Modeling Strategies for Adaptation
(in the context of climate change & LCLUC projects)

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Adaptation – what is it? Multiple definitions..
(in the context of United Nations efforts – from OECD)

*Adaptation* - Actions taken to help communities and ecosystems *cope with* changing climate conditions, such as the *construction* of flood walls to protect property from stronger storms and heavier precipitation, or the *planting* of agricultural crops and trees more suited to warmer temperatures and drier soil conditions (UNFCCC Secretariat)

*Adaptation* - Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which *moderates harm* or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation (IPCC TAR, 2001 a)

*Adaptation* is a process by which strategies to *moderate, cope with* and take advantage of the consequences of climatic events are enhanced, developed, and implemented. (UNDP, 2005)

*Adaptation* – The process or *outcome* of a process that leads to a *reduction in harm* or risk of harm, or realisation of benefits associated with climate variability and climate change. (UK Climate Impact Programme, 2003)
Adaptation –vs– Mitigation

**Mitigation** - “An anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases.” (IPCC)

i.e. action taken to eliminate or reduce the long-term risk and hazards of climate change to human life, property.

Adaptation is sometimes scorned but at this point is required to reduce vulnerability to future climate change.

Society’s options responding to climate change include a balance of mitigation, adaptation (coping) and suffering

“The greater the amount of mitigation that can be achieved at affordable cost, the smaller the burdens placed on adaptation and the smaller the suffering.” – John Holdren

A wide array of adaptation options are available.
e.g. Agricultural practices, flood control, sea walls, green development
We’re modeling coupled climate and land use change impacts on ecological processes across the U.S. using the Terrestrial Observation and Prediction System (TOPS), and assessing the potential influence of adaptation actions associated with “green infrastructure” or “low impact development”
Low Impact Development as an Adaptation Strategy

• We’re assessing the effects of realistic Best Management Practices / Low Impact Development techniques on runoff and vegetation productivity:
  ➢ increases of pervious surfaces (e.g. permeable pavement)
  ➢ green roofs, rainwater harvesting, downspout disconnection
  ➢ urban afforestation programs

  Credits towards compliance with stormwater requirements.

• We’re conducting both regional & national scale analyses

https://c3.ndc.nasa.gov/nex/
A Greener Approach to Runoff

New York City may have found an affordable way to reduce the flow of untreated sewage into the city’s surrounding waterways whenever there is heavy rainfall. Under an agreement with the state announced Tuesday, the city plans to commit $2.4 billion in public and private money over the next 18 years in innovative techniques to prevent rainfall from overwhelming the city’s waste treatment plants.

The city will provide $1.5 billion from water rates; developers of new buildings that must meet rigorous environmental standards will provide the other $900 million.

Like many older cities, New York has a combined sewer system where storm water and sewage are carried through the same pipes. The system often exceeds capacity during heavy storms and discharges the overflow into local waterways. Such overflows are a major pollution problem preventing many waterways from meeting standards under the federal Clean Water Act.

The state, which is responsible for enforcing the federal law, has been pushing the city to find an answer. Because building two separate systems would be prohibitively expensive, the Bloomberg administration has devised a plan for new “green infrastructure” projects to capture rainwater before it reaches the sewers. These could include rooftop gardens, which can retain rainwater, porous surfaces for parking lots that allow water to seep into the soil and more street-side vegetation.

What the plan is missing is a strategy to encourage retrofits of existing properties. But there are useful models New York City can emulate. Philadelphia, for instance, has begun providing a mixture of fees and tax credits to encourage owners of older buildings to install “green roofs” or other features.

Green infrastructure can reduce runoff by only 5 percent or so, and some old-fashioned “gray infrastructure,” like new storage tanks, will be necessary to achieve City Hall’s long-term goal of a 40 percent reduction. But this is definitely a creative step forward.
Motivation for our work

- The 4th IPCC Fourth Assessment Report (AR4) projects warming of 4-12 °C over the United States by 2100

- Urban land cover and associated impervious surface are forecast to increase 50% in the next few decades across much of the U.S.

- Coupled effects of changes in climate and land use - land cover are expected to intensify impacts on ecosystems (changes in productivity, disturbance and hydrological properties)

- Low impact development (LID) and associated Best management practices (BMPs) for land use planning and design can moderate harm resulting from changes in climate and LU
## Methods: TOPS

**Input Variable** | **Chesapeake / Delaware (250m)** | **United States (1km)**
--- | --- | ---
Impervious surface area | Spatially Explicit Regional Growth Model, SERGOM (Theobald et al., 2009) | 
Climate (baseline run) | TOPS-SOGS Weather Surfaces | 
Climate (forecast) | Scenarios A1B, A2, B1 AR4 (&AR5) Ensemble Averages WCRP CMIP3 (Maurer et al., 2007) GFDL CM2.0, NCAR CCSM3.0, GISS-ER | 
Elevation | National Elevation Dataset (resampled) | 
Leaf Area Index (baseline run) | MODIS MOD13Q1 NDVI and MOD15A2 LAI algorithm | MODIS MOD15A2 LAI (Myneni et al., 2000) | 
Leaf Area Index (forecast) | MODIS MOD15A2 LAI Climatology | Simulated by BIOME-BGC | 
Soils | U.S. STATSGO2 database | 
Land Cover | NLCD2001 (Homer et al., 2004) Cross-walked to IGBP | MODIS MOD12Q1 Land cover (Friedl et al., 2002) |
Approach: SERGoM Housing Density ⇒ Impervious

2000 housing density

A

C

B1 scenario

2100 modeled density

B

D

A2 scenario

Area covered by impervious surface over time for all five scenarios.

Bierwagen, Theobald et al. PNAS (2010) 107:20887-20892
National Scale Projected Impervious Surface under
IPCC SRES A1B  2010 to 2100
Projected Climate under IPPCC SRES A1B
1km Downscaled GFDL CM2.0

Precipitation

1950

2000

2100

Tave

1950

2000

2100

VPD

1950

2000

2100
Differences between A1B and A2 scenarios evident for ISA, average temperature, and vapor pressure deficit. No clear trends in precipitation but predicted changes in temperature drive strong increases in VPD.
As per Regional simulations, *increases* in impervious cover produce significant *increases* in runoff and *decreases* in GPP.
Baseline BAU: SRES A2 2010 “Low Reduction” (10% adoption rate, 13% BMP effectiveness)
SRES A2 2050 High Reduction

25% adoption rate, 95% BMP effectiveness
10% adoption rate, 13% BMP effectiveness
Land Cover Types

Cropped Farmland  Fallow Farmland  Transitional Land

Permanent Land Abandonment
Shrubland (abandoned 10-20 years)
Forest
Conducted 20 - 30 interviews per region (4) in May/June 2010, June 2011 and September 2011.
Each interview lasted 30-90 minutes.
Typically attended by 1-5 respondents.
Among farmers and administrators were people from Baskhir, Tatar and Chuvash ethnicities.
Visited regional offices to update data collected in 2000.
Field visits are linked with imagery.

May 25th, 2010

• Image Segmentation.
• Link segments with Google Earth to enrich training and validation data.
• Conduct basic maximum likelihood classification.
- Four path/rows.
- At least 5 images per scene (21 total):
  - Spring (June)
  - Summer (July/August)
  - Fall (September/October).

### Reference Data

<table>
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<tr>
<th>Classified</th>
<th>User Accuracy</th>
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</thead>
<tbody>
<tr>
<td>Water</td>
<td>0.938</td>
</tr>
<tr>
<td>Forest</td>
<td>0.963</td>
</tr>
<tr>
<td>Grassland</td>
<td>0.555</td>
</tr>
<tr>
<td>Cropland</td>
<td>0.918</td>
</tr>
<tr>
<td>Urban</td>
<td>0.722</td>
</tr>
</tbody>
</table>
Land Surface Phenology

- MODIS BRDF data: 500m. All years/composites.
- Determine land surface phenology metrics for each year (2002 - 2009).
- Determine annual mean and standard deviation per pixel.

- Link land surface phenology estimates based on MODIS with Landsat based land cover estimates.
Probability of Cropland
(based on logistic model of MODIS phenology and Landsat LC)
Satellite estimates compare well with regional statistics at the rayon (county) scale.
• Phenology helps determine if cropland is actually cropped for any particular year.

• Some evidence farmers are diminishing the number of years they actively use cropland
while the southern areas in Samara have more croplands, they are not used as often, and also fail more as a result of drought conditions.
### Successfully Sown Land

<table>
<thead>
<tr>
<th>Annual Validation (1000 ha)</th>
<th>Intercept</th>
<th>Slope</th>
<th>$R^2_{\text{adj}}$</th>
<th>RMSE (1000 ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>-11.451*</td>
<td>1.331</td>
<td>0.92</td>
<td>12.2</td>
</tr>
<tr>
<td>2005</td>
<td>-3.856*</td>
<td>1.189</td>
<td>0.91</td>
<td>11.7</td>
</tr>
<tr>
<td>2006</td>
<td>-3.944*</td>
<td>1.271</td>
<td>0.90</td>
<td>13.4</td>
</tr>
<tr>
<td>2007</td>
<td>6.984*</td>
<td>1.156**</td>
<td>0.86</td>
<td>15.0</td>
</tr>
<tr>
<td>2008</td>
<td>1.646*</td>
<td>1.160**</td>
<td>0.86</td>
<td>14.9</td>
</tr>
<tr>
<td>Overall</td>
<td>-1.457*</td>
<td>1.213</td>
<td>0.88</td>
<td>13.6</td>
</tr>
</tbody>
</table>

*: not significant different from 0 ($p = 0.05$).

**: not significantly different from 1 ($p = 0.05$).
Farmers are Adapting

- Shorter-term climate adaptations include changing crop season (e.g., winter vs. spring grains), cultivars, and sowing dates (*IPCC and citations therein, 2007*).
- Adaptation to new markets.
- Previously, farmers in Samara:
  - 7-year crop rotation → variety of grain + 1 year fallow.
- Now, crop rotation schedules are changing:
  - 3-year crop rotation → fallow-grain-sunflower.
- Anecdotal evidence suggest a switch to increased winter wheat growth.
- Also switch underway from cereal to different products such as chickpeas.
Agent-Based Modeling in Mongolian Grasslands

Jun Wang and Dan Brown

• Uses object-oriented programming …
  to represent and simulate the attributes, decisions, and behaviors of multiple interacting actors…
  and their collective impacts on landscape condition and pattern.
Traditional Resource Institutions for Pasture Use on the Mongolian Plateau

Seasonal and interannual *migrations* can use pastures efficiently and minimize the loss caused by frequent climate hazards.

*Flexible land property boundaries* and *reciprocal use of pastures* allow herders to adapt to the highly variable climate and vegetation productivity.
Current Resource Institutions in Inner Mongolia and Mongolia

- Inner Mongolia Autonomous Region (IMAR), China (1984-present)
  Pastures are owned by the state, but they are contracted to individual households and fenced. Large-scale migration becomes less feasible.

- Mongolia (1990-present)
  Pastures become open-access resources. Cooperative use of pastures now becomes competitive use. *Conflicts of pasture use are increasing*. Livestock grazing becomes less mobile. The migration frequency and distance have decreased.

- Current resource institutions in IMAR and Mongolia make local herders more vulnerable to adverse climate conditions.

- Changing resource institutions is the top-down adaptation strategy for changing climate and grassland degradation.
The Modeling Goal

- An agent-based model was built and used as a platform for comparing social-ecological performance of three resource institutions, *pasture privatization and grazing sedentarization*, *pasture rental market*, and *reciprocal use of pastures*:
  - in the semiarid and arid Mongolian grasslands with high interannual precipitation variability.

- Average agent utility and average pasture biomass are measured at each model step for all institutional scenarios to analyze social-ecological outcomes of pasture use.
The Conceptual Model

Social-Ecological Outcomes
Average agent benefit and pasture biomass in the grazing community are measured at each model step;

Model Initialization
Pasture and livestock privatization
Drought probability
Agent diversity

Cooperation Mechanisms
Cooperation mechanisms are turned on separately or together to test their effects on social-ecological outcomes of pasture use;

Grazing Sedentarization
IF drought hits the parcels, agents will (1) not migrate; (2) tend to overgraze pastures; (3) have to suffer benefit loss (e.g., sheep);

Pasture Rental Market?
Yes

Pasture Rental Market
IF drought hits the parcels, agents will (1) search available parcels; (2) bid on searched parcels; (3) migrate to the final available parcels;

Reciprocity & Market?
Yes

Reciprocity & Pasture Rental Market
IF drought hits the parcels, agents will (1) search cooperators; (2) calculate cooperation costs and benefits; (3) leave the cooperation group if they cannot benefit from it;

Pasture Reciprocal Use?
Yes
Outcomes of agent benefit and pasture biomass were measured for three experimental cases:

Experiment 1: Can land-rental market improve socioecological outcomes, compared to grazing sedentarization without migration?

Experiment 2: What are the effects of reciprocal cooperation and kinship cooperation?

Experiment 3: What is the effect of free riders in cooperation?
Modeling Results

Base Case: sedentarization

Exp 1: Pasture rental market

Exp 2: Reciprocal pasture use

Exp 3: The “free rider” problem

blue agents = hit by drought
red agents = hit by drought but adapted by renting new parcel
red agents = in cooperation group
yellow agents = free riders

Each institutional scenario was run for 30 steps to represent 30 years; results are averaged across 20 realizations.
Conclusions

1. cooperation mechanisms, such as pasture rental market and reciprocal pasture use, are valuable adaptations in the semiarid and arid Mongolian grasslands.

2. relaxing the “top-down control” and allowing local herders to self-organize can help grassland quality to recover and improve the livelihoods of herders.

3. policy responses can include development of pasture rental market or organizing and sustaining cooperation groups among local herders.
Interactive Changes of Ecosystems and Societies on the Mongolian Plateau

From Coupled Regulations of Land Use and Changing Climate to Adaptation

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**Collaborative Team:**
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- Burkhard Wilske & Ranjeet John, Univ. of Toledo, USA
- Jiaguo Qi: Michigan State University, USA
- Steve McNulty & Ge Sun, Southern Global Change Program of Forest Service, USA
- Dennis Ojima, Colorado State University
- Chuluun Togtokh, National Univ. of Mongolia, Mongolia
Standardized anomalies of EVI for 2010 (Jun-Aug) relative to the decadal mean

I - desert, II - grassland, III - forest
Standardized anomalies of GPP for 2010 (Jun-Aug) relative to the decadal mean

I - desert, II - grassland, III - forest
Standardized anomalies of ET for 2010 (June-Sept) based on 1-km MODIS ET

ET anomaly
High : 5.97
Low : -0.84
Changes in livestock numbers appear to be influenced by continuous changes of biophysical and socioeconomic conditions.

The green and brown arrows represent the El Nino and La Nina years. (Qi et al. 2012)
Conceptual framework to examine the coupled effects of climatic change (variability) and socioeconomic shifts on the interactions and feedbacks within and between the human system (HS) and natural system (NS).
Thank You...