The *FLAMES* Project

LCLUC Impacts on Atmospheric Processes

PI Darla Munroe[a]

Co Investigators: Kate Calder[b], Tao Shi[b], Ningchuan Xiao[a]

[a]Department of Geography

[b]Department of Statistics

Ohio State University

NASA Land-Cover and Land-Use Change Program Science Team Meeting

Spring 2009

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:

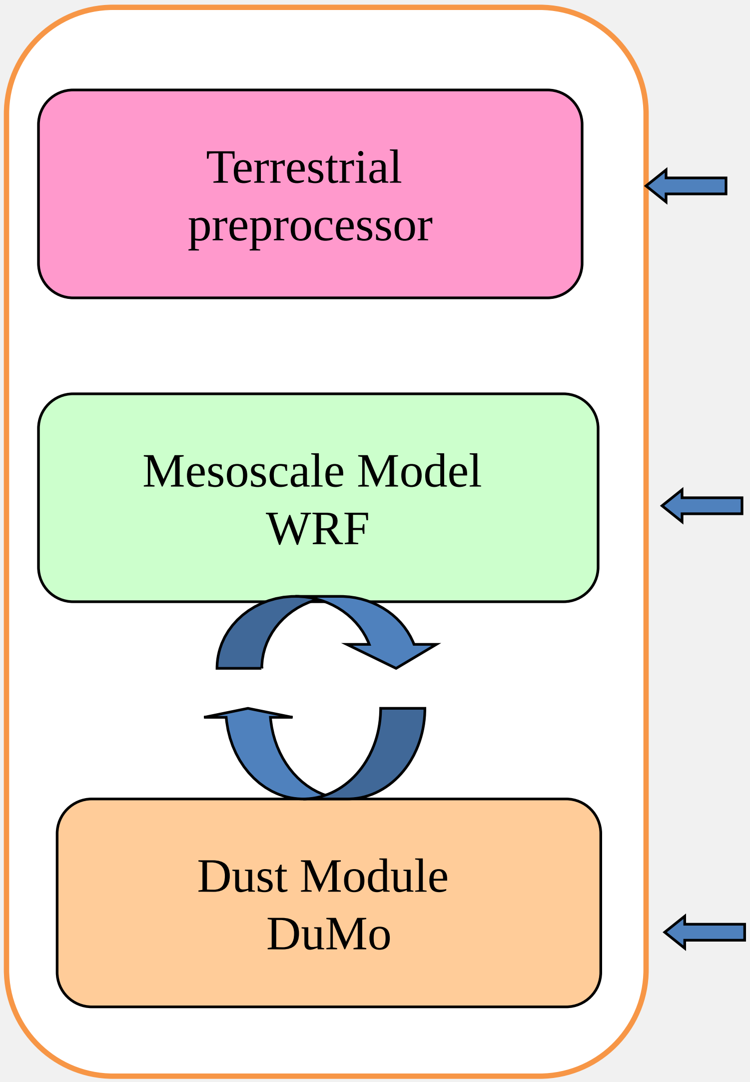
gain an improved how and to what extent land-use/land cover changes and varying dust loadings and their interactions have been affecting climate of drylands in the NEESPI study domain over the past 50 years.

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

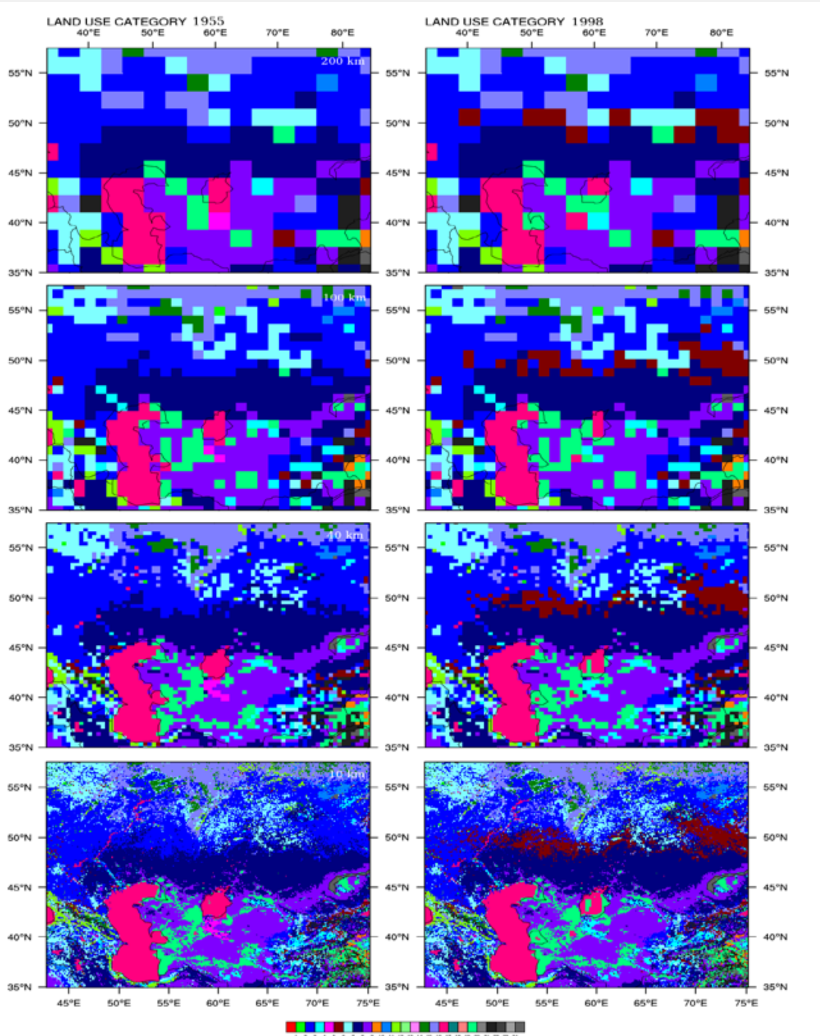
- Flexible nesting capability (down to 1 km)
- Driven by re-analysis data (NCEP or ECMWF)

- 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)

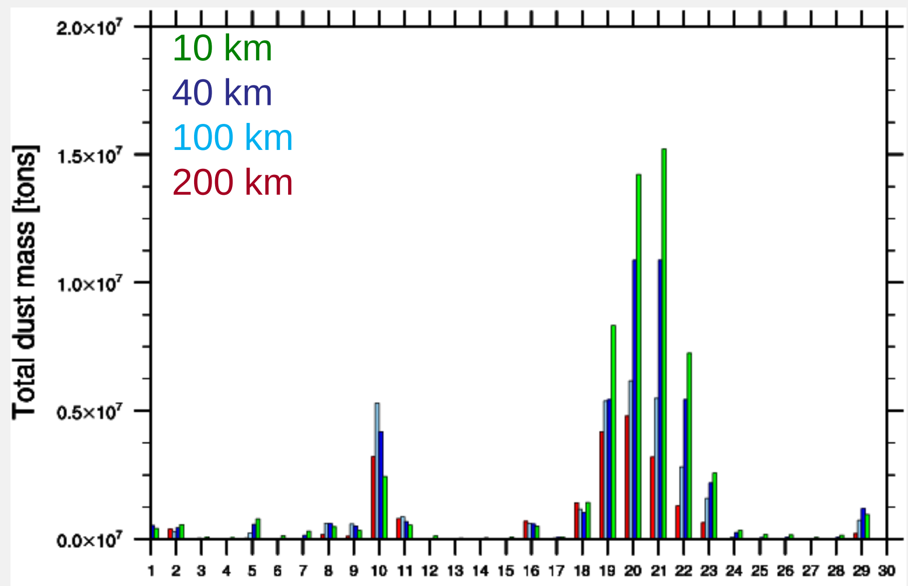
Dust emission modeling with WRF-DuMo

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



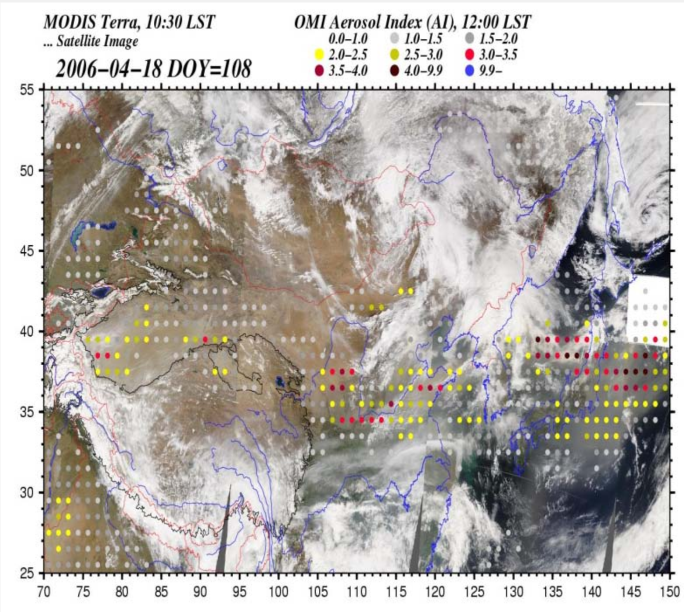
WRF-DuMo simulations performed for representative grid sizes reveal that GCM-like models significantly underpredict dust emission and hence dust burden in the atmosphere and associated impacts.

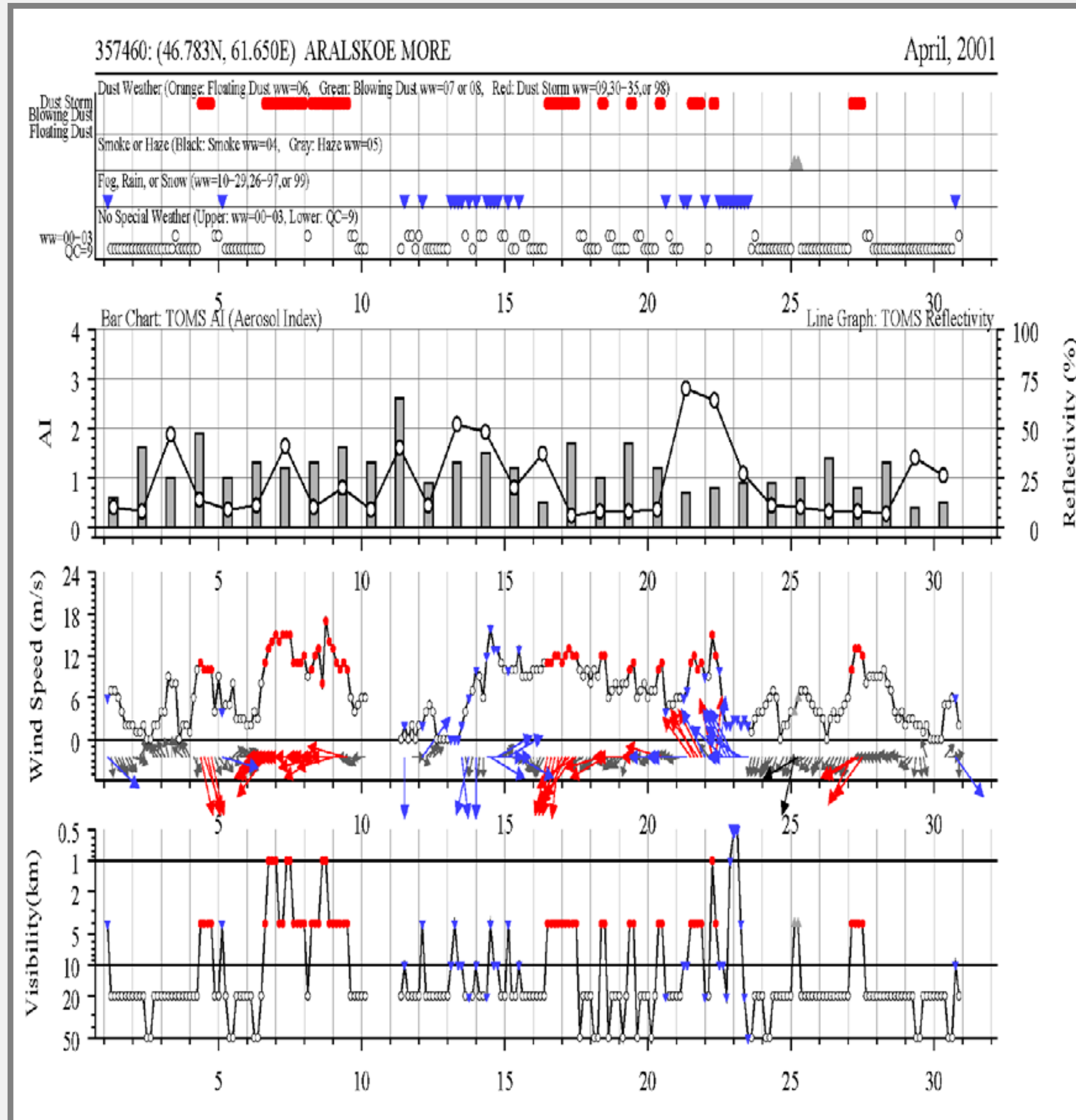
IPCC assessments (performed with GCMs) of radiative forcing of dust aerosol impacts on climate have significant biases, especially in regions affected by land-cover/land-use changes.



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

Asian Dust Databank:

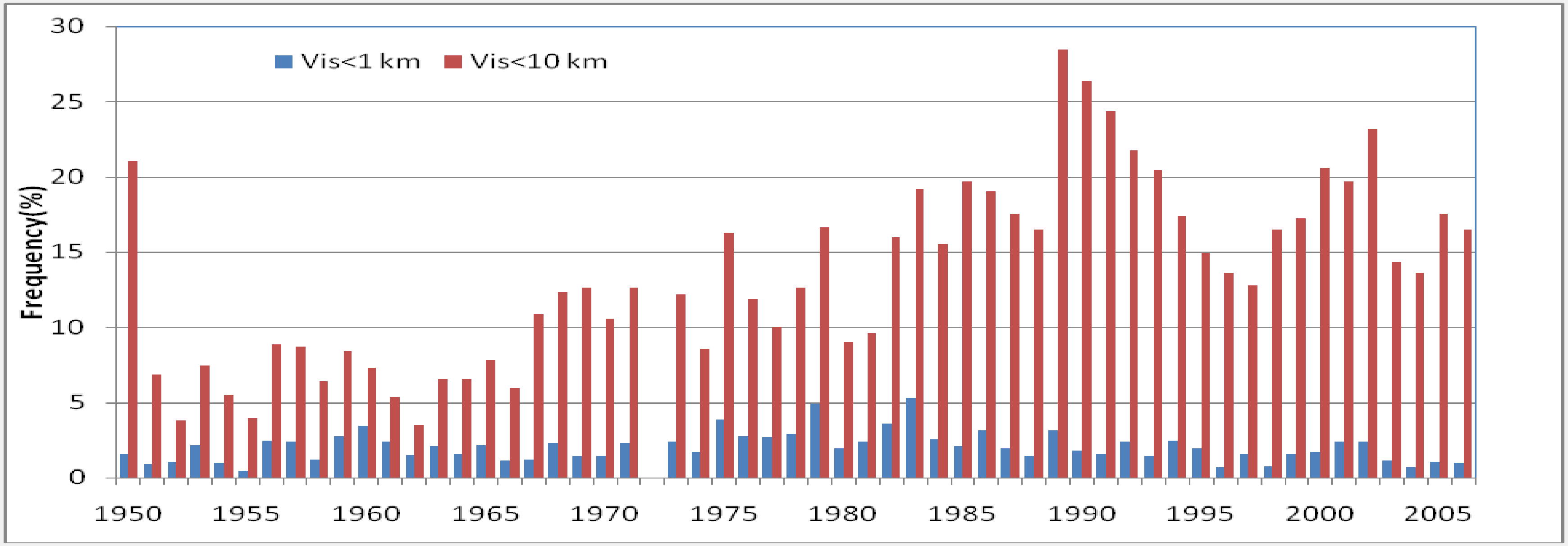




Examples of integrated analysis of satellite and ground-based observations. The upper panel shows satellite data of MODIS/Terra and OMI AI on April 18, 2006. The lower panels show time series of visibility, wind speed & direction, TOMS AI & reflectivity, and WMO present weather during April 2001 for 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

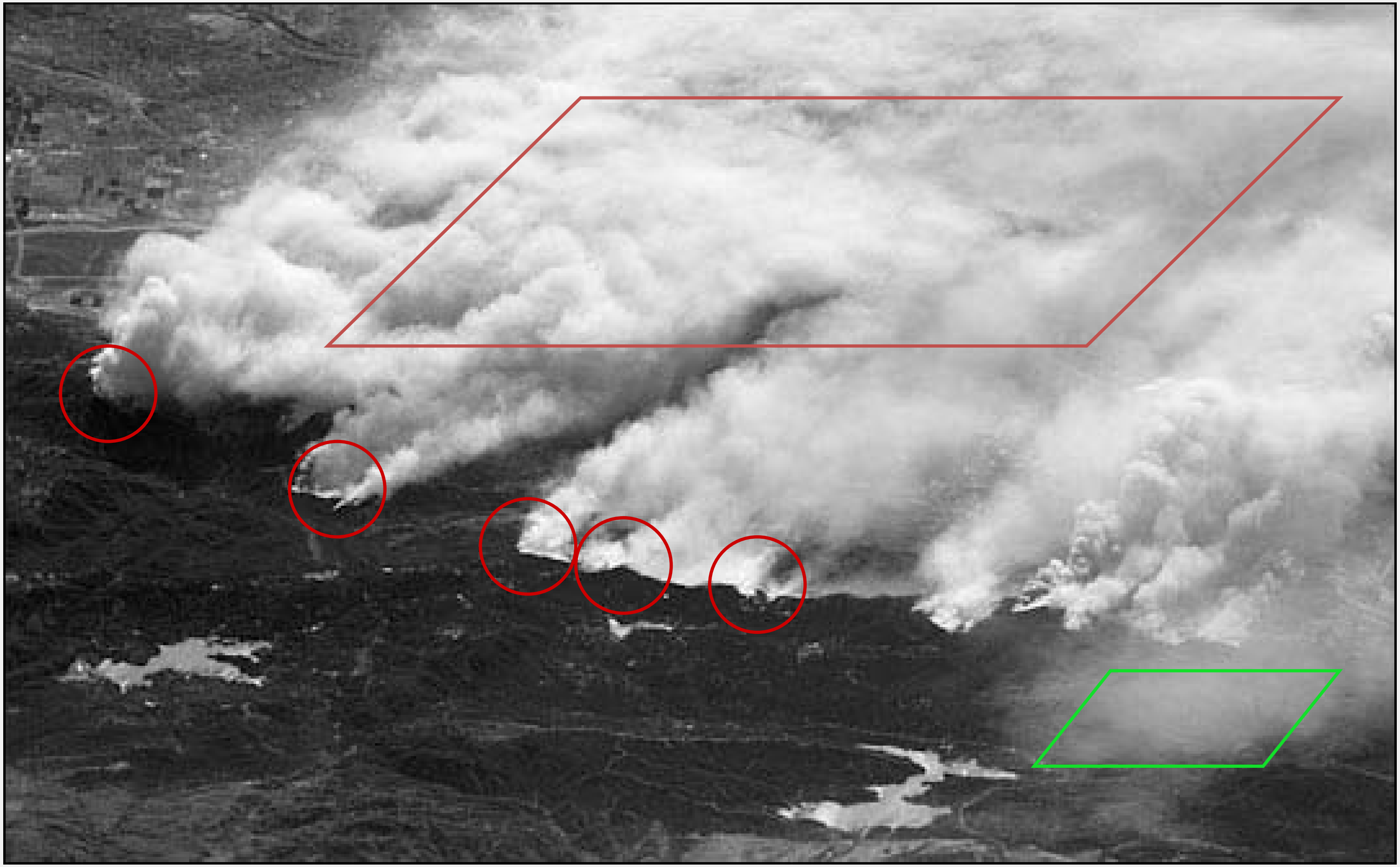
- Project goals
- Objectives/tasks
    1. Biomass burning and land-cover trajectories
    2. Data assimilation issues
    3. Statistical estimation of atmospheric transport
    4. Bayesian hierarchical model
    5. Geovisualization tools
    6. Policy applications

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

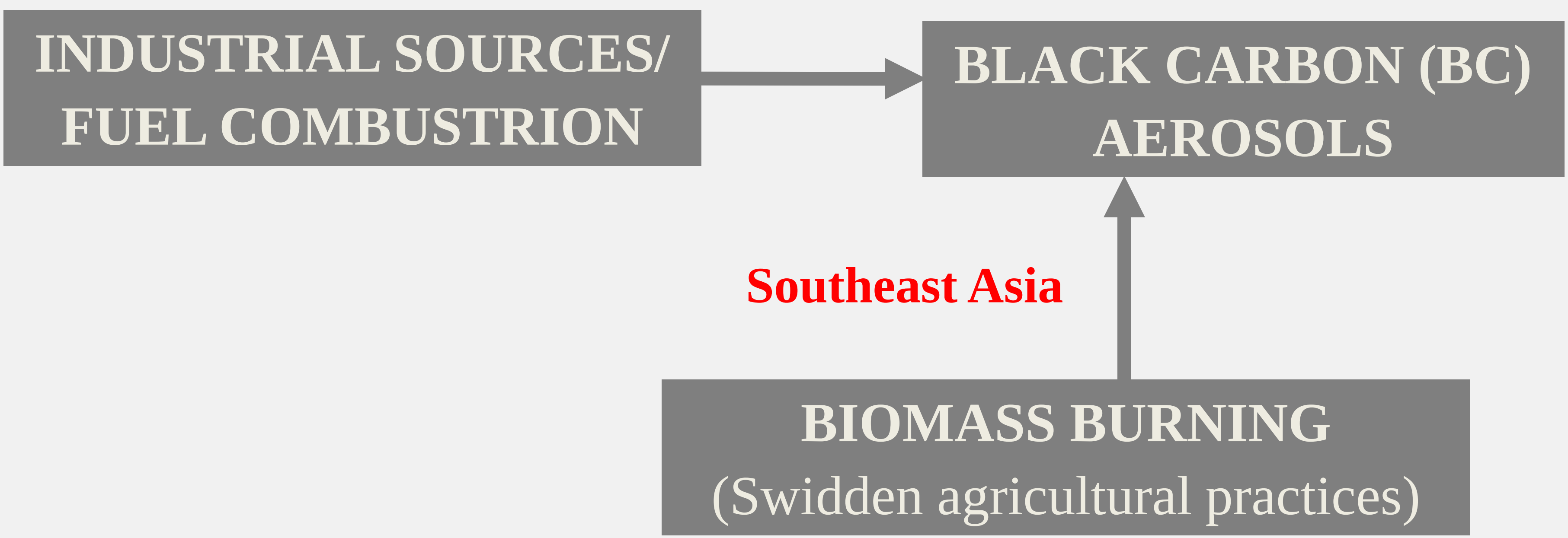


Project Overview

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

  MOTIVATION

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



1. Biomass burning and lcc trajectories

Biomass burning and lcc

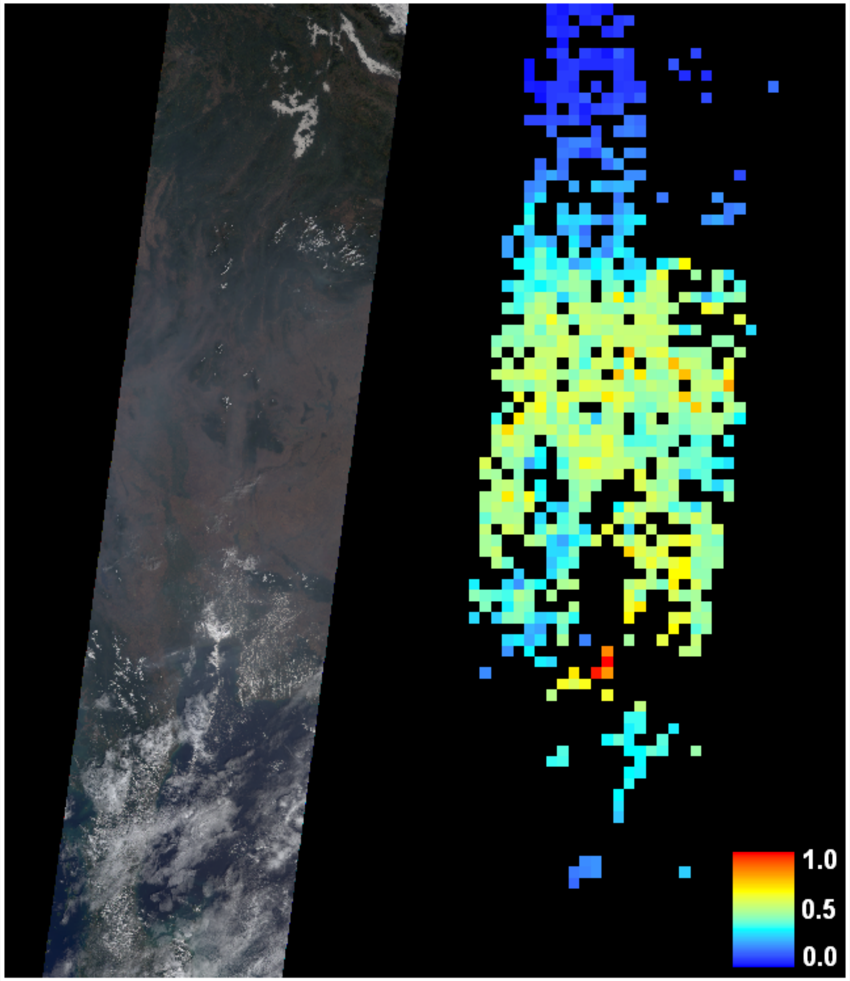
- Regional land-use transformations
  - Sources of burning (smallholders vs. larger farms)
    - Different patterns of burning
  - Cropping patterns
    - Lowland: more and more rice paddy
    - Upland: from shifting to cash crops
  - Greater uncertainty in mainland SE Asia about burning and carbonaceous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

Munroe, D.K., S.R. Wolfinbarger*, C.A. Calder, T. Shi, N. Xiao, C.Q. Lam*, and D. Li*. (2008). The Relationships Between Biomass Burning, Land-Cover/Use Change, and the Distribution of Carbonaceous Aerosols in Mainland Southeast Asia: A Review and Synthesis. *Journal of Land Use Science* 3(2-3): 161-183.

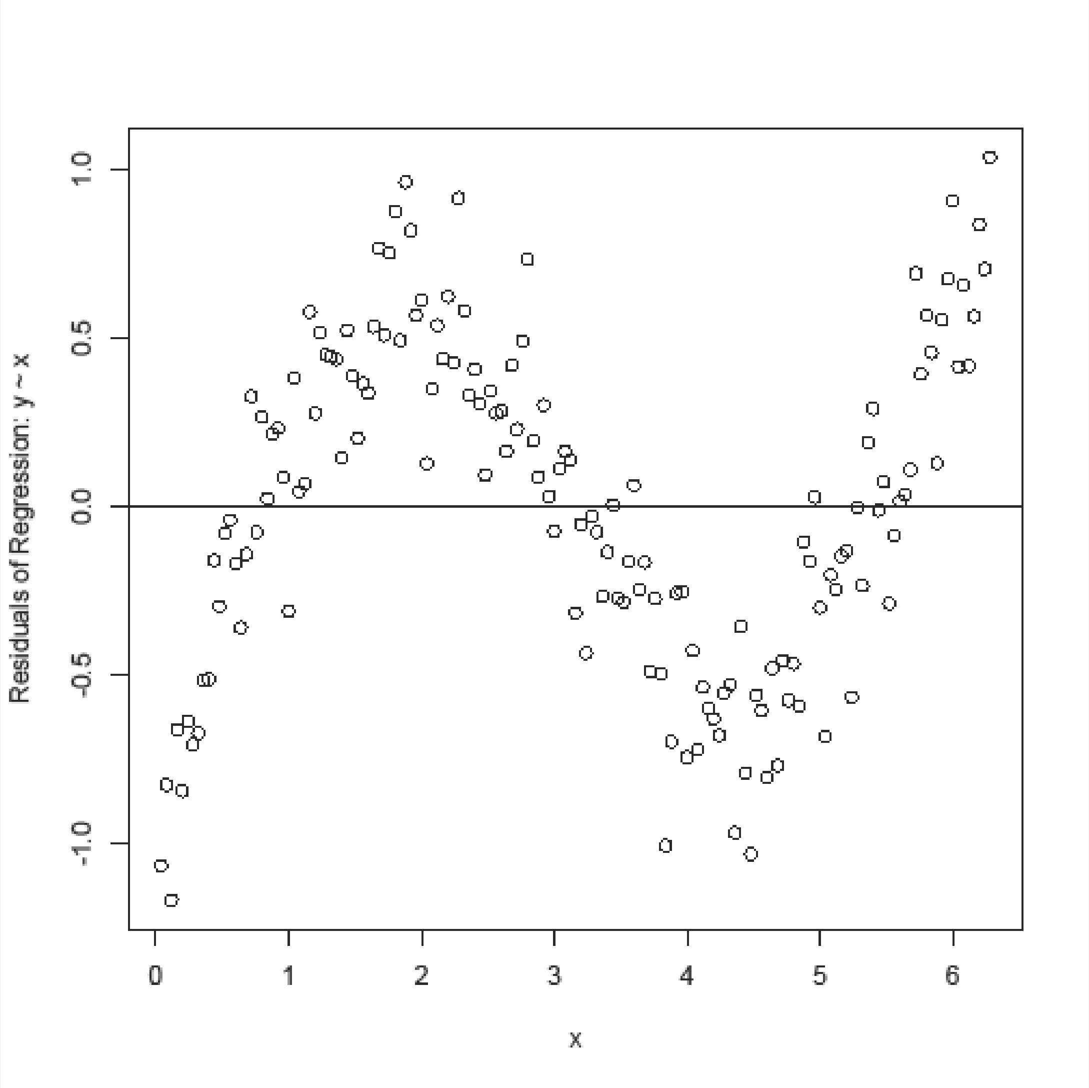
2. Data assimilation issues

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

Xiao, N., T. Shi, C. Calder, D.K. Munroe, C Berrett*, S. Wolfinbarger*, and Li*, D. (2008). Spatial Characteristics of the Difference between MISR and MODIS Aerosol Optical Depth Retrievals over Mainland Southeast Asia. *Remote Sensing of Environment* 113(1): 1-9.

Modeling spatial patterns in MISR/MODIS difference

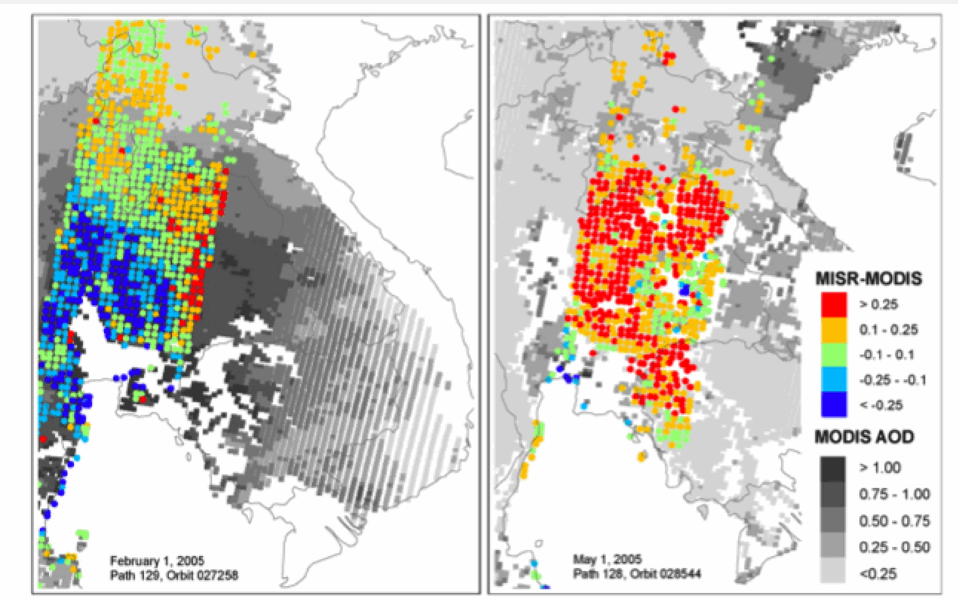


Table 2
Results of SAR models

	50 km			
	Simple model		Extended model	
Covariate	Estimate	Std. error	Estimate	Std. error
Intercept	0.227***	0.007		
τ^{MOD}	−0.776***	0.006	−0.780***	0.006
Dry	0.058***	0.008	0.056***	0.008
Water			0.233***	0.010
Forest			0.225***	0.010
Shrub			0.245***	0.011
Savanna			0.253***	0.010
Crop			0.250***	0.010
Wetland			0.251***	0.028
Urban			0.219***	0.024
Elevation			0.000***	0.000
droads			−0.030***	0.006
dcoast			0.007 ***	0.002
dbcity			−0.004**	0.002
docity			0.002	0.005
λ	0.893***		0.887***	

* Significant at the 0.01 level.
** Significant at the 0.005 level.
*** Significant at the 0.001 level.

Xiao, N., T. Shi, C. Calder, D.K. Munroe, C Berrett*, S. Wolfinbarger*, and Li*, D. (2008). Spatial Characteristics of the Difference between MISR and MODIS Aerosol Optical Depth Retrievals over Mainland Southeast Asia. *Remote Sensing of Environment* 113(1): 1-9.

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

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

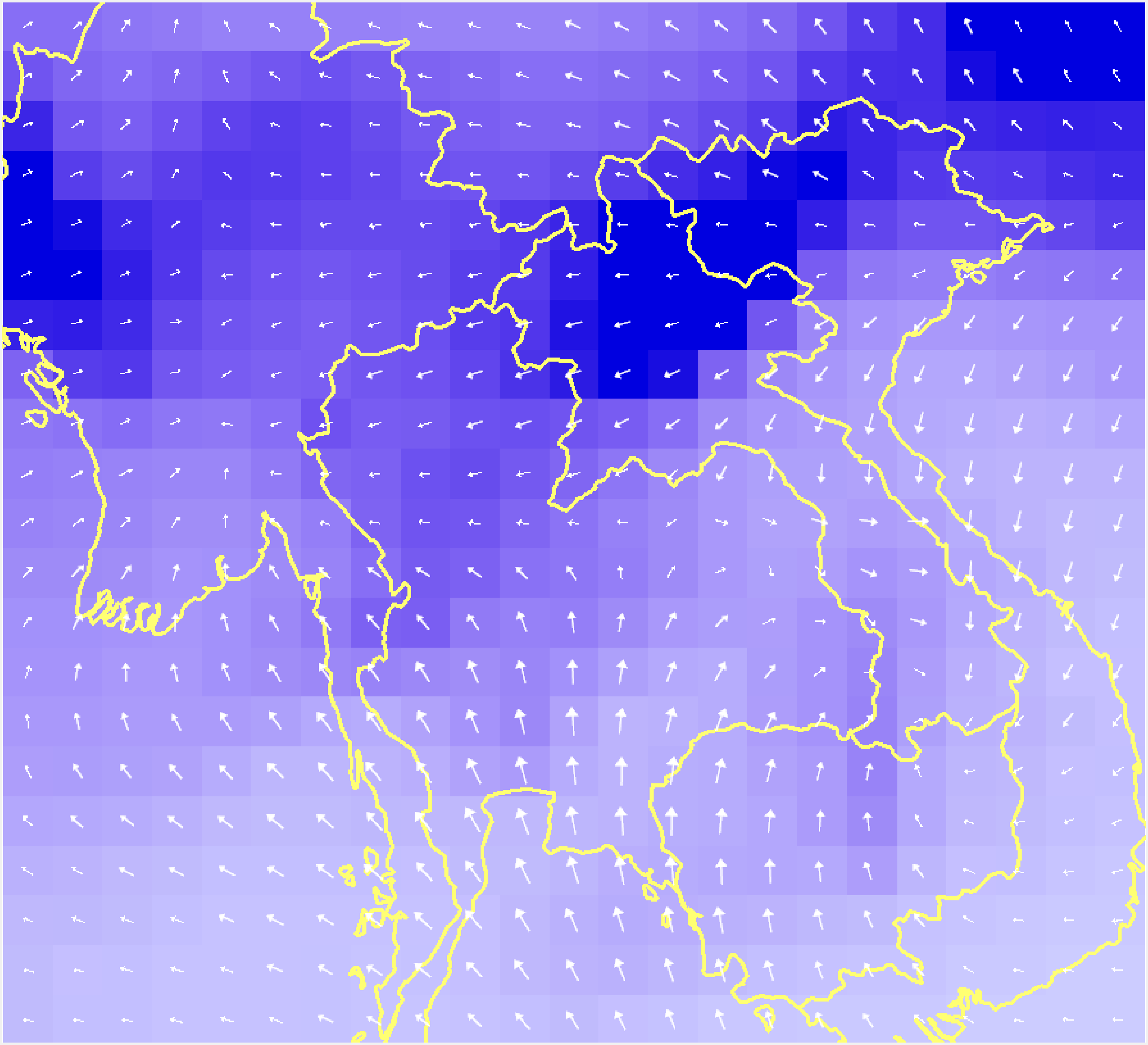
Transportation parameters derived from differential equations

Advantages of our approach

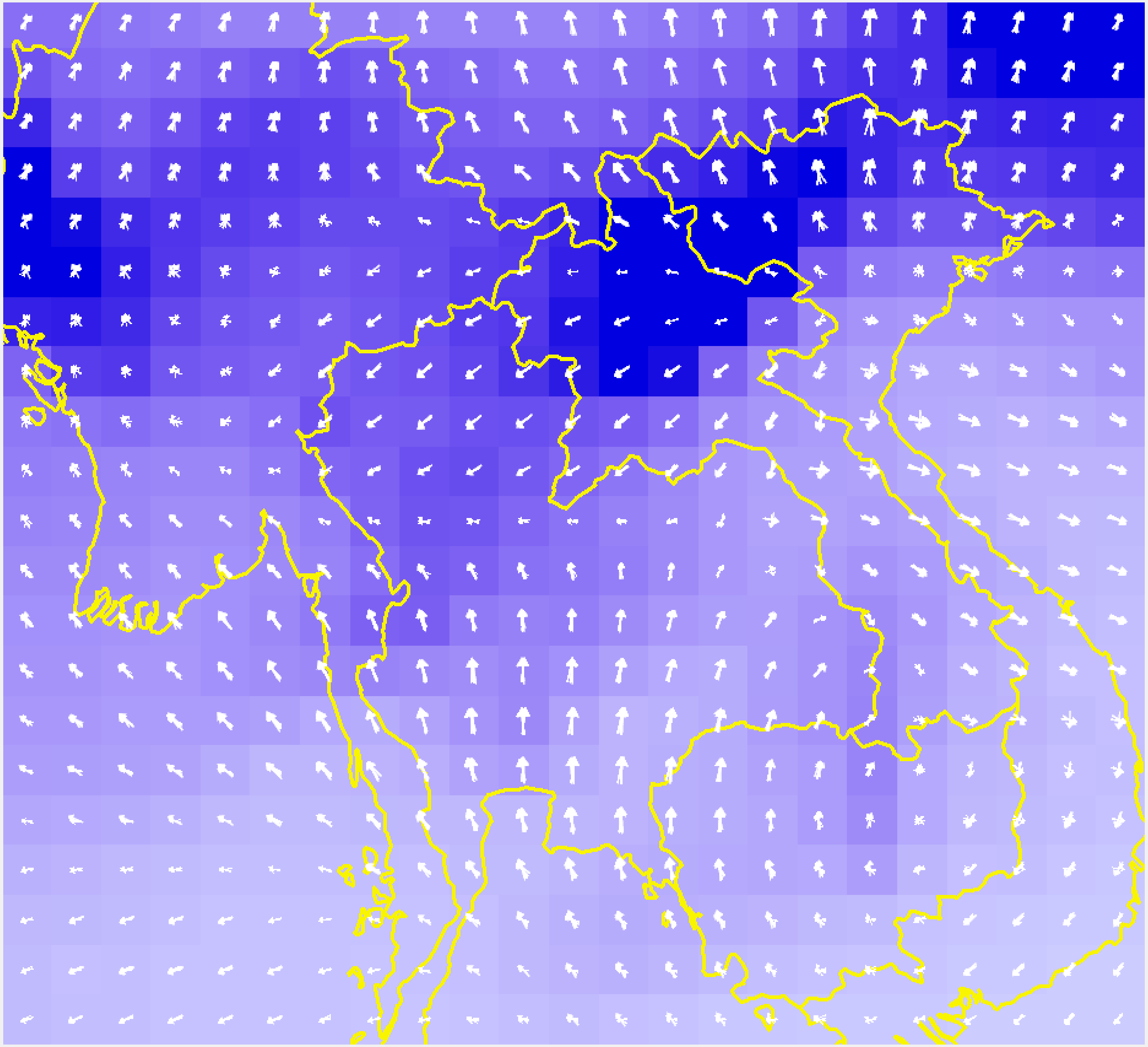
- Uncertainty
- Scalability
- Computation
- Estimation of emissions
- Forecasting

- Compare output against physical model results, and field observations

One run of estimated transport

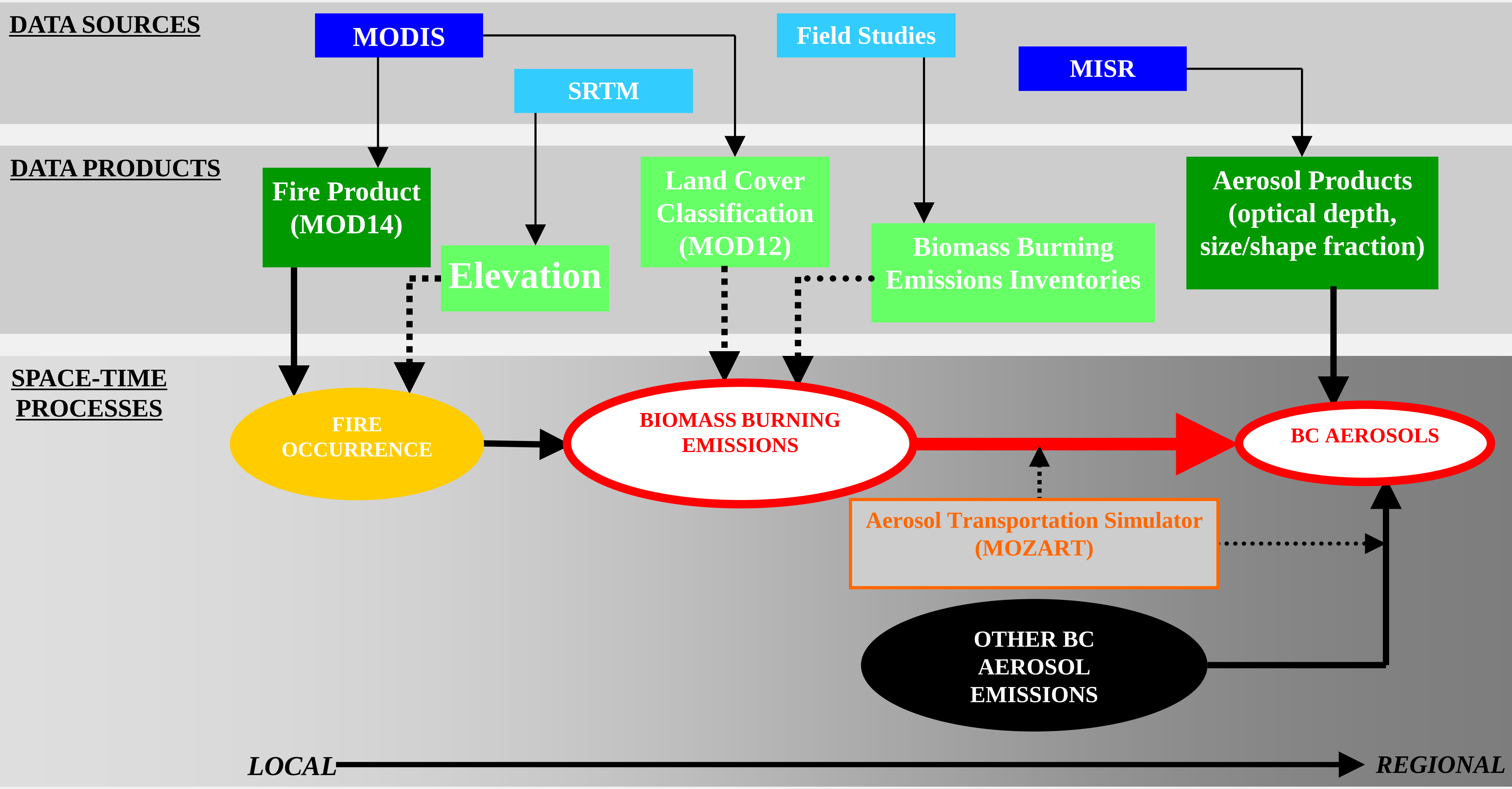


Multiple runs of estimated transport



4. Bayesian hierarchial modeling

Comprehensive Statistical Modeling System



Model

Data Model:

$$z_t(\mathbf{s}) = \mu + y_t(\mathbf{s}) + \epsilon_t(\mathbf{s})$$

Observed Aerosols

Data Mean

Latent Process

Measurement Error

Process Model:

$$y_{t+1}(\mathbf{s}) = \gamma \int_{\mathcal{D}} k_{\mathbf{s}}(\mathbf{r}; \boldsymbol{\theta}_{\mathbf{s}}) \, (y_t(\mathbf{r}) + c \, \mathrm{E}_t(\mathbf{r})) \; d\mathbf{r} + \eta_{t+1}(\mathbf{s})$$

Redistribution Kernel

Emissions

Process Error

Redistribution Kernel

Form of Gaussian Kernel:

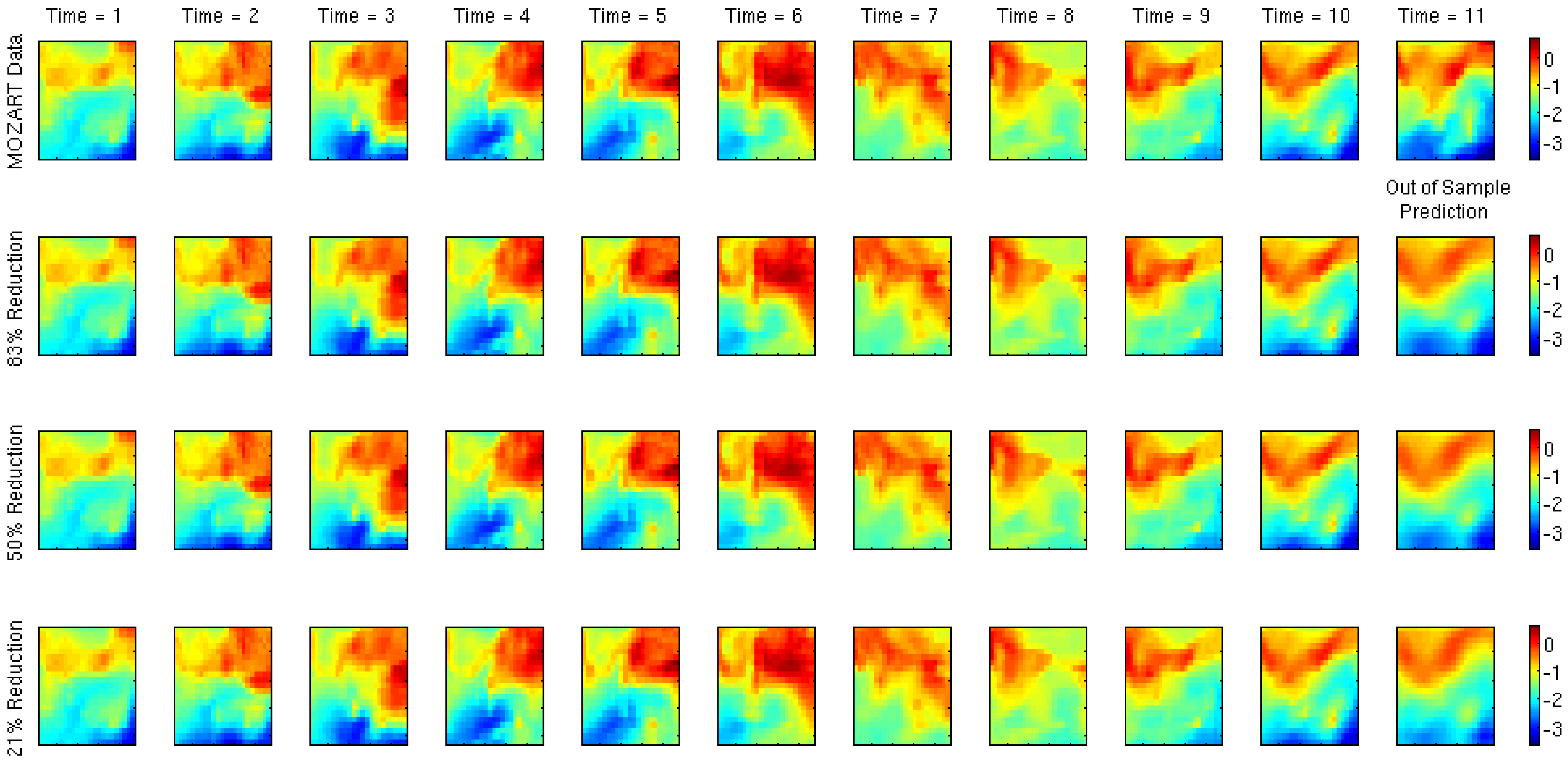
$$k_{\mathbf{s}}(\mathbf{r};\theta_{\mathbf{s}}) \propto \exp\left\{-\frac{1}{2}\left(\mathbf{r}-\underset{\text{Kernel Mean}}{\underbrace{\boldsymbol{\lambda}(\mathbf{s})}}-\mathbf{s}\right)'\left(\underset{\text{Kernel Covariance}}{\underbrace{\boldsymbol{\Sigma}^{k}(\mathbf{s})}}\right)^{-1}\left(\mathbf{r}-\boldsymbol{\lambda}(\mathbf{s})-\mathbf{s}\right)\right\}$$

- 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



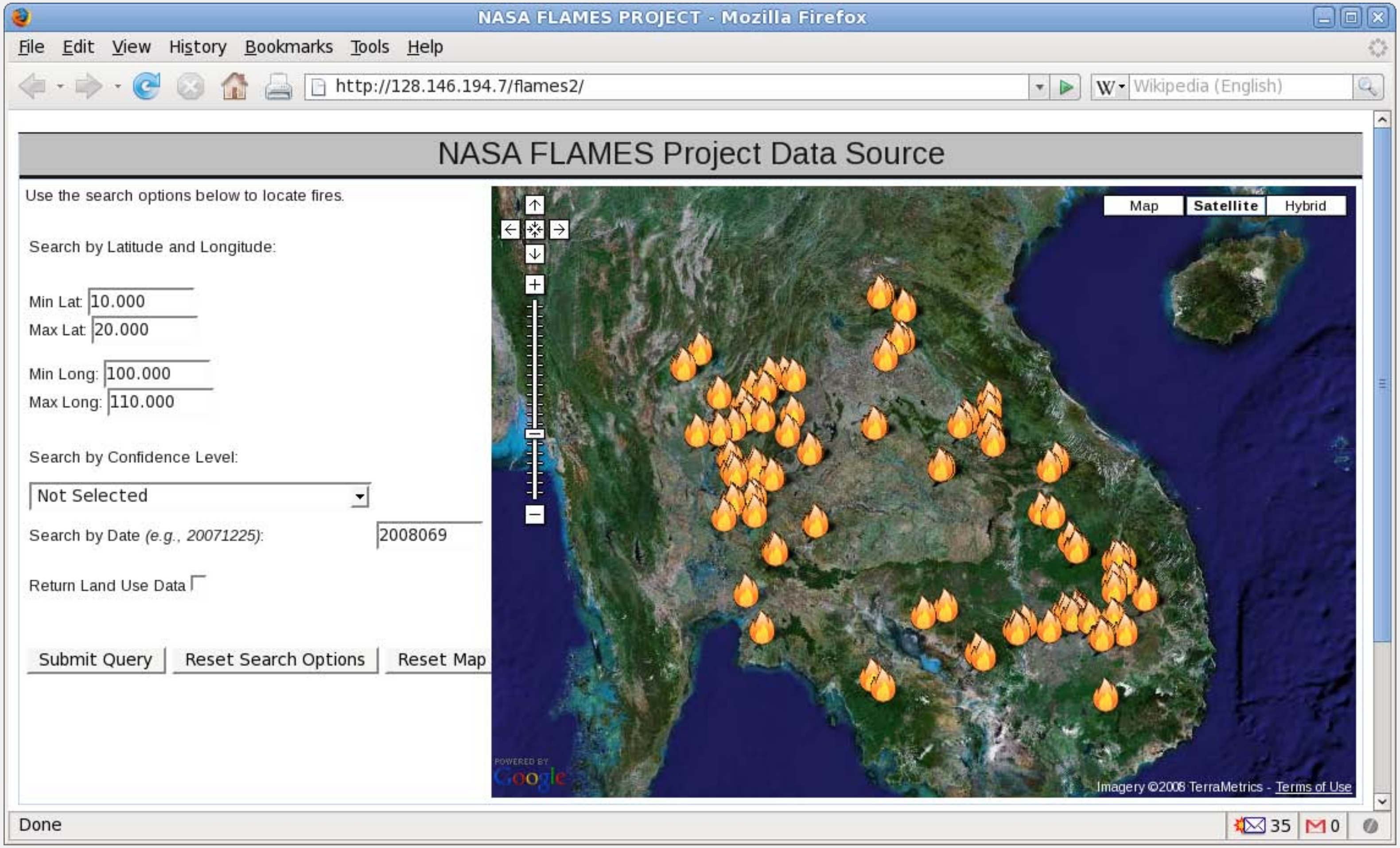
Full Model vs. Approximate Model Computational burden

# of Parameters Estimating	% of Total Parameters	Time to run 1000
1230	21%	4.5 hours
2910	50%	5.5 hours
4850	84%	6.5 hours
5796	100%	Still going… (so far: 14 hours for 200)

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



Web-based application includes:

- The database for our study area: land use data, elevation, major roads and cities, MODIS fire occurrences for 2001-2005, and MODIS and MISR aerosols optical depths for 2001-2005.
- 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

Munroe, D.K., S.R. Wolfinbarger*, C.A. Calder, T. Shi, N. Xiao, C.Q. Lam*, and D. Li*. (2008). The Relationships Between Biomass Burning, Land-Cover/Use Change, and the Distribution of Carbonaceous Aerosols in Mainland Southeast Asia: A Review and Synthesis. *Journal of Land Use Science* 3(2-3): 161-183.

Xiao, N., T. Shi, C. Calder, D.K. Munroe, C Berrett*, S. Wolfinbarger*, and Li*, D. (2008). Spatial Characteristics of the Difference between MISR and MODIS Aerosol Optical Depth Retrievals over Mainland Southeast Asia. *Remote Sensing of Environment* 113(1): 1-9.

Munroe, D.K., Xiao, N., Calder, C.A., and Shi, T. (2008). Fire-land-atmosphere modeling and evaluation for Southeast Asia. In the *Newsletter of the Global Land Project*. Issue No. 3. January, 2008.

<u>In progress</u>

- Calder, C.A., Shi, T., Berrett, C., Xiao, N., Munroe, D.K. Dimension Reduction Strategies for Dynamic Space-Time Models: Implications for Model Fit and Computational Efficiency.
- Shi, T., Calder, C.A., Berrett, C., Munroe, D.K. , Xiao, N. Space-Time Prediction of Aerosol Optical Depth Using Sparse Remote Sensing Observations and Aerosol Transportation Model Output.
- 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*

Acknowledgements

- NASA LCLUC program
- **Collaborators:** Louisa Emmons (NCAR), Jeff Fox (East-West Center), Ralph Kahn (NASA Goddard Space Flight Center), Gabriele Pfister (NCAR), Phil Rasch (NCAR)
- This project is also is endorsed by the Global Land Project, a joint research agenda of the International Human Dimensions Programme (IHDP) and the International Geosphere-Biosphere Programme (IGBP).