The influence of carbon, climate, and humans on energy and land

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Motivation
Human activity has a significant effect on the climate system.

Source: IPCC AR5. WG1. Ch. 12.
Changes in climate affect the productivity of crops and other ecosystems.

Source: IPCC AR5. WG2. Ch. 7.
These changes in ecosystem productivity affect land use and land cover decisions.

Change in Land Cover due to Climate Impacts

Source: Nelson et al. (2014) (redrawn)
The integrated Earth System Model (iESM)

- iESM couples the human components of GCAM with the CESM.
- Information between components is exchanged every 5 years.
- Current information exchange focuses on the carbon cycle.
- Can explore 1-way or 2-way feedbacks.
- Code is available at: [www.github.com/ACME-Climate/iESM](http://www.github.com/ACME-Climate/iESM)

An initial experiment using iESM showed increases in land productivity.

Questions:

1) What is the relative influence of CO₂ fertilization versus climate change?

2) How do those different factors influence human systems?

3) And, how do those changes feedback to the climate?

Decomposing the Effects of Climate, CO$_2$, and Humans
Experiment Design

- Decompose the effects of climate, CO₂, and humans, using a C4MIP style protocol.

- Simulations:

<table>
<thead>
<tr>
<th>RF</th>
<th>Configuration</th>
<th>Humans?</th>
<th># of Ensembles</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCP8.5</td>
<td>Climate &amp; CO₂</td>
<td>Yes</td>
<td>3</td>
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<tr>
<td></td>
<td>(Concentration-forced)</td>
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</table>
With both CO₂ and Climate, the productivity of land increases.
Both CO$_2$ and Climate increase productivity individually...

Change in Yield due to Climate, CO$_2$ or Both

- **Corn**
  - Climate Only
  - CO$_2$ + Climate
  - CO$_2$ Only

- **Forest**
  - Climate Only
  - CO$_2$ + Climate
  - CO$_2$ Only

% Change from due to Feedbacks

Year

2010 2040 2070

Change in Yield due to Climate, CO$_2$ or Both
But, there are regional differences, with some seeing productivity decreases.

**Average Change in Wheat Yield in the 2080s**
When faced with a decline in yield, regions tend to reduce cropland area.

**Correlation between Land & Yield in 2090**

- Data points are color-coded:
  - Orange: Climate Only
  - Blue: CO2 + Climate
  - Green: CO2 Only

Graph illustrates the correlation between changes in yield and changes in land due to climate and/or CO2.
In most parts of the world, cropland area declines in all three scenarios.

**Average change in cropland in the 2080s**
All three scenarios show declines in global cropland area.
These changes have implications for energy use...

Change in Energy Use due to Climate and/or CO$_2$

<table>
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<tr>
<th>Year</th>
<th>c coal</th>
<th>d biomass</th>
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<tr>
<td></td>
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</tr>
<tr>
<td>2010</td>
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<td>0</td>
</tr>
<tr>
<td>2040</td>
<td>-10</td>
<td>-5</td>
</tr>
<tr>
<td>2070</td>
<td>-10</td>
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</table>

Energy (EJ/yr)

- Green: Climate Only
- Orange: CO$_2$ + Climate
- Purple: CO$_2$ Only

ACME Accelerated Climate Modeling
for Energy
...and energy-related emissions.

Change in Energy–Related CO₂ Emissions due to Climate and/or CO₂

- Climate Only
- CO₂ + Climate
- CO₂ Only

MtC/yr

Year

2010 2040 2070

0 100 200 300

MtC/yr

0 100 200 300

Climate Only

CO₂ + Climate

CO₂ Only
Preliminary Conclusions

• We find increases in productivity in most parts of the world due to both climate and CO$_2$ fertilization. The productivity increase is larger with CO$_2$ than without.

• These increases lead to a decline in global cropland area; however, some regions to see increases.

• Changes in productivity spill over onto other segments of the economy, resulting in decreased fossil fuel use & emissions and decreased crop prices.
Comparing to Other Analyses
Other Estimates of Yield in an RCP8.5, with and without CO₂ Fertilization

Source: Ren et al. (2016)
Other Estimates of Yield in an RCP8.5, with and without CO₂ Fertilization

**AgMIP**

- **Maize**
- **Wheat**
- **Rice**
- **Soy**

**iESM**

- **Corn**
- **OilCrop**

**Fig. 4.** Relative change (%) in RCP8.5 decadal mean production for GGCM (based on current agricultural lands and irrigation distribution) ensemble median for all GCM combinations with (solid) and without (dashed) CO₂ effects for maize, wheat, rice, and soy; bars show range of all GCM combinations with CO₂ effects. GE_PIC, GAEZ-IMAGE, and LPJ-GUESS only computed one GCM without CO₂ effects.

Source: Rosenzweig et al. (2014)
We are using offline runs to explore the implications of these uncertainties.

Source: Bond-Lamberty et al. (submitted)
Thank you!