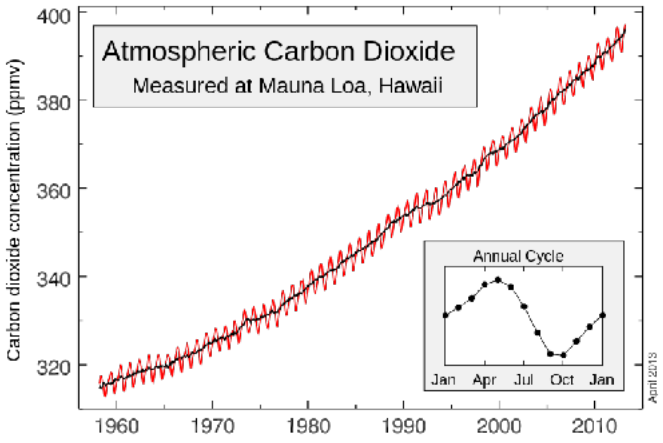
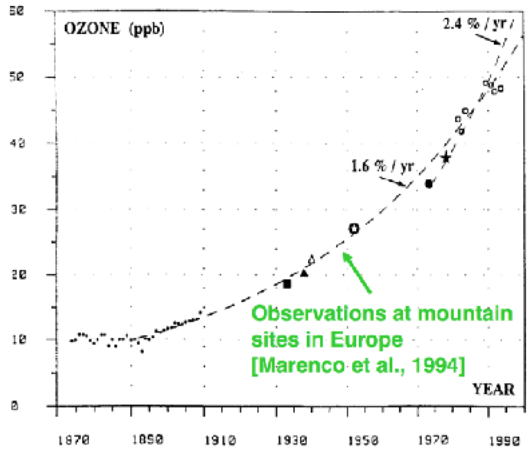
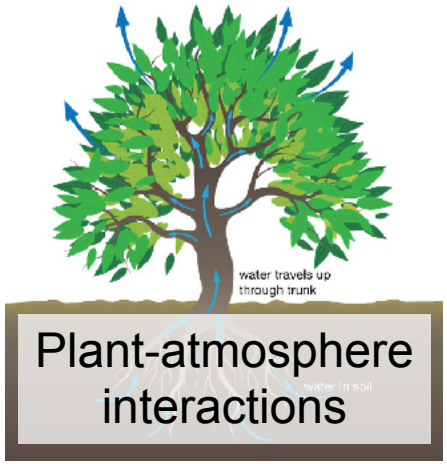
Effects of Ozone-CO_2-Induced Vegetation Changes on Boundary-Layer Meteorology and Air Pollution







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THE CHINESE UNIVERSITY OF HONG KONG

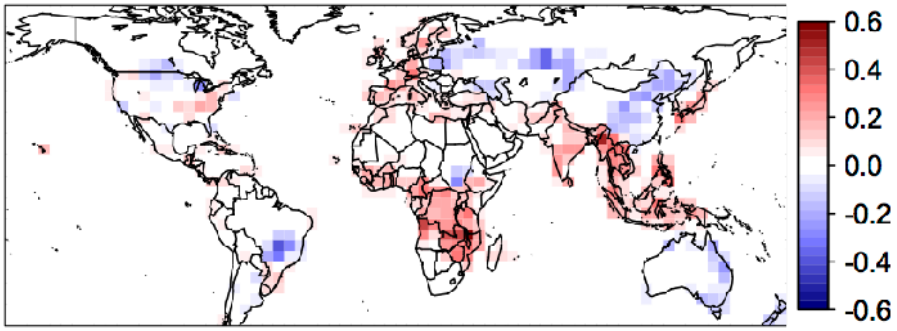
Amos P. K. Tai
Assistant Professor
Earth System Science Programme
Faculty of Science, CUHK

EARTH SYSTEM SCIENCE PROGRAMME

Urban Meteorology and Climate Conference
25 May 2017

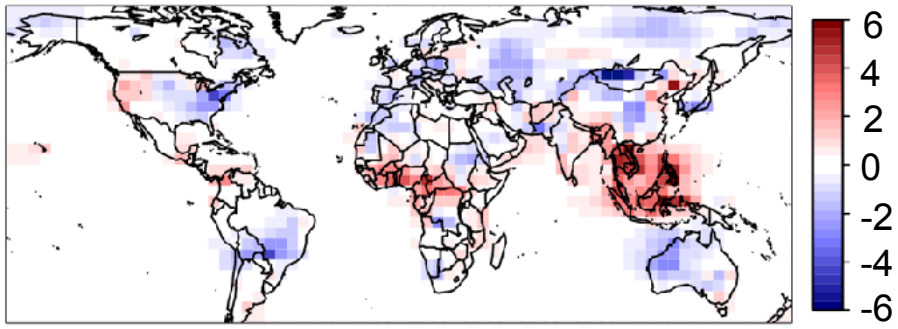
Land Use/Land Cover Change Affects Air Quality and Climate

2000-2050 change in **cropland fraction** following IPCC A1B



Asynchronously coupled climate-biosphere-chemistry models

2000-2050 changes in summertime **surface ozone** (ppbv)



[Tai et al., GRL, 2013]

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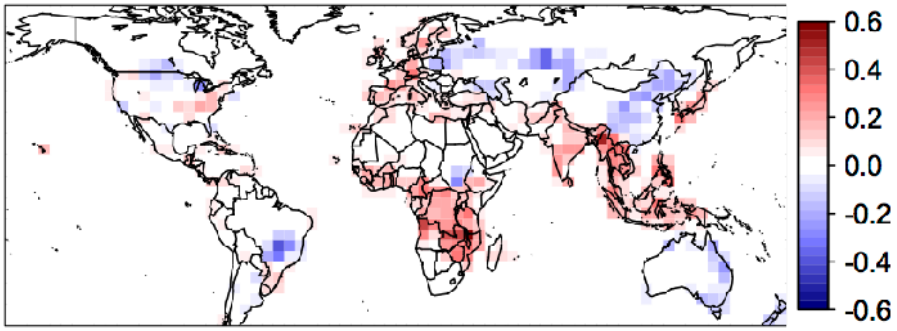

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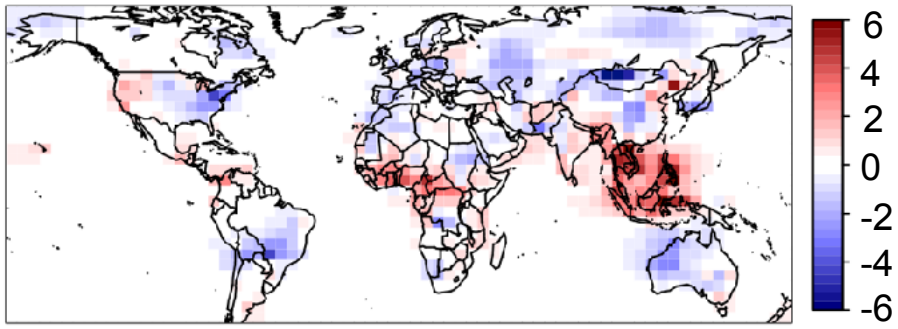

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- Many land use/land cover change studies only consider changes in:
  - Land/plant type **distribution** (category, fractional coverage) → most…
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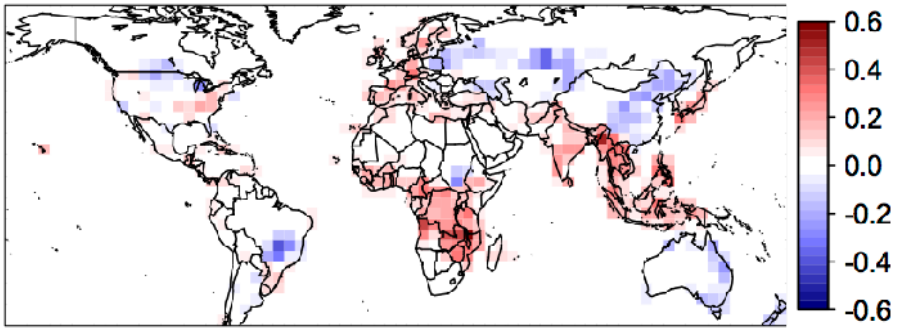

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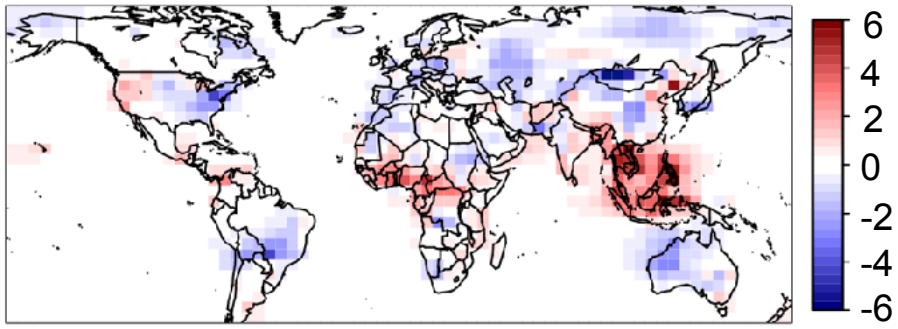

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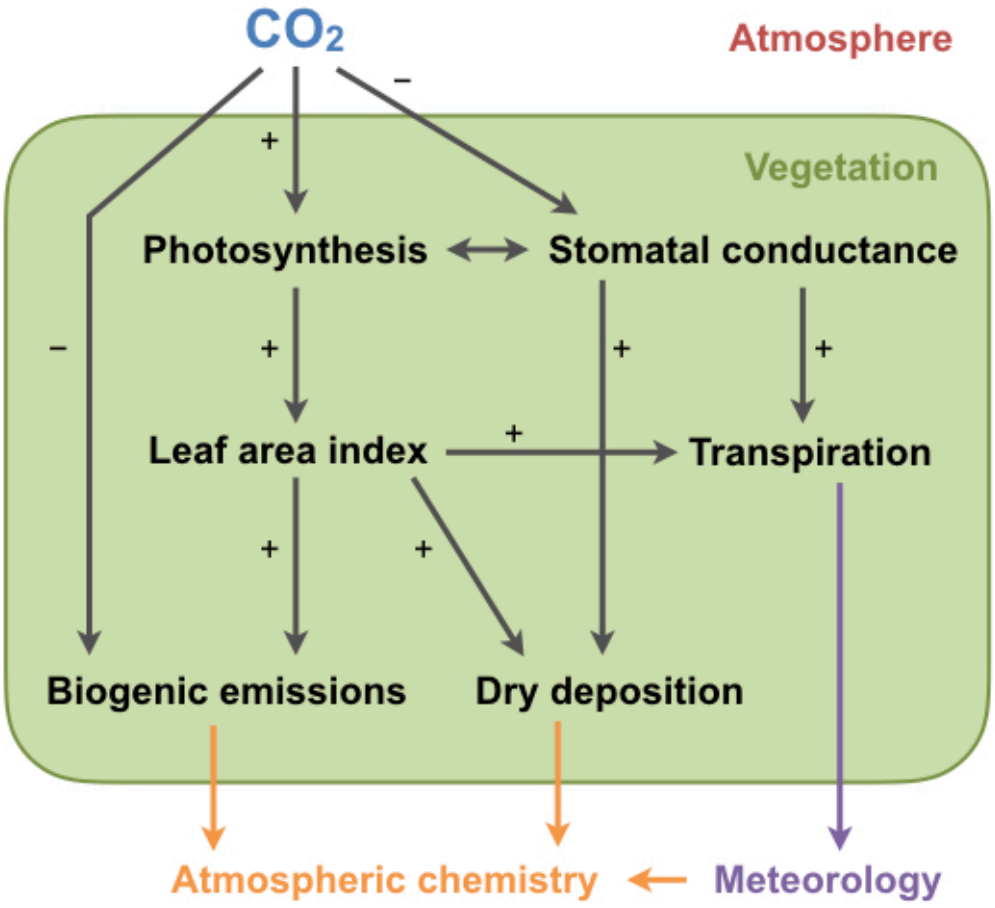
- Many land use/land cover change studies only consider changes in:
  - Land/plant type **distribution** (category, fractional coverage) → most…
  - Vegetation **structure** (LAI, canopy height) → some…
- Most do not consider simultaneous changes in **plant physiology** under varying atmospheric conditions…

Effects of Ozone-CO_2-Vegetation Coupling

Rising CO_2 and **ozone pollution** can both modify **plant physiology**, leading to changes in plant activities that can ultimately affect **climate** and **atmospheric chemistry** via transpiration, biogenic emissions, dry deposition, etc.



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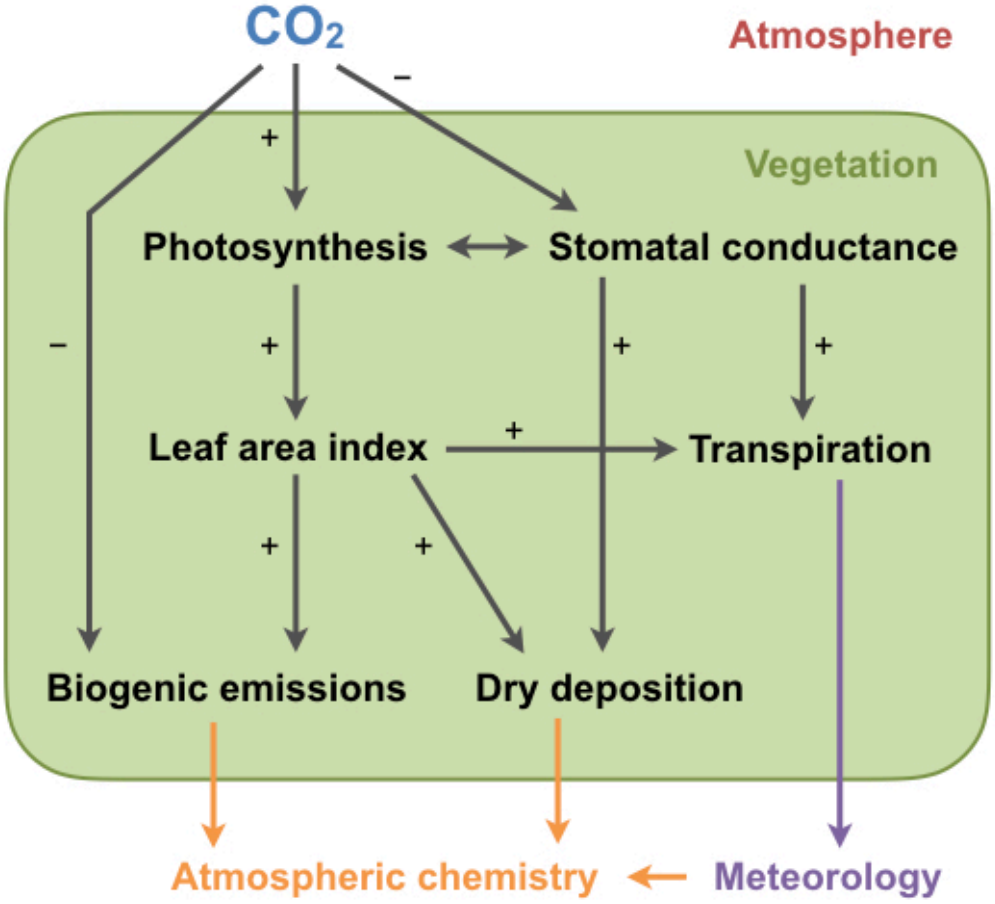

CO_2:

- Inhibits isoprene emission
- Enhances LAI (fertilization)
- Reduces stomatal conductance (to prevent water loss)

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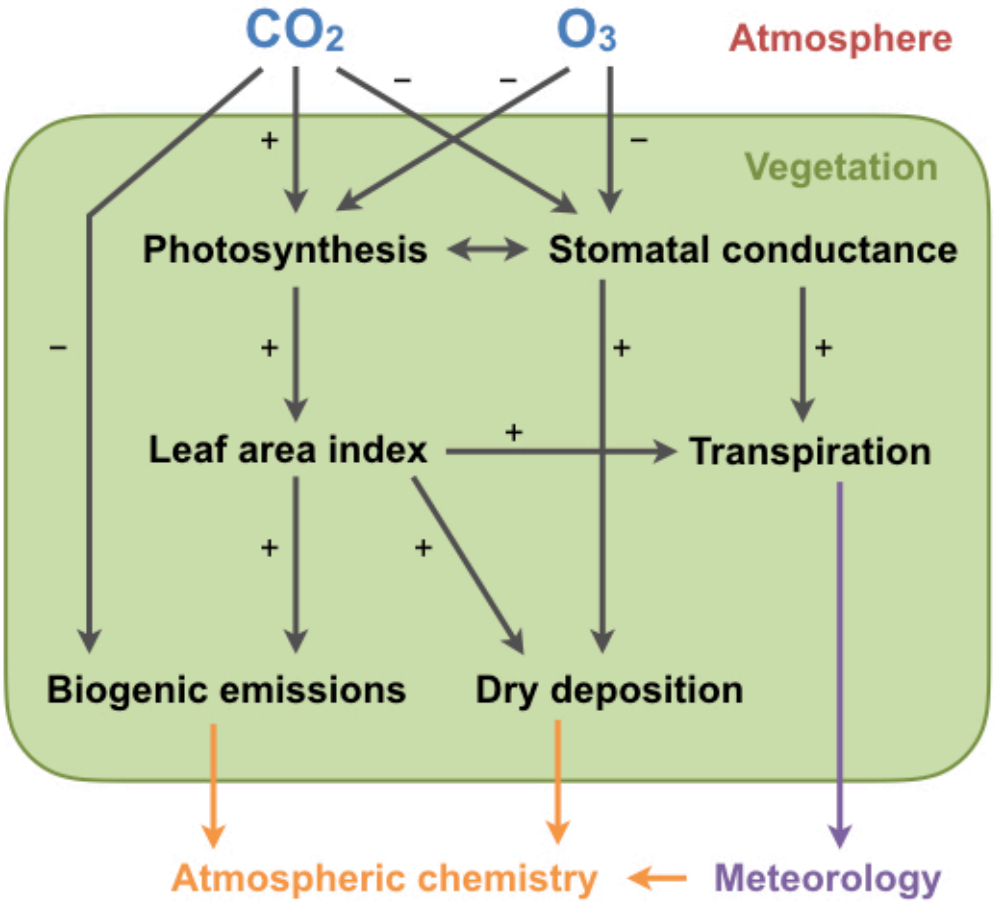

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O_3:

- Reduces LAI (damage)
- Reduces stomatal conductance (damage)

Effects of Ozone-Vegetation Coupling

- Surface **ozone** is a major air pollutant (causing ~0.7M deaths/year).
- **Dry deposition** onto leaves is a major sink for ozone, but also damages plant tissues → impacts on **ecosystems** and **crops**

Plants under ozone exposure

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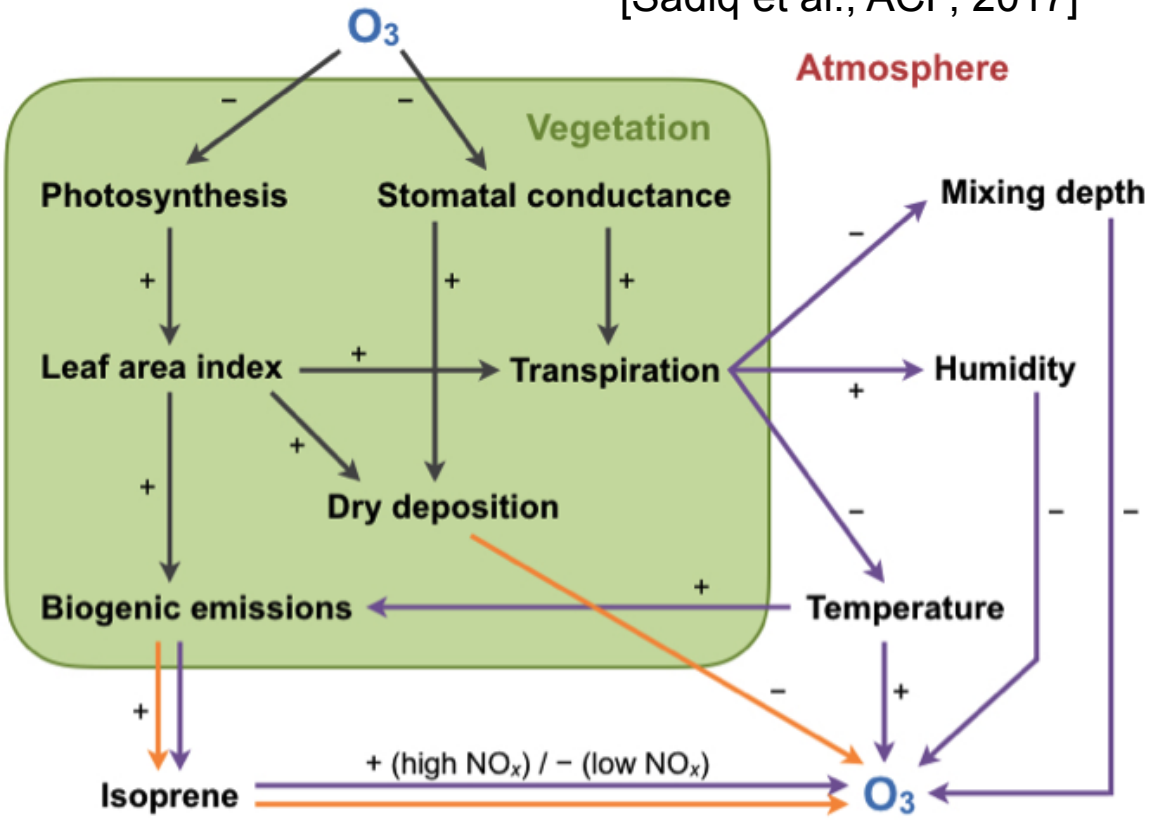

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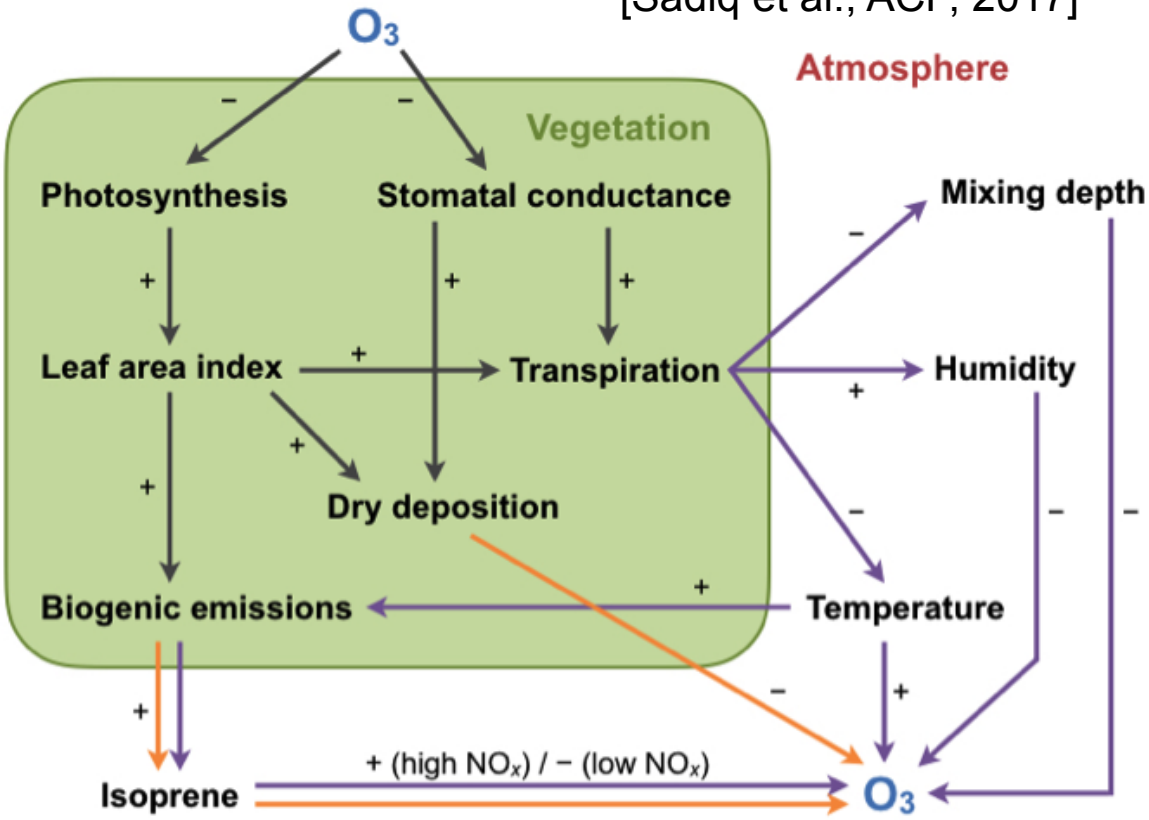
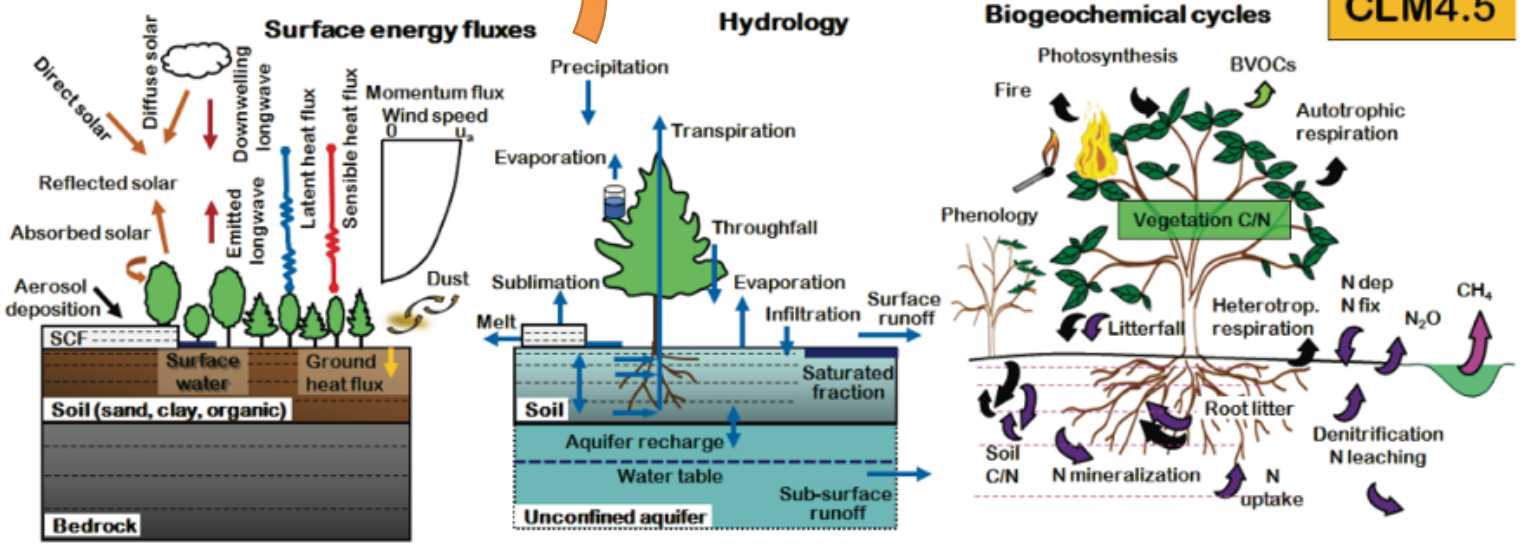
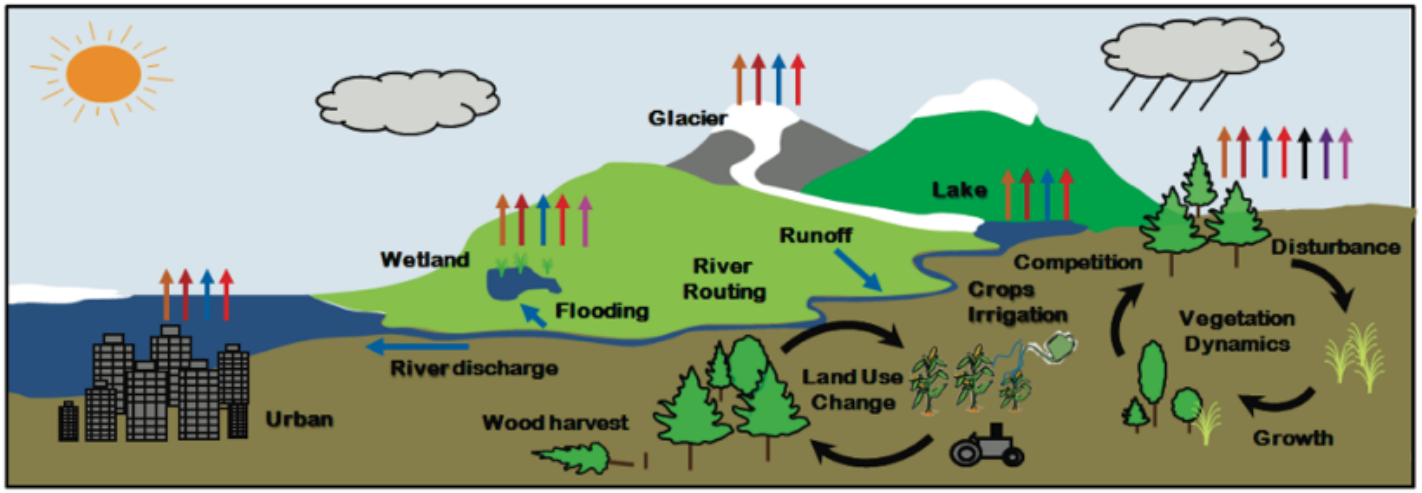


- Implemented in **Community Earth System Model (CESM)** (fully coupled land-atmosphere) empirical schemes for:
  - Ozone damage on vegetation [Lombardozzi et al., 2015]
  - Vegetation-dependent ozone deposition [Val Martin et al., 2014]

Coupled Land-Atmosphere Model

Atmosphere (CAM-Chem)



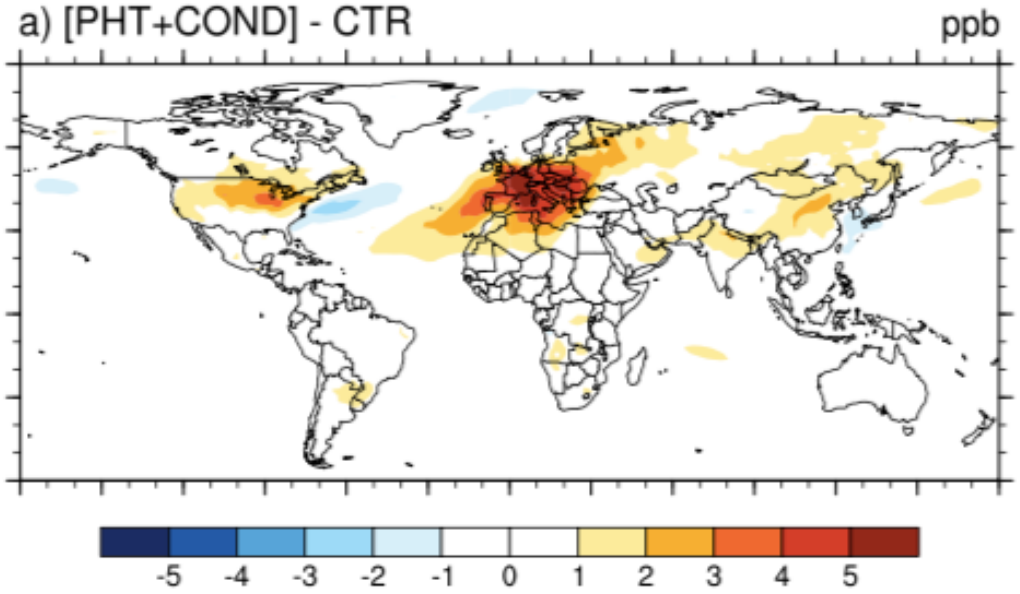


CESM

Ozone-Vegetation Coupling Induces Positive Feedback

Right: **Differences** in mean JJA **surface ozone** between 15-year simulations: **with** minus **without ozone damage** (on both stomatal conductance and photosynthesis)

[Sadiq et al., ACP, 2017]
CESM (CAM4 + CLM4CN) simulations with interactive **ozone damage scheme**



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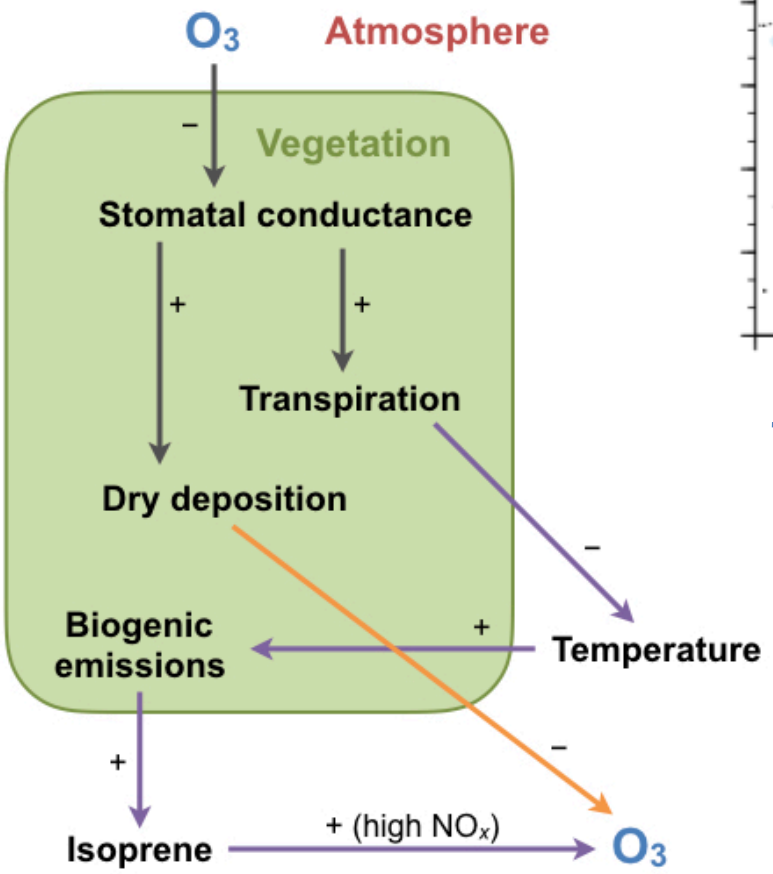

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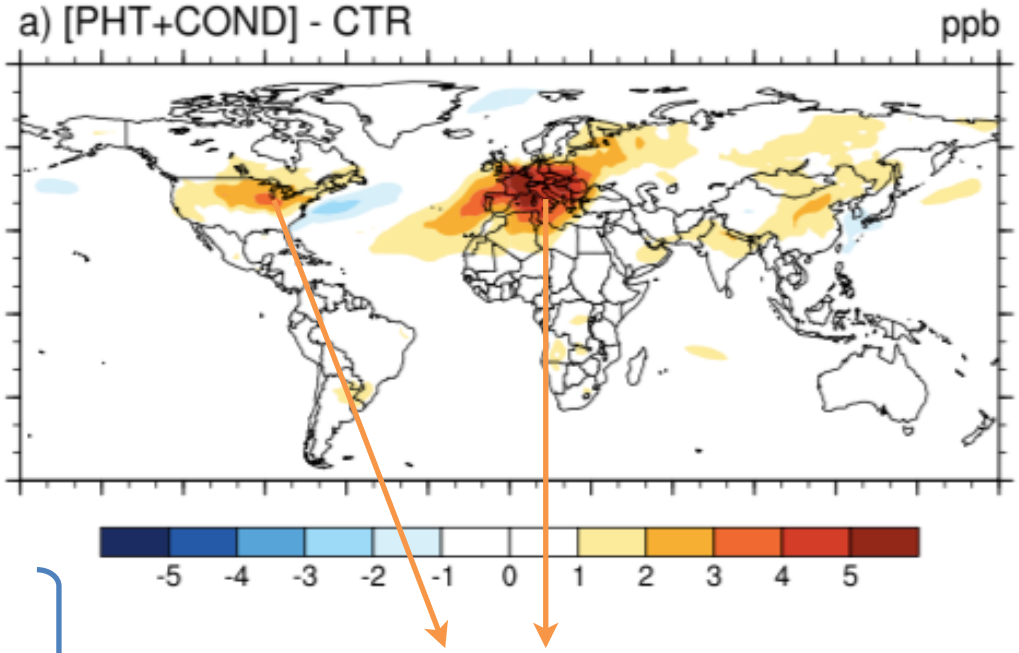
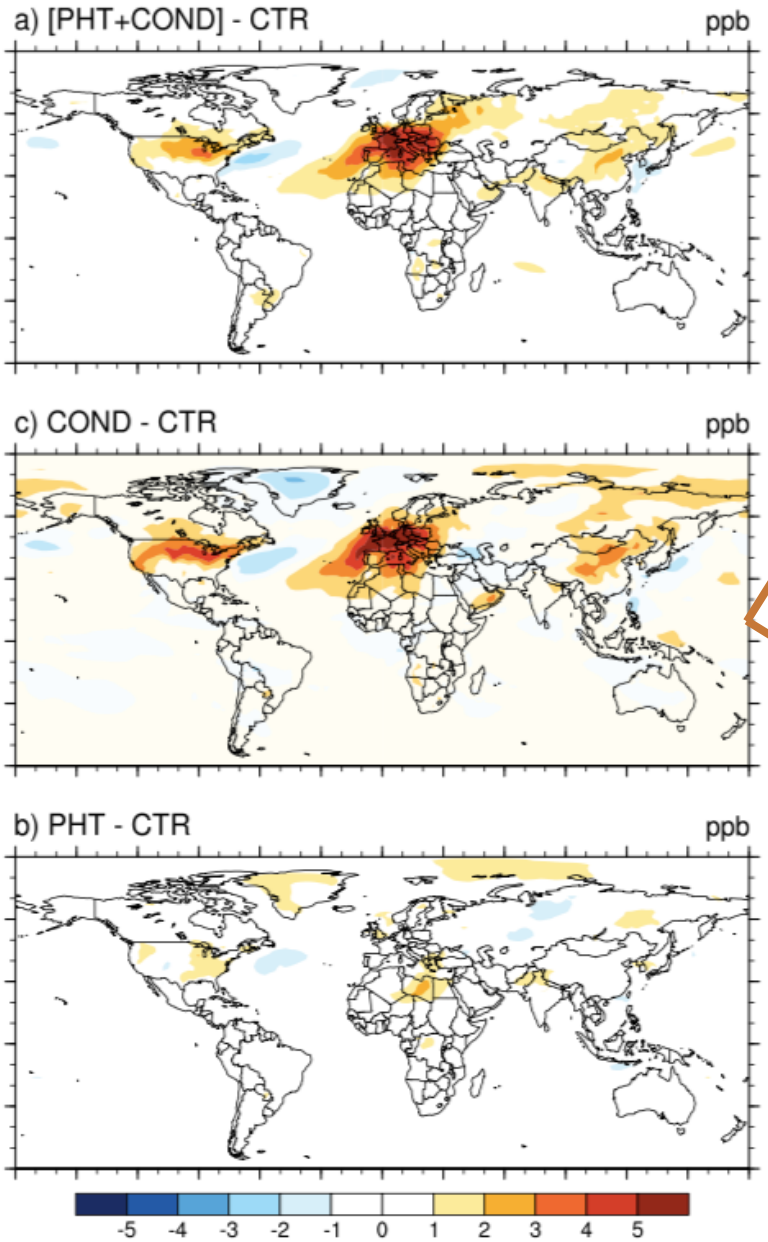
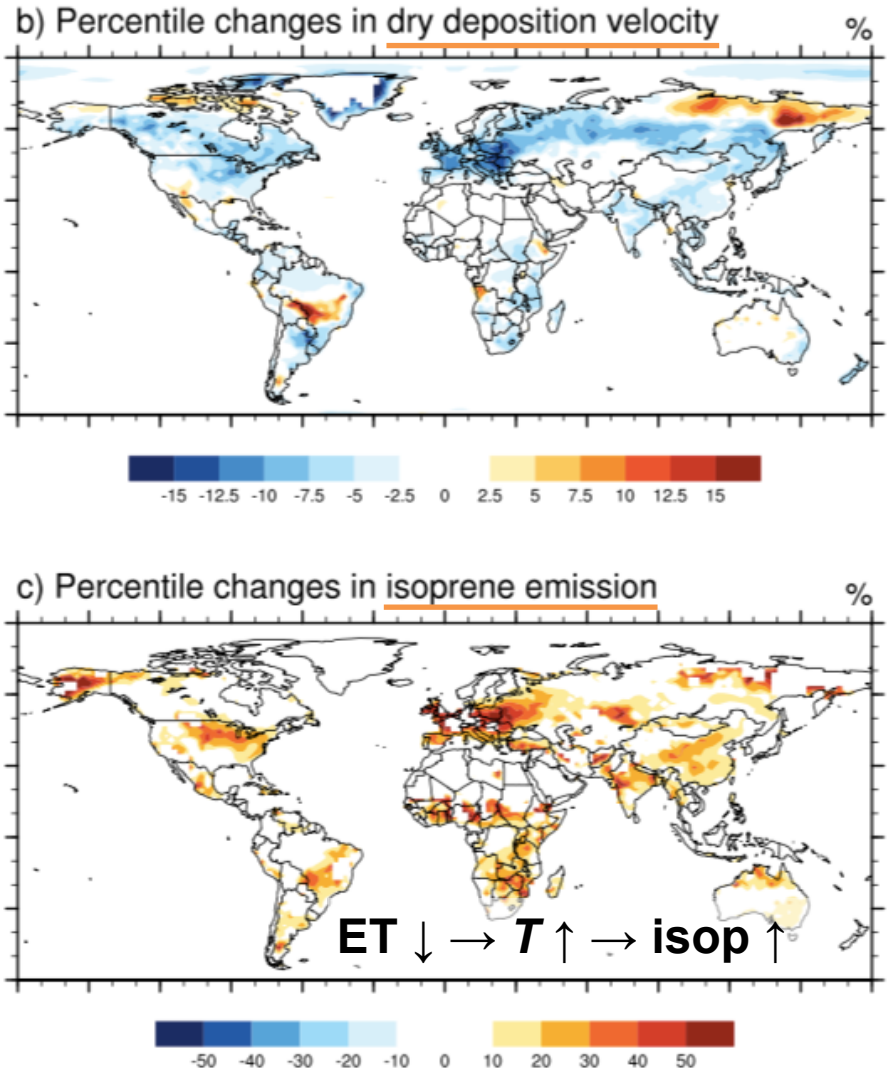


Reduced stomatal conductance enhances simulated **ozone** by up to 6 ppbv due to both **biogeochemical** (via dry deposition) and **hydrometeorological** (via transpiration) feedbacks.

Effects Due to Dry Deposition and Isoprene Emission





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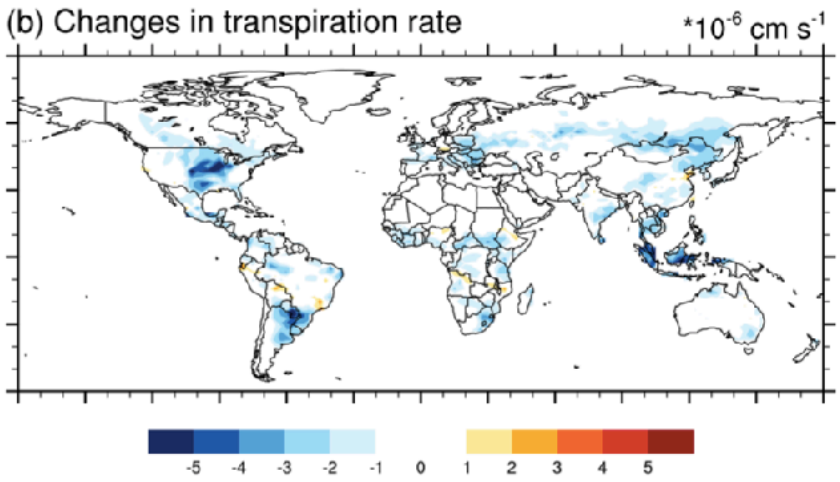
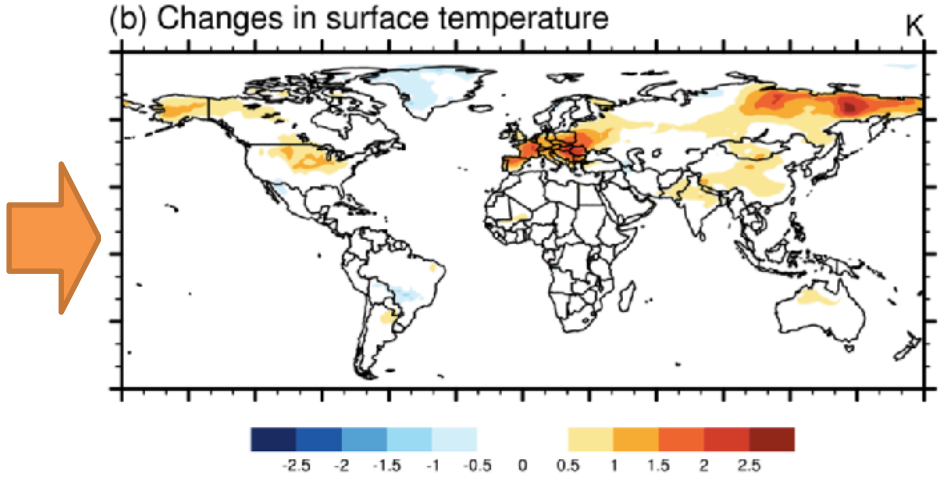
Ozone Damage Induced Meteorological Changes





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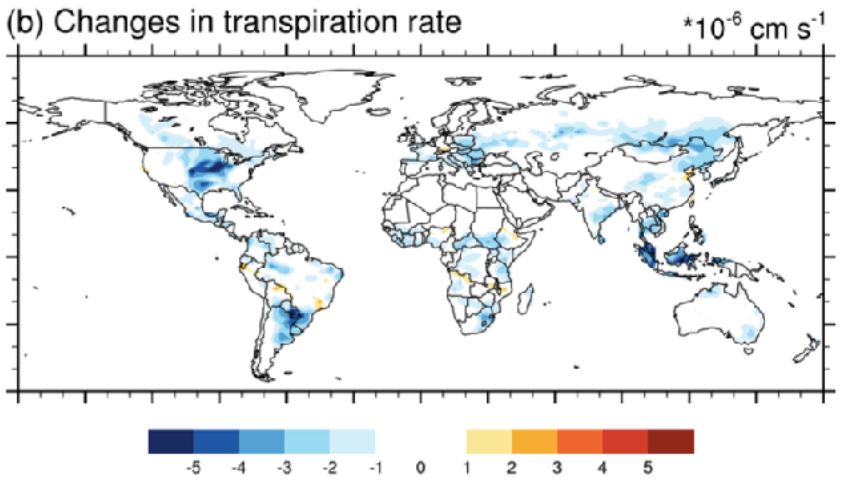
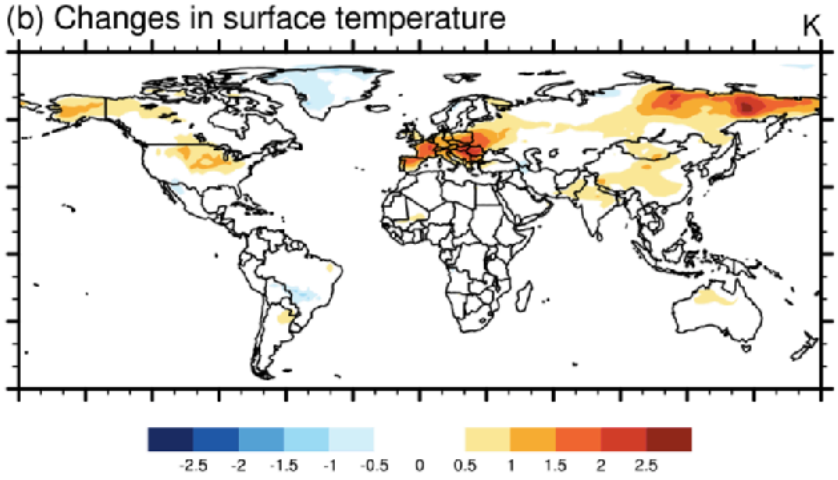
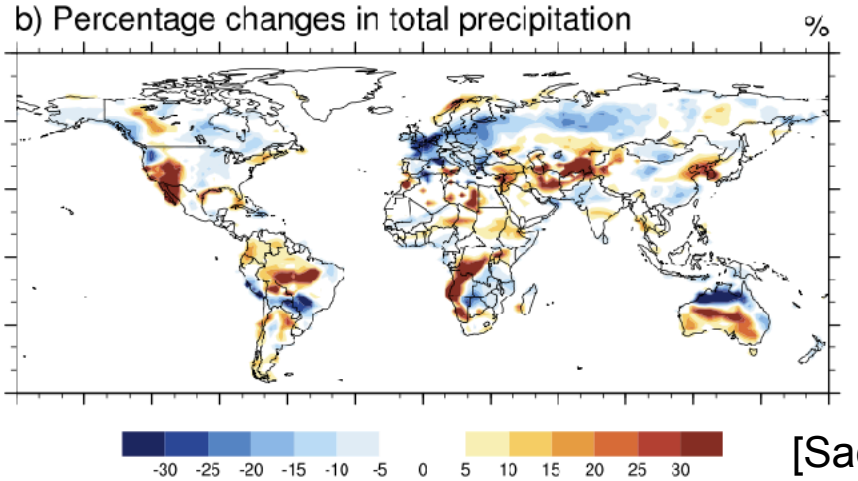
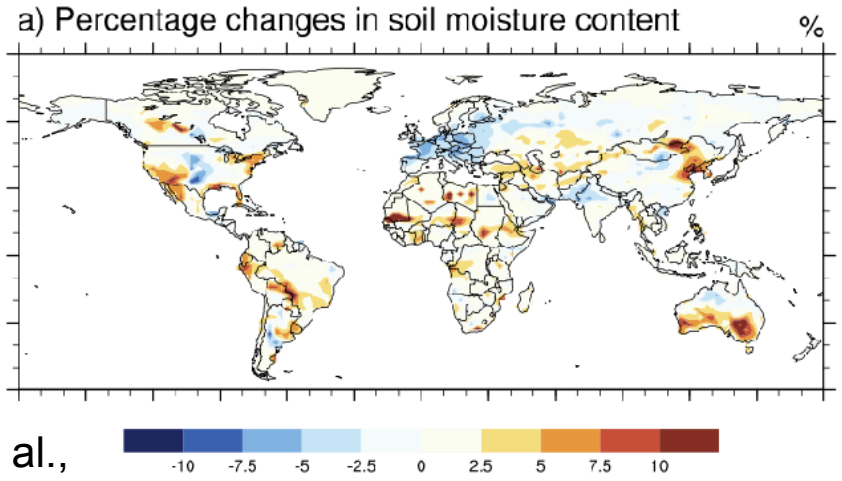




Precipitation may either increase or decrease depending on the compensation between **reduced water vapor content** and **enhanced sensible heat** thus **convergence/convection**.



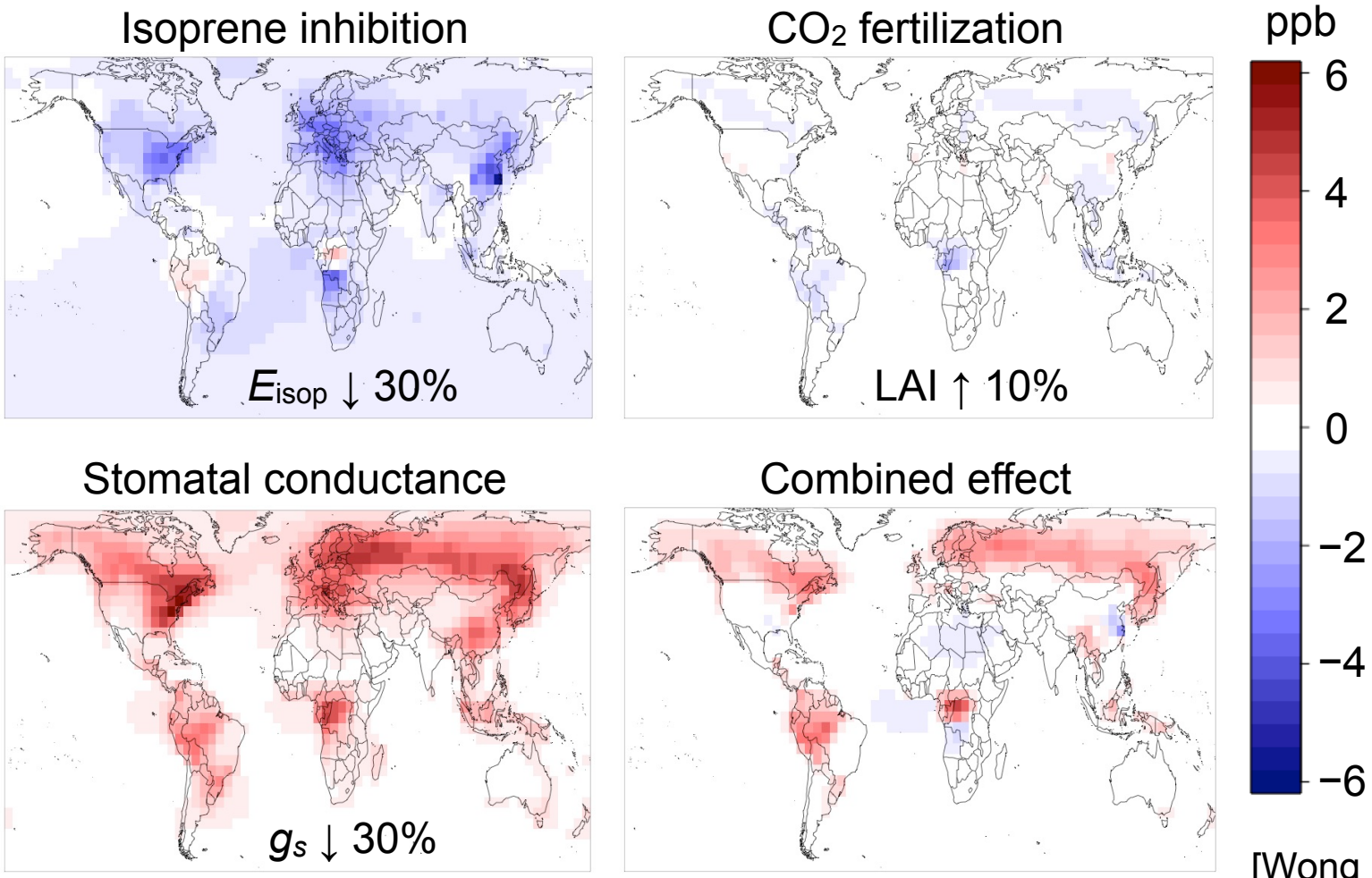


[Sadiq et al., ACP, 2017]

Effects of Elevated CO_2 in 2050 on Surface Ozone

1. Examine ozone changes due to RCP4.5 and RCP8.5 land use change
2. Examine additional effects of elevated CO_2 on top of land use change

Additional effects of 2050 RCP8.5 CO_2 (525 ppm) on surface ozone



[Wong et al., in prep]

Conclusions and Implications

Conclusions:

- O_3-induced damage on stomatal conductance leads to a positive ozone feedback of up to +6 ppbv, mostly due to changes in dry deposition and isoprene emission.
- Elevated CO_2 (525 ppm) suppresses isoprene emission and stomatal conductance, leading to compensating effects on surface ozone in the range of –1 to +4 ppb.
- Changes in stomatal conductance affect partition between latent and sensible heat flux, ultimately modifying surface temperature, precipitation and other boundary-layer meteorological variables.

Implications for urban climate and air quality:

- Intended effects of urban greening, forest management and land use change on climate and air quality can be substantially enhanced or compromised by the responses of plant physiology to changing atmospheric composition.
- Understanding and differentiating between physiological responses of different tree types may be a crucial consideration of urban climate-vegetation interaction studies.