The role of biogenic volatile organic compounds in aerosol-climate impacts & feedbacks

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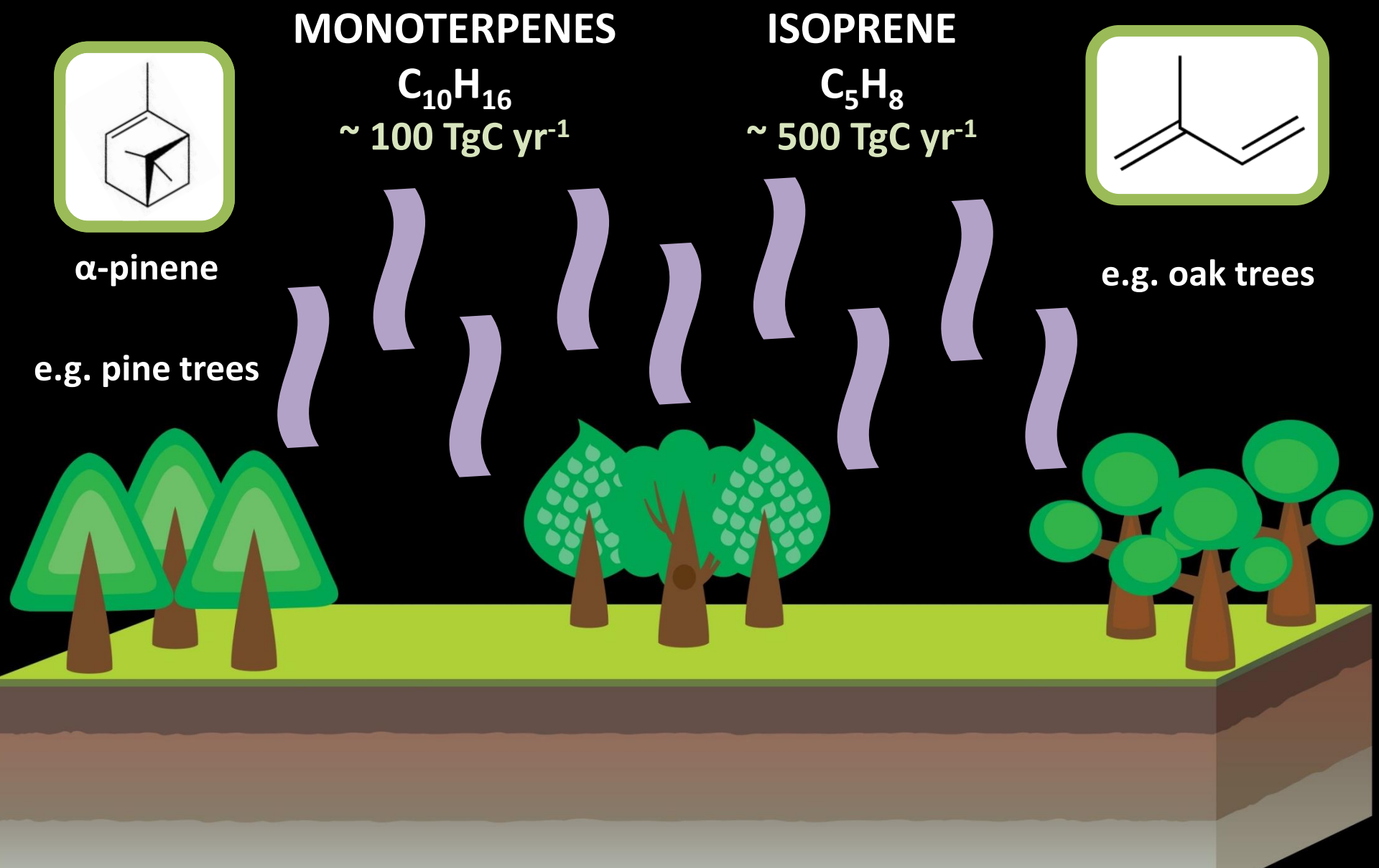
Biogenic Volatile Organic Compounds (BVOCs)

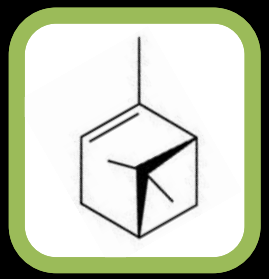


What controls BVOC emission?

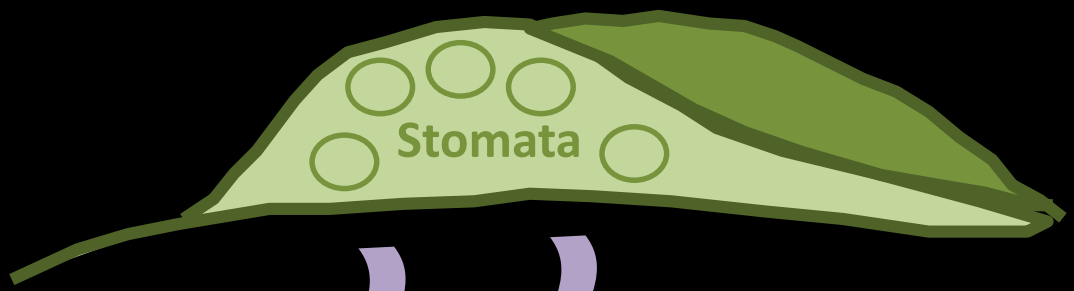
e.g. for a broadleaf species…

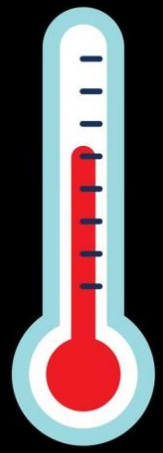
MONOTERPENES

$C_{10}H_{16}$



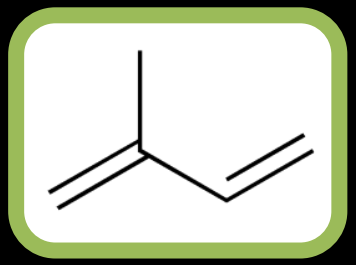
Stored in leaf





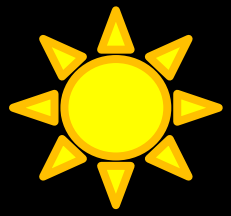
Strongly temperature dependent

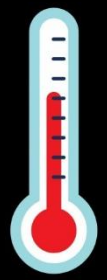
Not stored in leaf



ISOPRENE

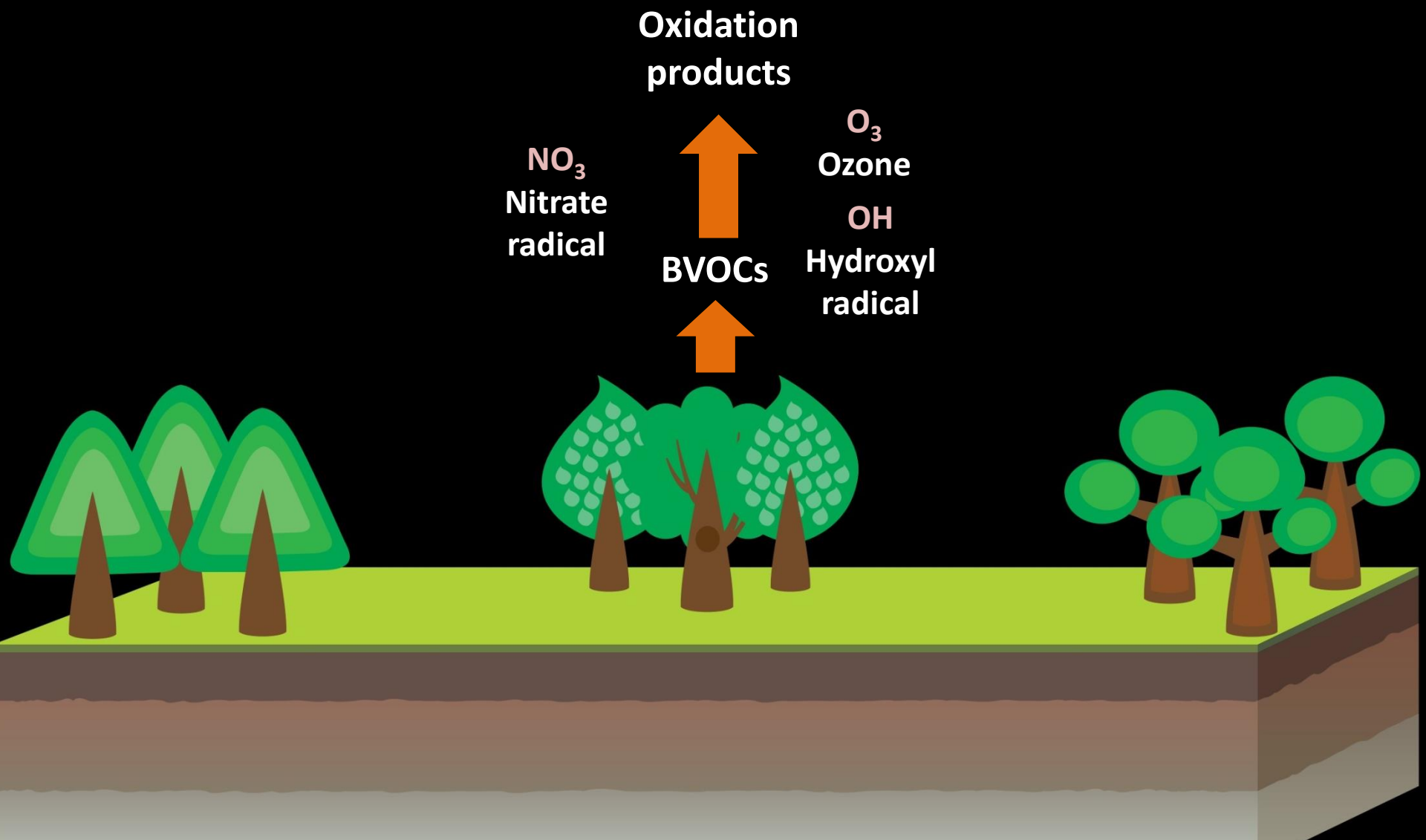
C_5H_8

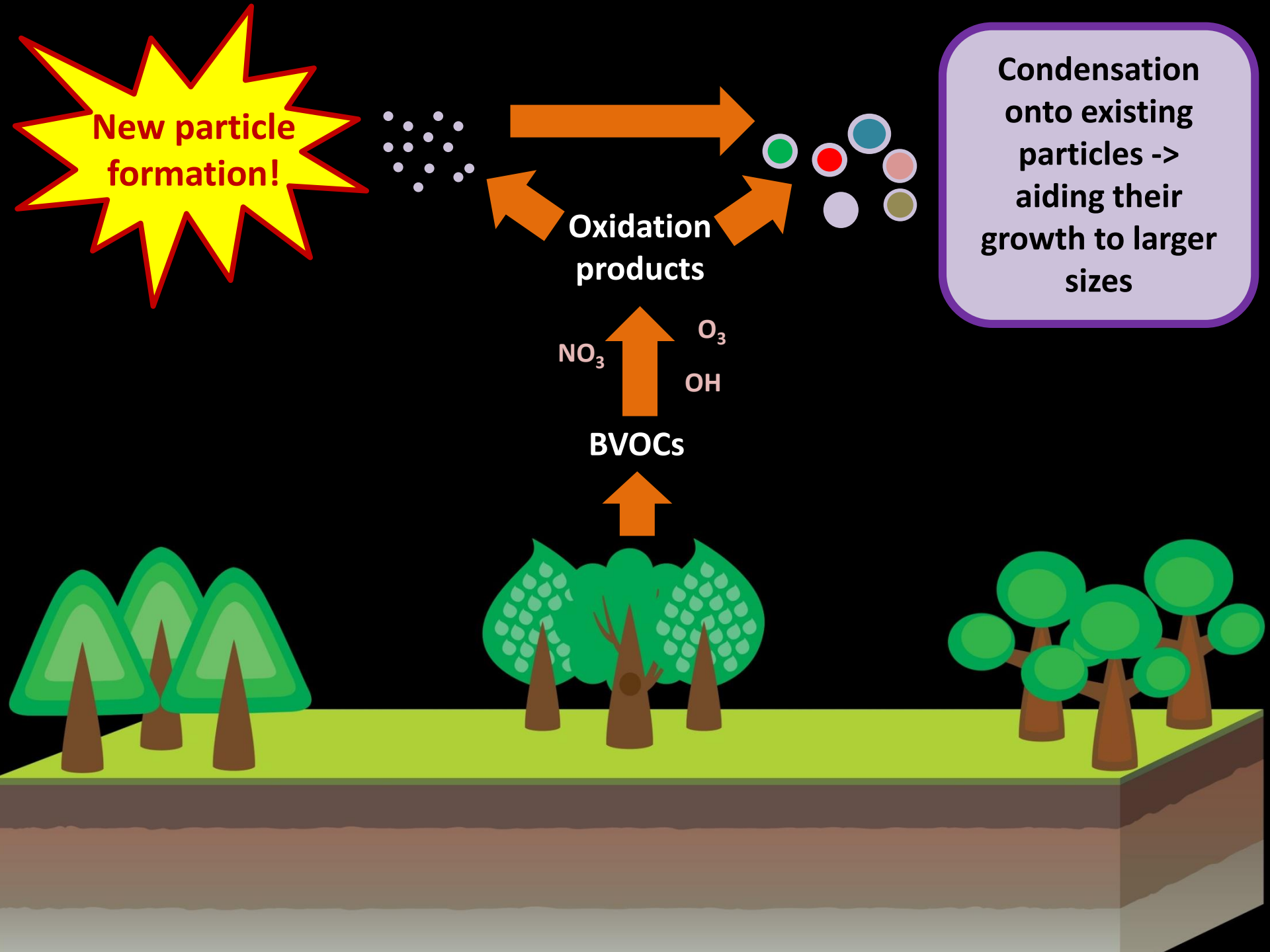


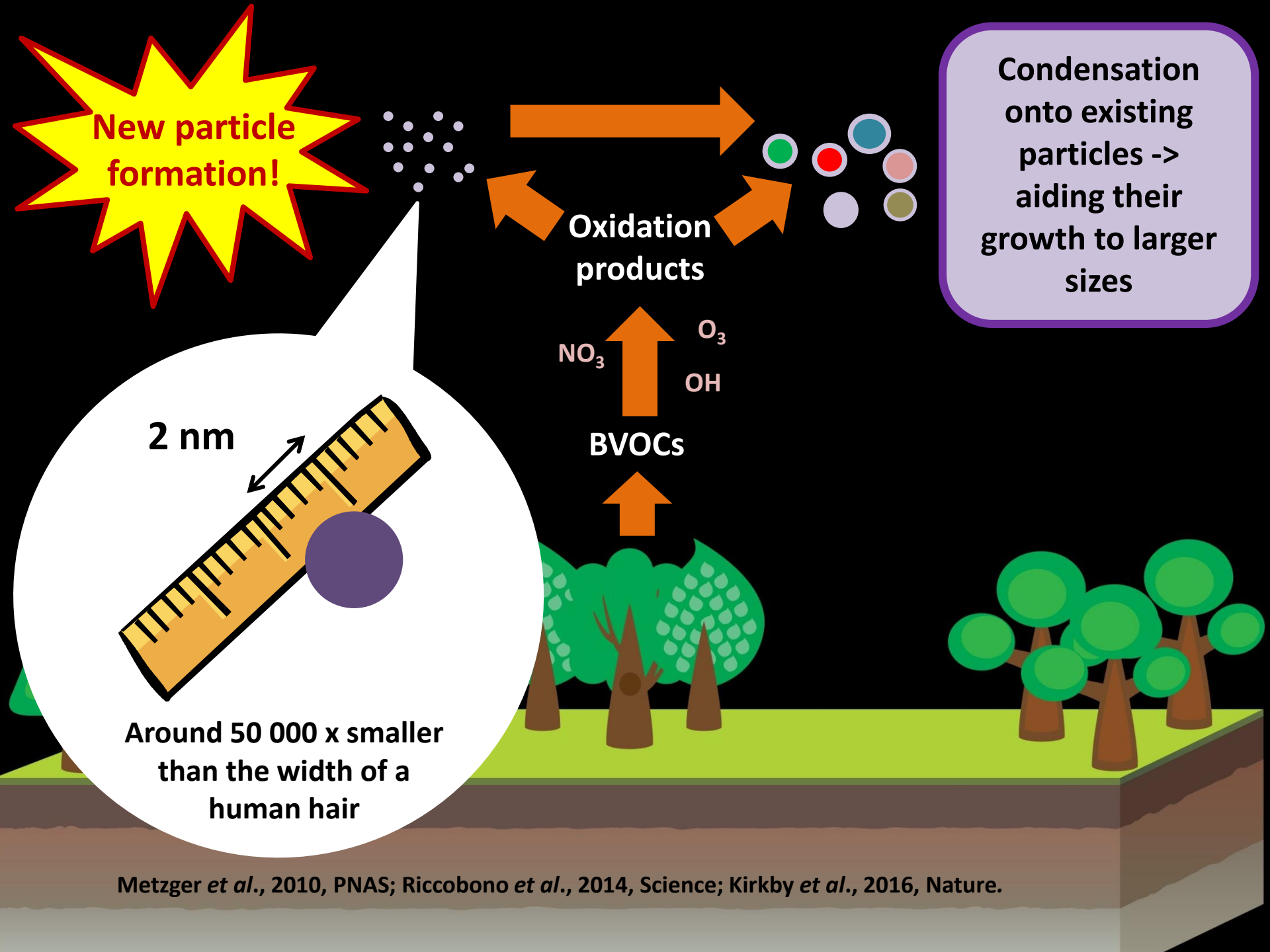


$[CO_2]$

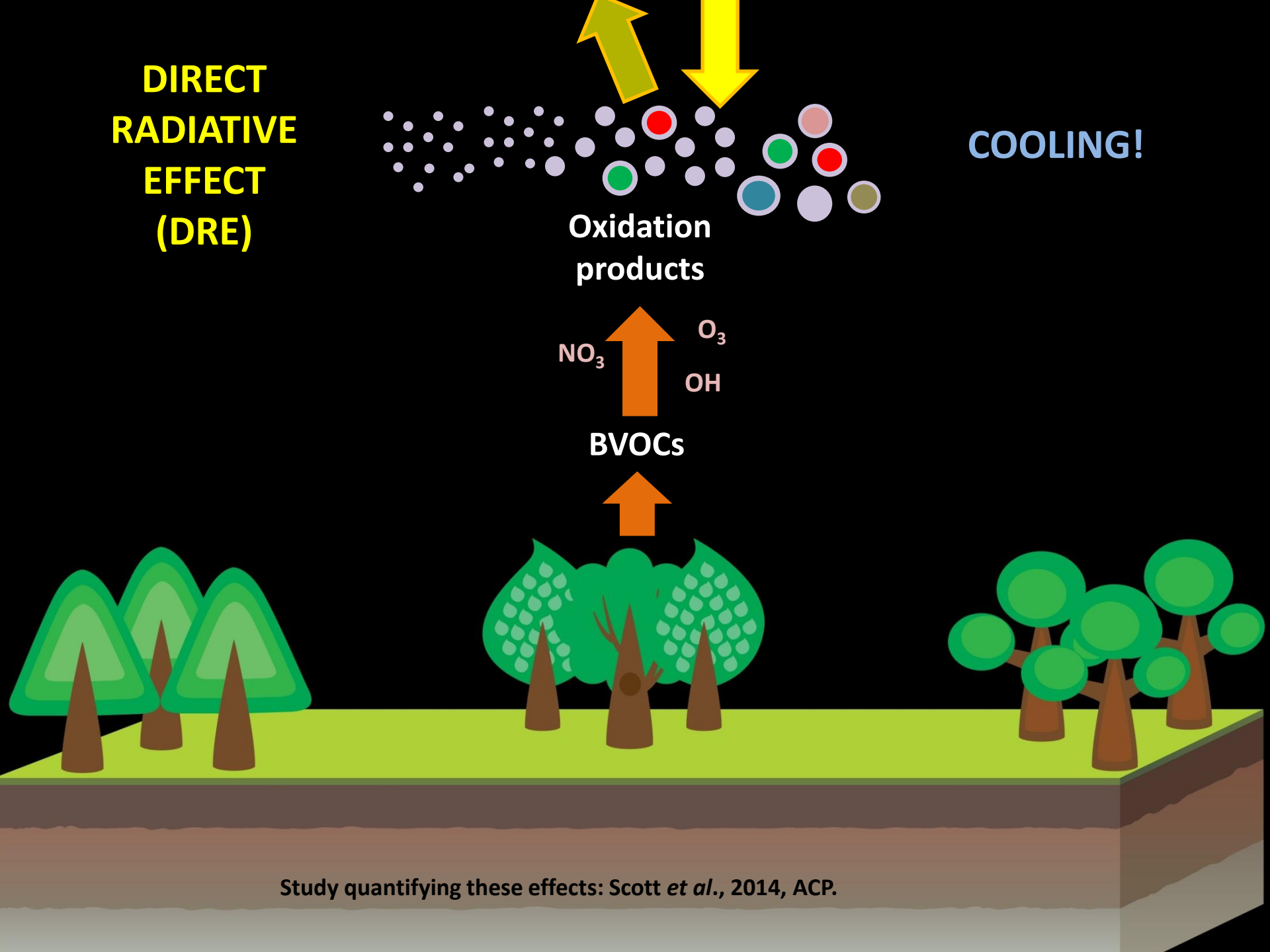
How do BVOC emissions affect the atmosphere?



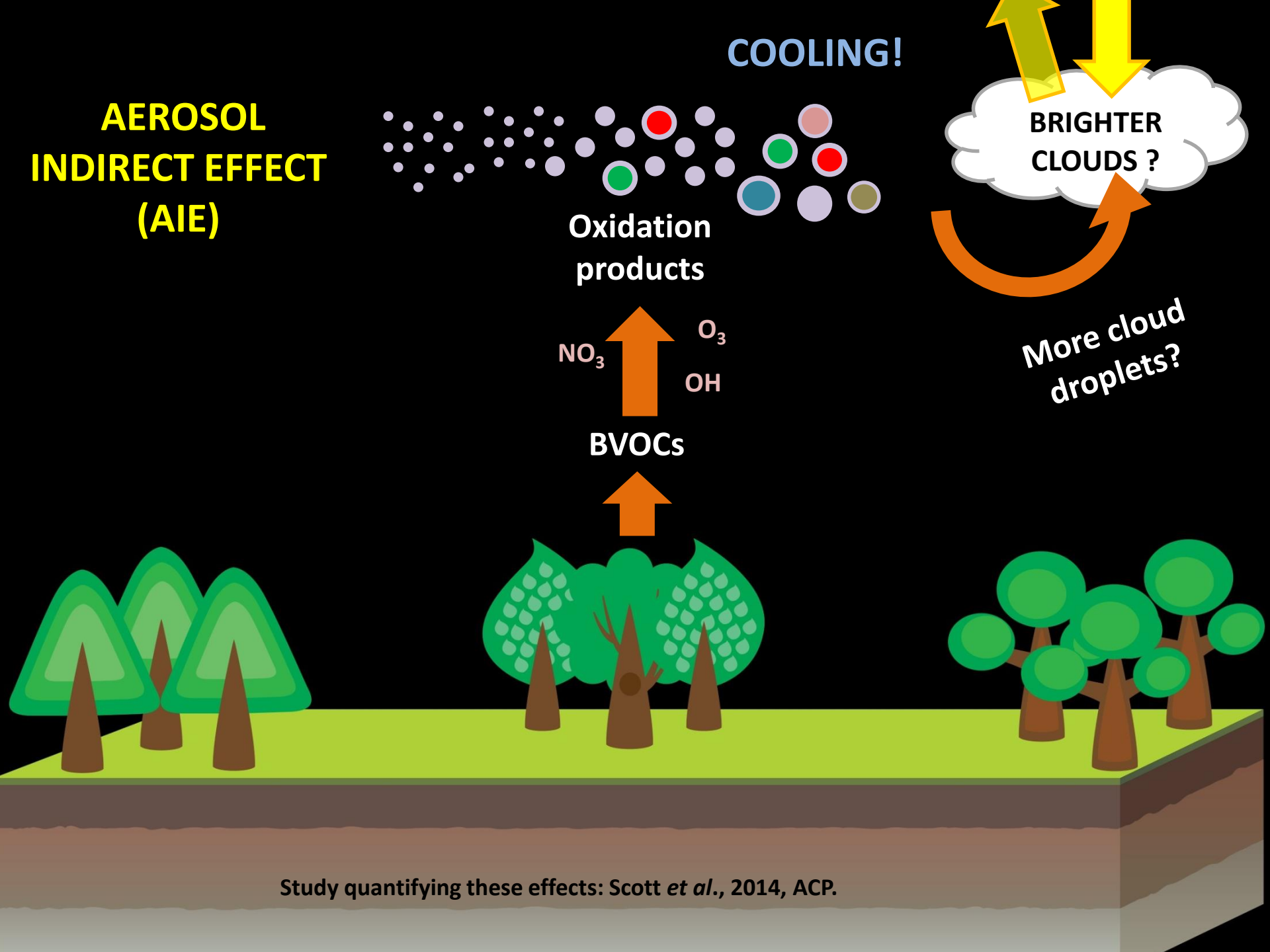

New particle formation!
Oxidation products
NO_3
O_3
OH
BVOCs
Condensation onto existing particles -> aiding their growth to larger sizes



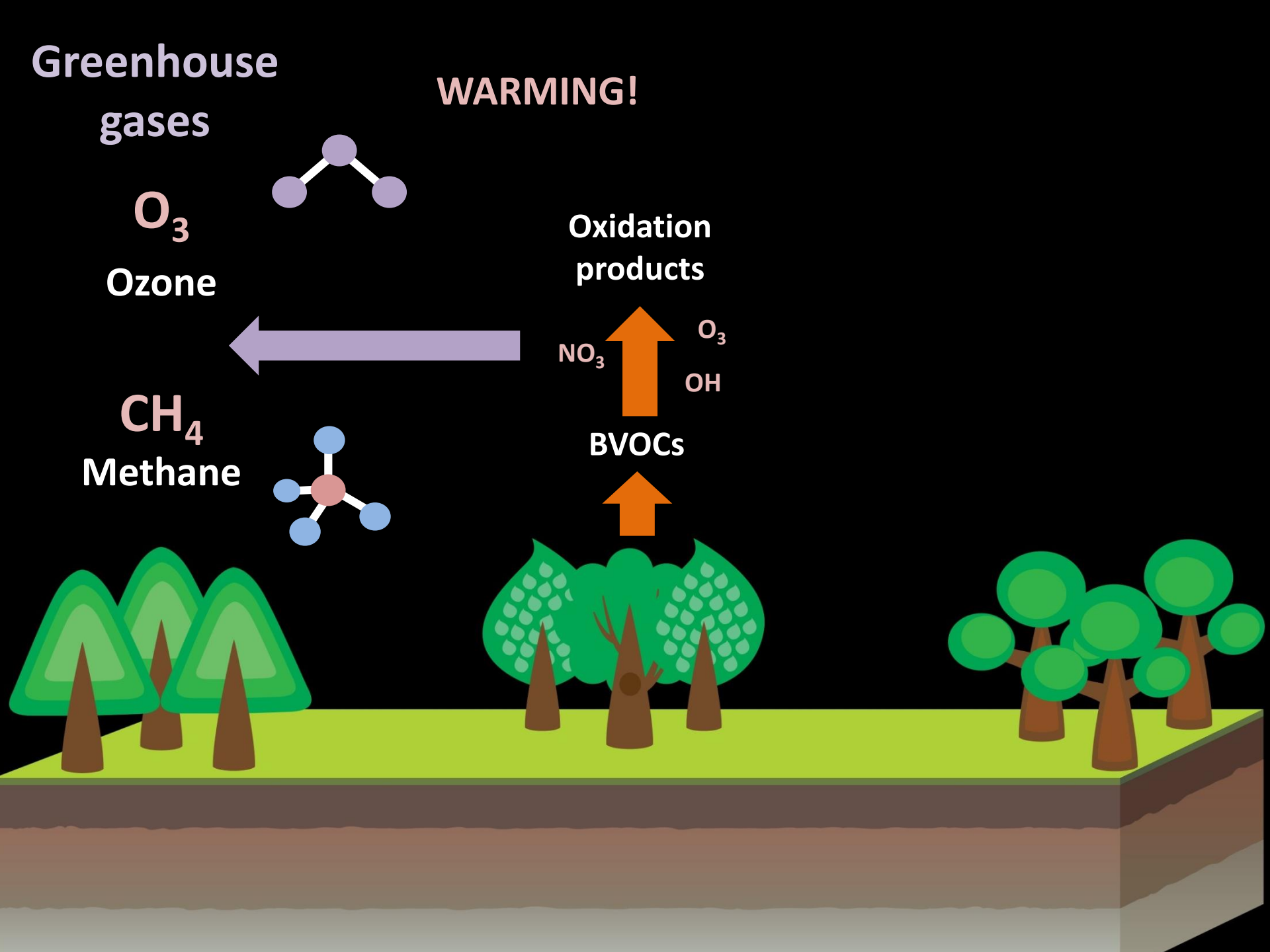
Metzger *et al*., 2010, PNAS; Riccobono *et al*., 2014, Science; Kirkby *et al*., 2016, Nature.

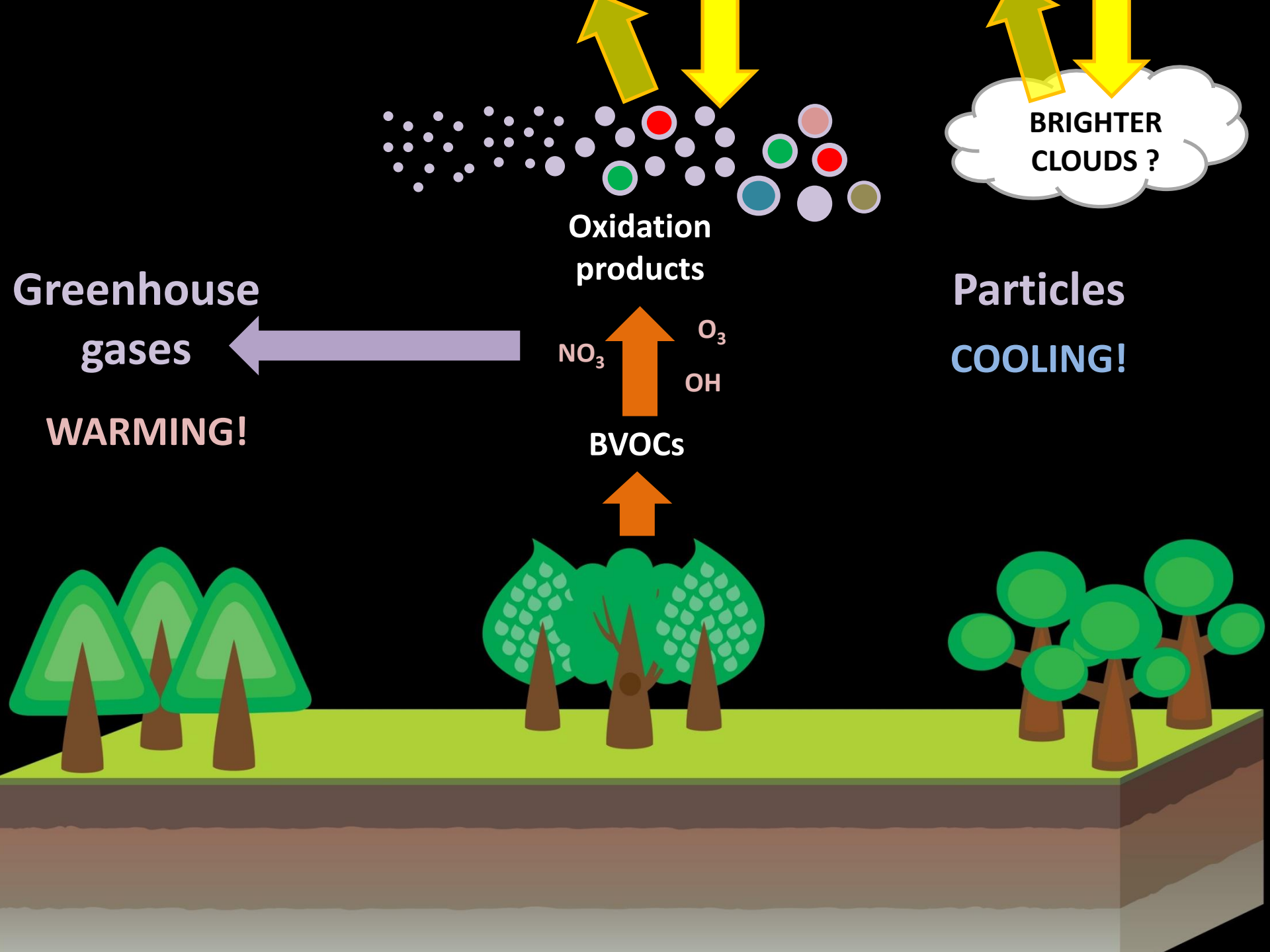


Study quantifying these effects: Scott *et al.*, 2014, ACP.

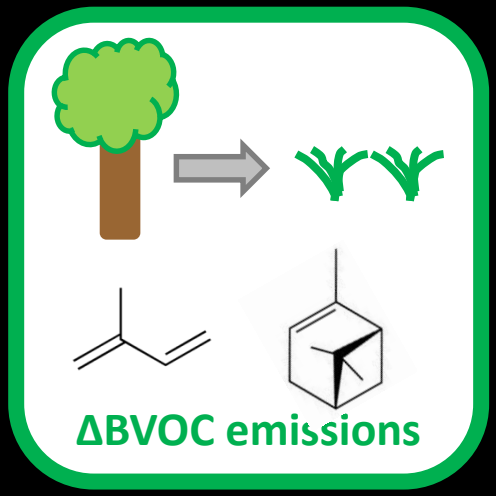


Study quantifying these effects: Scott *et al.*, 2014, ACP.


Greenhouse gases
WARMING!
O_3
Ozone
Oxidation products
NO_3
O_3
OH
CH_4
Methane
BVOCs


BRIGHTER CLOUDS ?
Oxidation products
Greenhouse gases
WARMING!
NO_3
O_3
OH
BVOCs
Particles
COOLING!

Simulating the impacts of deforestation on short-lived climate forcers



CLM + MEGANv2.1
Guenther *et al.*, 2012

- 90%

2.8° x 2.8°; ECMWF meteorology

TOMCAT
Chipperfield *et al.*, 2006;
Monks *et al.*, 2016

GLOMAP
Spracklen *et al.*, 2005;
Mann *et al.*, 2010;
Scott *et al.*, 2014

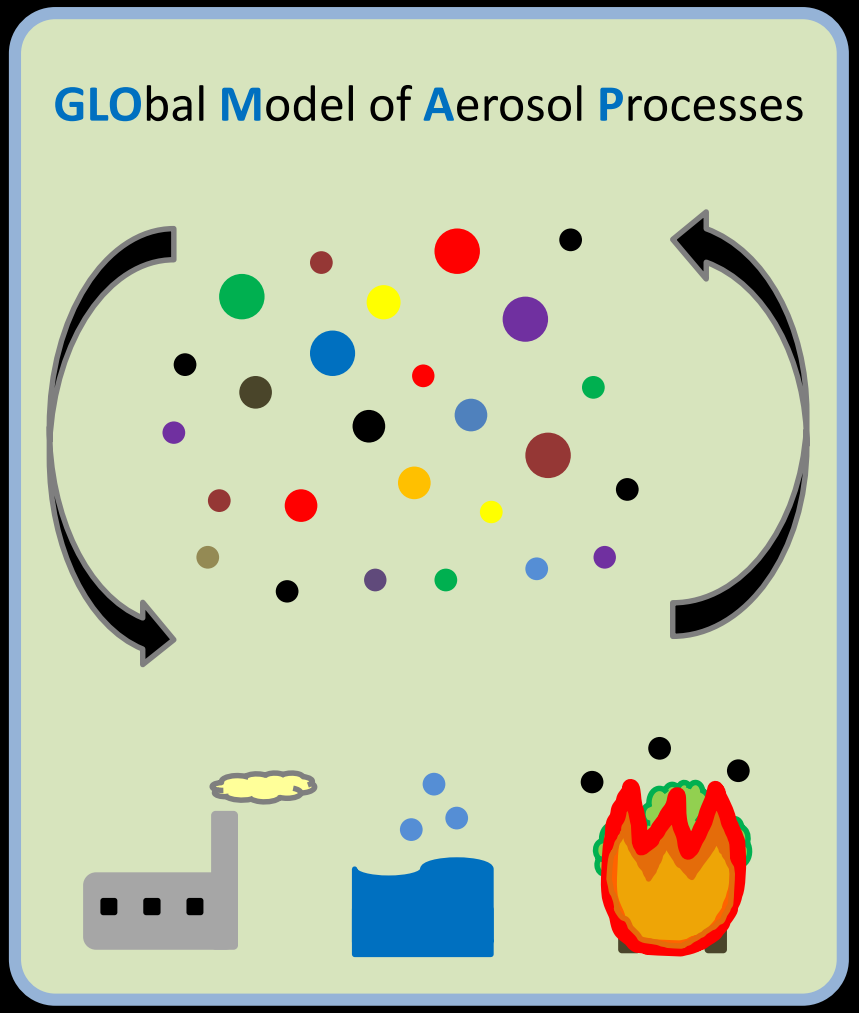
ISCCP

Offline **Edwards-Slingo** (1996) radiative transfer model

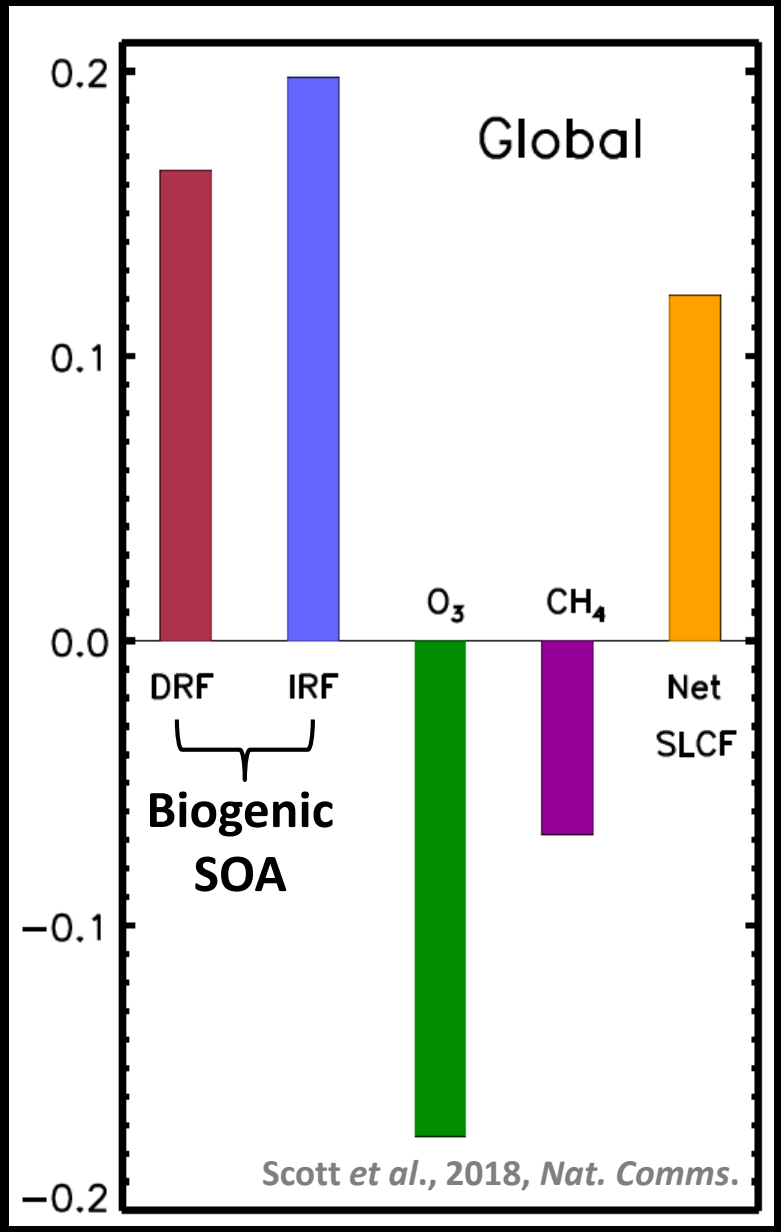
Global Model of Aerosol Processes (GLOMAP)

GLOMAP-mode v6 (Mann *et al.*, 2010)

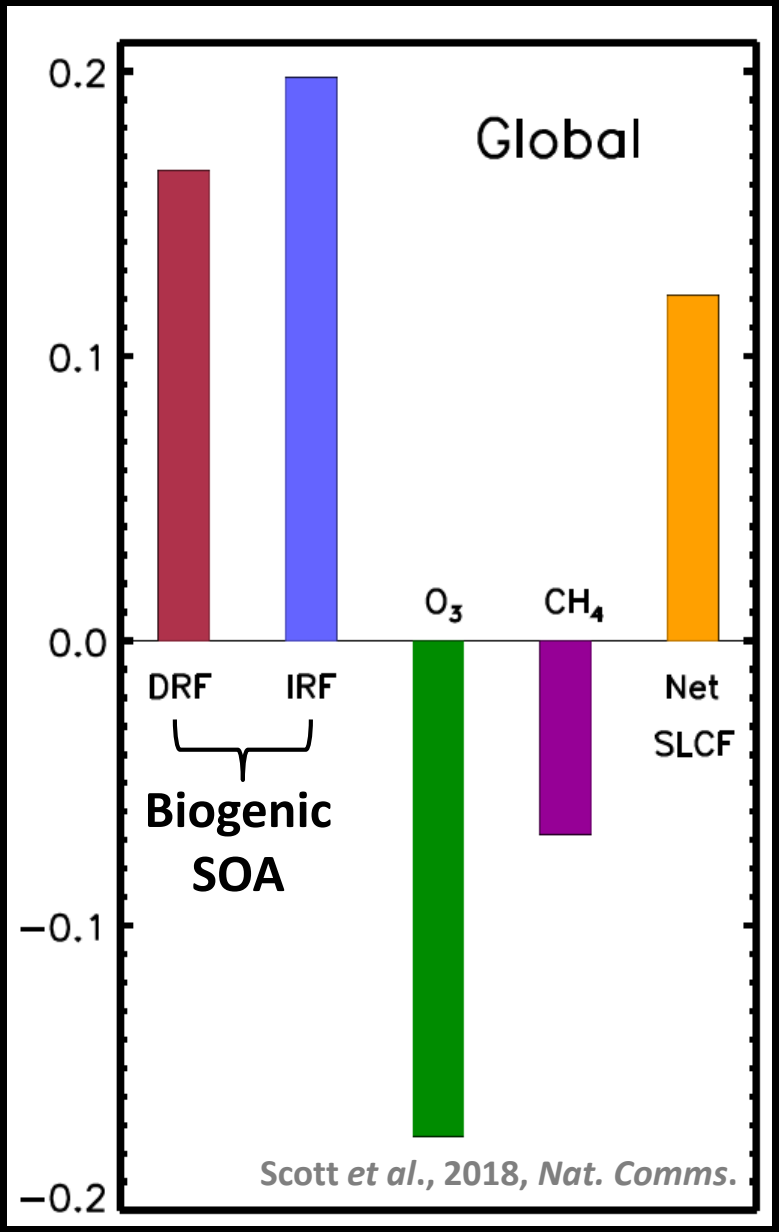
- Detailed global aerosol microphysics model – extension to the TOMCAT chemical transport model
- 2.8° x 2.8° model resolution
- Particle mass and number carried in log normal size modes
- Includes representations of: new particle formation, particle growth (via condensation, coagulation, cloud processing), wet and dry deposition and scavenging in/below clouds



Radiative Forcing due to ΔSLCF

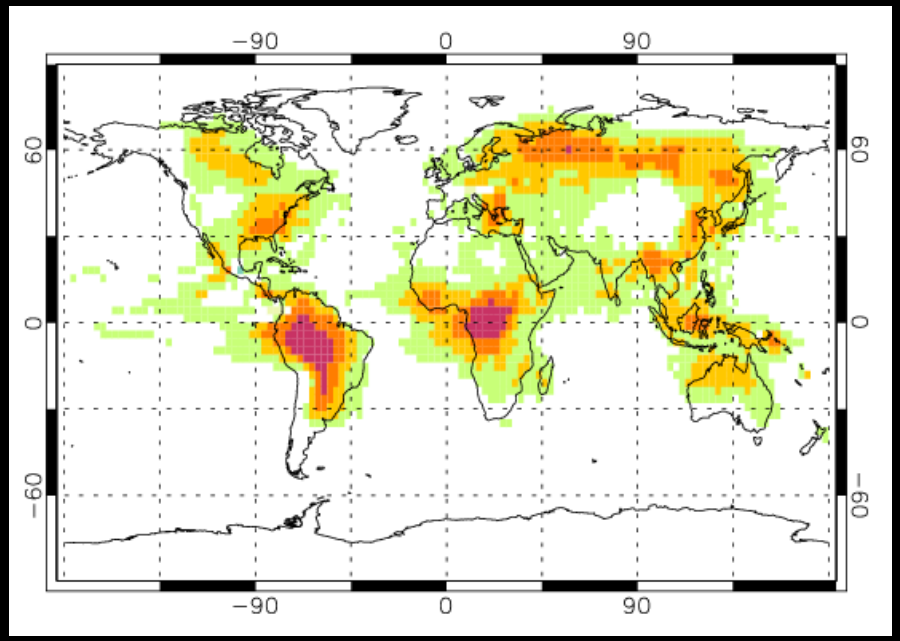


Radiative Forcing due to ΔSLCF

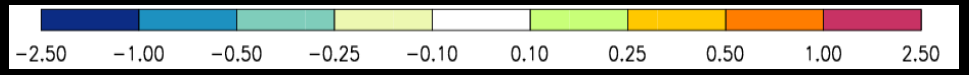


Direct Radiative Forcing

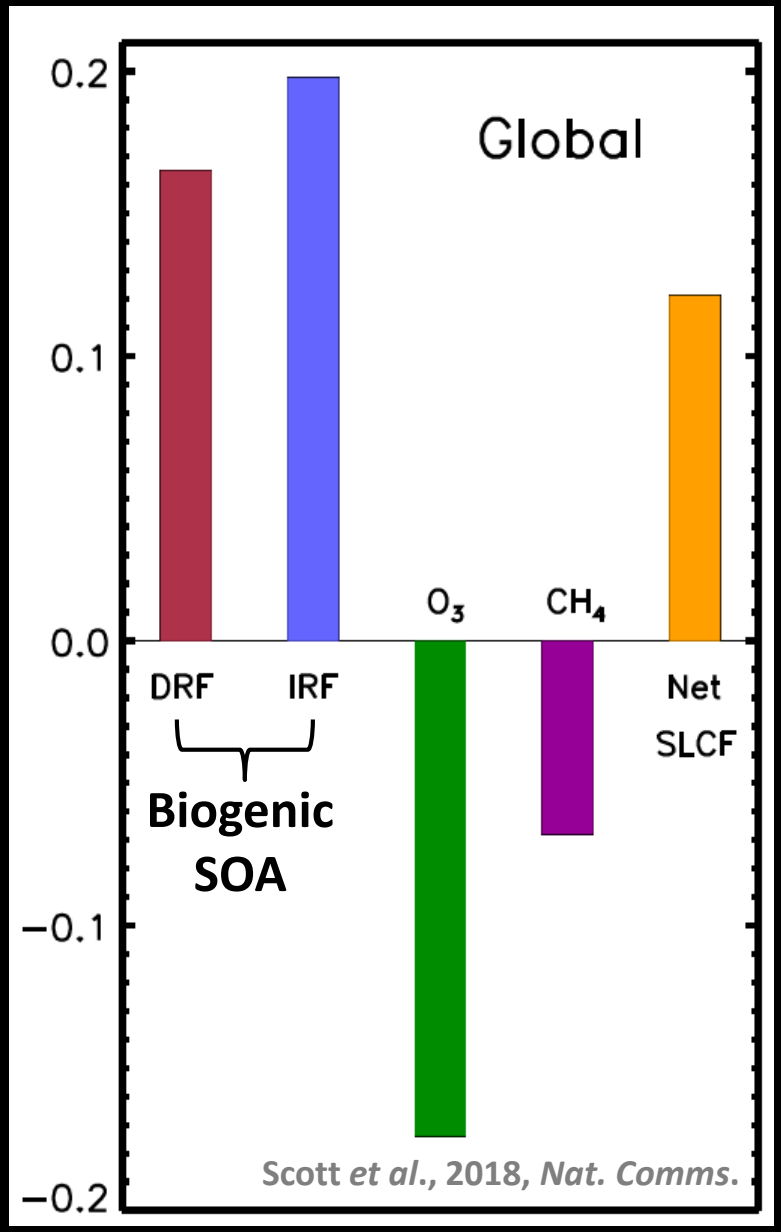
= +0.17 W m^{-2}



Annual Mean RF (W m^{-2})

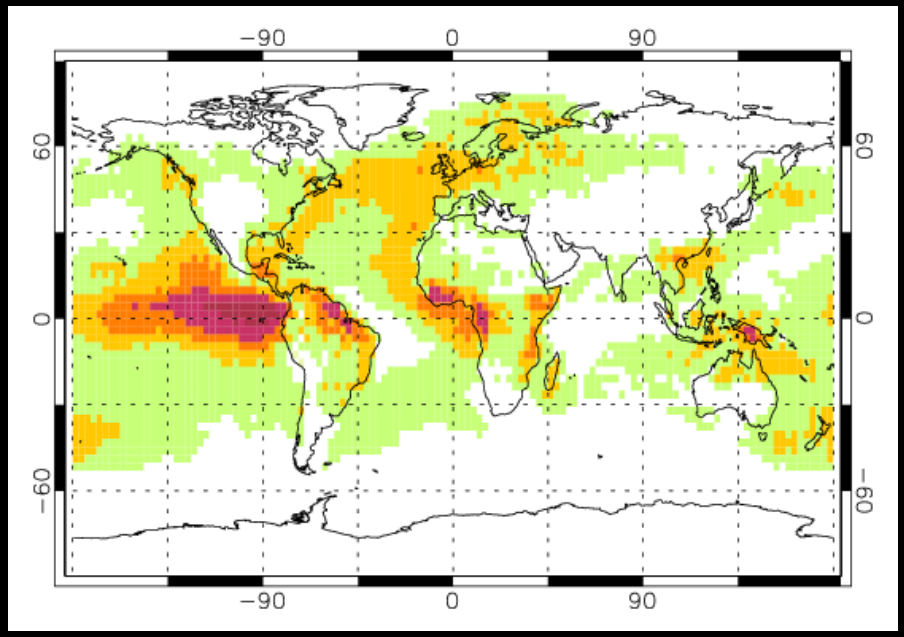


Radiative Forcing due to ΔSLCF

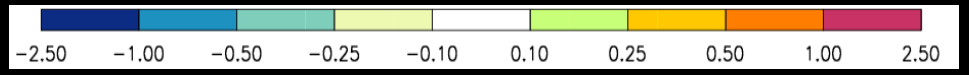


First Aerosol Indirect Forcing

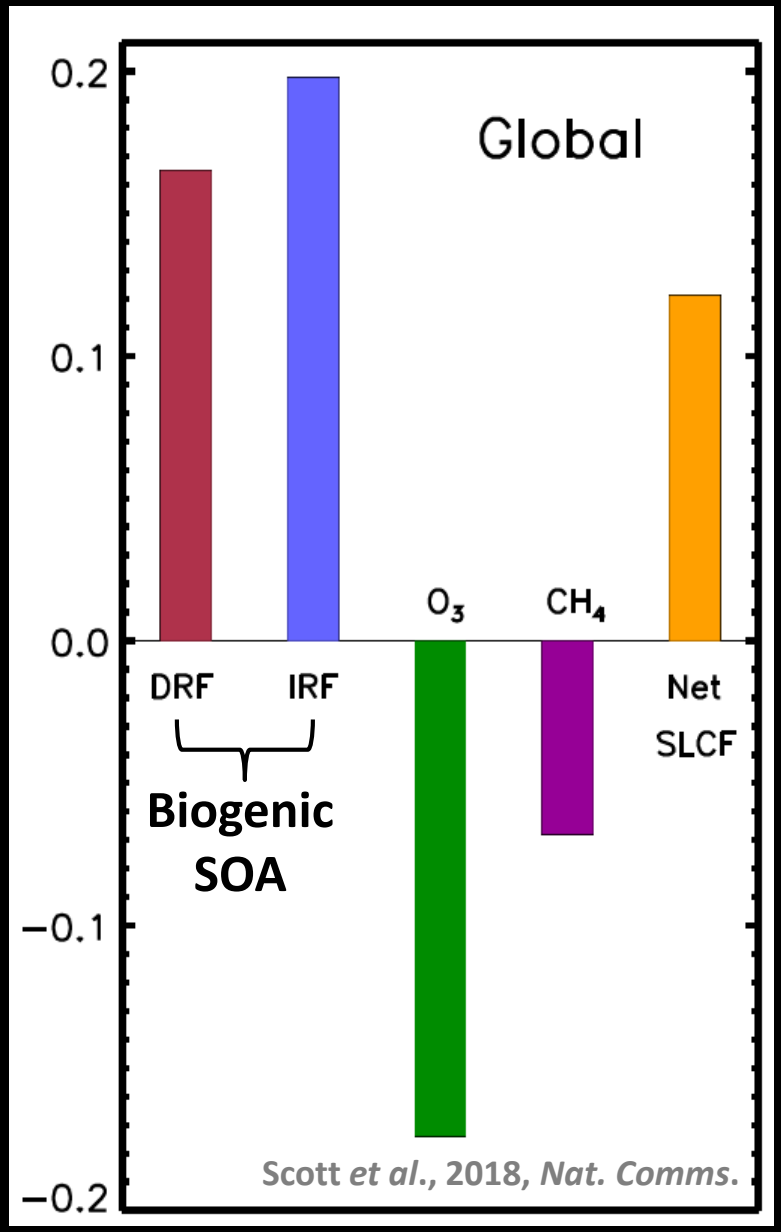
= +0.20 W m^{-2}



Annual Mean RF (W m^{-2})

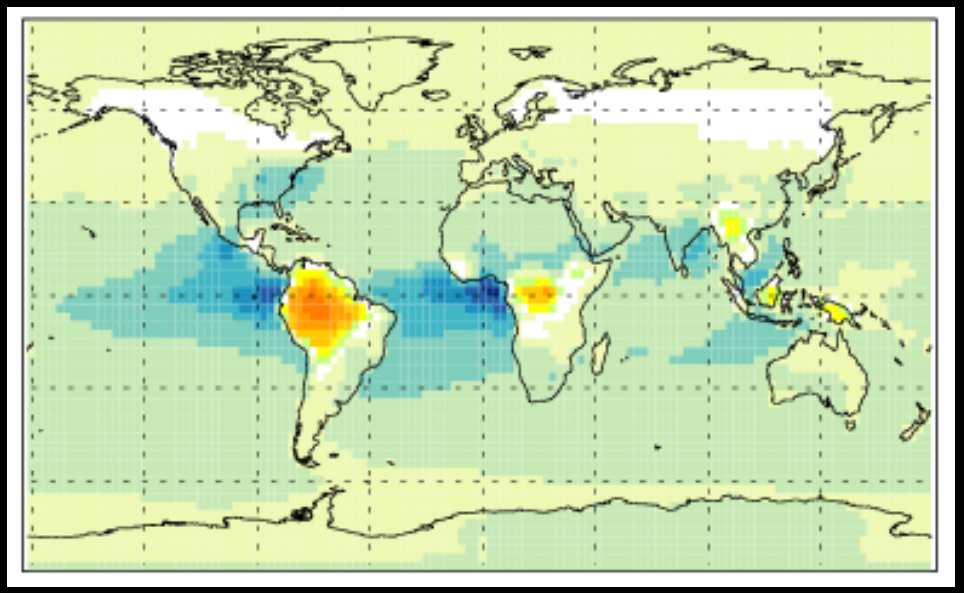


Radiative Forcing due to ΔSLCF



Ozone Radiative Forcing

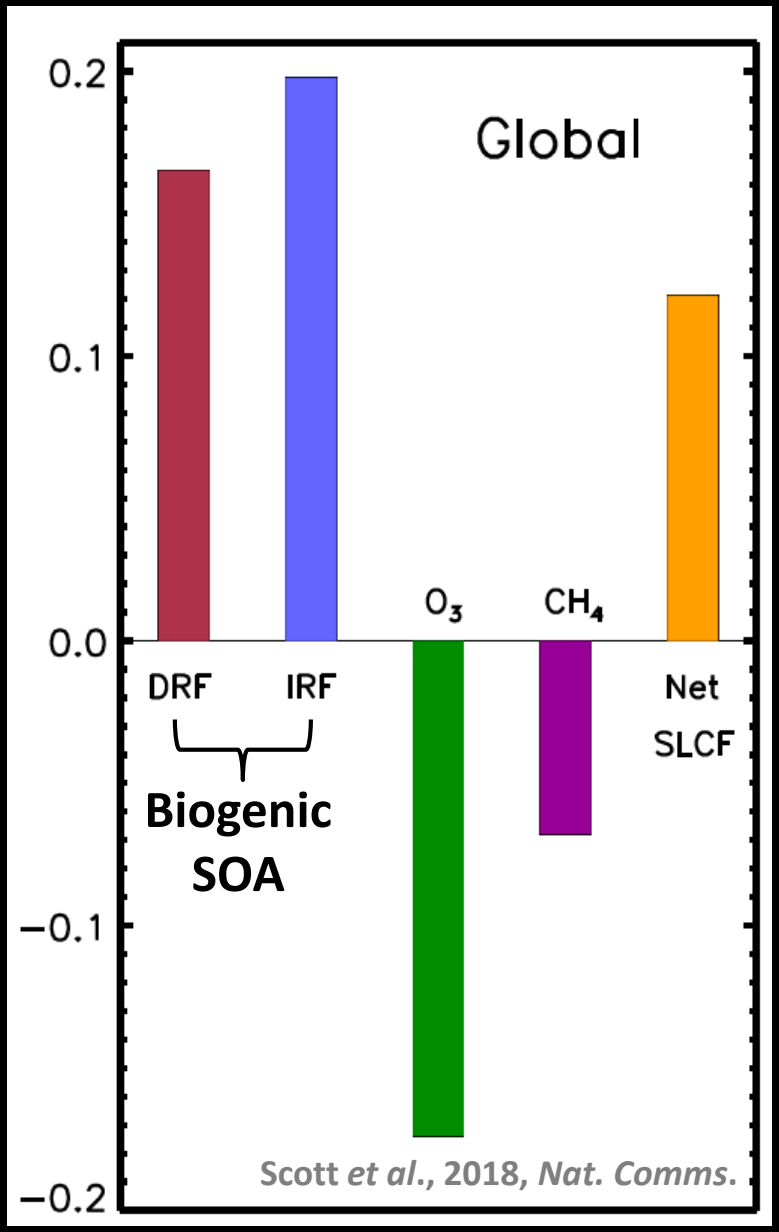
= -0.17 W m^{-2}



Annual mean Δ [O_3] (ppb) at surface

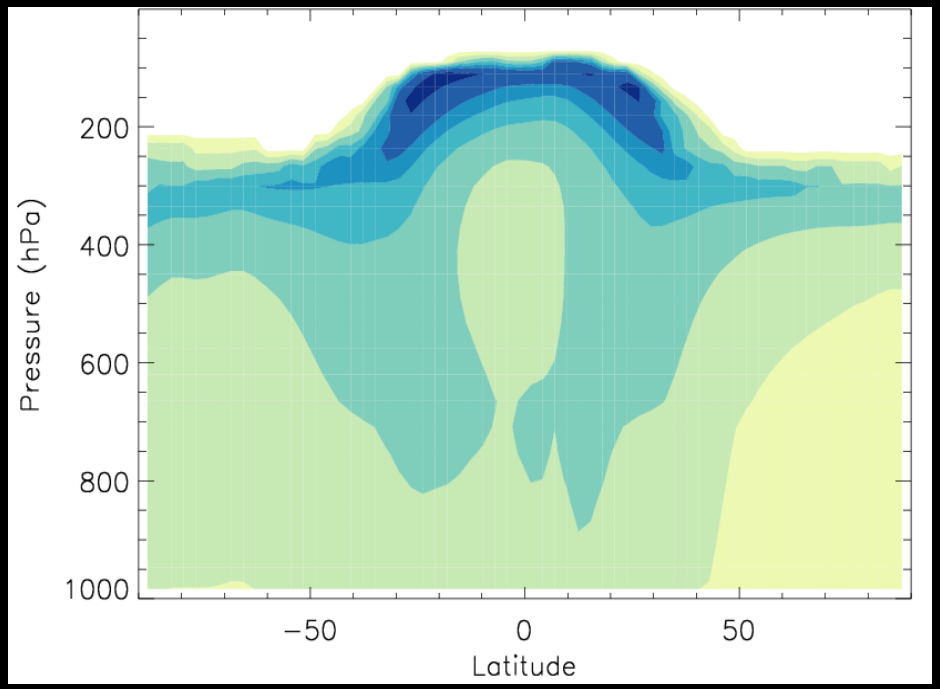
Following Rap *et al.*, 2015, *GRL*.

Radiative Forcing due to ΔSLCF



Ozone Radiative Forcing

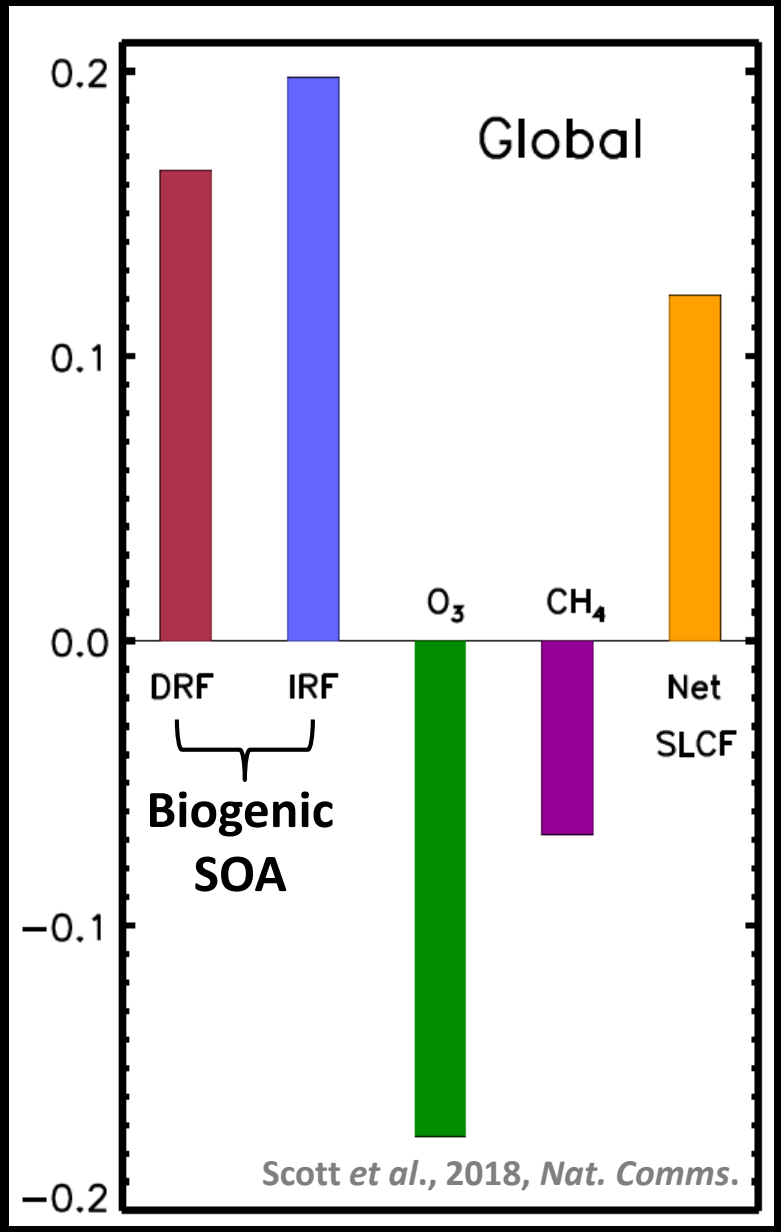
= -0.17 W m^{-2}



Annual zonal mean Δ [O_3] (ppb)

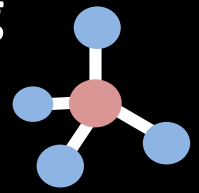
Following Rap *et al.*, 2015, *GRL*.

Radiative Forcing due to ΔSLCF



Methane Radiative Forcing

= -0.07 W m^{-2}

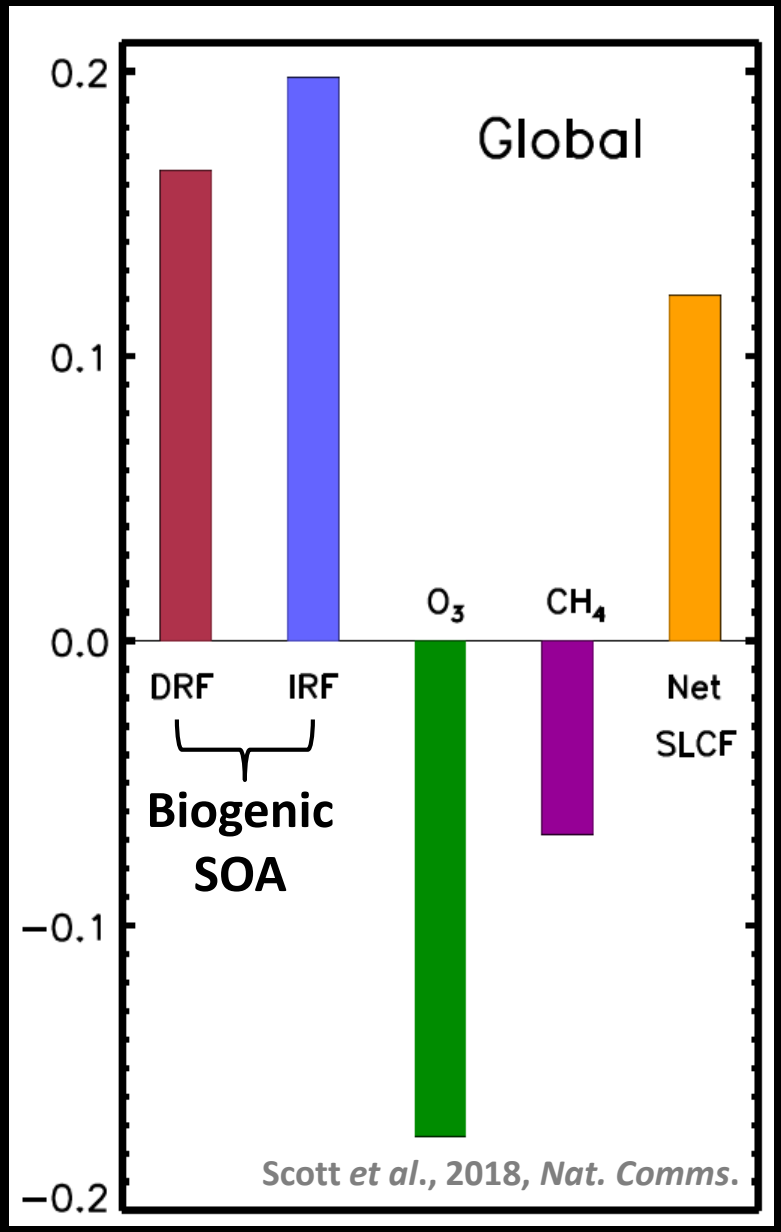


Determined from change in CH_4 chemical lifetime (τ) due to increase in [OH]

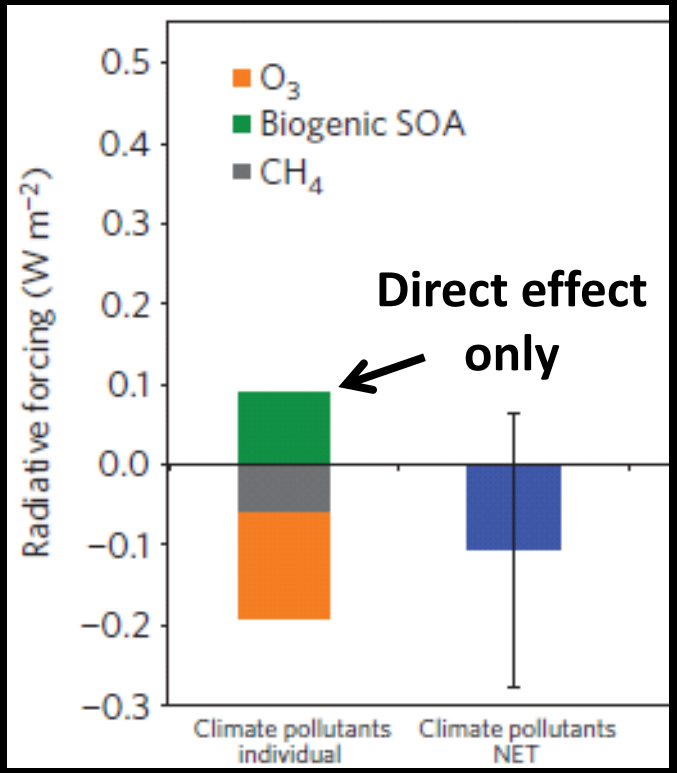
$\Delta\tau_{CH_4}$ = - 0.5 yrs

Following Myhre *et al.*, 1998 & Fuglestvedt *et al.*, 1999.

Radiative Forcing due to ΔSLCF

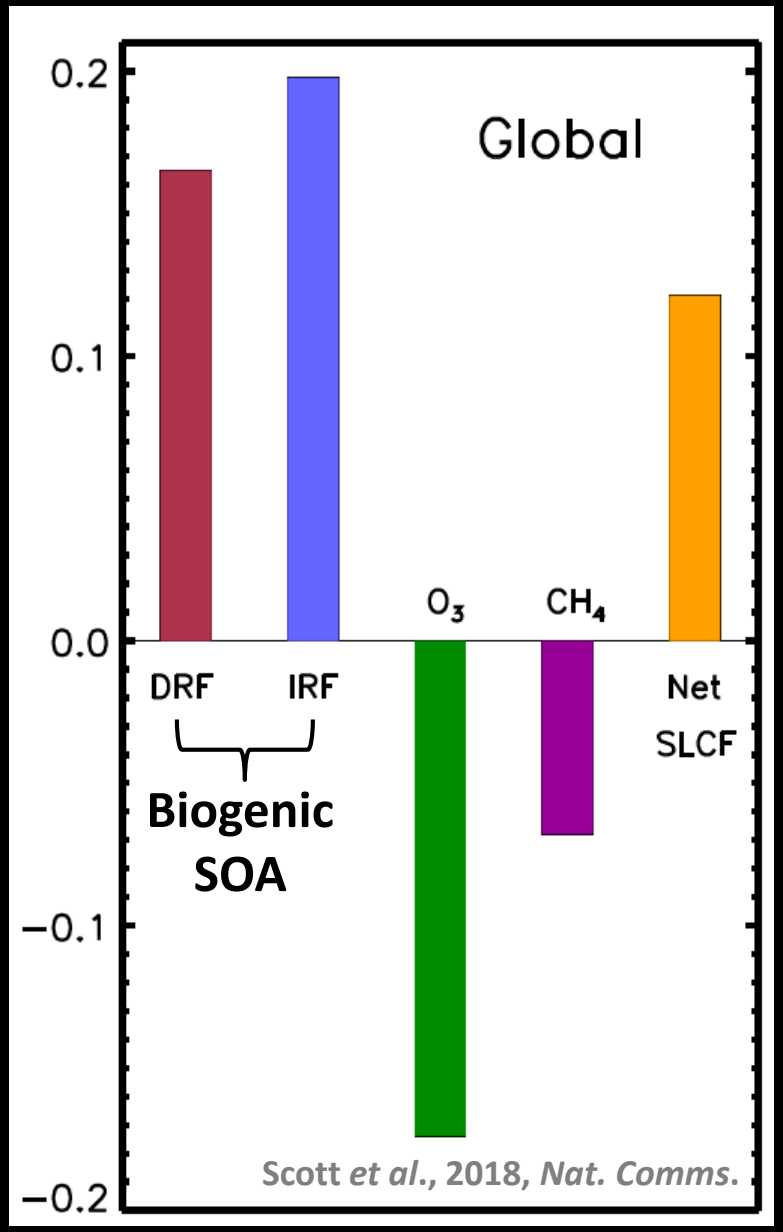


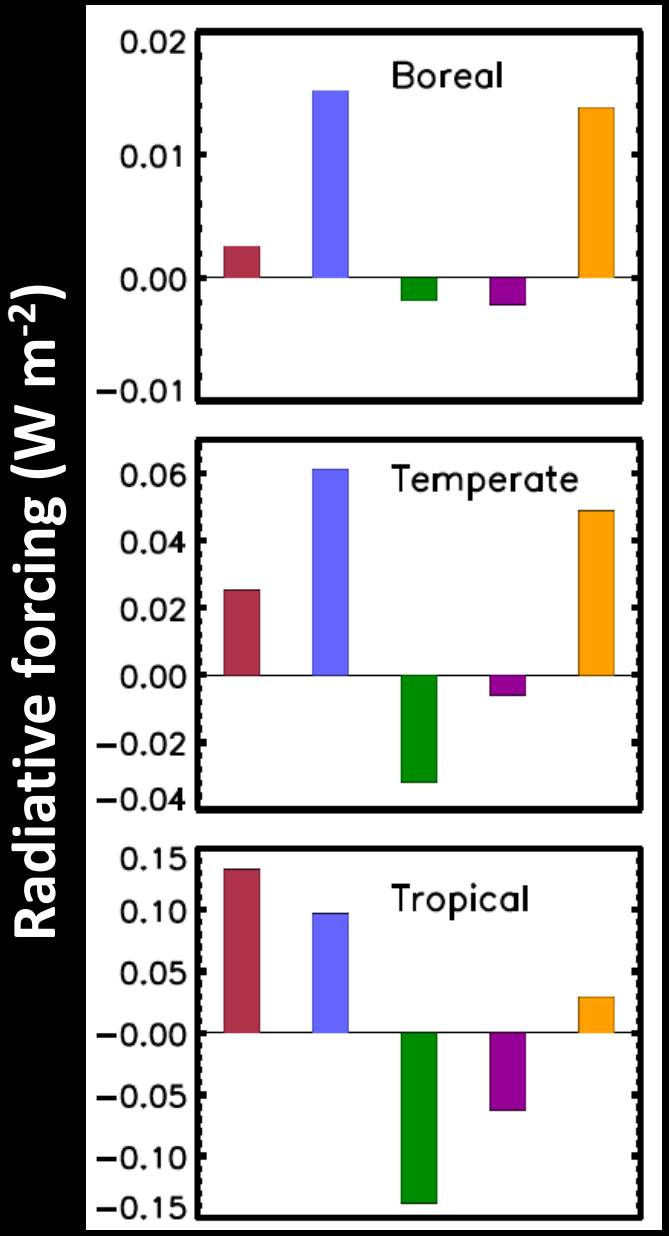
Changing land-cover from 1850 → 2000

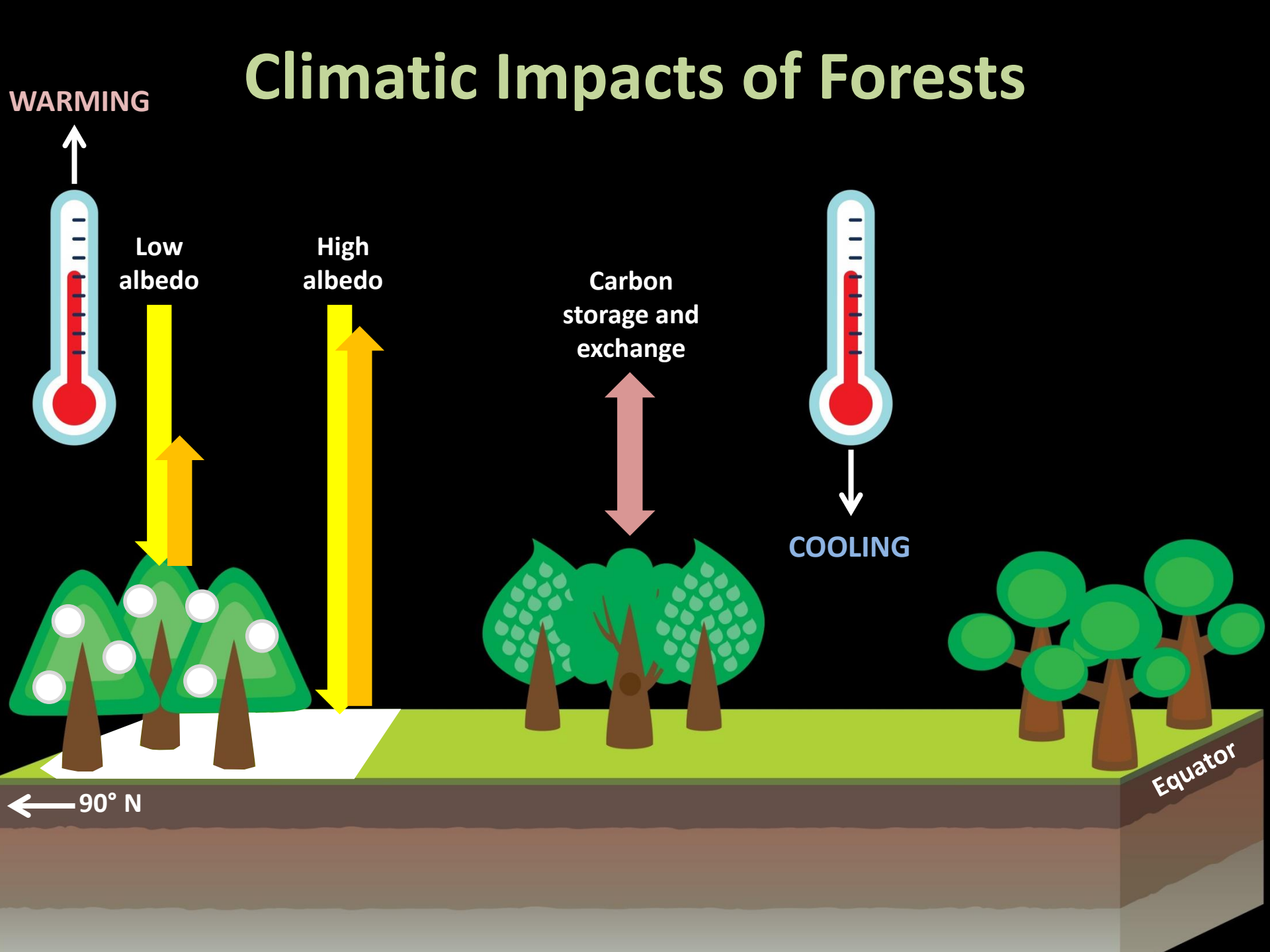


Unger, 2014, *Nature Climate Change*.

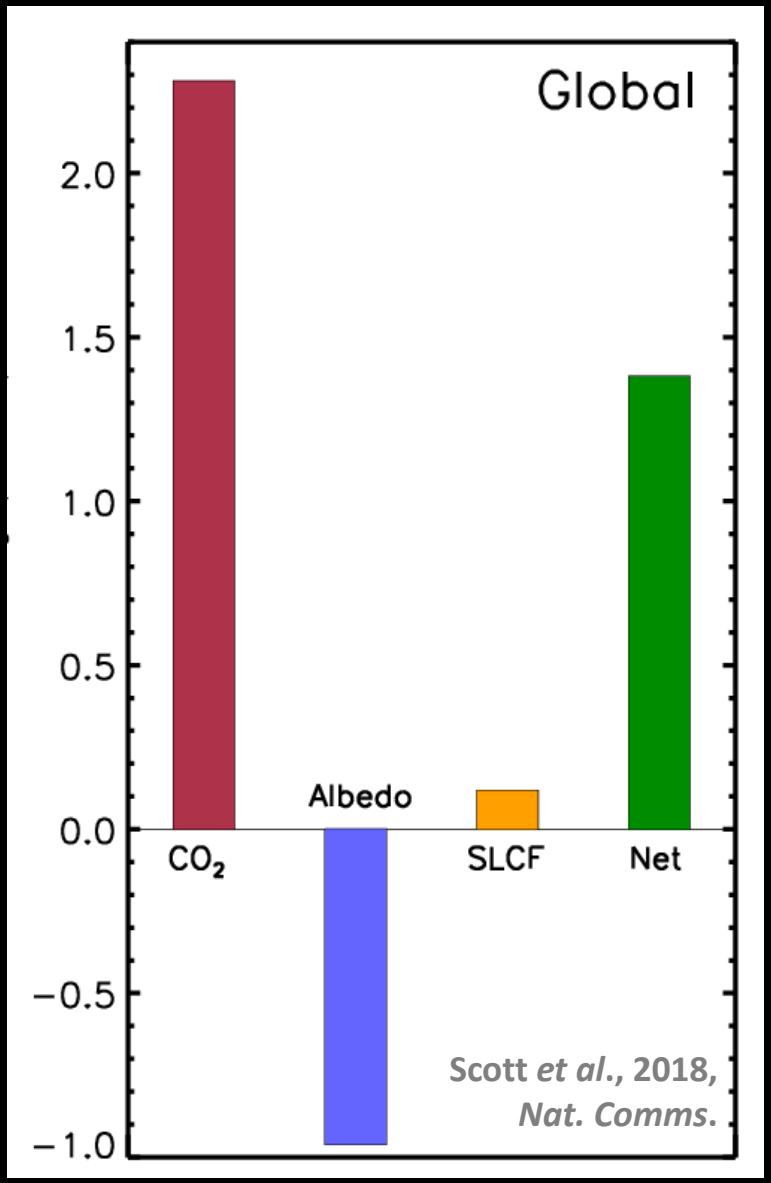
Radiative Forcing due to ΔSLCF





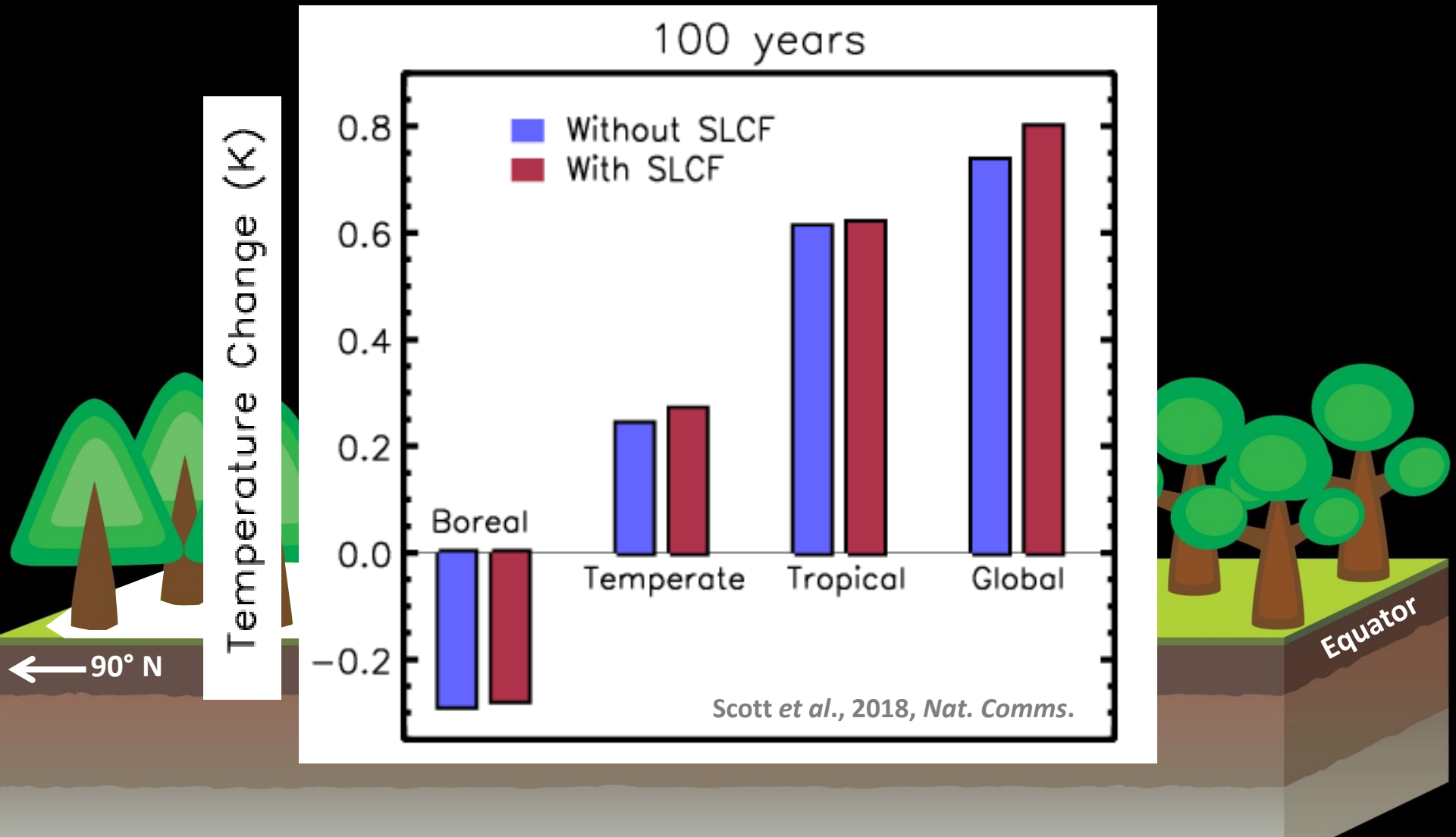

Climatic Impacts of Forests
WARMING
Low albedo
High albedo
Carbon storage and exchange
COOLING
90° N
Equator

Radiative Forcing due to Deforestation

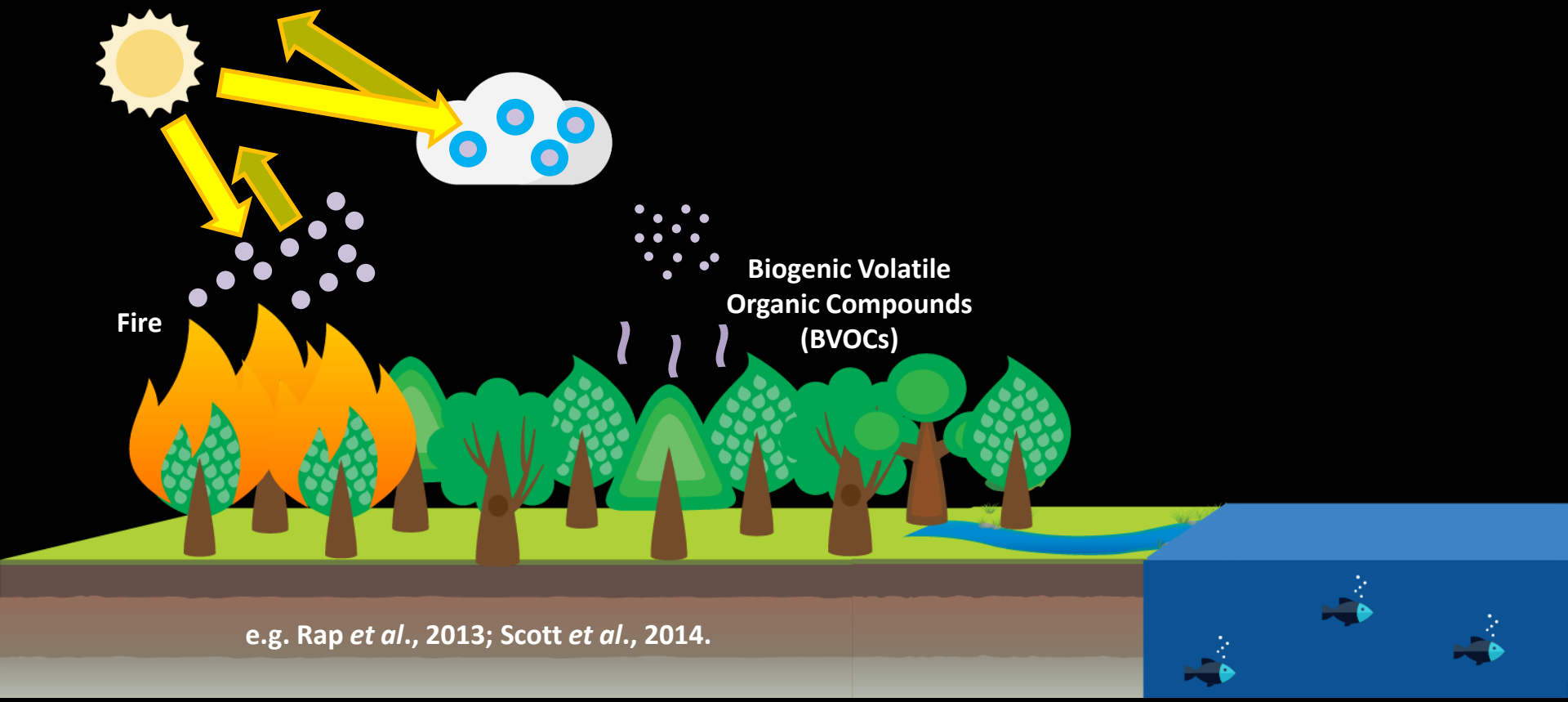


Including SLCFs increases net radiative forcing by 0.12 W m^{-2} (10%)

Global Temperature Potential (GTP) Change due to Deforestation

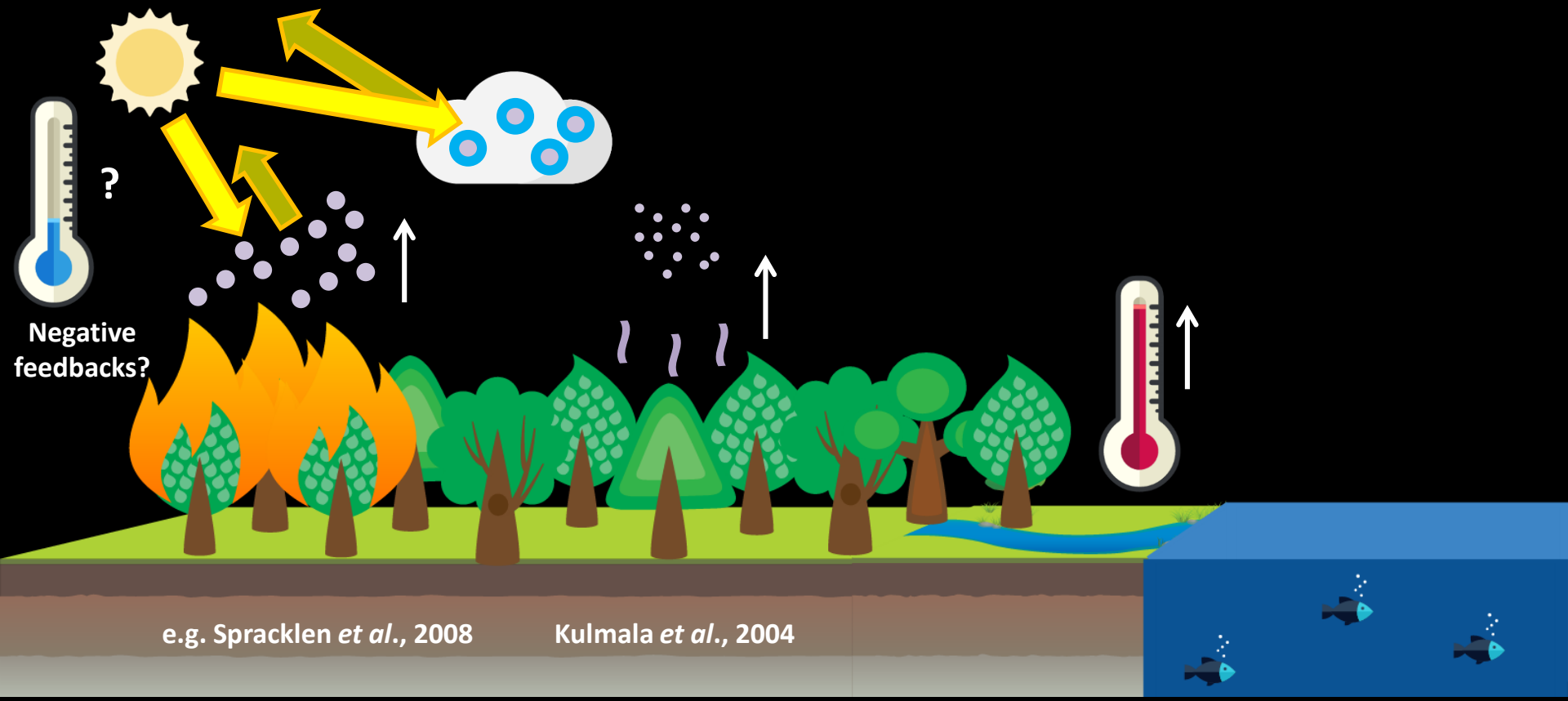


Natural aerosol – climate feedbacks

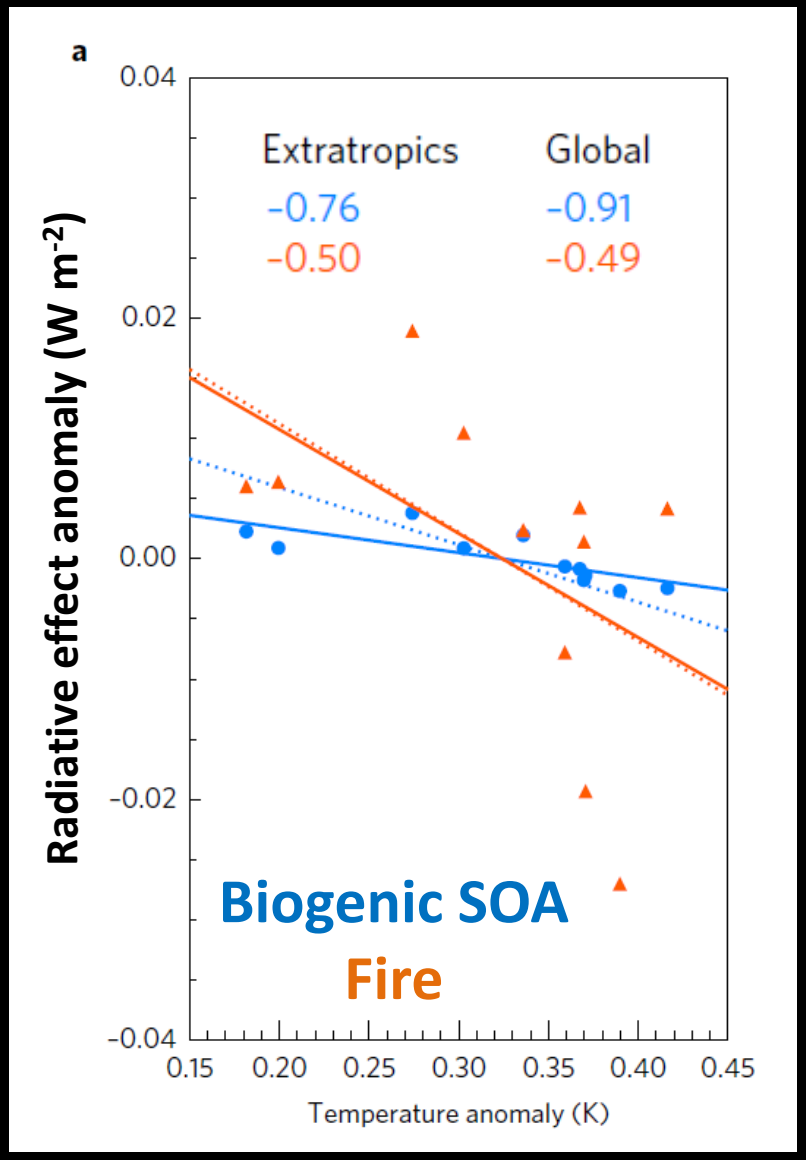


e.g. Rap *et al*., 2013; Scott *et al*., 2014.

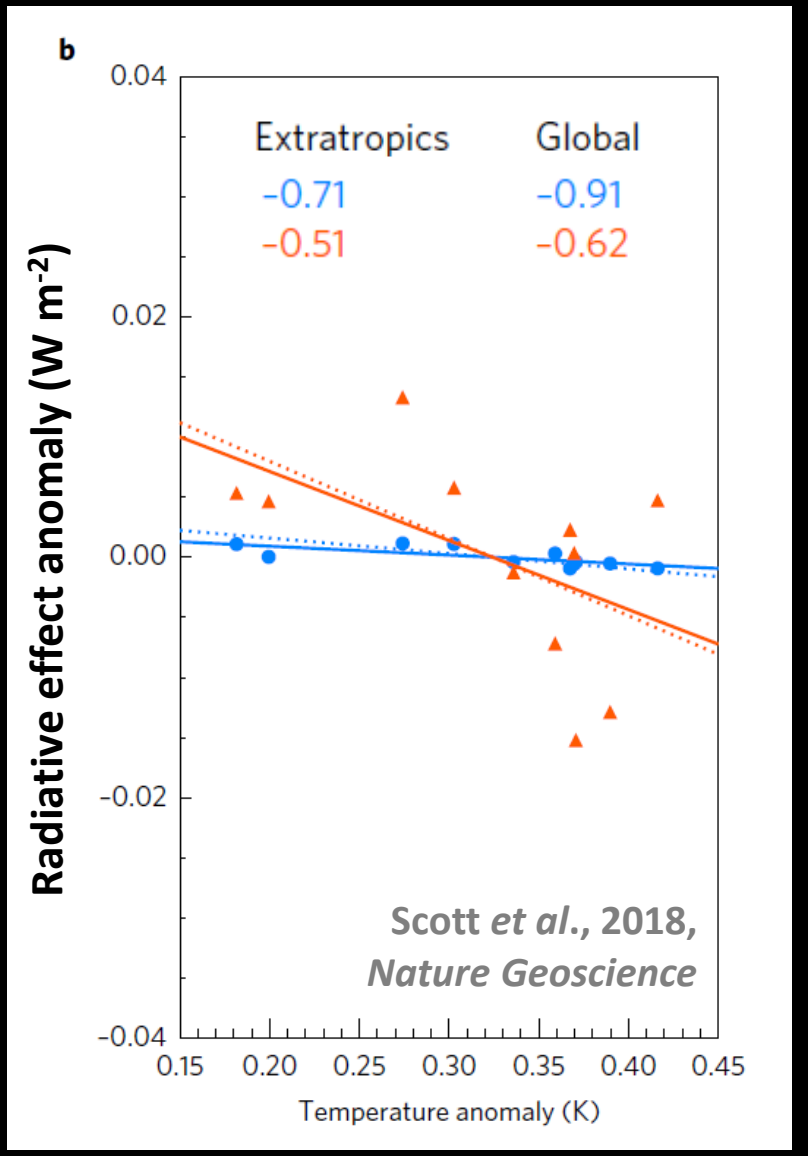
Natural aerosol – climate feedbacks



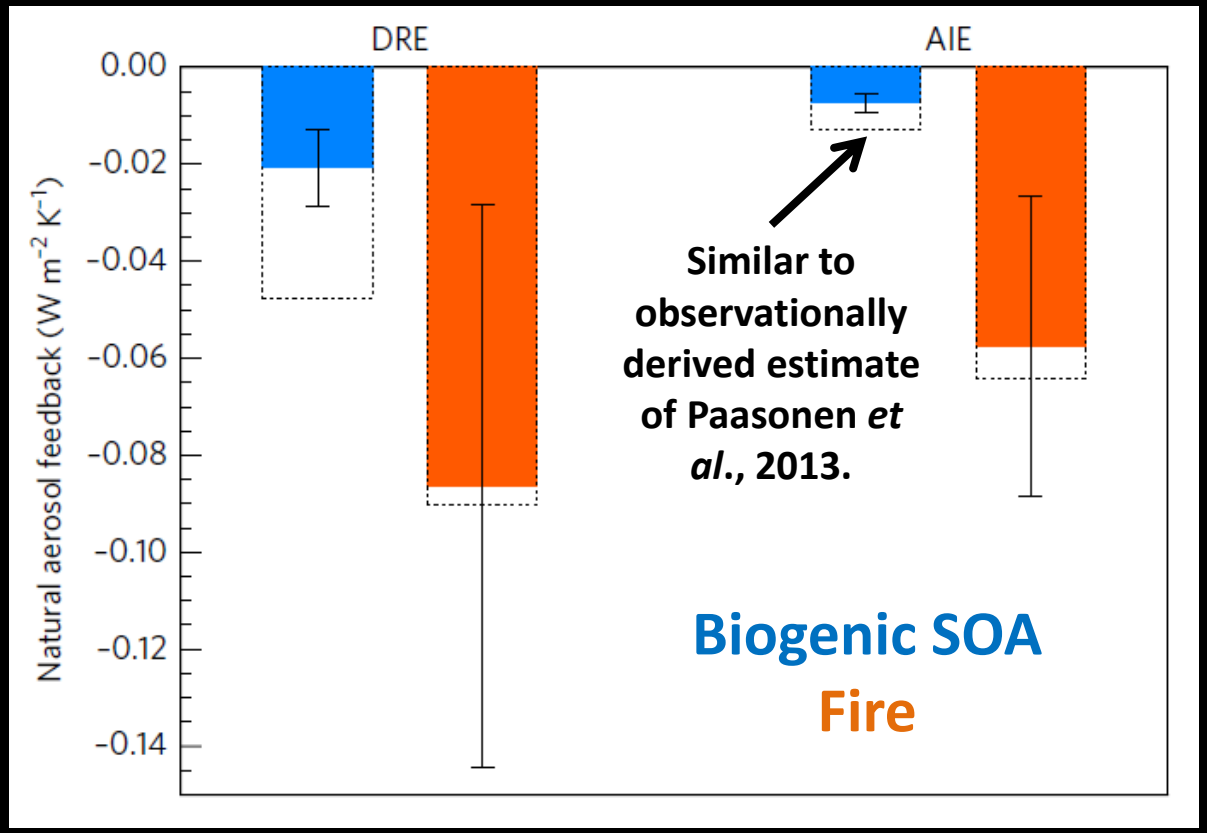
Direct Radiative Effect



Aerosol Indirect Effect



Diagnosing potential aerosol-climate feedbacks



Scott *et al.*, 2018, *Nature Geoscience*

Natural aerosol radiative feedbacks comparable in magnitude but opposite in sign to the snow albedo feedback

Fire aerosol feedback:
- 0.14 W m^{-2} K^{-1}

BVOC aerosol feedback:
- 0.03 W m^{-2} K^{-1}

Snow albedo feedback:
+ 0.1 W m^{-2} K^{-1}
(Thackeray *et al.*, 2016)

Summary

- Combining warming effect from reduction in aerosol and cooling effect from reduction in O_3 and CH_4 gives a positive net SLCF radiative forcing in response to global deforestation -> increases the net RF (due to CO_2 and surface albedo changes) by ~10%
- Annual mean aerosol radiative effects from fire and biogenic SOA are negatively correlated with global mean temperature anomaly
- Strength of extra-tropical aerosol-climate feedbacks (- 0.14 W m^{-2} K^{-1} for fire and - 0.03 W m^{-2} K^{-1} for biogenic SOA) is comparable to other biogeochemical feedbacks
- Natural aerosol-climate feedbacks *may* moderate net temperature response to warming driven by CO_2 increases, or other forcing agents