Using the CLM Crop Model to assess the impacts of changes in Climate, Atmospheric, CO₂, Irrigation, Fertilizer and Geographic Distribution on Historical and Future Crop Yields

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Project Scientist

NCAR – Terrestrial Science Section
Brian O’Neill, Sam Levis, Xiaolin Ren and many others
Gridcell

Landunit

Vegetated

Lake

Urban

Glacier

Crop

CLM 5 Crop subgrid tiling

Crop Model

Land Use Change

Planting

Leaf emergence

Irrig / Fertilize

Harvest

Grain fill

Unirrig

Irrig

Unirrig

Irrig

Crop1

Crop1

Crop2

Crop2 ...

V PFT1

V PFT2

V PFT3

V PFT4

C1I C1U

C2I C2U

U,T,H,M
CLM Crop – Crop Simulations

We would like to evaluate agriculture in CLM Crop with CESM forcing from the Historical, RCP 4.5 and RCP 8.5 time periods

Problems with CLM4.5 Crop:

- Fixed Crop distribution as crop land unit can not be changed through time like PFTs

- Only simulates Cotton, Corn, Rice, Soy, Sugarcane, Wheat (temperate/tropical)

- Nitrogen fertilizer is fixed by crop type independent of region or time period based on North American application rates

- Has fixed irrigation area based on crop distribution
CLM Crop – Idealized Crop Simulations

Idealized Crop simulations are suite of CESM simulation with transient CESM forcing from the Historical, RCP 4.5 and RCP 8.5 time periods that can be combined with cropping and management scenario.

Globally simulate in CLM Crop for every land grid cell:
- Cotton, Corn, Rice, Soy, Sugarcane, Wheat (temperate/tropical)

With Management:
- N Fertilizer and Irrigated
- N Fertilizer and Rainfed
- No N Fertilizer and Irrigated
- No N Fertilizer and Rainfed

With Atmospheric Forcing as:
- Transient Climate and CO$_2$
- Transient Climate and Constant CO$_2$
- Constant Climate and Constant CO$_2$
CLM Crop – Scenario Simulations

Crop Area time series CMIP5 / other scenario

CESM Climate / CO₂ Scenario – Hist/RCP4.5/RCP8.5

Crop Type / Irrigation time series

Portmann et al. (2010)

Global CLM Crop Simulation

- Scenario
- Crop
- Year
- Area
- Yield
- Fertilizer
- Irrigation
- Temp.
- Precip.
- Solar
- CO₂
Global Idealized CLM Crop Simulation Database
For Historical, RCP4.5 and RCP8.5 time series and for each crop

<table>
<thead>
<tr>
<th>Rainfed / Irrigated</th>
<th>N Fertilizer</th>
<th>CO2 Concentration</th>
<th>Climate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigated</td>
<td>UNFAO Fertilizer</td>
<td>Transient</td>
<td>Transient</td>
</tr>
<tr>
<td>Rainfed</td>
<td>UNFAO Fertilizer</td>
<td>Transient</td>
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# Global Historical CMIP5 – UNFAO Area, Yields, N Fert

## Historical Global Crop Area (millions hectares)

- **CMIP5 Hist**
- **UNFAO**

## Historical Global Production (millions tonnes)

- +Irrig
- +Fert
- +Climate & CO2
- RF NoFert Const Clim CO2
- UNFAO

## Historical Global Crop Yield (tonnes/ha)

## Historical Global N Fertilizer (kilograms/ha)

<table>
<thead>
<tr>
<th>Effect</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area Effect</td>
<td>+77.2%</td>
</tr>
<tr>
<td>Climate / CO2</td>
<td>+5.8%</td>
</tr>
<tr>
<td>N Fert Effect</td>
<td>+65.6%</td>
</tr>
<tr>
<td>Irrig Effect</td>
<td>+9.5%</td>
</tr>
<tr>
<td>Total Effect</td>
<td>+226.8%</td>
</tr>
</tbody>
</table>

*UNFAO only using Yields for CLM Crop Types over All Crop Areas*
Global Historical CMIP5 UNFAO Yields by Crop

Global Crop Yield (Tonnes/Ha) 1961 - 1966

Global Crop Yield (Tonnes/Ha) 2000 - 2005

*UNFAO Sugar Cane scaled by 0.12 for sugar from cane
CLM Crop – UNFAO Regional N Fertilizer Application

Regional Current Day CLM Crop N Fertilizer compare to UN FAO estimates
CLM Crop – N Fertilizer Application

Historical CLM Crop and UN/FAO - Yield Summary

1. CLM Crop represents the world with six crops with climate varieties as well as rainfed and irrigated management.

2. Historical Crop Area increased from 1901 – 2005 by 685 million hectares (83%) and Industrial Fertilizer increased from 0 to 77 kg/ha.

3. Crop Area increases resulted in an increase in Production of 77% with Fertilizer another 66% and irrigation 9.5%. CO₂ only added another 6%.

4. Compared to UNFAO, CLM Crop has a similar Production and Yield amounts for the crops simulated for current day.

5. UNFAO increases in Production and Yield occur slightly more quickly than CLM Crop (1961 – 2005) possibly due to differences in crop varieties and management such as planting density and irrigation.

6. Default N Fertilizer for CLM Crop are not applicable for much of the world and need to be changed to transient regional values.
Global CMIP5 RCP 8.5 (All Crops) Area, Yield, N

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<tbody>
<tr>
<td>Area Effect</td>
<td>+21.2%</td>
</tr>
<tr>
<td>Clim Effect</td>
<td>-23.4%</td>
</tr>
<tr>
<td>CO2 Effect</td>
<td>+43.3%</td>
</tr>
<tr>
<td>N Fert Effect</td>
<td>+39.6%</td>
</tr>
<tr>
<td>Irrig Effect</td>
<td>+8.0%</td>
</tr>
<tr>
<td>Total Effect</td>
<td>+64.6%</td>
</tr>
</tbody>
</table>
1. RCP 8.5 has an increase in: cropping area of 280 million hectares (18%); average land temperature of +4°C; CO$_2$ to 930 ppm (150%); and Fertilizer to 117 kg/ha (60%).

2. RCP 8.5 CLM Crop results in changes in Global Production of:

<table>
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<tr>
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<th>CO2 Effect</th>
<th>N Fert Effect</th>
<th>Irrig Effect</th>
<th>Total Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>+21.2%</td>
<td>-23.4%</td>
<td>+43.3%</td>
<td>+39.6%</td>
<td>+8.0%</td>
<td>64.6%</td>
</tr>
</tbody>
</table>

3. Future climate impacts may be underestimated as CLM Crop does not properly account for damage from Heat Waves, Droughts, Ozone, Insects, Diseases, and Floods.

4. Currently CLM Crop responds to temperature, vapor pressure, soil moisture and light to limit photosynthesis which then impacts grain production, but this is only one element impacting yield.
1. CLM Crop allows us to investigate changes in Agricultural Production as climate and CO₂ change in combination with cropping area and management.

2. Historical increases in cropping area result in a +77% gain with fertilizer and irrigation adding an additional +75% gain. CO₂ results in only another +6% gain.

3. RCP 8.5 crop expansion results in a +21% gain which is offset by climate losses of -23%. CO₂ results in a +43% gain which combines with a fertilizer and irrigation gain of +48% to leave a net +65% gain in Production for the scenario.

4. Historically differences from UNFAO may be due to no management to change varieties and planting densities. Future impacts do not properly account for damage from Heat Waves, Droughts, Ozone Insects, Disease, and Floods. All of these are current research.

Thanks – Questions?