Aviation's impact on global temperature:
Cumulative and Short-lived Climate Pollutants
October 13th, 2020

Myles Allen

Environmental Change Institute, School of Geography and the Environment & Department of Physics, University of Oxford

David Lee

Centre for Aviation, Transport and the Environment Manchester Metropolitan University

How is aviation contributing to global warming?

Atmospheric Environment
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In Press, Journal Pre-proof

The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018

Dedication: This paper is dedicated to the memory of Professor Ivar S. A. Isaksen of the University of Oslo, whose scientific excellence, friendship, and mentorship is sorely missed.

D.S. Lee [a], D.W. Fahey [b], A. Skowron [a], M.R. Allen [c, n], U. Burkhardt [d], Q. Chen [e], S.J. Doherty [f], S. Freeman [a], P.M. Forster [g], J. Fuglestvedt [h], A. Gettelman [i], R.R. De León [a], L.L. Lim [a], M.T. Lund [h], R.J. Millar [c, o], B. Owen [a], J.E. Penner [j], G. Pitari [l] ... L.J. Wilcox [m]

All data from David Lee.
All mistakes by Myles Allen.

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Improved calculation of warming-equivalent emissions for short-lived climate pollutants

Michelle Cain, John Lynch, Myles R. Allen, Jan S. Fuglestvedt, David J. Frame & Adrian H Macey

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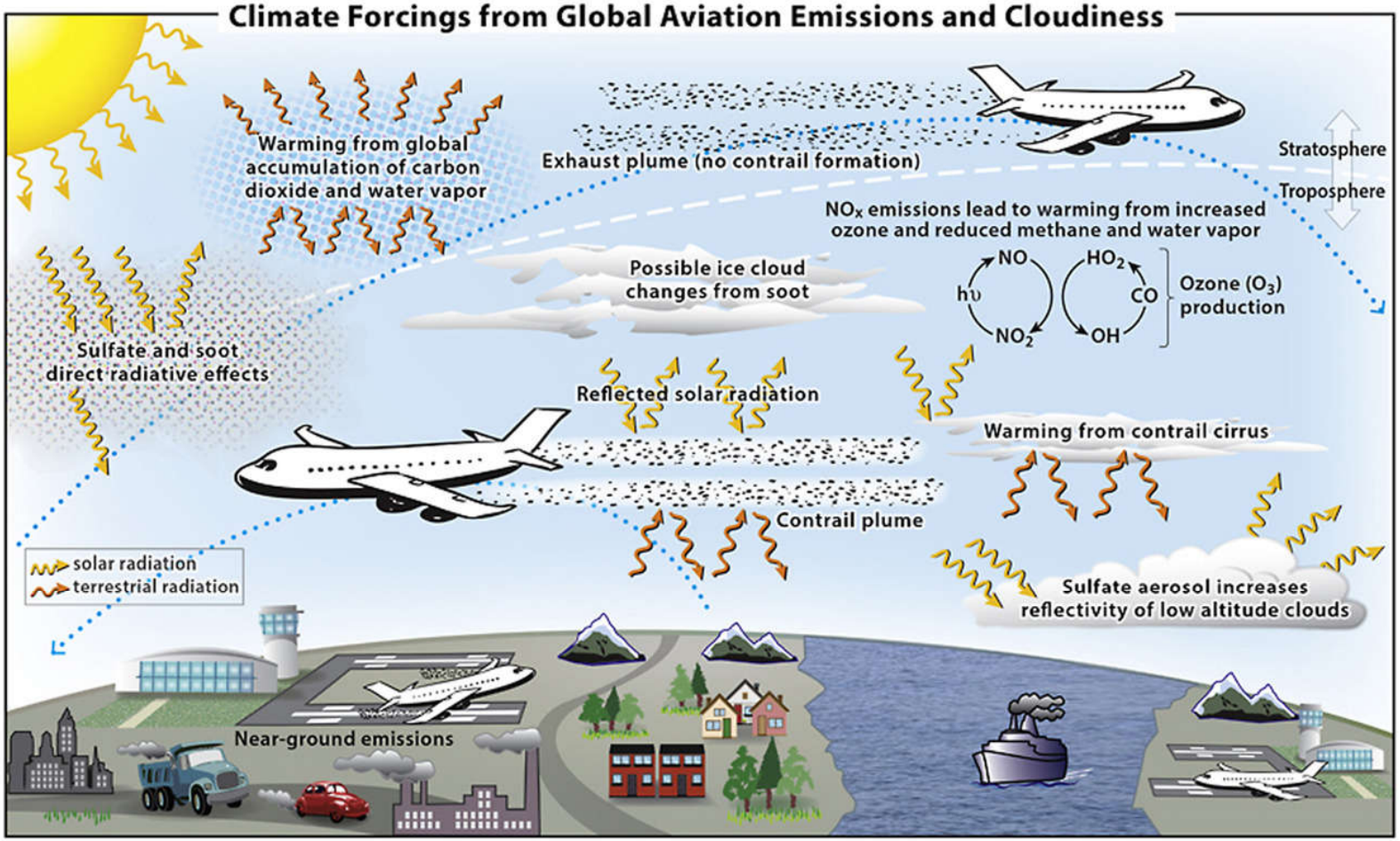
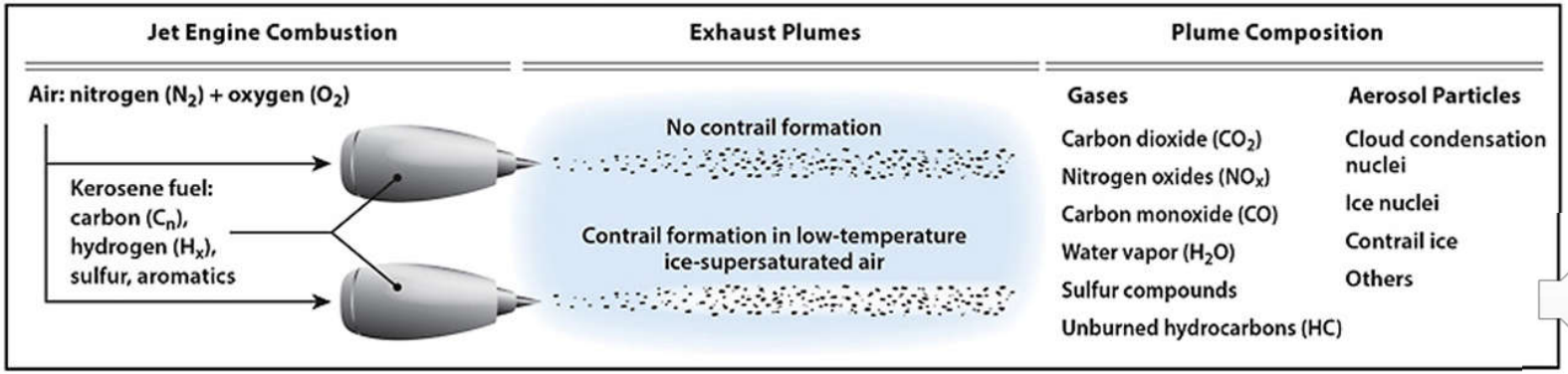
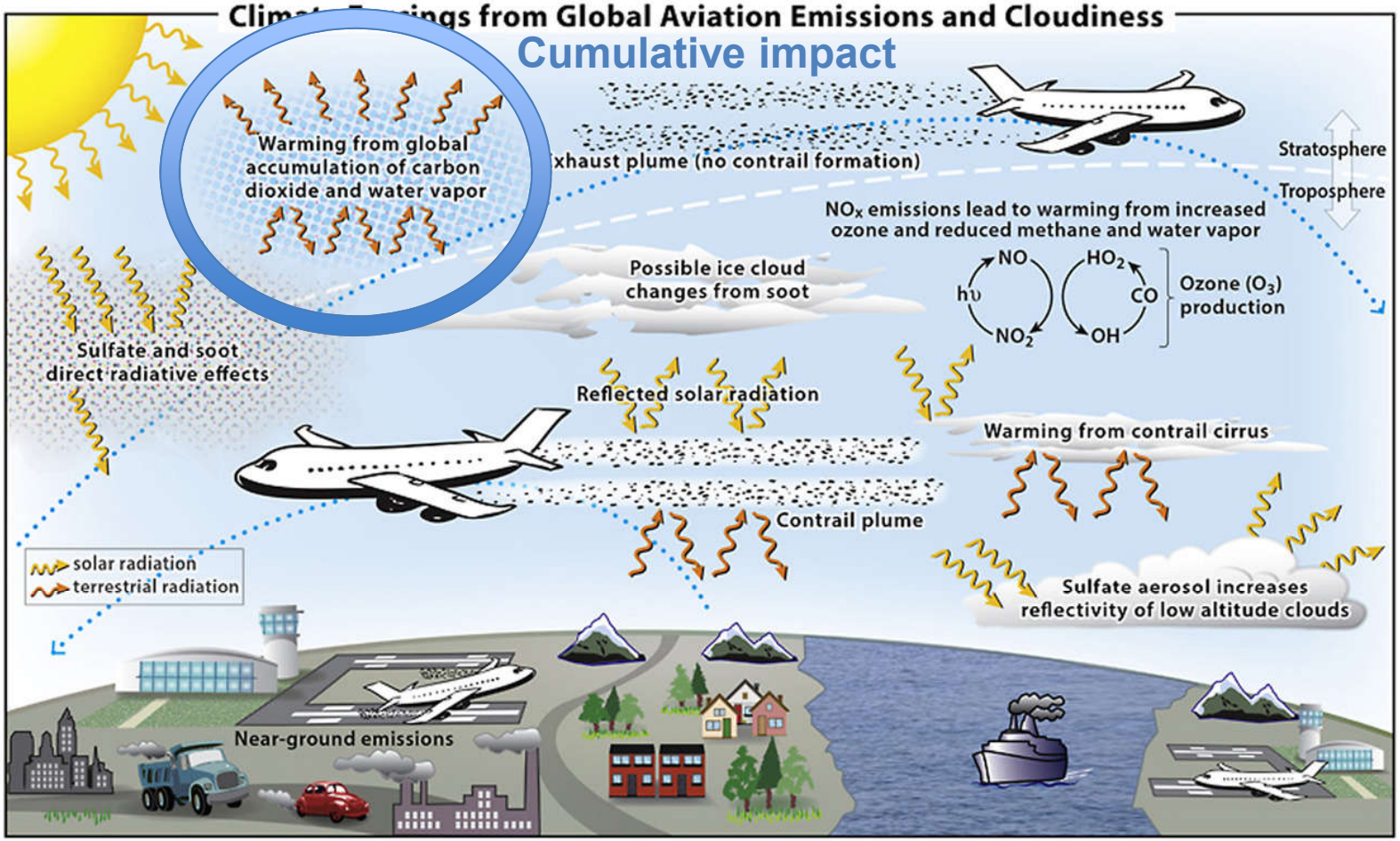

Climate Forcings from Global Aviation Emissions and Cloudiness
Warming from global accumulation of carbon dioxide and water vapor
Exhaust plume (no contrail formation)
Stratosphere
Troposphere
NOx emissions lead to warming from increased ozone and reduced methane and water vapor
Possible ice cloud changes from soot
NO
HO2
hυ
CO
NO2
OH
Ozone (O3) production
Sulfate and soot direct radiative effects
Reflected solar radiation
Warming from contrail cirrus
Contrail plume
solar radiation
terrestrial radiation
Sulfate aerosol increases reflectivity of low altitude clouds
Near-ground emissions


Jet Engine Combustion
Exhaust Plumes
Plume Composition
Air: nitrogen (N2) + oxygen (O2)
Kerosene fuel: carbon (Cn), hydrogen (Hx), sulfur, aromatics
No contrail formation
Contrail formation in low-temperature ice-supersaturated air
Gases
Carbon dioxide (CO2)
Nitrogen oxides (NOx)
Carbon monoxide (CO)
Water vapor (H2O)
Sulfur compounds
Unburned hydrocarbons (HC)
Aerosol Particles
Cloud condensation nuclei
Ice nuclei
Contrail ice
Others



Jet Engine Combustion	Exhaust Plumes	Plume Composition	
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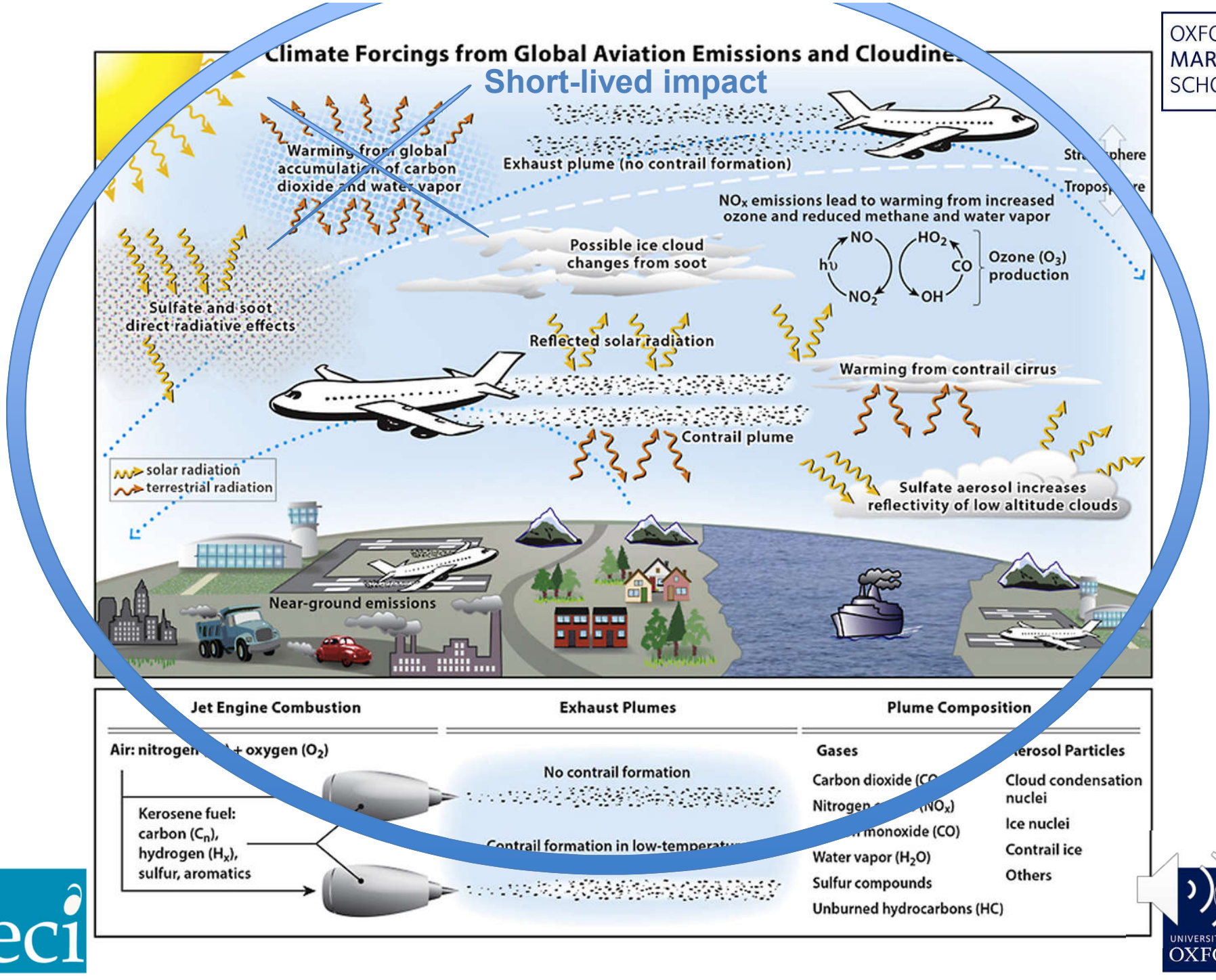
Air: nitrogen (N_2) + oxygen (O_2)	No contrail formation	Carbon dioxide (CO_2)	Cloud condensation nuclei
Kerosene fuel: carbon (C_n), hydrogen (H_x), sulfur, aromatics	Contrail formation in low-temperature ice-supersaturated air	Nitrogen oxides (NO_x)	Ice nuclei
		Carbon monoxide (CO)	Contrail ice
		Water vapor (H_2O)	Others
		Sulfur compounds	
		Unburned hydrocarbons (HC)	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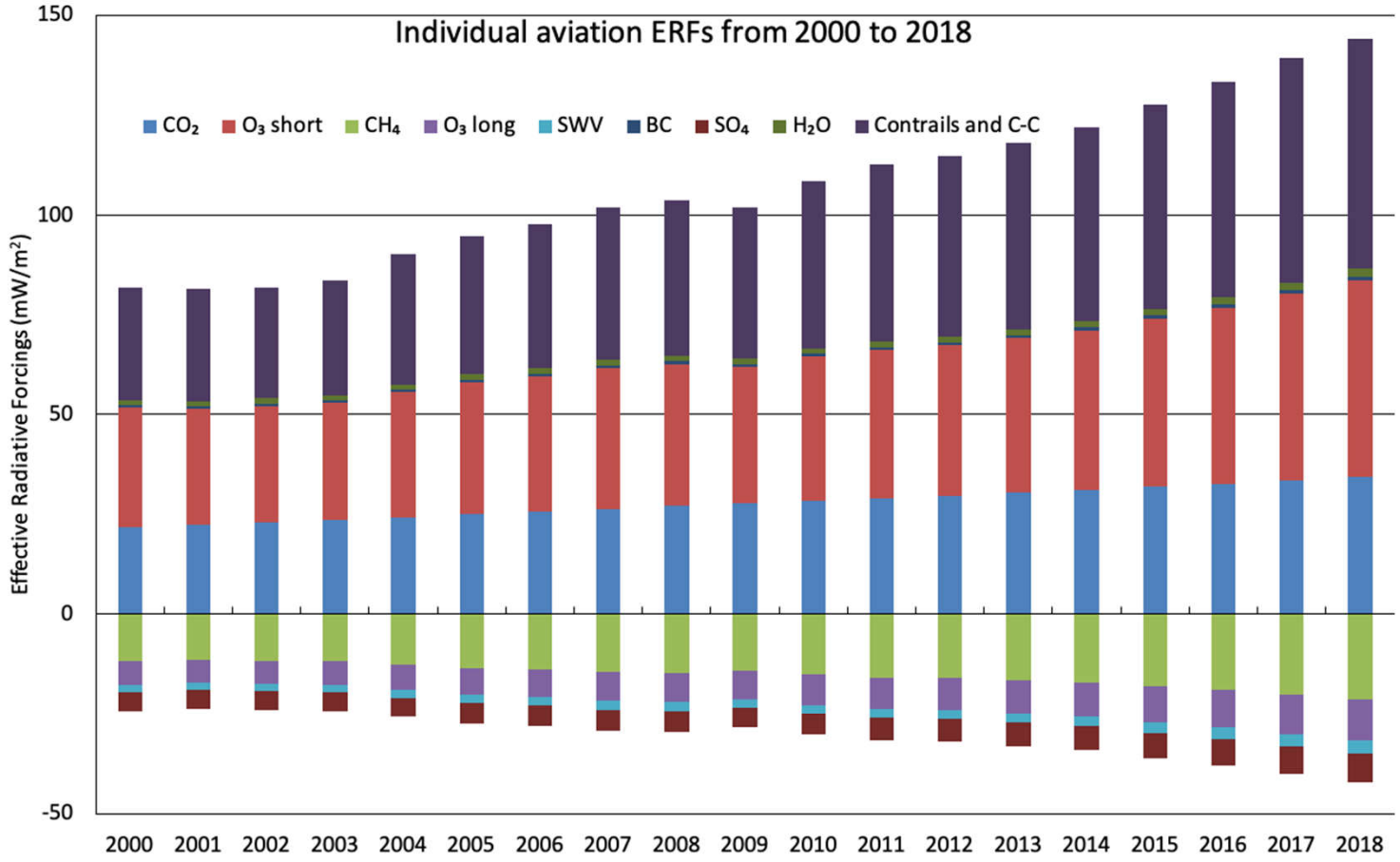
How drivers contribute to top-of-atmosphere energy imbalance (Effective Radiative Forcing)



How does this contribute to global warming?

Human-induced warming (ΔT) over a time-interval from a few years to a few decades is proportional to **total cumulative carbon dioxide emissions** over that time-interval (E) plus the **change in global energy imbalance** due to other human influences on climate (ΔF):

$$\Delta T = \kappa \left(E + \frac{\Delta F}{\alpha} \right)$$

- κ = "Transient Climate Response to Emissions" $\approx$ 0.4°C per $TtCO_2$
  - $TtCO_2$ = Trillion tonnes of CO_2; AR5 likely range for κ: 0.23-0.68°C
- α = "Normalized Absolute GWP" of CO_2 $\approx$ 1.0 W/m^2 per $TtCO_2$
  - AR5 values of 0.9-1.2 for H=20 to 100 years

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  - Slightly more accurate version, with $r \approx 0.25$

$$\Delta T = \kappa \left(E + (1 - r) \frac{\Delta F}{\alpha} + r \frac{\bar{F} \Delta t}{\alpha} \right)$$

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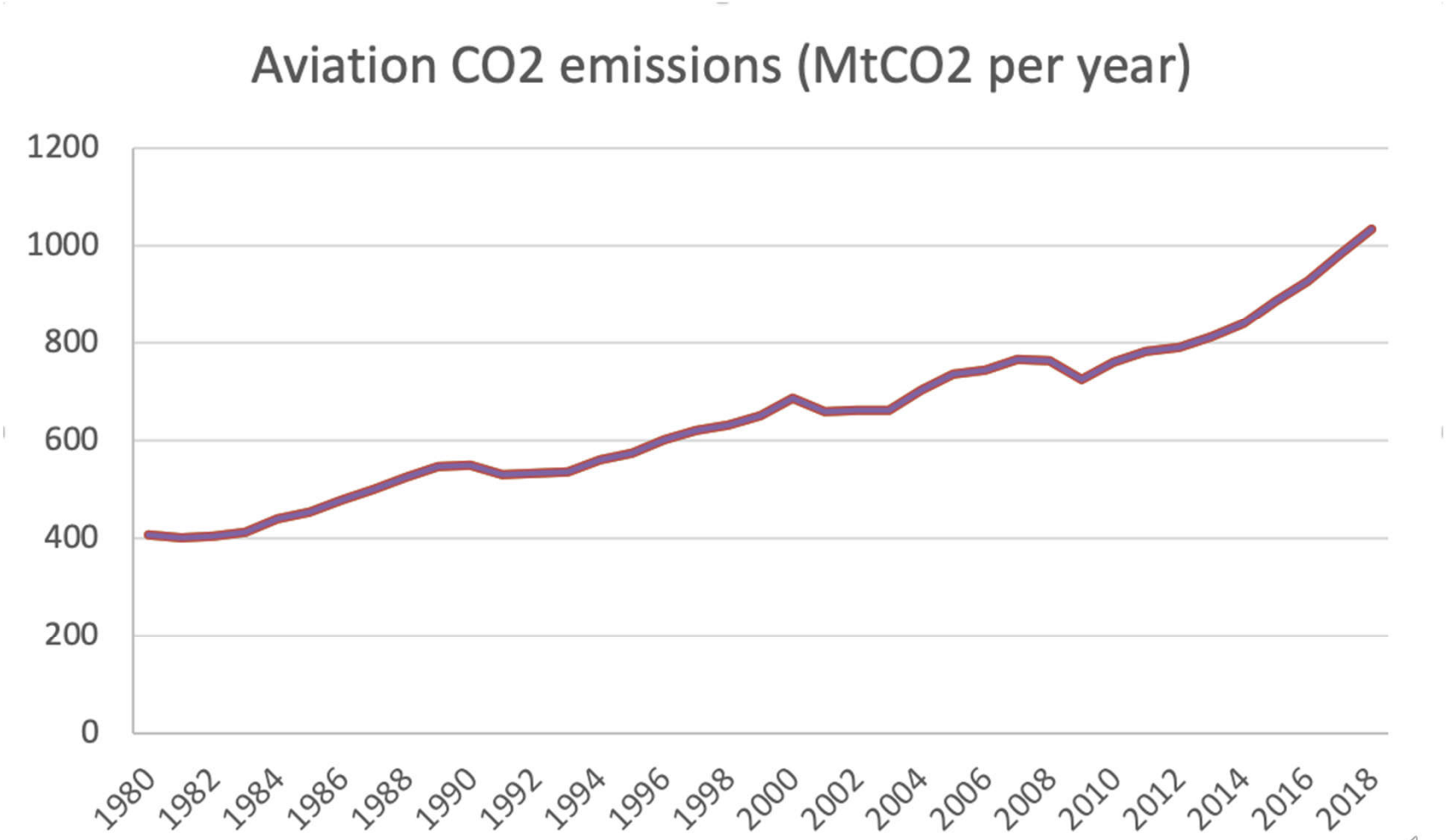
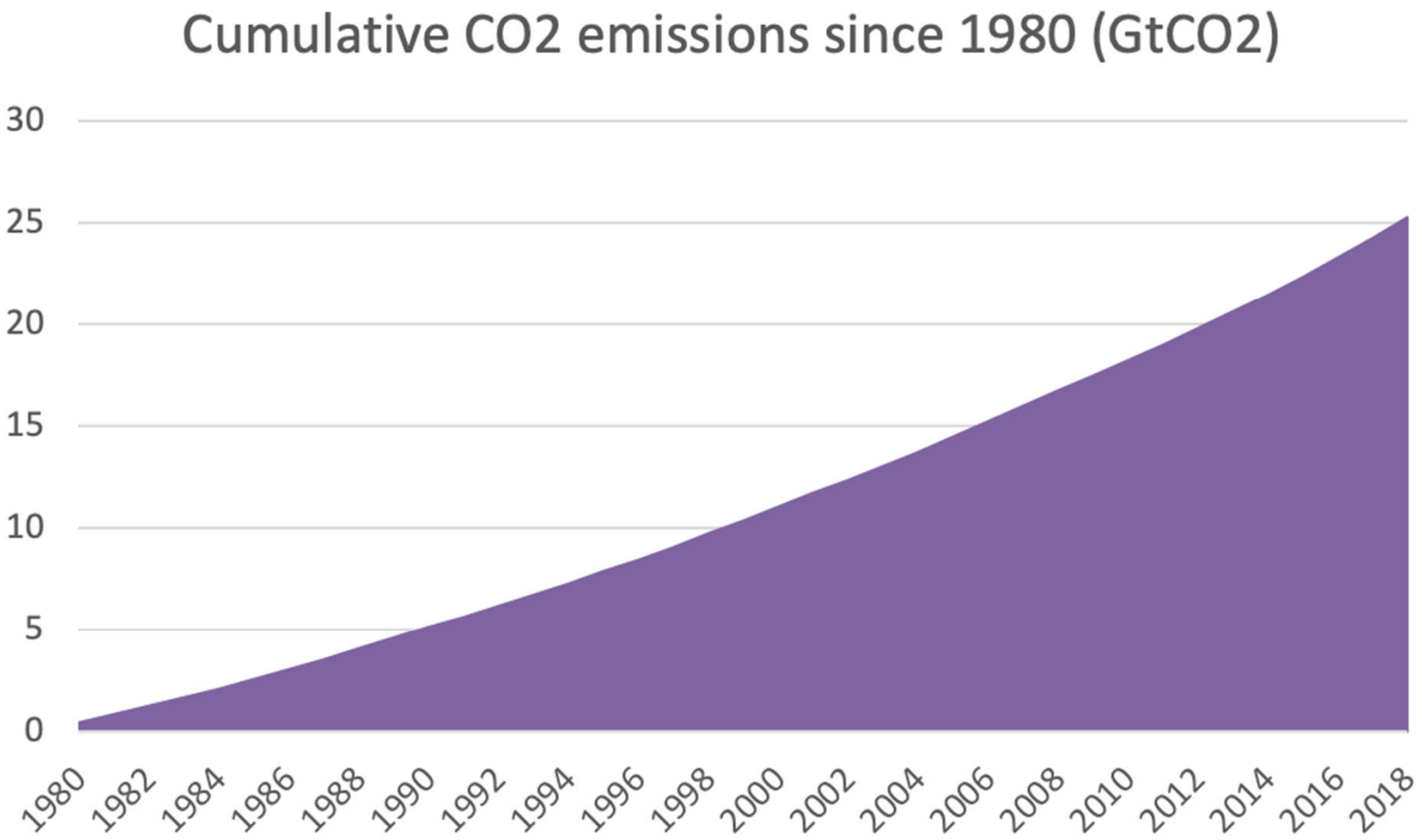
Total CO_2 forcing-equivalent emissions

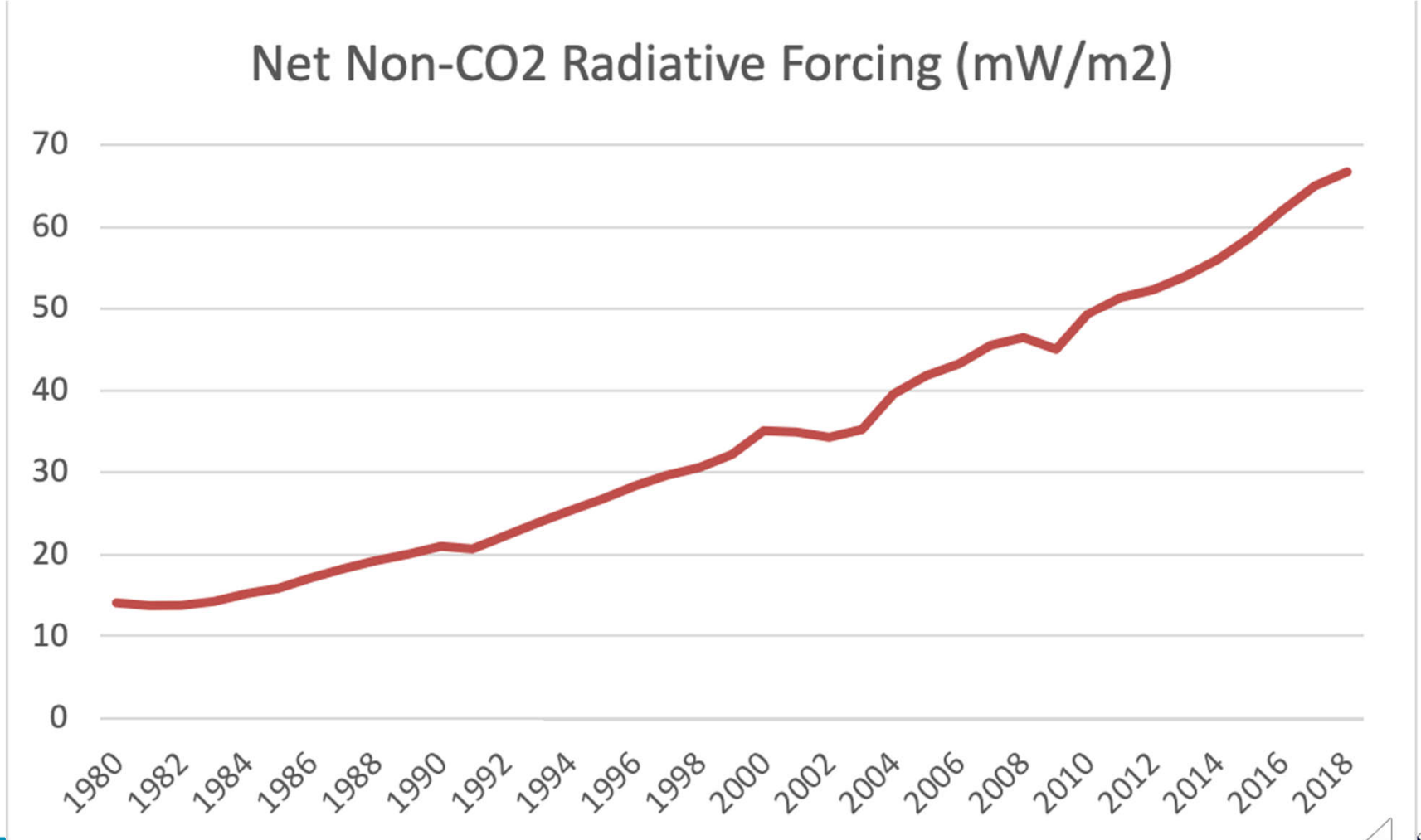
Aviation CO_2 emissions since 1980



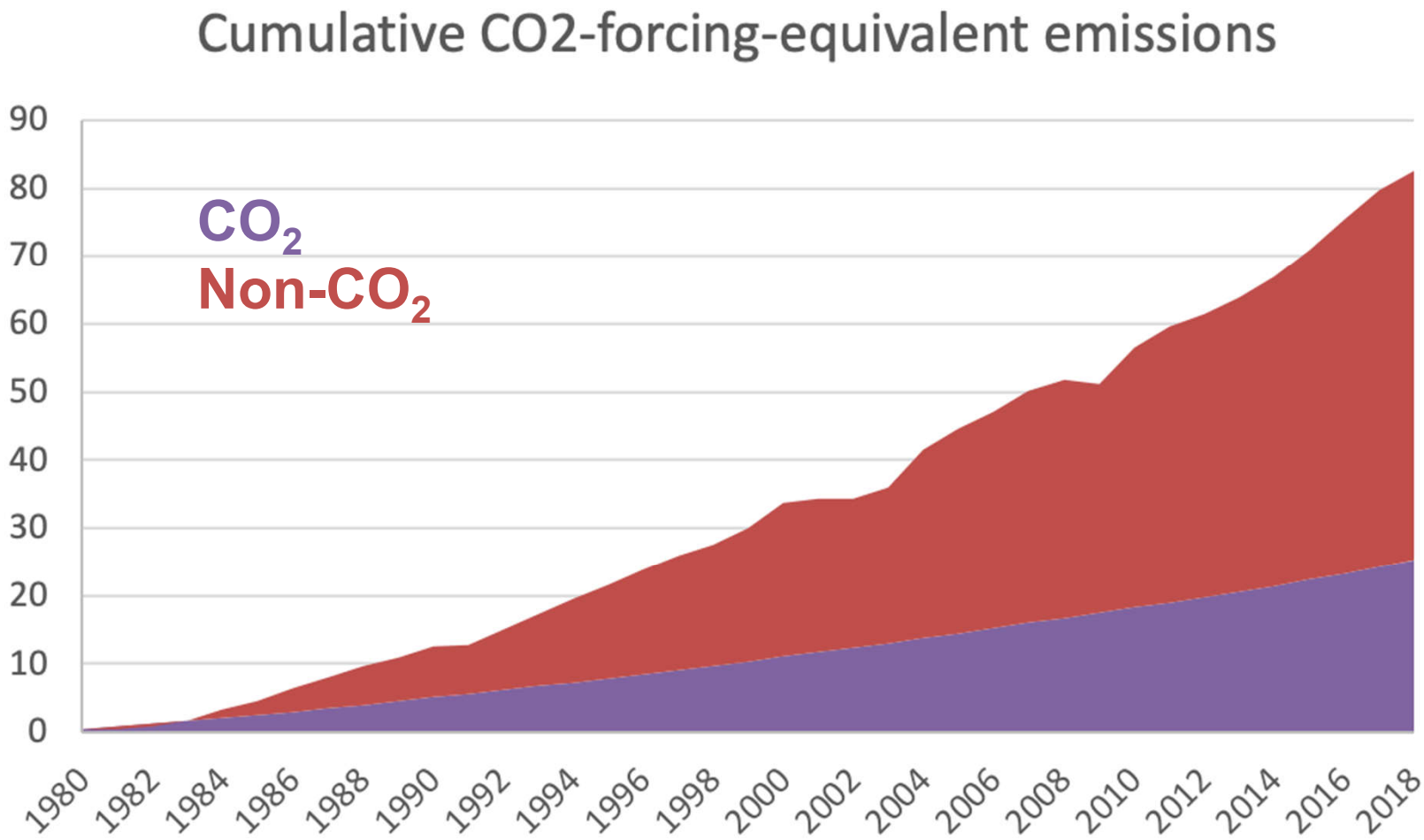
Cumulative CO_2 emissions, integrated over time



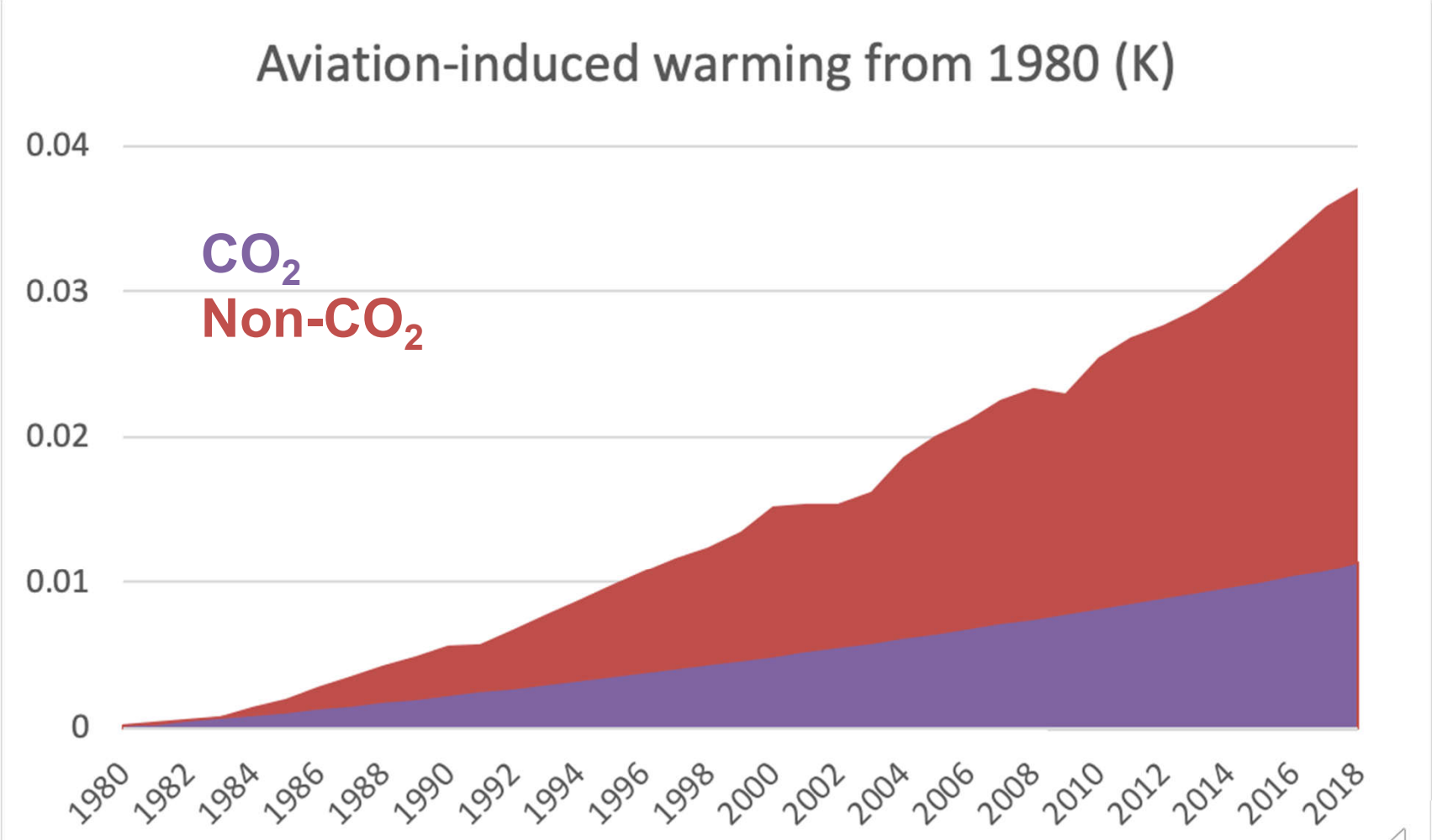
Net non-CO_2 Effective Radiative Forcing (mW/m^2)



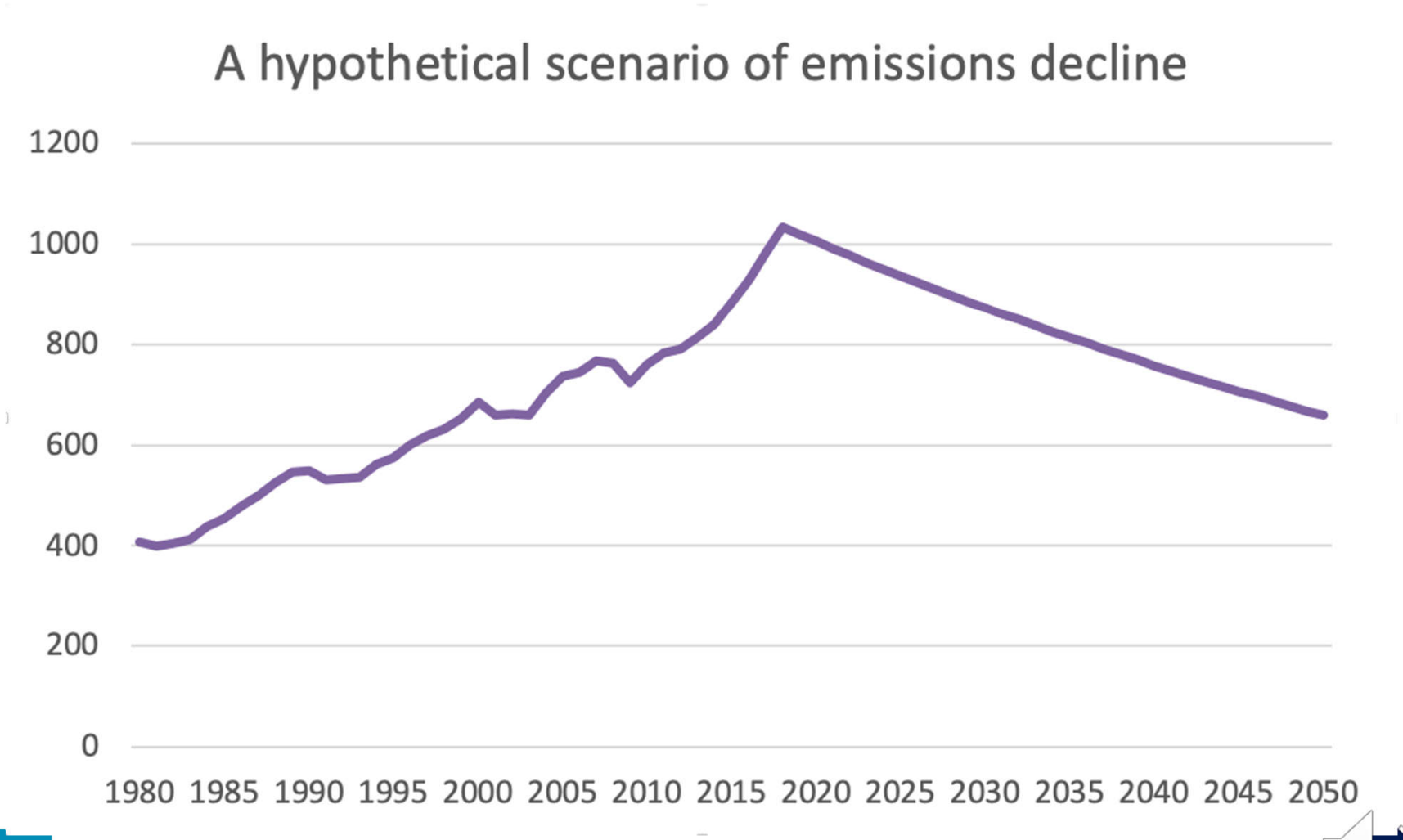
Cumulative CO_2 forcing-equivalent emissions



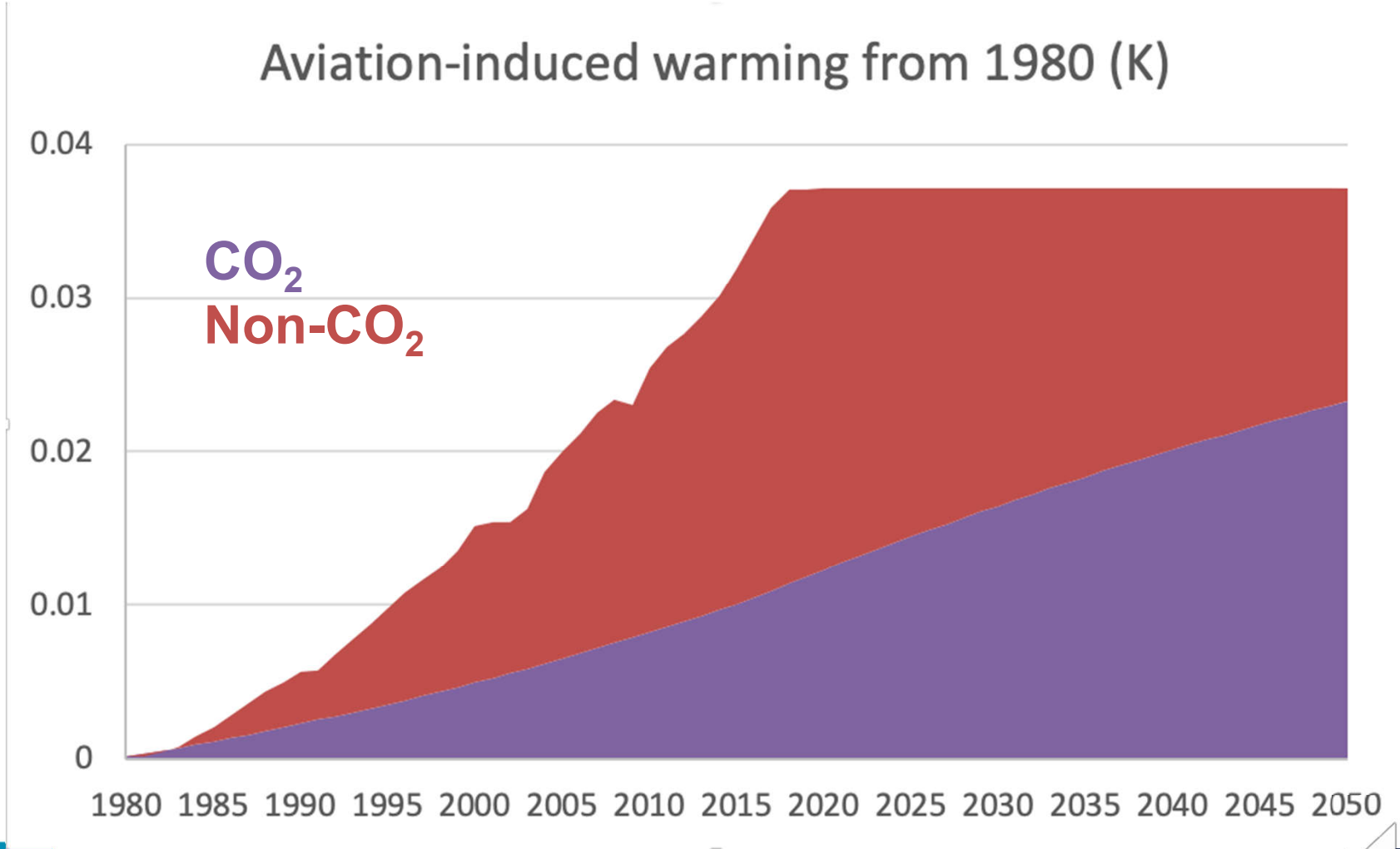
Aviation-induced warming: 0.037ºC = 6% of total human-induced warming over this period



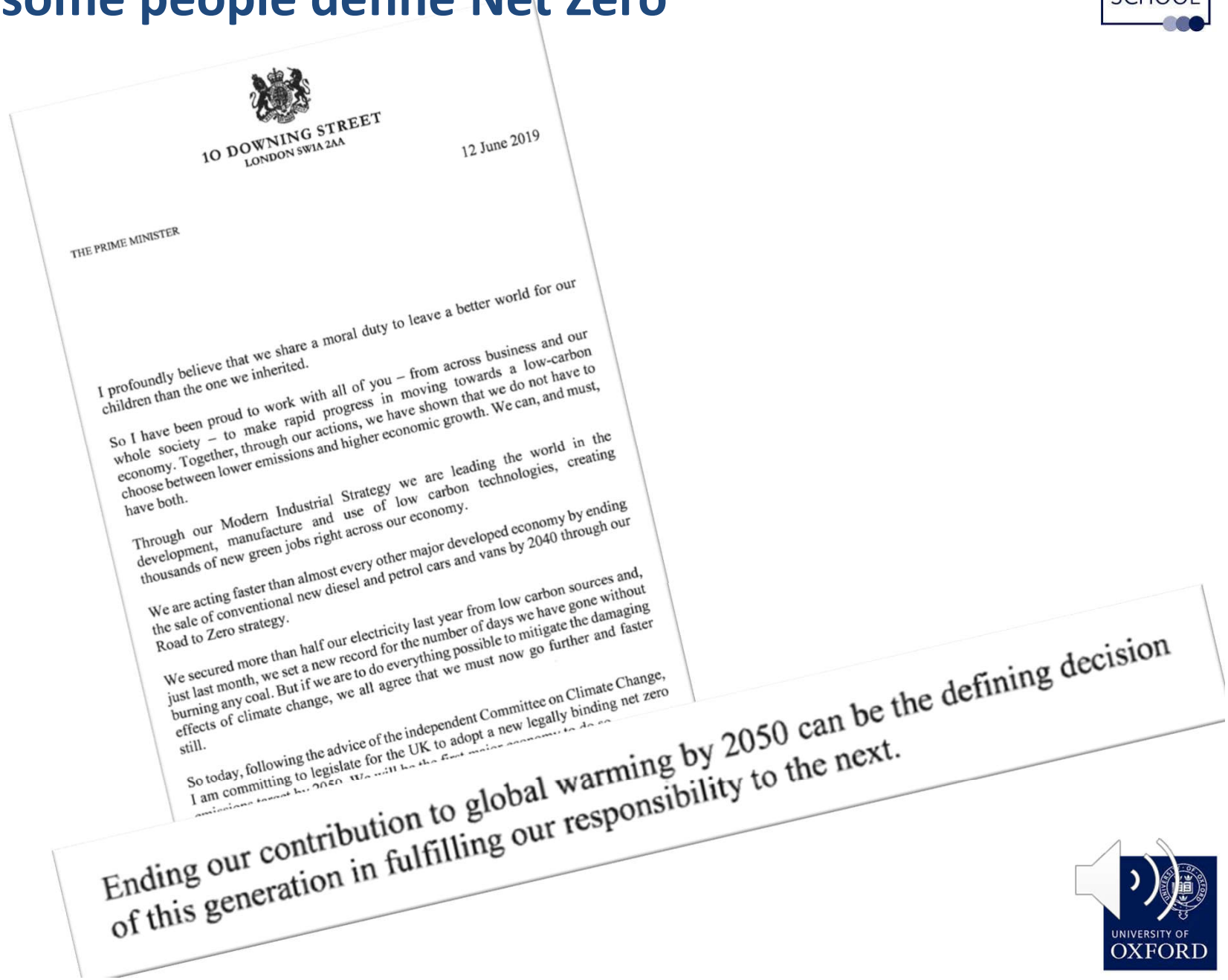
Suppose emissions decline by 1.4% per year from 2018 onwards: impact on global warming?



Aviation-induced warming under a 1.4% emissions decline scenario



How some people define Net Zero



10 DOWNING STREET
LONDON SW1A 2AA

12 June 2019

THE PRIME MINISTER

I profoundly believe that we share a moral duty to leave a better world for our children than the one we inherited.

So I have been proud to work with all of you – from across business and our whole society – to make rapid progress in moving towards a low-carbon economy. Together, through our actions, we have shown that we do not have to choose between lower emissions and higher economic growth. We can, and must, have both.

Through our Modern Industrial Strategy we are leading the world in the development, manufacture and use of low carbon technologies, creating thousands of new green jobs right across our economy.

We are acting faster than almost every other major developed economy by ending the sale of conventional new diesel and petrol cars and vans by 2040 through our Road to Zero strategy.

We secured more than half our electricity last year from low carbon sources and, just last month, we set a new record for the number of days we have gone without burning any coal. But if we are to do everything possible to mitigate the damaging effects of climate change, we all agree that we must now go further and faster still.

So today, following the advice of the independent Committee on Climate Change, I am committing to legislate for the UK to adopt a new legally binding net zero

Ending our contribution to global warming by 2050 can be the defining decision of this generation in fulfilling our responsibility to the next.

Key take-home conclusions

- We have yet to agree on exactly what Net Zero means, which depends on what we are trying to achieve.
  - This does NOT matter for CO_2, it matters a lot for SLCPs.
- Traditional "CO_2-equivalent" emissions based on GWPs are not fit-for-purpose in aiming for a global temperature goal.
- Alternative "CO_2-warming-equivalent" measures provide a more realistic indication of impact on global temperature.
- If aviation emissions were to decline by 1.4% per year from now on, aviation would not contribute to any *further* global warming: reduced warming due to SLCPs cancels cumulative impact of ongoing CO_2 emissions.