SELECTING A SUITABLE CLIMATE METRIC FOR AVIATION

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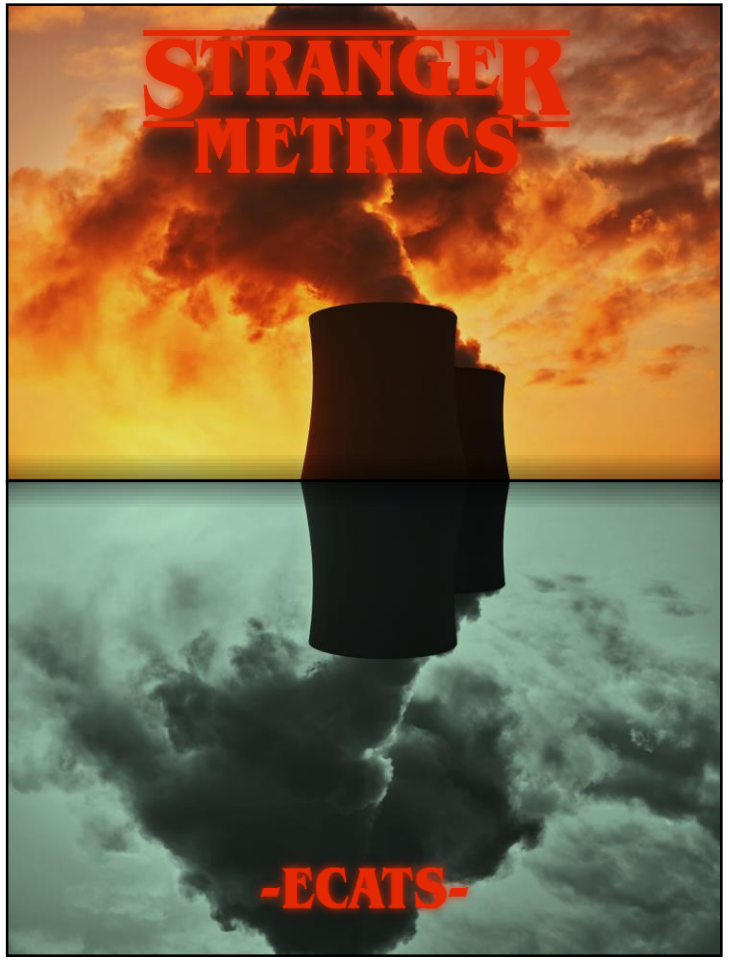
Overview of Climate Metrics

- Purpose: To relate non-CO_2 effects to their consequences on the climate and/or on society – “shortcut” between emissions and impacts
- Choice of climate metric is vital for effective policy
- Aviation **non-CO_2 emissions are particularly complex** due to their highly varying atmospheric lifetimes and efficacies, their dependence on emission altitude and location and their high degree of uncertainty

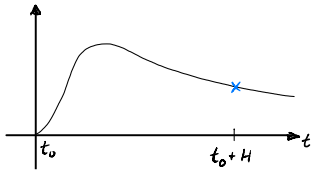
→ **No consensus** on most appropriate metric

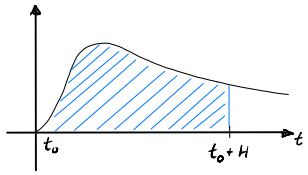


GWP_{100} > 0 warming!

GWP_{20} < 0 cooling?

Climate Metrics Used





	RF-based	ERF-based	ΔT-based
Endpoint	RFI		GTP
Integrated	GWP		iGTP, ATR
“Starred”	GWP*	EGWP*	

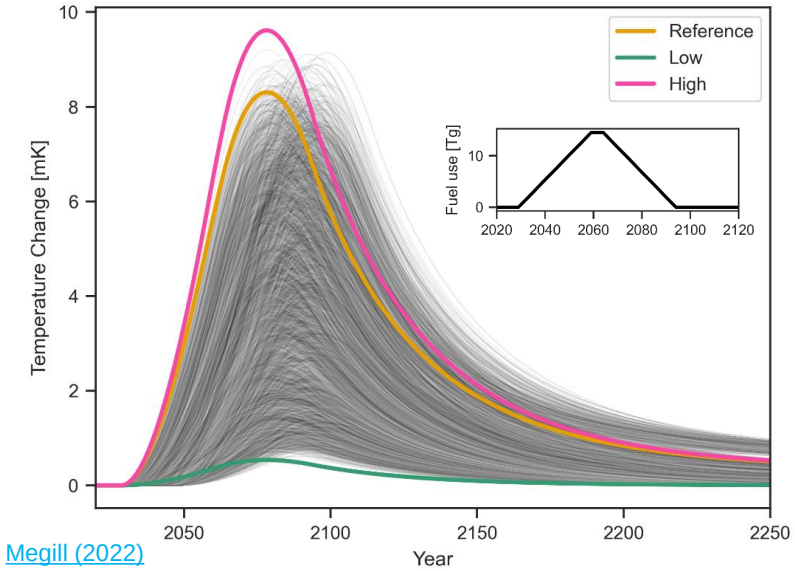
Climate Metric Requirements

Climate metrics shall:

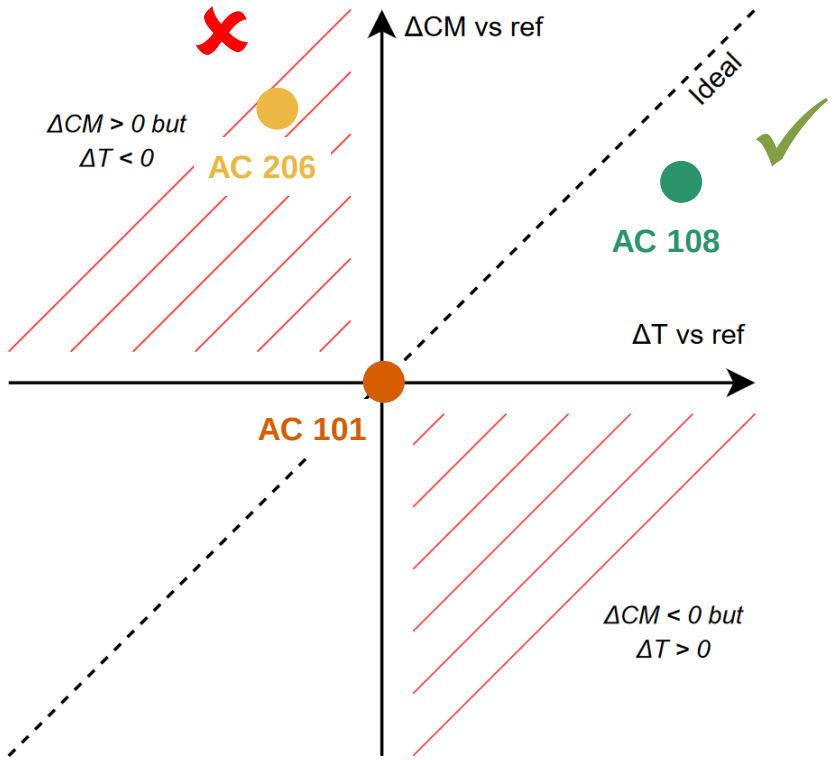
1. Neuturally represent the chosen climate indicator (*in this case: temperature change*);
2. Be temporally stable;
3. Be compatible with existing climate policy;
4. Be transparent and simple to understand and implement

REQ 1: Climate Metric Neutrality (1)

- Aim: identify **inherent biases** within each climate metric for different technologies or changes in aircraft design or trajectory
- Method: 10 000 future aircraft concepts created using a Monte Carlo simulation and analysed using AirClim v2.1
- Pairwise comparison of all aircraft to gauge neutrality against (peak and average) temperature change



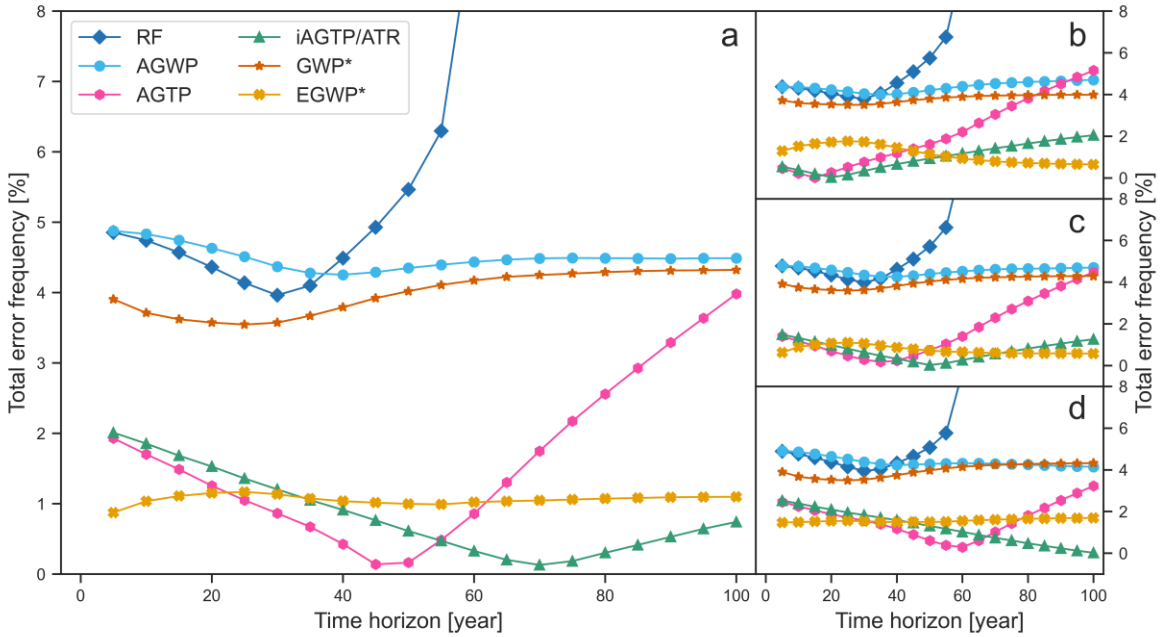
Adapted from Megill (2022)



REQ 1: Climate Metric Neutrality (2)

- We are looking for low error frequencies and time horizon independence

- RF: **ill-suited** at higher time horizons
- AGWP and GWP*: **largely linear response**, particularly for *H* > 60 yr
- AGTP: highly dependent on time horizon; fully dependent on the shape of the temperature response
- ATR: **low error frequency** but clear minimum
- EGWP*: **very stable behaviour**



From Megill et al. (2023 [preprint])

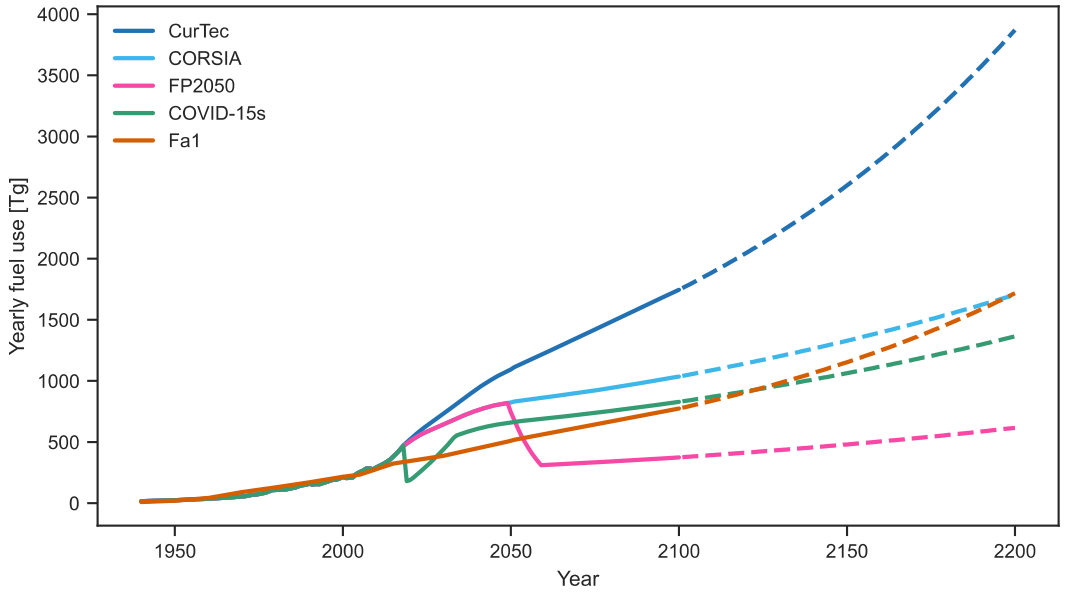
Climate indicators: a. = Peak temperature
b. = 20-year average temp.
c. = 50-year average temp.
d. = 100-year average temp.

REQ 2: Temporal Stability (1)

- Aim: analyse the performance of climate metrics for accounting CO_2-eq emissions for the whole aviation industry (policy-level)
- Method:
  - Perform AirClim simulations for different aviation fuel trajectories (right), assuming all fuel is Jet-A1
  - Calculation performed by:

$$E_{CO_2-eq}(t) = RMET_{100}(t) \times E_{CO_2}(t)$$

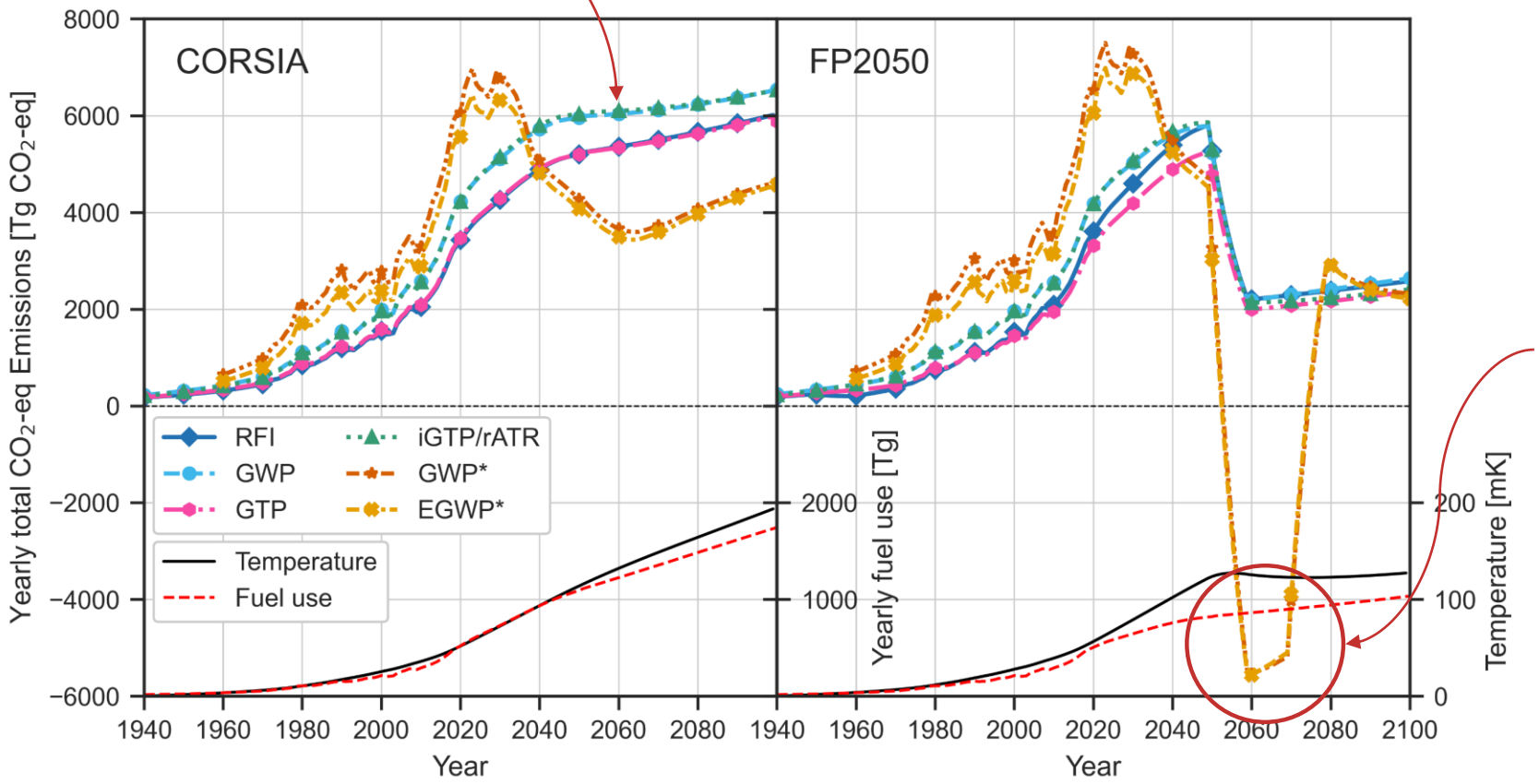
where $RMET_{100}(t)$ is the relative metric (e.g. GWP) with a time horizon of 100 years



Fuel scenarios adapted from Grewe et al. (2021)

REQ 2: Temporal Stability (2)

GWP and ATR produce similar results for total CO_2-eq [1]. **This may reduce the political capital required to change from GWP to ATR**. This is also found by Niklaß et al. (2019)



If a policymaker was to look at (E)GWP* CO_2-eq emissions between the years of 2050 and ~2080, they would find negative emissions. This is problematic!

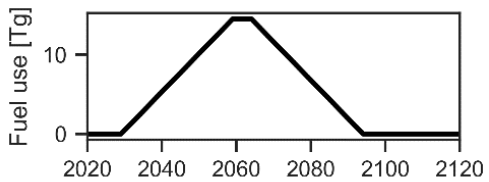
From Megill et al. (2023 [preprint])

[1] the very close similarity is likely model-dependent due to the relative importance of different emission species impacts (primarily NO_x and contrails) to the total

REQ 3: Compatibility with Climate Policy

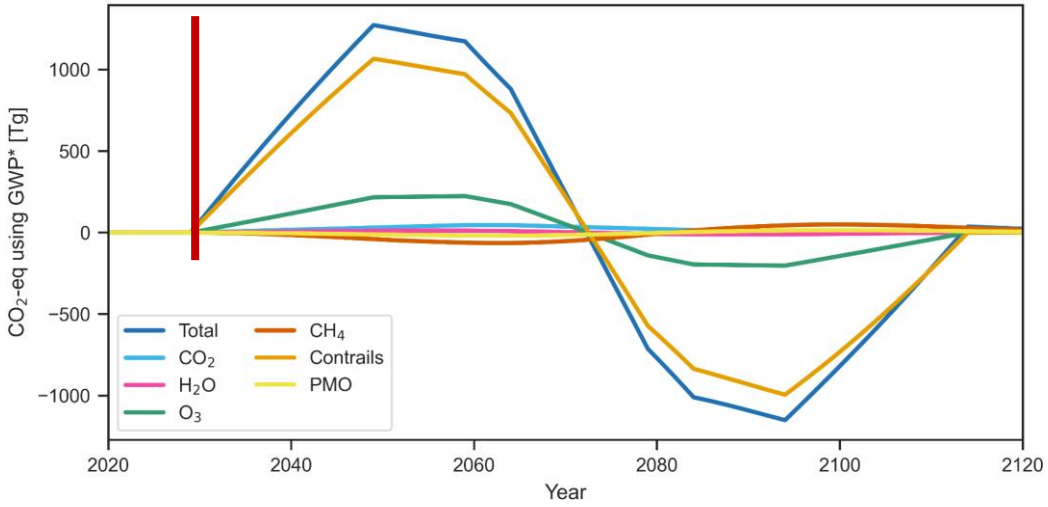
- All conventional climate metrics – RF, GWP, GTP, iGTP and ATR – can be used in existing climate policy.
- The GWP* method does not provide a single value and effectively has a **second time horizon**.

→ The GWP* is itself essentially a micro climate model, not a metric (cf. Meinshausen et al., 2022)



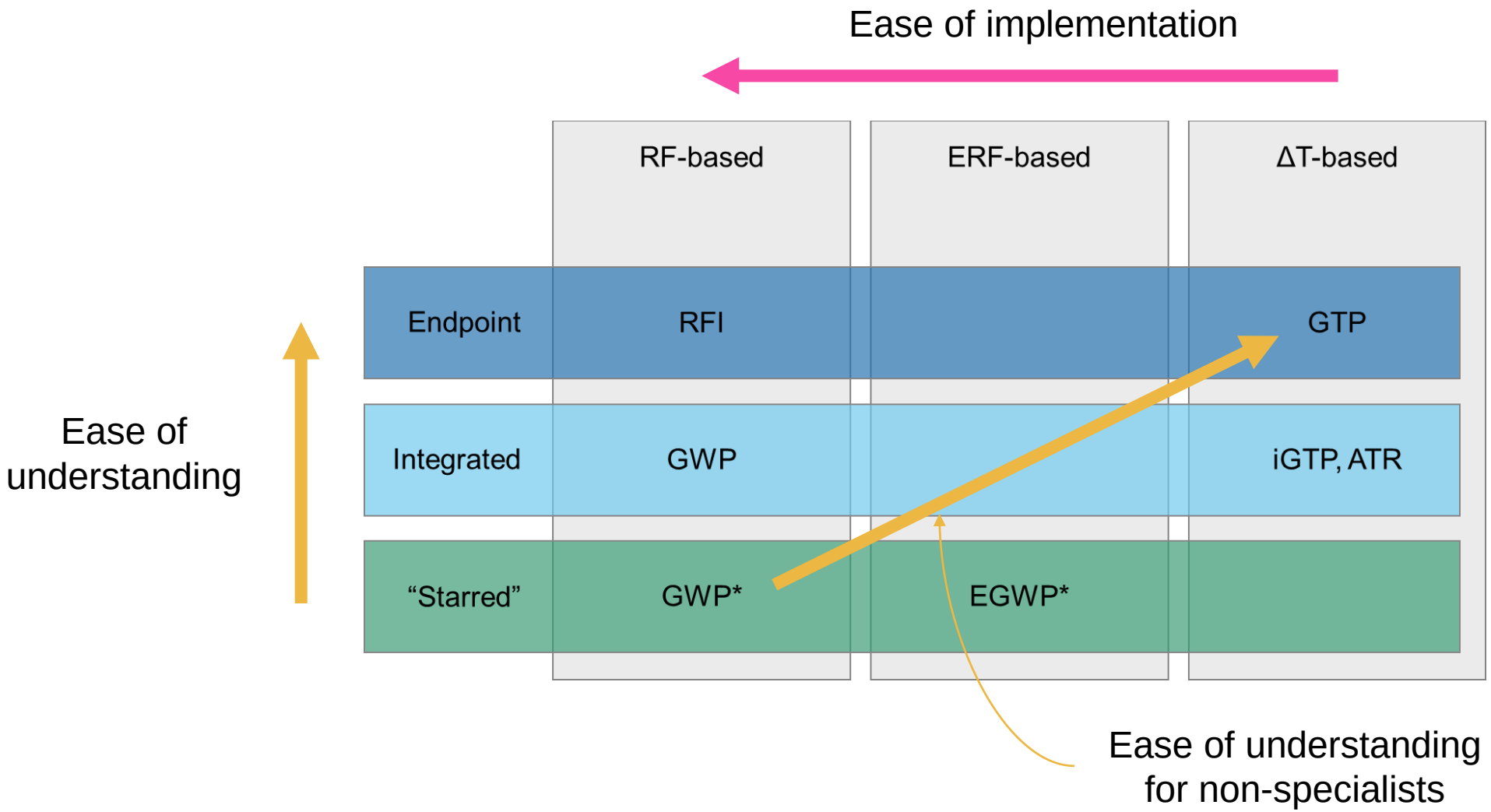
ATR_{100} = 5.2 mK

GWP^*_{100} = ??



Adapted from Megill et al. (2023 [preprint])

REQ 4: Climate Metric Transparency



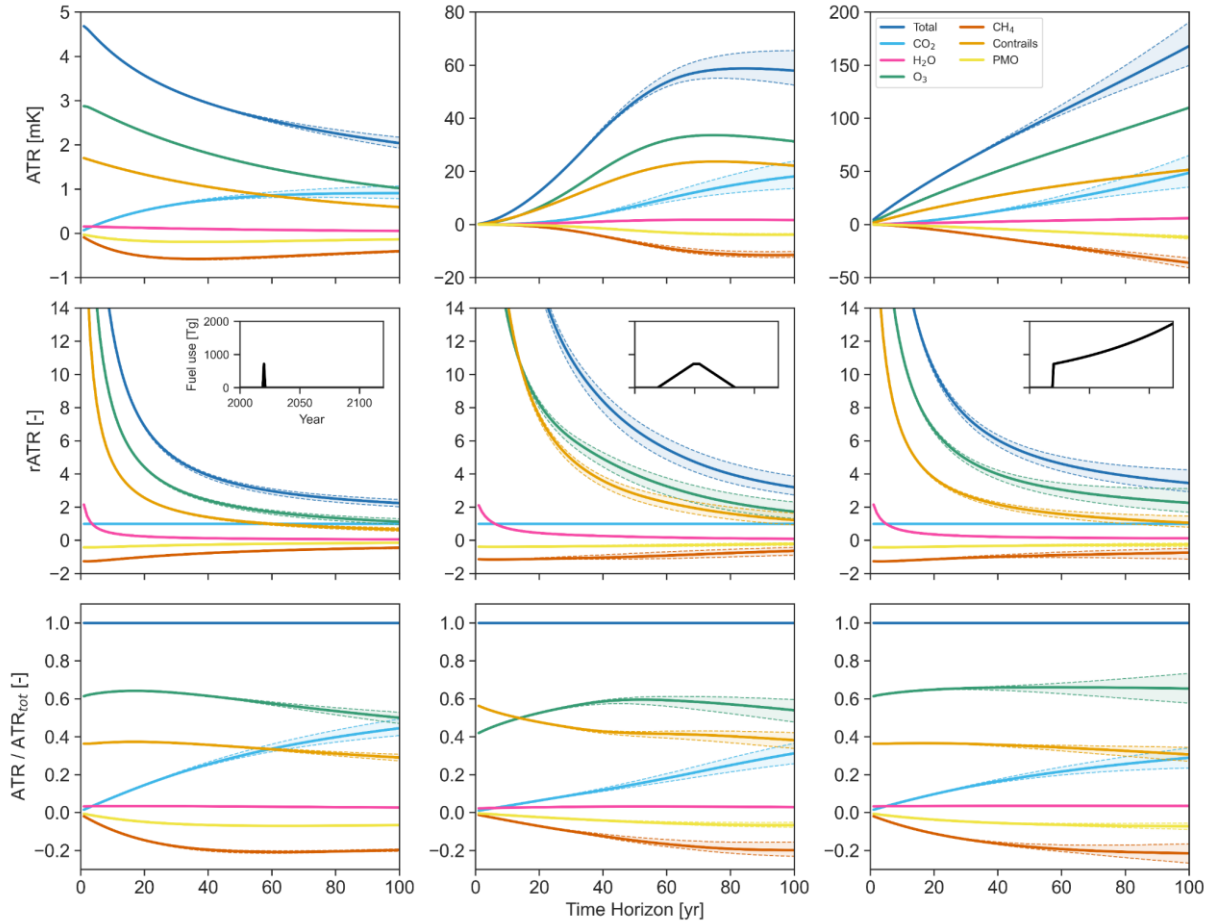
Overview: Choice of Climate Metric*

Climate Metric	REQ 1 Neutrality	REQ 2 Stability	REQ 3 Compatibility	REQ 4 Transparency	Notes
RF	---	-	-	+	
GWP (reference)	0	0	0	0	
GTP	-	-	0	+	
iGTP	++	0	-	0	More complex unit than ATR
ATR	++	0	0	0	Best overall
GWP*	0	---	---	---	
EGWP*	+++	---	---	---	

*trade-off only representative

Choice of Climate Metric and Time Horizon

- Ideally, a time horizon is selected where the gradient of the ATR or rATR values with respect to the time horizon is low: **The larger the gradient, the more important the choice of time horizon**.
- Results (right) show that the **ATR generally requires a longer time horizon** to properly account for the delay in the temperature response of the atmosphere (generally >70 years)



From Megill et al. (2023 [preprint])

Conclusions & Discussion

- All climate metrics have **inherent biases** and favour certain aircraft designs over others
- The choice of climate metric is always the result of a trade-off. Based on our requirements, **we recommend the ATR for aviation policy and aircraft design**.
- …but what about the **time horizon**?

  → We recommend using **> 70 years**, e.g. ATR_{100}
- The total CO_2-eq emissions calculated by the $rATR_{100}$ and GWP_{100} for current aircraft are similar and would enable a **timely introduction of the ATR** in aviation policy. This would allow a more accurate assessment of novel aviation fuels and aircraft designs in the future.

- Open questions & further research:
  - Climate metrics for individual flights, e.g. contrail avoidance
  - Policy implications of using ATR
  - Suitable models for non-CO_2 in ETS & CORSIA

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QUESTIONS?

Impressum

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