Review Of Methodologies
And
Possible Scenarios
For Conducting Vulnerability Assessments To Climate Change

Oct. 27th, 2009

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Sustainable Development & Productivity Division.
1 Outline

- The Earth System
- Modeling the Earth,
- Modeling the Arab World:
- Conclusions, Recommendations for Action
The “Whole Earth System”

- Climate
- Computer Models
- Atmosphere
- Biosphere
- Hydrosphere
- Lithosphere
- Humans
- Scenarios
Weather and Climate

- Weather: Short time scales (Day)
  - Determined by Atmospheric statistics:
    - Temperature,
    - Precipitation,
    - Wind velocity,

- Climate: “big picture” concept,
  - “Average weather” over 30 years

REF: GDFL; Simulation of Early 20th Century Global Warming
http://www.gfdl.noaa.gov/early-20th-century-global-warming
Weather and Climate: Chaotic System

• System: One physical state develops into another one over the course of time, often under the effect of extraneous influences (“Forcings”).

• Chaotic:
  - Solution displays “sensitive dependence on initial conditions on a closed invariant set”
  - “Intrinsic” or “Unforced Variability” in Climate models:
    • Unpredictable changes arise from dynamic interactions between subsystems

## Variables

<table>
<thead>
<tr>
<th>Domain</th>
<th>Essential Climate Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosphere</td>
<td>- Air temperature, precipitation, air pressure, surface radiation budget, wind speed and direction, water vapour.</td>
</tr>
<tr>
<td></td>
<td>- Earth radiation budget (including solar irradiance), upper air temperature (including MSU radiances), wind speed and direction, water vapour, cloud properties.</td>
</tr>
<tr>
<td></td>
<td>- Carbon dioxide, methane, ozone, other long-lived greenhouse gases, aerosol properties.</td>
</tr>
<tr>
<td>Ocean</td>
<td>- Sea-surface temperature, sea surface salinity, sea level, sea state, sea ice, current, ocean colour (for biological activity), carbon dioxide partial pressure.</td>
</tr>
<tr>
<td></td>
<td>- Temperature, salinity, current, nutrients, carbon, ocean tracers, phytoplankton.</td>
</tr>
<tr>
<td>River discharge</td>
<td>- River discharge, water use, ground water, lake levels, snow cover, glaciers and ice caps, permafrost and seasonally-frozen ground, albedo, land cover (including vegetation type), fraction of absorbed photo-synthetically active radiation (FAPAR), leaf area index (LAI), biomass, fire disturbance.</td>
</tr>
</tbody>
</table>

Forcings

Mechanisms that alter the Earth’s global energy balance between incoming energy from the Sun and outgoing heat from the Earth.

- Natural

- Anthropogenic ←
Feedbacks

Part of a system’s **output** is **returned as input**, and further affects the system’s performance.

- **Negative**
- **Positive**
No *Inbreeding*: All models should be developed *independently*. 

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Review Of Methodologies And Possible Scenarios
2 Outline

• The Earth System

• Modeling the Earth,
  - GCM’s
  - Uncertainty
  - Scenarios

• Modeling the Arab World:

• Conclusions, Recommendations for Action
2.1 Computer Climate Models

- Hierarchy:
  - 0-D
  - 1-D
  - 2-D
  - GCM: “4-D”

- Time-Dependent Variables,
0-D Computer Models

\[(1 - a)Sp r^2 = 4\pi r^2es T^4\]

\[S = \text{solar constant} = 1367 \text{ W/m}^2\]
\[a = \text{Earth's average albedo} = 0.3\]
\[r = \text{Earth's radius} = 6.371 \times 10^6 \text{ m}\]
\[p = 3.14159\]
\[s = \text{Stefan-Boltzmann constant} = 5.67 \times 10^{-8} \text{ J/K}^4\text{m}^2\text{s}\]
\[e = \text{effective emissivity of earth} = 0.612\]

1-D Computer Models: The Radiation Cascade

- Surface to Space: 6
- Atmospheric Absorption: 111
- Latent Heat: 23
- Evaporation
- Convection Conduction
- Sensible Heat: 7
- Atmosphere to Space: 96
- Could / Atmosphere Emission: 160
- Energy Released by Surface (units)

- Solar Radiation: 100
- Planetary Albedo: 30
- Cloud Reflection: 20
- Scatter: 6
- Diffused: 23
- Direct: 28
- Ground Reflection
- Energy Absorbed by Surface (units)

Energy Released by Surface (units)
2-D, 3-D Computer Models

Climate Variable: $y(t) = \text{ClimateParameter}(y) + \text{Forcing}$

Iterative Averaging

REF: Modeling Climate
http://www.oar.noaa.gov/climate/t_modeling.html
# Global Circulation Models (GCM)

<table>
<thead>
<tr>
<th>Model Name</th>
<th>Originating Group(s)</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCC-CM1</td>
<td>Beijing Climate Center</td>
<td>China</td>
</tr>
<tr>
<td>BCCR-BCM2.0</td>
<td>Bjerknes Centre for Climate Research</td>
<td>Norway</td>
</tr>
<tr>
<td>CCSM3</td>
<td>National Center for Atmospheric Research</td>
<td>USA</td>
</tr>
<tr>
<td>CGCM3.1(T47)</td>
<td>Canadian Centre for Climate Modelling &amp; Analysis</td>
<td>Canada</td>
</tr>
<tr>
<td>CGCM3.1(T63)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CNRM-CM3</td>
<td>Météo-France / Centre National de Recherches Météorologiques</td>
<td>France</td>
</tr>
<tr>
<td>CSIRO-Mk3.0</td>
<td>CSIRO Atmospheric Research</td>
<td>Australia</td>
</tr>
<tr>
<td>CSIRO-Mk3.5</td>
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</tr>
<tr>
<td>ECHAM5/MPI-OM</td>
<td>Max Planck Institute for Meteorology</td>
<td>Germany</td>
</tr>
<tr>
<td>ECHO-G</td>
<td>Meteorological Institute of U of Bonn, Meteorological Research Institute of KMA</td>
<td>Germany / Korea</td>
</tr>
<tr>
<td>FGOALS-g1.0</td>
<td>LASG / Institute of Atmospheric Physics</td>
<td>China</td>
</tr>
<tr>
<td>GFDL-CM2.0</td>
<td>US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory</td>
<td>USA</td>
</tr>
<tr>
<td>GFDL-CM2.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GISS-AOM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GISS-EH</td>
<td>NASA / Goddard Institute for Space Studies</td>
<td>USA</td>
</tr>
<tr>
<td>GISS-ER</td>
<td></td>
<td></td>
</tr>
<tr>
<td>INGV-SXG</td>
<td>Instituto Nazionale di Geofisica e Vulcanologia</td>
<td>Italy</td>
</tr>
<tr>
<td>INM-CM3.0</td>
<td>Institute for Numerical Mathematics</td>
<td>Russia</td>
</tr>
<tr>
<td>IPSL-CM4</td>
<td>Institut Pierre Simon Laplace</td>
<td>France</td>
</tr>
<tr>
<td>MIROC3.2(hires)</td>
<td>Ctr for Climate Sys Research / The U of Tokyo, Nat Inst for Enviro Studies, Frontier Research Ctr for Global Change (JAMSTEC)</td>
<td>Japan</td>
</tr>
<tr>
<td>MIROC3.2(medres)</td>
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<td></td>
</tr>
<tr>
<td>MRI-CGCM2.3.2</td>
<td>Meteorological Research Institute</td>
<td>Japan</td>
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<tr>
<td>PCM</td>
<td>National Center for Atmospheric Research</td>
<td>USA</td>
</tr>
<tr>
<td>UKMO-HadCM3</td>
<td>Hadley Centre for Climate Prediction and Research / Met Office</td>
<td>UK</td>
</tr>
<tr>
<td>UKMO-HadGEM1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
GCM’s: Grid


GCM’s: Time Scale


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GCM’s: Computer Model Development

Model Development

Physics
Chemistry
Biology
Approximations,
Parameterizations

Numerical Resolution

Observations

Forcings Boundary Conditions

Analysis

Validity Test
Mechanism Analysis
Forecasts

Simulation

Model

Results

Forcings Boundary Conditions

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GCM’s: Progress

Mid-1970s
- CO₂
- Rain

Mid-1980s
- Land Surface
- Prescribed Ice
- Clouds

FAR
- "Swamp" Ocean

SAR
- Volcanic Activity
- Sulphates
- Ocean

TAR
- Carbon Cycle
- Aerosols
- Overturning Circulation

AR4
- Chemistry
- Interactive Vegetation
GCM’s: Progress

**GCM**

- FAR: ~500 km (T21)
- TAR: ~180 km (T63)
- SAR: ~250 km (T42)
- AR4: ~110 km (T106)

**REF:** IPCC; (2007-b): Climate change 2007; Synthesis Report, Intergovernmental Panel on Climate Change (IPCC), IPCC Plenary session XXVII Valencia, Spain, 12-17 November 2007, Cambridge University Press, Cambridge, England

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GCM’s Progress: Application to Regional

Grid: 25 km x 25 km

GCM’s: Progress

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  - Uncertainty
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- Modeling the Arab World:
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Uncertainty (1/2): "Uncertainty Explosion"

Emission scenarios $\Rightarrow$ carbon cycle response $\Rightarrow$ global climate sensitivity $\Rightarrow$ regional climate change scenarios $\Rightarrow$ range of possible impacts

Risk Uncertainty: Probability of Occurrence

• **Specific weather events**: Probability of occurrence cannot be determined with certainty.

• Overall climate trends can be understood

However: In the current state of knowledge:

There is no doubt that the Arab world will experience:
- Rise in average temperatures,
- An increased frequency of extreme weather events (droughts)
- There is no way of determining when they will occur.
- A continuous period of rainy years is still possible
  • False sense of security until the drought cycle starts again.
Risk Uncertainty: Evaluating Impact

1. Natural scientists = 20 to 30 x conventional economists

2. Nasty Surprises” = much more likely “Pleasant Surprises”

3. IPCC AR4 may be considered generally optimistic

**Probability distributions of climate damages as a percentage of Gross World Product**

*Expert survey in which respondents were asked to estimate 10th, 50th, and 90th percentiles for the two climate change scenarios shown.*


Uncertainty: The 4th Quadrant

<table>
<thead>
<tr>
<th>Probability Sampling</th>
<th>Impact</th>
<th>Simple</th>
<th>Complex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal “Thin Tailed”</td>
<td></td>
<td>Mitigation</td>
<td>Adaptation</td>
</tr>
<tr>
<td>“Fat Tailed”</td>
<td></td>
<td>Affordable Risk</td>
<td>Manageable</td>
</tr>
</tbody>
</table>

Dealing with Uncertainty

• Bound the Uncertainty

• “Manage Uncertainty”:

– The IPCC’s “Degrees of Doubt”;

<table>
<thead>
<tr>
<th>Virtually Unlikely</th>
<th>Very Unlikely</th>
<th>Unlikely</th>
<th>“Medium”</th>
<th>Likely</th>
<th>Very Likely</th>
<th>Virtually Certain</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1%</td>
<td>1 - 10</td>
<td>10 - 33</td>
<td>33 - 66</td>
<td>66 - 90</td>
<td>90 - 99</td>
<td>&gt; 99%</td>
</tr>
</tbody>
</table>
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Scenarios: The “Whole Earth System”

- Climate
- Computer Models
- Atmosphere
- Biosphere
- Hydrosphere
- Humans
- Scenarios
Scenarios

- Temporal Analogues;
  - “Palaeoclimatic”
  - Historic climate: “measurement record”

- Spatial Analogues;
  - “These types of scenarios should not be used”
Scenarios: Shortcomings

- Outcomes = “path dependent”;  
  - Faster rate of temperature increase may create a worse impact than forecasted.

- “Surprises”: Possible events that are not investigated by the IPCC

- The “Texas Sharpshooter” fallacy
Scenarios: IPCC Approach

1. Consistency with global projections
   - Planetary warming projected to be in the range of 1.4°C to 5.8°C by 2100.

2. Physical Plausibility and strict adherence to physical laws.

3. Applicability in impact assessments.
   - This becomes an issue when “downscaling” to finer resolutions RCM’s.

4. Representativity.

5. Accessibility.
Scenarios: IPCC

- **A1**
  - Rapid Economic Growth
  - Population peaks in 2050, then decline
  - Rapid technological change
  - Lower growth than A1
  - More efficient technologies.

- **A2**
  - Slow Economic Growth
  - Population continuously increases
  - Slow technological change

- **B1**
  - Intermediate economic growth,
  - Intermediate population growth,
  - Local technological solutions

- **B2**
  - “Inspiration”

“Perspiration”

Economy

Demography

Technology

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  – Boundaries
  – Parameters
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  – Downscaling to RCM’s

• Conclusions, Recommendations for Action
Boundaries

- RCM’s rely on input from GCM’s

- GCM’s may understate some key problems:
  - No “Surprises” in ITCZ
  - Impact of some parameters may accelerate
  - ENSO-ITCZ modeling
3.1

**Boundaries: ENSO**

Decreased Rainfall: Sept (-) to May (+)

**Summer**

**Rainy Season**

**Spring**

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Boundaries: ENSO

Frequent drought episodes, when precipitation over Africa decreased by as much as 50% compared to the average between 1951 and 1997.

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Parameters

- **Changing Topography:**
  - Dunes over the large desert areas in Arabia and the Sahara may have a cumulative effect on surface winds,
  - Rapid urbanization and increased concentration is modifying local conditions in unique ways.

- **Albedo Variations:**
  - Spread of deforestation and land degradation is modifying surface reflectivity
  - GCM models may not have needed to factor in Albedo changes over the seasons.

- **Desert changes different from Oceans:**
  - Seasonally because of rain
  - Permanently because of the pollution.
Parameters

- Heat Islands
  - Impact already documented on local rainfall patterns,

- Water Table depletion:
  - Decreased the amount of water available for evaporation: impact on the radiation cascade

- Population movement:
  - Land pattern uses,
  - Heat Islands,

- Land degradation
Parameters

Evaporation / Cloud Formation:
- Small-scale

Thunderstorms / Squall Lines,
- Larger scale

Fronts, precipitation bands,
- Regional scale

Tropical depressions / cyclones
- Global scale

Global models remain very approximate in this respect.

There are still variations among models when investigating cloud formations, particularly “boundary-layer clouds, and to a lesser extent midlevel clouds”.

Observations have not yet been able to ascertain “which estimates of the climate change cloud feedbacks are the most reliable”
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Scenarios: Arab World

“Perspiration” Economy

A1

• Rapid Economic Growth
• Population peaks in 2050, then declines
• Rapid technological change

A2

• Slow Economic Growth
• Population continuously increases
• Slow technological change

Economy

Demography

Technology
Scenarios: Statistical-Dynamical Downscaling

1. Classification of large-scale weather
   - large-scale weather types characteristic for the region of interest:
     Multi-year time-series of a **GCM simulation** / Large-scale analyses
   - Classes defined on a scale which is well resolved by the GCM
   - Sequence of **weather types** lasting one or several days.

2. Determination of **weather-type** frequencies
   Counting the events in the climate period

3. **RCM Simulation**
   Carried out once for each **weather type**
   Mean or typical values of the corresponding large-scale fields during the episode.
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• Conclusions, Recommendations for Action
“Nested” Computer Models

Progressive Scaling down:

- Climate analysis from global to regional to micro-scales
- Generate hourly, high-resolution surface fields (Temperature, wind speed...)

REF: Nested-Grid model analyses by Colorado State University: http://traverse.npolar.no/spatial-extents/modeling/
Uncertainty (2/2): Cascade of Uncertainty

"Different regional models (or statistical downscaling methods) can yield different results even when conditioned by the same GCM"

Still no reliable method to translate global patterns into local information.

**PRUDENCE Project:**
Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects

**Statistical-Dynamical Downscaling**

Downscaling

**Example:**

**PRECIS RCM: HadRM3P**

*20th January, 1990*

Downscaling: Need to do More

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  - 5 Key Recommendations
  - Climate Impact Scoring
Conclusion and Recommendations for Action: 1, 2, 3

1. **Defining Current Knowledge Domain.**
   - Uncertainties will remain,
   - Apply the “Precautionary Principle”:
     “when a reasonable degree of doubt exists over the consequences of human action, there are, perhaps, sound reasons for taking a conservative approach”.
   - Improve knowledge about epiphenomena such as ENSO/ITCZ

2. **Build Region-Specific Scenarios.**
   - The Arab World and West Asia: very different configuration from other regions

3. **Investigate “Climate Surprises”.**
   - The region’s prevailing arid to semi-arid climate makes it uniquely vulnerable to extreme events
   - Many regions in the Arab World are already “on the brink” with limited resources, scarce water supply, and rapidly expanding populations.
### Region-Specific Scenarios & “Surprises”

#### Assessing Adaptability/Resilience:
- Financial metrics
- Development-related metrics
- **Vulnerable sectors of the economy**

#### Indicator | Target | Description
---|---|---
**adaptive capacity** | Proportion of population living on less than $1 (PPP) per day | Net enrolment ratio in primary education
| | | Literacy rate of 15-24 year-olds
| | | % Of National Budget Dedicated To Carrying Out Vulnerability Assessments

**Result-oriented**
- Prevalence of underweight children under-five years of age
- Share of preserved coastal wetlands
- Human and economic loss due to hydro-meteorological disasters
- % of land lost due to sea level rise
- % of population living on flood planes

**process-oriented**
- Availability of national climate change impacts and vulnerability assessments
- Availability of national adaptation strategies with identified adaptation priority actions
- National reports integrating adaptation into sectoral policies and planning
- Amount of funding directed for community adaptation projects

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Scenarios & “Surprises”: Assessing Adaptability/Resilience


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Conclusion and Recommendations for Action: 4

4. RCM Development: adapted to Arab World’s unique geography:

- Deserts in West Asia and North Africa
  - Proportionally large effect on radiative forcing,
  - Oases: effect on population movement, land impact...

- Changing topography:
  - In deserts, movement of dunes & surface wind patterns
  - Built environment,
  - Excavations in freshwater-rich areas,
  - Resource-extraction areas: ground subsidence,

- Growing Heat Islands,

- Groundwater:
  - Over-pumping,
  - Seawater intrusion,
  - Oases,

- Land Degradation:
  - Interactions: temperature, precipitation; deforestation.
Conclusion and Recommendations for Action: 5

5. Vulnerability Assessments:

“Road Map”:

- No absolute likelihood,

- Focus on relative likelihood(s) and expected impact(s)
Climate Impact Scoring

Key Climate Change Impacts

- Drought
- Reduced Precipitation
- Groundwater Depletion
- Seawater Intrusion

Country 1

Virtually Certain
Very Likely
Likely
“Medium”
Unlikely
Very Unlikely
Virtually Unlikely

Country 2

Country 3