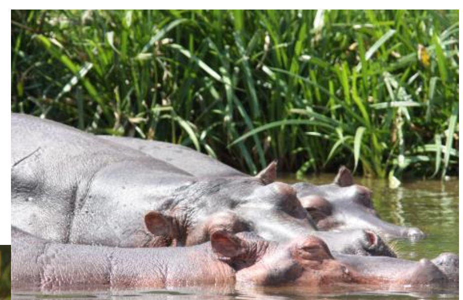
Mathematics of Planet Earth (MPE)



Fred Roberts
Rutgers University

The MPE Challenge

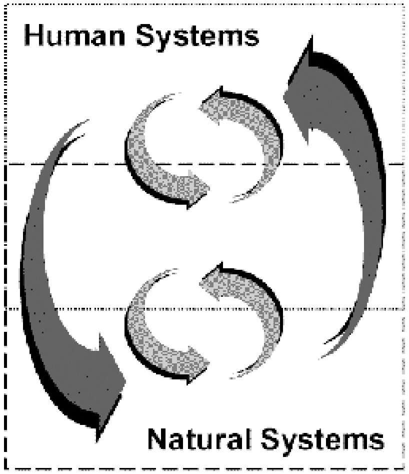
- Learning to live sustainably on Earth is going to require enormous advances in our understanding of the natural world, the human world, and their inter-relationships.
- To acquire that understanding, progress in the mathematical sciences is essential.

The MPE Challenge

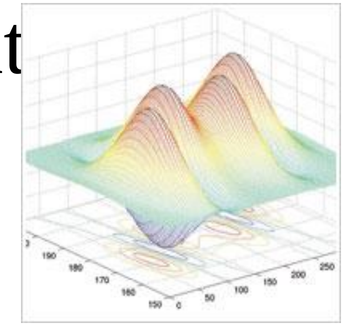
- The human population is swelling toward 10 billion.
- All of these people need food, clean water, housing, energy, health care, safety, (jobs), etc.
- To stay within the planet's carrying capacity, we are going to have to be extraordinarily clever about how we use the earth's resources and human re

Deepwater Horizon
Oil Spill

The MPE Challenge



- Need to understand
  - Impact of our actions on environment
  - How natural world functions
  - How human processes function
  - How we can deal with inevitable changes coming
- Doing so requires answering extremely complex, multidisciplinary questions in the emerging "science of sustainability."
- That science requires the precise insight that the mathematical sciences provide.



NSF SEES: Science, Engineering, and Education for Sustainability

- National Science Foundation initiative begun 2009.
- I served on NSF Advisory Committee on Environmental Science and Education – as a representative of the mathematical sciences
- “The two-way interaction of human activity with environmental processes now defines the challenges to human survival and wellbeing. Human activity is changing the climate and the ecosystems that support human life and livelihoods.”

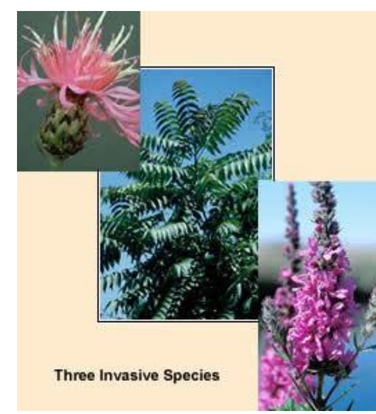

Dust storm in Mali

NSF SEES: Science, Engineering, and Education for Sustainability

"Reliable and affordable energy is essential to meet basic human needs and to fuel economic growth, but many environmental problems arise from the harvesting, generation, transport, processing, conversion, and storage of energy."

NSF SEES: Science, Engineering, and Education for Sustainability

"Climate change is a pressing anthropogenic stressor, but it is not the only one. The growing challenges associated with climate change, water and energy availability, emerging infectious diseases, invasive species, and other effects linked to anthropogenic change are causing increasing hardship and instability in natural and social ecologies throughout the world."



US – China Computer Science Leadership Summits

US – China Computer Science Leadership Summits

•Fall 2005: Peter Freeman (NSF Asst. Director) suggests US-China CS Leadership Summit

Beijing, June 14-15, 2010

The Third Summit:

- ***Minisymposium on CS & Sustainability***
  - –Discovery of patterns in global earth science data, including challenge of climate change
  - –Use of CS methods to track & decrease energy use
  - –Use of PDAs to encourage "green behavior"
  - –CS & design of ecosystems

Symposium organizer David Shmoys provided overview

Mathematics of Planet Earth 2013

- A joint effort initiated by North American Math Institutes: **MPE2013**
- But the problems of the planet are world-wide problems.
- More than 100 partner institutes, societies, and organizations in UK, France, South Africa, Japan, and all over the world
- www.mpe2013.org

Mathematics of Planet Earth 2013

- Activities world-wide throughout 2013
- Sponsorship by UNESCO
- Support from Simons Foundation
- Workshops, tutorials, competitions, distinguished lectures, educational programs

Some Themes of MPE2013+

- ***MPE continues beyond 2013: MPE2013+***
- ***Themes:***
  - ***Global Change***
  - ***Sustainable Human Environments***
  - ***Natural Disasters***
  - ***Management of Natural Resources***
  - ***Data-aware Energy Use***

Theme 1: Global Change

- The planet is constantly changing.
- But the pace of change has accelerated as a result of human activity:
  - Construction and deforestation change habitats
  - Over-fishing reduces wild populations
  - Fossil fuel combustion leads to atmospheric greenhouse gas buildup
  - Commerce and transport introduce non-native species.

Global Change

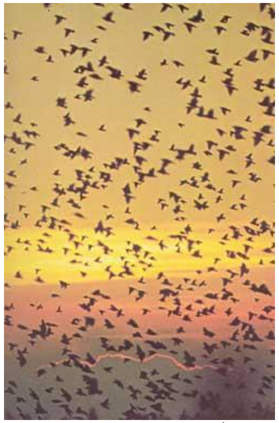
- We need to:
  - Monitor global change to understand processes leading to change
  - Learn how to mitigate and adapt to its effects
  - Determine if we are meeting goals for our planet
  - Get early warning of dangerous trends

Global Change

- ***The Age of Observation***:
  - The unprecedented amount of data about health of the planet provides great opportunities but also poses immense challenges
  - How do we choose what to observe and what data to save?
  - What are appropriate sampling and monitoring designs?
  - How to reconcile so many different variables with so many different spatiotemporal characteristics?

Global Change

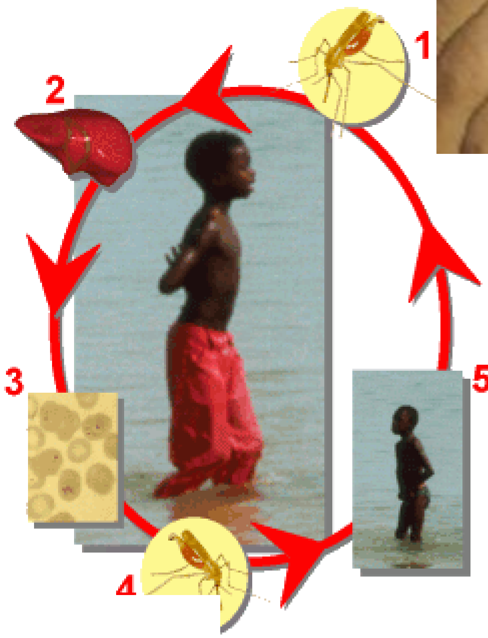
- ***Effects of Global Change***:
  - Goal is not so much to describe the many effects of global change as to understand:
    - ➢ Interface between change in one sector on another – e.g.. to understand Lyme Disease spread into Canada, need understand tick life cycles, bird migrations, climate change



    - ➢ Risk-based comparison of alternative adaptation and mitigation strategies – e.g., for control of invasive species or for more severe weather.

Climate and Health

- Some early warning signs:
  - Malaria in the African Highlands
  - Dengue epidemics along the Rio Grande & in Brazil



Dengue Fever

Climate and Health

- Some early warning signs:
  - Cholera affected by sea surface temperature
  - Increase in Lyme disease in Canada
  - St. Louis Encephalitis (Florida outbreak)
  - Animal and plant diseases too

–Complex interaction among climate, life cycle of hosts and vectors, migration patterns, etc.


Tick carrying Lyme Disease

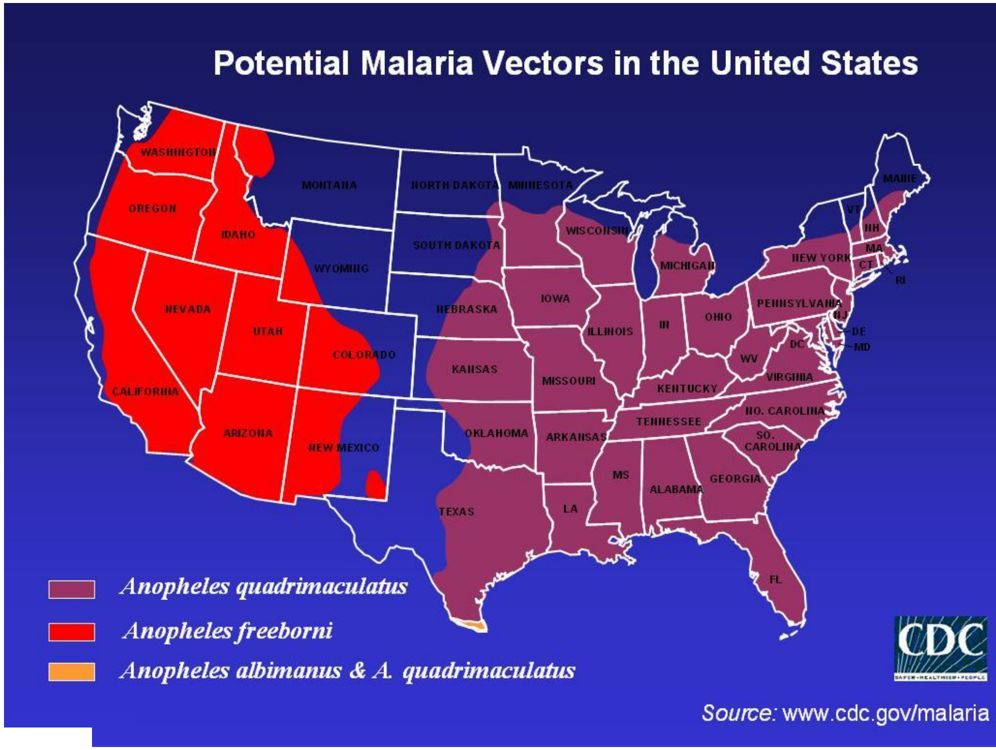

cholera

Malaria

- The challenge of climate change: Malaria springs up in areas it wasn't in before.
- Highlands of Kenya
- Potential for Malaria in the US – Texas, Florida, Washington, …
- A project at Morgan St.
- A key role for modelers:

Aid in early warning:

Surveillance.



Theme 2: Sustainable Human Environments

- In 1900, only 13% of the world's population lived in cities.
- By 2050, it is predicted that 70% will.

http://citadel.sjfc.edu/students/rnr00577/e-port/msti260/urban.htm

Sustainable Human Environments

- Rapidly growing urban environments present new and evolving challenges:
  - Growing needs for energy and water
  - Impacts on greenhouse gases
  - Public Health
  - Safety
  - Security

- As rapid city expansion continues, mathematical scientists can play key roles in shaping sustainable living environments – in collaboration with scientists from many fields

Sustainable Urban Environments

- ***One Example: Safety and Security***
- ***Math Science Challenges:***
  - Understanding crime patterns and deploying police
  - Modeling evacuations from large gathering places (stadiums, transportation hubs)
  - Inspection procedures for people entering restaurants, stores, stadiums, transportation hubs
  - Location and optimization of new security initiatives: cameras, barricades, street closures
  - Role of randomization
  - Interface between security and commerce

Sustainable Urban Environments

- ***One Example: Safety and Security***
- We did a project in Lower Manhattan near World Trade Center
- What is effect of putting access control into apartment buildings? Metal detectors in front of Barnes and Noble? Bag inspections at subways?
- Got us to inside of NYPD Lower Manhattan Security Initiative Command Center and new WTC complex.

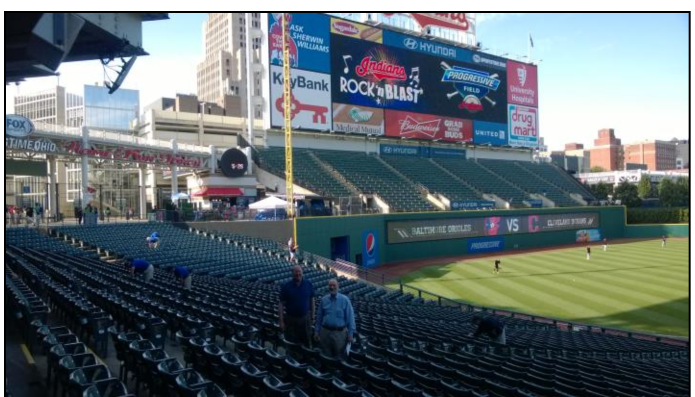
Example: Safety and Security at Sports Stadiums and Other Large Gathering Places

- I have worked with all major sports leagues: MLB, NFL, NBA, NHL, USTA, NASCAR, Special Olympics, LA Coliseum

It’s Gotten Me and Our students to Some Interesting Places

- To 50 yard line MetLife Stadium with DHS Deputy Under Secretary Dan Gerstein and to sideline to see Tom Brady warm up

- Progressive Field, Cleveland
- Training First Responders at USA Special Olympics

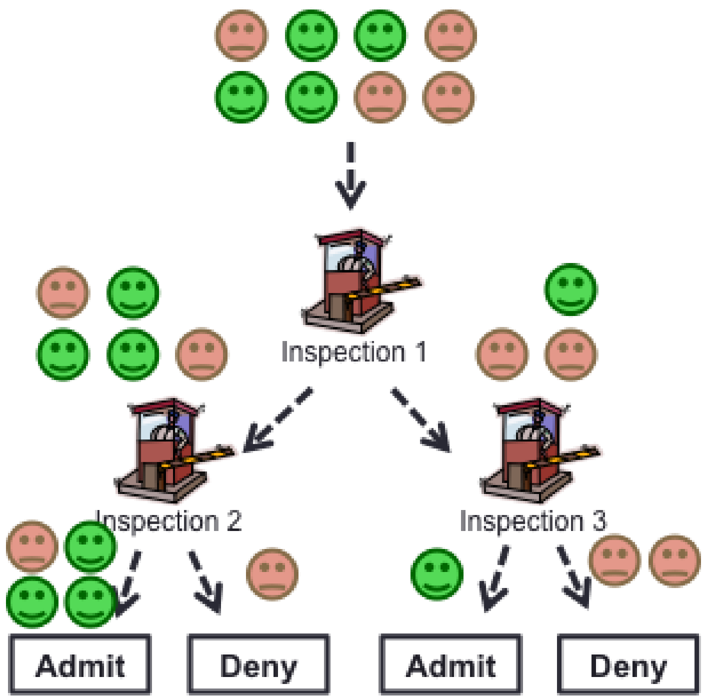


Security at Sports Stadiums & Large Gathering Places

- ***Example: safety and security at sports stadiums and other gathering places.***
- Example: modeling and simulation of sports stadium evacuation (in collaboration with Regal Decision Systems) led us to close collaborations with NFL security and stadium operators.
    - Worked with 6 NFL stadiums and Indianapolis Super Bowl
    - Work applied during lightning storm at an NFL stadium

Security at NFL Stadiums

- Example: Inspection of entering patrons
  - Modeling
  - Data Analysis
  - Simulation



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Stadium Inspection: Data Issues

- NFL asked all stadium security operators to perform 100% wanding of patrons.
- This didn’t always work. Close to kickoff time, lines got too long.
- Met with NFL Security
- Began analysis of security procedures at one stadium

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Stadium Inspection: Data Issues

- Started by looking at three types of inspection in use at NFL stadiums; later worked with all major sports leagues (MLB, NBA, NHL, MLS, etc.)
  - ***Wanding***
  - ***Pat-down***
  - ***Bag inspection***
- Observed stadium inspections and gathered data about each type of inspection, in particular how long it takes

Stadium Security: Simulation as a Planning Tool

- **Walkthrough Metal Detectors**
  - ➢When wanding wasn't sufficient, the NFL started to investigate use of walkthrough metal detectors like those in airports.
  - ➢Same now for MLB

Stadium Security: Simulation as a Planning Tool

- **Walkthrough Metal Detectors**
- We are in the process of analyzing the strategy of going to 100% use of walkthrough metal detectors (WTMDs)
- Issues:
  - ***Project*** number of WTMDs needed to deal with largest expected throughput challenges
  - Observe time required for throughput
  - Model physical location
  - Consider effect of weather on performance
  - Observe how WTMDs work in less than ideal conditions

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CEIA Robotic Tester

Invitation to Use it for Testing

CEIA Robotic Tester

Invitation to Use it for Testing

Stadium Security: Simulation as a Planning Tool

- **Simulation modeling – strategic planning:**
  - Based on the information obtained from the data collected during in-person observation and video analysis, we have developed a ***simulation*** of entrance queues.
  - Using the data from actual distributions, we have used the simulation to evaluate the speed and cost of inspection for various alternative policies.

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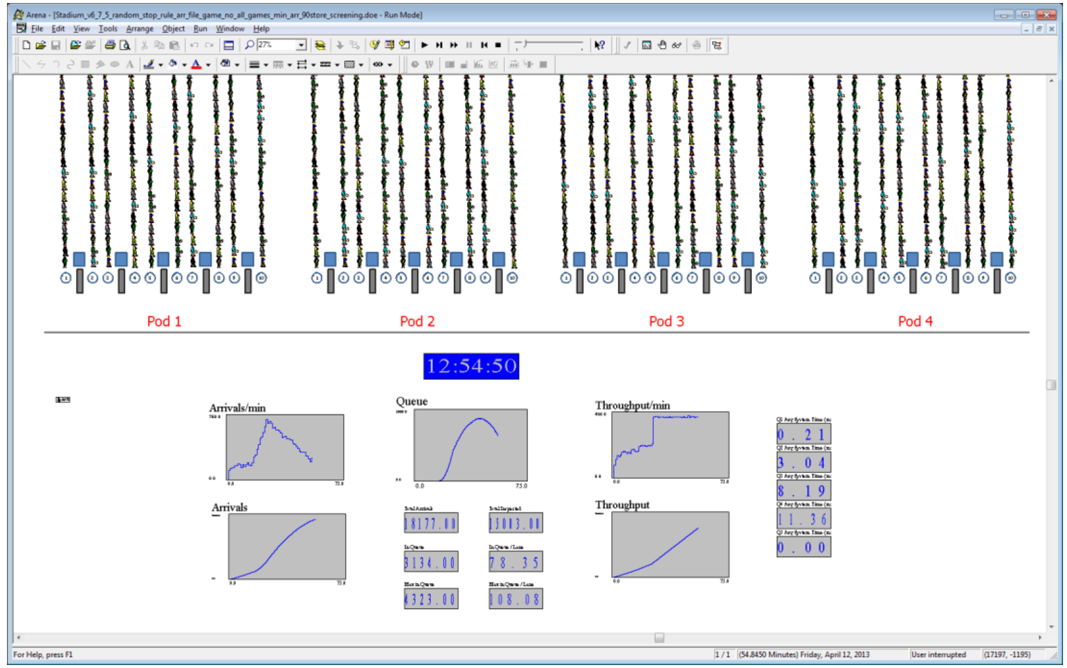
The Simulation Model

Most of the parameters can be obtained by ***choosing a representative game***

- Parameters
  - Arrival rates
  - Number of lanes
  - Wanding times
  - Pat-down times
  - Magnetometer times
- Screening Strategy
  - Switching inspection type (Y/N)
    - Number of patrons in queue to switch the process, or
    - Time of switch
  - Does phase 2 include randomization? (Y/N)
    - Ratio of patrons in each type of inspection in the randomization



The model output file includes:

- **In Queue @ kickoff**
- **Queue clearance time**
- **Max Waiting Time per patron**

Stadium Inspection

- **Other Key Security Issues with Math Sci Challenges:**
  - Access control
  - Credentialing
  - Perimeter control
  - Communications
  - Training and exercising
  - Transportation access
  - Cyber security

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Security at Sports Stadiums & Large Gathering Places

- I am also working with Port Authority of New York and New Jersey on simulation of crowd movements
- Port Authority Bus Terminal in NYC has major crowd movement issues, especially in case of emergencies.

Credit: wnyc.org

Credit: cityroom.blogs.nytimes.com

Security at Sports Stadiums & Large Gathering Places

- Port Authority Bus Terminal in NYC: world's busiest bus terminal
- 225,000 riders and 8,000 bus movements per day
- Critical transit facility to move people between NYC and NJ
- Central part of any emergency evacuation scenario for Manhattan

Credit: online.WSJ.com

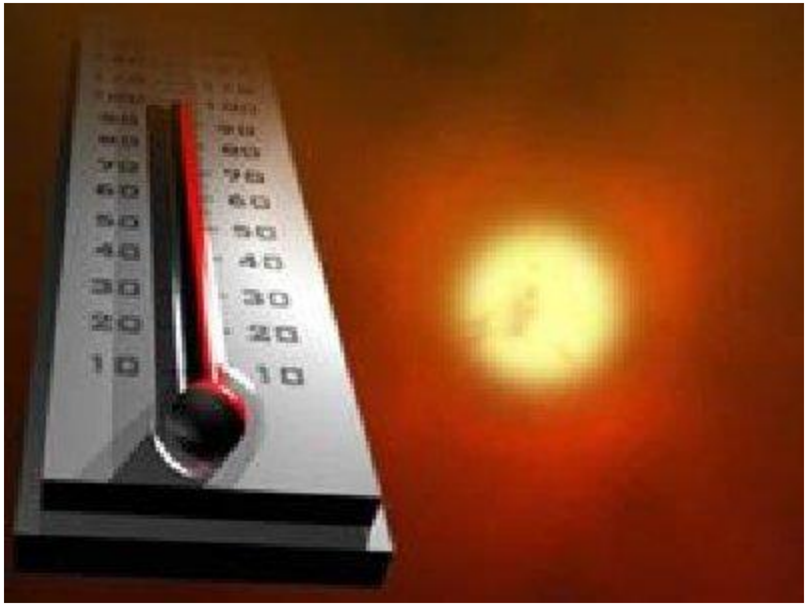
Credit: Wikipedia

Theme 3: Natural Disasters

- Storms, Hurricanes, Tsunamis
- Earthquakes
- Tornadoes
- Forest Fires
- Floods
- Epidemics

Natural Disasters

- We anticipate an increase in number and severity of extreme events due to global warming.
- More heat waves.
- More floods, hurricanes.



Hurricanes

Irene hits NYC – August 2011

Hurricanes

Irene hits NYC – August 2011

Hurricanes

Irene hits NYC – August 2011

Hurricanes

Sandy Hits NJ Oct. 29, 2013

My backyard

My block

Hurricanes

Sandy Hits NJ Oct. 29, 2013

My neighborhood

My block

Hurricanes

Sandy Hits NJ Oct. 29, 2013

NJ Shore – from Jon Miller

Hurricanes

Future Storms

- To plan for the future, what do we need to do?
- How can we use mathematical modeling, simulation, and algorithmic tools of risk assessment to plan for the future?
- To plan for more extreme events
- To plan for rising sea levels

Hurricanes

- Using mathematical modeling, simulation, and algorithmic methods of risk assessment to plan for the future:
  - What subways will be flooded?
  - How can we protect against such flooding?

Hurricanes

•Using mathematical modeling, simulation, and algorithmic methods of risk assessment to plan for the future:

– What power plants or other facilities on shore areas will be flooded?

- Do we have to move them?

Hurricanes

- Using mathematical modeling, simulation, and algorithmic methods of risk assessment to plan for the future:
  - How can we get early warning to citizens that they need to evacuate?
  - How can we plan such evacuations effectively?

Hurricanes

- Using mathematical modeling, simulation, and algorithmic methods of risk assessment to plan for the future:
  - –How can we plan placement of utility lines to minimize down time?

Hurricanes

- Using mathematical modeling, simulation, and algorithmic methods of risk assessment to plan for the future:
  - –How can we plan for getting people back on line after a storm?

Bringing in help from out of state

Hurricanes

- Using mathematical modeling, simulation, and algorithmic methods of risk assessment to plan for the future:
  - How can we set priorities for cleanup?

Sea Level Rise

- Sectors affected by sea level rise include:
  - Transportation
  - Communications
  - Energy
  - Construction
  - Water supply
  - Waste

- How do we prioritize among them?
- How are they interrelated? E.g., better communications might help us reroute transportation more efficiently.

Photo Source: Updating Maryland's Sea-Level Rise Projections, Maryland Climate Change Commission, June 26, 2013

Logistics: Supply Chains

- What supplies are needed during an emergency?
  - Water, Food, Fuel, Generators, Chainsaws?
- How and where can we stockpile them?
- What are good methods for getting these to those who need them in an efficient way?


Theme 4: Management of Natural Resources

- Natural resources affect the health of our planet
- They provide materials for buildings, food, and other essentials for our way of life
- How do we protect them for future generations?

Example: Fish Populations

- The United States sets rules for fishing with the goal of maintaining healthy fish populations.
- Rules depend on specific species and include
  - Allowable locations to fish
  - Allowable seasons to fish
  - Catch quotas
- Violations of the rules leads to fines – sometimes quite large

Endangered Atlantic Cod

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Enforcement of Fisheries Rules

- Many agencies are involved in enforcing the fisheries rules and regulations.
- One of those agencies is the US Coast Guard.
- Through the Laboratory for Port Security at Rutgers and the CCICADA Center, we have been working with the Coast Guard to define and enhance scoring rules to lead to better enforcement of fisheries rules.

LPS Modeling Technology Policy
LABORATORY FOR PORT SECURITY

United States Coast Guard
U.S. Department of Homeland Security

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Enforcement of Fisheries Rules

- This work has gotten me to some interesting places.

LPS Modeling Technology Policy
LABORATORY FOR PORT SECURITY

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Fisheries Law Enforcement

- The US Coast Guard District 1 (based in Boston) uses a ***scoring system called OPTIDE to determine which commercial fishing vessels to board to look for violations.***
- They asked us if their success rate in finding violations by boarding could be improved by use of sophisticated methods of data analysis.
- Just one example of mathematics and law enforcement

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Fisheries Law Enforcement

<u>Examples of Scoring Rule Components</u>

- Points for current or past negative intelligence reports
- Points depending upon date last boarded
- Points based on information about the type of boat
- Points for having found violations in past boardings – depending upon type of violations
- ***Board if total score (number of points) exceeds a threshold***
- Our methods did better than OPTIDE.

Many Other Projects with the Coast Guard

- Oil spill response in the Arctic
- Response to hoax calls
- How to allocate boats to boat stations and aircraft to air stations

Exchanging a ceremonial coin with Admiral Paul Zukunft, Commandant USCG

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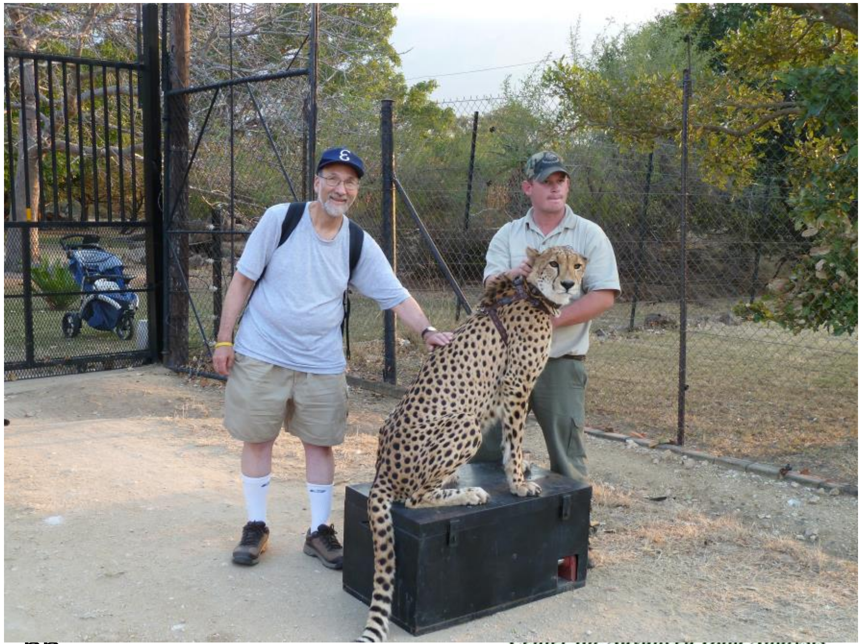
Theme 4: Management of Natural Resources

- My work has gotten me and our students to some amazing places.
- E.g., South Africa



Theme: Management of Natural Resources

- My work has gotten me and our students to some amazing places.
- E.g., South Africa and Ghana
- Morgan State people joined us

Ayanna Alexander

Asamoah Nkwanta

Theme: Management of Natural Resources

- I saw this baby rhino at the Mohololo Animal Refugee Reserve in South Africa
- It was rescued from dried mud in a waterhole where its mother had perished

Theme: Management of Natural Resources

- We were studying management of biological reserves.
- Some of the mathematical sciences issues:
  - How large should the reserve be?
  - How do you measure whether it is successful in preserving the "biodiversity"?
  - Should we treat animals for illness/injury?

Theme: Management of Natural Resources

Theme: Management of Natural Resources

- Some other issues:
  - Should one manage the water supply? Or let nature take its course?
  - Should one vaccinate animals?
  - Should one have taken the baby rhino from the reserve?

Theme 5: Data Aware Energy Use

- Need to make good choices about energy future
- Data can help
- Themes include:
  - Sensor networks and data acquisition.
  - Data mining
    - ➢E.g., understand state of the power grid
  - Optimization and control
    - ➢Real-time precision in operations and control of energy systems

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Theme: Data Aware Energy Use

- Themes include:
  - Smart grid
    - ➢To help customers be more efficient and operators to respond in real time or better
  - Smart buildings
    - ➢Real-time usage information to occupants and building managers
  - Electric vehicles

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Theme: Data Aware Energy Use

- This week I was in Vienna at a meeting at the International Institute for Applied Systems Analysis
- I was one of 3 US representatives. Others from Russia, Korea, Brazil, Germany, Norway, Finland, Japan, the Netherlands
- Discussion: what are possible alternative "energy futures" for our planet where more and more societies want to use more and more energy?

Today’s Electric Power Grid

- Today’s electric power systems have grown up incrementally and haphazardly – they were not designed from scratch
- They form *complex systems* that are in constant change:
  - –Loads change
  - –Breakers go out
  - –There are unexpected disturbances
  - –They are at the mercy of uncontrollable influences such as weather

Today's Electric Power Grid

- Today's electric power systems operate under considerable uncertainty
- Cascading failures can have dramatic consequences.

ROCHESTER

Democrat and Chronicle

Huge power failures
Parts of eight states and Canada left dark; cause remains in dispute.
Story below

Six pages of coverage
A roundup of blackout stories from around the region and nation.
Pages 10A-15A

No delays for PGA
Today's second round of the PGA Championship will not be affect
Story below

BLACKOUT

As the blackout rolled across vast portions of the northeastern United States and southeastern Canada, officials estimated that it affected as many as 50 million people. Gov. George Pataki said
BLACKOUT, PAGE 10A

Affected cities across the Northeast
Shortly after 4 p.m. power outages spread across the northeastern United States and parts of Ontario, Canada.

Some parts of these states or provinces were affected.

ONTARIO
NEW YORK
VT.
MASS.
CT.
MICH.
PA.
N.J.
OHIO
Toronto
Rochester
Albany
New York City
Detroit
Cleveland

Emergency declared in Monroe, Livingston

Today's Electric Power Grid

- Challenges include:
  - Huge number of customers, uncontrolled demand
  - Changing supply mix system not designed for complexity of the grid
  - Operating close to the edge and thus vulnerable to failures

Today's Electric Power Grid

- Challenges include:
  - Interdependencies of electrical systems create vulnerabilities
  - Managed through large parallel computers/ supercomputers with the system not set up for this type of management

The Need for a "Smart Grid"

- Massoud Amin defines the "smart grid" this way:

The term "smart grid" refers to the use of computer, communication, sensing and control technology which operates in parallel with an electric power grid for the purpose of enhancing the reliability of electric power delivery, minimizing the cost of electric energy to consumers, improving security, quality, resilience, robustness, and facilitating the interconnection of new generating sources to the grid.

The Need for a Smart Grid

Why do we need a smart grid?

- The electric grid is a massive, complex system.
- With sufficient information to determine what is happening in real time, grid operators would be able to contain a cascading outage or perhaps prevent one altogether.
- However:
  - The grid has hundreds of thousands of miles of transmission lines
  - Decisions have to be made really fast – in real time or faster

Acknowledgement: Article by Sara Robinson, SIAM News, Oct. 2003

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The Need for a Smart Grid

Why do we need a smart grid?

- Power grid operators need to see several moves ahead, sorting through millions of possible scenarios, to choose an appropriate response.

The Need for a Smart Grid

Why do we need a smart grid?

- It could be that humans just can't respond that quickly or calculate that fast.
- Either we give them some tools to aid them or we put the decision making into the hands of machines.
- This calls for the tools of "algorithmic decision theory."
- What is called for is a new complex, adaptive system that has self-healing properties.
- Need mathematical scientists to help design such a system.

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CONGRATULATIONS!!

Tim Killeen, Assistant Director, NSF

- **“It is the challenge of the century: How do we live sustainably on the planet? We all have to contribute.”**