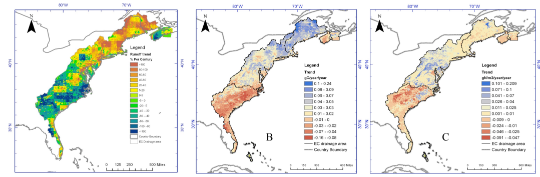

Figure 16 Spatial patterns of changing trend in runoff (A), TOC leaching (B) and TN leaching (C) during 1901-2008

Changes of runoff, TOC and TN leaching during 1901-2008 varied across the EC region (Figure 16). Runoff increased in the northern EC area but decreased in the central and southern EC. Spatial distribution of TOC leaching changes corresponds well to that of runoff. TN leaching has largely increased in the scattered area of central EC and slightly increased in the northern EC. The decreased TN leaching centered in the southern area, where runoff diminished.

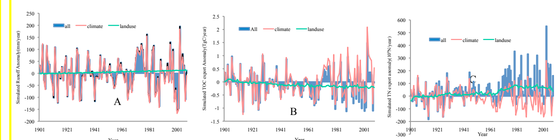

Figure 17 Driving forces analysis of land use and climate effects on runoff (A), TOC (B) and TN export(C)

Model simulation indicates that inter-annual variations of water, carbon and nutrient exports are mainly controlled by climate conditions (Figure 17). Land use played a minor role in the early half of the 20th century and then slightly increase runoff since the 1950s. Land use changes have reduced TOC leaching since the 1920s. However, TN leaching has been significantly enhanced by land use, especially after the 1960s, which might be attributed to N fertilizer application in agricultural management.

Summary

1. Our model simulations show that river discharge in the East Coast varied from year to year, and significantly decreased by ~19% during 1970-2008; Total organic carbon (TOC) export largely increased since the 1970s compared to that in the previous decades; Total nitrogen (TN) export gradually increase by ~35% during 1901-2008.
2. Factorial simulations with DLEM indicate that: 1) Climate variability/change is the dominant factor controlling the inter-annual variations of river discharge, TOC and TN export in the East Coast; 2) Land use and management practices play the major role in affecting TN export since the 1960s.
5. The validations of model performance against observations indicate that the DLEM model can well capture the magnitude and daily/seasonal variations of water and nutrient exports.
4. Improvement of DLEM in simulating dissolved inorganic carbon (DIC) will be needed to better represent carbon flux from land to ocean.

Acknowledgements : This work has been supported by NASA Interdisciplinary Science Program (NNX11AD47G).