Opinion: The importance of historical and paleoclimate aerosol radiative effects

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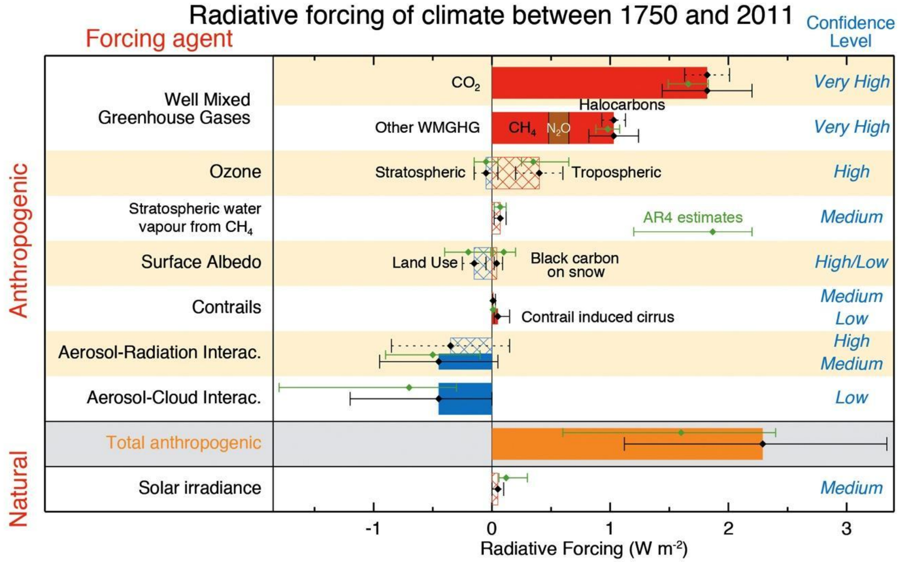
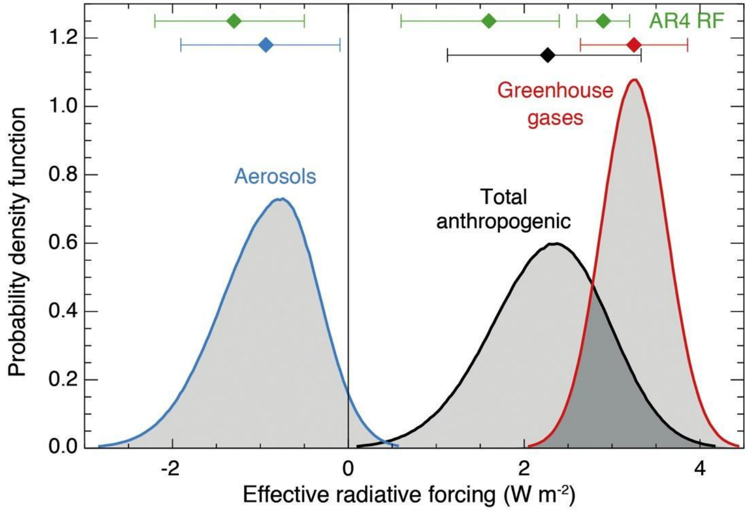


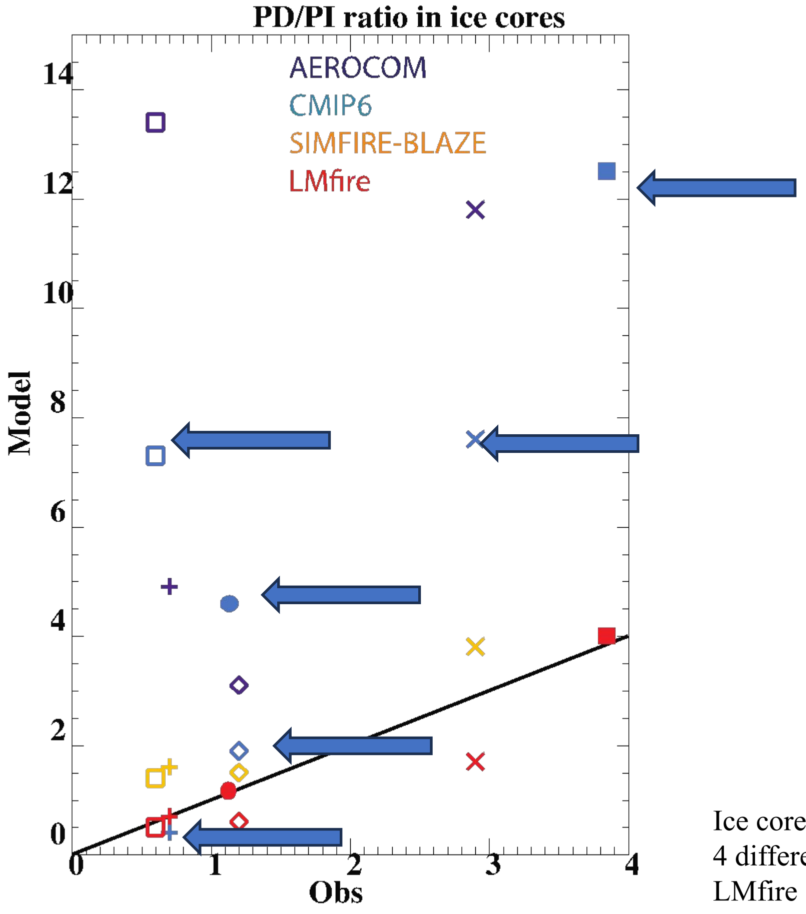
Main points:

- Aerosol impacts on radiation are very important for climate, and very sensitive to poorly known quantities like size, mixing state, spatial distribution relative to clouds, etc. in current climate.
- We do not have in situ data in the preindustrial or paleoclimate
- CMIP6 emission inventories/models are unlikely to be correct for dust or wildfires (but poorly known).
- Uncertainties in PI emissions are not accounted for currently (should be 1.7x larger)
- Therefore, estimates of aerosol radiative forcing for preindustrial to current are more uncertain than current estimates.
- Paleoclimate aerosol radiative forcings are even more uncertain (4.8 W/m2 90% confidence interval



IPCC, 2014

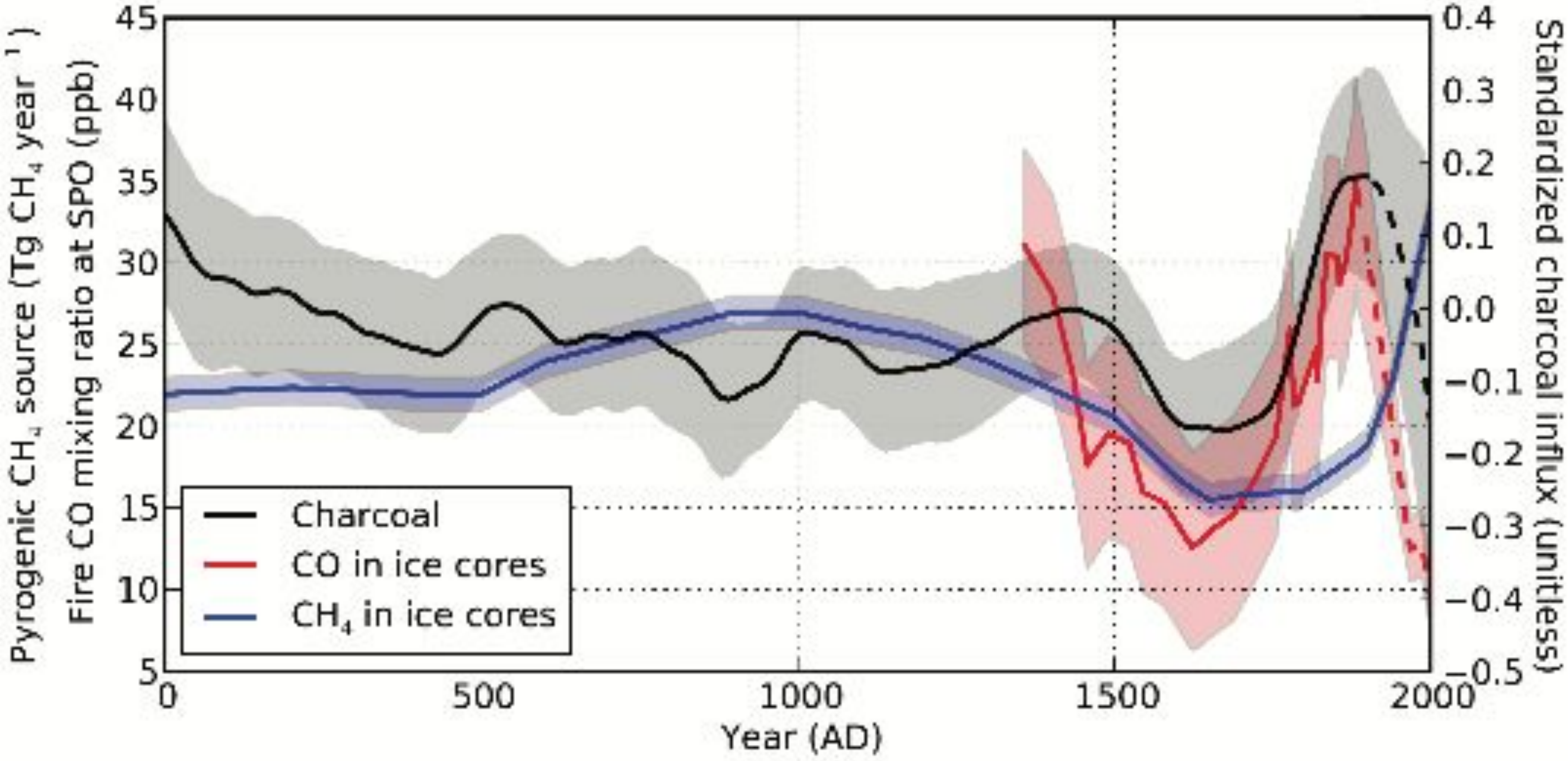
CMIP6 emissions/models not do a good job of ‘natural’ aerosols: wildfires



- We do not have good proxies for wildfires in past climates (need data every 5 degrees for short lived species)
- Using CMIP6 emissions, models get MUCH too high of ratio of PD/PI in MOST (but not all) ice cores
- LMfire (with much higher PI wildfires emissions) is more able to simulate ice cores

Ice cores sites are from Greenland (open square and plus signs), Wyoming (diamond) and France (x’s) for 4 different model simulations: AEROCOM (purple), CMIP6 (blue), SIMFIRE-BLAZE (yellow) and LMfire (red) are taken from (Hamilton et al., 2018). Ice core sites from Bolivia (solid circle) and Antarctica (solid square) using CMIP6 (blue) and LMfire (red) are taken from (Liu et al., 2021). The solid black line shows the 1:1 line.

Wildfire proxies suggest peak at 1850

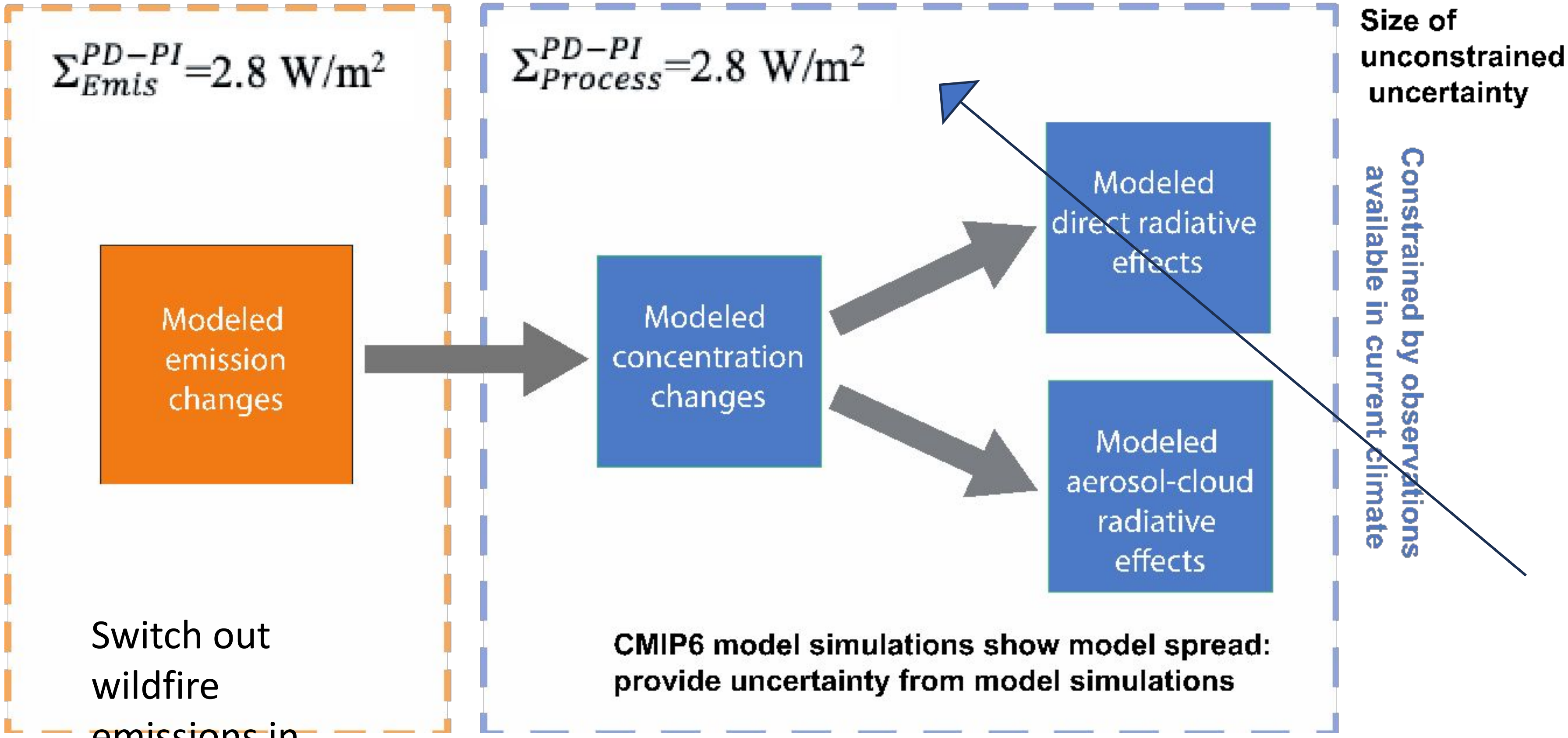


- Charcoal records are semi-quantative
- Suggest increase from 1700-1850, and downward after
- Suggest: both climate and human land use plays a role
- similar to recent trends in satellites, showing decrease in global wildfires Andela et al., 2017)?

Van der Werf, 20218, using Marlon et la., 2008; Ferretti et al., 2005; Wang et al., 2010)

Figure. 5. Variability of biomass burning rates over the last centuries based on a worldwide compilation of charcoal records (Marlon et al., 2008), CO mixing ratios from fires using CO concentration measurements at the South Pole (SPO), its isotopic signature, and a mass balance model (Wang et al., 2010) and a similar approach but based on CH_4 (Ferretti et al., 2005). The CO ice core data ended in 1897 but were extended (dashed line) by Wang et al. (2010) to present-day using firn samples (1968 and 1986) as well as modelling (year 2000). Shaded areas indicate reported uncertainty. Note that the datasets have different footprints and that absolute values cannot be compared directly. Reproduced with permission from (van der Werf et al., 2013) under CCC3.0.

Full uncertainty of aerosol changes requires multiple emission pathways and comparisons to observations



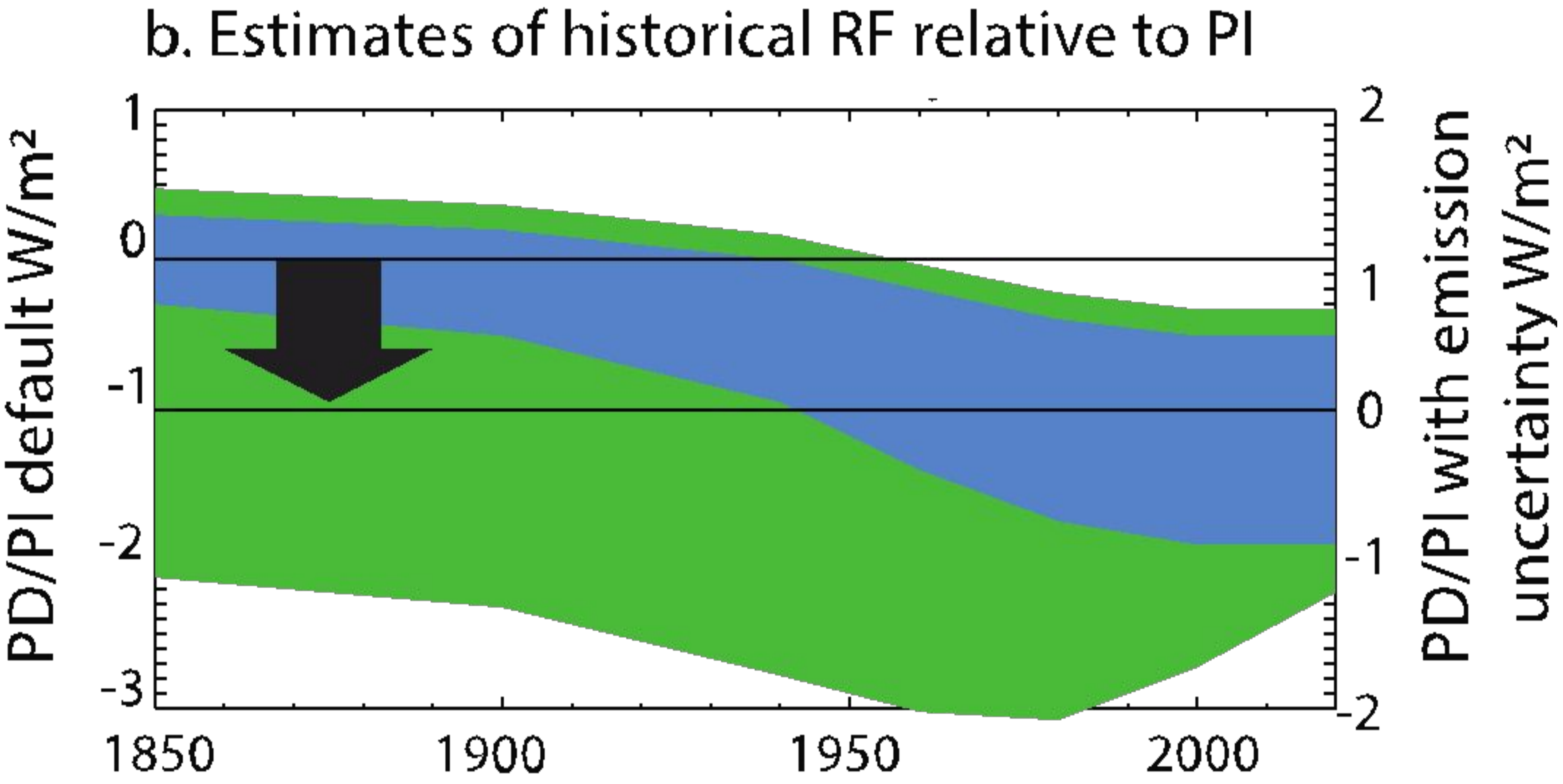
Switch out wildfire emissions in one model

- 90% confidence intervals for multi-model estimates (unconstrained) Bellouin et al. 2020 similar in size to emission uncertainty
- Dominant source of uncertainty is wildfires (Hamilton et la., 2018; Wan et al., 2018)

From Bellouin et al., 2020: unconstrained, across models using same emissions

Schematic of the sources of uncertainties in aerosol radiative effects, from emission models to modeled concentration changes to modeled direct and aerosol-cloud radiative effects. The CMIP6 unconstrained uncertainties using a single emission scenario have a 90% confidence interval range of 2.8W/m^2 (Bellouin et al., 2020; Sherwood et al., 2020). For the uncertainty using different emission scenarios for the past climate, the 90% confidence interval ranges from wildfires of 2.8 W/m^2 (Hamilton et al., 2018; Wan et al., 2021) is added to uncertainties from dust of 0.4 W/m2 (Kok et al., 2023) and added to an estimate of industrial emission uncertainties (assuming 10% error) of 0.2 W/m^2. We square these errors and take the square root to obtain 2.8 W/m^2 uncertainty in emissions.

Implications: Estimates of RF



Blue: Smith et al., 2021
Green: add in emission uncertainty.
Arrow: PI could have more aerosol than assumed in CMIP6

- PI (1850)could have had as much aerosol emissions as today
- Increase from industry
- Decrease from wildfires

- Change from 1850 smaller.

- Could have large anthropogenic RF right now: will cause warming as we clean up.
- Gives us 90% confidence interval PD to PI: 4 W/m2

Paleoclimates? Let's look at Last glacial maximum (LGM) vs. PD

- Dust: 2-3x dustier in LGM than current (Mahowald et al., 1999; 2006; Albani et al., 2014, etc.): maybe: -0.2+/- 1 W/m2 (but probably smaller estimate because optics constrained today). Bigger changes than PD to PI
- Wildfires are the most important? What do we know?? Not much!
- Similar or bigger changes in LGM to PI…than PD to PI from charcoal records
- Assume uncertainty in emissions is similarly large?

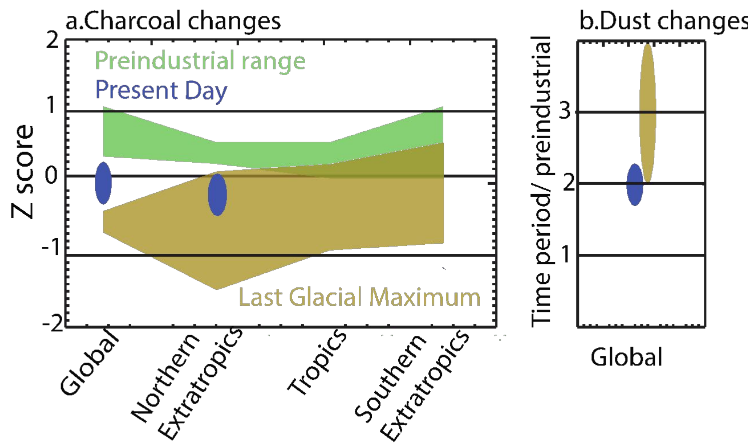
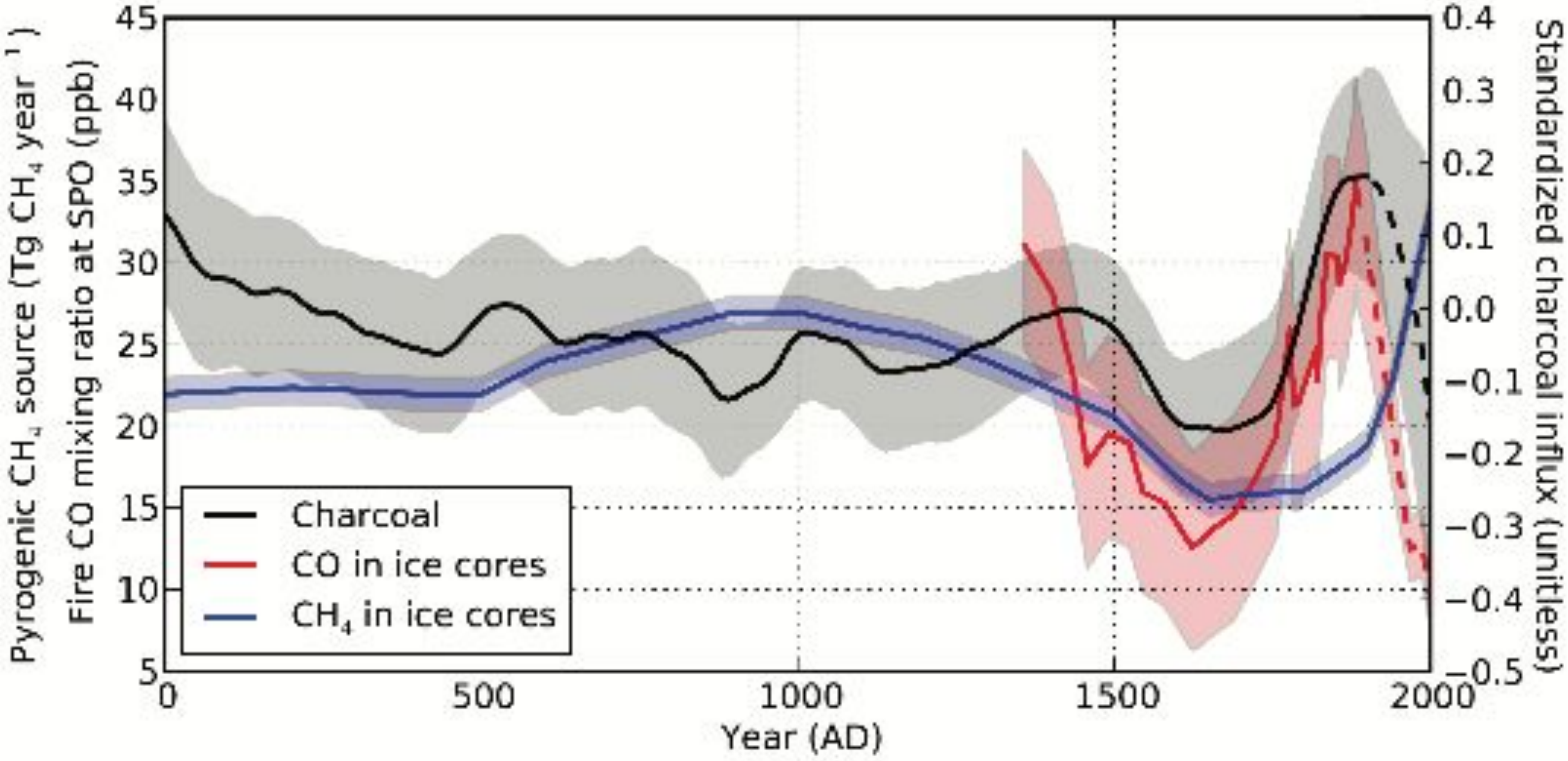


Figure 6: Relative size of paleoclimate and historical changes in aerosols. A) Based on z scores from charcoal records, the variability across preindustrial time periods (green), present day (blue) and last glacial maximum is shown in global, northern extratropics, tropics and southern extratropics based on data from (Marlon et al., 2008, 2016). Charcoal reconstructions use z-scores, which normalize around the mean value at a site, divided by the variability, and thus a -2 z-score for LGM suggests significantly lower charcoal amounts. B) global dust changes ratio of deposition between present day and preindustrial (blue oval; (Mahowald et al., 2010; Kok et al., 2023), and for the last glacial maximum relative to preindustrial (gold oval) (Mahowald et al., 1999; Albani et al., 2014, 2018; Lambert et al., 2015).

Wildfire proxies suggest peak at 1850

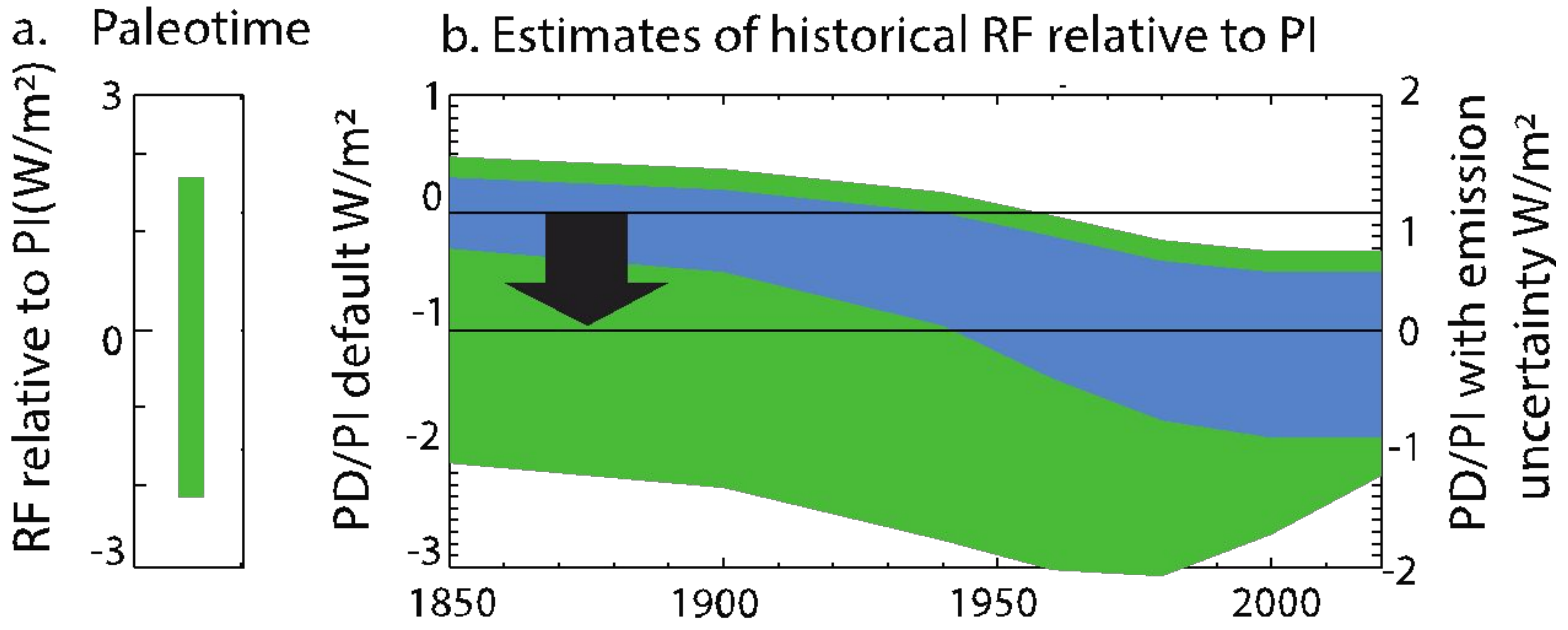


- In addition there is a large uncertainty in wildfires in "PI"
- LGM to current temperatures from ocean cores use last 500 years average.
- Need to add in variability to uncertainty.

Van der Werf, 20218, using Marlon et la., 2008; Ferretti et al., 2005; Wang et al., 2010)

Figure. 5. Variability of biomass burning rates over the last centuries based on a worldwide compilation of charcoal records (Marlon et al., 2008), CO mixing ratios from fires using CO concentration measurements at the South Pole (SPO), its isotopic signature, and a mass balance model (Wang et al., 2010) and a similar approach but based on CH_4 (Ferretti et al., 2005). The CO ice core data ended in 1897 but were extended (dashed line) by Wang et al. (2010) to present-day using firn samples (1968 and 1986) as well as modelling (year 2000). Shaded areas indicate reported uncertainty. Note that the datasets have different footprints and that absolute values cannot be compared directly. Reproduced with permission from (van der Werf et al., 2013) under CCC3.0.

Paleoclimate aerosol LGM/PI uncertainties bigger than PI/PD



- Add in PI variability
- Only can get from obs emission changes
- Need to add in ‘process’ uncertainties since we can’t measure in situ concentrations in paleoclimate
- 90% range: 4.8 W/m2

- Aerosols are really sensitive to climate +very uncertain
- Whatever your uncertainties are that impact climate (CO2, CH4, insolation, ice forcing, surface albedo, etc…), aerosol uncertainties should be larger.

Summary/conclusions

- Aerosol impacts on radiation are very important for climate, and very sensitive to poorly known quantities like size, mixing state, spatial distribution relative to clouds, etc. in current climate.
- We do not have in situ data in the preindustrial or paleoclimate
- CMIP6 emission inventories/models are unlikely to be correct for dust or wildfires in PI (but poorly known).
- Uncertainties in PI emissions are not accounted for currently and approximately same size as model spread/process uncertainties.
- Therefore, estimates of aerosol radiative forcing for preindustrial to current are more uncertain than current estimates (1.7x larger).
- Paleoclimate aerosol radiative forcings are even more uncertain (4.8 W/m2 90% confidence interval