Coupling for ESM: The IGSM

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Week 2
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THE IGSM

Economic Projection & Policy Analysis (EPPA):
- Global model
- Multi-region (18)
- Multi-sector
- Recursive dynamic computable general equilibrium (CGE) model

MIT Earth System Model (MESM):
- Earth System Model of Intermediate Complexity (EMIC)
- Land, atmosphere and ocean
- Full carbon cycle
- Atmospheric chemistry

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THE MESM

ATMOSPHERE

LAND

OCEAN

NORTH

SOUTH

DEPTH

WEST

EAST

HEIGHT

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PROBABLISTIC PROJECTIONS

- Computational efficiency
  - A century-long run takes 12 hours on 1 cpu
  - Can easily run 1000s simulations

- Flexibility to change key climate parameters
  - climate sensitivity
  - strength of aerosol forcing
  - ocean heat uptake rate
  - strength of carbon cycle

- PDFs of climate parameters
- Probabilistic projections of climate variables
STATISTICAL DOWNSCALING

Pattern scaling method:

\[ V_{x,y}^{IGSM} = C_{x,y} \cdot \overline{V}_y^{IGSM} \]

\[ C_{x,y} = C_{x,y}^{OBS} + \left[ \frac{dC_{x,y}^{AR4}}{dT_{Global}} \cdot \Delta T_{Global}^{IGSM} \right] \]

\[ C_{x,y}^{(OBS or AR4)} = \frac{V_{x,y}^{(OBS or AR4)}}{\overline{V}_y^{(OBS or AR4)}} \]
WATER IMPACTS

EPPA
Economic Projection and Policy Analysis

MESM
MIT Earth System Model

Municipal and Industrial Demand

Environmental Regulations

Water System Management Routing

Population GDP

Runoff

Temperature Precipitation

Irrigation Demand

Monthly climate variables, biased corrected


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DISTRIBUTIONS OF WATER IMPACTS

CHANGE IN WATER STRESS INDEX (WSI) BY 2050

INDIA

CHINA

DYNAMICAL DOWNSCALING

MIT IGSM-CAM framework:

3D atmospheric model is driven by IGSM:
- SST and sea ice
- greenhouse gases concentrations
- aerosols concentrations
- Land use land cover change

Earth System

Human System

Economic Projection and Policy Analysis (EPPA)
National and/or Regional Economic Development,
Emissions & Land Use

Hydrology/water resources
Land use change
Agriculture, forestry, bio-energy, ecosystem productivity
Trace gas fluxes (CO₂, CH₄, N₂O) and policy constraints
CO₂, CH₄, CO, N₂O, NOₓ, SOₓ, NH₃, CFCs, HFCs, PFCs, SF₆, VOCs, BC, etc.
Human health effects
Climate/energy demand
Sea level change

Atmosphere
2-Dimensional Dynamical, Physical & Chemical Processes

Urban Airshed
Air Pollution Processes

Ocean
3-Dimensional Dynamical, Biological, Chemical & Ice Processes (MITgcm)

Land Water & Energy Budgets (CLM) Biogeochemical Processes (TEM & NEM)

Volcanic forcing
Solar forcing
Wind stress

Coupled Ocean, Atmosphere, and Land

SSTs and sea ice cover
CO₂, CH₄, N₂O, CFCs, HFCs, PFCs, SF₆, SOₓ, BC and O₃

Human System

Economic Projection and Policy Analysis (EPPA)
National and/or Regional Economic Development,
Emissions & Land Use

Human health effects
Climate/energy demand
Sea level change

Atmosphere
3-Dimensional Dynamical & Physical Processes

Coupled Land and Atmosphere

Land Water & Energy Budgets (CLM)

Volcanic forcing
Solar forcing

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AIR QUALITY AND HEALTH FRAMEWORK

Anthropogenic and biogenic emissions

- Climate (IGSM-CAM)
- Air Quality (CAM-Chem)
- Population (BenMAP)
- Health Incidence (BenMAP)
- Valuation (BenMAP)

Change in Climate & Emissions
3-hourly 3D meteorological fields (temp, humidity, wind...) non biased corrected

Change in O3 & PM Concentrations

Future Population Demographics

Concentration Response Functions
Future Health Incidence Rate

Valuation (Cost of Illness, Lost Income, Contingent Valuation)

New Health Incidence Rate
Economic Impact by Policy

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## AIR QUALITY AND HEALTH IMPACTS

**Avoided deaths**

<table>
<thead>
<tr>
<th>Year</th>
<th>Ref -&gt; Pol4.5</th>
<th>Ref -&gt; Pol3.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>2050</td>
<td>11,000 (4,000–19,000)</td>
<td>13,000 (4,800–22,000)</td>
</tr>
<tr>
<td>2100</td>
<td>52,000 (19,000–87,000)</td>
<td>57,000 (21,000–95,000)</td>
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</table>

**Life years saved (thousands)**

<table>
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<th>Year</th>
<th>Ref -&gt; Pol4.5</th>
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</tr>
</thead>
<tbody>
<tr>
<td>2050</td>
<td>570 (210–940)</td>
<td>620 (230–2,600)</td>
</tr>
<tr>
<td>2100</td>
<td>1,300 (240–2,500)</td>
<td>1,400 (240–2,600)</td>
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Changes in summer 8-h-max O₃ by 2100

AIR QUALITY AND HEALTH IMPACTS

Changes in summer 8-h-max \( O_3 \) by 2100

### Strengths and limitations of the 2 downscaling methods

<table>
<thead>
<tr>
<th>APPROACH</th>
<th>STRENGTHS</th>
<th>LIMITATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGSM-Pattern scaling</td>
<td>• Can emulate multiple models</td>
<td>• Limited to T and P</td>
</tr>
<tr>
<td>(statistical approach)</td>
<td>• Computationally efficient</td>
<td>• Limited to monthly time scale</td>
</tr>
<tr>
<td></td>
<td>• Can derive full distributions</td>
<td>• Cannot simulate changes in variability and extremes</td>
</tr>
<tr>
<td>IGSM-CAM</td>
<td>• Can explore natural variability and extremes events</td>
<td>• Limited to a single model</td>
</tr>
<tr>
<td>(dynamical approach)</td>
<td>• Not limited to T,P (can drive models requiring various input variables</td>
<td>• Computationally intensive</td>
</tr>
<tr>
<td></td>
<td>or 3D fields)</td>
<td>• Can only approximate the bounds of the distributions</td>
</tr>
<tr>
<td></td>
<td>• High temporal resolution</td>
<td></td>
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</table>

Limited represented feedbacks (i.e. for regional climate change)
Mesm 3D

- EFFICIENT -> DETAILED CHEMISTRY
- FLEXIBILITY TO CHANGE CLIMATE SENSITIVITY AND STRENGTH OF AEROSOL FORCING

- METHANE MODEL
- CROP MODEL
- CARBON-NITROGEN
- LAND-USE CHANGE
- BIOGENIC EMISSIONS

CHEMISTRY
Chemical Gases, Aerosols and Carbon Cycle

SEA ICE
Thermodynamical and Dynamical Processes

OCEAN
Dynamical, Biological and Chemical Processes

LAND
Hydrology, Biogeophysics, Biogeochemistry and Ecosystem Dynamics

LAND ICE
Ice Sheet Dynamics and Sea Level Rise

COUPLED SYSTEM

Earth System

- SIMPLE -> FULL DYNAMICAL
- FLEXIBILITY TO CHANGE OCEAN HEAT UPTAKE RATE

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3 PATHWAY FOR COUPLING BETWEEN HUMAN AND EARTH SYSTEMS:

- AIR QUALITY & HEALTH
- WATER RESOURCES
- LAND
3 PATHWAY FOR COUPLING BETWEEN HUMAN AND EARTH SYSTEMS:

**Human System**
- MORTALITY & MORBIDITY
- HEALTH MODULE
- CONCENTRATIONS OF AIR POLLUTANTS
- ANTHROPOGENIC EMISSIONS

**Earth System**
- CHEMISTRY
  - Chemical Gases, Aerosols and Carbon Cycle
- ATMOSPHERE
  - Dynamical and Physical Processes
- OCEAN
  - Dynamical, Biological and Chemical Processes
- LAND
  - Hydrology, Biogeophysics, Biogeochemistry and Ecosystem Dynamics
- LAND ICE
  - Ice Sheet Dynamics and Sea Level Rise

**Coupled System**
- WATER RESOURCE MANAGEMENT MODULE
  - PHYSICAL WATER SUPPLY, AGRICULTURE WATER NEEDS
  - WATER AVAILABILITY FOR DOMESTIC, ENERGY AND INDUSTRIAL USE
  - WATER NEEDS FOR DOMESTIC, ENERGY AND INDUSTRIAL USE
  - IRRIGATION AVAILABILITY

**CONSUMER SECTORS**
- GOODS & SERVICES
  - INCOME
  - EXPENDITURES

**PRODUCER SECTORS**
- TRADE FLOWS BETWEEN REGIONS

**REGION A**
- PRIMARY FACTORS
  - INCOME
  - EXPENDITURES

**REGION B**
- CONSUMER SECTORS
  - GOODS & SERVICES

**REGION C**
- PRODUCER SECTORS
  - GOODS & SERVICES

**REGION D**
- TRADE FLOWS BETWEEN REGIONS

**ANTHROPOGENIC EMISSIONS**
- CONCENTRATIONS OF AIR POLLUTANTS

**HEALTH MODULE**
- PHYSICAL WATER SUPPLY, AGRICULTURE WATER NEEDS
- WATER AVAILABILITY FOR DOMESTIC, ENERGY AND INDUSTRIAL USE
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**WATER RESOURCE MANAGEMENT MODULE**
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**WATER AVAILABILITY FOR DOMESTIC, ENERGY AND INDUSTRIAL USE**
- WATER NEEDS FOR DOMESTIC, ENERGY AND INDUSTRIAL USE
- IRRIGATION AVAILABILITY

**CONCENTRATIONS OF AIR POLLUTANTS**
- PHYSICAL WATER SUPPLY, AGRICULTURE WATER NEEDS
- WATER AVAILABILITY FOR DOMESTIC, ENERGY AND INDUSTRIAL USE
- WATER NEEDS FOR DOMESTIC, ENERGY AND INDUSTRIAL USE
- IRRIGATION AVAILABILITY

**AGGREGATED BIO-EMISSIONS**
- WATER AVAILABILITY FOR DOMESTIC, ENERGY AND INDUSTRIAL USE
- WATER NEEDS FOR DOMESTIC, ENERGY AND INDUSTRIAL USE
- IRRIGATION AVAILABILITY

**WATER AVAILABILITY FOR DOMESTIC, ENERGY AND INDUSTRIAL USE**
- WATER NEEDS FOR DOMESTIC, ENERGY AND INDUSTRIAL USE
- IRRIGATION AVAILABILITY
3 PATHWAY FOR COUPLING BETWEEN HUMAN AND EARTH SYSTEMS:

**Human System**
- Water availability for domestic, energy and industrial use
- Water needs for domestic, energy and industrial use
- Physical water supply, agriculture water needs
- Irrigation availability

**Earth System**
- Land hydrology, biogeophysics, biogeochemistry and ecosystem dynamics
- Ocean dynamical, biological and chemical processes
- Sea ice thermodynamical and dynamical processes

**Primary Factors**
- Goods & services
- Income
- Expenditures

**Trade Flows**
- Between regions

**Region A**
- Consumer sectors
- Producer sectors

**Region B**
- Region C

**Region C**
- Goods & services
- Income
- Expenditures

**Health Module**
- Mortality & morbidity

**Anthropogenic Emissions**
- Concentrations of air pollutants

**Concentration of Air Pollutants**
- Physical water supply, agriculture water needs

**Water Resource Management Module**
- Physical water supply, agriculture water needs
- Irrigation availability

**Snowmass week 2 / Coupling for ESM: the IGSM**
3 PATHWAY FOR COUPLING BETWEEN HUMAN AND EARTH SYSTEMS:

**Human System**
- CONSUMER SECTORS
- PRODUCER SECTORS
- PRIMARY FACTORS
- INCOME
- EXPENDITURES
- GOODS & SERVICES
- REGION A
- REGION B
- REGION C
- TRADE FLOWS BETWEEN REGIONS

**Earth System**
- SEA ICE
  - Thermodynamical and Dynamical Processes
- OCEAN
  - Dynamical, Biological and Chemical Processes
- LAND ICE
  - Ice Sheet Dynamics and Sea Level Rise
- LAND
  - Hydrology, Biogeophysics, Biogeochemistry and Ecosystem Dynamics
- ATMOSPHERE
  - Dynamical and Physical Processes
- CHEMISTRY
  - Chemical Gases, Aerosols and Carbon Cycle

**Pathways**
- AIR QUALITY & HEALTH
- WATER RESOURCES
- LAND

**Mortality & Morbidity**
- Health Module
- Concentrations of Air Pollutants

**Trade Flows**
- Between Regions

**Regions**
- Region A
- Region B
- Region C

**Sectors**
- Consumer Sectors
- Producer Sectors

**Factors**
- Goods & Services
- Income
- Expenditures

**Pathways**
- Agriculture, Forestry, Bio-energy & Ecosystem Productivity
- Fertilizer Application, Land-use Change

**Water Availability**
- For Domestic, Energy and Industrial Use
- Water Needs for Domestic, Energy and Industrial Use

**Water Resource Management**
- Physical Water Supply, Agriculture Water Needs
- Irrigation Availability

**Land**
- Hydrology, Biogeophysics, Biogeochemistry and Ecosystem Dynamics
GOAL OF NEW IGSM VERSION

- Build a more complete hierarchy of IGSM frameworks

- Toward a more integrated representation of the human-earth system
  - more realistic(?)

- Are feedbacks between human and earth systems important?
  - Land-use change <-> regional climate change

- Are interactions between multi-sector impacts/co-benefits important?
  - Air quality & land-use change (biogenic emissions, ozone damage)
  - Water scarcity & crop production (irrigation)

- Better explore the role of natural variability on climate impacts
ALWAYS THE SAME ISSUES

- Spatial resolution/complexity of model vs. uncertainty analysis
  Is it too complex?

- Bias correction vs. representation of feedbacks

- Temporal resolution / coupling strategies

- Consistency in data / management practices within the framework

- Many more I couldn’t think about when I prepared the presentation...
THANK YOU

ANY QUESTIONS?