Climaviation – Action de recherche sur Aviation et Climat

CO_2 equivalence metrics and contrail avoidance

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Contrail avoidance

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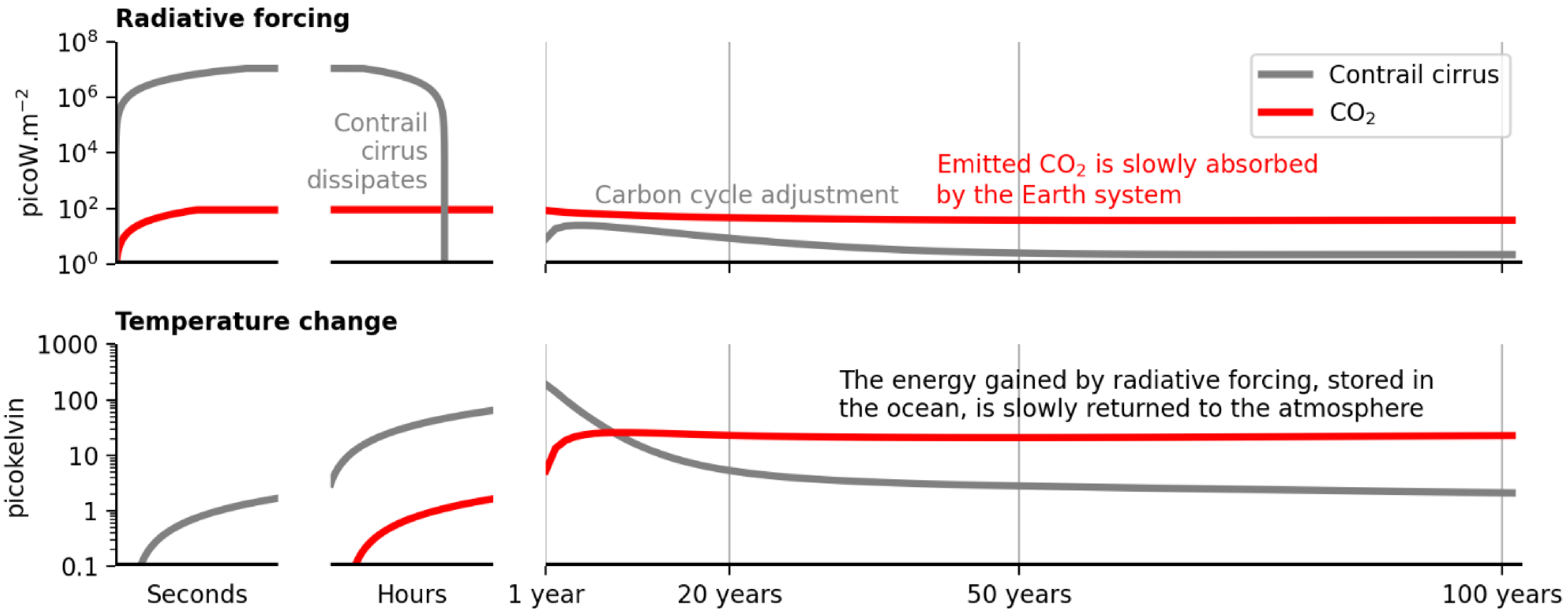
- Several possible strategies.
  - Flight-by-flight, sector-based, dispatch or enroute, set carbon budget, …
- Requires a quantification of the climate impact of individual flights.
  - CO_2, contrails, and other non-CO_2 effects (NOx), …
  - Non-CO_2 effects depend on weather so cannot use climatology or fleet-averaged numbers
- The flight-by-flight view is not completely appropriate.
  - More on that later

Setting the scene

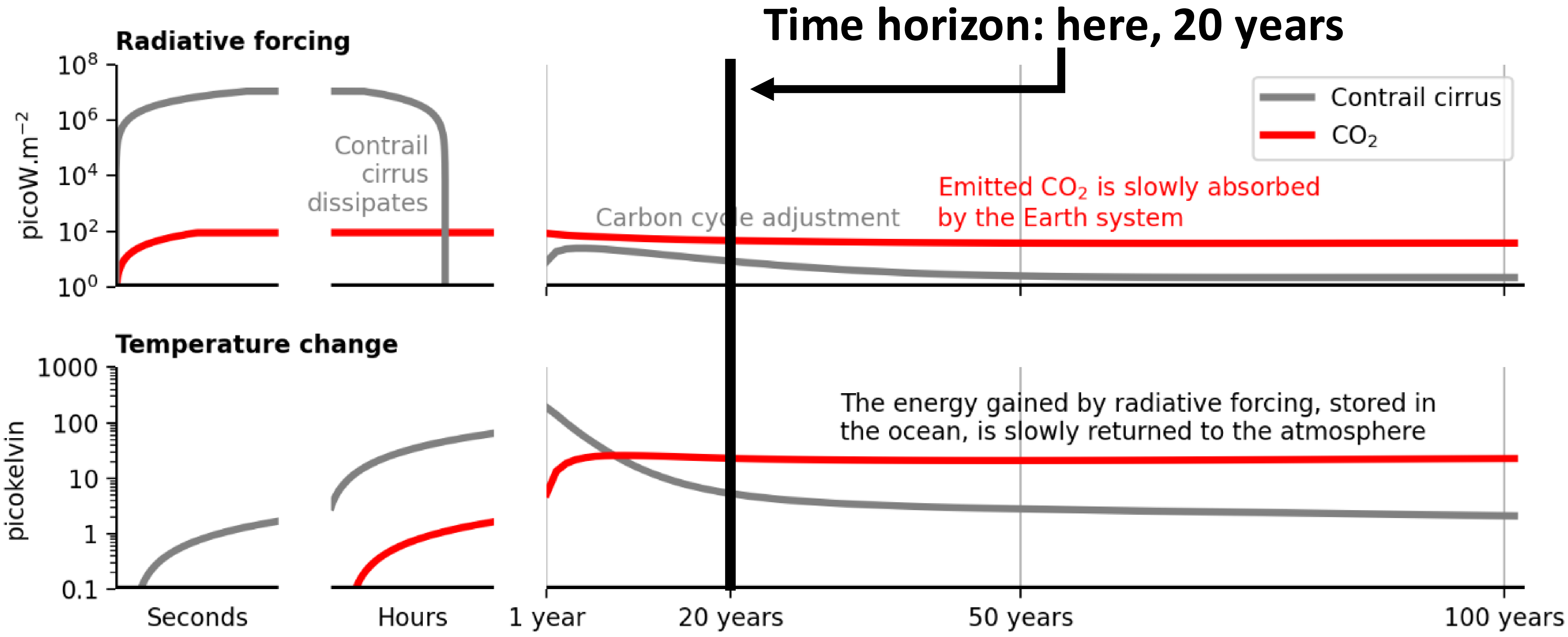
- North Atlantic in 2019
  - 477,923 flights
- CO_2 emissions and contrail energy forcing calculated by Teoh et al. (2022)
  - Aircraft trajectories, ERA5 meteorology, BADA aircraft performance model, CoCiP contrail life cycle
- Here, CO_2 and contrail radiative forcing and surface temperature response calculated with the OSCAR model
  - Reduced complexity Earth System model
  - Uncertainty in contrail energy forcing not considered for the moment
  - Contrail efficacy set to 0.35 (Bickel et al. 2020)

Time scales

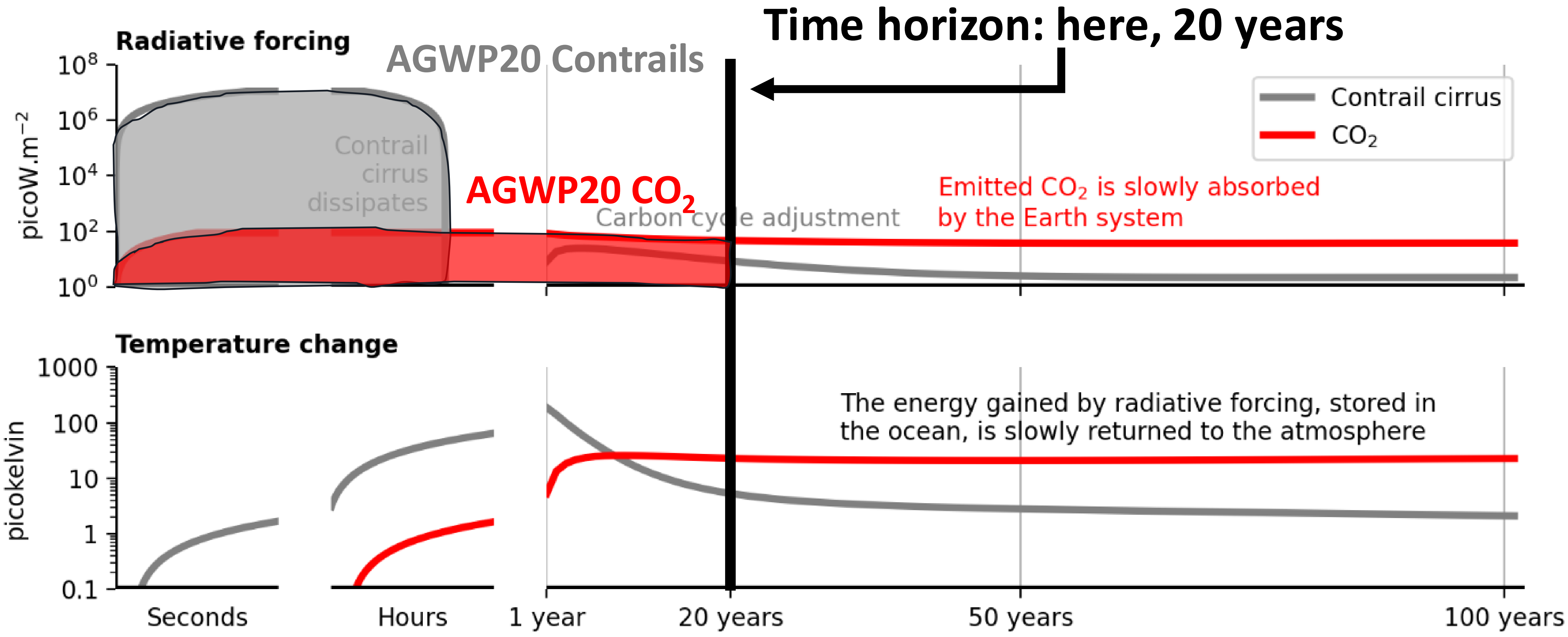
Median contrail-forming North Atlantic flight in 2019: 53 tCO_2, contrail energy forcing 2.9 10^{10} J km^{-1}



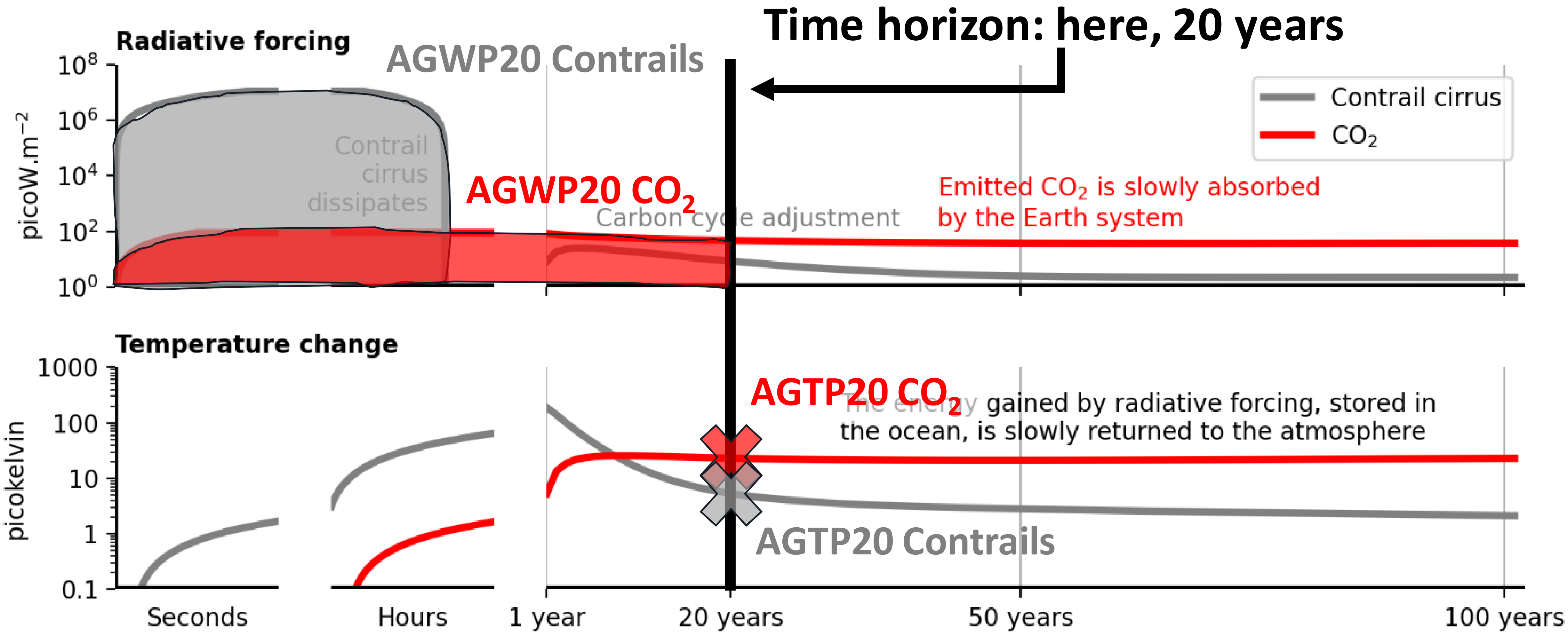
CO_2 equivalence metrics



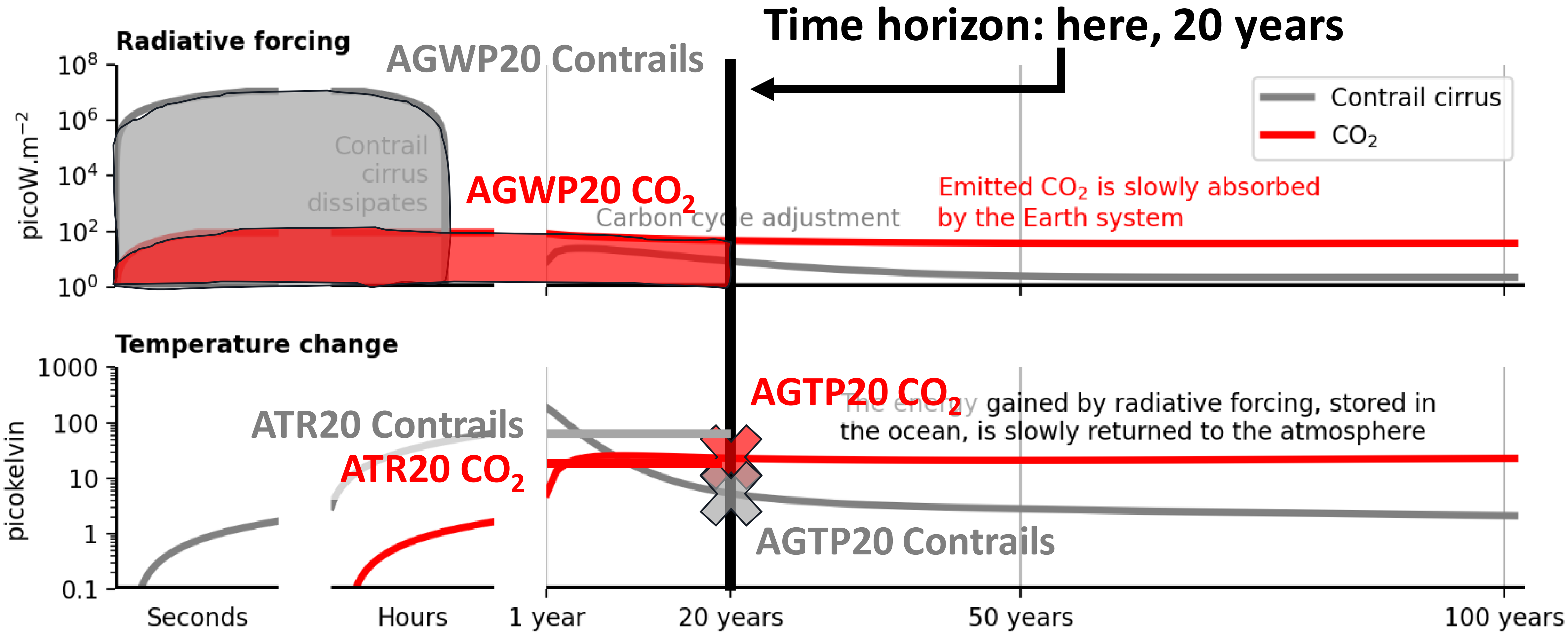
CO_2 equivalence metrics



CO_2 equivalence metrics



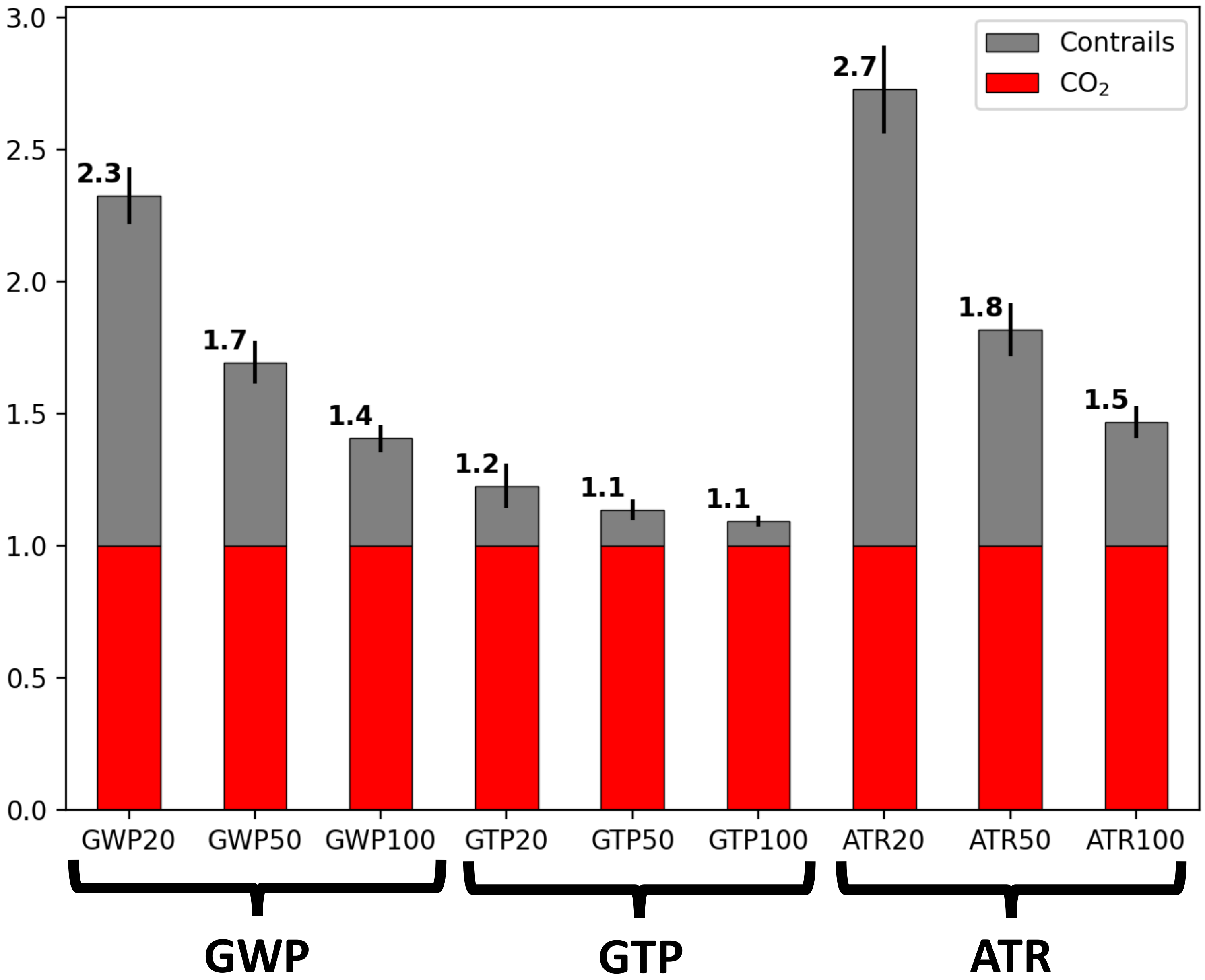
CO_2 equivalence metrics



Median flight CO_2 equivalences

Median contrail-forming North Atlantic flight in 2019:
- 53 tCO_2
- Contrail energy forcing $2.9\ 10^{10}\ J\ km^{-1}$

Contrail efficacy 0.35



Climate impact of N Atlantic flights 2019

(CO_2 and contrails only)

Flight subset	Number of flights	AGTP20 (2039)	AGTP50 (2069)	AGTP100 (2119)
All flights	477,923	16.9 µK	13.5 µK	14.0 µK
Contrail-forming flights	260,854 (55%)	11.8 µK (70%)	8.90 µK (66%)	8.90 µK (64%)
→ warming contrails	208,965 (44%)	10.59 µK (63%)	7.74 µK (57%)	7.59 µK (54%)
→ cooling contrails but CO_2 warming dominates		1.21 µK (7%) 50,135 flights	1.16 µK (9%) 51,348 flights	1.30 µK (9%) 51,677 flights
→ cooling contrails and contrail cooling dominates		−0.017 µK 1,754 flights	−0.003 µK 541 flights	−0.000 µK 212 flights

Contrail avoidance scenarios

- Idealised contrail avoidance:
  - Emit 1/2/5% additional CO_2 to avoid contrail formation
  - Assume that long contrails are more difficult to avoid than short contrails
    - Here, rerouting efficiency factor defined as ratio contrail length to total distance flown
    - For N Atlantic 2019 flights, average rerouting efficiency is 0.71

Climate benefit of contrail avoidance

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- Analysis of 260,854 contrail-forming flights over the North Atlantic in 2019

CO_2-equivalence metric	**Number of flight reroutings beneficial to climate**	**Absolute climate benefit of all reroutings**	**Reduction in climate impact of 260+k flights.**
AGWP100	188,372	0.83 mW m^{-2} yr	29%
AGWP50	191,580	0.82 mW m^{-2} yr	36%
AGWP20	194,608	0.80 mW m^{-2} yr	43%
AGTP100	173,623	0.97 µK	8%
AGTP50	178,558	1.30 µK	15%
AGTP20	184,130	2.51 µK	28%
ATR100	189,309	4.80 <µK>	31%
ATR50	192,395	8.49 <µK>	38%
ATR20	195,631	18.8 <µK>	46%

Decision to reroute: metric independent

Climate benefit of rerouting: metric dependent

Risk associated with choice of metric

- Time-integrated metrics incentivise contrail avoidance, especially when combined with short time horizons.
- Those metrics hide increased climate damage after 100 years in up to 10% of the reroutings.

Rerouting 260,854 contrail-forming flights, assuming 1% additional CO_2

CO_2-equivalence metric	Climate damage	Climate benefit
AGWP100	69,735	191,119
AGWP50	66,865	193,989
AGWP20	**64,151**	**196,703**
AGTP100	**82,352**	**178,502**
AGTP50	78,099	182,755
AGTP20	73,409	187,445
ATR100	68,918	191,936
ATR50	66,074	194,780
ATR20	**63,160**	**197,694**

Dealing with uncertainty

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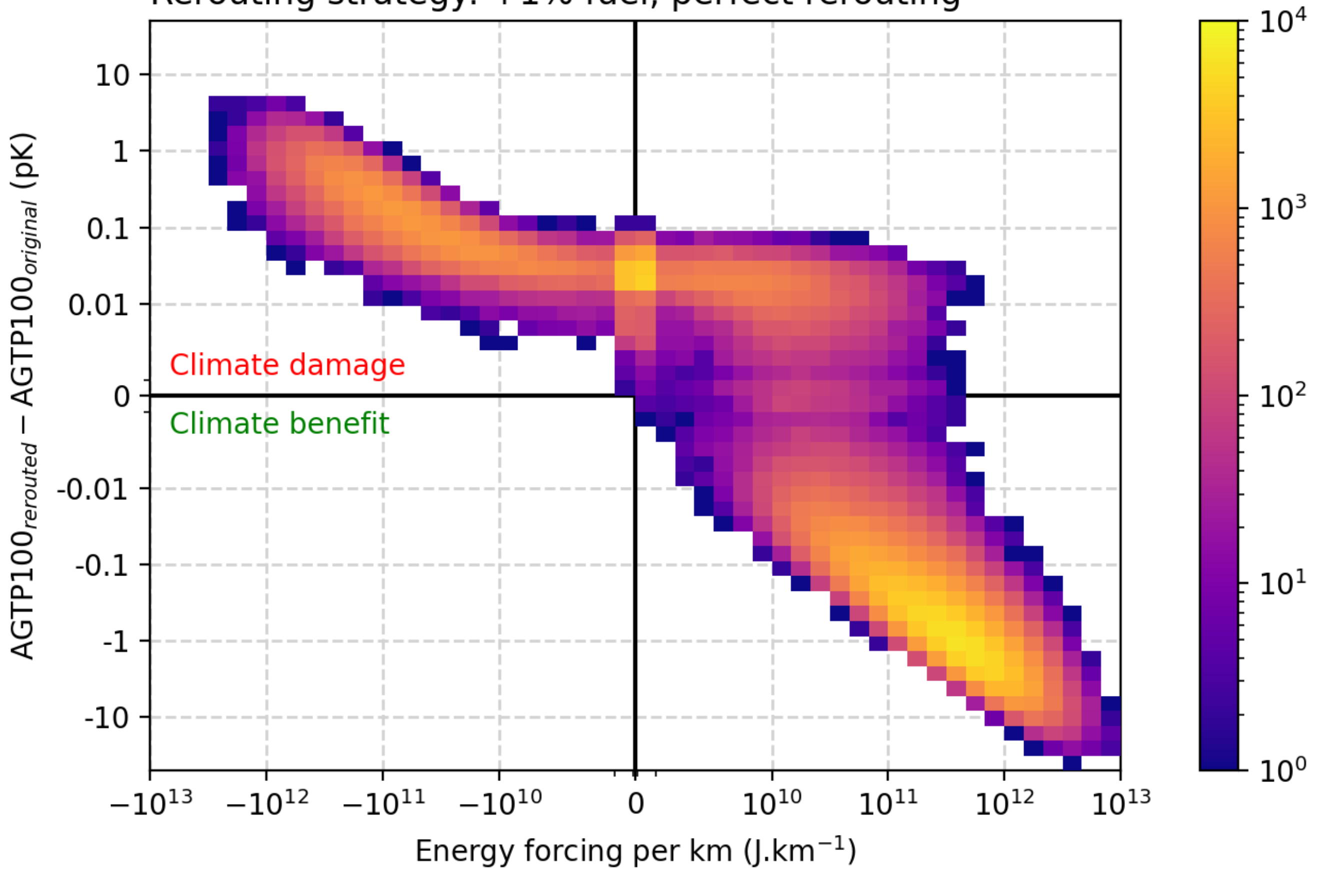
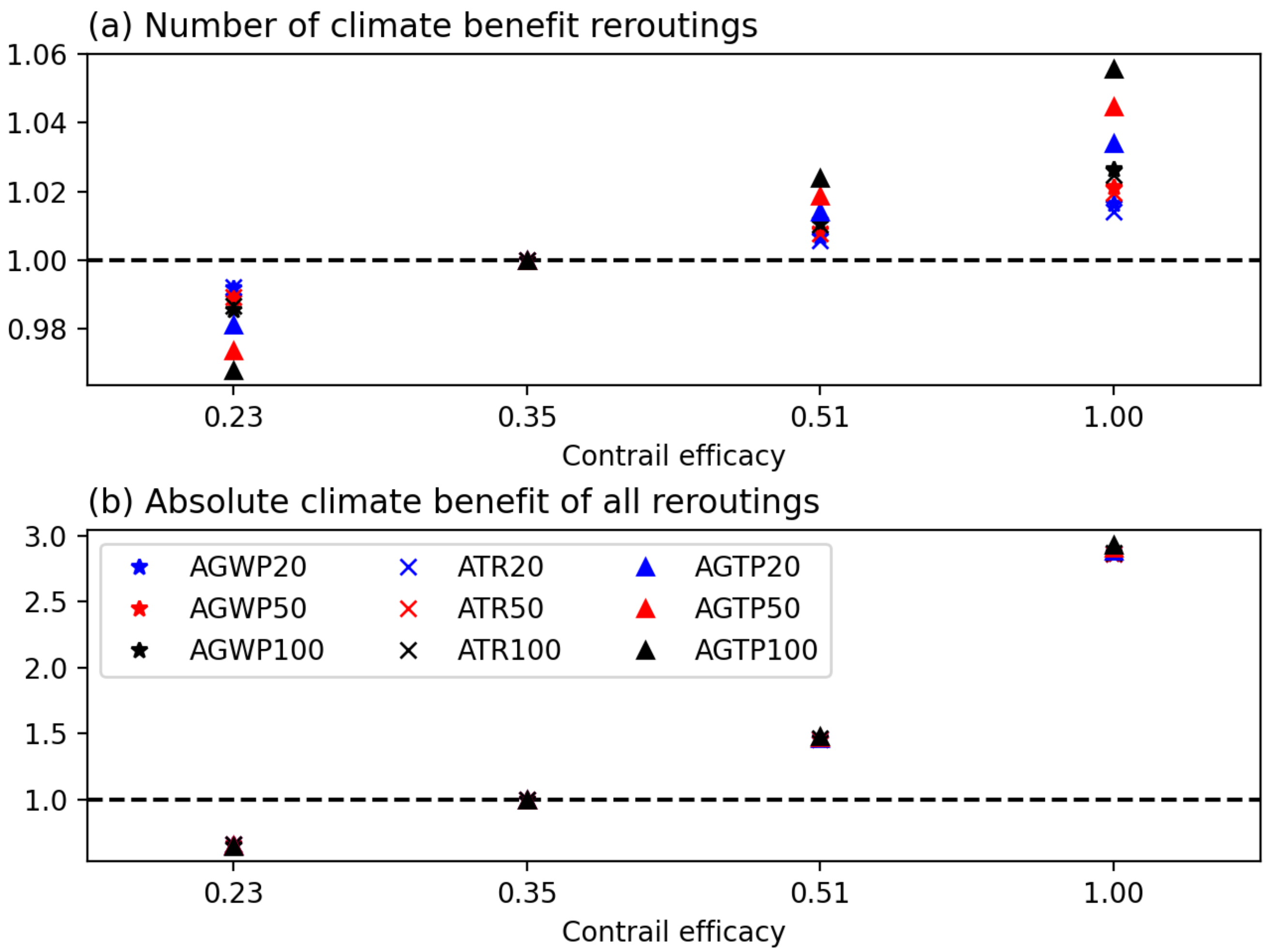
Metric used: AGTP100
Contrail-forming flights over NA in 2019 (261k)
Rerouting strategy: +1% fuel, perfect rerouting



- Uncertainty in contrail energy forcing is *very* large
  - And not just caused by uncertainty in ISSR prediction
- Flights in the lower right corner are attractive targets
  - But both the selection of flight to reroute and the climate outcome are now metric-dependent

Contrail efficacy

- So far, assumed an efficacy of 0.35 but 5-95% interval is 0.23 to 0.51.
  - Bickel et al. (2020)
- Most reroutings that benefit climate remain beneficial for different contrail efficacies.
- But quantification of climate outcome is very strongly dependent on contrail efficacy.
  - CO_2 equivalence metrics become a minor consideration



Limitation of flight-by-flight view: Non linearities

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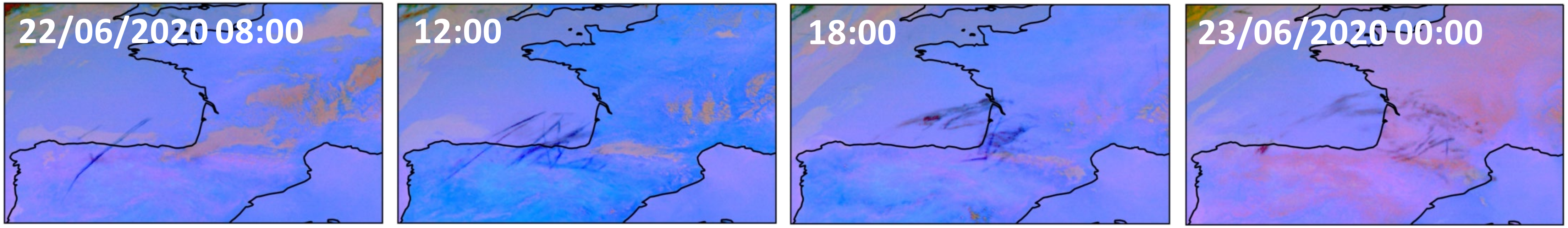
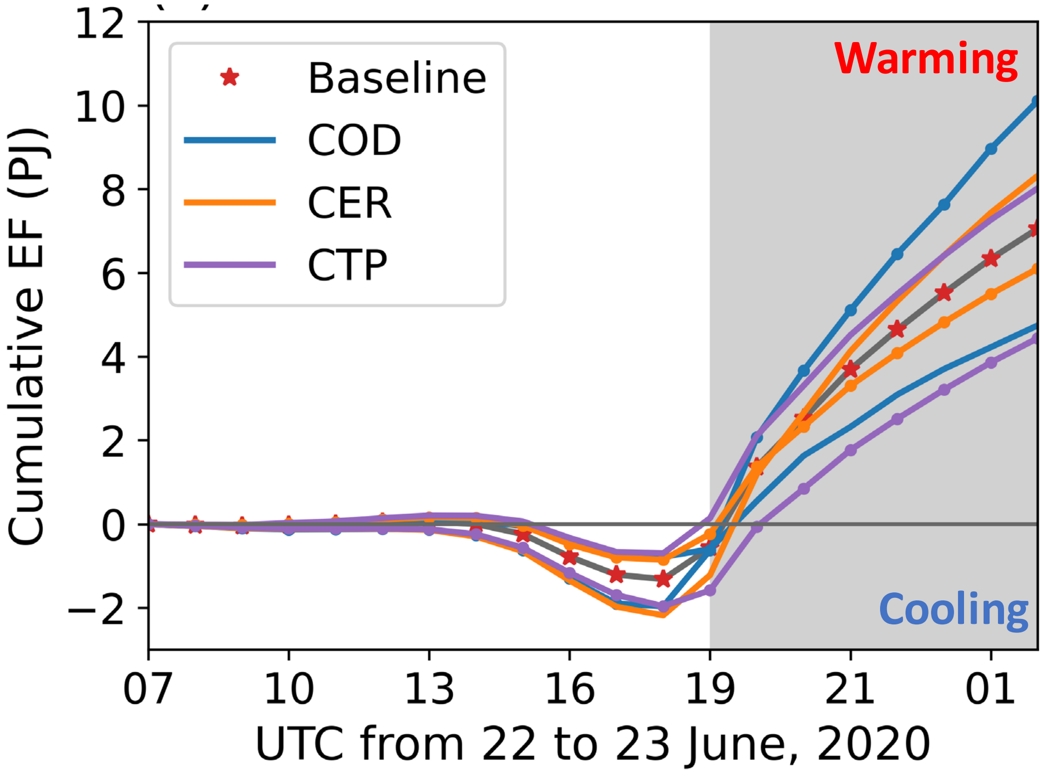


- Satellite estimate of contrail cirrus energy forcing for an outbreak on 22 June 2020

- Contrail cirrus formed from 15-20 individual flights

- Need to work with groups of flights



Wang et al. (submitted)

Summary

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- Based on North Atlantic flights in 2019:
  - Decision to reroute to provide a climate benefit is weakly dependent on the choice of CO_2-equivalence metric and on contrail efficacy
  - However, quantifying that climate benefit is strongly dependent on the choice of CO_2-equivalence metric and on contrail efficacy
  - Choosing ATR20/AGWP20 hides long-term climate damage for up to 10% of reroutings.
- Need to account for uncertainties and non-linearities
  - Do not optimise based on best estimates alone
  - Focusing on the most warming contrails is attractive but metric-dependent
- More results and analysis in Borella et al. (in prep)