Air Quality Modeling and Cost-Benefit Optimization

Design of a Software Prototype for Managing Urban and Industrial Development

Keynote Address by

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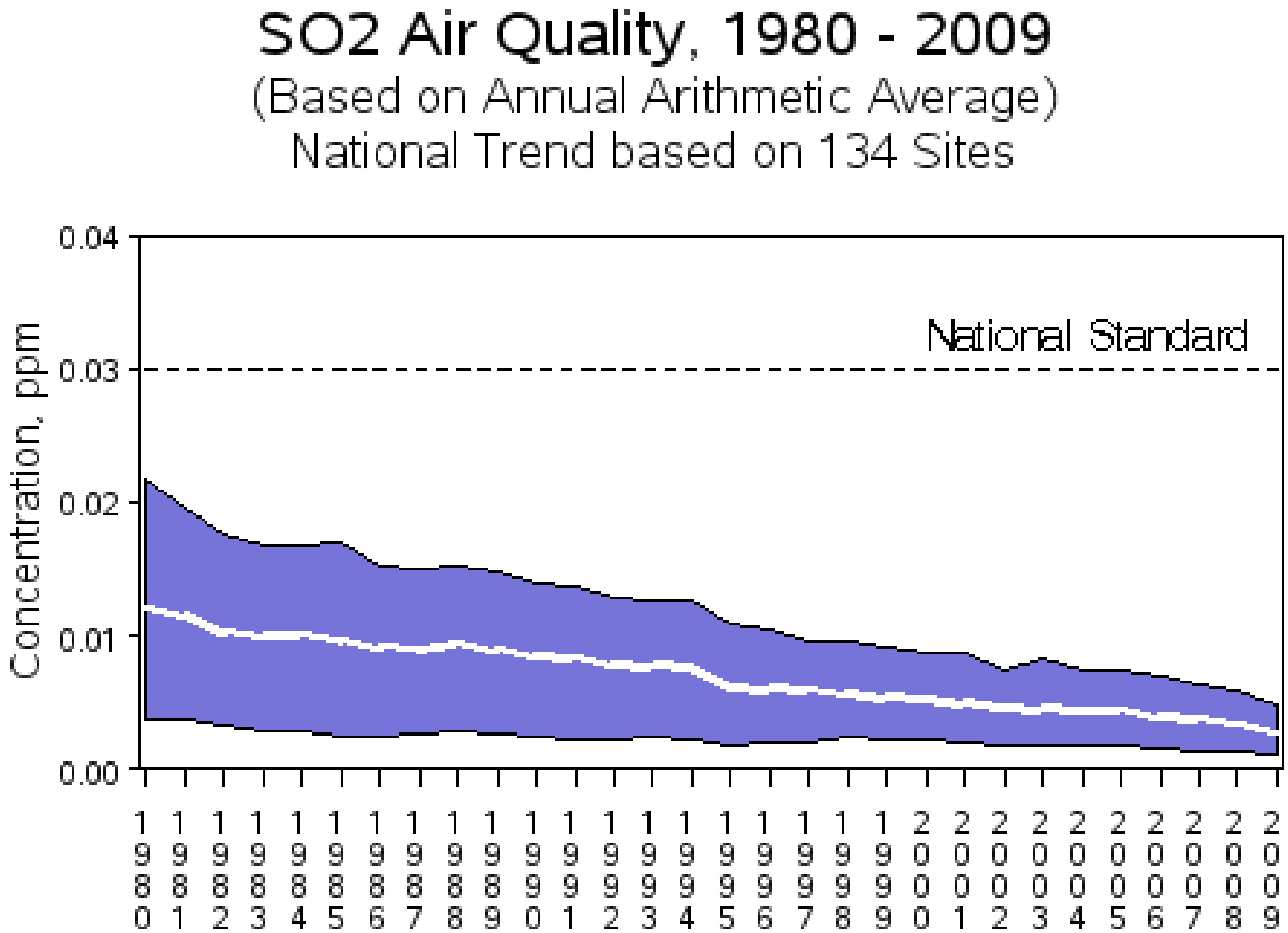
History of Air Quality Studies

Two main goals:

1. The improvement of air quality in areas contaminated by air pollution (e.g., US Clean Air Act of 1970) ➔ AQ standards
2. The protection of regions with good air quality from possible future deterioration due to urban and industrial development (e.g., US Prevention of Significant Deterioration, 1977) ➔ better than AQ standards

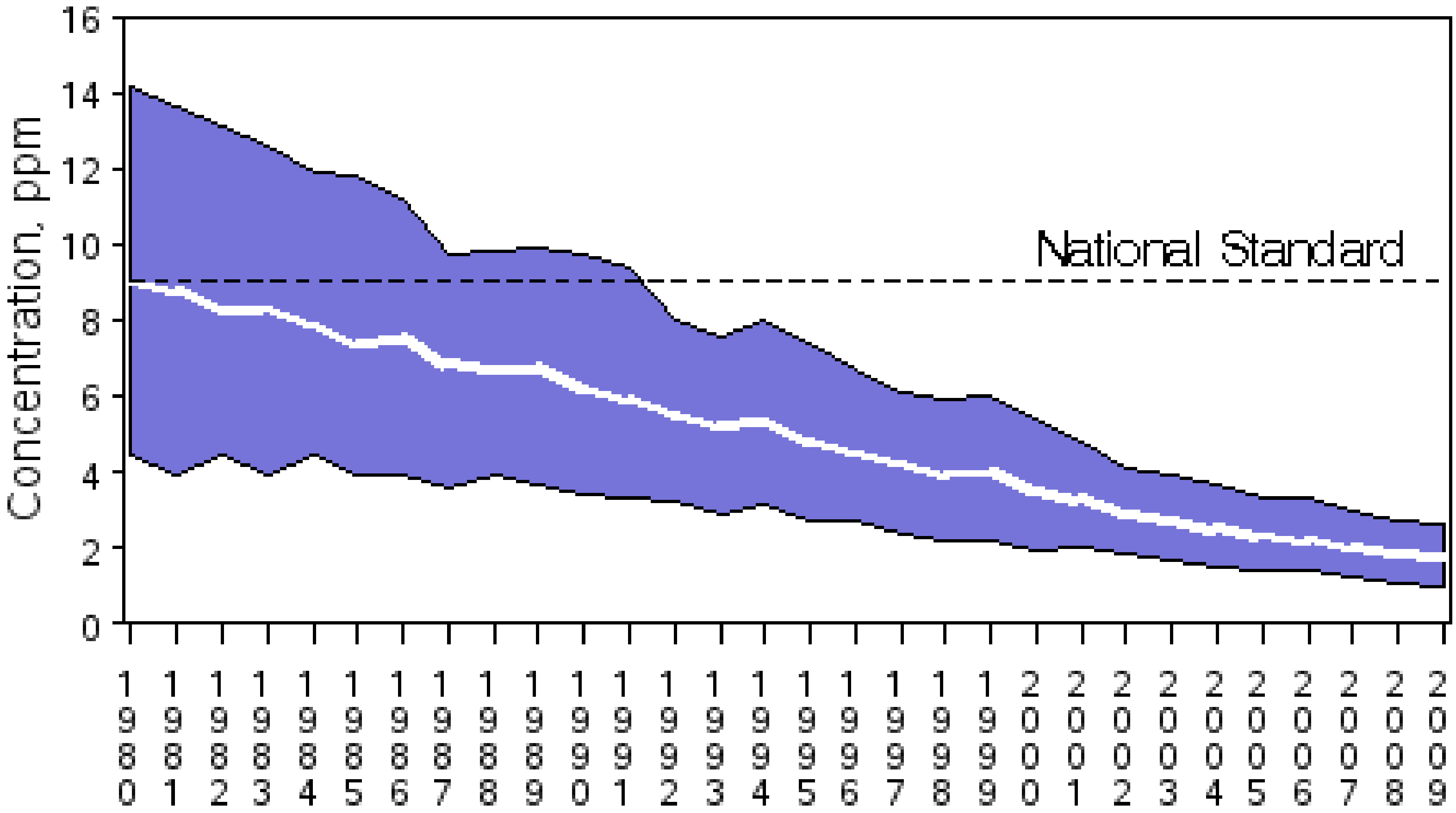
Major Results!



1980 to 2009 : 76% decrease in National Average

CO Air Quality, 1980 - 2009

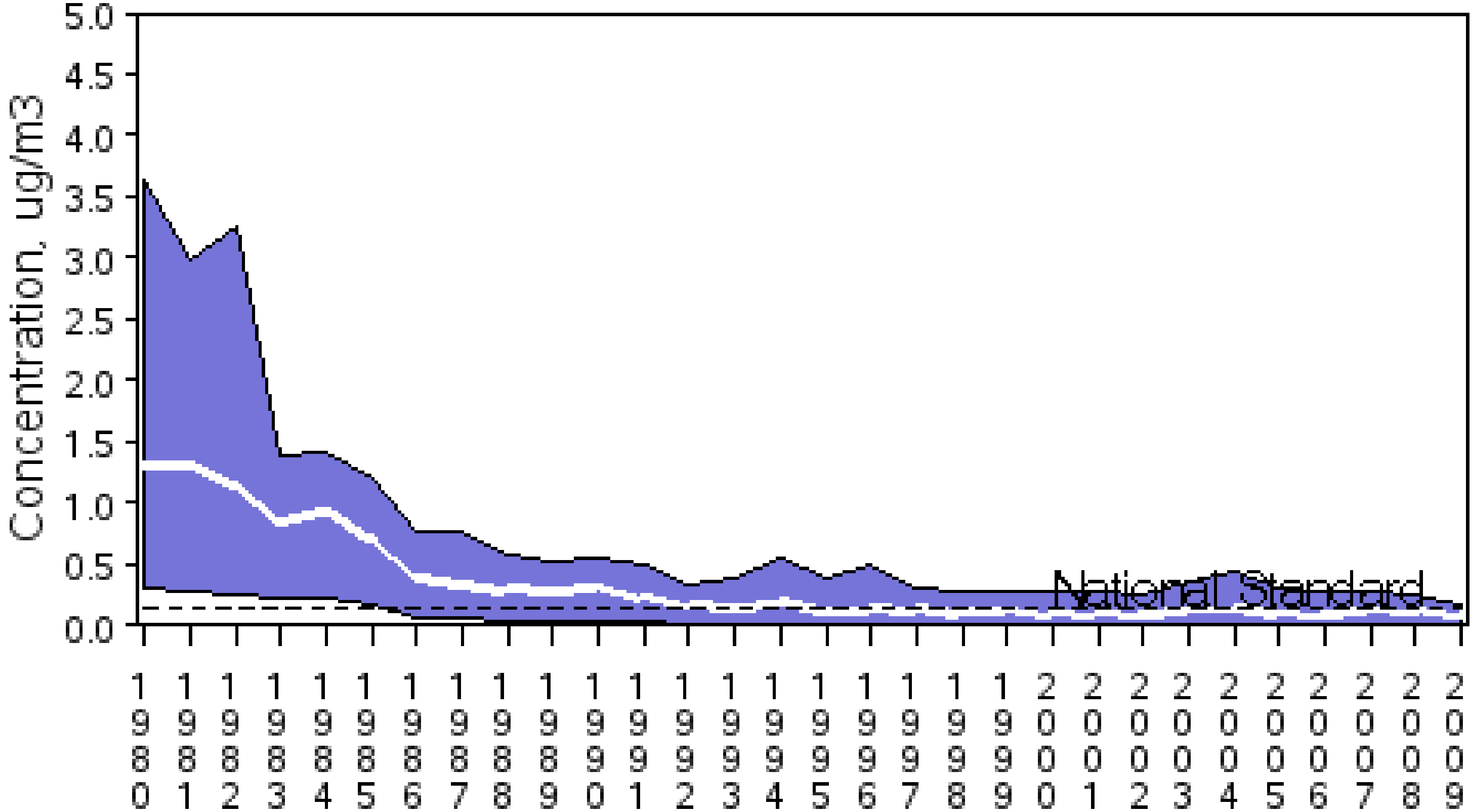
(Based on Annual 2nd Maximum 8-hour Average)
National Trend based on 114 Sites



1980 to 2009 : 80% decrease in National Average

Lead Air Quality, 1980 - 2009

(Based on Annual Maximum 3-Month Average)
National Trend based on 20 Sites



1980 to 2009 : 93% decrease in National Average

Costs vs. Benefits

- Enormous costs of study, design, implementation, and enforcement of regulations, and the costs carried by businesses and industries to comply
- Questions:
  - Were benefits greater than costs?
  - Were air quality improvement plans designed to maximize benefits or minimize costs?
  - Could we have applied better cost-benefit planning and achieved better results?
  - Can we use cost-benefit optimization in the future?
    (we should focus on what can be done today with the current technology!)

It is a Fact! Let's Admit it!

- Advanced computer simulation/optimization techniques have never been used so far to guide the actions of governments and agencies toward a well organized
  - maximization of benefits (with fixed costs) or
  - minimization of costs (with fixed benefits)
- The actions of governments have focused instead on
  1. air quality standards (that should not be exceeded, but often are) verified by air quality measurements, even though air monitoring is costly and we cannot of course measure all pollutants in all locations;
  2. emission standards, that again are not always easy to control;
  3. enforcement, often partial and selective.

Some Data

- Benefits: According to a 1997 EPA Report to Congress (http://www.epa.gov/oar/caa/40th_highlights.html), the first 20 years of Clean Air Act programs, from 1970 - 1990, led to the prevention in the year 1990 of:
  - 205,000 premature deaths,
  - 672,000 cases of chronic bronchitis,
  - 21,000 cases of heart disease,
  - 843,000 asthma attacks,
  - 189,000 cardiovascular hospitalizations,
  - 10.4 million lost I.Q. points in children - from lead reductions, and
  - 18 million child respiratory illnesses
- Costs: it has been estimated that the costs of the 1990 Clean Air Act Amendments over the period 1990-2020 in the US were 380 billion dollar (in 2006 US$) (http://www.epa.gov/oar/sect812/feb11/fullreport.pdf)

It is Reasonable to Believe...

- ... that computer simulation/optimization techniques offer a tool for optimal planning that should play a key role in the future
- This is particularly true for emerging countries, e.g., China
  - rapid industrialization,
  - distressing deterioration of air quality, especially in major cities

What do we Recommend to Emerging Countries?

- We all expect countries like China eventually to follow the historical pattern of the West (e.g., Europe and North America),
  - after major industrial developments ➔development of environmental protection regulations
  - major investments in remediation and emission control
  - positive results that can be measured and verified in most (but certainly not all) regions.
- But is this historical path the best, today, especially for emerging countries that need fast solutions at minimum costs?
- We believe that any country today investing funds for air quality improvement/protection can benefit from planning through computer simulation modeling and optimization techniques
- The discussion below elaborates our views on this matter and presents the design of a conceptual software prototype developed for this purpose

China, as an Example

- Special place for its size and the rapidity of its recent industrial and urban growth
- High levels of urban and industrial air pollution in many areas of its territory, especially in its highly populated coastal region
- History teaches us that, eventually, with time, increase of GNP, pressure from public opinion, industrial awareness, and proper government actions and investments, these problems will be mitigated
- The issue is how to accelerate this process and, more importantly, how to make sure that investments will produce maximum benefits

China: Unique Historic Position

- Take full advantage of previous experiences in the Western world, including successes and mistakes, good investments and wasteful ones
- Intelligent use of today's advanced computer simulation tools - Air Quality Models - that have been well tested and calibrated
- These tools, combined with other computer methods (e.g., optimization simulations and cost-benefit analysis), are capable today of providing objective results that can guide and assist decision makers in implementing their future air pollution mitigation actions and developing urban/industrial development plans

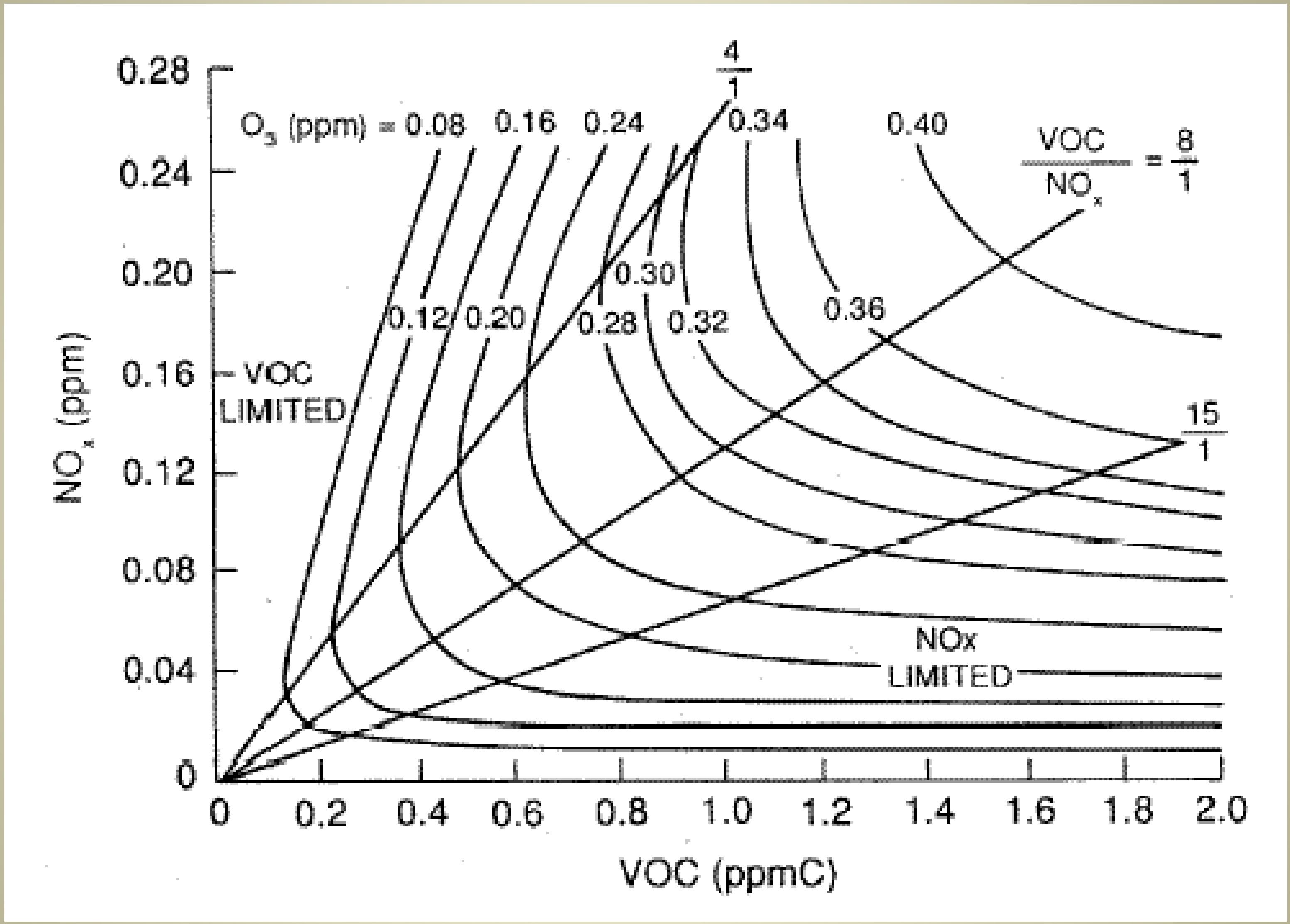
If This Approach is not Followed...

- Decision making will be subjective and incomplete and, unavoidably, affected by waste of resources and delay in solving the most pressing problems
- Long-term air pollution mitigation strategy should not be guided by fixed regulatory standards, but instead by today's advanced computer simulation tools
- This approach assures cost-effectiveness where, for every investment allocated to improve air quality, the efforts are channeled in the right directions, i.e. those that produce maximum benefit
- These problems are extremely complex and non-linear
- Only a set of well tested computerized tools can identify and provide optimal solutions producing
  - the maximum health and environmental benefits with fixed, pre-defined costs, or
  - the minimum costs for fixed, pre-defined benefits

The Challenge of Non-Linearity

- It is not a coincidence that the best improvements in the US were achieved for primary pollutants, like SO_2, CO, Pb
  - Linear relationship with emission rates
- Secondary pollutants (O_3, secondary fraction of $PM_{2.5}$) are more difficult
  - Precursors ➔ O_3, $PM_{2.5}$
  - Decrease in emissions of precursors (e.g., NO_x, VOC, SO_2) does not assure proportional decrease of O_3, $PM_{2.5}$

Challenge: Non-Linearity (e.g. Ozone)



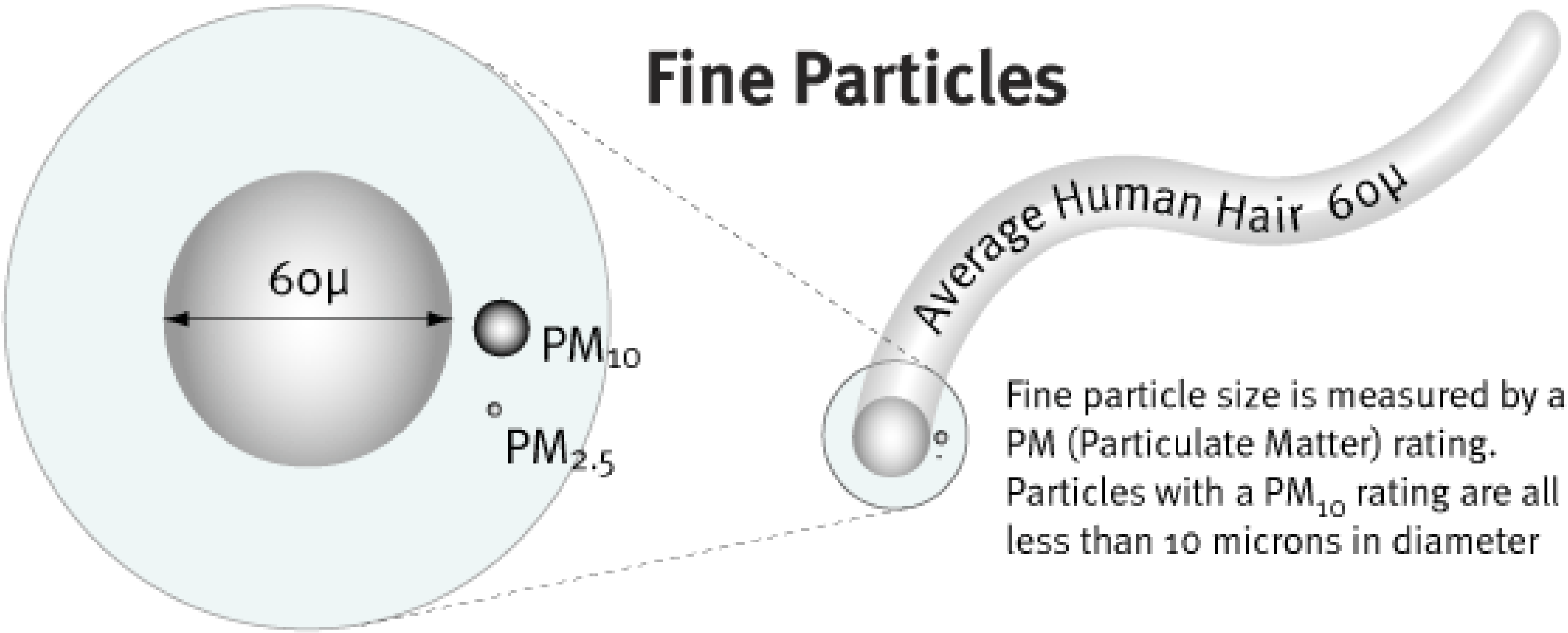
Empirical kinetic modeling approach (EKMA) diagram. SOURCE: NRC 1991, adapted from Dodge 1977.

Ozone Challenge

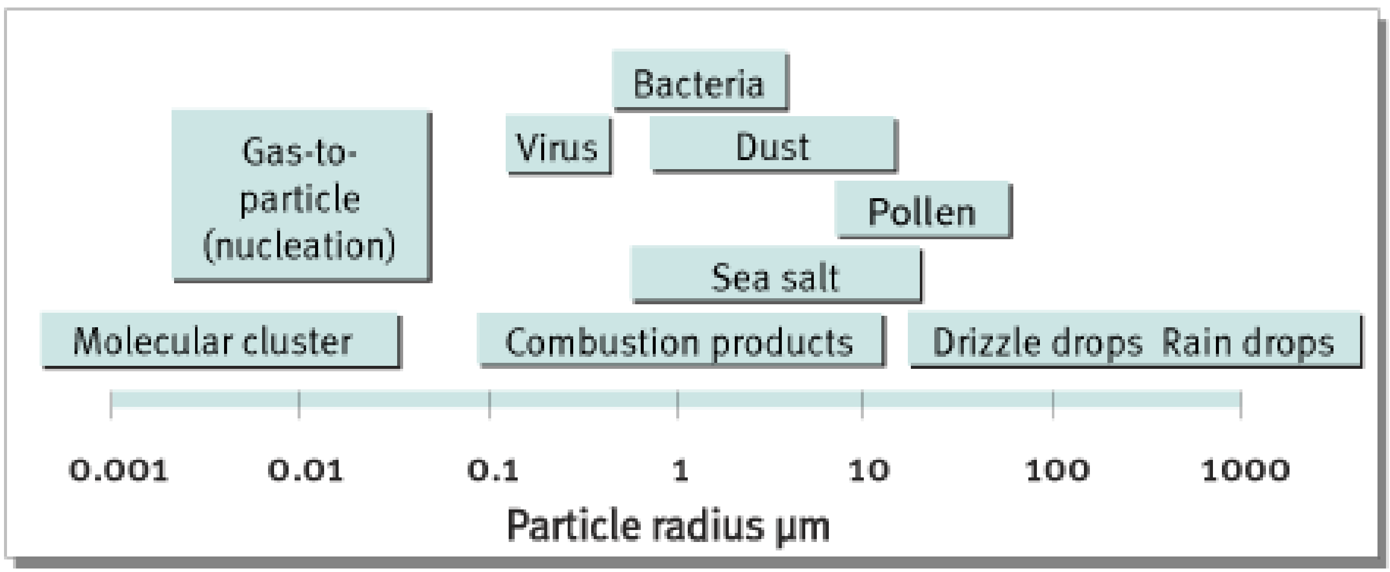
After we design and implement costly emission reduction strategies for the ozone precursors (VOCs and NO_x) emitted by anthropogenic sources, we may still achieve a very limited reduction of ozone. In fact, advanced computer modeling shows that

- some emission reduction strategies in "NO_x-limited" regions may produce no change at all in ozone concentrations, and paradoxically,
- some strategies in "VOC-limited" regions may even cause an increase in ozone concentrations.

Fine Particles



Fine particle size is measured by a PM (Particulate Matter) rating. Particles with a PM_{10} rating are all less than 10 microns in diameter



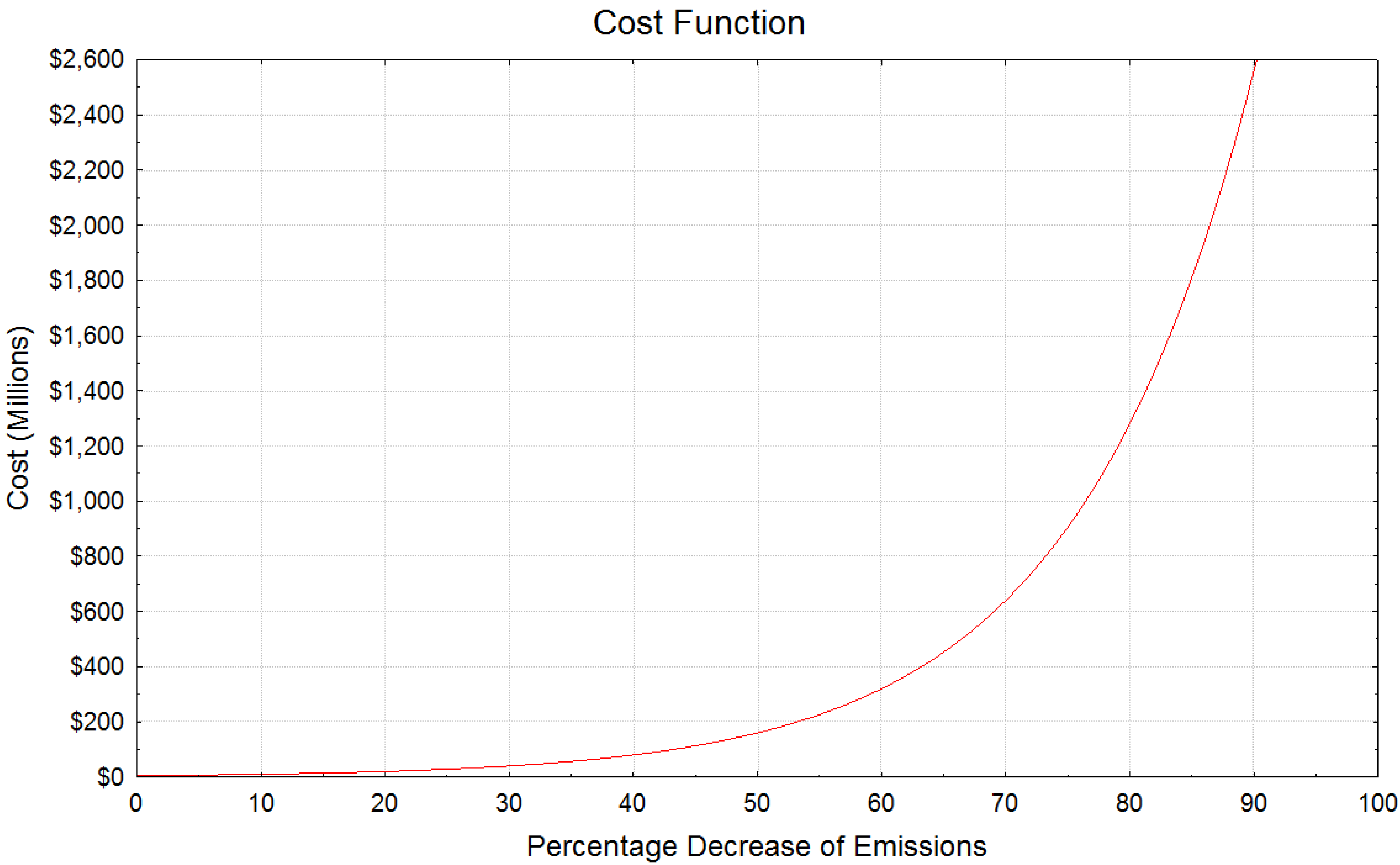
Queensland Government
Environmental Protection Agency

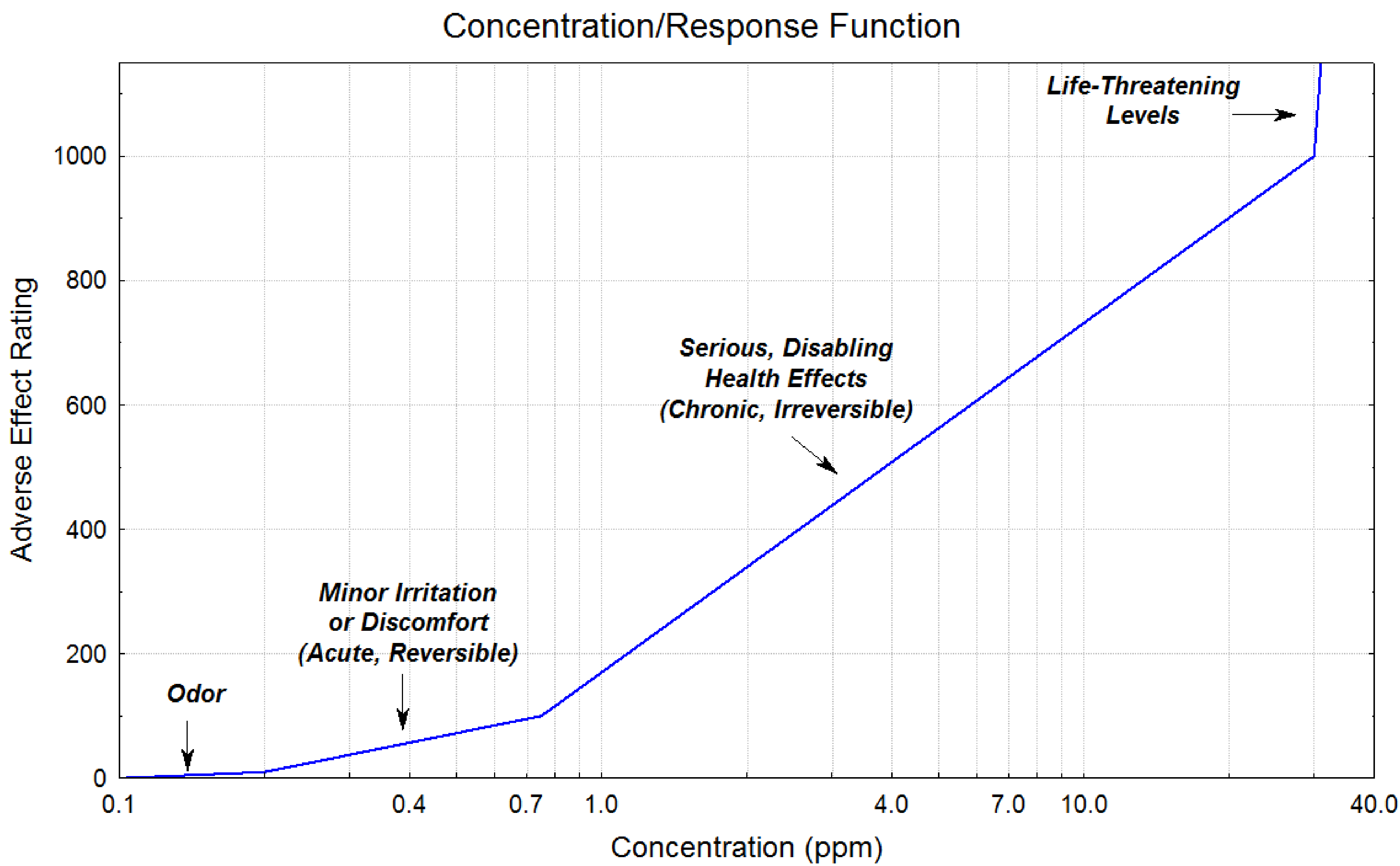
PM2.5 Challenge

- Recent (January 2013) air pollution episodes in Beijing, China, have been characterized by very unhealthy ambient concentrations of $PM_{2.5}$ of 900 $\mu g/m^3$. See:
  - http://www.forbes.com/sites/jackperkowski/2013/01/21/air-quality-in-china/
- These values are more than an order of magnitude greater than $PM_{2.5}$ air quality standards in Europe and North America (e.g., see: http://www.epa.gov/air/criteria.html)

Example

- 10 B$ are allocated to improve air quality in the Shanghai region of China
- Can we spend them wisely? E.g. to maximize public health?
- In theory yes, but ...
  - Team
  - Data collection
  - Modeling: CALPUFF, CAMx, ...
  - Δ$ ➔ΔE ➔ ΔC ➔ ΔHB ... All non-linear
  - Maybe a year later we have an “optimal” investment plan
  - Results difficult to re-utilize in another region

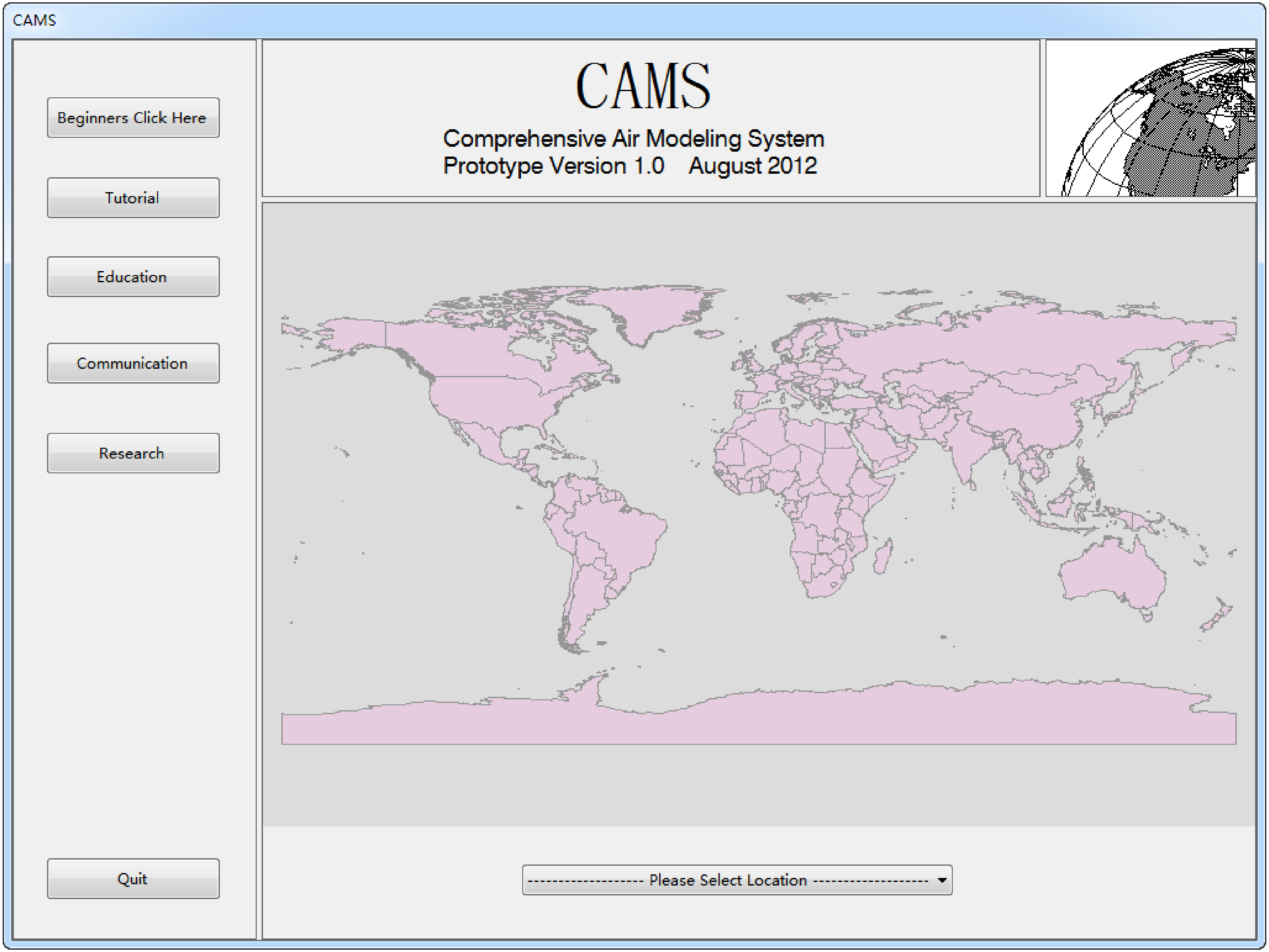

Cost Function
$2,600
$2,400
$2,200
$2,000
$1,800
$1,600
$1,400
$1,200
$1,000
$800
$600
$400
$200
$0
Cost (Millions)
0
10
20
30
40
50
60
70
80
90
100
Percentage Decrease of Emissions

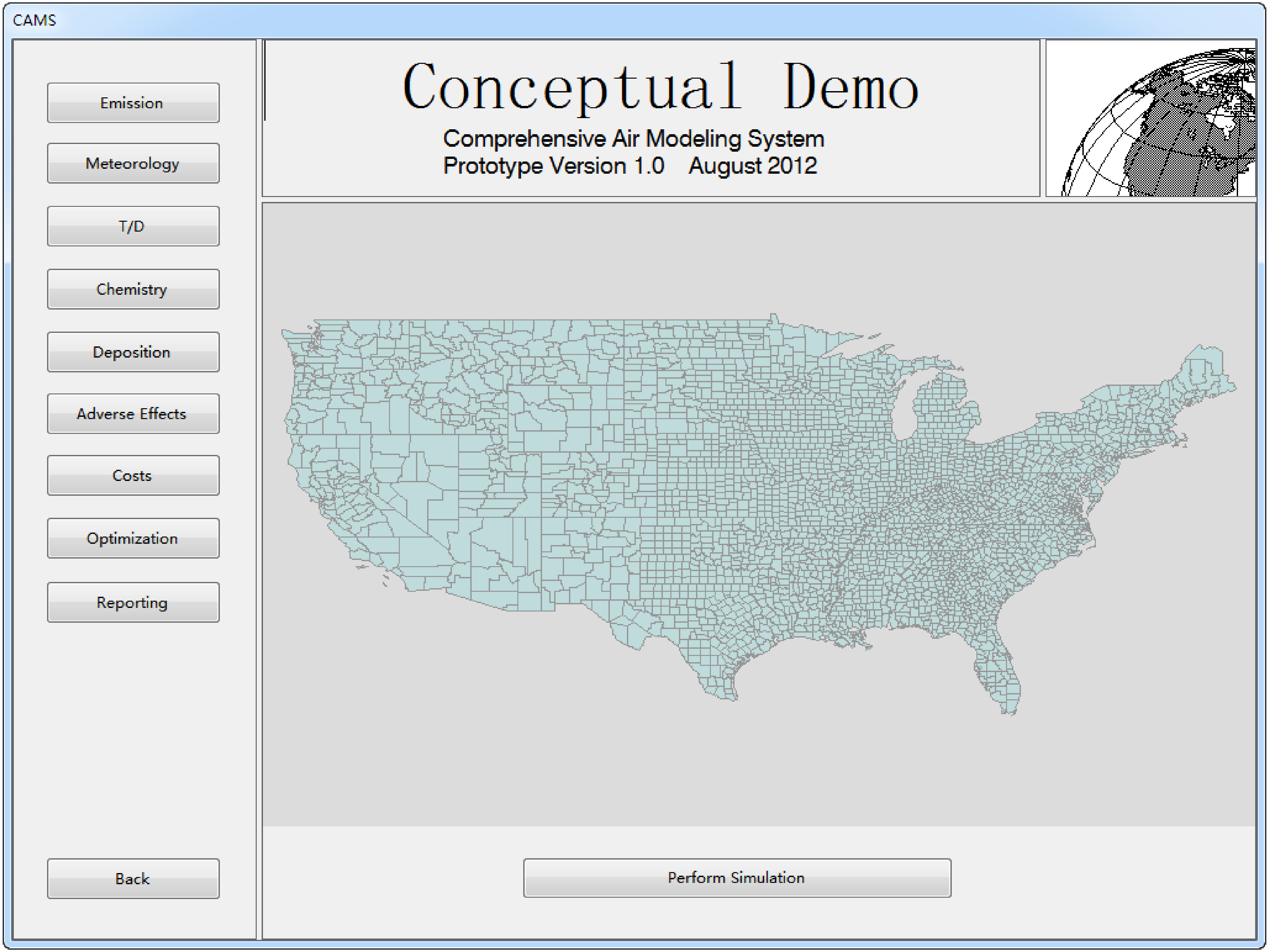


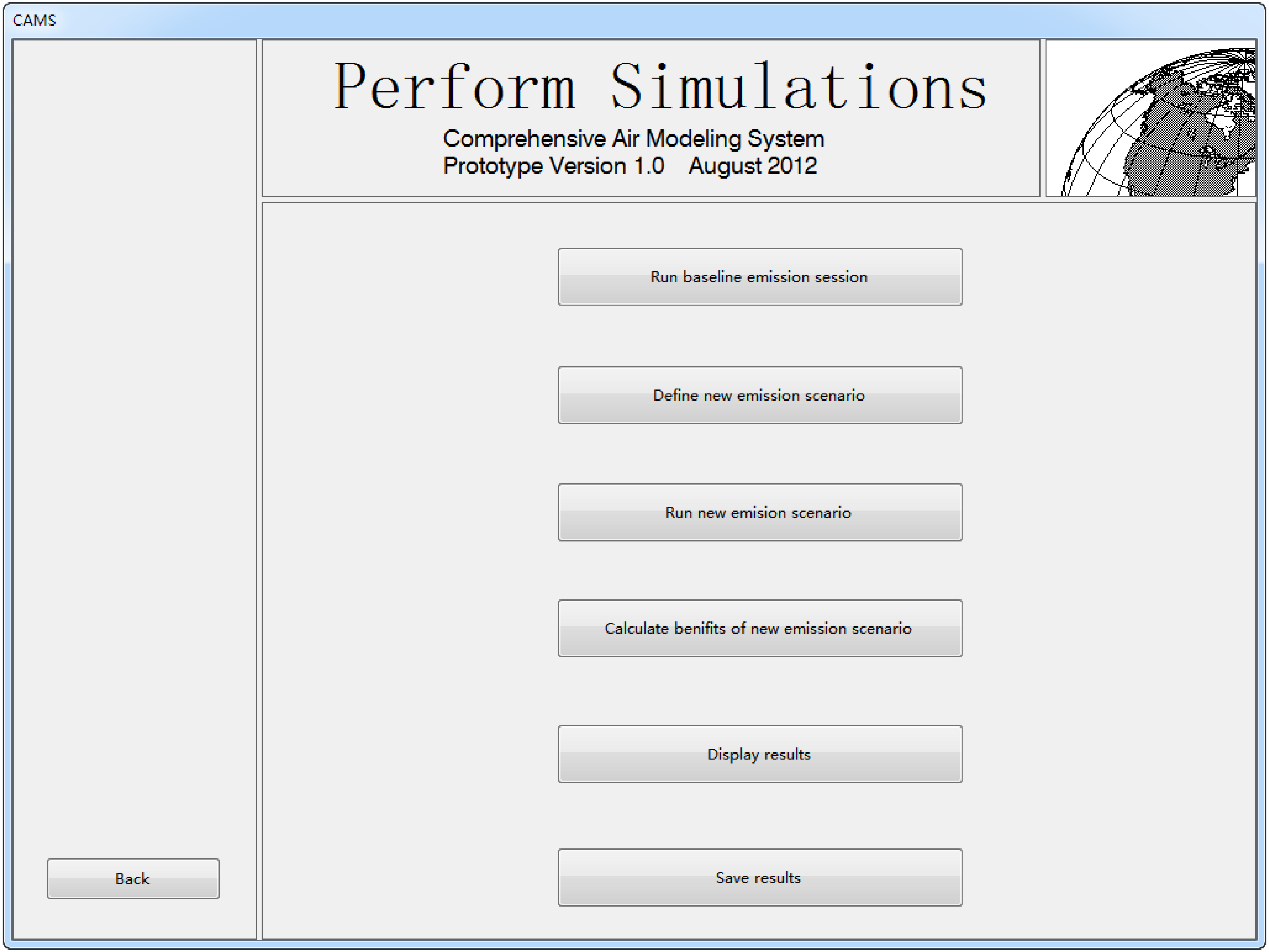
Concentration/Response Function
Adverse Effect Rating
1000
800
600
400
200
0
0.1
0.4
0.7
1.0
4.0
7.0
10.0
40.0
Concentration (ppm)
Life-Threatening Levels
Serious, Disabling Health Effects (Chronic, Irreversible)
Minor Irritation or Discomfort (Acute, Reversible)
Odor

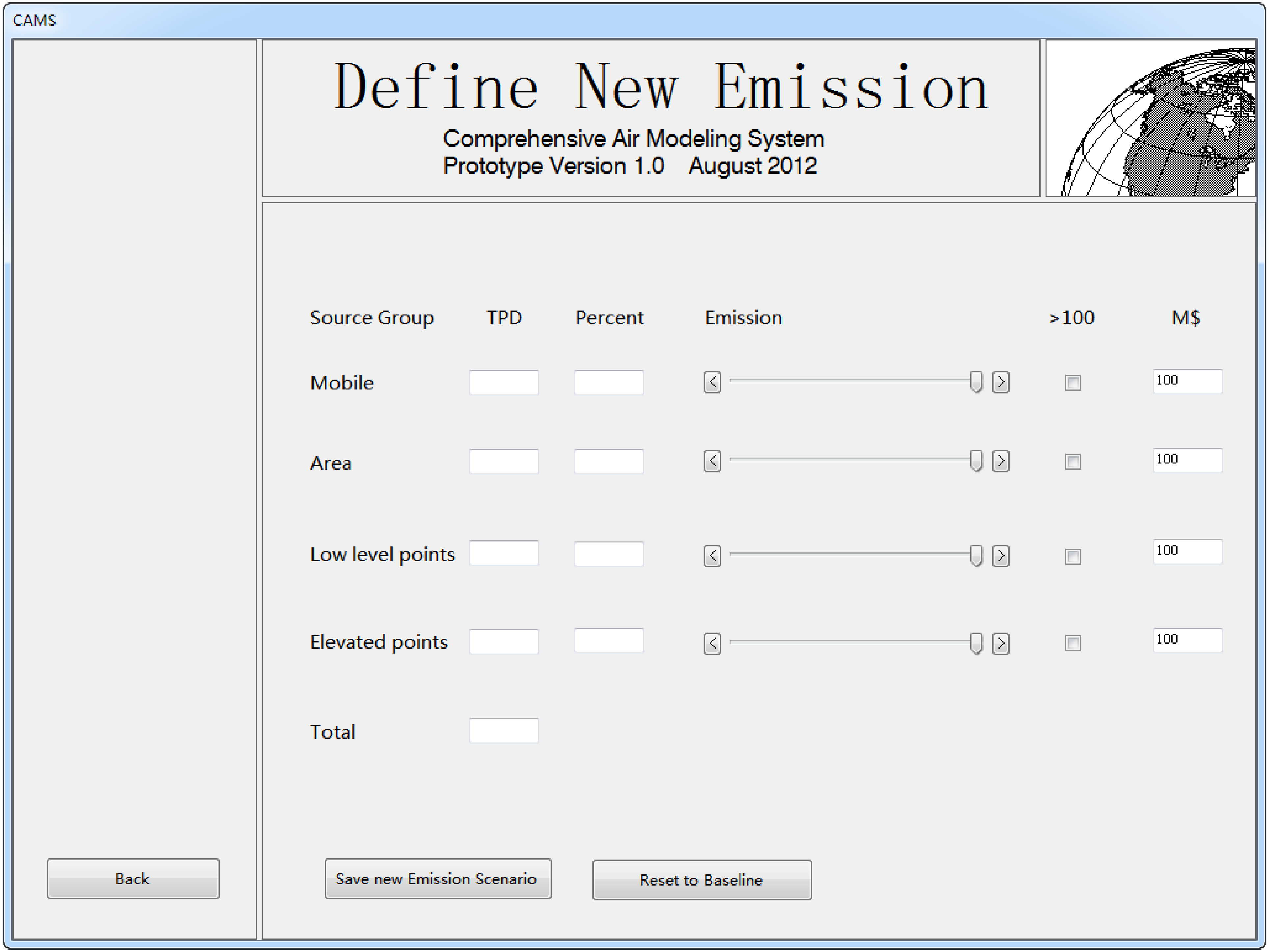
Conceptual Design

- We envision the development of a series of interacting software modules that the user can access through a user-friendly GUI on a PC Microsoft Windows-based computer platform
- The software system will be installed on our own Servers and made available to authorized users as a Web-Application
- We call it Comprehensive Air Modeling/Optimization System (CAMOS)
- Authorized users will be able to access the system with user name/password at the site www.camos.co (under construction)


CAMS
Beginners Click Here
Tutorial
Education
Communication
Research
Quit
CAMS
Comprehensive Air Modeling System
Prototype Version 1.0 August 2012
------------------ Please Select Location ------------------


CAMS
Conceptual Demo
Comprehensive Air Modeling System
Prototype Version 1.0 August 2012
Emission
Meteorology
T/D
Chemistry
Deposition
Adverse Effects
Costs
Optimization
Reporting
Back
Perform Simulation


CAMS
Perform Simulations
Comprehensive Air Modeling System
Prototype Version 1.0 August 2012
Run baseline emission session
Define new emission scenario
Run new emision scenario
Calculate benifits of new emission scenario
Display results
Save results
Back


CAMS
Define New Emission
Comprehensive Air Modeling System
Prototype Version 1.0 August 2012
Source Group
TPD
Percent
Emission
>100
M$
Mobile
100
Area
100
Low level points
100
Elevated points
100
Total
Back
Save new Emission Scenario
Reset to Baseline

Thank You!

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