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OzoneLUNA: Ozone damage in CLM revisited

2021 February 25 | CESM land surface working group meeting 2021 | zoom

Ozone vulnerability of vegetation

Ozone formation, transport & removal

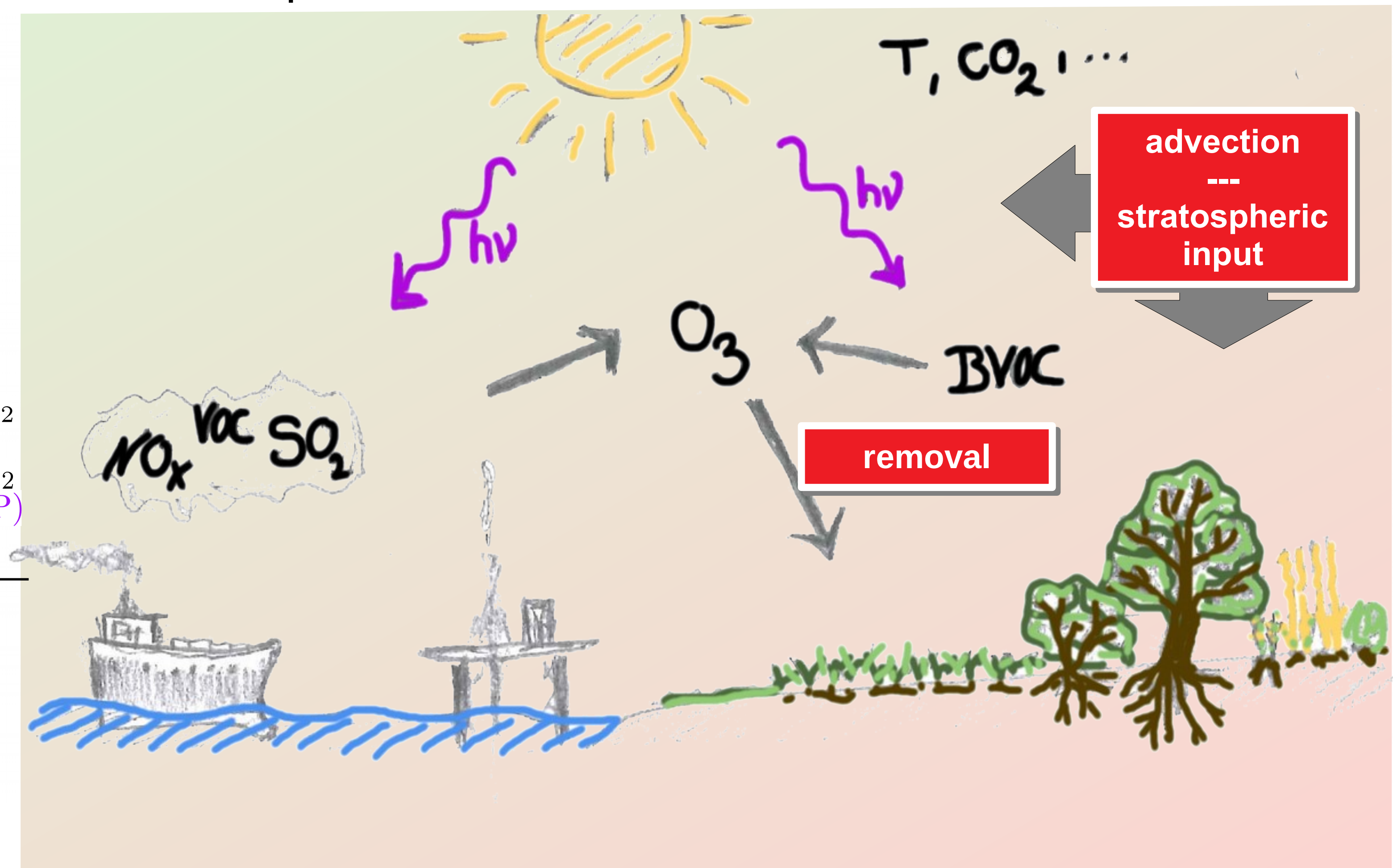
in situ formation

$$^{\bullet}\mathrm{OH} + \mathrm{CO} \rightarrow {}^{\bullet}\mathrm{HOCO}$$
$$^{\bullet}\mathrm{HOCO} + \mathrm{O_2} \rightarrow \mathrm{HO_2} + \mathrm{CO_2}$$
$$^{\bullet}\mathrm{HO_2} + \mathrm{NO} \rightarrow {}^{\bullet}\mathrm{OH} + \mathrm{NO_2}$$
$$\mathrm{NO_2} + h\nu \rightarrow \mathrm{NO} + \mathrm{O(^3P)}$$
$$^{\bullet}\mathrm{O(^3P)} + \mathrm{O_2} \rightarrow \mathrm{O_3}$$

$$\mathrm{CO} + 2\mathrm{O_2} + h\nu \rightarrow \mathrm{CO_2} + \mathrm{O_3}$$

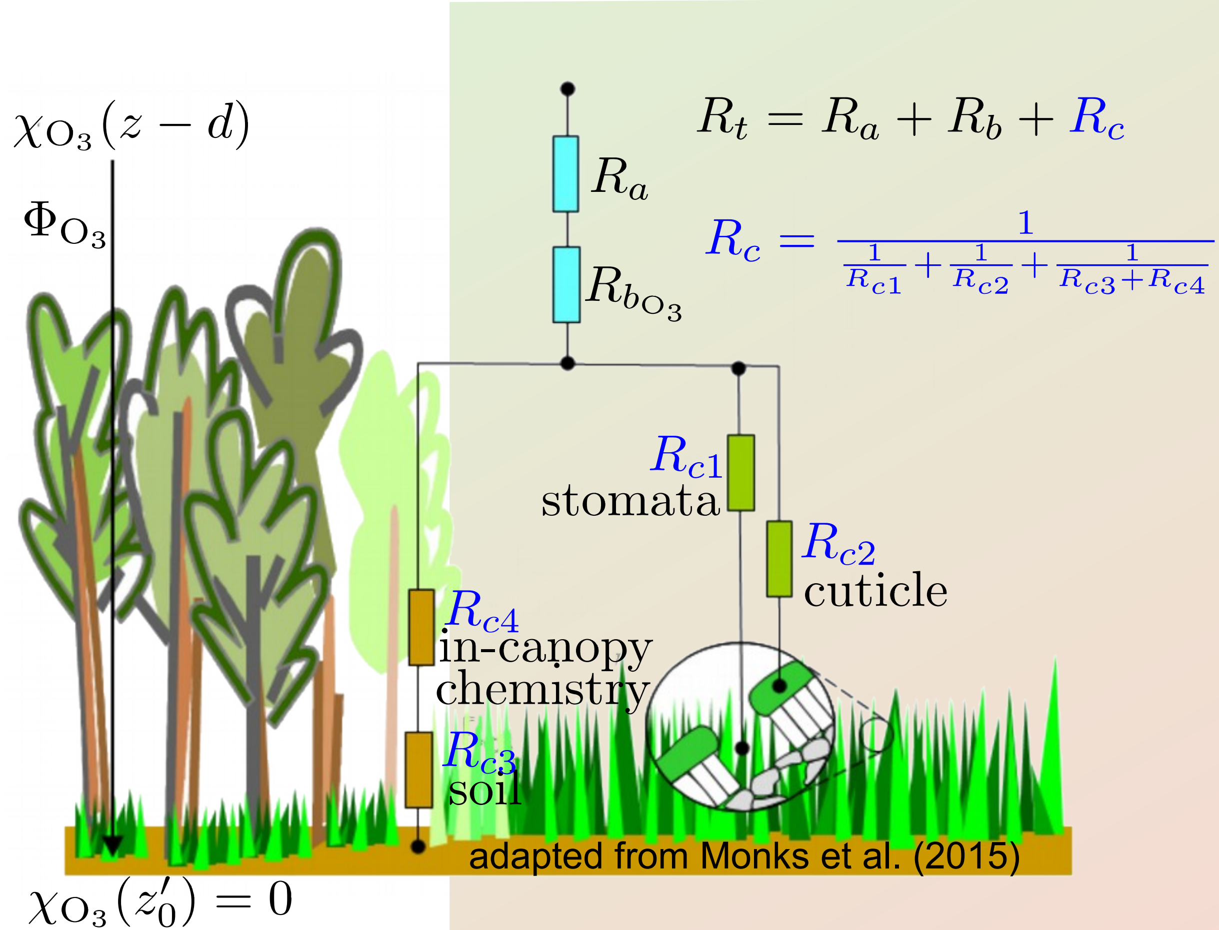
ozone titration

$$\mathrm{NO} + \mathrm{O_3} \rightarrow \mathrm{NO_2} + \mathrm{O_2}$$
$$\mathrm{NO_2} + \mathrm{O_3} \rightarrow \mathrm{NO_3} + \mathrm{O_2}$$



Ozone vulnerability of vegetation

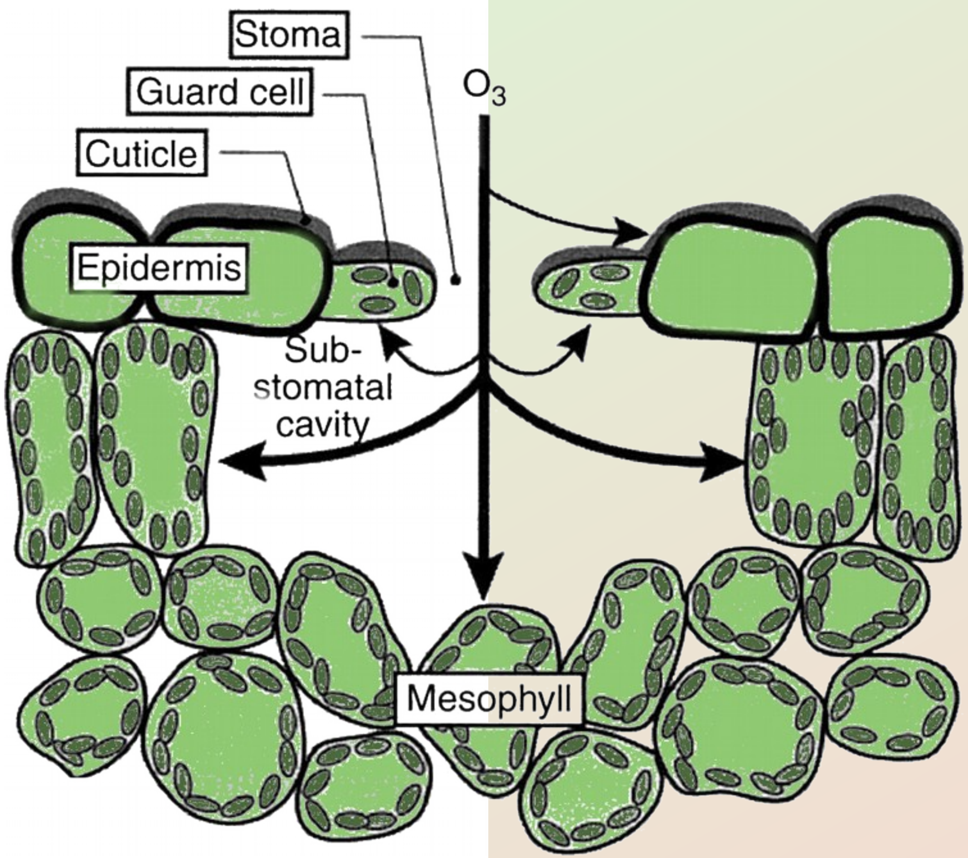
Ozone dry deposition



- **Resistance analogous approach**
  - Aerodynamic resistance (R_a)
  - Quasi-laminar resistance (R_b)
  - Canopy resistance (R_c)
- **Ozone removal**
  - $\Phi_{O_3} = \nabla \chi_{O_3}$
- **Uptake by stomata**
  - $\Phi_{O_3}^{sto} \propto g_{sto} \propto \frac{1}{R_{c1}}$
- **Medlyn et al. (2011) model**
  - $g_{sto} = g_0 + 1.6 \left(1 + \frac{g_1}{\sqrt{VPD}}\right) \frac{A_n \cdot P_{atm}}{\chi_{CO_2}}$

Ozone vulnerability of vegetation

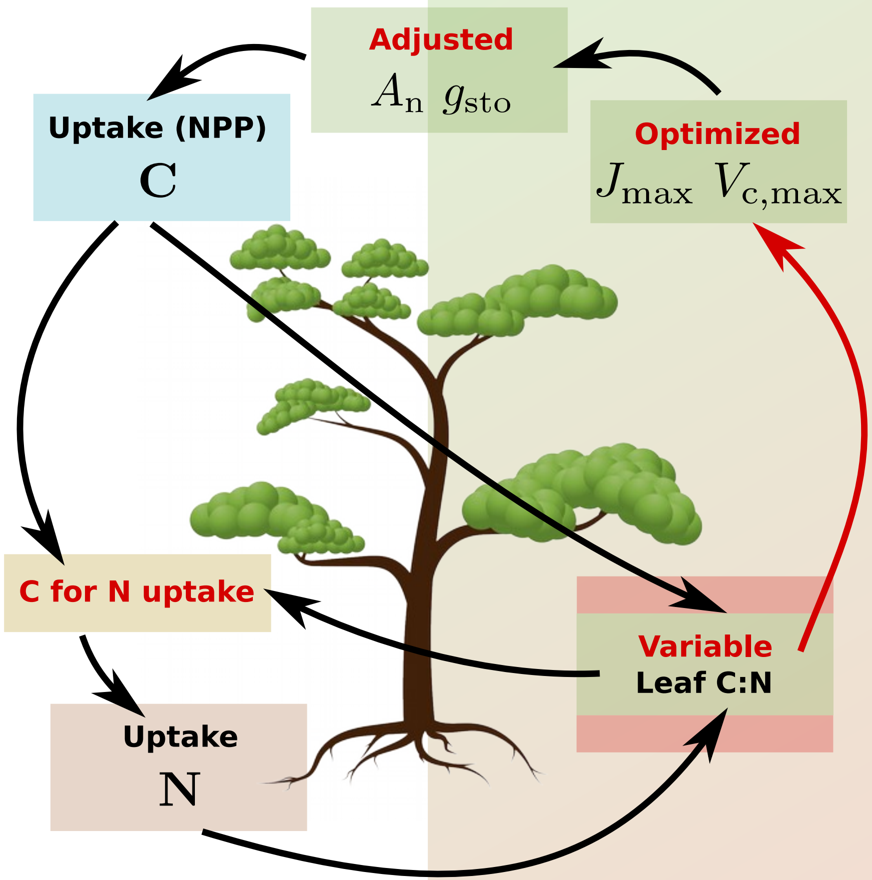
Stomata & ozone damage



- **Favorable conditions for gas-exchange through stomata**
  - Light (photosynthetic photonflux density – *PPFD*)
  - Temperature (*T*)
  - Vapor pressure deficit (*VPD*)
  - Soil water potential (*SWP*)
- **Ozone in intercelluar medium**
  - Short lifetime → reactive oxygen species (ROS)
  - Plant defense mechanism (antioxidants)
  - Too few antioxidants → ROS reacts with cell membrane
- **Ozone damage on cell membrane**
  - Reduction of photosynthesis (A_n)
  - Decoupling of A_n and stomatal conductance (g_{sto})
  - Programmed cell death
  - Increased sensitivity to other stress factors

Ozone vulnerability of vegetation

LUNA model scheme



- **Plant nitrogen at leaf level**

$$\mathrm{LNC}_\alpha = N_{psn} + N_{str} + N_{store} + N_{resp}$$

photosyn. structural storage respiration

- **Nitrogen for light capture**

$$N_{psn} = N_{et} + N_{cb} + N_{lc}\ ?$$

e-transp. carboxyl. γ-capture

$$\mathrm{N_{et}} = \frac{J_{max}}{\mathrm{NUE_{J_{max}}}}$$

$$\mathrm{N_{cb}} = \frac{V_{cmax25}}{\mathrm{NUE_{V_{cmax25}}}}$$

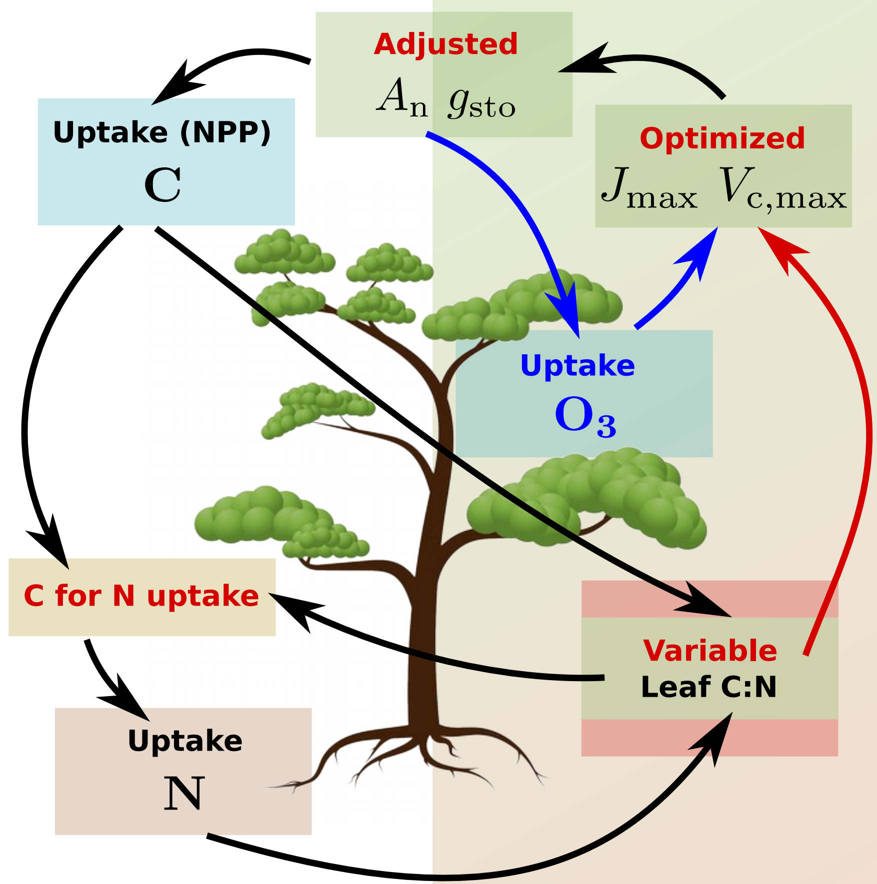
$$\mathrm{N_{res}} = \frac{R_d}{\mathrm{NUE_r}} \propto V_{cmax}$$

- **Photosynthesis rate (A)**

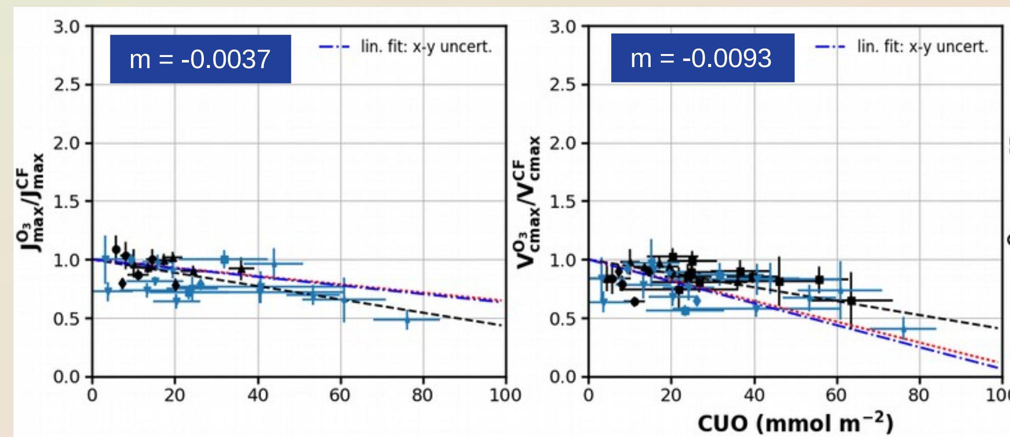
$$\mathrm{A}(\chi_{CO_2}, J_{max}, V_{cmax})$$

Ozone vulnerability of vegetation

OzoneLUNA model scheme



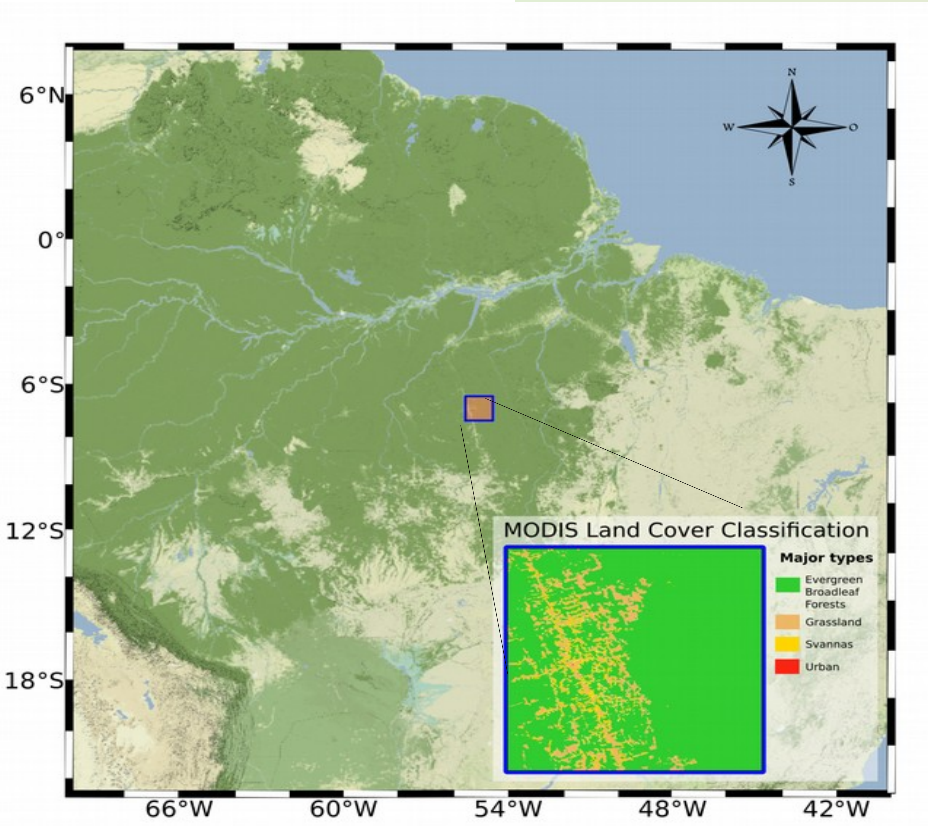
- **Ozone damage reduces J_{max} and V_{cmax}**
- **Metadata (deciduous trees 2011-2019)**



- **Damage function**
  - $\Gamma(\mathrm{CUO}) = |J_{\mathrm{max}}| = m \cdot \mathrm{CUO} + b$
  - $\mathrm{V}_{\mathrm{cmax}} \propto J_{\mathrm{max}}$
- **Extend existing OzoneMod in CLM**
  - PR#1276, PR#1232, ISSUE#1224

CLM single cell test: Brazil

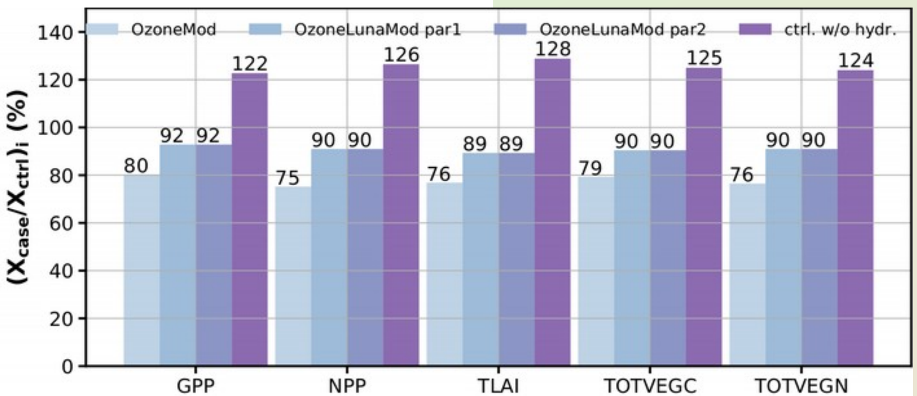
Equilibrium state



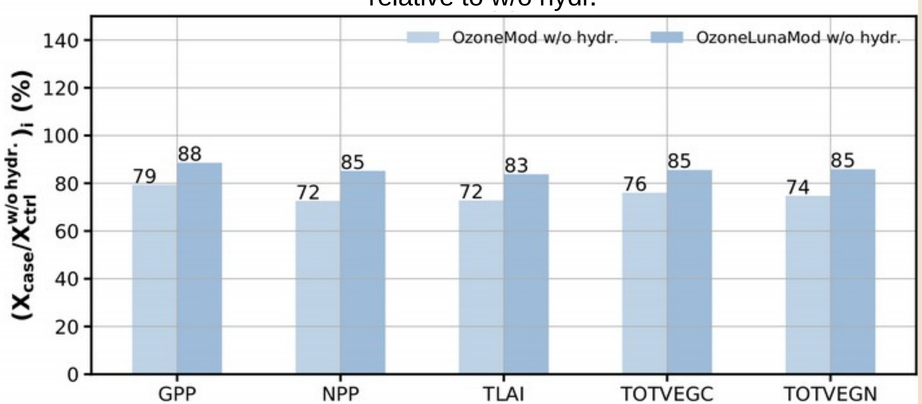
- **Simulations: CLM release 5.0.26-20 extended**
  - Control run (ctrl.) with hydraulic stress on
  - Control run without hydraulic stress (w/o hydr.)
  - OzoneMod (Lombardozzi, 2012, [O_3] = 100 ppb)
  - OzoneLunaMod (this work, [O_3] = 100 ppb)
- **Spin-up from cold start → C equilibrium state**
  - 1991-2010 GSWP3 atmospheric forcing
    - 100 years with accelerated decomposition
    - 100 years with normal decomposition
  - *2000-2010 GSWP3 atmospheric forcing*
    - *10 years production run*
- **Ozone effect on GPP, NPP, TLAI, TOTVEGC&-N**
  - → Reduction
    - → OzoneMod up to 24 (28)%
    - → OzoneLunaMod up to 11 (17)%
  - → OzoneLunaMod more sensitive to hydraulic stress on/off

CLM single cell test: Brazil

Equilibrium state



relative to w/o hydr.



$[CO_2]$ = 369 ppm

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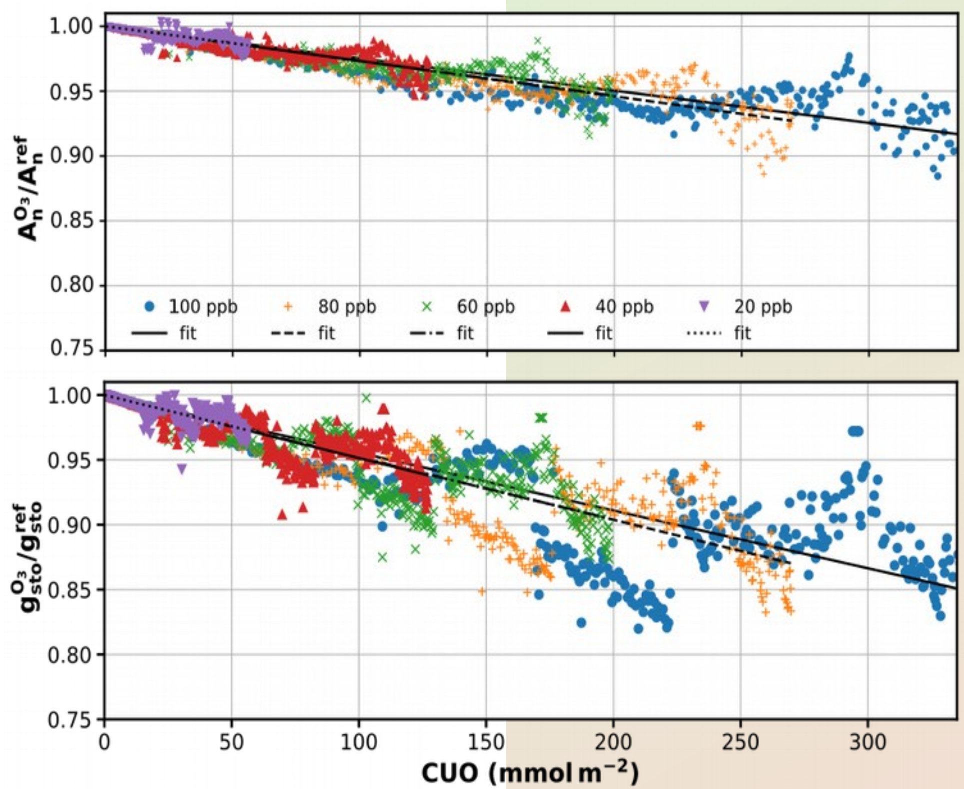
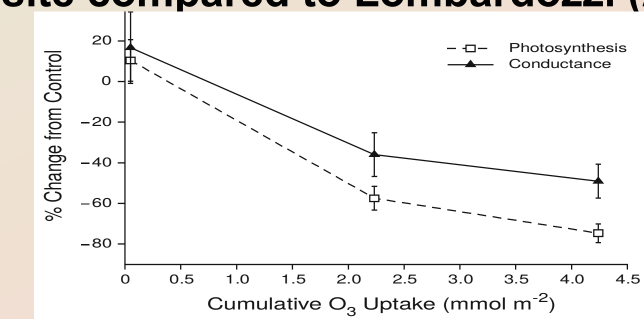
CLM single cell test: Brazil

Photosynthesis & stomatal conductance response



- **Sensitivity study (production runs)**
  - Spin-up: $[O_3]$ = 0 ppb
  - $[O_3]$ = Є {0, 20, 40, 60, 80, 100} ppb
- **Effective decoupling of A_n and g_{sto}!**
  - $dA_n/dCUO$ = -0.00025 m^2 mmol^{-1}
  - $dg_{sto}/dCUO$ = -0.0005 m^2 mmol^{-1}
- **Opposite compared to Lombardozzi (2012)?!**

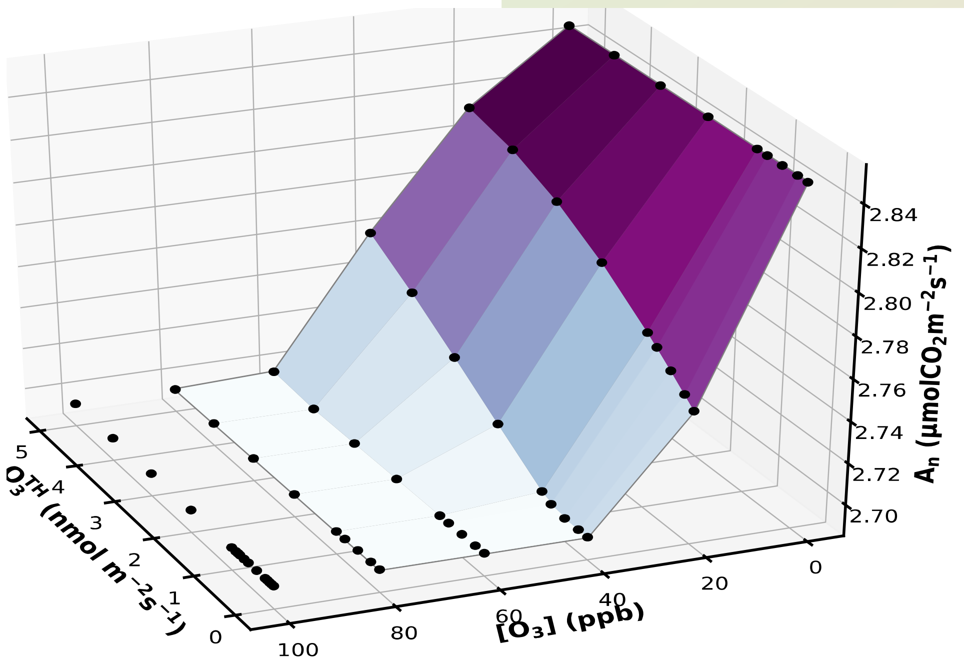


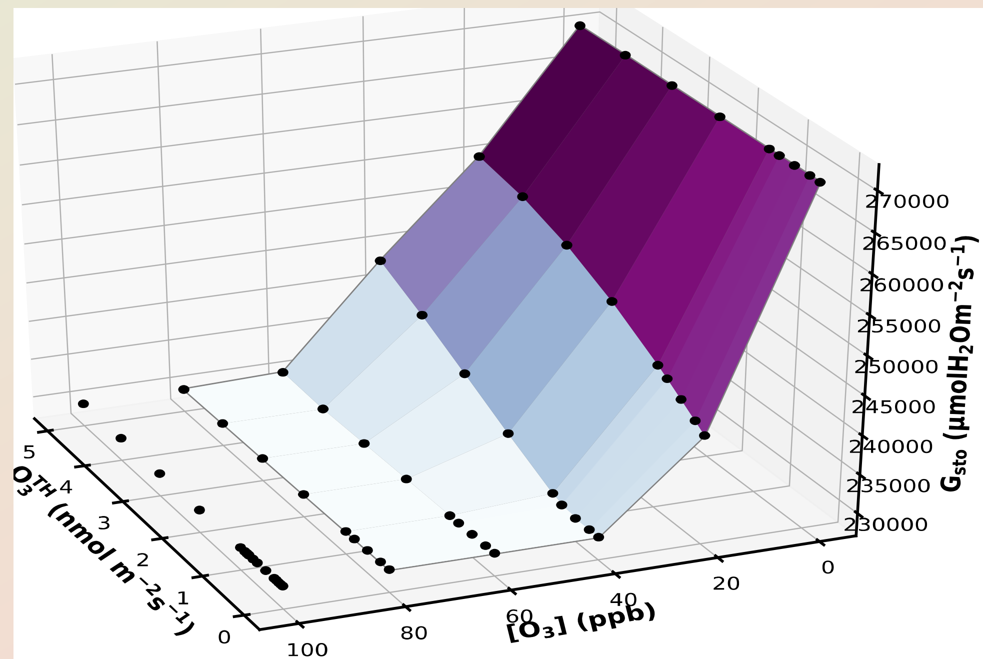
- **Too little response? Expected from metadata**
  - $dg_{sto}/dCUO$ = -(0.0022-0.0094) m^2 mmol^{-1}
  - $\Delta AndCUO$ = -(0.0053-0.0089) m^2 mmol^{-1}
- **Bug?**

CLM single cell test: Brazil

Sensitivity test: flux threshold & ozone forcing

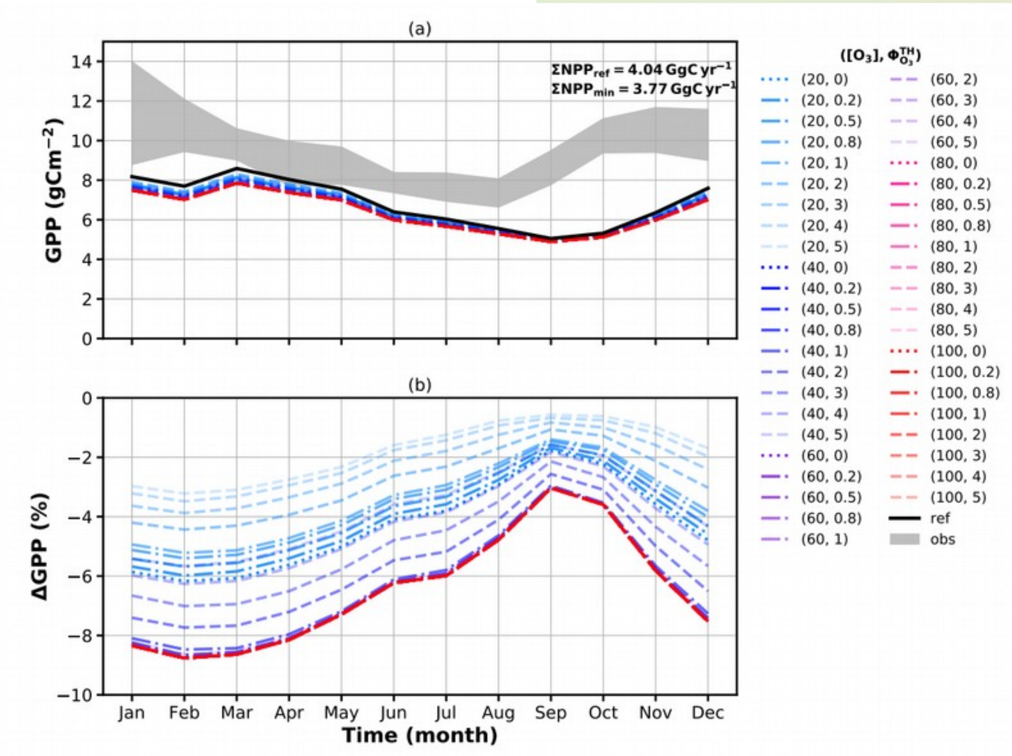
- **Decoupling of A_n and g_{sto} depended on flux threshold**
- **Ozone threshold at low forcing → less reduction in A_n than g_{sto}**





CLM single cell test: Brazil

Seasonal cycle in GPP

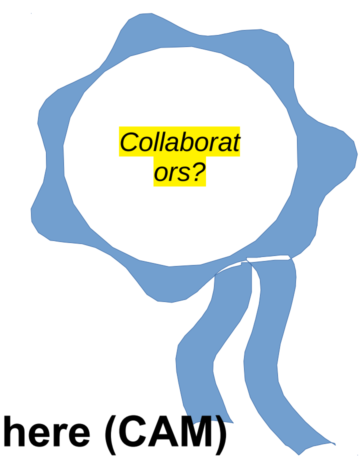


- **Slightly different from observations published by Restrepo-Coupe (2013)**
  - Differing years
  - Differing location
    → Local variability (e.g. rainy season)
- **Saturation at high ozone forcing (80-100) ppb**
- **Sensitivity to ozone damage**
  - Highest in austral summer (Feb/Mar)
  - Lowest in austral winter (Sep/Oct)
- **Low susceptibility to biomass burning in winter?**

→ Over prediction of ozone penalty in carbon uptake in Amazon region (Sitch, 2007; Pacifico, 2015)

Outlook

- **Model development paper**
- **Integration in recent CLM development**
  - PR#1276, PR#1232, ISSUE#1224
  - Influence of LUNA bug fixes?
  - Bugs?
- **Expend to other PFTs**
  - Evergreen needleleaf
  - Grassland/crops
  - Shrubs
- **Integration tests**
  - Other locations
  - Local domains
  - Global runs
- **Full coupling to atmosphere (CAM)**
  - Feedbacks!



Thank you!