PROPERTIES AND PROCESSING OF AVIATION INDUCED AEROSOL WITHIN THE UTLS OBSERVED FROM THE IAGOS-CARIBIC FLYING LABORATORY (EGU22-908)

EGU 2022 AS3.7 – Dynamics and chemistry of the upper troposphere and lower stratosphere (UTLS)

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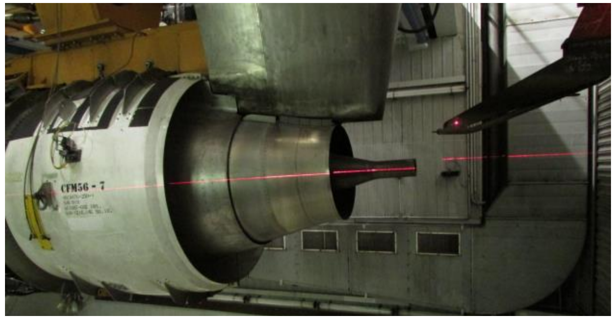
Lufthansa ACACIA IAGOS IN-SERVICE AIRCRAFT FOR A GLOBAL OBSERVING SYSTEM

JÜLICH Forschungszentrum

MOTIVATION / INTRODUCTION

- The impact of aviation on atmospheric aerosol, its processing, and its effects on climate is still subject to large uncertainties.
- Global models can't resolve aircraft plume processing. → Need for emission indices of aviation emitted aerosol.
- How to measure aerosol properties within aircraft exhaust plumes?

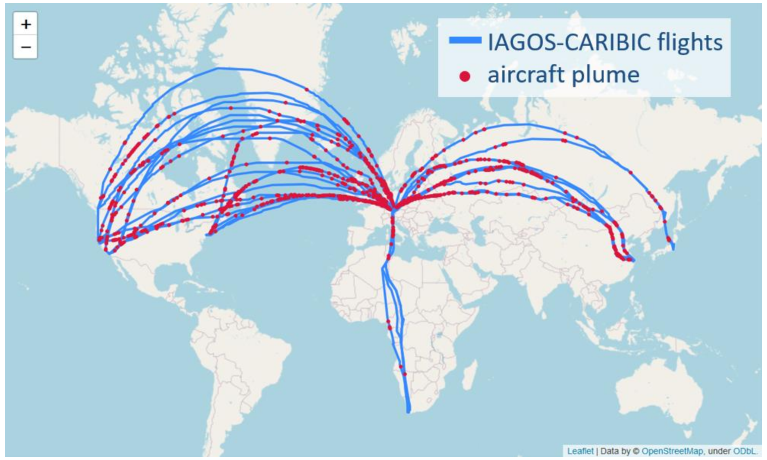


Credit: University of Bern /SR Technics Switzerland AG

Problems:
- different environmental conditions compared to cruising altitude
- only very early aging stages


Source: Schröder et al. (JGR, 2000)

Problems:
- expensive and highly restricted
  → only few data sets available
- limited to a few engine types
- only information about very fresh plumes



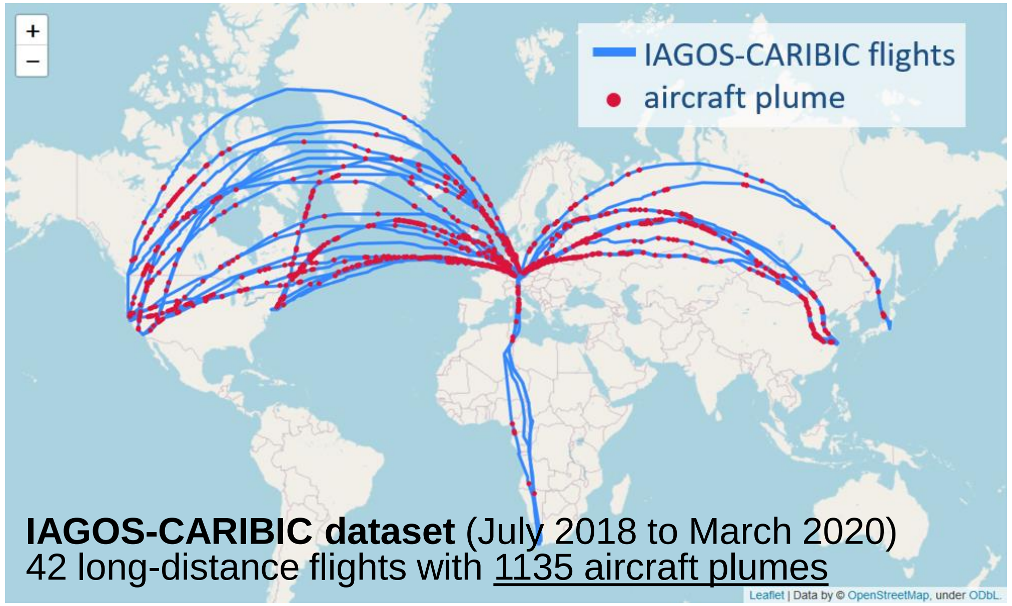
AIRCRAFT EXHAUST PLUME DETECTION AND ANALYSIS

IAGOS-CARIBIC Flying Laboratory

Instrumented airfreight container on Lufthansa Airbus A340-600

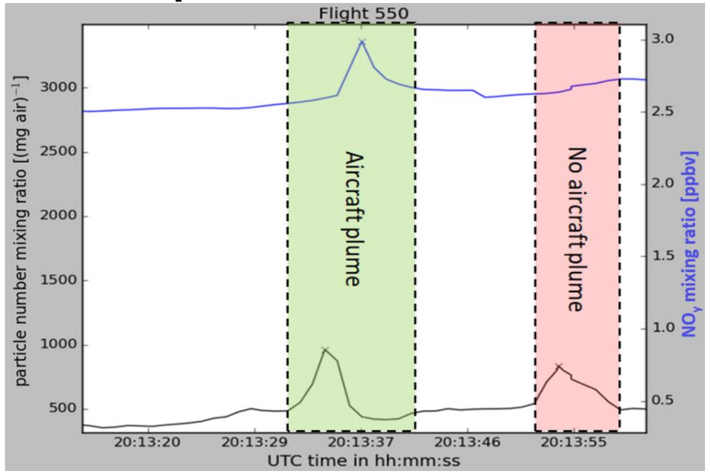
Properties:

- ✈ Total aerosol
- ✈ Volatile aerosol (sulphuric acid)
- ✈ Non-volatile aerosol (soot)
- ✈ Accumulation mode aerosol
- ✈ NO_y
- ✈ and more…



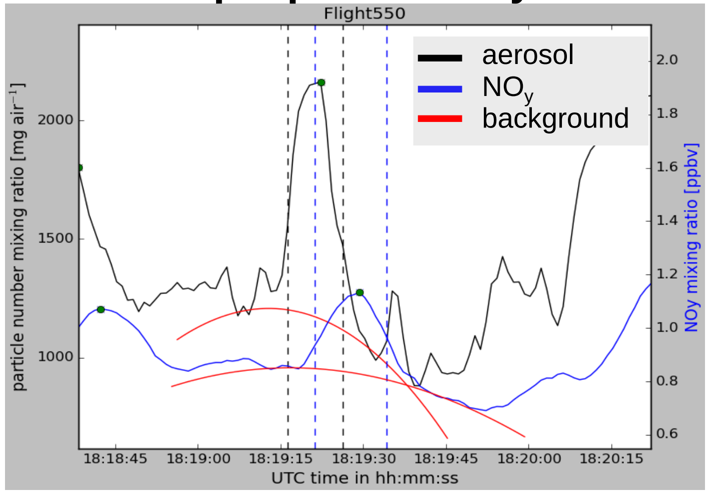
IAGOS-CARIBIC dataset (July 2018 to March 2020)
42 long-distance flights with 1135 aircraft plumes

Aircraft plume detection method



Automated detection algorithm

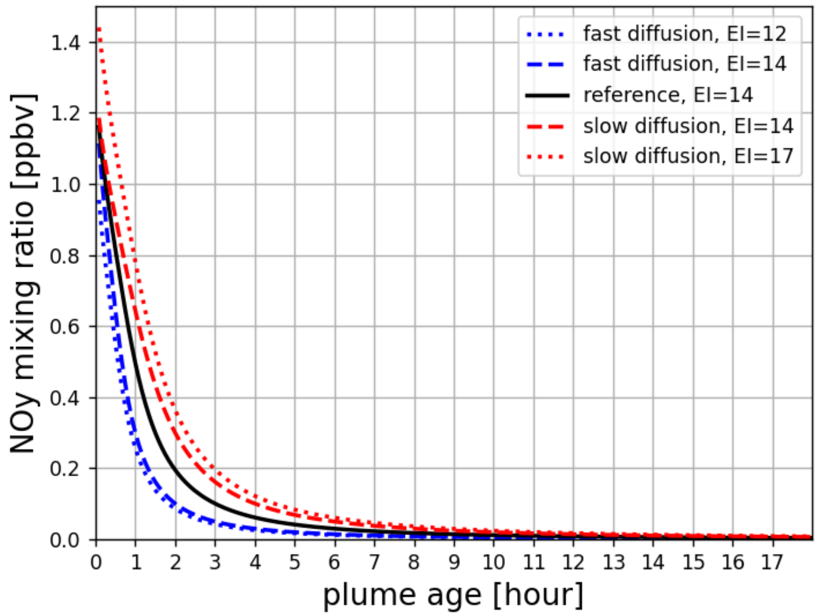
Unique plume analysis



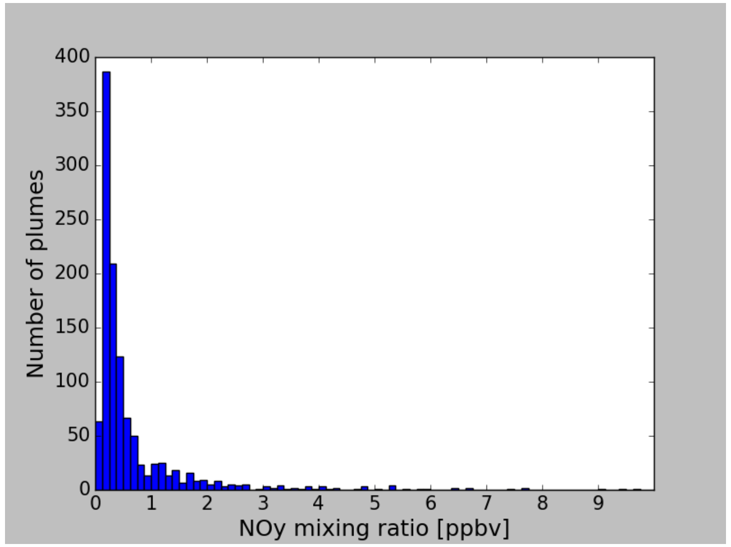
Automated plume analysis

PLUME AGE AND PARTICLE EMISSION INDICES

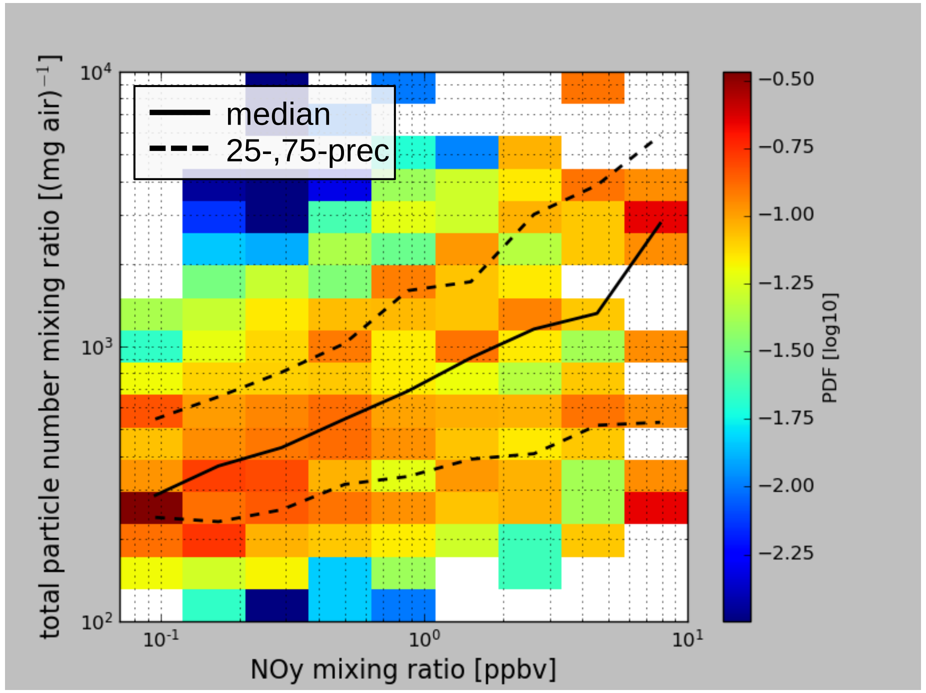
Plume dispersion model



Observed plume excess NOy



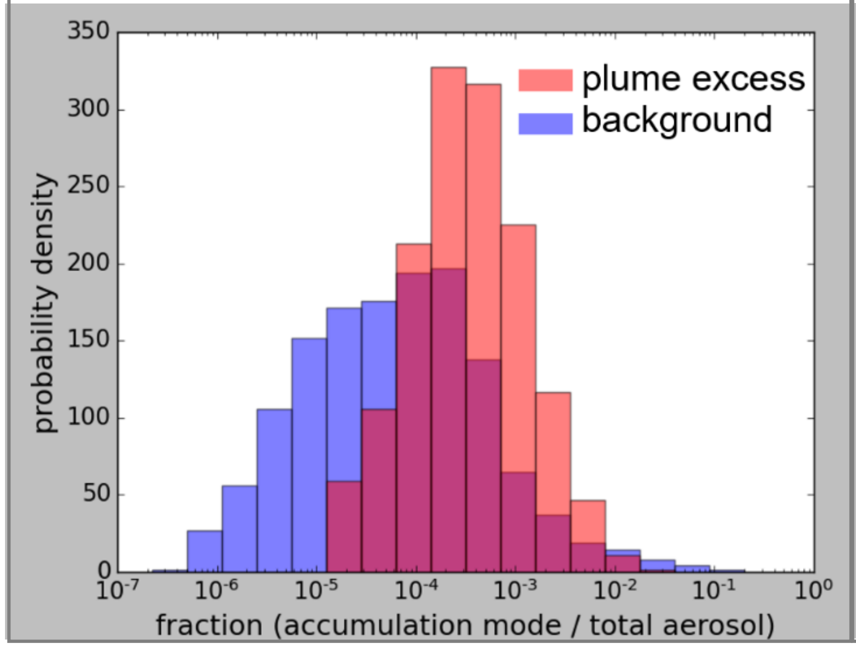
Total aerosol to NO_y relation



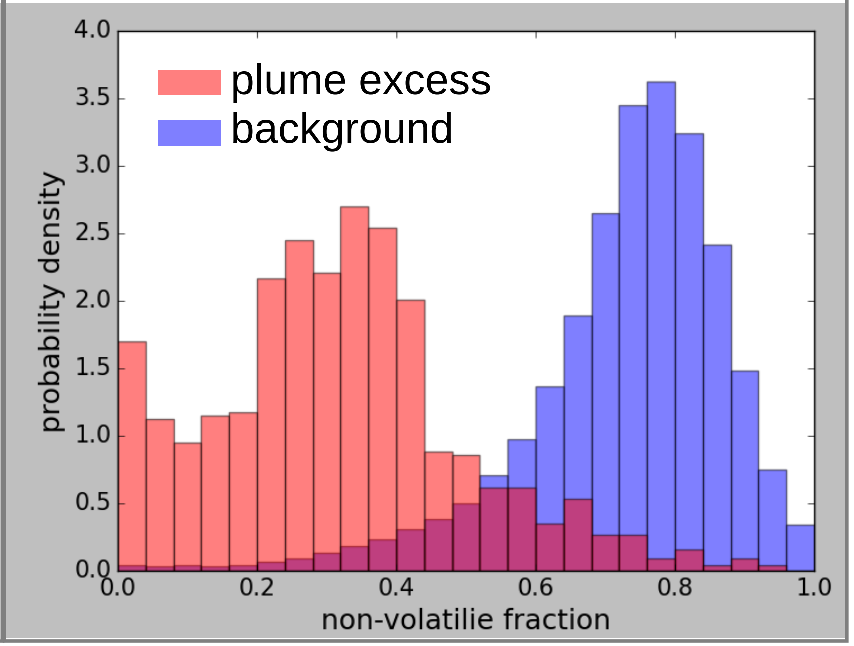
Main mode of plume excess NO_y bewteen 0.1 – 0.5 ppb.
➡ Plume age of about 1 to 3 hours.

STATISTICAL ANALYSIS OF ALL AIRCRAFT PLUMES

accumulation mode fraction
(diameter > 250nm)



non-volatile fraction
(diameter > 15 nm)



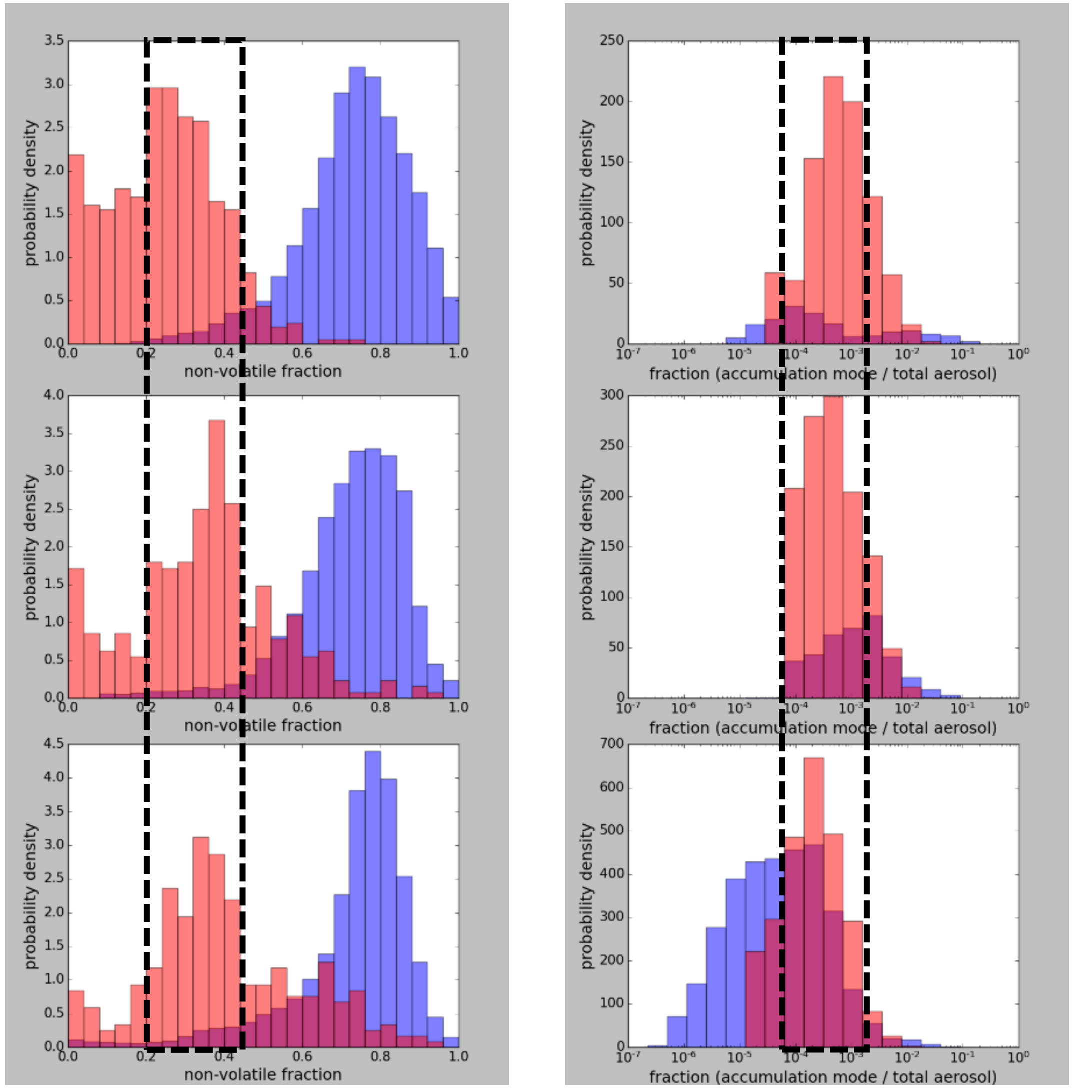
plume excess: Mean value for plume after removing the plume's individual background.
background: Data of full flights with the 1135 detected aircraft plumes removed.

- **Accumulation mode fraction** shows peak at higher values for plume excess compared to background.
  → More larger particles ("soot") within the aircraft plume compared to background aerosol.
- Histogram of **non-volatile fraction** shows distinct peak between 0.2 and 0.4 for aircraft plumes excess aerosol.
  → Even "aged" a/c plume aerosol is still more externally mixed compared to background.

STATISTICAL ANALYSIS OF ALL AIRCRAFT PLUMES

Non-volatile fraction | Accumulation mode fraction (d > 250nm)

Lowermost stratosphere | Tropopause region | Upper troposphere



plume excess: Mean value for plume after removing the plumes individual background.
background: Data of full flights with the 1135 detected aircraft plumes removed.
Lowermost stratosphere: P rel. th. tropopause < -15 hPa
Tropopause region: P rel. th. tropopause ± 15 hPa
Upper troposphere: P rel. th. tropopause > 15 hPa

Separation of plumes into upper troposphere, tropopause layer and lowermost stratosphere.

Analysis of plume excess characteristics show that aerosol properties inside the plume are similar for all atmospheric layers.

Allows parameterization of plume aerosol properties independent of flight altitude.

SUMMARY / CONCLUSION

- Observational climatology of aviation aerosol containing over 1100 aircraft plumes, providing solid global statistical bases for the main flight corridors.

- Analysis is easy extendable for new incoming data.

- Separation of plumes into upper troposphere, tropopause layer and lowermost stratosphere shows that plume excess aerosol properties are similar for all atmospheric layers.
  ➡ Allows parameterization of plume aerosol properties independent of flight altitude.

- Results clearly indicate that encountered plumes have reached a “stable state” concerning chemical and aerosol processing.
  ➡ Derived plume aerosol properties can be applied directly to models.

- Work in progress / final step: Extraction of emission indices and their range for aviation aerosol parameters based on the plumes NO_y mixing ratios, and available NO_2 emission indices.

Thank you for your attention!

For questions, please contact:

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SUPPLEMENTARY SLIDES

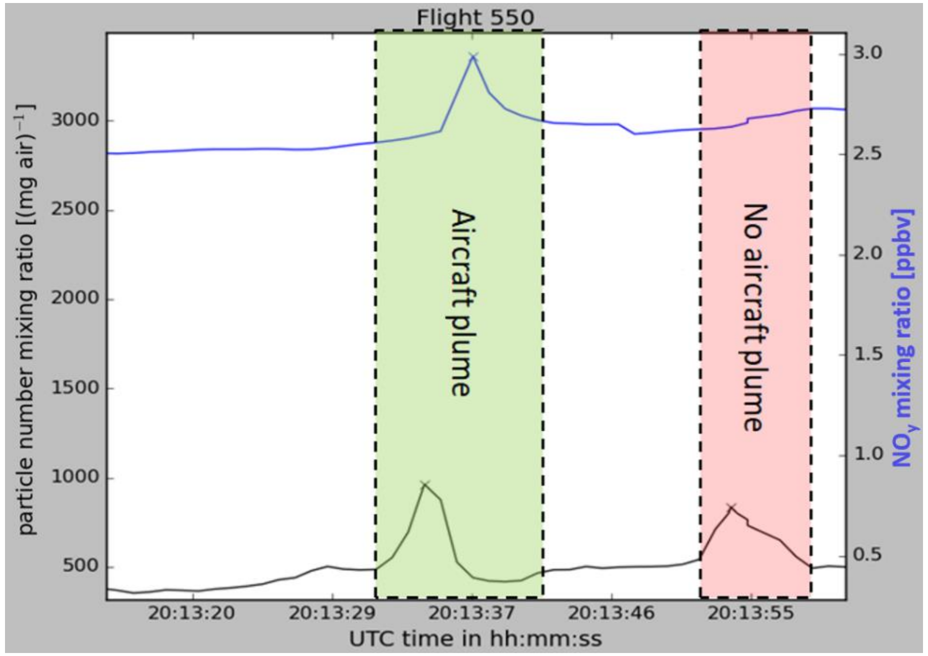
AEROSOL MICROPHYSICS AND NO_Y INSTRUMENTATION

The IAGOS-CORE aerosol instrument provides 1 Hz data on:

(Bundke et al., Tellus 2015)

- the total number concentration of aerosol particles with diameter > 15 nm;
- the number concentration of non-volatile particles with diameter > 15 nm, after being heated up to 250 °C in a thermal denuder;
- the number concentration of accumulation mode particles with diameter > 250 nm.

Aerosol data are reported in particles per cm^3 (number concentration) and particles per mg air (mixing ratio)



The DLR NO_y instrument provides 1 Hz data of the volume mixing ratios for NO and NO_y in ppbv.

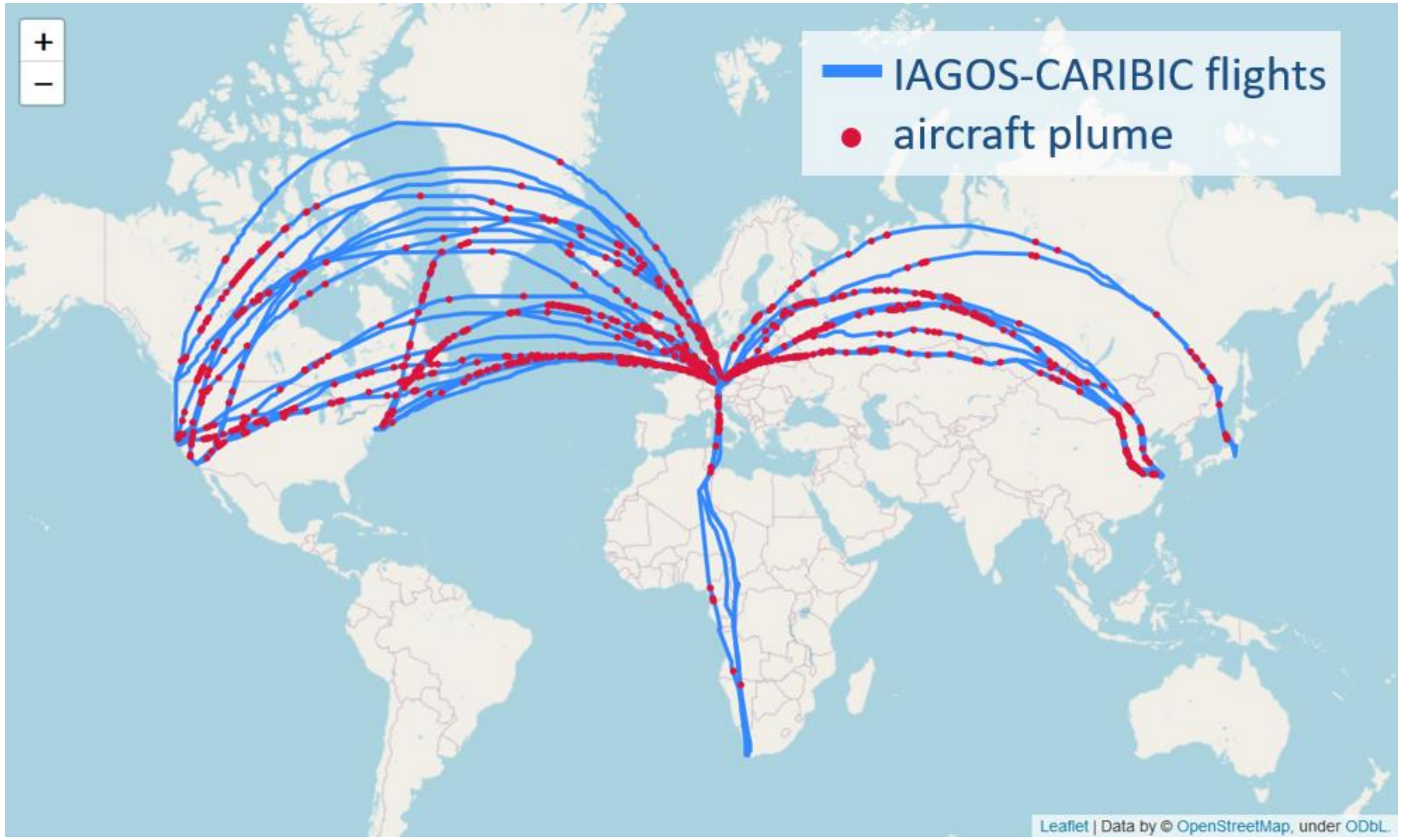
- NO_y detection limit (1 Hz data): 8 pmol/mol

(Stratmann et al., Atmos. Environ. 2016)

OBSERVATIONAL CLIMATOLOGY OF AVIATION AEROSOL

IAGOS CARIBIC dataset (July 2018 to March 2020)

In total 42 flights are available for analysis:
41 with aerosol data, 37 with NO_y data, and 36 containing both



Aircraft plume detection identified :

- Aerosol peaks: 5996
- NO_y peaks: 2621
- Aircraft plumes: 1135
  (matching unique aerosol and NO_y peaks)

OBSERVATIONAL CLIMATOLOGY OF AVIATION AEROSOL

Identified aircraft exhaust plumes were further classified into:

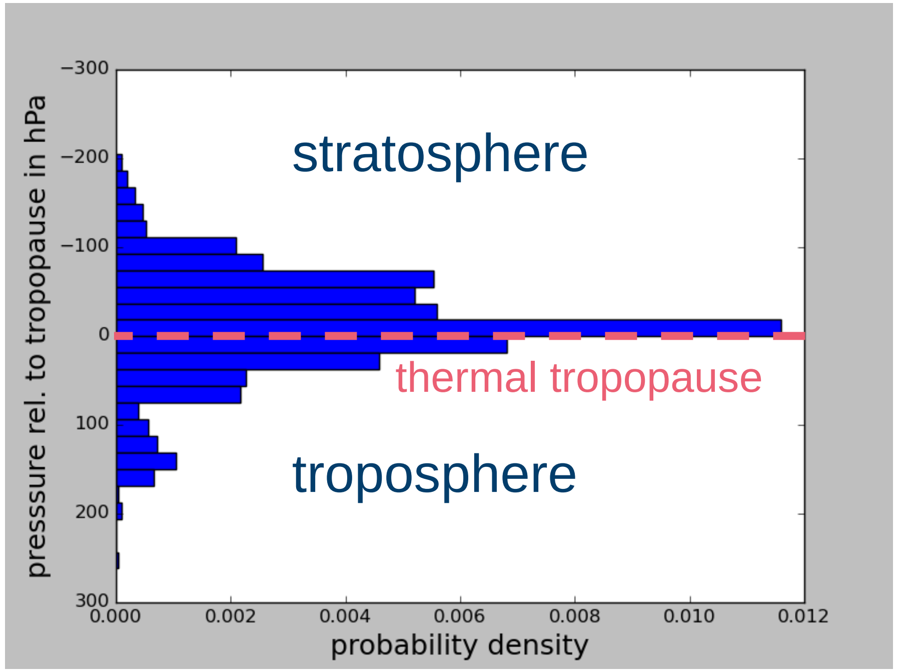
- Tropospheric / stratospheric (by means of the pressure level relative to the thermal tropopause)
- In-cloud / clear sky (by means of the difference between total water and gas phase water)

Total plumes: 1135

- Tropospheric: 415 (37 %) / stratospheric: 720 (63 %)

Plumes with H_2O_{total} and H_2O_{gas} data available (current status): 488

- In-cloud: 58 (12 %) / clear sky: 430 (88 %)



Seasonal distribution of the detected aviation exhaust plumes:

Season:	total a/c plumes	tropospheric	stratospheric	clear sky	in-cloud
Dec-Feb	200	62	138	116	21
Mar-May	48	20	28	40	8
Jun-Aug	513	251	262	145	20
Sep-Nov	374	82	292	129	9

ESTIMATING PLUME AGE FROM NO_Y TRACER EVOLUTION

Method: Determination of plume age by using NO_y as a chemically inert tracer (< 18 h) during plume evolution in the plume dispersion phase and compare to observations.

Plume dispersion modelling:

- Dispersion model based on Petry et al. (1998)

Parameters	Value	Reference
Emission index	14 [$g(NO_2)\ kg(fuel)^{-1}$]	Lee et al., 2010
Fuel consumption	8200 kg fuel per hour	Petry et al., 1998 (B-747 aircraft)
Aircraft speed	870.7 km/h	Petry et al., 1998 (B-747 aircraft)
Altitude	262 hPa	Typical value at cruise altitude
Temperature	213.44 K	Typical value at cruise altitude (taken from 3D model simulation)