Effects of elevated CO$_2$ and nitrogen limitation on stomatal conductance in CLM-CN  
(Preliminary experiments)

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Carbon-Nitrogen-Water coupling through leaf’s stomata

Internal leaf CO₂ \( (c_i) \) → GPP (Photosynthetic rate) → Stomatal conductance \( (g_s) \) → CO₂

Leaf surface CO₂ \( (c_s) \) → Relative humidity \( (h_s) \)

N-limitation

Temperature

GPP

Amplifying Effect

Dampening Effect

Runoff

Transpiration

Ball-Berry Model

\[ g_s = k \frac{A h_s}{c_s} \]

(Ball et al., 1987)

\( g_s \): Stomatal conductance

\( k \): Slope constant of the model

\( A \): CO₂ assimilation rate

\( h_s \): Relative humidity

\( c_s \): CO₂ concentration at the leaf surface

GPP: Gross Primary Productivity

Felzer et al., in review
In current CLM-CN

- **Stomatal resistance** from Ball-Berry model:
  Stomata subroutine within CanopyFluxesMod in biogeophys

- **Nitrogen limitation** from carbon and nitrogen allocation:
  CNAllocationMod in biogeochem

*The stomatal resistance is not linked to the down-regulated GPP by nitrogen limitation.*

- In CNAllocationMod, total gross photosynthesis (GPP) is coming from CanopyFluxesMod, then it’s scaled by nitrogen limitation.

✓ The photosynthesis used to control stomatal conductance in CLM-CN is not affected by the GPP downregulated by nitrogen limitation.
Modifications of CLM-CN model (in progress)

We are incorporating “CNAllocationMod” into “Stomata subroutine” within CanopyFluxesMod.

1. Calculate photosynthesis
2. GPP before downregulation
3. Nitrogen demand, availability, and limitation
4. Downregulate GPP due to nitrogen limitation
5. Update photosynthesis using the downregulated GPP
6. Stomatal resistance
7. Transpiration and runoff
Experimental design: Initial conditions

• CESM CAM-CLM CN: “Compset E” includes CLM-CN with the prognostic atmosphere and sea ice, but slab ocean model under future Representative Concentration Pathway scenarios.

• Initial model experiments
  1. E1850CN (30-yr equilibrium run)
     : Pre-industrial fully active ice and som ocean, with CN
  2. E20TRCN: 1850-2005 transient run starting with a reference from 1
  3. E2005CN: 30-yr equilibrium run starting from 2

➢ Control run
  E21RCPCN: 2005-2100 transient run starting from 3 with RCPs

RCP scenarios- New scenarios for the next IPCC and beyond (Moss et al. 2010)
  : RCP 8.5- close to the radiative forcing from SRES A1F1 (higher than SRES A2)
  RCP 4.5- very close to SRES B1
  (personal communication with Jerry Meehl)
## Experimental design

<table>
<thead>
<tr>
<th>Control run (E21RCPCN)</th>
<th>Elevated CO₂ → Stomata</th>
<th>Nitrogen limitation on GPP in Stomata</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>No*</td>
<td>No</td>
</tr>
</tbody>
</table>

* No “elevated CO₂ → Stomata” means that CO₂-level in stomata is held constant at 2005 value for the 21st century.

- All model runs will be performed using both RCP 8.5 and 4.5 scenarios.
Preliminary results: Elevated CO$_2$ effects during 21st century (RCP8.5)

- Atmospheric CO$_2$ partial pressure (Pa)
- Canopy transpiration (mm s$^{-1}$)
- Runoff (mm s$^{-1}$)
- Photosynthesis (umol CO$_2$ m$^{-2}$s$^{-1}$)
- Stomatal conductance
- CO$_2$ fertilization

**Atmospheric CO$_2$ partial pressure (Pa)**
- 9.00E-07
- 8.00E-07
- 7.00E-07
- 6.00E-07
- 5.00E-07
- 2000 2010 2020 2030 2040 2050 2060 2070 2080 2090 2100

**Canopy transpiration (mm s$^{-1}$)**
- 70.5
- 71
- 71.5
- 72
- 72.5
- 73
- 73.5
- 2000 2010 2020 2030 2040 2050 2060 2070 2080 2090 2100

**Runoff (mm s$^{-1}$)**
- 5.50E-06
- 6.00E-06
- 6.50E-06
- 7.00E-06
- 7.50E-06
- 2000 2010 2020 2030 2040 2050 2060 2070 2080 2090 2100

**Photosynthesis (umol CO$_2$ m$^{-2}$s$^{-1}$)**
- CO$_2$ fertilization

**Stomatal conductance**
- Amplifying effect
- Dampening effect

**Direct dampening**
- 0.118
- 0.119
- 0.12
- 0.121
- 0.122
- 0.123
- 0.124
- 0.125
- 0.126
- 2000 2010 2020 2030 2040 2050 2060 2070 2080 2090 2100
**Preliminary results**: Elevated CO₂ effects during 21th century (RCP8.5)

Differences between late (2071-2100 mean) and early (2010-2039 mean) 21th century (%)
Expected results

Effects of elevated CO$_2$ and N-limitation on stomatal conductance and the resulting evapotranspiration and runoff

- Biogeochemical and biogeophysical feedbacks
Questions and comments

Thank you!
Why are carbon-nitrogen interactions in stomata important?

Vitousek and Howarth (1991); Thornton et al. (2007 and 2009); Sokolov et al. (2008); Felzer et al. (2009 and in review)

- Nitrogen limitation reduces GPP increase due to elevated CO$_2$, so CO$_2$ fertilization not as strong.

- Nitrogen dynamics is more sensitive to warming, as warming leads to increased net nitrogen mineralization and therefore increases GPP.
Preliminary results: Difference between constant CO2 and control runs

Model evaluation

To examine if the model outputs from the modified CLM-CN version can improve the reproduction of the observed conditions e.g. runoff from Global Soil Wetness Project 2 (GSWP-2)