GLIMPSE decision support system for air quality management: Overview and application

Dan Loughlin*, Yang Ou*ο, Steve Smithp, and Chris Nolte*

* U.S. EPA Office of Research and Development
ο Oak Ridge Institute for Science and Education participant
p Pacific Northwest National Laboratory, Joint Global Change Research Institute
Foreword

• Additional contributors to this work
  • EPA: Tai Wu, Carol Lenox
  • ORISE: Wenjing Shi, Samaneh Babaee
  • PNNL: Catherine Ledna, Gokul Iyer
  • UNC-CH: Jason West

• Purpose of this presentation
  • Discuss development and application of GLIMPSE, a GCAM-USA-based decision support tool for air quality management

• Intended audience
  • The emissions and air quality modeling communities

• Caveats
  • All results shown are intended to be illustrative. Caveats and assumptions are not fully discussed here. Please do not cite results.

• Disclaimer
  • The views expressed in this presentation are those of the authors and do not necessarily represent the views or policies of the U.S. EPA
Abbreviations

• Emissions species
  • BC – black carbon
  • CH$_4$ – methane
  • CO – carbon monoxide
  • CO$_2$ – carbon dioxide
  • N$_2$O – nitrous oxide
  • NH$_3$ – ammonia
  • NO$_2$ – nitrogen dioxide
  • NOx – nitrogen oxides
  • O$_3$ – ozone
  • OC – organic carbon
  • PM$_{2.5}$ – particulate matter with diameter < 2.5 microns
  • SO$_2$ – sulfur dioxide
  • VOC – volatile organic compounds

• Policies and regulations
  • CAFE – Corporate Vehicle Fleet Economy Standard
  • CSAPR – Cross-State Air Pollution Rule
  • NAAQS – National Ambient Air Quality Standards
  • NSPS – New Source Performance Standards
  • RGGI – Regional Greenhouse Gas Initiative
  • RPS – Renewable Portfolio Standard

• Modeling
  • GCAM – Global Change Assessment Model
  • GCAM-USA – GCAM with state-level resolution for the U.S.
  • GLIMPSE – GCAM Long-term Interactive Multi-Pollutant Scenario Evaluator

• Energy and technologies
  • CCS – Carbon capture and sequestration
  • CNG – Compressed natural gas
  • CHP – Combined heat and power
  • NG – natural gas

• Units
  • EJ – Exajoules (exa is $10^{18}$)
  • MTC – Mega tonnes of Carbon (mega is $10^{6}$)
  • TWh – Terawatt hours (tera is $10^{12}$)
  • bil – billion
  • mil – million

• Standard state postal abbreviations are used
Outline

• Background and objectives
• GLIMPSE overview
• Illustrative application: Co-benefits assessment
• Additional considerations and future steps
• Future directions
• Questions?

Note: A demo of the GLIMPSE graphical user interface will be available at the next break at the U.S. EPA Office of Research and Development table in the lobby
Background and objectives
U.S. air quality trends

The U.S. has made great strides in reducing air pollution since the passage of the Clean Air Act Amendments

Nat’l average concentration changes since 1990

- Carbon Monoxide (CO) 8-Hour, ↓ 77%
- Lead (Pb) 3-Month Average, ↓ 80%
- Nitrogen Dioxide (NO₂) Annual, ↓ 56%
- Nitrogen Dioxide (NO₂) 1-Hour, ↓ 50%
- Ozone (O₃) 8-Hour, ↓ 22%
- Particulate Matter 10 microns (PM₁₀) 24-Hour, ↓ 34%
- Particulate Matter 2.5 microns (PM₂.₅) Annual, ↓ 41%
- Particulate Matter 2.5 microns (PM₂.₅) 24-Hour, ↓ 40%
- Sulfur Dioxide (SO₂) 1-Hour, ↓ 88%

Source: https://gispub.epa.gov/air/trendsreport/2018/#highlights
Remaining air quality issues

- Despite this progress, an estimated 132 million people (40% of the U.S. population) live in areas that exceed a NAAQS or that have been re-designated to attainment subject to maintenance.

Attainment in the future

• State-level factors that will affect future air pollutant emissions
  • Population growth and migration
  • Economic growth and transformation
  • Energy supplies and their depletion
  • Technology stock and turnover
  • Technology development
  • New and emerging demands for energy
  • Transformations in mobility and land use patterns
  • Supply limits and competition among sectors for water
  • Climate change impacts on energy demands, cooling water availability, and atmospheric chemistry
  • Human behavior and choices
  • Other energy, environmental, and climate policies

• Can we model how will these factors may affect attainment in the future and proactively develop air quality management strategies?
GLIMPSE

GCAM Long-term Interactive Multi-Pollutant Scenario Evaluator
The GLIMPSE project

• Objective: Provide a state-level tool for supporting air quality planning
  • Understand future threats to attainment
  • Evaluate potential management strategies under uncertainty
  • Assist in identifying management strategies that simultaneously, cost-effectively, and robustly meet state energy, environmental, and climate goals
  • Complement other detailed sector-specific modeling tools by providing insights about cross-sector interactions, counterintuitive responses, and unintended consequences

• Approach
  • The Global Change Assessment Model with U.S. state-level resolution (GCAM-USA) is being modified to more fully reflect U.S. air quality regulations and state-level policies
  • “Levers” reflecting management options are being integrated into the model
  • A GLIMPSE graphical-user-interface prototype has been developed to facilitate running GCAM-USA and examining its results
  • Internal beta testers are using GLIMPSE to evaluate its installation and use
  • GCAM-USA is being used within a range of applications, one of which is summarized here
GCAM-USA model

*Human-Earth System Models*

- Economy
- Energy
- Water
- Agriculture
- Buildings
- Land Use

Simulates evolution of these systems through time, accounting for their interactions

**GCAM-USA**

Global Change Assessment Model with U.S. Resolution

**Background:**
- 30-yr track record of scenario assessment applications
- Air pollutant emissions added in 2000s
- U.S. state level resolution added in 2010s

**Type:** Technology-rich, energy focused simulation model

**Maintained by:** Pacific Northwest National Laboratory/JGCRI

**Time Horizon:** 2010 – 2100, 5-year increments

**Spatial Resolution:** 32 global regions, 50 states

**Pollutants:** CO\(_2\), NO\(_x\), SO\(_2\), PM\(_{2.5}\), CO, NH\(_3\), VOC, CH\(_4\), N\(_2\)O, BC, OC (emission factors are derived from EPA models and analyses)

**Policies included:** CAFE, CSAPR, Tier 3, RGGI, and many NSPSs (not yet included: state-level RPS, Regional Haze, other state-specific actions)

**Runtime:** 1 to 5 hours

**Requirements:** Desktop PC

**Availability:** Public domain, open source, free
GCAM-USA regions

Energy-economic geographic regions

32 geopolitical regions

50 states + D.C. in the U.S.

Agricultural economic zones

U.S. electricity grid regions

Source of graphics: PNNL GCAM 5.1 documentation
Example GCAM-USA outputs

Electricity production by category (TWh)

- Hydro
- Wind
- Solar
- CHP
- Nuclear
- Natural gas
- Coal

Light duty travel by technology (billion passenger-km)

- CNG
- Electric
- Hybrid
- Conventional

Electricity Use By Sector (EJ)

- Transportation
- Industry
- Other
- Buildings

Industrial energy use by fuel (EJ)

- Electricity
- Biomass
- Natural gas
- Fuel oil

CO2 emissions by sector (MTC)

- Nonroad
- On-road
- Industry
- Electric sector

Change relative to 2010

- NOx
- SO2
- PM2.5
- NH3
- CO
- VOC
- PM2.5 mortality
GLIMPSE Scenario Builder

Scenario building blocks

Creating a scenario

Analysis of results

One-click scenario execution

Library of scenarios
GLIMPSE Enhanced ModelInterface

Scenarios in results database

List of scenario outputs that can be queried

Modeled regions

Query results

Query visualization

An extension of the GCAM ModelInterface
See EPA booth next to registration table for demo at next break
Illustrative application
Co-benefits assessment
Application: Co-benefits assessment

Goal: Estimate changes in air pollutant emissions and associated PM mortality costs of current and proposed Regional Greenhouse Gas Initiative (RGGI) targets

Region-wide electric sector CO$_2$ caps

- 2015: 89 x 10$^6$ tons
- 2020: 78 x 10$^6$ tons
- 2025: 66 x 10$^6$ tons
- 2030: 55 x 10$^6$ tons

RGGI region: CT, DE, ME, MD, MA, NH, NY, RI, VT (total population: >40 million)
Application: Co-benefits assessment

### Electricity production (EJ) without RGGI

<table>
<thead>
<tr>
<th>State</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
<th>2045</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT</td>
<td>0.3</td>
<td>0.2</td>
<td>0.1</td>
<td>0.01</td>
<td>0.02</td>
<td>0.03</td>
<td>0.04</td>
<td>0.06</td>
</tr>
<tr>
<td>DE</td>
<td>0.03</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
<td>0.03</td>
<td>0.04</td>
<td>0.06</td>
</tr>
<tr>
<td>ME</td>
<td>0.08</td>
<td>0.06</td>
<td>0.04</td>
<td>0.03</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>MD</td>
<td>0.3</td>
<td>0.2</td>
<td>0.1</td>
<td>0.01</td>
<td>0.02</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
</tr>
<tr>
<td>MA</td>
<td>0.15</td>
<td>0.1</td>
<td>0.05</td>
<td>0.01</td>
<td>0.02</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
</tr>
<tr>
<td>NH</td>
<td>0.3</td>
<td>0.2</td>
<td>0.1</td>
<td>0.01</td>
<td>0.02</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
</tr>
<tr>
<td>NY</td>
<td>0.8</td>
<td>0.6</td>
<td>0.4</td>
<td>0.2</td>
<td>0.1</td>
<td>0.08</td>
<td>0.06</td>
<td>0.04</td>
</tr>
<tr>
<td>RI</td>
<td>0.03</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
</tr>
<tr>
<td>VT</td>
<td>0.06</td>
<td>0.04</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
</tbody>
</table>

### Electricity production (EJ) with RGGI

<table>
<thead>
<tr>
<th>State</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
<th>2045</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT</td>
<td>0.3</td>
<td>0.2</td>
<td>0.1</td>
<td>0.01</td>
<td>0.02</td>
<td>0.03</td>
<td>0.04</td>
<td>0.06</td>
</tr>
<tr>
<td>DE</td>
<td>0.03</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
<td>0.03</td>
<td>0.04</td>
<td>0.06</td>
</tr>
<tr>
<td>ME</td>
<td>0.08</td>
<td>0.06</td>
<td>0.04</td>
<td>0.03</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>MD</td>
<td>0.3</td>
<td>0.2</td>
<td>0.1</td>
<td>0.01</td>
<td>0.02</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
</tr>
<tr>
<td>MA</td>
<td>0.15</td>
<td>0.1</td>
<td>0.05</td>
<td>0.01</td>
<td>0.02</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
</tr>
<tr>
<td>NH</td>
<td>0.3</td>
<td>0.2</td>
<td>0.1</td>
<td>0.01</td>
<td>0.02</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
</tr>
<tr>
<td>NY</td>
<td>0.8</td>
<td>0.6</td>
<td>0.4</td>
<td>0.2</td>
<td>0.1</td>
<td>0.08</td>
<td>0.06</td>
<td>0.04</td>
</tr>
<tr>
<td>RI</td>
<td>0.03</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
</tr>
<tr>
<td>VT</td>
<td>0.06</td>
<td>0.04</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Illustrative results

- **Coal**
- **Gas**
- **Biomass**
- **Nuclear**
- **Geothermal**
- **Hydro**
- **Wind**
- **Solar**
- **CHP**
Electricity production by aggregated technology category in the RGGI region

Without RGGI

With RGGI

Change in electricity production (With RGGI – Without RGGI)

Illustrative results
Application: Co-benefits assessment

Comparison of emission trajectories for CO$_2$, NO$_x$, SO$_2$, and PM$_{2.5}$ in the RGGI region states with and without the proposed regional targets.

Bars show annual estimates of avoided PM$_{2.5}$ mortality costs from RGGI.

Source- and pollutant-specific PM$_{2.5}$ mortality impact factors obtained from OAQPS report: “Estimating the benefit per ton of reducing PM$_{2.5}$ precursors from 17 sectors.” National average values used.

Illustrative results

Solid = RGGI
Dash = no RGGI
Application: Co-benefits assessment, part 2

In November, 2017, Virginia developed a draft rule that would allow it to join RGGI.

The would expand the number of people living within the RGGI region by ~22% and the electric generation by ~25%.

RGGI would comprise approximately 9% of US generation.

Can GLIMPSE provide insights into the emissions and health co-benefits of adding Virginia to RGGI?

Note: This is an illustrative application. We did not attempt to model Virginia’s proposal in detail.
Adding VA to the RGGI region results in a reduction of up to $1.75bil in PM mortality costs in 2050

NY could see additional benefits; NY generates additional electricity to make up for a reduction from VA. However, NY must do so with lower-emitting technologies and fuels because of CSAPR and RGGI

Other states may see some disbenefits as GHG emission reductions and air pollution co-benefits shift to VA

Note: This is just one scenario of VA joining RGGI. It is indicative of the types of insights that could be gained using GLIMPSE
Other applications

• Technology assessment
  • Electric vehicles
  • Electrification of space and water heating in buildings

• Co-benefit assessment
  • alternative electric sector technology pathways
  • state-level energy and emission goals

• Air quality management
  • challenges associated with population growth and climate change on air pollutant emissions
  • Optimal control strategies, simultaneously considering traditional controls, energy efficiency, renewable energy, and end-use electrification
Future directions
Future directions

• Ongoing GCAM-USA improvements:
  • Add seasonality (winter or summer) and time-of-day (day or night) to energy supply and demand
  • Continue to improve policy representations within the model
    • Incorporate existing state-level renewable portfolio standards
  • Continue to update technology characterizations to account for new developments
  • Improve the industrial sector representation to represent state-level fuel and technology decisions more fully
  • Add life cycle factors to represent emissions associated with fuel extraction and transportation

• Ongoing GLIMPSE improvements:
  • Working with a small set of internal beta-testers to improve design and functionality
  • Adding “levers” to allow air quality managers to use the system to evaluate policy options
  • Improving visualization and analysis tools
Questions?

Loughlin.Dan@EPA.gov
(919) 541-3928
Summary

Objectives:
• Describe U.S. EPA modifications to GCAM-USA to support air pollutant emission projections
• Apply the updated GCAM-USA to project emissions of NOx, SO2, and PM2.5
• Compare the projections by comparing to EPA regulatory analyses
• Introduce and apply “Quality Metric (QM)“ to evaluate national- and state-level results

Findings:
• GCAM-USA is a fast and flexible mechanism for projecting state and national air pollutant emissions
• After the modifications, GCAM-USA projections much more closely matched EPA estimates, capturing major trends at the national and sectoral levels
• The QM provides information that may be useful in examining state- and sectoral-level performance, helping determine the types of questions that can be answered
**Projection of air pollutant emissions**  
**Application to alternative scenarios**


---

**Summary**

**Objectives:**
- Apply the modified GCAM-USA that was described by Shi et al.
- Describe the addition of PM mortality and water use factors
- Evaluate the low-carbon scenarios from the Energy Modeling Forum 24 exercise to compare their relative air quality-related health co-benefits

**Pathways:**
- All technologies; Renewables focus; Nuclear and carbon capture focus

**Low-carbon targets:**
- 50% reduction from 2005; 80% reduction from 2005

**Findings:**
- GCAM-USA can be used to evaluate co-benefits of alternative low-carbon pathways
- Co-benefits are shown to differ by pathway and spatially
- RE (as modeled) achieves greater water use co-benefits
- NUC/CCS (as modeled) achieves greater health co-benefits
- Treatment of residential biomass and assumptions about the adoption of cleaner biomass combustion technologies has a large effect on health results

---

**PM mortality health benefits by sector for low-carbon pathways**

- **BASE** – all technologies are available
- **RE** – emphasis on renewable technologies
- **NUC/CCS** – emphasis on nuclear power and CCS

---

**Legend:**
- Building
- Electricity
- Industry
- Transportation
- Net