Advances in Air Pollution Science: Meteorological Modeling, Cost-Benefit Optimization, Litigation Support

Dr. Paolo Zannetti, QEP
President
EnviroComp Consulting, Inc. (www.envirocomp.com)
The EnviroComp Institute (www.envirocomp.org)

Aarhus University, Denmark

June 24, 2019

An Introduction

- Worked on Air Pollution Modeling since 1971
- First half-life: R&D; second half-life: R&D and consulting
- Italy, Los Angeles, Kuwait, Norway, San Francisco
- Books:
  - Air Pollution Modeling (1990) http://www.amazon.ca/Pollution-Modeling-Theories-Computational-Available/dp/0442308051
  - Air Quality Modeling series (4 books; 2003-2010) http://www.envirocomp.org/aqm
- Intensive litigation work

Three Topics Today

1. The increasing role of full 3D meteorological modeling in air pollution studies
2. The development and possible future use of Cost-Benefit Optimization techniques in managing industrial/urban development
3. The unique scientific (and non-scientific) challenges of litigation work and expert testimony

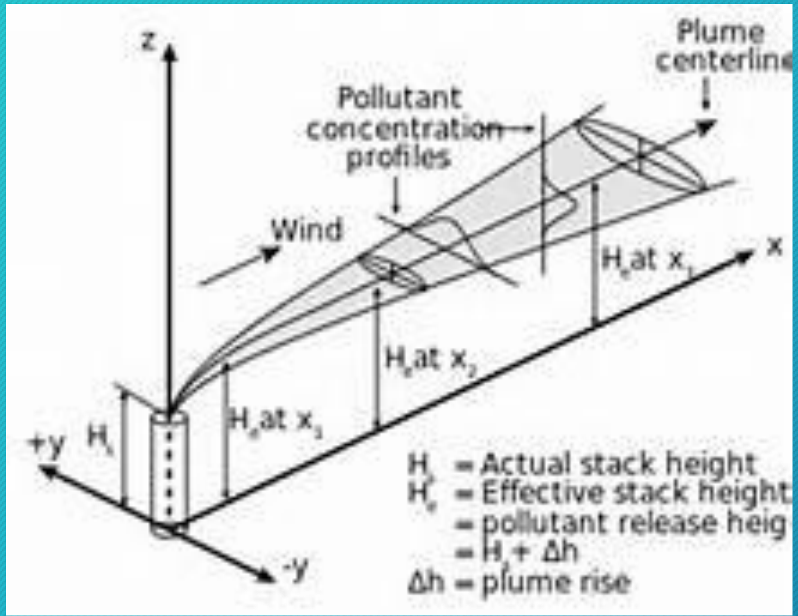
1. The increasing role of full 3D meteorological modeling in air pollution studies

Air Quality Modeling Approaches

- Gaussian Plume models (e.g., EPA's AERMOD)
  - Hourly, stationary, straight line plume
- Gaussian Puff models (e.g., EPA's CALPUFF)
  - Allow plume dynamics, calm conditions, accumulation, bending of the plume
- Lagrangian Particle Models (e.g., LAPMOD)
  - Allow highest degree of spatial/temporal resolution
  - http://www.envirocomp.com/zcv/L.16.DynamicSimulationsUsingParticleModels.pdf
- Other Models
  - Photochemical smog (O3), secondary particles (SO4), etc.

Mathematical Methods

- Either very simple …
  - Empirical engineering formula (simple algebraic formulas)
  - E.g.: the Gaussian Plume Equation



$$C(x,y,z) = \frac{Q}{2\pi u \sigma_y \sigma_z} \times \left[\exp -\left(\frac{y^2}{2\sigma_y^2}\right)\right]\left\{\exp\left(\frac{-(z-H)^2}{2\sigma_z^2}\right) + \exp\left(\frac{-(z+H)^2}{2\sigma_z^2}\right)\right\}$$

C = Concentration of the chemical in air. $[M/L^3]$
Q = Rate of chemical emission. [M/T]
u = Wind speed in x direction. [L/T]
σ_y = Standard deviation in y direction. [L]
σ_z = Standard deviation in z direction. [L]
y = Distance along a horizontal axis perpendicular to the wind. [L]
z = Distance along a vertical axis. [L]
H = Effective stack height. [L]

Mathematical Methods (cont.)

- … Or very complex
  - Numerical solutions of partial differential equations
  - E.g.: the Navier-Stokes equations

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u}{\partial x} + \frac{\partial \rho v}{\partial y} + \frac{\partial \rho w}{\partial z} = 0 \quad (1)$$

$$\frac{\partial \rho u}{\partial t} + \frac{\partial (\rho u^2)}{\partial x} + \frac{\partial (\rho u v)}{\partial y} + \frac{\partial (\rho u w)}{\partial z} = -\frac{\partial p}{\partial x} + \nu \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} \right) \quad (2)$$

$$\frac{\partial \rho v}{\partial t} + \frac{\partial (\rho u v)}{\partial x} + \frac{\partial (\rho v^2)}{\partial y} + \frac{\partial (\rho v w)}{\partial z} = -\frac{\partial p}{\partial y} + \nu \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2} \right) \quad (3)$$

$$\frac{\partial \rho w}{\partial t} + \frac{\partial (\rho u w)}{\partial x} + \frac{\partial (\rho v w)}{\partial y} + \frac{\partial (\rho w^2)}{\partial z} = -\frac{\partial p}{\partial z} + \nu \left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2} \right) \quad (4)$$

$$\frac{\partial \rho E}{\partial t} + \frac{\partial (\rho u E)}{\partial x} + \frac{\partial (\rho v E)}{\partial y} + \frac{\partial (\rho w E)}{\partial z} = -\frac{\partial p u}{\partial x} - \frac{\partial p v}{\partial y} - \frac{\partial p w}{\partial z} + S \quad (5)$$

where ρ is the air density, u, v, w are the components of the air's velocity, E is measure of the air's internal energy (which allows us to compute its temperature) and p is the air pressure.

EPA Guideline on Air Quality Models (Federal)

- Enhancements to the **preferred near-field** (up to 50 km) dispersion model, **AERMOD**
- To provide more flexibility and improve the meteorological inputs used for regulatory modeling, the EPA is finalizing the use of **projected meteorological data** **(!)** in AERMOD where there is no representative National Weather Service (NWS) station and it is prohibitive or not feasible to collect adequately representative site-specific data
- For **long-range**, beyond 50 km from an emissions source, air quality assessments, the EPA is **removing CALPUFF** as a preferred model and now will consider it as a screening technique, along with **other Lagrangian models**, to be used in consultation with the appropriate reviewing authority

2017 Appendix W Final Rule (https://www3.epa.gov/ttn/scram/appendix_w-2016.htm)

Projected Meteorological Data

- Appendix W now allows the use of **projected meteorological data** derived from meteorological models.
- Data derived from meteorological models are very useful when:
  - Lack of representative meteorological measurements
  - Available meteorological measurements do not meet quality standards (e.g., poor treatment of calms, many missing data, insufficient number of data)
  - Meteorological stations not ideally suited for specific purposes
    - Represent instantaneous readings and we need time averages
    - Vertical profiles not available
    - Some variables not available (e.g., solar radiation, cloud cover)

AERMOD (“Traditional” Use)

- **AERMOD** is the US-EPA preferred model for near-field applications
  - https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models#aermod
- It requires surface meteorological data from a single station, and upper air data that are typically obtained from a different station
- Meteorological data derived from the closer station (or the more representative one) are elaborated by the **AERMET** processor, which also includes information about geophysical parameters (roughness length, albedo and Bowen ratio) obtained from the AERSURFACE processor
- The meteorological station may be several km away from the source(s) of interest, **therefore the meteorological data might not always be representative**

AERMOD (New Option)

- The meteorological data very close to the sources, or over them, can be obtained from complex meteorological grid models and their processors.
- It is possible for example to use the **WRF** (Weather Research and Forecasting) model to get the hourly meteorological fields for one or more years over a location, then extract specific variables and format them as needed by AERMOD though the **MMIF** (Mesoscale Model Interface) program.

WRF: https://www.mmm.ucar.edu/weather-research-and-forecasting-model
MMIF: https://www.epa.gov/scram/air-quality-dispersion-modeling-related-model-support-programs#mmif

CALMET/CALPUFF ("Traditional" Use)

- The **CALMET/CALPUFF** modeling system (http://www.src.com/) may be used for atmospheric dispersion over complex orography, where the single point meteorology and straight-plume of AERMOD are not enough to fully describe the circulation pattern
- CALMET is the diagnostic meteorological model associated to CALPUFF. It requires in input the **geophysical parameters** of the domain (at least terrain elevation and land use), hourly **surface meteorological data** from several stations within its domain, and one or more **vertical profiles** (at least one every 12 hours).
- CALMET calculates the **3D, non-stationary, meteorological fields** over the whole simulation domain, plus the micro-meteorological variables related to **turbulence** (Monin-Obukhov length, friction velocity, convective velocity, mixing height, etc.).
- This output is used to feed CALPUFF (and other dispersion models).

CALMET/CALPUFF (New WRF Option)

- The preparation of the meteorological data is a very long and delicate process. Many **subjective decisions** may enter in the data preparation
- The output data of complex prognostic meteorological models, such as WRF may be used to prepare the input of CALMET, or directly of CALPUFF
- The output of **WRF** may be entered in the **CALWRF** processor in order to prepare data to be used in CALMET in place of, or together with, the observations
- The output of **WRF** may also be processed by **MMIF** to get directly the meteorological input file of CALPUFF.

2. The development and possible future use of Cost-Benefit Optimization techniques in managing industrial/urban development

Costs vs. Benefits

- Enormous costs of study, design, implementation, and enforcement of regulations, plus the costs carried by businesses and industries for compliance
- 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_rev_a.pdf)

It is Reasonable to Believe...

- ... that today's 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

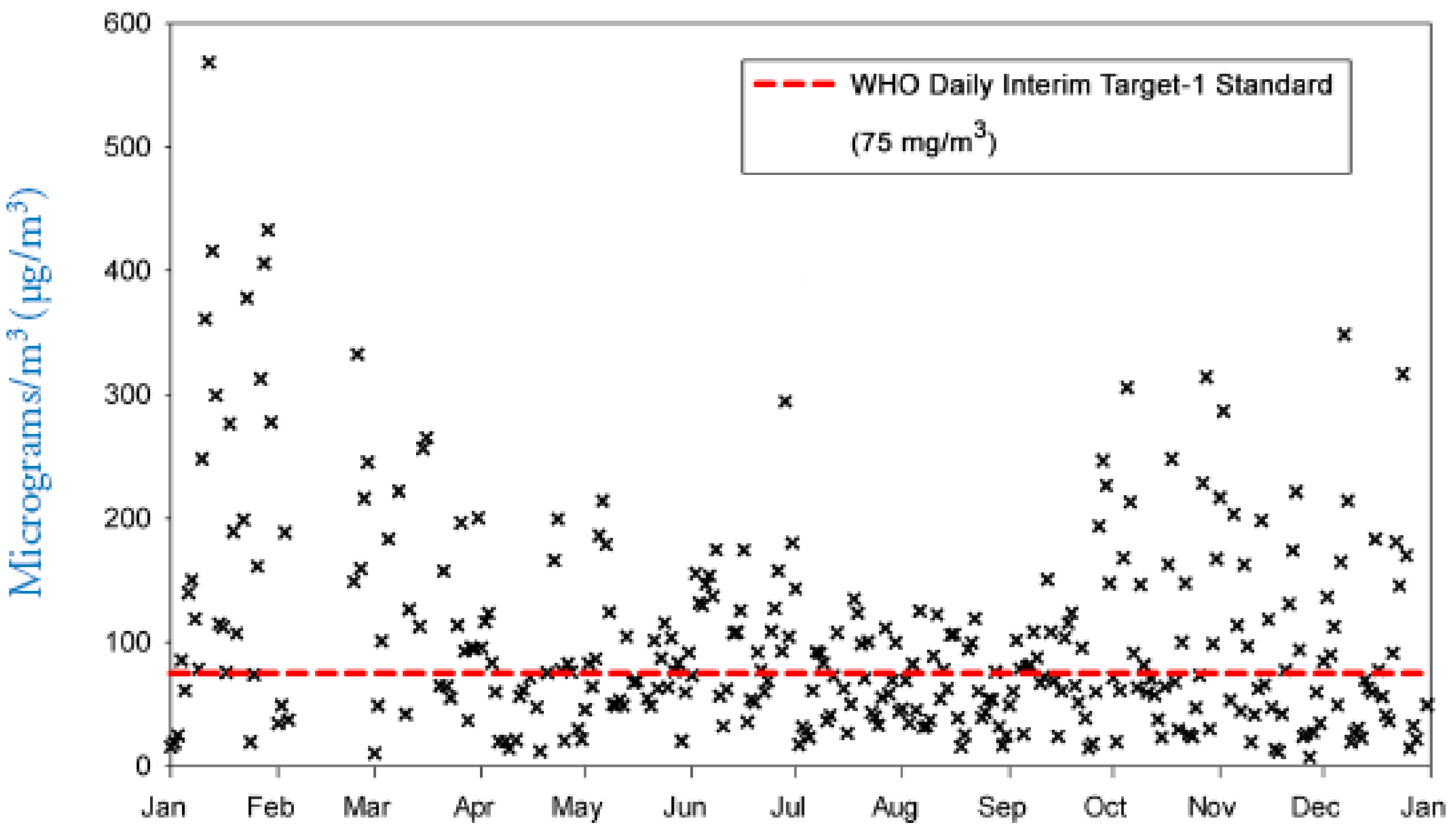
What do we Recommend to Emerging Countries?

- 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 in wealth, 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

2013 Daily $PM_{2.5}$ Concentrations Measured in Beijing, China



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

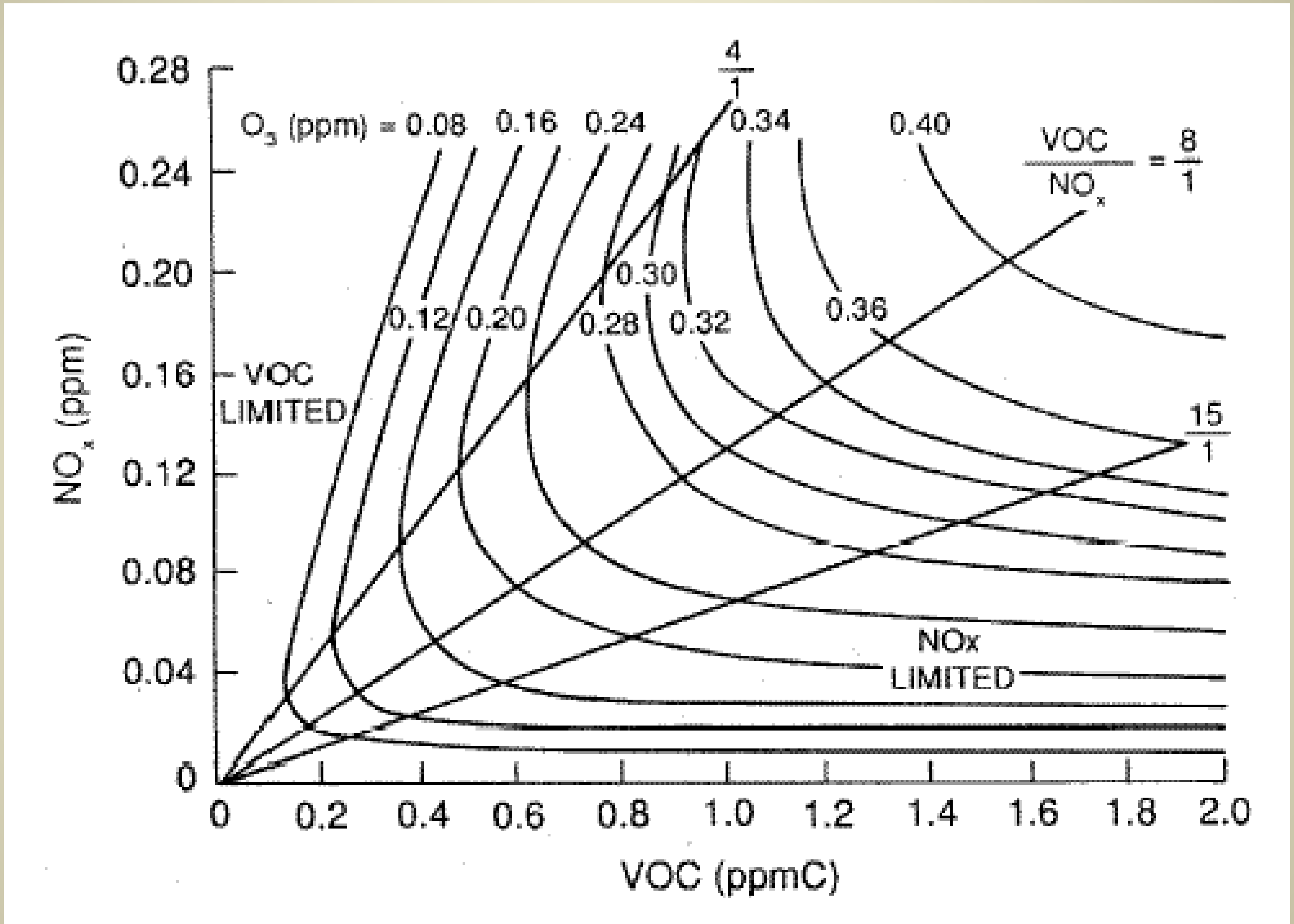
If This Approach is not Followed...

- 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)

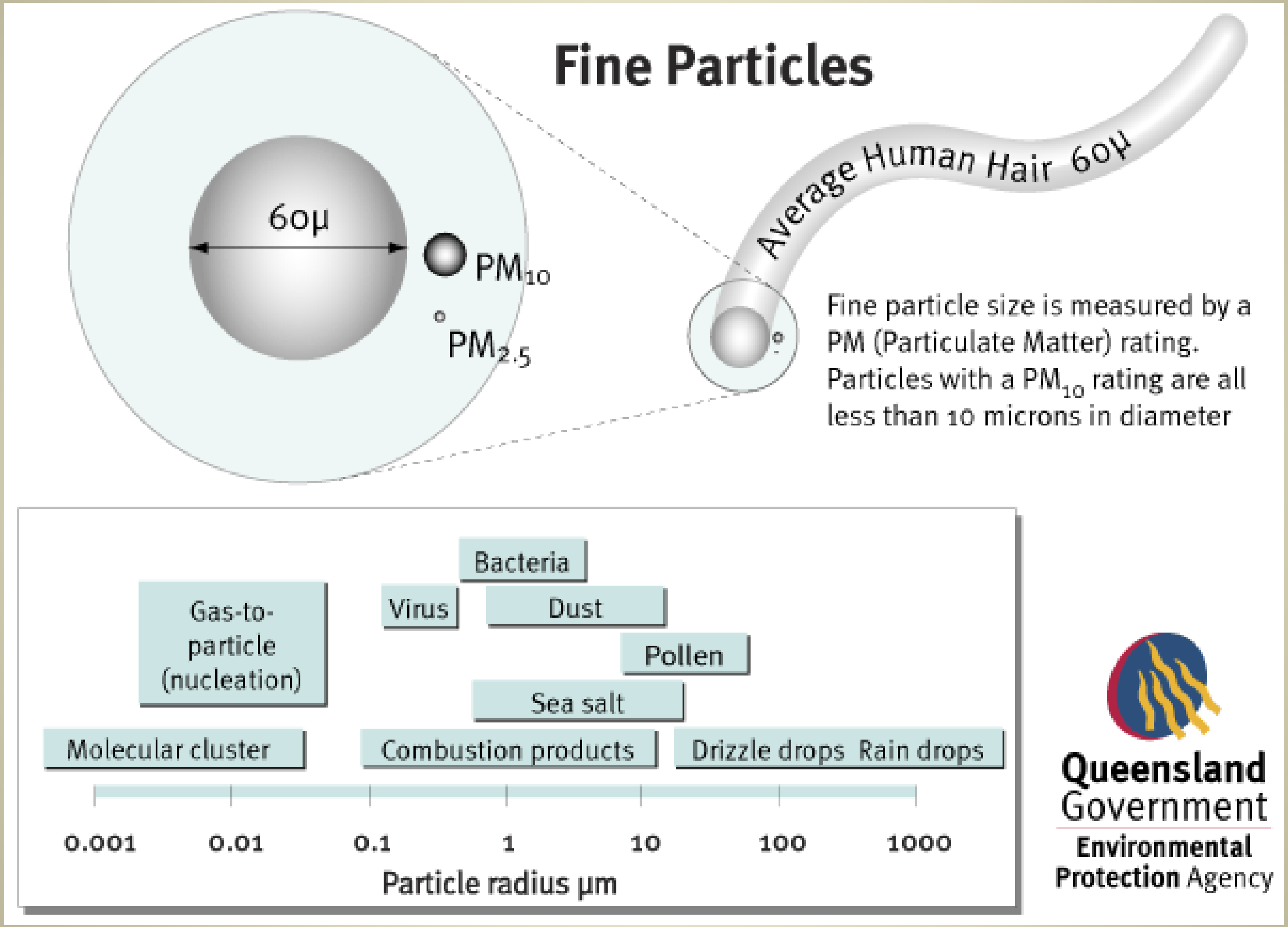


Empirical kinetic modeling approach (EKMA) diagram. SOURCE: NRC 1991, adapted from Dodge 1977.

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.



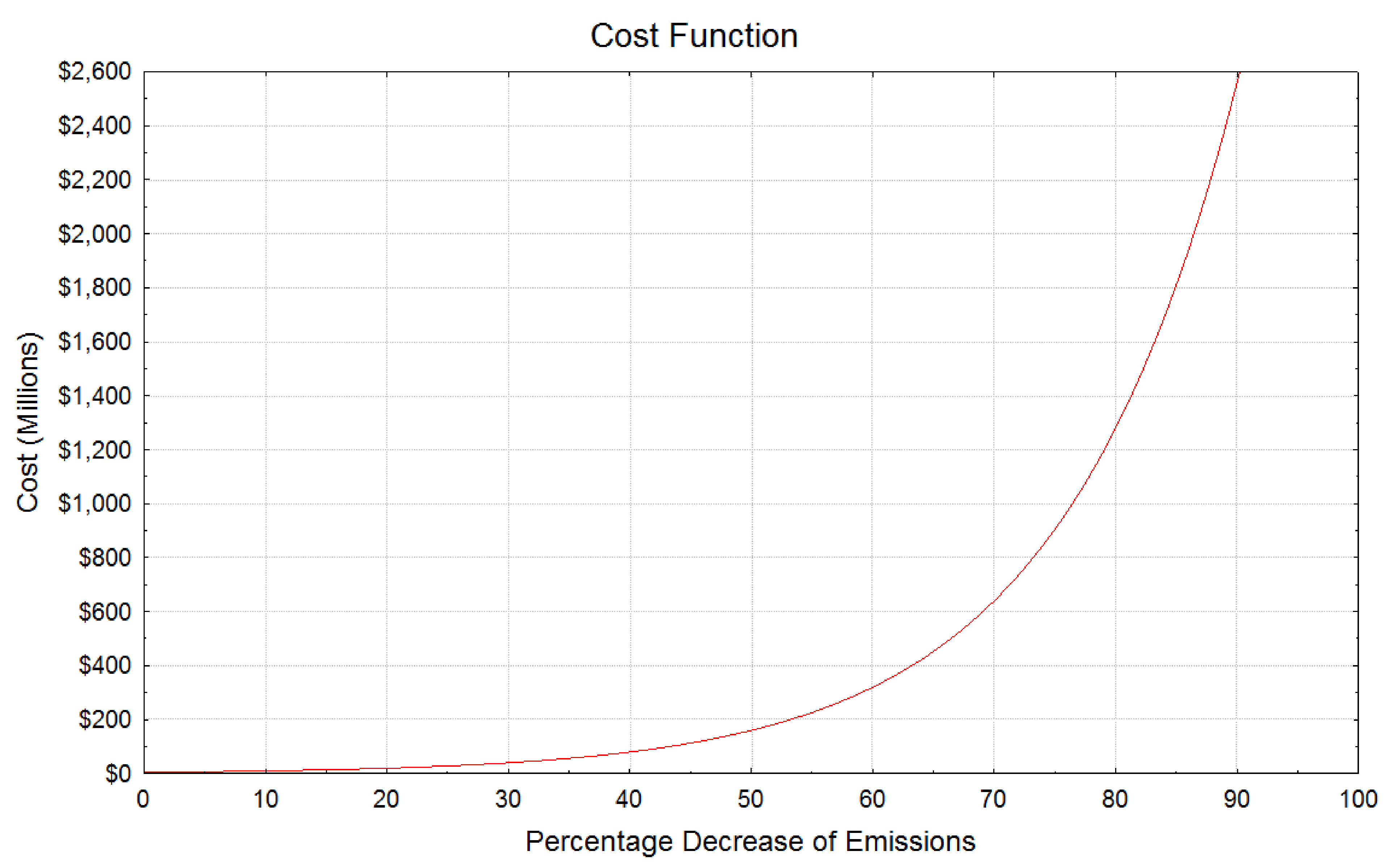
Fine Particles
60µ
PM10
PM2.5
Average Human Hair 60µ
Fine particle size is measured by a PM (Particulate Matter) rating. Particles with a PM10 rating are all less than 10 microns in diameter
Bacteria
Gas-to-particle (nucleation)
Virus
Dust
Pollen
Sea salt
Molecular cluster
Combustion products
Drizzle drops Rain drops
0.001
0.01
0.1
1
10
100
1000
Particle radius µm
Queensland Government
Environmental Protection Agency

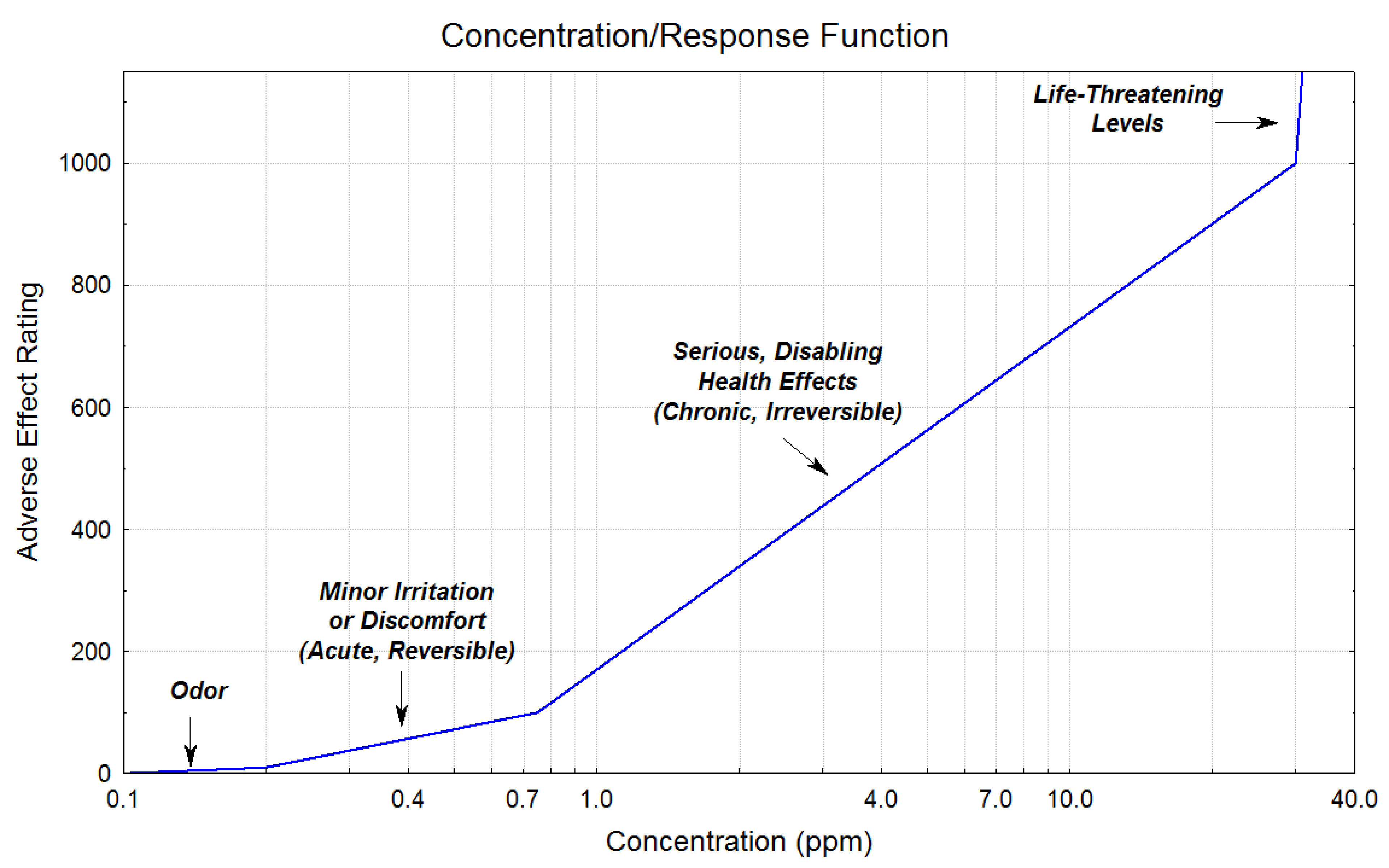
PM2.5 Challenge

- 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

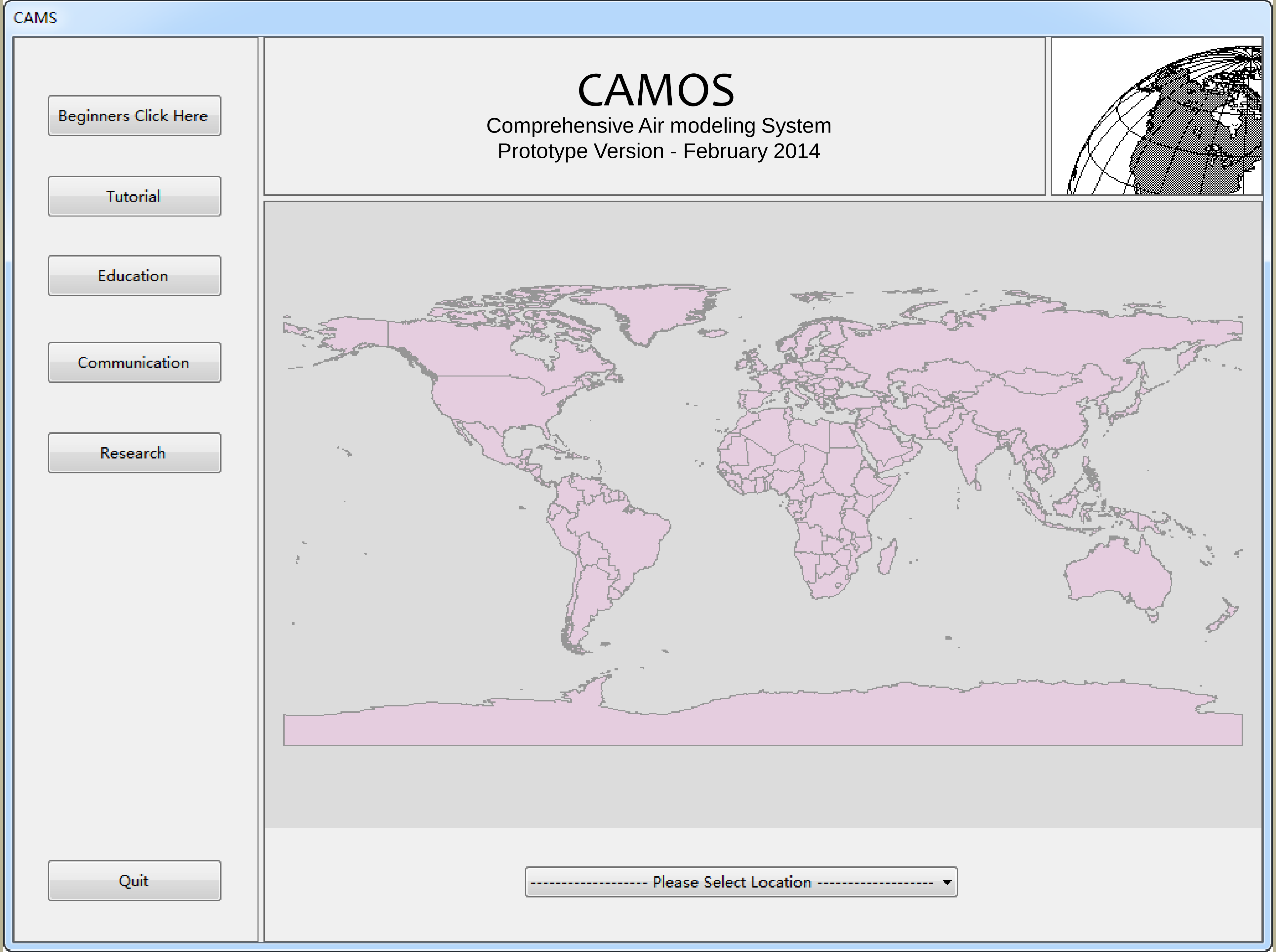

Cost Function
Cost (Millions)
$2,600
$2,400
$2,200
$2,000
$1,800
$1,600
$1,400
$1,200
$1,000
$800
$600
$400
$200
$0
0
10
20
30
40
50
60
70
80
90
100
Percentage Decrease of Emissions



Concentration/Response Function
Life-Threatening
Levels
Serious, Disabling
Health Effects
(Chronic, Irreversible)
Minor Irritation
or Discomfort
(Acute, Reversible)
Odor
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)

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 (just activated for demo purposes)


CAMS
CAMOS
Comprehensive Air modeling System
Prototype Version - February 2014
Beginners Click Here
Tutorial
Education
Communication
Research
Quit
------------------ Please Select Location ------------------

frmCostFunctions

Cost functions

For each source category the cost of the emission reduction is calculated with the following expression: Cost = A*(DE) + B*(DE)^P Where cost must result in M$, and DE is the percent emission reduction.

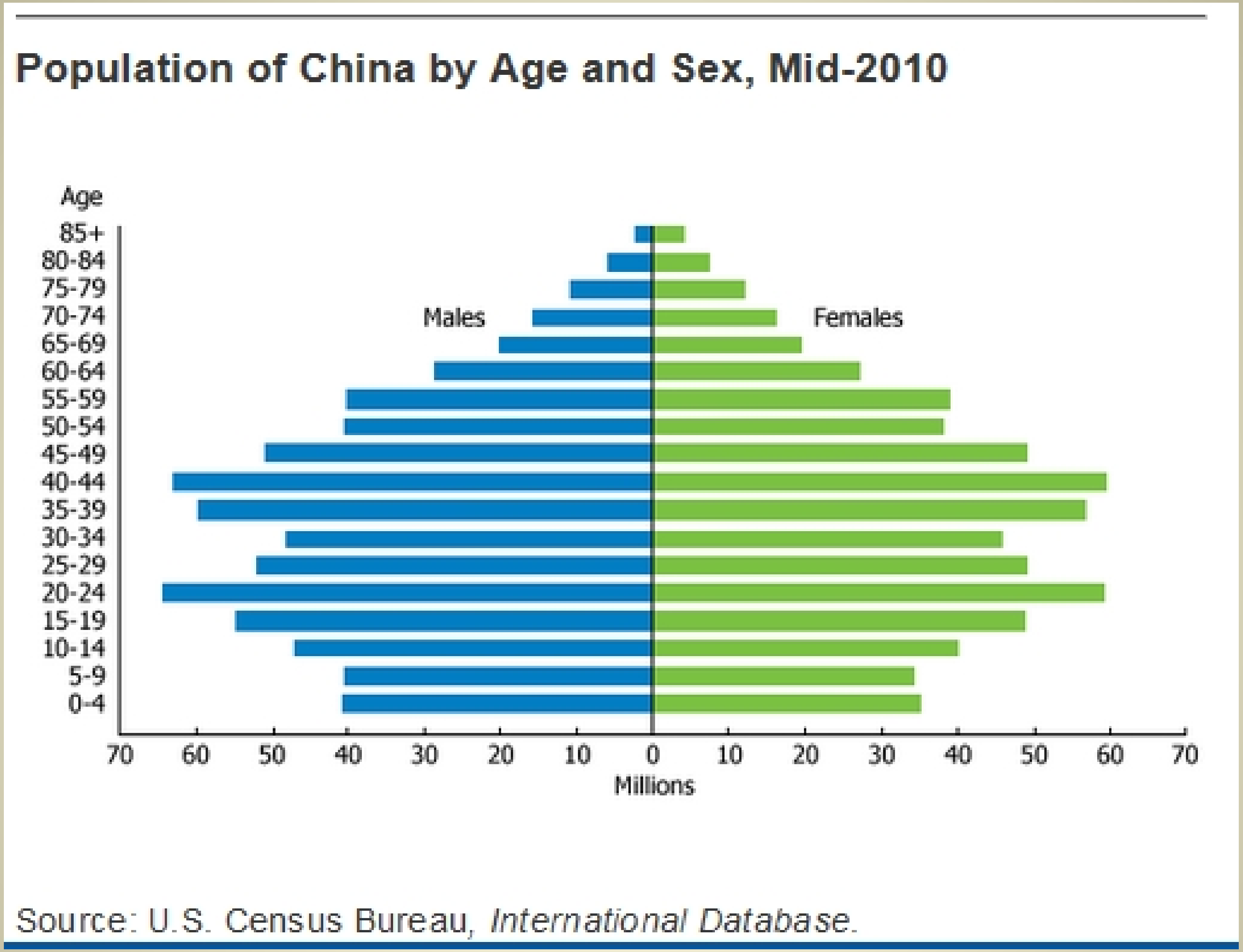
Cost functions coefficients

Category	A	B	P
Mobile	1	0.4	0.2
Area	3	0.1	1.5
Power_plants	0.5	0.5	2
High_stacks	1.2	0.8	2.3
Low_stacks	0.9	0.4	1.9

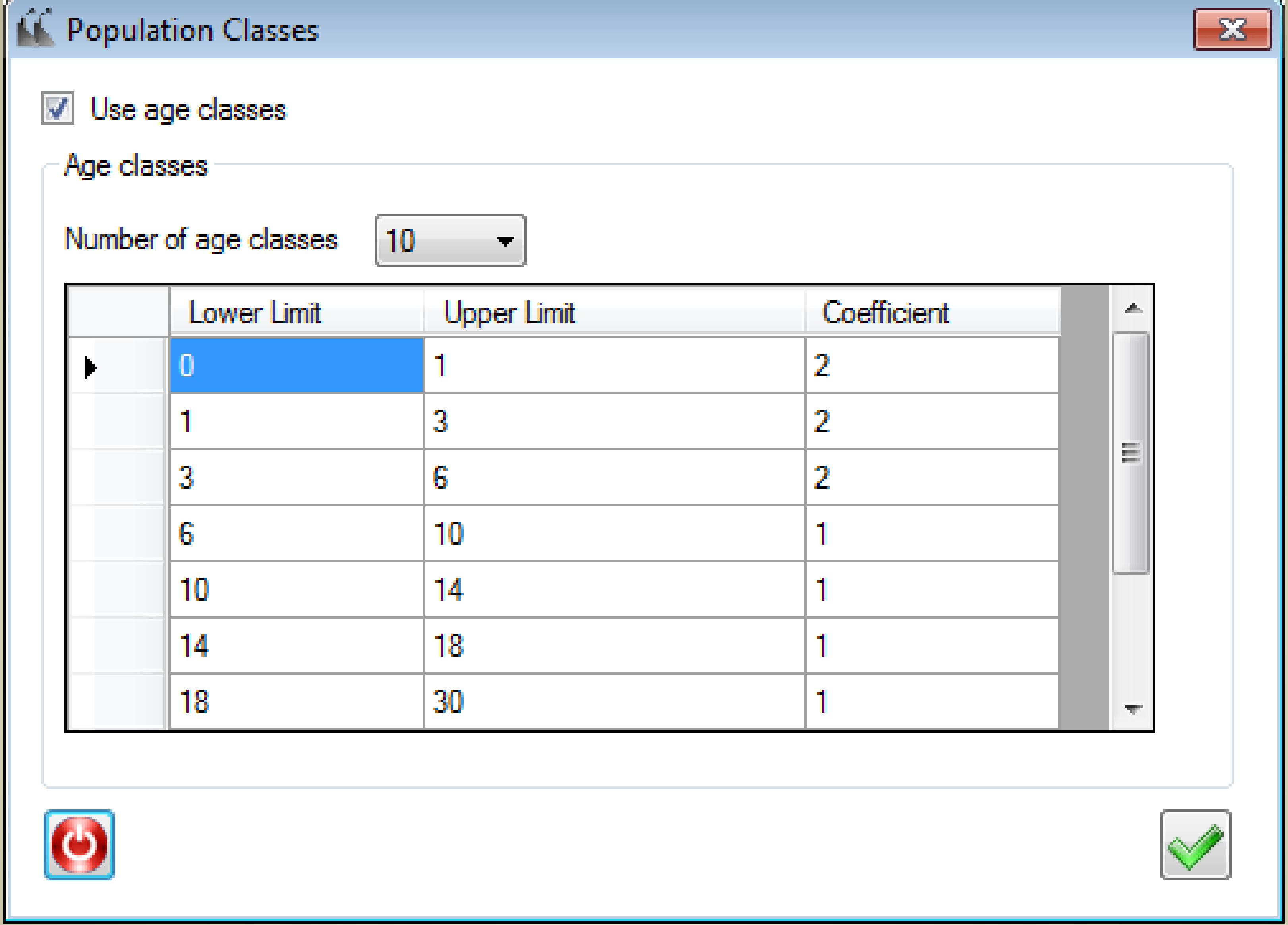
Cost Functions

Benefit Functions

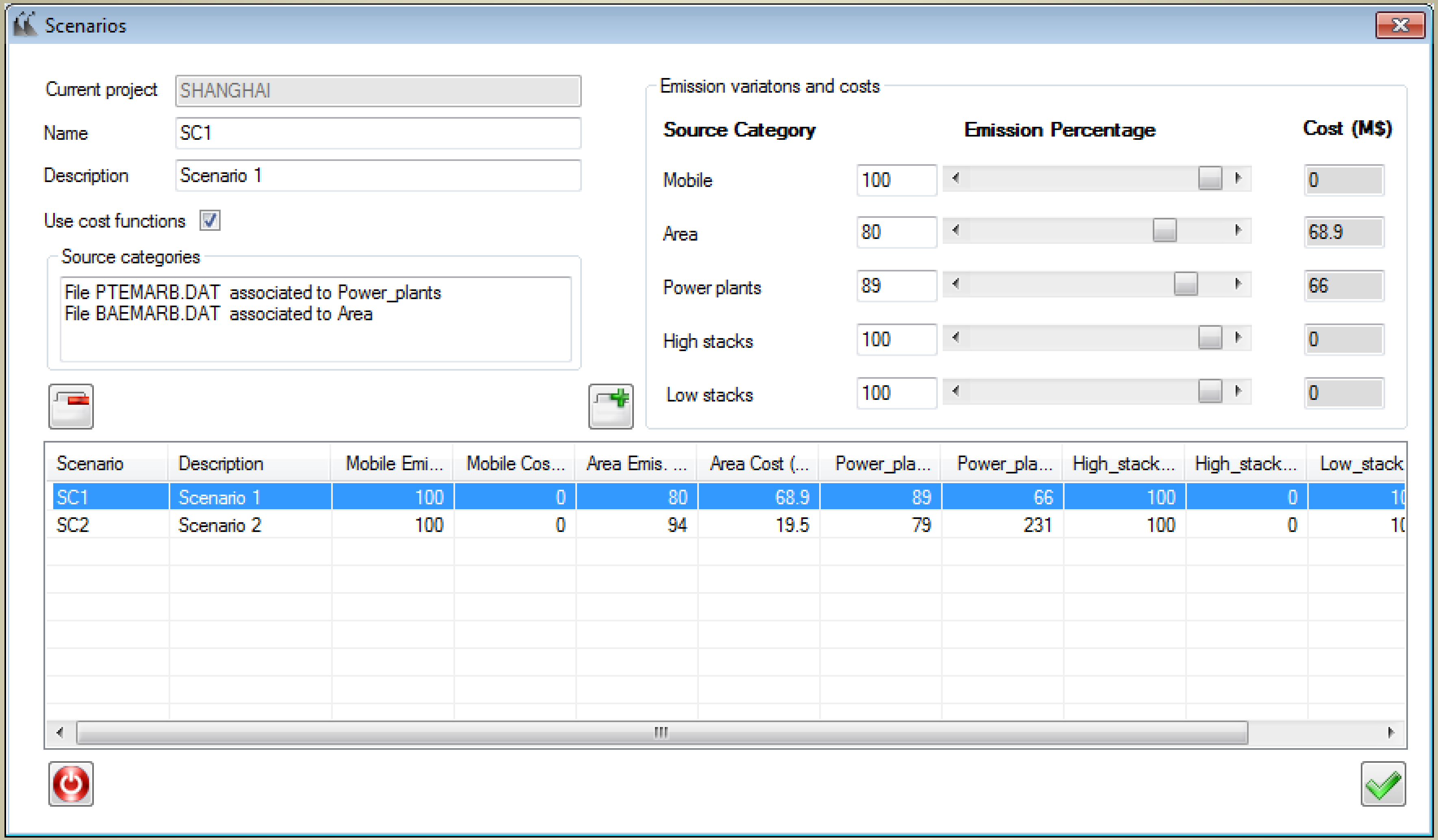
- Benefits are calculated in each cell of the modeling domain, as a function of the concentration reductions, multiplied by the density of population
- Additional benefits are calculated at "special interest" receptor locations (e.g., schools, hospitals)



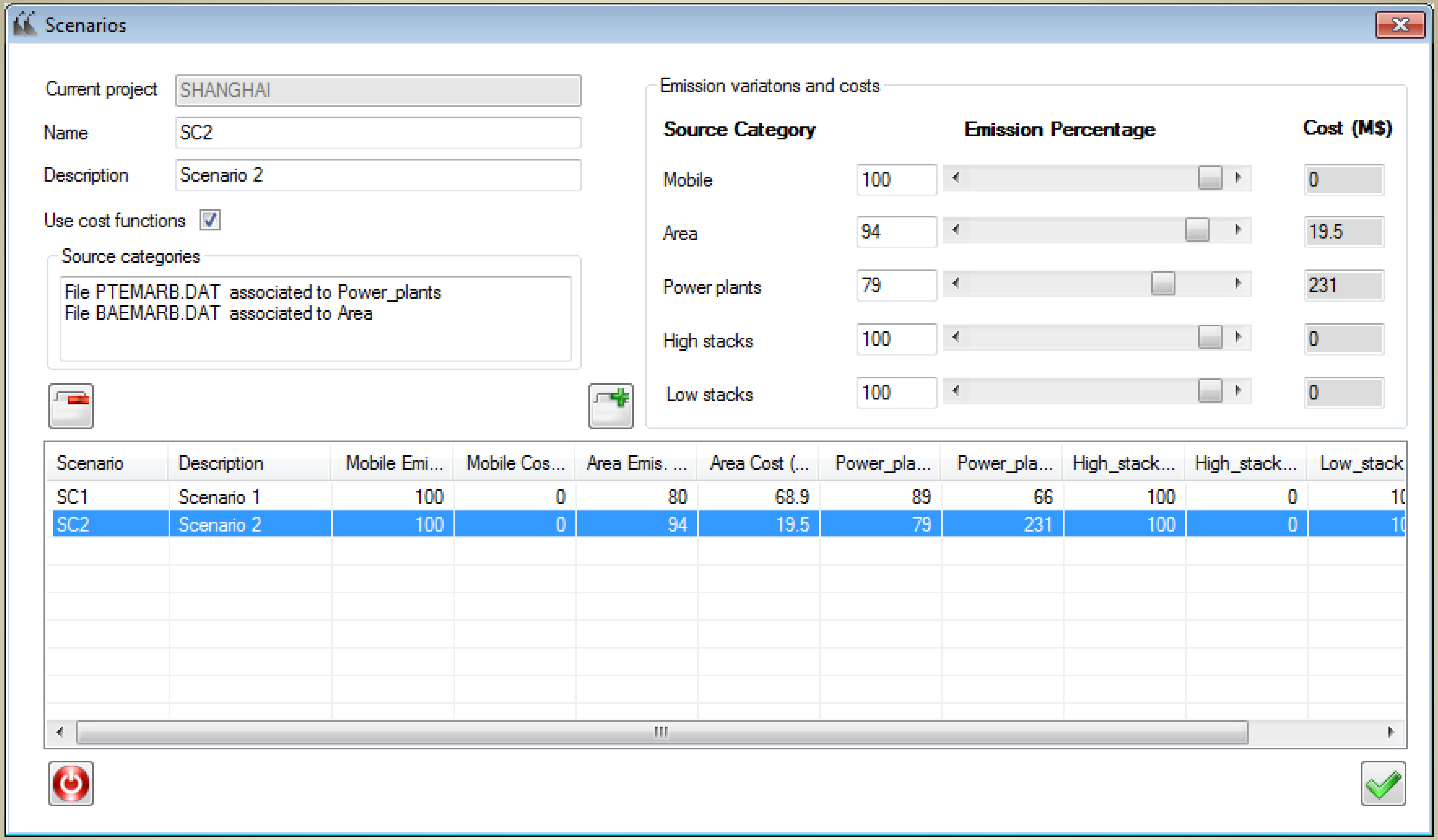
Population Distribution - China



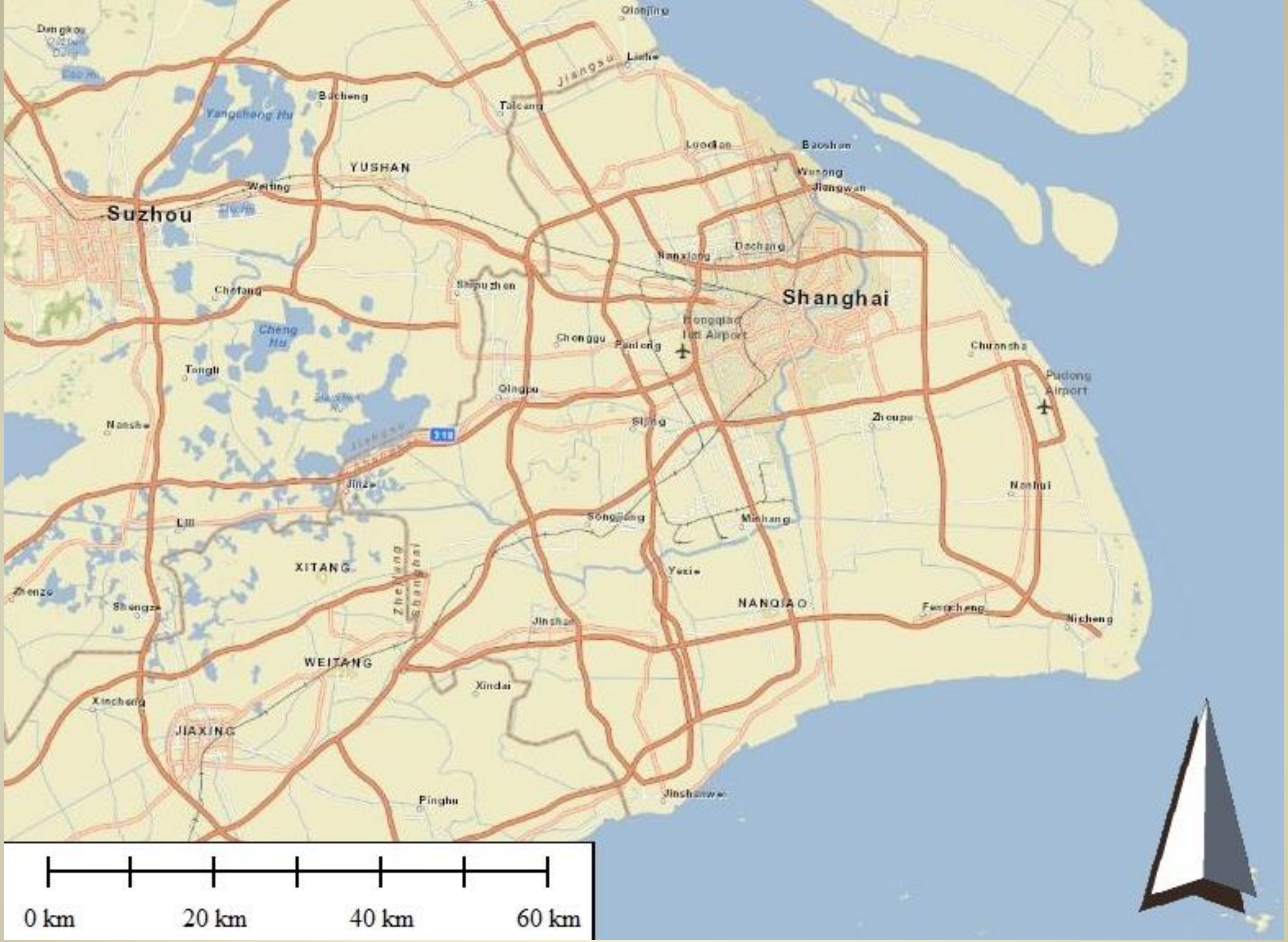
Population Classes
and Weights



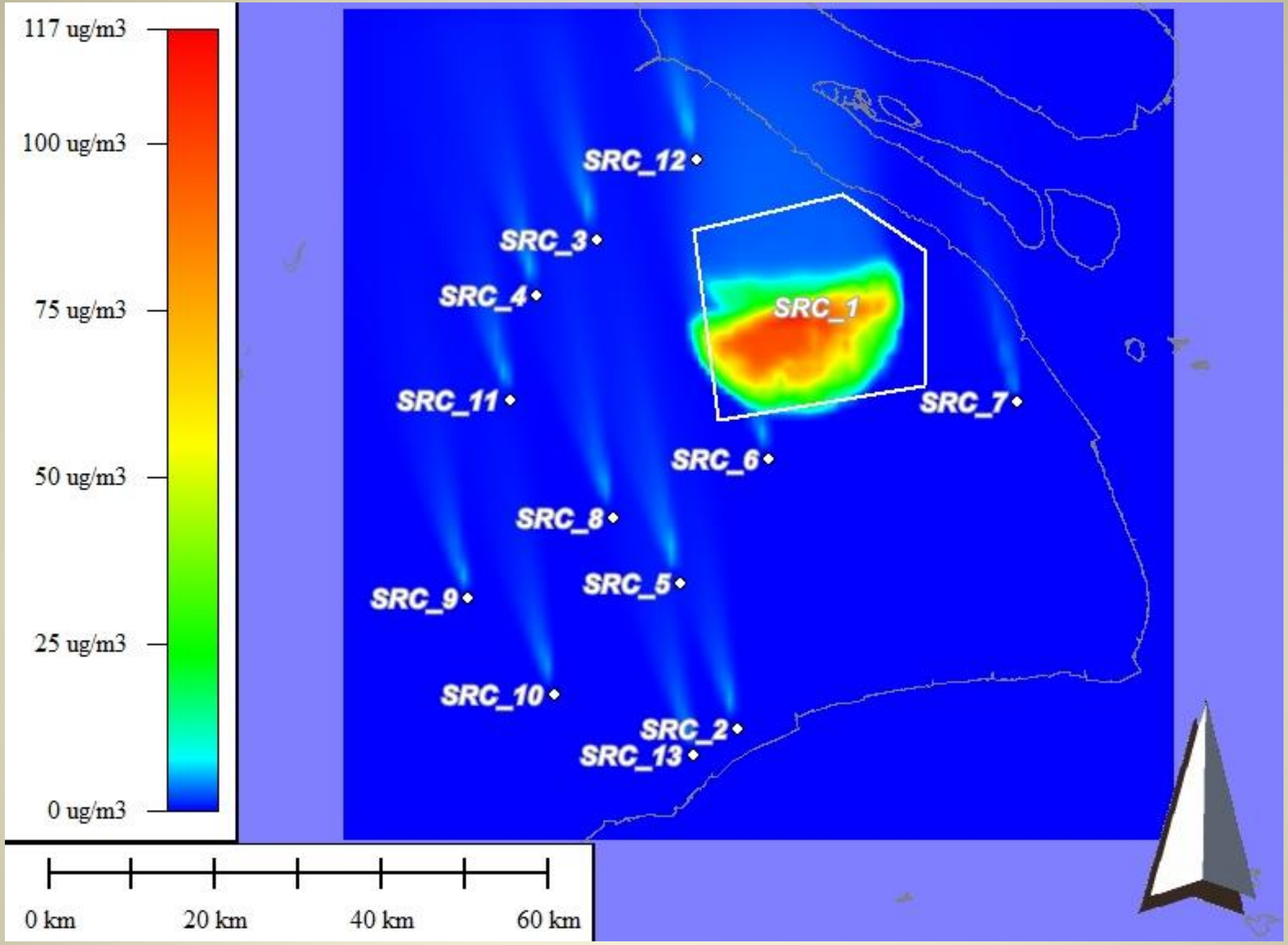
Modify SO_2 Emission Scenarios
by adjusting Base Case:
Scenario 1



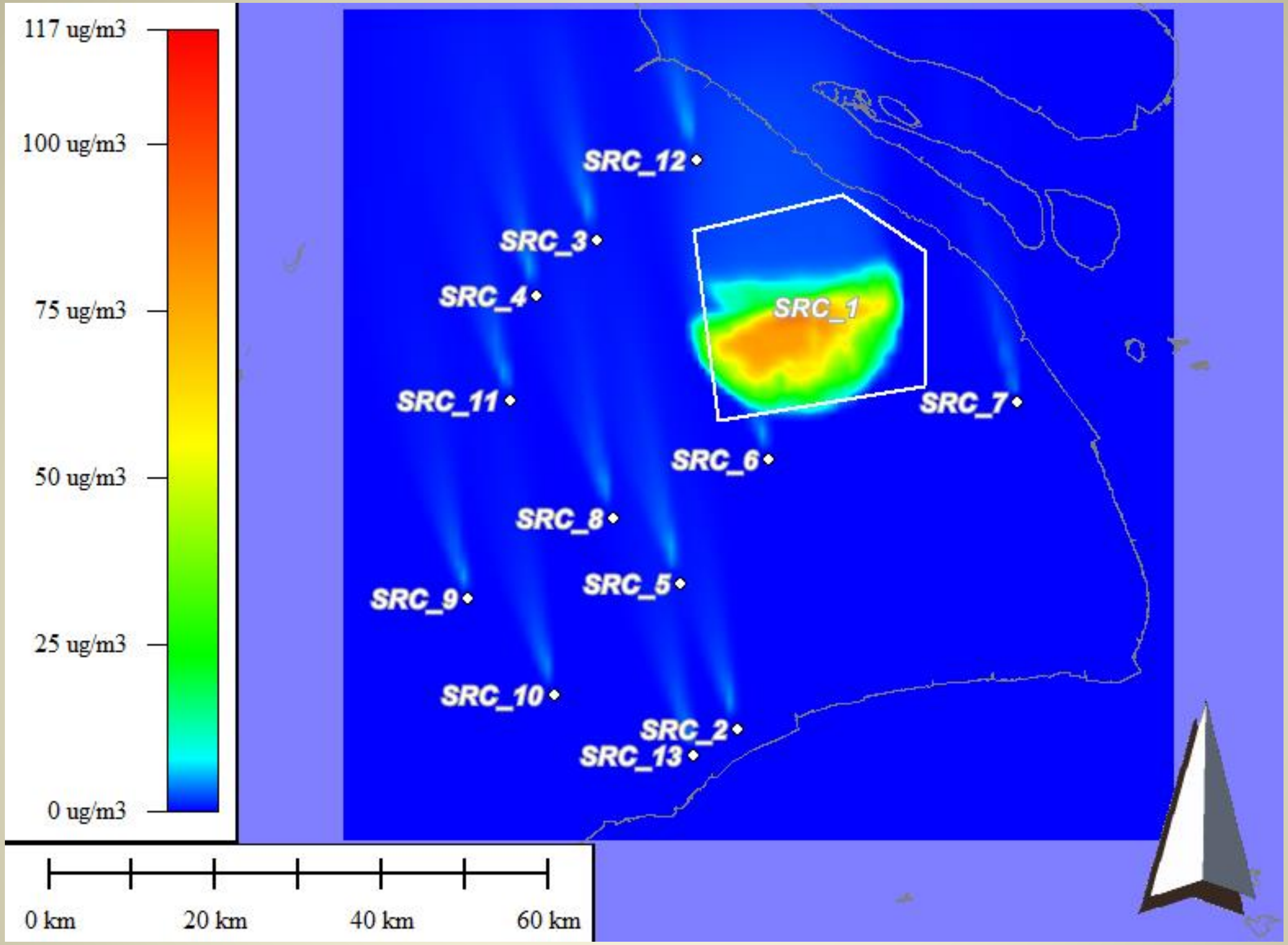
Modify SO_2 Emission Scenarios
by adjusting Base Case:
Scenario 2



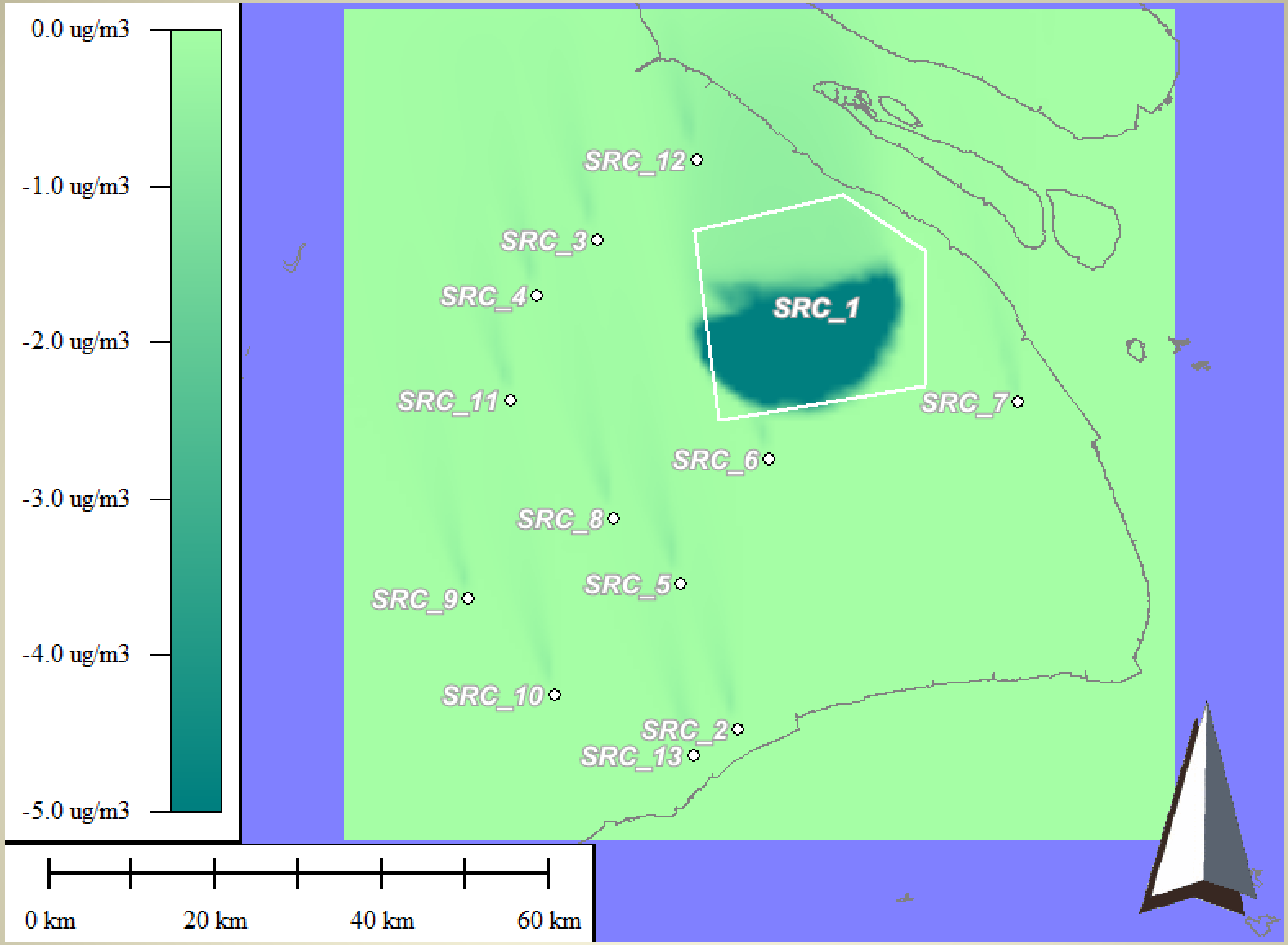
Zoom-In to Shanghai, China



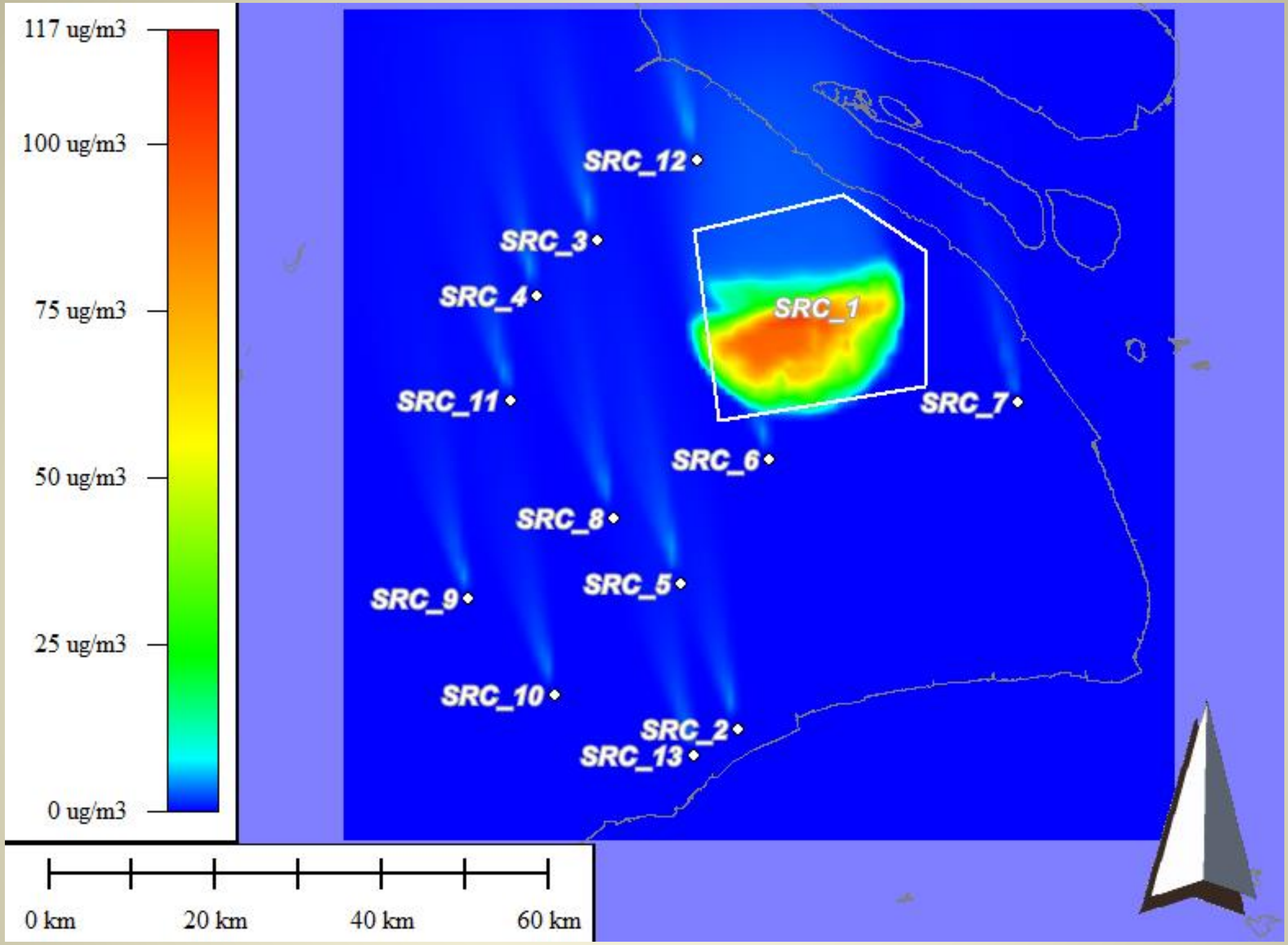
Base Case: SO_2 Emissions
(12 Hour SO_2 Concentrations)



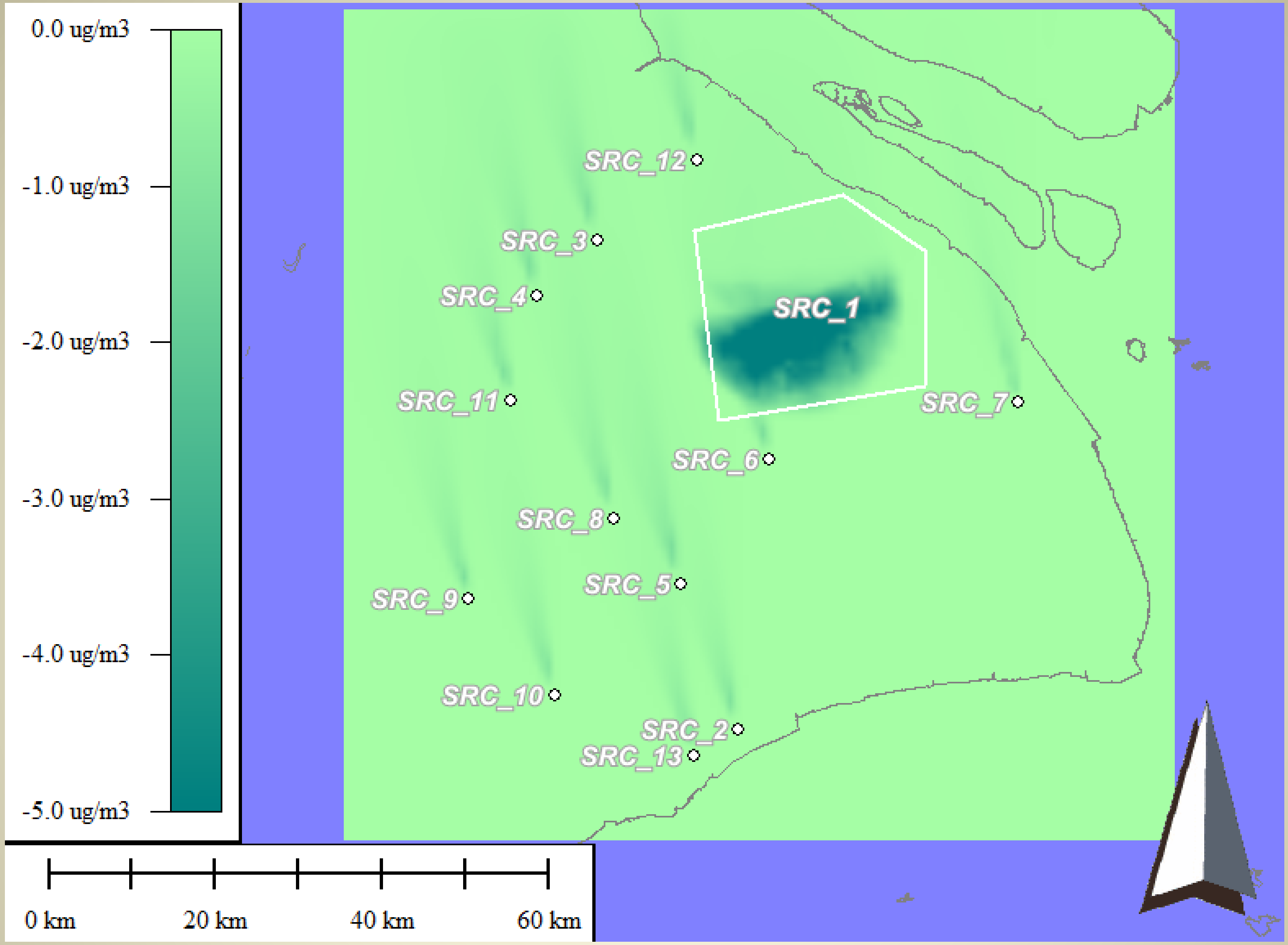
Scenario 1: Reduced SO_2 Emissions
(12 Hour SO_2 Concentrations)



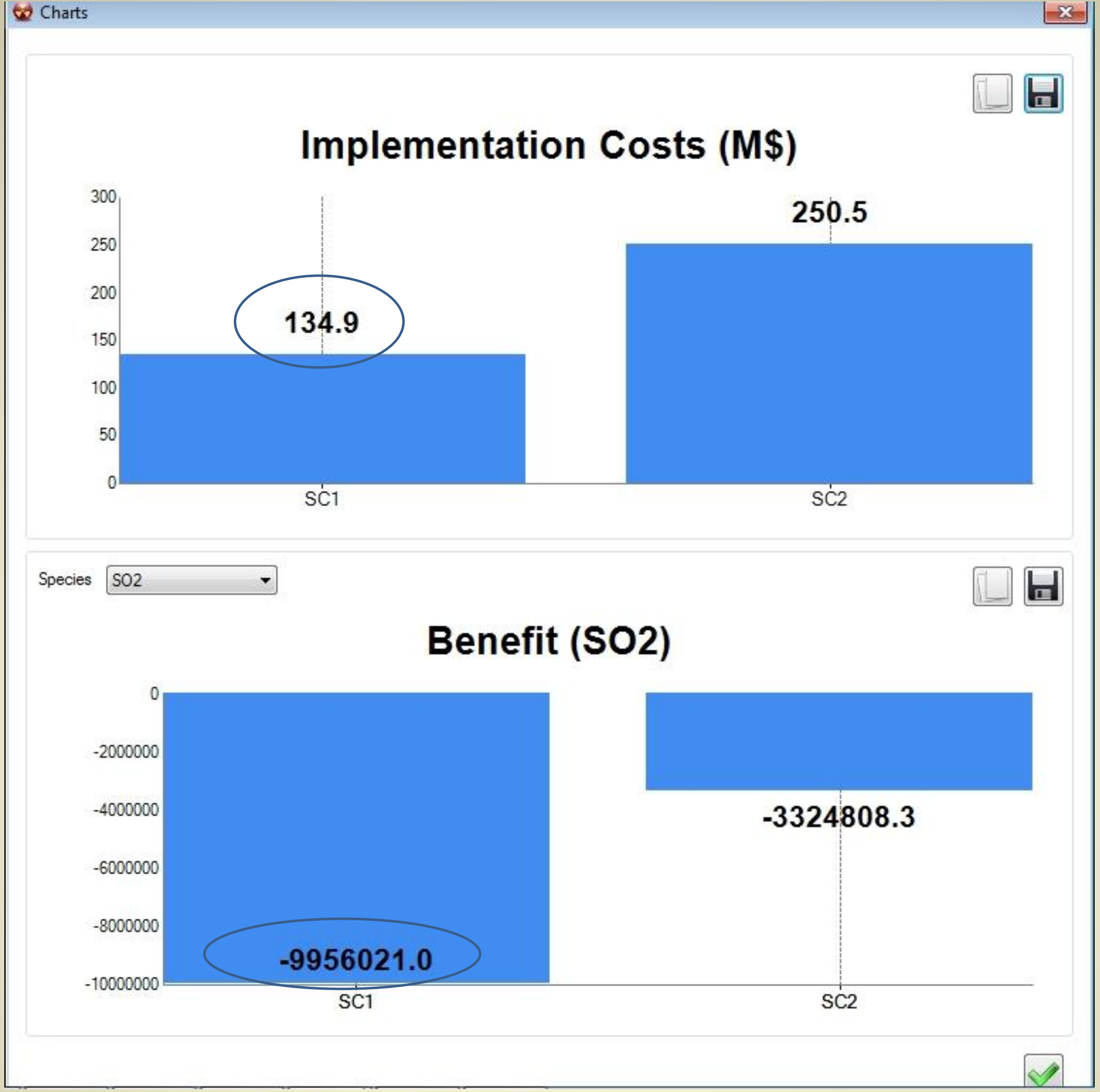
Scenario 1: SO_2 Difference from Base Case
(12 Hour “Delta” SO_2 Concentrations)



Scenario 2: Reduced SO_2 Emissions
(12 Hour SO_2 Concentrations)



Scenario 2: SO_2 Difference from Base Case
(12 Hour "Delta" SO_2 Concentrations)



By combining gridded Differences with Population Density and Age Weights, Scenario 1 has less Cost, but greater benefit (lower SO_2 impact over the Population)

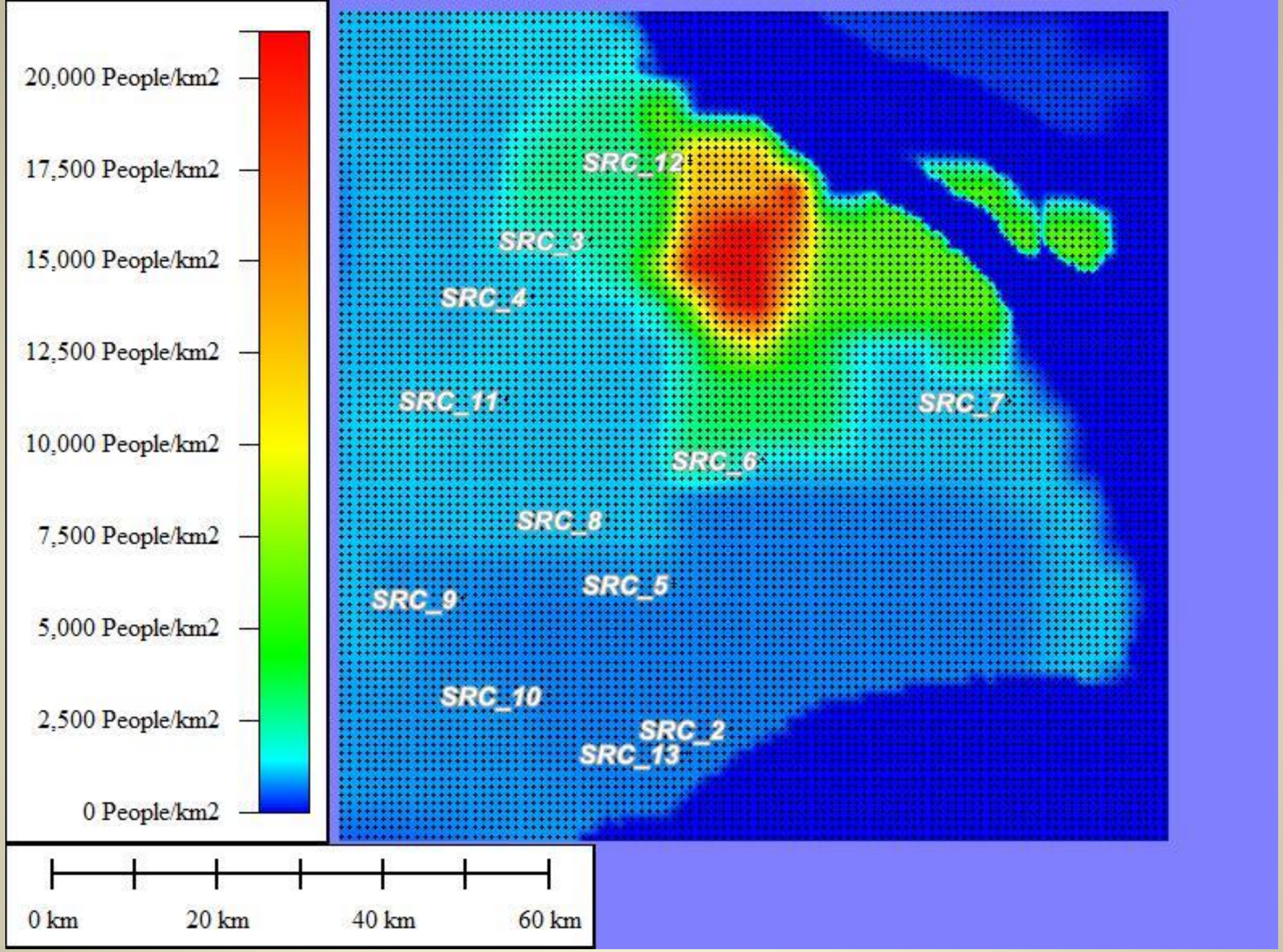
Sulfate (SO_4) Simulation

Power Plant Scenarios,
Costs, and Benefits

3-Day Simulation (~15-min PC simulation)
April 2-4, 2012

SO_2 to SO_4 Chemistry

- Complex set of reactions
- Role of photochemistry
- Role of meteorology (relative humidity)
- In-cloud chemistry
- A typical value: 1% gas SO_2 is converted to SO_4 fine particles over 1 hour



- Shanghai Population Density
- CALPUFF 1-km grid (100km by 100km)
- 12 point sources (power plants)

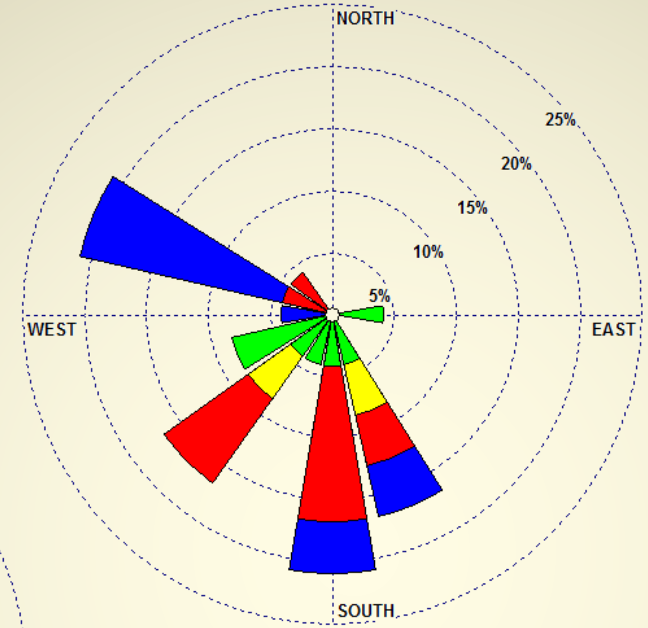
12 Power Plant Point Sources (simplified input)

Stack height: 75 m
Stack Diameter: 3 m
Exit Velocity: 10 m/s

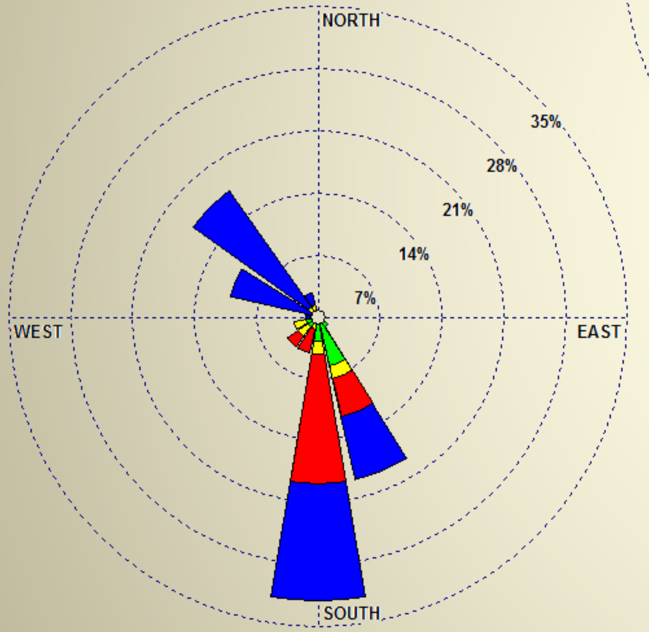
Power Output of each source:
2,500 MW

SO_2 baseline emission rate of each source:
1,200 g/s

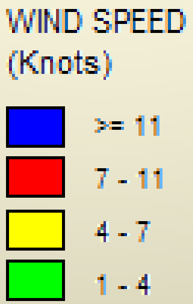
Wind Roses for April 2-4, 2010
(direction from)

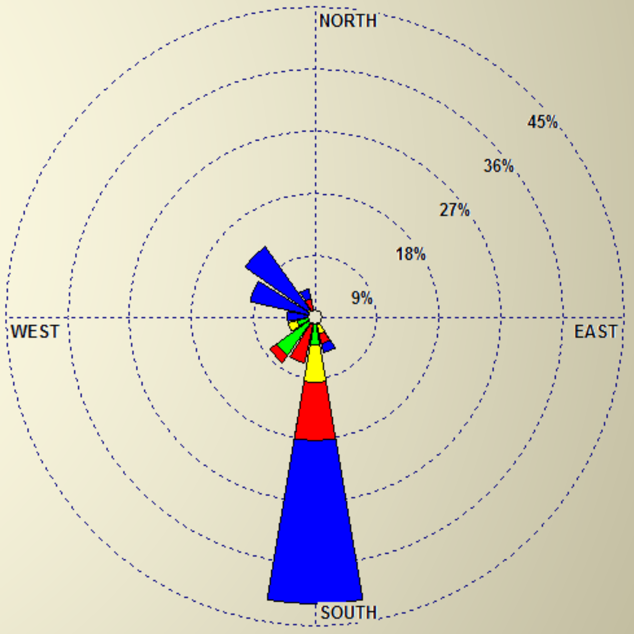


Shanghai Station
Average Wind Speed:
8.4 knots
Calms: 0%

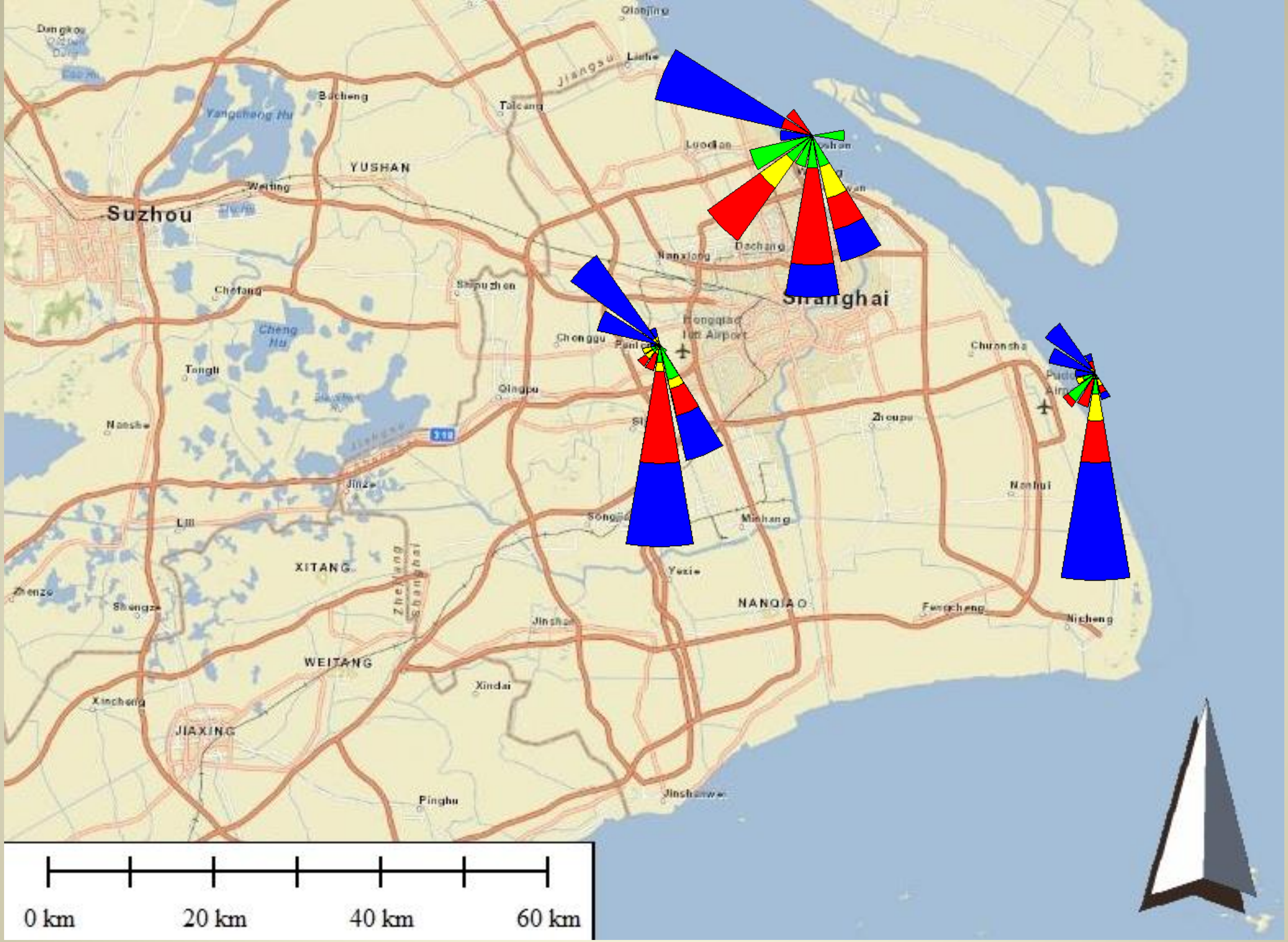


Hongqiao Airport
Average Wind Speed:
10.8 knots
Calms: 4.1%

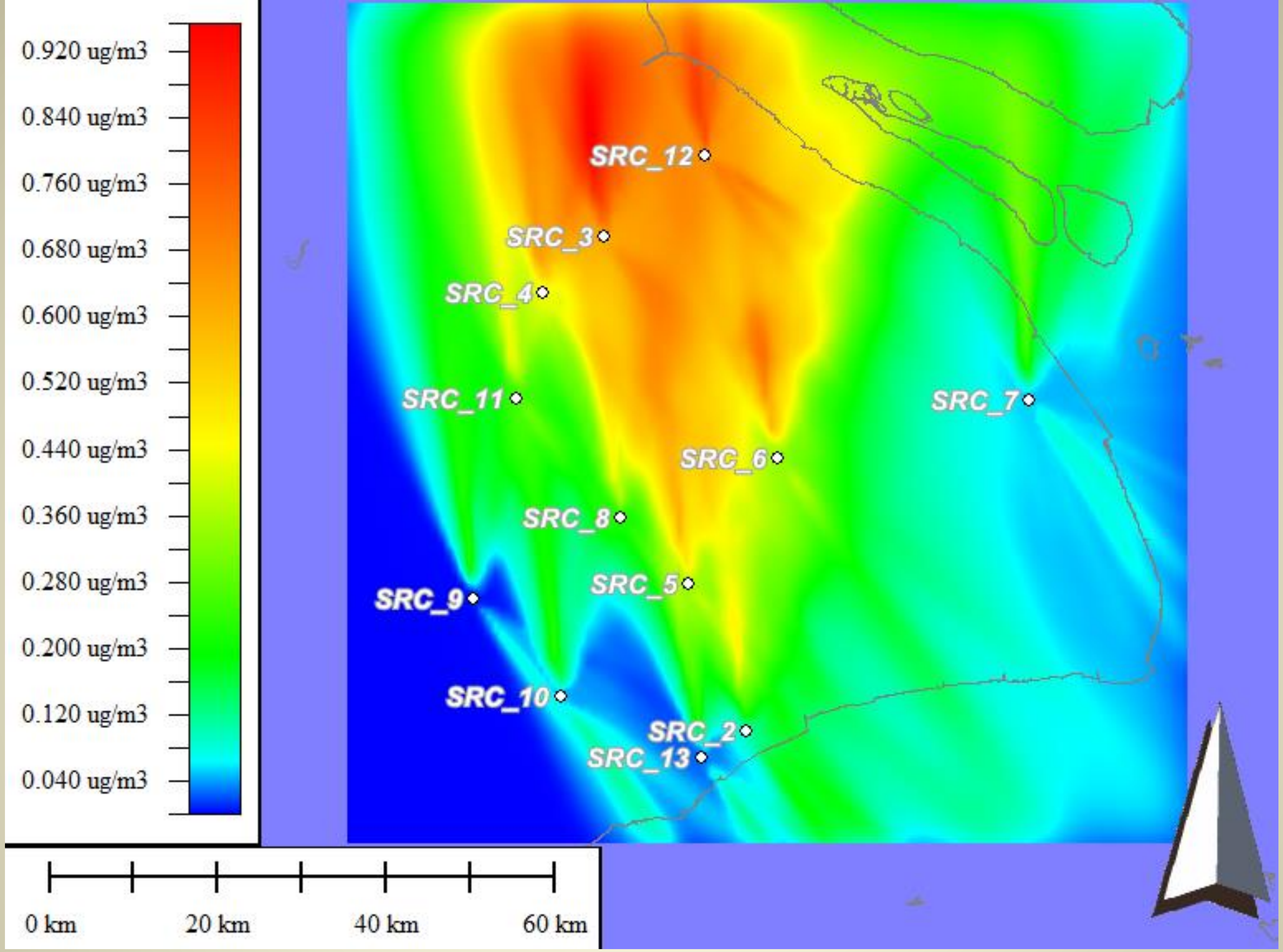




Pudong Airport
Average Wind Speed:
12 knots
Calms: 2.7%



Prevailing Winds in Shanghai Area
for April 2-4, 2010



3-day baseline CALPUFF SO_2 Emissions (72 hours)
Plot 3-day average baseline SO_4 concentrations

Some Possible Relationships of Health Cases and Costs to Sulfate Concentrations

Estimated annual probability per person per 1 µg/m^3 change in Annual SO_4 Concentrations (middle values)	Abbreviation	Health Case Name	Relative Cost Index
3.50E-05	PM	Premature Mortality	220,346
6.60E-05	CB	Chronic Bronchitis	29,381
1.60E-05	RHA	Respiratory Hospital Admission	1,042
1.30E-05	CHA	Cardiac Hospital Admission	1,042
9.30E-05	RAD	Restricted Activity Day	8.5
3.10E-02	ASD	Asthma Symptom Day	3.2
9.30E-05	LRSD	Lower Respiratory Symptom Day	1

(*) These values are adapted from 1997 China data published in 2003 (Journal of Environmental Sciences vol 15 no 5 pp 611) and clearly underestimate today's costs

Example:

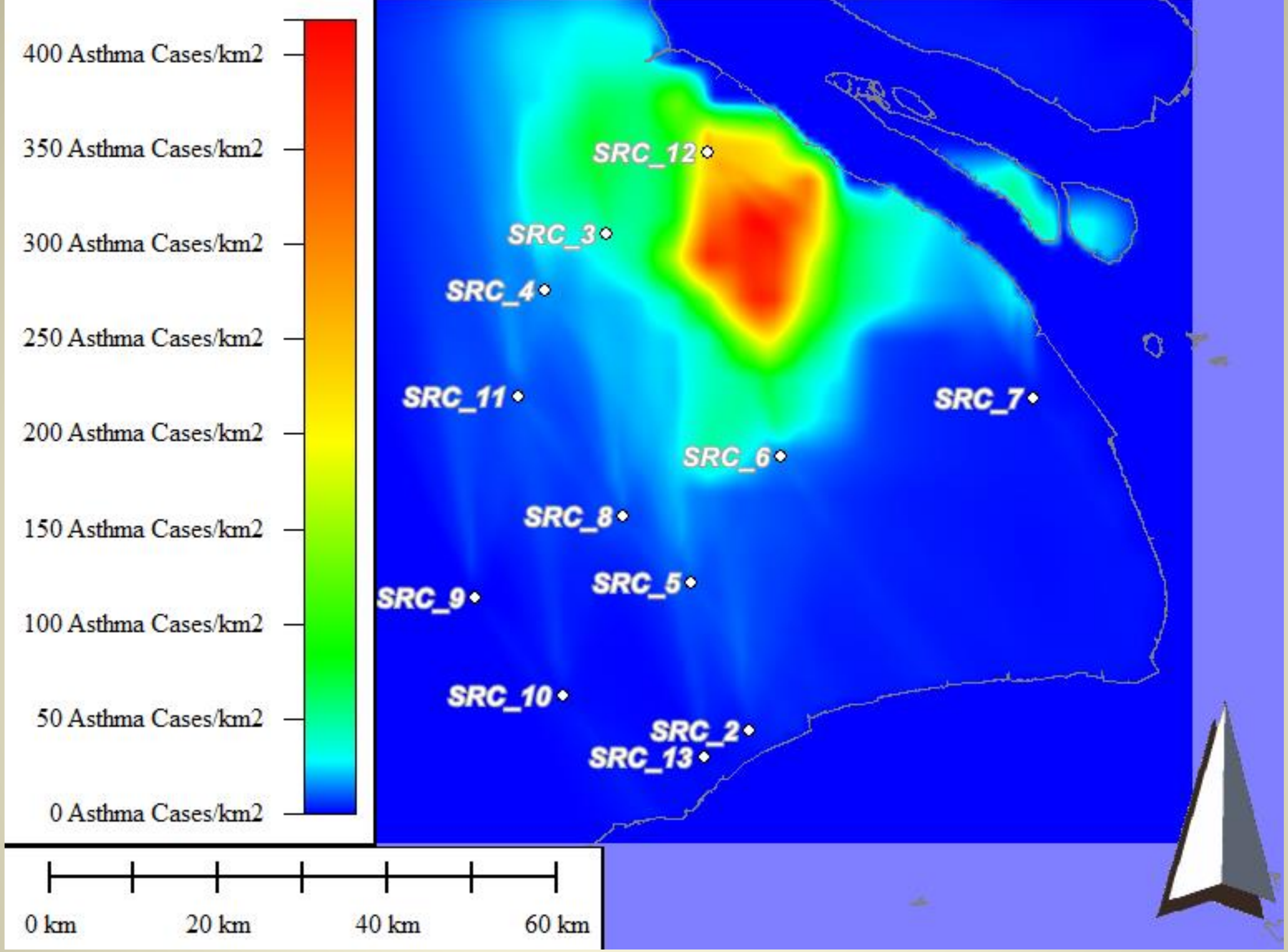
Estimate number of Asthma Symptoms and Relative Cost for one grid cell:

Grid cell population: 1,000
Grid cell average baseline SO_4 concentration: 0.5 μg/m^3

Estimated cases of Asthma Symptoms:
(1,000)*(0.5)*(0.031) = 15.5

Relative Cost Index due to Asthma Symptoms:
31*(3.2) = 49.6

Repeat analysis for all grid cells,
and all other Health Case types,
and calculate total cases and costs



Estimated Density of baseline Asthma Symptom Cases in CALPUFF Grid

	Premature Mortality	Chronic Bronchitis	Respiratory Hospital Admission	Cardiac Hospital Admission	Restricted Activity Day	Asthma Symptom Day	Lower Respiratory Symptom Day		
	PM	CB	RHA	CHA	RAD	ASD	LRSD	Total	
Totals	220	415	101	82	585	195,112	585	**197,100**	Health Cases
Percent	0.0014%	0.0026%	0.0006%	0.0005%	0.0037%	1.2%	0.0037%	**1.3%**	Percent of Population
Cost	48,539,443	12,204,735	104,963	85,283	4,953	630,360	585	**61,570,323**	Cost Index

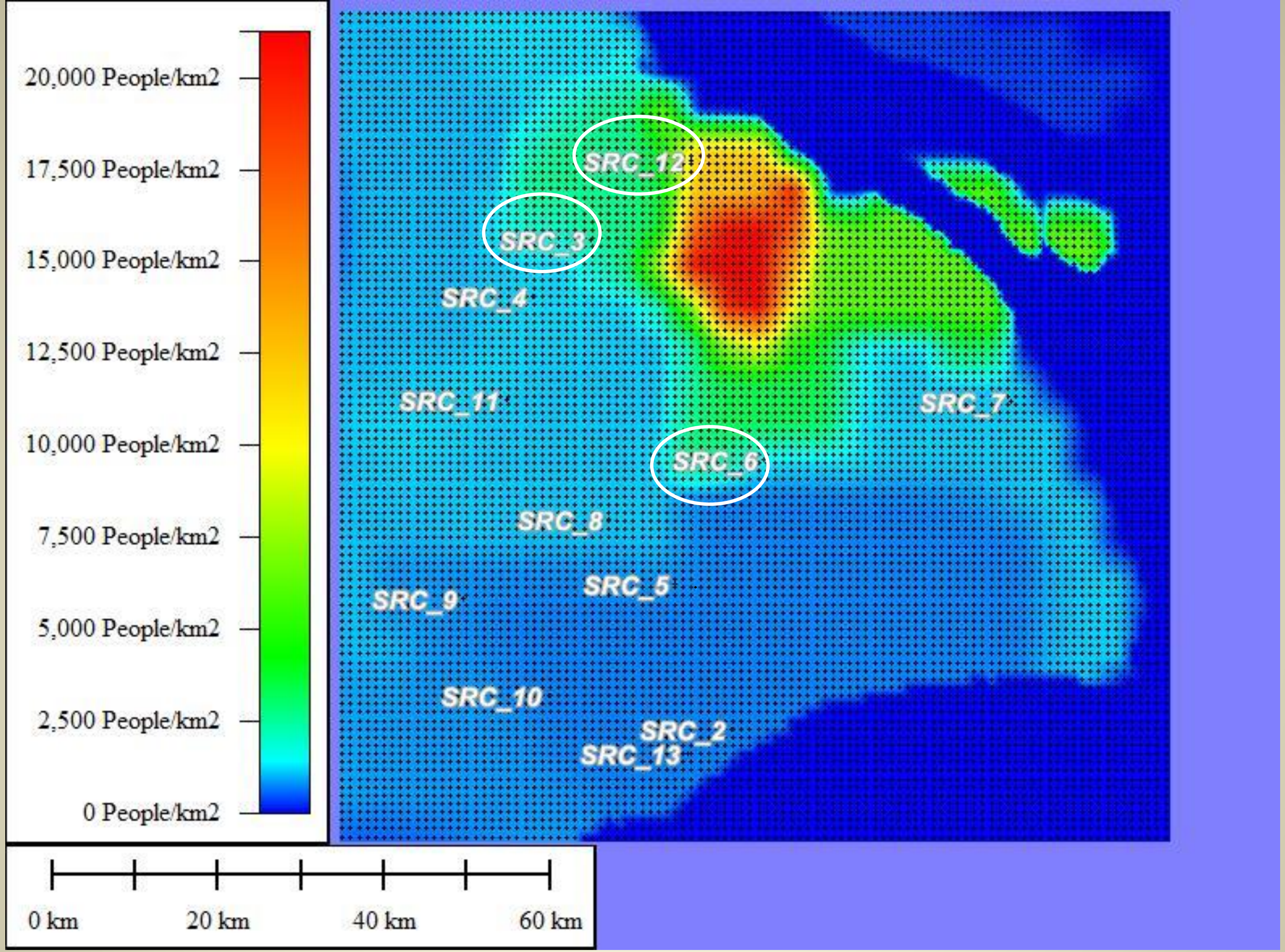
Baseline Health Cases and Costs due to Sulfate Concentrations (total population = 15,761,275)

Some Literature Information:

- **Cost of Installing Wet Scrubber:**
  ~ $200,000 per MW

- **Cost of Installing Wet Scrubber for one 2,500 MW power plant:**
  ~ $500,000,000

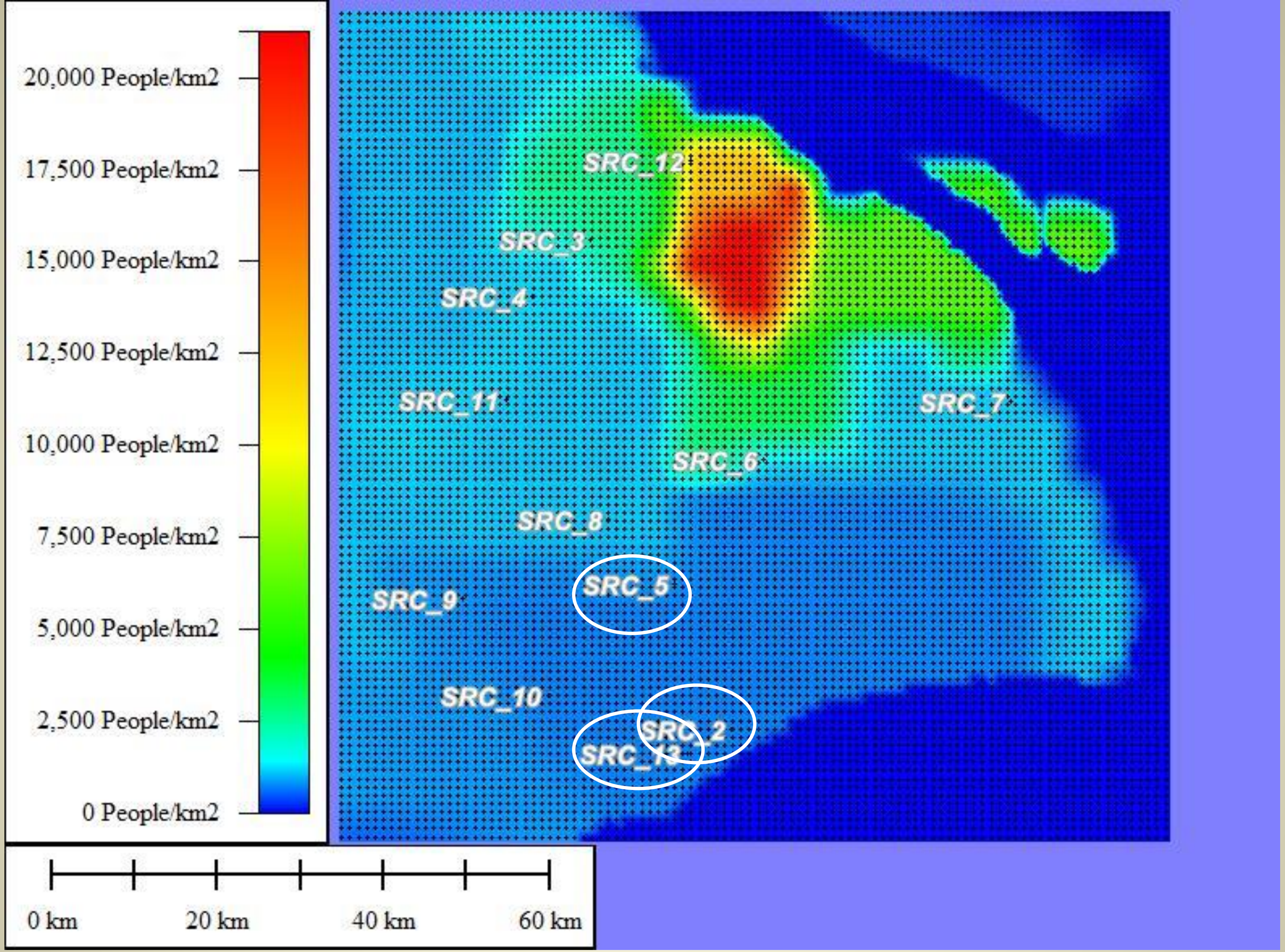
Total Cost of scrubbers for 3 power plants:
<u>$1.5 B</u>



“Common Sense” Scenario: reduce emissions of 3 closest stacks from the densest population area by ~80% (Wet Scrubbers for Sources 3, 6, and 12)

	Premature Mortality	Chronic Bronchitis	Respiratory Hospital Admission	Cardiac Hospital Admission	Restricted Acitivity Day	Asthma Symptom Day	Lower Respiratory Symptom Day		
	PM	CB	RHA	CHA	RAD	ASD	LRSD	Total	
Totals	183	345	84	68	486	162,048	486	**163,700**	Health Cases
Percent	0.0012%	0.0022%	0.0005%	0.0004%	0.0031%	1.0%	0.0031%	**1.0%**	Percent of Population
Cost	40,313,890	10,136,506	87,176	70,831	4,114	523,539	486	**51,136,542**	Cost Index

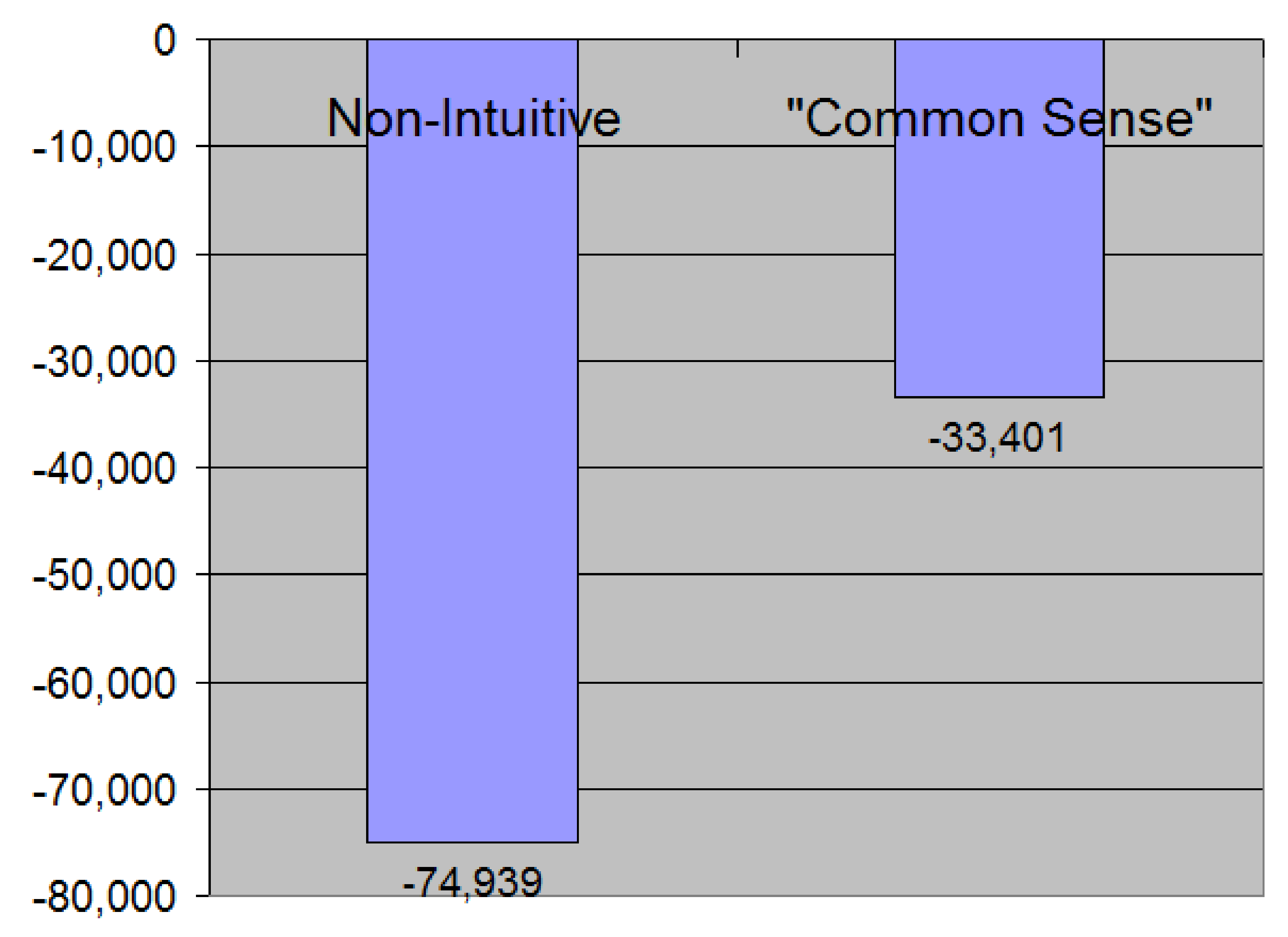
"Common Sense" Scenario: Health Cases and Costs due to 80% reduced Sulfate Concentrations for Sources 3, 6, and 12 (Health Cases reduced by 33,401, Cost Index reduced by 10,433,781)



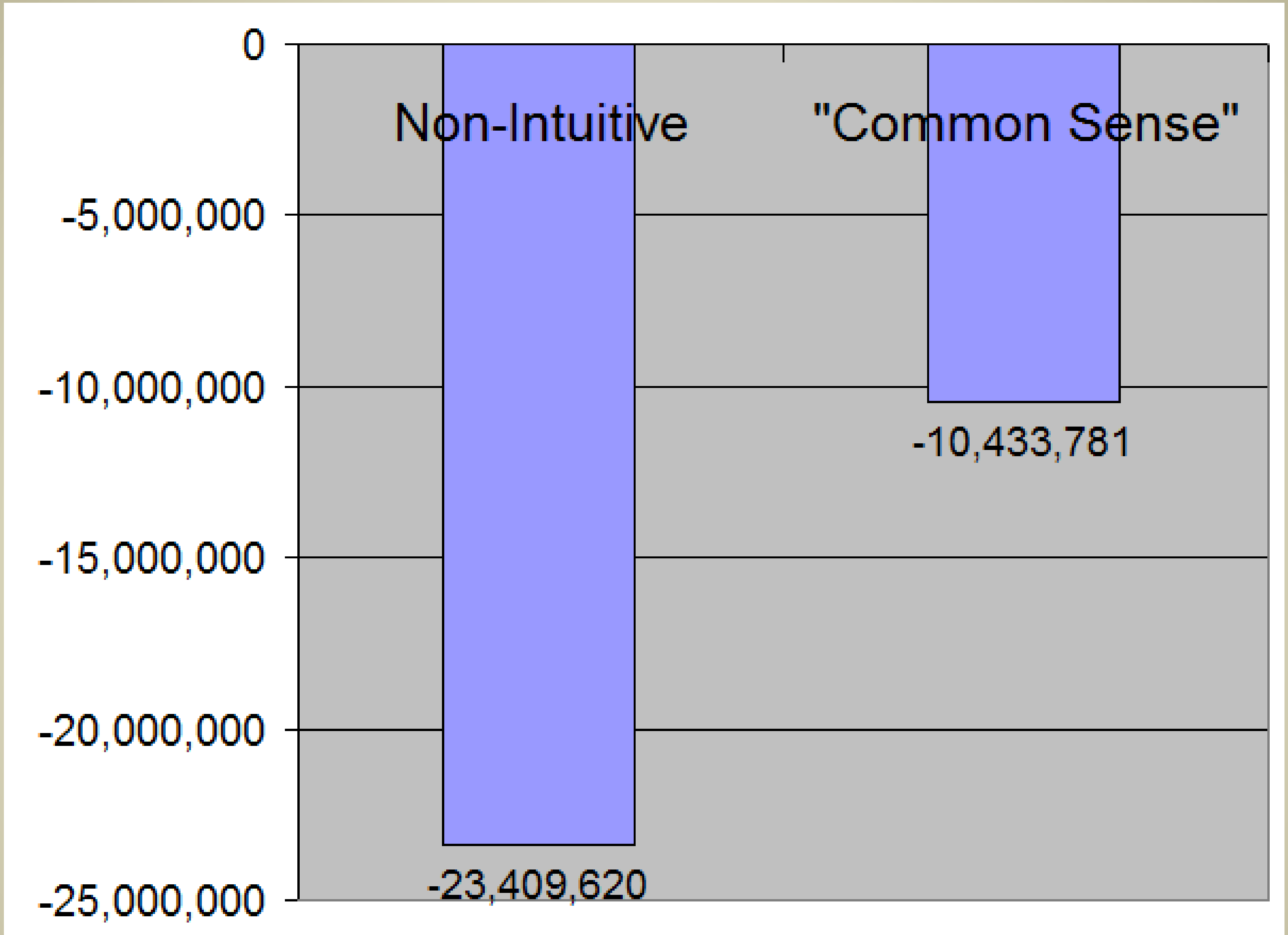
"Non-Intuitive" Scenario: reduce emissions of 3 distant stacks from the densest population area by ~80%
(Wet Scrubbers for Sources 2, 5, and 13)

	Premature Mortality	Chronic Bronchitis	Respiratory Hospital Admission	Cardiac Hospital Admission	Restricted Acitivity Day	Asthma Symptom Day	Lower Respiratory Symptom Day		
	PM	CB	RHA	CHA	RAD	ASD	LRSD	Total	
Totals	137	257	62	51	363	120,928	363	**122,161**	Health Cases
Percent	0.0009%	0.0016%	0.0004%	0.0003%	0.0023%	0.8%	0.0023%	**0.8%**	Percent of Population
Cost	30,084,287	7,564,379	65,055	52,857	3,070	390,691	363	**38,160,703**	Cost Index

"Non-Inuitive" Scenario: Health Cases and Costs due to 80% reduced Sulfate Concentrations for Sources 2, 5, and 13 (Health Cases reduced by 74,939, Cost Index reduced by 23,409,620)



Reduction in Total Health Cases for both Scenarios



Reduction in Relative Cost Index for both Scenarios

3. The unique scientific (and non-scientific) challenges of litigation work and expert testimony

What is "Litigation" Work?

- In litigation, one party (the plaintiff) files a legal case - a dispute - against another party (the defendant)
- Both parties, typically, hire attorneys to represent them
- The legal case goes to court in front of a judge and, sometimes, a jury
- In special cases, attorneys hire experts to investigate the matters of the case and provide expert opinions
- Experts may be medical doctors, scientists/engineers, crime investigators, financial specialists, etc.
- Experts often prepare reports and sometimes testify under oath
- Litigation, and the use of experts, is very common in the United States. Why?

Litigation in the US

- Very common
  - Plaintiff attorneys can work on “contingency” fees, i.e., for a fraction of the final settlement (e.g., 30%), and require no payments from individual plaintiffs
  - Class actions in which hundreds/thousands of plaintiffs are represented in a single case
- Of course, 30% of $0 is $0 …
- Final settlement amounts can be very high, especially in class actions, and therefore, there is an incentive, on both sides, to hire capable experts to help understand the technical/scientific/medical aspect of a case
- Litigation is increasing outside the US, even though the legal systems of other countries are different and US-style litigation is not always possible

Environmental Litigation

- Environmental litigation mostly deals with
  - Air/water/soil/groundwater pollution
  - Claims of toxic impacts of pollutants
    - Acute human exposure, for short times (e.g., a few hours)
    - Chronic human exposure, for long times (e.g., several years)
  - Remediation/clean up costs
  - Regulatory compliance
  - Accidental releases from fires, explosions, leaks, unplanned events
- Computer modeling plays an important role!

Computer Modeling

- Environmental cases are so complex that, often, a valid scientific opinion can be given only with the use of computer models
- For example, in air pollution cases, models are used for:
  - Estimating the amount of chemicals released into the atmosphere
  - Simulating the turbulent transport and diffusion of these chemicals in the atmosphere
  - Including special issues, such as complex terrain, ground deposition, chemical reactions, decay
  - Calculating the chemical exposure at different locations and times (e.g., plaintiffs' locations)

A Typical Air Pollution Litigation Case: Accidental Release

The Accident

Technical Tasks

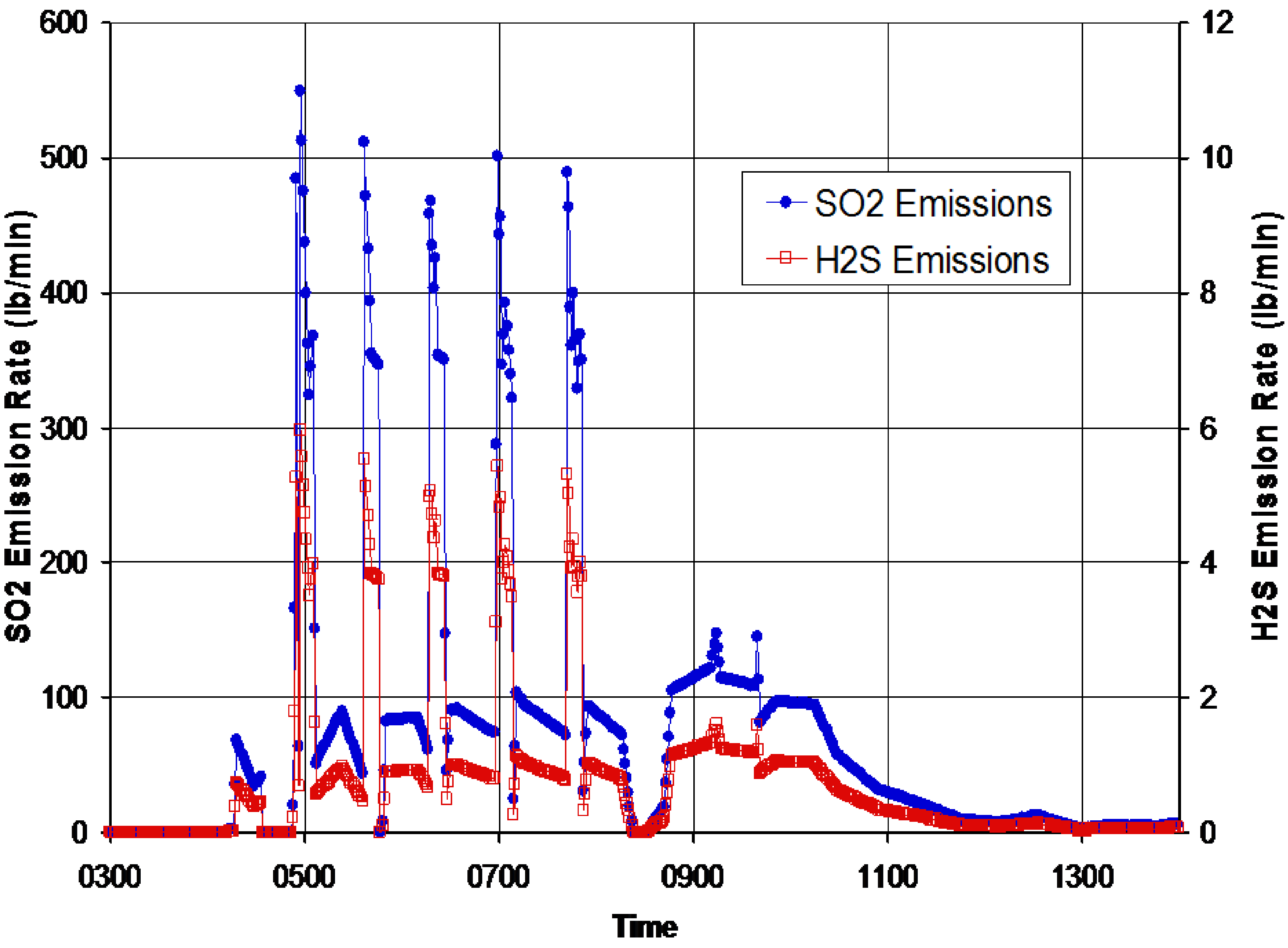
1. Accident Reconstruction
2. Emission Characterization (➔)
3. Meteorological Characterization
4. Plume/Puff Modeling (➔)
5. GIS Visualization
6. Adverse Effects

Example of Emission Characterization

- Average release rate and parameters
- Minute-by-minute estimates

- E.g., a flaring incident (1990s)


FreeFoto.com



SO2 Emissions
H2S Emissions
SO2 Emission Rate (lb/min)
H2S Emission Rate (lb/min)
Time
600
500
400
300
200
100
0
12
10
8
6
4
2
0
0300
0500
0700
0900
1100
1300

Some Available Simulation Models

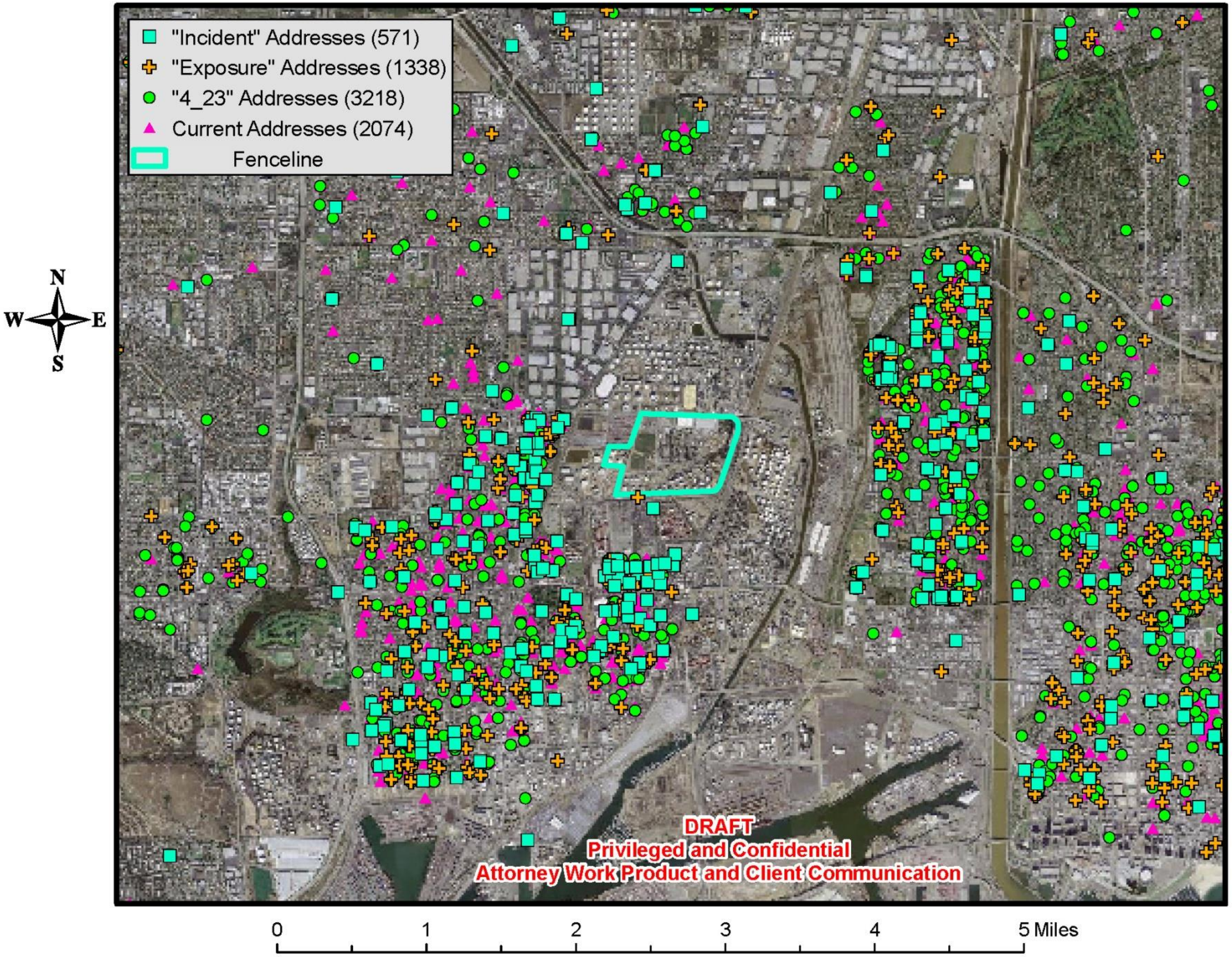
- Dispersion Models developed/recommended by government agencies https://www.epa.gov/scram
  - AERMOD
  - CALPUFF
  - Photochemical models, e.g., CAMx
- Models developed at National Laboratories and Universities
- Models developed by private industrial groups and consulting companies
- Models/Methodologies to calculate adverse health effects, e.g., risk assessment: https://www.epa.gov/fera/risk-assessment-and-modeling-epa-risk-assessment-policy-guidelines-and-related-materials)
- Our Lagrangian particle simulation model LAPMOD: https://www.enviroware.com/lapmod/

Results from: Accident Reconstruction, Modeling, and Visualization

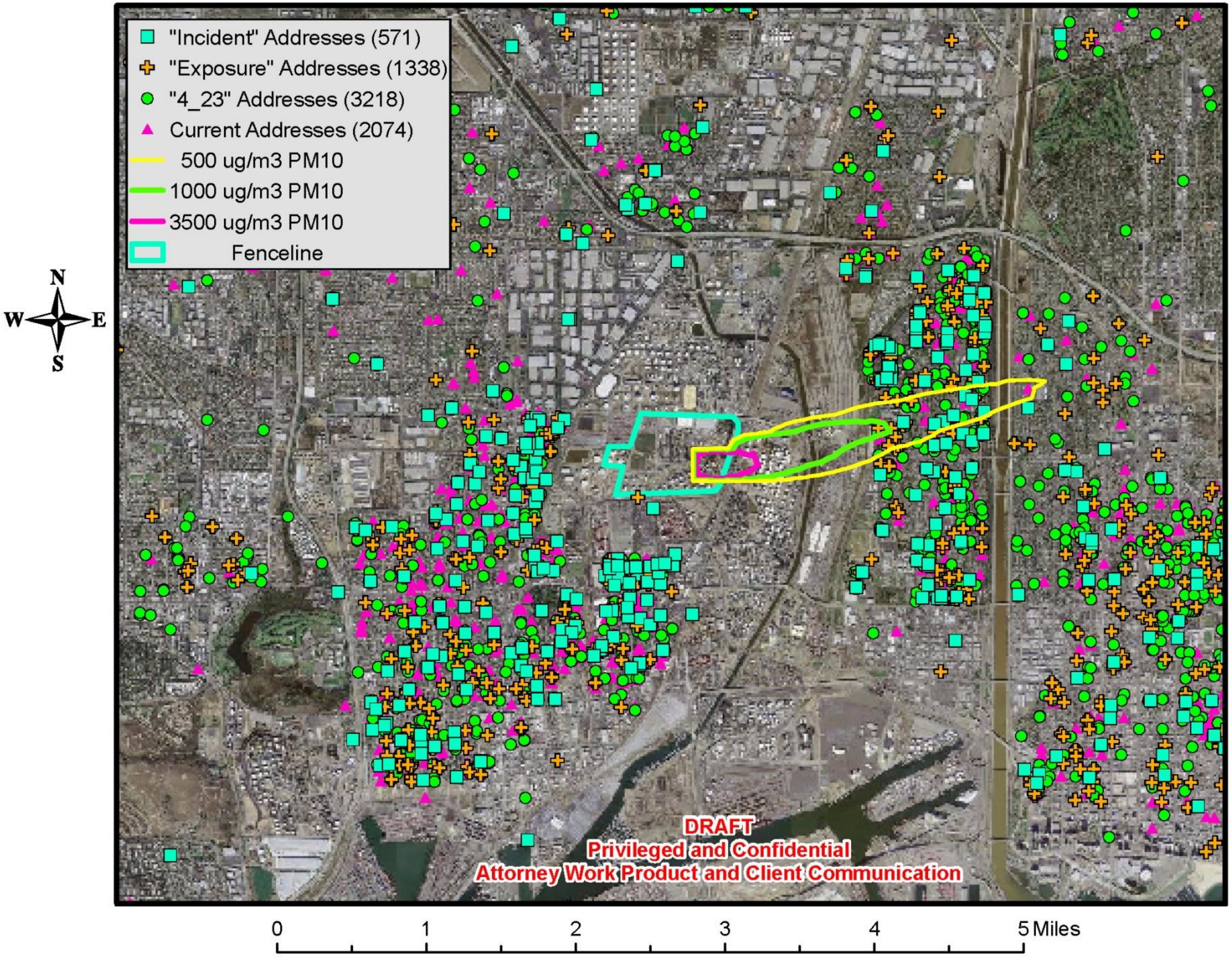
➔ Animations

The Use of GIS is Crucial

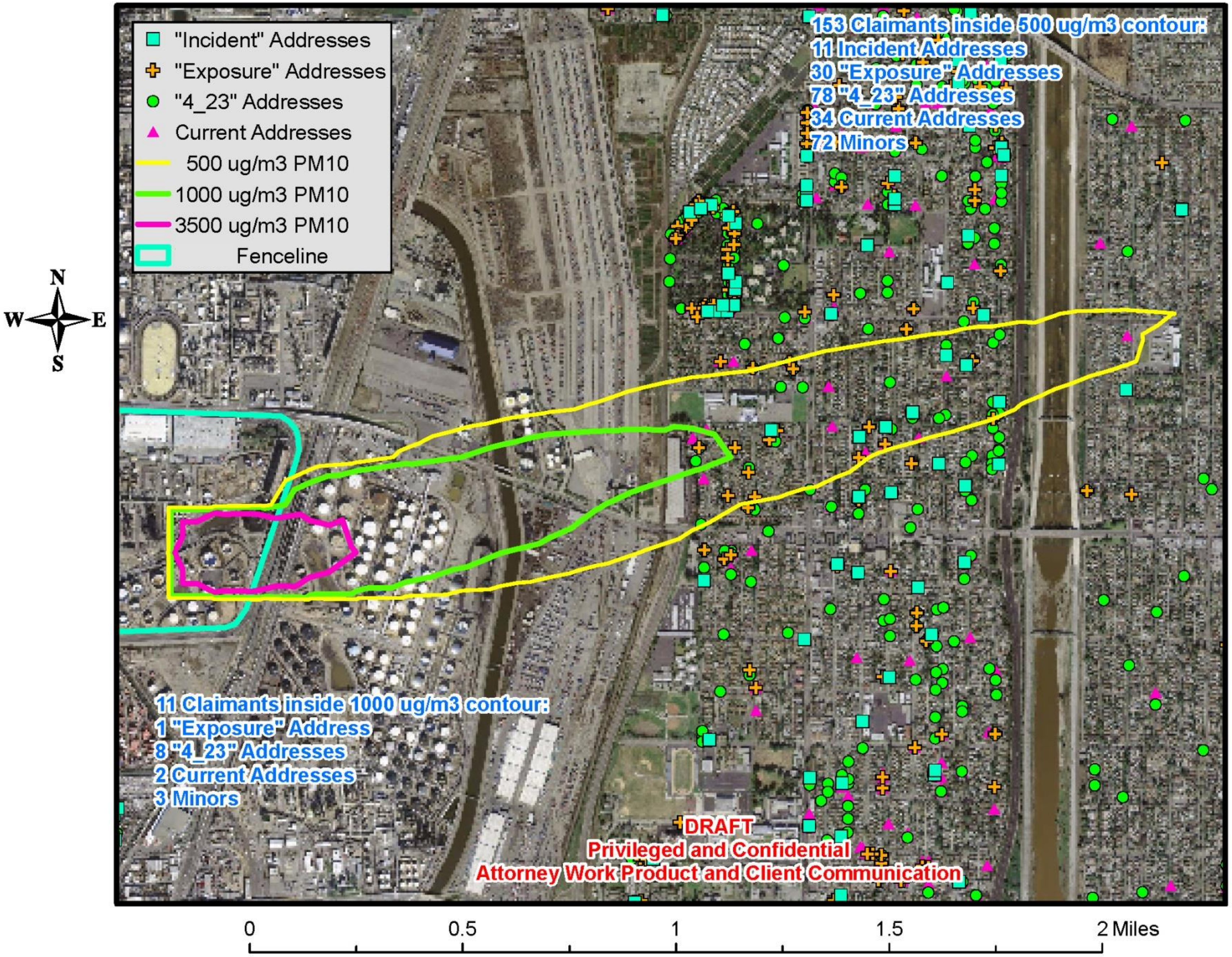
Geocoded Addresses



1-Hour Maximum Pointwise PM10 Concentrations and Geocoded Addresses



1-Hour Maximum Pointwise PM10 Concentrations and Geocoded Addresses



Conclusions

- Environmental litigation work will probably increase in Europe in the next few years
  - Opportunity for interesting scientific work and extra income
- Many scientists may be asked to work as experts
  - Litigation work is not for everybody
  - Very demanding, often with "impossible" deadlines; work under pressure
  - Interactions with attorneys may present challenges
    - Language, goals, culture are different

More reading on this topic

- My article "Environmental litigation - air pollution models and modelers in court" http://www.envirocomp.com/zcv/P.49.pdf
- Material under "Selected Projects" at http://www.envirocomp.com/

Thank you!

zannetti@envirocomp.com