

The banner features a stylized illustration of a white airplane flying over a green and blue landscape. The sun is in the top left corner, and a globe is in the top right. The text is centered in the upper half of the banner.

# ICAO Symposium on Non-CO<sub>2</sub> Aviation Emissions

16 — 18 September 2024  
Montréal, Canada

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and Environment

**ONERA, The French Aerospace Center**

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**Speaker**

Session 2: Enhancing Scientific Knowledge  
**Part I – NO<sub>x</sub> and Particulate Matter**



# Reducing uncertainties on non-CO<sub>2</sub> effects NOx and particulate matters

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Institut Pierre-Simon Laplace (IPSL)

Sciences du climat



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- **Context**

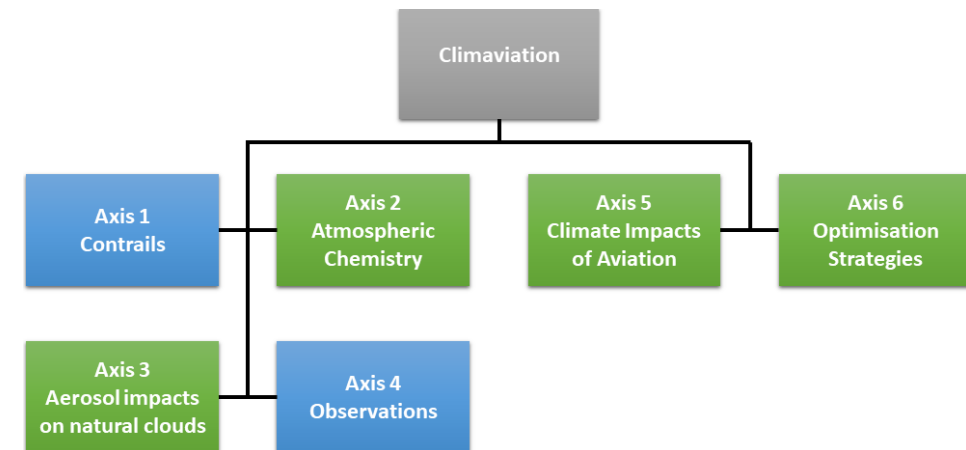
- Non-CO<sub>2</sub> possibly dominating radiative forcing but highly uncertain
- Only addressed through modelling with no straightforward way of validation
- ***Need for multiple approaches to check convergence and reduce uncertainties***

- **CLIMAVIATION**

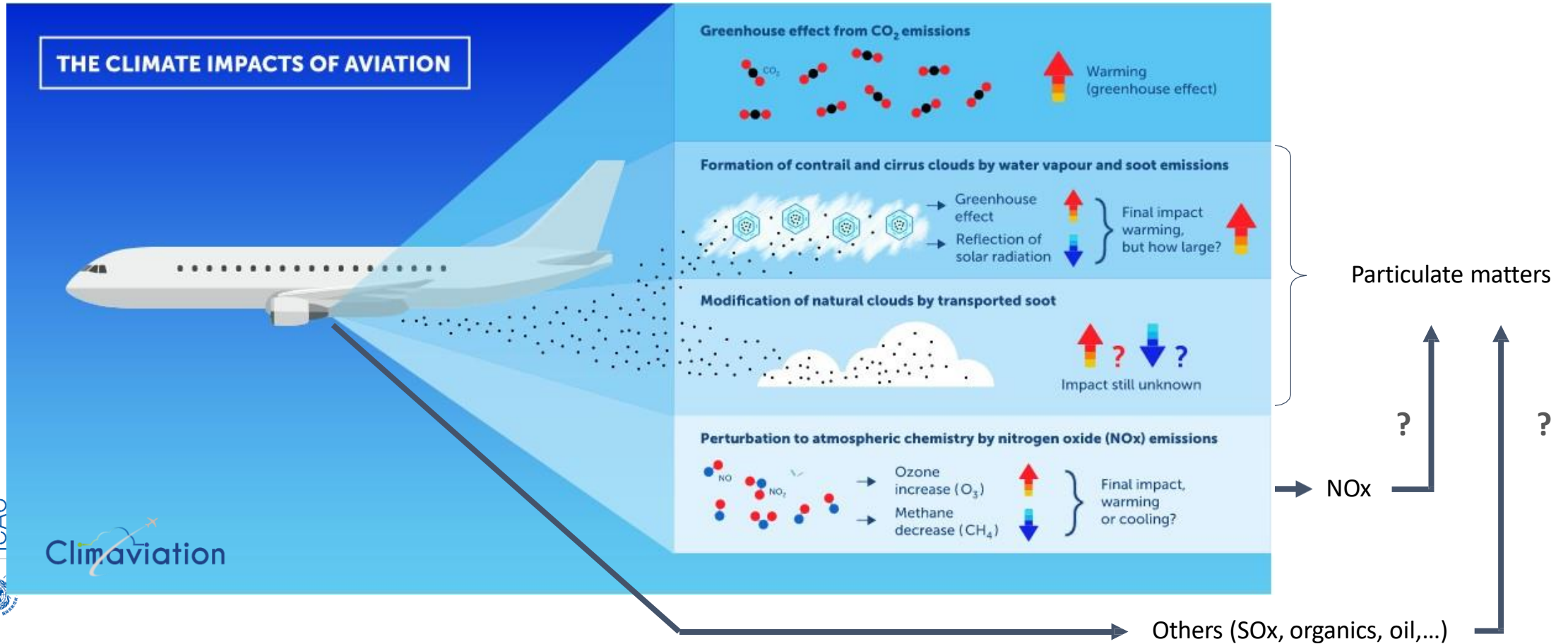
- A will to re-energize French scientific community on non-CO<sub>2</sub> effects
- Partnership between climate research (IPSL) and aeronautic research (ONERA)
- Five years research project (30 to 40 scientists contributing)
- Funded by French DGAC

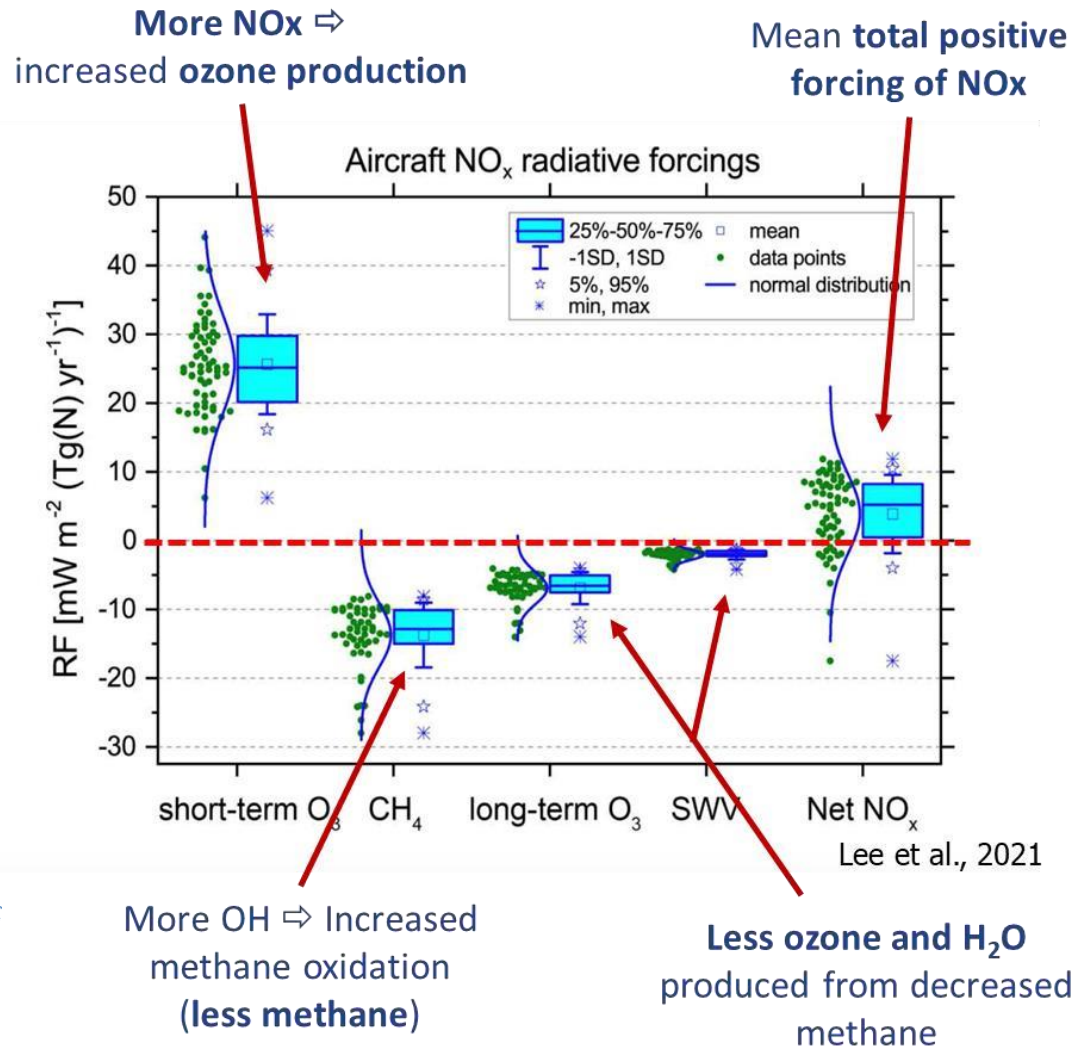
**4 objectives**

- Reducing uncertainties : contrails, NO<sub>x</sub>, particles/clouds interaction
- Quantifying current impact on climate
- Assessing possible future evolutions
- Investigating strategies to minimize impact



# Focus : the role of emissions and the associated uncertainties





## Scientific questions :

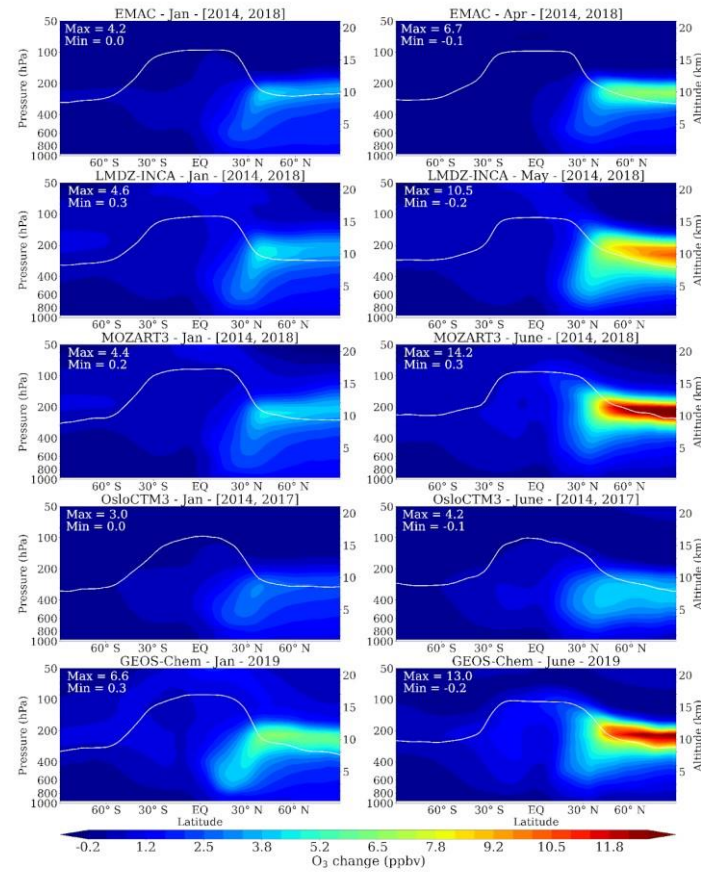
- Spreading of model results
  - Need to understand differences between models
- Multiple possible chemical pathways not always represented
  - In particular chemistry feedback onto aerosols
- Chemical evolution in engine plume (at sub-grid scale in GCM)
- Dependency to background NO<sub>x</sub> concentration

## On-going in Climaviation:

- Introduction of a plume scale parametrization to account for chemical evolution in engine's plume
- Improvement of NO<sub>x</sub> chemistry in LMDZ-INCA global model
- Comparison of LMDZ-INCA model with other models and IAGOS database in the framework of the ACACIA H2020 project.

# Impact of NOx on ozone and methane

## Change in ozone due to aircraft emissions



ACACIA

## Present-day (2015) RFs associated with aircraft NOx emissions (all in mW/m<sup>2</sup>)

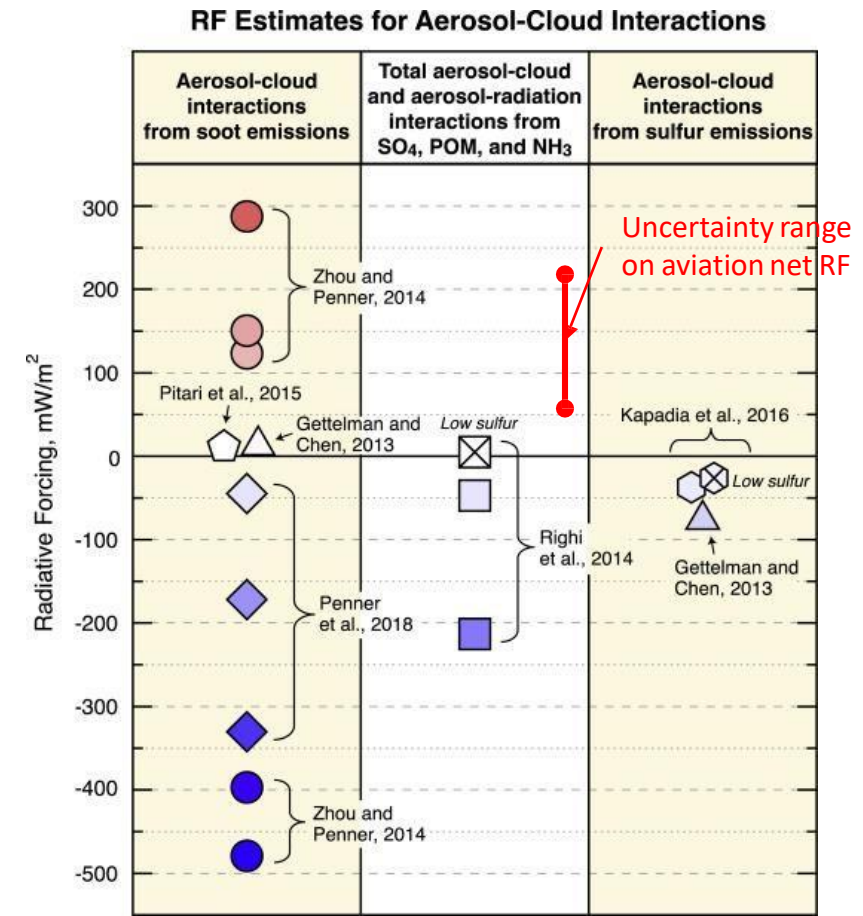
Model	Ozone		Methane			Total
	Short-term ozone	Methane direct incl. feedback	Long-term ozone	Stratospheric H <sub>2</sub> O	Total CH <sub>4</sub>	
EMAC	27.7	-13.3	-5.4	-1.7	-20.4	7.3
LMDZ-INCA	43.0	-17.3	-7.0	-2.2	-26.4	16.6
MOZART3	42.0	-12.9	-5.2	-1.7	-19.9	22.1
OsloCTM3	34.0	-12.9	-5.2	-1.7	-19.9	14.1
GEOS-Chem	55.3	-24.5	-9.9	-3.2	-37.6	17.7

- Significant uncertainty on resulting RF remains
  - Not all models represent all the possible chemical pathways
    - In particular chemistry feedback onto aerosols
  - Difference between models not sufficiently understood at the process level

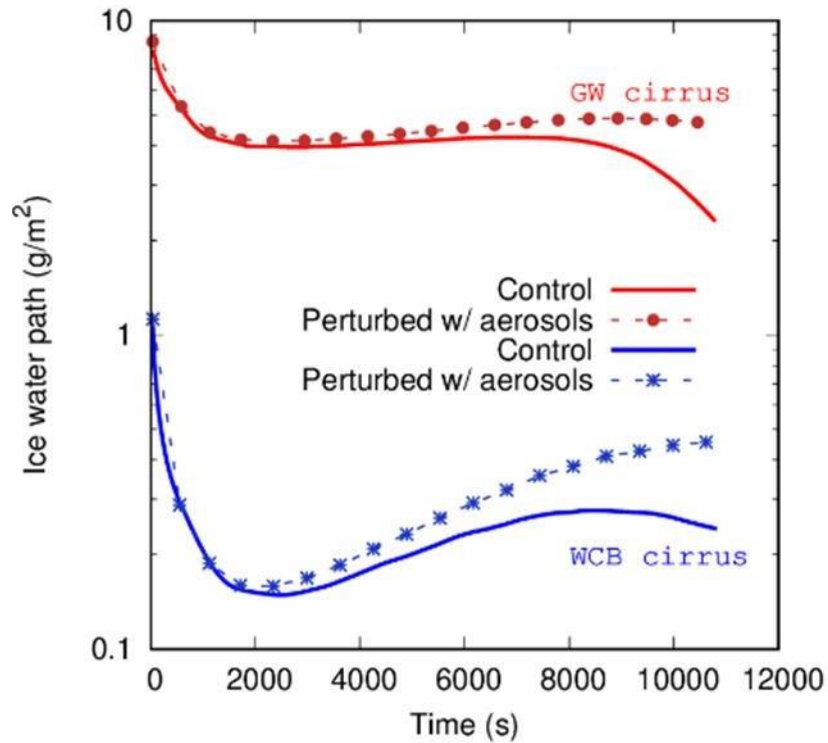
Cohen, Hauglustaine and the ACACIA team, in prep., 2024

# Interactions between aerosols and clouds

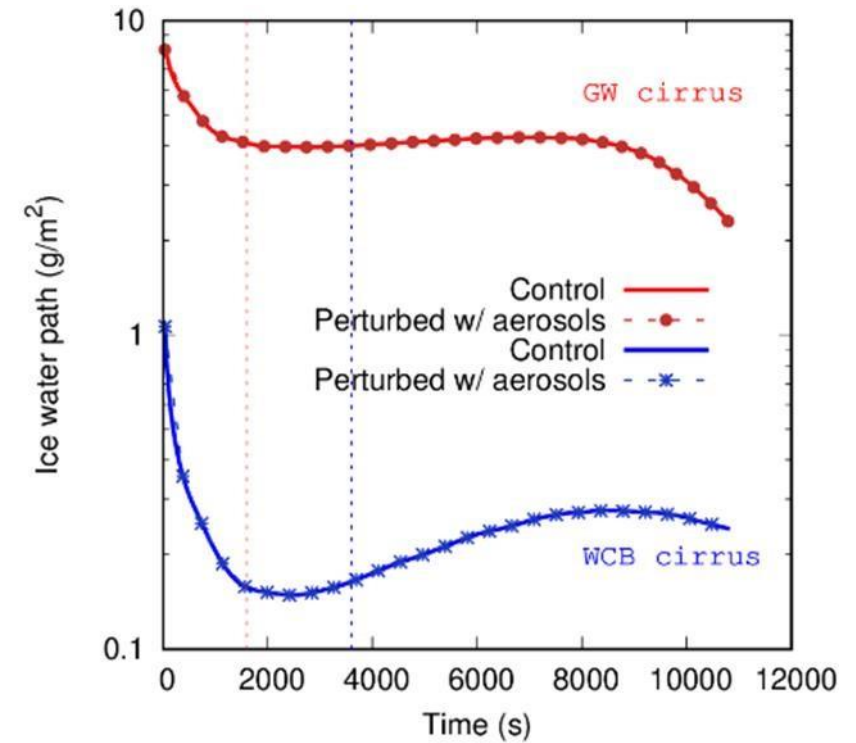
- **A particularly uncertain contributor to aviation impact on climate**
  - No estimate could be provided by Lee et al. in their 2021 review due to too large disagreement between models
- **An interaction notoriously difficult to represent in climate models**
- **Scientific questions:**
  - What are the concentrations, sizes, and INP/CCN properties of aviation aerosols hours after emission?
    - Need for observation to characterize properties
  - How far are aviation aerosols transported horizontally and vertically?
    - *On-going work on BC removal schemes in LMDZ-INCA and comparison with airborne measurements*
  - How do ice and liquid clouds respond to changes in aviation aerosols?
    - How do aviation aerosols enter the cloud evolution process?
    - How do aviation aerosols compete with background aerosols?
    - *LES investigation of ice cloud response to aerosol perturbations*



➤ Ice clouds' response to aerosols: response when perturbing aerosols, but only at cloud formation stage



Aerosol perturbation applied when the cirrus cloud forms:  
similar response to idealised ICNC perturbations

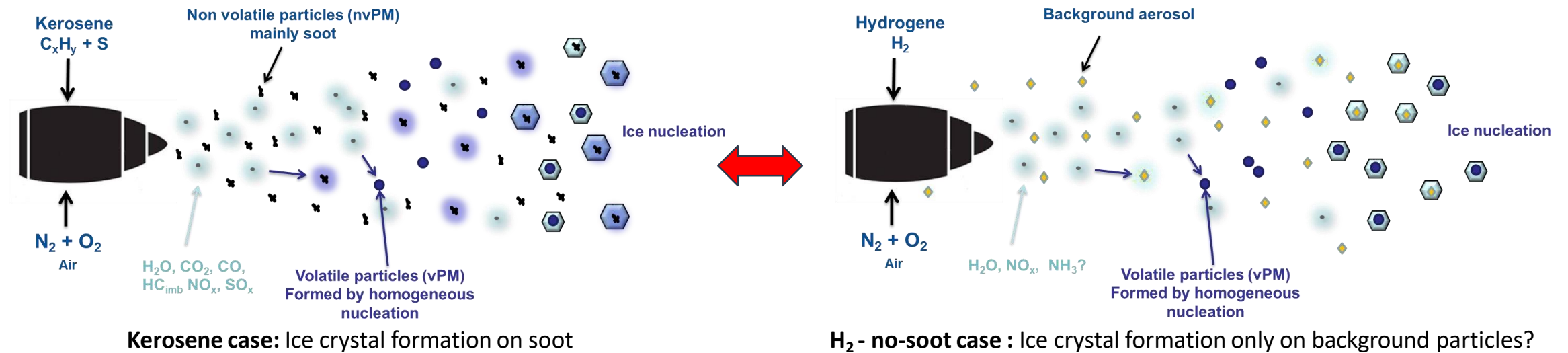


Aerosol perturbation applied after cirrus has formed: no response  
Lack of humidity + competition from water vapour deposition onto ice crystals

⇒ Analysis to be extended to more cirrus cases

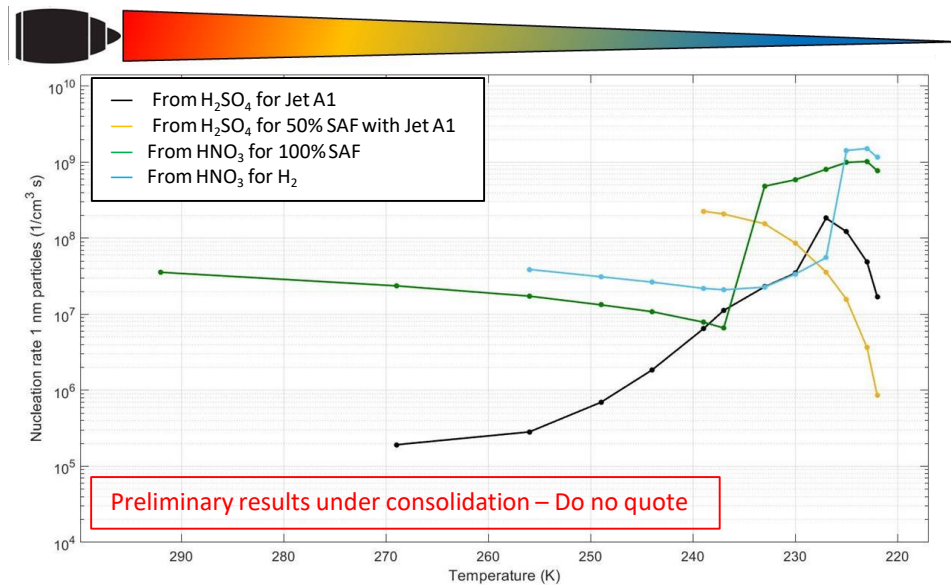
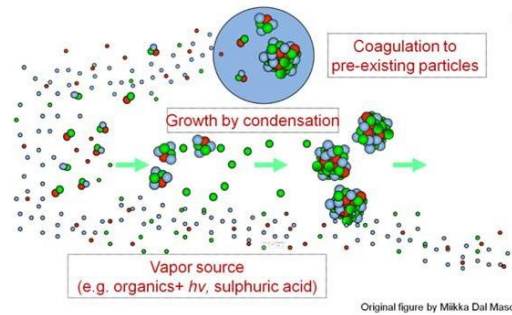
# Contrails: the role of emissions

- Conventional fuel : dominating role of soot for ice crystal formation
- Leading question: what happens in case of low soot emissions ?  $\Rightarrow$  *lean burn, SAF, H<sub>2</sub>*
  - Only background atmospheric particles or possible role of secondary aerosols?
    - ✓ E.g.: Nitric acid (H<sub>2</sub>, 100% SAF), sulfuric acid or organics (50% SAF, lean burn)



- Study of formation mechanisms of secondary aerosols in the exhaust jet (new condensation nuclei)
- Parallel effort on modelling of contrail formation, ageing and radiative forcing (*coming presentation by N. Bonne*)

## Formation of secondary aerosols

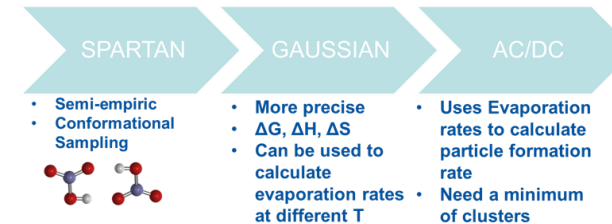


Simulation of the formation of secondary aerosols

**Step 1** : identification of potential precursors for volatiles

➤ Quantum chemistry for the case H<sub>2</sub>: HNO<sub>3</sub> potential candidate ?

**Step 2** : computation of nucleation rate of particles



### Preliminary results:

- Charged particles are required
  - Need for characterization of charges in engine plumes
- Current results suggest a role of volatiles as condensation sites, possibly leading to even more ice crystals than for kerosene

➤ Consolidation and model improvement on-going

- **Strong concern for reducing uncertainties on non-CO<sub>2</sub> effects with regard to mitigation strategies and possible emerging regulations**
- **Significant uncertainties on physical and chemical phenomena themselves**
  - Both at understanding and modelling / representation levels
- **Additional uncertainties exist:**
  - Intrinsic difficulty of assessing the small perturbation of aviation in the climate complex system of interactions with significant variability and noise
  - Knowledge and characterization of emissions themselves
    - Actual emissions in flight ? Dependency on aircraft conditions, actual fuel burned in flight ...
    - Emissions inventory
  - Different situation when looking at an individual flight or the global fleet
- **A national effort initiated in France on major non-CO<sub>2</sub> contributors**
  - Effort to reduce uncertainties on major contributors (contrail, NO<sub>x</sub> and clouds/aerosol interaction)
  - Going from near field to synoptic scale
  - Integrating all non-CO<sub>2</sub> effects in a unique model, LMDZ-INCA
  - ***A will to bring a contribution to the scientific community effort***

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# Thank You

