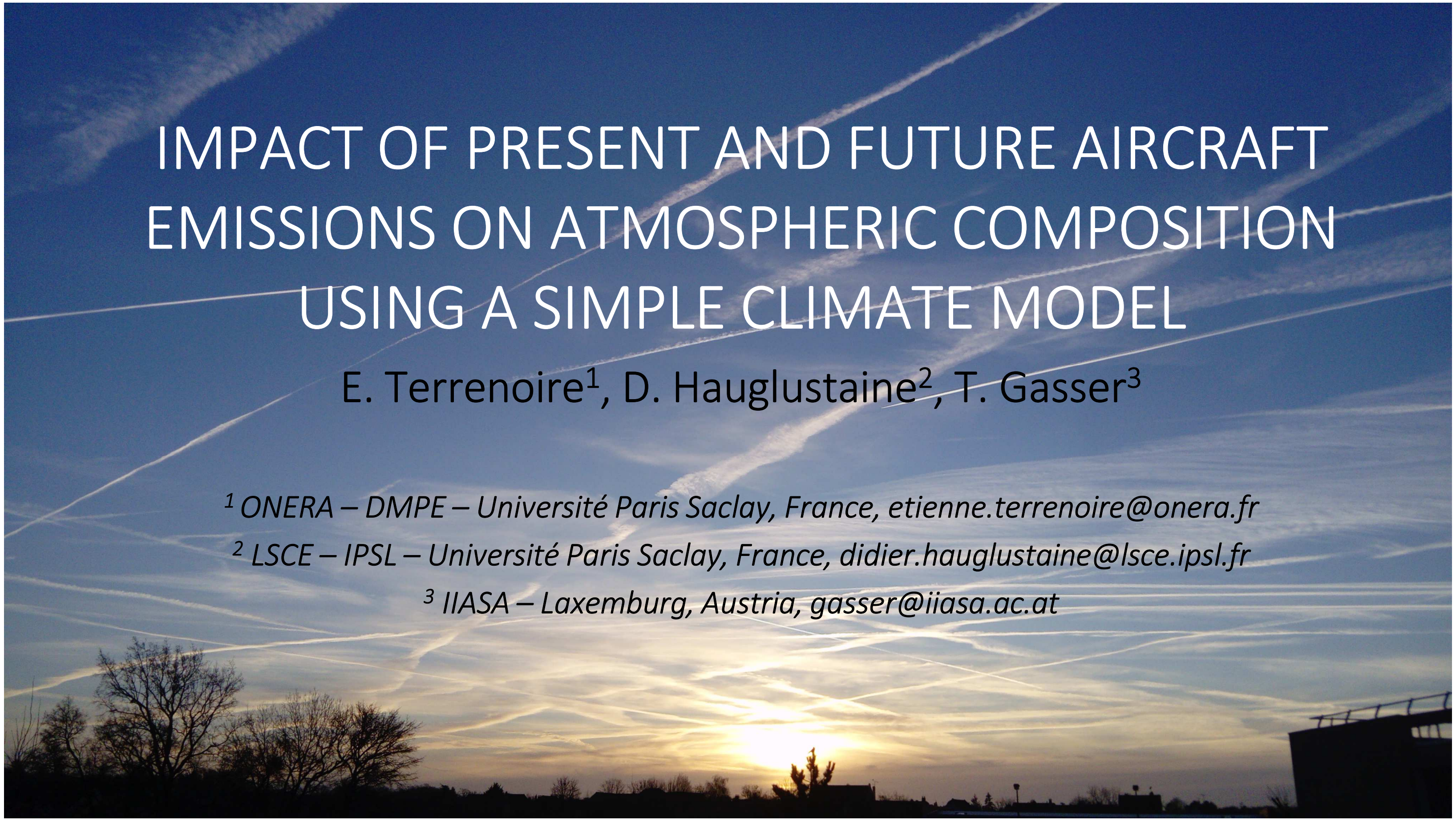

IMPACT OF PRESENT AND FUTURE AIRCRAFT EMISSIONS ON ATMOSPHERIC COMPOSITION USING A SIMPLE CLIMATE MODEL

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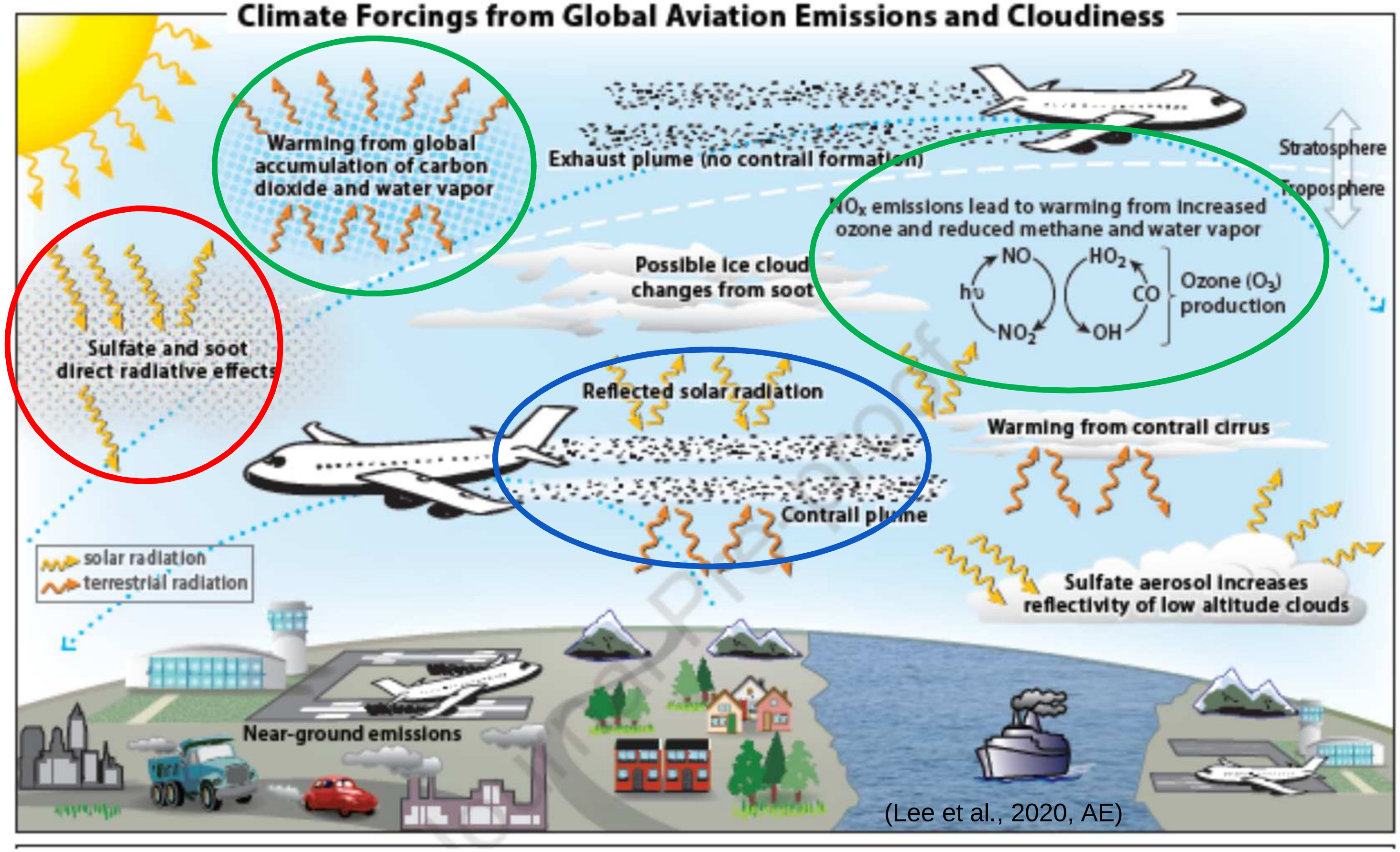
Aviation and climat : a complex system to model

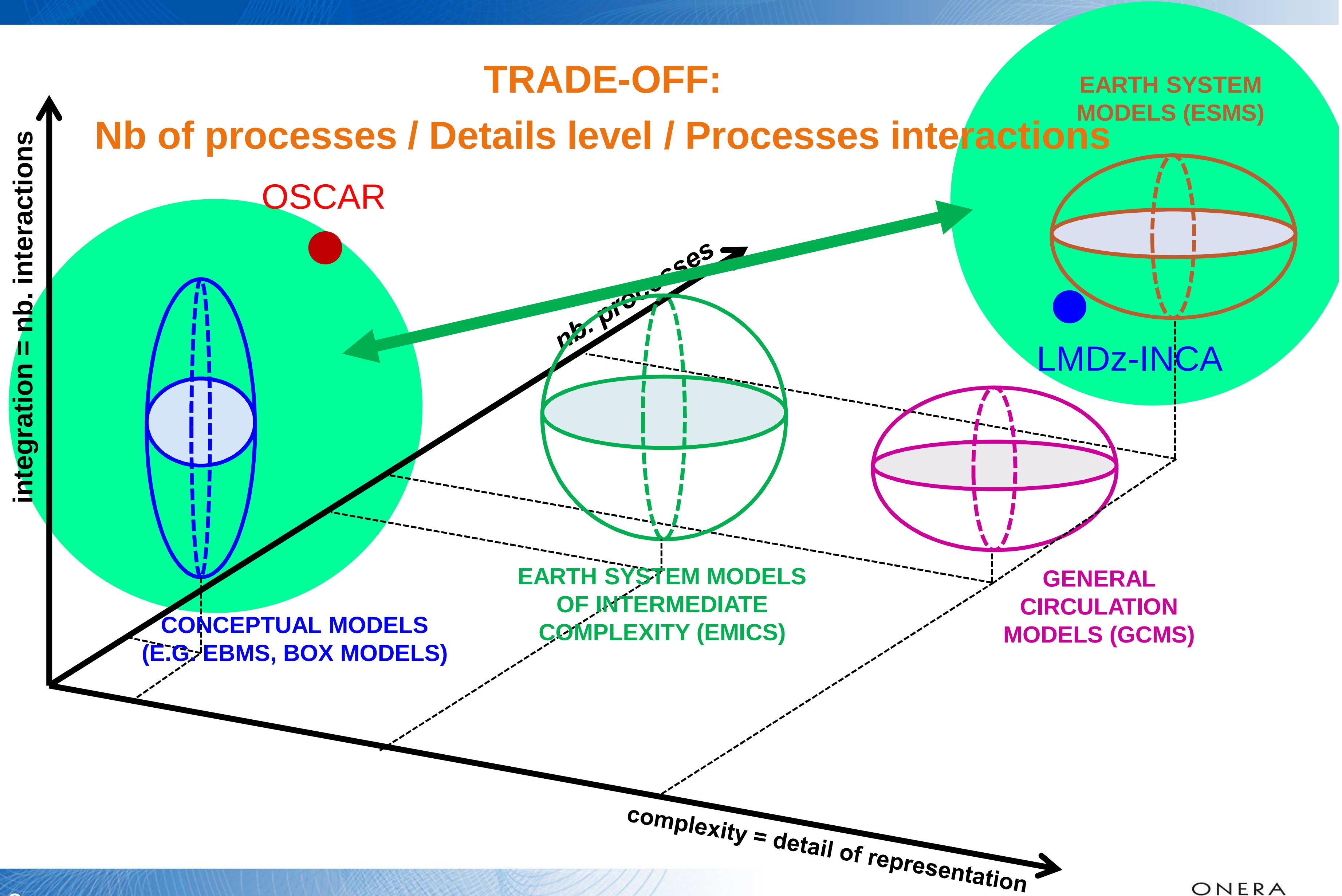


(Lee et al., 2020, AE)

- Complex multiple interaction with multiple non-linear feedbacks

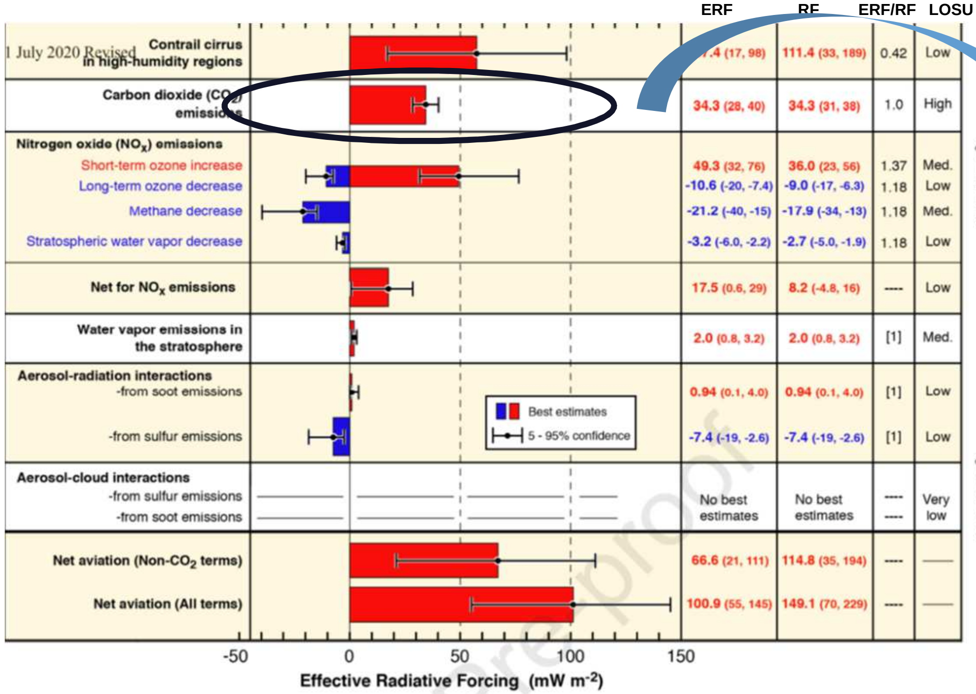
TRADE-OFF:

Nb of processes / Details level / Processes interactions



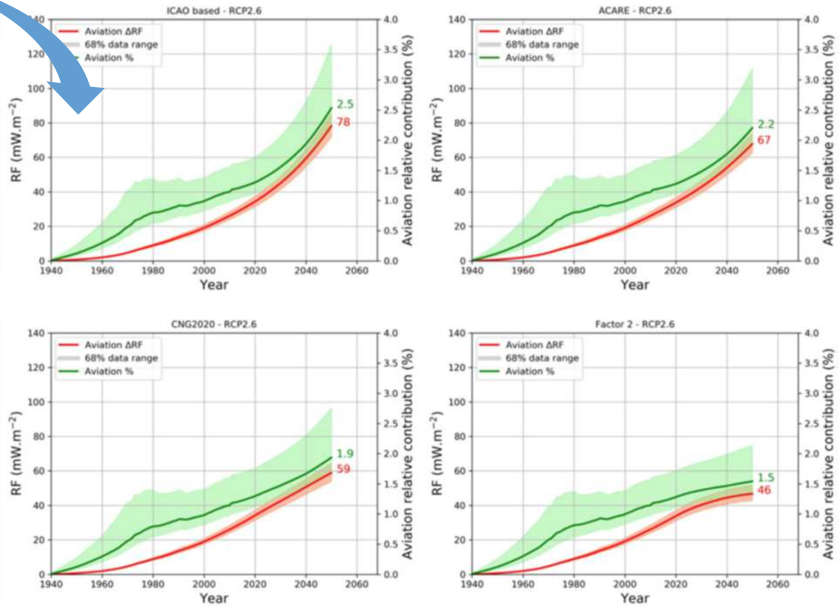
Aviation and climate : use 3D coupled climate models responses to calibrate simple climate model (SCM)

from complex models



(Lee et al., 2020, AE)

SCM model outputs



Terrenoire et al., *Environ. Res. Lett.,* 2019

- Quantification can be done using simple climate change models calibrated over complex 3D models
- In this work, we use the coupled climate IPSL model LMDz-INCA to calibrate the SCM OSCAR used to quantify the aviation emissions climate response of CO_2 and non-CO_2 components using multiple emissions scenario from 1940 to 2050.

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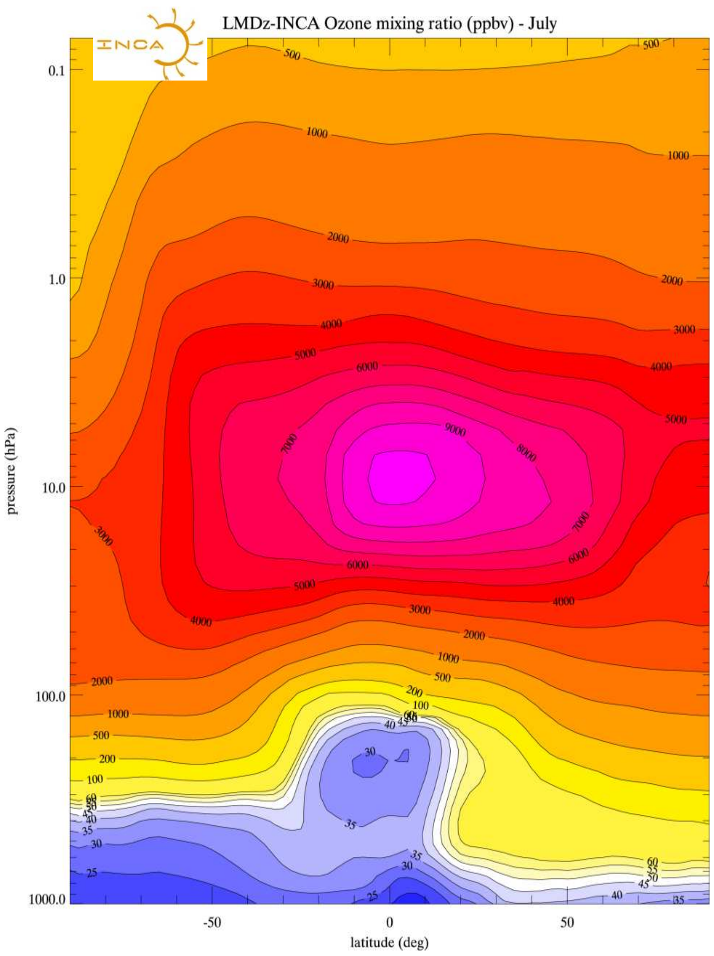
Model LMDz-INCA characterisics (state of the knowledge model)

- Tropospheric and stratospheric chemistry model couple to the LMDZ-INCA general circulation model (Hauglustaine et al., 2014)
- Spatial discretization : 2.5° long. x 1.27° lat (39-79 levels)
- Tropospheric NOx chemistry (100 chemical species) and stratospheric chemistry (50 chemical species)
- Typical aerosols include into INCA (soot,primary and secondary organic aerosols, sulfates, nitrates, dust, sea salt) and heterogeneous chemistry on aerosols
- Surface and aviation emissions and NOx from lightning; dry deposition and scavenging
- Van-Leer (1977) advection; K. Emanuel convection; Louis (1972) boundary layer mixing
- Evaluation done using in-situ data (e.g.. O3) using commercial planes measurements: IAGOS program (In-service Aircraft for a Global Observing System) since 1994.



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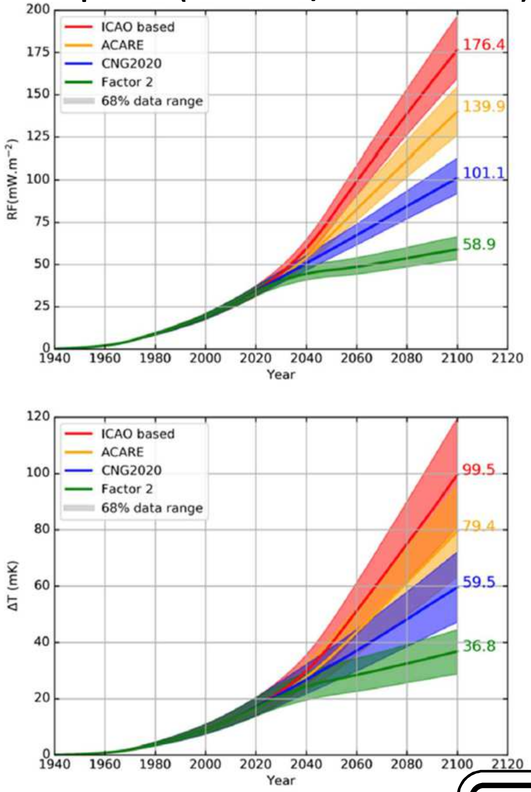
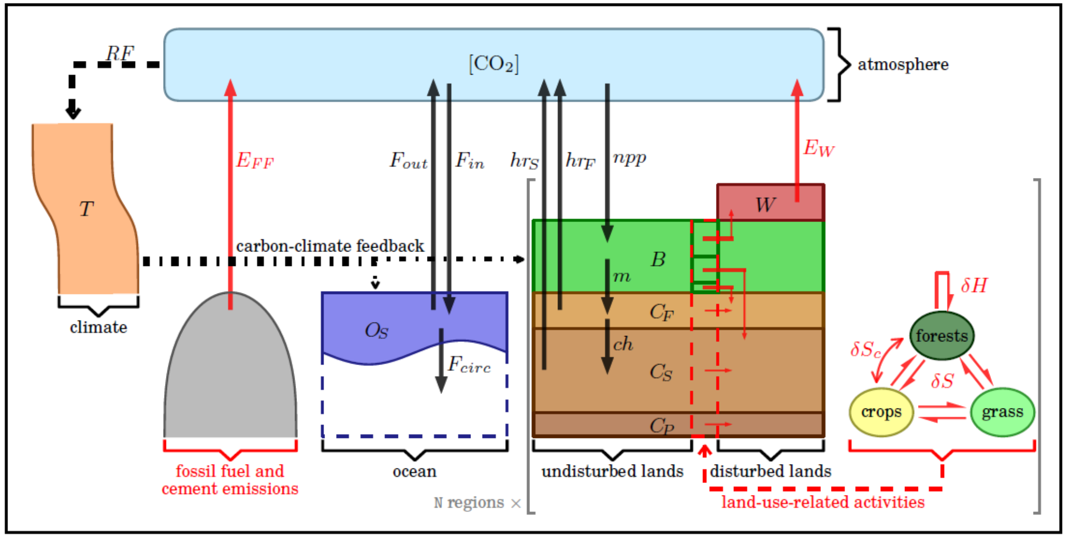
Multiple scenarios approach using OSCAR (SCM)

Aviation carbon emissions induced climate responses (RF in mW/m² and T in mK)

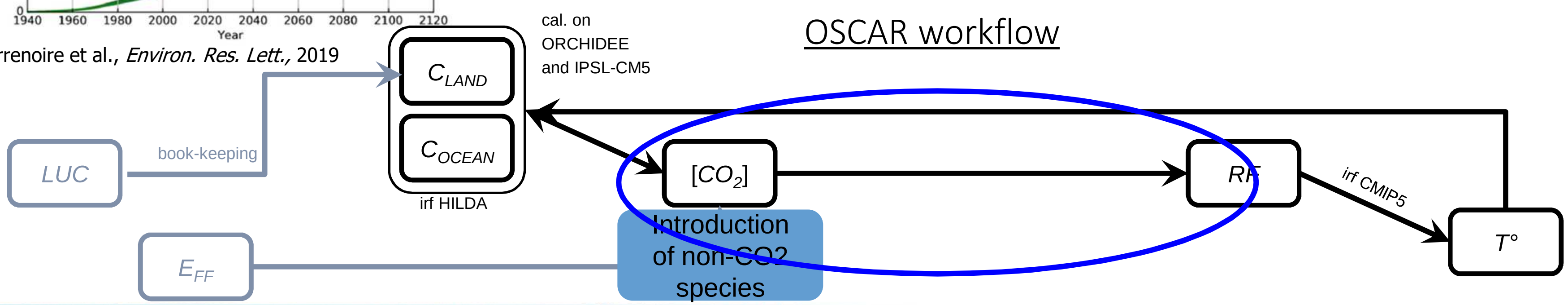


Terrenoire et al., *Environ. Res. Lett.*, 2019

Simple climate model OSCAR2.2 global architecture



OSCAR workflow



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Use 3D coupled model: relationship between emissions and RF calculated by LMDz-INCA for non-CO_2 species

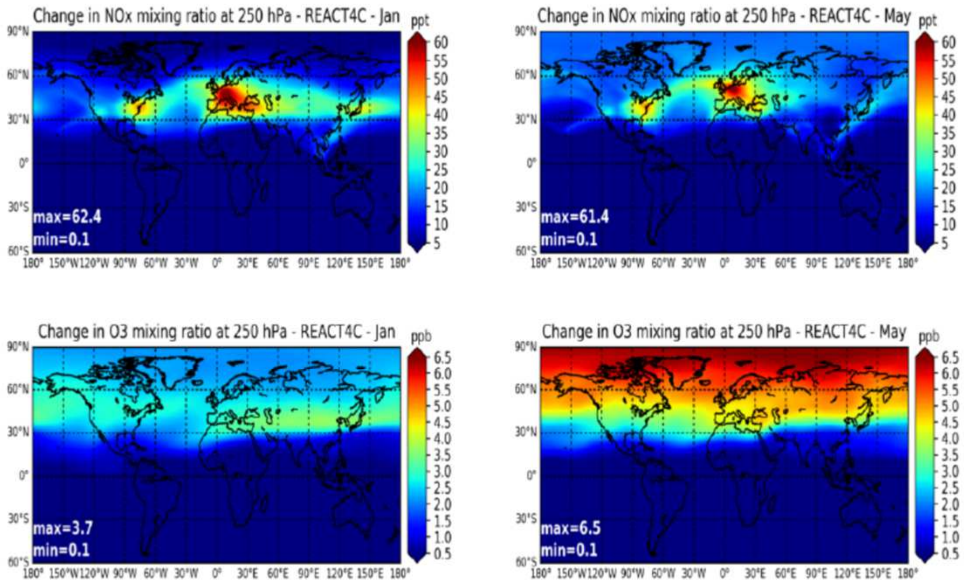
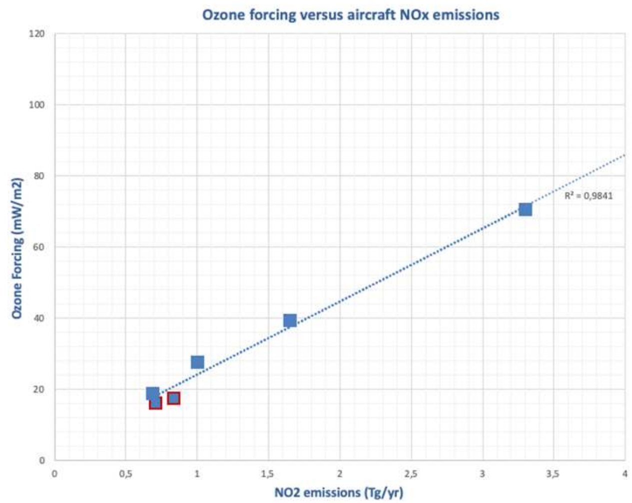
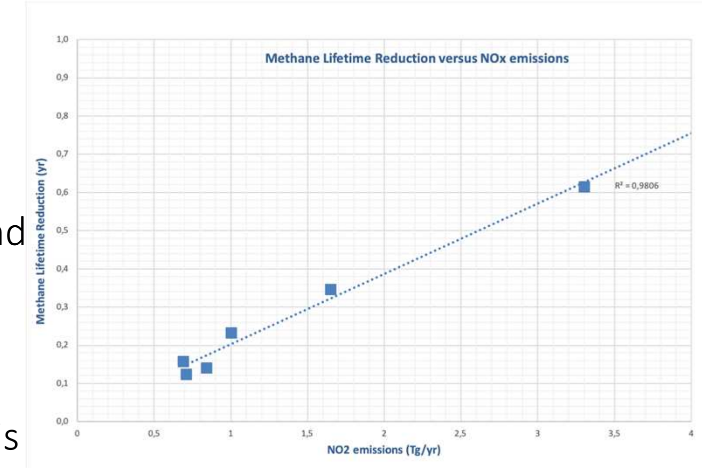


Figure 4. Spatial distributions of perturbation at 250 hPa for the months of January (left) and May (right) for NOx (ppt) and ozone (ppb) mixing ration for the REACT4C_2006 scenario.





In OSCAR, we use a linear relationship between a selected proxy and the calculated RF:

- For O_3 and CH_4 species, the NOx emissions is used as a proxy
- For other species, the fuel burn is used as a proxy
- For contrail cirrus, the ERF best estimate from Lee et al., 2020 is used (57 mW/m^2)

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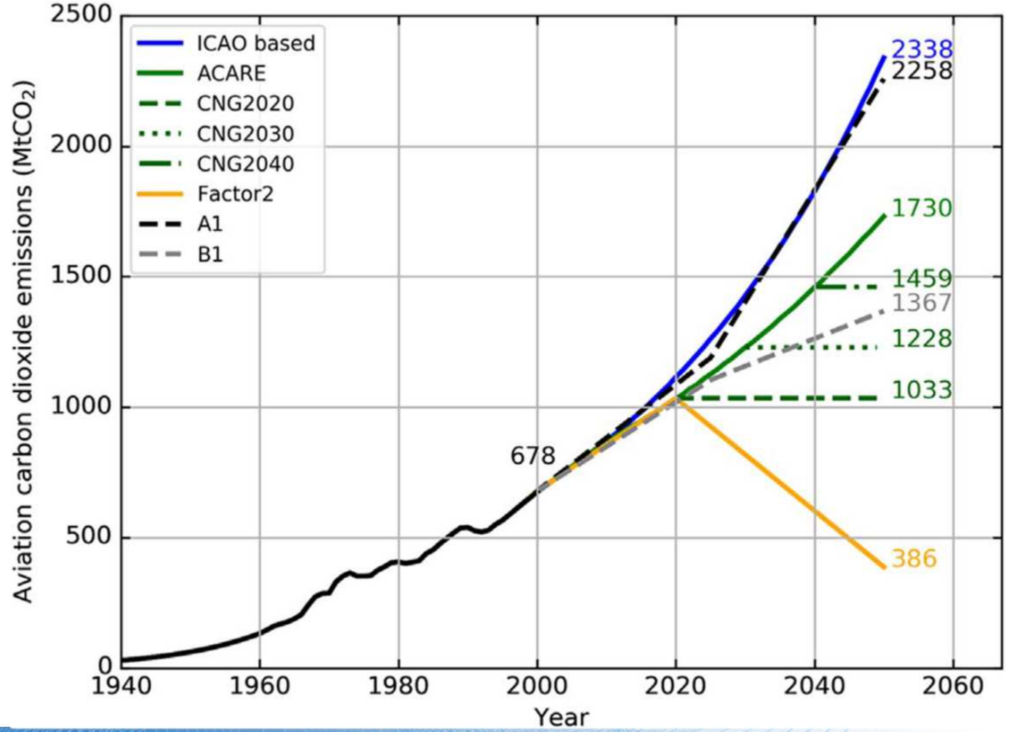
The RF calculated by the climate model LMDz-INCA (REACT4C 2006) is used to quantify the RF climate response in OSCAR

Agents	RF (mW/m^2)
CO_2	OSCAR
O_3 (short- live)	15.9
CH_4	Based on CH4 lifetime reduction
Nitrates	0.1
Sulfates	-3.9
Soot (BC+OC)	0.4
Contrail cirrus	57.4 (17, 98) Lee et al., 2020

- The RF calculated using complex model is used to calibrate OSCAR RF response from non-CO_2 species only.
- Multiple climate sensitivities available (e.g. CMIP5) to calculate the temperature response (mK)
- Monte Carlo approach to calculate robust uncertainties (e.g. 1000 runs)

Different aviation emissions scenario (Fuel/CO_2)

Scenario	Assumptions for the 2000–2050 period	Emissions in 2050 $MtCO_2$ (%)
ICAO based	Traffic: 4.6%/yr. Efficiency gain: 2.0%/yr.	2338 (16%)
ACARE	Traffic: 4.6%/yr. Efficiency gain: 2.7% /yr.	1730 (12%)
CNG 2020	ACARE up 2020. Carbon neutral growth after 2020.	1033 (7%)
CNG 2030	ACARE up 2030. Carbon neutral growth after 2030.	1228 (8%)
CNG 2040	ACARE up 2040. Carbon neutral growth after 2040.	1459 (10%)
Factor 2	ACARE up to 2020; linear reduction after 2020 to achieve in 2050 50% of ACARE 2005 value.	386 (3%)
QUANTIFY A1	Traffic: 4.3%/yr up to 2020, GDP based afterwards (see Owen *et al* 2010). Efficiency gain: 1.0%/yr to 2050.	2258 (15%)
QUANTIFY B1	Traffic: 4.3%/yr up to 2020, GDP based afterwards (see Owen *et al* 2010). Efficiency gain: 1.0%/yr to 2020 and 1.3%/yr for 2020–2050.	1367 (9%)



- The SRES scenarios were developed by the Intergovernmental Panel on Climate Change (IPCC), as four main family storylines: A1B, A2, B1, and B2. Each scenario family involves a storyline and a number of quantifications, including estimates on population and GDP.
- Focus on A1 and B1 as well as Carbon neutral grow (ICAO) and Factor 2 (IATA).

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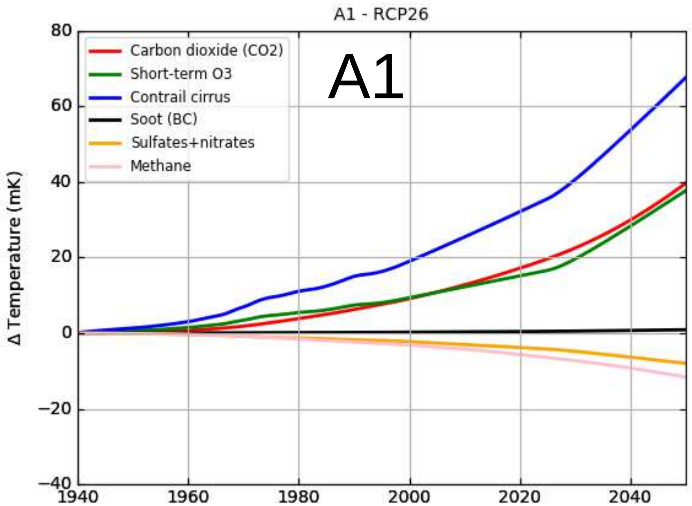
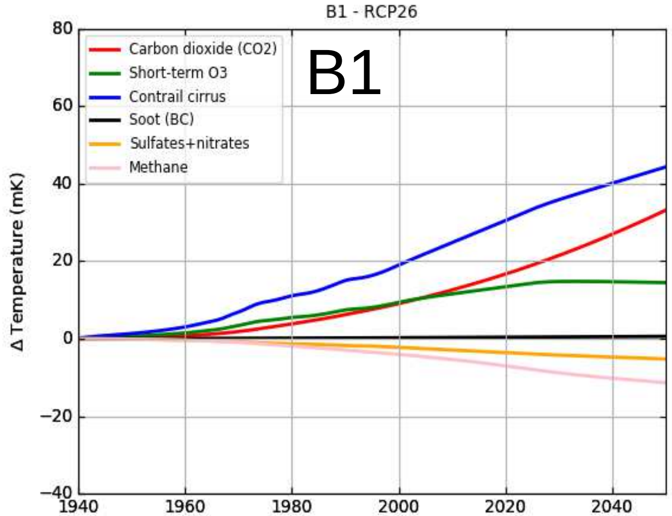
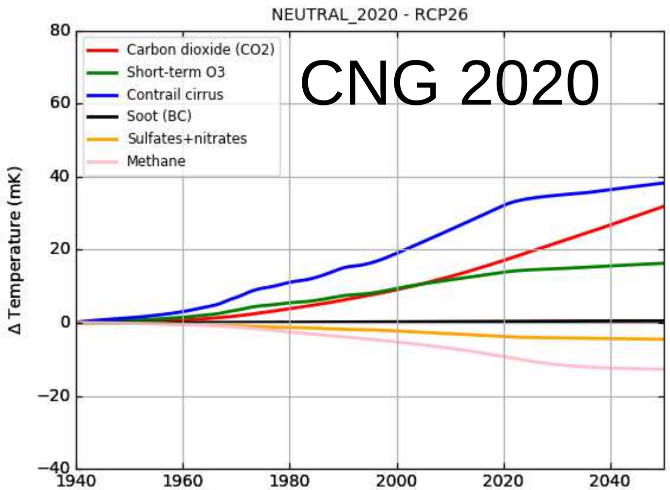
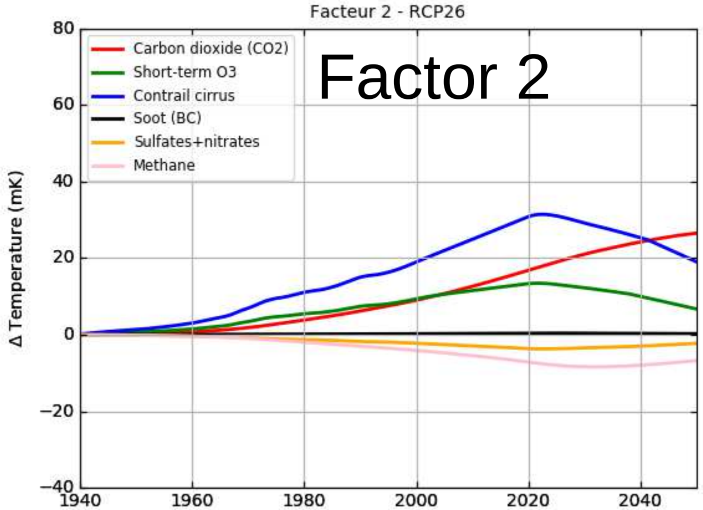
The climate transient response to aviation emissions calculated by OSCAR for four scenarios in a “Paris agreement” context (RCP2.6)



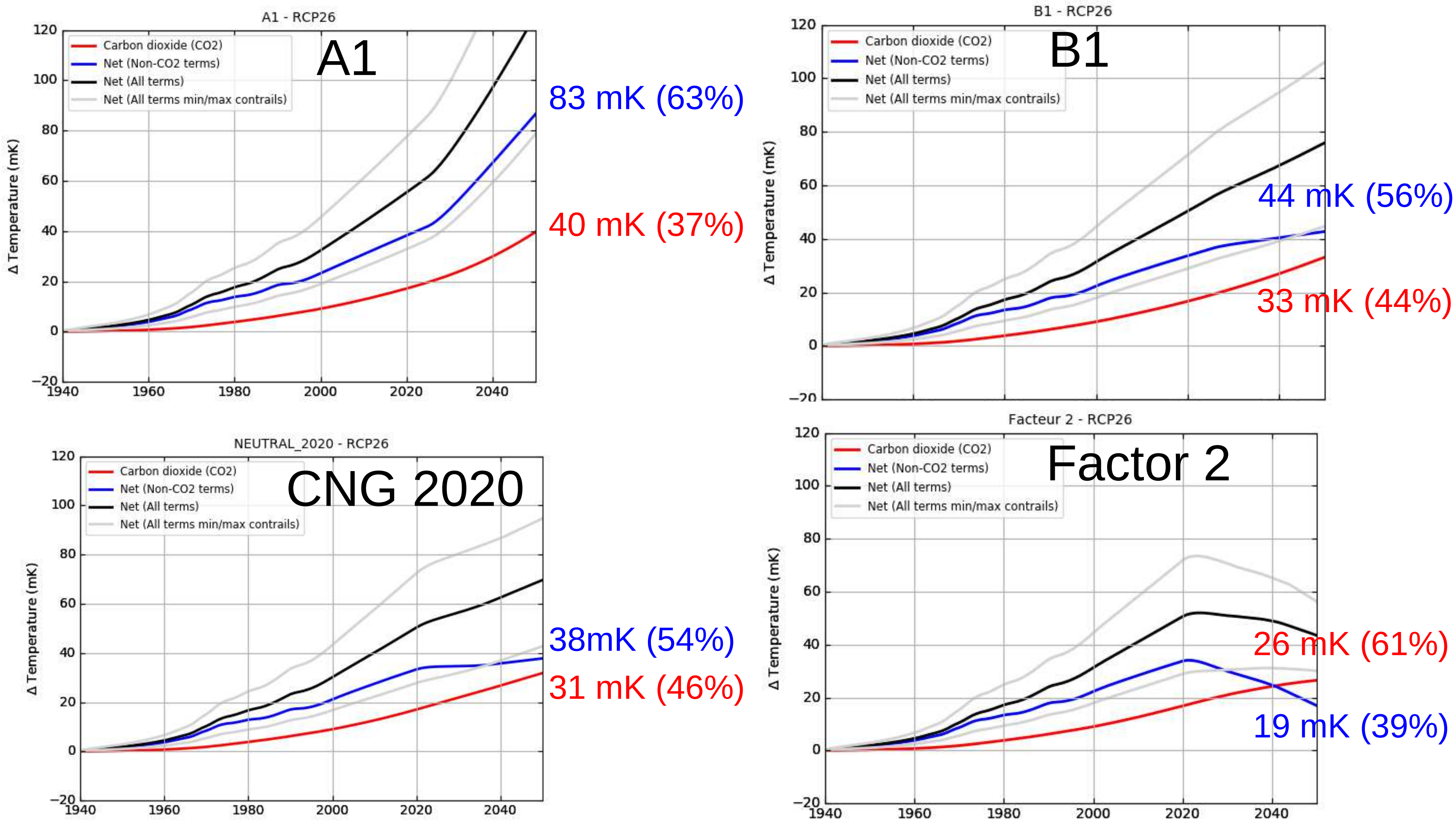






- Contrails cirrus dominate the climate response from aviation emissions for A1 and B1 scenarios
- The CNG 2020 scenarios is not a sufficient effort to inverse the increasing tendency of the climate response

Same but for CO_2 and aggregated non-CO_2 components (using the best estimate as well as the min/max ERF for contrails cirrus (in grey))



- From 2040, **non-CO2 terms do not dominate** the climate response **using Factor 2 scenario** as the climate response is dominated by the CO_2 inertia.

Sum up of the climate impact of CO_2 and non-CO_2 components (2050)

	A1	B1	CNG2020	Factor 2
CO_2	40 mK (37%)	33 mK (44%)	31 mK (46%)	26 mK (61%)
non-CO_2	83 mK (63%)	44 mK (56%)	38 mK (54%)	19 mK (39%)

- In 2050, non-CO2 species is expected to dominate the climate response for BAU (A1) and mitigation (B1) scenarios
- Then a equilibrium between non-CO_2 and CO2 is observed for ambitious mitigation scenario (CNG2020) while the CO_2 dominate for very challenging scenarios (Factor 2)

Key messages and future work

- OSCAR (SCM) is very efficient to quantify climate impact of aviation or any other economic sector using the RF response from complex 3D models (e.g. IPSL CM6) for multiple scenarios

- Contrails cirrus dominate the climate response from aviation emissions for A1 and B1 scenarios (42 to 60 mW/m^2 in 2050)

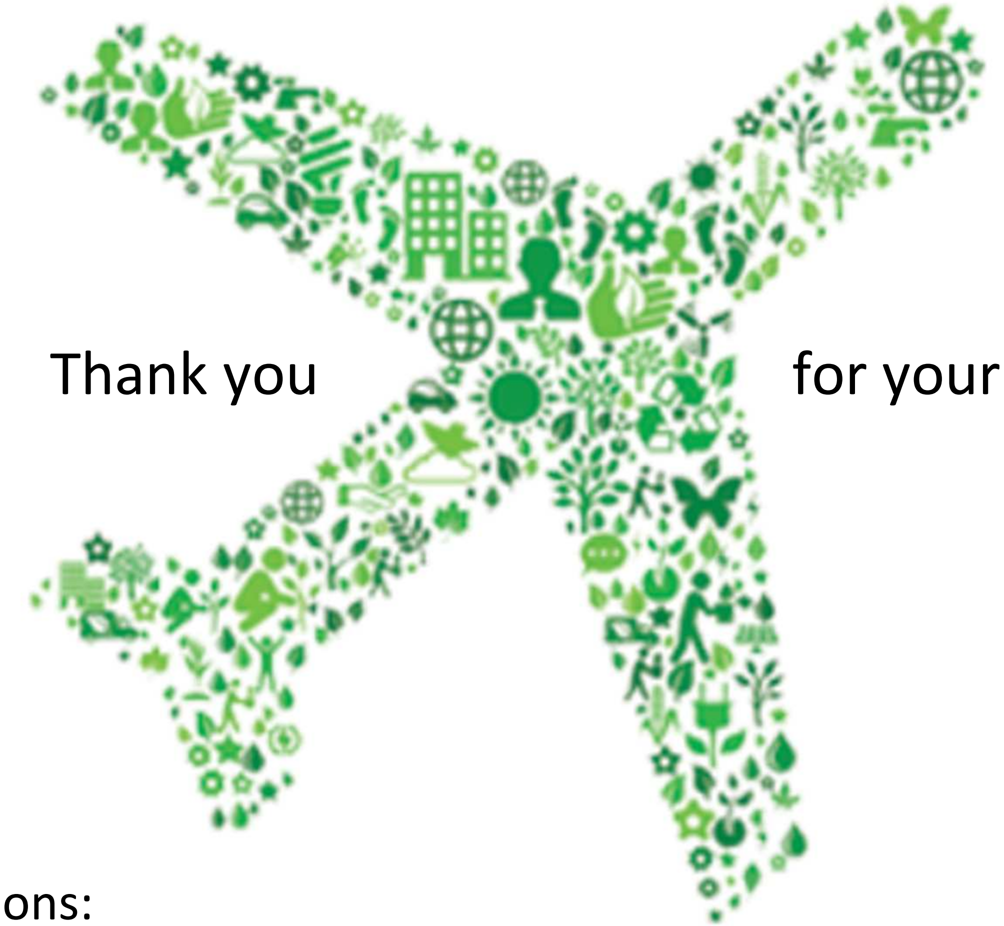
- CNG 2020 is not a sufficient effort to inverse the increasing tendency of the climate response to aviation emissions

- Contrails cirrus do not dominate from 2040 using Factor 2 scenario as the climate response is dominated by the CO_2 inertia from 2040 (61 % of the net contribution in 2050)

- The aviation version of the OSCAR SCM should be developed the climate LMD-INCA climate response according to the location of the aviation emissions (e.g. Airclim)

- Interdependency and role of the other climate system components: in a warmer climate the land and sea carbon sinks are expected to be less efficient (different behavior using RCP6 context)

The end



Thank you for your attention

More informations:

Terrenoire E, Hauglustaine DA, Gasser T , & Penanhoat O (2019). The contribution of carbon dioxide emissions from the aviation sector to future climate change. *Environmental Research Letters* 14 (8): e084019. DOI:10.1088/1748-9326/ab3086.

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