Quantifying radiative forcing impacts of a shift to a hydrogen economy using a chemistry-climate model

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Slides available at **https://bit.ly/2N2U4ZL**

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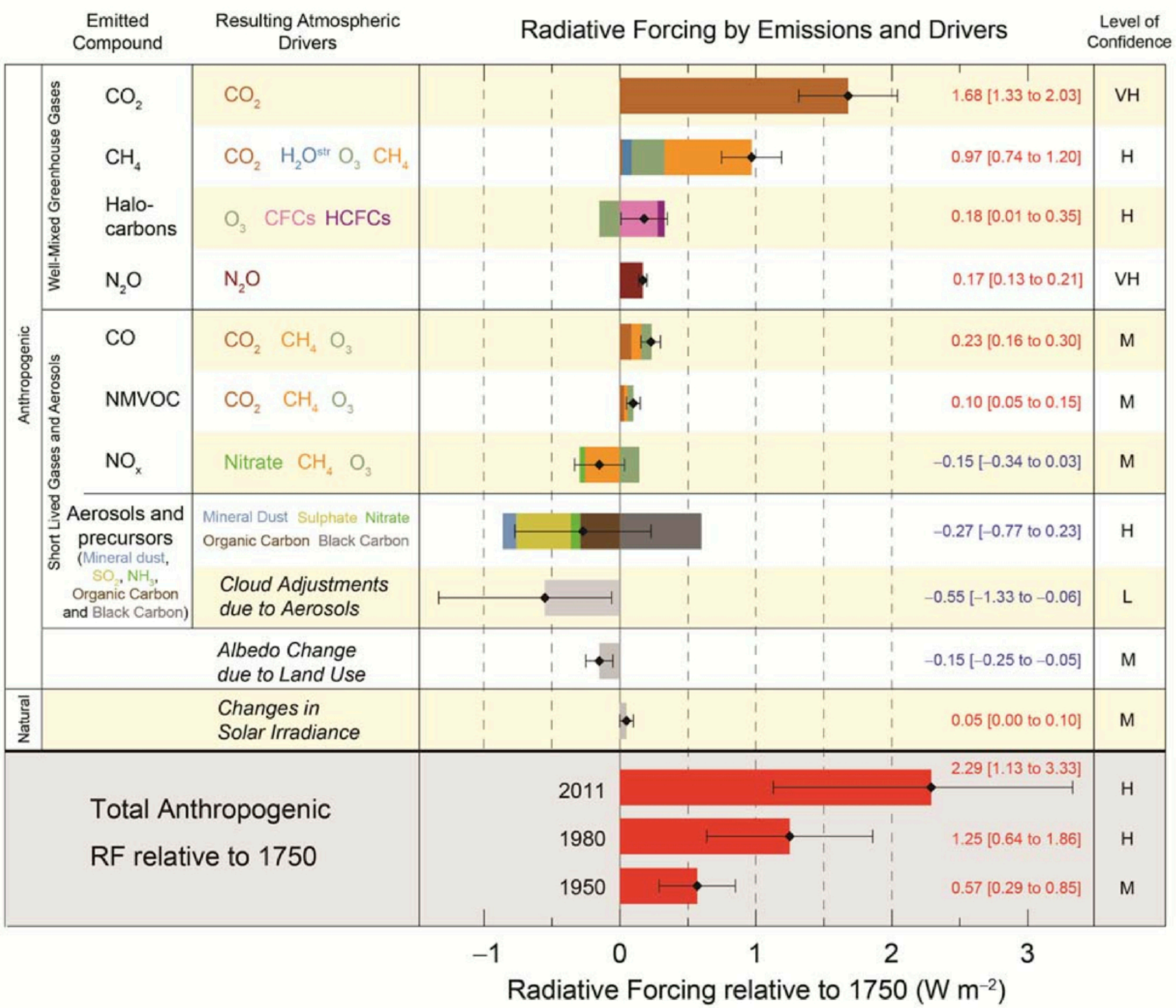
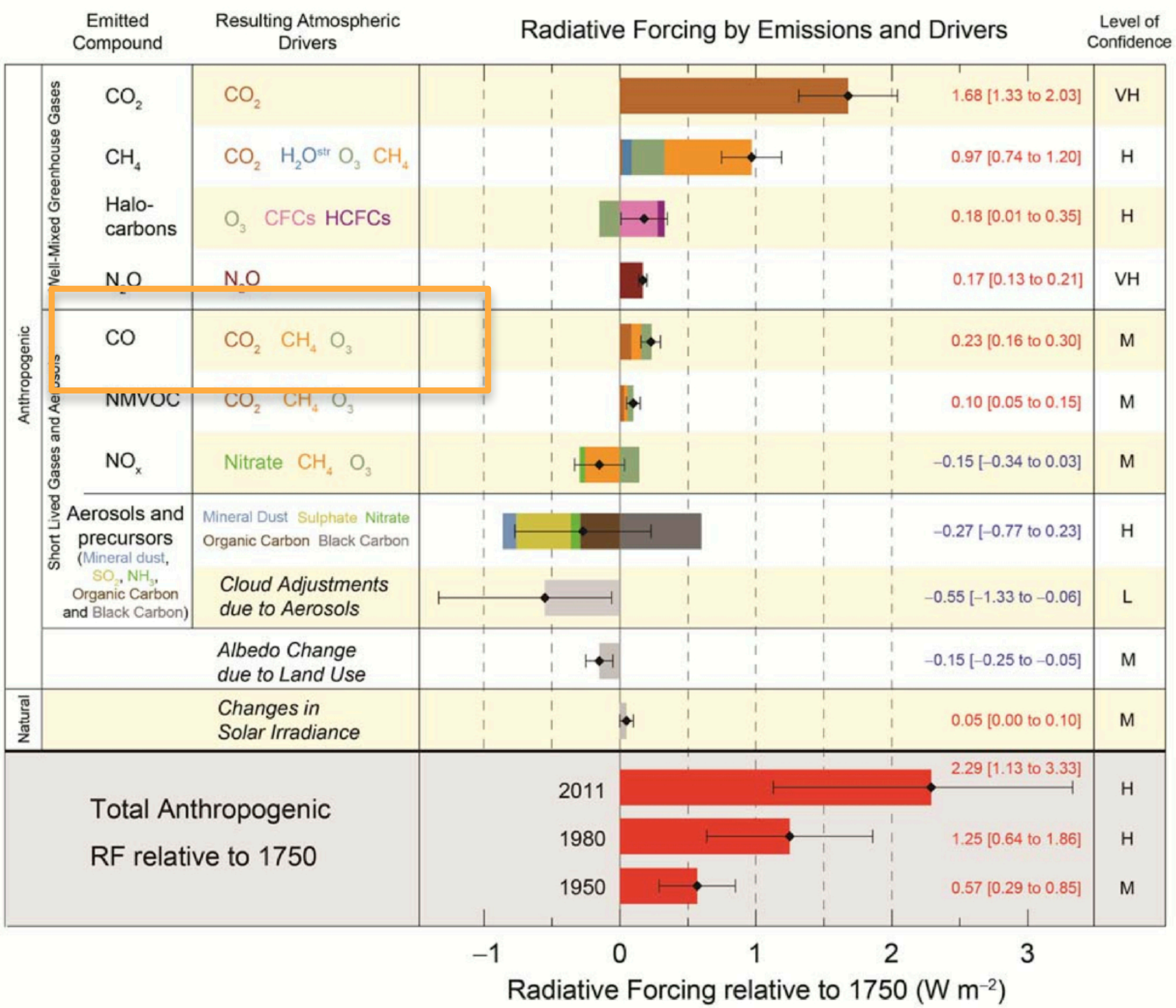
Effective radiative forcing - CMIP5 picture



- The radiative forcing can be used to estimate the resulting global temperature change via

$$\Delta F = \lambda \Delta T$$

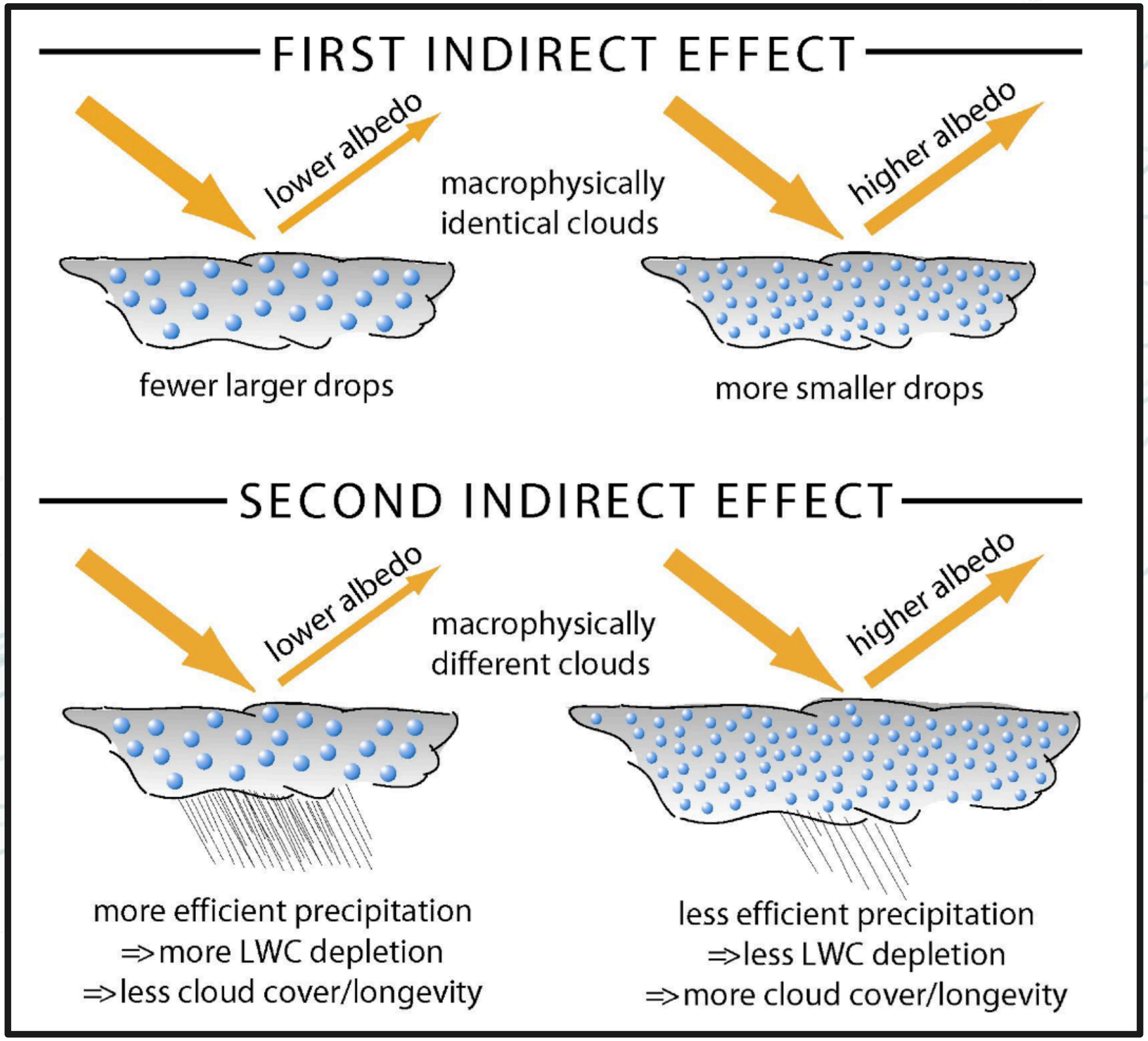
Effective radiative forcing - anthropogenic emissions



- Anthropogenic emissions affect the concentration of radiatively important gases such as CH4, O3
- Oxidants such as O3 also affect aerosol formation which can also perturb cloud properties
- ERF = ΔCS + ΔCRE - clear-sky (GG-dominated in the long wave) + Cloud Radiative Effects

Cloud radiative properties respond to aerosol changes

- Aerosol (CCN) controlled by atmospheric oxidation of gases like SO2, biogenic emissions, NOx.
- Clouds form on the aerosol (CCN) present in the atmosphere
- The cloud properties are sensitive to the number of aerosols
    - more aerosol → more cloud droplets
- More droplets means
    - a brighter cloud
    - a longer cloud lifetime
- Leading to negative forcing (increased energy at the top of the atmosphere) and less energy reaching the surface



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Atmospheric chemistry of H_2

- Present-day sources

Sources	Fossil fuel	Biomass burning	N2 fixation	Photochemical production	Total
Strength / Tg per yr	17 ± 4	15 ± 6	9 ± 3	36 ± 7	76 ± 10

- Present day sinks

Sinks	Photochemical removal	Uptake by soil	Total
Strength / Tg per yr	23 ± 8	50 +30 / -20	70 ± 30

- Low temperature combustion in the atmosphere (without the 'squeaky pop')
- Giving an atmospheric burden of 155 Tg H2, a mean mixing ratio of 550 ppb and a lifetime of 2.5 years
- H2 affects
  - ozone levels (H2 oxidation functions as a source of ozone)
  - methane levels (H2 removes OH, decreasing the size of the CH4 sink)
  - aerosol and cloud properties via removal of OH and modification of sulfate aerosol number

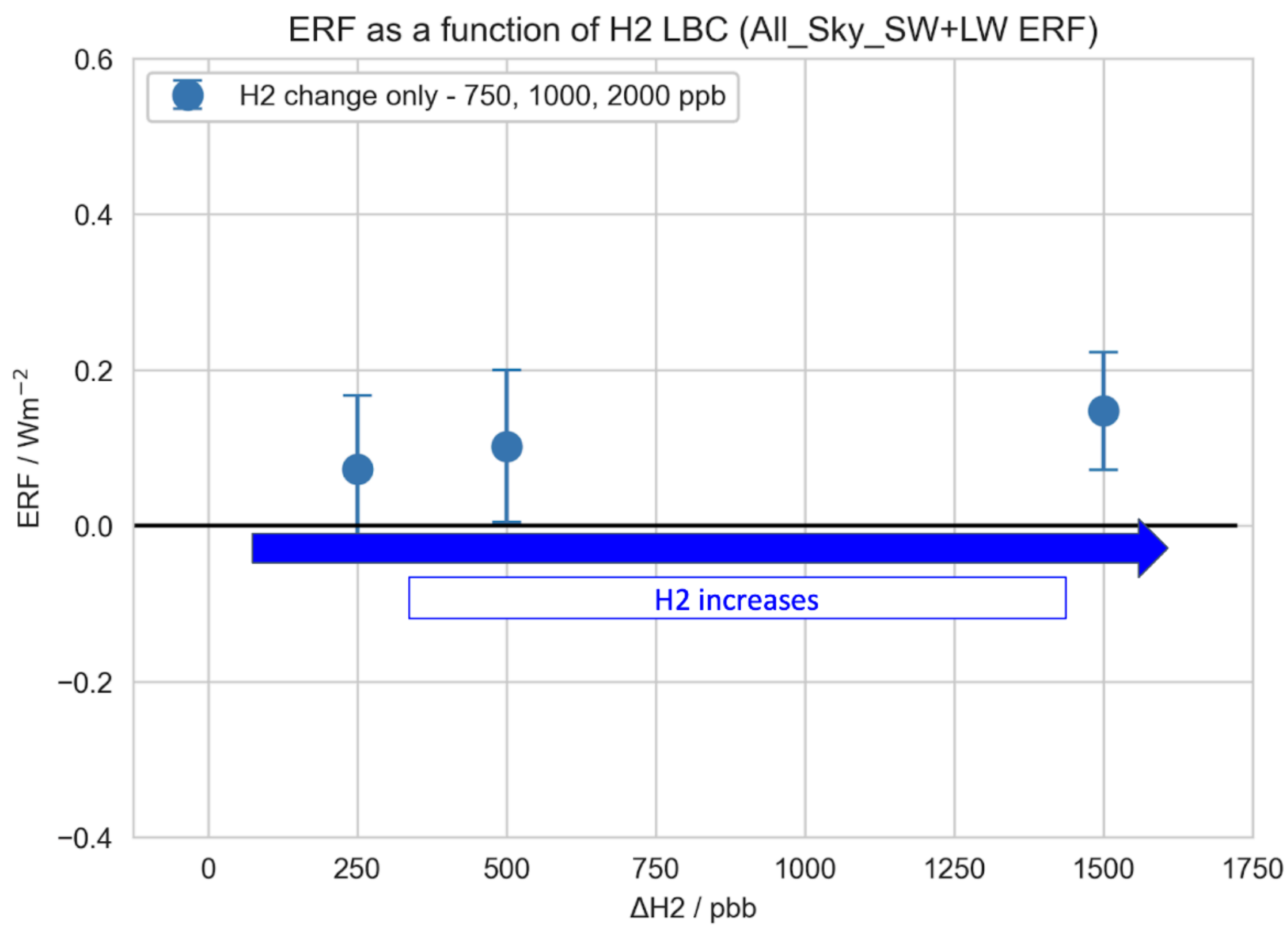
Scenarios studied

1. H_2 leakage emissions increase as a result of a move to H_2 as a fuel source.
   - 750 ppb, 1000 ppb and 2000 ppb (approx increase from 76 Tg to >200 Tg H_2 emissions)
2. Adoption of H_2 as a fuel source means that there is a co-benefit of reduction in other anthropogenic emissions such as CO, NOx, NMVOCs.
   - Consider this under low-H_2 and high-H_2 leakage scenarios
3. Adoption of H_2 as a fuel source means there are CH_4 emissions decreases and other other anthropogenic emissions such as CO, NOx, NMVOCs
   - Consider this under low-H_2 and high-H_2 leakage scenarios

- Using the UKCA chemistry-climate atmospheric model (a component of the UK's CMIP6 Earth System Model)
  - Numerical experiments with different levels of H_2 to capture different leakage scenarios.
  - Atmospheric conditions representative of year 2014 - uses standard forcings.
  - Hold sea-surface temperatures constant to focus the radiative response onto the ERF, method (c). Gives us numbers comparable to IPCC assessments.

Scenarios studied - what is the effect of H2 fugitive emissions?

- Experiments with varying H2 concentration in the atmosphere.
- The radiative forcing increases with increasing H2 concentration, and is positive = a warming. Maybe a plateau?
- For the highest leak rates (an effective tripling of the global atmospheric H2 source) ERF = 0.15 ± 0.08 Wm^{-2} which is approx 5% of the warming effect of CO2
- Increasing H2 levels see increases in methane lifetime and in ozone burden - can expect positive GG forcing.
- Increasing H2 levels leads to decreased OH
- Potential impacts on stratospheric ozone.
- How to attribute the RF increase?



Experiment	H2 LBC	OH	TAU CH4	O3 Burden
	ppb	$10^6 cm^{-3}$	Years	Tg
Base	500	1.22	8.48	348.6
TS2014_750H2	750	1.20	8.67	347.3
TS2014_1000H2	1000	1.18	8.83	349.7
TS2014_2000H2	2000	1.11	9.46	353.5

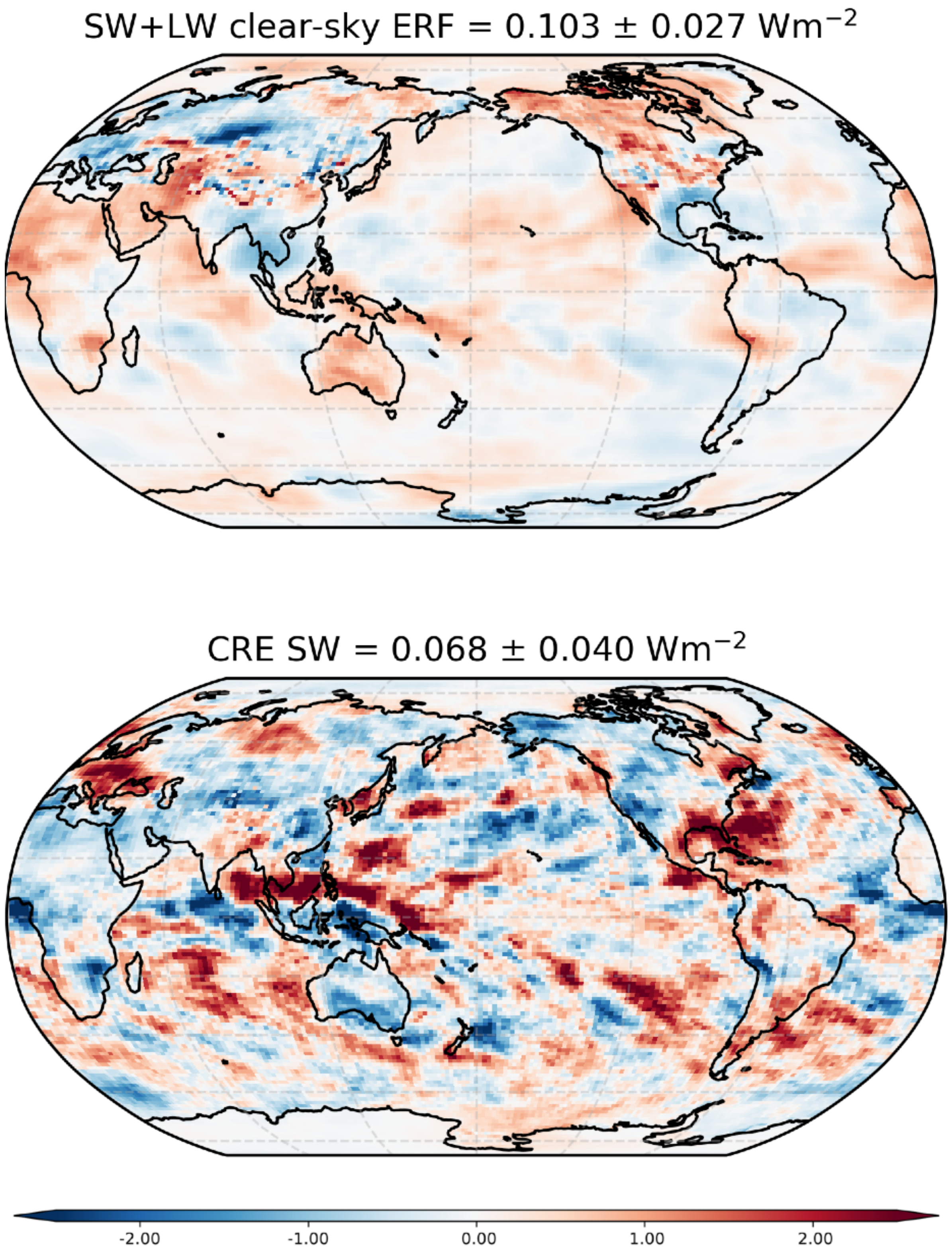
Breaking ERF down into clear-sky and cloud effects

- Can break the change in radiative flux at the top of the atmosphere down further. Focusing here on the 2000 ppb H2 case.

- The change in the greenhouse gas forcing, a.k.a. the Clear Sky (cloud-free) forcing
  - ERF = 0.103 Wm^{-2}
  - Presumably from the small increase in tropospheric ozone (a greenhouse gas)

- The change in the radiative properties of the clouds (global averaged effects)
  - ΔCRE = 0.036 Wm^{-2}
- Which can be broken down further
  - Shortwave ΔCRE = 0.068 Wm^{-2}
  - Longwave ΔCRE = -0.032 Wm^{-2}

- i.e. the clear sky forcing is of the same order as the cloud radiative effect

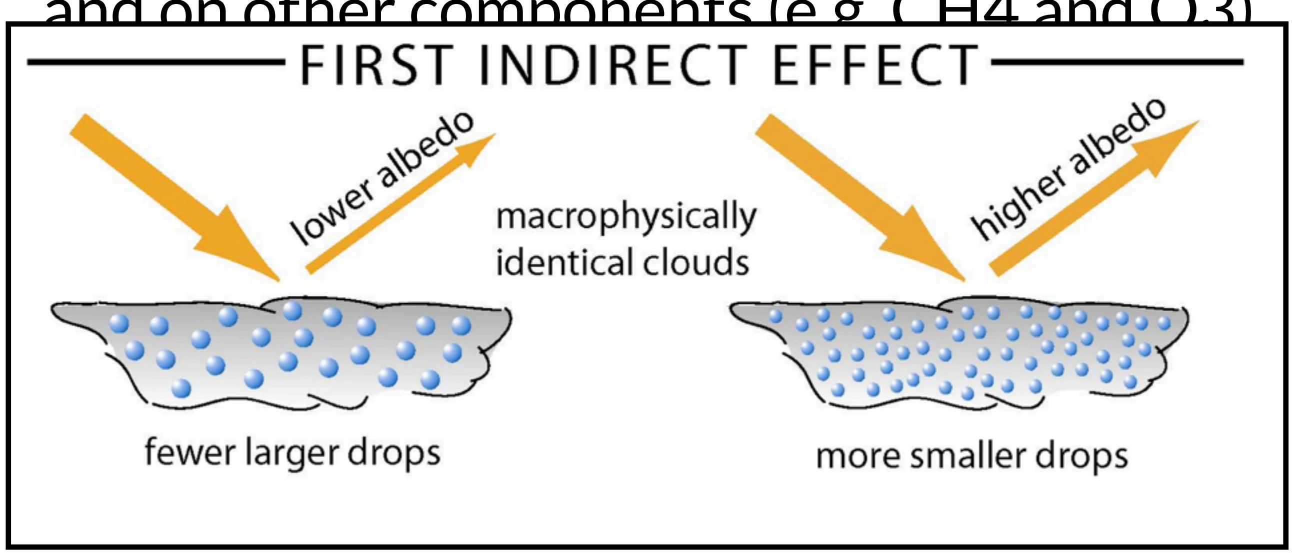


ERF - the coupling of gas phase oxidant to aerosol levels and cloud properties

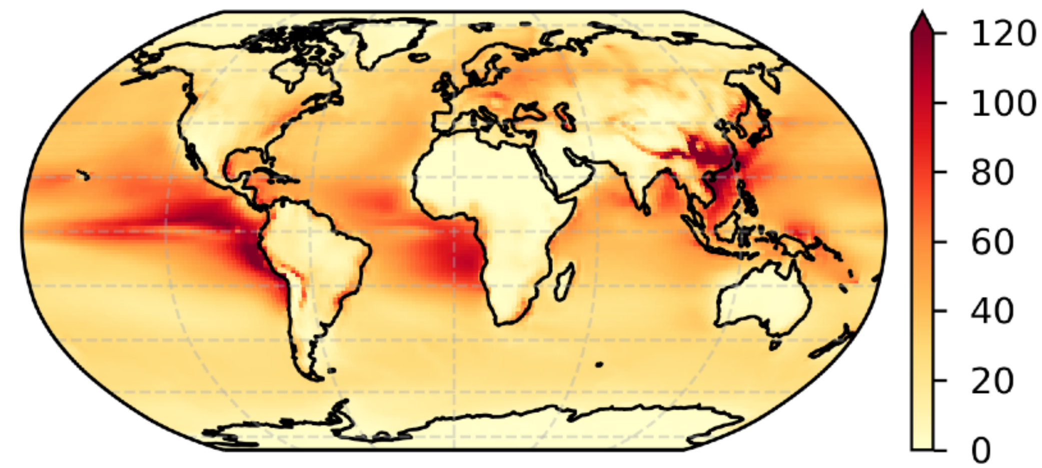
- The additional H_2 has caused a decrease in cloud droplet number concentration (CDNC). Seen here as a decrease in cloud droplet number with respect to our low H_2 base case.

- We can associate this decrease with the lower levels of the OH free radical oxidant in the region where aerosol is formed. There are fewer aerosol particles as a result.

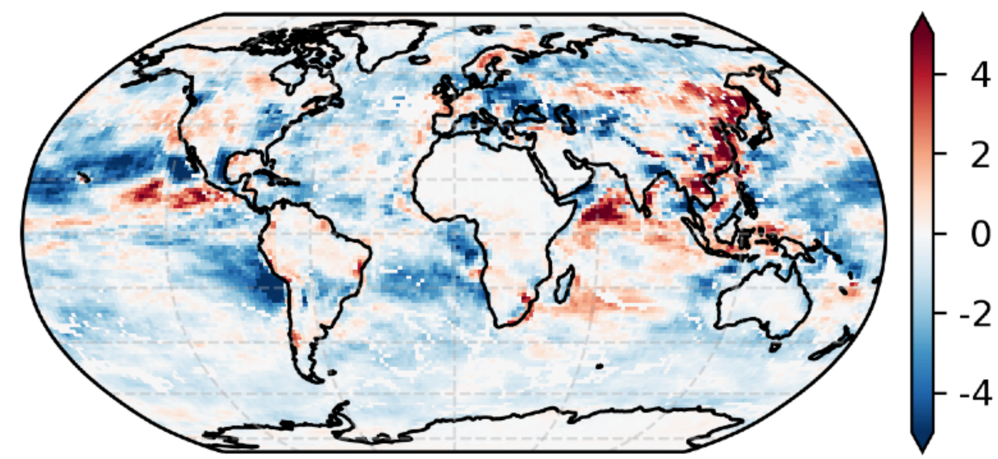
- The effect of elevated H_2 is to suppress OH, and this is having knock-on effects on aerosol and on other components (e.g. CH_4 and O_3)



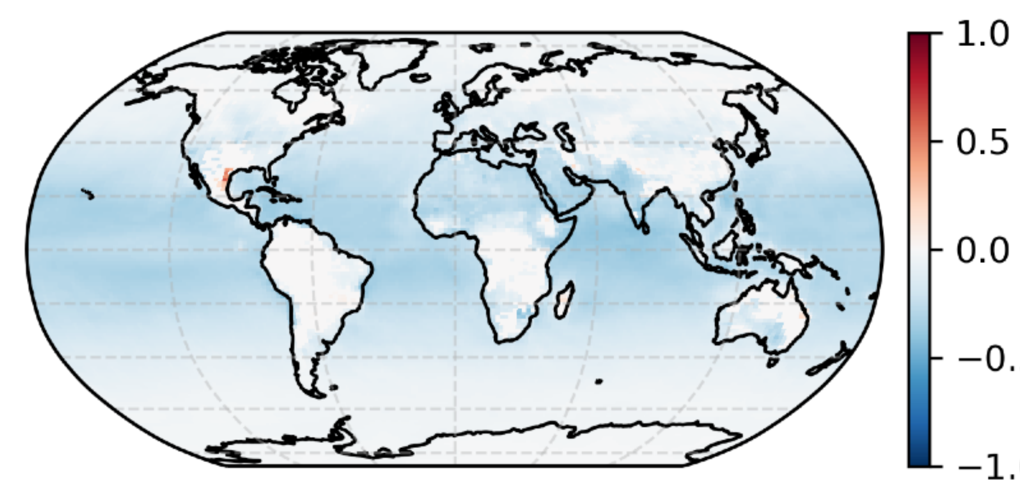
BASE CDNC /cm^{-3}



EXPT - BASE CDNC /cm^{-3}



EXPT - BASE OH / $10^6 cm^{-3}$



Thank you

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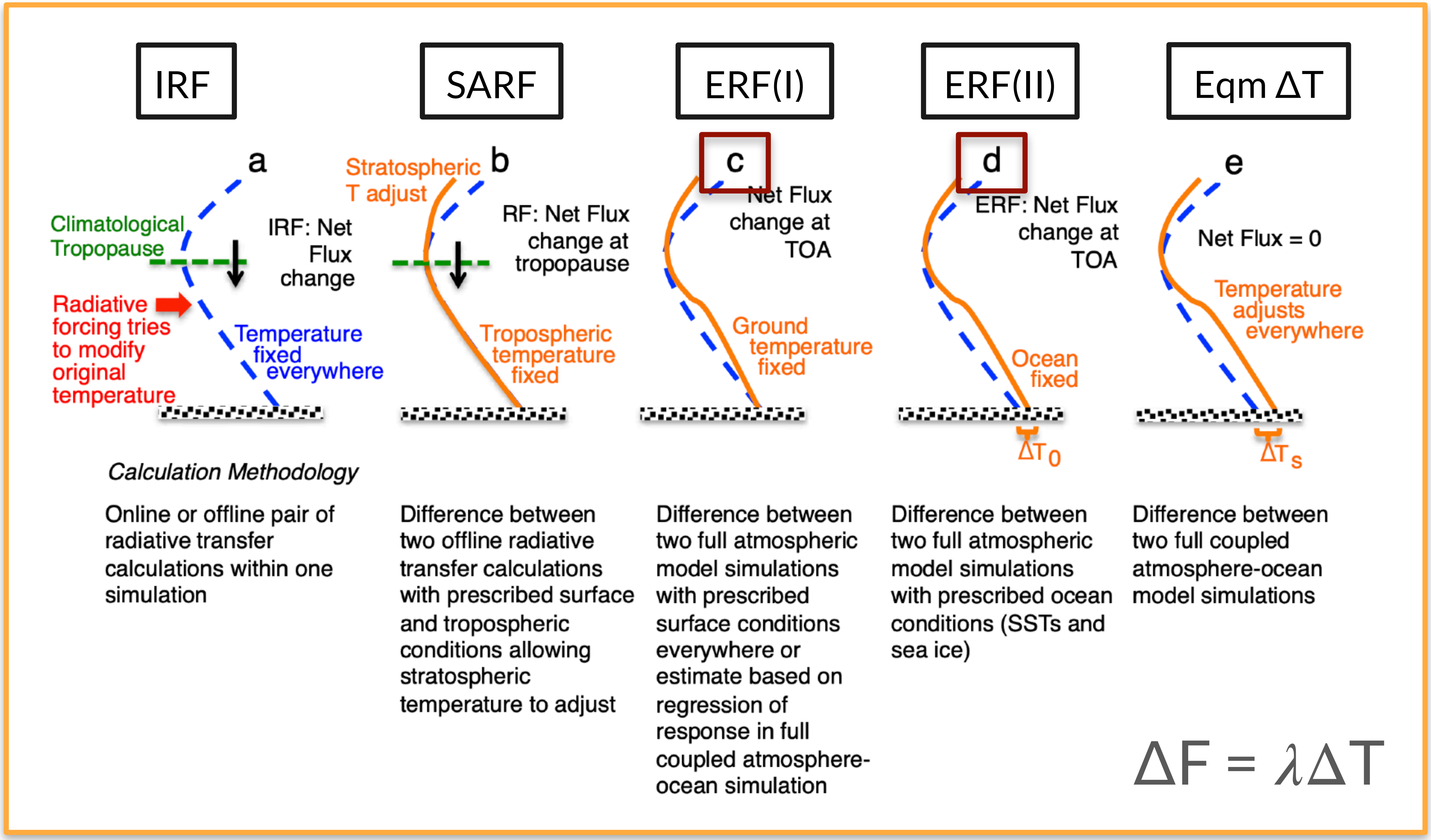
Effective radiative forcing - definitions



- Calculation of ERF (Wm^{-2}) as the change in energy flux at the top of the atmosphere following a perturbation (natural or anthropogenic).
- ERF includes all the tropospheric and land-surface adjustments - all the responses on a short timescale that occur as a result of the forcing agent, distinct from the slow feedbacks that arise due to temperature perturbations.

Table 1. Major global tropospheric sources and sinks of H_2 (Tg H_2 yr^{-1}) from various authors

	Novelli et al. (1999)	Hauglustaine and Ehhalt (2002)	Sanderson et al. (2003)	Rhee et al. (2006a)	Price et al. (2007)	Xiao et al. (2007)	This work
Fossil fuel	15 ± 10	16	20.0	15 ± 6	18.3	15 ± 10	11 ± 4
Biomass burning	16 ± 5	13	20.0	16 ± 3	10.1	13 ± 3	15 ± 6
Biofuel					4.4		
N_2 fixation, ocean	3 ± 2	5	4.0	6 ± 5	6.0		6 ± 3
N_2 fixation, land	3 ± 1	5	4.0	6 ± 5	0		3 ± 2
Photochemical production							
from methane	26 ± 9		15.2		24.5		23 ± 8
from VOC	14 ± 7		15.0		9.8		18 ± 7
total	40	31	30.2	64 ± 12	34.3	77 ± 10	41 ± 11
Sources total	77 ± 16	70	78.2	107 ± 15	73	105 ± 10	76 ± 14
Oxidation by OH	19 ± 5	15	17.1	19 ± 3	18	18 ± 3	19 ± 5
Soil uptake	56 ± 41	55	58.3	88 ± 11	55 ± 8.3	85 ± 5	60^{+30}_{-20}
Sinks total	75 ± 41	70	75.4	107 ± 11	73	105[a]	79^{+30}_{-20}
Tropospheric Burden, Tg H_2	155 ± 10	136	172[b]	150[c]	141	149 ± 23	155[d] ± 10
Tropospheric Lifetime, yr	2.1	1.9	2.2[b]	1.4	1.9	1.4	2.0

[a]Includes export to stratosphere of 1.9 Tg H_2 yr^{-1}.

[b]Model domain reached 100 hPa; thus the burden includes about 1/2 of the stratosphere. Reduced to a troposphere holding 0.82 of the total air mass the burden would be 157 Tg H_2 and the tropospheric lifetime 2.0 yr.

[c]Calculated from sources and lifetime.

[d]From Novelli et al. (1999).

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