Prévoir les traînées de condensation persistantes pour limiter leur effet sur le climat : enjeux et perspectives

Forecasting persistant contrails to limit their effect on climate: challenges and prospects

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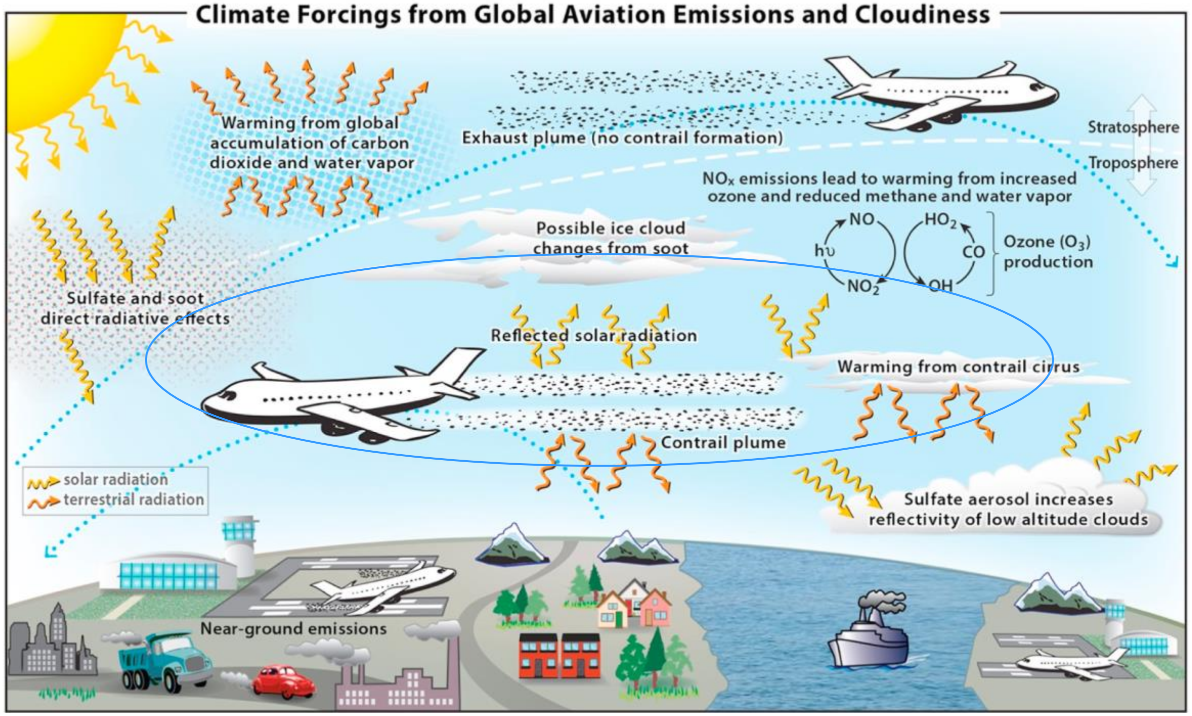
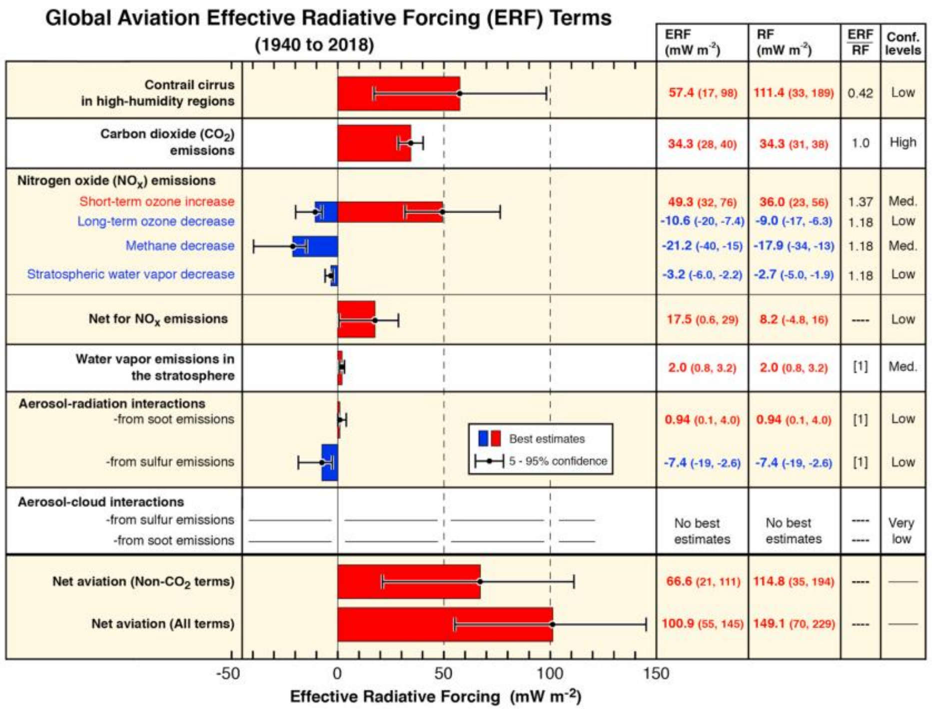
Toulouse, 15 December 2023

Contrails : radiative climate impact





(Lee et al, 2021)

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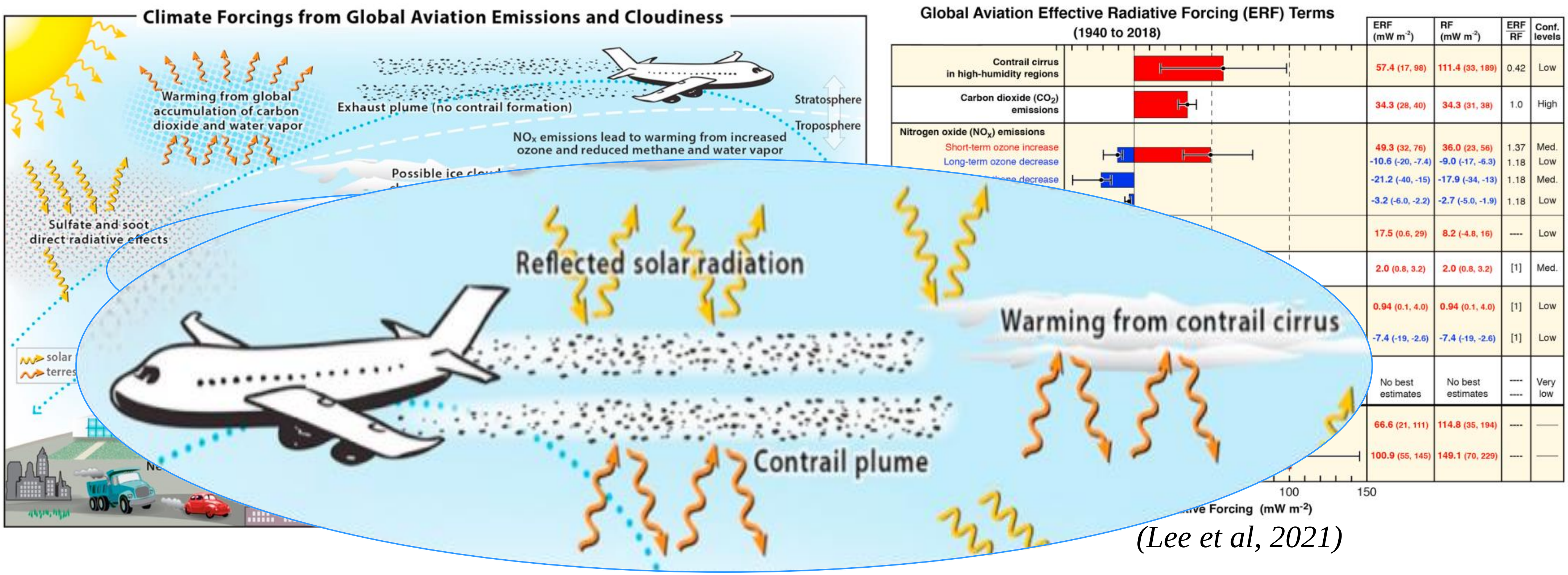

(Lee et al, 2021)

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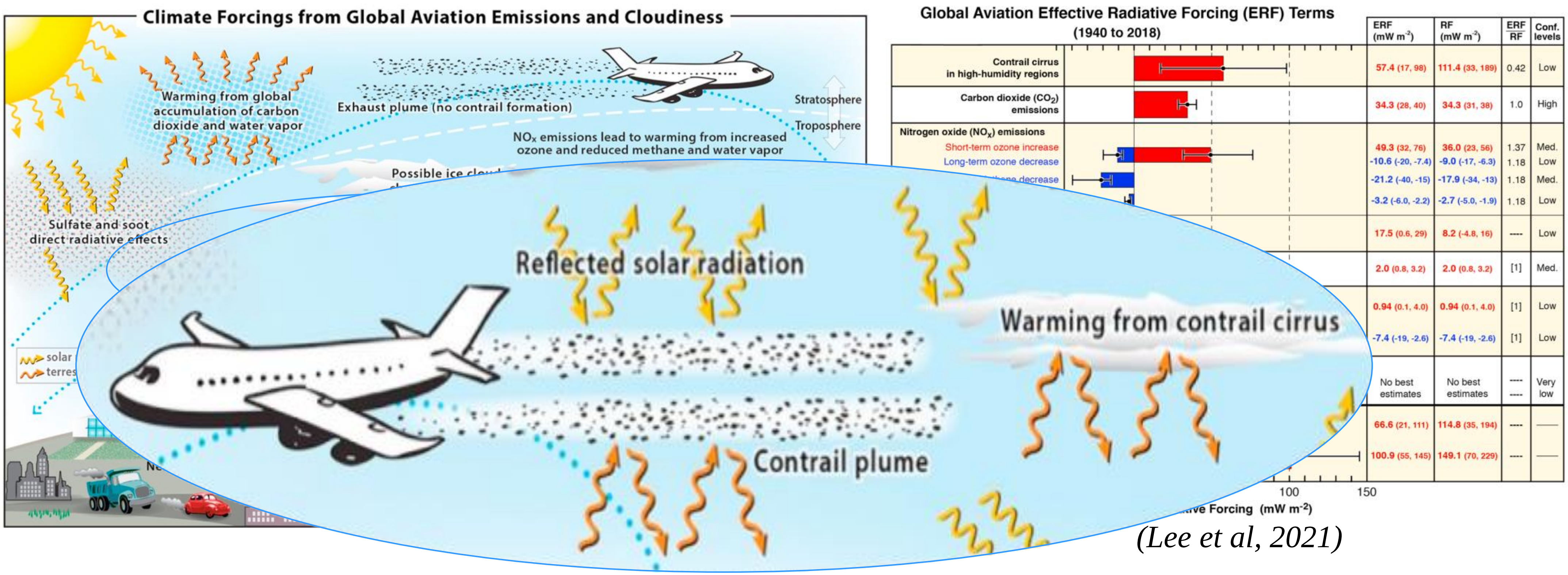


(Lee et al, 2021)

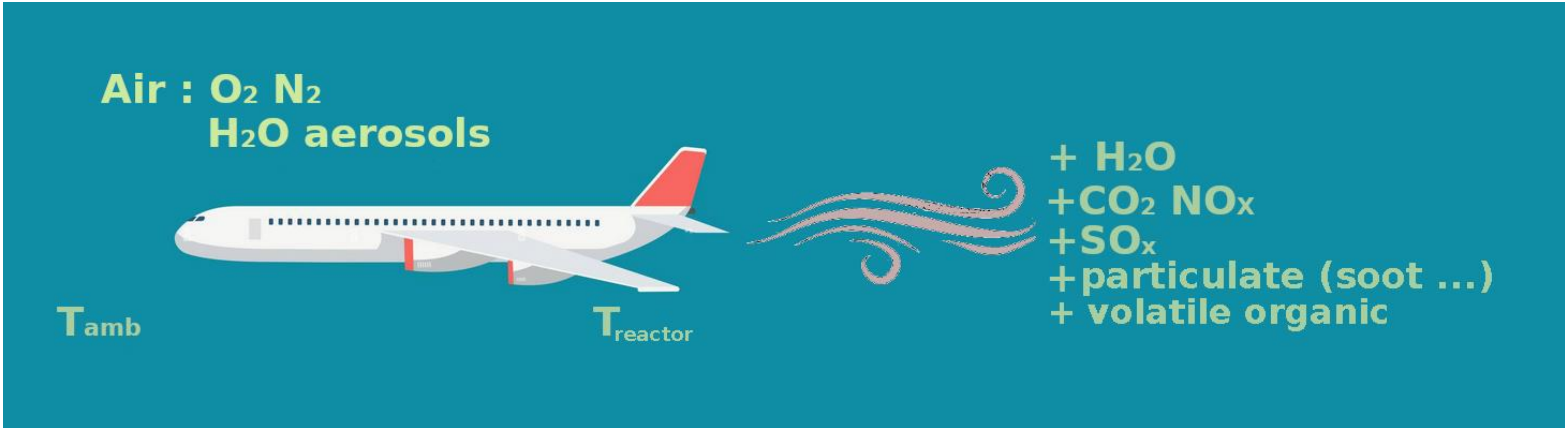
<u>In 2018, part of aviation among the human activities:</u>

CO_2 emissions <u>~2,4 %</u>

Radiative forcing <u>~3 à 4 %</u>

√ For an aviation without climate impact, the « non-CO_2 » effects must be avoided

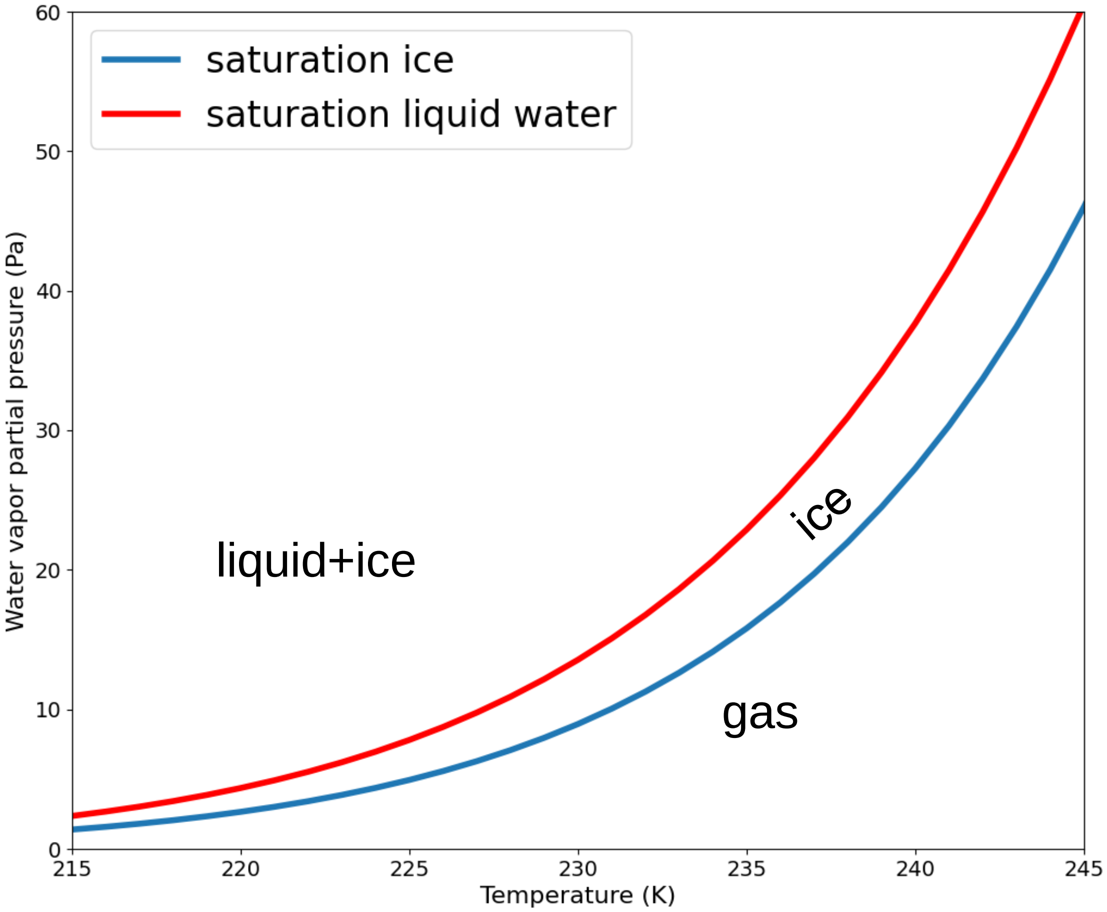
Contrails : formation



- <u>Ambiant conditions:</u>
- Very low T (~230K), low $Pv_{sat}H_2O$
- « Dry » air (few H_2O molecules)
- « Clean » air (few aerosols)

- <u>Aircraft brings:</u>
- H_2O
- aerosols (NOx, SOx, soot, …)
- momentum

Contrails : formation

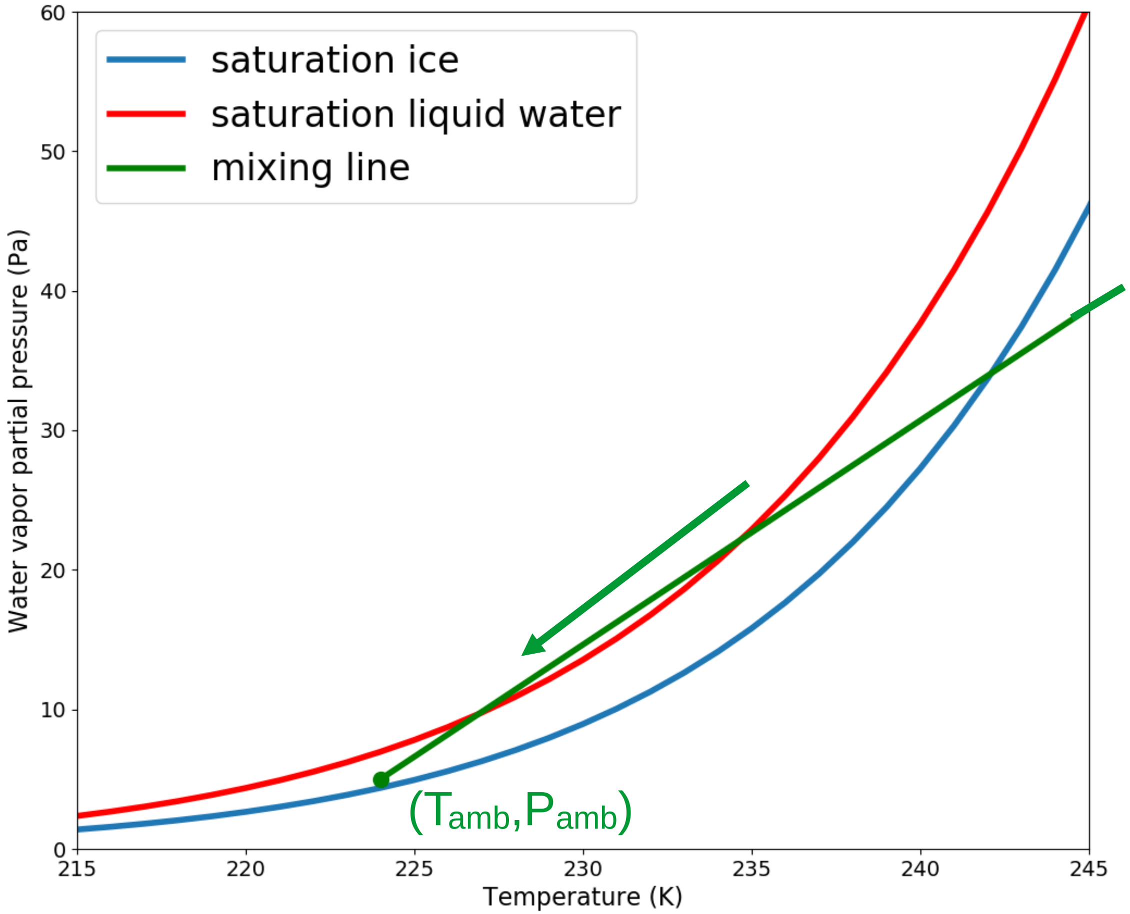


- Pathways to form ice cristals :
  - Liquid-phase heterogeneous nucleation : need hydrophilic aerosols (SOx, NOx, organic …, that may « coat » on solid particles),
  - Homogeneous nucleation : need humidity above ~150 %,
  - Solid-phase heterogeneous nucleation : not efficient

√ Need hydrophilic aerosols

√ Need enough humidity to pass through liquid-phase

Contrails : formation



Thermodynamics criterion of Schmidt-Appleman

(Schumann, 1996)

Slope G $= \dfrac{C_p P EI_{H_2O}}{\epsilon Q (1-\eta)}$

EI_{H2O} : emission index (kg water / kg fuel)

Q : heat / kg fuel

η : propulsion efficiency

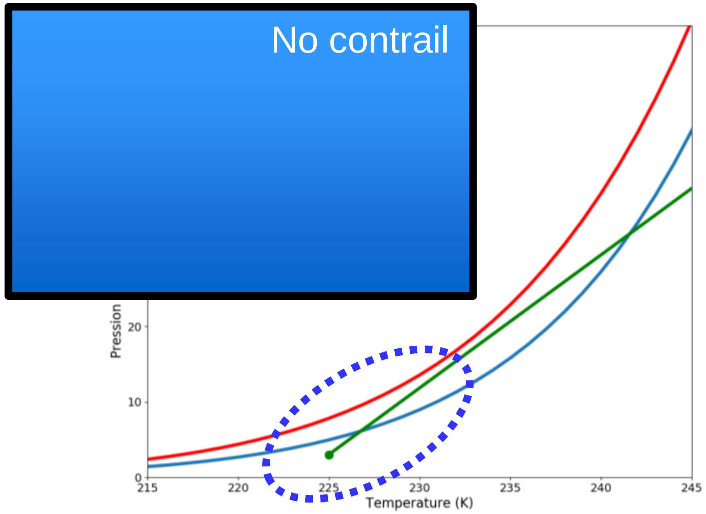
C_p : air thermal capacity

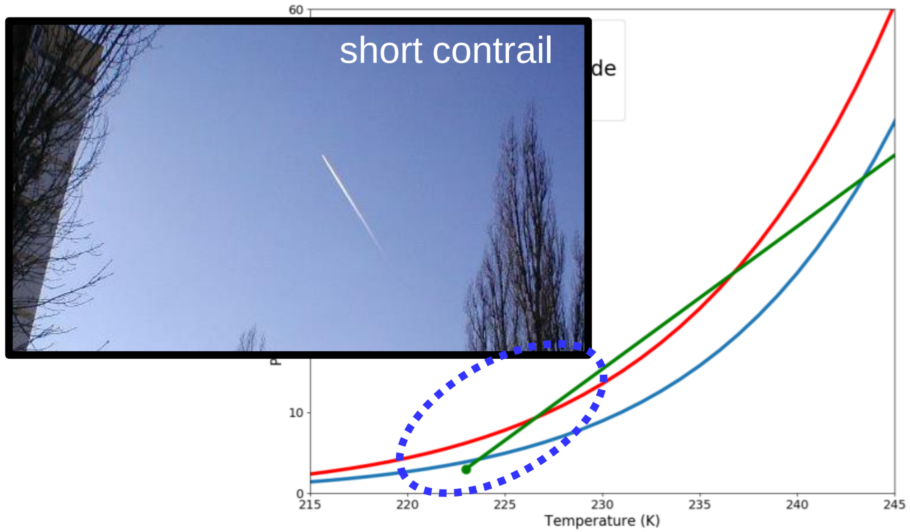
P : atmospheric pressure

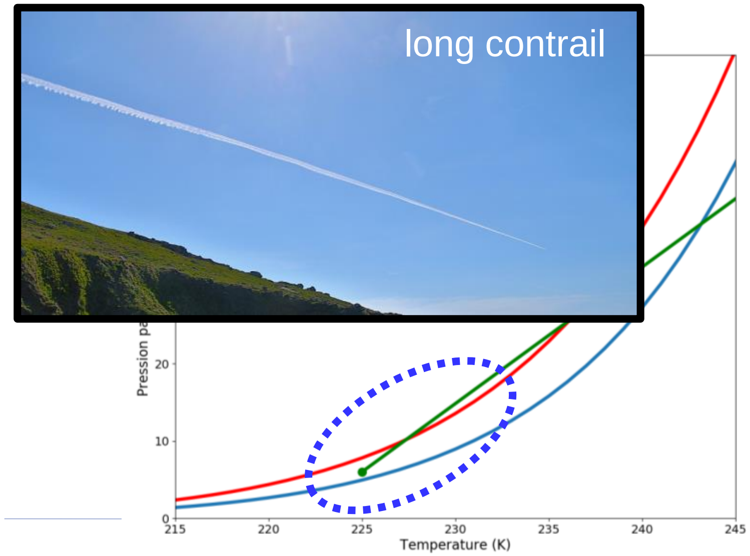
ε=0,622

√ more efficiency → more contrails

Contrails : persistance







persistance

(if ambiant humidity > 100%)

√ Formation depends on aircraft, fuel composition, and atmosphere

√ Persistance depends on atmosphere
(RHi >100 % = Ice SuperSaturated Region, ISSR)

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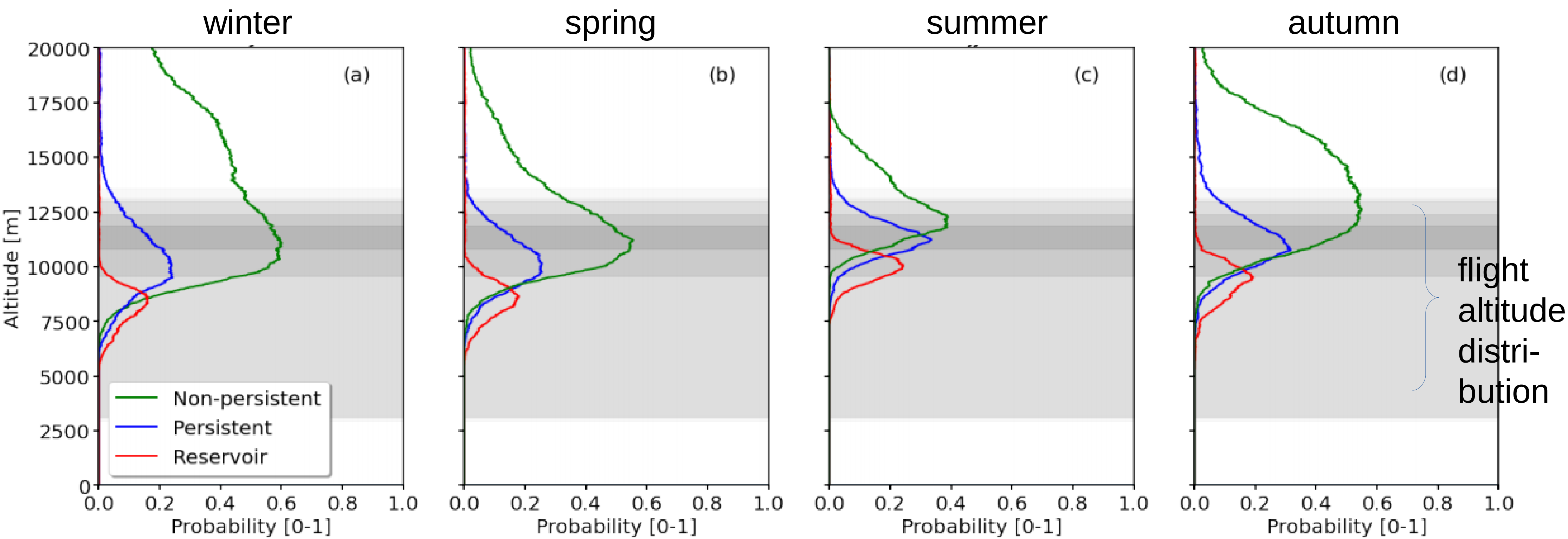
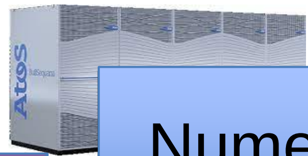
Where may contrails form and persist

- ISSR are variable in space, in altitude, and in time,
- depends on meteorological conditions (humid air brought to higher&colder altitudes),
- ISSR occurrence is possible at every seasons,



From radiosondes over Paris area *(Wolf et al,, 2022, ACP)*

Atmosphere and weather forecasting

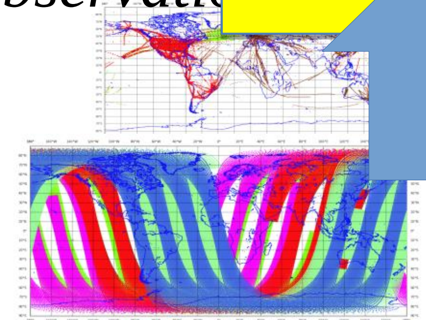


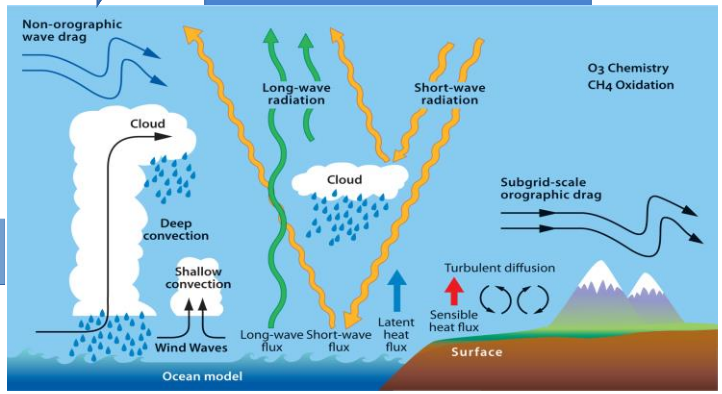
Analysis

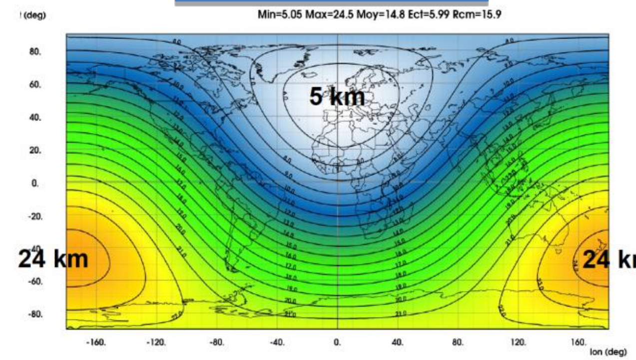
Numerical model

Forecast

Observatio





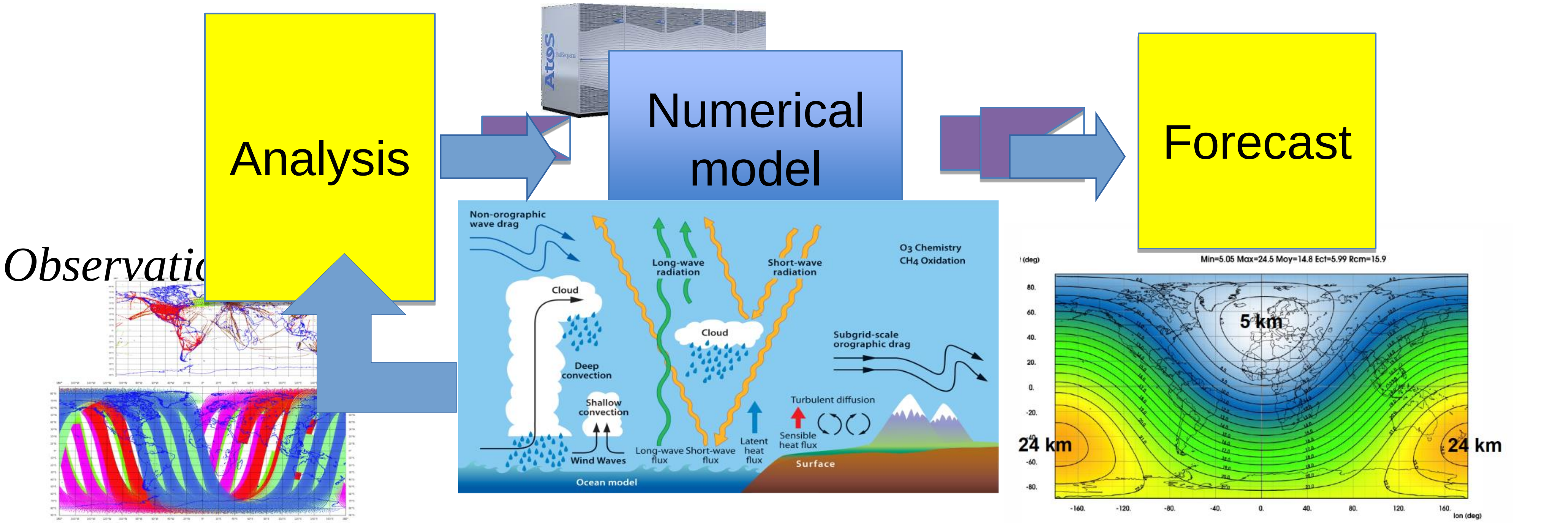


<u>Analysis</u> = a 3D grid forecast corrected by observations

<u>Observations</u> = in-situ measurements (ground, onboard, radiosondes), satellite radiances, GNSS-RO refraction, scatterometer, etc
… if they are available in near-real time !

<u>Forecast</u> = full & consistent representation of weather variables (temperature, humidity, pressure, wind, clouds, …) on a 3D grid, in time

Atmosphere and weather forecasting



√ Humidity in the upper-troposphere (cruise level) has received little attention so far (except for global

– radiative budget and temperature forecasts),

√ Learn from past developments in climate models to develop ISSR forecasts.

… and, in fact, the forecast is ran dozens of times (=members) with small perturbations

<u>→ ensemble probabilistic forecasting</u>

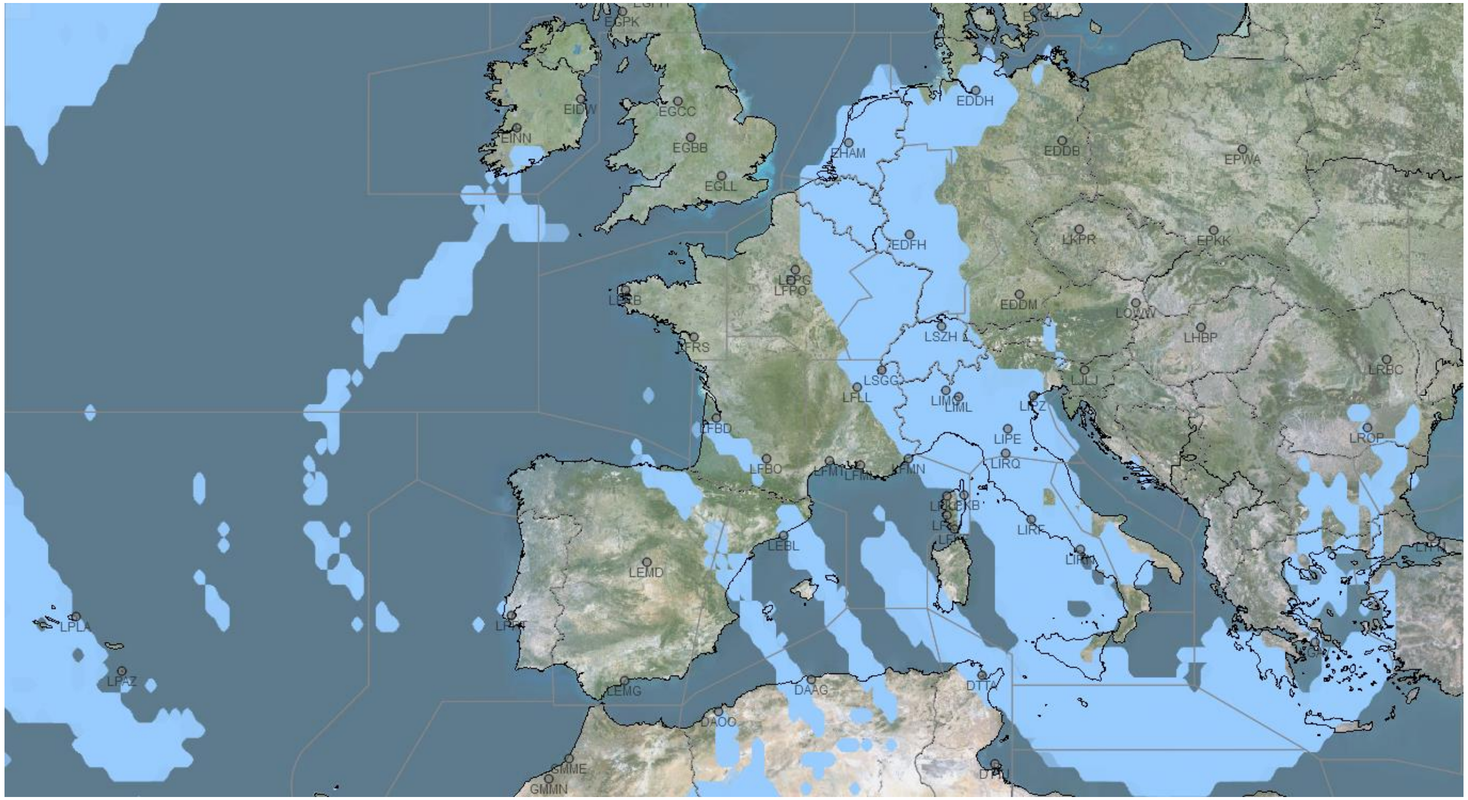
Atmosphere and weather forecasting

Exemple of ISSR forecast :

- 60 % probability from the ensemble of contrail persistant risk (hu>100%)

Forecast for 04/09/2023 at 10UTC
from 03/09/2023 12UTC

Risk of contrail persistence
Between FL300 and FL450 :



V. Curat, Météo-France

Atmosphere and weather forecasting

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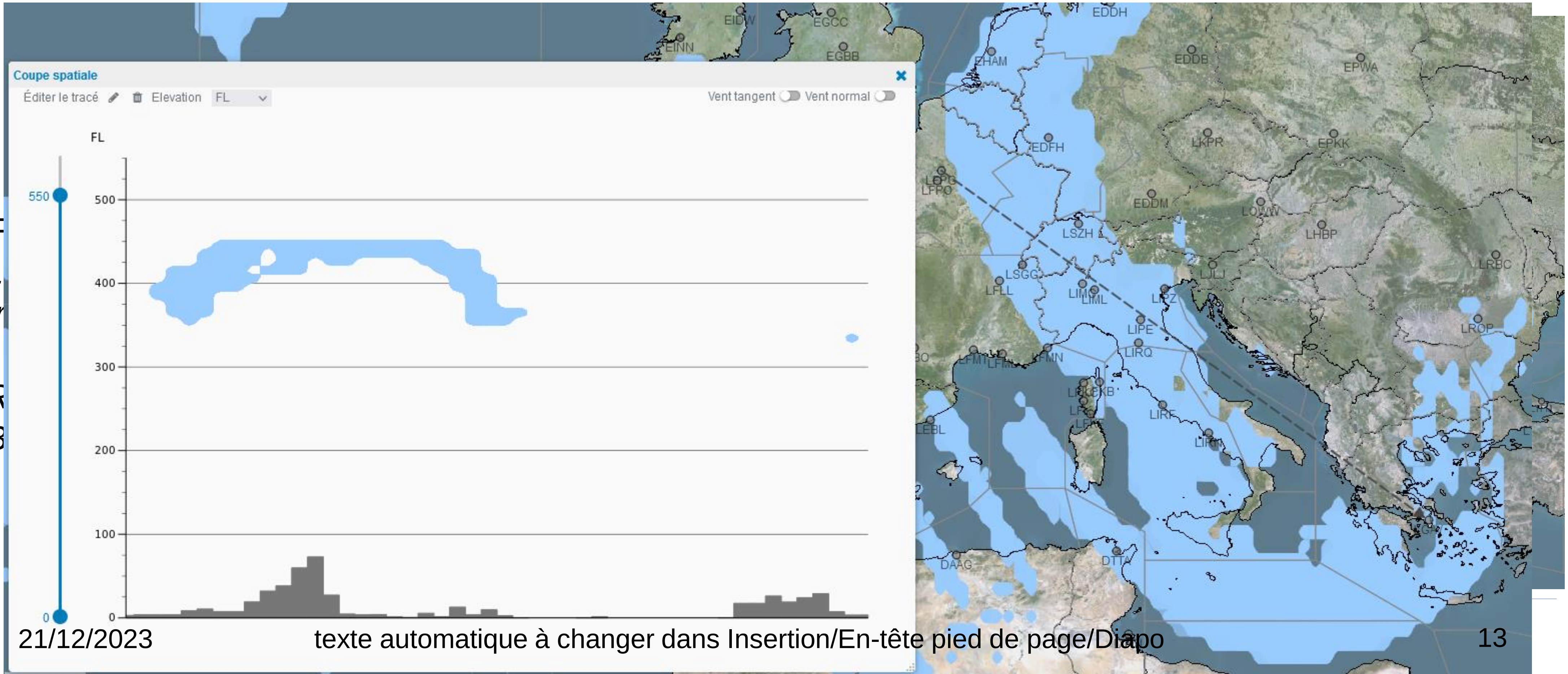


The SESAR3 CICONIA project

- A broad industrial project for operational mitigation solutions of non-CO_2 climate effects (focus on contrails),

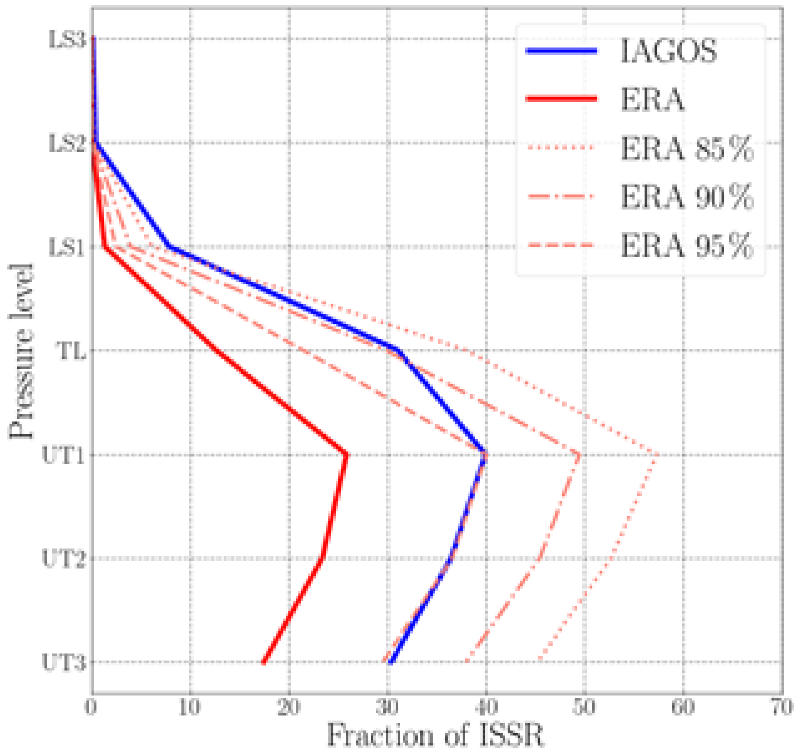
- Lead : AIRBUS, Weather lead : METEO-FRANCE, Climate lead: DLR, Concept lead : AIRBUS, Trials lead : NATS,

<u>- Weather/MET aspects:</u>

- Develop observations means (on-board humidity, contrail observations from satellites, ground-based cameras, lidars, from on-board pilots, etc),
- Model forecast development and evaluation,
- Gap analysis in measurements,
- Data provision.

Operational challenges

The quality of ISSR forecasts



Comparison of fraction of ISSR from ERA-Interim and IAGOS data (Reutter et al, 2020)

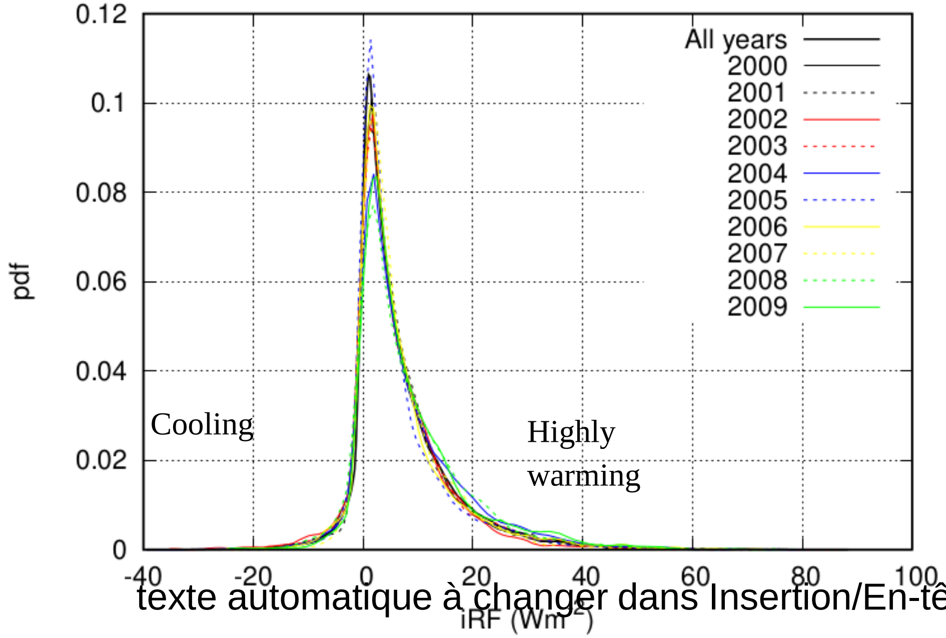
→ humidity values in the upper-troposphere are generally lower in models than in observations,

→ ISSR areas in models are underestimated

Operational challenges

The prediction of the potential radiative impact of ISSR

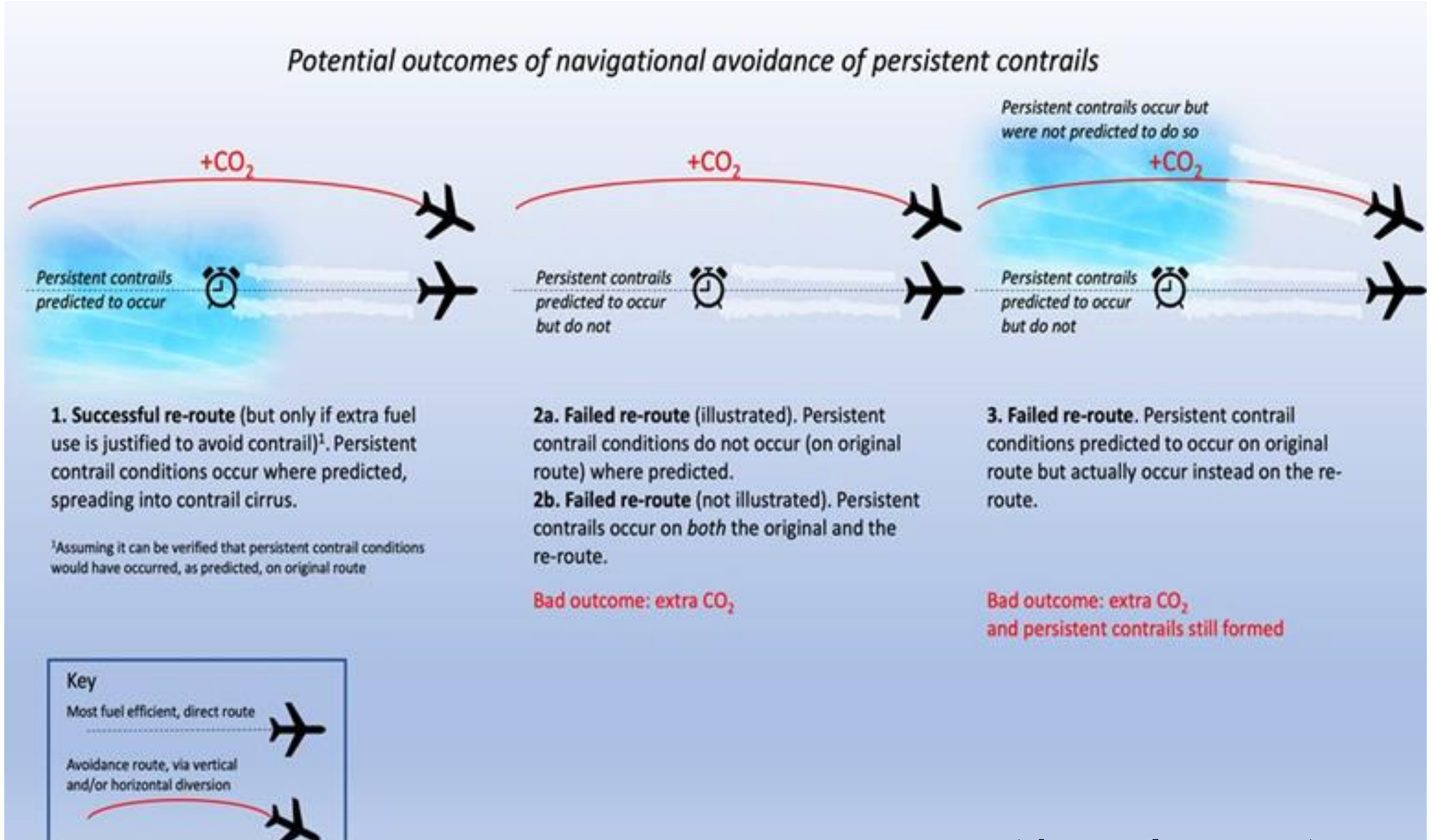
- Requires information on aircraft, fuel composition, real efficiency, etc
- Radiative effect depends (non-linearly) on pre-existing natural clouds,
- Can we discriminate zones favorable to « big hits » (2 % contrails have the highest impact)



Instantaneous radiative forcing of contrails (Wilhem et al, 2021)

Operational challenges

The CO2 & non-CO_2 trade-off



(Shine and Lee, 2021)

+ metrics to compare :
- the strong short-term effect of contrails,
- the long-term effet of CO_2,

?

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Operational challenges

The CO2 & non-CO_2 trade-off : formulation as a cost/loss problem

	Decision based on forecasts: no-contrail route	Decision based on forecasts: avoid contrail
Verification : no contrail formation	-	Cost (extra-fuel and extra CO_2)
Verification : contrail formation	Loss (climate impact or … tax)	Cost+Loss

If we can measure and compare the loss and cost (still an opened question ...)

→ we can define the economic value of forecasts,

→ in such cases probabilistic weather forecasts have a higher economic value than single forecasts : decision based on optimal probabilistic threshold

Broader challenges

Future fuels impact

- Biofuels & SAF

Less sulfates
Different organic composition
→ impact on ice cristals
(size & numbers)
→ what impact on clouds?

- H_2

More humidity
Less particles
No sulfates, no soot
→ different cloud processes
→ what impact?