Regional Infrastructure and Air Quality Planning in Light of Global Change

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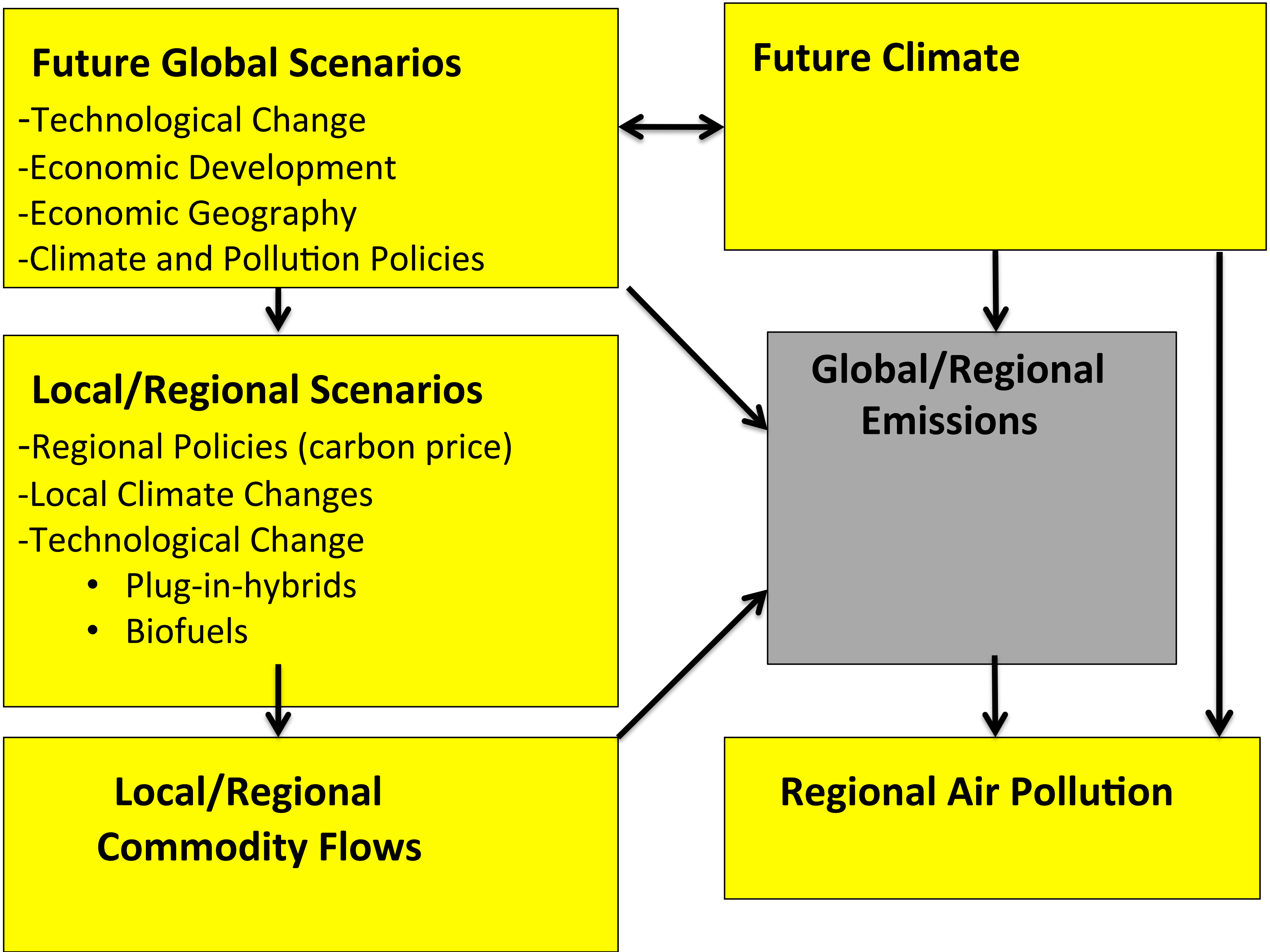
1. Review of Research Objectives and Questions of Interest

1) How will emerging technologies and infrastructure changes (including transportation) and global climate and air pollution policies impact regional air quality by 2050?

2) How will urban and regional landscapes evolve in response to changes in production and distribution at regional and global scales? How will associated changes in land use affect emissions and air quality?

3) How will regional and national policy decisions affect the urban landscape and what are the implications for air quality under a future climate scenario?

4) What are the synergies between climate and air quality regulation? How can the results of these studies be best used to inform present and future policy decisions?


Future Global Scenarios
-Technological Change
-Economic Development
-Economic Geography
-Climate and Pollution Policies
Future Climate
Local/Regional Scenarios
-Regional Policies (carbon price)
-Local Climate Changes
-Technological Change
• Plug-in-hybrids
• Biofuels
Global/Regional Emissions
Local/Regional Commodity Flows
Regional Air Pollution

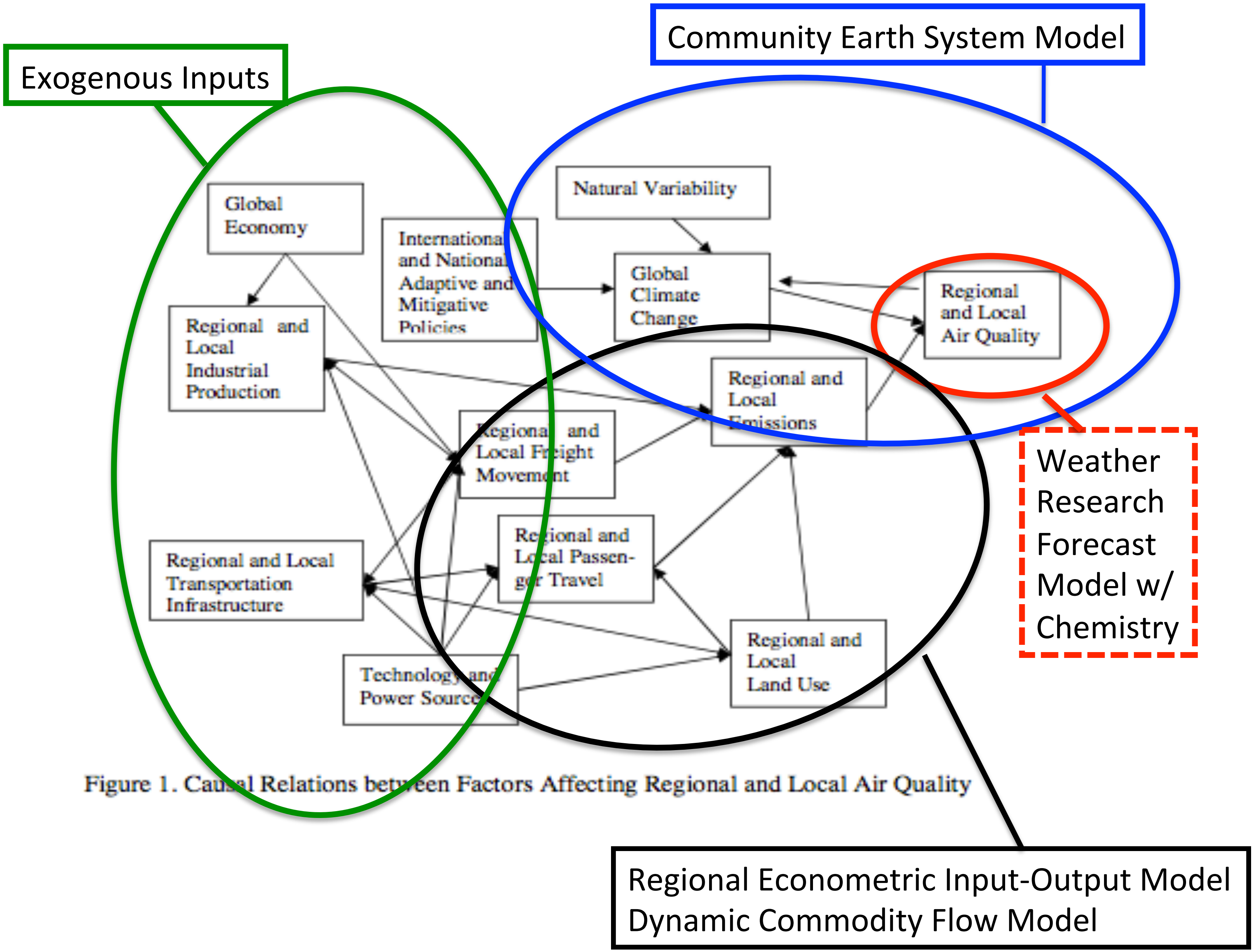


Figure 1. Causal Relations between Factors Affecting Regional and Local Air Quality

Approach and Activities:
In order to address the four study questions, we are undertaking the following cross-disciplinary tasks:

Task 1: Generate trajectories for economic, technological, and infrastructure changes to 2050, both globally and within the U.S. which will impact air quality.

Task 2: Generate chemical emissions consistent with the above trajectories. These scenarios will implicitly include the effect of climate mitigation policies and their consequences on the global and regional scale.

Task 3: Use emission scenarios in a chemical transport model to predict the impact of climate change on air quality (ozone and aerosols), including possible mitigation strategies.

Task 4: Conduct sensitivity analyses and synthesize our findings.

To carry out the first two tasks, we have needed to generate spatial time series data on interstate inter-industry freight flows.

Large Scale Picture

- The spatial economy has increasingly come to be viewed as a *space of flows*. Moving along the links of networks are ever greater quantities of people, goods, material, money, and information.

- These developments have enabled firms to exploit *economies of scale* and *scope* by fragmenting production processes and dispersing activities to least-cost locations (Jones and Kierzkowski, 2001).

- Consequently, the production of most goods worldwide now takes place in a distributed pattern over many locations in which semi-finished goods are shipped from one *specialized* establishment to another.

- And with the increased use of just-in-time inventory management methods, all production has become more *transport intensive*.

- Economic fragmentation lead to a higher emission intensity in transportation industry as an effect from structural change;

- Technology advancement and strict regulations on emissions (in the U.S.) reduce emission on the other hand, starting later 1990s.

The volume of freight movement (in value terms) for all distances has been increasing at a faster annual rate, 6.6%, than GNP.

Distance Shipped (1) (Based on Great Circle Distance)	Value		
	2007 (million $)	2002 (million $)	Percent change
All distances	11,684,872	8,397,210	39.2
Less than 50 miles	3,851,545	2,503,895	53.8
50 to 99 miles	1,074,137	757,601	41.8
100 to 249 miles	1,777,031	1,329,245	33.7
250 to 499 miles	1,606,034	1,221,437	31.5
500 to 749 miles	1,019,498	844,880	20.7
750 to 999 miles	720,623	548,768	31.3
1,000 to 1,499 miles	730,366	501,419	45.7
1,500 to 1,999 miles	494,992	353,663	40.0
2,000 miles or more	410,646	336,302	22.1

Source: Bureau of Transportation Statistics

Generation of Emissions over the NE U.S.

- The synergies between climate change and air pollution need to consider the linkages between global and regional scales.

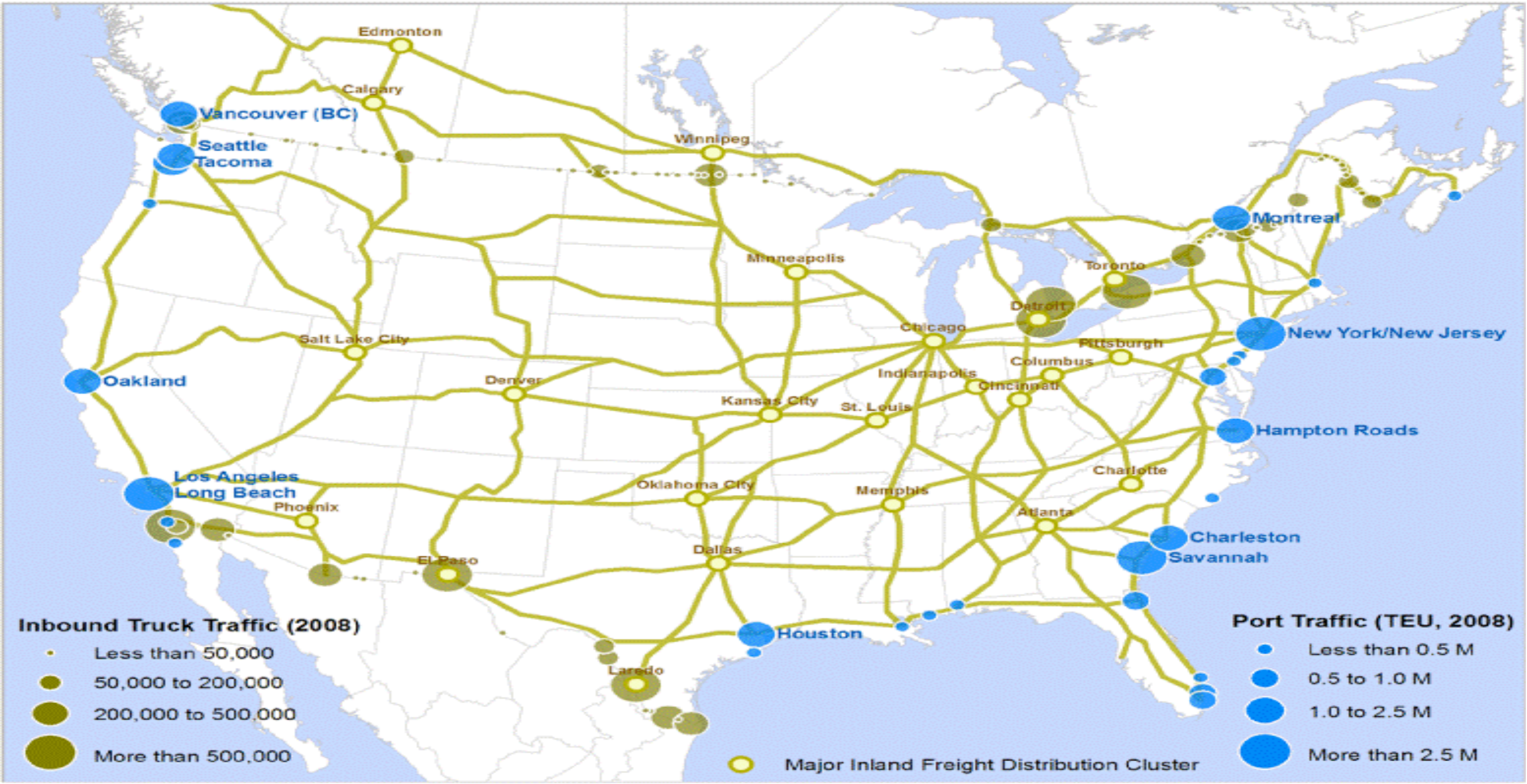
- While acknowledging the influence of global and national changes on local and regional conditions, we note that many of the decisions affecting emissions of air pollutants and global warming are not made at the global or national level, but at local and regional levels.

- Thus, the tools this research develops are oriented more to helping public and private actors at local and regional levels make choices that will as much as possible have synergistic effects.

To generate emissions we need to calibrate a *structural model* of commodity flow evolution:

- Commodity Flow Data
- Unit Transportation Cost Data By Mode
- Cost to Carriers
- Geographic Data

We are considering freight flows between 13 industrial sectors in 13 states in the Northeast, Atlantic, and Midwest regions of the U.S. and the rest of the U.S. Together these account for about 38% of the tonnage of all freight movement in the country.



http://people.hofstra.edu/geotrans/eng/ch2en/conc2en/ch2c3en.html

Develop Regional Input-Output Econometric Model

- We have constructed a three-region regional econometric input-output model (REIM), that is benchmarked to data from a national 2001 social accounting matrix;

- Using the estimated REIM, we have derived imputed interregional input-output tables for the 31-year period, from which we have generated the observations on interstate inter-industry trade flows.

- Relationship with exogenous variables

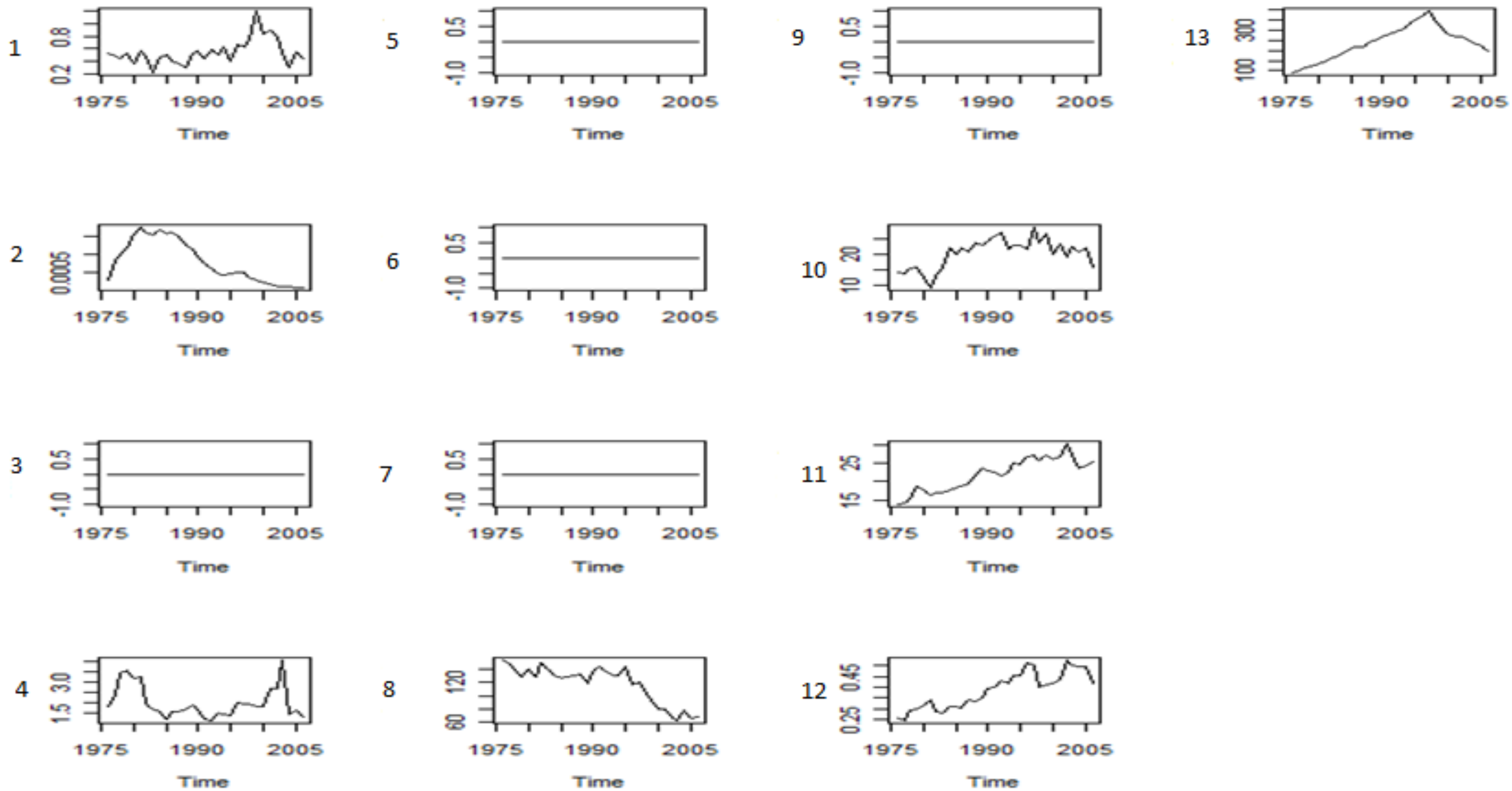
Sectoral Classification System

Sector	Description	NAICS Code
1	Agriculture, forestry, fishing, and hunting	11
2	Mining	21
3	Construction	23
4	Food product manufacturing	311
5	Chemical manufacturing	325
6	Primary metal manufacturing	331
7	Fabricated metal product manufacturing	332
8	Machinery manufacturing	333
9	Computer and electronic product manufacturing	334,335
10	Transportation Equipment	336
11	Other Non-durable Manufacturing	312-316,322-324,326
12	Other Durable Manufacturing	321,327,337,339
13	TCU, Service and Government Enterprises	42,44,45,48,49,51-56,61,62,71,72,81

Characteristics of the Three-Region REIM

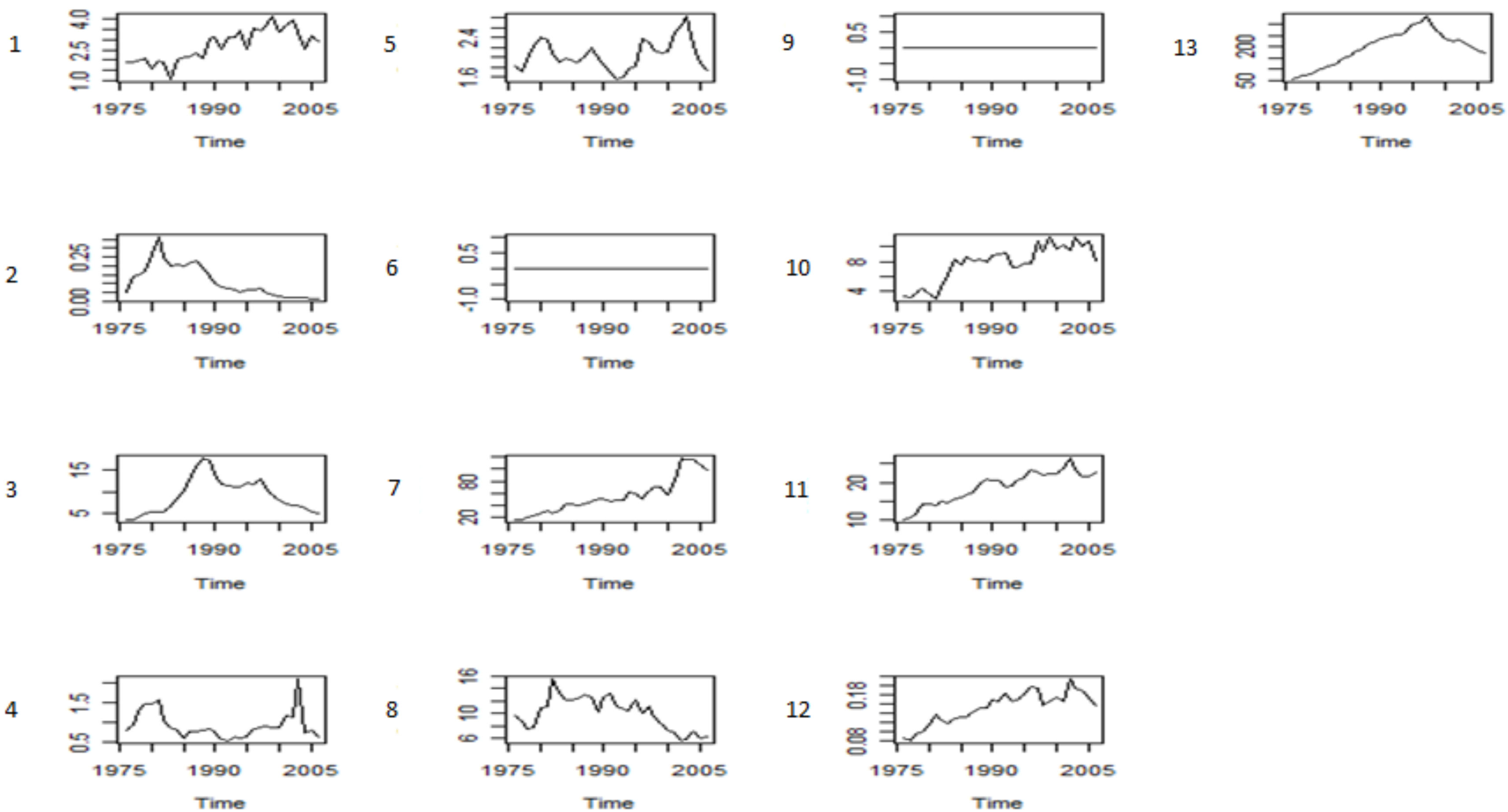
Project Horizon	1977-2007 (31 years)
Model Sizes	169 sets of linear equation system
Industry Detail	13 industries with projections of output and inter-industry/regional commodity flow
Selected Endogenous Variables	Gross Regional Product
	Personal consumption
	Residential and non-residential investment
	Federal government expenditure
	State and local government expenditure
	Population
	Unemployment rate
	Personal income
	Consumer Price Index (CPI)

Time Profiles of same-sector Trade Flows from Connecticut to Illinois for all 13 sectors



1. Agriculture,2. Mining, 3. Construction, 4. Food product manufact., 5. Chemical Manufact., 6. Primary metal manufact., 7. Fabricated metal product manufact. 8. Machinery manufact., 9. Computer and Elec. Manufact., 10. Transportation Equip., 11. Other Non-durable Manufact., 12., Other Durable Manufacturing, 13. TCU, Service

Time Profiles of Intra-sectoral Trade Flows between Connecticut and Illinois



Summary of REIM model:

• We have developed a regional econometric input-output model (REIM) over the North Eastern US, that is benchmarked to data from a national 2001 social accounting matrix;

• Using the estimated REIM, we have derived imputed interregional input-output tables for the 31-year period, from which we have generated the observations on interstate inter-industry trade flows and associated commodity or freight flows

•. These data will be made available to the wider research community.

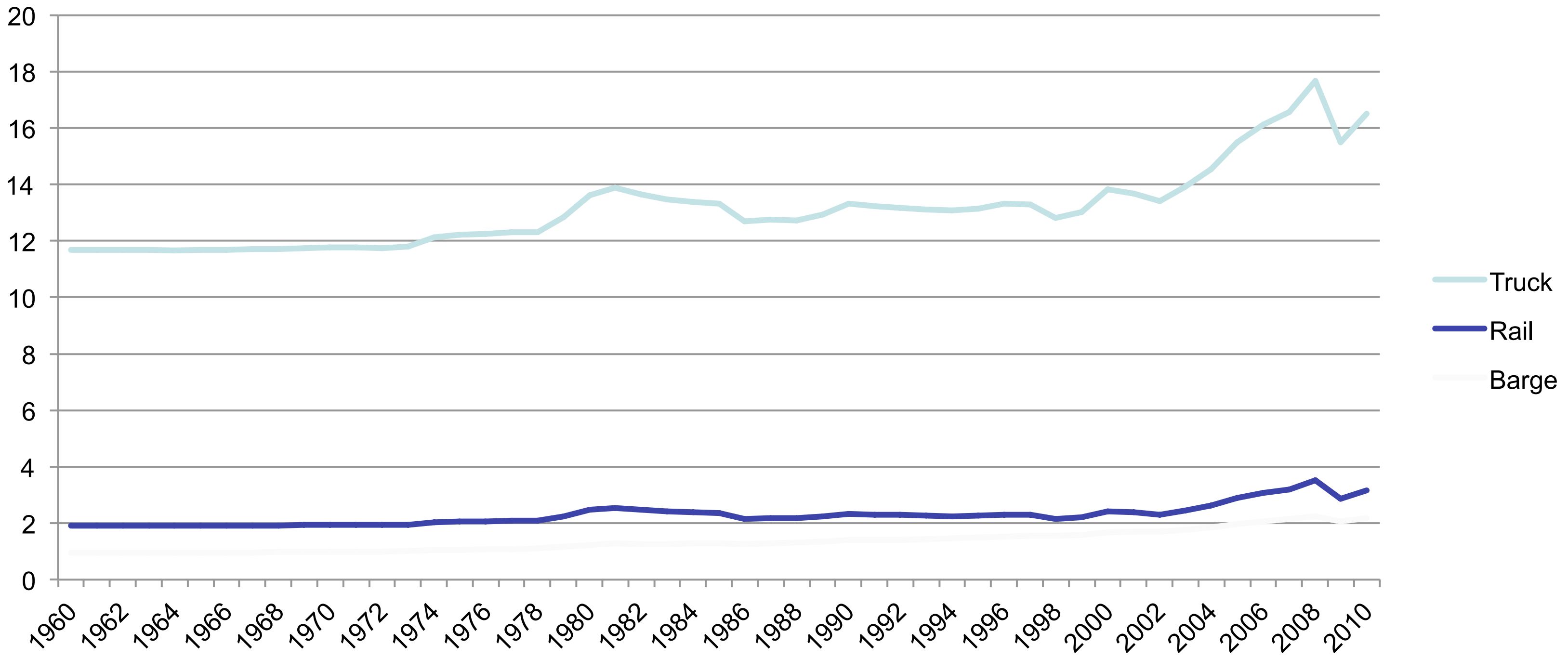
•These data will be employed in econometrically estimating dynamic structural-equation behavioral models characterizing the evolution of interregional commodity flows.

•Such models will be used in forecasting what the effects on infrastructure, air quality, and nodal communities increasing trade may have and conducting thought experiments about what appropriate policy responses may be.

Transportation Cost

Partially available from Bureau of Transportation Statistics (BTS)

Linear estimation to handle missing data (with real GDP and real gasoline price)



Transportation Cost per Ton/Mile

Average Cost to Carrier per Mile

Most recent data are available from American Transportation Research Institute (ATRI) and Associate of American Railroads (AAR).

Linear estimations needed to compute the previous years

Motor Carrier Costs	2008	2009	2010	2011
Vehicle-based				
Fuel & Oil Costs	$0.633	$0.405	$0.486	$0.590
Truck/Trailer Lease or Purchase Payments	$0.213	$0.257	$0.184	$0.189
Repair & Maintenance	$0.103	$0.123	$0.124	$0.152
Truck Insurance Premiums	$0.055	$0.054	$0.059	$0.067
Permits and Licenses	$0.016	$0.029	$0.040	$0.038
Tires	$0.030	$0.029	$0.035	$0.042
Tolls	$0.024	$0.024	$0.012	$0.017
Driver-based				
Driver Wages	$0.435	$0.403	$0.446	$0.460
Driver Benefits	$0.144	$0.128	$0.162	$0.151
TOTAL*	**$1.653**	**$1.451**	**$1.548**	**$1.706**

Source: ATRI

Share of Cost to Carriers

Motor Carrier Costs	**2008**	**2009**	**2010**	**2011**
Vehicle-based				
Fuel & Oil Costs	38%	28%	31%	35%
Truck/Trailer Lease or Purchase Payments	13%	18%	12%	11%
Repair & Maintenance	6%	8%	8%	9%
Truck Insurance Premiums	3%	4%	4%	4%
Permits and Licenses	1%	2%	3%	2%
Tires	2%	2%	2%	2%
Tolls	1%	2%	1%	1%
Driver-based				
Driver Wages	26%	28%	29%	27%
Driver Benefits	9%	9%	10%	9%
TOTAL*	100%	100%	100%	100%

Geographical Data

- Industry Center for each State/Industry is specified to county level through payroll and survey data
- Transportation network information could be obtained from National Transportation Atlas Database (NTAD).

Emission determination

An Evolutionary Model of Industrial Structure, Goods Movement, and Associated Impacts: A dynamic structure-equation behavioral model

The original framework from which we embark is that of a static commodity flow model.

Commodity flow models are used to forecast equilibrium flows of goods between locations (usually regions) and identify local production levels necessary to meet system demand levels. They are also used to identify transportation network bottlenecks and forecast the impacts on regional economies of changes in transport capacity e.g., link outages due to disasters.

Commodity flow models in multi-period programming settings are used to simulate the evolution of patterns of regional production and interregional trade for purposes of planning regional transportation infrastructure (highways, railroads, and port facilities).

We still lack theories and models that *explicitly link decision-making of producers (or shippers) and carriers with impacts on nodes as well as links in transportation networks*.

Emission determination

Develop dynamic structural-equation behavioral model:

- Cost Minimization for Shipper

  Inter-Regional/Industry Freight Movement: determines annual increments in prices, capital, labor and freight movement

- Profit Maximization for Carrier

  Shipment Pricing and Route Selection: determines the charge of shipping and route of shipment for the next period

- Solution determined by non-cooperate equilibrium between representative shipper and carrier

The intertemporal optimization decision of a representative establishment in sector *j* at location *m* is to choose: 1) commodity flows, 2) capital, 3) labor and price so as to minimize the present value of costs of operation and adjustment to equilibrium levels of capital, intermediate goods, and labor:

Shipper Cost Minimization:

$$\int_{t_0}^{t_1} e^{-\lambda_m^{sj} t}\{\sum_i \sum_l p_{lm}^i \cdot x_{lm}^{ij} + w_m^j L_m^j + ucc_m^j K_m^j + q_m^j I_m^j + \frac{\omega_m^{Kj}}{2}(I - \upsilon_m^{Kj}(K_m^j * - K_m^j))^2$$

$$+\sum_i \sum_l \frac{\omega_{lm}^{xij}}{2}(a_{lm}^{xij} - \upsilon_{lm}^{xij}(x_{lm}^{ij} * - x_{lm}^{ij}))^2 + \frac{\omega_m^{Lj}}{2}(a_m^{Lj} - \upsilon_m^{Lj}(L_m^j * - L_m^j))^2$$

$$+\frac{\omega_m^{pj}}{2}(a_m^{pj} - \upsilon_m^{pj}(p_m^j * - p_m^j))^2\}dt,$$

- Control Variables: capital, time rate of change of commodity flows, labor and price

  $I_m^j = \dot{K}_m^j$, $a_{lm}^{xij} = \dot{x}_{lm}^{ij}$, $a_m^{Lj} = \dot{L}_m^j$, and $a_m^{pj} = \dot{p}_m^j$

Carrier Profit Maximization:

time varying schedule of prices, ϑ_{lm}^{ti} , and time-varying flows of commodities along available routes *r*, x_{lm}^{ij} and FD_{lm}^{ik}

$$\int_{t_0}^{t_1} e^{-\lambda_i^c t}\left\{\sum_i \sum_m \vartheta_{lm}^{ti}(\sum_j x_{lm}^{ij} + \sum_k \mathrm{FD}_{lm}^{ik}) - \sum_i \sum_m \sum_r h_{lmr}^i D_{lmr} p_{lmr}^{ti}\right\}dt$$

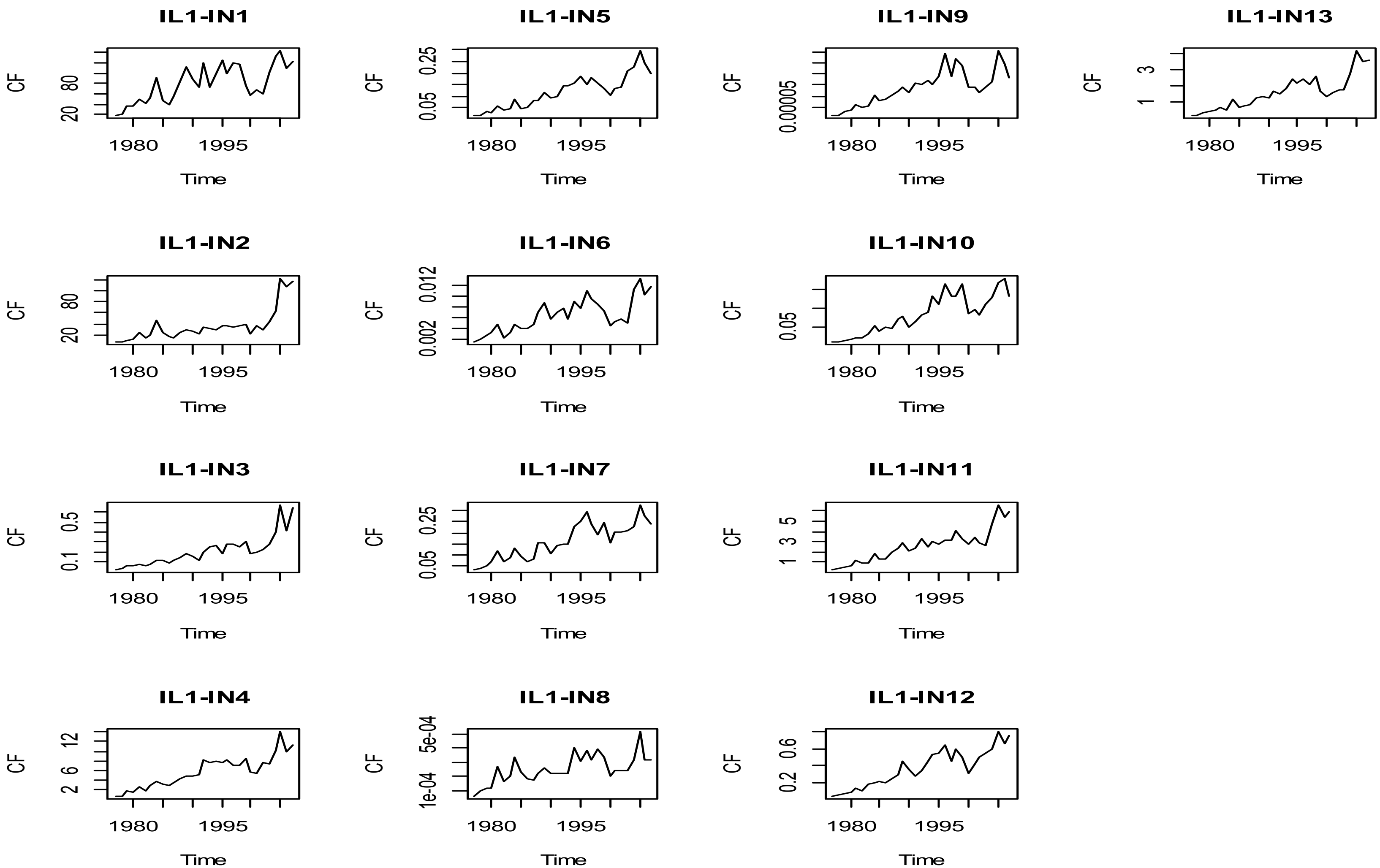
Model Simulations

Operationalization of the model entails generating spatial time series data, estimating the model, and solving it.

Data Requirements

- Commodity Flow Data
- Unit Transportation Cost Data By Mode
- Cost to Carriers
- Geographic Data

Time Profile for Commodity Flow: Ag to 13 sectors



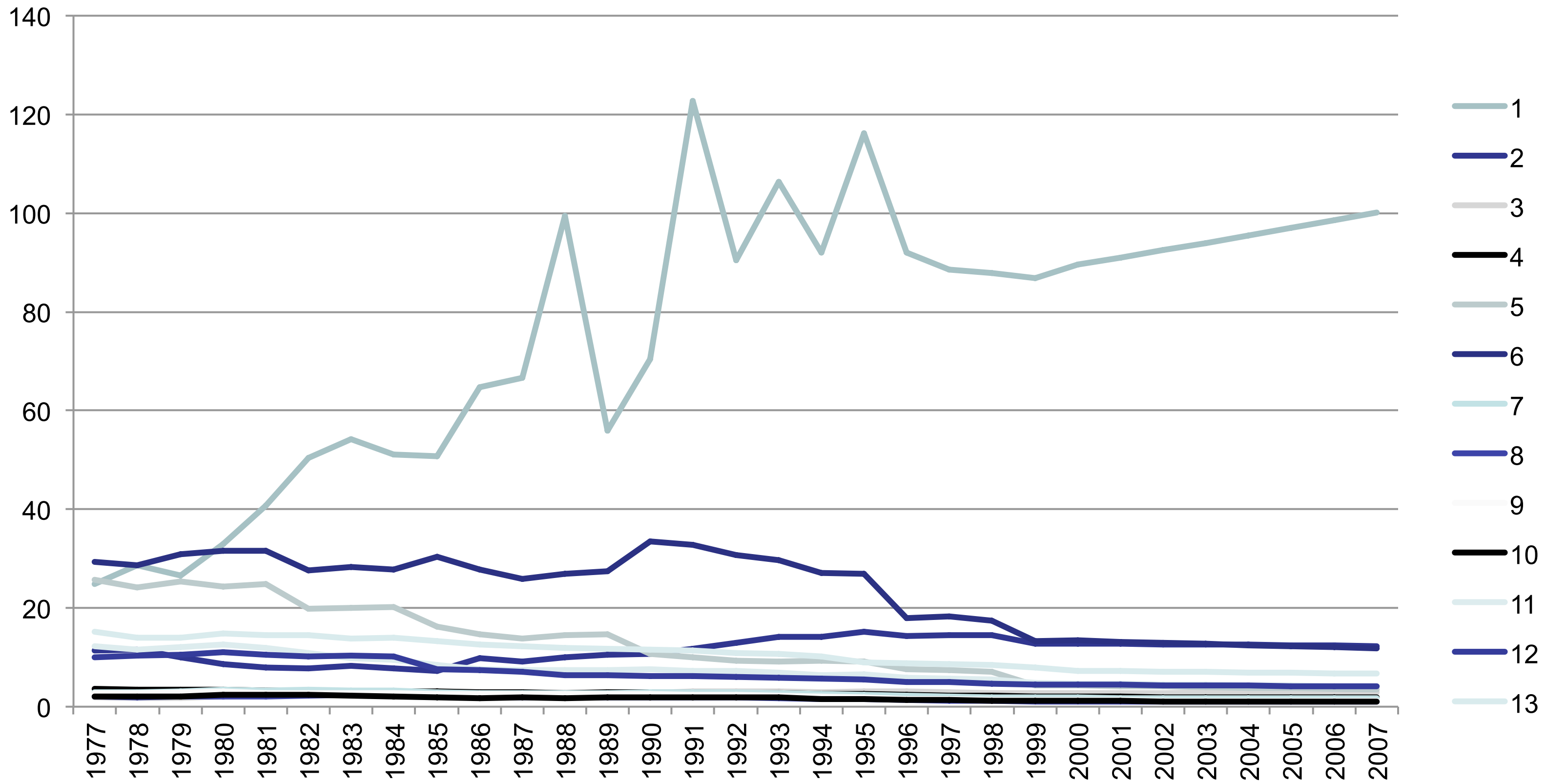
In-Sample Percentage Root-Mean-Square Errors for Commodity-Flow Equations

Illinois	Indiana	Michigan	Ohio	Wisconsin	RUS
13.45%	10.15%	8.78%	15.09%	13.23%	22.76%

Emission

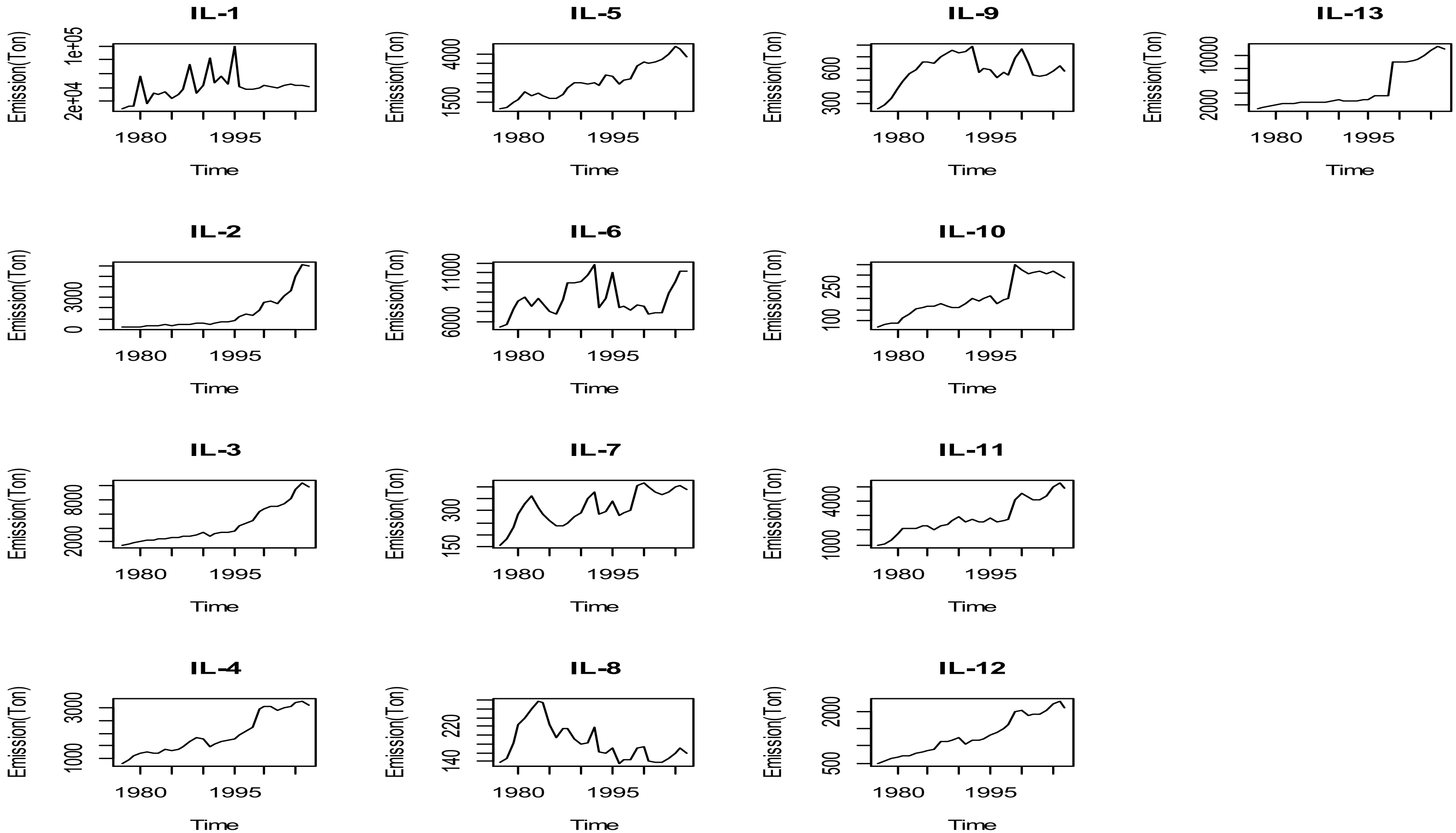
- Tao et al(2010) estimated annual emission coefficients from 1970-2000 for Mid-West states(IL,IN,MI,OH,WI)

Emission, Cont.,

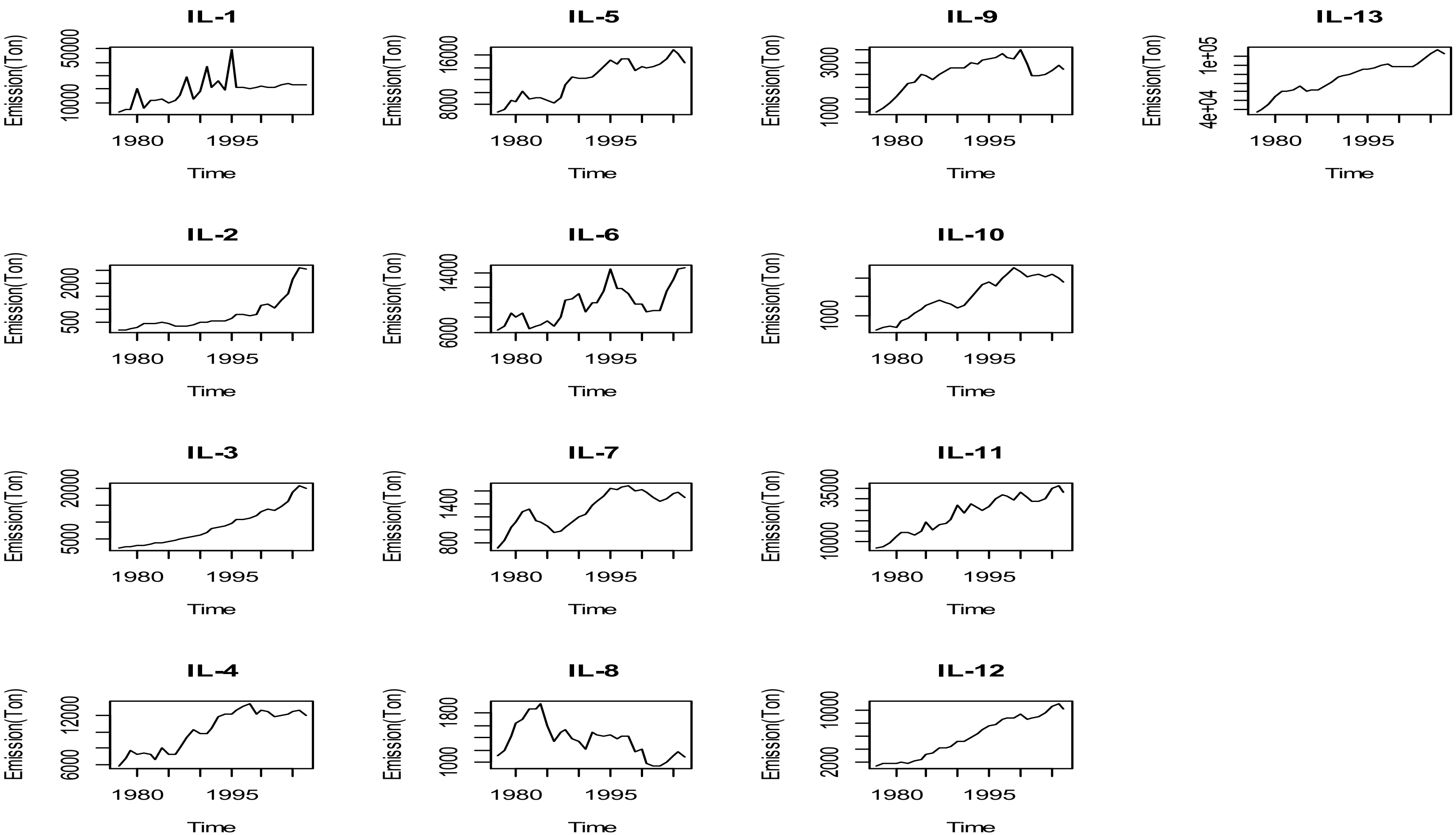


Time Profile for Emission Coefficients By Industry for Mid-West States(tons/million)

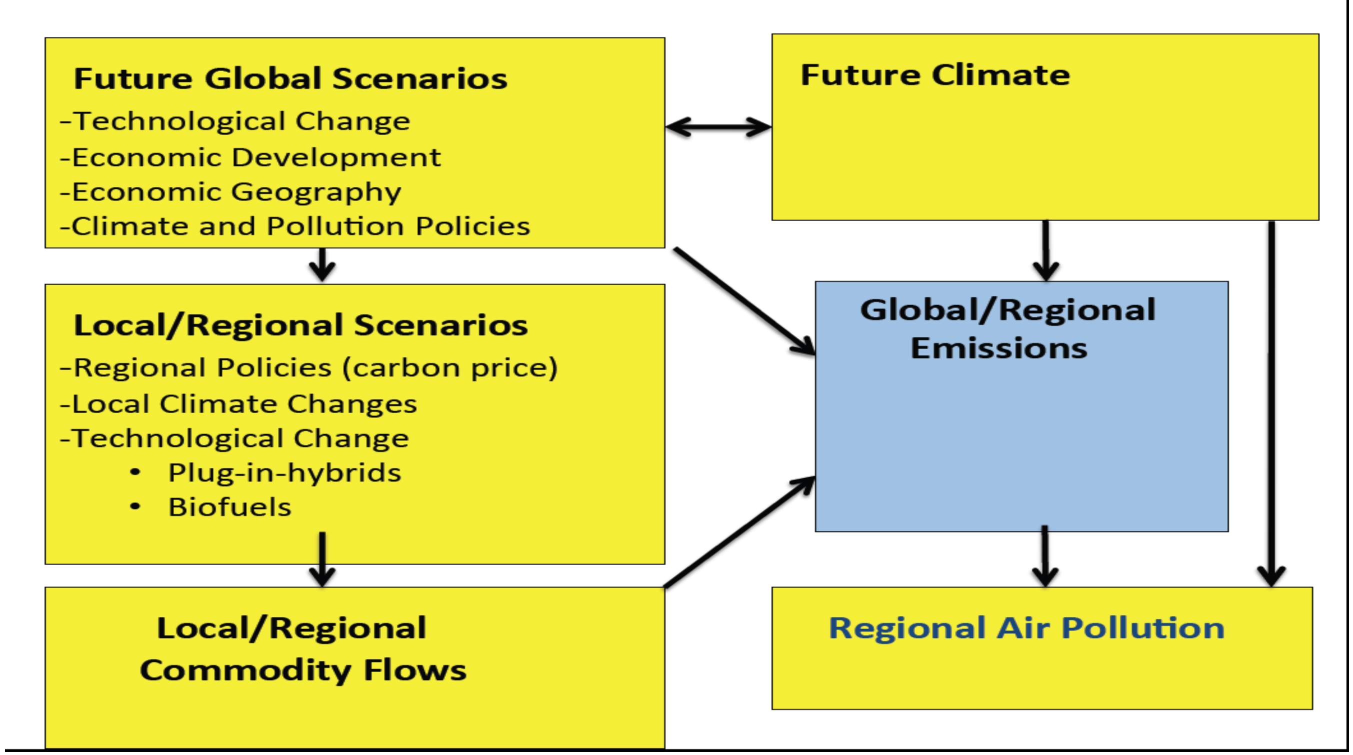
PM25 Emission-Illinois



NOx Emission-Illinois



◆ Emissions also can be generated for many other species.



Before we evaluate impact of future generated emissions in a future climate:

- ➢ **Control emission dataset**
- ➢ **Control simulation**

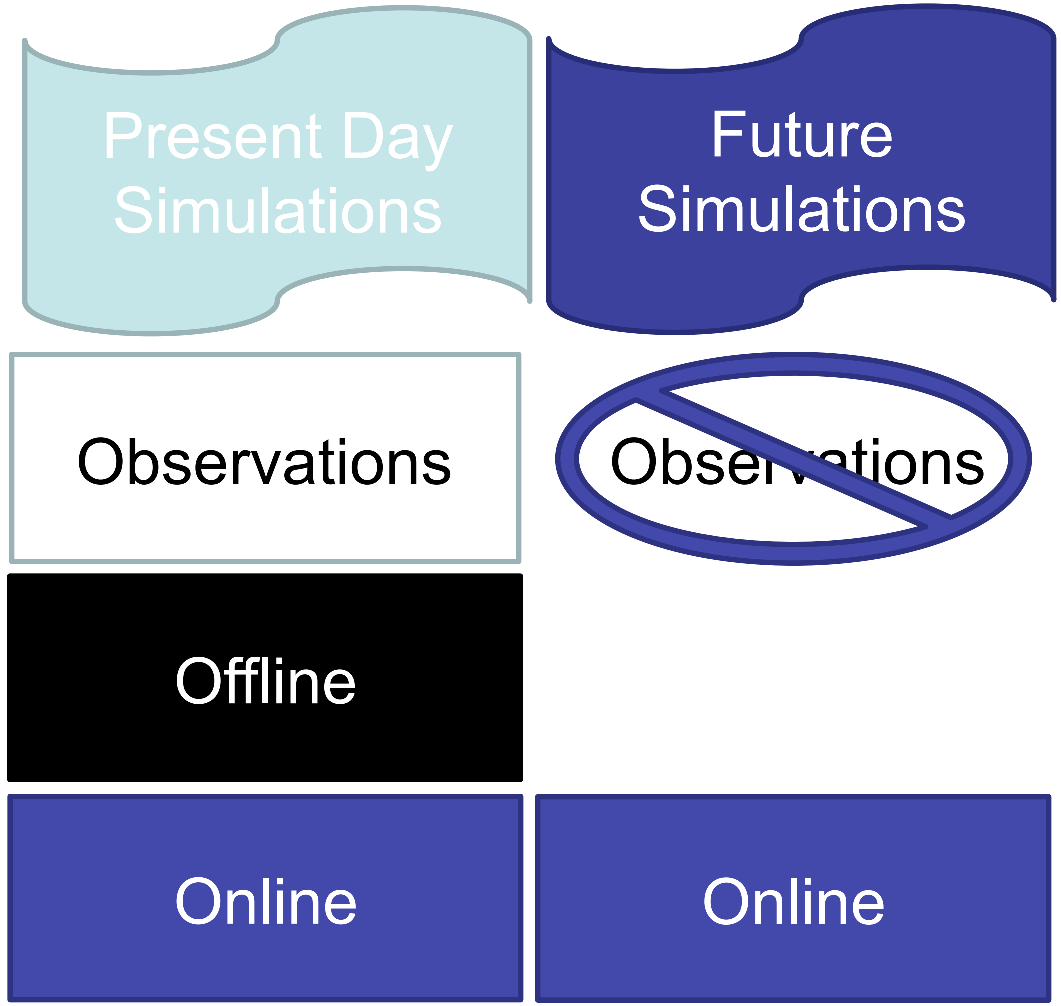
Control Simulations

Chemistry simulations frequently use online winds to compare with observations

-How does the impact of GCM meteorology bias the results?

-To what extent do SSTs determine summertime pollutant levels over the NE US?

Configurations



Configurations

Present Day Simulations

- EPA CASTNet:

Observations

  - 23 sites in Eastern US, hourly

Offline

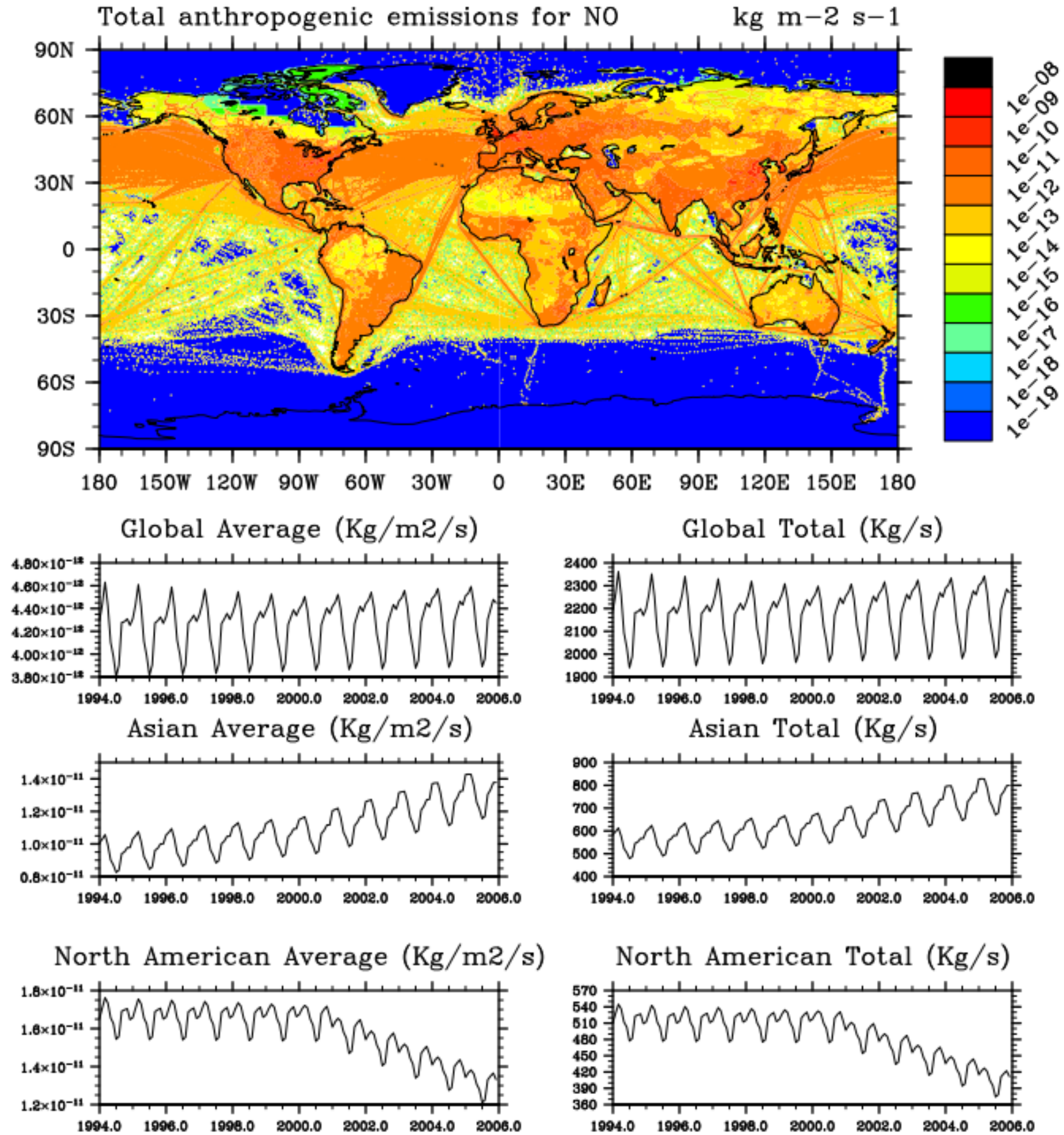
  - ...nds, forced ocean/ice

Online

  - Online winds, forced ocean/ice

1. Emissions

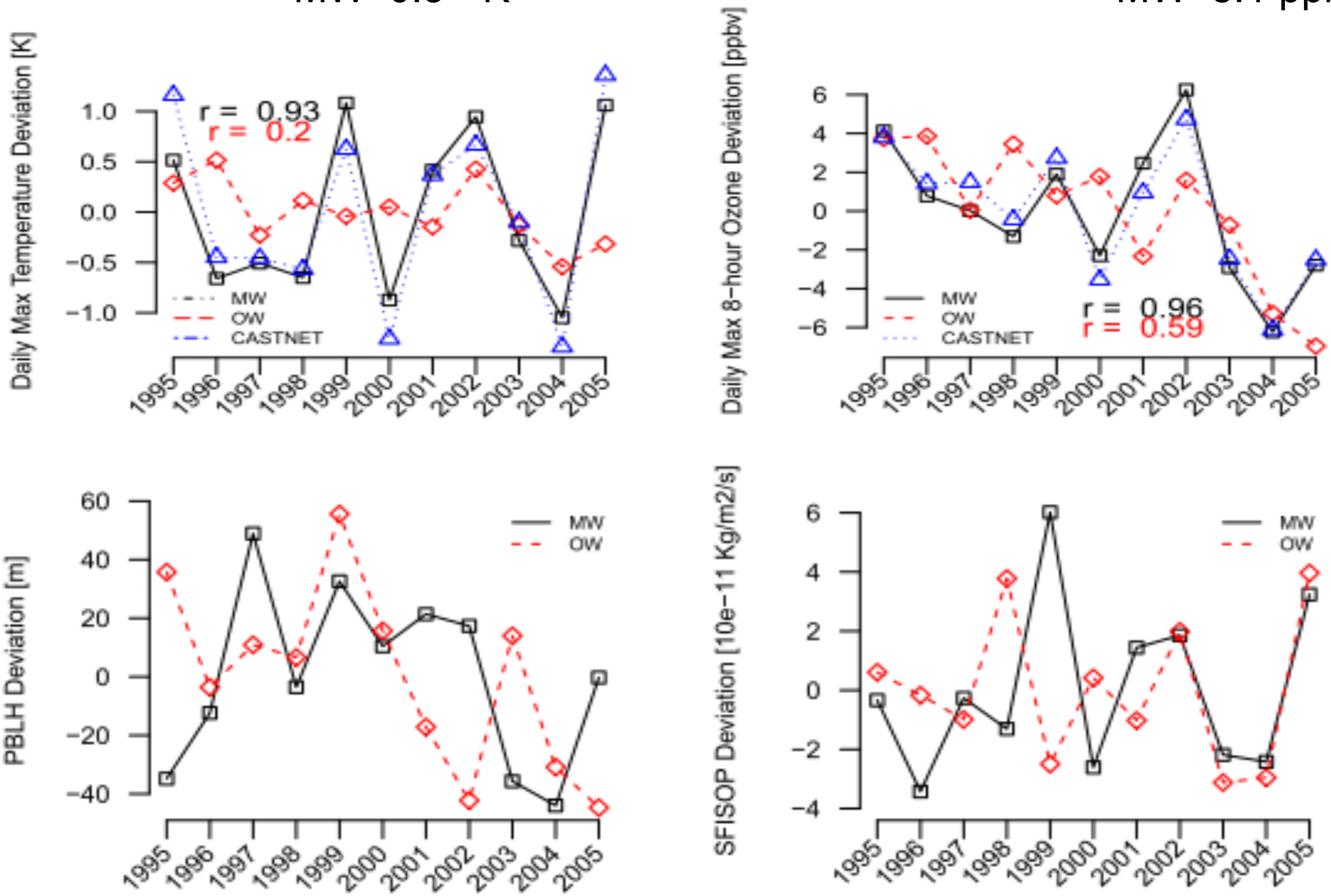
- 21 MOZART-4 species from MACCity and EPA NEI 2005
- Seasonality taken from MACCity
- NO decrease starting in 2000 a result of 1998 NOx SIP
- Biogenic Emissions from MEGAN, online for isoprene and $C_{10}H_{16}$



Control Simulations: Interannual Variability

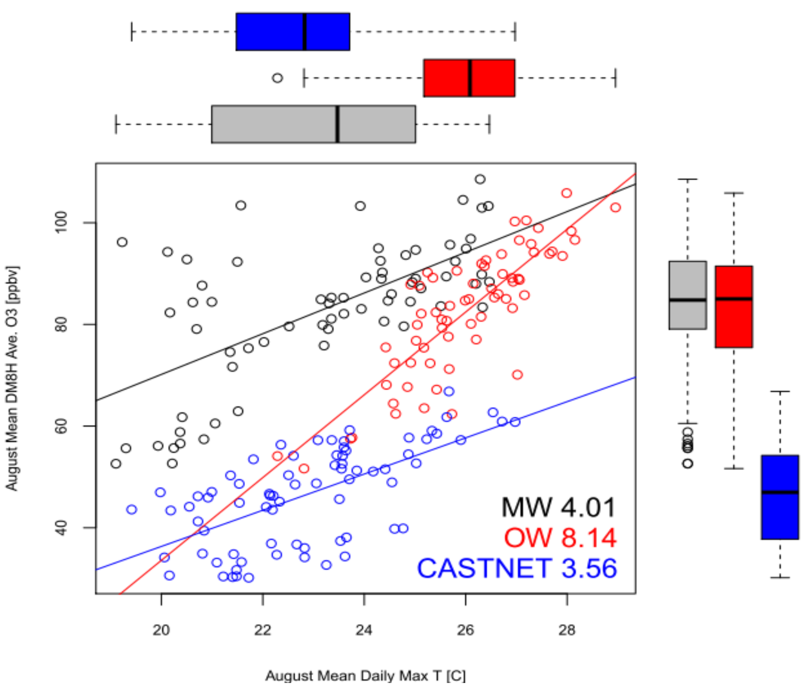
T Bias: OW 3° K
MW 0.3 ° K

O3 Bias: OW 9.1 ppbv
MW 8.1 ppbv

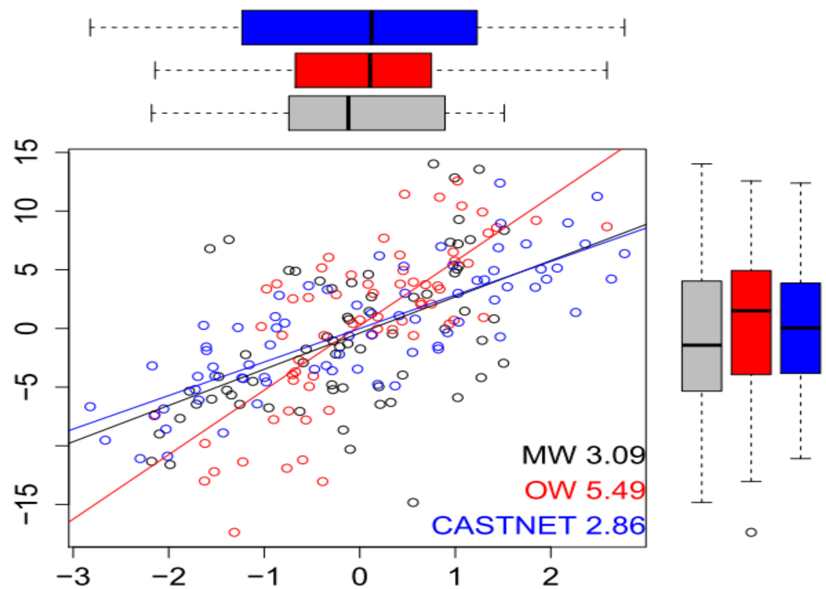


Control Simulations: Climate Penalty

AUG.
T vs . O3



AUG.
T. vs. O3 deviations



We have shown that:

- the dynamic commodity flow model model can be solved numerically in a widely available computational package and the solution comports reasonably well with historical data and trends in economic geography;

- the model can be used to conduct simulations of alternative scenarios involving different assumptions about international trade and transportation infrastructural investments and generate associated emissions.

Remaining tasks

- remaining tasks include computations of non-point source emissions from model.

- the design and implementation of thought experiments to analyze impacts of interest:
  (i) Cost and production of energy (ii) Costs of transportation, labor, and capital (iii) Changes in transport infrastructure (iv) Changes in exogenously generated freight movements through transportation networks (v) Changes in economies of scale and scope in production

- Consequences of resulting emission changes on atmospheric chemistry in the present as well as in the future.