LCLUC Impacts on Atmospheric Processes

PI Darla Munroe\textsuperscript{a}

Co Investigators: Kate Calder\textsuperscript{b}, Tao Shi\textsuperscript{b}, Ningchuan Xiao\textsuperscript{a}

\textsuperscript{a}Department of Geography

\textsuperscript{b}Department of Statistics

Ohio State University
Projects

• Sokolik et al.
  – Understanding the role of changes in land use/land cover and atmospheric dust loading and their coupling in climate change in the NEESPI study domain drylands

• Munroe et al.
  – Fire-Land-Atmosphere Modeling and Evaluation for Southeast Asia (FLAMES) Project
UNDERSTANDING THE ROLE OF CHANGES IN LAND USE/LAND COVER AND ATMOSPHERIC DUST LOADING AND THEIR COUPLING IN CLIMATE CHANGE IN THE NEESPI STUDY DOMAIN DRYLANDS

Science Team:

Irina N. Sokolik (PI), Georgia Institute of Technology, Atlanta, Georgia, USA
Robert Dickenson, Kremena Darmenova, Anton Darmenov, Yasunori Kurosaki
Georgia Institute of Technology, Atlanta, Georgia, USA
Yongjiu Dai, Beijing Normal University, Beijing, China
George Golitsyn, Institute of Atmospheric Physics, Russian Academy of Sciences, Moscow, Russia

International Collaborators:

Y. Shao, City University of Hong Kong, China;
B. Marticorena and G. Bergametti, CNRS/LISA/University of Paris 12, France;
D. Jugder, Institute Meteorology and Hydrology, Ulaan Baatar, Mongolia;
M. Mikami, MRI/JMA, Japan;
I. Uno, Institute Applied Mechanics, Kyushu University, Japan;

Goals:

gain an improved how and to what extent land-use/land cover changes and varying dust loadings and their interactions have been affecting climate of drylands in the NEESPI study domain over the past 50 years.

Objectives:

Development of a suite of the process-based models, including a new regional coupled modeling system WRF-DuMo

Development of Asian Dust Databank: 50-years climatology of dust events, climatic variables and land-use/land cover changes in Central and East Asia by merging available data from satellite, weather and monitoring stations, and historical records.
A coupled regional modeling system WRF-DuMO

- Adjustable water/land cover mask to reproduce different historical LULC scenarios in Central and East Asia;
- Data base of land properties for dust emission

- Flexible nesting capability (down to 1 km)
- Driven by re-analysis data (NCEP or ECMWF)

- Physically based-dust production schemes (coupled with the land model)
- Physically based-treatments of size-resolved dust composition

Darmenova, K., I.N. Sokolik, Y. Shao, B. Marticorena, and G. Bergametti, Development of a physically-based dust emission module within the Weather Research and Forecasting (WRF) model: Assessment of dust emission parameterizations and input parameters for source regions in Central and East Asia (J. Geophys. Res., 2009)
Dust emission modeling with WRF-DuMo

Land-use/land-cover changes in Central Asia
1950s vs. 1990s
Model's grid size: 200, 100, 40 and 10 km

WRF-DuMo simulations performed for representative grid sizes reveal that GCM-like models significantly underpredict dust emission and hence dust burden in the atmosphere and associated impacts.

IPCC assessments (performed with GCMs) of radiative forcing of dust aerosol impacts on climate have significant biases, especially in regions affected by land-cover/land-use changes.

Time series of daily dust loadings simulated with WRF-DuMo at four model grid sizes (April 1955)
Asian Dust Databank:

Examples of integrated analysis of satellite and ground-based observations. The upper panel shows satellite data of MODIS/Terra and OMI AI on April 18, 2006. The lower panels show time series of visibility, wind speed & direction, TOMS AI & reflectivity, and WMO present weather during April 2001 for Aralskoe More meteorological station.
Asian Dust Databank:
an observation-based climatology of dust event

• A 50-years data analysis revealed complex patterns of spatial and temporal distributions of dust events in Central and East Asia.
• No “simple” connections” with the LCLU changes => an increase in the extent of the dust source (e.g., resulting from the desiccation of the Aral Sea) does not necessarily result in an increase of dust storms (…more problems for IPCC assessments)
• In the Aral Sea region, a decrease in dust storm frequency was found. However, moderate dust outbreaks show an increasing trend, pointing to severe environmental and health problems in the region caused by dust and desertification in general.

Trends in annual frequency of dust storms (visibility below 1 km) and moderate dust events (visibility below 10 km) in the Aral Sea region reported at the Aralskoe More meteorological station for the past 50 years (Kurosaki and Sokolik, J. of Climate, 2009).
FLAMES
Outline

• Project goals
• Objectives/tasks
  1. Biomass burning and land-cover trajectories
  2. Data assimilation issues
  3. Statistical estimation of atmospheric transport
  4. Bayesian hierarchical model
  5. Geovisualization tools
  6. Policy applications
Project goals
Objectives

• To develop a hierarchical Bayesian framework to study the association between biomass burning and regional carbonaceous aerosol concentrations that incorporates a process-based description of aerosol transport over space and time;

• To quantify explicitly the uncertainty involved in the relationship between biomass burning and regional aerosols, given available data and the nature of complex, circulatory atmospheric transport patterns;

• To contribute to the understanding of the implications of current land-use changes in Southeast Asia given the measured effects of biomass burning in the last 5 years on regional aerosol concentrations; and

• To conduct scenario and sensitivity analyses at a regional level that advance the understanding of the implications of biomass burning.
Overview
Project Overview

• Fire-Land-Atmosphere Modeling and Evaluation for Southeast Asia (FLAMES) Project

MOTIVATION
Understand the environmental consequences of land cover/land use change (LCLUC)

INDUSTRIAL SOURCES/FUEL COMBUSTION

BLACK CARBON (BC) AEROSOLS

Southeast Asia

BIOMASS BURNING (Swidden agricultural practices)
1. Biomass burning and Lcc trajectories
Biomass burning and Icc

- Regional land-use transformations
  - Sources of burning (smallholders vs. larger farms)
    - Different patterns of burning
  - Cropping patterns
    - Lowland: more and more rice paddy
    - Upland: from shifting to cash crops
  - Greater uncertainty in mainland SE Asia about burning and carbonaceous aerosols

2. Data assimilation issues
Data assimilation

- Objective to combine, compare information from various sources
- BHM should allow us to fill in missing data; align data of differing resolutions
Spatial patterns in data discrepancies

In order to predict AOD/AOT locally, need to use data in concert

Literature to date mainly focused on global discrepancies (but see Liu et al. 2007)

Oscillation in the local differences between MISR AOT and MODIS AOD

Modeling spatial patterns in MISR/MODIS difference

3. Statistical estimation of atmospheric transport
General approach

• Learning from Mozart output to forecast aerosols without running Mozart each time
• Physical model plus stochastic terms
  – Differential equations
  – Error term
• Berliner and Winkle (2003): physical statistical modeling; process-based statistical modeling
**Statistical Modeling**

Data -> model

Can be used for forecasts

“Mean” should correspond to physical model + std error

Statistical: model is calibrated to observation

Structure is based on unknown parameters: parameters are derived from the data

Transportation parameters: train statistical model with numerical model

Hierarchical models: differing spatial/temporal resolutions

Emissions estimated given time, location of BB events

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**Physical Models**

Model characterized by physics

- e.g., Atmospheric transportation

Small time interval: every step very precise, based on underlying physics

Different components describe different aspects

- e.g., land model, atmospheric model

Constant emissions

Transportation parameters derived from differential equations
Advantages of our approach

- Uncertainty
- Scalability
- Computation
- Estimation of emissions
- Forecasting

- Compare output against physical model results, and field observations
One run of estimated transport
Multiple runs of estimated transport
4. Bayesian hierarchical modeling
Comprehensive Statistical Modeling System

DATA SOURCES

- MODIS
- SRTM
- Field Studies
- MISR

DATA PRODUCTS

- Fire Product (MOD14)
- Land Cover Classification (MOD12)
- Biomass Burning Emissions Inventories
- Aerosol Products (optical depth, size/shape fraction)

SPACE-TIME PROCESSES

- FIRE OCCURRENCE
- BIOMASS BURNING EMISSIONS
- BC AEROSOLS

- Aerosol Transportation Simulator (MOZART)
- OTHER BC AEROSOL EMISSIONS

LOCAL --> REGIONAL
Model

Data Model:

\[ Z_t(s) = \mu + y_t(s) + \epsilon_t(s) \]

- Observed Aerosols
- Data Mean
- Latent Process
- Measurement Error

Process Model:

\[ y_{t+1}(s) = \gamma \int_D k_s(r; \theta_s) \left( y_t(r) + c E_t(r) \right) dr + \eta_{t+1}(s) \]

- Redistribution Kernel
- Emissions
- Process Error
Redistribution Kernel

Form of Gaussian Kernel:

\[ k_s(r; \theta_s) \propto \exp \left\{ -\frac{1}{2} \left( r - \lambda(s) - s \right)' \left( \Sigma^k(s) \right)^{-1} \left( r - \lambda(s) - s \right) \right\} \]

- Kernel means control direction and distance of aerosol movement across the space
- Kernel variances control the diffusion of aerosols across the space
Dimension Reduction

• Large number of parameters in our model
  – 5796 parameters we are estimating!
• Model approximation (reduction in # of unk parameters)
  – Use a spectral representation of the latent space-time process and the redistribution kernel
  – Use eigen decomposition of the kernel parameters
  – Keep only the largest of these transformed values
• Compare full and approximate versions of the model
Estimates Using Dimension Reduction

MOZART Data

63% Reduction

50% Reduction

21% Reduction

Out of Sample Prediction

3/31/2009 SP 09 LCLUC Science Team Meeting
Full Model vs. Approximate Model
Computational burden

<table>
<thead>
<tr>
<th># of Parameters Estimating</th>
<th>% of Total Parameters</th>
<th>Time to run 1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>1230</td>
<td>21%</td>
<td>4.5 hours</td>
</tr>
<tr>
<td>2910</td>
<td>50%</td>
<td>5.5 hours</td>
</tr>
<tr>
<td>4850</td>
<td>84%</td>
<td>6.5 hours</td>
</tr>
<tr>
<td>5796</td>
<td>100%</td>
<td>Still going... (so far: 14 hours for 200)</td>
</tr>
</tbody>
</table>

Model is fit using a Markov chain Monte Carlo (MCMC) algorithm implemented in Matlab. Our algorithm gives us samples from the joint posterior distribution of ALL unknown parameters.
5. Geovisualization
Current web interface

NASA FLAMES Project Data Source

Use the search options below to locate fires.

Search by Latitude and Longitude:

- Min Lat: 10.000
- Max Lat: 20.000
- Min Long: 100.000
- Max Long: 110.000

Search by Confidence Level
- Not Selected

Search by Date (e.g., 20071225): 2008069

Return Land Use Data

Submit Query | Reset Search Options | Reset Map
Web-based application includes:

- Java and C programs that can be used to extract information from this database.
- An initial web server that allows a user to query individual datasets and display the results in map images.
- An AJAX framework to implement an interactive web site that can support dynamic querying and displaying of the database.
Future developments

• Tools to explore statistical model predictions under a variety of environmental and policy scenarios
• Additional features (e.g., querying multiple data sets and displaying search results in maps, tables, and charts)
6. Policy applications
Planned - 2009

• Collaboration with Jeff Fox, East-West Center
  – Lowlands: increasing paddy rice production
  – Uplands: less and less shifting cultivation, more cash crop production (tea, rubber, cashews, coffee, etc.)
  – Shifting land management: from commons to privately owned

• Given data on land transformations, what are local contributions to regional aerosols?
Summary of current progress

• Novel statistical model developed and fit
• Currently adding MISR/MODIS aerosol, fire and land-cover data (Spring)
• Developing MapObjects tools for retrieval, display, visualization of model input/output (Summer)
• Policy implications (Summer/Fall)
Project publications


In progress
- Munroe, D.K., Xiao, N. Calder, C., Shi, T. Biomass burning, regional land-use/cover transformations, and carbonaceous aerosols in mainland Southeast Asia. *Global Environmental Change*
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