REPRESENTING WINTER WHEAT IN THE COMMUNITY LAND MODEL (VERSION 4.5)

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OVERVIEW

PROCESS BASED CROP MODELS

Agronomic crop model
ARCWHEAT (Porter, 1984; Weir et al., 1984)

CERES-Wheat (Ritchie and Otter, 1985)

1980s Thermal time and photoperiod control on crop growth stages, but simplified treatment of important upstream processes (e.g., photosynthesis is a linear function of iPAR)

1990s-2000s Agro-ecosystem model
CERES  DSSAT (Jones et al., 2003)
Modified CERES  APSIM (Keating et al., 2003)

Improved land managements and soil CNP dynamics, simplified others, not for studying land-atmosphere interactions

2000s Dynamic crop growth greatly impact on the land-atmosphere interactions
CENTURY  RAMS (Lu et al., 2001)
seasonal vegetation phenology strongly influences climate patterns over the central US
AgroBATS  RegCM (Tsvetinskaya et al. 2001)
up to a 45% change in surface energy fluxes in response to dynamic leaf area index
GLAM  HadAM3 (Osborne et al. 2007, 2009)
growing season temperature variability was increased by up to 40% with the inclusion of dynamic crops

2010-2012 Crop model in CLM

• Soybean N fixation (Drewniak et al., 2013 GMD)
• Ozone damage (Lonbardozzi et al., 2015 JCLI)
• Winter wheat (Lu et al., 2017 GMD)
• Up to 78 crops (8 active)
• Grain product pool
• Transient gridded nitrogen fertilization
• Updated irrigation

2013-2017 CLM4.5 (BGC)
• AgroBIS (Kucharik et al., 2003)  CLM4 (Levis et al., 2012)
• Temperate corn, cereals, soybean

2018 CLM5 (BGC)
• Up to 70 crops (oats)
• Grain product pool
• Transient global nitrogen fertilization
• Updated irrigation

OVERVIEW CROP MODEL IN CLM - PHENOLOGY

Phase 1: Planting (Planting window, temperature thres)
Phase 2: Leaf emergence
Phase 3: Grain fill
Phase 4: Harvest

Growing degree days threshold

\[ GDD = \sum \left( T_{2mA} < T_{2m} < T_{MAX} \right) \]

planting windows

<table>
<thead>
<tr>
<th>Sugarcane</th>
<th>Spring wheat</th>
<th>Corn</th>
<th>Soybean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>Cotton</td>
<td>Tea</td>
<td>Wheat</td>
</tr>
<tr>
<td>Mar</td>
<td>Apr</td>
<td>May</td>
<td>Jun</td>
</tr>
<tr>
<td>Apr</td>
<td>May</td>
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<td>Nov</td>
</tr>
<tr>
<td>Sep</td>
<td>Oct</td>
<td>Nov</td>
<td>Dec</td>
</tr>
</tbody>
</table>

Planting windows

NH
SH
Grain carbon increasing
Leaf, stem, root carbon increasing
GDD
Base temperature is 0
Leaf carbon decreasing
days>Sep
GDD
alfalfa
US
over US
daily
ALLOCATION
OVERVIEW
CROP MODEL IN CLM – CARBON
ALLOCATION
Leaf carbon => yield
CN allocation
ARM: a crop site of AmeriFlux, corn, soybean, winter wheat, alfalfa
Calibration data: US–ARM 6-year daily LAI and winter wheat yield

Motivation 1: Winter wheat is the dominant wheat in many regions (US, Europe, China)
Additional processes for winter wheat:
- Vernalization process
  - winter crops must expose to low, nonfreezing temperatures (optimum temperature=4.9°C) to enter the reproductive stage
  - A generalized vernalization function for winter wheat (Streck et al., 2003), effective vernalization days and vernalization factor
- Cold tolerance and damage
  - Survival rate and winter killing degree days

Phenology phases
Phase 1: Planting:
- \( T_{\text{planting}} < T_{\text{d}} \) (10°C)
- days>Sept
Phase 2: Leaf emergence:
- \( \text{GDD}_{\text{pre}} > 3\% \text{GDD}_{\text{ref}} = 51 \)
- base temperature is 0°C
- Leaf, stem, root carbon increasing
Phase 3: Grain fill:
- \( \text{GDD}_{\text{pre}} > 40\% \text{GDD}_{\text{ref}} = 680 \)
- Leaf carbon decreasing
- Grain carbon increasing
Phase 4: Harvest:
- \( \text{GDD}_{\text{pre}} > \text{GDD}_{\text{ref}} = 1700 \)

Winter wheat yield
Spring wheat yield

key parameters for phenology and CN allocation

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Description</th>
<th>Degree Model</th>
</tr>
</thead>
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<tr>
<td>( \text{GDD}_{\text{pre}} )</td>
<td>Minimum growing degree days for planting</td>
<td>( 50 )</td>
</tr>
<tr>
<td>( \text{GDD}_{\text{ref}} )</td>
<td>Minimum growing degree days for vernalization</td>
<td>( 50 )</td>
</tr>
<tr>
<td>( \text{GDD}_{\text{pre}} )</td>
<td>Percentage of plant biomass to anthesis</td>
<td>( 3% )</td>
</tr>
<tr>
<td>( \text{GDD}_{\text{ref}} )</td>
<td>Percentage of plant biomass to anthesis</td>
<td>( 3% )</td>
</tr>
<tr>
<td>( \text{GDD}_{\text{pre}} )</td>
<td>Percentage of leaf carbon allocation to anthesis</td>
<td>( 40% )</td>
</tr>
<tr>
<td>( \text{GDD}_{\text{ref}} )</td>
<td>Percentage of leaf carbon allocation to anthesis</td>
<td>( 40% )</td>
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<tr>
<td>( \text{S}_{\text{ref}} )</td>
<td>Initial value of root carbon allocation</td>
<td>( 0.1 )</td>
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<tr>
<td>( \text{S}_{\text{ref}} )</td>
<td>Final value of root carbon allocation</td>
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<tr>
<td>( \text{S}_{\text{ref}} )</td>
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<td>( 0.05 )</td>
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<tr>
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</tr>
<tr>
<td>( \text{S}_{\text{ref}} )</td>
<td>Initial value of stem carbon allocation</td>
<td>( 0.05 )</td>
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<tr>
<td>( \text{S}_{\text{ref}} )</td>
<td>Final value of stem carbon allocation</td>
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</tr>
<tr>
<td>( \text{S}_{\text{ref}} )</td>
<td>Initial value of shoot biomass</td>
<td>( 680 )</td>
</tr>
<tr>
<td>( \text{S}_{\text{ref}} )</td>
<td>Final value of shoot biomass</td>
<td>( 680 )</td>
</tr>
<tr>
<td>( \text{S}_{\text{ref}} )</td>
<td>Leaf area index decline factor</td>
<td>( 1.05 )</td>
</tr>
<tr>
<td>( \text{S}_{\text{ref}} )</td>
<td>Leaf carbon allocation decline factor</td>
<td>( 3 )</td>
</tr>
<tr>
<td>( \text{S}_{\text{ref}} )</td>
<td>Stem carbon allocation decline factor</td>
<td>( 1 )</td>
</tr>
</tbody>
</table>
COLD TOLERANCE AND DAMAGE

- The Lethal temperature at 50% of the individuals are da
  \( \text{LTH}_{50} = \text{LT}_{50} - \text{RAT}_{E} + \text{RAT}_{E} + \text{RAT}_{E} + \text{RAT}_{E} \) (Bergjord et al., 2006)

  - Hardening
  - Dehardening

- Survival probability (Vico et al., 2014)
  \( \text{Survival rate} = \frac{1}{T(t)} \) representing the likelihood that an individual is damaged by exposure to certain temperature

- Winter killing degree days (Vico et al., 2014)
  \( \text{WDD} = \max(T_{\text{LTH}_{50}} - T(t) \cdot 0, T_{\text{LTH}_{50}} - T(t)) \)

Two stages of cold damage:

- Stage 1: instant damage
  \( \text{VF}, \text{WDD} > 0 \)
  \( \text{Leaf}_{\text{damage}} - 5.0 \times (1 - \text{fsurv}) \)

- Stage 2: accumulated damage
  \( \text{VF}, \text{WDD} > 0 \)
  \( \text{Leaf}_{\text{damage}} - \text{Leaf}_{\text{damage}} \times (1 - \text{acrsurv}) \)
  Reset WDD=0, and restart accumulate for the next damage

Validation data:
- energy fluxes at 4 flux tower winter wheat sites
- LAI, leaf, stem, grain weight at 4 agronomic winter wheat sites
- US county level winter wheat yield

Site simulations and US domain simulation using compset
CLM5.1BCC/REP
Each site simulation runs spin up (~hundreds of years) to reach the steady state
Results: CLMWHE (CLM with the updated winter wheat) versus CLMBASE
(CLM with the default winter wheat)

RESULTS

- CLMWHE showed better LAI variation, peak in April
- Leafc and LAI patterns are same in CLM, not true in obs due to SLA changes
- CLMWHE could simulate the higher grain weight in wetter year 1986
- CLMWHE showed more grain weight in NESA and NDMA than TXLU

Improved seasonal variation
Underestimated peak LAI → less carbon gain
After harvest: bare ground in CLM, weeds in obs

Spring LE RMSE was reduced by 10–70%
LE reaches peak one month later than the LAI peak
- Trade off between soil evaporation and leaf transpiration
- The overestimation of LE in summer and fall can be reduced using the dry surface layer-based soil resistance parameterization (Swenson and Lawrence 2014, available in CLM).

Vegetation strongly controls evaporative fraction LE/(H+LE) (Williams et al., 2015). LAI only explained 5% of EF in CLMWHE.

What matters for crop yield?

Improve the representation of soil hydrology, especially the interannual variability of soil moisture may improve the simulations of yield variation.

SUMMARY

- Our new winter wheat model in CLM better captured the monthly variation of leaf area index and improved the latent heat flux and net ecosystem exchange simulation in spring, but the overall improvement on energy fluxes is limited by CLM weak vegetation controls on energy fluxes.
- Crop growth calibration at the US–ARM site introduced a low–yield bias that produced underestimates of the yield in high–yield site (US–CRT) and region (Southeastern US). Using gridded parameters may solve the problem.
- Further crop model development: crop response to extreme events (drought, strong wind), improve land managements (prognostic nitrogen fertilization based on NDVI), global gridded crop parameters, calculate rooting depth and distribution based on root biomass.

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