Agriculture provides food and also changes biogeophysical
and biogeochemical properties of the land surface.
Land management and land-cover change have impacts on surface temperature of similar magnitude since 1993.

Luyssaert et al., 2014

Paired Tower sites
Synthesis of land management impacts

Deforest to crop

Biophysical effects
Low
Medium
High

Biogeochemical effects
Ecosystem
crop
forest
grassland

Extent (Mkm2)
10
20
30
40
50

Erb et al., GCB, 2016
Synthesis of land management impacts

- Species selection
- Harvest
- Irrigation
- Wetland drainage
- Grazing & mowing
- Fire

Biophysical effects:
- High
- Medium
- Low

Biogeochemical effects:
- Ecosystem
- Crop
- Forest
- Grassland

Extent (Mkm²): 10, 20, 30, 40, 50

Erb et al., GCB, 2016
Land management in Community Land Model (CLM5)

- Global crop model with 8 crop types: planting, grain fill, harvest, residue management
- Crop irrigation, including irrigation methods
- Crop industrial fertilization
- Wood harvest
- Urban environments
- Human fire ignition and suppression

- Corn*
- Soy*
- Winter wheat
- Sugarcane
- Cotton
- Rice

* Temperate and tropical varieties

Fertilization

Irrigation

Erb et al., GCB, 2016

Deforest to crop

Synthesis of land management impacts

Erb et al., GCB, 2016

= represented in CLM

Biophysical and Biogeochemical effects
Impact of Simulated Managed Crops
(relative to simulating generic crops)

1991-2010 Average

Change in Annual Maximum Gross Primary Productivity (g C m$^{-2}$ day$^{-1}$)

Lombardozzi et al., submitted
Impact of Simulated Managed Crops
(relative to simulating generic crops)

Annual Monthly Maximum

1991-2010 Average

Change in Latent Heat Flux (W m$^{-2}$)

Lombardozzi et al., submitted
Impact of Simulated Managed Crops
(relative to simulating generic crops)

Annual Monthly Maximum

Annual Average

Change in Latent Heat Flux (W m⁻²)

Lombardozzi et al., submitted
History of the Crop Model

CLM4

Temperate Crops only: Corn, Cereals, Soybean

No N limitation

(Original crop code based on Agro-IBIS, Kucharik & Brye, 2003)
Levis et al. 2012
### History of the Crop Model

#### CLM4
- Temperate Crops only:
  - Corn, Cereals, Soybean
- No N limitation

#### CLM4.5
- Temperate Crops only
- Options to fertilize and irrigate
- Soybean N fixation

*(Original crop code based on Agro-IBIS, Kucharik & Brye, 2003)*

Levis et al. 2012

Levis et al. 2013; Drewniak et al. 2013
## History of the Crop Model

<table>
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<th>CLM5</th>
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<td>Crop distributions through time</td>
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*(Original crop code based on Agro-IBIS, Kucharik & Brye, 2003)*

Levis et al. 2012

Levis et al. 2013; Drewniak et al. 2013

Levis et al. 2016; Lombardozzi et al, submitted
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Note: Crops are only active in the BGC configuration with component sets that specify “Crop” in the name (e.g., IHistClm50BgcCropG). All CESM CMIP6 simulations will include active crops.

Levis et al. 2013; Drewniak et al. 2013
Levis et al. 2016; Lombardozzi et al, submitted
Today’s Objectives

1) Crop types and distributions
2) Crop phenology
3) Allocation in crops
4) Management options
5) Crop Yields
6) Ongoing & Future Developments
1) Crop Types & Distributions
Active Crop Types

Corn*  Spring Wheat  Sugarcane

Soy*  Cotton  Rice

* Temperate and tropical varieties
Active Crop Types

Corn*, Soy*, Spring Wheat, Sugarcane

- *Temperate and tropical varieties

C$_4$ photosynthesis

N fixer

C$_4$ photosynthesis
Additional Crops: Placeholders

winter wheat
barley
winter barley
rye
winter rye
cassava
citrus
cocoa
coffee
date palm
fodder grass
grapes
groundnuts
millet
oil palm
potatoes
pulses
rapeseed
sorghum
sugarbeet
sunflower
miscanthus
switchgrass

The surface dataset includes distributions for these crops, but we do not have the required parameters to represent them.

Note that there are irrigated and rain-fed PFTs for each crop type. When crops are active, the surface dataset has 78 (instead of 16) PFTs.
<table>
<thead>
<tr>
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</table>
Yields can be calculated for 31 crop types.

Assumption that inactive crops have same growing triggers & allocation as the active crop.

Need to use surface dataset for remapping during analysis.

A full list of which parameters are used for each crop type is included in the CLM5 Tech Note.
Crop Distributions

1991-2010 Crop Area

Crop distributions are found on the surface dataset (‘fsurdat’ in the clm namelist)
2) Crop Phenology
1) Plant Phenology
Phase 1: Planting

Planting occurs **within the planting window** when a **10-day running mean 2-meter air temperature** reaches a crop-specific threshold (parameters listed in CLM5 Tech Note). Planting will occur at the end of the planting window if the T threshold is not met.
1) Plant

Phenology

2) Leaf Emergence
Phase 2: Leaf Emergence

Leaf emergence occurs when **soil temperature** reaches a crop-specific threshold (parameters listed in CLM5 Tech Note).

During leaf emergence, seed C is transferred to the leaf C pool and leaves continue to expand until they reach a crop-specific maximum leaf area index.
1) Plant

2) Leaf Emergence

Phenology

3) Grain Fill
Phase 3: Grain Fill

Grain fill starts when 2-meter air temperature reaches a crop-specific threshold (parameters listed in CLM5 Tech Note) or when the crop-specific LAI threshold is reached.
Phenology

1) Plant
2) Leaf Emergence
3) Grain Fill
4) Harvest
Harvest occurs when **2-meter air temperature** reaches a crop-specific threshold for maturity (parameters listed in CLM5 Tech Note) or at a maximum number of days past planting.

Harvest occurs in a single time-step using CLM’s leaf offset algorithm. Therefore, the default monthly average Grain C history field will estimate grain yields. To calculate grain yields, we recommend summing the “GRAINC_TO_FOOD” variable.
Phenology

1) Plant

2) Leaf Emergence

3) Grain Fill

4) Harvest
3) Allocation
Allocation

2) Leaf Emergence
3) Grain Fill

Allocation changes depending on which phenological phase the crop is in. Allocation parameters also vary by crop type.
Allocation changes depending on which phenological phase the crop is in. Allocation parameters also vary by crop type.
During Leaf Emergence (Phenological Phase 2)

Carbon and nitrogen are allocated to the following pools:

Allocation to these pools are based on crop-specific parameters.
Allocation changes depending on which phenological phase the crop is in. Allocation parameters also vary by crop type.
During Grain Fill (Phenological Phase 3)

C and N allocation changes:

- Decreases:
  - Leaf
  - Livestem
  - Fine Root

- Added/Increases:
  - Grain

Stays the same:

Allocation to these pools are based on crop-specific parameters.
At harvest

Stubble
(stem area index = 0.25)

Litter
(all leaf, stem, root)

Atmosphere
(all grain)
4) Management Options
Management

Fertilization

Irrigation
Crops exist on their own column so they don’t compete for water or nitrogen.

Separate irrigated and rain-fed columns. Every crop type has one of each.
Irrigation

Irrigation is only applied to irrigated crop columns

Irrigation is triggered by the soil moisture state in the root zone

The amount of irrigation depends on three parameters: root zone depth, target soil moisture, and difference between actual and target soil moisture.

Root zone depth (60 cm)

Stippling indicates soil moisture below threshold value

Wet

Dry

VWC

0.33

0.42

0.53

0.65

0.77

0.88

1.00

2006.0 2006.2 2006.4 2006.6 2006.8 2007.0
Fraction of Crop Area That Is Irrigated

1850

2001

2100

S. Swenson
Example: California's Central Valley

Tulare, CA

- Precipitation
- CLM ET
- FLUXNET-MTE
- Irrigation Flux

ET underpredicted without irrigation

S. Swenson
How is irrigation limited?

Irrigation demand is calculated independently of water availability, and irrigated water is removed from river water storage.

If river water is inadequate to meet irrigation demand:

1) additional water can be removed from the ocean

2) irrigation can be constrained to maintain river water storage above a threshold
New Irrigation Capabilities

Annual irrigation
Northern India

Introduce groundwater pumping

Assess relative withdrawals from surface water versus groundwater

Swenson/Lawrence
More realistic treatment of sources of irrigation water

Annual irrigation

Northern India

New Irrigation Capabilities

Swenson/Lawrence
Fertilization begins during leaf emergence and runs for 20 days

*Note that the slow application minimizes N loss and limits N application to emergence phase*

Fertilizer is applied as two sources:

**Manure (manunitro)**
- Applied at a rate of 0.002 kg N m\(^{-2}\) yr\(^{-1}\)

**Industrial (FERTNITRO_CFT)**
- Based on LUMIP land use and land cover change time series (LUH2 and SSPs)
- Prescribed by crop functional type
- Varies spatially and temporally and specified on the land use time series

*Note that for non-transient simulations, industrial fertilizer is constant and specified on the land surface dataset (CONST_FERTNITRO_CFT)*
5) Crop Yields
Crop-type analysis: requires regridding from 1D to 3D, weighting by irrigated and rain-fed crop fractions, and weighting by % crop area and % crop type

Lombardozzi et al. in review
C$_3$ Crops
1991-2010

Soy

Rice

Wheat

Cotton

FAO-EarthStat

CLM5

Lombardozi et al. in review
C₄ Crops
1991-2010

Corn

FAO - EarthStat

CLM5

Sugarcane

Annual Grain Yield (tonnes ha⁻¹)

Lombardozzi et al. in review
C₄ Crops
1991-2010

FAO - EarthStat

CLM5

Underestimate Temperate Yields

Overestimate Tropical Yields

C₄ Crops
1991-2010

Lombardozzi et al. in review
Irrigation Effect

Fertilizer Effect

Crop Expansion Effect

Transient Forcing (without irrigation interaction)

**Effect Size in 2010 (million tonnes)**

- Irrigation: 522
- Fertilization: 807
- Irrigation + Fertilization Interaction: 170
- Cropland Expansion: 712
- Transient Forcing: 144

*Lombardozzi et al. in review*
6) Ongoing & Future Developments
Ongoing or planned development activities

- Multiple irrigation application methods
- Soil tillage
- Cover crops
- Manure application, NH$_3$, & N$_2$O emissions
- APSIM crop model with additional phenological stages, including heat stress
- Spatially explicit planting windows
- Shifting cultivation
- Additional crop types (switchgrass, oil palm, winter wheat)
- Managed pasture
- Managed trees/timber
New: CTSM Agriculture Working Group
To facilitate development and application of CTSM-Crop

Interested in joining? Contact me (dll@ucar.edu)
Jiangsu, China

Latent Heat Flux (W m$^{-2}$)

Month