Welcome!
The Webinar will start at 10am.

MIT Joint Program
Multi-Sector Dynamics

- https://globalchange.mit.edu/research/focus-areas/multi-sector-dynamics
- https://mst.mit.edu/
Before We Start

• Please MUTE your microphone
• Recording is ON (during presentations only)
• **Questions / Open Discussion** (after presentations)
  – Use the Q&A feature (enter text at any time, bottom of the screen)
• Presentation slides to be shared ([Dropbox](http://globalchange.mit.edu/))
Multi-Sector Dynamics Webinar

Agenda

- **Introduction** (MIT Joint Program Director Ronald Prinn)
- **MSD Overview and Triage** (JP Deputy Director C. Adam Schlosser)
- **MSD and Water** (JP Research Scientist Xiang Gao)
- **MSD and Land** (JP Research Scientist Angelo Gurgel)
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- **Q&A**

**Moderator:** Horacio Caperan, MIT Joint Program
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MIT Joint Program – Who we are

Team of natural and social scientists to provide:

- scientific research that integrates risk management with policy and industrial strategies
- communication and interaction with decision-makers, media outlets, government and nongovernmental organizations, schools and communities
- education of the next generation with the skills to tackle complex global and regional challenges

We envision a world in which community, government and industry leaders have the insight they need to make environmentally and economically sound choices.
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Climate and our natural environments are changing. Global society is growing and becoming more complex.

We must view the world as growing, complex, interwoven networks that co-evolve, interact, and become increasingly inter-connected.

**Multi-Sector Dynamics (MSD)** explores interactions and interdependencies among human and natural systems and how these systems may adapt, interact and co-evolve in response to short-term shocks and long-term influences and stresses.

By doing so — we sharpen understanding and foresight of the structure, function, and evolution of complex human-environmental landscapes that embody these systems.
Primary Stressors:
- Climate and Weather
  - Long-term climate trends; extreme events
- Economic
  - Rapid/slow overall economic growth or decline; change in sectoral demand/output
- Demographic
  - Rapid/slow population growth or decline; changing trends of poverty, elderly, infirm population...

Receptors:
- Socio-economic
  - Economic Vulnerability
  - Social Vulnerability
  - Infrastructure/Network Vulnerability
- Natural Resources
  - Land
  - Water
  - Air
  - Energy
  - Ecosystems

What, where, when, and how do these interact and amplify?

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INTERACTIONS OCCUR AT LOCAL TO GLOBAL SCALES AND INFLUENCES OFTEN TRANSFER ACROSS SCALES. INTERACTIONS ACROSS THESE SYSTEMS OFTEN RESPOND TO STRESSES IN NON-LINEAR WAYS.

These systems can experience cascading effects or failures after crossing tipping points.

But many tipping points are not well understood in and of themselves.

By improving understanding of interrelated systems, we better understand the potential trajectories, vulnerabilities, responses, and resilience of those systems.
Assessing Compounding and Co-Evolving Risks Across Multiple Systems and Sectors: The MIT Socio-Environmental Triage (MST) Approach

C. Adam Schlosser, Cypress Frankenfeld, Shelli Orzach, Xiang Gao, Angelo Gurgel, Alyssa McCluskey, Jennifer Morris, Sebastian Eastham, Sergey Paltsev, and John Reilly

MIT Joint Program on the Science and Policy of Global Change
The “hotspots” depict salient west and east flanking regions along lower Mississippi, Appalachian/Mid-Atlantic, and isolated regions across the Western U.S.

**FLOOD AND POVERTY RISK**
(i.e. ability to cope with and/or rebound from flooding)
WATER QUALITY INTERSECTION WITH POVERTY, RACIAL, AND EMPLOYMENT LANDSCAPES
VERIFICATION AND EXTRAPOLATION

"Hotspot" areas aligned with EJAtlas' documented survey of severe environmental injustices relating to water quality issues

But as risk triage visualization depicts - there are other U.S. counties with equally pre-conditioned risk-prone environments
# MIT Global Change Outlook

## Scenario Description

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paris Forever</td>
<td>Current (as of March 2021) Paris Nationally Determined Contribution (NDC) targets are met by all countries by 2030 and retained thereafter.</td>
</tr>
<tr>
<td>Paris 2°C</td>
<td>Paris Nationally Determined Contribution (NDC) targets are met by all countries by 2030, after which there is a emissions cap based on a global emissions trajectory designed to ensure that the 2100 global surface mean temperature does not exceed 2°C above pre-industrial levels with a 50% probability.</td>
</tr>
<tr>
<td>Accelerated Actions</td>
<td>More near-term actions are taken relative to Paris 2°C (including those planned changes to NDCs announced in April 2021), and global emissions are consistent with ensuring that the 2100 global surface mean temperature does not exceed 1.5°C above pre-industrial levels with a 50% probability. Note: Climate results are shown for a slightly different 1.5°C scenario (Paris 1.5°C) that uses a global emissions price.</td>
</tr>
</tbody>
</table>

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Multi-Sector Dynamics

**MSD includes representations of energy, water and land systems, infrastructure, natural resources, economies, technologies, populations, health, climate, and weather patterns and extremes.**

**MSD’s strength—and biggest challenge—is how it links socioeconomic, physical, engineering, and earth-system data, model components, as well as risk and decision-making frameworks.**

The goal of our research is to understand:

1. Forces and patterns that affect economic and infrastructure development across and within regions;
2. Characteristics of interacting natural, managed, and built environments and human processes that lead to stabilities, instabilities, and tipping points in economic and infrastructure development; and
3. How foresight could increase system resilience to future forces, stressors, and disturbances (both natural and as a result of economic and infrastructure development).

Based on our assessment of structure, function, and evolution of interactions in physical, natural, and socioeconomic systems addressed above, we will identify extractable insights of relevance to other regions.

**Advances in assessment and foresight all support informative action towards a sustainable, resilient, and prosperous world.**
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- **Q&A**
Significance

- Complicate drinking water treatment and distribution systems
- Affect water supplies (human health and welfare)
- Force restrictions on recreational and commercial activities (economic impacts).

Interactions with MSD

- Climate (air & water temperature, precipitation, runoff, extreme events)
- Agriculture (fertilizer)
- Human (wastewater treatment)
- Municipal waste (facility-level pollutants, etc.)
Unique Properties of Water

• Excellent solvent for gases, minerals, and organic compounds.
• Temperature-density relationship of water-induced thermal stratification of lakes
  • Redistribution in concentrations of dissolved oxygen, phosphorus and nitrogen, metals and other compounds
  • Affects phytoplankton (algae) populations, water supply quality, fisheries management

![Lake stratification diagram]

- warm (lighter), well-mixed zone
- transitional zone with rapidly changing temperature, resistant to wind mixing
- colder (heavier), dark, and relatively Undisturbed zone
High-resolution Water Quality Model Over the US

Spatial Scale

Global Version (14 basins)

18 Basins (2-digit HUCs, US Water Resources Council)

2,119 basins (8-digit HUCs, USGS)
Model Overview

• climate & socioeconomic

• Water Quality Measures
  - Water Temperature
  - Dissolved Oxygen
  - Organic Carbon (particulate & dissolved)
  - Nitrates (Ammonia, Nitrogen & Organic)
  - Phosphates (Organic & Inorganic)
  - Phytoplankton
  - Metals
  - Salts

• Valuation
  Willingness to Pay (WTP)
Point and non-point Loadings

- **Point sources**
  - Municipal wastewater treatment

- **Non-point sources**
  - Agricultural nitrogen and phosphorus from fertilizer
  - Human waste

Average Seasonal Nitrogen Loading (kg)

Maps showing nitrogen loading for different seasons:
- Dec-Feb
- Mar-May
- Jun-Aug
- Sep-Nov

High-resolution Water Quality Model Over the US

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Water Quality Valuation (Van Houtven et al. 2007)

Water Quality Parameters
- Dissolved Oxygen
- BOD
- Phosphorous
- Nitrogen
- Temperature

Multiply by watershed population for willingness to pay (WTP)

Water Quality Curves
- Scale to value between 0 and 100 using transformation function

Change in WQI

Constitute Specific Weight
- DO: 0.17
- P: 0.10
- N: 0.10
- T: 0.10

Weighted water Quality Index (WQI)

Calculate weighted QI

Multiply by watershed population for willingness to pay (WTP)
Moving Forward

• Future projections under various policy scenarios (economic costs and/or benefits associated with water quality)

• Large ensemble runs to account for various sources of uncertainty in water quality (regional climate, socioeconomics)

• Identify water quality risk hotspot or be integrated into triage platform for assessing compounding risk stressors
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Why and How Useful/Important?

- Land use impacts and is impacted by multiple drivers and forces (human activity and natural systems);
- Multi-scale economics influence and propagate within and between several sectors and systems associated to land use;
- These interactions can lead to stabilities, instabilities, and systems resilience within multi-sector, multi-scale landscapes.

Source: USDA
MSD and Land

Resources and Tools

- Data sources
  - USDA
    - Agricultural Census and Surveys (National Agricultural Statistical Service – NASS)
    - Forest Resources (Forest Service – FS)
    - Prices, trade, policies, income (Economic Research Service)
  - WiNDC, IMPLAM (input-output data)
  - EPA, ...
- Key model/tools employed:
  - Global multisector, multisystem model (economic/environmental)
  - US multiregional, multisector, multisystem model (economic/environmental)
- Challenges
  - Complexity, multidimensions, spatial representation

Source: USDA
Example of Application

• How future forces affecting land use changes at the global level may impact the US?
  – Forces: income and population growth, yield improvements, trade policy, climate change, changing diets, ...
  – Impacts: land use changes, pollution, carbon storage, biodiversity, ...
  – Multiple and compounding forces: is there a tipping point in land use in the US?

Source: Bigelow, 2017
http://globalchange.mit.edu/
Approach/Framework

Country- and State-Level Drivers and Teleconnections

Global Drivers and Boundary Conditions

Regions
- AFR: Africa
- ANZ: Australia & New Zealand
- ASI: Dynamic Asia
- BRA: Brazil
- CAN: Canada
- CHN: China
- EUR: Europe (EU+)
- IDZ: Indonesia
- IND: India
- JPN: Japan
- KOR: Korea
- LAM: Other Latin America
- MES: Middle East
- MEX: Mexico
- REA: Other East Asia
- ROE: Other Eurasia
- RUS: Russia
- USA: United States

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Results

Changes (%) in input use, emissions and agric. areas

Higher pressures

- less trade
- less clim. imp. crops
- less clim. imp crops&livest.
- less yield constraint
- less meat demand
- less pop. growth
- less econ. growth
- less all
- more trade
- more clim. imp. crops
- more clim. imp crops&livest.
- more yield constraint
- more meat demand
- more pop. growth
- more econ. growth
- more all

Lower pressures

- Cropland area
- Manag. Forest area
- Pasture area
- Fertilizer/chemicals use
- N2O Emissions
- CH4 Emissions
- Cum. CO2 Emiss. LUC

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Current land use trends are intensified under higher pressures for agricultural land and food production.

No evidence of tipping points on land use changes in the U.S. from global forces.

However, fertilizer use, N2O and CH4 emissions from agriculture activities and CO2 emissions from land use changes are substantially impacted under several land use forcing scenarios.

Next steps:
- Refine spatial resolution to extend the MSD analysis to the state level, regional and local levels.
- Improve economic – environmental connections.

Source: EPA
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Why is this important for MSD?

- Economic markets link sectors and systems
- Economic growth is key driver of many changes and is highly uncertain
- Objectives are often economic-based (e.g. minimizing costs, cost-effective investments, equity, etc.)
- Energy plays a key role in most sectors
  - Impacts overall economy as well as other sectors and natural systems
  - Energy-Water-Land Nexus
MIT Economic Projection and Policy Analysis (EPPA) Model

Major goals:
Energy, economy, GHG and air pollutants projections.

Representation: Global coverage, All sectors of economy

Expansion: Industrial CCS options, Hydrogen production options, Hydrogen Pathways, Direct Air Capture, CO₂ utilization pathways

Model Features: Theory-based; Prices are endogenous; International Trade; Inter-industry linkages; Distortions (taxes, subsidies, etc.); GDP and Welfare effects

Trade-off: Aggregated representation of regions, sectors, technologies

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Linking Across Systems and Scales

MIT Integrated Global System Modeling (IGSM) Framework

Global Drivers and Boundary Conditions
Country- and State-Level Drivers and Teleconnections
Impacts on Local Systems
Decision-Making Frameworks at Local Levels

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Risk Triage: What is Currently Represented

**Economy**
- Employment in all industries
- GDP 2018
- GDP 2018 Per Capita
- Employment in Mining, Quarrying, and Oil & Gas Extraction
- Employment in Construction
- Employment in Agriculture, forestry, fishing, and hunting
- Employment in Healthcare and social assistance
- Per capita personal income 2018
- Property Count
Risk Triage: What is Currently Represented

**Energy**
- Employment in Fossil Fuels
- Employment in Renewables
- Employment in Efficiency
- Employment in Transmission
- Employment in Motor Vehicles
- Energy Expenditure Per Capita
- Residential Energy Expenditure Per Capita
- Transportation Energy Expenditure Per Capita
- Energy Expenditure as Share of GDP
- Residential Energy Expenditure as Share of GDP
- Transportation Energy Expenditure as Share of GDP
Example 1: Targeted Job Training Programs

Employment in Fossil Fuels

Population Below Poverty Level

Combined

http://globalchange.mit.edu/
Example 2: Fossil Assets and Flood Risk

Employment in Fossil Fuels

Flood Risk

Combined

http://globalchange.mit.edu/
Example 3: Energy Poverty

Energy Expenditure as Share of GDP

Population Below Poverty Level

Combined

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Economics, Energy and MSD

Projections and Uncertainty

Global GDP

USA GDP

Welfare Impact (2030) by Income Quintile

% Change from Low-Cost Baseline

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• Picture of economic and energy landscape
• Can highlight interactions with different sectors/systems
• Extending to include projections from multi-system, multi-sector dynamic regional model of the U.S.
• Adding additional data
  – Energy: production, consumption, resources, prices, infrastructure...
  – Economy: sectoral output, imports/export (interstate trade), cost of living, economic complexity index....
• Limited data at county-level
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Why is this part of MSD?

• Air pollution is a serious problem: 100k mortalities per year in the US from combustion emissions (Dedoussi et al, 2020)

• Significant inequity in impacts

• Complex response to changes in other MSD components, including climate
Background

Understanding **current day pollution** so that we know **where the problems are** – and **how they compound**

- Currently using present-day population and air quality data
- Plan: air quality through 2100 using the **IGSM-GCHP** system
Example: intersection of air quality and poverty
Accelerating identification of “risk hotspots”

Combining risk metrics allows rapid identification of “risk hotspots”

Applies to **current risks** – but also the **role of climate change**

*Water quality, air quality, and poverty*
Going from observations to insights

• Tool incorporates **health data** for every county, enabling unified **visualization and computation** of air pollution health impacts from **simulated interventions**

• Can directly quantify **public health consequences** of:
  – Changing climate
  – Environmental policy – both **climate and air quality related**
  – Economic interventions

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Now: air quality and public health as part of MSD research

In progress
• Incorporation into “hotspot” identification
• Extension to include other criteria pollutants

Planned
• Expansion to future climate and global perspective
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Why do we care about infrastructure in the MultiSector Dynamics context?

– The main focus of MSD is the interaction and interdependencies between human and natural systems, including between different sectors.

– Infrastructure critically links different systems and sectors.
  • Near term multisector infrastructure investments shape long term pathways
  • Requires coordination across scales and sectors

– MST Framework
  • Prioritize need for capital investment while enhancing resilience and equity
  • Alert to risks of cascading failures across different configurations of infrastructure, operating rules, demands, and settlement patterns
What is currently represented

- Highways
- Major Railroads
- Marine Highways

Tonnage of
- Coal Petro
- Food
- Crude Materials
- Chemical
- Manufacturing
- Other
- Total

[Map of the United States showing population density and infrastructure]
What is currently represented cont’d

**Transmission Lines**
- Level 2 (230kV-344kV)
- Level 3 (>= 345 kV)
- Level 2&3 (>= 230kV)
  - **Source:** Homeland Infrastructure Foundation Level Data

**Critical Habitats**
- All critical habitat for all species listed as threatened or endangered
  - **Source:** USFWS

[Image showing Population Density map of the US with transmission lines and critical habitats marked]
INFRASTRUCTURE AND CRITICAL HABITATS

Example 1: Business Relocation – Access to Transport and Energy

Highways, Railroads and Waterways

Transmission Lines
Level 2 (245 kV – 345 kV)
Level 3 (> 345 kV)

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Example 2: Combined Flooding, Temperature Stress, Population Density

Transmission lines >=230kV

OK, AR, MO, TN, NC
Example 3: Combined Water Stress, Water Quality, Flood Risk, Land Disturbance, Temperature Stress

Critical Habitat
North Carolina
Georgia
Example 4: Employment in Construction 2019 with Critical Habitats

Idaho

Florida
Highlights/Limitations/Future

• Supports MSD Goals
  – Prioritize need for capital investment while enhancing resilience and equity
  – Alert to risks of cascading failures across different configurations of infrastructure, operating rules, demands, and settlement patterns

• Quick Visual Analysis
  – Overlay on maps
  – Thickness of line represents size (highways and marine highways)
  – Infrastructure overlay provides additional information on how life could be impacted/hot spots.

• Limitations
  – Can’t include information into combined impact value (multi-system metrics)

• Future
  – Can add more overlays as needed (Superfund/toxic sites).
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Q&A

Please enter text at any time using the Q&A feature at the bottom of the screen.

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Thank you!

For any additional questions: hcapenan@mit.edu

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