Interactions of SLCPs and air pollutants with land-use change

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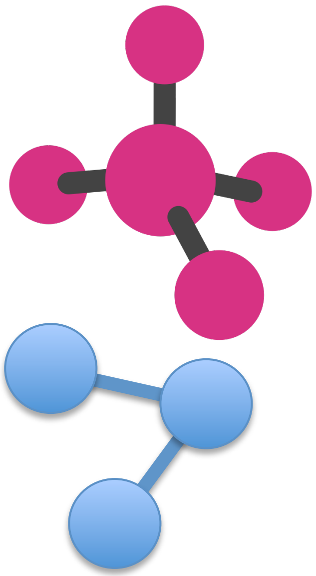
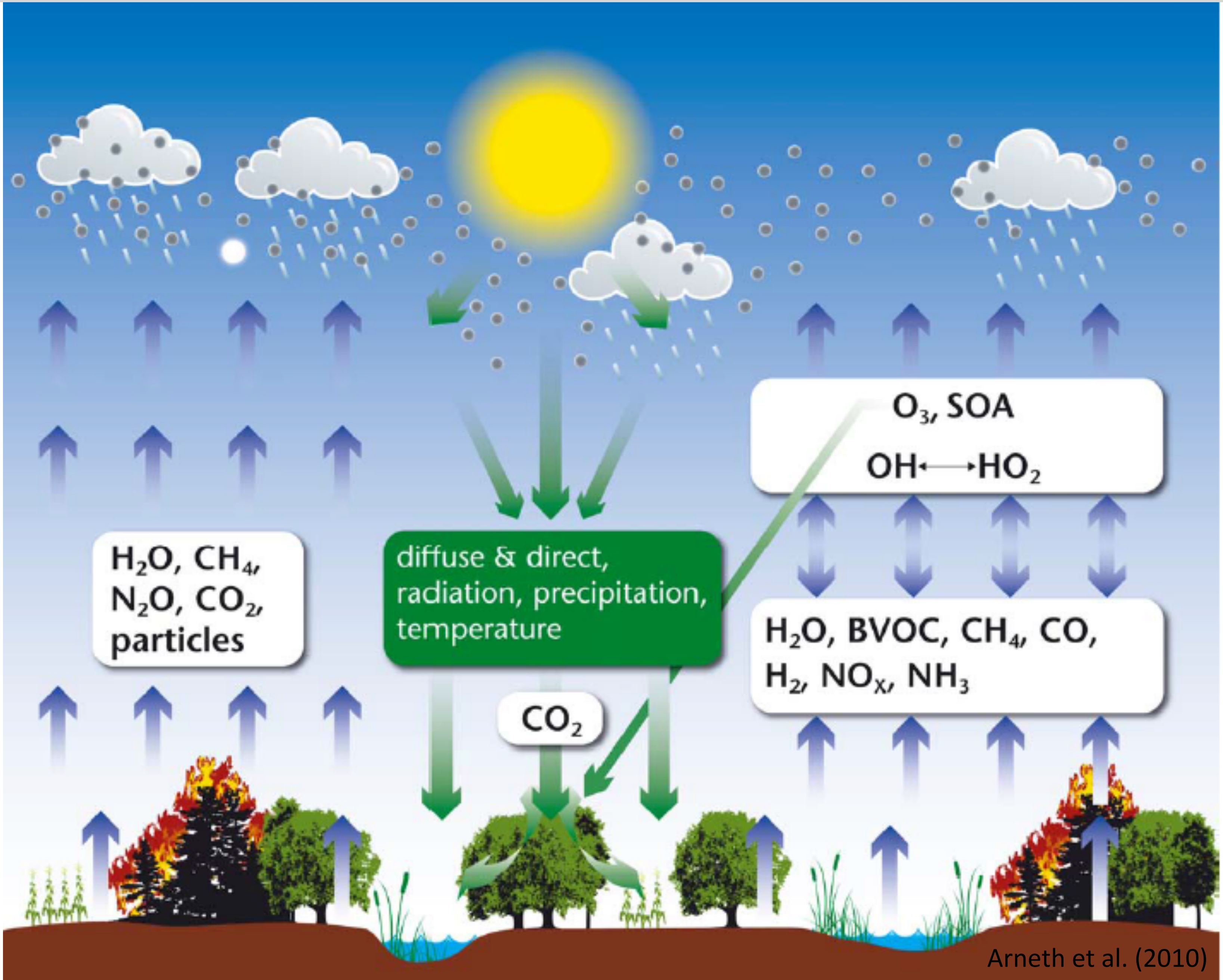
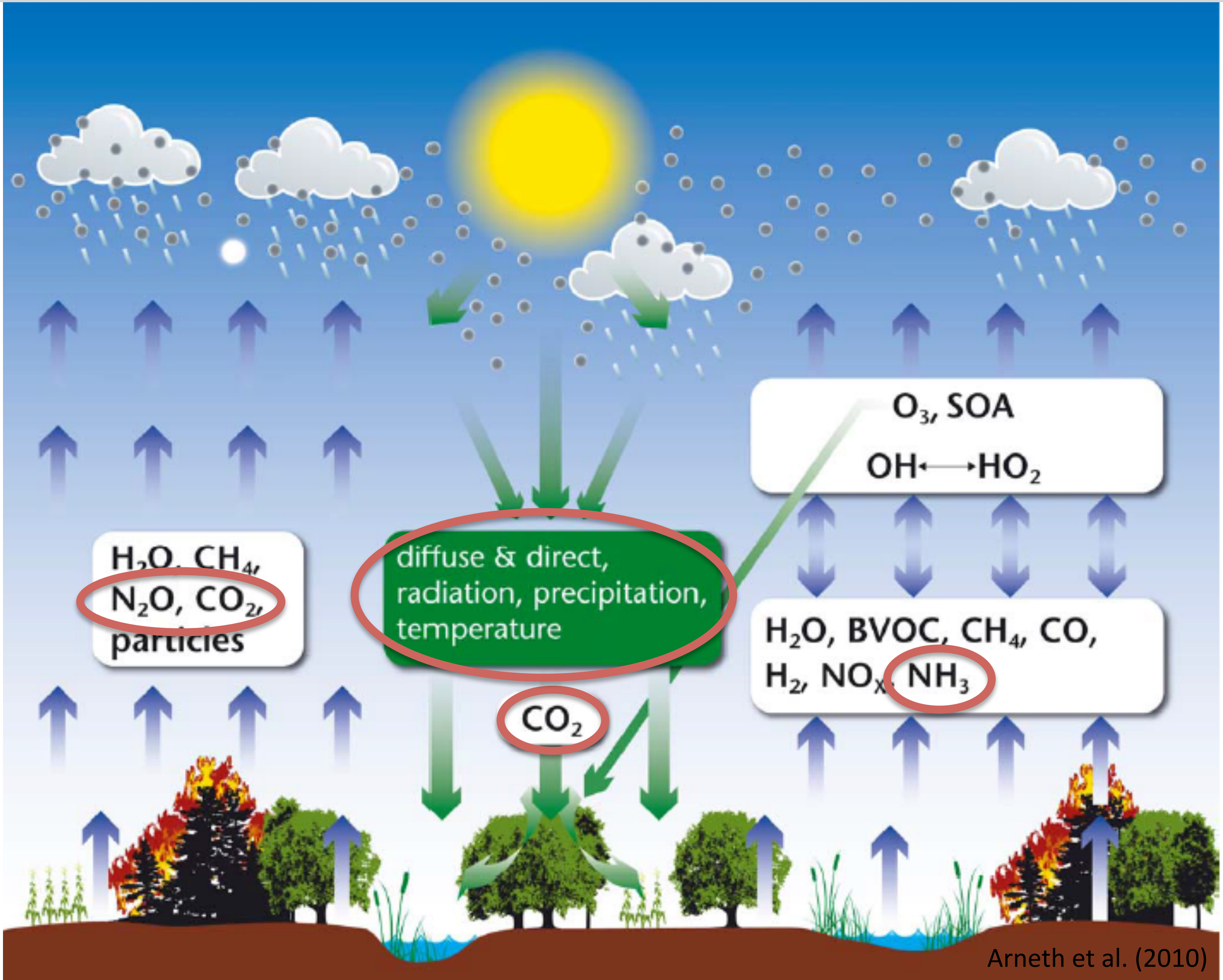


SLCPs



Arneth et al. (2010)

SLCPs



O$_3$, SOA
OH ⟷ HO$_2$
H_2O, CH_4, N_2O, CO_2, particles
diffuse & direct, radiation, precipitation, temperature
CO_2
H_2O, BVOC, CH_4, CO, H_2, NO_X, NH_3
Arneth et al. (2010)

SLCPs

Short-lived climate pollutants: Climate-altering substances with a short atmospheric lifetime of days to *ca.* 1 decade

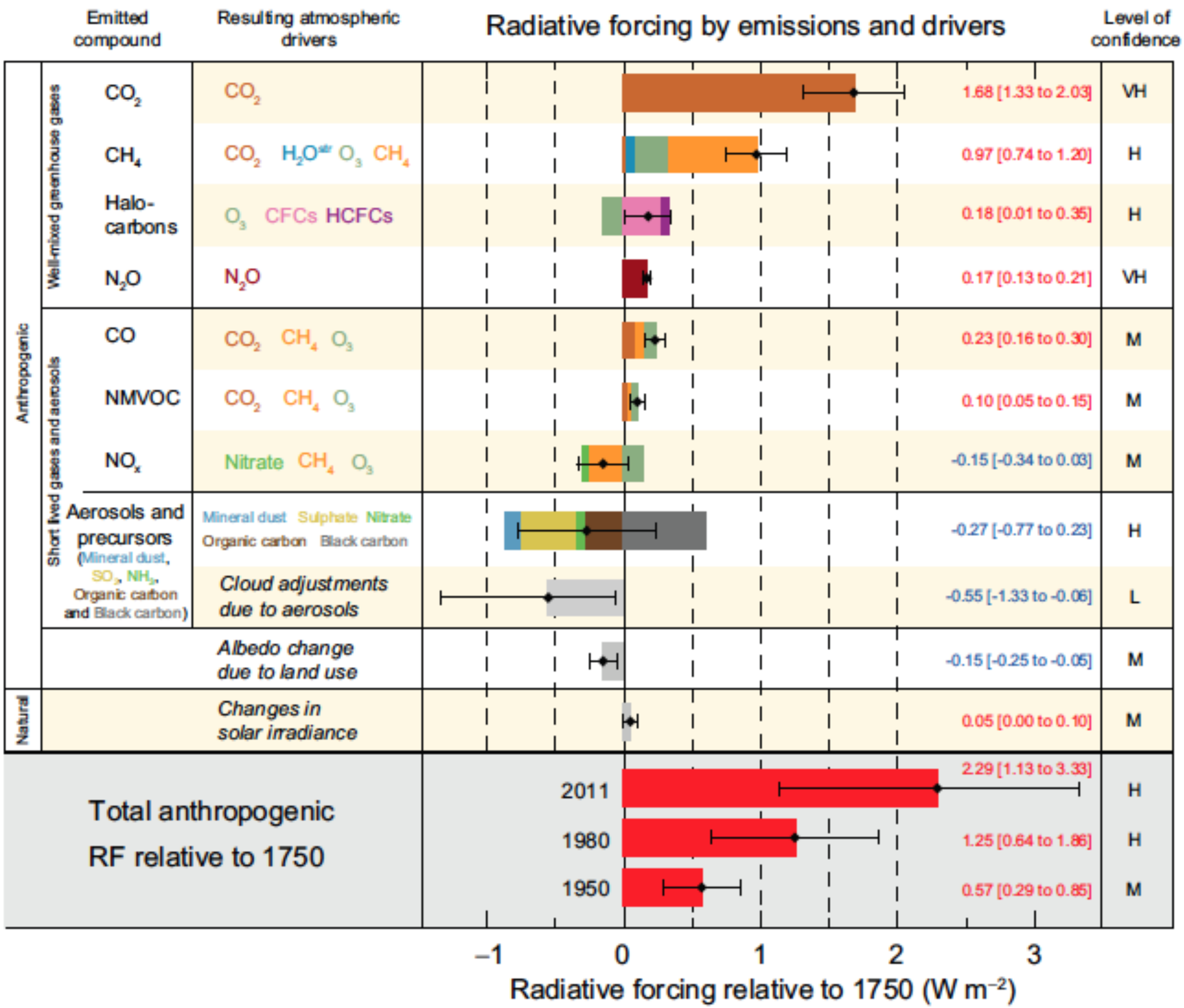
- Particulate matter (PM)
  - Black carbon
- Tropospheric ozone
- Methane
- Hydrofluorocarbons
  (industrially produced, not discussed further here)

Also precursors:

- BVOCs
- NO_x ($NO + NO_2$)

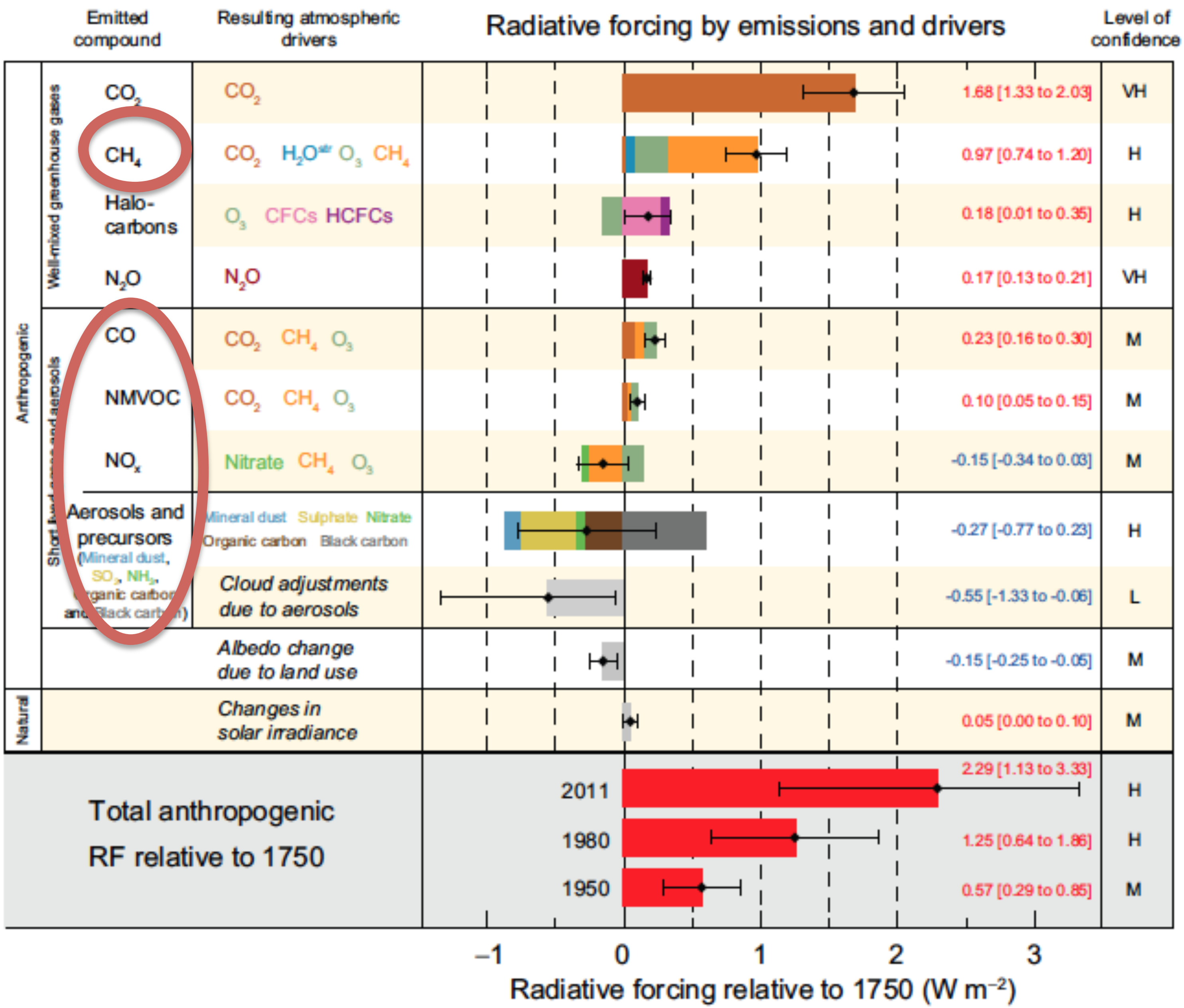
Will focus here on those pollutants relevant to land-use change

SLCPs: Climate influence



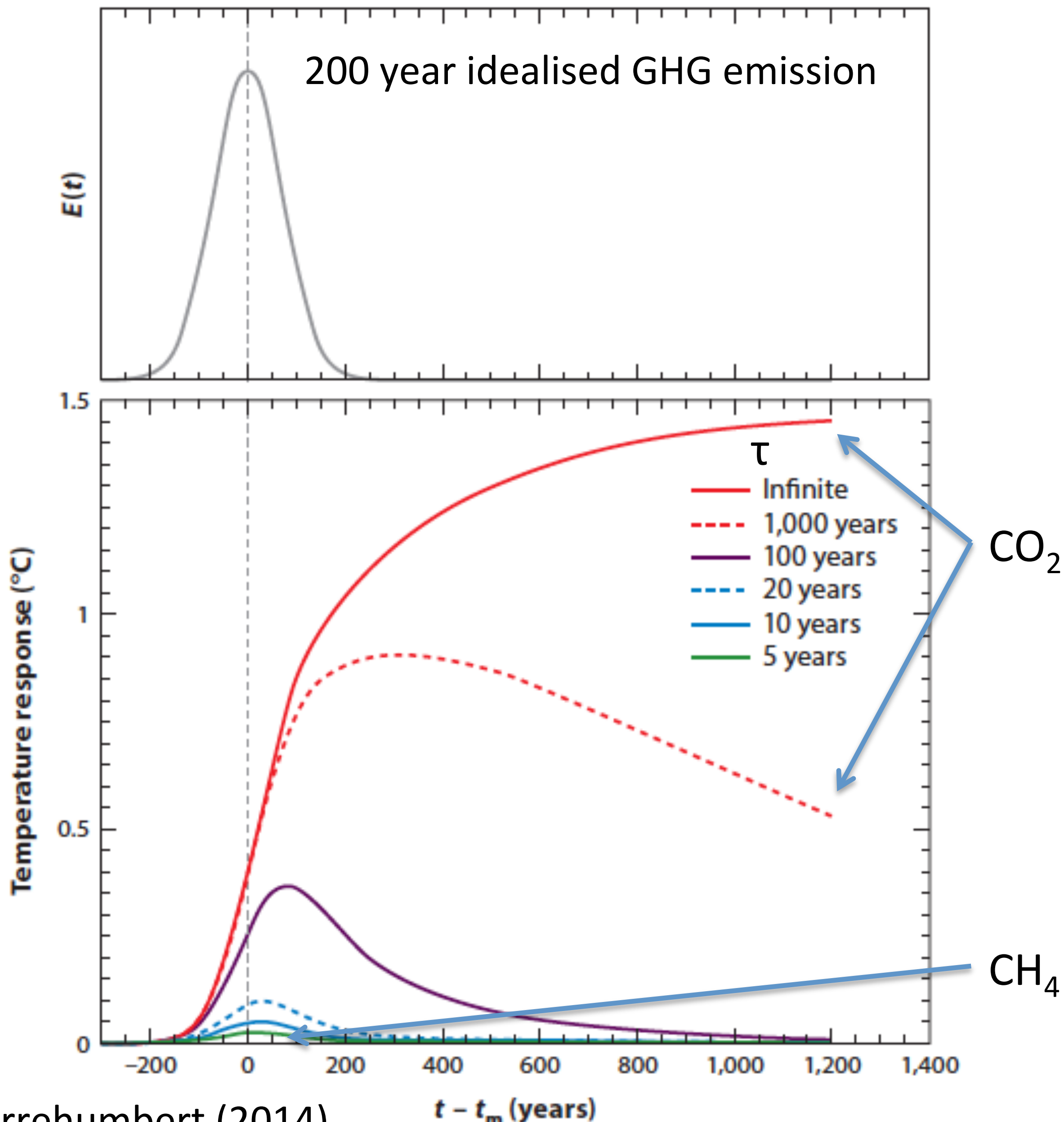
IPCC (2013)

SLCPs: Climate influence



IPCC (2013)

SLCPs: Climate influence



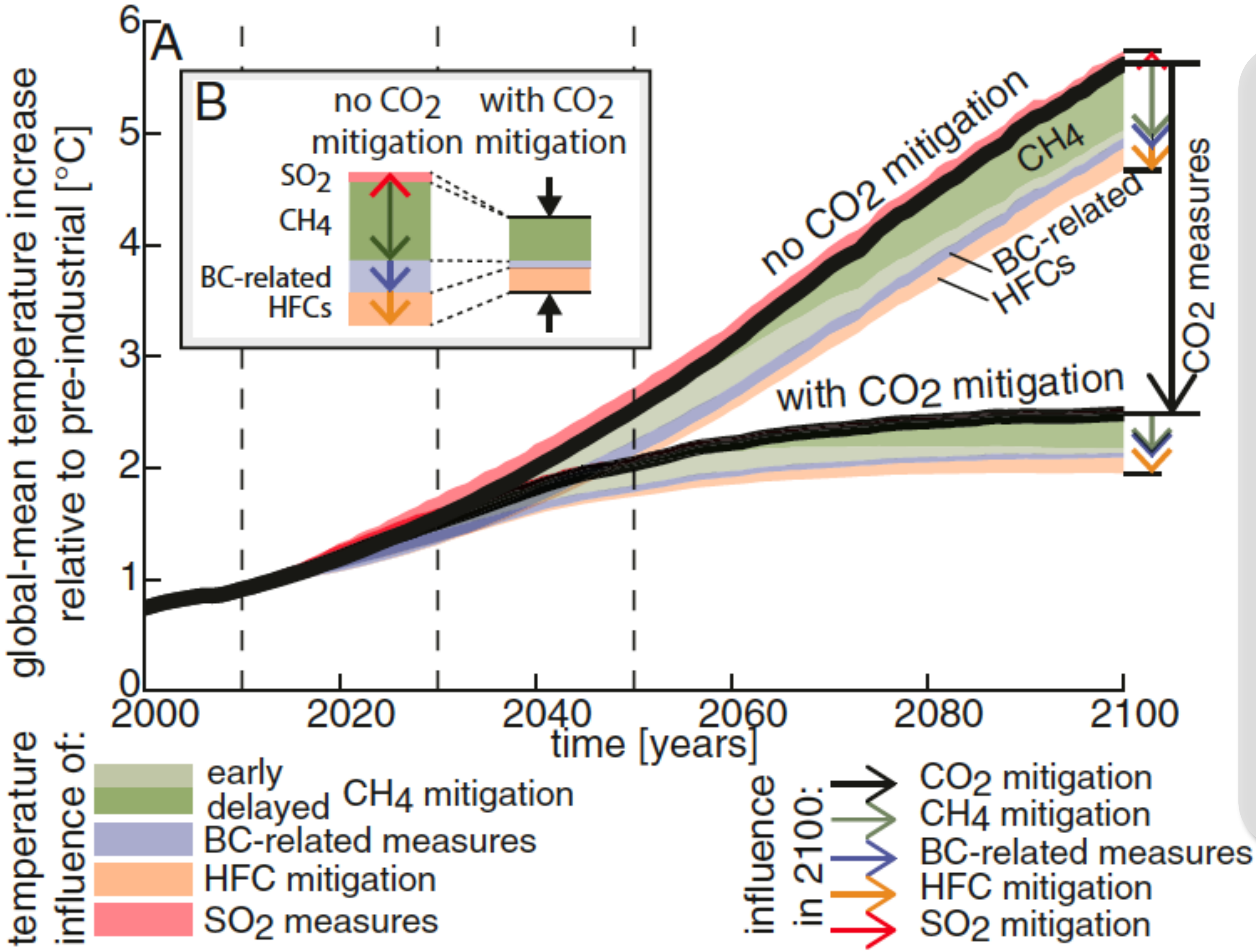
Pierrehumbert (2014)

Short-lived gases do not accumulate in the atmosphere. Thus reductions in their emissions quickly translate to reductions in temperature.

CO2 has a very long lifetime, so its emissions have a cumulative effect on temperature.

Not enough to compare radiative forcings alone!

SLCPs: Climate influence



SLCPs do NOT buy us time

SLCPs have a substantial influence on climate. But reductions will not outweigh increases in [CO_2] in the long-term

Rogelj et al. (2014)

Particulate matter

Particles small enough to be suspended in the atmosphere
>20 µm in diameter rapidly lost
<10 µm commonly known as PM_{10}

Reflect solar radiation, therefore giving cooling effect.

- EXCEPT black carbon which absorbs & therefore warms.

However, black carbon sources all emit precursors to reflecting aerosols. The best estimate of the net effect is a slight cooling (Pierrehumbert, 2014)

Causes respiratory and circulatory problems in humans and animals. Especially very fine particles (<1µm).
Total deaths from air pollution 3.7 million in 2012 (WHO)

Lifetime of days to weeks -> Not well mixed

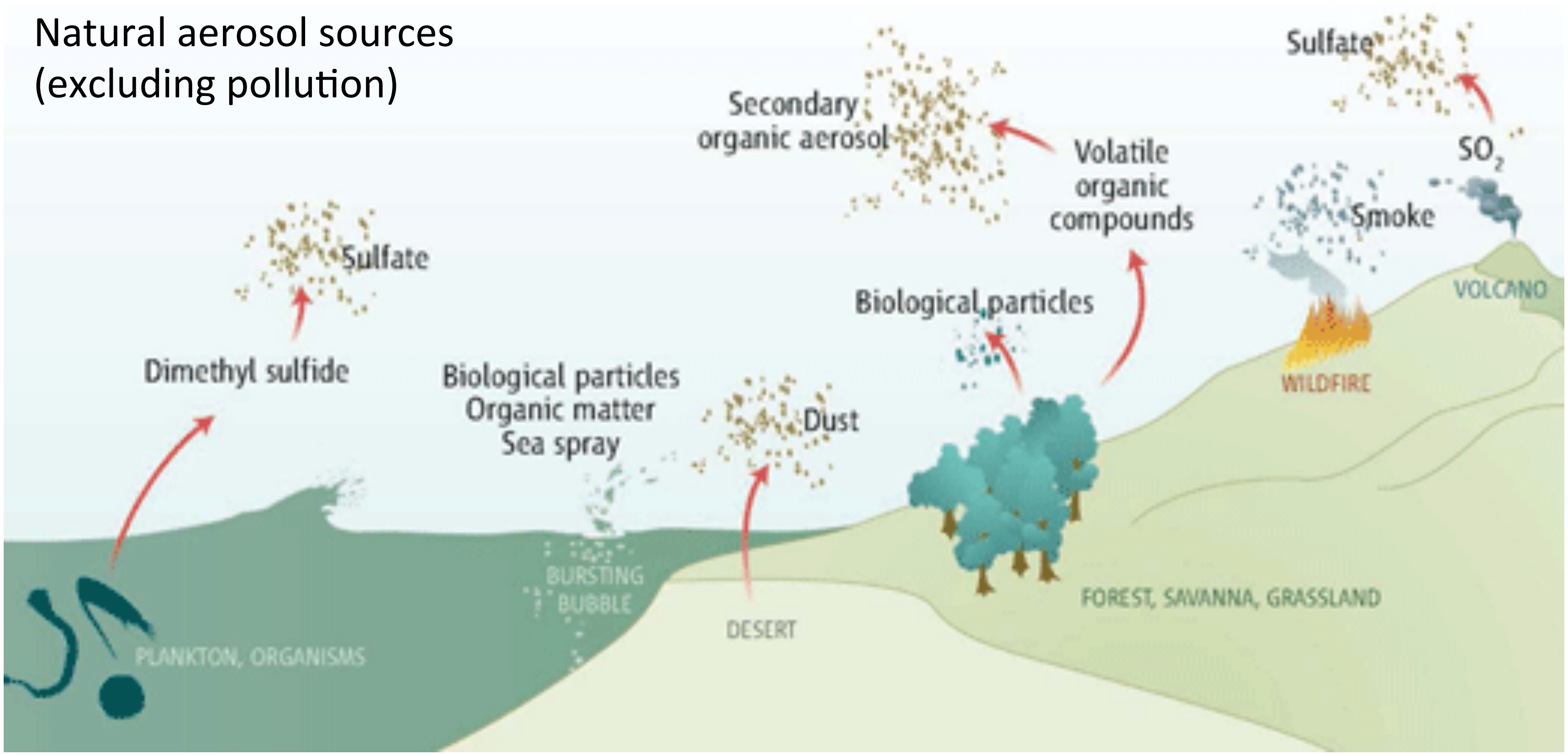
Either directly emitted (primary aerosol) or formed from condensing of vapours in the atmosphere (secondary aerosol), such as those from the oxidation of large VOCs

Particulate matter

Land-use related sources:

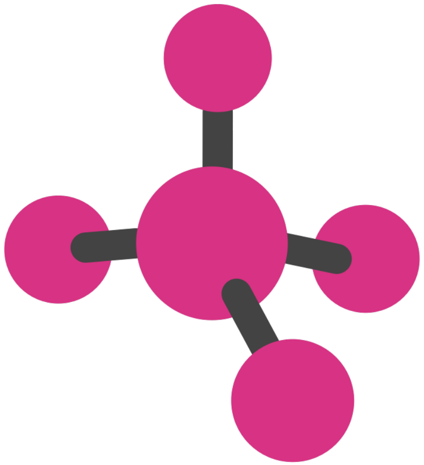
- Biomass burning (modification of land-management and clearing practices)
- Change in plant cover modifies BVOC emissions (discussed later), nitrate emissions, and biological particle release (e.g. pollen).
- Change in land management modifies BVOC, nitrate and pollen emissions
- Desertification?

Natural aerosol sources
(excluding pollution)



Picture, Andreae (2007)

Methane



Major GHG
Radiative forcing:
3.7×10^{-4} W m^{-2} ppbv^{-1} (26× that for CO_2)
Increase in direct radiative forcing relative to 1750:
0.483 W m^{-2} (26% of that for CO_2)
Also increases stratospheric H_2O (small warming)

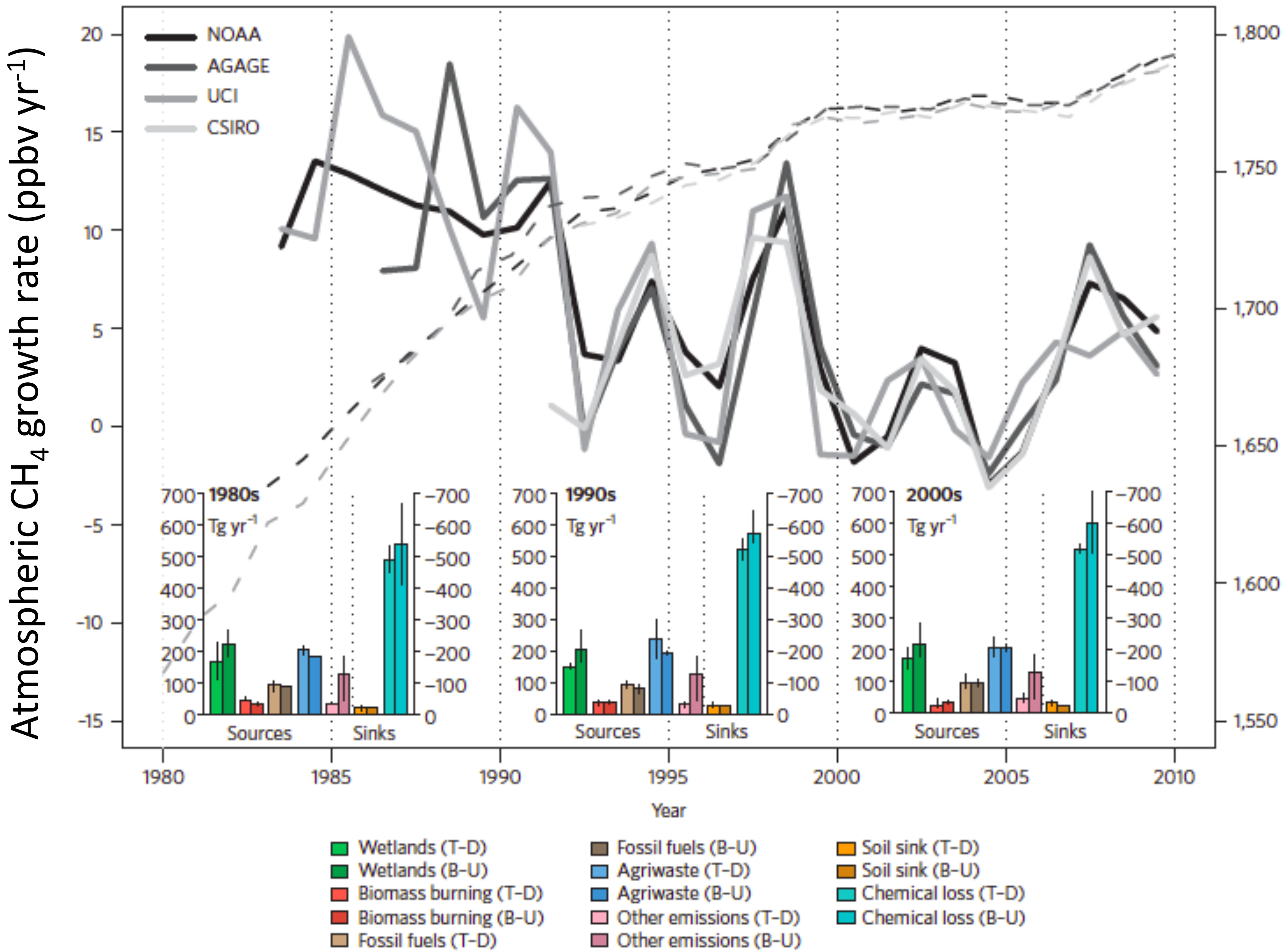
Primary precursor for tropospheric ozone, although effect is relatively diffuse due to slow oxidation rate.

Atmospheric lifetime of *ca.* 12 years -> Well mixed.
(depends primarily on the concentration of the OH radical)

Anthropogenic biogenic sources:
Rice paddies, ruminant livestock, landfills, wetlands, waste treatment (break-down of organic matter in anaerobic conditions)

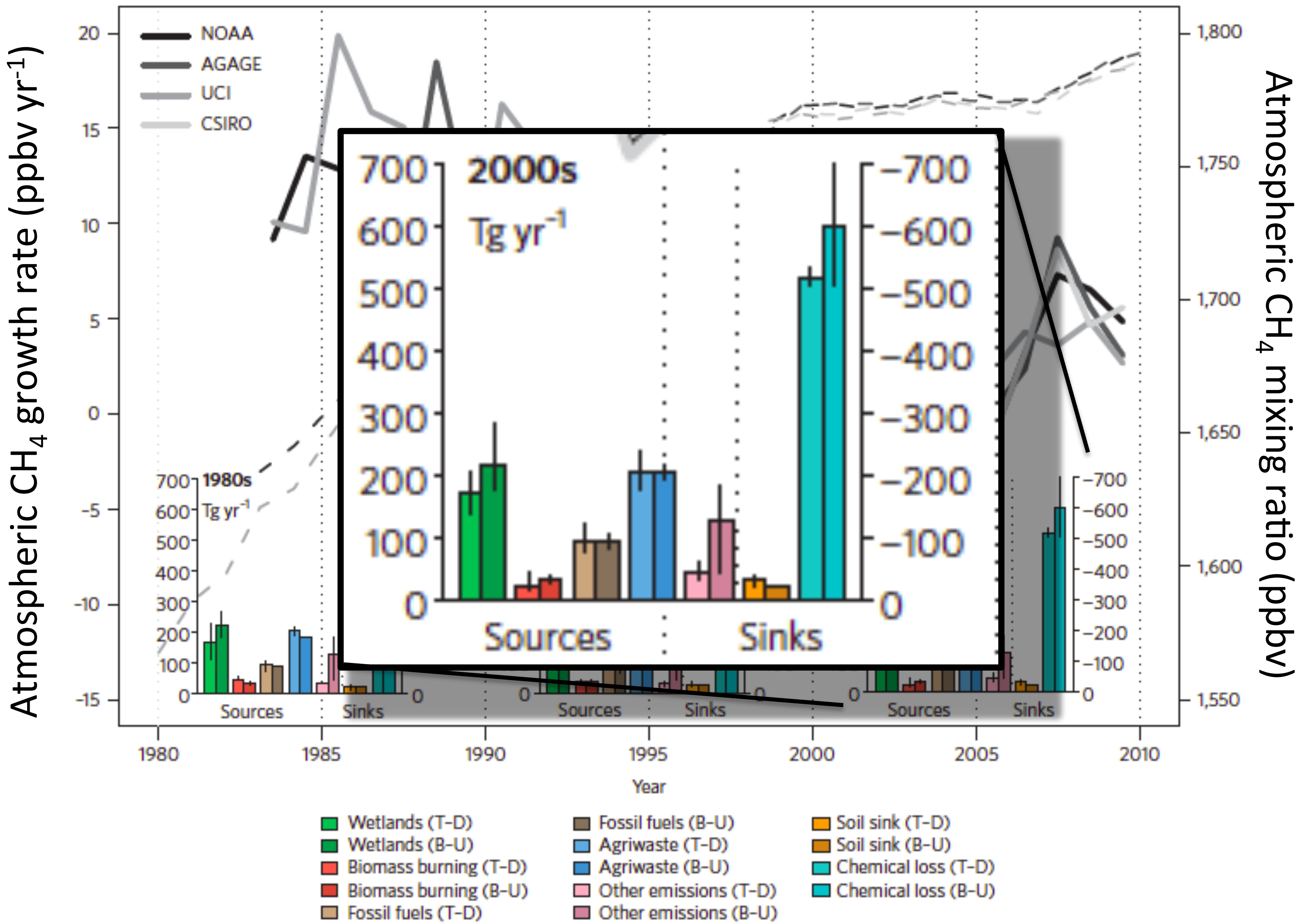
Data, Pierrehumbert (2014)

Methane



Figure, Kirschke et al. (2013)

Methane



Figure, Kirschke et al. (2013)

Methane: Interactions with LUC

Rice paddies
Currently 5-6% of global emissions

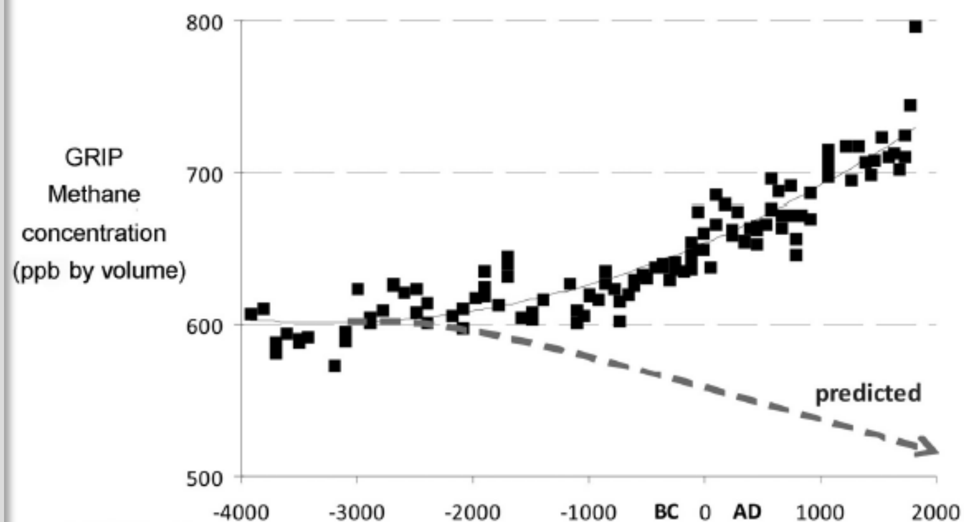
Ruminant number
Currently ca. 14% of global emissions

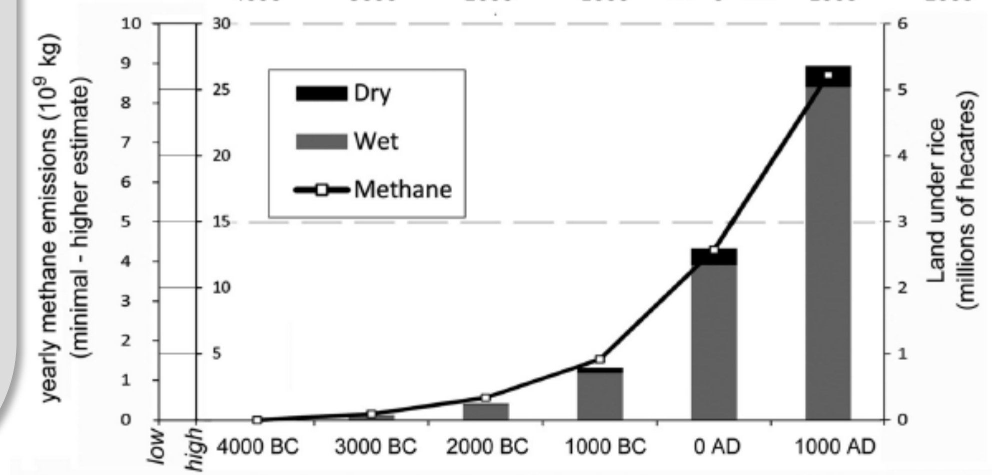
Draining of wetlands
Natural wetlands currently ca. 30% of global emissions

Biomass burning
(can be related to land clearance and management)
Currently *ca.* 2-3% of global emissions are from tropical and boreal forest burning from (all causes)

Numbers from Ciais et al. (2013), based on bottom-up estimates

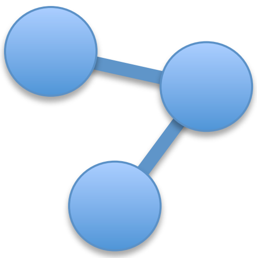
Expansion of rice agriculture in Holocene





Figures, Fuller et al. (2011)

Major GHG
Increase in radiative forcing relative to 1750:
0.4 W m^{-2} (21% of that for CO_2)



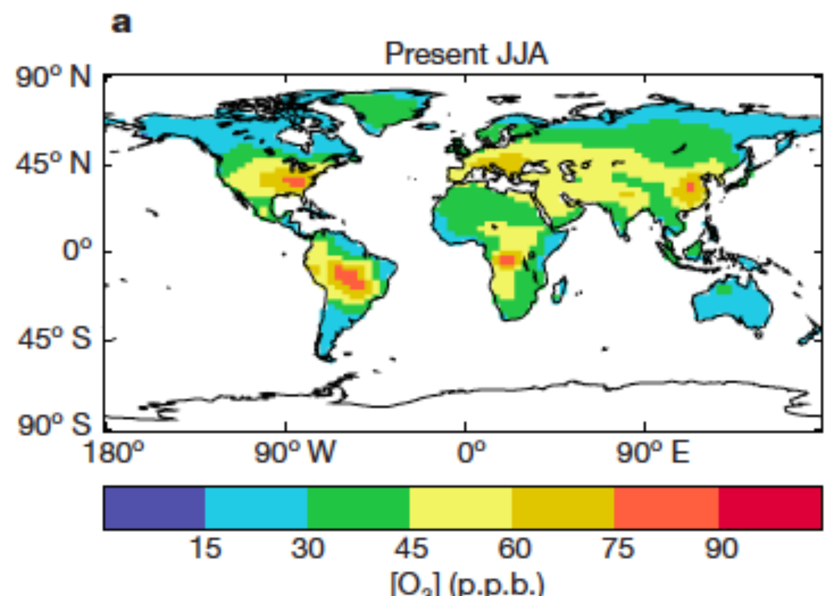
Mixing ratios above *ca.* 50 ppbv considered damaging for human and plant health (WHO)

- Causes respiratory problems

Atmospheric lifetime of hours to days

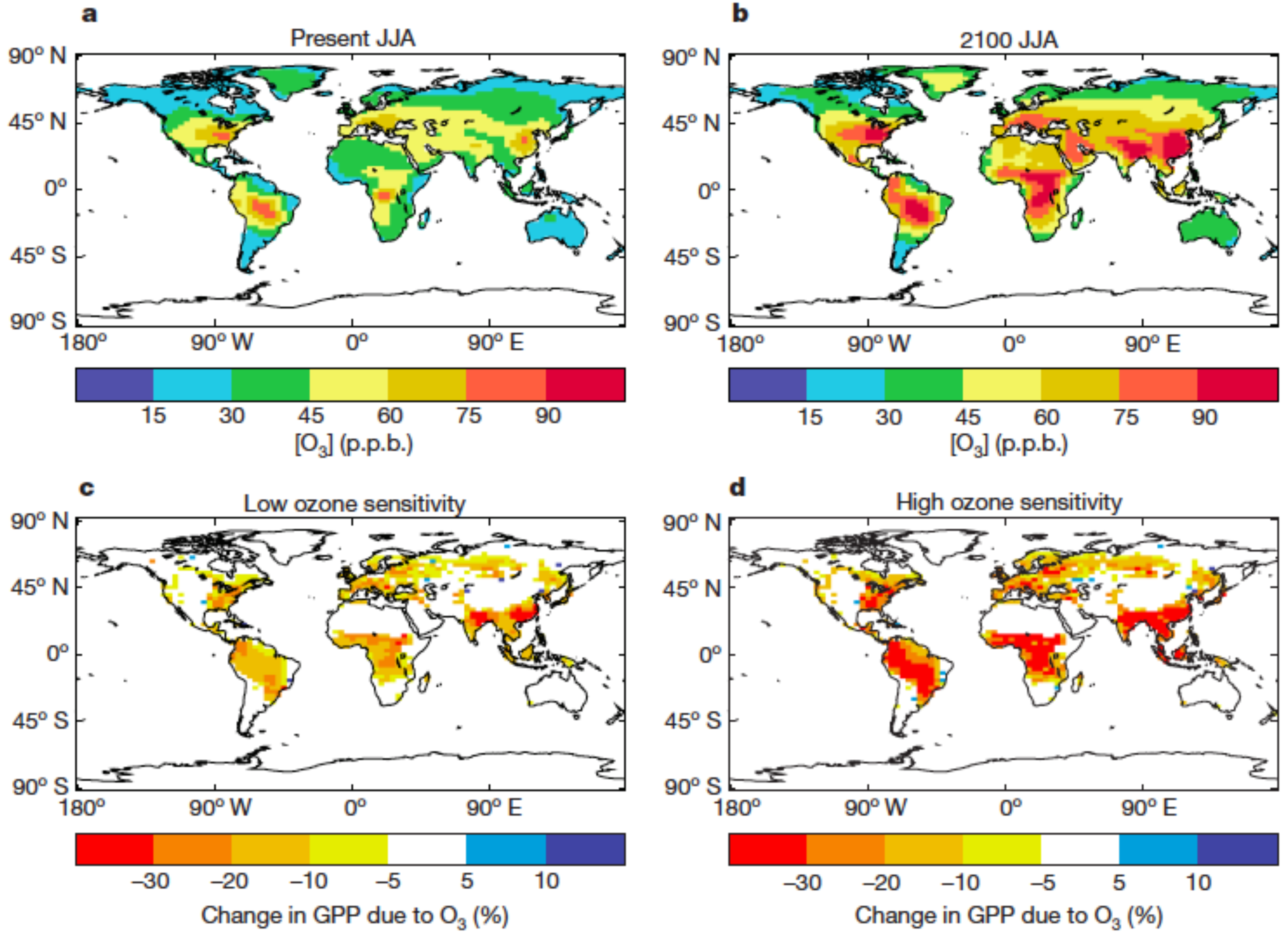
- Not well-mixed

Sources
Formed at in troposphere from reactions involving BVOCs/CH_4/CO and NO_x



Figure, Sitch et al. (2007)

Ozone



Ozone is believed to lead to large reductions in plant productivity

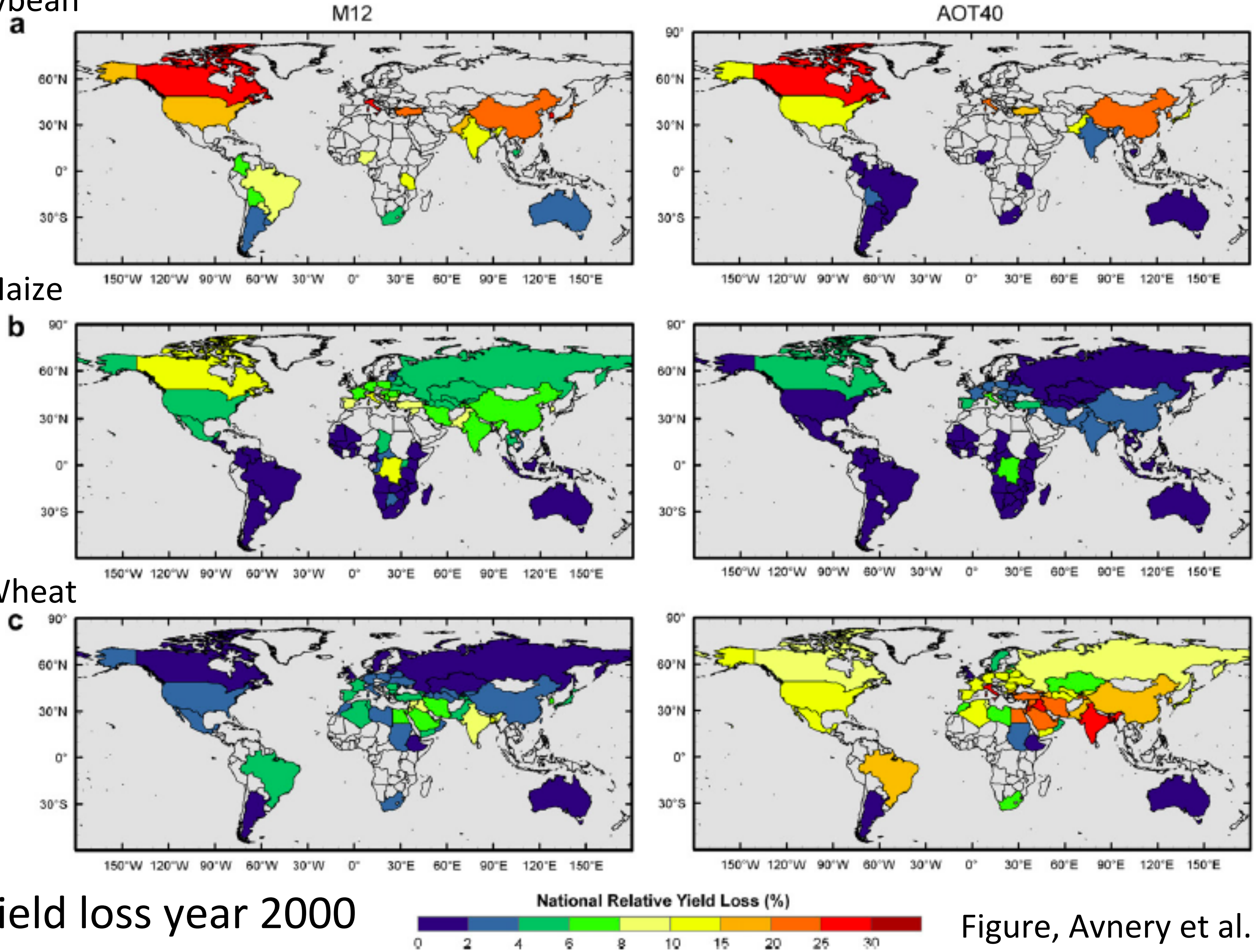
Figure, Sitch et al. (2007)

Ozone

Soybean

Maize

Wheat



Yield loss year 2000

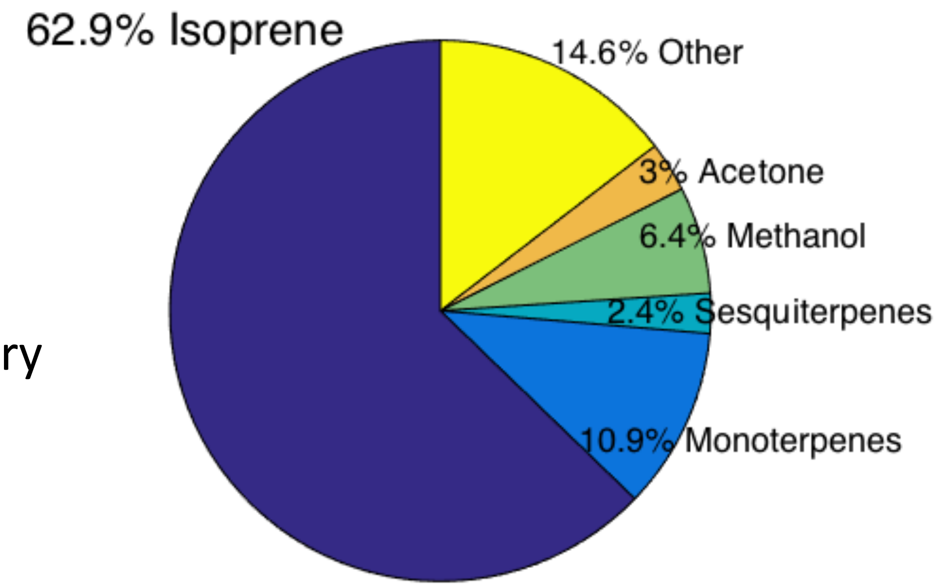
Figure, Avnery et al. (2011)

BVOCs

Biogenic volatile organic compounds
Emitted by plants
10:1 anthropogenic VOCs
Major precursor for tropospheric ozone

Also precursor for production of Secondary Organic Aerosol:

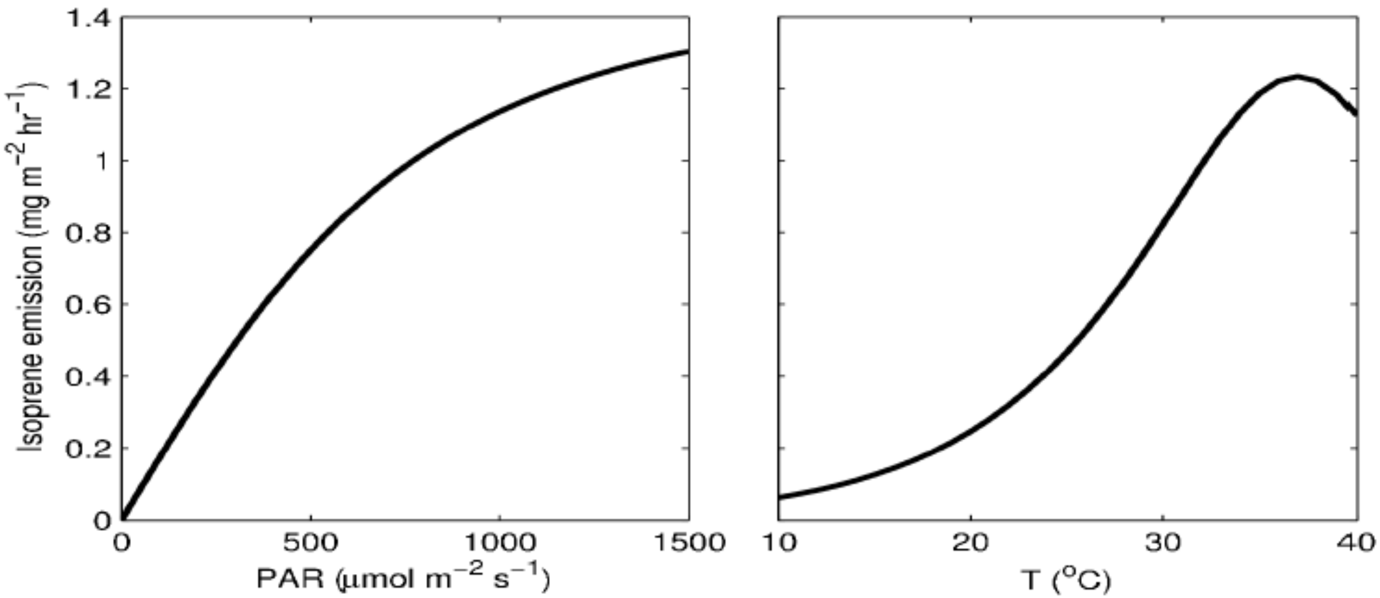
- Broadly speaking, the heavier the compound, the more likely it is to condense. Thus monoterpenes ($C_{10}H_{16}$) typically condense more readily than isoprene (C_5H_8).
- Condensing of organic vapours has been shown to enhance the growth of aerosols to cloud condensation nuclei, affecting cloud albedo (Paasonen et al., 2013)



Global BVOC emission breakdown
(numbers from Sindelarova et al., 2014

BVOC emissions

Isoprene emission dominated by temperature and light response:



Plots based on MEGAN algorithm, Guenther et al. (2006)

Although also inhibition of isoprene by high [CO_2]

BVOC emissions

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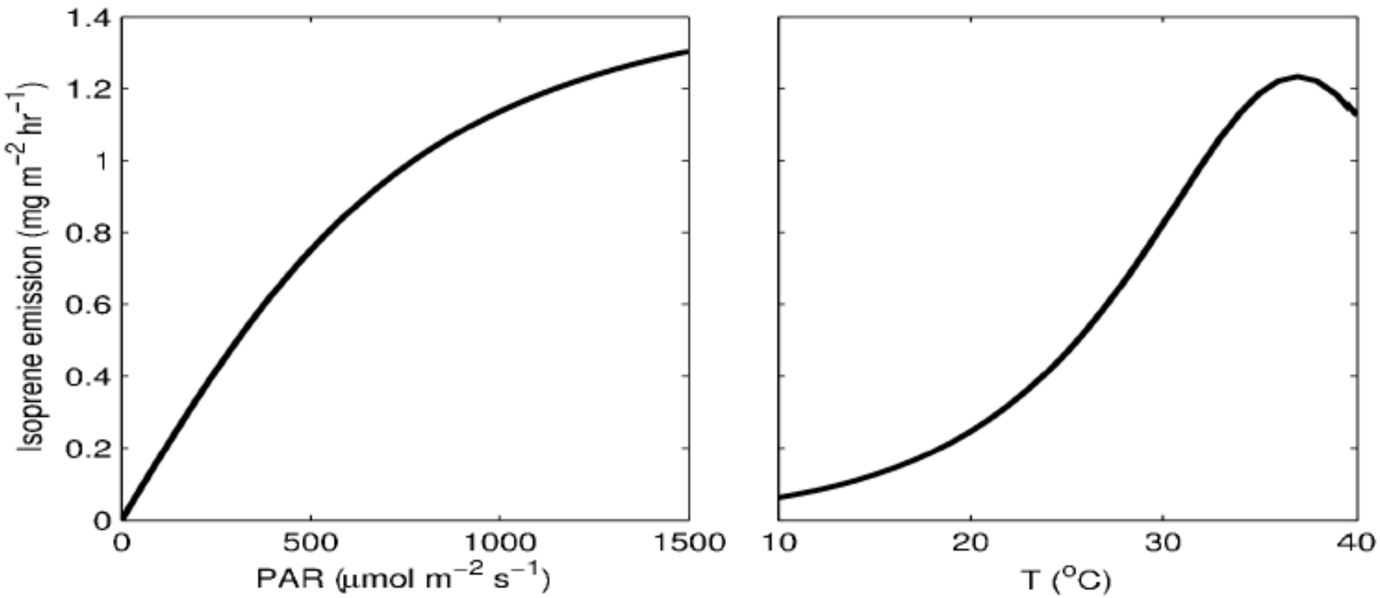

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Although also inhibition of isoprene by high $[CO_2]$

…and by species, e.g. from Guenther et al. (2012)

Plant type	Isoprene BER ($mg\ m^{-2}\ h^{-1}$)	Monoterpene BER ($mg\ m^{-2}\ h^{-1}$)
Broadleaf tree	7 – 11	1.0 – 1.4
Needleleaf tree	0.001 – 3.0	1.45
Crop	~0	~0
Grass	0.2 – 0.8	~0

Basic tropospheric chemistry

Tropospheric ozone production

$$NO_2 + h\nu \rightarrow NO + O \quad (\lambda < 400\ nm)$$

$$O + O_2 + M \rightarrow O_3 + M$$

However…

$$NO + O_3 \rightarrow NO_2 + O_2$$

The result is a steady-state ozone mixing ratio
Level depends on [NO_x] and radiation intensity
Usually 10 – 25 ppbv

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Level depends on [NO_x] and radiation intensity
Usually 10 – 25 ppbv

However, if another route of NO ➔ NO_2 exists,
then ozone mixing ratios could increase…

Basic tropospheric chemistry

Peroxy radicals can also make this conversion

$$NO + HO_2 \rightarrow NO_2 + OH$$

$$NO + CH_3O_2 \rightarrow NO_2 + CH_3O$$

$$NO + RO_2 \rightarrow NO_2 + RO$$

OH = hydroxyl radical
HO_2 = hydroperoxy radical
CH_3O_2 = methyl peroxy radical
RO_2 = generic organic peroxy radical

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Organic peroxy radicals formed from oxidation of organic compounds e.g.

$$CH_4 + OH \rightarrow CH_3 + H_2O$$

$$CH_3 + O_2 + M \rightarrow CH_3O_2 + M$$

Basic tropospheric chemistry

So both BVOCs and NO_x are needed for large ozone mixing ratios to exist in the troposphere. But under low $[NO_x]$…

$$HO_2 + HO_2 \rightarrow H_2O_2 + O_2$$

$$RO_2 + RO_2 \rightarrow \text{peroxide} + O_2$$

Plus the direct reaction of BVOCs with ozone becomes significant

$$R + O_3 \rightarrow \text{products}$$

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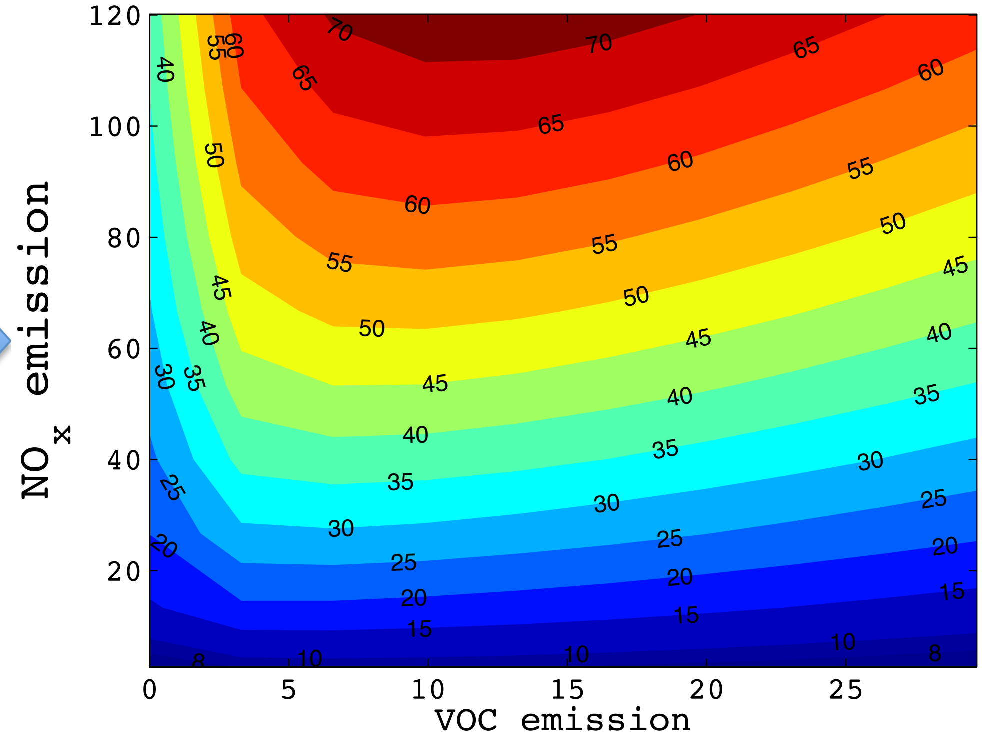
This means that BVOCs can either increase or decrease $[O_3]$ depending on $[NO_x]$. Typically BVOCs decrease $[O_3]$ in remote low-$[NO_x]$ regions, and increase $[O_3]$ in polluted high-$[NO_x]$ regions.



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OH regenerated very effectively in the presence of HO_2

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Increases in BVOCs reduce the concentration of the OH radical in the atmosphere.
OH is the main atmospheric sink for CH_4.
Isoprene emissions influence CH_4 lifetime to the tune of about 10% (Young et al., 2009)

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Organic peroxy radicals formed from oxidation of organic compounds e.g.

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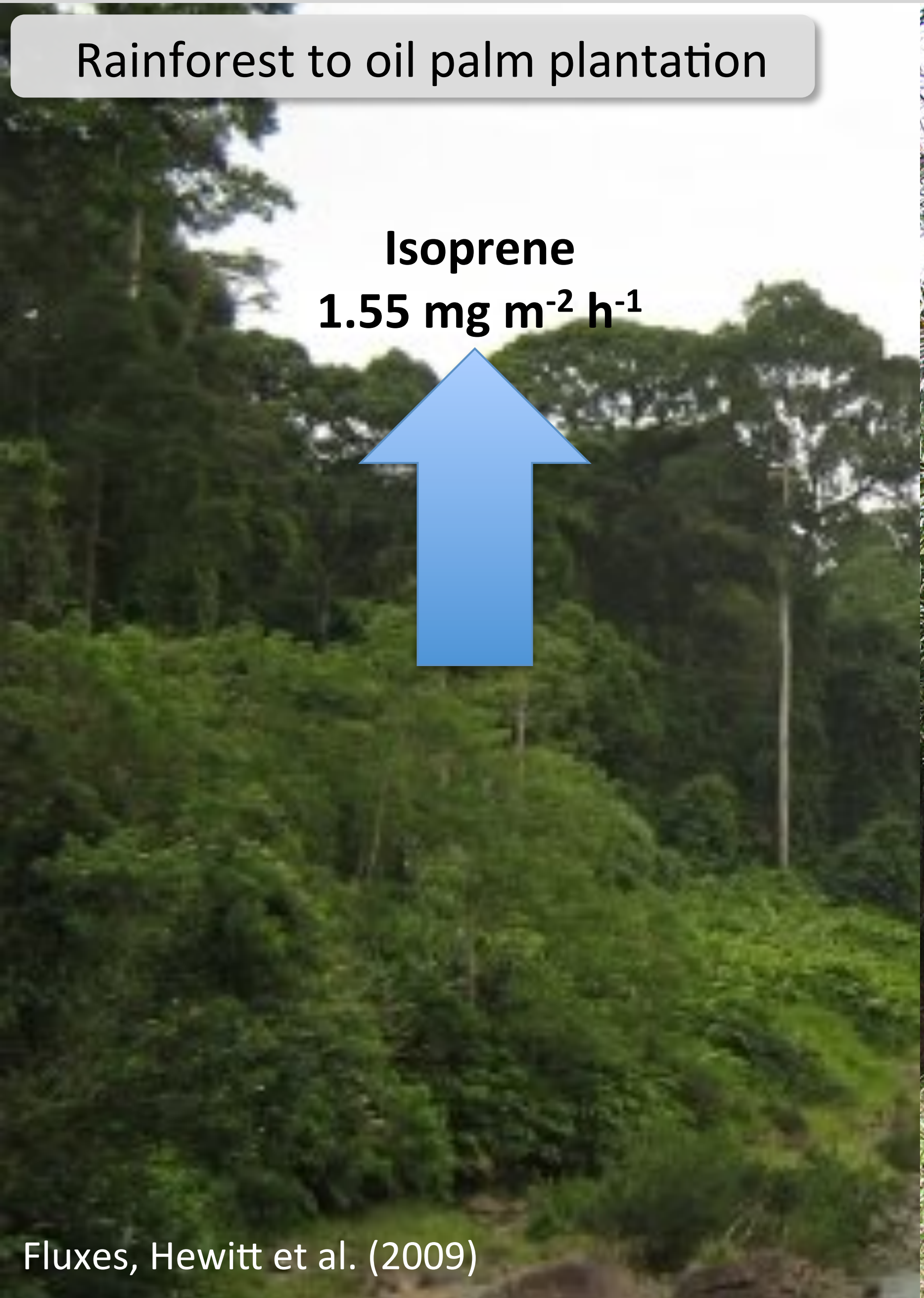
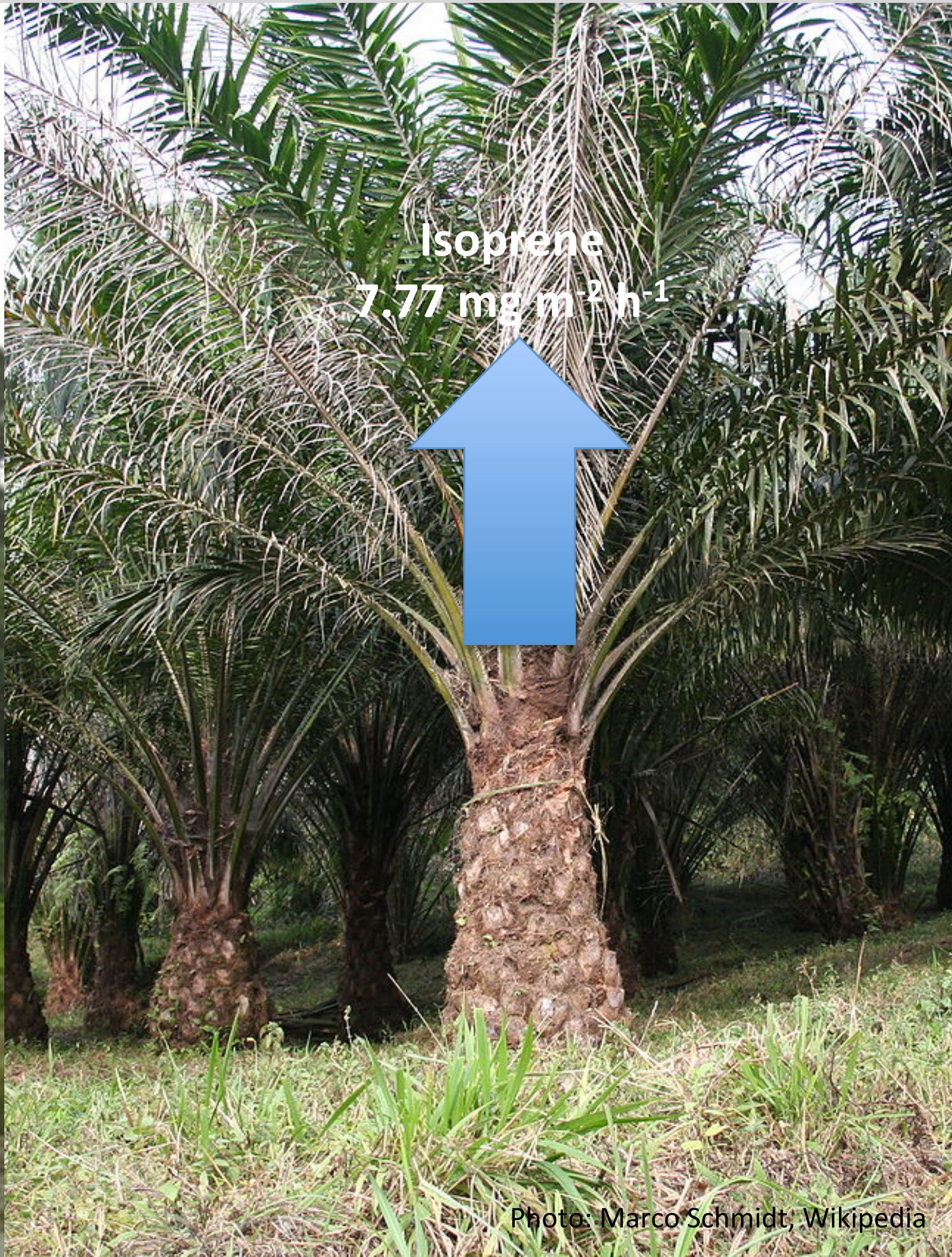
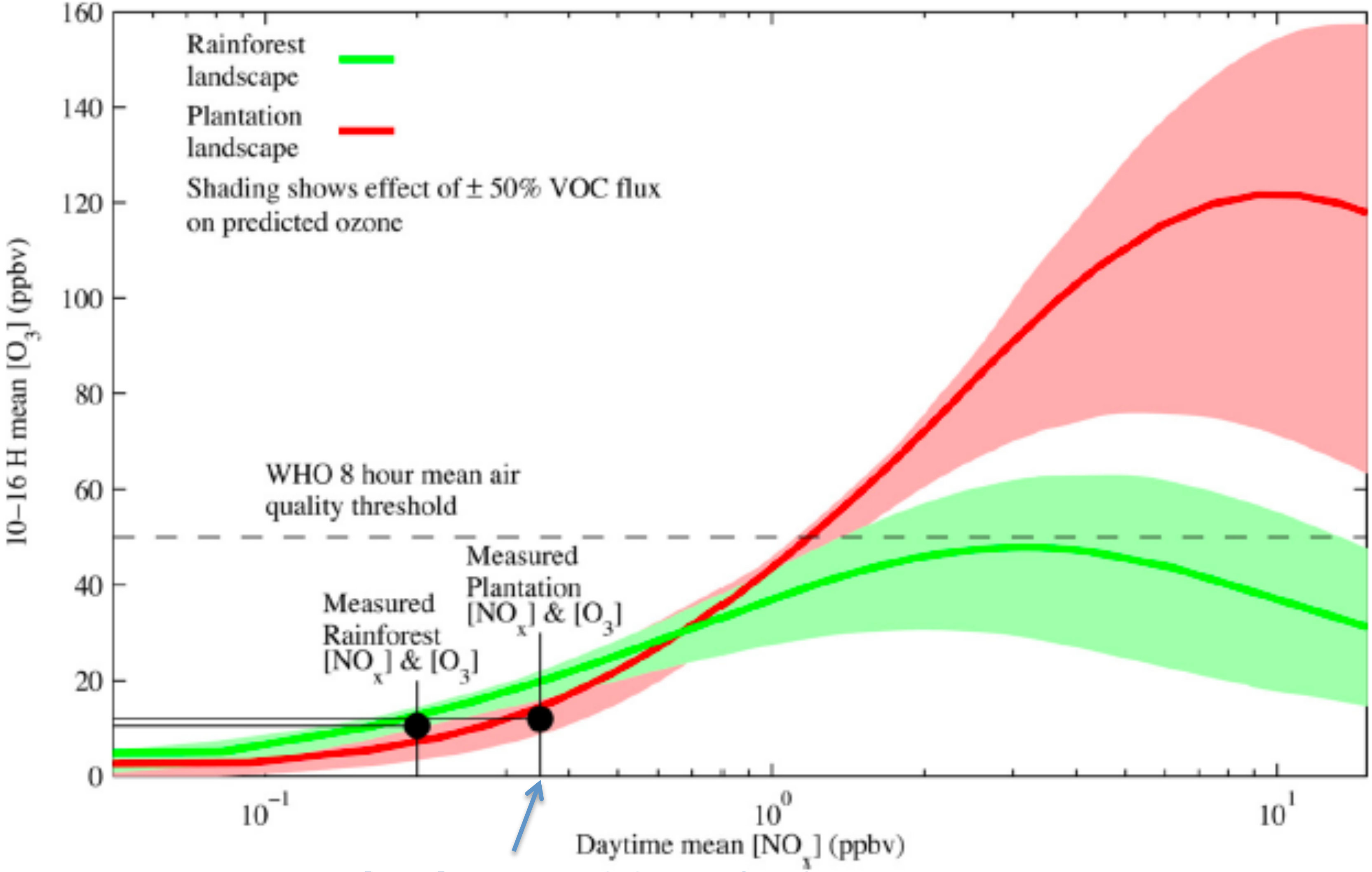
Effects of LUC on BVOCs, ozone & aerosol





Effects of LUC on BVOCs, ozone & aerosol

Rainforest to oil palm plantation

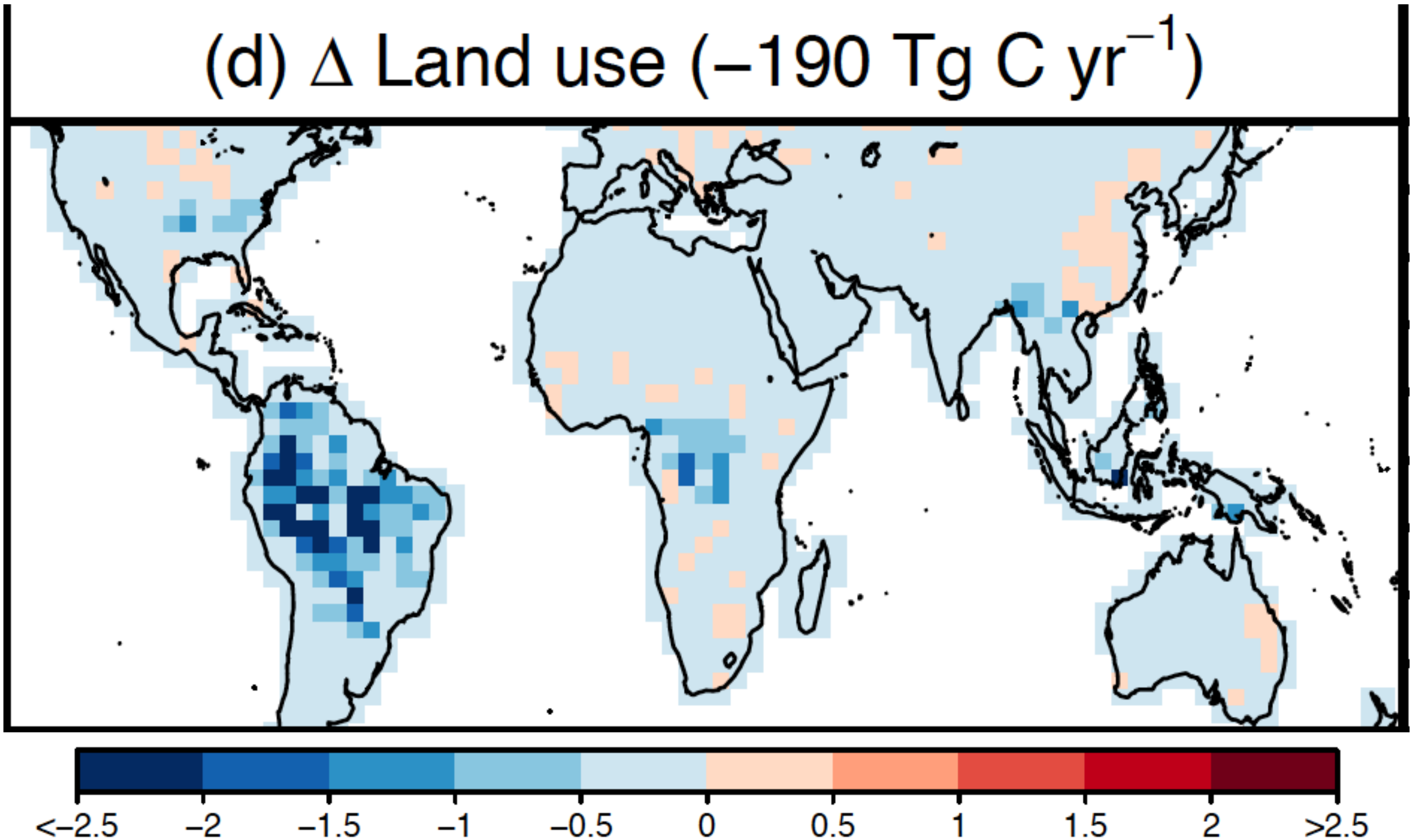


$[NO_x]$ increased due to fertilisation, mechanisation, biomass burning

Hewitt et al. (2009)

Effects of LUC on BVOCs, ozone & aerosol

Forest to cropland (tropics)



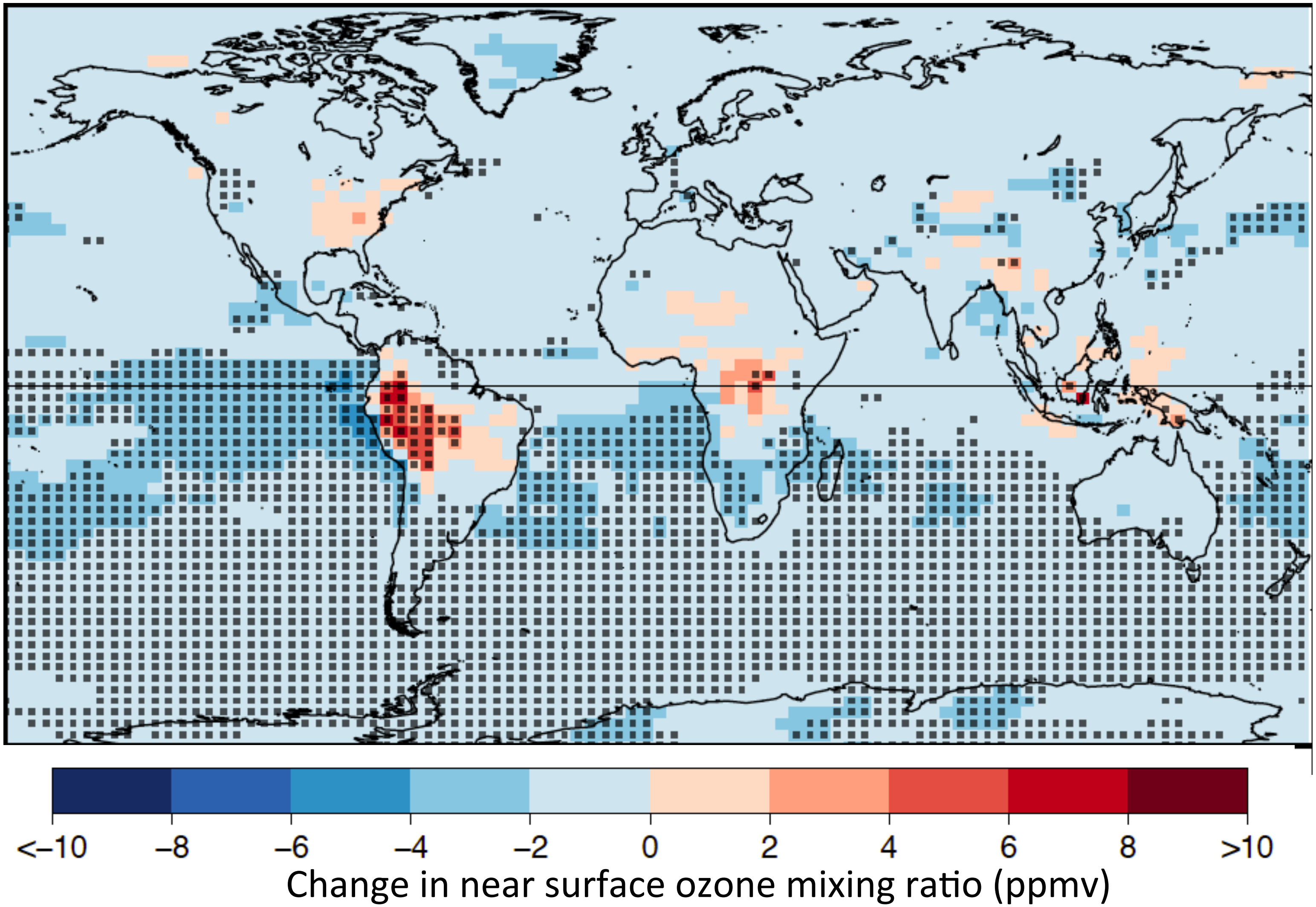
Change in isoprene emission (mg C m^{-2} h^{-1})

Due to a strong increase in cropland at the expense of forest

Results and figure, Squire et al. (2014)

Effects of LUC on BVOCs, ozone & aerosol

Forest to cropland (Amazon)



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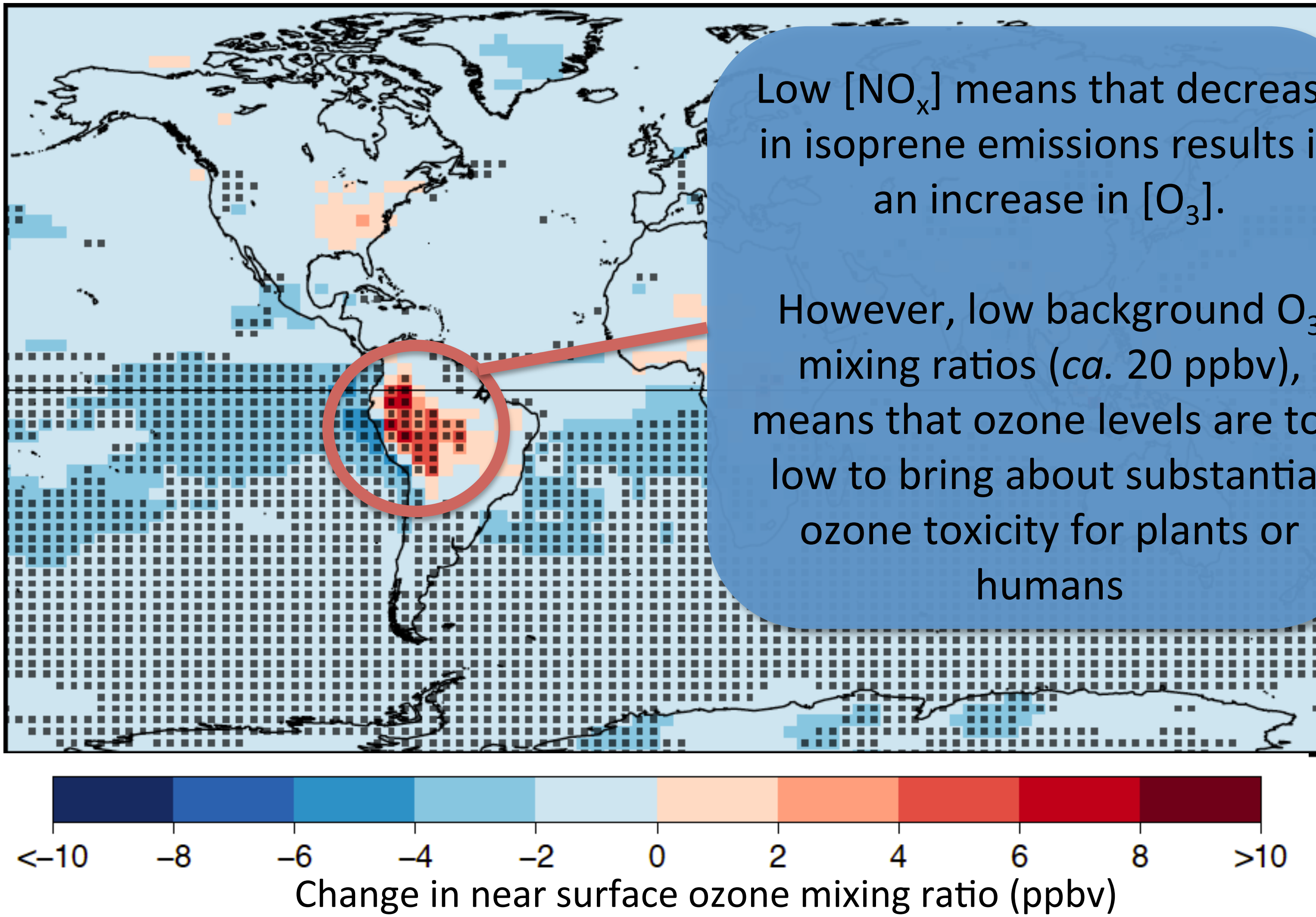


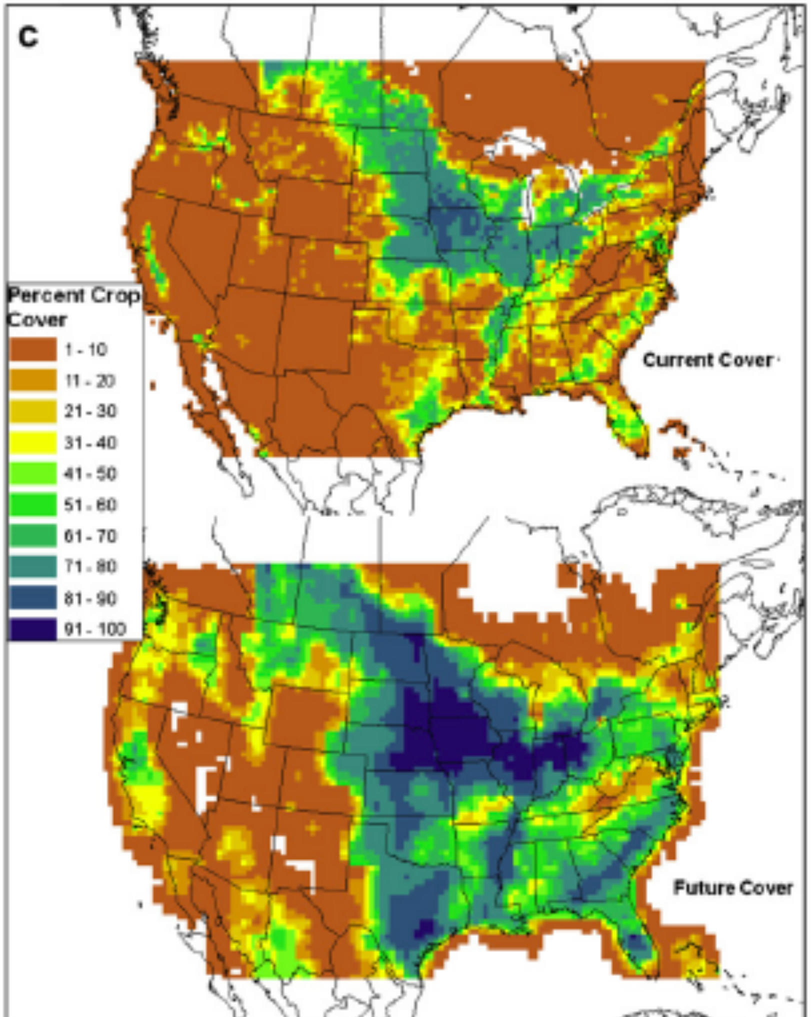
Low $[NO_x]$ means that decrease in isoprene emissions results in an increase in $[O_3]$.

However, low background O_3 mixing ratios (*ca.* 20 ppbv), means that ozone levels are too low to bring about substantial ozone toxicity for plants or humans

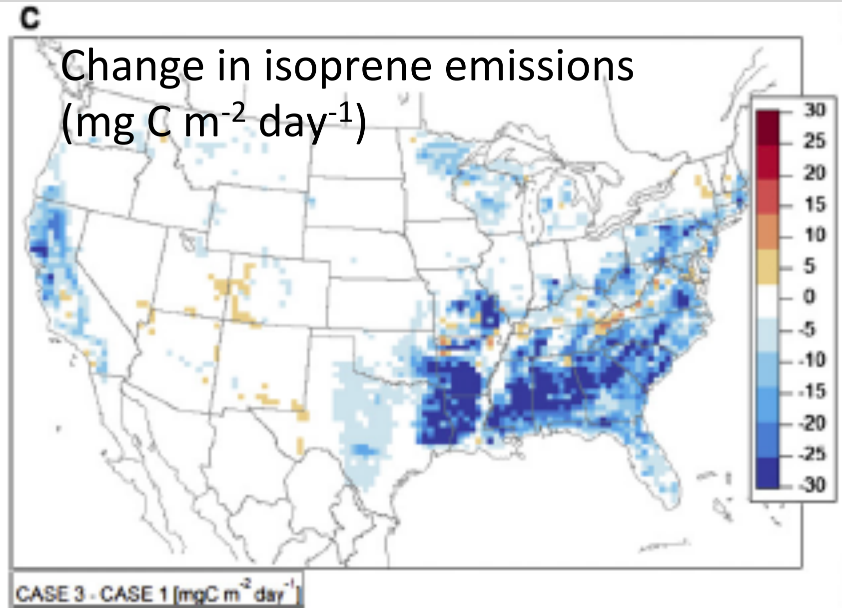
Results and figure, Squire et al. (2014)

Effects of LUC on BVOCs, ozone & aerosol

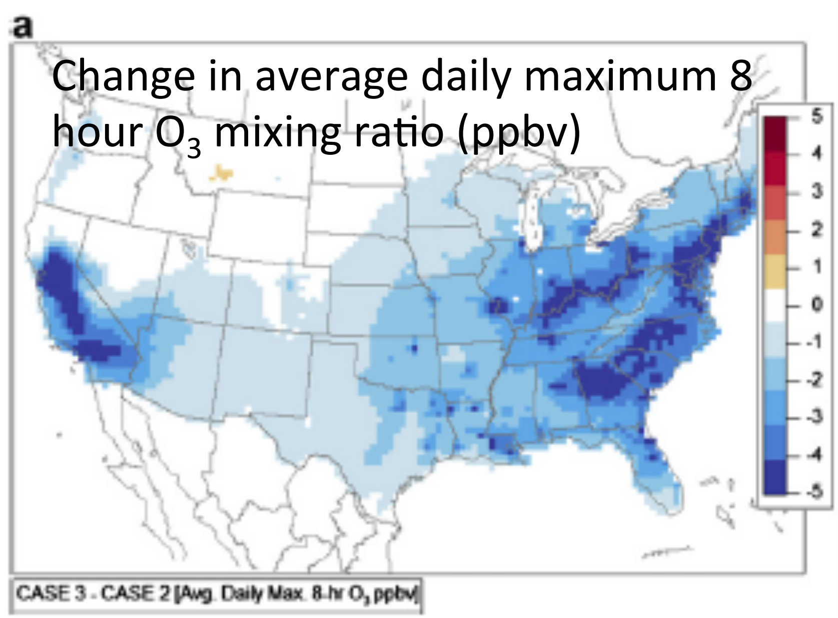
Forest to cropland (mid.-latitudes)



Future scenario with strong increase in cropland cover



Change in isoprene emissions (mg C m^{-2} day^{-1})

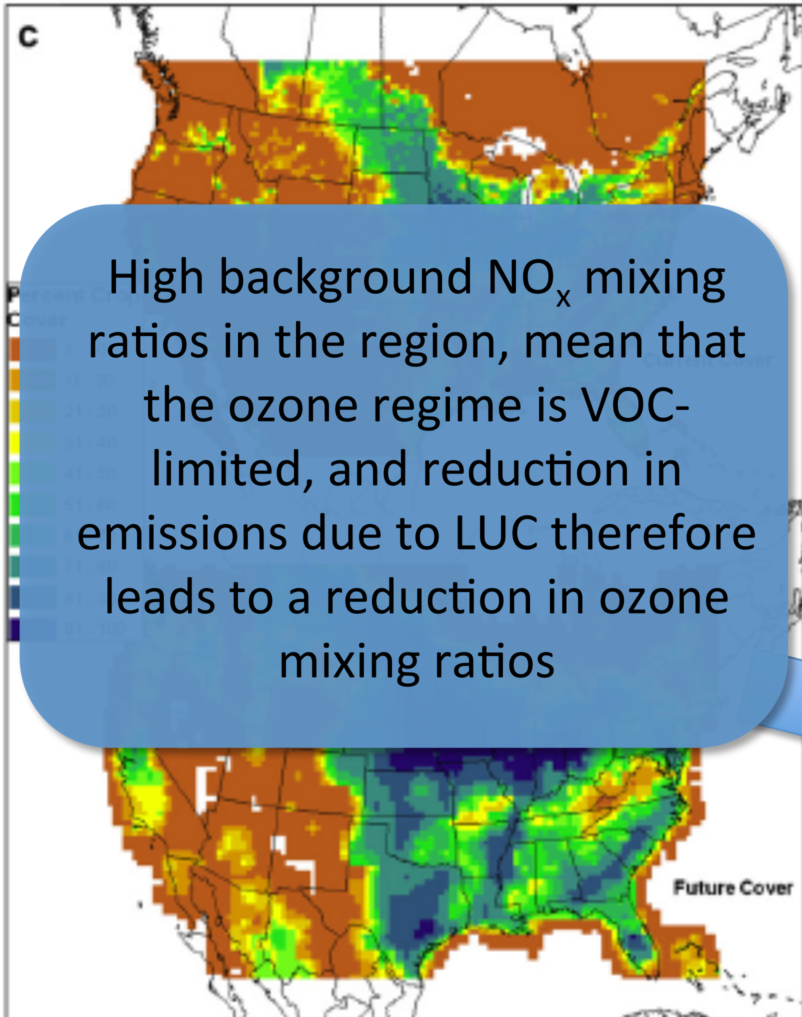


Change in average daily maximum 8 hour O_3 mixing ratio (ppbv)

Results & figures, Chen et al. (2009)

Effects of LUC on BVOCs, ozone & aerosol

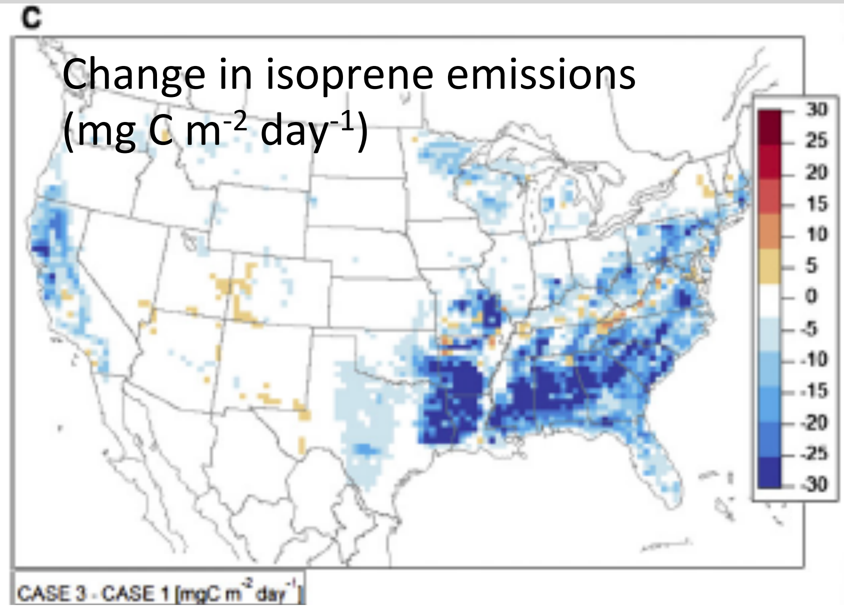
Forest to cropland (mid.-latitudes)



High background NO_x mixing ratios in the region, mean that the ozone regime is VOC-limited, and reduction in emissions due to LUC therefore leads to a reduction in ozone mixing ratios

Future scenario with strong increase in cropland cover

Change in isoprene emissions ($mg\ C\ m^{-2}\ day^{-1}$)



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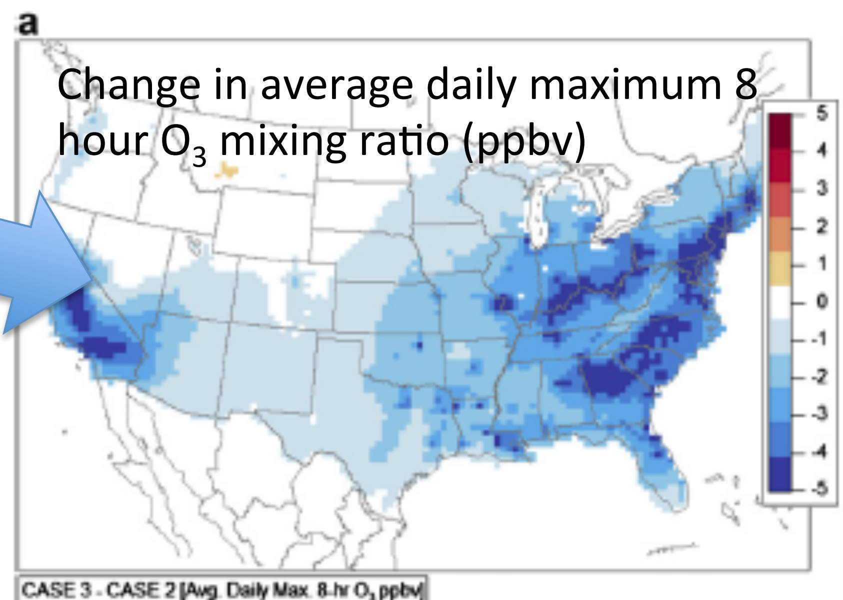


Results & figures, Chen et al. (2009)

Effects of LUC on BVOCs, ozone & aerosol

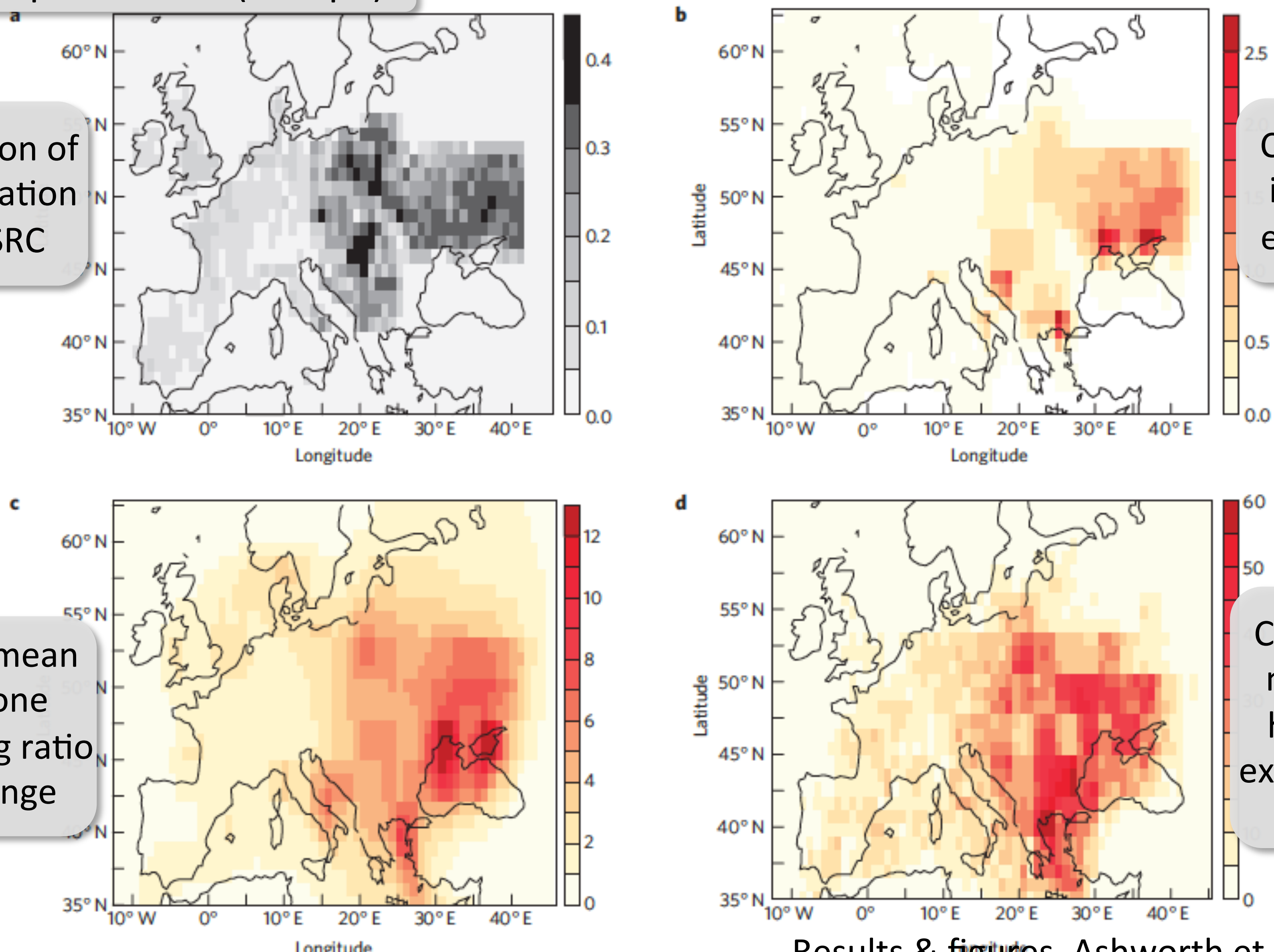
SRC plantations (Europe)

Fraction of vegetation as SRC

Change in isoprene emissions

July mean ozone mixing ratio change

Change in no. of 8-hour O3 exceedance days



Results & figures, Ashworth et al. (2013)

Effects of LUC on BVOCs, ozone & aerosol

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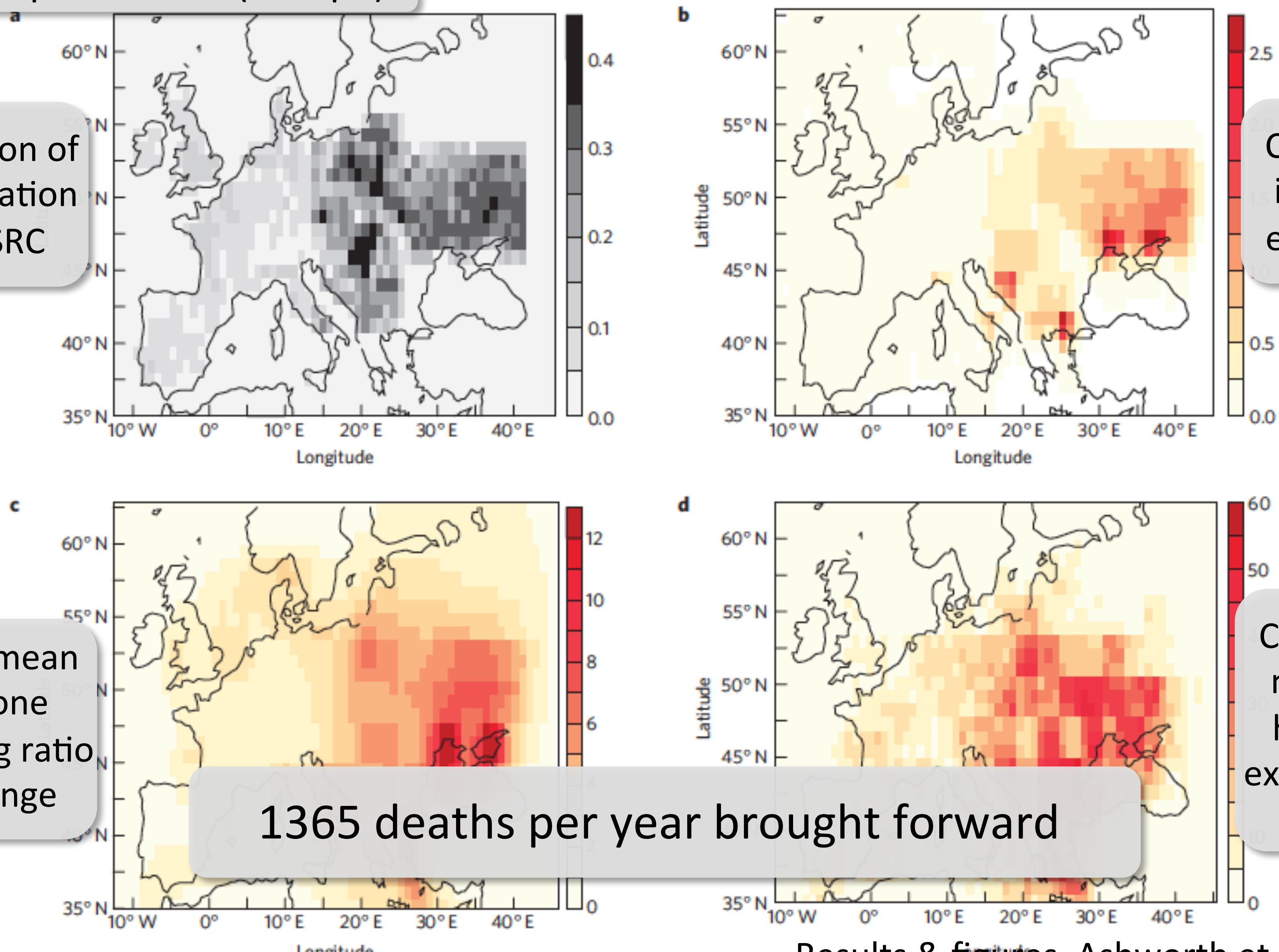


Fraction of vegetation as SRC

Change in isoprene emissions

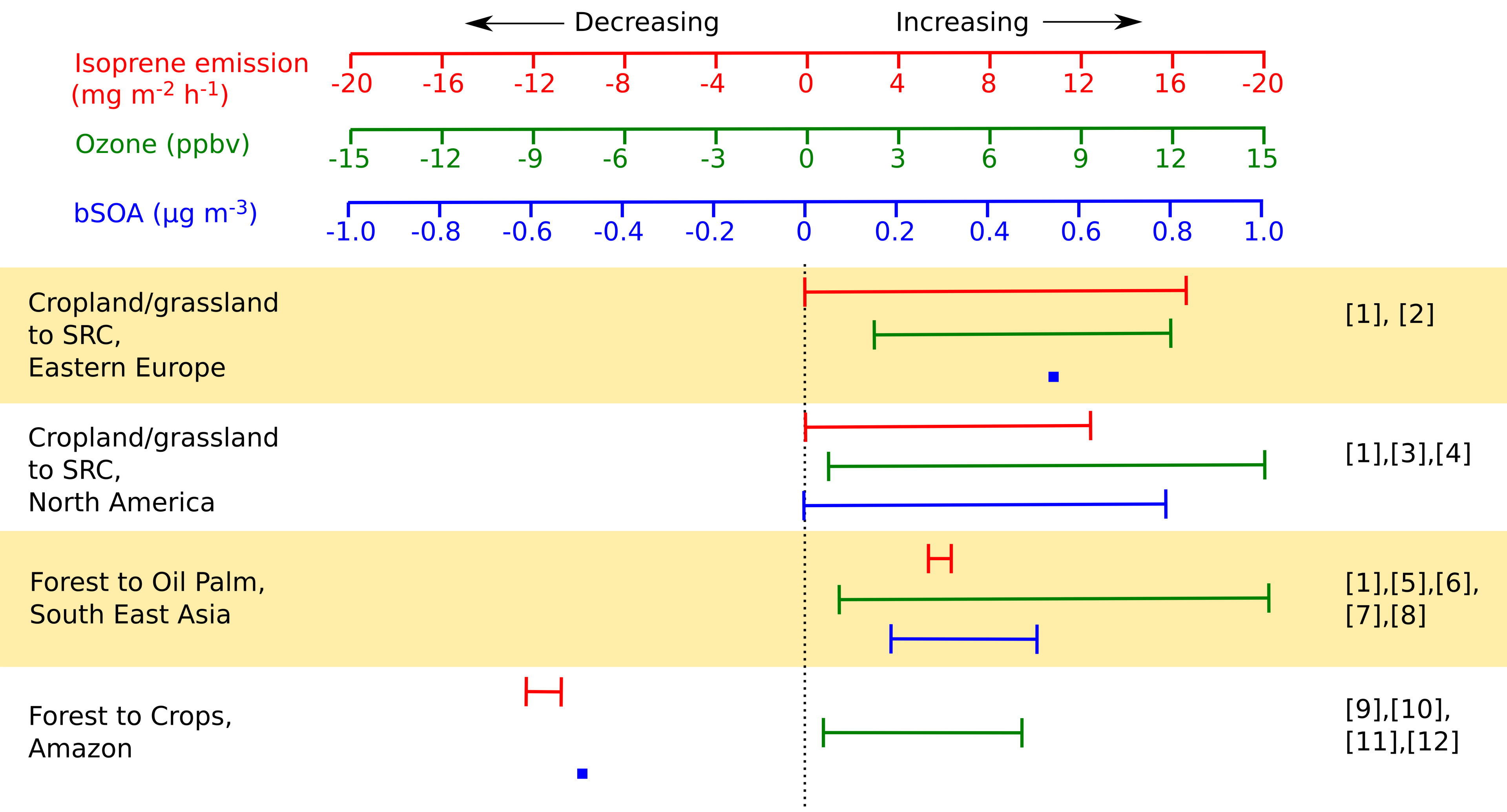
July mean ozone mixing ratio change

Change in no. of 8-hour O3 exceedance days

1365 deaths per year brought forward

Results & figures, Ashworth et al. (2013)

Effects of LUC on BVOCs, ozone & aerosol



Rosenkranz, Pugh et al. (2014)

Effects of LUC on BVOCs, ozone & aerosol

It's not all about emissions though.
Ozone, particles, and some VOCs are deposited to plants
25% of tropospheric ozone is lost by deposition

$$F_d = v_d \bullet C$$

$$v_d = \frac{1}{r_a + r_l + r_s}$$

F_d = deposition flux
v_d = deposition velocity
C = concentration of substance (at reference height)

r_a = Aerodynamic resistance(wind speed, atmospheric stability, surface roughness)
r_l = laminar boundary layer resistance
r_s = surface resistance (e.g. leaf surface, stomatal opening)

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F_d = deposition flux
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Examples of O_3 dry deposition velocities (Zhang et al., 2003)

Land-cover	v_d (cm s^{-1})
Trees	1.2-1.7
Long grass	1.3-1.4
Short grass	0.8-0.9

r_a = Aerodynamic resistance(wind speed, atmospheric stability, surface roughness)
r_l = laminar boundary layer resistance
r_s = surface resistance (e.g. leaf surface, stomatal opening)

Summary

- Land-use change can influence the atmospheric concentrations of some SLCPs, particularly ozone and particulates (partially through their precursors)
- The overall effect of land-use change on atmospheric SLCP concentration is not always clear, often being heavily dependent on the atmospheric chemical context.
- Nor is the overall magnitude (or in some cases even direction) of the effect of these changes on the climate system clearly understood.
- Ozone and particles have deleterious effects on human health, whilst ozone significantly reduces plant/crop productivity, meaning that a reduction in their concentrations is always positive in this respect.
- Air quality impacts of land-use change are therefore probably a more relevant consideration in many cases than SLCP climate impacts, although even then only in some locations.

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